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THE SURFICIAL GEOLOGY OF SKELDAL, MESTERS VIG, NORTHEAST GREENLAND

BY

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WITH 9 FIGURES AND 3 TABLES IN THE TEXT
AND 5 PLATES

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Abstract

Skeldal is located in the Mesters Vig district, Northeast Greenland (72°15′ N. lat., 24°15′ W. long.). The surficial deposits were studied and sampled for analysis in the laboratory. Thirteen radiocarbon dates of shell material, and one of peat helped to establish a chronology for glacial retreat since the last glacial (Würm/Wisconsin) maximum.

Conclusions: (1) The maximum height of the ice surface in Skeldal during the last glaciation is tentatively set at 500 m (Phase I) and probably corresponds to the last glacial maximum. (2) The first period of downwasting from the 500 m level is the result of glacial thinning and retreat (Phase II). (3) A glacial readvance probably occurred (Phase III), followed by general uncovering of the Mesters Vig district during postglacial time (Phase IV). (4) A glacial readvance occurred more recently than 1,500 B.P. (Phase V). (5) The early rate of emergence, 8,000–7,000 B.P., related to delevelling in Skeldal was of the order of 3 m per 100 years, but slowed approximately to 1 m per 100 years between 6,500 and 6,000 B.P. From 6,000 B.P. to the present emergence is tentatively set at 6 to 7 cm per 100 years. (6) The highest peaks rising from Skeldal were nunataks during the last ice maximum, and very probably during the entire Pleistocene. (7) Valley profiles and a slide block in the area suggest multiple glaciation occurred in Skeldal.

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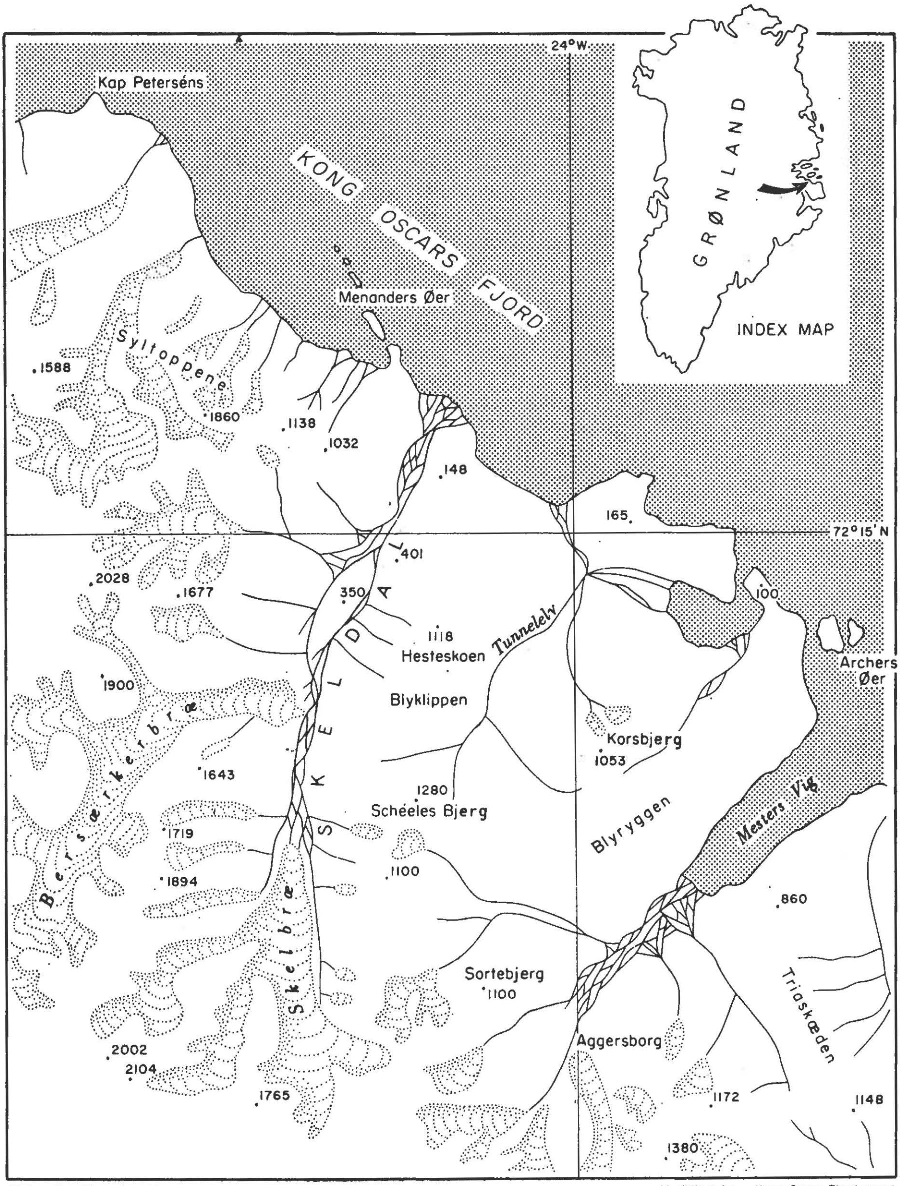
INTRODUCTION

Location

The Skeldal (72°15′ N. lat., 24°15′ W. long.) is situated in Scoresby Land, Northeast Greenland (see Fig. 1, Pl. I and II). Skeldal is a northeast-trending valley extending about 30 km from its mouth on the fjord to its head in the alpine glaciers of the Staunings Alper. The igneous and metamorphic complex of the Staunings Alper, some Paleozoic sediments, glacial and fluvial materials are found on the west Skeldal slopes which rise approximately 2000 m. A major north-trending fault, the Staunings Alper fault, separates the igneous-metamorphic complex from the sediments (Fig. 2). The eastern slopes which rise to about 1100 m are composed of Permo-Carboniferous sediments, ridge-forming Tertiary(?) intrusives, and glacial and fluvial materials. Maximum relief in the area exceeds 2000 m. The regional climate is polar-arid with annual precipitation about 30 cm of which 20–25 cm is in the form of snow. Annual temperatures range from a minimum of −45° to a maximum of +19° C. The spring thaw usually begins in May, and the first winter snows fall during September. For further discussion of the area's accessibility, culture and climate, see Washburn, 1965.

Previous work

There is no published work so far as I know on the surficial geology of the Skeldal area. The principal geologic research undertaken in the area was by the Danish expeditions under the leadership of Lauge Koch (Koch, 1954) during the years 1926 to 1954, and was devoted to investigation of bedrock geology, paleontology and structural geology. A reconnaissance study of the general physiography and glacial geology of the fjord region of Northeast Greenland was done by the Louise A. Boyd Arctic expeditions of the late 1930's (Bretz, 1935; Flint, 1948). Members of the Cambridge University (Knox, 1963), Imperial College (Imperial College, 1963), and Oxford University (John and Sugden, 1962) East Greenland expeditions have made some observations on glaciers and related features in the surrounding area, as has Sugden (1962) in Alpe-



Note: elevations in meters

Modified from Kong Oscar Fjord sheet
Geodætisk Institut, København, 1952

MAP OF SKELDAL-MESTERS VIG AREA
NORTHEAST GREENLAND

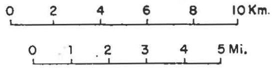


Fig. 1. Index map.

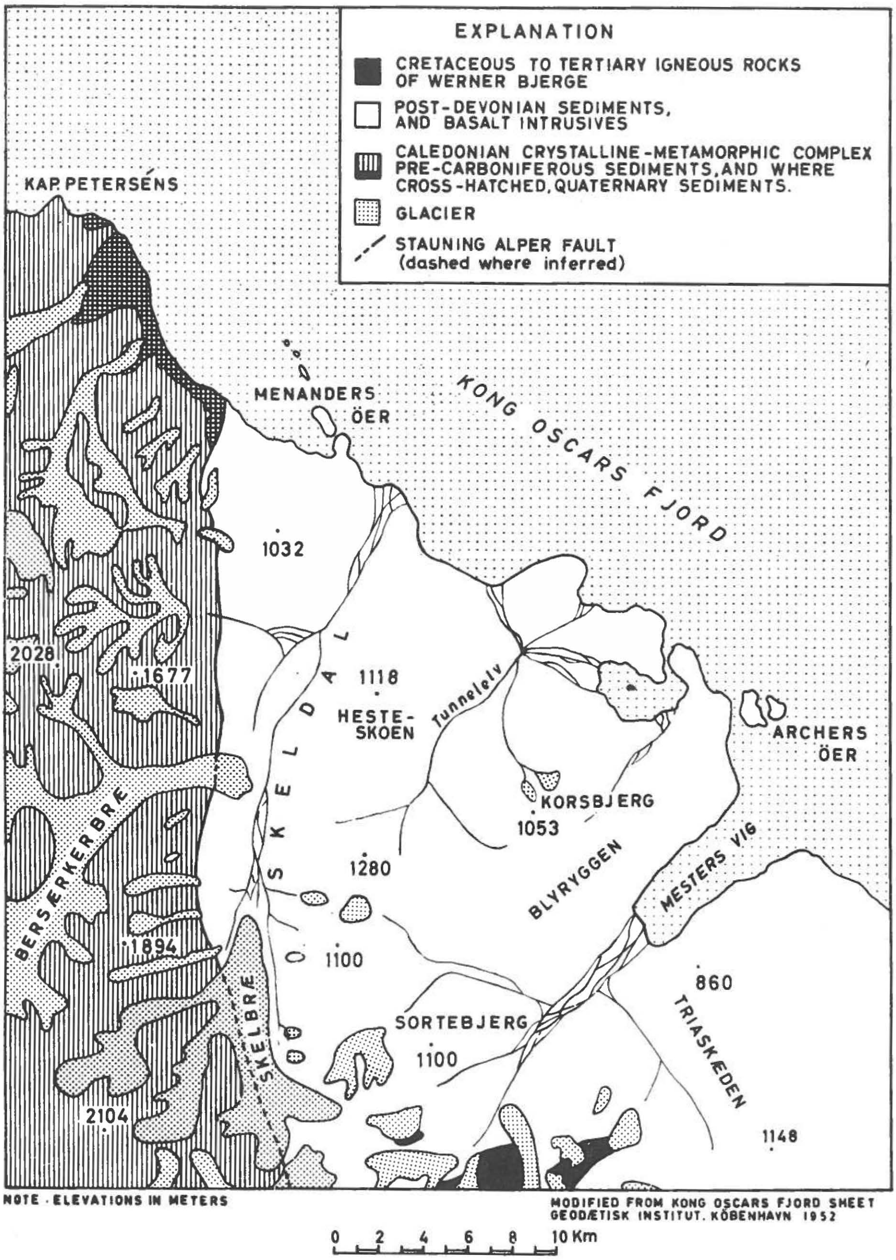


Fig. 2. Bedrock geology of the Skeldal area, after BEARTH (1959), BIERTHER (1941), FRÄNKL (1953), WITZIG (1954), and my own observations.

fjord, west to northwest of Skeldal. A history of the early exploration and scientific investigations of Northeast Greenland is found in volume one of *Greenland* (VAHL, 1928).

Present work

The present work in the Skeldal extends the work in surficial geology begun by A. L. Washburn (ms.) in the Store Blydal area (Pl. I), and F. Pessl in the Sortebjerg area (Fig. 1); both areas lie east to southeast of Skeldal. The area was first visited by the writer with Pessl and D. F. Eschman in 1961. Supplies were placed during the Winter-Spring of 1962. Field work commenced in July, and was concluded at the end of August. In 1963, field work extended from July to the first snow in September. In 1964, I was fortunate in accompanying A. L. Washburn and F. C. Ugolini into the area for four additional field days.

Methods used

Field observations were plotted directly on vertical aerial photographs, obtained from the Geodætisk Institut, Copenhagen, with the exceptions of small areas in the southeast and northeast corners of Plate V, where only oblique aerial photographs were available. From these photographs, supplemented by the 1:50,000 Geodætisk Institut map of the southeastern slopes of the upper Skeldal, a drainage map of Skeldal, Plate V, was drawn. Altitudes which appear on the index map, Figure 1, have been taken from the 1:250,000 Kong Oscars Fjord topographic map published by the Geodætisk Institut; the index map has been modified to correspond with my field observations.

Field altitudes were determined primarily by Paulin aneroid corrected for temperature and pressure changes. Since the tidal range is approximately 1 m (Det Kongelige Søkortarkiv, Copenhagen, personal communication) no corrections were made in computing altitudes to compensate for differences in high-tide and mean-tide levels. Accuracy for altitudes of less than 5 m is estimated to be $\pm$.5 m; between 5 and 25 m, $\pm$1 m; and above 25 m, $\pm$2 m (cf. Washburn and Stuiver, 1962, p. 67).

Surveying of the fresh-water strandlines was done with a Wild T-2 theodolite reading directly to one second. Marine shell material, and a peat sample, were dated by the radiocarbon laboratory of the University of Michigan using a radiocarbon half life of 5568 years. The equipment and counting techniques used by the laboratory have been described by Crane (1961a, 1961b).

Terminology

Unless otherwise stated all geologic terms follow the definitions given in the *Glossary of Geology and Related Sciences* (Howell, 1960).

The text follows Washburn (1965) in the use of the terms "Northeast Greenland," and "Mesters Vig district" in this report.

The upper Skeldal is defined as that portion of the valley upvalley from the Bersærkerbræ; the lower Skeldal, the area from the Bersærkerbræ to Kong Oscars Fjord (see Pl. V). The upper portion of the Skeldal trends north, while the lower Skeldal trends northeast. For purposes of discussion those areas to the west and northwest of the central drainage (Skeldal Elv) will be considered as the west Skeldal; those on the east and southeast as the east Skeldal.

Kong Oscars Fjord ice refers to all ice in Kong Oscars Fjord valley. Skeldal ice refers to all ice in Skeldal. Skelbræ ice or lobe includes all ice from the upper Skeldal glaciers. Bersærkerbræ ice or lobe includes all ice from Bersærkerbræ valley glaciers. Vifteelv ice or lobe includes all ice from Vifteelv valley glaciers.

Acknowledgements

I wish to express my thanks to the Danish Government, particularly Director Eske Brun of the Ministeriet for Grønland, and the Nordisk Mineselskab A/S for permission to work in the Mesters Vig district. The friendship and assistance given by the personnel of Nordisk Mineselskab, Statens Luftfartsvæsen, and the J. Lauritzen Line in Mesters Vig, were invaluable. Special thanks are due Consul-General Ludvig Storr and his staff who assisted in all negotiations in Iceland.

In the field I was assisted by Kield Schmidt during the winter supplying in 1962, and during the field season in 1963; and by Darwin R. Spearing during the 1962 field season. Horace G. Richards of the Philadelphia Academy of Natural Sciences kindly identified the marine shell material. Fiorenzo C. Ugolini, the Institute of Polar Studies, Ohio State University, described an Arctic Brown soil profile in Skeldal. Derwin Bell of the University of Michigan drafted most of the maps and figures. Air photographs were furnished by the Geodætisk Institut, and tidal information was provided by the Kgl. Søkortarkiv. The University of Michigan radiocarbon laboratory carried out the radiocarbon age determinations.

I am particularly indepted to D. F. Eschman for his support an encouragement, and to many persons at the University of Michigan for their suggestions and helpful criticism throughout the project. Most sincere thanks are given A. L. Washburn who permitted the use of his house as base headquarters in Mesters Vig, loaned equipment, and gave generously of his time. B. G. Andersen kindly read the present manuscript.

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GENERAL GEOLOGY

The rock types found in Skeldal include sandstone, limestone, dolomite, shale, conglomerate, and crystalline-metamorphic granite, migmatite gneiss, basalt, slate, and quartzite. The Staunings Alper fault (BÜTLER, 1957)[1] separates the Caledonian crystalline-metamorphic complex and pre-Carboniferous sediments of west Skeldal from the Permo-Carboniferous and Tertiary-Quaternary sediments east of the fault (Fig. 2). The rock types are discussed by age.

Migmatite gneisses are found in the area together with the late Precambrian Greenlandian sedimentary rocks which grade both vertically and laterally from a metamorphosed to a non-metamorphosed sedimentary series. These sediments have been classified by HALLER (1958, p. 34) as follow:

Psammitic para-rocks:	Mica quartzite, Feldspar quartzite, Gneissic quartzite.
Pelitic para-rocks:	Phyllite, Mica schist, Mica gneiss.
Carbonate- and calc-silicate rocks:	Marble, Dolomite quartzite, Calc-mica schist, Calc-silicate felses.

The crystalline rocks, Caledonian in age, consist of two series of intrusions. As described by HALLER (1958) the older intrusives may be divided into two groups: the granites and the quartz-monzonites. The former consists of pegmatite granite, alkali-feldspar granite, and biotite-rich alkali-feldspar granite; the latter of biotite quartz-monzonite and muscovite-bearing biotite quartz-monzonite. The younger generation intrusives consist of two mica (binary) granite, and biotite granodiorite.

Cambro-Ordovician and Devonian sediments crop out in a small area on Syltoppene west of the Staunings Alper fault. The Cambro-

[1] FRÄNKL (1953, Fig. 10, and p. 35) has called this the "Skeldal-Verwerfung" [Skel valley fault]. "Staunings Alper fault" is used in this report, following BÜTLER (1957) and HALLER (1958).

Ordovician sediments (Cowie and Adams, 1957, p. 146 f.; Fränkl, 1953, p. 29 f.) consist of limestone, dolomite, and sandstone. The Devonian sediments (Fränkl, 1953, p. 32–35) consist of a basal breccia, conglomerate, and red, gray, and green sandstones.

East of the Staunings Alper fault are the Upper Carboniferous Blyklippen Series and the Permo-Carboniferous Lebachia Series (Bierther, 1941; Witzig, 1951, 1954; Fränkl, 1953; Bondam, 1955) which compose the eastern slopes of Skeldal, and the Skeldal conglomerate (Fränkl, 1953, 1956) which crops out on both sides of the Bersærkerbræ near the fault is late Tertiary or early Quaternary in age.

The Blyklippen Series consist of 800–1000 m of light-green to gray, fine to coarse-grained continental sandstone, with some interbedded shale and conglomerate. The following plant fossils have been described (Witzig, 1951, p. 26–28):

Lepidodendron sp. (cf. *L. aculeatum* Sternb).
Calamites sp. (cf. *C. undulatus* Sternb).
Calamites sp. (cf. *C. cisti* Brgt).
Calamites carinatus Sternb.

Above the Blyklippen Series is the Lebachia Series containing 1300–1500 m of fine to coarse-grained gray sandstones, sandy and limy shales, and limestone. Fossil fish (Palaeoniscidae) described by Moy-Thomas (1942) and reported by Witzig (1954) were found in a black limy shale near the base of Øvre Gefionpas. Plant fossils in the Series include (Witzig, 1954):

Lebachia (*Walchia*) *parvifolia* Florin.
Calamites gigas Brgt.
Calamites sp. (cf. *C. undulatus* Sternb).
Cordaites sp.

Based on the fossil evidence Witzig (1954) considers the Lebachia Series lowermost Permian.

"The Skeldal conglomerate is a breccia, polymictic conglomerate, whose components lie in a gray-green, sandy groundmass (Fränkl, 1953, p. 35)." White quartzite pebbles are common, and the entire conglomerate appears to be a mixture of locally derived slide rock and fluvial gravels (Fränkl, 1953).

Numerous basaltic dikes and sills intrude the sediments along minor faults and fractures. Witzig (1954) has described the dikes and sills as dolerite, olivine basalt, and diabase-type intrusives. For purpose of discussion in this report, they will be called "basaltic." The sills cap low-lying hills, locally called trap knobs, which account for much of the relief below 300 m in the lower valley. The trap knobs have influenced the position of the surficial deposits (see p. 13).

The north-trending Staunings Alper fault and minor faults, some of which parallel the main fault and some of which strike northwest from it, have been observed. The sediments to the east of the Staunings Alper fault strike eastnortheast, and dip between 7° and 14° northwest. This trend of the sediments appears to have controlled much of the former ice marginal drainage from the glaciers (see p. 32). Three major joint directions were noted in the basalt sills: north, westnorthwest, and northeast. The minor faults and the joints control the direction of many of the streams tributary to the Skeldal Elv.

A large section on the east face of Syltoppene, comprising a sedimentary block approximately 1 km long, has been dropped downward several hundred meters (Pl. IV) and now forms the west Skeldal slopes in this area. The block lies just below the protalus rampart debris mapped at the east end of Syltoppene; it matches in geologic section the sediments found at the east end of Syltoppene which include sandstone and conglomerate that are capped by a basaltic sill. The frontal slopes of the block consist of highly weathered bedrock and will be discussed in the section titled "Weathered bedrock" (see p. 37).

SURFICIAL DEPOSITS

Map units were chosen on the basis of their significance in interpreting the glacial chronology of Skeldal. The distribution of surficial deposits is shown on Plate V. For convenience the surficial deposits are divided into the following kinds of deposits: alluvial, beach, colluvial, delta, fjord-bottom, kame, lacustrine, and morainal. Interpretation of deposit character, stratigraphic position, and distribution suggests a relative chronology which in part is confirmed by absolute dates (discussed later, p. 45).

Criteria for identification

Criteria used in deposit identification were of three types:

1. Geographic position and extent:
   - Areal extent.
   - Altitude.
   - Location in respect to other features.
2. Surficial appearance:
   - Topographic expression.
   - Types of surface material.
   - Vegetation cover.
   - Soil development.
   - Color.
   - Stability.
3. Sediment characteristics:
   - Sedimentary features (cross-bedding, involutions, interbedded layers).
   - Grain size.
   - Color.

Weathering differences could sometimes be detected between young and old moraines by determining the general roughness (flaking) of surface boulders due to weathering; this kind of direct observation was not useful in separating deposits. Stream incision was useful in determining relative age, particularly when used with other criteria, e.g., vegetation cover, topographic position, amount of soil. The amount of slopewashed material covering a deposit was also useful in determining relative age relations.

Determination of sediment grain size (Wentworth scale) was done roughly in the field, then confirmed in the laboratory by mechanical analysis. Generalized probability curves of sediment distribution are presented for the following sediment types: delta, fjord-bottom, moraine (Fig. 3; see discussion p. 19f.). Stability of deposits was estimated from (1) the amount of fines filling interstices between cobbles and boulders, (2) vegetation cover, and (3) the detectable amount of reorientation of material as one walked over the deposit. Deposits were designated as stable or unstable. In some areas a soil profile is well developed (cf. Ugolini, 1965; see p. 50) and was another criterion in determining the relative age of deposits. In evaluating a deposit's surficial appearance the percentages of the finer fraction, the boulders and the erratics were considered along with the rock types present, the vegetation, and the amount of soil development. It was found that vegetation was not useful in distinguishing relative age differences. However, the vegetation cover was helpful in discriminating between fjord-bottom material and delta material since the fjord-bottom deposits had very sparse vegetation cover in comparison to the delta deposits.

Moraines

Four moraines are recognized in the area (cf. work from adjacent areas, Flint, 1948, p. 156 f.): the oldest moraine, the 500 meter moraine, the 300 meter moraine, and the recent moraines. Included in the recent moraines are the ice-cored moraines found near the active ice. The 500 meter moraine which is found on both sides of Skeldal ranges from 511 to 601 m in altitude. It is at the same altitude as the erratic line (p. 28) and the general break in slope on the east side of Skeldal. The younger 300 meter moraine ranges from 265 to 399 m in altitude and is found only on the west side of Skeldal. Although drift occurs on many of the eastern slopes, it is mixed with alluvial and slopewash material. Solifluction has disturbed the drift, and the underlying bedrock structure, through its control of drainage and sediment entrapment, has obscured any general morainal pattern. As a result it was impossible to separate the east Skeldal drift into any moraine sequence. For these reasons the drift is not mapped; in any case it does not contribute significantly to an understanding of the glacial chronology in Skeldal (see p. 38 f.). Recent moraines lie at the front of all glaciers in the area. They are divided into three parts: the terminal moraine, the morainal debris often containing smaller recessional moraines between the terminal moraine and the ice, and the ice-cored moraine of the glacier. The moraines consist of a wide variety of rocks derived from the sediments and the crystalline-metamorphic complex of the Staunings Alper described earlier (p. 10). The moraines generally consist of clayey-silty, or silty-sandy, sub-angular to angular, pebble-cobble gravels with boulders that may reach a maximum of 5.3 m in size. The color of the moraines varies greatly and is dependent on the dominant rock types present in each moraine. In some areas the moraines are washed so that the debris is a pebble-cobble, or cobble-boulder gravel containing a very low clay-silt-sand fraction.

Oldest moraine

The oldest moraine is found on the north side of Vifteelv, and consists of three moraine remnants at altitudes between 570 and 594 m. This moraine sequence[1] lies above the 500 meter moraine, and is the oldest of the moraines found in the area. This conclusion is based on the topographic position, stability, and the mature character of dissection found on the moraine in comparison to the other moraines in Skeldal.

500 meter moraine

The 500 meter moraine is found in several localities on the west side of Skeldal, and in two localities in the upper east Skeldal. The most prominent and continuous part of this moraine is located on the north side of Vifteelv, where the moraine curves from the Vifteelv valley into the main Skeldal (Pl. III). Between Vifteelv and Bersærkerbræ the 500 meter moraine curves from the main Skeldal into the south side of Vifteelv; it corresponds in height to the 500 meter moraine on the north side of Vifteelv.

In the upper west Skeldal a lateral moraine from the second glacier south of Bersærkerbræ joins the main valley at the 500 m level. In the upper east Skeldal the 500 meter moraine occurs in two places: at the erratic line, and where the moraine from the second glacier south of Øvre Gefionpas joins the main valley. The 500 meter moraine corresponds in height to the erratic line found on the eastern slopes of Skeldal (Pl. V).

300 meter moraine

The 300 meter moraine is the most prominent of the older moraines in Skeldal. It is found along the entire west side of the lower valley, and on the north side of Vifteelv. In the upper west Skeldal the lateral moraine from the third glacier south of Bersærkerbræ joins the main valley at the 300 m level. On the east side of Skeldal the 300 meter moraine cannot be distinguished from the general drift of the eastern slopes (see discussion p. 14).

[1] The word "sequence" as used here means a series of deposits having physical continuity.

On the north side of Vifteelv the 300 meter moraine extends into the main Skeldal (Pl. III). Lying above the main moraine are some higher kame-moraine deposits which are included in the 300 meter moraine sequence (Pl. V). Between Vifteelv and Bersærkerbræ a moraine sequence occurs at the 300 m altitude.

Recent moraines

Recent, terminal, and ice-cored moraines found in front of the modern glaciers in Skeldal occur in four localities: (1) the Vifteelv valley, where two groups occur, those at the head of Vifteelv, and those originating in the cirque glacier at the east end of Syltoppene (Pl. III), (2) the Bersærkerbræ area where the largest complex of stagnant ice features found in Skeldal occur, (3) the upper east Skeldal where only small recent moraine complexes are seen, and (4) the upper west Skeldal. Only the upper west Skeldal moraines will be discussed in detail. Each locality has a terminal moraine which may reach a height of 30 m, ice-cored moraine, and smaller recessional moraines. The distance between the ice and the recent moraines appears to be a function of the size of the respective glaciers' source areas. For example, the Bersærkerbræ with its large source area has not withdrawn as far upvalley from its terminal moraine as has the Vifteelv glacier (Pl. V) which has a smaller source area.

The composition of the recent moraines reflects the local rock types through which the ice moved. Three general observations can be made. First, although sediment size varies greatly, an increase in percentage of the coarse sediment fraction is noted as one moves closer to the active ice. Second, within the recent moraine complexes are many fluvial features caused by meltwater distribution of sediment around the stagnant ice in front of the active glacier. This results in a series of kame deposits (mapped on Pl. V as moraine and ice-cored moraine) distributed through the moraines currently or recently formed in front of the active ice. In this connection it should be remembered that the sediment's composition in the ice-cored moraines, the end moraines, and the debris found in the moraine complexes is generally the same, but sediment size distribution differs within the complex. Third, the recent moraines found in the upper east Skeldal lack the crystalline and metamorphic rocks found in all moraine sequence of west Skeldal and in the 500 meter moraine at the erratic line in the upper east Skeldal (Pl. V).

The moraines of the upper west Skeldal originate in the cirque glaciers tributary to the Skelbræ, and contain locally derived rock material from the Staunings Alper described by Haller (1958). The moraines consist of angular to sub-angular pebble-cobble gravels with a silt-sand matrix, and commonly boulders that may reach 2 m in size. Remnant lateral moraines occur on the north sides of the glaciers, but are conspicuously absent from the south sides, although lateral moraines do occur in direct contact with the ice on the south sides of the glaciers. The lack of south lateral moraines may be attributed to two processes. Slopewash and mass movement of material from the very steep (Table 1) southern walls of the tributary valleys continuously clean the slopes of debris and deposit material on the active ice, which then carries the debris to the main valley. The main Skeldal ice then incorporates the tributary debris as a medial moraine. The lateral moraines which occur on the northern slopes of the tributary glaciers are preserved because of the less intense slopewash and mass movement on the more gentle slopes (Table 1).

Table 1. *Comparison of north-south slope angles of tributary valleys in the upper west Skeldal.*

Tributary glacier south of Bersærkerbræ	Slope angles	
	South wall	North wall
Glacier No. 2	84°	40–48°
Glacier No. 3	76°	46–50°
Glacier No. 4	60–75°	38–43°

At the 700 m level a few hundred meters in front of the first glacier south of the Bersærkerbræ in the upper west Skeldal, a lateral moraine appears to be overridden by a second moraine. The general composition of both moraines is the same, as would be expected since they originate in the cirque glacier a few hundred meters away. However, lichen cover is better developed on the overridden moraine, and in some places the moraine is covered with slide rock. This is the only place where there is evidence of overriding of one moraine by another in the Skeldal.

Delta sediments

Emerged delta deposits are restricted to two areas of Skeldal, one in the upper and one in the lower valley (Pl. V). The delta deposits of the lower Skeldal are found in many localities between Vifteelv and Kong Oscars Fjord, and are marine deposits as indicated by the molluscan faunas they contain (see Table 3 and discussion, p. 45 f.). In the upper Skeldal the delta deposits occur between the Skelbræ and the Bersærkerbræ where they were deposited in a fresh water lake formed when the upper valley was dammed by the Bersærkerbræ. Delta deposits were distinguished on the basis of location, surface appearance and extent, appearance in profile, and in some cases by their sedimentary structures. In each case before the deposit was mapped as deltaic, study of the bedding established that the material had been deposited in a quiet water environment.

With the exception of a small delta remnant on Kong Oscars Fjord at an altitude of 119 m, the delta deposits of the lower Skeldal are parts of a single large delta which occupied much of the area between Vifteelv and the present fjord at a time when the sea was considerably higher. The main delta, herein referred to as lower Skeldal marine delta, ends abruptly upvalley against the kame deposits of the west Skeldal (Pl. III). Interfingering with the delta sediments are fjord-bottom sediments reported by WASHBURN and STUIVER (1962) which will be discussed later (p. 22 f.). The delta deposits will be discussed as three units: the lower Skeldal marine delta deposits, the Kong Oscars Fjord delta remnant, and the upper Skeldal delta deposits.

Lower Skeldal marine delta deposits

The lower Skeldal marine delta deposits are found below an altitude of 120 m on both sides of the Skeldal Elv drainage downvalley from the Vifteelv alluvial fans (Pl. V). The highest level where evidence of marine seas is observed in Skeldal is at 88 m where a small quantity of molluscan material was found in the delta complex just southwest of shell locality 10. WASHBURN and STUIVER (1962) reported a molluscan fauna in two localities at 76 m, and in Skeldal a molluscan fauna from two localities at 60 m altitudes was collected and dated (see p. 45 f.). Since the highest molluscan fauna indicates a minimum altitude for the highest sea level, and since some delta deposits are continuous from shell localities to altitudes of 101 m, delta-type material probably represents sediment deposited in a marine environment above the highest known altitude recorded for molluscan faunas in Skeldal.

In the lower valley the delta deposits surround parts of some trap knobs and extend east and west from the entrance of Skeldal along the fjord. Along the coast of Kong Oscars Fjord delta deposits commonly have strandlines[1] superimposed on them, presumably formed as the delta emerged. The character of the sediment varies greatly in these deposits. The delta deposits which lie against the kames downvalley from the Vifteelv fans contain much coarser material than delta deposits nearer the fjord. This suggests that the head of the delta originated near Vifteelv and is consistent with the reconstruction discussed under "Glacial chronology."

[1] The term "strandline" as used here means, "the line traced on shore rocks, either firm or unconsolidated, by erosional or depositional shore features developed at mean sea level or at the level of a lake, whether or not the line is now at mean sea level or lake level (FLINT, 1948, p. 163, after R. A. DALY)."

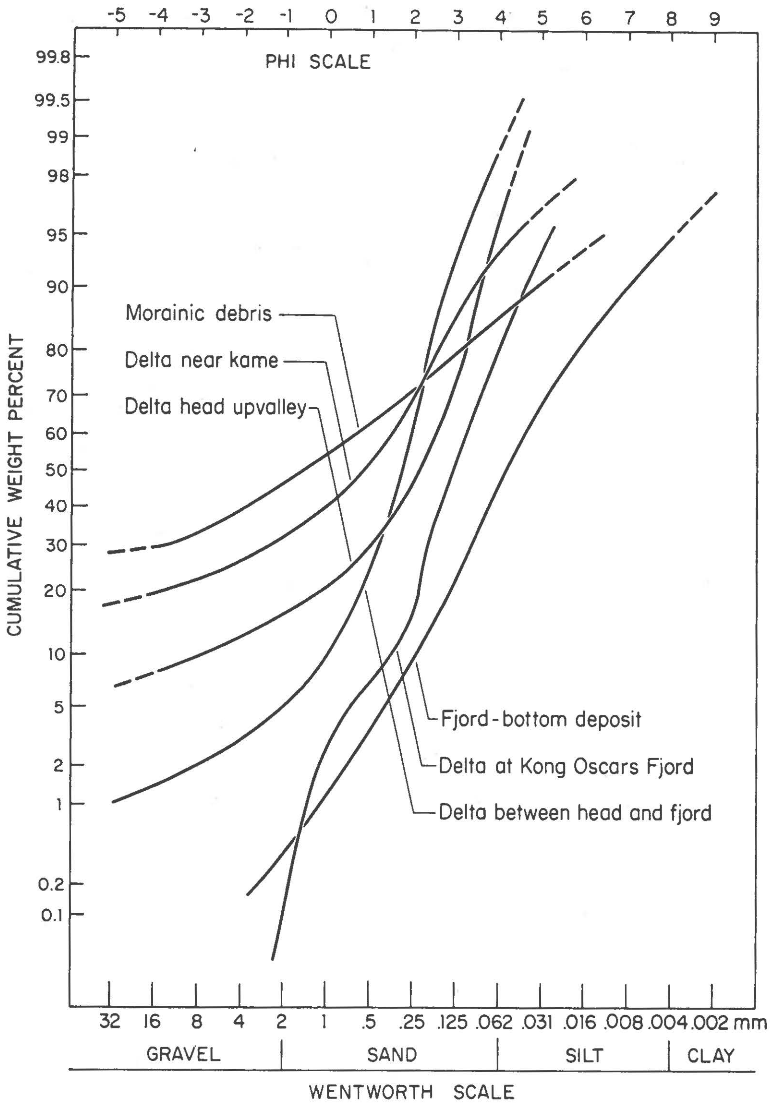

Fig. 3. Generalized distribution curves for lower Skeldal marine delta, fjord-bottom, and moraine sediment (see discussion p. 19 f.).

The delta deposits just north of the kame-kettle complex downvalley from Vifteelv on both sides of Skeldal Elv are similar in composition. The parts in contact with the kames are very coarse and grade quickly to finer sediments toward the fjord. This gradation of delta sediments toward Kong Oscars Fjord is represented by size distribution curves in Figure 3.

Several points pertinent to Figure 3 deserve comment. (1) The curves for the delta sediment are compiled from twenty samples as follow:

Delta near kame: five sample localities between 0 and 0.2 km from the head of the delta.

Delta head upvalley: five sample localities between 0.2 and 0.5 km downvalley from the head of the delta.

Delta between head and fjord: five sample localities between 3 and 3.5 km downvalley from head of delta.

Delta at fjord: five sample localities between 4.7 and 5 km downvalley from head of delta.

For each group of five samples listed above the weight percent of individual fractions did not vary more than 5 percent by weight between samples. Therefore, an average of each group was taken and used in plotting the generalized delta curves. (2) Twenty-three samples were taken from moraines. The generalized moraine curve is the average of the five samples containing the greatest percent by weight of fine material, i.e., the remaining eighteen samples had higher percentages of coarse material. The curve suggests the lower size limit for moraine material. (3) Sixteen samples of fjord-bottom material were taken. The generalized fjord-bottom material curve is the average of the five samples containing the greatest percentage by weight of the coarse material, i.e., the remaining eleven samples had a higher percentage of fine material. The curve suggests the upper size limit for fjord-bottom material. (4) The sand fraction of the unconsolidated sediments in Skeldal seems to permit discrimination between different areas of the delta, and between delta sediments and fjord-bottom sediments.

The delta near its head consists of dark brown sub-angular to round pebble-cobble gravels, whose matrix ranges from clay-silt to granules. These gravels interbed with, or grade laterally into layers of clayey silt or fine quartz-feldspar sands with accessory biotite. At the fjord the delta consists of well sorted medium to fine, buff to orange-brown sands, interbedded with occasional discontinuous clay-silt layers of variable thickness, and rarely very coarse sand and sub-round to round pebble-cobble gravel. The bedding has a 2° dip toward the fjord, and in several localities overlies fjord-bottom deposits.

Kong Oscars Fjord delta remnant

In the west Skeldal near Kong Oscars Fjord at an altitude of 119 m there is a deltaic deposit containing moderately well sorted sands, interbedded with sandy sub-round to sub-angular pebble gravels with some cobbles. No cross-bedding was found in the deposit. The top surface is a deflation surface where the finer fraction has been blown out from around pebbles and cobbles. This small remnant is evidence of water levels higher than 100 m in Skeldal (cf. p. 27). No marine fossils have been found at this altitude in Skeldal, but it seems probable (see p. 18 f.) that the water was marine.

Upper Skeldal delta deposits

The upper Skeldal delta deposits were deposited in a former freshwater lake upvalley from the Bersærkerbræ when the Bersærkerbræ ice dammed the upper valley. They may be divided into two types of deltaic deposits: those deposited as a kame delta in front of the Bersærkerbræ moraines, and those formed of material from the slopes of east and west Skeldal. The main deltaic deposit in the upper Skeldal lies at the south edge of the Bersærkerbræ, where it was deposited as a kame delta in the lake formed from the Bersærkerbræ ice. This delta consists of sub-angular to sub-round, fair to poorly sorted, granule-pebble to cobble-boulder gravels with some layers of very well sorted silts and sands at its eastern edge. The coarse fraction, which accounts for about 85 percent of the material, is debris carried by the Bersærkerbræ, viz.: the white and pink granites, and various colored quartzites found in the Staunings Alper, and the sandstones and conglomerates of the sediments just east of the Staunings Alper fault.

The other deltaic deposits of the upper valley, occurring on both sides of the present Skeldal Elv braided drainage between Bersærkerbræ and Skelbræ (Pl. V), are much finer in texture. These deposits appear in two sequences and consist of debris carried from the eastern and western slopes of Skeldal by slopewash and streams and deposited in the former lake. The lower highly dissected sequence consists in the upper 15–20 cm of well sorted, light to medium gray, silt-clay or sand-silt, and is underlain by locally derived pebble gravels. The lower deposits are partly overlain by a higher sequence which consists of medium to dark dirty brown, poorly sorted pebble gravels with a very coarse sand matrix.

Kame complexes

Several kame complexes are found in the lower Skeldal. They were deposited around stagnant ice blocks which lay in areas surrounded by the basaltic trap knobs of the lower valley, and as kame terraces related to ice marginal drainage. Each kame complex has sediments which range from silt to sand size material found in lenses or layers, to cross-bedded gravels. The gravels are poorly to fairly well sorted, medium to very coarse sandy, sub-angular (rarely angular) to sub-rounded pebble-cobble gravels, and are commonly interbedded with coarse sand layers.

Some kame terrace sequences which were deposited around stagnant ice, and some which are related to ice marginal drainage, occur in the east Skeldal. They are found in the following localities (Pl. V): (1) at the north end of the Skeldal Elv brained drainage between Bersærkerbræ and Vifteelv, (2) just north of shell locality 2, and (3) between Bersærkerbræ and Vifteelv on the east Skeldal slopes. In many places the upper 10–15 cm of these deposits consists of very fine sand or silt, and locally an Arctic Brown soil is developed at the surface (cf. UGOLINI, 1965). Although there are some erratic boulders on top of these deposits, the general character of the deposits is indicative of the sedimentary rocks of the eastern slopes of Skeldal.

The kame-kettle complex located on both sides of the Skeldal Elv drainage upvalley from the head of the lower Skeldal delta is the largest of the kame deposits found in Skeldal, and includes all kame deposits between the head of the delta and Vifteelv (Pl. V). It has many kettles and ice channel fillings and consists of sediments ranging in size from clay to boulders. On the east the sediments are principally derived from the sedimentary rocks of the Lebachia Series and the trap knobs of east Skeldal, but also contain erratic material from west Skeldal. On the west near Vifteelv the Staunings Alper rocks give a dusky brown to brownish-black color to the entire western side of the complex. The kettles serve to distinguish the kame complex from the delta deposits to the north.

Boulder lag deposits are found in the bottoms of many kettles in the kame complex. There seem to be at least two explanations for this: (1) the finer fraction was washed from around the boulders after the boulders were deposited, or (2) that the boulders are a lag deposit, melting out of the ice which formed the kettle, i.e., the boulders are lowered into the center of the depression as a reversal of topography occurs (discussion with A. L. WASHBURN, 1964).

A kame terrace deposit, the Kong Oscars Fjord kame terrace, occurs on the western slopes at an altitude of 182 m where Skeldal joins the Kong Oscars Fjord valley; it was deposited against the Kong Oscars Fjord glacier by ice marginal drainage. It can be argued that this deposit is a kame moraine, but I think that the fluvial nature of the deposit as indicated by the sorting and large amount of finer material justify calling it a kame terrace. This very small remnant is the only indication in Skeldal of a minimum height for the Kong Oscars Fjord ice.

Fjord-bottom sediment

Fjord-bottom sediment is found only in the lower Skeldal, downvalley from Vifteelv. It was described by WASHBURN and STUIVER from the Store Blydal area of the Mesters Vig district (1962, p. 69) as a "fossiliferous till-like ... emerged fjordbottom deposit." I followed WASHBURN and STUIVER's (1962, p. 66) reasoning in this matter:

> A till-like aspect of a fiord-bottom deposit could be due to deposition from debris-loaded icebergs as they floated past sites colonized by molluscs, and solifluction following emergence could have contributed to it. Lithologic criteria were useless, for material carried and deposited by a glacier could have been picked up from the fiord bottom. Even the presence of uncrushed, paired mollusc valves need not be diagnostic in some situations [DONNER and WEST, 1957, p. 25–6]. However, if the till-l'ke deposit was laid down during a major glacier advance it should be (1) significantly older than fossiliferous deltaic beds deposited after the ice retreated, and (2) much more nearly of one age and lack any systematic correlation between age and altitude.

In Skeldal the fossiliferous fjord-bottom material consists of fine sand-clay to clay of uniform composition, generally without bedding and containing small angular pebbles and cobbles of erratic material, i.e., material from the Staunings Alper complex to the west. Some boulders occur in the deposit. The presence of the Staunings Alper material and lack of local material in the deposits suggest that the material is either from an earlier glacial phase which deposited till, or a fjord-bottom deposited material.

Molluscan dates from the Skeldal (see p. 45 f.) confirm WASHBURN and STUIVER's (1962, p. 69) conclusion from another part of the Mesters Vig district that "the fossiliferous till-like material is an emerged fiord-bottom deposit." This conclusion is based on the altitudes and associated ages of the till-like material and the fossiliferous deltaic deposits found in Skeldal (see p. 17 f.) and the Mesters Vig district.

The fjord-bottom material is found in the lower Skeldal where it interfingers with the deltaic sediments of the lower Skeldal delta. The fjord-bottom material consists of silt-clay$_{50-60}$[1], and very fine sand$_{20-30}$ with occasional pebbles and cobbles, or rarely boulders. Size analysis was effectively used to separate deltaic deposits from fjord-bottom deposits as is shown by the size distribution curves Figure 3, (see discussion, p. 19 f.). In several places the fjord-bottom material underlies delta deposits, but south of shell locality 1 fjord-bottom material has flowed over the delta deposits by solifluction causing drag folds to form and materials to mix at the contact. The fjord-bottom material is distinguished in Skeldal by its till-like appearance, sparse vegetation cover, and color which varies from a light medium to medium gray. In the Store Blydal area the local rock materials give a slightly pinkish hue to some fjord-bottom deposits (A. L. WASHBURN, personal communication,

[1] Subscripts indicate percents, see WASHBURN, SANDERS, and FLINT, 1963.

1964); this was not noted in Skeldal. Frost mounds commonly form in the fjord-bottom deposits and generally develop polygonal patterns at the surface. One pingo occurs in fjord-bottom material; it will be discussed together with the alluvial-outwash pingos later in this report (discussed below).

Alluvial fans and outwash

The alluvial deposits consist of material deposited in alluvial fans by rivers tributary to the Skeldal Elv braided drainage. The Skeldal Elv braided drainage area (Pl. V) consists primarily of outwash sediment. Both the alluvial deposits and the outwash deposits of the lower Skeldal are of very coarse pebble-cobble gravels with some boulders. The Skeldal Elv braided drainage of the upper Skeldal, and the outwash between Bersærkerbræ and Vifteelv on the west side of the valley consist of pebble-cobble gravels with silt-sand matrix. The main Skeldal Elv drainage follows the east side of the valley below Bersærkerbræ, and encompasses the entire braided drainage below Vifteelv (Pl. V). Additional debris has been contributed to the alluvial fans by slushflows (Washburn and Goldthwait, 1958). Where slushflows have occurred the alluvial fans have many more boulders and frequently a higher silt-clay percentage than is found in the surrounding alluvial deposits. The boulders are strewn over large areas of the fan peripheral to the small rivers (often only 10–30 cm deep and 2–3 m wide) which drain across the fans. The slushflows contribute much coarse debris to the alluvial fans; this is especially true in the east Skeldal. The alluvial deposits consist primarily of locally derived material; the outwash material contains a wide variety of rock types from the glacial debris and modern alluvium. In both the alluvial and outwash materials the coarse fraction comprises more than 50 percent of the material in the deposit.

Pingos occur in several places in the alluvial and outwash deposits of the lower Skeldal. The formation of the East Greenland pingos has been described by Müller (1959, p. 56–71). Briefly Müller's hypothesis states that pingos are formed when water is forced by hydrostatic pressure into a permafrost zone where the rising water produces a hydrolaccolith; as the temperature is lowered the water freezes. The resulting crystallization pressure and continuing hydrostatic pressure cause the overlying unconsolidated debris to be forced upward forming the pingo. As the process continues the top of the pingo is ruptured and partial melting produces subsidence at the center. If conditions remain the same further growth will occur, but if conditions change complete melting of the ice core, followed by collapse of the pingo, results.

The pingos of lower Skeldal occur in the following localities (Pl. V): (1) on the east side of the Skeldal Elv braided drainage between Bersærkerbræ and Vifteelv, (2) at the northeast edge of the Vifteelv alluvial fan, (3) in the fjord-bottom deposit south of shell locality 3, and (4) in the Skeldal Elv braided drainage between shell locality 3 and Kong Oscars Fjord. The pingos are formed in alluvial and outwash material, which consists of very coarse pebble-cobble gravels. These pingos are about 10 m high, 120 m in diameter. The highest pingo found in Skeldal is formed in fjord-bottom material and is 26 m high. The eleven pingos of Skeldal are found in all stages of development: some occur as collapsed pingos with ponds in their craters; others remain as ice-cored hills of unconsolidated debris.

Lacustrine deposits

Lacustrine sediments occur at the northeast end of the Skeldal Elv braided drainage between Bersærkerbræ and Vifteelv. The deposits are overlain by alluvial materials from the eastern slopes of Skeldal, and therefore appear only in a small area on the surficial map (Pl. V).

The lacustrine sediments consist of interbedded fine to coarse sands with occasional pebble or granule layers. These deposits commonly have involutions where frost heaving has occurred. Many of the deposits are tilted 2°–4° toward the eastern slopes of Skeldal because of vertical force exerted by present day ice wedges or ice lenses at the base of the deposit near Skeldal Elv. The lacustrine deposits found in west Skeldal just south of Vifteelv consist of silts and clays. They occur in a small collapsed pingo where the lacustrine sediments have been brought to the surface. Since this is the only lacustrine material found in west Skeldal, it seems probable that either the lacustrine sediment is from local ponding or it is a more extensive buried lacustrine deposit which was subsequently covered by Bersærkerbræ outwash.

At the north end of the Skeldal Elv braided drainage a series of varved sediments occurs. The varved sediments were found in only one locality and indicate a ponded area upvalley from the southernmost fjord-bottom deposits. The annual paired layers of the varves are of different colors. The light summer color is gray brown (Munsell color 10YR 5/2) to olive gray (5Y 5/2); the winter color is dark gray (5Y 4/1). Graded bedding separates the winter from the succeeding summer layer. The average width of the paired varve is 1 cm; rarely they are as much as 10 cm wide. Unfortunately the varve sequence has been brought to the surface by vertical pushing from below by frost heaving or pingo development which has disturbed the normal bedding of the varves. It was therefore impossible to estimate the time involved in the ponding from the varve sequence. Varve-like material was found underlying several deposits upvalley; it is possible that the varve sequence extends under all other lacustrine sediments in the area (cf. p. 44).

Beaches and marine strandlines

The beaches in Skeldal are of three types: modern, remnant with strandlines, and ice pushed. Although lacustrine strandlines could be discussed here, a separate section is devoted to them (p. 33 f.). The deposits considered in this section are the modern and remnant beaches and ice pushed beach ridges found in the lower Skeldal near Kong Oscars Fjord.

Modern beaches

The modern coastline has many trap knobs (p. 11 f.) and where they extend into the fjord they are commonly connected by beaches. These deposits do not appear on Plate V since they are only 3 to 20 m wide measured from mean sea level. The modern beaches found along the coast of Kong Oscars Fjord vary from well sorted sand beaches with a normal size distribution, to those which are shingled with flat or subrounded to round pebbles and cobbles.

Typical of the modern beaches is one found at "Skelhytte" (Fig. 8). This beach is made of coarse sandy$_8$ gravel$_{85}$, mainly pebbles in the breaker zone, but grades to gravely$_{15}$ sand$_{85}$ five meters from mean sea level in the foreshore area. The beach sand has a normal distribution with a median diameter of .38 mm. Scattered over the beach are cobbles and very rarely boulders. In late July, seasonal frost was encountered at 5 cm below the surface near mean sea level, and at 30 cm below the surface eight meters further shoreward. The difference in depth of the seasonal frost is presumably due to the length of time that each locality is exposed to the sun, since the incoming tide would afford some protection to the area at, and immediately onshore from, mean sea level.

In other sections of beach along Kong Oscars Fjord the beach surface is covered with a lag deposit of pebbles (from 2 cm square by 1 cm thick), cobbles, and flat boulders (6 by 30 cm across by 1 cm thick) with the finer fraction washed out; underlying the lag deposit were interbedded fine and coarse sands. Many ice pushed ridges commonly 1 m high were noted along the modern beaches during May and June, but by July normal fjord wave action had destroyed them.

Remnant beaches

Remnant beaches which form strandlines occur in several areas along Kong Oscars Fjord (Pl. V). Some of the strandlines are superimposed on delta deposits as is indicated in Plate V. At the easternmost beach deposit on Kong Oscars Fjord, beach deposits overlie delta deposits. At the other beach localities along Kong Oscars Fjord entire deposits consist of beach sediments. The remnant beaches in Skeldal have many features found in the modern beaches. The westernmost Kong Oscars Fjord beach deposits with strandlines to altitudes of 22 m contain well sorted sands with normal size distribution. The beach deposits east of Skeldal Elv on Kong Oscars Fjord have strandlines to altitudes of 19 m and consist of lichen covered, sub-angular to sub-round pebble-cobble lag deposits in the upper 5 cm where the finer fraction has been washed out, and then granule-pebble gravels to the frozen ground which occurred at a depth of 20 cm in late July.

Ice pushed beach ridges

Marine ice pushed ridges have been described from polar regions by Hume and Schalk (1964), Nichols (1953; 1961) and Washburn (1947). Ice pushed ridge features were noted in the modern beaches in Skeldal during the spring months, but were subsequently destroyed during the summer by storm action except for features well up on the foreshore slope. In Skeldal the ice pushed ridges which are preserved occur in a beach deposit (west of shell locality 5 and 6, Pl. V) at an altitude of between 110 and 120 m above the present mean sea level. This beach deposit consists of two areas: to the south it is partially protected by the bedrock slopes of Syltoppene and is an undisturbed beach surface; to the north it has the ice pushed ridges commonly seen on Arctic beaches. These ridges generally are 1 to 3 m high, and in one area reach a height of 8 m. The entire deposit consists of medium to coarse sand gravels with sub-angular to nearly-round pebbles and cobbles. The position of the deposit indicates that a tombolo extended from the edge of Syltoppene to the trap knob at the fjord, and ice pushed beach features formed both east and west of the bar. The appearance of lower-lying materials to the east, i.e., lower ice pushed material in the colluvial debris, indicates that more ice push activity was directed at the bar from the east. The ice pushed ridges together with the high Kong Oscars Fjord delta deposit (p. 20) are the only evidence of water levels higher than 100 m in Skeldal.

Colluvium

Colluvial deposits in the lower Skeldal (Pl. V) vary widely in texture. The deposits consist of clays, silts, sands, gravels, and in some places bouldery slide rock concentrations. The term colluvial deposit usually refers to a deposit, "composed chiefly of the debris from sheet erosion deposited by unconcentrated surface runoff or slope wash, together with talus and other mass-movement accumulations (Howell, 1960, p. 78)." In this report, in addition to the usual sediments mapped under the term colluvium a variety of deposits too small to map separately has been included. In each case these smaller units are partly covered with colluvium. The extensiveness of the colluvial deposits suggests a long period of rigorous climate and by implication a long period that Skeldal was ice free (see p. 39 f.).

For example, many of the lower Skeldal deposits consist of the interfingering delta and fjord-bottom sediments which are in part covered with colluvium. The thin veneer of colluvium is constantly being eroded to expose the underlying delta or fjord-bottom material. To map each of these deposits separately would require a much larger map scale, and it would not contribute significantly to the interpretation of the surficial deposits to map these units individually. Therefore, unless the delta or fjord-bottom sediments could be separated into mappable units, they were included under the term colluvium. The same criterion was used in mapping beach and kame deposits partly covered with colluvium.

Erratics

An erratic line mapped on the east side of Skeldal (Pl. V) corresponds in altitude to the 500 meter moraines of the western slopes. East of the Staunings Alper fault it was possible to use Staunings Alper rock types as erratics, since the bedrock east of the fault consists of sedimentary rocks and basaltic dikes only (see discussion of general geology, p. 10 f.; and Fig. 2). Three rock types considered to be erratics were used in mapping the erratic line: migmatite or gneissic (white) granite, biotite rich alkali feldspar (pink) granite, and biotite quartz monzonite. In each case only angular boulders with a minimum diameter of 30 cm were considered erratics; in 90 percent of the localities where erratics were found the boulders were over 0.5 m in size. In none of the conglomerates of the east Skeldal were boulders of migmatite or gneissic (white) granite, or biotite quartz monzonite found. However, there were well rounded boulders of alkali feldspar (pink) granites to 30 cm in size in some of the conglomerates of the Lebachia Series. Therefore, when pink granites were concerned I was careful to regard only *angular*, *biotite* alkali feldspar (pink) granites a minimum of 50 cm in size as erratics.

In the east upper Skeldal no erratics appear on any of the moraine remnants. At Øvre Gefionpas, A. L. Washburn (personal communication, 1963; see p. 31, and Pl. V) has recorded glacial striae parallel to Øvre Gefionpas on a grayish-green conglomerate sandstone ledge, and has noted evidence of glacial plucking of the bedrock exposures in the pass. I have also observed, in company with Washburn, large pink migmatite granite, and gray granite erratics at the base of Øvre Gefionpas near Tunnelelv in the Store Blydal (Pl. I, Fig. 1). In Skeldal it was noted that boulders greater than 1 m in size occurred more commonly downvalley from Øvre Gefionpas, presumably due to the major contribution of debris from the Bersærkerbræ. These observations indicate that ice, probably from the upper Skeldal, moved across Øvre Gefionpas from Skeldal.

Slide and protalus rampart debris

Slide rock debris is mappable in three areas of Skeldal: (1) on the west slopes of Hesteskoen in the lower east Skeldal, (2) in the lower west Skeldal just north of Bersærkerbræ, and (3) at the east end of Syltoppene in the lower west Skeldal (Pl. IV, and V). Other less extensive areas of slide rock debris occur in Skeldal, but were not mapped because of their small size: some are included under colluvium. The debris in each case consists of rock debris derived locally from the cliffs immediately above the deposits. The deposits have generally arcuate forms.

The landslide area on Hesteskoen lies above the erratic line at an altitude of about 680 m. The debris consists of angular boulders to 4 m in size of basaltic dike material, sandstone, and conglomerate and lies at the base of the cliff that extends to the top of Hesteskoen. The material rests at its angle of repose (33°) and is unstable on the frontal slope. Some medium to coarse sands and angular cobbles occur in small deposits between the boulders. The deposit has a 22° backslope.

On the western slopes of Skeldal just north of Bersærkerbræ an extensive slide rock accumulation is found with several arcuate lobes of material derived from the slopes directly above. This area of slide rock debris lies next to the Staunings Alper fault slightly below the 300 meter moraine of the west lower Skeldal. The debris is well weathered and consists in large part of material from the Skeldal conglomerate and the metamorphic rocks adjacent to the fault. The debris has weathered to a $sandy_{20}$ pebble-cobble $gravel_{80}$ which is orange-brown to gray in color and has been highly dissected by intermittent streams. Much of the material comes from the highly fractured zone at the fault.

At the top of the large sedimentary slide block at the east end of Syltoppene there are a number of protalus ramparts. These deposits are called protalus ramparts for the following reasons:

1. They consist of local material.
2. Some lobes are made up entirely of large angular boulders up to 4 m square; others consist of pebbles, cobbles, and boulders.
3. Very small backslopes occur (angles from 1–3°).
4. They form in a series of lobes at the foot of the cliff.
5. There are small ponds in some of the lobes which suggest the presence of a snow or ice core.
6. The finer fraction is totally absent or constitutes a very small percentage of the deposits which suggests that the blocks and fines were deposited on snow with the fines washed out when the melting occurred.

The area between the protalus ramparts and the front edge of the slide block has a moderate to heavy lichen cover and a light to moderate vascular plant cover. No erratic material is found on the protalus ramparts, but erratic material occurs on the front edge of the block. Erratics include biotite alkali feldspar (pink) granite, and migmatite or gneissic (gray) granite; they are usually rough on the surface which is not true of the recent debris found on the protalus ramparts. This may indicate that the erratic material has undergone a longer period of weathering. Very few erratics were found on the front slope between the edge of the slide block and Skeldal Elv, although some morainic debris consisting of sandy pebble-cobble gravels with boulder erratics to 1.5 m in size was seen at the north end of the slide block and on the tops of small slide ridges on the front slope of the block. The smaller slides on the front slope of the block have probably occurred after the withdrawal of ice from the area. This would account for the small number of erratics on the frontal slopes since local slide material would effectively bury the erratics. The sequential relations and significance of these deposits are discussed under "Glacial chronology," (p. 38 f.).

STRIATIONS

Glacial striations are found on the basaltic trap knobs of the lower Skeldal and in Øvre Gefionpas on a greenish-gray conglomeratic sandstone. The striation bearings were originally taken with magnetic compass, but were corrected to true bearings before plotting on the surficial map (Pl. V). A declination of 33° west was used in conversion from magnetic to true bearings as suggested by the Navigation Officer, U.S. Naval Air Station, Keflavik, Iceland, and confirmed by Flyvepladsen, Mesters Vig, Northeast Greenland in 1963. The striations on Øvre Gefionpas (N 84° E to S 85° E true) parallel the pass[1] and give some indication that ice moved from Skeldal over the pass into Store Blydal (see Pl. I and V, cf. p. 28). Striations in the lower Skeldal (trend N 25° E true) parallel the valley until near the fjord where the direction changes toward the east (trend N 65° E true). A second set of striations parallels Kong Oscars Fjord (trend S 70° E true). Both east and west of Skeldal Elv near the fjord the striations from Skeldal are superimposed on those from Kong Oscars Fjord, indicating that the Skel ice advanced over an area formerly striated by Kong Oscars Fjord ice at a time following the withdrawal of the Kong Oscars Fjord ice (see discussion, p. 41 f.). There were no striations found on the mountain tops.

[1] Striations on Øvre Gefionpas are from observations made by A. L. Washburn in 1958. The readings have been corrected to true bearings from Washburn's magnetic bearings using a declination of 32° west as suggested by the Navigation Officer, U.S. Naval Air Station, Keflavik, Iceland, for the year 1958.

ICE MARGINAL DRAINAGE

During deglaciation ice marginal drainage channels developed on the east and west sides of Skeldal. These channels have been preserved in the sedimentary strata east of the Staunings Alper fault, and on the trap knobs of the lower valley. Ice marginal channels were recognized by the following criteria: (1) they are obviously drainage channels but are not now occupied by streams, (2) they have glacial debris, including erratics, in or adjacent to them, (3) they are a systematic series of parallal drainages which more or less parallel the contours but slope downvalley, (4) they parallel the main valley, (5) they correspond to ice marginal drainage features reported from other regions, (6) there are debris concentrations where the ice marginal drainage channels meet Kong Oscars Fjord valley, (7) some channels are open-ended upvalley.

Ice marginal drainage channels are conspicuous at the north end of Hesteskoen where a nearly continuous sequence of drainage channels, which have since been dissected by recent streams, occurs from the erratic line downward. The most prominent ice marginal drainage features occur in the trap complex on the north end of Hesteskoen, at about 400 m. Here ice marginal drainage channels have been cut 40 m through basaltic cap rock and underlying sediments by meltwater channeled along the edge of Hesteskoen. This marginal drainage has resulted in boulder concentrations where the channels discharged into the main Kong Oscars Fjord valley. The 40 m of incision indicate either tremendous discharge of sediment-filled waters at some point in time, or continuous heavy discharge over a long period of time.

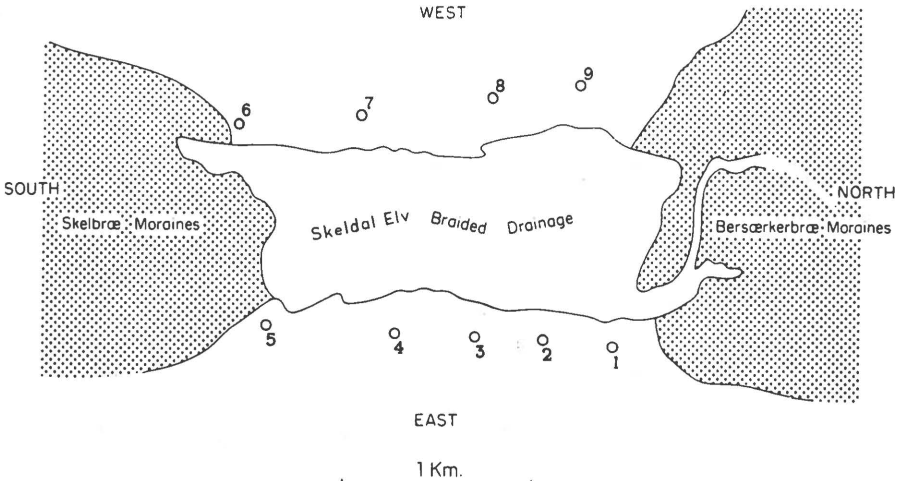

Fig. 4. Site localities for lacustrine strandlines of the upper Skeldal.

LACUSTRINE STRANDLINES

In the upper Skeldal between Bersærkerbræ and Skelbræ a number of lacustrine strandlines formed when the Bersærkerbræ ice blocked the upper valley damming the meltwaters of Skelbræ ice and forming a lake whose maximum dimensions were approximately 2.4 by 1.4 km. The strandlines were surveyed using a Wild T-2 theodolite reading directly to one second. Standard surveying procedures were used; for-

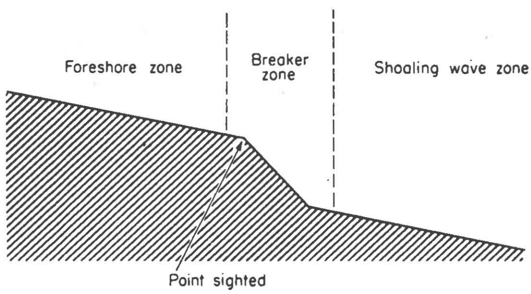

Fig. 5. Diagrammatic section of strandline indicating point used in sighting.

ward and reverse sights were taken at both ends of the baseline and each set of readings was closed to the initial site (Fig. 4) with no more than a two-second error. Sets of readings were taken in the forenoon, afternoon, evening and night. The beach breaker zone's contact with the foreshore was used as the point for measuring the strandlines (Fig. 5).

There is a continuous series of strandlines from an altitude of about 170 m down to the outwash of the Skeldal Elv braided drainage at about

120 m. Three major strandlines are traceable around all parts of the lake except at the Bersærkerbræ where dissection of the moraines prevented their recognition. The three major strandlines have altitudes of 156, 160, and 164 m and are herein referred to as the lowest, middle, and highest strandlines respectively. Since the baseline was set up in the former lake bottom (now outwash debris) the readings in Table 2 are in elevations in meters above the baseline. The readings for each site listed in Table 2 are the average of the four readings taken at each site.

From the data in Table 2, and Figure 6, the following generalizations may be made: (1) Strandlines are generally progressively higher

Table 2. *Upper Skeldal strandlines. Numbers and measurements in meters above baseline. See Figures 3 and 5, and text p. 33 f.*

	South end ········	········	········	North end
West Skeldal:	**Site 6**	**Site 7**	**Site 8**	**Site 9**
Highest	36.63	37.07	36.45	37.53
Middle	33.56	33.42	33.45	34.39
Lowest	29.86	29.46	29.06	29.48

	South end ········	········	········	········	North end
East Skeldal:	**Site 5**	**Site 4**	**Site 3**	**Site 2**	**Site 1**
Highest	36.62	36.55	36.48	36.90	–
Middle	34.06	33.94	33.23	32.89	33.02
Lowest	30.02	29.93	29.12	28.12	28.92

south of sites 2 and 8, with the exception of the middle west strandline, i.e., from site 5 toward site 2 of east Skeldal and from site 6 toward site 8 of west Skeldal strandlines are lower to the north. (2) All strandlines rise to the north from a low at sites 2 and 8 toward sites 1 and 9. (3) The strandlines on the western side are higher than those on the eastern side at the north end (cf. sites 1 and 9).

Several factors may contribute to these variations. First, the Staunings Alper fault lies close to the west side of the former lake. Small movements along the fault may have tilted all or part of the strandlines. Second, some tilting may be due to glacial unloading following the downwasting and withdrawal of the Skeldal ice (the term "Skeldal ice" refers to all ice in the Skeldal). Third, while the winds which acted upon the former lake surface are unknown, they may have altered the water surface and consequently the strandlines. Fourth, meltwater discharge from the ice may have locally modified portions of the strandline.

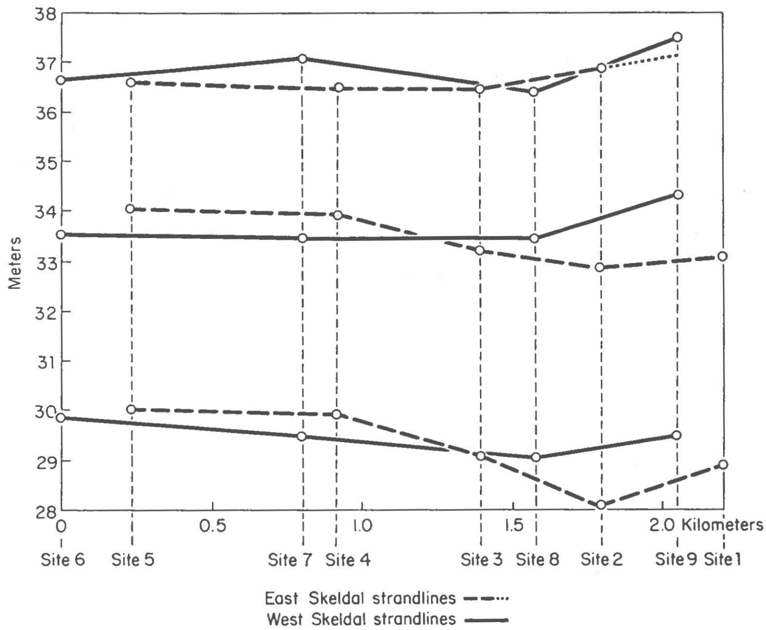

Fig. 6. Plotted results of freshwater strandline survey. Note: see Fig. 4, for site localities.

Although all these factors could have acted separately or in combination I feel that glacial unloading and wind action are the major factors influencing the present strandline configuration for the following reasons: (1) No evidence of recent fault movement was seen. (2) The meltwater discharge would have modified only local parts of the strandlines; the additional water would have uniformly changed the level of the lake. (3) Winds blowing downvalley from the ice, having a fetch of 2.4 km over the lake, could, when storm waves generated by the wind are considered, account for the 1 m (maximum) height increase of the strandlines at the north end of the lake. (4) The major emergence in Skeldal took place prior to 6,000 B.P., and the present rate of emergence is tentatively set at 7 cm/100 years based on comparison of radiocarbon dates and deposit altitudes discussed later (p. 45). Assuming that emergence is primarily due to glacial unloading and isostatic adjustment (see p. 46 f.), the rate of emergence indicates the order of magnitude of possible tilting which could occur with isostatic adjustment. About 4 m of emergence has occurred during the last 6000 years; if tilting occurred, it should be no greater than 4 m over the same period of time, or at the same rate of emergence less than 3 m during the last 4500 years and possibly only 1 m during the last 1500 years. (5) Isostatic adjustment is related to ice thickness. Since ice at least 500 m thick covered Skeldal (see discussion p. 14 f. and p. 28 f.), it is possible that glacial rebound of about 170 m could occur with glacial unloading.[1] Since thinning and retreat of the Skeldal ice was from north to south, it seems reasonable to assume that differential rebound occurred in Skeldal.

In summary, there is clear evidence of glacial rebound in Skeldal, and the adjustment probably caused some tilting. It is therefore suggested that the decrease in height from the south end of the strandlines to the north toward sites 2 and 8 is the result of tilting caused by glacial unloading.

[1] For a discussion of glacial loading and isostasy see MACLEAN, 1961, p. 14–26. Use of the formula suggested by MACLEAN, p. 25, assuming that the ice has a density of .92 and a thickness of 500 m (minimum thickness of Skeldal ice), and that the asthenosphere has a density of 2.7, results in depression of about 170 m. Therefore, it seems likely that about 170 m of rebound could occur in Skeldal. Formula: $D = t\frac{di}{da}$ where "D" is depression, "di" is density of the ice, "da" is density of asthenosphere, and "t" is thickness of ice.

WEATHERED BEDROCK

Covering much of the front slope of the sedimentary slide block at the east end of Syltoppene are irregular hills consisting of the weathered bedrock. These are exposed for nearly 1 km, extending 130 m vertically above Skeldal Elv on the front side of the slide block; the exposure includes the entire sequence of lower hills on the block. Topographic expression is very irregular, in part due to small slides which have occurred on the front face of the slide block, and in part due to the bedrock weathering. The parent material consists of two quartz pebble conglomeratic sandstones, one buff, the other pale green in color, from which the unconsolidated debris is derived.

There is no erratic material at the surface of the deposit, even though erratics are found on deposits immediately to the north and south. From the surface of the exposure, where quartz pebble sands occur, to the bedrock contact one progressively encounters more consolidated material. In the intermediate area boulder-size bedrock blocks are found which crumble as pebbles are pried from the matrix sands.

The three zones of the deposit may be described as follow: (1) In the surface zone, 5 cm to 1 m thick, are medium to very coarse brownish-yellow sands with quartz pebbles and cobbles. (2) At intermediate depths between the surface zone and the bedrock progressively more and more bedrock float is encountered. In this zone boulders disintegrate as pebbles or cobbles are pried from the sand matrix of the conglomerate. (3) Finally, bedrock is encountered.

In summary, from the surface to the bedrock, quartz pebble sands grade to quartz pebble sands with very soft sub-angular to angular boulders easily broken with the hands, to more consolidated material which is easily cut with a trench shovel and preserves the bedrock structure, and finally to harder bedrock which can be broken only with a geologic hammer.

GLACIAL CHRONOLOGY

Earlier glaciations

Skeldal, a tributary valley of Kong Oscars Fjord in the fjord region of Northeast Greenland, has several modern glacier complexes, and surficial deposits that reflect a period of more extensive glaciation. In other areas of Northeast Greenland workers have cited evidence of multiple glaciation (Flint, 1948; Lister and Wyllie, 1957), and have stated that glaciers of the fjord region followed pre-existing valleys which were either fault-controlled valleys or stream-eroded valleys now greatly modified by glacial erosion (Bretz, 1935). The evidence for multiple glaciation rests on multiple valley profiles found in the main and tributary valleys in the fjord region.

In Skeldal a change in valley profile was noted in four areas. First, above the erratic line on Hesteskoen and Gletscherryggen there is a marked break in slope. The break in slope may have been caused by (1) a former higher glaciation, (2) two-cycle stream incision which was subsequently eroded by ice changing the two step V profile to a two step U valley profile, or (3) by weathering and mass movement of material above the break in slope while ice protected the lower slopes. It is not structurally controlled since the break in slope cuts across structure on Hesteskoen and Gletscherryggen. The lack of slide rock and landslide debris on the eastern slopes suggests either a former higher glaciation, or mass movements prior to, or nearly simultaneous with the highest ice of the last glaciation so the material could have been incorporated into the lateral moraines and cleared from the slopes. Had the latter been the case one would expect to find some evidence of prominent moraines on the eastern slopes, but none is found. Therefore, a higher glaciation seems probable.

Second, on both sides of Bersærkerbræ valley (although not as clearly seen on the south) a break in slope occurs; the upper slopes are 20–30° less steep than the lower slopes. The break in slope continues into Skeldal between Bersærkerbræ and Vifteelv, and suggests higher levels of ice prior to the last glaciation in Skeldal. Third, in Vifteelv valley a similar break in slope occurs and continues into Skeldal; the upper slopes are more gentle than the lower slopes. Fourth, there is a truncation of tributary valley spurs in the upper Skeldal. These points, although not conclusive, suggest a more extensive glaciation than is indicated by the glacial deposits in Skeldal, and tend to support earlier work which suggests multiple glaciation in the fjord region.

The slide block (Pl. IV) located on the east end of Syltoppene provides additional evidence for multiple glaciation. The following observations are cited to suggest a time of movement for the slide block:

1. If the slide block were replaced in its original position, the profile formed would show the same break in slope found to the south where Vifteelv enters Skeldal, i.e., the valley profile would show gentle higher and steeper lower slopes suggestive of a former glaciation.
2. Replaced in its original position the top of the slide block would lie above (at about 800 m) the 500 m maximum established for the last ice.
3. The top of the slide block now lies below an altitude of 500 m (Pl. V).
4. Morainal debris with erratics up to 1.7 m in diameter is found on top of the slide block.

The sequential relations of the materials on the slide block indicate (1) that the block slid prior to the last glaciation, and after any postulated higher glaciation, (2) that morainic debris found on the top and sides of the slide block is from the most recent glaciation (500 m maximum) in Skeldal, and (3) that minor slides and protalus ramparts (discussed p. 29) were developed after the last ice in Skeldal withdrew.

Two additional points should be mentioned. In a careful study of the upper areas and tops of mountains in east Skeldal no striations or other grooves were noted, and no erratics were found above the previously established erratic line (Pl. V). Further, on the west side of the valley the profiles previously discussed always end in rugged mountain peaks. These observations strongly suggest (1) that the area once had more extensive ice cover than is indicated by surficial deposits of the last glaciation, and (2) that the area was a nunatak region.

Relative chronology

The last glaciation in Skeldal is indicated by the surficial deposits that are distributed throughout the valley. The withdrawal of this ice from Skeldal may be divided into six major phases (Fig. 7):

Phase I. Ice covered the entire valley to a minimum altitude of 500 m and was connected to the Kong Oscars Fjord ice (see section on "Terminology," p. 9).

Phase II. Gradual downwasting and recession of the Skeldal ice. The Skelbræ, Bersærkerbræ, and Vifteelv lobes remain one. Separation of the Skeldal ice from the Kong Oscars Fjord ice, with stagnant ice blocks in several areas.

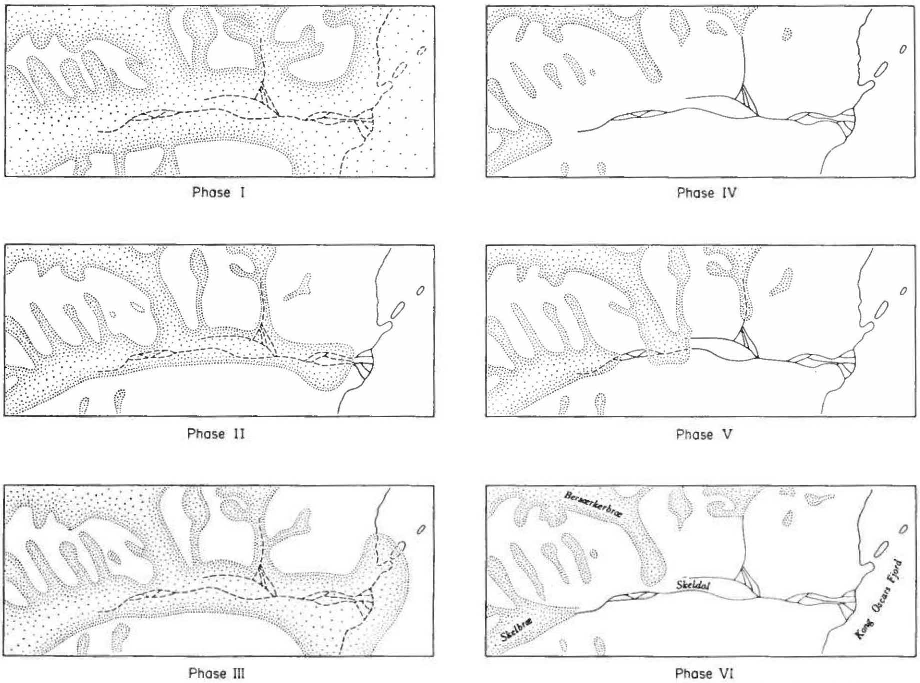

Fig. 7. Diagrammatic sketch showing phases in the deglaciation of Skeldal.

Phase III. Readvance of Skeldal ice to Kong Oscars Fjord. Deposition of 300 meter moraine, and superposition of Skeldal ice striations on Kong Oscars Fjord striations.

Phase IV. Downwasting and recession of the Skeldal ice. Separation of the Skelbræ, Bersærkerbræ, and Vifteelv lobes. Stagnant ice blocks in several areas.

Phase V. Readvance of all glaciers producing the recent moraines of Skelbræ, Bersærkerbræ, Vifteelv, and the smaller glaciers of Skeldal. Blocking of the upper valley by the Bersærkerbræ and the formation of the lacustrine strandlines.

Phase VI. Recent deterioration of the glaciers and development of the modern landscape.

Phase I

During the last glaciation the ice in Skeldal filled the main valley to a point slightly above 500 m, and deposited the oldest and 500 meter moraines. These correlate in altitude with the upper limit of erratics on the eastern slopes of Skeldal. Some moraines occur at higher altitudes in the Skeldal cirque glaciers, but may not mean the main valley ice reached heights of more than about 500 m since these moraines are local in extent. The oldest moraine, the 500 meter moraine, the 500 m erratic line, and the striations at Øvre Gefionpas are the only evidence of the highest ice in Skeldal during the last glaciation.

The valley profiles which show a break in slope between the higher and lower slopes (discussed earlier p. 38) may be additional indications of the highest altitude reached by ice during the last glaciation. During this first phase in the last glaciation ice covered Skeldal to a minimum altitude of 500 m and was connected with the Kong Oscars Fjord ice which was continuous to Mesters Vig (Pessl, 1962; Washburn, 1965) and beyond.[1]

Phase II

The major ice advance which covered Skeldal and the main valley of Kong Oscars Fjord beyond Mesters Vig, was followed by downwasting and recession of ice in Skeldal. The thinning and recession of ice caused the separation of Skeldal ice from Kong Oscars Fjord ice (see discussion p. 41 f.).

One point deserves further comment: the assumption that downwasting and thinning is suggestive of warmer climate has frequently proved compatible with other evidence (e.g., the invertebrate and vertebrate fossil record, and pollen stratigraphy) for warming climate in many areas of the world. In Greenland, very little is known about the causes, or environmental relationships controlling glacial fluctuations. It is possible, for example, to maintain a rigorous climate, and still have glacial fluctuations by changes in alimentation not related to climatic *temperature* changes. The first evidence suggesting a warming climate in Skeldal is large mass movements of material during Phase IV (see p. 42). Prior to Phase IV, there is no evidence to indicate the cause either of deglaciation or renewed glacial activity.

Phase III

Following Phase II which resulted in general deglaciation from the 500 m maximum, there was renewed glacial activity. The moraines at the 300 m level belong to this phase in Skeldal; they lie on the western slopes and are most prominent on the north side of Vifteelv. The glacial phase extended to Kong Oscars Fjord, where striations from the Skeldal ice have been superimposed on the Kong Oscars Fjord striations. The striations suggest that (1) there was a separation of the Kong Oscars Fjord and Skeldal ice prior to a readvance of Skeldal ice, and (2) that the advancing 300 m ice reached Kong Oscars Fjord, where the ice front may have extended into either ponded freshwater, or sea water.

[1] See Figure 7 for series of sketches showing the suggested phases in the glaciation of Skeldal.

Alternatively, the 300 meter moraine could have been deposited during a period of stillstand with relatively stable climatic conditions persisting to maintain a 300 m ice level and permitting accumulation of morainal debris. Had this occurred Skeldal ice and Kong Oscars Fjord ice may not have separated until the general downwasting from the 300 m ice level. The striations from Skeldal which are superimposed on Kong Oscars Fjord striations (discussed p. 31) might then be interpreted to mean that Skeldal ice became relatively stronger than Kong Oscars Fjord ice, and a critical velocity was reached where Skeldal ice became dominant. I prefer to account for the large moraine deposits associated with the 300 m ice level in Skeldal by readvance rather than stillstand, arguing that it is far more difficult to maintain the long period of climatic stability necessary for a stillstand, than to have a period of generally colder but unstable climate which would result in a glacier's readvance.

The estimated gradient of the 300 m ice provides additional evidence that the Skeldal 300 m ice reached the fjord. Using the 300 meter moraine to estimate former glacial surface gradient, a gradient of 10 m per kilometer may be inferred for the ice between Bersærkerbræ and Vifteelv. Even if the estimated gradient were to increase to 30 m per kilometer (which is suggested by the gradient of the 300 meter moraine between the upvalley side of Vifteelv and the furthest downvalley position of the moraine) and extrapolated to the fjord, there would still be a 60 m ice front extending into Kong Oscars Fjord.

Phase IV

Following the glacial phase that deposited the 300 meter moraine, thinning and recession of the ice from the 300 m level began, opening a passage from the fjord upvalley toward Vifteelv. Into this inlet the lower Skeldal marine delta[1] was deposited. It formed first on the west side of Skeldal as outwash debris, carried by meltwater from the downwasting Skeldal ice, was deposited in the sea. Accompanying downwasting was the formation of successively lower marginal drainage channels found today on the valley slopes.

The Kong Oscars Fjord kame delta was deposited from the retreating ice front at this time into the sea (or dammed lake); no faunal assemblage is found in the deposits related to the sea at this time. The lack of marine fossils suggests that either very limited circulation with the open sea existed, or that there was no opening to the sea. The smallness of the deposit suggests that the ice withdrew quickly, retreating

[1] Term used for consistency, see p. 18f., even though the deposit is not known to be marine at this time.

over the trap knob against which the Kong Oscars Fjord kame delta deposit lies. Sediment from the retreating ice and debris carried by ice marginal drainage were deposited as a tombolo which extended from Syltoppene to the trap knob at the Fjord. The beach deposits west of shell localities 5 and 6 formed as the ice retreated freeing the area to an encroaching sea. Icebergs calving from the retreating Kong Oscars Fjord ice on the west and the Skeldal ice on the east grounded on the bar forming the ice pushed ridges which are seen today at an altitude of 110 m (discussed earlier, p. 27).

Deglaciation continued, and gave rise to mass movements of material which resulted in features found on Hesteskoen and the front of the slide block at the east end of Syltoppene (see discussion p. 29 and 37). These deposits of mass wasted material are the first evidence suggesting that a warmer climate was at least in part causing deglaciation. The deterioration of the ice extended the inlet between Kong Oscars Fjord and Vifteelv east and west permitting deposition of fjord-bottom material over the entire Skeldal downvalley from Vifteelv as the ice withdrew. Throughout this time the lower Skeldal marine delta continued to form. Simultaneously with deposition of delta sediment in the lower Skeldal, silts and clay were deposited in the area which extended from Kong Oscars Fjord to the Skeldal ice front, partially inundating the trap knobs of the lower Skeldal. The sediment composing the fossiliferous fjord-bottom material (discussed p. 22) was deposited in localities which at present are up to 88 m above sea level; the fossil assemblage (Table 3, p. 48) provides the first evidence of an open passage to the sea. Erratic angular pebbles, cobbles and boulders released from debris-loaded icebergs were incorporated into the fjord-bottom deposit. The fjord-bottom sediment in front of the delta interfingers with the deltaic deposits, a relationship seen in the deposits of the lower valley.

During the deglaciation several kame complexes formed in the stagnating ice left behind as the Skeldal ice retreated and separated into three lobes (Skelbræ, Bersærkerbræ, and Vifteelv). As recession continued the smaller tributary glaciers separated from the main lobes to form the cirque glaciers of the upper Skeldal. As downwasting progressed drainage channels formed at the margins of the ice on the eastern and western slopes of the valley. In addition, large blocks of stagnant ice were left by the retreating ice, first downvalley from Vifteelv, and then as the Skeldal ice and Vifteelv ice separated, farther upvalley toward Bersærkerbræ. The main areas of stagnant ice around which kame deposits were deposited are north of shell locality 2, the area surrounding shell localities 5 and 6, immediately upvalley from the head of the lower Skeldal marine delta, in east Skeldal between Bersærkerbræ and Vifteelv where the kame deposits now found at an altitude of 100 m formed, and at the north end of the Skeldal Elv braided drainage near peat deposit locality 14 (Pl. V).

The trap knob which extends from the north end of Skeldal Elv braided drainage near peat locality 14 (Pl. V), west to the central bedrock ridge (the ridge separating the Skeldal Elv braided drainage on the east from the braided drainage on the west) acted as a partial dam to the waters of Skeldal Elv causing deposition of bottom sediments and varves in the area upvalley. First ponded sediments and later outwash materials filled the area above the dam over which a 10 m waterfall now flows. Emergence continued in the lower valley, and meltwaters contributed outwash to the Skeldal Elv braided drainage. In the ponded area where the lacustrine sediments had been deposited small marginal ponds developed and gave rise to bog vegetation. In one of these bog areas peat was deposited (discussed later, p. 50) and subsequently buried by alluvial material. The peat was deposited as the ice withdrew from the area to a position of maximum retreat. The slide rock deposits of the west Skeldal began to form as the ice thinned freeing the slopes of ice and permitting mass wasting activity to proceed.

Continuing emergence caused rejuvenation of the streams which were carrying large volumes of meltwater from the downwasting ice and cut 23 m through the bedrock in Vifteelv; the streams tributary to Skeldal Elv on the eastern and western slopes show similar incision. Coinciding with the downwasting of the ice, isostatic readjustment began; the early rate of rebound was approximately 3 m per 100 years (cf. p. 45 f.). Thus, coincident with downwasting and delta formation, rapid emergence occurred. As vertical adjustment took place rejuvenated streams began to incise their stream beds. Although rates of isostatic adjustment varied, and deglaciation was interrupted by a period of glacial advance, the events of the fourth phase may be characterized as follows:

1. Downwasting of the Skeldal ice from the 300 m level.
2. Formation of the Kong Oscars Fjord kame delta, and a tombolo extending between Syltoppene and the fjord coincident with downwasting and recession.
3. The early deposition of delta sediments in the lower Skeldal marine delta as an outlet to the sea was established.
4. The Vifteelv, Bersærkerbræ, and Skelbræ ice lobes became separated.
5. Deposition of a series of kame deposits around stagnating ice in the lower valley.

Phase V

In recent time a readvance occurred which deposited the major moraines located in front of Skelbræ, Bersærkerbræ, Vifteelv glacial complex, and the smaller cirque glaciers in Skeldal. Most prominent of these is the Bersærkerbræ complex which extended across Skeldal at

Øvre Gefionpas, effectively blocking the upper Skeldal. The lake which formed at this time was a freshwater lake created by the meltwaters from the Skelbræ and other minor glaciers of the upper valley. In the upper west Skeldal in front of the first glacier south of Bersærkerbræ a recent moraine overlies an older moraine (discussed earlier p. 17) demonstrating this period of readvance.

Phase VI

Since the last readvance a warmer climate has contributed to a general recession and downwasting of ice in Skeldal. The stagnant ice around which the most recent kame and kame terrace deposits were deposited in the lower Skeldal has completely melted. Emergence continues, but at a much slower rate. As sea level changed three major terrace levels were cut into the Vifteelv alluvial fans. During recent time the glaciers in Skeldal have receded and the ice has withdrawn from its position of maximum readvance (Phase III), opening the dammed lake of the upper Skeldal. Minor fluctuations in the glaciers are recorded in the sequence of moraines between the outermost moraine and the ice front. The fluctuations have caused small kame complexes, ice channel fillings, and fluvial terraces to form within the modern moraine complex.

The final downwasting and recession of the modern glaciers have contributed to the development of the recent landscape. Emergence continues at a much reduced rate, and alluvial deposits are beginning to bury the older bottom, delta, and fjord-bottom sediments. The processes of fluvial erosion and deposition, mechanical weathering, frost creep and solifluction (Washburn, 1965, p. 39, suggests a rate of up to 6 cm per year on a slope of about 10°–14° in the Mesters Vig district) continue to modify the landscape.

Absolute dating

As has been pointed out by Washburn and Stuiver (1962) several studies have been made of emerged strandlines in Northeast Greenland (Bretz, 1935, p. 204–222; Flint, 1948, p. 162–192; Noe-Nygaard, 1932), but until Washburn and Stuiver's paper (1962) information was lacking on absolute dating of emergence. Since 1962, F. Pessl (personal communication) has added some shell dates from the Sortebjerg area, Mesters Vig; J. P. Schafer (personal communication, 1965) has added a shell date from Schuchert Dal. In Skeldal thirteen radiocarbon dates on shell material have been determined; my localities (Pl. V and Fig. 8), species, altitudes, and dates are summarized in Table 3, and plotted in Figure 9. The molluscan shell material collected in Skeldal indicates a fauna, "typical of the Quaternary and Recent seas of Greenland. It

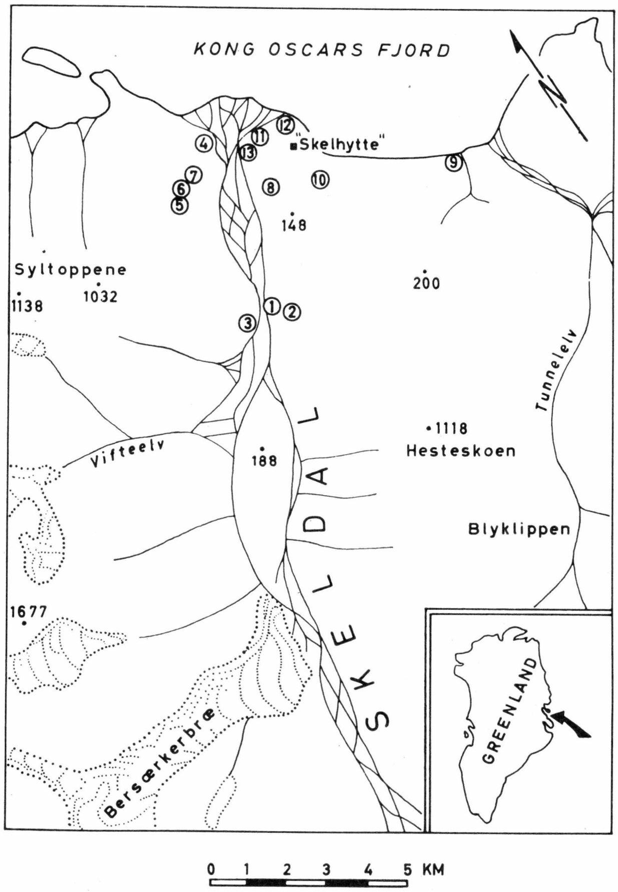

Figure 8. Map of Skeldal showing the localities from which shell material was collected for radiocarbon dating. For locality descriptions, see Table 3.

suggests cold, relatively shallow sea water (Horace G. Richards, personal communication, 18 March 1965)." Information on the distribution of the species is found in *Studies on the Marine Pleistocene* (Richards, 1962).

All the samples were collected from very narrow horizons. Only samples M-1613, M-1616, M-1618, and M-1621 were taken from horizons as great as 1 m thick; all other samples were taken from horizons less than 30 cm thick. In only two cases were shells collected from soliflucted material (samples M-1611 and M-1615). The remaining shells were found in delta top-set or foreset beds, and in sandy shore deposits *in situ*. Shells were considered to be *in situ* when the following criteria were met: (1) shells were complete shells rather than fragments, and (2) there were shells with united valves, or delicate shells which remained intact, or both found in the deposit.

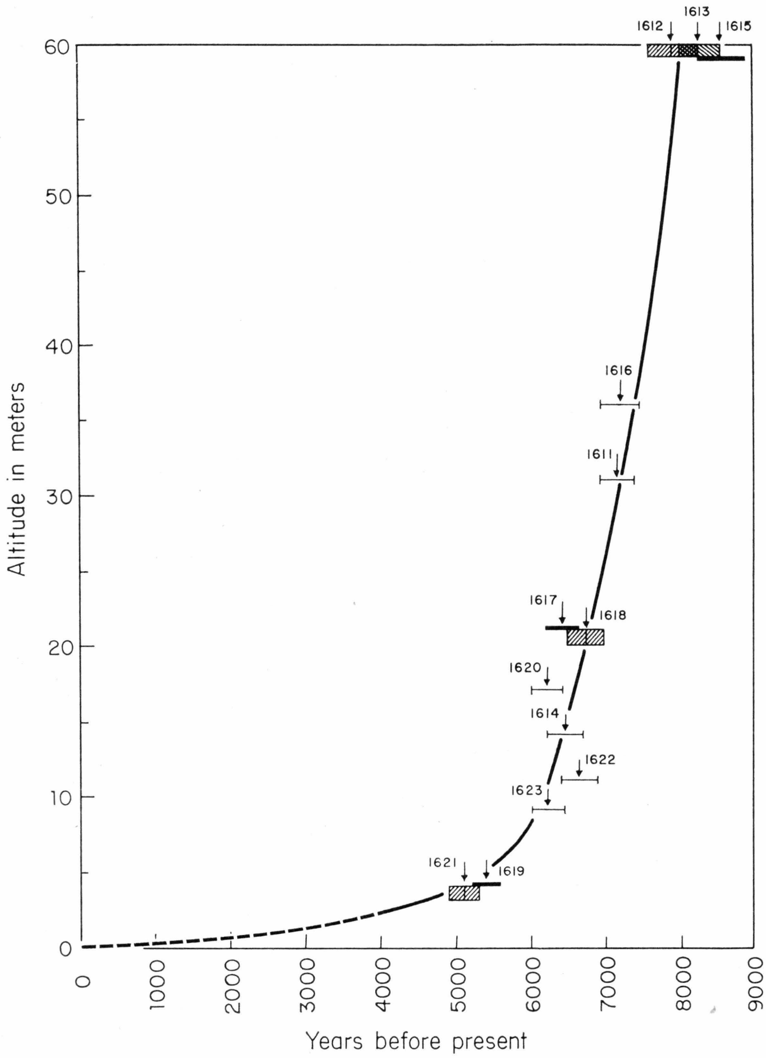

Fig. 9. Radiocarbon ages of shells from Skeldal, Mesters Vig district, Northeast Greenland, relative to altitudes. All dates have been corrected for an apparent age of 550 years based on WASHBURN and STUIVER's (1962) modern shells collected in the area and used as a standard. For descriptions of material see Table 3, p. 48.

Two of the samples were found in shore deposits at strandlines; four were found in top-set delta beds, and two samples (M-1618 and M-1622) are from probable top-set delta beds; three were found in probable foreset delta beds lying not more than 10 m below known top-set beds (samples M-1619, M-1620, M-1621). The final two samples (M-1611 and M-1615) were from a soliflucted fossiliferous till-like material. Eight of the shell samples therefore seem to be closely related to specific former sea levels, since the shells deposited in the shore deposits and in the top-set delta

Table 3. *Radiocarbon dated shells and peat from Skeldal, Mesters Vig district, Northeast Greenland. Note: the second date (in parenthesis) has been corrected in each case for an apparent age of 550 years based on modern shells collected in the area and used as standard (Yale Geochronology Lab. No. Y-606*; Washburn and Stuiver, 1962).

Loc. No.	Mich. Lab. No.	Locality	Species	Field Altitude	C-14 age years B.P.
1	M-1611	E cut bank emerged delta in soliflucted fjord-bot. material, E side Skeldal Elv, c. 2.5 km downvalley fr. waterfalls, and 4 km S of "Skelhytte."	*Mya truncata* Linné *Macoma calcarea* (Gmelin)	31 ± 2	7740 ± 250 (7190 ± 250)
2	M-1612	c. 0.4 km E shell loc. 1 NW bank emerged delta, E side Skeldal Elv.	*Hiatella arctica* (Linné) *Mya truncata* Linné	59–60 ± 2	8490 ± 300 (7940 ± 300)
3	M-1613	SE cut bank emerged delta 1 km west shell loc. 2 W side Skeldal Elv.	*Macoma calcarea* (Gmelin) *Hiatella arctica* (Linné) *Mya truncata* Linné	59–60 ± 2	8840 ± 300 (8290 ± 300)
4	M-1614	SE cut bank emerged delta W side Skeldal Elv at Kong Oscars Fjord.	*Macoma* sp. *Hiatella arctica* (Linné) *Mya truncata* Linné	14 ± 1	7010 ± 250 (6460 ± 250)
5	M-1615	N face bank cut by trib. drainage, soliflucted material, fjord-bot. and delta, W side Skeldal Elv, c. 1.5 km upvalley fr. shell loc. 4.	*Mya truncata* Linné *Hiatella arctica* (Linné)	59 ± 2	9140 ± 300 (8590 ± 300)
6	M-1616	N face strandline, in shore deposit, W side Skeldal Elv, c. 1.2 km upvalley fr. shell loc. 4.	*Mya truncata* Linné	36 ± 2	7770 ± 250 (7220 ± 250)
7	M-1617	Shore deposit at strandline W side Skeldal Elv c. 1 km upvalley fr. shell loc. 4.	*Hiatella arctica* (Linné) *Mya truncata* Linné *Macoma calcarea* (Gmelin) *Mytilus edulis* Linné	21 ± 1	6960 ± 220 (6410 ± 220)

(continued)

Table 3 (cont.)

Loc. No.	Mich. Lab. No.	Locality	Species	Field Altitude	C-14 age years B.P.
8	M-1618	NW cut bank emerged delta E side Skeldal Elv, c. 1 km SW of "Skel-hytte."	*Hiatella arctica* (Linné) *Mya truncata* Linné *Astarte* sp.	20–21 ± 1	7270 ± 250 (6720 ± 250)
9	M-1619	NW cut bank emerged delta c. 4.5 km SE of "Skelhytte" on SW side Kong Oscars Fjord.	*Macoma calcarea* (Gmelin) *Mya truncata* Linné *Mya arenaria* Linné [?, cf. LAURSEN, 1966] *Hiatella arctica* (Linné)	4 ± 0.5	5980 ± 200 (5430 ± 200)
10	M-1620	NW cut bank emerged delta c. 1.5 km SE of "Skelhytte" on SW side Kong Oscars Fjord.	*Mya truncata* Linné *Macoma calcarea* (Gmelin)	17 ± 1	6830 ± 200 (6280 ± 200)
11	M-1621	NW cut bank emerged delta SE side Skeldal Elv at entrance to Kong Oscars Fjord.	*Astarte* sp. *Macoma* sp. *Serripes grönlandicus* (Bruguiere) *Mya truncata* Linné *Mya arenaria* Linné [?, cf. LAURSEN, 1966] *Mytilus edulis* Linné	3–4 ± 0.5	5680 ± 200 (5130 ± 200)
12	M-1622	NE cut bank emerged delta c. 0.7 km E of Skeldal Elv on SW side Kong Oscars Fjord.	*Hiatella arctica* (Linné) *Mya truncata* Linné	11 ± 1	7160 ± 250 (6610 ± 250)
13	M-1623	NW cut bank emerged delta SE side Skeldal Elv at entrance to Kong Oscars Fjord.	*Hiatella arctica* (Linné) *Mya truncata* Linné	9 ± 1	6790 ± 220 (6240 ± 220)
14	M-1624	1.45 m below interbedded sands, silts, peb. gravel S exposure cut bank, E side Skeldal Elv c. 7 km S of "Skelhytte."	Peat	51 ± 2	4930 ± 200

beds were deposited very near sea level. The curve (Fig. 9) therefore seems to establish an accurate rate of emergence in Skeldal as delevelling occurred.

Drawing on material discussed in the text, and on data presented in Table 3, and Figure 9, the following conclusions are presented: (1) The marine shell material in Skeldal is suggestive of a cold, shallow sea. Since emergence was continuous (see Fig. 9) the shell material was probably deposited in a cold shallow sea in front of retreating Skeldal ice. (2) The closeness of ages of emerged delta deposits, and the fossiliferous till-like material found in Skeldal indicate that the latter is a fjord-bottom (glacial-marine) deposit (see discussion p. 22). (3) The marine character of the fossils indicates that Skeldal was at least partially open to the sea by about 8,500 B.P. (4) Based on the curve (Fig. 9) the early emergence (8,000–7,000 B.P.) was of the order of 3 m per 100 years, and slowed to about 1 m per 100 years between 6,500–6,000 B.P. The early emergence rate of 3 m per 100 years agrees closely with curves from other regions (Olsson and Blake, 1961; Feyling-Hanssen and Olsson, 1960). The emergence rate may have been greater prior to 8,500 B.P. as Washburn and Stuiver's (1962) data suggests. (5) The uninterrupted nature of the curve (Fig. 9) indicates that emergence was continuous from at least 8,500 B.P. to 6,000 B.P. By implication Skeldal has been relatively ice-free since 8,500 B.P., and the deglaciation of Skeldal is related to postglacial time beginning about 10,000 B.P. (cf. Deevey and Flint, 1957). (6) Since the Bersærkerbræ, with large moraines at its snout, is only 7 km from an emerged delta with shells dated at 8,290 ± 300 B.P. (M-1613, corrected for 550 years based on modern shells collected in the area; Y-606, Washburn and Stuiver, 1962), it seems likely that the climate since about 8,500 B.P. has not been significantly better for glaciation than the present climate. (7) At least 60 m of emergence has occurred since 8,500 B.P. It is probable that emergence began prior to 8,500 B.P. for two reasons: higher sea levels are indicated by delta and beach deposits to altitudes of 120 m; and some adjustment would be expected as the ice thinned prior to encroachment upvalley by the sea. Therefore, it seems probable that emergence is related almost entirely to isostatic adjustment due to glacial unloading. (8) These conclusions confirm those of Washburn and Stuiver (1962).

The following points should be noted: (1) plotted altitudes in Figure 9 are field altitudes taken with Paulin aneroid (see note p. 8), i. e., they have not been corrected for eustatic rise in sea level. (2) The shell dates in Figure 9 have been corrected for an apparent age of 550 years based on Washburn and Stuiver's (1962) modern shells (Yale Geochronology Laboratory number Y-606) collected in the area and used as a standard. (3) There may be an error of several meters when correlating a shell date with a former sea level since the exact depth at which the mollusk died is unknown. (4) In Figure 9, each arrow points to a radiocarbon date, and the horizontal line shows the statistical error of the date; the vertical width of the line, or box, indicates the range in altitude from which the sample was collected.

In addition to the shell material which was dated, a peat deposit (loc. 14, Pl. V) was dated at 4930 ± 200 years B.P. Preliminary investigation demonstrates that the peat contains some grasses, sedges, and mosses indicative of cold periglacial environments (D. R. Spearing, personal communication, 1965). The deposit is buried at a depth of 1.45 m under lacustrine sediment and alluvial fan materials which have an Arctic Brown soil developed at the surface, and indicates a minimum time for retreat of the Skeldal ice upvalley. The Arctic Brown soil profile has been described by F. C. Ugolini (personal communication, 6 May 1965) as follows:

Depth in cm	Horizon	Morphology
4 to 0	–	Medium to coarse sand.
0 to 1	02	Dark organic layer, partially decomposed.
1 to 5, 9, 12	A1	Very dark brown (Munsell color 10YR 3/2), silty loam horizon, single grained, loose. Few cracks are visible. Roots tend to penetrate cracks.
5, 9, 12 to 18, 22	B	Yellowish brown (10YR 5/4) horizon with a coarse sand texture, single grained, loose. A few roots.
18, 22 to 40	C	Light brown gray (10YR 6/2) horizon with a very coarse sand texture. The sand is bedded. Single grained, loose.

The radiocarbon date of the peat strengthens the conclusion that the last deglaciation in the Skeldal occurred during postglacial time. The peat deposit also indicates that Skeldal was ice-free upvalley from Vifteelv by 5,000 B.P.

Summary and correlation.

The maximum height of the ice in Skeldal during the last glaciation was about 500 m (Phase I). I assume that this maximum corresponds to the last glacial (Würm/Wisconsin) maximum. The first deglaciation (Phase II) from the 500 m level was accompanied by glacial thinning and retreat in Skeldal, resulting in separation of the Skeldal and Kong Oscars Fjord ice lobes.

A glacial phase caused the Skeldal ice to readvance (Phase III) to Kong Oscars Fjord (see Fig. 7). Following the readvance which deposited the 300 meter moraines general deglaciation occurred in Skeldal, probably caused by a warmer climate as is indicated by features of masswasted debris in the valley (Phase IV). Radiocarbon dates of shell material indicate that deglaciation in Skeldal was sufficiently advanced by 8,500 B.P. that the area was open to the sea. The dates also indicate that deglaciation was directly related to postglacial time (beginning 10,000 B.P., Deevey and Flint, 1957, p. 183). The presence of a peat deposit (loc. 14, Pl. V) dated at 4,930 B.P., found half-way up the lower Skeldal, indicates that the lower valley was ice-free by 5,000 B.P. (cf. p. 50). Hence the date supports the conclusion that deglaciation was related to postglacial time.

A radiocarbon date of a turf zone buried in a recent moraine at the head of Ivar Baardsøn Gletscher, Schuchert Dal, Northeast Greenland, (Levin, *et al*, 1965; and J. P. Schafer, personal communication; U.S. Geol. Survey radiocarbon laboratory no. W-1378), indicates that the present glacial advance started after 1,500 B.P. As Schuchert Dal lies just across the pass at the head of Skeldal, it seems likely that conditions were similar in both areas, and that the recent readvance (Phase V) in Skeldal occurred more recently than 1,500 B.P. Ahlmann (1941; 1953) suggests that the recent readvance of glaciers in Greenland, occurred during the "little ice age" (Matthes, 1939; 1942). Although the tilt of the upper Skeldal freshwater strandlines (discussed p. 33) seems to suggest that the recent readvance could have been earlier than the "little ice age," there is no clear evidence in Skeldal indicating a more precise time than post 1,500 B.P. for the readvance.

Since the last readvance, a warmer climate has contributed to general recession and downwasting of ice in Skeldal (Phase VI).

CONCLUSIONS

1. The maximum height of the ice surface in Skeldal during the last glaciation was about 500 m; it is tentatively equated with the last glacial (Würm/Wisconsin) maximum, and is called Phase I.

2. The first period of downwasting and thinning of the ice from the 500 m level occurred during Phase II (cf. discussion p. 41).

3. A glacial readvance probably occurred during Phase III covering Skeldal to an altitude of 300 m.

4. Based on shell and peat radiocarbon dates, deglaciation in Skeldal (Phase IV) is directly related to postglacial time, beginning about 10,000 B.P. (Deevey and Flint, 1957).

5. Skeldal was open to the sea by about 8,500 B.P., and glacial thinning and retreat continued until the recent advance (Phase V) after 1,500 B.P.

6. Emergence has been primarily due to glacial unloading. This is established by comparison of radiocarbon dates of shell material with altitudes of the deposits in which the material was found, and the probable isostatic adjustment due to glacial unloading. The early emergence (8,000–7,000 B.P.) was of the order of 3 m per 100 years, but slowed to 1 m per 100 years between 6,500–6,000 B.P. From 6,000 B.P. to the present emergence is tentatively set at between 6 and 7 cm per 100 years.

7. Based on the correlation of shell dates with altitudes of deposits in Skeldal, the till-like material found in the Skeldal is a fjord-bottom (glacial-marine) deposit.

8. As no erratics, or striations occur on the upper slopes, and as the valley profiles end in rugged mountain peaks, it is concluded that some peaks rising above Skeldal were nunataks during the last ice maximum, and very possibly throughout the Pleisticene.

9. The valley profiles in Skeldal, the slide block at the east end of Syltoppene, and the truncation of tributary valleys in the west Skeldal suggest multiple glaciation occurred in Skeldal.

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PLATES

Plate I.

Aerial view of the lower east Skeldal. View southeast, showing the Mesters Vig district. BK = Blyklippen, BR = Blyryggen, CT = "Camp Tahoe," D = Domkirken, DD = Deltadal, GS = Government station, H = Hesteskoen, K = Korsbjerg, KOF = Kong Oscars Fjord, L = Lejrelv, MV = Mesters Vig (inlet), N = Noret, ØG = Øvre Gefionpas, NG = Nedre Gefionelv, R = Rungsted Elv, S = Skeldal, SB = Store Blydal, T = Tunnelelv, WB = Werner Bjerge. Photo courtesy of the Geodetic Institute, Denmark, copyright; and A. L. Washburn (1965).


WB
S
DD
NG
ØG
SB
BK
L
BR
K
D
S
H
MV
CT
R
T
KOF
N
GS

Plate II.

Aerial view of the lower west Skeldal. View northwest. B = Bersærkerbræ, H = Hesteskoen, K = Kap Peterséns, KOF = Kong Oscars Fjord, S = Skeldal Elv braided drainage, SY = Syltoppene, V = Vifteelv. Photo courtesy of the Geodetic Institute, Denmark, copyright.


K
KOF
SY
SY
V
S
S
H
H
B

Plate III.

Aerial view of the 500 meter moraine, 300 meter moraine, and recent moraines at Vifteelv. View northwest. D = upper end of lower Skeldal marine delta, M = 300 meter moraine, R = recent Vifteelv moraines, S = Skeldal Elv braided drainage, SY = Syltoppene, V = Vifteelv, X = 500 meter moraine. Photo courtesy of the Geodetic Institute, Denmark, copyright.


SY
R
D
S
S
M
R

Plate IV.

Aerial view of Syltoppene showing slide block. View northwest. S = Skeldal Elv braided drainage, SY = Syltoppene, dashed line = trace of fault at back side of slide block. Photo courtesy of the Geodetic Institute, Denmark, copyright.

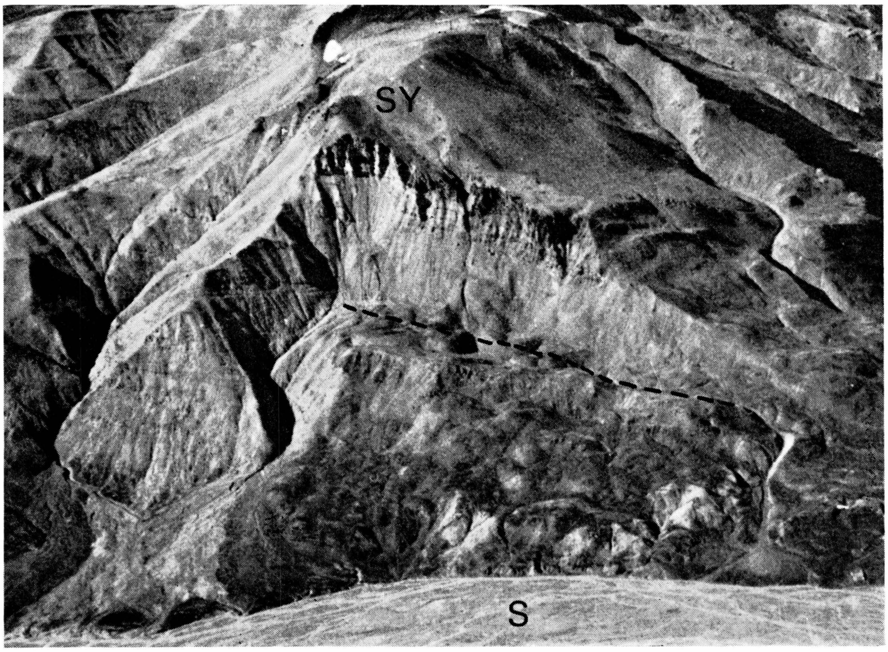
SY
S

Plate V.

The surficial geology of Skeldal, Mesters Vig, Northeast Greenland.


SURFICIAL GEOLOGY OF SKELDAL, MESTERS VIG, NORTHEAST GREENLAND
SCALE
1 0 1 2 Km.
1 0 1 2 Mi.
EXPLANATION
Colluvium
Slide and protalus debris
Delta deposit
Morainic debris
Alluvium
Beach deposit
Fjord-bottom deposit
Ice-cored moraine
Outwash
Lacustrine deposit
Kame deposit
Glacier
Freshwater strandline
Lake
Erratic line
Shell and peat localities
Stream
Glacial striation
Elevations in meters
Fault
(Dashed where approximately located, dotted where concealed)
Pingo
Staunings Alper Fault
Bersærkerbræ
Skelbræ
Skeldalelv Braided Drainage
GLETSCHERRYGGEN
ØVRE GEFION PAS
HESTESKOEN
SYLTOPPENE
KONG OSCARS FJORD
Vælbræ
24° 30'
72° 10'