MEDDELELSER OM GRØNLAND
UDGIVNE AF
KOMMISSIONEN FOR VIDENSKABELIGE UNDERSØGELSER I GRØNLAND
Bd. 147 · Nr. 2

DEN BOTANISKE EKSPEDITION TIL VESTGRØNLAND 1946

CLIMATE, SOIL, AND LAKES IN CONTINENTAL WEST GREENLAND IN RELATION TO PLANT LIFE

BY

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WITH 19 FIGURES IN THE TEXT
AND 4 PLATES

KØBENHAVN
C. A. REITZELS FORLAG
BIANCO LUNOS BOGTRYKKERI
1949

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1. INTRODUCTION

In a preliminary report (Böcher 1949) an account has been given of the Botanical Expedition to West Greenland in 1946 including some information on the conditions of climate and soil in the most continental parts of West Greenland, the country round the head of the Søndre Strømfjord. The finding of salt lakes is also briefly described there. In what follows there will be a more detailed discussion of the climatic and edaphic conditions and of the lakes, and the results will be considered in relation to conditions of vegetation.

With the exception of the macroclimatic data nearly the whole material from Greenland produced here has been collected by myself. In the preparation of the work I have been assisted by Professor F. Steenbjerg, Dr. agro., of the Royal Veterinary and Agricultural College, and Mr. Werner Christensen, Sectional Geologist, of the Geological Survey of Denmark. Professor Steenbjerg made the chemical investigations of the soil samples and Mr. Werner Christensen the chemical analyses of salt crusts and water samples. I offer both of them my cordial thanks. The macroclimatic material from the two Greenland air-bases and Simiutaq was kindly placed at my disposal by the Weather Bureau of the United States Department of Commerce, the material from Ivigtut by the Meteorological Institute of Copenhagen.

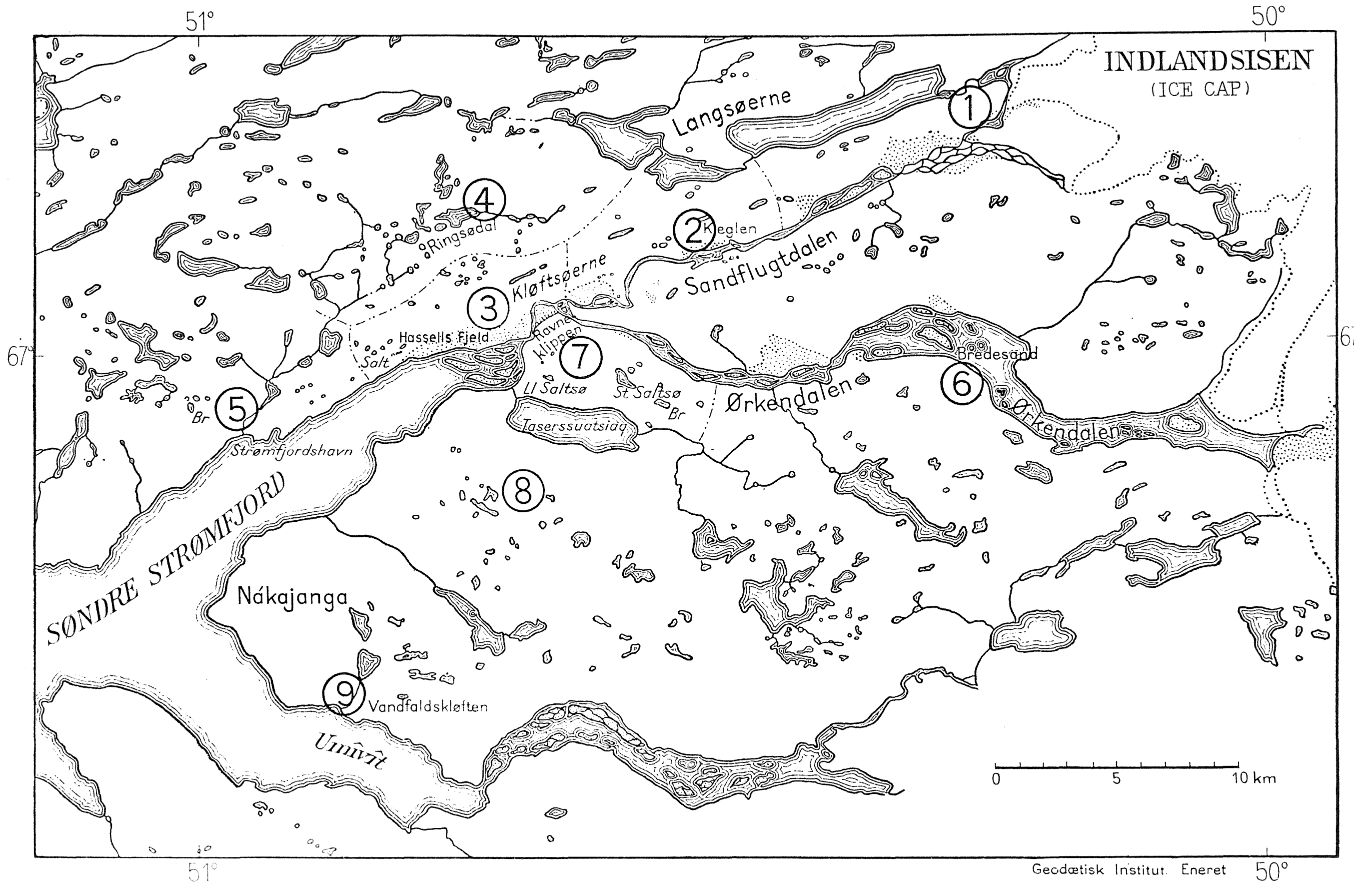

Fig. 1. Map of the area round the head of the Søndre Strømfjord in West Greenland. The figures indicate main localities. Dotted areas are desertlike areas or sandbanks in the river-beds. Descriptions of the various localities are found in Böcher 1949.

2. MACROCLIMATE

The climate in the continental parts of Greenland closest to the inland ice has hitherto been very insufficiently known. Apart from the measurements at Qôrnoq in the Godthaab Fjord and a nearly triennial observation period at Ella Ø in the Franz Joseph Fjord in North-East Greenland (see Sørensen 1941, Table 2), both localities being places situated only half-way into the fjords, only scattered observations were known. For the continental parts within Holsteinsborg on the west coast such observations are mentioned by Nordenskjöld (1914) and Hobbs (1927). The data originating from the weather-stations at the two recently established air-bases in South and West Greenland therefore, from a biological point of view, are very welcome, as they are of the greatest importance to our understanding of a number of plant-geographical conditions.

The figures placed at the writer's disposal from the air-bases originate from the end of 1941 and the following four whole years. From the Meteorological Institute of Copenhagen I have for the same period obtained material from Ivigtut. The other meteorological data mentioned in what follows are, if nothing is said to the contrary, adduced from the survey in Helge Petersen (1935).

A. The Climate at the Head of the Søndre Strømfjord as Compared with the Climate in the Rest of South-West Greenland.

The chief climatic curves for the station at the head of the Søndre Strømfjord (Loc. 3, fig. 1) are rendered in the hydrotherm figure fig. 2, and the principal values are found in Table 1. The highly continental climate of the place appears from the great annual amplitude and the extremely low precipitation.

Helge Petersen (*loc. cit.* pp. 39 and 43) gives climatic curves for the coastal stations in West Greenland. From these it appears that the degree of oceanity increases along the outer coast in a southerly direction. The same is true of East Greenland (cf. Böcher 1933, 1938).

A comparison between the station at the head of the Søndre Strømfjord and the coastal stations clearly shows that the greatest similarity is between the Strømfjord station and the northern coastal stations. Holsteinsborg, which is at the same latitude as the Strømfjord station, is, indeed, different from the latter by its lower summer temperature and

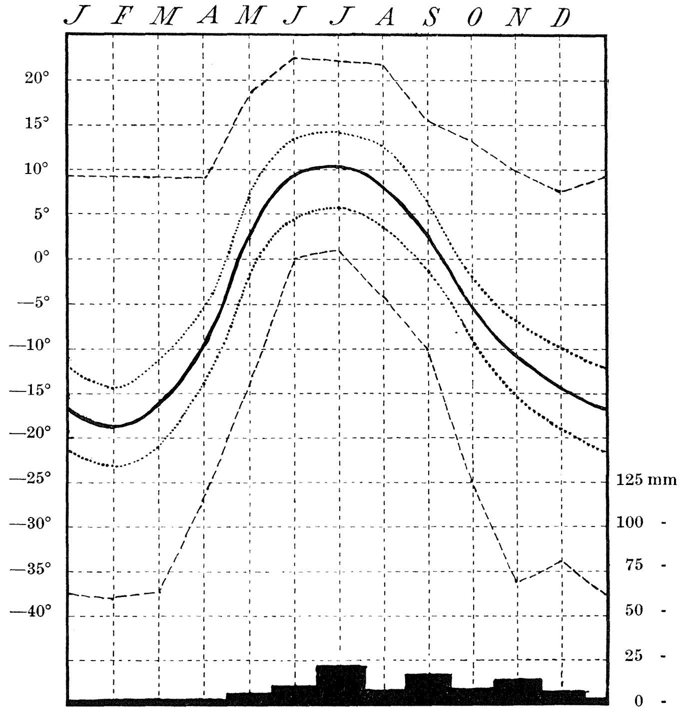

Fig. 2. Temperature and precipitation at the station at the head of the Søndre Strømfjord in West Greenland. Temperature in C., precipitation in mm. Uppermost and lowermost curves: absolute maxima and minima, dotted curves mean maxima and mean minima, continuous fat curve: mean temperature. At bottom precipitation indicated by filled-in blocks.

a precipitation nearly three times as great, but the contrast is not striking, a fact which is due to Holsteinsborg in spite of its outlying situation having a comparatively continental climate. There is a much more marked difference in climate if the Strømfjord station is compared with the station Simiutaq at the mouth of the Søndre Strømfjord, where the winters are much milder and where the precipitation amounts to 844 mm a year. The very heavy precipitation of Simiutaq may be due to local orographic factors (high mountains situated near the sea).

A comparison between the three inland stations, the Strømfjord station, Qôrnoq in the Godthaab Fjord, and Narsarssuaq at the head of the Tunugdliarfik Fjord in South Greenland (fig. 3), as in the case of the coastal stations, shows an increasing degree of oceanity from north to south. Just as Holsteinsborg, in spite of its situation on the coast, had a comparatively continental climate, thus Narsarssuaq, in spite of its being situated on the innermost part of the fjord, has a rather

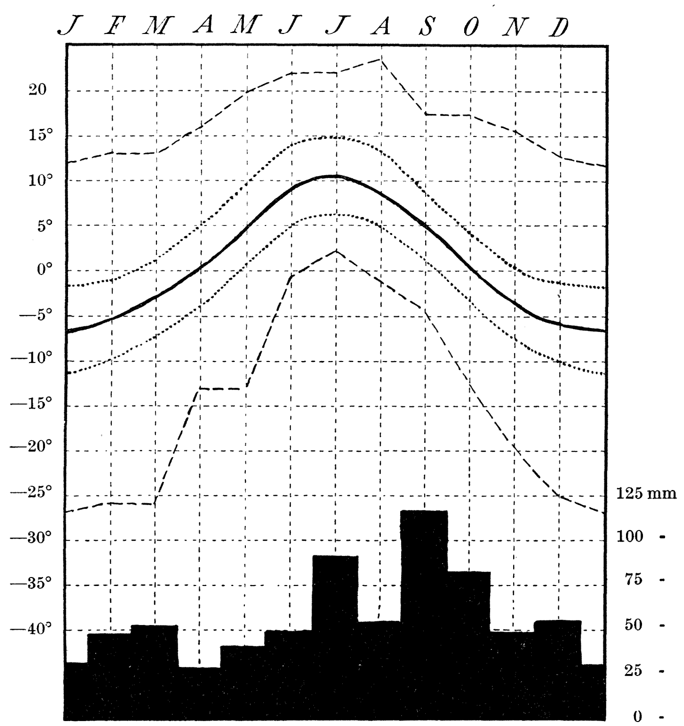

Fig. 3. Temperature and precipitation at the station Narsarssuaq at the head of the Tunugdliarfik Fjord in South-West Greenland. Temperature in C., precipitation in mm. Curves indicate temperature, cf. fig. 2. Precipitation indicated at bottom by filled-in blocks.

oceanic climate. Of course Ivigtut, Julianehaab, and Nanortalik in the coastal regions and outer fjord districts in South Greenland have still more oceanic climates.

The index of humidity used by Martonne (1926), Hesselmann (1932), and Godske (1944) has been calculated on the basis of material from the stations mentioned in Table 1. This index, which gives the annual precipitation in mm divided by the annual mean temperature on the centigrade scale plus a constant put at 10, is usable for the southern stations of Greenland, but gives rather misleading figures for the northern stations with a very negative annual mean temperature. For the Strømfjord station this index is 20, for Narsarssuaq 67, and for Ivigtut 121.

As compared with Norway (GODSKE, *loc. cit.*) Ivigtut has the same index of humidity as the Bergen region, Narsarssuaq as Kongsberg, and the Strømfjord station as Ulstad in the Dovre area or certain stations in the fjords in Finmarken, i. e. exactly the climatically most continental parts of Norway.

Table 1.

Station (i) inland stations	Latitude	July mean temp. C.	Mean annual temp. C.	Mean annual temp. range C.	Mean annual precipitation in mm	Mean no. of days with precipitation of 2.5 mm or more	Index of of humidity	Index of oceanity
Simiutaq[1]	66° 00′	5.6	0.4	12.2	844	139.3	81	131.4
Holsteinsborg	66° 56′	7.6	—4.8	25.2	270	..	52	..
(i) Head of Søndre Strømfjord[2]	67° 00′	10.1	—4.8	28.8	103	60.9	20	.. 3.8
Godthaab	64° 11′	6.5	—1.9	16.6	596	..	74	..
(i) Qôrnoq	64° 26′	8.5	—1.7	19.4	369	..	45	..
Ivigtut[2]	61° 12′	10.0	1.0	14.2	1330	..	121	..
(i) Narsarssuaq[2]	61° 10′	10.6	1.5	17.0	775	123.3	67	78.0

[1] 1942—1945
[2] 1941—1945

As we have very little material in hand concerning the number of spring and autumn days, i. e. the number of days with a mean temperature between 0 and 10° C., it has only been possible to calculate the index of oceanity proposed by KOTILAINEN (1933) as regards Simiutaq, the Strømfjord, and Narsarssuaq. KOTILAINEN's index above the line has the annual precipitation in mm multiplied by the number of days with a mean temperature between 0 and 10° C. and below the line the amplitude of annual temperature multiplied by a constant put at 100. This index gives 131 for Simiutaq, 78 for Narsarssuaq, and nearly 4 for the Strømfjord. Simiutaq corresponds to stations in the Lofoten region. Narsarssuaq nearly corresponds to Göteborg in West Sweden (see KOTILAINEN p. 56) or Byglandsfjord in Sætesdalen (see GODSKE, *loc. cit.*), whereas no Scandinavian (including Finnish) stations get down to so low values as the Strømfjord station. The lowest value in Scandinavia is 10, which is reached in the Central North Scandinavian area where the Norwegian, Swedish, and Finnish frontiers meet. A figure of a similar order of magnitude will be found at Holsteinsborg, whereas Ivigtut will reach values twice as high as that of Narsarssuaq, i. e. of an order of magnitude as those of stations in South-West Norway.

The duration of the frost-free period is of great interest for our understanding of plant-geographical conditions. Fig. 4 shows the percentage number of days with continuous frost and continuous thaw, and the percentage number of days with a mean temperature of more than 0° for the Strømfjord station and Narsarssuaq. Similar curves have been prepared for Ivigtut for the same period, but are not rendered here, as they deviate insignificantly from Narsarssuaq. The difference between the two South Greenland stations and the Strømfjord station

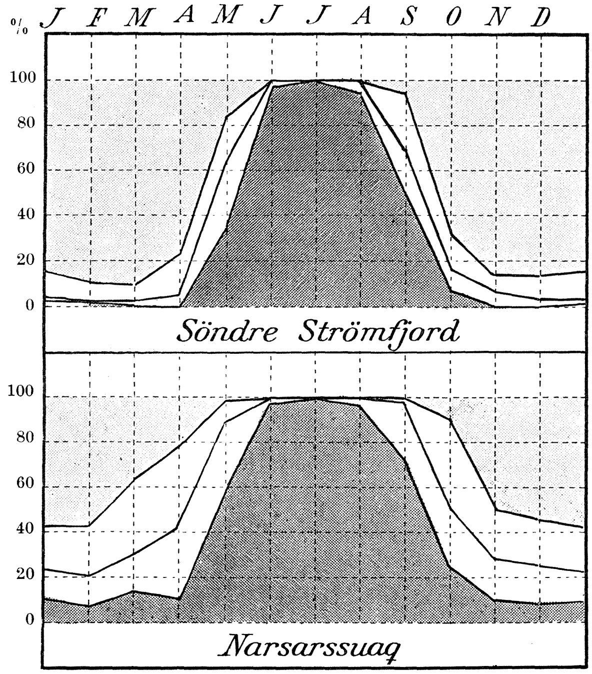

Fig. 4. Total thaw (dark grey area) and total frost (pale grey area) at the stations of Strømfjord and Narsarssuaq during the years 1941—45. Uppermost curves: percentage of days with a maximum temperature below 0°, middle curves: percentage of days with a mean temperature above 0°, lowermost curves: percentage of days with a minimum temperature above 0°.

is great and appears by the winter in the Strømfjord being what might be termed total, i. e. without any prolonged mild spells, whereas such are fairly frequent in South Greenland, even inland. At the Strømfjord station thaws in winter are exceptional, and probably due to föhn winds, while thaws in the south also highly are due to the inflow of oceanic air-masses. Fig. 4 further shows the great difference between the stations as regards the number of days on which the temperature fluctuates between frost and thaw. This fluctuation is great in the southern areas and very small in the continental area around Strømfjord. Here it is an either—or. We may try to use the curves for an estimate of the length of the period of vegetation. The annual percentage of days of

Table 2.

		Simiutaq	Søndre Strømfjord	Narsarssuaq
Percentage of days with snow depths (1941—1945)	60—150 cm	3.1	—	—
	15—60 cm	29.9	4.6	6.5
	traces—15 cm	30.7	55.6	37.3
Totals		63.7	60.2	43.8

thaw is at Narsarssuaq 45, at Ivigtut 43, and at the head of the Strømfjord 32. We cannot, however, without further circumstances draw any conclusions as to the length of the period of vegetation, as this is highly influenced by the snow-covering. It might be supposed that Narsarssuaq with its higher precipitation would have a relatively thick carpet of snow and hence a prolonged snow-covering. The figures from the two inland stations (Table 2), however, clearly show that indeed there are some few days more with a thick carpet of snow in South Greenland, but in return there are fewer days with a thin carpet and more days without any snow at all. Hence the snow-covering will hardly cause the period of vegetation to be relatively shorter at Narsarssauq, and hence it must be considered that the period of vegetation will be somewhat longer in the interior of South Greenland than at the Strømfjord, thus also because it must be taken for granted that some of the days on which the temperature changes between frost and thaw will be serviceable for the growth and production of matter of the plants.

In the coastal station Simiutaq days with thick snow carpets are very numerous as compared with both inland stations. The contrast is striking and corresponds to the great differences in vegetation (occurrences of snow patches and herb fields at the outer coast, absence of these communities in the continental lowland areas).

Table 3. Number of months in which the mean temperature exceeds 0°, 4°, 6°, 8°, and 10° C.

	Coastal zone						Mid-fjord zone						Inland zone					
		0°	4°	6°	8°	10°		0°	4°	6°	8°	10°		0°	4°	6°	8°	10°
ab. l. 66—67° N.	(a)	5(6)	3	1	0	0							(c)	5	3	3	*3*	*1*
	(b)	5	3	2	0	0												
ab. l. 63—64° N.	(d)	5	3	2	0	0	(e)	5	3	3	*1*	0						
	(f)	5	3	2	0	0												
ab. l. 60—61° N.	(g)	*6*	*4*	3	0	0	(h)	6	5	3	*3*	0	(i)	6	5	3	*3*	*1*
	(j)	*6*	*4*	1	0	0												

Stations: (a) Simiutaq, (b) Holsteinsborg, (c) The Strømfjord station, (d) Godthaab, (e) Qôrnoq, (f) Fiskenæs (g) Julianehaab, (h) Ivigtut, (i) Narsarssuaq, (j) Nanortalik,

Fig. 4 offers a possibility of a valuation of conditions in the interior of the country from South Greenland to about l. 67° north. For a survey of the magnitude of the summer heat, and hence of the length of the period of vegetation both in the coastal region and inland, we may like Böcher (1943) use the number of months with a mean temperature above a certain value (Table 3).

In spite of the unmistakeable difference between the two inland stations here expressed in the number of months with a mean temperature of more than 0° and 4° C., the resemblance between them is just as obvious as the resemblance between all the coastal stations, where no month exceeds 8°.[1] In the innermost regions of West Greenland and South Greenland there is a zone with three months exceeding a mean temperature of 8° C., a zone which reaches the mid-fjord area in South Greenland (g), while Qôrnoq (d) has only one month with more than 8° C. Both inland stations have one month exceeding 10° C.

Because of lower heat in summer and the greater precipitation and amount of snow in the outer coastal regions many plant communities are here covered with snow well into the summer. These snow-patch communities have an extremely short vegetation period. The contrast between the coastal areas rich in snow and the inland poor in snow is very sharp in summer in the region east of Holsteinsborg. Both Nordenskjöld (1914) and myself noted complete absence of snow in the inland in summer. This also appears from Table 2 and the aerial photographs of the area which were taken in 1936 by the Danish Geodetic Institute. In July these only show streaks of snow along escarpments facing north at a height of about 1,000 m above sea level in the high part of the inland between the Strømfjord and the large lake Tasersiaq at the inland spit of ice off the Evighedsfjord. In the more northerly lower inland all snow has disappeared.

Unfortunately there is not yet any working up of measurements of air humidity from the two inland stations in existence. The small number of observations mentioned by Hobbs (1927) from the hinterland of Holsteinsborg only, as might be expected, shows that air humidity decreases in the direction of the inland ice. As there are no measurements from the Holsteinsborg region, nothing can be learnt about the size of the difference in air humidity between coastal and inland stations. The few measurements of the relative humidity made by me at the head of the Strømfjord show that it may decrease to values about 55 to 65 per cent. and on slopes facing south close to the surface of the earth even to between 25 and 40 per cent. As at the same time there are rather high temperatures (see p. 23), there will be fairly high and rather extreme deficiencies of saturation on the slopes facing south.

[1] The station Sukkertoppen (65° 30′) is an exception, as deviating from all other coastal stations along the west coast. The material from this station originates from a five-year observation period which may have included some particularly warm summers or be encumbered with other errors. Hence the best thing so far is to disregard these measurements from Sukkertoppen completely.

From the two inland stations we have exact data as regards sky conditions. There is a fairly great difference between the two stations, particularly as regards the percentage of days with low overcast conditions. Narsarssuaq all the year round has nearly 10 per cent. more days of this type. In winter there are most days with a clear sky or scattered cloudiness at the Strømfjord station, while in summer there are somewhat fewer of this kind of days here, as compared with Narssarsuaq.

B. Some Climatically Conditioned Main Features of the Plant Geography of South-West Greenland.

It is evident from what precedes that curves connecting points with the same degree of oceanity in West Greenland will not run parallel to the outer coast, but will take an oblique course, as they will approach nearer and nearer to the coast, the farther we get towards the north. Godthaab on l. 64° 11′ and Narsarssuaq on l. 61° 10′ thus are on the same line both as regards degree of humidity and difference between the warmest and the coldest month. An isohyet of 600 mm will from Godthaab take a south-easterly direction, but will reach the inland ice before reaching South Greenland. In my work (1938) a number of distributions of plants were demonstrated, the boundaries of whose areas, whether north or south boundaries, ran obliquely down through West Greenland, and the courses of these boundaries were explained on the assumption that the species in question required either an oceanic or a continental climate. As at that time, as a consequence of the lack of prolonged observations from the inland, the determination of the courses of the climatic curves must chiefly be based on theoretical considerations, the explanations of the plant distributions offered could not be said to be sufficiently well-founded. Now the available material from the two inland stations seems to offer a good foundation. However, not even the oblique courses of the boundaries were always equally well established. They were fairly well established in the Godthaab region, which had been fairly thoroughly investigated, as here, at all events, they must represent boundaries of frequency (boundaries of frequent occurrence) of the species, but in the region north of the Godthaab area they were unreliable because the inland was here rather an unknown country in a botanical respect. With reference to the floristic material collected by the expedition in 1946 from the head of the Strømfjord, which will be published in a later paper, it should here be remarked that the oblique courses of the area-boundaries in the hinterland of Holsteinsborg have been strongly supported by this material as regards practically all such species as, in consequence of their occurrence elsewhere, were considered to have an oceanic or continental tendency of distribution.

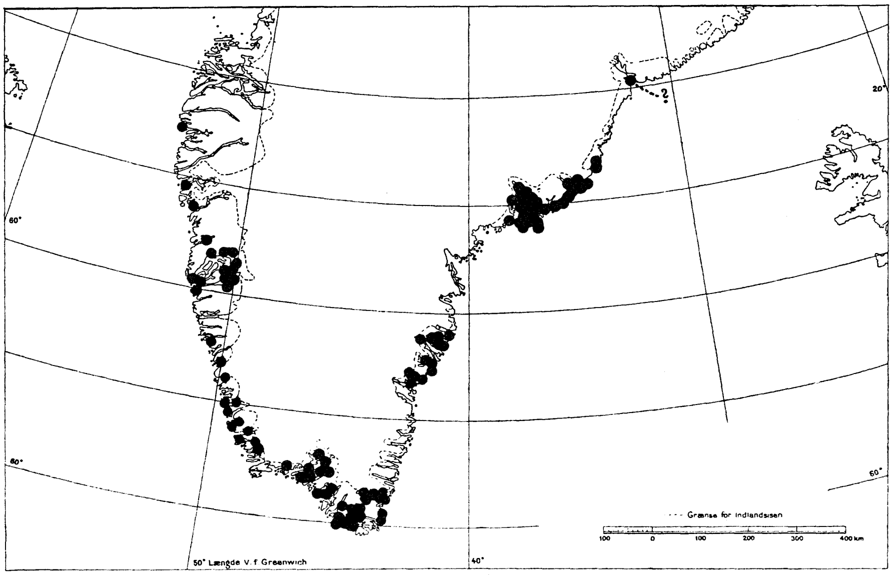

Fig. 5. Greenland range of *Thymus arcticus* Ronn. (according to Böcher 1938).

Thymus arcticus (see fig. 5) may be mentioned as a species with an oceanic tendency of distribution and an oblique boundary of occurrence from the interior of the Godthaabsfjord to Holsteinsborg on the coast. Particularly as a consequence of its great abundance in the Angmagssalik district with its oceanic character this species was considered oceanic. Now the establishment of the course of its northern boundary in West Greenland may contribute further to a decision of the question to what type of distribution it belongs. Another good instance of an oceanic species with an oblique northern boundary of distribution in West Greenland is *Cornus suecica* (fig. 80 in Böcher 1938). Other species which according to the material of maps in the same paper have oblique northern boundaries in the region between the Godthaabsfjord and Holsteinsborg are *Dryopteris Linnaeana*, *Polystichum lonchitis*, *Coptis groenlandica*, *Sedum annuum*, *Alchemilla alpina* and *filicaulis*, *Epilobium anagallidifolium*, *Pirola minor*, *Veronica fruticans*, *Gnaphalium supinum*, and *Phleum commutatum*. *Scirpus caespitosus* and *Potentilla Crantzii* have oblique boundaries of frequency. Finally there are a number of species which are found farther north in West Greenland, but which make for the coast from the interior along the above-mentioned oblique line. These species are *Cerastium cerastioides*, *Arabis alpina*, *Cassiope hypnoides*, *Loiseleuria procumbens*, and *Phyllodoce coerulea*. Besides these, the oceanic tendency of distribution of which it has been possible to corroborate through the work of the expedition, I may mention *Montia lamprosperma*, which behaves differently. This species was of fairly frequent occurrence at the head of the Strømfjord, but certainly mostly on the mountains. Otherwise its distribution was clearly oceanic.

There are not so many species with oblique southern boundaries withdrawing more and more from the coast. *Arabis Holboellii*, *Calamagrostis purpurascens*, and *Carex supina*, all with a continental distribution may be mentioned. Such species as *Dryopteris fragrans*, *Carex misandra*, and *Tofieldia coccinea* disappear from the outer coast in the Holsteinsborg region, but have not been found south of the large spit of inland ice behind the Evighedsfjord.

All things considered there is thus rather a considerable floristic decline at right angles to an oblique line from the interior of the Godthaabsfjord to Holsteinsborg. This decline is climatically determined. The ultimate number of species entering in this decline cannot be stated until the material collected by the expedition has been worked up.

The distribution of a good number of species is neither oceanic nor continental, but there are boundaries of area which in the first place seem to be dependent on the summer heat and the length of the vegetation period. In each of the three zones, the coastal, the mid-fjord, and the inland zone (Table 3), the values increase from the north towards the south, but the increase is far from being so pronounced as the one at right angles to the coast in the three investigated parts of Greenland. Hence the lines connecting points with the same amounts of summer heat will withdraw more and more from the outer coast the farther we get towards the north; but the angle of deflection in relation to the longitudinal direction of the coast will be very small, so small that the lines within minor areas will practically run parallel to the outer coast. *Alnus crispa*, *Salix uva ursi*, *Juniperus communis* var. *montana*, which are southern species and in the north make for the inland, and *Alopecurus alpinus*, which is a northern species and in the south makes for the coast, may be mentioned as particularly good examples of species which according to the material of maps in my work of 1938 and experience from the expedition in 1946 seem to follow such lines of summer heat.

As is well known, stations with a mean temperature in July of about 10° C. are considered to have a subarctic climate. Such a climate is generally combined with the occurrence of woods or wood-like scrubs. Both the Strømfjord station and Narsarssuaq reach about 10° C. in July, but only in the latter place there is a woodlike vegetation in the forms of birch scrubs 4 m in height. This peculiar fact makes a closer examination of the woodland limit in Greenland desirable.

A woodland limit may be conditioned by cold, oceanity (low summer temperature), by continentallity (drought), or a combination of some of the factors inherent in these concepts. The difference between the Strømfjord station and Narsarssuaq first of all manifests itself in the precipitation and the mean annual temperature, less in summer temperature. The northern limit of wood-like birch scrubs, as far as is known, is in the inmost part of the Arsuk Fjord at l. 61° 18′ in an area in which the precipitation is still high even in the inmost part of the fjords. Hence it is not immediately intelligible that the birch does not reach farther north in the interior of the country. The fjords north of the Arsuk Fjord are even deeper than this; hence the summer temperature in the innermost part of the country hardly decreases materially. According to HELLAND (1912) the birch would require a mean temperature of at least 7.5° C. during the period Juni—September, and even as far north as at the Strømfjord station the mean temperature of these months is about 7.6°. It should also be remembered that the birch—in the form of low shrubs, it is true—reaches the coastland in southernmost Greenland, which is cool in summer. Oceanity in the form of a cool summer may here set a limit to the wood, but not to the species. Thus it can hardly be the failing heat in summer which determines the northern limit of the birch in the innermost part of the country, and we should no doubt try to find the cause in the climatic continentality. From Europe it is known that the birch forms the woodland limit in the more oceanic parts, but in the east, in Northern Russia and Western Siberia, it is supplanted by *Pinus silvestris* and *Larix sibirica*, which here reach the woodland limit (see e. g. a survey in HEIN 1932). The question then arises whether the degree of continentality north of the Arsuk Fjord may be imagined suddenly to rise about the level critical to the birch. There are two facts which must here be taken into consideration. The great precipitation at Ivigtut in the middle of the Arsuk Fjord is no doubt orographically conditioned. The country here rises steeply to a height of 900—1400 m immediately at the outer coast, which will cause the precipitation to concentrate on a comparatively narrow zone. There is then a possibility that the inland north of the Arsuk Fjord comes to be in a "rain-shadow" behind the coastal mountains and the mountains in the south and hence becomes so dry that the birch can no longer hold its own. Another possibility which should be kept in mind is that the birch in Greenland represents a special biotype group of the *Betula pubescens* complex. This complex must have immigrated from Europe and during its migration towards the west it may have been exposed to a biotype elimination which removed the comparatively continental races (cf. BÖCHER 1938, p. 269).

The Greenland mountain ash, *Sorbus americana* var. *groenlandica*, is closely related to the birch as regards distribution, but it goes farther north, right up to Fiskenæs at l. 63° north. At Ivigtut it grows scattered in the luxuriant willow scrub behind the quarry and here reaches a height of nearly three metres.

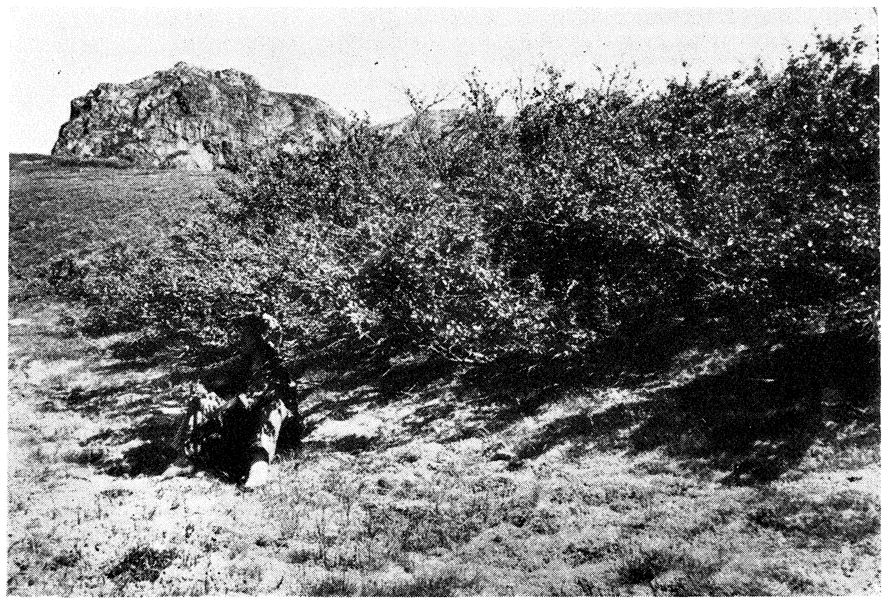

Fig. 6. Scrub of birches (collective species *Betula pubescens*) at the northern limit of the birch in West Greenland. Bjørnedal in the Arsuk Fjord. In the foreground dry lichen heath. D. Anfeldt phot.

The Greenland alder, *Alnus crispa*, also has an interesting and problematic distribution. On the whole it becomes frequent in the inland as the birch disappears. It does not by competition prevent the birch from forcing its way towards the north, for the two species are ecologically very different, the birch being found on rather dry, oligotrophic soil, the alder on moist, well-drained soil around the rivers (fig. 7). The account of the occurrence of the alder in the Arsuk Fjord near its southern limit given by Helms (1895) does not give a correct picture; for on south-facing slopes it reaches a height of nearly 300 metres above sea level, where it may form scrubs along the mountain brooks one metre in height, and it is capable of forming large, mostly two metre high scrubs in the Ivigtut valley, Grønnedal and in the North Country on the north side of the Arsuk Fjord. The alder thus here shows no sign of less vigorous growth or any particular degree of exclusiveness with regard to habitat.

Hultén (1944) gives an exact account of its total distribution, which supports the view formerly advanced by the writer, that the species prefers a subcontinental type of climate. The map of its distribution in Alaska shows that it is found here only in the central parts and near the Bering Strait, but is missing in the oceanic areas near the Bering Sea and the Pacific, where it is replaced by *A. crispa*

Fig. 7. Scrub of alder (*Alnus crispa*) along the river near Grønnedal in the Arsuk Fjord. T. W. B. phot. July 1946.

ssp. *sinuata*, which is also found on Kamchatka. It further appears from HULTÉN's account that in Northern Europe it is found from the river Mezen to the Ural in Northern Russia and from there farther east. Thus it starts in the very area where the birch decreases in importance. The parallel between Northern Russia and Greenland is obvious and supports the view that the alder and birch, when meeting in Greenland have climatically conditioned limits.

The northern limit of the alder in America fairly well follows the 10° C. July isotherm. In Labrador, however, it reaches l. 60° north. Here this isotherm thus has been crossed somewhat, a fact that completely corresponds to conditions in Greenland, where the species in the central parts of the Godthaabsfjord is found in an area with 8.5° C. in July. And it agrees with the fact that in the mountains of Alaska it forms dense scrubs above the timber line. The distribution in Greenland (BÖCHER *loc. cit.*, fig. 29), as mentioned above, offers a good example of a species which follows summer isotherms. In the north it tries to get farther and farther into the fjords, until it disappears completely north of the Evighedsfjord. The south-east limit of the alder in Sermilik in South Greenland cannot be a limit of summer heat as towards the south-east we just have the most subarctic parts of the country. In spite of its somewhat continental tendency this limit is hardly either conditioned by greater oceanity, for *Alnus* grows at Ivigtut in a climate richer in precipitation and with smaller mean annual range than the interior of the southmost fjords of Greenland. Hence there is a possibility that the limit is historically conditioned. If the locality at Sermilik represents a new colonization it might be supposed that an ice-tongue between Kap Thorvaldsen and Julianehaab had formerly cut off the species in the south. If so it ought to have had a refuge north and west of this ice-tongue. There is also a possibility that it has immigrated postglacially to West Greenland proper north of Kap Thorvaldsen and that its advance to South Greenland has been rendered difficult by suitable localities missing in the mentioned coastal area east of Kap Thorvaldsen, where the inland ice at present is separated from the sea only by a narrow low coast with skerries.

At the northern limit the alder stops at the great spit of ice on the level of the Evighedsfjord. We cannot, of course, exclude a historical explanation of the limit here either, but it seems much more natural to think of a climatic cause. In the country north of the Evighedsfjord there are numerous localities which ought to be edaphically suitable for the alder (Plate 1, fig. 1). No doubt it is warmer than at a height of nearly 300 metres at Ivigtut or a height of 200 metres in the middle of the Godthaabsfjord; thus a summer heat limit is out of the question. However, we have here reached an area where the degree of continentality increases highly and no doubt rather suddenly, as the mentioned highland spit of ice seems to stop many depressions coming from the south and to function as a screen from the rain to the regions situated more northerly, where the precipitation, as indicated above, decreases to an extremely low level. Hence it is probable that the northern limit of *Alnus* in Greenland is conditioned by the drought. If so, it is a continentality limit to a deciduous tree.[1]

KÖPPEN (1931, p. 129) has a survey of the relation between temperature and precipitation in which he shows that the boundary between wood- and steppe-climate is at stations the annual mean precipitation of which in cm is equal to twice the annual mean temperature +14 in regions with summer rain and +7 in regions with precipitation in all seasons. The boundary between steppe and desert is where the annual mean precipitation in cm is equal to the annual mean temperature +14 or 7, respectively, at stations with summer rain or precipitation in all seasons. The climate figures of the Strømfjord station show that according to KÖPPEN's survey the station is on the border between steppe and desert if the station is considered to have summer rain. In the same way Narsarssuaq comes to be in the woodland climate far from the steppe boundary. An imaginary station in the innermost part of the Godthaabsfjord from our experiences from Qôrnoq in the middle

[1] *Alnus crispa* according to A. E. PORSILD often reaches a height of 25 ft. in Alaska.

Fig. 8. The subarctic steppe dominated by *Carex supina* as the vegetation form covering the ground on loess deposits facing south at the head of the northern branch of Søndre Strømfjord (Loc. 5.). In the hollow through the middle of the picture an *Arctostaphylos uva ursi* heath, a few specimens of *Betula nana* and some shrubs of *Salix glauca* more than a metre in height. On the transition between the *Carex supina*- and the *Arctostaphylos*-community there are particularly many individuals of *Erigeron compositus*. T. W. B. phot. 3rd Aug., 1946.

of the fjord will have an annual mean precipitation of about 25 cm and an annual mean temperature of about —1.5 and will be on the border between steppe and wood, still provided that we have summer rain. Now there is no pronounced summer rain either at Narsarssuaq or in the Strømfjord (figs. 2—3), but something between summer rain and precipitation in all seasons, and if this is used as basis of a similar calculation where the boundary between wood and steppe will be at stations with the annual mean precipitation equal to twice the annual mean temperature +10.5, the head of the Strømfjord will be in the steppe climate, the head of the Godthaabsfjord in the woodland climate at some distance from the boundary of the steppe, and Narsarssuaq still a good distance from the steppe limit in the woodland climate. The climatic border values found elsewhere on the earth where woods are supplanted by steppes, thus seem to be reached in the inland south of the Søndre Strømfjord, and hence we must give special attention to the mentioned northern limit of *Alnus*, as the *Alnus* limit seems to be where there ought to be a continental woodland limit, i. e. a steppe limit; for the alder scrubs 2—3 m in height at the head of the Godthaabsfjord can hardly be termed woods. The question now arises whether the parts of the *Alnus* area in Greenland with the highest summer isotherms cannot in some places bear a more wood-like vegetation. In other places subarctic steppe areas will border on coniferous forest. This applies e. g. to the Northwest Territories of Canada (A. E. PORSILD 1937).[1] Hence one ought to try to plant northern proveniences of different conifers in the innermost part of the Godthaabsfjord, e. g. *Larix sibirica*, *Picea mariana*, and *P. canadensis*. The planting experiments being made in Iceland at present (see BJARNASON 1943) look so promising that there is any reason to try afforestation in the subarctic parts of Greenland, but probably only from the Godthaabsfjord and southwards. Such experiments will be of great plant geographical interest; for there is a possibility that the Glacial Periods drove away the conifers from Greenland and that these have not later immigrated to the subarctic areas, where conditions at any rate locally must be so that they may grow there.

The dominant vegetation on south-facing slopes and some level areas in the lowlands at the head of the Søndre Strømfjord is rather a varied steppe vegetation, mostly dominated by *Carex supina*. In fig. 8 one of the large steppe-covered slopes is seen. The soil consists of loess (cf. p. 25). On the smooth slope there are shallow oblong depressions, which have probably been formed by melting snow in spring. In these the steppe disappears and is replaced by heath and scattered willows. When there is locally somewhat greater humidity, the scrub vegetation gets the upper hand. On slopes facing south near more constantly moist beds of brooks there may be scrubs of *Salix glauca* to a height of 2.5 metres (fig. 9). The soil under these scrubs with the exception of the bed of the brook is very dry and does not at all remind of the soil on which the *Alnus* scrubs grow in more southerly parts of the country. Such

[1] On this area A. E. PORSILD writes (1937, p. 134): "Recent discoveries have shown that at least in Canada large parts of the 'barren grounds' are treeless not because of an inadequate summer temperature, but more likely because of insufficient precipitation during summer coupled with extreme dryness of the air during winter, and that they really should be classified as true prairies or steppes, and, therefore, strictly speaking, should not be included in the Arctic zone."—The annual precipitation is here below 7 inches, i. e. about 150 mm.

Fig. 9. Scrub of *Salix glauca* round a nearly completely dried-up bed of a brook on a slope facing south in Sandflugtsdalen ('the Sand-drift Valley'). In the background the entrance to Ørkendalen ('the Desert Valley') is seen, cf. fig. 1. T. W. B. phot. Aug. 1946.

a constantly moist soil through which water has been running was found on certain slopes facing north in the Ringsödal (Loc. 4). Here the willow scrubs in several places reached a height of 3 metres and contained growths of *Angelica archangelica* as tall as a man. The willow which in such places formed scrubs belonged to the *callicarpaea* type, which formerly was termed *Salix arctophila* × *glauca*. The vegetation is seen in Plate 1, fig. 1. There is hardly any doubt that in more southerly areas such places will bear alder scrubs.

From south to north the subarctic area in Greenland will include three fairly distinct plant geographical areas: the birch scrub zone, the alder scrub zone, and the steppe zone. In future investigations the boundaries between these zones must be investigated in more detail. Thus e. g. the northern limit of the subarctic steppe area is unknown. It probably nearly reaches l. 68° north.

3. MICROCLIMATE

During the expedition microclimatical measurements were made from July 30th to August 30th within a suitable area near the house used by the expedition as its basis during the stay at the head of the Søndre Strømfjord (Loc. 3, see fig. 1). Three self-registering thermographs were placed in three fairly different plant communities. Their heat-percipients were placed in the surface of the soil covered by 0.5 cm earth or humus and some withered leaves or straw. The three communities were composed and situated as follows: (1) Steppe vegetation dominated by *Calamagrostis purpurascens* and *Carex supina* with plenty of vigorous individuals of *Artemisia borealis*, *Arabis Holboellii*, and *Arabis Hookeri;* south exposure (30°), cf. Plate 1, fig. 2.—(2) Dry south-facing scrub soil under *Salix glauca* one metre in height. Loess covered by a layer of dry leaves; single specimens of *Juniperus communis* var. *montana*, *Cystopteris fragilis*, *Pirola grandiflora*, and *Campanula rotundifolia.*—(3) Half-moist *Rhododendron lapponicum* moor on level country at the bottom of the valley below the south-facing slope; greatly tussocky vegetation; soil rich in humus; the heat-percipient placed in the uppermost part of a tussock. On the moor many specimens of *Betula nana*, *Dryas integrifolia*, and *Equisetum arvense*, and a dense carpet of mosses, particularly *Drepanocladus uncinatus* and *Camthothecium nitens.*

Table 4 is a survey of the chief figures to be deduced from the thermograph curves. The mean temperature in the steppe is 15° C. or nearly 7° above the air temperature of August measured at the metereological station in the middle of the valley. The mean temperature of the rhododendron moor is more than 1° below the air temperature. There were 6 sunny days, on which the maximum temperature on the steppe exceeded 40° C., the highest value being 50.2°. The maximum temperatures in the surface of the soil on such days resembled those reached on Danish slopes facing south, but the minimum temperature was much lower, in two cases 0°, and one night with quiet weather and a clear sky after one of the warmest days, —0.5°. The widest amplitude of temperature measured for 24 hours was 50.3° C.

Table 4. The microclimate in the surface of the earth in the three plant communities at the head of the Søndre Strømfjord in August 1946 as compared with the macroclimate in the same month measured during a four-year period at the meteorological station in the same place. All values centigrade.

	Mean max.t.	Mean min.t.	Absol. max.t.	Absol. min.t.	Mean temp.	Highest day mean temp.	Lowest day mean temp.
1. South-facing steppe vegetation (*Calamagrostis-Carex supina*)....	29.1	5.2	50	—0.5	15	25	7
2. South-facing willow scrub (*Salix glauca*)........................	17.9	5.1	28	1.0	11	14	6
3. *Rhododendron* moor; tussocky, on level ground..............	11.9	2.4	20	—2.0	7	11	4
Air temperature.................	12.9	3.7	21.1	—4.4	8.3	15.6	1.7

In the month during which the measurements were made the weather was generally calm; only three days windy. There were about a fortnight with a clear sky or haze, 7 days with a cloudy sky without rain and with much sunshine, about 4 rainy days and 5 days with a completely overcast sky (the days represent the aggregate period for these weathers; there were in all 9 days with rainfall at some time or other). The weather was not extraordinarily fine; it showed nearly the same number of hours of rainfall as the average found for August at the weather station during the period 1941—45.

In the assimilating layers in the vegetation above the surface of the soil the temperature will by day be lower than in the surface. On the steppe the difference will be particularly great. Here the temperature down below leaves and straw is 20—30° C., while at the same time it is 40—50° C. in the surface, and raised a little higher to the uppermost part of the leaves and the straws the temperature shows a further fall to 13—15°. In the other communities the difference is not so great. All things considered the steppe has a comparatively warm microclimate with wide temperature oscillations, a fact which is closely connected with the dryness of the soil. The relative humidity of the air may decrease to 25—30 per cent. on warm days close to the ground. This implies a very high deficiency of saturation, which few species will stand. Time and again one sees dead willows or dead branches on willows in the surroundings of the steppe-covered expanses, undoubtedly due to the drought (Plate 1, fig. 2).

SØRENSEN (1941) has made more comprehensive series of microclimatic observations. It appears from his material of figures from the surface of the soil in a south-facing slope on Ella Ø in North-East Greenland that in the month of August (1932) a mean temperature of 13.4° C. is reached here (lowest day mean temperature 8.3° C., the highest 17.7° C.), while in the Strømfjord we reached a mean temperature of 15° C. and day mean temperatures varying between 7° and 25° C. The difference is not particularly great, and is no doubt connected with the fact that Ella Ø is situated more northerly and that the southward sloping of the vegetation was here 20° while it was about 30° in the Strømfjord. On Ella Ø SØRENSEN further found the temperature on slopes facing south to be 5—7° above the air temperature, a fact which is in good agreement with my observations. On August 1st he found a maximum temperature of 49° C. and a daily range of 46° C. These extremes are only a trifle below the figures from the Strømfjord mentioned above. The fairly great similarity between Ella Ø and the Strømfjord locality is undoubtedly due to the fact that both localities have a highly continental dry macroclimate. There are also many points of similarity in the flora and vegetation, even though Ella Ø does not belong to the subarctic area. It will undoubtedly be of interest to make similar series of observations in future in other places in Greenland, not least in the oceanic areas, from which only sparse observations are available.

4. SOIL

Besides the direct effect on plant life the climate has an indirect effect by having a share in determining the question what soil develops in a given area. In the most continental parts of West Greenland this effect is striking. We are here in an area of Archean rocks, the rocks of which, mainly gneiss, by weathering generally gives acid soils poor in chalk. In the maritime region near the Søndre Strømfjord, at Godthaab and Ivigtut, there are Archean rocks, and here, as usual, there are acid soils rich in humus, and often more or less podsolized. The vegetation is characterized by dwarf shrub heaths and *Salix herbacea* snow-patches. At the head of the Søndre Strømfjord also rather acid soils rich in humus may be found, but they only prevail on the north-facing mountain-sides, where the humidity of the soil is comparatively great. On the sunny sides in the lowlands there are generally circumneutral or basic soils, and in hollows without sufficient outlets, there are highly basic soils, in some places so basic that they may be termed alkaline. This may no doubt be ascribed to the climate which is extremely poor in precipitation. The leaching of the soil due to rainwater seeping down in climates rich in rainfall is practically excluded in a climate with an annual precipitation of only 100 mm. In such a climate, on the other hand, there is a possibility of a rising movement of the water in the soil, and this may give rise to accumulation of salts in the uppermost part of the soil, as the water evaporates either from the plant cover or the ground.

NORDENSKJÖLD (1914) was the first to ascertain the existence of loess-like deposits near the inland ice in Greenland. He discusses these deposits and states that they differ only on unessential points from what is generally termed loess. The chief difference from the deposit in continental West Greenland and loess from Austria and Hungary was observed in respect of the content of chalk and the cohesivity of the soil. In the European loess soils the content of chalk is fairly great and thus is supposed to cause their cohesivity to be greater than that of the Greenland soil. Now, NORDENSKJÖLD only mentioned one type of Greenland loess, which has 0.0 per cent. $CaCO_3$. The rather different pH values found in Greenland loess soils examined by me, are highly indicative of a very fluctuating content of chalk, and in Table 9 a loess soil from Greenland with 10.5 10^{-3} equiv. Ca per 100 g dry soil is mentioned. Thus there is no reason to insist on the importance of the content of chalk. This can hardly be used for a distinction between genuine loess and loess-like soil. There is no reason at all why the Greenland fine-grained soils should not be termed loess, but many of them are so loose that they fall under the concept of dust loess. Table 5 gives the figures of some examinations of the size of grains made with WAHNSCHAFFE's grids. For the soil samples collected by him NORDENSKJÖLD mentions an analysis of the size of grain made by ATTERBERG from which it appears that the Greenland soil is only a trifle larger-grained than the loess soils from Austria and Hungary. In Table 5 the Greenland loess is compared with a sand sample from the river plain and with two Danish sandy soils. The high percentage of fine-grained sand and dust sand (particles below 0.2 mm in diameter) in the Greenland river-plain sand is remarkable. It is this fine-grained material which forms the starting-point of the loess deposits. It is glacier mud which by the river at high tide in spring is deposited together with the more coarse-grained sand. Then the summer drought sets in, during which the wind may take hold of the fine particles and carry them to the mountain slopes, where they are deposited and detained by the vegetation. During the

Table 5. Percentage size of grains in loess soils from West Greenland compared with sandy soils partly from the riverplains there, partly from Denmark.

	Classes of sizes of grains in mm.				
	> 2	0.6–2	0.2–0.6	0.1–0.2	0.0–0.1
1. Loess, south-facing steppe vegetation, Loc. 3	0.0	0.2	3.6	9.7	*86.4*
2. Loess, south-facing steppe vegetation, Loc. 3	0.0	2.2	8.4	19.1	*70.3*
3. Loess deposit on rock in south-facing scree, Loc. 3	0.0	0.2	4.5	10.3	*85.0*
4. Loess deposit on rock in south-facing scree, Loc. 3	0.0	0.2	10.8	19.7	*69.3*
5. Sand from the river-plain, Sandflugtsdalen, Loc. 2	0.3	2.5	*43.7*	27.4	26.0
6. Sand from Køge Ås near Kværkeby, Denmark	0.6	5.9	*31.0*	*45.3*	17.2
7. Sand from Corynephoretum, Gilleleje, Denmark	0.0	1.3	*80.3*	16.3	2.1

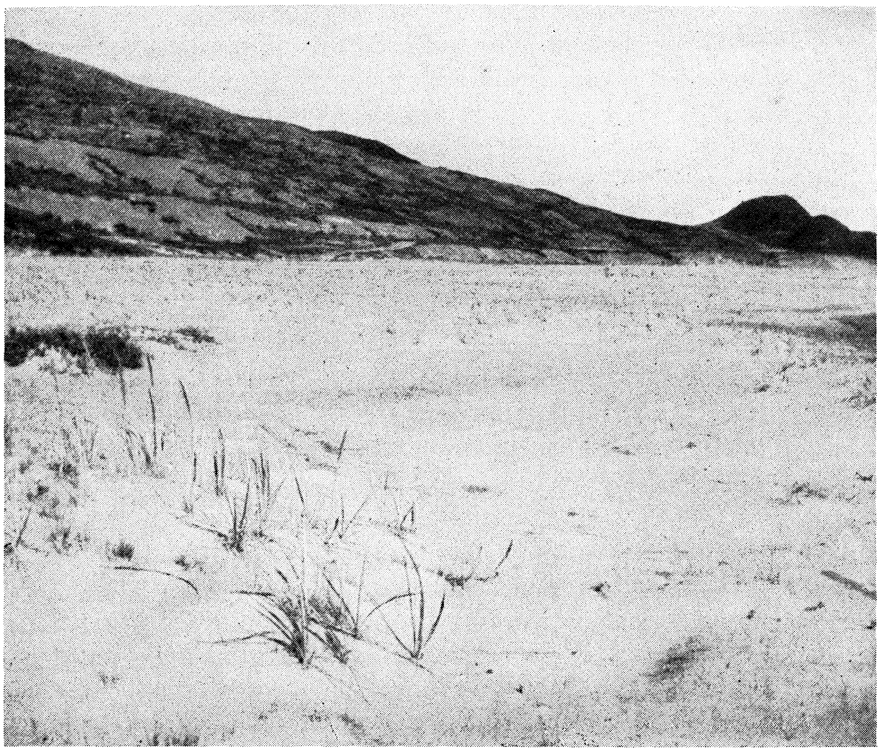

Fig. 10. Sandflugtsdalen west of Mount Keglen, which is seen in the background on the left. In the foreground the dry river-plain with beginning formation of dunes. In the drift-sand *Elymus mollis* and *Festuca rubra*. In the background on the left the south-facing mountain-side is seen, the lowermost part of which is completely covered with loess overgrown by *Carex supina* steppe. The dark spots are *Salix glauca*. T. W. B. phot. 31.7.1946.

excursion through Ørkendalen (cf. Böcher 1949, p. 12) a violent sand drift was observed during which sand was deposited in dune- and desert-like areas along the river-plain, but further it was seen that the finer particles were raised high and deposited on the mountain-sides. The moss-carpet under the heath vegetation on the north exposures of the valley was powdered a faint grey with dust, and a dust was raised when one walked through summer-dry bogs. The dust which is deposited on the moor- and heathland will add basic particles to the raw humus, and this is probably a chief cause of the fact that heath- or moor-soils in the most continental part of West Greenland are not very acid (see below). It is a peculiar fact that this dust is allowed to remain. Here, again, the small amount of precipitation is decisive: frequent violent showers of rain would quickly wash the dust into the rivers and carry it into the fjord. But the small number of showers in summer can hardly do more than bind the dust in the place where is has settled. The loess soil often bears a sparse half open vegetation. Hence there is nothing strange in the fact that the content of humus is very low. In Sample 1 (Table 5) there was a loss of ignition of 1.8 per cent., in another sample 2.2 per cent. During the sifting of the soil samples it was clearly seen that the brown humus particles were particularly found in the classes of grain sizes above 0.2 mm. In samples 2 and 4 (Table 5) no small part of the coarser particles were of organic origin.

While the supply of loess is of great importance to the soils formed in the lowlands nearest to the inland ice, it is of no importance farther away from this. The large steppe-covered loess escarpments leave off nearly where the fjord divides into a northern and a southern branch. At Itivdlínguaq we did not see a vestige of loess. The fact that we still found some of the most basic soils in this area shows that the supply of loess is not the only factor that makes the soils basic in the continental parts of the country.

The chemical investigations of the Greenland soils, include analyses of the hydrogen ion concentration, the electrical conductivity in a soil suspension made under special experimental conditions (the conductivity value p. 29) and the amount of potassium and phosphorus accessible to the plants. In seven selected soils besides the exchangable amount of potassium also the exchangable amounts of sodium, calcium, and magnesium were investigated.

A. The Hydrogen Ion Concentration.

The hydrogen ion concentration was determined electrometrically and at the examination of the most alkaline soils the glass electrode was used. A total of 43 samples from the maritime region and 86 samples from the interior of the country near the Søndre Strømfjord were examined. Both in the coastal areas and the inland the samples originate from widely different plant communities. All the samples from the coastal areas show acid reaction, while more than one third of the samples from the interior are basic and more than half are circumneutral or basic. A fairly good number of the samples with acid reaction from the inland originate from alpine areas and the rest chiefly from north-facing slopes in the lowlands. See further fig. 11.

The difference in *p*H on southern and northern exposure in the interior is very striking. 10 very different soil samples from the sunny, dry slopes in the lowlands showed *p*H values between 6.4 and 8.4, whereas 6 samples from north-facing slopes in the lowlands showed *p*H values between 4.8 and 5.4.

Table 6. The hydrogen ion concentration in soil samples from different plant communities (*p*H and specific acidity).

		Mean[1]	Range
9 dwarf shrub heaths in the coastal region	*p*H	4.5	4.1— 5.35
	Spec. Acid.	338.0	800.0—45.0
6 *Betula nana-Ledum decumbens* heaths inland, northern exposures, lowland	*p*H	5.1	4.8— 5.4
	Spec. Acid.	87.0	160.0—40.0
6 *Cassiope tetragona* heaths, inland, northern exposures, alpine	*p*H	5.4	5.2— 6.45
	Spec. Acid.	37.0	63.0— 3.5
9 *Rhododendron* or *Vaccinium* heaths, inland, lowland, not north-facing	*p*H	6.1—6.2	5.8— 6.9
	Spec. Acid.	7.12	16.0— 1.25
9 different *Dryas integrifolia* communities, inland, highland and lowland	*p*H	6.4—6.5	5.9— 9.2
	Spec. Acid.	3.45	12.5— 0.006
9 steppe communities on southern exposures in the lowlands inland	*p*H	7.2	6.7— 8.9
	Spec. Acid.	0.62	2.0— 0,013
9 different communities on shores of lakes without or with defective outlets, inland	*p*H	7.4	6.7— 8.6
	Spec. Acid.	0.41	2.0— 0.025

[1] At the calculation of the mean values expressed in *p*H the various *p*H values have first been converted into specific acidity values (WHERRY 1920).

With a single exception the soils in question from north-facing slopes are heath soils with a fairly high content of humus. If these heath soils (particularly from *Betula nana—Ledum decumbens* heath) are compared partly with seven heath soils from the coastal areas, partly with eight heath soils from other places than northern exposures in the lowlands in the continental parts of the country (e. g. *Rhododendron lapponicum* heaths, but not *Dryas* heaths, which hold a special position), it is seen that they come to hold and intermediary position as regards the hydrogen ion concentration (Table 6).

The *Dryas integrifolia* communities inland are very heterogeneous and are found on soils being from slightly acid, through neutral to highly basic. The steppes (i. e. *Carex supina* or *Calamagrostis purpurascens* sociations and similar vegetation types) have developed on neutral-basic soils, and this also applies to the shore vegetation in the depressions where lakes without any outlet or with an outlet which only functions for a short time, presumably in spring, have developed; cf. Table 6.

B. Electric Conductivity (the Conductivity Value).

By the determination of the electric conductivity in watery suspensions of soil a measure of the amount of easily soluble salts in the soils in question is obtained. The analyses of the electric conductivity of the Greenland soils were made by a method described by STEENBJERG (1946). 25 g air-dried soil was transferred to a 300 ml Erlenmeyer flask, after which 225 ml distilled water was added. The flask was placed in a STOHMANN shaker, which was then set rotating for an hour. After the shaking the flask was left to stand for about half and hour in order that the larger soil particles might be precipitated. Before the measuring

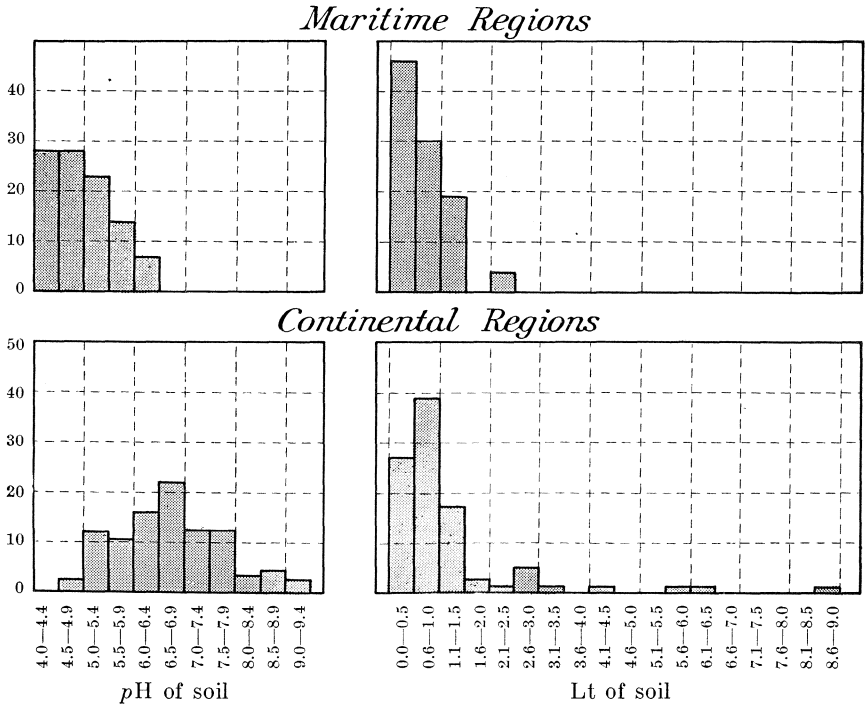

Fig. 11. Variation in hydrogen ion concentration (pH) and electrical conductivity (Lt) in all soil samples from coastal areas in Greenland and from the continental area at the head of the Søndre Strømfjord. Ordinate: percentage frequency.

the electrodes were washed in a small amount of the suspension. The resistance capacity of the electrodes used was determined as described in KOHLRAUSCH & HOLBORN (1916). At the measuring of the resistance of the deposits alternating current was used in order to avoid polarization. All measurings were made at 20° C. For practical reasons the specific conductivity, which is inversely proportional to the resistance measured, was multiplied by 10^4. The resulting figure is termed the conductivity value (Lt).

In fig. 11 there is a survey of the conductivity values partly in the 26 soil samples from the plant communities of the coastal areas in West Greenland, partly in 79 samples from the continental area at the head of the Søndre Strømfjord. The distribution is in good agreement with the distribution of the *p*H values. The most important difference between the groups of soils appears in the fact that in the coastal areas there are most soils in the group Lt 0.0—0.5, while in the continental parts there are most soils in the group Lt 0.6—1.0. Another important difference appears in the occurrence of soils with extremely high Lt values, the highest value in the coastal areas being 2.4. The soil in question originates from a vegetation in the skerries at Godthaab, where *Rubus chamaemorus* was abundant on a spot behind a rock which was often used as a look-out by birds. The soil must be supposed to have been manured both by birds and by sheep seeking shelter behind the rock. The next highest value from the coastal areas (a soil sample from a meadow with luxuriant high perennials, rich in species) is 1.4. In the continental area Lt values up to 8.7 have been found. The highest values measured, of about 6 or more, are so high that we may rightly term the soils in question saline. A conductivity value of 6 indicates that there are about 10—12.000 kg salt per hectare at a depth of about 20 cm.

The conductivity is very different in the soils from the different groups of plant communities and also varies highly within the groups; but this is only due to the fact that the groups are so large that they come to include many ecologically different communities. Still we see that on the whole the conductivity values are distributed in the same way as the *p*H values (Table 7). Among the groups of communities particularly the *Dryas* vegetations are very different. Here there are partly more or less open *Dryas* "fjaeldmarks" on gravelly windswept soil in the mountains, which may show a very low conductivity value

Table 7. Electric conductivity in soils from different groups of plant communities.

	Lt	
	Mean	Range
14 dwarf shrub heaths and open "fjaeldmarks" in the coastal region	0.5	0.2—1.3
23 dwarf shrub heaths and open "fjaeldmarks" inland (not *Dryas* communities)	0.8	0.3—2.8
10 *Dryas integrifolia* heaths and open "fjaeldmarks" inland	1.6	0.3—5.7
9 steppe communities on southern exposures in the lowlands inland	1.1	0.6—2.3
11 shore communities on lakes with defective outlets or without outlets, inland	2.9	0.6—8.7

(0.3), partly dense *Dryas* "heaths" in the lowlands close to the salt lakes, and here the Lt may even reach 5.7. Such *Dryas* communities have a floristic composition very different from the alpine "fjaeldmarks".

According to STEENBJERG (1946) the conductivity values in Danish farming soils generally are about 0.5, while in the more heavily manured soils from greenhouses, market-gardens, and ordinary gardens, they are higher, mostly about 1.5. Some conductivity values from heavily manured soils may even reach 60. Already at values about 3 damaging effects begin to appear as far as cultivated plants are concerned. The majority of the Greenland soils from the continental area are thus above farming soils as regards the conductivity values and a good number have Lt values above the level where a damaging effect may be ascertained on plants in market-gardens.

Electric conductivity in soil suspensions has been investigated by numerous workers, among them TERÄSVUORI (1930), FURLANI (1930, 1931), REPP (1939), ANDERSSON & WALDHEIM (1946), and WALDHEIM (1947). Unfortunately the various workers have not used quite the same methods. There is particularly a difference in the applied proportion between water and soil. FURLANI used 40 g soil with 100 ccm water, ANDERSSON & WALDHEIM 1 portion of soil with 4 portions of water, and STEENBJERG (cf. above) 1 portion of soil with 9 portions of water. According to STEENBJERG (*loc. cit.*) the conductivity is changed considerably with a change in the proportion between soil and water. If the proportion is changed from 1:9 to 1:4.5 the conductivity will be approximately 1.3 to 1.6 times as high. Hence it is not possible to compare the values of the various workers direct in the same way as *p*H measurings. Still, the below comparison offers certain facts of interest.

		Spec. conductivity ($\varkappa$ (20°) 10^4)
Poor sandy soil (*Corynephorion*) (ANDERSSON & WALDHEIM)	Sweden	0.05—0.2
Sandy soil (*Koeleria glauca—Rhacomitrium*) (ANDERSSON & WALDHEIM)	Sweden	0.2—0.6
Sand rich in chalk (*Tortella inclinata*) (ANDERSSON & WALDHEIM)	Sweden	0.4—0.9
Circumneutral soil (*Phascion*) (WALDHEIM 1947)	Sweden	0.2—2.6
Alpine plant communities (FURLANI 1930)..	The Alps	0.2—2.8
Soils on the saline lake Neusiedlersee (FURLANI 1931)	Austria	ab. 2.4—24.0 (a single saline soil with *Salicornia:* values from ab. 60 to 85)

It is easily seen that the distribution of the figure for the conductivity in this series of different groups of plant communities is in good agreement with the one appearing from Table 7. The Greenland soils, however, on the whole have comparatively high Lt values; for it should be remembered that the values for the Greenland soils as a consequence of the degree of dilution of the suspensions are to be multiplied with about 1.3—1.6 in order that we may fairly compare them with the figures given in the above list.

C. Special Investigations of Some Selected More or Less Saline Soils and of Salt Crusts on the Ground.

In the depressions in the ground where saline soils have developed there were sometimes, as mentioned above, *p*H values above 9 and very high conductivity values. Even though the conductivity values in themselves give some information it is of great interest, just as regards the saline soils, to examine how great a part of the ion exchange capacity of the soils is held by sodium and potassium ions. With a sufficiently comprehensive saturation with Na and K we get

Table 8.

Soil No.	Vegetation and locality	*p*H	Lt	T_K	10^{-3} equiv. K per 100 g air-dried soil
1.	*Puccinellia* cf. *groenlandica*[1] steppe on southern exposure, loess. Loc. 3	7.3	0.8	10.0	0.40
2.	*Puccinellia deschampsioides*[1], shore of Lille Saltsø, Loc. 7	7.8	1.1	7.0	0.28
3.	*Scirpus pauciflorus* on the shore of Lille Saltsø, Loc. 7	7.2	1.5	12.0	0.48
4.	*Scirpus pauciflorus* on the shore of alkaline lake near Strømfjordshavn, Loc. 5, cf. p. 49	7.9	3.5	13.0	0.52
5.	*Puccinellia deschampsioides-Plantago maritima* (*juncoides*) near salt lake on the harbour road, cf. p. 52	8.4	4.3	24.0	0.96
6.	*Primula stricta-Lomatogonium* near Store Saltsø, Loc. 7	7.8	2.9	15.0	0.60
7.	*Gentiana detonsa-Puccinellia deschampsioides*, Store Saltsø, Loc. 7	9.1	2.6	54.0	2.16

[1] *Puccinellia groenlandica* and *deschampsioides*, two new species which will be described in a paper by Dr. TH. SØRENSEN.

Tab

Soil No.	Vegetation and locality	Lt	T_K
1.	*Calamagrostis purpurascens* steppe vegetation on southern exposure, loess soil cracked in polygons, cf. fig. 13. *Gentiana detonsa* and *G. aurea* frequent. Loc. 3	1.8	15.0
2.	*Puccinellia deschampsioides-Cetraria cucullata* sociation. Ground slightly sloping towards the east beside small lake on river terrace. *Plantago maritima (juncoides)* frequent. Loc. 2	0.8	15.0
3.	*Scirpus pauciflorus* sociation on shore of small, slightly alkaline lake near the large round lake farthest east in Loc. 5. Loamy soil covered with algae	1.0	7.0
4.	*Carex capillaris-Distichium inclinatum* sociation on the shore of Lille Saltsø, Loc. 7. In the vegetation amongst others *Primula stricta* and *Gentiana tenella*	0.6	6.2
5.	*Calamagrostis purpurascens* sociation rich in *Braya humilis* and *Lomatogonium rotatum* beside small alkaline pond near the harbour road, Loc. 3	6.4	13.0
6.	*Juncus arcticus-Distichium inclinatum* sociation on moist, somewhat loamy sand on the river plain in Sandflugtsdalen, Loc. 2. *Lomatogonium*, *Primula stricta*	1.2	5.8
7.	*Dryas integrifolia-Artemisia borealis* sociation on dry soil cracked in polygons and covered by salt crusts. Total cover by the vegetation 60 per cent. Itivdlinguaq	5.7	43.0

[1] Calculated on the basis of Danish analyses the soil samples being too small for this determination.
[2] Approximately 0 or 100.

genuine alkaline soils, the *p*H values of which are about *p*H 9. At a further increase of the percentage saturation with Na and K we get extremely alkaline soils. Near the saline Neusiedlersee in Austria *p*H values up to 9.7 have been measured in the most saline soils (POZDENA 1932, REPP 1939) and on the Hungarian alkaline steppe Hortobágy *p*H values of more than 10 have been measured on dry saline soils (*Camphorosma ovata* association), and the same applies to damp saline soils (*Puccinellia distans-limosa* association), where the *p*H values ranges from 9.5 to 10 (R. v. Soó 1935).

Out of the soil samples from Greenland seven were sufficiently large to admit of close examinations of exchangeable Na, K, Ca, and Mg. Of these samples one originates from the steppes of the south-facing slopes, while six were from the salt-lake basins or the river valley, between Loc. 2 and Loc. 3. The results of the examinations appear from Table 9. In Table 8 a number of soil samples from similar places are listed. In these only the potassium value (T_K), the exchangeable

	10^{-3} equiv. per 100 g air-dried soil						S	T $(S+H^{+})$	Percentage degree of saturation	Percentage of Na + K of T (S + H)
:. ly .	H (acc. to clayey soil)[1]	H (average, sandy soil clayey soil)[1]	S: K	S: Na	S: Ca	S: Mg				
	0[2]	0[2]	0.60	2.42	10.51	4.23	17.76	17.76	100[2]	17.0
	2.34	1.69	0.60	1.31	4.20	4.60	10.71	12.40	86	15.4
!	5.16	4.94	0.28	0.33	9.89	0.32	10.82	15.76	69	3.87
›	2.69	2.07	0.25	0.69	2.09	1.27	4.30	6.37	68	14.8
;	1.99	1.31	0.52	1.83	9.36	0.68	12.39	13.70	90	17.2
	0[2]	0[2]	0.23	3.30	17.78	6.00	27.31	27.31	100[2]	12.9
	0[2]	0[2]	1.72	7.60	26.16	2.16	37.64	37.64	100[2]	24.8

amount of potassium, the conductivity value and the *p*H have been investigated.

In one of the soil samples (No. 7, Table 9) a percentage sodium-potassium saturation of 24.8 was found. This soil thus is a genuine saline-steppe soil, an alkaline soil. It originates from a *Dryas* vegetation on a flat tongue of land near the large lake at Itivdlínguaq in the middle of the Strømfjord. The place where this vegetation was found is seen in fig. 12. The lake itself is alkaline, but its water was not analyzed more closely. The outlet to the Itivdleq Fjord seems small in relation to the size of the lake and the size of the basin drained through this outlet (cf. fig. 2 in Böcher 1949). The *Dryas integrifolia* vegetation covered about 60 per cent. of the ground. Besides *Dryas* and *Artemisia borealis* there was much *Gentiana detonsa* in the plant cover, and in some places *Braya linearis*, *Ameria sibirica*, *Saxifraga aizoides*, *S. oppositifolia*, and *Kobresia bipartita.* The soil was cracked in polygons and partly covered by a thin white crust. I tried cautiously to detach the crust

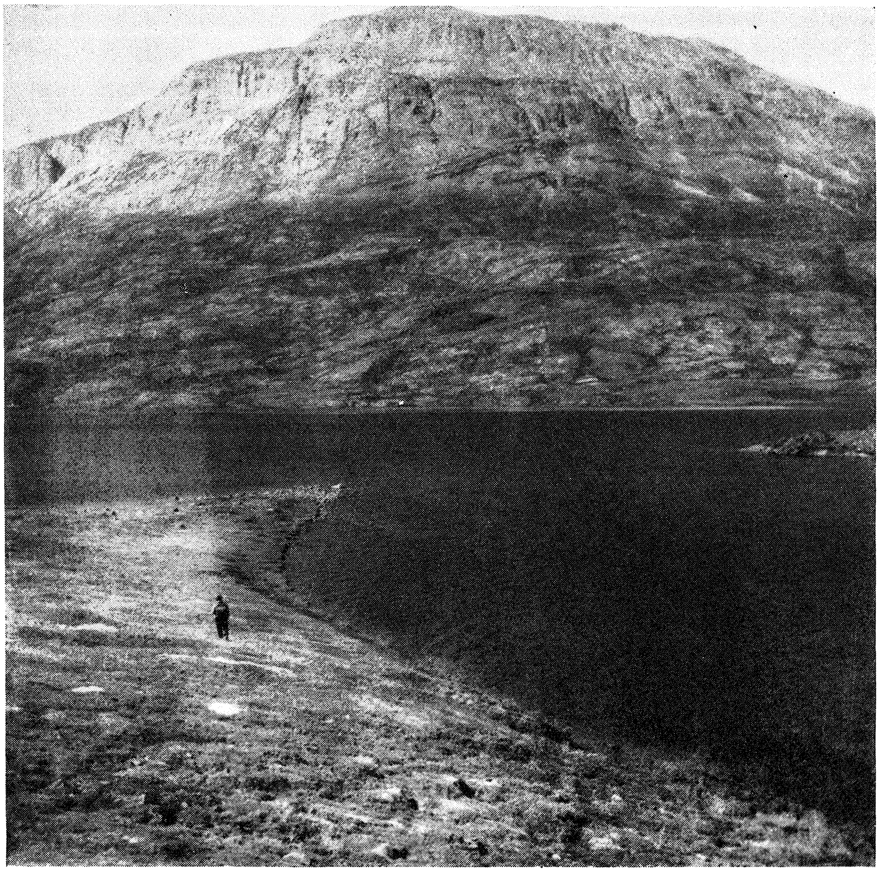

Fig. 12. The lake at Itivdlínguaq midway in the Søndre Strømfjord. On the small tongue of land in the foreground behind and to the left of the person there is a *Dryas integrifolia* vegetation on genuine alkaline soil (cf. Table 9, no. 7). The mountain Qaqortorssuaq (1300 m in height) in the background. The light colour on the upper part of the mountain is probably due to the sporadic vegetation which is a consequence of the drought and the alpine conditions. T. B. W. phot. July 24th, 1946.

with a knife and took a sample of it. The sample was analyzed by Mr. WERNER CHRISTENSEN of the Geological Survey. Extraction with hot water dissolved only 1.9 per cent. of it, the crust thus being in the main insoluble in water. Addition of acid gave rise to a vigorous development of air, which made it probably that the crust contained calcium- or magnesium-carbonates. An analysis showed that the sample contained 9.5 per cent. CO_2. A suitable quantity of the sample was treated with a small excess of hydrochloric acid and in the solution calcium and magnesia were determined (Table 10).

The water extract was very strongly coloured by dissolved organic substances and was very difficult to filter. Hence an extraction was

Table 10. Analysis of salt crust. Itivdlinguaq.

	Percentages	Equivalents / 100 g	
CO_2	9.5	0.43	
CaO	11.2	0.40	0.435
MgO	0.7	0.035	

made with ether in 10 g of the soil sample. The extraction was made with hot ether for four hours. After evaporation of the ether a yellowish, greasy rest was left, which amounted to about 1 per cent. of the sample.

The amounts of CaO and MgO found are nearly equivalent with the content of CO_2; hence the crust consists of $CaCO_3$. Below the crust there was in the soil 26.16 10^{-3} equiv. of exchangeable Ca per 100 g soil (see Table 9). Hence the chalk crust has most probably developed in connection with an upward movement of water in the soil as a consequence of an intense evaporation and drought.

From the environs of Store Saltsø in the ice-margin area (see p. 53, Plates 2—4, and fig. 1) at the head of the fjord there were among a number of highly alkaline soils two soil samples of special interest. One originates from a slightly south-facing slope covered with a *Puccinellia deschampsioides* sociation close to the lake. The soil consisted of loess with undecomposed subfossil rests of moss (see p. 54). *p*H was measured at 8.6 and the conductivity value at 8.7, which corresponds to an amount of salt in the soil of 15—20 tons per ha in the uppermost layers of the soil (i. e. per ab. 2500 tons soil). The other sample originates from a spot with dense abundant *Gentiana detonsa* together with the *Puccinellia* species. Here, too, the soil consisted of loess and dead rests of moss. The vegetation was found on the lowermost moss-loess terrace beside the lake and is seen on Plate 2. Here a *p*H of 9.1 was reached and an extremely high potassium value (54, Table 8). The exchangeable amount of potassium constitutes 2.16 10^{-3} equiv., thus more than that of the alkaline soil from Itivdlínguaq. It is probable that this soil, as regards the percentage potassium-sodium saturation, resembles the Itivdlínguaq soil, even though the conductivity value is somewhat lower (2.6).

On the terraces of loess and moss surrounding the lake on two sides, salt crusts were found in several places. Of these crusts a sample was collected which contained other substances than salt. 40.5 per cent. of the sample dissolved in hot water (Table 11).

A salt lake was also found near Loc. 3 (see the mention on p. 52). Near this lake a soil sample was collected in a *Puccinellia-Plantago maritima* sociation on the dried-up shore. The *p*H, Lt and T_K values are high in this place, too (Table 8, no. 5). Near the place where this sample was taken, salt-crusts were found in a similar vegetation or in places completely devoid of vegetation. Of these crusts a sample was also collected, which was scraped off cautiously with a knife, but still became rather impure so that only 15.3 per cent. dissolved in hot water (Table 11).

In Table 11 the salt-crust from Ilivilik mentioned by PJETURSSON (1898) is included. It was found on the talus slopes down towards a small stream which had cut into a broad terrace beside the Ilivilik Lake. The analysis was made by WINTHER and converted by WERNER CHRISTENSEN. According to WINTHER about 20 per cent. of the crust dissolved by boiling. By evaporation a crystalline mass of salt was left, which was analyzed with the result rendered in Table 11.

The comparison of the material in Table 11 shows a fairly good agreement between the three salt crusts. Sodium is the most important metal in all the three crusts. Among the anions SO_4 is absolutely dominant in all crusts. While there are equal amounts of Ca and Mg in the sample from Ilivilik, the proportion between these substances is very different in the two other samples.

Besides the parts soluble in water the two samples of salt crusts collected by me no doubt contained some calcium- and magnesium-carbonates which were difficult to bring into solution. The crust from Store Saltsø contained 3.7 per cent. CO_2 corresponding to 8.3 per cent.

Table 11. Parts of salt crusts soluble in water from continental parts of West Greenland.

	Percentages of substances soluble in water			Equivalents / 100 g		
	Talus slope of Ilivilik (PJETURSSON)	Store Saltsø, Loc. 7[1]	Salt lake on harbour road, Loc. 3[1]	Talus slope at Ilivilik (PJETURSSON	Store Saltsø Loc. 7	Salt lake on harbour road, Loc. 3
Cl..........	9.1	10.2	3.0	0.26	0.29	0.084
SO_4	53.3	55.2	64.6	1.11	1.15	1.35
				Anions: 1.37	1.44	1.43
Ca	2.2	0.49	2.9	0.11	0.024	0.15
Mg	2.1	5.0	0.45	0.17	0.41	0.037
Na	20.9	22.2	25.6	0.91	0.97	1.11
K	4.3	3.8	1.7	0.11	0.097	0.043
				Cations: 1.31	1.50	1.34
	91.9	96.9	98.3			

[1] Analyzed by WERNER CHRISTENSEN.

calcium- and magnesium-carbonate, while the crust from the salt lake on the harbour road had a CO_2 content of 0.5 per cent. and hence very little carbonate, which was difficult to bring into solution.

In Table 9, Sample 5 is the one which in respect of percentage saturation with Na-K in the ion exchange complex approaches nearest to the sample from Itivdlínguaq. No. 5 originates from the beach of a

Fig. 13. Surface of the loess soil on southern exposure at the head of the Søndre Strømfjord. The soil is cracked in numerous small more or less regular polygons. The vegetation is extremely sparse. M. Skytte Christiansen phot. Aug. 1946.

small pond within main Loc. 3. The pond probably was nearly without any outlet, but its situation had been disturbed by the road built by the Americans. Farthest below on the beach were narrow zones with *Puccinellia deschampsioides* and *Plantago maritima*, which were not here analyzed in much detail, next followed a dry *Calamagrostis* vegetation on southern exposure, with the rare *Braya humilis* and *Lomatogonium*, *Gentiana tenella*, and others. Lt here was 6.4 and the Na-K percentage in the exchange complex was 17.2. Samples were collected from the shore of Lille Saltsø, too (see p. 49). Here the Na-K percentage was only 14.8, but this lake is not very saline, either.

Sample 6 in Table 9 is of special interest. It originates from the river plain at the head of the Sandflugtsdalen not far from the place seen in fig. 10. The vegetation, in which *Juncus arcticus* was abundant, was found in an oblong depression in the sandy plain close to the south-facing slope of the lowermost terrace surrounding the river plain. The sand was somewhat loamy and showed a relatively high content of exchangeable Ca (17.78 10^{-3} equiv. per 100 g soil) and a *p*H value of

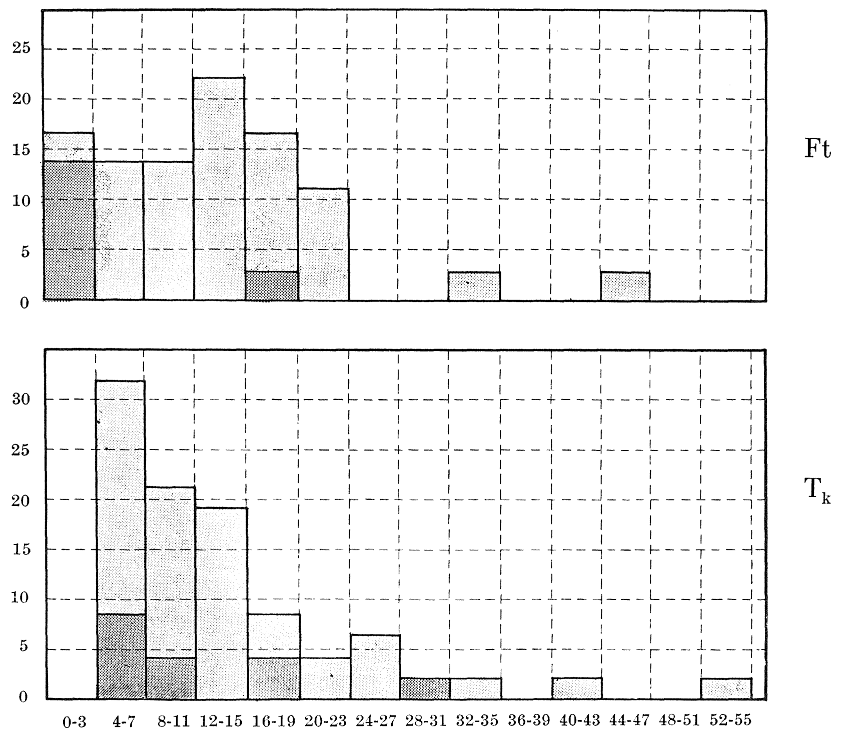

Fig. 14. Variation of phosphoric acid values (Ft), above, and potassium values (T_k), below, in a number of Greenland soils. Ordinate: percentage frequency. Dark parts of columns are samples from the maritime parts of West Greenland.

8.8. The soil in question has been deposited by the river, which comes from the inland ice. This would seem to indicate that the river conveys fairly great quantities of particles rich in chalk, which e. g. as a component of the loess might benefit the vegetation in all the places where the loess remained. However, it is not probable that all the chalk should originate direct from the river. The place is close to the foot of a slope, and hence it is possible that water is here pressed out slowly, water which will evaporate when reaching the surface and hence give rise to accumulation of salts, in particular chalk, in the surface of the soil.

Finally there is reason to mention Sample 1 in Tabel 9. It originates from a loess soil on a steep south-facing slope. It is very remarkable that the percentage of Na-K in the ion exchange complex is 17 and *p*H reaches 8.9. The very warm and dry microclimate (cf. p. 22), however, may explain this, as it is very probable that upward movements of the water and a consequent accumulation of salt in the soil occur in such places. A sample of a crust which covered the ground in some parts of the dry slope, only contained 0.6 per cent. salts soluble in hot water and 1.7 per cent. CO_2 corresponding to 3.8 per cent. $CaCO_3$. On some of the spots where the formation of crusts was most in evidence, *Plantago maritima* suddenly became fairly predominant in the very sporadic desert-like vegetation.

D. The Potassium Value (T_k Value).

The potassium value (T_k) states the content in the soil of exchangeable potassium ion in 10^{-3} equiv.s per 2.5 kg soil. If the weight of the soil in one hectare to a depth of 20 cm is evalulated at 2500 tons, T_k at the same time indicates the content of potassium in kilo/equiv. per hectare. In investigations of farming soils the potassium value plays an important role, see Bondorff & Damsgaard-Sørensen (1937), Damsgaard-Sørensen (1942). In the former of these papers investigations of the T_k values in 6,000 Danish farming soils are mentioned. Values from about 1 to 20 were found, most values being about 3.5, the mean value being 5.45. A T_k value of about 14 is rare in farming soils, but frequent in highly manured market garden soils, the average value of which is about 15 and which reach maximum values about 50. In Damsgaard-Sørensen (1942) a number of analyses are mentioned, amongst others analyses of some Icelandic bog soils. Their potassium values are high, 17, 27, 29, and 31. Some samples from Danish shore localities manured with sea-weed according to my own unpublished investigations have very high potassium values (about 36). It is known from experiments with cultivated plants that low potassium values about 1—4 indicate potassium deficiency in these plants. Unfortunately the limits of potassium deficiency in species growing wild are unknown, thus also in Greenland species; hence nothing definite can be said about the importance of the potassium values from the Greenland soils. However, it is remarkable that all the potassium values from Greenland (47 in all, see fig. 14 below) are above 4, while those of most Danish farming soils are about 3.5. This seems to indicate that the vegetation in such natural soils completely uninfluenced by culture will hardly meet with potassium deficiency. It is peculiar how slight the difference is between heath- and steppe-soils from Greenland as regards potassium value. 10 samples from different dwarf-shrub heaths had an average potassium value of 10.8 (ranging from 5.2 to 16.0), while the samples from the steppe-soils (11 samples including 4 from *Kobresia myosurioides* sociations) had an average potassium value of 14.8 (4.9—32.0). The two highest potassium values from Greenland (43, 54) originate from the saline soils mentioned above. A single soil from a steppe vegetation reaches the value 32; then follows a soil from a very luxuriant vegetation at Ivigtut dominated by high perennials (*Streptopus amplexifolius* sociation), where the value 31 was reached. The lowest potassium values were found in an alpine open *Dryas* vegetation on gravelly soil (4.6) and an alpine *Cassiope tetragona* heath (5.2), both from the inland, and a snow patch vegetation (*Cerastium cerastioides* sociation) from the outer coastal area (5.2). It is interesting that in dwarf-shrub heaths in the maritime areas it is possible to find values right up to 16.

The potassium value is of no decisive importance to the distribution of plants and differences of vegetation in Greenland. Like the phosphoric acid value it may no doubt within the same group of plant communities be of importance as a cause of minor differences between the vegetation units. Two heaths occurring side by side at Ivigtut may be mentioned as examples. One was a *Betula glandulosa-Hylocomium Schreberi* sociation on a soil with a fairly prolonged snow cover, the other a *Betula glandulosa-Cladonia rangiferina-alpestris* sociation with plenty of *Juncus trifidus* on drier soil which probably became bare of snow earlier. The former soil showed a potassium value of 16 and a phosphoric acid value of 3.6, the latter a potassium value of 6.8 and a phosphoric acid value of 0.4. Here both phosphoric acid value, potassium value, content of humus, humidity of the soil and the time of snow covering decrease from the former to the latter community. It is difficult to decide what is most important; but so great differences in phosphoric acid values and potassium values can hardly be without importance. It should be added that the *p*H values were measured at 4.3 and 4.5 and the conductivity values at 0.6 and 0.4 in the two heath communities.

E. The Phosphoric Acid Value (Ft Value).

The phosphoric acid value (Ft) is a measure of the amount of phosphate in the soil accessible to the plants. On the determination of the F_t values see BONDORFF & STEENBJERG (1932) and BONDORFF & DAMSGAARD-SØRENSEN (1942). For Danish farming soils the majority of F_t values are below 12, only a few highly manured soils reach high values. The 36 Greenland soils investigated as compared with these have comparatively high phosphoric acid values (cf. fig. 14 top). Very little is known of the relation of species growing wild to the phosphoric acid value. To judge from a preliminary report on the relation of Danish species of weeds to the nutrients of the soil (INGV. PETERSEN 1946), the Ft value is of great importance for the occurrence of these species. *Equisetum arvense* and *Polygonum aviculare* thus occurred most frequently in soils with Ft from 2 to 5.6, while e. g. *Galium aparine*, *Veronica persica* and *hederifolia* were most frequent on soils with Ft above 6.4. The lowest Ft values from Greenland originate from heaths and snow patches in regions of a maritime climatic type. The two highest Ft values from Greenland originate from two peculiar places in the interior. One (44) is from the soil under a moist *Carex microglochin* vegetation. This was found in the innermost part of the Søndre Strømfjord on bluish, greasy clay deposited by the big glacier-fed streams, where these rivers fall into the head of the fjord and the current decreases so much that a fine-grained clay may be deposited. The next highest Ft value (34) originates from a soil from the top plateau of a mountain where there was a peculiar dyke of amphibolite of diabasic origin and mica schist. The open fjaeldmark flora on the weathered gravel on this dyke was different from that on other fjaeldmarks in the region, a number of specimens of the very rare high-arctic *Lesquerella arctica* being found here. The *p*H value was 7.4 and Lt 0.7. The weathering which took place led to the formation of a rust-like soil, which, when it was carried down to a vegetation-covered area farther down by the streams formed by the melting snow from the mountains in spring, killed the vegetation nearest to the streams. The poisonous effect observed her is probably due to a content of magnetic pyrite in the rocks of the dyke. The compounds rich in sulphur and iron at the weathering gives the rock its rusty appearance. When the sulphides are released they will under certain circumstances, e. g. in streams of melted snow, be oxidized into sulphuric acid. In some rock samples collected we did not find any particularly high content of magnetic pyrite or other minerals which may have such an effect, but as the rock need not have the mineral evenly distributed, it is very conceivable that there may be greater quantities of it elsewhere, and the weathering of these areas then may be able to lead to a production of sulphuric acid great enough to kill the vegetation. The samples collected originated from the fjaeldmark area where *Lesquerella* was growing and from where the soil rich in phosphate originated. The coating on the stones according to an analysis made by Miss Marie Louise Mauritzen, B. Eng., contained much iron and calcium and fairly great quantities of phosphate, and further sulphate, magnesium, and ammonium, but no sulphide or chloride. Hence both the high phosphoric acid value and the high *p*H value are easily explained.

5. THE LAKES

I. A. D. JENSEN's finding (1889) of a salt lake, Tarajornitsoq, in the interior end of the Søndre Strømfjord and his remark on p. 62, that according to statements by the Greenlanders there were more salt lakes in the area, of course made the expedition search for salt lakes here. The aerial photographs left us by the Geodetic Institute here were of great value. All lakes which in the photos seemed to have bare, stony or clayey shores without any connected vegetation, were more or less basic, and among those investigated after a preceding study of the aerial photographs there were, indeed, four which might be characterized as salt lakes. The boundary between such saline lakes and the others obviously was quite blurred. In order to make a closer examination of the various types of lakes a number of samples of water were collected. These samples were collected in 500 ml bottles with patent stoppers, with one exception two bottles from each lake so that there was in all 1 litre available for the analysis.

The hydrogen ion concentration of the water was determined on a rough estimate in Greenland a few hours after the sampling. A universal indicator (GURR's Universal Indicator) was used, which allows of a *p*H determination with an accuracy of 0.5.

The rest of the chemical examinations were made at the Geological Survey of Denmark by Mr. WERNER CHRISTENSEN. The analysis of the water was made according to "Danish standard", though because of the fairly small amounts of water available it was necessary to use less water in each analysis than is the rule.

The lakes examined naturally fall into four groups.

A. Lakes with Acid Water Poor in Salt.

Lakes with *p*H values between 5 and 6 were observed in numerous places in the large vegetation area at the head of the Søndre Strømfjord. *Potentilla palustris* (*Comarum palustre*) proved to be very suitable as a guiding species. This species was found in acid lakes, only, and was already missing in lakes with circumneutral water. The acid lakes examined

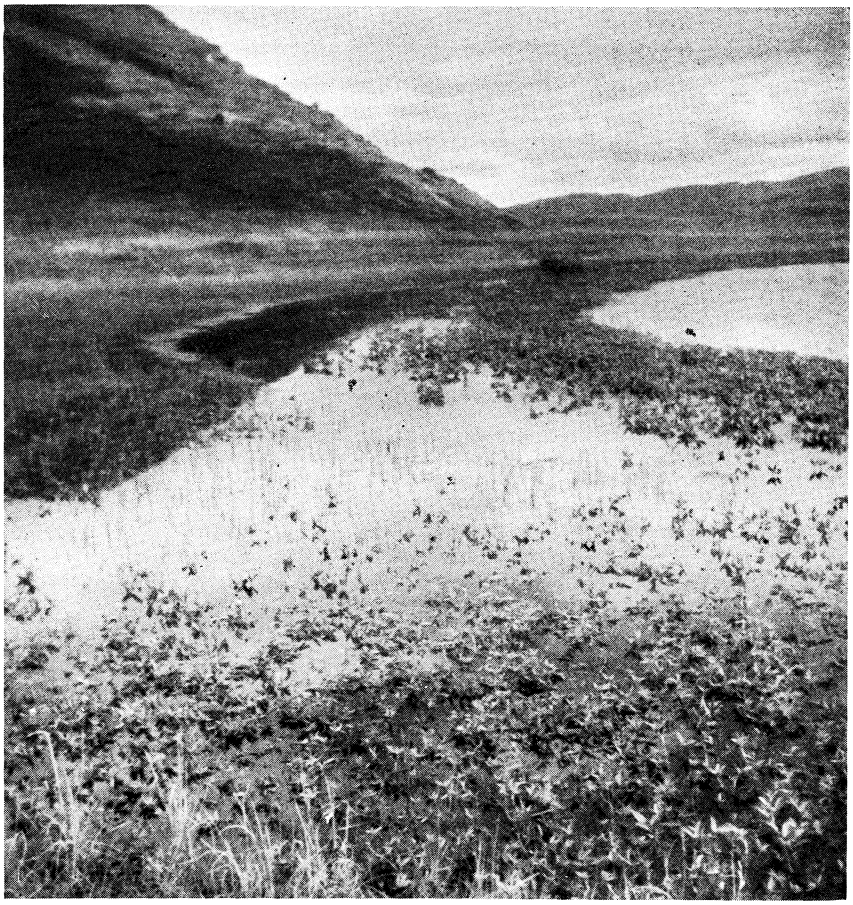

Fig. 15. Acid lake in the neighbourhood of Strømfjordshavn (Loc. 5). The outer fringe of marshy plants consists of *Menyanthes trifoliata*, the inner fringe (in the foreground and on the left) of *Potentilla palustris*. *Hippuris vulgaris* is seen in the middle of the picture between the two zones. T. W. B. phot. Aug. 1946.

in the continental area were all small and with a fairly luxuriant, generally bog-like marginal vegetation. The water was yellowish or brownish because of the content of humus. All lakes had outlets, at any rate in the greater part of the year. During the drought in the height of summer there was in some cases no running water in the beds of the brooks draining off the lakes; but the beds were moist and the soil at the bottom of them completely saturated with water. Obviously there was always a slow downward movement of water. After some showers at the end of August 1946 there appeared at once running water in these beds of brooks. Fig. 15 shows a typical acid lake, rich in humus, with a *p*H value of about 5.5. On the situation of this lake see further p. 49.

Table 12. Acid lakes poor in salts (Loc. 3).

	The Menyanthes lake (400 m above sea level)		Kløftsøerne (The ravine lakes) (300 m above sea level)		Small lake with Sphagnum margin (400 m above sea level)	
	*p*H 5–6		*p*H 6		*p*H 5	
	mg/l	Millival/l	mg/l	Millival/l	mg/l	Millival/l
HCO_3^-	64	1.05	37	0.60	29	0.48
SO_4^{--}	2	0.04	2	0.04	0[1]	0.00
Cl^-	12	0.34	7	0.20	4	0.11
Anions...		1.43		0.84		0.59
Ca^{++}	11	0.55	7	0.35	3	0.15
Mg^{++}	5	0.38	4	0.33	2	0.16
Na^+ (calculated)	12	0.50	4	0.16	6	0.28
Cations...		1.43		0.84		0.59
SiO_2	7		10		9	
Consumption of oxygen, O_2	26		38		40	

[1] Qualitatively.

Table 12 shows three water analyses from this type of lake. The water is very poor in salts. The contents of bicarbonate, sulphate, and chlorine is very poor as compared with those of the alkaline lakes. The content of calcium is higher than the content of magnesium, which is an important difference from the highly alkaline lakes in the area. All the three samples showed a great consumption of oxygen, and hence were rich in organic matter. Qualitative examinations showed that none of the samples contained nitrate or ammonium. The contents of iron and manganese were so low that they must be characterized as traces, only. The alkaline and circumneutral lakes had similar contents of these substances and nitrate and ammonium.

B. Lakes with Circumneutral Water Poor in Salts.

Within this group there are two subgroups, one of which (a) is closely related to the preceding one.

(a) Near Keglen in Sandflugtsdalen (Loc. 2) and in a few other places there were lakes with some water rich in humus the *p*H value of which was considerably higher, about 7, and where *Potentilla palustris* was missing. But *Menyanthes trifoliata* was abundant here, too. The surrounding heath rich in *Rhododendron lapponicum* would seem to indicate that the water oozing into the lake was less oligotrophic. In

Fig. 16. Lake Taserssuatsiaq at the head of the Søndre Strømfjord. Oligotrophic, neutral lake with poor vegetation. On the south-facing mountain-slope there are low *Salix glauca* scrubs or dry *Betula nana* heath (dark parts) and dry steppe-like vegetation (open *Artemisia borealis-Carex supina* sociation, dense *Carex supina* soc. and *Kobresia myosurioides* soc.; light parts). T. W. B. phot. 30.7.1946.

the water sample from this lake (Table 13(a)) there was a trifle more calcium than in the samples from the acid lakes, but this difference is too small to allow of any conclusions being drawn from it. The correspondence with the acid lakes is very great, except for the reaction. Also conditions of outlet are as in these. The correspondence with the Menyanthes lake (Table 12) is particularly great, *Potentilla palustris* also missing and the content of calcium being comparatively great there.

(b) The second subtype is the oligotrophic circumneutral lake with clear water. This type was particularly found in alpine areas and in some of the large lakes in the lowlands, these being lakes through which large brooks or small rivers flow and which have always plenty of water. A good example of a large lowland lake of this category is Taserssuatsiaq at the head of the northern branch of the Søndre Strømfjord. According to Table 13 it has an extremely low consumption of oxygen (low contents of organic matter) and it is very poor in plankton. Further, according to

Table 13. Neutral lakes poor in salts in the lowlands.

	a. Lake near Mt. Keglen (Loc. 2)		b. Taserssuatsiaq (Loc. 7—8)	
	*p*H 7		*p*H 7—7.5	
	mg/l	Millival/l	mg/l	Millival/l
HCO_3^-	67	1.10	43	0.70
SO_4^{--}	6	0.12	1	0.02
Cl^-	9	0.25	6	0.17
Anions:...		1.47		0.89
Ca^{++}	13	0.65	11	0.55
Mg^{++}	7	0.54	4	0.33
Na^+ (calculated)	6	0.28	0	0.01
Cations:...		1.47		0.89
SiO_2	13		11	
Consumption of oxygen, O_2	38		5.1	

computations, it contains no alkali, whereas the acid lakes and the lake at Mt. Keglen according to the same computations contained very little sodium bicarbonate. There is, however, a fairly great factor of uncertainty in the case of such small amounts of salt when there are comparatively small quantities of water available. Fig. 16 shows a view of the shore of Taserssuatsiaq. It is characteristic of lakes of this type, as of the alpine oligotrophic neutral lakes, that any proper marginal vegetation of marshy or aquatic plants is missing or that it is very sparse.

C. Lakes with Rather Saline, Alkaline Water.

This type is fairly frequent and is found in all such lakes of which the size of the inflow, the evaporation, and the form of the terrain prevent the lake from having any outlet proper. In most cases there may be a slight flow-off at high water in the spring. In one case the water might ooze through the soil in the surroundings of the lake (see below). The *p*H value from this type of lake is between 7.5 and 8.5. Botanically the lakes belonging here are characterized by the absence of *Menyanthes* and *Potentilla palustris* and a great reduction of the *Potamogeton* flora, which now nearly exclusively consists of *Potamogeton filiformis*. The lakes are approaching to being characteristic saline lakes and may be recognized by the fact that their shores are more or less bare with open vegetations of scattered plants, among which *Primula stricta* and *Pinguicula vulgaris* are typical. There are also small patches of *Scirpus* *pauciflorus* and *Leptobryum pyriforme*. Near some of the lakes *Plantago maritima* is found. Lakes of this type were not found in the uplands. The lake most highly situated was at 300 m above sea level.

Two samples from lakes with water of this type were examined in more detail. Their situation appears from the map fig. 1.

(a) Small alkaline lake near Strømfjordshavn (Loc. 5, Br, ab. 200 m above sea level). The lake is situated between low rounded-off mountains in a small basin a few kilometres west of the harbour at the head of the fjord. Of the two lakes examined this one clearly is most closely related to the circumneutral lakes, even though it is a far cry from it to these. The vegetation, too, is distinct from that of circumneutral lakes; but still there is here, particularly along the western side a dense shore vegetation, consisting of, amongst others, *Hippuris* and *Eriophorum Scheuchzeri*. In other places there is a beach of loamy, clayey material, with, amongst others, some *Scirpus pauciflorus* sociations (*p*H 7.9), A spit of land jutting into the lake is fairly bare of plants (Fig. 17).

In the same valley system there were a number of other small lakes, which, as distinct from the alkaline lake, had outlets. They had completely vegetation-covered shores and acid water. Most closely related to the alkaline lake were two lakes with *p*H about 6, brown water and great quantities of *Menyanthes*. They had outlets in the form of small brooks running in a north-westerly direction to a valley-system with somewhat larger lakes. East of these there was then a lake with a somewhat greater outlet, here towards the east to the lakes immediately at Strømfjordshavn. Here there were both *Potentilla palustris*, *Menyanthes*, and plenty of *Sphagnum* along the shore (fig. 15), and *p*H was ab. 5.5. The lake system in this valley area very strikingly seems to show the connexion between the chemical conditions of the water and conditions of outlet.

(b) *Lille Saltsø* (Loc. 7 see fig. 1). This name was given to a small lake the water of which had a slightly bitter taste and was highly basic. It is situated about 100 m above sea level near the head of the northern branch of the Søndre Strømfjord. The lake basin is divided from Lake Taserssuatsiaq by the mountain ridge seen in fig. 16. In the direction towards the fjord the lake is bordered by the broad, sloping, nearly quite bare beach. Above the beach (in the background on the right in fig. 18) there are few metres with a nearly level heath vegetation; then the ground suddenly falls off towards the fjord. The steep north-west-facing slope immediately west of the lake is covered with different types of heath; but on a single smaller area the vegetation is dominated by *Poa glauca* and *Equisetum arvense*. It seems that there was here a rather unsettled soil in which there might now and then be some very small landslips, and the local occurrence of *Equisetum arvense* clearly indicated an effect of a slow upward movement of water. The water oozing out quite slowly here might very well be imagined to originate from the lake the surface of which perhaps was raised 40—50 m above the place.

Fig. 17. Alkaline lake with nearly bare shores near Strømfjordshavn; *p*H ab. 8. In the foreground a rather dry *Betula nana-Ledum decumbens* heath rich in lichens. In the background a south-facing mountain-side with a steppe-like vegetation. T. W. B. phot. Aug. 3rd, 1946.

There was never any running water, anything like a spring. The lake actually was without any outlet at all. It must be extremely small

Table 14. Rather saline, alkaline lakes.

	a. Lake near Strømfjordshavn Aug. 3rd.		b. Lille Saltsø July 30th		b. Lille Saltsø Aug. 20th	
	*p*H 8		*p*H 8–9		*p*H 8–9	
	mg/l	Millival/l	mg/l	Millival/l	mg/l	Millival/l
HCO_3^-	317	5.20	397	6.50	397	6.50
SO_4^{--}	2	0.042	0	0.00	2	0.042
Cl^-	154	4.34	169	4.77	169	4.77
Anions:...		9.582		11.27		11.312
Ca^{++}	25	1.25	27	1.35	30	1.50
Mg^{++}	41	3.37	61	5.02	62	5.10
Na^+ [1]	114	4.96	113	4.90	65	2.83
K^+ [1]					44	1.13
Cations:..		9.582		11.27		10.56
SiO_2	15		8		13	
Consumption of oxygen, O_2	20		53		50	

[1] Na and K were calculated in the two first samples, while the contents of these ions were analyzed in the sample from August, 20th.

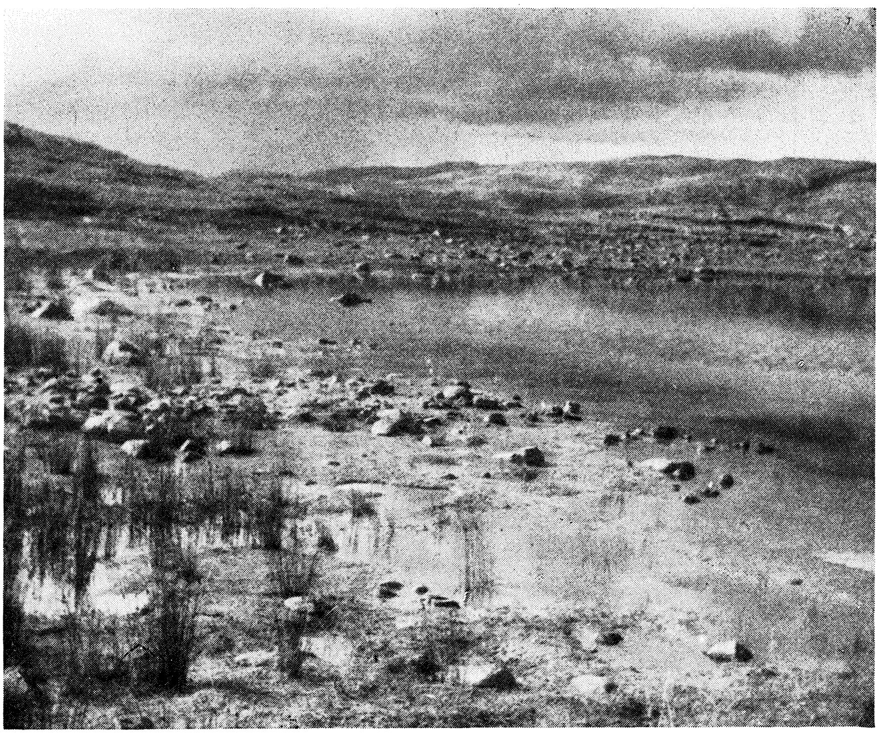

Fig. 18. The western end of Lille Saltsø at the head of the northern branch of the Søndre Strømfjord. In the height of summer the beaches are nearly bare with a very scattered vegetation. On the left *Juncus arcticus* is seen in the loamy clay between the stones on the beach. A shower of rain is approaching from the west. T. W. B. phot. Aug. 20th, 1946.

quantities of water which are removed by downward movement of the water through the soil. Evaporation is decidedly of greater importance. The broad beach which was bare in the height of summer (fig. 18) would, indeed, be narrower in the spring; but there was nothing to indicate that the surface of the water could rise so high that the water would run down the mountain-slope into the fjord.

On the shore of this lake amongst others *Puccinellia deschampsioides*, *Plantago maritima*, *Primula stricta*, *Scirpus pauciflorus*, and the pretty little *Ranunculus Cymbalaria* were seen. This last-mentioned plant was found only along the north side, and here particularly beside the stones jutting out of the loamy soil on the beach (*p*H 7.8). While on the north side there were rather bare beaches, there was along the south side, particularly near the western end of the lake, a short stretch with an *Eriophorum Scheuchzeri* sociation rich in moss, and behind this a *Calamagrostis neglecta* sociation also rich in moss. Inside these two zones there was an area where the moss, particularly *Drepanocladus* *aduncus* formed carpets, but in the height of summer it seems liable to dry up and in several places it had begun withering.

The water analyses from the two lakes (Table 14) show a high content of bicarbonate ion. They are on the point of containing sodium bicarbonate. The content of chloride is rather high. No sulphate or only traces were observed. The content of magnesium is high here as compared with the content of calcium. The consumption of oxygen shows that the contents of organic matter are high in Lille Saltsø and fairly high in the lake at Strømfjordshavn. Lille Saltsø was very rich in plankton; it practically teemed with yellowish-red daphniae. Two water analyses differing insignificantly from each other originate from this lake. In the sample from August 20th, the contents of sodium and potassium were determined, whereas they were otherwise calculated in relation to the other ions. According to WERNER CHRISTENSEN the alkali determination as compared with other analyses shows a comparatively high content of potassium in proportion to the content of sodium. It should, however, be noted that the amount of water available for the determination of alkali in this case was not so large as could be desired.

D. Lakes with Saline, Highly Alkaline Water.

Lakes with saline water so alkaline that the *p*H value rises to about 9 (8.5—9.5). Here three lakes belong of which I have seen two, only. This type of lake is hardly common at the head of the Søndre Strømfjord, but there are undoubtedly a number of lakes of this type; for the terrain gives many possibilities of the formation of closed basins without outlets. The three lakes are situated at similar heights above sea level as those just mentioned.

(a) Small lake beside the harbour road (Loc. 3; marked "salt" in fig. 1). This lake is most similar to those just mentioned. The *p*H value is a little below 9. In the lake there is a macroscopical vegetation, some scattered individuals of *Potamogeton filiformis* being found there. There is no water analysis from the lake. The water had a slightly salt and somewhat bitter taste. The topographical conditions of this lake are fairly interesting; hence they will be mentioned in some detail.

About half-way between Strømfjordshavn and the head of the northern branch of the fjord there is a low mountain-ridge immediately north of the road between the harbour and the air-base. Behind the ridge there is a valley running parallel to the fjord, and in it there are three lakes, the westernmost of which is the saline lake just mentioned. The easternmost lake was full of water at the end of August, but showed signs of drying-up. It had a slightly developed vegetation of aquatic plants (*Potamogeton filiformis*); the *p*H value was measured at ab. 7.5.

At a great height of the water this lake will be able to give off a little water to the middle lake the surface of which is lower. This at the end of August was completely dried-up. The bottom of the lake was cracked in polygons. From this dried-up lake there was no outlet. In the more westerly basin in the valley then followed the salt lake, on the nearly bare beaches of which *Plantago maritima*, *Braya linearis*, and *Puccinellia deschampsioides* were found, to mention only the most characteristic plants. Around the lake there were a couple of low terraces, which testified to a drying-up by stages having taken place. The uppermost terrace was on a level with the bottom of a ravine, which from the basin with the lakes ran south. At a greater height of the water in the basin the water would be able to run through the ravine and farther down to the fjord. This had no doubt taken place at an earlier period. A small pond filled with water north-west of the salt lake, which was raised a little above the latter and had a slight outlet to it, had completely vegetation-covered banks. In two cases there are thus in this valley water-bearing lakes emptying into the somewhat lower basins, where a drying-up takes place and in one case there is a clearly observable, although so far rather slight accumulation of salts. The salt crusts from the ground beside this lake have been mentioned on p. 38. Around the saline lake a drying-up of *Drepanocladus aduncus* moss carpets was observed in several places. The dying and dead moss was mixed with loess that had drifted to the place and a dust was raised when somebody trod on it.

(b) Store Saltsø, Loc. 7, fig. 1, Plates 2—4, and fig. 9 in Böcher (1949). This name ('Great Salt Lake') was given to a lake, the water of which had so bitter a taste, at the same time slightly salt, that it was unpalatable. The *p*H value of the water was measured at somewhat above 9. The lake was found at the bottom of a pot-like depression between the Taserssuatsiaq valley and Ørkendalen (see Plate 4 and description in Böcher, *loc. cit.*). The water from the terrain surrounding the pot-like depression mainly runs down into these valleys. There is no water-course, not even any dry bed of a brook leading down to the salt lake. It obviously receives only water oozing out into it from the shores or the bottom. The height of the water would have to rise more than 30 m before there would be any outlet. In the lake itself no macroscopical vegetation was observed, only plankton and a very few microscopical sedentary algae (amongst others an *Oedogonium* species). Round the lake there was a distinct terrace formation. There are four distinct terraces, of which the erosion slope of the lowermost one is recent, under development. The circumference of the lake is, if anything, triangular, its beaches being in the south, west, and north-east. The north-facing shore on the south side of the lake has completely vegetation-covered terraces. The vegetation is dominated by luxuriant *Rhododendron-Dryas* heath (fig. 19). Along the east-facing shore the terraces are particularly broad and at the same time very peculiar by being composed of loess and dead moss, which by KJELD HOLMEN has been identified as *Drepanocladus aduncus*, particularly a submersed form of this species. On Plates 2 and 3 fig. 1 these peculiar deposits are seen. They mostly consist of alternate layers of mainly loess and mainly moss. The depth of the layers varies between 0.5 and 2 cm. The moss, is yellowish or reddish-brown and lends a strange tint to the whole deposit. The moss even in deep-lying strata was fairly well-preserved. The plants, if anything, were only a little broken. Often the leaves remained on the stems. Obviously there was no putrefaction. In some places the deposit contained large quantities of small bright scales, rests of daphniae. There were also well-preserved ephippia of daphniae. An analysis of a salt-crust from the surface of the lowermost terrace is mentioned above (p. 38); further an analysis of the loess soil, which here showed a *p*H of 9.1 and a high content of salts, is found in Table 8. A sample of the mossy deposit was examined more closely (Table 15). It appeared that 40 per cent. (weight) belonged to an order of magnitude of grains below 0.1 mm. This order of magnitude chiefly consisted of inorganic particles, i.e. loess. In the other classes there were, with an increasing size of grains, increasing contents of organic matter. The material passing through the 0.6 mm grid is mainly of organic origin, consisting of rests of moss and daphniae. The *p*H value was somewhat influenced by the admixture of moss.

Table 15. Percentage size of grains and contents of organic matter in moss-loess deposit from Store Saltsø.

	Classes of sizes of grains in mm			
	> 0.6	0.2–0.6	0.1–0.2	0.0–0.1
Size of grains, weight per cent.	14.0	26.2	20.1	39.7
Loss of ignition per cent.	47.3	35.4	27.3	7.2
*p*H				7.8
	7.1 (all classes together)			

It should be noted that *Drepanocladus aduncus* does not at present live in the lake nor on its shores. At the west end of the lake there is erosion in the moss-loess deposit and the stems of moss hang down into the water when the loess is washed away, thus coming to look like small threads of red algae. Conditions of the growth of the moss are known from the description of Lille Saltsø and the lake on the harbour road. The species lives partly submersed in the marginal vegetation of the

Fig. 19. Store Saltsø (Loc. 7). View from the south shore towards the west. Two completely vegetation-covered terraces are seen. The vegetation mainly consists of *Betula nana*, *Rhododendron lapponicum* and *Dryas integrifolia*. A few shoots of *Salix glauca* are seen in the foreground. T. W. B. phot. Aug. 8th, 1946.

lakes, partly on the beach, where it is exposed to being dried up. Similarly also *Drepanocladus fluitans* may form large moss-carpets, which are exposed at low water in the lakes. This species, however, chiefly occurred in and at slightly acid-neutral lakes, whereas *D. aduncus* particularly occurs along the shores of alkaline lakes, a fact which agrees very well with our knowledge of the ecology of the species from other regions. No doubt *Drepanocladus* lived on the beach of Store Saltsø at a time when the lake was less saline, perhaps under similar conditions as those found at Lille Saltsø at present. The growths of moss (or detached pieces of moss washed together on the exposed beach) have time and again been completely or partly covered with loess drifting to the place and thus the stratified deposit has developed.

The four terraces at the west end of the lake were measured on an estimate by counting of steps. Each terrace is about 30—40 m in breadth and ends in a steep erosion slope. In the case of the upper terraces this slope is 1 m in height, in the case of the lower ones ab. 2 m. The surface of each terrace is, if anything, level but in the inmost part of each terrace, in front of the erosion slope, there is a more or less narrow depression. This may be supposed to have arisen as a consequence of the erosion. When the waves strike the slope the loess is washed away. A deposit which thus comes to consist mainly of moss, will subside, and the depression will develop. Along the south side of the lake, where the terraces consist of earth (fig. 19), there is not a vestige of this kind of depressions. While the dry, fairly high, outer parts of the terraces mostly have a sparse vegetation, there is somewhat more in the depressions. On the margin of these there are often willow shrubs (see Plate 2—3), and in the depressions there is *Juncus arcticus* or *Lomatogonium rotatum*. In one of the depressions the soil on August 8th was still moist and on the ground there were reddish layers of dead or dying daphniae, on which flies had settled. I tried if it was possible trace any smell of putrefaction, but even right down at the layers of daphniae nothing could be smelt. The daphniae obviously had lived in a small pool in the depression, and this had not completely dried up. Also the plankton of the lake itself teemed with daphniae, and as stated above, they form a not quite immaterial constituent of the deposit. This is obviously a characteristic feature. Wesenberg-Lund (1937) writes that daphniae (species of *Artemia*) play a very great part in salt lakes all over the world. They contribute to the red colouring of the water "and it is stated that they may be found lying as red fringes along the shores." This statement thus may be corroborated by me.

As for the plants it was of decisive importance whether the moss formed pure or nearly pure layers, or whether the layers mainly consisted of loess. When the pure layers of moss formed the surface of the terrace there were practically no plants, whereas, when the loess dominated in the surface, there were a good number of plants. These must often be greatly exposed to drying-up. The deposit gave way when somebody walked on it, and at each step a dust was raised. The deposit was filled with deep cracks in which loess had gathered, and in these cracks the plants were standing in rows, among them such rare species as *Gentiana detonsa*, *Primula stricta*, and *Braya linearis*.

(c) Tarajornitsoq. This lake was visited by I. A. D. Jensen (*loc. cit.*), and a sample of water from it has been analyzed by K. Rørdam. In 1946 Dr. Hans Ramberg, the Norwegian geologist, found a salt lake, and the place and description of the locality he gave me indicates that it must be the same lake as that found by I. A. D. Jensen. The lake was fairly close to Strømfjordshavn inside the first fairly low mountain ridge stretching along the fjord. According to Dr. Ramberg there were terraces on the north side of the lake. Four terrace erosion slopes were seen over the present erosion slope, the uppermost one being about

100 m above the surface of the lake and higher than the mountain-ridge between the fjord and the lake. Hence the lake must have been ice-dammed along the south side when the uppermost terrace was formed. I. A. D. JENSEN states that the lake was without aquatic plants and that its sandy beach, too, was quite bare of vegetation; but he found some snails washed ashore. Hence there is no doubt phytoplankton in the lake, as in Store Saltsø.

While the water samples from the small lake at Strømfjordshavn and Lille Saltsø contained bicarbonate ion only (Table 14), there are in Store Saltsø very high contents of both carbonate ion and bicarbonate ion (Table 16). According to WERNER CHRISTENSEN's analyses there is further in this lake a fairly high content of chloride, and there is also some sulphate in the water. The content of calcium is comparatively low, whereas there is a very high content of magnesium. It is remarkable that together with carbonate ion there are large amounts of calcium and magnesium in the water. There is further a fairly high content of potassium, which otherwise generally occurs in smaller quantities in both surface water and bottom water. The consumption of oxygen, which is an expression of the contents of organic matter is very high, as in Lille Saltsø. RØRDAM's analysis of the water from Tarajornitsoq on the whole shows good agreement with the Store Saltsø analysis. But Tarajornitsoq is a good deal more saline. The difference is that Tarajornitsoq has a relatively lower content of potassium and that it does not contain calcium at all.

Table 16. Saline, highly alkaline lakes.

	Store Saltsø *p*H ab. 9.5		Tarajornitsoq	
	mg/l	Millival/l	mg/l	Millival/l
CO_3^{--}	408	13.60	(983)	(32.77)
HCO_3^{-}	878	14.40	?[1]	?[1]
SO_4^{--}	45	0.94	91	1.90
Cl^{-}	708	19.97	903	25.47
Anions:		48.91		(60.14)
Ca^{++}	32	1.60	0	0.00
Mg^{++}	236	19.41	308	25.30
Na^{+}	514	22.35	824	35.84
K^{+}	206	5.27	66	1.68
Cations:		48.63		62.82
SiO_2	10		0	
Consumption of oxygen, O_2	47			

[1] Possible bicarbonate has no doubt by RØRDAM been given as carbonate.

WERNER CHRISTENSEN has tried to convert RØRDAM's figures from Tarajornitsoq (Table 16), which are adduced by I. A. D. JENSEN (*loc. cit.*), to ion figures. In the analysis RØRDAM only states the contents of CO_2, and most probably this represents both carbonate and bicarbonate. Hence it is impossible to distinguish between bicarbonate and carbonate in this lake.

East of the large Lake Taserssuaq, which is situated half-way between the inland ice and Holsteinsborg, HOBBS (1927) found a lake the water of which "was so salty as to be unpalatable." In his Table II he has an analysis of the water, which is rendered in Table 17, the values here, however, are converted to ions. Strangely enough, HOBBS makes no statement about the absolute amount of salts in the lake, but only gives the relative proportions. In the same table in HOBBS' paper two analyses of water are mentioned which are said to have been made by NORDENSKJÖLD. But HOBBS obviously has misunderstood NORDENSKJÖLD's paper, for the two analyses originate from I. A. D. JENSEN's and PJETURSSON's investigations (1889 and 1898), which are quoted by NORDENSKJÖLD, and they do not originate from salt lakes at all, but are analyses of salt crusts from the ground (cf. Table 11). The mentioned analysis from the lake east of Taserssuaq is interesting by its content of sulphate and—perhaps—the high contents of iron and aluminium oxides. HOBBS' analysis, for that matter, looks somewhat defective, as there is no balance between anions and cations. The anions give 0.73 equivalents and the cations 1.68 equivalents per 100 g water. As neither the occurrence of carbonate nor of bicarbonate is stated from the lake, while these ions are plentiful in the two lakes mentioned in Table 16, it is tempting to assume that carbonates and bicarbonates may somehow have been forgotten or omitted in the analysis published by HOBBS. Hence I have put a mark of interrogation in the place of the ions in question in Table 17.

There are three principal types of saline water: water rich in chloride, rich in sulphate, and rich in carbonate. The three types clearly appear from Table 17. According to CLARKE (1924, pp. 179—180) carbonates are abundant in recently formed bodies of water, derived from igneous rocks. When the salinity or concentration increases, the slightly soluble calcium carbonate is thrown down, leaving sulphates and chlorides in solution. If more calcium is available gypsum is precipitated, and the final result is water containing little except chlorides. Thus, the carbonate water forms the beginning , the chloride water the end of the series. The two Greenland salt lakes included in Table 16 belong to the carbonate waters (Store Saltsø) or the carbonate-chloride waters (Tarajornitsoq). The content of magnesium, however, is so high that they approach to the bitter type. The relative content of potassium in Store

Table 17. Water analyses from three Greenland salt lakes compared with the ocean and various other salt lakes mentioned in F. W. Clarke (1924). (Percentages of mg/l).

	The Ocean (N. Atlantic)	Great Salt Lake, Utah	Koko-Nor, Tibet	Issyk-Kul, Siberia	Utah Lake, Utah	Lake above Taserssuaq	Omak Lake, Washington	Summer Lake, Oregon	Store Saltsø, cf. Tab. 16	Tarajornitsoq, cf. Tab. 16
CO_3^{--} (HCO_3^{-})..	0.30	0.00	5.55	1.26	12.35	?	*36.75*	*35.57*	*41.56*	*30.90*
SO_4^{--}	7.59	6.57	17.84	*55.94*	*28.25*	*28.3*	21.12	4.18	1.81	2.87
Cl^{-}	*55.46*	*55.99*	*40.05*	15.64	24.75	5.0	2.96	18.27	23.31	28.57
Ca^{++}	1.21	0.17	1.77	0.94	5.90	*11.8*	0.23	trace	1.05	0.00
Mg^{++}	3.79	2.52	2.90	*12.50*	6.18	3.5	1.82	trace	*7.78*	*9.70*
Na^{+}	30.53	33.15	30.60	11.76	18.19	17.3	32.60	39.48	16.92	25.95
K^{+}	1.12	1.60	1.08	1.85	2.17	2.3	*4.52*	1.59	*6.78*	2.08
SiO_2........	0.00	0.00	0.09	0.06	2.00	4.0	0.00	0.62	0.33	0.00
Fe_2O_3, Al_2O_3.	0.00	0.00	0.02	0.00	0.00	(16.4)[1]	0.00	0.27	0.00	0.00
Salinity, percent ..	3.37—3.56	14.99	1.11	0.357	0.117	?	0.570	1.663	0.304	0.318

[1] In a footnote obviously due to the chemist who made the analysis, Hobbs writes: "Iron and aluminum content would probably be lower when the water was fresh and in its original state."

Saltsø is exceptionally high, also as compared with that of most other salt lakes. Among the large number of salt lakes mentioned in Clarke there are only certain lakes in north-western Nebraska and a lake in Yucatan which have 2—4 times as much potassium as Store Saltsø. —The next stage, sulphate waters, also seems to have been realized in West Greenland, although in a deviating form with a strangely high content of calcium. But chloride waters have not been found in West Greenland. As to the relative content of salts in the water such lakes resemble the sea, cf. Table 17.

The salt-crust on the ground which was found sporadically near Store Saltsø (Table 11) is essentially different in composition from the water of the lake. The high content of sulphate and the comparatively low content of carbonate in the crust is particularly remarkable.

As appears from Table 17 salinity varies extremely highly in the various saline waters. Store Saltsø has 0.3 per cent. and Great Salt Lake has 15 per cent. Hence, it is questionable where the border-line between freshwater and saline lakes is to be drawn. V. Brehm (1930) in support of Rob. Fischer draws the line at 100 mg SO_3+Cl per litre. Thus both the fairly saline lakes mentioned in Table 14 and the saline lakes mentioned in Table 16 should be classed among salt lakes.

E. Some Remarks on the Terraces at the Salt Lakes.

According to Dr. RAMBERG the uppermost terrace at Lake Tarajornitsoq must have been formed at a time when the lake was ice-dammed. A large glacier thus must have advanced through the Strømfjord valley and formed the southern beach of the lake. At that time the more easterly small valley, in which Store Saltsø is now found, probably was filled with ice. During the following retreat of the ice-margin the ice must gradually have withdrawn from this valley and probably left a moraine-ridge, which now demarcates the present lake basin towards the west. Probably the water first filled the basin, then a lowering of the surface of the water took place and this decrease in the height of the water must have been very considerable, the height of the water at last having been below the present one. The first accumulation of salts in the lake probably took place at that time. The lake during the whole lowering of the water-level must have had a vigorous marginal vegetation of *Drepanocladus aduncus*, which was exposed to a rain of loess particles. In certain periods the supply of loess was greater than in others; hence the moss deposits arose on the beach and were exposed as the lake withdrew, and came to consist of layers with a greater or less admixture of loess. After the drying-up period there must then have been a period when the surface of the water probably rose to a level higher than the uppermost terrace slope at Store Saltsø and the uppermost but one at Tarajornitsoq. As the lowering of the water-level may be supposed to be due to a climatic continentalization, a rise may very well have been due to an oceanization, which may be supposed to have been followed by an advance of the ice. At such an advance the ice may have reached the region around Mount Keglen in Sandflugtsdalen; for it is characteristic that large loess deposits as well as large old terraces in the river valley (fig. 9 in the background) are only found west of Keglen. The big glacier-fed rivers which during the advance came from the ice margin may have deposited the uppermost terrace in the valley. Then a somewhat more continental period followed during which the uppermost terrace slopes in the valley at the Store Saltsø were formed, while at Tarajornitsoq it was the uppermost slope but one which was cut out. Later there has obviously again been a lowering of the water-level and a corresponding continentalization, but this has occurred by stages, as at Store Saltsø there are three erosion slopes below the uppermost one, and at Tarajornitsoq three below the uppermost but one. West of Keglen there are also in the river-valley three terrace slopes below the uppermost one. It is only natural to suppose that these terraces in the river-valley and at the salt lakes have developed at the same time, and this might indicate that there have been three periods of stagnation during the withdrawal of the ice. Every time when a terrace slope has been formed there has been climatic stability and stagnation of the ice-margin. At present, when the lowermost terrace slope is exposed to erosion both in the river-valley and at the salt lakes, we have stagnation of the ice edge. The vigorous, perfectly stabilized vegetation, which reaches right up to the ice-margin shows this (cf. Böcher 1949).

At all events the deposits at Store Saltsø indicate that in the region around the head of the Søndre Strømfjord there was during a long period in the Quaternary Period a very continental climate with a possibility of loess formation. The fluctuations of the climate suggested by the terraces therefore were hardly great. The oceanization in connexion with the advance of the ice need only have meant that the degree of continentality became somewhat less. If this is so, the continental flora and vegetation must have had long periods in which to develop in this region of Greenland.

The advance of the inland ice to the region around Mount Keglen, which is assumed on account of the observations of terraces at Store Saltsø, is of a certain interest. At present we have almost no knowledge of the position of the ice margin during the last glaciation (the Wisconsin glaciation). The possibility exists that this glaciation in the most continental parts of Greenland was only a little more extensive than the present one and, if so, the advance to Mount Keglen might correspond to the Wisconsin epoch. This radical and unfortunately very badly grounded hypothesis leads to the consequence that there may have been a vast refugium in this part of Greenland during this glaciation, an idea which is supported by a number of phytogeographical facts. A discussion of the phytogeographical data which may support the theory must, however, be postponed till a later paper.

6. LITERATURE

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Færdig fra trykkeriet den 30. december 1949.

Plate 1.

Fig. 1. Lake south of the western part of Ringsødalen (Loc. 4) at the head of Søndre Strømfjord. On a north-facing slope there is a permanent water-bearing brook around which there are a 2—3 m high willow scrub and growths of angelica (*Angelica archangelica*) as tall as a man. Such a patch of vegetation looks very strange in this region, nearly like an oasis. T. W. B. phot. Aug. 1946.

Fig. 2. Steppe-covered south-facing slope at Loc. 3 in Søndre Strømfjord. Behind the cane a scrub of *Salix glauca*, which is on the point of dying, no doubt as a consequence of the drought. In the steppe vegetation *Artemisia borealis*, *Calamagrostis purpurascens*, and on the right, in front of the bush, *Roegneria violacea* (*Agropyrum violaceum*) are abundant. T. W. B. phot. Aug. 1946.

Fig. 1.

Fig. 2.

Plate 2.

Fig. 1. Store Saltsø in main Loc. 7 at the head of Søndre Strømfjord. The lowermost terrace at the western end of the lake consisting of moss and loess. The stratification of the terrace is clearly seen in the near foreground. T. W. B. phot. Aug. 8th, 1946.

Fig. 2. The same locality as fig. 1. On the right the lowermost terrace with two saltcrusts and willow-shrubs in the depression in front of the erosion slope of the lowermost terrace but one. Below the cane the alternate layers of moss (*Drepanocladus aduncus*) and loess are very distinct. T. W. B. phot. Aug. 8th, 1946.

Fig. 1.

Fig. 2.

Plate 3.

Fig. 1. Store Saltsø in main Loc. 7 at the head of Søndre Strømfjord. View of three of the terraces consisting of moss and loess. A vegetation-covered depression in front of an erosion slope runs through the middle of the picture. In the foreground the surface of dead rests of moss nearly quite bare of vegetation. In the background the valley leading towards the innermost part of the Strømfjord. T. W. B. phot. Aug. 8th, 1946.

Fig. 2. Salt lake at the harbour road, main Loc. 3, at the head of Søndre Strømfjord. In the foreground the dried-up cracked ground on the shore of the lake. A few individuals of *Puccinellia deschampsioides* are seen. T. W. B. phot. Aug. 28th, 1946.

Fig. 1.

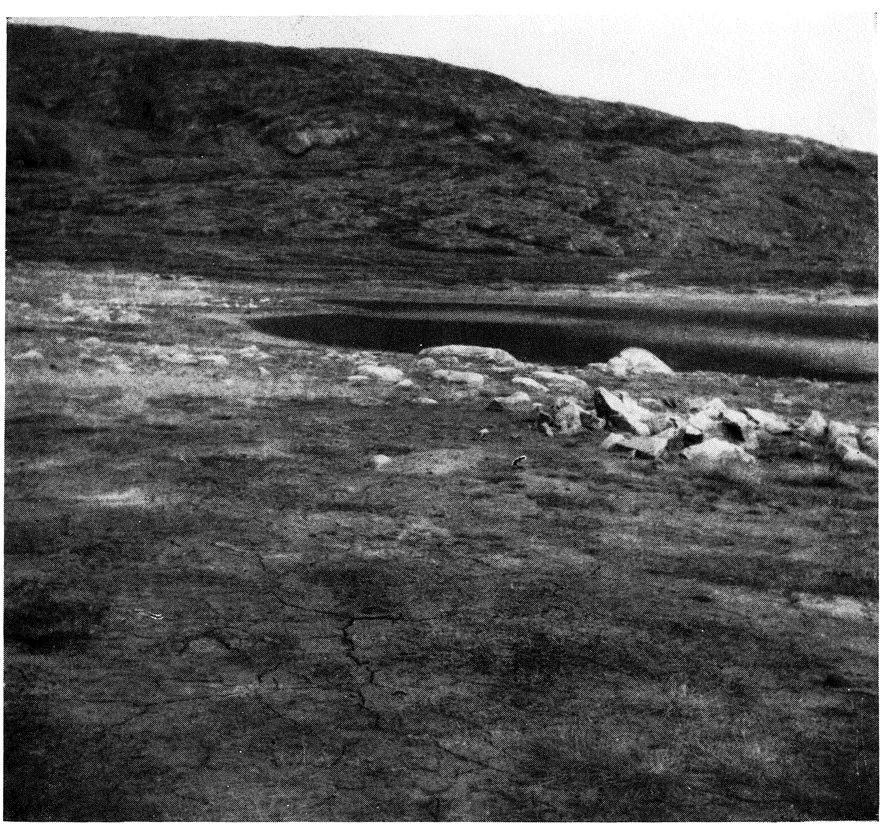

Fig. 2.

Plate 4.

Fig. 1. Aerial photograph of the region around Store Saltsø, which is seen in front in the middle of the picture. In one corner of the lake (below on the right) the system of moss-loess terraces. The dark stripes are vegetation on the innermost part of the terraces in front of the erosion slope of the next terrace. On the right the easternmost part of Lake Tasersuatsiaq, on the left the lower part of the Ørkendalen with the steep north-facing heath-covered escarpment. In the background the inland ice. Aerial photograph A 6 R a/10, Geodetic Institute, copyright.

Fig. 1.