All three curves thin out between 1100 and 1700 metres above sea level. This indicates that the height of the Inland ice and the Julianehåb ice cap must have been rather constant through most of the holocene period. It is in accordance with the theoretical considerations of the plasticity of an ice cap, as given by J. Orowan and J. Nye.

It must be noticed, that the trim line thins out ca. 1200 metres above sea level. One factor could be that the Inland Ice and the Julianehåb ice cap, expressed as a function of the altitude, than have an ablation less than the local glaciers (after H. Ahlmann).

Another and more possible cause for the fast thinning out of the lowermost curve could be a new wave of ice indicating a future advance. Push moraines in higher altitudes of the Qoroq and Kiagtut sermia glaciers could be so interpreted. Considering this mechanism, we should have a melting and retreating system in the lowermost parts of the lobes from the ice cap, but an expanding system of ice in the areas near the firn limit.

Glacial Geology of Northern Greenland*

William E. Davies, Washington **)

Abstract. From 1956 through 1960 studies on the glacial geology of northern Greenland have been made in cooperation with the U. S. Air Force Cambridge Research Laboratories. As a result of these studies four distinct phases of the latest glaciation have been recognized. The last glaciation extended over most of the land and removed traces of previous ones. Retreat of the ice mass began some time previous to 6000 years ago. This was followed by a rise in sea level which deposited clay-silt succeeded by kame gravels around stagnant ice lobes in the large valleys. Marine terraces, up to 129 meters above present sea level, developed as readjustment occurred in the land free of ice. About 3700 years ago an advance of glaciers down major fjords took place followed by retreat to approximately the present position of the ice. Till in Peary Land, north of Frederick E. Hyde Fjord, contains only locally derived materials indicating that the central Greenland ice cap did not cover the area.

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Zusammenfassung: Glazialgeologie von Nordgrönland. Von 1956 bis 1960 wurden in Zusammenarbeit mit den U.S. Air Force Cambridge Research Laboratories Studien über die Glazialgeologie von Nordgrönland gemacht. Als ein Ergebnis dieser Untersuchungen wurden vier getrennte Phasen der letzten Vereisung erkannt. Die letzte Vereisung dehnte sich über den größten Teil des Landes aus und beseitigte Spuren von vorhergegangenen. Der Rückzug des Eises begann vor gut 6000 Jahren. Dieses wurde aus dem Anstieg des Meeresspiegels festgestellt, wobei Ton und Schluff gefolgt von Kame Schottern rund um die stagnierenden Gletscherzungen in den großen Tälern abgelagert wurden. Marine Terassen — bis zu 129 m über dem jetzigen Meeresspiegel — zeigen, wie der Rückzug in dem eisfreien Land eintrat. Vor etwa 3700 Jahren fand ein Vorrücken der Gletscher durch die Hauptfjorde statt, gefolgt von einem Rückzug auf etwa den gegenwärtigen Eisstand. Grundmoränen in Peary-Land, nördlich des Frederick E. Hyde-Fjordes, enthalten nur örtliches Material, was beweist, daß das zentrale grönländische Inlandeis dieses Gebiet nicht bedeckte.

Since 1956 the U.S. Air Force Cambridge Research Laboratories has conducted studies of landforms and engineering properties of soils in northern Greenland. Members of the U. S. Geological Survey participated in the geological aspect of this research, and investigated the glacial geology of Peary Land, Kronprins Christian Land, and adjacent areas.

Northern Greenland consists of three major physiographic divisions:

1) an area of low alpine mountains in Peary Land, north of Frederick E. Hyde Fjord,
2) similar mountains along the northeast coast south of Independence Fjord, and
3) a dissected plateau formed of non-folded late Precambrian and early Paleozoic rocks inland from the mountainous coastal areas.

The glacial geology of northern Greenland has been given scant attention. Lauge Koch outlined the basic concepts of former glaciation, which were based on observations made while on the Danish Bicentenary Jubilee Expedition in 1921 (Koch, 1927, 1928a, b). Troelson (1949, 1952), while on the Dansk Pearyland-Ekspedition 1947-50, filled in details around Brønlund Fjord.

*) Publication authorized by Director, U. S. Geological Survey

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Eigil Knuth, on his traverse of Danmark Fjord in 1955 (Knuth, 1958), collected information concerning marine terraces. Fieldwork for the present paper was done during the summers of 1956, 1957, 1958, and 1960.

Features of Glaciation

Four major types of deposits, moraines, clay-silt, kames, and marine terraces, reflect more extensive glaciation in the past. These features occur throughout all of northern Greenland but they are best developed along, and south of, Independence Fjord.

Clay-silt Deposits — Deposits of clay-silt occur along may of the fjords and river valleys of northern Greenland, as well as on portions of the narrow coastal plain bordering the mountains on the north side of Peary Land (figure 1). These deposits have two origins, lacustrine and marine; and along the lower part of river valleys in coastal areas they grade from one type to another in short distances.

The marine clay-silt occurs throughout most of northern Greenland and is uniformly gray, poorly-bedded, and generally contains large quantities of pelecypod shells. The maximum height of the deposits is 105 meters on Polaris Promontory in northwest Greenland, whereas elsewhere in northern Greenland the height varies greatly. Along Danmark Fjord the maximum height rises from 24 meters at the head of the fjord to 41 meters midway along the fjord in a distance of 90 km. This gradient, 0.45 meter per kilometer, is 10 times as great as that of the tilt of the younger raised marine terraces that have been formed on the clay-silt. Along the coastal areas of Peary Land the gradient appears to be reversed. At Brønlund Fjord the maximum height of the marine clay-silt is 68.6 meters. Eastward and northward along the coast of Peary Land it declines in altitude until along the coast west of Kaffeklubben ø and on Kaffeklubben ø it is only 2 meters above present sea level. In most of this area the clay-silt is covered by later terrace gravel.

The pelecypod fauna in the marine clay-silt beds is uniform throughout North Green-

Davies fig. 1

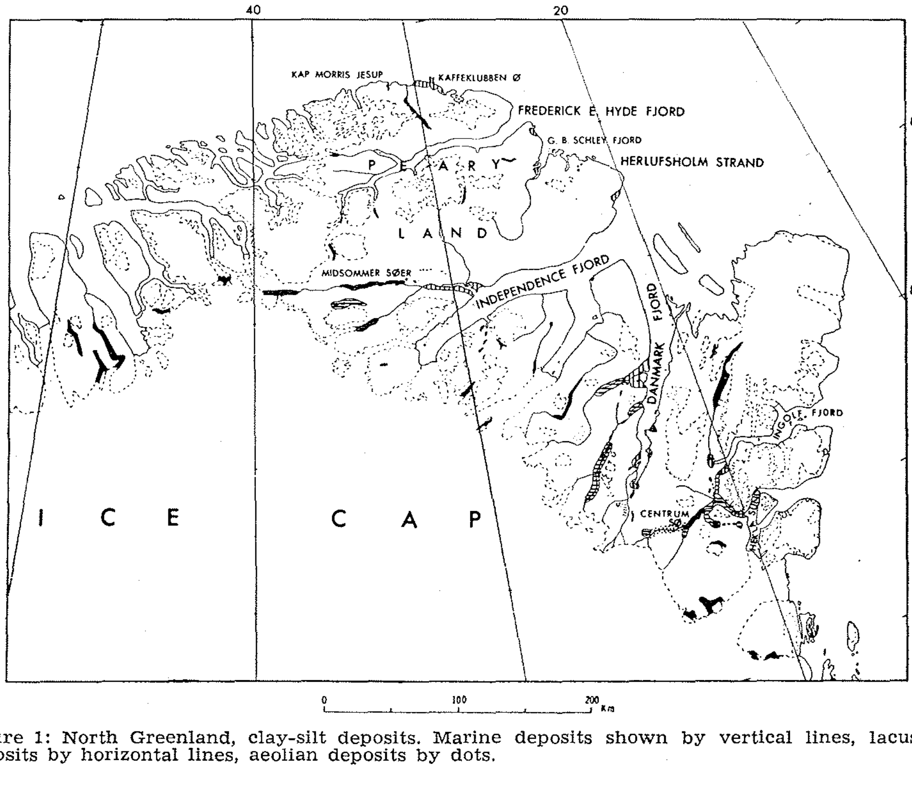

Figure 1: North Greenland, clay-silt deposits. Marine deposits shown by vertical lines, lacustrine deposits by horizontal lines, aeolian deposits by dots.

land and is characterized by an abundance of *Hiatella arctica* (Linne) and *Mya truncata* Linne. A few gastropods are also present.

Lacustrine clay-silt deposits are extensive south of Independence Fjord and occur over much of the large valleys between Centrum Sø, Ingolf Fjord, and Hekla Sund, and in the long parallel valleys west of Danmark Fjord. They are generally overlain by kame terrace deposits; but in an area 15 km long and 5 km wide east of Centrum Sø, the clay-silt is at the surface. Maximum height of the clay-silt in the area of Centrum Sø is 137 meters above sea level, 37 meters above the level of Centrum Sø. Topography of the clay-silt where not covered by kame deposits is typically "Badlands" with relief of 10 to 30 meters. The lacustrine deposits are thinly bedded and appear to be varves (figure 2). No fossils have been found in the lacustrine beds.

In the valleys west of Danmark Fjord and near the ice cap west of Centrum Sø the lacustrine clay-silt beds are as much as 36 meters above the valley floor, and extend inland 70 km to an altitude of 200 meters. In these areas the clay-silt has been greatly eroded by wind action, and the deposits form low rounded hills with dunes developed on broad, flat areas.

Moraines and Kames — Three groups of moraines developed during the latest glaciation occur in northern Greenland. The oldest moraines, antedating clay-silt deposition, lie along the coastal plain on Herlufsholm Strand and on the north coast between Frederick E. Hyde Fjord and Kap Morris Jesup (figure 3). A large morainal system on the northeast side of Independence Fjord opposite Danmark Fjord is probably of the same age.

The moraines on Herlufsholm Strand have been modified by a marine invasion that planed and covered them with a veneer of gravel but a few of the larger ridges still are readily distinguishable. One ridge extends northwest along the central part of the Strand, while the others are close to the mountains.

On the coastal plain northwest of Frederick E. Hyde Fjord marine planation has remo-

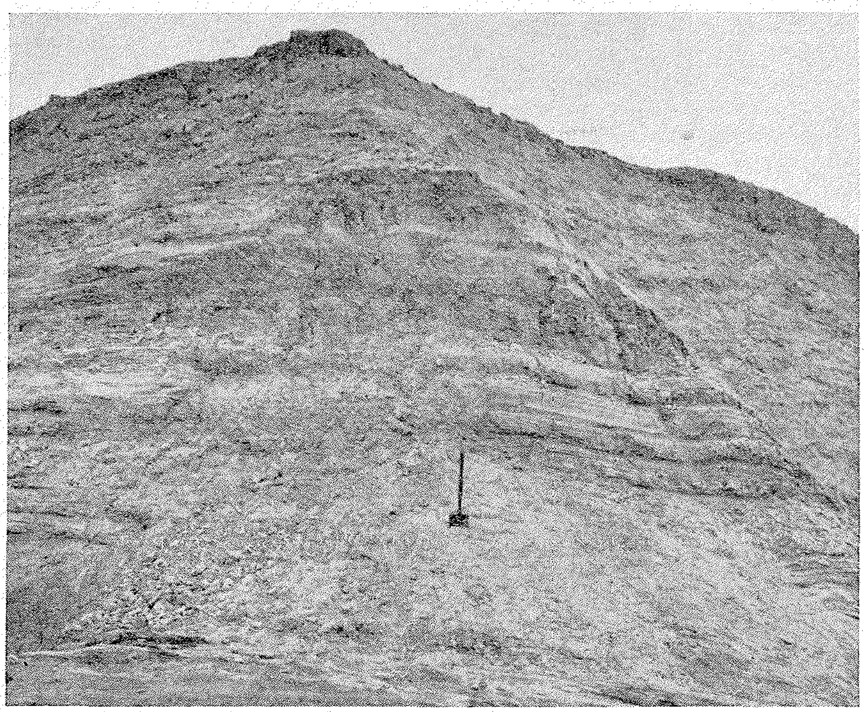

Figure 2: Lacustrine clay-silt 1 mile east of Centrum Sø showing varvelike bedding.

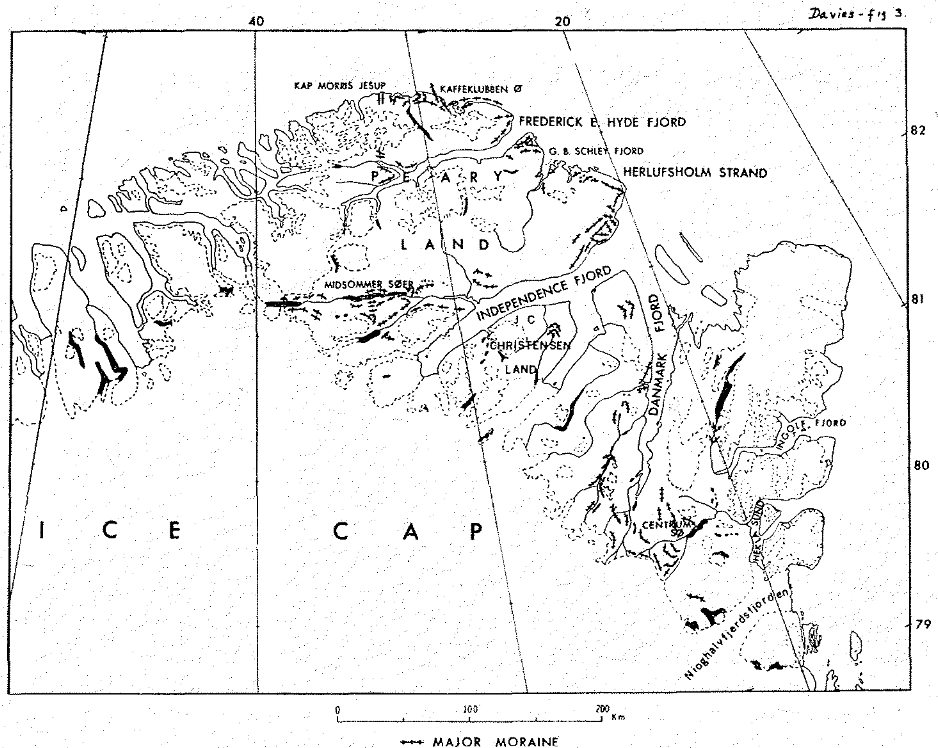

Figure 3: North Greenland, major moraines

ved most of the old moraine. In this area the plain above 110 meters is formed of bedrock with little or no moraine except at the mouth of Frederick E. Hyde Fjord where later moraines occur. Below 110 meters the plain is formed of strands of beach gravel. Old moraines from a glacier formerly extending into Bliss Bugt, southeast of Kaffeklubben ø, form irregular gravel ridges as well as 3 parallel groups of islands along the coast 40 km northwest of Frederick E. Hyde Fjord.

On the coastal plain south of Kaffeklubben ø old moraines are larger and more numerous than elsewhere along the Arctic coast of Peary Land. Three large moraines are parallel to the coast and mountain front; a fourth moraine forms a series of low islands and shoals several kilometers offshore. Kaffeklubben ø is the most prominent part of these moraines. West of this area no prominent moraines exist and the rock platform along the coast rises rapidly in altitude. At Kap Morris Jesup the platform is formed of frost-rived bedrock with very few erratics, and old moraines are confined to the side of the river valley.

The largest and most extensive system of old moraines in Peary Land is on the north side of Independence Fjord opposite Danmark Fjord. This area, 600 square km, is made up of a complex of morainal ridges and intervening outwash plains. The major moraines on the north side trend east-west; in the rest of the area they trend north-south. The highest moraine is the northernmost one; at its eastern end, 6 km north of Independence Fjord, it reaches an altitude of 150 meters (figure 4). The top of this moraine consists of a series of peaks separated by narrow saddles. Up to 106 meters altitude the moraine consists of gray boulder clay; above this it is mainly boulder cobble moraine with sand. North of the moraine is a broad area of outwash. The smaller moraines to the south form irregular, low rounded ridges and are mainly cobble gravel with clay and boulders. Marine shells occur in these moraines within 4 km of the coast indicating the moraine was

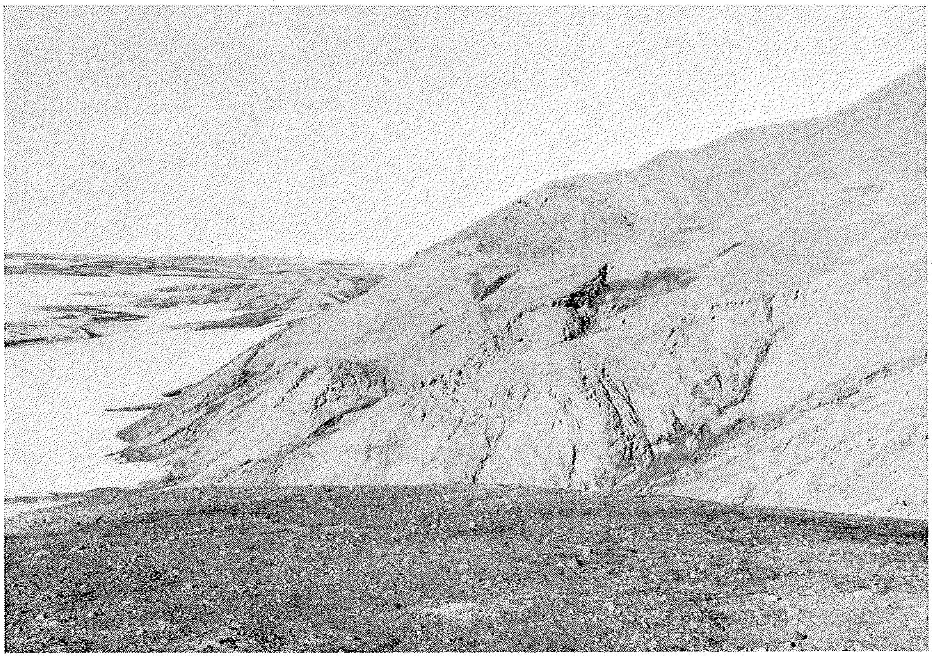

Figure 4: Major moraine, 6 km north of Independence Fjord opposite Danmark Fjord. Lower part (light color) is cobbly clay; upper part is gravel.

probably deposited in shallow coastal seas. Moraines younger than the clay-silt deposits are not common in North Greenland. In the area between Centrum Sø and the ice cap 6 morainal ridges are developed on the upland surface. These moraines end in marginal channels and terraces in the valleys. Similar upland moraines occur on the plateau north of the lake.

Along Hekla Sund moraines lie above the clay-silt beds at the mouths of large river valleys. Along the northern part of the sound these moraines are only a few meters above sea level while to the south they are as much as 118 meters above present sea level. They are probably related to an advance of a tongue of the Nioghalvfjerdsfjorden north along Hekla Sund.

Other moraines of similar age are in the tributary valleys of the rivers draining to Hekla Sund and on the eastern side of J. C. Christensen Land.

Recent moraines have been built up at the front of many valley glaciers. The most prominent are along Ingolf Fjord and the large valleys extending north and south from the fjord.

Kame areas coincide closely with the distribution of lacustrine clay-silt (figure 5). In the large interconnecting valleys south of Ingolf Fjord, west of Danmark Fjord, east of Midsommer Søer, and at the head of Danmark Fjord kame terraces with large lakes cover most of the valley floors. The surfaces of the terraces are smooth with little discernible slope. They are formed of rounded pebbles and cobbles a meter to over 30 meters thick, generally lying on clay-silt. The lakes are in steep-sided kettles extending into the clay-silt.

Marine Terraces — Throughout northern Greenland raised marine terraces are common (figure 5). The best developed terraces are at the mouths of major streams where delta terraces occur. Here, deltaic material is planed and reworked as the sea level is lowered relative to former positions of land (figure 6). The terraces are well-developed but are limited to the small areas of the delta. This type of development is typical on rivers entering Hekla Sund, Independence Fjord, and Danmark Fjord.

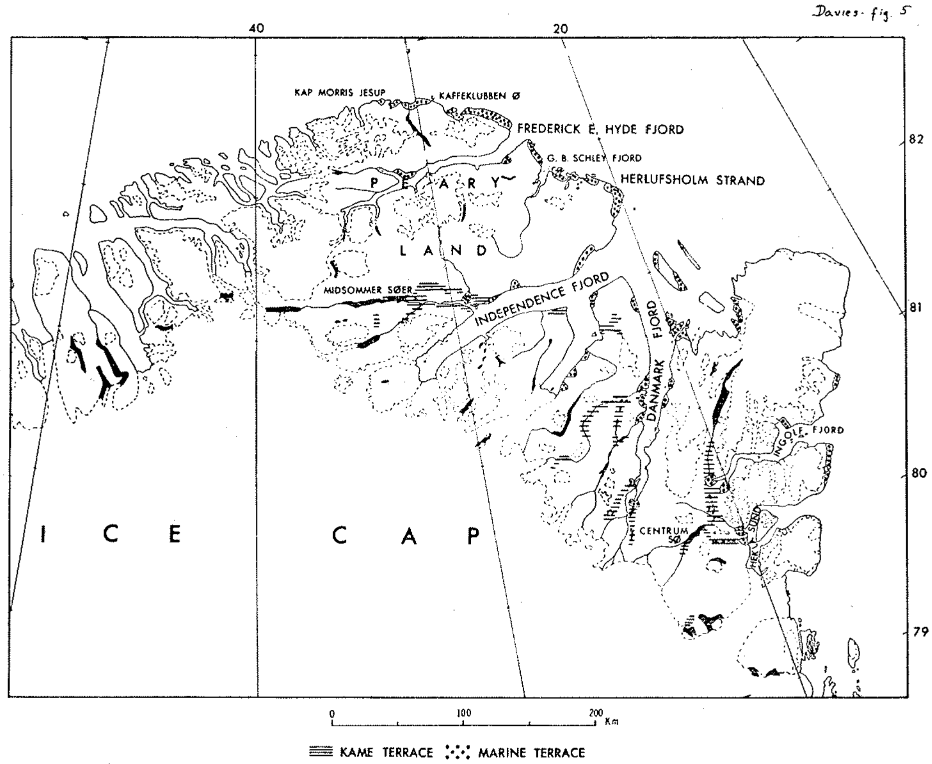

Figure 5: North Greenland, distribution of kame and marine terraces

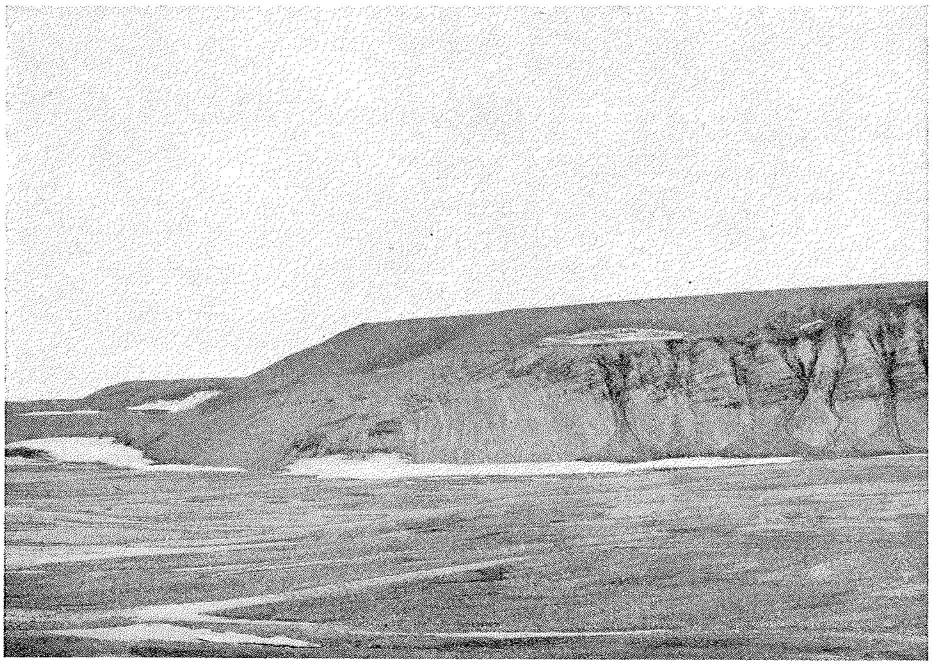

Figure 6: Delta terraces, east side Danmark Fjord, 45 km from south end. Delta beds are deposited on marine clay.

Marine terraces also occur along the broad coastal lowlands on the north coast of Peary Land and along Independence Fjord. In contrast to the delta terraces, these beaches are developed by reworking of materials along a rising coast; and they extend for greater distances, but are less developed, than the delta terraces.

Most of the marine terraces contain deposits of gravel with a matrix of fine to coarse

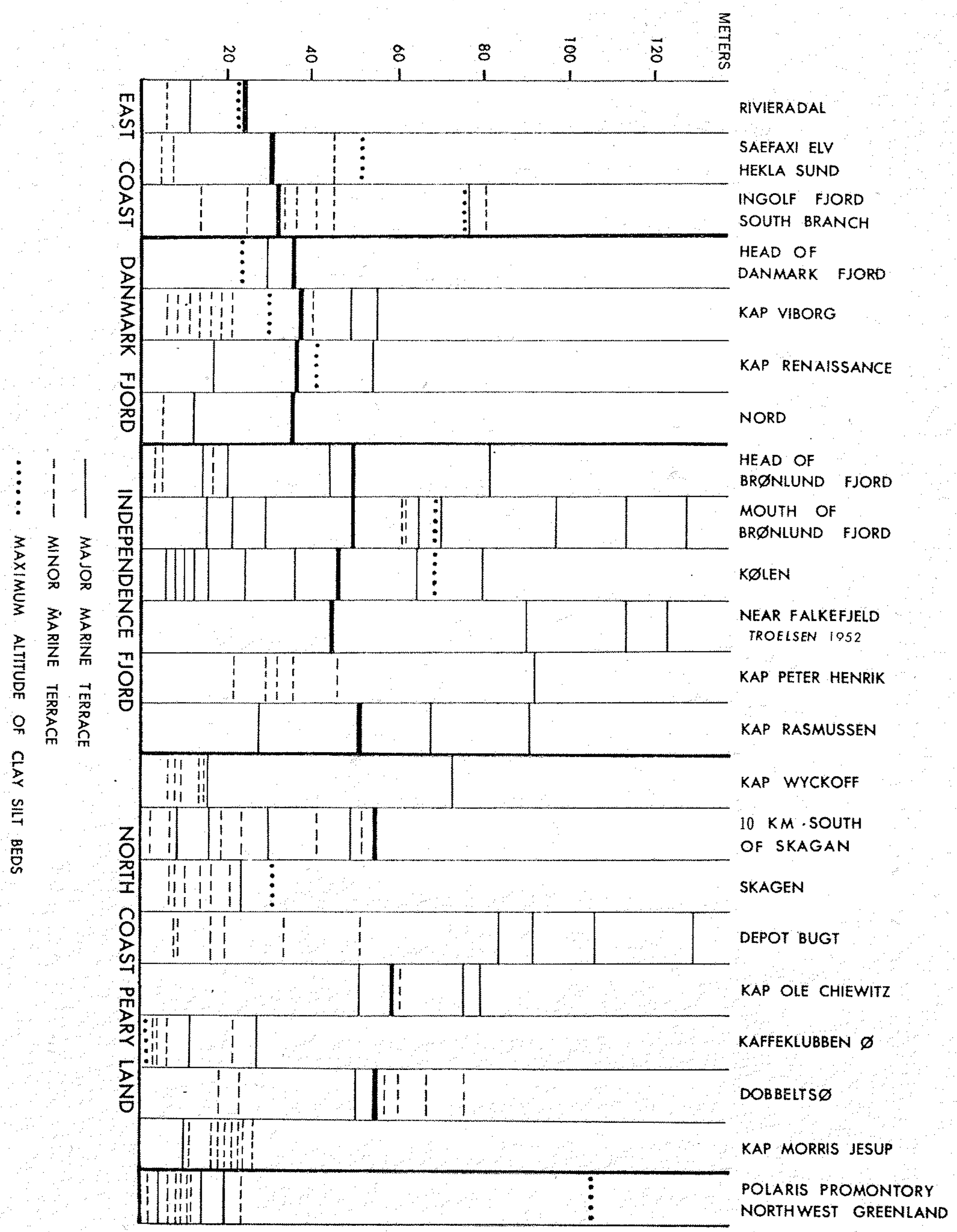

Figure 7: Major terraces, North Greenland. 25-37, 45-57 terrace accentuated by heavy line.

sand. Subroundet to rounded pebbles and cobbles as much as 10 cm in size are common. The deposits are derived mainly from reworked morainal material and, except along the north coast of Peary Land, are composed of many different rocks.

Terrace development is not uniform at all points and the number of terrace levels present varies from point to point. However, throughout northern Greenland one group of terraces is persistent. South of Independence Fjord it is from 25 to 37 meters above present sea level and north of the fjord, 45 to 57 meter (figure 7).

The higest distinct beach is 127 to 129 meters above sea level, and is along the middle part of Independence Fjord and near the mouth of Frederick E. Hyde Fjord. Below this level at least 16 terraces are recognizable although all are not present at one locality.

In addition to marine terraces, well-developed storm ridges along raised strand lines occur below an altitude of 17 meters. On Herlufsholm Strand 11 well-defined storm ridges can be distinguished; near G.B. Schley Fjord 14 to 19 are recognizable; and at the head and the mouth of Danmark Fjord, 18.

The overall tilt of the terraces is towards the south. However, a secondary tilt is superimposed, and locally the terraces along Danmark and Independence Fjords are tilted toward the junction of these fjords. The tilt in the southern part of Danmark Fjord is to the south at 0.05 meter/km; in the northern part it is to the northeast of 0.015 meter/km.

Some radiocarbon dating of shells from within the main terraces have been made, and more are being made. From the data on hand, the beaches above an altitude of 24 to 50 meters are between 3700 and 6100 years old. Those below this level are 500 to 3700 years old. This subdivision is based on dating of the prominent terraces in the 24- to 50-meter zone *) as 3780±300 years, and the lowest strand above present high tide as 500 years. The maximum date of 6100±300 years is from the marine clay. Where clay is present, marine terraces are cut into the clay and are clearly younger than it.

Composition of Glacial Till

Independence Fjord and the southern part of Peary Land demarcate the boundary between two distinct types of glacial till. South of a line 33 km north of Independence Fjord (Troelsen, 1952) and extending eastward to a point opposite Danmark Fjord, the till contains a heterogeneous assemblage of metamorphic, igneous, and sedimentary rocks of late Precambrian and early Paleozoic age (table 1). Included in this type are large quantities of unique pink granite with prominent angular quartz particles, and only small quantities of dark minerals. The granite is similar to that which crops out on the north side of Parker Snow Bugt south of Thule, Northwest Greenland. This heterogeneous till, characterized by the pink granite pebbles, is common from Thule north through Nyeboe Land and extends west into eastern Ellesmere Island near Alert (R. L. Christie, oral communication) and east throughout the area south of Independence Fjord.

North of the line 33 km north of Independence Fjord, till components vary from point to point, but at all points the till is formed of locally derived material. The characteristic pink granite pebble is lacking in the northern till.

Glacial History

In northern Greenland only one glaciation is recognizable. This glaciation, much of which still exists, erased evidence of former glaciation. During maximum development of this glaciation the central ice cap of Greenland transported till characterized by pink granite pebbles. This glaciation extended 33 km north of Independence Fjord where it was buffered by local ice caps from the high mountain areas along the south side of Frederick E. Hyde Fjord. Till lacking the distinctive pink granite pebbles and with only locally-derived materials is characteristics of the glacial deposits of the mountain ice caps. Movement of the ice cap along the north side of the central ice

*) Radiocarbon dating by Meyer Rubin, U. S. Geological Survey

Table I

COMPOSITION OF TILL

NORTH GREENLAND

LOCALITY (percent present)

Rock Type	Kap Cohn	Head of Danmark Fjord	Rivieradal	Ingolf Fjord	Brønlund Fjord	Kap Peter Henrik	20 km SW of Kap Peter Henrik	Kap Renaissance	Kap Rasmussen	Mudder Bugt moraine	Kap Wyckoff	10 km. south of Skagen	Skagen	Depot Bugt	Kap Ole Chiewitz	Kaffeklubben ø	Dobbeltsø	Kap Morris Jesup
Thule red sandstone & quartzite	30	30	5	40	15	15	15	50	5	40	3							
Thule withe sandstone & quartzite	20	50	5	20	15	40	40	20	15	40				40				
Red Carboniferous sandstone									25									
Gray sandstone							20		5	20								
White coarse sandstone				5														
Brown sandstone											5			P				
Black sandstone									20									
Black slaty shale		5												P				
Limestone		5	15		30	30			15		90	25	5	50		5		
Basalt															10			
Amphibolite																		
Felsite		5														5		
Andesite-black															40			
Red porphyritic andesite																50		
Pink granite	P		10	P	5	P	10	10	P	P								
Diabase	30			20	30	15	20	20	15		1	5	4		P		30	
Red granite gneiss													2					
Gray gneiss	20	P		5	5						P	20	2		10	5		30
Chlorite schist		P	40										2	P	20	10	70	20
White quartzite			5									35			P			20
Brown-gray quartzite													75					
Buff, columnar quartzite																5		30
Dark purple quartzite											P	15	10		P			
Marble			10								P					10		
Gray phyllite																5		
Slate			5	10														
Greenstone			5								P							
Quartz pebbles															20	5		

cap was eastward and northeastward down the troughs of Independence and Danmark Fjords and other major fjords; movement along Frederick E. Hyde Fjord was eastward. North of Frederick E. Hyde Fjord and along Herlufsholm Strand glaciation was of an alpine type with valley glaciers extending onto and across the flat coastal plain. South of Kaffeklubben ø valley glaciers formed a piedmont ice sheet covering the coastal plain. This piedmont glacier was probably similar in form to the shelf ice on the north side of Ellesmere Island.

About 6000 years ago an abrupt change occurred, and a relatively rapid retreat of the ice took place. The ice caps shrunk to about their present size and the major fjords and valleys were occupied by stagnating remnants of the former ice sheet. Contemporaneously with the melting, large quantities of silt were deposited in the open portions of fjords and along valley floors. Increased melting culminated in the resorting and depositing of kame terrace materials overlying the silt. Isolated remnants of buried ice blocks eventually melted and formed lakes along the major valleys.

North of Frederick E. Hyde Fjord the valley glaciers and piedmont ice melted back, with most of the outwash material carried off to sea.

At the point of maximum retreat the main ice cap and outlet glaciers were as much as 60 km inland from their present position.

After deposition of silt and kame materials the lag in isostatic readjustment resulted in an inundation of the land which was equivalent to a rise in sea level of as much as 129 meters along the Arctic coast of Peary Land. With readjustment, as the land emerged, distinct marine terraces developed in coastal areas.

An advance of ice, primarily by glaciers afloat in major fjords, occurred about 3700 years ago. This advance was about 30 to 60 km down fjord, and disrupted the terrace forming stage just prior to the formation of terraces in the zone 24 to 50 meters above present sea level. Since that time retreat occurred until 500 years ago, after which only minor readjustments in the position of the glacier fronts have occured.

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Die Polarlichtzone der Südhalbkugel*

Von Otto Schneider, Buenos Aires **

Zusammenfassung: Nach einer kurzen Einleitung über die Schwierigkeit der Bestimmung der Lage der Polarlichtzone auf der Südhalbkugel behandelt der Verfasser methodische Fragen über die Möglichkeit der Definition der Polarlichtzone sowie über die zeitliche Veränderlichkeit, Inhomogenitäten der Beobachtungen und über die Form der Zone. Bei den Lösungsversuchen werden zunächst die älteren Vorschläge, sodann die Isochasmen nach Hultqvist, ferner andere theoretisch abgeleitete Südlichtzonen sowie die neuesten Versuche von Bond und Jacka dargelegt, die Zone mit Hilfe von wirklichen Südlicht-Beobachtungen festzulegen. Danach folgen einige zusätzliche Ergebnisse, die sich auf Grund der japanischen, britischen und argentinischen Beobachtungen ergaben. Mit der abschließenden Bemerkung, daß die Südlichtzone nur über die Hälfte ihres Umfanges einigermaßen sicher festgelegt ist, beendet der Verfasser seine Darlegungen, denen er eine Tabelle über die Koordinaten der erwähnten Stationen und ein ausführliches Literatur-Verzeichnis anfügt.

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Abstract: The Polar Light Zone of the Southern Hemisphere. After a short introduction dealing with the difficulties of the determination of the position of the polar light zone on the Southern Hemisphere the author treats methodical questions of the possibility of the definition of the polar light zone as well as of the temporal

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