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SOIL INVESTIGATIONS IN INGLEFIELD LAND, GREENLAND

BY

J. C. F. TEDROW

WITH 67 FIGURES AND 22 TABLES
IN THE TEXT

KØBENHAVN
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BIANCO LUNOS BOGTRYKKERI A/S
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Abstract

During 1966, pedologic studies were conducted in Inglefield Land, Northwest Greenland (*c.* 78°31′ N, 70°55′ W). Climate is typical of the high arctic with the July temperature approximating 40° F and the annual precipitation approximating 2 to 6 inches of water. The area has a desert appearance with most of the landscape free of vascular plants. Narrow swales and meadows, however, tend to be wet and covered with a continuous vegetative mat. The Archean basement complex is capped with Paleozoic rocks consisting of conglomerate, sandstone, shale, dolomite and limestone, together with a few intrusions of diabase. In the study area there is evidence of 3 glacial stages with the earliest ice probably reaching Rensselaer Bugt and beyond. A buried organic layer in a glacio-fluvial terrace yielded a C-14 date of 20,800 yr. B.P. Six genetic soils or soil conditions are recognized: (1) Polar Desert soils, (2) Arctic Brown soils, (3) Tundra soils, (4) soils of the Hummocky Ground, (5) soils of the Polar Desert-Tundra interjacence, and (6) bedrock and boulder fields. Mechanical, mineralogical, and chemical analyses of the soils, including micromorphology, are given. Desert pavement and secondary carbonates form extensively in the well-drained sites. Laboratory data as well as field observations confirm a desert-like type of soil formation. Salts effloresce on certain soils during the rainless periods. Percent base saturation of the exchange complex is relatively high thoughout the area. Organic matter content approximates the 1 pct. level in the Polar Desert soils but increases in the wet positions. Many soil grains show allogenic clay coatings. Slight alteration of some feldspar was noted, but for the most part minerals are fresh-appearing. Some iron-stained aggregates have formed in the Polar Desert soils. Chemical composition of a number of native plants is given.

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FOREWORD

The high arctic of North America has been heretofore studied very little from the standpoint of the development, characteristics, classification and distribution of soils. In order to provide some pedologic information on the far north, investigations were conducted in Inglefield Land, Greenland, just south of Rensselaer Bugt during 1966. This chosen location provided the opportunity to add general pedologic information on a new area. It is hoped that this report will serve as a factual account of the soils and related terrain conditions in central Inglefield Land.

This study was carried out under Grant #DA-ARO-D-31-124-G820, U.S. Army, awarded to the Arctic Institute of North America, with this author serving as principal investigator. A number of individuals and organizations gave considerable assistance in carrying out the studies. Mr. R. C. Faylor and Mr. J. E. Sater, both of the Arctic Institute of North America, contributed a great deal of time and effort in planning and executing the overall study. Mr. G. F. Walton, Rutgers University, collaborated very closely with the author during both the field studies and subsequent laboratory investigations, for which the author is most grateful. Mr. D. A. Gaskin of the Cold Regions Research and Engineering Laboratory, U.S. Army, also assisted the author in innumerable ways in the field, although he was making independent studies.

The Danish Government kindly gave permission to carry out these studies and furnished aerial photography and related information on conditions in Inglefield Land. The Geodetic Institute of Copenhagen permitted the reproduction of a number of aerial photographs.

Transportation between Thule, Greenland and Inglefield Land was furnished by Detachment 18, Eastern Aero Space Recovery and Rescue Center, U.S. Air Force. For this assistance special thanks are extended to Capt. R. R. Dreibelbis and the officers and men of his command. Field equipment including tents, radio, rations and medical supplies was furnished by the U.S. Army at Camp Tuto.

Special thanks are also extended to a number of investigators for assistance in carrying out the laboratory studies of the project. Prof. Pa Ho Hsu, Prof. S. J. Toth, Prof. L. A. Douglas, Dr. D. K. Markus and Mr. D. A. Rickert, all of Rutgers University, gave generously of their time in connection with chemical analyses and mineral identification.

Prof. W. L. Kubiena spent a great deal of time and effort in working out certain phases of the micromorphology of the samples, for which the author is most grateful. Many thanks are also extended to Mrs. Gunde Kubiena for preparing and photographing the thin-sections.

Prof. P. A. Colinvaux, of Ohio State University, identified the pollen in the samples of buried organic matter, and for this special help the author is most appreciative. Dr. A. E. Porsild of the National Museum of Canada made positive identification of a number of plant specimens.

Finally, thanks are extended to Miss Ann Tyra Ames, of Rutgers University, who served as typist, and Miss Eileen O'Mullen, also of Rutgers University for copy editing.

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HISTORICAL REVIEW

Inglefield Land (Fig. 1) was discovered by KANE (1857a, b) late in 1853. The expedition approached Ingelfield Land via Etah and continued to Kap Inglefield and Rensselaer Bugt, where winter headquarters were established for 1853–54–55. Explorations were made beyond the Humboldt Gletscher to Washington Land as well as to other locations in the vicinity of northern Greenland. KANE's party was primarily a coastal party, but they did make a few inland journeys to the edge of the glacier ice. In addition to general exploratory work and topographic surveys, some plant collections and observations on animal life were made. Fragmentary geologic notes were made by the group, but except for brief passages relating to the rocky terrain and green meadows, there were few notations on soil conditions.

From 1855 until the Second Thule Expedition of 1917, Inglefield Land was visited only casually. HAYES' (1867) expedition stopped at Etah as did PEARY's (1910), MACMILLAN's (1918) and others, but the parties did not penetrate inland into Ingelfield Land proper. SCHEI (1903) and BUGGE (1910) made some preliminary observations on petrology in the vicinity of Etah.

The Second Thule Expedition of 1917 ushered in an era of considerable scientific accomplishment (RASMUSSEN, 1927; KOCH, 1928). WULFF's untimely death virtually terminated the scientific botanical work of the expedition, but KOCH continued on with his geologic studies and left an outstanding record. Fortunately, OSTENFELD (1923a, b) worked over the collections of WULFF, Rev. GUSTAV OLSEN and Capt. GODFRED HANSEN, and included in the report his own observations. KOCH was concerned with topographic mapping and geology, including ice studies. KOCH continued his studies of geology, geography, and cartography in Inglefield Land in 1920, 1921 and 1922 (KOCH, 1926, 1933).

Following KOCH's great work there was, for a number of years, only fragmental scientific activity in Ingelfield Land. WRIGHT (1939) was primarily concerned with the inland ice of Prudhoe Land and made a number of inland traverses of the ice cap. TROELSEN (1950) reported a number of observations on geomorphology and structural geology in Northwest Greenland and the eastern Canadian Arctic Archipelago.

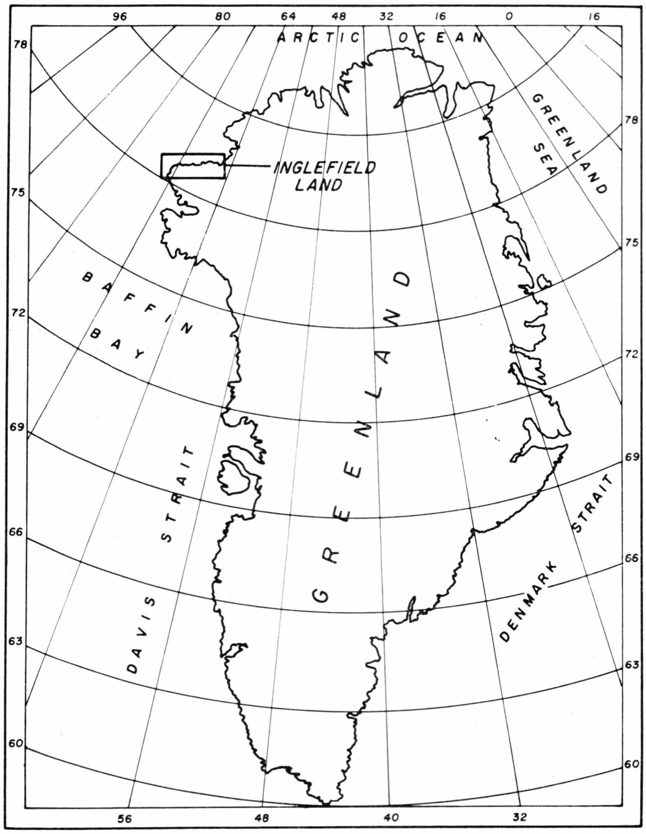

Fig. 1. Map of Greenland showing the general location of Inglefield Land.

Malaurie (1954), in conducting his geomorphic studies of Inglefield Land, made a number of inland journeys, including one to Rensselaer Bugt. Detailed surficial geologic and geomorphologic studies were carried out more recently by Nichols (1969) south of Rensselaer Bugt.

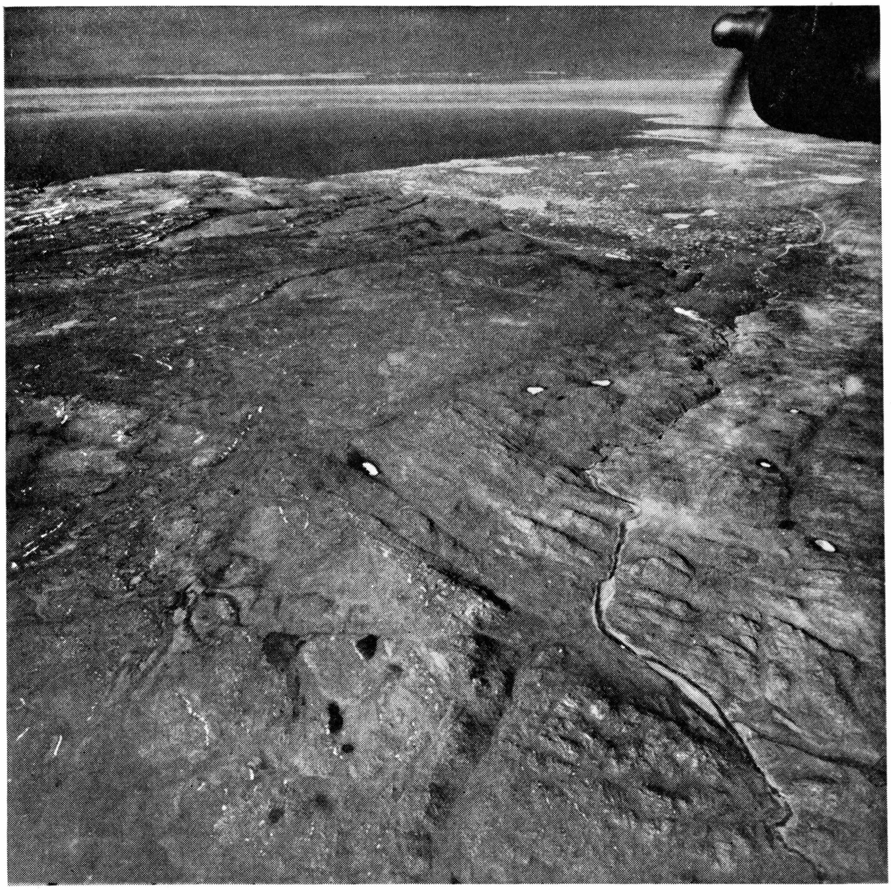

Fig. 2. Aerial view of a portion of Inglefield Land just south of Rensselaer Bugt. Photo courtesy of the U.S. Army.

GEOLOGY

Inglefield Land (Fig. 2) consists of a dissected plateau of rolling relief. The plateau is formed on a Pre-Cambrian basement complex of gneisses and related rocks. The basement rocks are capped with Paleozoic sediments – conglomerate, sandstone, shale, limestone, and dolomite (Poulsen, 1927; Koch, 1933; Troelsen, 1950). A few diabase sills are exposed in the western sectors. With the sedimentary rocks are complex quartzites and quartz-diorites. The main geologic features of Inglefield Land are shown in Fig. 3.

The study herein reported covers a sector immediately south of Rensselaer Bugt. The headlands of Rensselaer Bugt rise boldly some 600

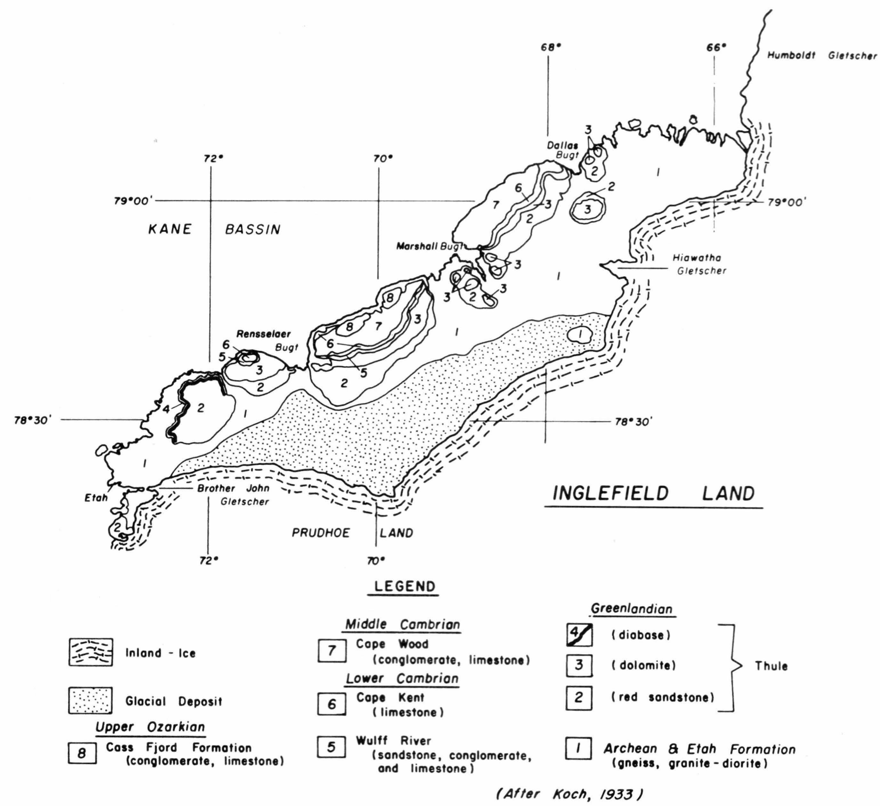

Fig. 3. Geologic map of Inglefield Land, Greenland. Modified from Koch (1933).

feet, exposing the horizontally bedded sedimentary rocks (Fig. 4). South of the precipitous landscape adjacent to the Kane Bassin, topography is undulating with the land usually at an elevation of 600–1500 ft. asl. From a point some 6 miles south of Rensselaer Bugt to the Prudhoe Land icecap (Fig. 5), topography is undulating with the bedrock covered almost completely by glacial drift. In northwestern Inglefield Land several main streams have down-cut through the Algonkian peneplain surface, exposing much bedrock, including rock walls. The best example of this is the gorge which has formed between Queen's College Sø and Rensselaer Bugt where cliffs and rock walls in places attain heights of 300 to 400 feet (Fig. 6).

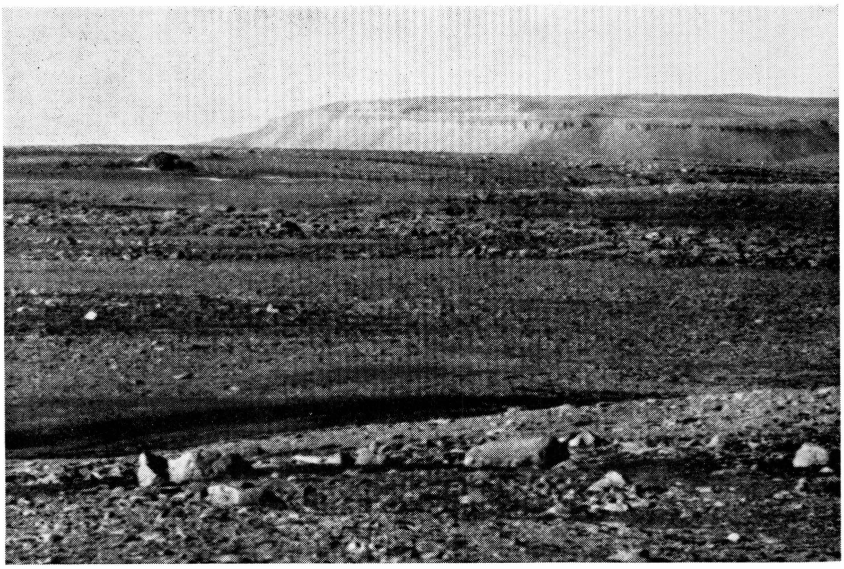

Fig. 4. View from Inglefield Land to the North, showing in the distance the sedimentary rocks along the Rensselaer Bugt.

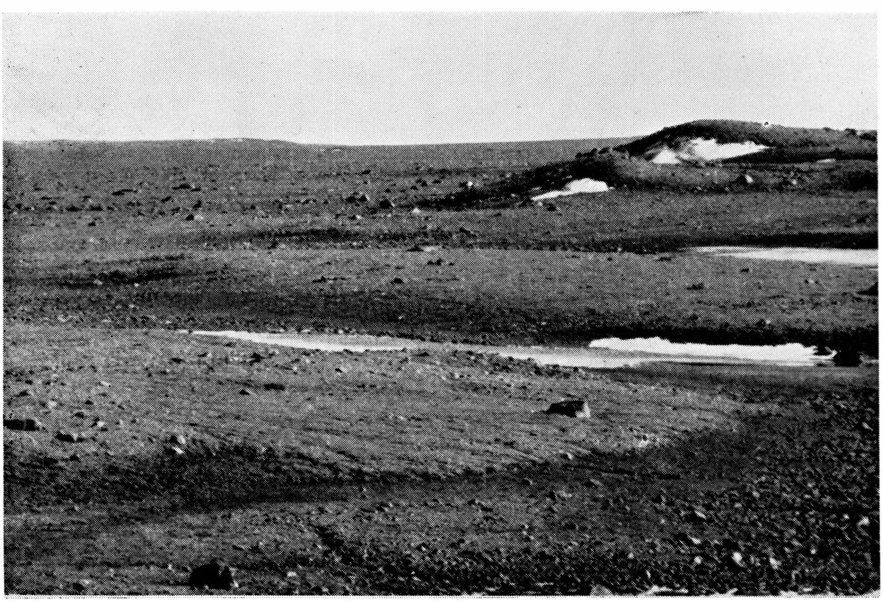

Fig. 5. Glacial drift of Inglefield Land. Most of the area south of Rensselaer Bugt is undulating with few bedrock exposures.

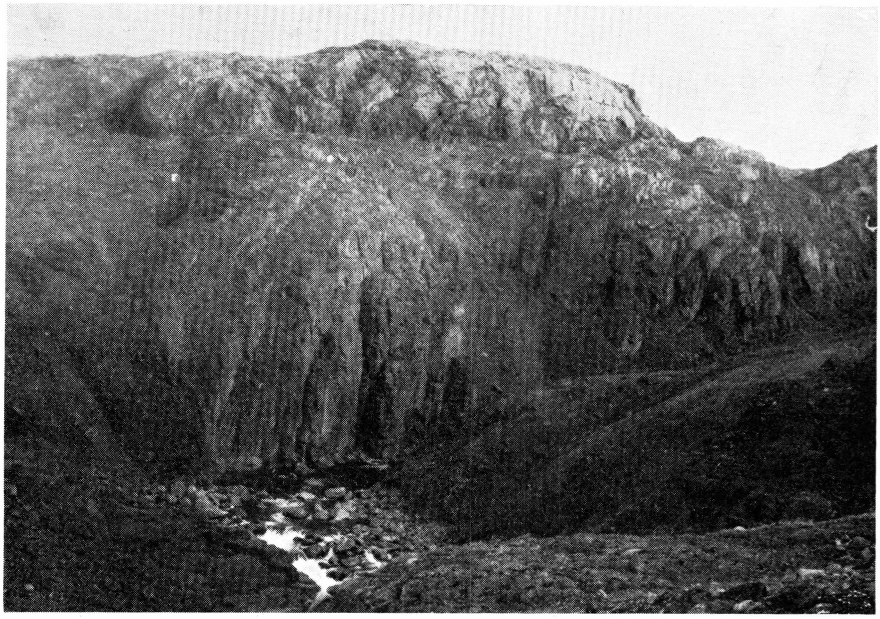

Fig. 6. View of the gorge 1 mile south of Rensselaer Bugt. Photo courtesy of D. A. Gaskin.

Surficial Deposits

Glacial history bears special significance to this investigation because virtually all of the pedologic studies are confined to the glacial deposits. Koch's work (1933) indicated that about one third of Inglefield Land is mantled with glacial drift (Fig. 3). Troelsen (1950) states "Though the Algonkian surface plateau evidently has been completely covered by the Pleistocene icecap, glacial erosion seems to have played but a minor part in the modeling of the surface". Nichols (1969) had indicated that all of Inglefield Land was once glaciated.

The origin of some of the glacial erratics on the eastern edge of Ellesmere Island is uncertain but several investigators have advanced the possibility of North Greenland as being the source (Christie, 1967). Probably the glacier ice moved across the Kane Basin and onto the eastern fringes of Ellesmere Island. The southeastern edge of the Kane Bassin is rather shallow, probably in part a result of glacial drift being deposited from the advance of the Greenland ice. Davies (1961b) and Krinsley (1961) also indicated that in Peary Land the present ice-free land was, at one time, completely glaciated. Fig. 7 shows the northern extent of glacial drift as mapped by Koch (1933). The area mapped as Stage 1 is mantled with glacial erratics even on the highest promentories.

There appears to be little doubt that the entire surface had been scoured by glacial ice with deposits of glacial debris of unknown thichness remaining. Throughout the Stage 1 area, bedrock is exposed extensively with

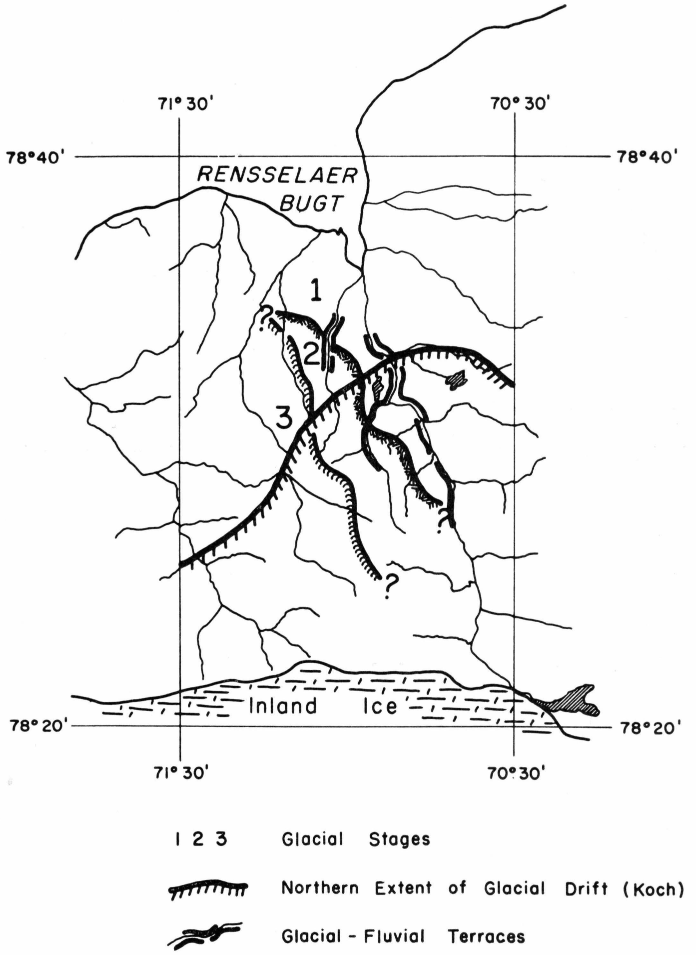

Fig. 7. Glacial geology map of a portion of Inglefield Land, Greenland.

glacial debris consisting almost entirely of large erratics, some measuring 12 to 15 feet across (Fig. 8). The only situations in which sand, silt and clay are present in distinct quantities are the shallow swales and depressions. A few pockets of weathered loamy material are present on the steep land immediately south of the bay. Even in the depressions, boulder fields with a continuous mantle of large, well-rounded rocks and a paucity of fines is the gneral rule (Fig. 9). Iron-stained silicate rocks

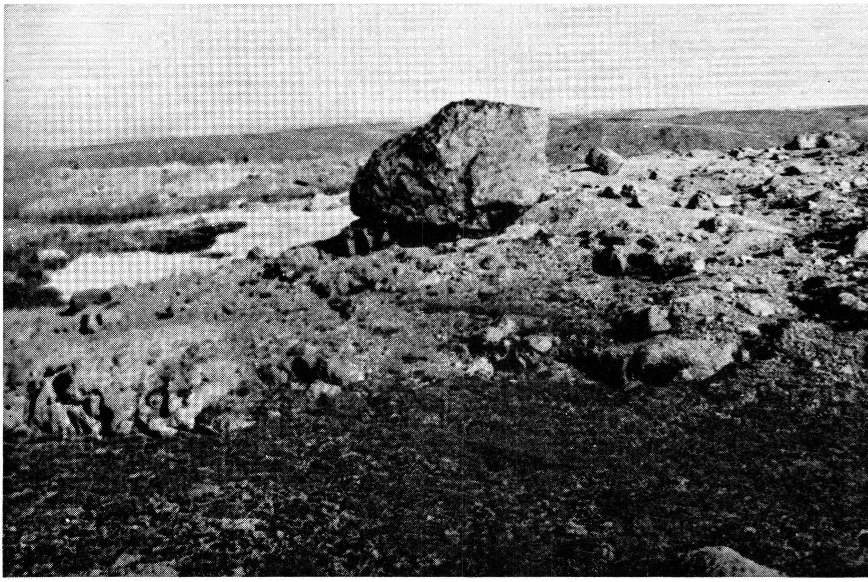

Fig. 8. Glacial erratics resting on the Algonkian peneplain about 3 miles south of Rensselaer Bugt (Glacial Stage 1, see also Fig. 7).

and limestone boulders with solution cavities are scattered throughout the landscape. It appears that following glacial Stage 1 there was a period of great fluvial activity in which the finer material and even many of the larger boulders were transported. The landscape designated as Stage 1 (Fig. 7) consists of many extremely rough bedrock areas and boulder fields (Figs. 10 and 11). The uplands are made up of outcrops and boulder-strewn low ridges interspersed with wet swales, the latter becoming dry later in the season.

Following glacial Stage 1 there was another glacial advance from the south which is exemplified on the map as Stage 2. The drift of Stage 2 is continuous and bedrock is seldom exposed except along some of the entrenched streams. The drift of Stage 2 probably has a thickness of 10 to 40 feet. Unlike the rocky conditions in Stage 1, the drift of Stage 2 has dominant sand and gravel components with small quantities of silt and clay. A few large boulders are scattered over the landscape (Fig. 12). The drift of Stage 2 is weathered to 3 to 4 feet and even below this depth there is an iron staining of the matrix. Limestone is weathered on the surface horizon and carbonate-clay complexes are precipitated on the lower sides of the cobbles. Morainal features are poorly expressed or absent at the northern fringes of drift sheet No. 2. This indicates either post deposital erosion of the moraine or that the glacial activity was not con-

Fig. 9. A boulder field about 5 miles south of Rensselaer Bugt.

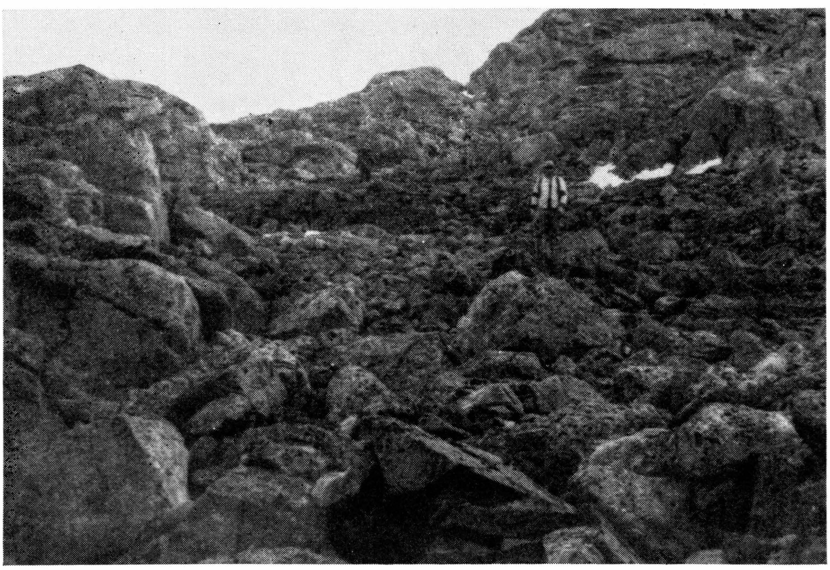

Fig. 10. Rough, broken terrain with many outcrops just south of Rensselaer Bugt.

ducive to moraine-building. Field evidence suggest the latter—probably there was a relatively short time interval separating the advance and the retreat of the ice.

Fig. 11. Boulder field of the uplands showing predominantly sub-angular rock.

The northern advance of Stage 3 (Fig. 7) is represented by a prominent semi-continuous morainal belt rising 200 to 300 feet above the undulating landscape (Fig. 13). The moraine marking the northern advance of Stage 3 has a maximum known altitude of about 2100 feet. The moraine has not suffered a great deal of post-glacial erosion, and the drift is not weathered to the extent of that of Stage 2. Stage 3 has an unweathered gray appearance while that of Stage 2 has more of a yellowish color.

South of Stage 3 the surficial deposits were discussed in detail by Nichols (1969). The relation of glacial Stage 3 to the northern extremities of Nichols' work has not been studied.

Following either the second or the third glacial stage there was great fluvial activity along the water courses. Large, barren terraces, some several hundred feet wide, now line the valleys (Figs. 7, 14). One terrace was excavated and a buried organic bed at a depth of 2 feet exhumed. C14 datum and pollen analysis are given in Table 1. The high terraces show a degree of weathering but not to the extent of that found in the drift of glacial Stages 1 and 2. These high terraces may predate or are contemporaneous with glacial Stage 3, but the problem requires more study.

The valley of the main stream draining into Rensselaer Bugt is mantled extensively with complex glacial features such as kame terraces

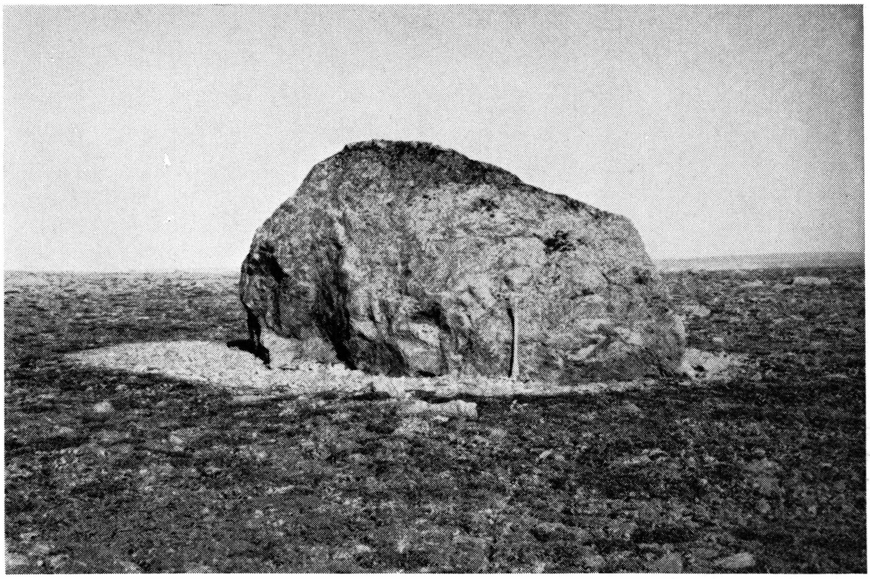

Fig. 12. Large glacial boulder resting on the undulating drift of glacial Stage 2. The pick resting against the boulder is 3 feet high (See Fig. 7).

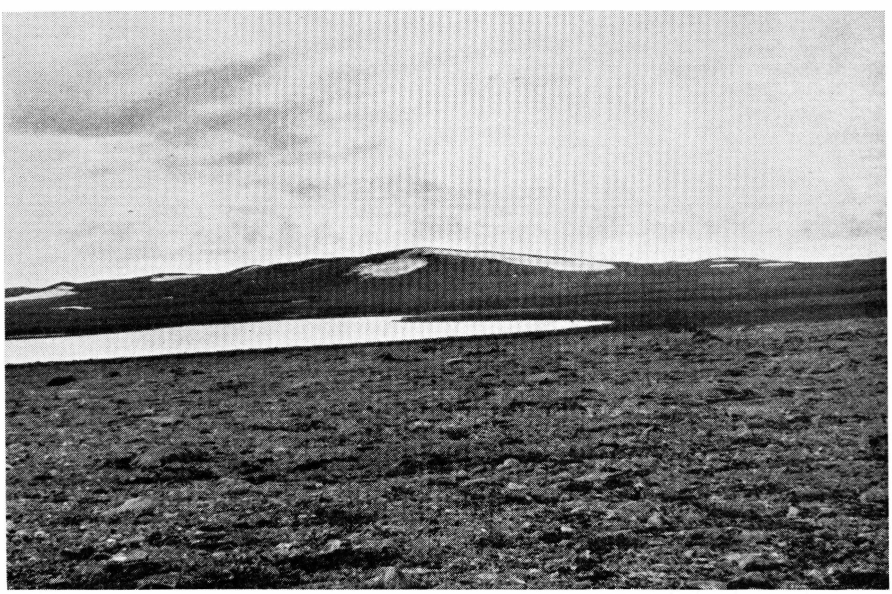

Fig. 13. Looking south towards the moraine which marks the northern extent of glacial Stage 3. The moraine attains a height of *c.* 2100 ft. asl. Photo courtesy of D. A. Gaskin.

Fig. 14. Glacio-fluvial terrace about 300 feet above the river. Bedrock protrudes above the terrace.

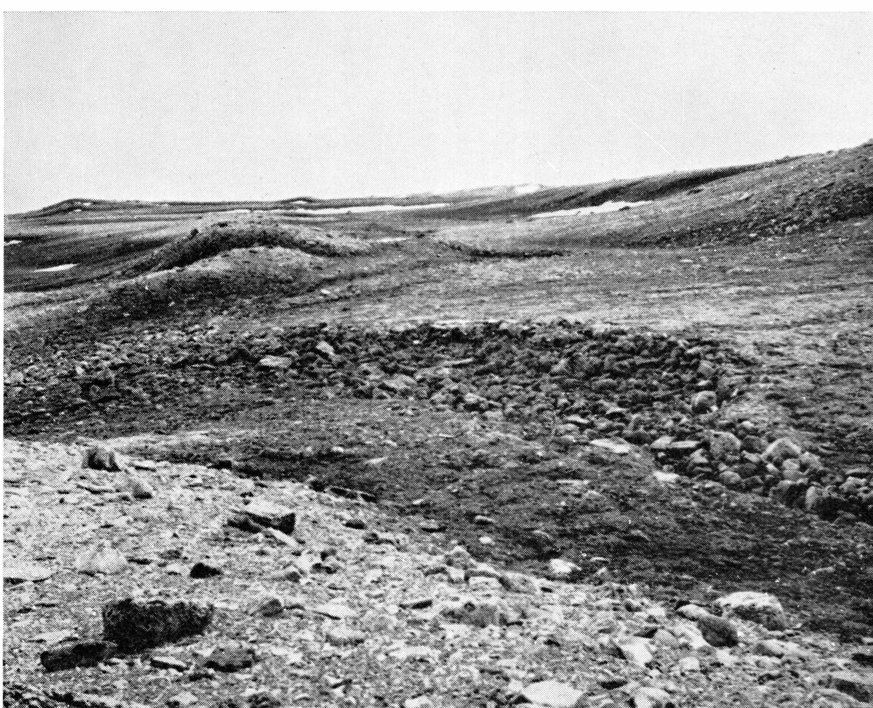

Fig. 15. Complex glacial drift of Inglefield Land.

Fig. 16. Aerial view of the raised beach ridges adjacent to Rensselaer Bugt. Upper right of the photograph shows drifting pack ice of the Kane Bassin. Photograph courtesy of the Danish Geodetic Institute. Copyright, Geodetic Institute, Denmark (A. 266/67).

Table 1. *Pollen*[1]) *analysis of buried organic matter on a glacio-fluvial terrace, Inglefield Land, Greenland. The sample, a sandy clay, contained 1.6 pct. organic matter and yielded a C14 date of 20,800 ± 2900 yr. B.P.* (*I-2322*)

Species	Pollen %	Species	Pollen %
Gramineae	10	*Picea*	+
Cyperaceae	7	*Hippuris*	+
Betula	30	*Ranunculaceae*	+
Alnus	5	*Senecio*	4
Empetrum	8	*Taraxacum*	+
Salix	+	*Ambrosia*	–
Artemisia	13	*Thalictrum*	+
Caryophyllaceae	10	*Umbelliferae*	+
Saxifragaceae	5	Others	8

and cone moraines as described by NICHOLS (1969) together with related glacio-fluvial derived deposits (Fig. 15).

[1]) The original sample contained 43 pct. reniform fern spores and 20 pct. *Lycopodium selago* spores. The percentages in the table are exclusive of the reniform fern and *Lycopodium selago.*

Table 2. *Provisional outline of glacial events just south of Rensselaer Bugt, Inglefield Land, Greenland*

Event	*Characteristics*
Modern fluvial deposits.	Fresh appearing sediments – some local iron staining.
Terrace building inland from glacial melt water. Extensive fluvial activity – age may predate glacial Stage 3.	Stratified yellowish gray colored drift. Buried organic matter 20,800 yr. B.P. Some weathering in coarse sediments.
Deglaciation. Slight erosion with little weathering of drift.	
Glaciation (Stage 3). Large moraines formed.	Gray-colored drift; glacial land forms a well-preserved with boulders, sand, silt and clay. Glacial lakes present.
Deglaciation. Slight erosion with intermediate weathering of drift.	
Glacial (Stage 2). Glacial advance to *c.* 5 miles south of Rensselaer Bugt.	Weathered yellow-colored drift; boulders sand, silt and clay. Shallow glacial lakes present. Smooth topography.
Deglaciation. Great fluvial erosion followed by intermediate weathering of drift.	
Glaciation (Stage 1). Continental glacier reached Rensselaer Bugt (Probably Ellesmere Island).	Boulders with a few fines; isolated pockets of yellowish brown drift. A few glacial lakes remain. Boulder fields in some depressions.

Narrow floodplains and gravel bars now occur discontinuously along the active stream channels.

In order to provide a chronology of glacial events in Central Inglefield Land, Table 2 is tentatively proposed.

Marine terraces now form a complex, discontinuous pattern along the margins of Greenland and the Canadian arctic archipelago (Fig. 16), (Troelsen, 1950; White, 1956). They reach an altitude of 200 meters asl. near Disko (Laursen, 1950). On Ellesmere Island, Christie (1967) reported them as high as 75 m asl. whereas in the Arctic Islands to the west, Craig and Fyles (1960) reported some much higher ones. In northern Peary Land, Davies (1961 a, b) reported marine terraces up to 129 m asl. Washburn and Stuiver (1962) published on the age of driftwood and shells on many emerged strandlines in northeast Greenland.

The problem of ice balance in the Greenland Icecap has been discussed by numerous investigators and the overall dynamics has been set forth by Fristrup (1966). Loewe (1936) indicated that the Greenland ice sheet is stationary. Bauer (1955), however, presented an analysis of the Greenland Icecap which depicted a negative balance (1955). Benson (1962) after considering earlier reports along with present climatic data supported Loewe's interpretation that the Greenland Icecap is now in balance with existing climate. In order to determine any possible short term changes in the position and configuration of the northern edge of the ice at Prudhoe Land some more recent photographs of outlet glaciers were compared with earlier maps. Koch (1928) mapped the Brother John Gletscher and Hiawatha Gletscher in 1917 and these maps are compared with aerial photographs made in 1959 by the Danish Geodetic Institute. Allowing for earlier mapping irregularities as well as photographic distortion, it appears that during the 1917–1959 period, the Brother John Gletscher advanced about 1 kilometer, with a slight broadening of the glacier snout (Fig. 17). The small stream entering Alida Sø from the south (Fig. 17, top) where the glacier met the lake in 1917 was, in 1959, completely overrun by the Brother John Gletscher (Fig. 17, bottom).

Comparing the changes in configuration of the Hiawatha Gletscher during the 1917–1959 interval it appears that there was a slight advance of the glacial snout, and there is a suggestion that the main edge of the icecap may have had some irregular changes advancing in some locations while retreating in others (Fig. 18).

CLIMATE

Systematic long-term weather observations in Inglefield Land are virtually non-existent, but certain data are available from a number of high arctic stations from which some extrapolations can be made.

In Inglefield Land continuous daylight exists from mid-April to late August whereas continuous darkness exists between early November and early February.

The length of time soil processes are in an active state are limited to some 2 to 3 months each year. Thaw begins in June and continues until late August or early September. Because the higher, drier positions are comparatively free of late snow cover, the soil in these locations is in a dry frost condition and thaws comparatively early and rapidly. The wetter sites, however, usually occurring in depressions, have a late snow cover and thaw may not begin in these locations until mid or even late July.

Air temperatures from a number of high arctic weather stations are given in Table 3. Kap Alexander, the closest weather station to Inglefield Land, has a mean July temperature of 30° F. Three other stations (Thule, Eureka and Bache Peninsula) have mean July temperatures approximating 42° F. FRISTRUP (1952 b) reported detailed temperatures for Peary Land and his data for the month of July are similar to those reported for Thule, Eureka and Bache Peninsula. It is of interest to note that KANE (1857 b) projected a 36.5° F July isotherm through Inglefield Land. The Crocker Land Expedition indicated that the mean temperatures in the vicinity of Etah and Refuge Harbor are 35° F for June, 41 for July and 37 for August (MACMILLAN, 1927). RAE's (1951) sketch maps of the July isotherms for northern Canada indicate that the western tip of Inglefield Land should have a mean July temperature of slightly below 40° F. If data are extrapolated from a number of sources to Inglefield Land, it would probably be realistic to state that of the three warmest months, July should have a mean temperature of about 40° F, whereas June and August should have temperatures approximating 35° F.

Precipitation values for land in the vicinity of the Kane Bassin are given in Table 4. The data indicate that the total annual precipitation

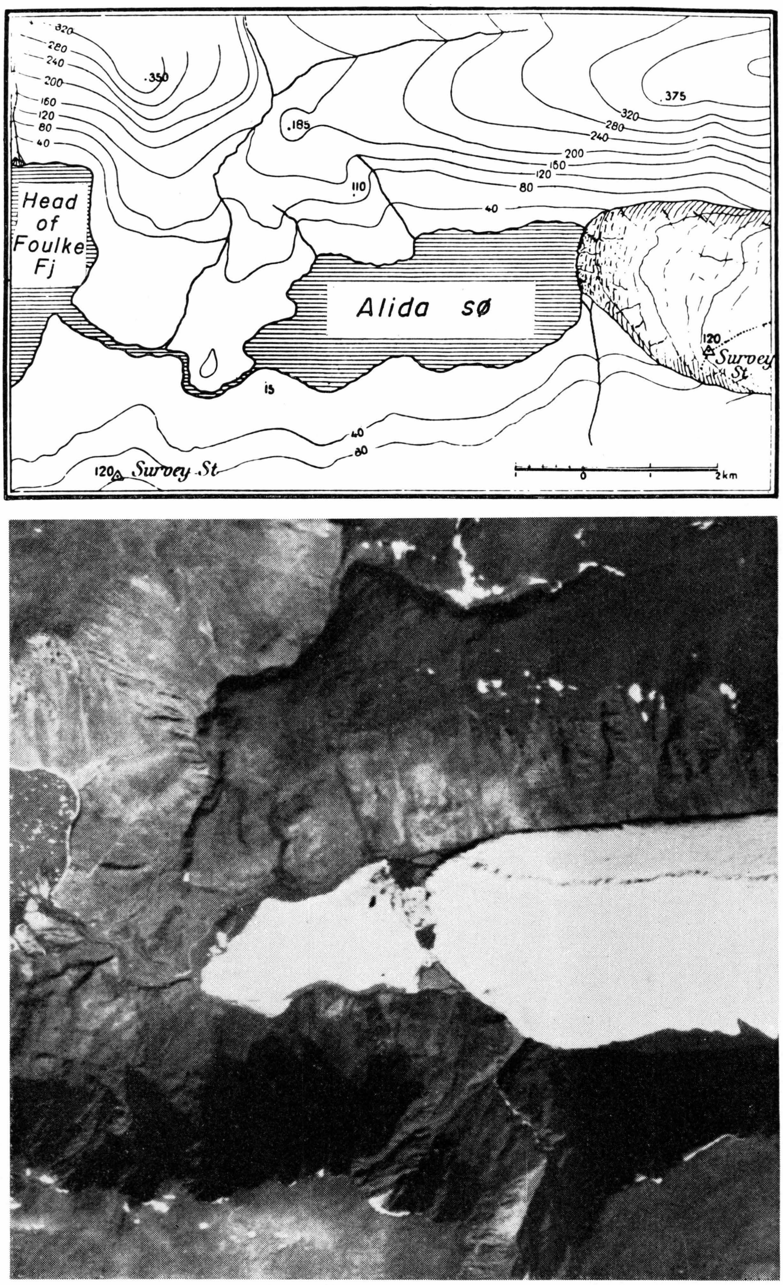

Fig. 17. Top view shows the Brother John Gletscher terminating in Alida Sø as mapped by Koch in 1917 (Koch, 1928). The bottom picture shows the same landscape as it appeared in 1959. There appears to be a slight advance of the outlet glacier. Photograph is through the courtesy of the Danish Geodetic Institute. Copyright, Geodetic Institute, Denmark (A. 266/67).

Table 3. *Mean monthly temperatures of selected sites in the vicinity of the Kane Bassin*

Month	Thule[1] 76°30′ N 68°50′ W	Kap[2] Alexander 78°08′ N 71°37′ W	Eureka[3] 80°00′ N 85°56′ W	Bache[3] Peninsula 79°10′ N 76°45′ W
	°F	°F	°F	°F
January	− 12	− 22	− 28	− 26
February	− 14	− 22	− 39	− 26
March	− 16	− 23	− 30	− 23
April	+ 1	− 7	− 21	− 9
May	+ 23	+ 6	+ 13	+ 17
June	+ 37	+ 25	+ 38	+ 37
July	+ 43	+ 30	+ 42	+ 41
August	+ 41	+ 26	+ 38	+ 37
September	+ 28	+ 10	+ 19	+ 26
October	+ 14	+ 2	− 6	+ 5
November	0	− 12	− 21	− 7
December	− 10	− 23	− 36	− 24

[1]) Unpublished data, Air Weather Service (U.S.A.).
[2]) Hogue (1964).
[3]) Rae (1951).

Table 4. *Precipitation in the vicinity of the Kane Bassin*

Month	Thule[1] 76°30′ N 68°50′ W	Eureka[2] 80°00′ N 85°56′ W	Bache Peninsula[2] 79°10′ N 76°45′ W
	in.	in	in.
January	0.31	1.10	0.17
February	0.35	0.06	0.46
March	0.18	0.10	0.11
April	0.12	0.01	0.10
May	0.22	0.02	NR
June	0.28	0.02	NR
July	0.72	0.03	0.34
August	0.55	0.02	2.04
September	0.64	0.59	0.45
October	0.72	0.11	0.75
November	0.52	0.14	0.72
December	0.22	0.07	0.05

NR Not reported.

[1]) Unpublished data, Air Weather Service (U.S.A.).
[2]) Rae (1951).

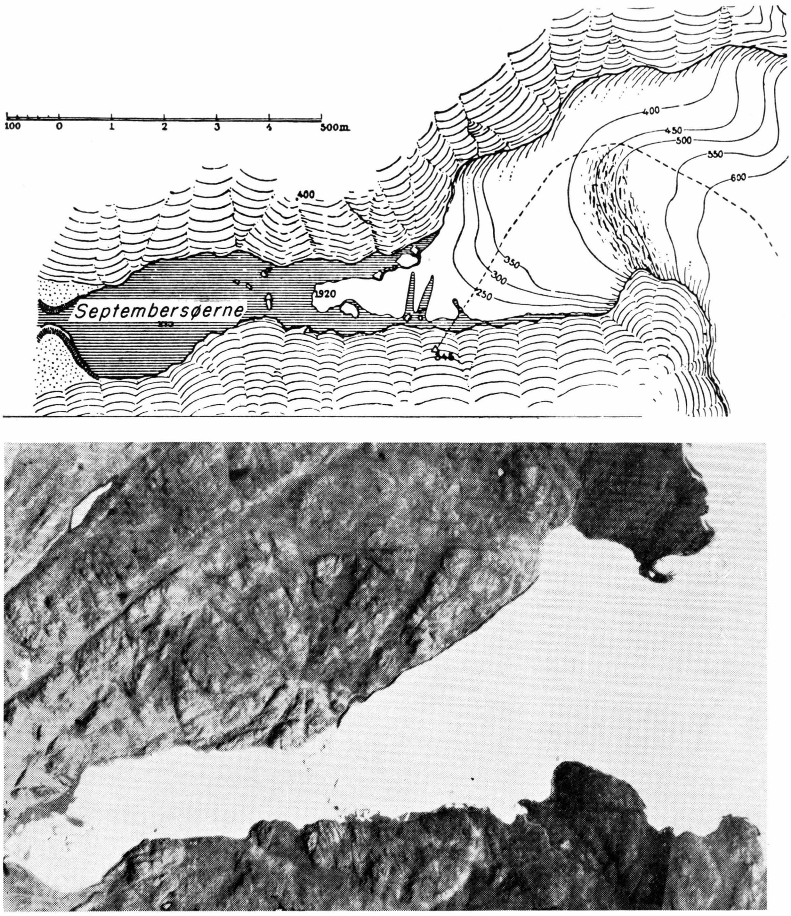

Fig.18. Top illustration is of the Hiawatha Gletscher as mapped in 1917 (Koch, 1928). The bottom photograph shows the same landscape in 1959. There appears to be a slight advance of the outlet glacier with minor changes in position of the edge of the main inland ice. Air photograph is through the courtesy of the Danish Geodetic Institute.

approximates 2 to 5 inches. Probably at least one-half of the precipitation is in some form of snowfall.

Relative humidity is of prime importance in the high arctic – especially in connection with soil formation. Rae (1951) indicates that the relative humidity for the month of July in the Canadian arctic archipelago averages 83 pct. whereas in August it averages 87 pct. At Tuto East and Stations 2 and 3, all in the vicinity of Thule, relative humidity for the three summer months approximates 80 pct. (Hogue, 1964).

Malaurie (1958) presented a digest of the meteorologic conditions in the Rensselaer Bugt area. This work compiled in part from Kane's observations, includes temperatures, wind direction and speed together with relative humidity, among other information.

While in the field in Inglefield Land in July, 1966 little fog was encountered in the uplands, but from the gorge north to Rensselaer Bugt the valley was frequently blanketed with fog.

VEGETATION

The vegetation of Inglefield Land is best described as typical high arctic. The uplands are strikingly barren with vascular plants usually covering less than 5 pct. of the surface (Figs. 14, 15). Unlike conditions most climatic regions, vascular plants in the high arctic do not compete for open space but instead cluster together. Among the common plants of the upland barrens are *Salix arctica*, *Dryas*, *Saxifraga*, *Luzula confusa*, *Festuca*, *Poa*, *Carex*, and others. *Dryas* forms a heavy mat in local shallow, well-drained micro depressions (Fig. 19). Vegetation on the slopes is similar to that of the uplands with *Cassiope*, *Dryas* and *Carex* dominating. In the depressions and swales, a somewhat closed cover of *Eriophorum*, *Arctogrostis latifolia*, *Carex stans*, *Saxifraga*, mosses and related species exist (Fig. 20).

Ostenfeld (1923 a) listed the plants from Inglefield Gulf at Kangerdlugssuak and Kap Agassiz. Ostenfeld (1923 b) quotes from Wulff's diary, "The vegetation up here [Inglefield Land] seems on the whole, only to start its growth at the time of or after the summer solstice. The explosive development of arctic plants is absolutely staccato, fast in the warm and sunny hours, but at a complete standstill during the many cold and windy days".

Reconstructing from Wulff's notes, Ostenfeld (1923 b) recognized the following plant formations in Inglefield Land:

1. Fjaeldmark. Isolated plants with much bare ground.
2. Vegetation on manured soil. Vegetation forms a carpet where there is abundant animal excrement.
3. Heath shrubs. Small patches in the Fjaeldmark.
4. Bogs.
5. Shore vegetation.

Hartz (1896) gave a good report of the vegetation in East Greenland as did Ostenfeld (1915). Holmen (1957) lists 98 vascular plants in North Greenland and Fredskild (1966) identified 7 additional species. An informative contribution to soil-plant relationships was made in the Jakobshavn sector by Fredskild (1961). Special mention is made of the work of Porsild (1957 a, b) for his description and maps of vascular plants in the northeastern Canadian sector.

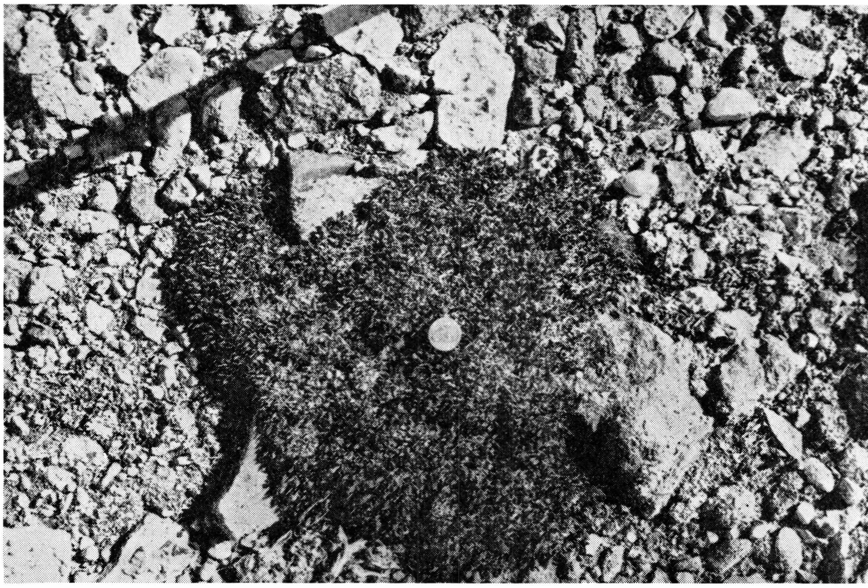

Fig. 19. Photograph of *Dryas* on the polar deserts. The organic mat is underlain by a 1-inch humus layer.

While the above works are of great value for the pedologist, what is equally important is broad outline of the plants, their distribution and frequency and how they contribute to and affect the soil system. In this connection it is important to record the work of POLUNIN (1951) in which he describes a biologicolatitudinal division of the arctic into low-arctic, middle-arctic and high-arctic. Inasmuch as no polar investigator has ever given a more realistic picture of the botany of the high arctic, it is appropriate to quote at length some of POLUNIN's work.

"Most land areas that lie north of the seventy-fifth parallel of latitude may be considered high-arctic as may some to the south such as Prince of Wales Island. Good examples are Ellesmere, the north coast of Greenland, and Spitsbergen. The general aspect in those top-of-the-world lands is apt to be desolate in the extreme, with most of the terrain occupied, for example, by sparsely vegetated *Papaver* or *Saxifraga* "barrens" with perhaps a few tussocks of *Dryas* or various grasses on well-drained banks and very occasionally a limited tract of poor and thin *Vaccinium* or *Empetrum* heath developed under the most favorable conditions of shelter, soil and southerly prospect. But often one can trek for days without encountering such a 'heath'. Thus, most areas have scarcely a plant to be seen, and the only at all extensive tracts of more or less closed vegetation are apt to be marshy, the tallest

Fig. 20. A wet meadow with a continuous vegetative mat. The ice-axe rests on frozen ground.

plants of the region being their dominant grasses, sedges, or *Eriophora* which, however, rarely exceed 30 cm (1 ft.) in height. There are no real bushes or even groundshrubs more than a few centimeters high, and, in general, mosses form a large part of the vegetation in damp areas and lichens in dry ones. Sphagna are usually little in evidence and bogs of any depth nowhere to be found, althought the soil reaction may be distinctly acid and the feet in summer sink as much as 30 cm into a swamp before reaching hard frozen subsoil. But although in most areas plants tend to be scarcely at all in evidence, taking very little hold of the surface, the total flora in reality is usually considerable; especially may a wide array of Algae and other lowly forms be collected even at the highest latitudes of land, as well as in the sea where life is relatively plentiful and the planktonic forms enable large mammals to flourish.

For plant life in the high-arctic the struggle is rather with the inimical forces of nature than with ranker competitors, and so the flora as well as vegetation tends to be remarkably reduced as compared even with the middle-arctic zone. Thus, for example, only a few of the hardier salt-marsh and other strand plants persist, while the late-snow zones are commonly reduced to two or three. Indeed owing to the general reduction of the gowing season to a few weeks, much of the land takes on a late-snow aspect, with *Cassiope tetragona* the chief ground-shrub and quickly flowering *Saxifraga*, *Ranunculi*, and dwarf Salices widely important. In these circumstances of very small vegetation turnover there is little humus accumulation or true soil formation – in spite of the extreme slowness of decay under the prevailingly cool or frozen conditions. Other noteworthy features include the ubiquity and very various manifestations of frost-heaving and sorting which leads to all manner of 'polygon' and other soil phenomena such as solifluction streaks, and the lack of disturbance by man but the presence here and there of extraordinary concentrations of nesting wildfowl or sea-birds – for example on certain cliffs which they revisit year after year, and which, with their immediate surroundings, come to support a remarkably luxuriant grassy or cryptogamic sward".

PORSILD's work (1957 b) fits in well with that of POLUNIN. The former shows the northernmost Canadian arctic archipelago as "rock desert or fell field" corresponding to POLUNIN's high arctic. The stony sedge-moss-lichen-tundra of PORSILD corresponds to middle arctic of POLUNIN and the dwarf shrub-sedge-moss-lichen tundra zone of PORSILD corresponds to POLUNIN's low arctic. At this point it is pertinent to mention briefly the work of SOCHAVA (1954) in northern Eurasia in which the phytogeographic divisions of the northern sectors included (1) Arctic deserts and glaciers and (2) arctic tundras, typical moss-lichen tundras, and shrub and hillock tundras. While it is permature to suggest that a factual categorization of vegetative zones can now be established on a circumpolar basis some approximate equivalents are set forth:

POLUNIN (1951)	PORSILD (1957 b)	SOCHAVA (1954)	Zonal Great Soil Group Equivalent
High-arctic	Rock desert or fell field	Arctic[1]) Deserts	Polar Desert
Mid-arctic	Stony sedge-moss-lichen-tundra	Arctic Deserts	Polar Desert-Arctic Brown transition
Low-arctic	Dwarf shrub-sedge-moss-lichen tundra and mature sedge grass tundra	Arctic tundras typical tundras and shrub and hillock tundras, etc.	Arctic Brown with Dwarf podzol in southern sector.

[1]) Apparently the high arctic of Northern Eurasia is not as xeric as the northern land extremities in North America.

Fig. 21 shows the general region of Polar Desert soils in North America, including Greenland. This delineation is based on climatological and botanical data together with personal observations. The map does not include, however, the Polar Desert soils having altitudinal distribu-

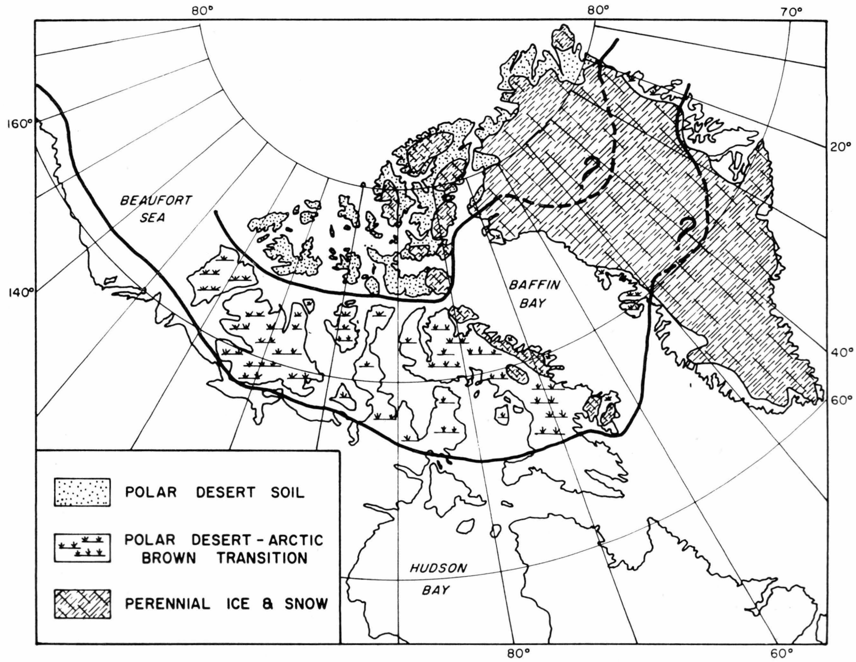

Fig. 21. Distribution of Polar Desert soils in North America.

tion (Tedrow and Brown, 1962). The Polar Desert-Arctic Brown soil transition as shown in Fig. 21 has many Polar Desert as well as Arctic Brown soils, and Tundra soils are also very common throughout this sector.

SOILS OF THE HIGH ARCTIC – A REVIEW

From a pedologic standpoint the barren, dry aspect of the high arctic received little attention until late in the 19th century. HARTZ (1896) while conducting botanical investigations in the Scoresby Sund region of Greenland, a sector somewhat south of the polar deserts, recorded evidence of desert-like conditions and mentioned the formation of salt crusts and certain drainage waters being charged with soluble soil constituents. NORDENSKJOLD (1914) described conditions in Greenland similar to those reported by HARTZ, and the salt crusts were found to consist mainly of sodium and sulphate.

IVANOV (1931) in Franz Josef Land and Novaya Zemlya reported on the chemical-physical weathering of soils with a concentration of fines at the surface. Soil temperatures at the 3 cm depth reached as high as 9.3° C. IVANOV's work was perhaps the first to attempt to recognize the pedogenic processes of the high arctic. In this he recognized that a podzolic process does occur and also described an initial stage relating to a sod-podzolic[1]) process. In addition IVANOV makes mention of strong salinization and "salt fading crusts" and presents chemical data on the adsorbed bases and composition of water extracts. Along with the terrestrial soils, the swampy and peat-like soils are also described.

GORODKOV (1939) made a critical review of Soviet phytopedologic work in the far north and made many outstanding observations of his own. His work separated soils from weathering products and recognized the desert process with carbonate crusts, alkali spots, together with an embryonic podzolic process on the sandy materials. Further, GORODKOV did not portray a unique soil formation in the polar regions, instead recognized the various northern processes (*e.g.* podzolization) coupled with low temperatures and attendant cryogenic factors. Not only did GORODKOV (1939) report on the qualitative pedologic changes with increasing latitude but also described the longitudinal changes within the Siberian arctic.

The work of FRISHENFELD (1933) is of special interest because of his use of the term "polar steppe" to depict the landscape of the far

[1]) A. MUIR, 1961. The podzol and podzolic soils. Advances in Agronomy 13: 1–56.

north. While the introduction of this term by Frishenfeld has been questioned, it does convey a realistic meaning in the landscape description.

Following World War II there as a greatly expanded effort on the investigation of soils of the far north in both North America and Eurasia. Gorodkov (1947) continued his earlier work and designated two zonal landscapes of the polar regions: polar desert and tundra. The polar desert was described as one in which the influence of the severe environment stopped in the former primitive stages of development. Gorodkov (Mikhailov, 1962–63) reported that the Polar Desert soils are thawed for a period of 2 to $2^1/_2$ months and there is a seasonal thaw of 30 to 50 cm. Thawing during the first 2 to 3 weeks is very rapid, then slows down. Temperature gradients may reach 5–20° C within a distance of $^1/_2$ meter. Gorodkov (1939) reported 2 to 3 pct. organic matter in the Polar Desert soils with the main contributors being diatoms and blue-green algae. The polar deserts included all islands of the Soviet Arctic with the exception of southern Nova Zemlya, Vayvgach and Kolguya Islands but it included a section of the Taimyr Peninsula.

Svatkov (1958) delineated special types of soil formation on Wrangel Island and accordingly designated Arctic Polygonal, Arctic Sod, Arctic Gley, Bog and Arctic Mountain soils. In the Arctic Polygonal (Polar Desert) soil was recognized salinization and efflorescence of salts.

Karavayeva (1965) used the term Arctic Tundra for the soils of Bol'shoy Lyakhovskiy Island and described the main features as (1) permafrost at the 30 to 40 cm depth (2) little water-logging and gleying (3) low degree of leaching (4) slow rate of cryogenic processes (5) slight quantity of vegetation. The surface was described as a brownish-pale yellow color and at the 2 to 32 cm depth, a dark brown clay loam, with no trace of gley. The soil had a pH of approximately 5.0 which increased at depth and was saturated with calcium and magnesium.

So far in this report we have seen that the description of the soils and their chemical parameters have pointed to one set of fundamental processes in the deserts of the high arctic and that the local soil variations can be ascribed to minor differences, climate, relief, parent materials and other local conditions. Prior to *circa* 1950 there was only minor concern in classification of the high arctic soils on a systematic basis but since then there have been numerous attempts at placing the various soils of the polar regions into a classification system. It is of little importance to go into the earlier works of Dokuchaev, Sibirtzev, Neustreuv and Glinka because these investigators did not have a full understanding of conditions in the high arctic and their views were usually theoretical and largely incomplete. Nevertheless it is important to consider their broad views on taxonomy.

Prasolov (1937) correctly outlined that a soil type[1]) should reflect a common origin, transformation and migration of substances and should possess similar moisture and temperature regimes, similar ecologic conditions, similar genetic horizons resulting from the development process and similar degree of plant nutrients. Ivanova (1956 a) later proposed a list of arctic soils with several subdivisions, namely:

Arctic gley-turf soils

1. arctic gley-turfy solonchak soils
2. arctic gley-turfy soils
3. arctic gley-humus-turfy soils

Arctic crypto-gley-polygonal soils

1. arctic crypto-gleyey polygonal soils
2. arctic crypto-gley soils of stone polygons

Ivanova's system has its merits, but does not provide a solution to the core of the problem of the soils of the polar deserts. Other proposed systems such as those of Ivanova et al. (1961) and Sokolov and Sokolova (1962) discussed the polar soil classification problem but, unfortunately, did not make adequate provision for soils of the polar deserts. Gerasimov (1956) separated the soils of the polar regions into the gley soils of the subpolar tundra (Tundra) and primitive soils of the polar tundra (Polar Desert). Ivanova and Rozov (1962) divided the arctic deserts into three zones all with a blurred zonality: (1) grassy-mossy deserts, (2) impoverished undershrub moss and (3) southernmost moss-undershrub moss. A rather detailed account of physical features of the polar deserts was given. Liverovskii (1964) in reviewing the Soviet contribution on soils of the polar deserts, discussed the absence of gley soils, the presence of ferric oxide formation, efflorescences of carbonates and saturation of bases. Targul'yan and Karavayeva (1964) not only reported on the general chemistry of soils of the polar regions but set forth important broad relationships of the desert-like conditions of the far north to those of Antarctica.

Sweden and Norway have extensive barren-like soil conditions in the highest altitudes of the northern mountains. Whereas surface features in the Northern Scandinavian sectors appear to be similar to Polar Desert soils, detailed morphology shows quite different characteristics. Kubiena (1953) listed these Scandinavian soils as Climax Raw soils and divided them into Arctic Rawmark, Arctic Hamande Rawmark, and Structure Rawmark. Due to the high quantity of precipitation and relatively higher temperatures in the Scandinavian mountains the soils have a raw-like

[1]) *Soil type* of the Soviet investigators corresponds approximately to Great Soi-Group of American investigators.

appearance with few genetic horizons[1]) DAHL (1956) believed that some of the weathered surfaces in the high mountains of Norway were relic conditions.

Turning to North America we find virtually no pedologic investigations *per se* on the polar desert prior to 1950. Since that time, however, a number of reports have been forthcoming. It is pertinent to first list the work of a number of Canadian botanists who described the vegatation and other environmental conditions of the high arctic: MACDONALD (1952–53), PORSILD (1957 a, b), SAVILE (1959, 1961, 1964), BESCHEL (1961) and others have described the sparse vegetation, desert-like conditions, alkaline and saline soils and salt crusts of the Northern Canadian archipelago.

The term Polar Desert soil was introduced to the pedologic literature in America by TEDROW et al. (1958) and TEDROW and CANTLON (1958). It was shown that the zonal soil of the tundra region was exemplified by the Arctic Brown soil but in the high arctic the zonal soil was the Polar Desert. In Northern Alaska, Polar Desert soils are found only in the higher portions of the Brooks Range but even in this region the profiles do not manifest the development as those of the high arctic (TEDROW and BROWN, 1962). On Banks Island, Polar Desert soils are quite extensive but the island as a whole should be considered somewhat of a transition between the main tundra (Arctic Brown) belt and the high arctic (TEDROW and DOUGLAS, 1964 and Fig. 21). Prince Patrick and Cornwallis Islands are a part of the high arctic and on these islands the Polar Desert soils are highly developed and widespread (TEDROW, 1966). A reconnaissance map of Prince Patrick Island shows that Polar Desert soils are the most extensive (TEDROW, et al., 1968). MCMILLAN (1960) showed the barren character of the high arctic in the Queen Elizabeth Islands sector and used Kubiena's term – Climax Raw soils. But if one examines the morphology of the soils of the Canadian Arctic archipelago in much detail some of the conclusions reached by MCMILLAN can be seriously questioned because the morphology of the Rawmark soils of Scandinavia is quite different from those of northern Canada. DAY (1964) presented some interesting findings on the soils of the Lake Hazen sector of Ellesmere Island. The Polar Desert soils were shown to be present throughout the area and Day classified them under the name Subarctic Saline Regosol and Subarctic Orthic Regosol, in keeping with the Canadian classification system.

In northern Greenland there have been few pedologic investigations. FRISTRUP (1952 a, 1952–53) and DAVIES (1961 a, b), however, reported the desert-like conditions of Northern Greenland. SORENSEN (1935) reported on the soils and plant cover of Greenland. In the Jakobshavn sector of

[1]) J. C. F. TEDROW. Soils of the sub-arctic regions. Symposium. Ecology of the sub-arctic regions. Helsinki (1966). (In press).

West Greenland, Arctic Brown soils were reported by FREDSKILD (1961). UGOLINI recognized Arctic Brown, Tundra and other soils in the Mesters Vig District of Northeast Greenland (UGOLINI, 1966a, b). Fredskild's work extended to about 73° N on the west coast of Greenland. How much farther north the Arctic Brown soils occur as prominent soils than had been reported by these two investigators has not been worked out but on the west coast of Greenland, Arctic Brown soil apparently does not extend as far north as Thule except under special circumstances. Based on fragmental reports, it appears that on the west coast of Greenland the regional line separating the Arctic Brown soil zone from that of the Polar Desert zone should be about as shown in Fig. 21. On a circumpolar basis the 40° July isotherm has special significance in that can be used as a crude dividing line separating the two soil zones. It is more realistic to speak of gradients rather than lines separating the two soils zones (TEDROW, 1968; TEDROW and THOMPSON, 1968).

The latitudinal zonation of soils and plants in Greenland was recognized at a very early date in history in that EGEDE (1745) stated "I must observe to you, that all that has been said of the fruitfulness of the Greenland soil, is to be understood of the latitude of 60 to 65; and differs according ot the different degrees of latitude. For the most northern parts you find neither herbs nor plants; so that the inhabitants cannot gather grass enough to put in their shoes, to keep their feet warm, but are obliged to buy it from the southern parts".

Svalbard was the location of some of the important early work in polar pedology with BLANCK (1919) and MEINARDUS (1930) making important discoveries on soil processes relating to leaching and mineral alteration. SMITH (1956) and FITZPATRICK (1960) made additional observations, particularly in connection with cryodynamics. The recent work of FEDEROFF (1966), however, marks the most detailed contribution on polar pedology from this sector of the globe. From FEDEROFF's work it can be stated that Spitsbergen can be considered in somewhat of a trasition between the Arctic Brown and Polar Desert soil zones. Apparently in Spitsbergen there are many soils that can be considered Polar Desert, or at least a para variety of them.

SOIL FORMATION IN INGLEFIELD LAND

The arid appearance of the north coast of Greenland has been documented by the reports of Fristrup (1952 a, 1952–53), Davies (1961 a, b), Krinsley (1961) and others. Desert pavement is present in many sectors and it commonly forms a continuous mantle (Fig. 22). Fristrup (1952 a) reported ventifacts in Peary Land and Nichols (1969) reported similar features just north of the Prudhoe Land icecap. In the area encompassed by this study, however, ventifacts were not observed. Late snow patches were covered discontinuously with wind-blown organic debris (Fig. 23) but very little silt or sand was observed on the late snow.

Rock Weathering

Gravel and boulders exhibit virtually all degrees of weathering. In some situations the rock fragments are fresh and hard, while in others there is virtually complete disintegration of the matrix (Fig. 24). The older glacial deposits show more of an advanced stage of alteration than do the younger ones. A striking feature of the glacial rocks is the high degree of iron staining. Whereas the more resistant rocks such as quartzites are invariably hard and fresh-appearing, the more easily weathered ones are commonly weathered throughout. Fig. 25 shows a weathered boulder from the "Stage 2" drift area. The boulder could have been completely crushed by hand.

Limestone boulders show some of the greatest amount of alteration with the exposed surfaces covered with solution cavities (Fig. 26). The sides of the limestone fragments are usually covered with a veneer of travertine. The lower sides of the cobbles have, in some instances, a dense carbonate-clay matrix covering up to $^1/_2$ inch thick. A thin-section of the carbonate-clay matrix is shown in Fig. 27. The clay substance, combined with carbonates, builds up in a layered fashion resembling annual growth rings in trees. In other instances the carbonate on the undersides of the boulders exists as well-crystallized calcite (Fig. 28). Fig. 29 shows a broken limestone boulder, the top of which is an extended network of iron-stained material. The interior of the limestone boulder is highly jointed with a reddish clay substance filling in the joints (Fig. 29).

Fig. 22. Continuous desert pavement on a Polar Desert soil.

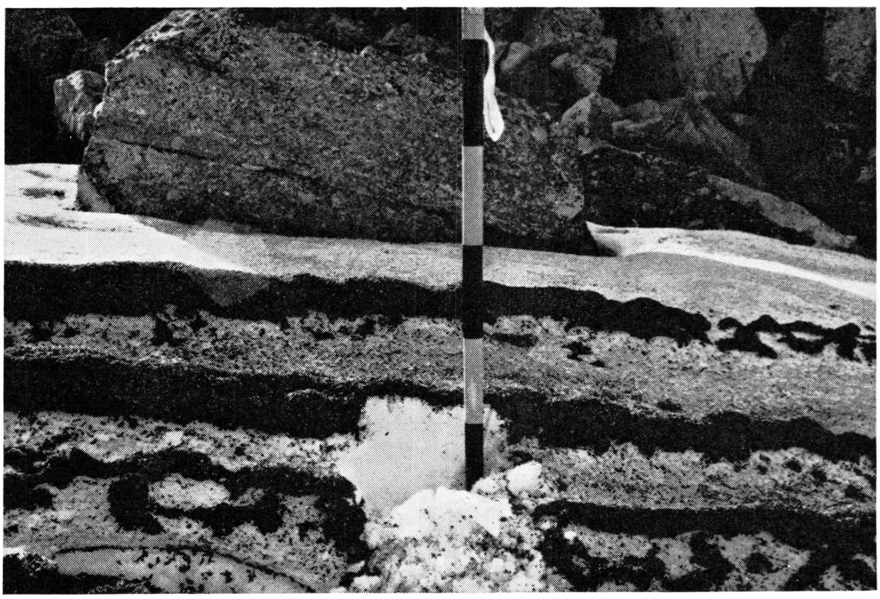

Fig. 23. Organic debris covering on a late snow bank.

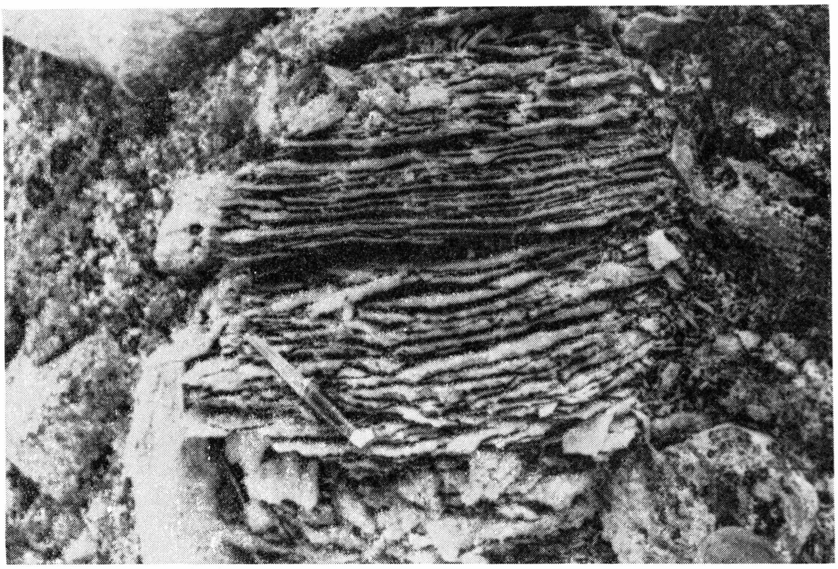

Fig. 24. Weathering of an exposed boulder in the Stage 2 drift area.

Fig. 25. Deep-seated weathering of a crystalline boulder. The rock matrix can be easily crushed by hand.

Fig. 26. Solution cavities on the upper side of an exposed limestone boulder.

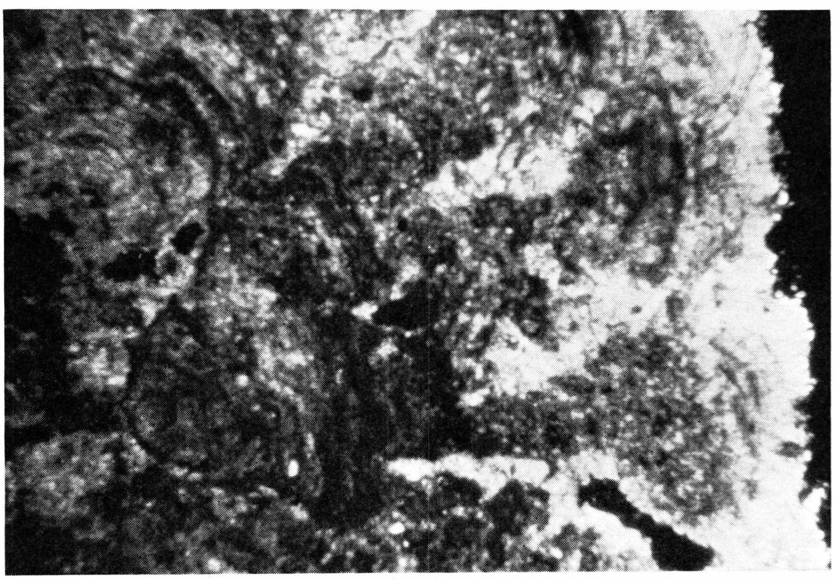

Fig. 27. Thin-section of a travertine-clay matrix from the lower side of a limestone boulder. Light sections are travertine with the darker areas being a carbonate-clay mixture 35 ×.

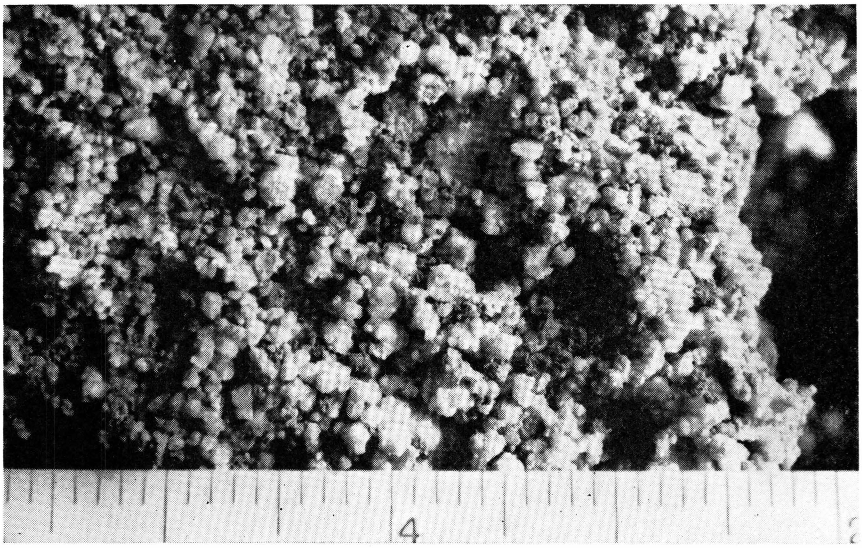

Fig. 28. Calcite crystallized on the lower side of a cobble. Scale is in inches.

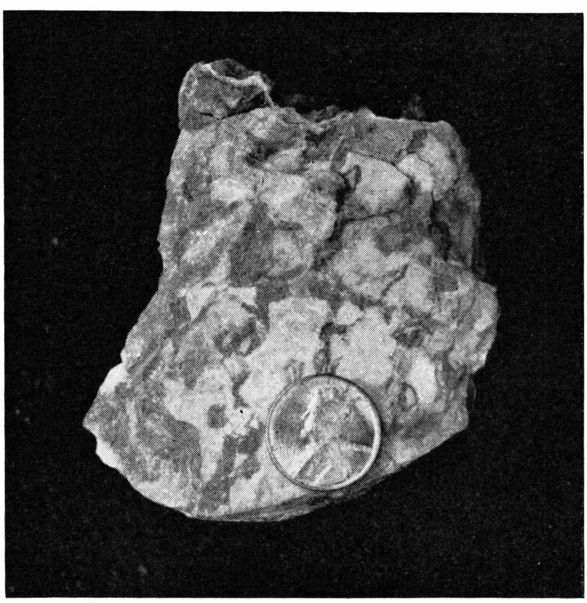

Fig. 29. A broken limestone boulder. The dark coloring along the joints is a reddish clay.

Perennially Frozen Ground

Inglefield Land is within the zone of perennially frozen ground. Because of the aridity of the landscape, the frost features are not as widespread nor as well-developed as is the case of the main tundra region to the south. As Davies (1961 a) stated, North Greenland is more a reflection of desert conditions rather than permafrost (Fig. 30). Much of the landscape is well-drained and in such situations there is little ground ice in the soil pores. By early July the well-drained sites are thawed to a depth of 3 or more feet whereas the wetter positions tend to remain completely frozen at this time. The low, wet positions (Fig. 31) with a large quantity of ground ice and mantled with an organic cover, do not possess conditions conducive for early seasonal thaw.

Soils of Inglefield Land

The main purpose of this study was to determine the properties of the soils of Inglefield Land. In order to depict the nature of the soils, particular attention was given to soil processes and to providing for a tentative classification scheme. After a brief reconnaissance it was decided that nearly all conditions encountered could be expressed by six soils or soil "conditions" (Fig. 32). The three most abundant soils; Polar Desert, Tundra and soils of the Polar Desert-Tundra interjacence are shown as type locations in Fig. 33. The foreground consists of Polar Desert soil, the snow-covered areas are mainly Tundra soil whereas the dark-colored area in the lower center of the photograph is soil of the Polar Desert-Tundra interjacence. The major soil positions are shown diagrammatically in Fig. 34.

Polar Desert soil is the most abundant genetic soil and tends to mantle the landscape of the uplands, slopes and many flat sectors. Not only is there a considerable degree of profile development on the level and undulating sites but on the steeper slopes as well. With precipitation at a low level there is only slight erosion even on the steep slopes; therefore, one encounters good profile development on the steep land as is the case with the more level terrain.

Arctic Brown soil is present only in special situations. It exists only in well-drained sites covered with vascular plants and insofar as distribution is concerned in this sector, it is somewhat of a rarity with the solum developing to a depth of only 2 to 4 inches. With Kubiena's (1953) terminology, it could be considered as a Ranker soil.

Tundra soil is present along many water courses where there is an adequate water supply. The narrow depressions are underlain with perennially frozen ground near the surface which, in turn, is conducive to

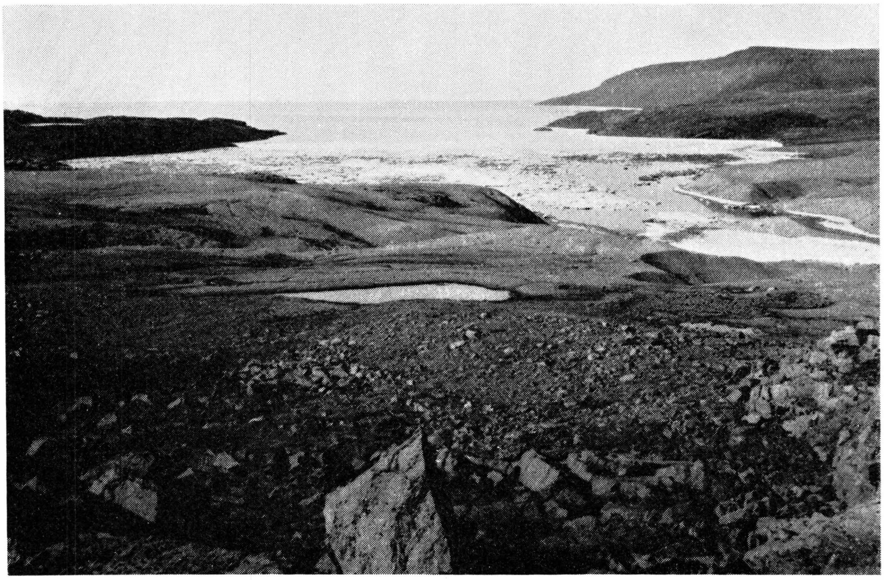

Fig. 30. View of the polar deserts in the vicinity of Rensselaer Bugt.

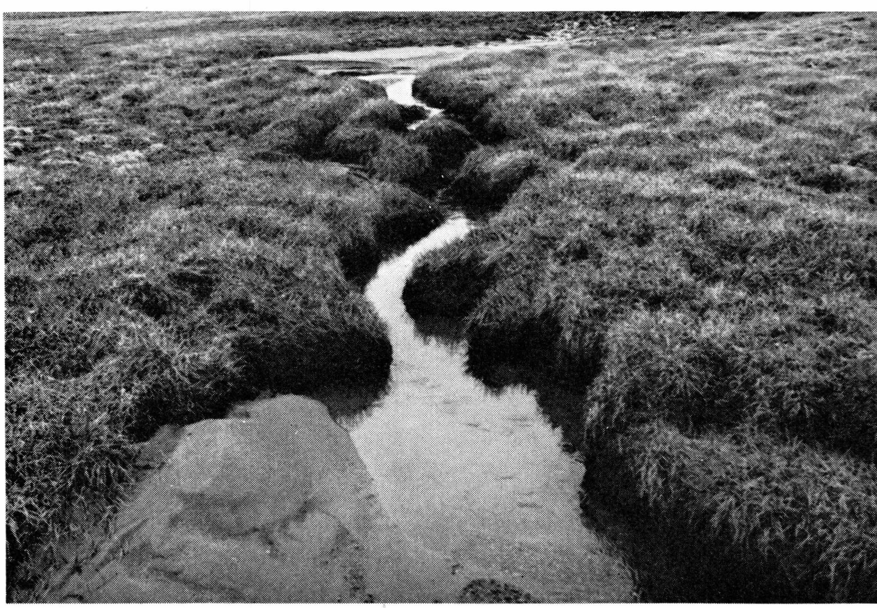

Fig. 31. The wet swales and depressions throughout Inglefield Land tend to be covered with continuous vegetation.

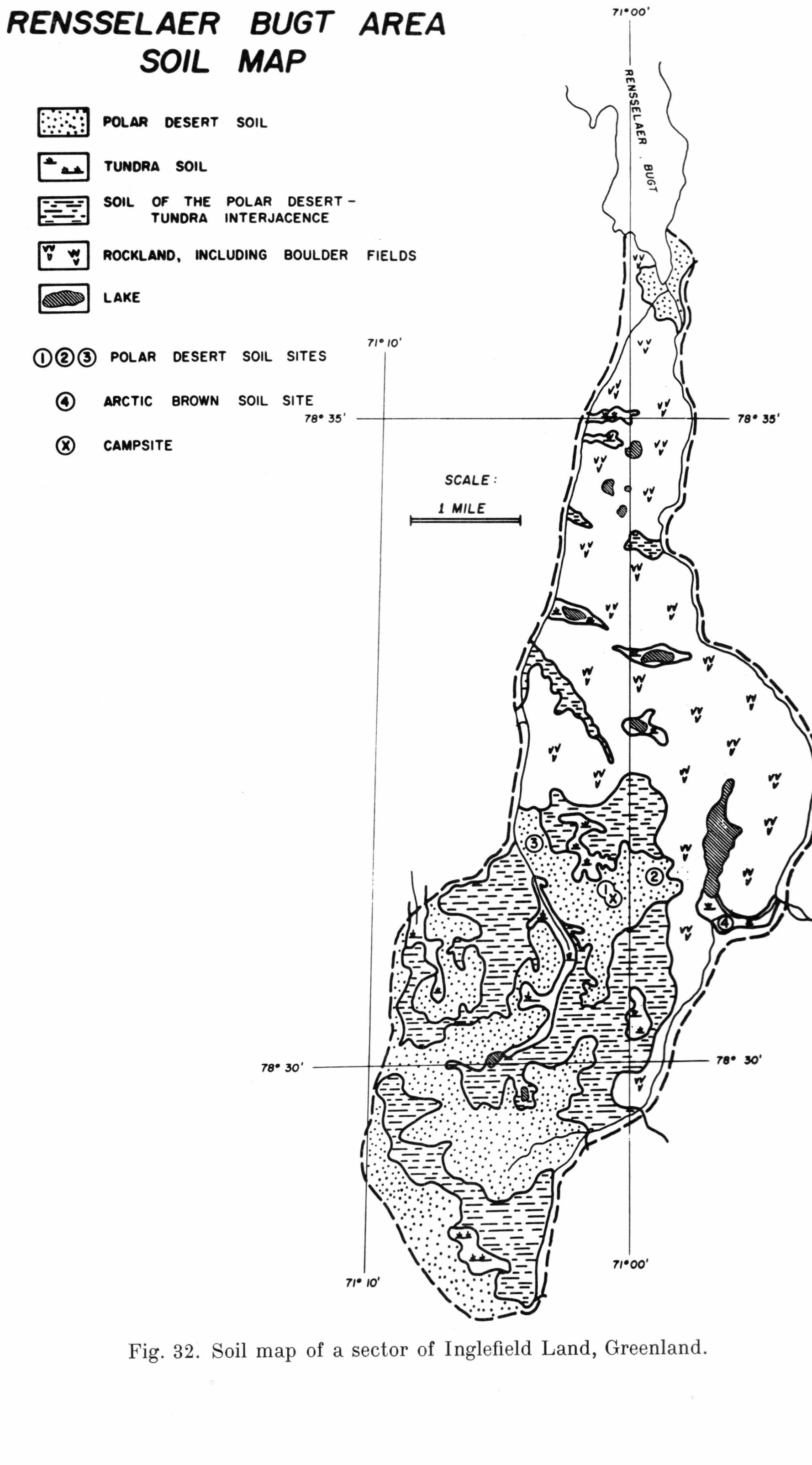

Fig. 32. Soil map of a sector of Inglefield Land, Greenland.

Fig. 33. The right foreground consists of Polar Desert soil, whereas the snow-covered sector is a typical Tundra soil position. The dark-colored portion between the two above mentioned soils consists of soil of the Polar Desert-Tundra interjacence.

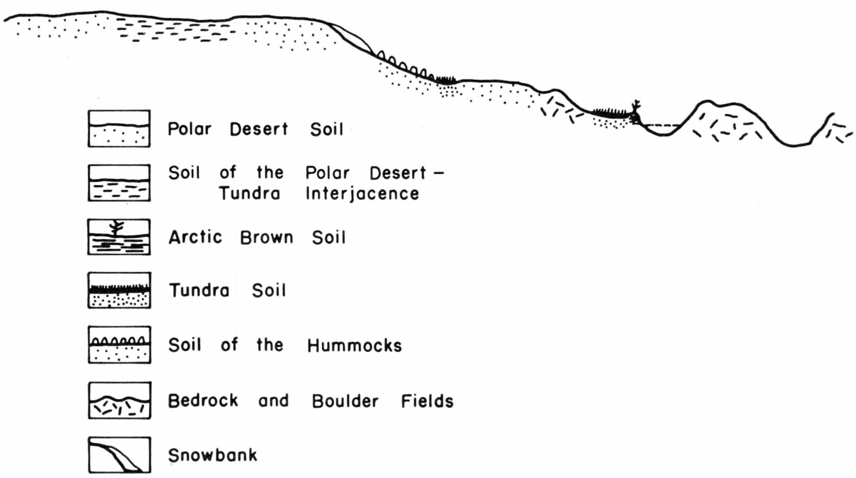

Fig. 34. Diagrammatic cross section of a landscape showing the major soil varieties in Inglefield Land, Greenland.

water build-up and retention. The moisture allows vegetation to fluorish. These mentioned properties permit a shallow but well-defined profile to develop.

Soil of the Polar Desert-Tundra interjacence represents a condition unreported before in the literature. Positions between the Polar Desert and Tundra soils are extremely wet during the early summer thaw but become progressively drier as the season advances. By mid-summer they become dry and later on salt efflorescence appears. Vascular plant cover is very sparse (< 5 pct.). The designation of this soil condition is admittedly somewhat unsatisfactory and it is hoped that as additional observations are made and nomenclature is discussed that a more satisfactory term will evolve.

Soil of the hummocky ground is formed on sloping land supplied by a small amount of runoff from late snow banks and other sources. The soils have a distinct hummocky micro-relief resulting from intense frost action. The term *soil of the hummocky ground* is used as described on Banks Island (TEDROW and DOUGLAS, 1964) and Prince Patrick Island (TEDROW et al., 1968).

Rockland and boulder fields make up a set of conditions in which there are virtually no soils per se. These barren conditions have few fines present and are nearly void of vascular plants. Included with these conditions are a few gravel bars along the streams.

The distrubutions of the soils just south of Rensselaer Bugt is shown in Fig. 32. Only four soil conditions are shown on the map. The soil of the hummocky ground and Arctic Brown soil are not extensive enough to show on such a small scale map. Since most of the detailed laboratory data are based on the Polar Desert soils, the sites of sample collection of these soils are shown on the map (Fig. 32). The site of the Arctic Brown soil is also recorded on Fig. 32.

Polar Desert Soils

Soils of Inglefield Land can be considered collectively as Polar Desert. Polar Desert is the most common genetic soil and tends to mantle the landscape extensively where there is mineral material of sufficient thickness for the soil processes to fully manifest themselves. Not only is there a considerable degree of soil development on the level and undulating sites but steeper slopes likewise show a genetic profile. With precipitation at a low level erosion, even on the steeper land, appears to be at a slow rate. Nevertheless solifluction lobes are present in some places, especially on the older drift areas (Fig. 35). Whether these solifluction lobes are active at the present time or are more of a relic condition is not known.

The problem of summer temperatures of Polar Desert soils is of special interest because there are suggestions in the literature that the arctic soils have summer temperatures near the freezing point of water (NEEDLEMAN, 1960; TEDROW and DOUGLAS, 1964; TEDROW et al., 1968). There was first a suggestion on Banks Island that summer temperatures of the well-drained soils of the high arctic may actually be higher than those of the main tundra belt to the south (TEDROW and DOUGLAS, 1964). The above statement was further supported by my observations on Prince

Fig. 35. Terminus of a solifluction lobe.

Patrick Island. In Inglefield Land a pit was dug in Polar Desert soil and thermocouples inserted laterally into the undisturbed soil horizons (Fig. 36, Site 1). The previously excavated soil was then replaced. Temperature readings were made over a 10-day period, the results of which are given in Table 5.

At the 1-inch depth, soil temperature averaged 52° F whereas at the 3-inch depth it approximated 49° F. At the 9- and 2-inch depths, tempera-

Table 5. *Temperatures of Polar Desert soil (Site 1), Inglefield Land, Greenland, 1966* (°F, *9 a.m. readings*)

Date	Depth in Inches				Air	Precipitation
	1	3	9	26	Temperature	(24 hrs.)
June 30	50	49	43	34	44	0
July 1	49	47	40	34	43	0
July 2	45	44	39	34	40	0
July 3	59	54	43	34	54	0
July 4	57[1]	54	43	34	50	0
July 5	57	52	43	34	40	Trace
July 6	50	45	39	34	40	0
July 7	55	52	43	34	54	0
July 8	50	50	43	33	44	0
July 9	47	47	40	34	44	0

[1]) Sunny, surface temperatures of rocks – Sun, 80°, Shade 47°.

Fig. 36. Polar Desert soil Site 1. The vertical face of the exposure measures 30 inches. See Fig. 32 for location of site.

tures were somewhat lower but they never dropped to the freezing point. Numerous investigators have suggested that the sparseness of vegetation in the high arctic is a result of low temperatures, but such a concept can rightfully be questioned. Of course, if there were a continuous vegatative mat covering the mineral substrate, soil temperatures would drop accordingly. It appears that if one factor could be singled out as limiting plant growth in the polar deserts, it would be lack of moisture.

Morphology. Morphology of three sites of Polar Desert soil sampled for laboratory analyses follows:

Profile 1: *Polar Desert Soil* (*Fig. 36*)

Polar Desert soil, Site 1 (See Fig. 32). Smooth upland position on glacial drift. Plant cover consists of a very sparse (< 1 pct.) scattering of *Dryas*, *Salix*, *Saxifraga oppositifolia*, *Poa arctica*, and lichens. Coarse rock fragments constitute about 50 pct. of the soil matrix. The soil is well-drained throughout.

Depth	*Morphology*
0– 6 in. (A)	Desert pavement of closely knit gravel with a carbonate-clay matrix covering the undersides of rock fragments. Desert pavement is underlain by a brown (7.5 YR $^5/_4$)[1]) gravelly sand. When air dry, the soil has speckled appearance, with colors approximating a strong brown (7.5 YR $^5/_6$) color. Loose consistence with a few roots. Carbonate-clay crusts underneath virtually all rock fragments.
6–18 in. (B_1)	Strong brown (7.5 YR $^5/_6$) gravelly loamy sand becoming slightly lighter in color with depth. Slightly firm in place. No field evidence of clay skins among cleavage planes. Carbonate crusts on the lower sides of cobbles. Pockets of vesicular structure visible where there is more clay present. A few fine roots present.
18–24 in. (B_2)	Similar to above, but of slightly lighter color.
24–36 in. (C)	Light yellowish brown (10 YR $^6/_4$) gravelly sand, firm. Dry frost at the 36-inch level (June 30, 1966).

Profile 2: *Polar Desert Soil* (*Fig. 37*)

Polar Desert soil, Site 2 (See Fig. 32). Polar Desert soil on a glaciofluvial deposit, about 400 ft. above the valley floor. The deposit is probably younger than drift of Polar Desert soils at Sites 1 and 3. Topography is flat. Plant cover consists of a scattering (< 1 pct.) of *Saxifraga oppositifolia*, *Poa arctica* and lichens. The entire profile shows little genetic horizon development.

Depth	*Morphology*
0–4 in. (A)	Desert pavement of fine gravel underlain by a brown (7.5 YR $^5/_4$) gravelly sand. Carbonate crusts are present on the undersides of virtually all rock fragments throughout the profile. Very loose consistence with no discernible compound structure. Soil temperature at 1-inch depth was 58° F on July 3, 1966.
4–24 in. (B)	Brown (7.5 YR $^5/_4$) sands set in a heavy gravel matrix. The slightly indurated condition is from pedogenic carbonate accumulation.

[1]) Munsell Color Co., Baltimore, Maryland.

Fig. 37. Polar Desert soil, Site 2. The scale on the pick handle measures 6 inches. See Fig. 32 for location of site.

24–30 in. (C) Gray, brown and red gravel mixed with sand. Rather loose and unweathered. Soil temperature at the 36-inch depth was 44° F on July 3, 1966.

The above profile had a concentration of gravel at the 4 to 24-inch depth with a stone line at the 20-inch depth.

Profile 3: *Polar Desert Soil* (*Fig. 38*)

Polar Desert soil, Site 3 (See Fig. 32). Glacial drift. Topography is flat. Vascular plant cover (< 1 pct.) consists of a few isolated clumps of *Saxifraga oppositifolia* and *Salix*. A few black lichens are present. The soil is well-drained. Coarse fragments constitute about 60 pct. of the soil matrix.

Fig. 38. Polar Desert soil, Site 3. The pick handle is about 36 inches long. See Fig. 32 for location of site.

Depth	*Morphology*
0– 6 in. (A)	Continuous desert pavement underlain by a brown (7.5 YR $^5/_4$) gravelly loamy sand with pockets of reddish brown (5 YR $^4/_4$) gravelly sandy loam, loose and friable. Reddish brown carbonate crusts on the undersides of rock fragments are about $^1/_4$ inch thick. Immediately underneath the desert pavement the soil has a gray-like appearance which grades into the brown color at the 1-inch depth. A few fine roots are present.
6–24 in. (B)	Reddish brown (5 YR $^4/_3$) gravelly sand with patches of yellowish red (5 YR $^4/_6$) and reddish brown (2.5 YR $^4/_4$) gravelly sand. Soil is firm but without compound structure and readily yields to crushing by hand. The soil

matrix has a mottled appearance due to differential weathering of the minerals. A few roots are present. Carbonate crusts on the undersides of rocks.

24–36 in. (C) Reddish brown (5 YR 4/3) gravelly sand. Rather loose consistence and no compound structure. Carbonate crusts continue as above. No frost at the 36-inch depth (July 9, 1966).

Mechanical Composition. Mechanical composition shows that sand is the major component throughout all horizons (Table 6). The glaciofluvial terrace (Site 2) was the most xeric of the 3 reported sites in appearance, a condition verified by mechanical analysis. As found in other sectors of the high arctic, there appears to be no specific trend of particle-size with depth. Silt plus clay is nearly always higher, however, in the solum than is the case with the C horizon. With such high quantities of pedogenic carbonate formed in the solum of all horizons there is some clay and silt cemented in the carbonate fragments and therefore reported as sand.

Table 6. *Mechanical composition of some Polar Desert soils, Inglefield Land, Greenland*

Horizon	Depth in.	Sand 2–0.05 mm	Silt 0.05–0.002 mm	Clay < 0.002 mm
		%	%	%
		Site 1		
A	0– 6	88	6	6
B_1........	6–18	82	14	4
C	24–36	93	5	2
		Site 2		
A	0– 4	95	2	2
B	5–24	93	5	2
C	24–36	97	2	1
		Site 3		
A	0– 6	83	10	7
B	6–24	88	7	5
C	24–36	91	5	4

Compound structure in the coarse-textured Polar Desert soils of Inglefield Land is poorly defined. In those sites where there is more silt and clay in the matrix, however, a pronounced vesicular structure is present. A raw, clay-rich till exposed 100 yards east of the main campsite had such a vesicular structure (Fig. 39). Micromorphology indicates that after pores had once formed they were interconnected with fissures, but

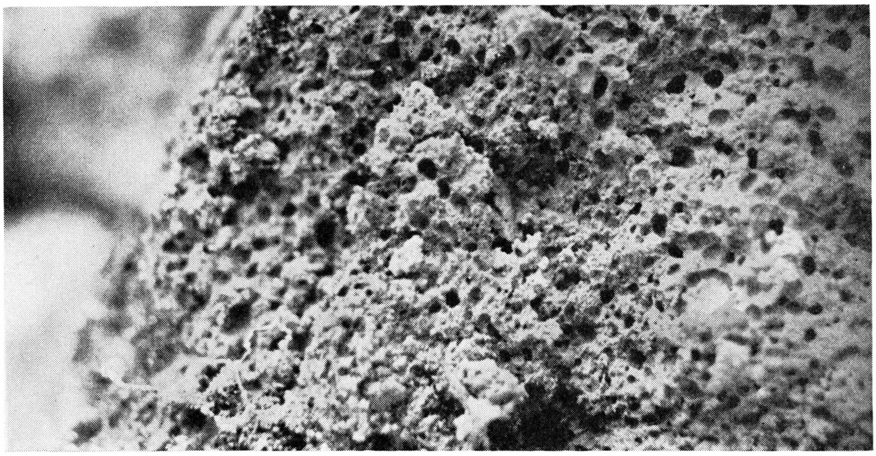

Fig. 39. Vesicular structure in clay-rich till. 1.1 ×.

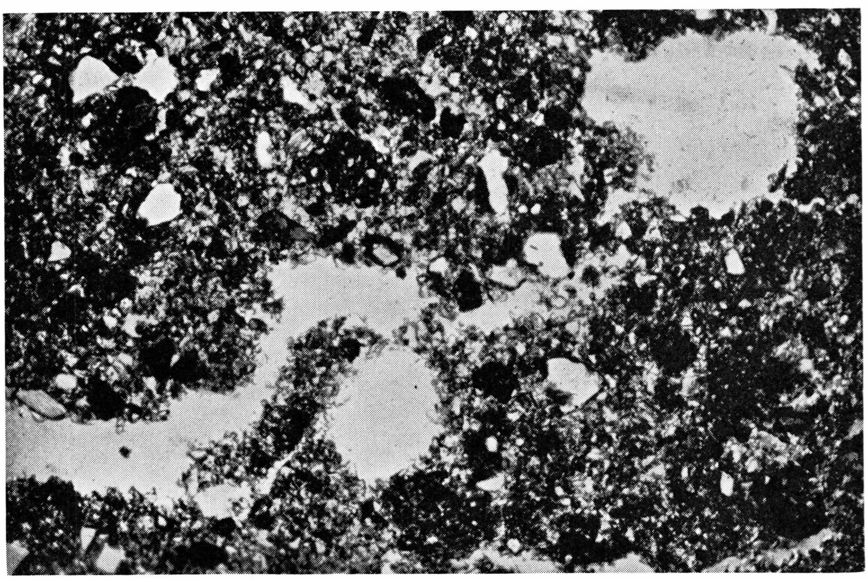

Fig. 40. Photomicrograph showing details of vesicular structure shown in Fig. 39. The spherical voids are connected by partially clay-filled arteries. 35 ×. Crossed (Nicols.)

a clay substance later blocked some of the narrow passageways (Fig. 40). While this is a suggestion of processes that took place following formation of the original structure, it does not give a clue as to the process leading to the formation of the pores themselves.

Mineralogy. Site 1 (Table 7) shows rather uniform characteristics with depth, the light minerals consisting of about 60 pct. quartz, 20 pct. orthoclase, 20 pct. calcite, and a little plagioclase. Most of the calcite is in the form of travertine, which earlier was broken off the larger soil particles, through frost action and sample collection. The heavy mineral suites not only show qualitative but quantitative similarity with depth indicating a very uniform regolith. The most common heavy minerals are garnet, dolomite, common hornblende, ilmenite, magnetite and basaltic hornblende (Table 7).

Site 3 is on the same tongue of glacial drift as was Site 1 and the minerals are very similar in the two sites. There is less quartz present

Table 7. *Distribution of minerals in Polar Desert soils (0.25–0.10 mm)*

	Site 1			Site 2			Site 3		
	0–6	6–18 in.	24–36	0–4	5–24 in.	24–36	0–6	6–24 in.	24–36
Light Minerals[1]									
quartz	59	59	61	56	71	62	70	37	65
calcite	21	17	20	23	16	22	11	36	20
orthoclase	19	22	17	19	11	14	18	25	14
Heavy Minerals (pct.)[2]	12.0	11.0	11.8	13.3	7.2	19.3	7.0	17.1	7.6
magnetite	8.9	5.5	7.2	9.6	9.0	6.9	7.6	10.5	10.0
Non-opaques[3]									
garnet	47	52	53	47	51	57	50	40	40
dolomite	15	17	12	11	10	11	13	35	13
ilmenite	6	4	11	17	17	8	14	13	18
common hornblende	17	15	16	15	12	14	16	8	18
basaltic hornblende	5	4	1	2	1	1	1	1	1
diopside	2	3	2	2	1	+	2	1	1
sillimanite	1	2	1	1	1	1	1	1	3
hypersthene	1	–	–	+	+	–	–	–	+
staurolite	1	–	+	–	–	–	–	–	–
biotite	1	1	–	+	–	–	–	–	–
tourmaline	–	–	1	1	+	+	–	–	2
monazite	1	–	+	+	+	–	–	–	2
zircon	–	–	+	–	–	+	–	–	–
rutile	+	–	–	–	+	+	+	–	–
titanite	–	–	–	–	–	–	–	–	+
Opaques	3	2	1	3	5	6	2	1	2

[1]) Total light minerals = 100.
[2]) Total heavy minerals = 100 (Sp. g. > 2.85).
[3]) Total non-opaques = 100.
Pct. heavy minerals by weight, all others by grain count.

Table 8. *Distribution of minerals with particle size.*
Polar Desert soil – Site 1, A (0–6 in.) horizon

	2–1 mm	1–0.5 mm	0.5–0.25 mm	0.25–0.10 mm	0.10–0.05 mm
	%	%	%	%	%
Light Minerals[1])					
quartz	ND[2])	78	68	59	47
calcite	ND	12	10	21	16
orthoclase	ND	10	21	19	35
plagioclase	ND	–	1	1	2
Heavy Minerals (pct.)	7.3	7.4	9.7	12	7
magnetite[3])	12.2	11.1	7.8	8.9	5.6
Non-opaques[4])					
garnet	+	54	57	47	37
dolomite	–	13	18	15	23
ilmenite	–	5	3	6	6
common hornblende	+	28	18	17	16
basaltic hornblende	–	–	–	5	–
diopside	–	–	–	2	+
sillimanite	–	–	1	1	4
hypersthene	–	–	–	1	–
staurolite	–	–	–	1	–
biotite	–	–	–	1	–
tourmaline	–	–	–	–	+
monazite	–	–	–	1	–
rutile	–	–	–	+	+
Opaques	–	–	3	3	13

[1]) Total light minerals = 100.
[2]) ND = Not determined.
[3]) Total heavy minerals = 100 (Sp. G. > 2.85).
[4]) Total non-opaques = 100.

Pct. heavy minerals by weight, all others by grain count.

at Site 3, probably a dilution effect from the greater quantity of autochthonous calcite formed.

Site 2 is on a terrace probably post-dating sites 1 and 3. Despite the fact that site 2 has a somewhat different history as to age and origin, the mineral composition of the sands is very similar to that of sites 1 and 3.

In order to show the possible changes in mineral composition with particle-size, grain counts were made of the coarse, medium, fine and very sands. Table 8 shows that with decreasing particle size the percentage of quartz tends to decrease whereas feldspar increases. Because of the nature of chemical cycling, and attendant frost processes in the polar desert environment, it is inadvisable to attach much significance to low order changes in carbonate content with particle size. Heavy mineral suites showed few changes with particle size. There was a tendency for garnet and common hornblende to decrease whereas dolomite tended to increase with decreasing sand size.

The X-ray diffractograms of Polar Desert soils at all 3 sites showed similar clay mineral suites. There were only minor changes between the sites and with depth at any one site. Major clay components in all samples were vermiculite (some of that reported as vermiculite may include a small quantity of chlorite), illite and kaolinite. Small quantities of clay-size quartz were present. In the A horizon at site 1 there may have been some alteration of illite to vermiculite. At site 2, the most xeric of the 3, there was a small amount of montmorillonite in the B and in the C horizons. Also at site 2 there was a minor 9.24 A° reflection in all 3 horizons which possibly may have been contributed by pyrophyllite or talc. All X-ray reflections in the A horizon of site 2 were weak, suggesting alteration of the clays and/or presence of an amorphous substance, but there was no suggestion of a mica-intermediate being present.

Of the 3 major clay components (vermiculite, illite and kaolonite) in all 3 of the Polar Desert Soil sites, the gross picture showed considerable qualitative and quantitative uniformity. The clays are considered to be mainly of an allogenic nature.

Chemistry. The chemistry of Polar Desert soils from three sites is given in Table 9. The highly siliceous nature of the material is reflected in the soil composition, with the lowest SiO_2 value being about 67 pct. Al_2O_3 shows highest values in the surface horizons of Sites 1 and 3 but not in Site 2, the latter condition possibly being a reflection of stratification in the profile. Fe_2O_3 values were, in all cases, highest in the surface horizon and decreased with depth. Calcium and magnesium values show an accumulation of these elements in the B and C horizons, indicating a calcification process within the soil. Even though the calcium and magnesium values are expressed as oxides, in reality they existed mainly as carbonates in the profile. Sodium and potassium showed little change with depth in the profile. These two elements were probably associated with the feldspars in the sand and silt fractions.

In all three Polar Desert soils, manganese accumulated on the surface horizon as is often the case under desert conditions. Copper and zinc, however, showed no specific trend with depth.

All of the Polar Desert soils showed high pH values at the various sites (Table 10). The pH values ranged from 6.8 to 9.2, with only one value being below pH 8.0. The pH value of 6.8 in the one sample is somewhat anomalous because free carbonates were present in this as well as

Table 9. *Chemical composition of some Polar Desert soils, Inglefield Land, Greenland*

Horizon	Depth in.	SiO_2	Al_2O_3	Fe_2O_3	CaO[1])	MgO[1])	Na_2O	K_2O	Mn ppm	Cu ppm	Zn ppm
		%	%	%	%	%	%	%			
				Site 1 (< 2 mm)							
A	0–6	70.43	10.97	4.00	3.64	1.54	3.51	2.92	590	100	130
B_1.....	6–18	67.67	9.93	4.43	5.32	2.46	3.51	3.12	590	70	130
C	24–36	78.81	6.70	2.15	5.04	1.45	3.11	1.97	340	40	100
				Site 1 (< 0.002 mm)							
A	0–6	42.52	19.30	11.20							
B	6–18	41.96	19.60	14.56							
C	34–36	44.10	22.90	14.10							
				Site 2 (< 2 mm)							
A	0–4	76.88	6.90	2.15	5.30	1.54	2.11	2.11	390	160	70
B	5–24	70.92	6.44	1.57	6.30	1.71	3.17	2.11	280	20	100
C	24–36	74.40	8.15	1.43	6.02	1.54	3.24	1.92	280	25	80
				Site 3 (< 2 mm)							
A	0–6	76.85	8.35	3.29	1.82	1.40	3.64	2.92	540	20	80
B	6–24	80.31	6.67	2.72	2.04	1.40	3.03	2.54	390	20	70
C	24–36	77.38	6.84	2.72	3.64	1.71	2.97	2.30	360	25	80

[1]) Carbonates present but not determined.

Table 10. *Chemical properties of some Polar Desert soils*

Horizon	Depth in.	pH	O.M.	Na	K	Ca	Mg	Σ	CEC me/100 gms soil
				Exchangeable Cations me/100 gms soil					
			%						
				Site 1					
A	0–6	6.8	1.24	0.09	0.12	5.22	0.81	6.24	6.2
B_1........	6–18	8.0	0.48	0.08	0.10	3.78	0.01	3.97	4.0
C	24–36	8.7	0.12	0.10	0.05	2.05	0.01	2.21	2.3
				Site 2					
A	0–4	8.8	0.42	0.10	0.03	0.75	0.30	1.18	0.9
B	5–24	9.0	0.10	0.08	0.01	1.75	0.25	2.19	2.1
C	24–30	9.2	0.02	0.10	0.01	1.55	0.16	1.82	2.2
				Site 3					
A	0–6	8.7	0.96	0.08	0.11	1.20	0.41	1.80	5.1
B	6–24	8.8	0.20	0.08	0.09	2.25	0.01	2.43	2.6
C	24–36	8.9	0.06	0.08	0.09	2.75	0.01	2.94	3.0

all other Polar Desert soil samples. The presence of carbonates in all samples was verified by mineral analyses.

Origin of the organic matter in the deserts of the high arctic has been discussed by a number of investigators. On dry wind-swept uplands and flats with less than 1 pct. vegetative cover, the soils consistently have 1 to 2 pct. organic matter in the upper mineral horizon, whereas with those soils rich in silt and clay the organic content is higher (Table 10). Barthel (1922) and Jensen (1951) showed that the bacteria in North Greenland soils were of the same general species as found in other climatic regions except for *Azotobacter* which were commonly absent. While the general paucity of *Azotobacter* in North Greenland soils appears to be real, this species has been found in more frigid climates (Boyd et al., 1966). More details on the subject of polar soil microbiology have been presented by Mishustin and Mirzoeva (1964), and Boyd et al. (1966).

The main organic matter in Polar Desert soils is considered to be derived from algae and diatoms (Gorodkov, 1943, 1947; Mikhailov, 1962–63, Tedrow et al., 1968). Micromorphological examination of the soil fabric showed an absence of visible humic components; however, when the soil pits were dug a few fine root hairs were visible to a depth of about 2 feet. In all three Polar Desert soil sites the organic matter content decreased with depth. Site 2, which, as compared to sites 1 and 3, was the most gravelly and barren appearing, had the lowest quantity of organic matter present throughout.

The age of the organic matter in the surface of Site 1 of the Polar Desert soil is 3,300 ± 110 yr. B. P. (Table 11). In order to provide some information on the nature of pollen present on the surface of Polar Desert soil the 0- to 3-inch layer of soil at Site 1 was sampled and identified, the results of which are given in Table 11.

Cation-exchange capacities of all three Polar Desert soils were quite low, ranging from 0.9 to 6.2 me. per 100 gms of soil (Table 10). This is a reflection of the low organic matter and clay contents. Free carbonates were present, and inasmuch as the determination of cation-exchange capacity in the presence of carbonate-bearing minerals has some inherent fallacies, these particular data must be considered only as an approximation. The data were arrived at by assuming a constant rate of carbonate solution in the presence of ammonium acetate, with the exchange capacity being reported as the difference between the first and second leachings. The very low value for the cation-exchange capacity of the A horizon at Site 2 is a reflection of the very sandy nature of the substrate and the paucity of organic matter.

The total exchangeable bases, which collectively were about equivalent to the cation-exchange capacities of the samples, indicated complete base saturation. The dominating exchangeable base was invariably

Table 11. *Pollen analysis of 0–3 inch depth of Polar Desert soil, Inglefield Land, Greenland*

Species	Pollen %	Species	Pollen %
Gramineae	6	Trilete fern	+
Cyperaceae	7	*Lycopodium selago*	3
Betula	+	*Lycopodium annotinum*	+
Salix	8	*Ranunculaceae*	+
Artemisia	+	*Ambrosia*	+
Caryophyllaceae	6	*Rumex*	+
Saxifraga oppositifolia	52	*Claytonia*	+
Other *Saxifraga*	3	*Cruciferae*	+
Pinus	5	minor elements	8
Reniform fern	5		

Pollen somewhat weathered.
C-14 date of surface sample = 3,300 ± 110 yr. B.P. (I-2324).

calcium with only small quantities of sodium, potassium and magnesium. Some of the calcium values reported were probably from solution of calcium carbonate. A question can be raised as to why there were not higher values for exchangeable sodium and potassium present. The very dry sites, exemplified by Polar Desert soils, probably have only small quantities of water migrating upward to carry the soluble salts to the surface. The occasional downward movement of water in the profile is adequate to keep the salts flushed from the surface. During dry periods there is little rapid salt transfer in Polar Desert soils, but in the contiguous poorly drained locations salts effloresce.

Reducible iron was determined in Polar Desert soils (Table 12). In all situations the quantity of reducible iron was greater in the A and B horizons than was the case with the C horizons, thus signifying pedogenic processes involving the weathering of iron-bearing minerals.

Table 12. *Reducible iron*[1] *in some Polar Desert soils, Inglefield Land, Greenland*

Horizon	Site 1		Site 2		Site 3	
	Depth in.	Fe_2O_3	Depth in.	Fe_2O_3	Depth in.	Fe_2O_3
		%		%		%
A	0– 6	1.05	0– 4	0.61	0– 6	1.03
B	6–18	1.14	5–24	0.58	6–24	0.76
C	24–36	0.64	24–36	0.24	24–36	0.59

[1]) M. L. Jackson, 1956. Soil Chemical Analysis – Advanced Course. University of Wisconsin, Madison. 991 pp.

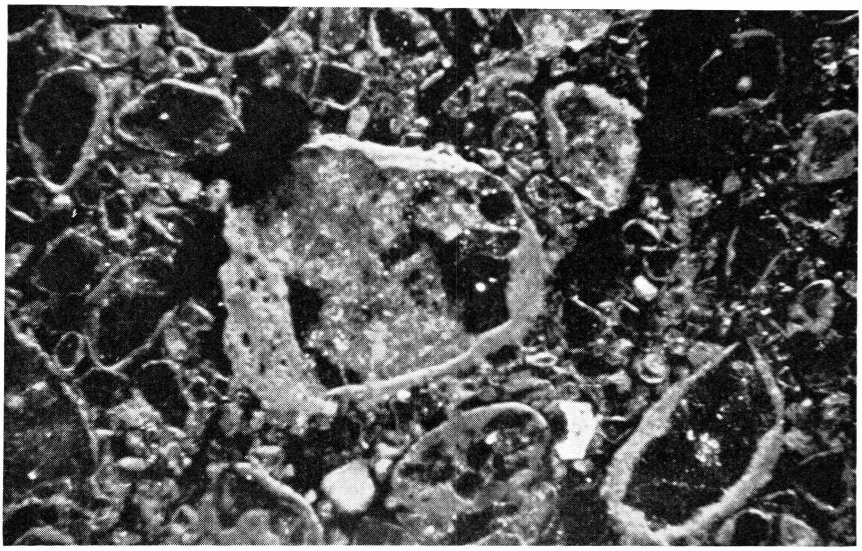

Fig. 41. Photomicrograph of a thin-section of the A horizon of Polar Desert soil showing mud coatings along the indentations of sand grains. Note vesicular structure in the mud coating in the left center of photograph. 35 ×.

Micromorphology. Professor W. L. Kubiena introduced the subject of soil micromorphology to the scientific community over 40 years ago. The concept involves the microscopic examination of soil fabric (Kubiena 1953, 1967). After a volume of soil is collected, preferable with the least amount of disturbance, it is impregnated with a plastic from which a thin-section is made by sawing, grinding, and polishing the specimen to a thickness of 0.03 mm, then studied by microscopic techniques. A great amount of information can then be deduced from the fabric. Fortunately, Kubiena was a visiting professor at Rutgers University while these studies were being made, and many of the interpretations were under his guidance.

Most of the primary minerals show a fresh appearance, but in others there is a certain degree of alteration. The A horizon (Fig. 41) shows a number of mud coatings filling the peripheral cavities. The sharp junction between the clay substance and margins of the primary minerals suggests that the clay substance has not formed *in situ.*

Preservation of fresh biotites and fresh feldspars is the general rule, but many of the cleavage planes of the feldspars are iron-stained and there are certain situations in which an embryonic type of clay substance has formed. Plagioclase appears to be well-preserved. No humic components were recognizable in thin-sections but a few root hairs can be seen

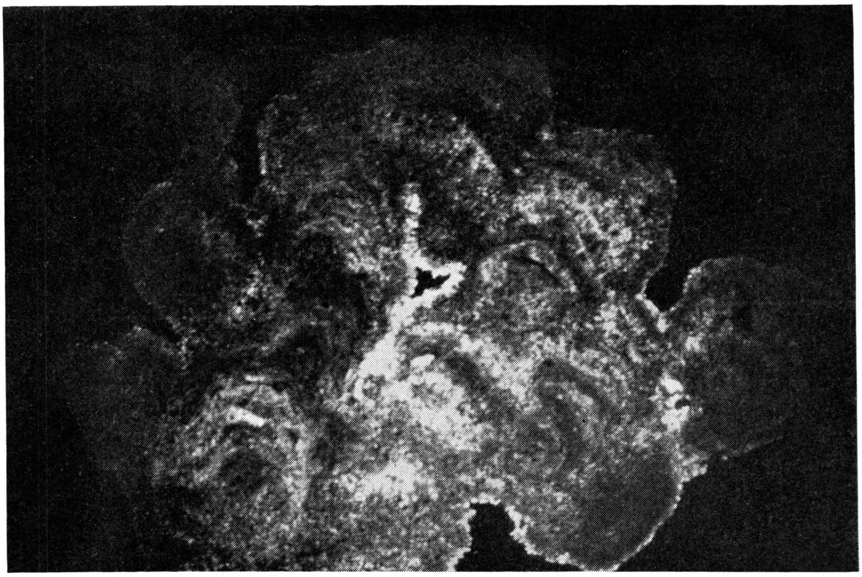

Fig. 42. Photomicrograph of pedogenic carbonate formed in Polar Desert soil. 35 ×.

occasionally in the field. A small amount of clay has been weathered from clay aggregates which originally was part of the drift. Travertine coatings are common throughout, some in a good state of preservation, others spalled off from frost action. The travertine coatings are built up in concentric fashion with calcite-clay "growth rings" present. Cross sections of the carbonate aggregates have the appearance of lobate annual growth rings in the wood (Fig. 42). In site 2 of the Polar Desert soil, travertine is less common than in sites 1 and 3. Since site 2 is a younger (chronologically) deposit than sites 1 and 3, there is a suggestion that a long period of time is required to form travertine.

The B horizons of the Polar Desert soils have a very similar morphology to that of the A horizons. There are a few clay coatings present on the primary minerals, with their occurrence primarily in the mineral cavities. A few iron concretions are present (Fig. 43). Nearly all of the mineral grains are fresh-appearing, particularly the plagioclases. Travertine has formed along the margins of many sand grains in the B as in the A horizons.

The C horizons of Polar Desert soil appear quite similar to those of the A and B. Clay is present in the cavities of the margins of sand grains and there is a small amount of iron staining present in the minerals themselves. The micaceous material is bound with an allogenic clay substance. Some of the clay substance has formed iron-stained aggregates. According

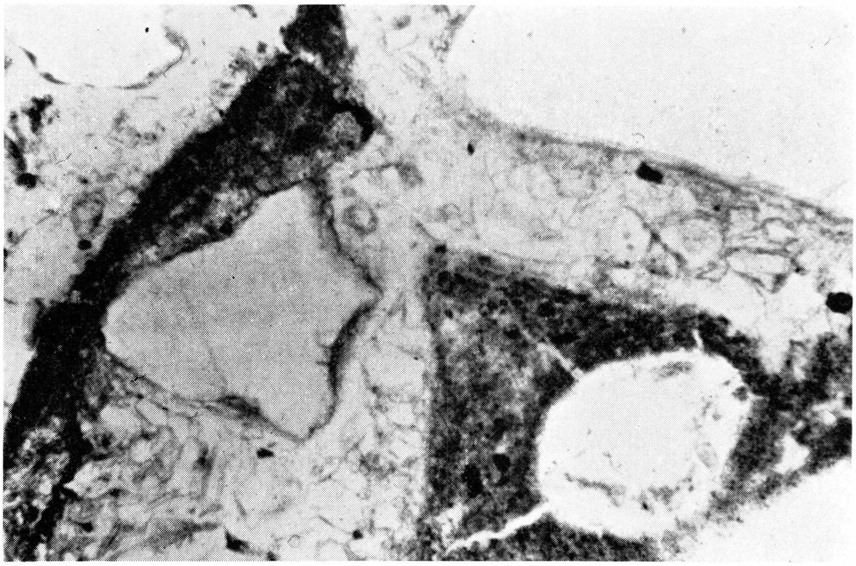

Fig. 43. Photomicrograph of a thin-section showing loose iron precipitations (large dark areas) formed in Polar Desert soil. 35 ×.

to Prof. Kubiena, this condition is found throughout the arctic and high in the Himalayan Mountains. Travertine is preserved in the C horizon in a manner similar to that in the A and B horizon.

Patterned Ground. The most common form of patterned ground associated with Polar Desert soil is the high center polygon. The smooth uplands usually have a fairly continuous system developed but the channels are only 1 to 2 inches lower than the adjacent ground. Fig. 44 shows 3 intersecting channels, each about 1-inch deep. These slight depressions have a more favorable moisture regime than do the adjacent land, and accordingly plants tend to colonize the channels. On the more sloping land soil stripes are present in isolated cases, but they are not common (Fig. 45).

In situations where Polar Desert soil has a water table 2 to 3 feet below the surface, complex forms of patterned ground are present in a somewhat continuous pattern. Complex stone rings, stone nets, and stone circles tend to show well-developed patterns. This mechanism of patterned ground formation has received special attention in recent years (Corte, 1961). Fig. 46 shows a complex pattern of stone nets in bouldery drift in which free water existed at about the 2-foot depth. There are many situations in which miniature polygons form in Polar Desert soil (Fig. 47). It appears that wind-exposed positions with appreaciable quantities of silt and clay are especially conducive to the miniature polygon formation.

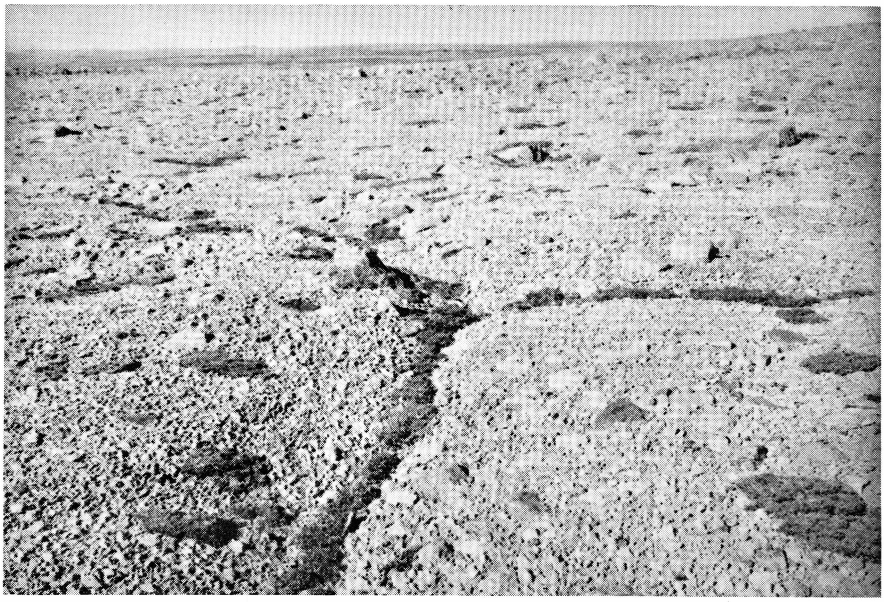

Fig. 44. Intersecting shallow throughs along the margins of high center ice-wedge polygons. The more favorable moisture conditions in the channels permits vegetation to become established.

Fig. 45. Soil stripes are present on sloping ground in isolated situations.

Fig. 46. Stone nets in Polar Desert soil area. The water table is about 2 feet below the surface.

Fig. 47. Miniature polygons in Polar Desert soil.

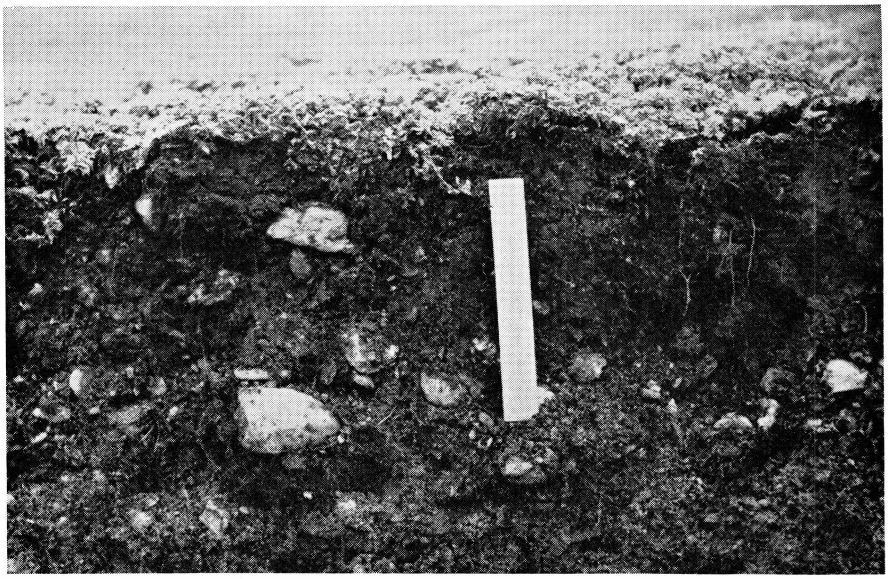

Fig. 48. Arctic Brown soil on a fluvial deposit. Scale is 6 inches.

Arctic Brown Soil

Arctic Brown soil was encountered in only a few isolated situations along stream terraces. Arctic Brown soil, which in Inglefield Land is considered perhaps the northernmost extension of its occurrence, has only shallow development. The soil occurs on well-drained sites where moisture conditions are favorable for a mat of vascular plants to become established. In order for Arctic Brown soil to form, the substrate must be freely drained to an adequate depth, otherwise a tundra-like soil will develop. Arctic Brown soil, while forming under well-drained conditions, occupies positions having slightly more favorable moisture supply than is the case with the more xeric conditions of Polar Desert soil. The site shown in Fig. 48 was sampled for laboratory analyses (See also Fig. 32).

Morphology. Vegetation consists of a closed sward of *Dryas*, *Saxifraga oppositifolia*, *Salix*, *Carex* and lichens.

Morphology of the Arctic Brown soil follows:

Depth	*Morphology*
0– 4 in. (A)	Dark reddish brown (5 YR $^3/_2$) moist, gravelly sandy loam with black organic inclusions, very friable. A thin veneer of calcite was present underneath the surface cobbles, but no calcite was detected in the sand fraction.
4–20 in. (C)	Loose, stratified, iron-stained sand and gravel, very irregular.

Temperatures play a very important role in development of the vegetation as well as the soil. Air temperature near the Arctic Brown soil site was 50° F, [10 degrees warmer than the uplands where the Polar Desert soils exist (July 2, 1966)]. Soil temperature at the 3-inch depth was 45° F.

Mechanical Composition. Mechanical composition of the Arctic Brown soil is given in Table 13. The surface horizon contains considerable quantities of silt and clay but the C horizon contains virtually nothing but sand and gravel. While the Arctic Brown soil nearly always contains more silt and clay in the solum than in the C horizon there is usually not such a high order change in texture as shown at this site. Undoubtedly the difference of texture with depth is primarily a reflection of the different textural strata in the original fluvial deposit.

Table 13. *Mechanical composition of Arctic Brown soil, Inglefield Land, Greenland*

Horizon	Depth in.	Sand 2–0.05 mm	Silt 0.05–0.002 mm	Clay 0.002 mm
		%	%	%
A	0– 4	74	15	11
C	7–10	98	1	1

Mineralogy. The light minerals consist of about 65 pct. quartz and 35 pct. orthoclase with a little plagioclase (Table 14). Heavy minerals total about 17 pct. in the A and 53 pct. in the C horizon. The high percentage of heavy minerals in the C horizon probably represents a local condition brought about during the fluvial process. Garnet, common hornblende, ilmenite, magnetite and sillimanite make up over 90 pct. of the heavy minerals. One of the most important features of the Arctic Brown soil reported above is the absence of both calcite and dolomite in the sand fraction of the profile. This is a difficult situation to explain in view of the alkaline reaction of the soil and carbonate veneers on the cobbles of the A horizon. If carbonate minerals were, at one time, present in the matrix they would normally be expected to persist, especially under such an arid environment. KREBS and TEDROW (1957) reported dolomite persisting in glacial drift even under humid conditions in eastern North America.

Clays in the Arctic Brown soil consisted of montmorillonite, vermiculite, illite and kaolonite, and a little clay-size quartz. Except for the greater quantity of montmorillonite in the A horizon, the A and C horizons were very similar.

Table 14. *Distribution of minerals in Arctic Brown soil (0.25–0.10 mm)*

	A Horison 0–4 in.	C Horizon 7–10 in.
	%	%
Light Minerals[1])		
quartz	62	66
orthoclase	36	33
plagioclase	2	1
Heavy Minerals (pct.)	16.7	52.6
magnetite[2])	3.3	5.9
Non-opaques[3])		
garnet	55	67
ilmenite	3	10
common hornblende	26	16
basaltic hornblende	1	—
diopside	5	+
sillimanite	3	2
hypersthene	+	—
staurolite	2	2
tourmaline	2	—
monazite	—	1
titanite	+	—
Opaques	2	1

[1]) Total light minerals = 100.
[2]) Total heavy minerals = 100 (Sp. G. > 2.85).
[3]) Total non-opaques = 100.
Pct. heavy minerals by weight, all others by grain count.

Chemistry. Reducible iron for the Arctic Brown soil as given in Table 15 indicates virtually identical values for both A and C horizons. If reducible iron values were equated with clay content of both the A and C horizons, the C horizon would show a much greater quantity of reducible iron per unit of surface area.

Table 15. *Reducible Fe_2O_3[1]) in Arctic Brown soil, Inglefield Land, Greenland*

Horizon	Depth in.	Fe_2O_3
		%
A	0– 4	1.24
C	7–10	1.18

[1]) M. L. Jackson, 1956. Soil Chemical Analysis – Advanced Course. University of Wisconsin, Madison. 991 pp.

Table 16. *Chemical properties of Arctic Brown soil*

Depth in.	Horizon	pH	O.M.	Exchangeable Cations (me 100 gms soil) Na	K	Ca	Mg	Σ	CEC me/100 gms soil
			%						
0– 4	A	7.5	10.92	1.10	0.05	18.50	3.83	22.48	38.7
7–10	C	7.6	0.42	0.13	0.01	2.50	0.66	3.30	7.8

Arctic Brown soil has an alkaline reaction (Table 16) but free carbonates are present only on the cobbles of the profile analyzed. A rather high organic matter content is present but in other situations in which sites are more xeric, the organic content will, of course, decrease accordingly. The Arctic Brown soil has a high cation-exchange capacity in the A horizon with base saturation at the 60 pct. level (Table 16). In the C horizon, however, where the organic matter content is low, the cation-exchange capacity decreases markedly. Nearly all of the saturating bases are accounted for by calcium, but there are also small quantities of exchangeable magnesium, sodium and potassium present.

Micromorphology. The A horizon of the Arctic Brown soil consists of a moder of loose plant remains mixed with animal droppings (Fig. 49). The fabric shows the presence of some undecomposed plant remains and

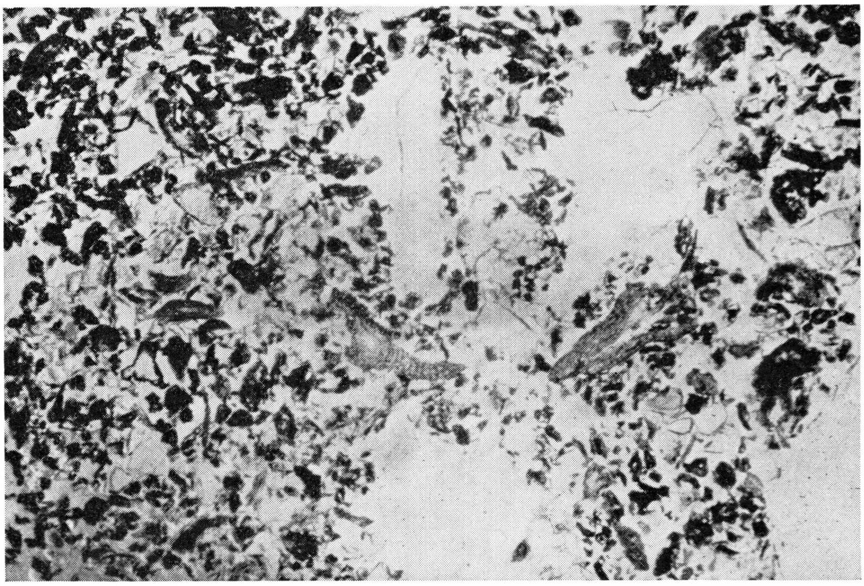

Fig. 49. Photomicrograph of Arctic Brown soil showing the loose moder of the A horizon. 35 ×.

Fig. 50. Photomicrograph of Arctic Brown soil showing the fresh-appearing minerals of the C horizon. 48 ×.

others in which there has been a "chewing-effect" by the soil organisms. With the presence of the rounded droppings there is proof of natural humus formation.

The C horizon of the Arctic Brown soil does not show any recognizable humic components (Fig. 50). The mineral grains are fresh and unaltered, with no clay evident. There is in some instances a little iron-staining along the margins and joints of the minerals but otherwise the grains are fresh-appearing. The iron-staining is probably more of a result of iron being carried in the ground water rather than natural weathering.

The term Arctic Brown soil should be viewed as a rather broad one. Throughout virtually all of the polar regions Arctic Brown soils are united mainly by morphology alone. But the degree of leaching, pH values and base saturation will vary in this soil from one polar sector to another, depending upon climate, materials and related factors.

Tundra Soils

Tundra soils have been reported extensively throughout the years but most of the descriptions are from the southern sectors of the polar regions. Tundra soils occur as far north as the northern fringes of the ice-free land but the morphology is usually not the same as that found in the more southerly sectors of the polar regions in the vicinity of the tree line. Tundra soils of the main tundra belt tend to mantle most of the landscape – uplands, slopes and valleys. In the high arctic, however, these soils are confined primarily to narrow isolated belts along the drainageways and related concavities (Figs. 51 and 52). Most depressions of the high arctic have been subjected to rather complex geologic processes such as slope wash and solifluction among others, which adds to the complexity of the soil history. Whereas in the main tundra region, the Tundra soils usually have a set of horizons with a degree of specificity (TEDROW et al., 1958; DOUGLAS and TEDROW, 1960), in the high arctic this may or may not necessarily be the case.

In the high arctic Tundra soils, with snow cover persisting until late June or early July, the seasonal thaw does not begin in the depressions until late in the season. Whereas Tundra soils in early July are in most cases completely frozen; the adjacent Polar Desert soils have already thawed to a depth of 3 or more feet.

Unfortunately we did not have equipment for deep excavations into Tundra soils, therefore our observations had to be confined in most cases to depths of 12 to 14 inches.

Tundra soils of Inglefield Land can be divided into Upland Tundra and Meadow Tundra varieties in a manner previously described (TEDROW et al., 1958; TEDROW and CANTLON, 1958), but for purposes of soil mapping, these two varieties were grouped together (Fig. 32).

Morphology. Upland Tundra soils are generally colonized by a continuous sward of *Carex*, *Cassiope tetragona*, *Salix*, *Dryas* and Sphagnum (Fig. 53). Idealized morphology follows:

Depth	*Morphology*
2– 0 in.	Wet mat of living and dead plants, dark reddish brown to black. Thickness of the mat varies greatly.
0– 1 in.	Black, greasy fine sandy loam.
1–14 in.	Brown (10 YR $^4/_3$), wet sandy loam with color resembling protogley.
14–17 in.	Brown sandy loam with organic inclusions. Frozen (July 6, 1966).

Meadow Tundra are similar to the Upland Tundra soils but the former occupy wetter positions (Fig. 54). Vegetation consists of *Carex stans*, *Arctogrostis latifolia*, with the hummocks colonized by *Dryas* and *Cladonia*. The organic mat is nearly continuous with free water covering the mineral substrate between the tussocks. Idealized morphology follows:

Depth	*Morphology*
6–0 in	Reddish brown to black organic mat, water saturated.
0–2 in	Brown to black organic-stained sand.
2–6 in	Gray to brown water-logged sand. Frozen at the 6-inch depth (July 6, 1966).

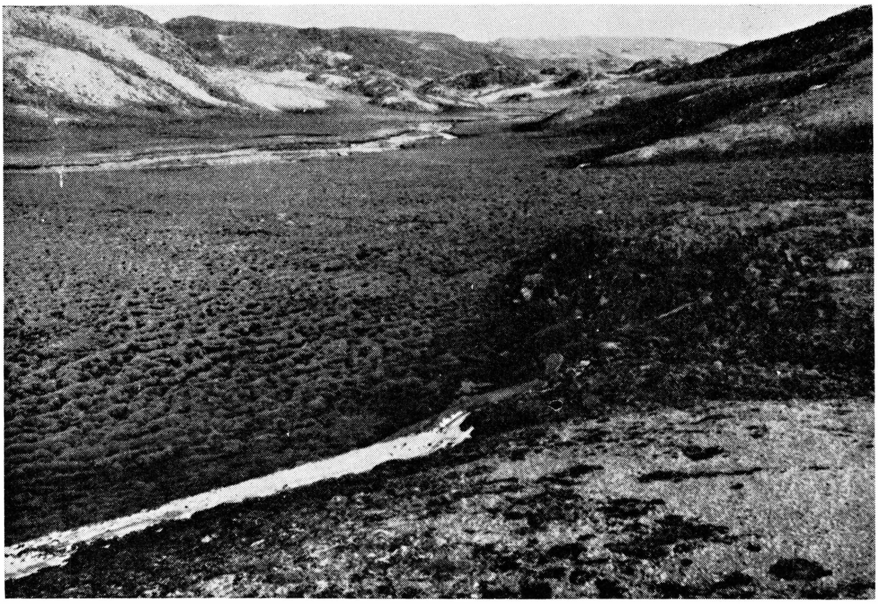

Fig. 51. View of a valley covered continuously with Tundra soil. This was the largest area of Tundra soil seen in Inglefield Land.

Fig. 52. View of Tundra soil along a drainageway.

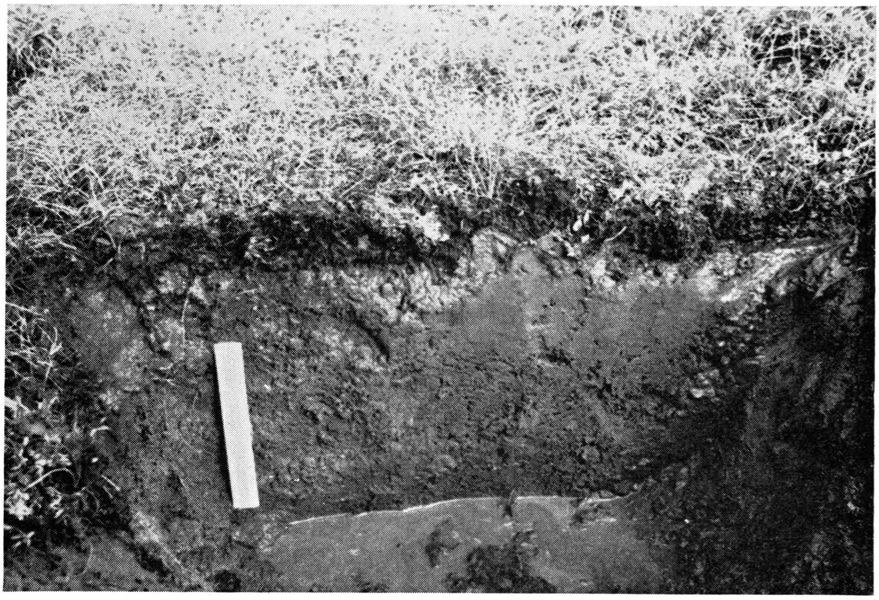

Fig. 53. Upland Tundra soil. Note water at the bottom of the pit. Scale is 6 inches.

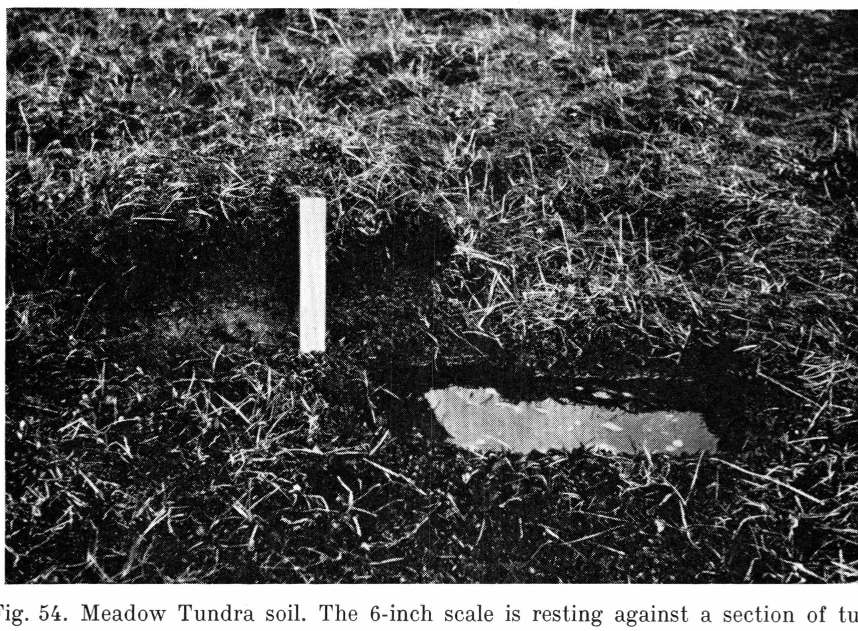

Fig. 54. Meadow Tundra soil. The 6-inch scale is resting against a section of turf removed from the shallow pit. Free water is present at the 2-inch depth.

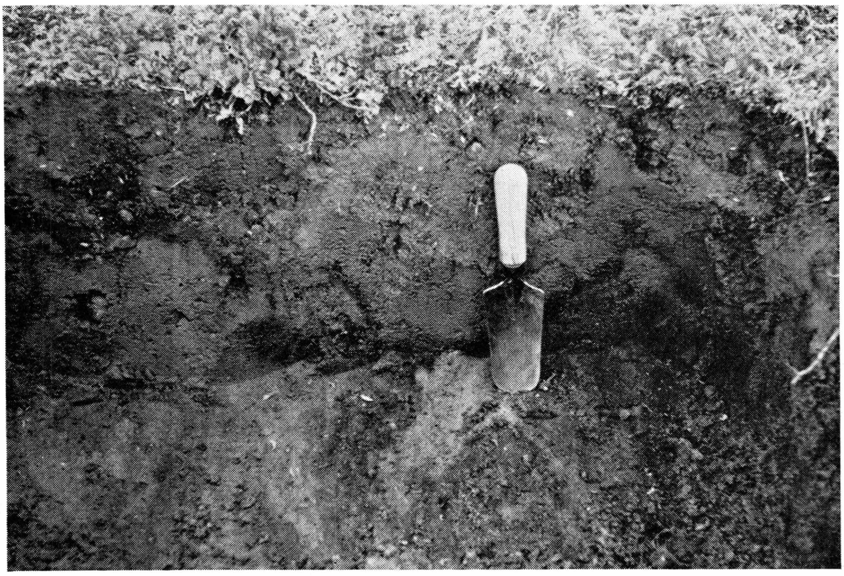

Fig. 55. Upland Tundra soil on glacial drift. The trowl rests on a buried organic horizon which has an age of 1200 yr. B.P. (I-2323).

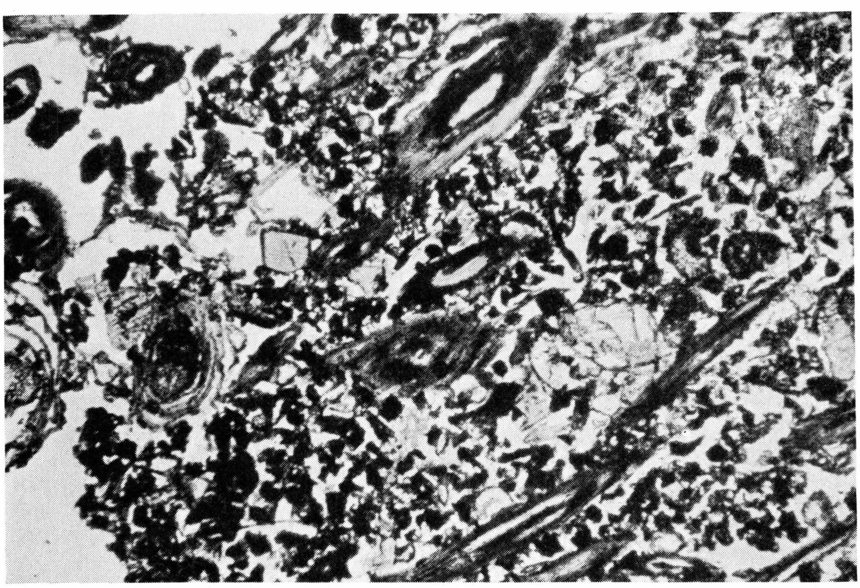

Fig. 56. Photomicrograph of a thin-section of Tundra soil. The sample was from the A_0 horizon and is a moder-like material with numerous animal droppings. 35 ×.

Chemistry. Table 17 gives data on a number of Tundra soil profiles. Organic matter decreases with depth. In those situations in which it was possible to excavate the soil to greater depths a greater concentration of organic matter was encountered at depth than was present in the upper mineral horizons (Fig. 55). The buried organic matter shown in Fig. 55 yielded an age value of 1,200 ± 95 yr. B.P. (I-2323) but pollen was not detected in the sample. The Tundra soils yielded pH values varying from 5.8 to 6.4 (Table 18). Eight random samples in addition to those shown in Table 1 yielded pH values of 5.8 to 7.1. Cation-exchange values showed a low degree of base saturation (Table 17). In general these reported values are similar to those found in the Tundra soils throughout many polar regions.

Micromorphology. The thin-section of the Upland Tundra surface mat shows a highly organic fabric with a moder-like appearance similar to that of the Meadow Tundra. Undecomposed plant remains are common (Fig. 56). In some instances the organic residues showing the effect of chewing insects are common throughout the organic fabric.

Minerals including biotite and augite are sharp-edged and unweathered with virtually no clay substance visible. A small amount of iron-staining is evident in the joints of the mineral grains, particularly the feldspars.

Table 17. *Properties of some Tundra soils of Inglefield Land, Greenland*

Depth in.	Texture	O.M.	Conductivity 1:2	pH	Exchangeable Cations me/100 gms soil Na	K	Ca	Mg	CEC me/100 gms soil	Dialyzable P ppm
		%								
				Upland Tundra (terrace)						
0–1	Sa. l.	24.1	11	5.8	0.27	0.07	1.25	4.30	58.2	4.0
1–6	Sa. l.	2.6	10	5.9	0.23	005.	4.10	1.66	16.2	6.5
				Upland Tundra (glacial till)						
0–4	L. sa.	7.1	—	6.2	—	—	—	—	21.3	—
				Meadow Tundra (terrace)						
0–2	Sa. l.	28.2	28	6.4	—	—	—	—	—	7.0
2–5	Sa. l.	5.3	10	6.0	0.14	0.04	4.00	1.58	15.2	7.5

The upper mineral horizon of Tundra soil is qualitatively similar to the overlying organic mat in that it is comprised of partially humified substances in the form of small animal droppings and partially chewed plant remains. Mineral grains are fresh-appearing with virtually no clay

Fig. 57. Soil of the Hummocky Ground. This condition exists on sloping land with a moderate supply of moisture during the summer months.

Fig. 58. Soil of the Hummocky Ground showing the effects of intensive frost action. Scale is 6 inches.

substances coating sand grains. There is a little carbonate present along the margins of some of the sand grains.

The surface organic mat of the Meadow Tundra is a moder comprised of animal droppings and plant residues. There is virtually no aggregate formation. Mineral grains are clear with no clay evident. Probably there is little animal activity during the early part of the summer when conditions are quite wet, but as the soil moisture content decreases later in the summer, there is increased animal activity.

An organic cushion from Tundra soil shows animal droppings and partially humified plant remains in a fresh mineral matrix. Soil minerals are fresh. There is a small amount of iron staining in some of the feldspar joints.

Soils of the Hummocky Ground

On sloping positions where there is a moderate but fairly constant supply of water from melting snowbanks or other natural sources, the landscape acquires a hummocky appearance (Fig. 57). While the soils of these areas apparently do not exist in a water-saturated condition for extended periods of time, they are in a somewhat moist state throughout most of the summer months. The soils show evidence of intensive frost action (Fig. 58). Edaphically, soils of the Hummocky Ground approximate an Upland Tundra soil, but morphology and phenology are quite different. The general features of the hummocky ground in East Greenland have been set forth by RAUP (1965). A similar condition of hummocky ground was seen on Banks Island and the Bernard series was established to provide for the soil condition (TEDROW and DOUGLAS, 1964). On Prince Patrick Island, similar conditions were also noted (TEDROW et al., 1968).

Soils of the Polar Desert-Tundra Interjacence

Throughout much of the area studied there are extensive locations in which the soils occupying relatively low, flat positions have a rather unique moisture regime. During late June and early July, water saturates the soil to the surface from runoff and seepage but as the season progresses there is a continuous loss of moisture from the sites. By late July the sites are quite dry. There are no alternating wet-dry soil conditions every few days during the summer; instead, there is a rather constant seasonal loss of moisture by seepage and evapo-transpiration. During early summer the soils are so wet that upon walking over them one will sink into the ground 4 to 6 inches, but by mid-July conditions are dry enough to support a man's weight. Fig. 59 shows the appearance of a site where the soil occurs. The relative position of the site is usually such

Fig. 59. Soil of the Polar Desert-Tundra interjacence. The higher ground on the left has become relatively dry whereas that on the right remains quite wet.

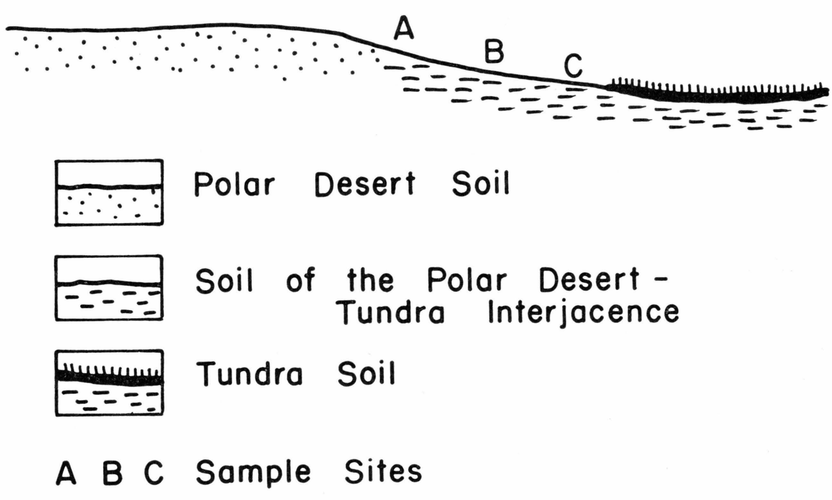

Fig. 60. Diagrammatic sketch of the relative position of the soil of the Polar Desert-Tundra interjacence.

that the adjacent higher ground is occupied by Polar Desert soil whereas the adjacent lower position is occupied by Tundra soil (Fig. 60). The quantity of moisture has such a high seasonal amplitude that few vascular plants become established. Late in the season the surface of the soil

Fig. 61. The appearance of soils of the Polar Desert-Tundra interjacence after conditions have become relatively dry. Note salt efflorescence on the vegetation-free portions.

becomes hard and dry and salt crusts begin to form. Fig. 61 shows the appearance of the terrain after it has become fairly dry.

Little information is given on morphology of the soil of the Polar Desert-Tundra interjacence because there is a high order change of physical appearance of the soil as the season progresses. In the early summer it consists of a supersaturated gravelly sand (Fig. 62), however, as the sites become drier with time the soil consists of a dry structureless, gray material with a covering of hard salt crusts (Fig. 63). The soil is, of course, in somewhat of a dynamic physical state from intensive frost action and patterned ground formation.

In order to determine whether there is any trend in certain chemical properties of the soil from the higher to lower positions within the swales, a short transect was made, as shown in Fig. 60. Table 18 gives certain chemical properties across the transect. Free carbonates were present in all samples and pH values were high. Where the organic content was high the cation-exchange capacity was likewise high. The saturating cations, except for calcium, remained rather uniform throughout the various sites. Dialiazable phosphorus likewise did not show a specific trend with depth between the various positions.

Fig. 62. Soil of the Polar Desert-Tundra interjacence. This is a complex of saturated mineral material becoming progressively drier as the summer season progresses.

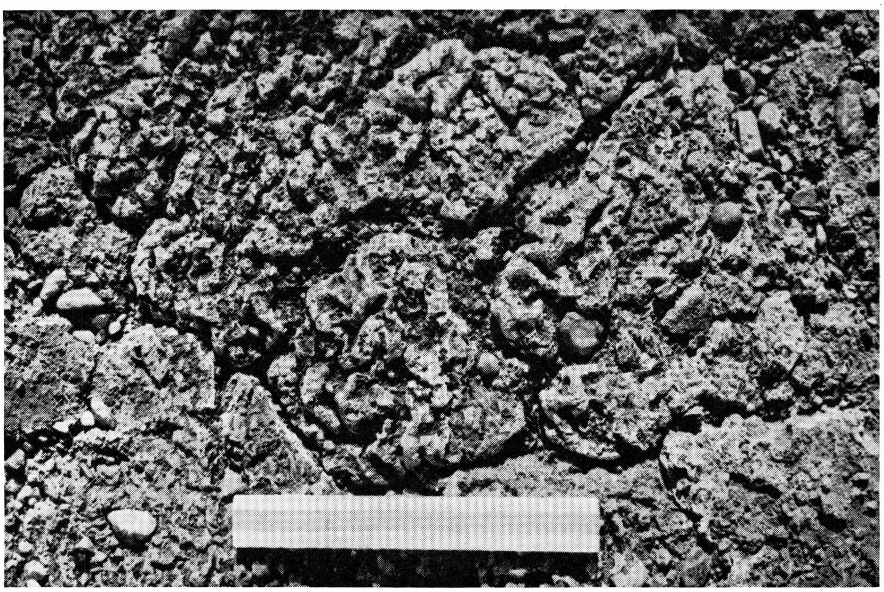

Fig. 63. Salt efflorescence in mid-summer on the soil of the Polar Desert-Tundra interjacence. Scale is 6 inches.

Salt Crusts. Salt crusts have been reported within the polar regions for over a half-century. They have been reported in virtually all sectors of the high arctic as well as in isolated situations within the main arctic belt. Hartz (1896) and Nordenskjold (1914) gave analyses of the salt crusts in Greenland; the data showing a dominance of sodium and sulphate ions. In the Ellesmere Island sector, Day (1964) reported saline conditions and on Prince Patrick Island; Tedrow (1966) and Tedrow et al., (1968) gave analyses of the salt crusts.

In Inglefield Land, salt crusts were recorded but they are by no means universally present. Instead they appeared to be confined largely to the soils of the Polar Desert-Tundra interjacence. There was little efflorescence on the continuously dry soils. Tundra soils with a continuous supply of moisture likewise did not show any visible signs of efflorescence. The intermediate drainage positions, however – those with soils that were very wet during the early summer, but dry during the later part of the field season, were the ones in which there was widepsread salt accumulation. Figs. 64 and 65 show typical locations for surface salt accumulation. Salt crusts were collected at three locations. The samples were first leached with distilled water which showed the presence of sodium, potassium, calcium and magnesium (Table 19). Chloride was also present in considerable quantity but there was only a trace of sulphate. Carbonates were present but not determined quantitatively. Following the leaching with water, the samples were then leached with 0.1 N hydrochloric acid, the results of which are shown in Table 19. Perhaps the most interesting feature of the data is not the total quantity of salt solubilized,

Table 18. *Chemical Properties of some Soils of the Polar Desert-Tundra Interjacence. Inglefield Land, Greenland. (See Fig. 60 for a schematic diagram of sites)*

Depth in.	O.M.	pH	Carbonates	Ec 1:2	Exchangeable Cations me/100 gms soil				CEC 100 gms soil	Dialyzable P ppm
					Na	K	Ca	Mg		
	%				Site A					
0–1	3.3	8.2	+	21	0.29	0.08	18.4	0.8	20.8	10
1–6	1.6	7.6	+	16	0.23	0.03	10.0	1.9	12.4	12
					Site B					
0–1	5.5	8.9	+	59	0.51	0.07	17.0	2.33	23.0	16
1–6	0.6	8.2	+	28	0.50	0.04	13.5	1.50	.0 17.0	13
					Site C					
0–1	1.6	8.3	+	14	0.23	0.05	8.5	1.08	11.6	8
1–6	1.4	8.3	+	16	0.51	0.07	17.0	2.33	11.1	14

[1]) See Fig. 62.

Fig. 64. Patterned ground on the soil of the Polar Desert-Tundra interjacence. The water table is at the 4-inch depth.

Fig. 65. Desiccation cracks in soil of the Polar Desert-Tundra interjacence. The surface is covered by black gelatinous lichens. Scale is 6 inches.

but the ionic ratios. The literature covering the polar regions depicts the widespread presence of thenardite (Na_2SO_4) on the surface of the soils, but in Inglefield Land apparently this is not the case.

Table 19. *Chemical composition of salt crusts from Inglefield Land, Greenland*

	Water Soluble Constituents[1]) mgm/100 gm. soil					
Sample	Cl	SO_4	Na	K	Ca	Mg
GrS 1	36	+	15	4	28	13
GrS 2	45	+	25	6	19	16
GrS 3	54	+	18	7	28	13
	Acid Soluble Constituents[1]) mgm/100 gm. soil					
Sample	Cl	SO_4	Na	K	Ca	Mg
GrS 1	ND	—	6	7	88	23
GrS 2	ND	—	8	5	130	25
GrS 3	ND	—	3	5	83	20

[1]) 5 gm. of soil, leached to 250 ml. with distilled water, followed by leaching with 250 ml. 0.1 N HCl.
\+ = Trace.
— = Not detected.
ND = Not determined.

Patterned Ground. Some of the most complex and intricate patterned ground features of Inglefield Land were observed on the soils of the Polar Desert-Tundra interjacence. It is understandable that a variety of patterned ground features would be present because of the high order seasonal moisture changes in the soil. Figs. 59, 61, 64 and 65 show some of the varieties of patterned ground present. Fig. 64 shows soil of the Polar Desert-Tundra interjacence in which the mineral material is a gravelly sand. A complex pattern of stone rings and stone nets has developed. In situations in which there is an appreciable quantity of fines present in the soil of the Polar Desert-Tundra interjacence the soil will, upon drying, show desiccation cracks (Fig. 65).

Bedrock and Boulder Fields

Bedrock is exposed in a semi-continuous belt several miles wide adjacent to Rensselaer Bugt. Bedrock and boulder fields make up the greatest portion of the landscape in this area (Fig. 32). South of Queen's

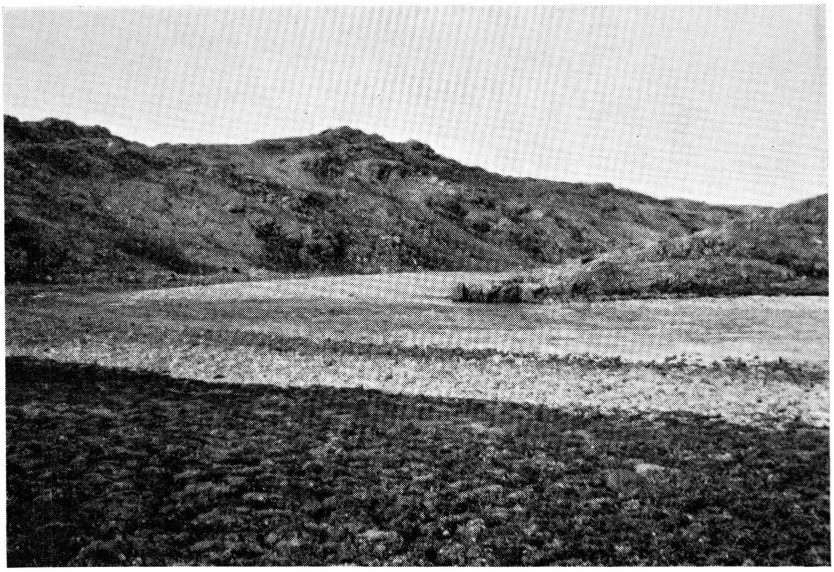

Fig. 66. View of the head of the gorge leading into Rensselaer Bugt showing many outcrops with virtually no soil cover. The center of the photograph shows bare gravel bars, whereas the foreground is mantled Tundra soil.

College Sø however, there are few exposures. Near Rensselaer Bugt the uplands are comparatively void of a soil cover, but some local depressions have small shallow lakes with sandy Tundra soils at their peripheries. Boulder fields, however, occupy most of the depressions (Fig. 8). Fig. 6 shows the appearence of the head of the gorge just south of Queen's College Sø with dry, rocky uplands. The fast flowing river leading into the gorge is mantled with narrow, bare gravel bars.

MISCELLANEOUS STUDIES

Salt Content of Drainage Waters

It has been long known that the drainage waters of the high arctic have a considerable quantity of soluble salts present. In order to provide some quantitative data on the total salt content of surface waters in Inglefield Land, a few conductivity readings were made in the vicinity of the campsite (Fig. 32). The values are listed in Table 20. The highest salt content was found in a closed depression, the next highest in a shallow lake. A small stream showed the lowest value. Tests for specific ions were not made.

Table 20. *Salt content of some Inglefield Land waters (July 7, 1966)*

	% Salt	°F[1])
Small stream	0.08	52
Shallow lake	0.35	52
Pond 1	0.18	52
Pond 2	0.15	50
Pond 3	0.08	52
Closed depression	0.44	46

[1]) Water at time of sampling.

Soil Properties Induced by Vegetation

Whereas the polar deserts are generally void of plant cover there are local situations in which a closed vegetation mat occurs. Plants such as *Saxifraga* or *Carex* may represent only clusters of vegetation in the otherwise raw mineral soil, but *Dryas*, *Salix* or *Cassiope* usually tend to form an organic mat. Fig. 67 shows the partially humified material under a *Salix* mat together with the adjacent non-vegetated soil. There seems to be no doubt that the organic mat forms favorable physical and chemical soil conditions for plant rooting in that the upper mineral material has a loose, well-aggregated, friable structure.

Fig. 67. The left side of the photograph shows initial humus formation under a *Salix* clump whereas the right side shows no vascular plant cover and consequently no visible humus. See Table 21 for chemical analyses. Scale is 6 inches.

In order to determine possible chemical changes in the soil induced by vegetation, three locations were sampled for analyses. In each case the upper 2 inches of soil was sampled underneath a loose *Salix* mat, under a tight *Dryas* mat and under a non-vegetated condition. The results are given in Table 21. In addition to more friable conditions underneath the mats, the organic content had increased markedly to about 19 pct. under the *Dryas* mat. The pH values tend to be a little lower under the

Table 21. *Effect of vegetation on soil properties*

Depth in.	O.M. %	pH	Carbon-ates	Exchangeable Cations me/100 gms soil[1]) Na	K	Ca	Mg	Electro-dialyzable P (ppm)
	Polar Desert Soil – No vegetative cover (Fig. 67)							
0–2	1.67	8.3	+	0.38	0.04	4.75	3.30	7
	Polar Desert soil area – under a loose mat of *Salix* (Fig. 67)							
0–2	5.76	7.7	+	0.30	0.03	3.90	7.66	8
	Polar Desert soil area – under a dense mat of *Dryas*							
0–2	18.8	7.6	+	0.27	0.20	36.85	5.20	30

[1]) Difference between first and second extractions with ammonium acetate.

organic cover but still all reactions were alkaline. Perhaps one of the most striking changes in chemical properties of the soils was the high quantities of phosphorus and calcium underneath the *Dryas* mat (Table 21).

Plant Composition

A number of plants were collected for chemical composition determinations. *Arctogrostis latifolia* and *Carex stans* were from a Tundra soil site whereas all other plants listed in Table 22 were growing in Polar Desert soil. Nitrogen was highest in the *Salix* leaves with the *Arctogrostis* and *Carex* also ranking high. Potassium showed a similar trend with *Salix* leaves. *Arctogrostis* and *Carex* all showing the highest contents of the samples analyzed. An unusually high content of iron was recorded in the *Dryas* and *Saxifraga*, both species being from the Polar Desert soil. *Saxifraga* and *Cladonia* were the greatest accumulators of calcium. The other elements listed in Table 22 are not discussed in this report.

Table 22. *Partial chemical composition of plants from Inglefield Land, Greenland.*[1]) *Data expressed on dry (105° C) weight basis (Collected July 8, 1966)*

N	S	Na	K	Ca	Mg	Fe ppm	Cu ppm	Mn ppm	Zn ppm
%	%	%	%	%	%				
				Arctogrostis latifolia					
1.78	0.17	0.02	0.87	0.37	0.16	2000	44	312	40
				Carex stans					
1.85	0.15	0.02	0.70	0.90	0.19	825	40	560	30
				Cassiope tetragona					
0.89	0.07	0.004	0.15	0.60	0.12	490	28	88	22
				Dryas					
0.89	0.08	0.006	0.10	2.5	0.33	3750	100	100	60
				Cladonia					
0.35	0.02	0.03	0.60	3.7	0.24	1625	65	47	30
				Saxifraga oppositifolia					
0.94	0.10	0.01	0.13	4.8	0.26	3250	70	112	29
				Salix (leaves)					
2.28	0.18	0.06	1.11	0.9	0.33	210	33	45	65
				Salix (stem)					
0.66	0.05	0.01	0.23	0.9	0.11	125	33	18	88

[1]) Identification by A. E. Porsild.

RELATION OF THE SOILS OF THE HIGH ARCTIC TO THOSE OF ANTARCTICA

A number of investigators have discussed the possibility of the soils of Northern Greenland being quite similar to those of Antarctica. There is no question that the northern fringes of the high arctic have certain soil properties in common with those found in Antarctica. Both regions have soils with morphologic affinities of a desert type of soil formation. It seems desirable to retain the term *desert* in the soil nomenclature for both regions but to provide for certain regional quantitative differences. The soils of Antarctica form under more frigid conditions and have less moisture in the matrix during the summer months, have virtually no organic matter in the system and display somewhat more primitive conditions than is the case of the high arctic.

The soils of the antarctic deserts are now fairly well stated in the reports by Markov (1956), Glazovskaia (1958), McCraw (1960, 1967, Claridge (1965), Tedrow and Ugolini (1966), Allen et al. (1967) among others. The problem of soils of the high arctic has been outlined in this report. An attempt at showing the relationships of the desert soils of Antarctica to those of the northern polar regions has been given previously (Tedrow and Thompson, 1968; Tedrow, 1968). The following statements set forth a comparison of the two soil regions.

1. Both high arctic and antarctic soils show a distinct desert type of soil formation with a desert pavement and a crude A-B-C horizon sequence.

2. The Cold Desert soils of Antarctica have a more xeric environment, higher degrees of alkalinity and salinity than do Polar Desert soils.

3. The high arctic deserts have an effective organic component in the soils whereas the cold deserts of Antarctica do not.

4. Gypsum layers in the "B-C" horizon of antarctic soils are quite common, but rarely present in the high arctic. Pedogenic carbonates, however, accumulate in both locations.

5. Depth of thaw in the high arctic soils is greater than in Antarctica.

6. Summer soil temperature of the high arctic are much higher than in Antarctica.

7. Surface boulders in Antarctica effloresce far more than those in the high arctic.

The above listing described both similarities and differences in the soils of the far north as compared to those of Antarctica. From available information, including my own observations on Prince Patrick Island, Cornwallis Island and Inglefield Land there is no conclusive evidence for recognizing Cold Desert soils in the high arctic. On the other hand, there is a strong probability that Polar Desert soil, as described in this and other reports will be found on the northern fringes of the Antarctic Peninsula. Allen et al. (1967) have already recorded soil conditions on an antarctic island similar to those of the high arctic.

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