Preliminary Studies of Soils in North-East Greenland between 74° and 75° Northern Latitude

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The geography of soils has been studied in north-east Greenland between latitudes 74° and 75° N. The study ranges from the outer coast to the interior of the ice-free land area. Well-drained soils show a characteristic sequence determined by the east-west climatic gradient. Fossil soil characteristics and secondary formed features supply information on the palaeoclimate.

Keywords: *North-east Greenland, arctic soil formation, palaeoclimate.*

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The National Park of North and East Greenland has been selected as a MAB Reserve (UNESCO Man and Biosphere Programme). On the initiative of Danish polar researchers and the Danish Polar Centre a group of scientists representing both bio- and geo-sciences visited the Young Sound area in the summer of 1991. The aim of the two-week reconnaissance was to select an area for comprehensive arctic-system research and a suitable location for the establishment of a research station. Due to the important role played by high arctic environments in relation to global change, it is important that high-arctic Greenland forms part of the network of ecological research sites in the Arctic. It is planned to formulate a comprehensive, long-term research programme for the area, coordinated with arctic-system science programmes of other countries, and to encourage international and interdisciplinary research projects. Both basic research and monitoring activities are strongly needed in the high-arctic ecosystem of northern Greenland. The present paper gives the results of the 1991-reconnaissance based on the geography of soils.

STUDY AREA

The reconnaissance group recommends the establishment of a research area for the ZERO-programme (Zackenberg Ecological Research Operation), stretching from the outer coast of Wollastone Forland (D in fig. 1) to the interior of Ole Rømers Land (K in fig. 1). The scientific research station will probably be placed in the low land area north of Zackenberg Bay in Young Sound, marked by Z in fig. 1. The location of the station has been primarily selected on the basis of its biological diversity and the luxuriance of this particular area, and because the total research area will be within easy reach of this location.

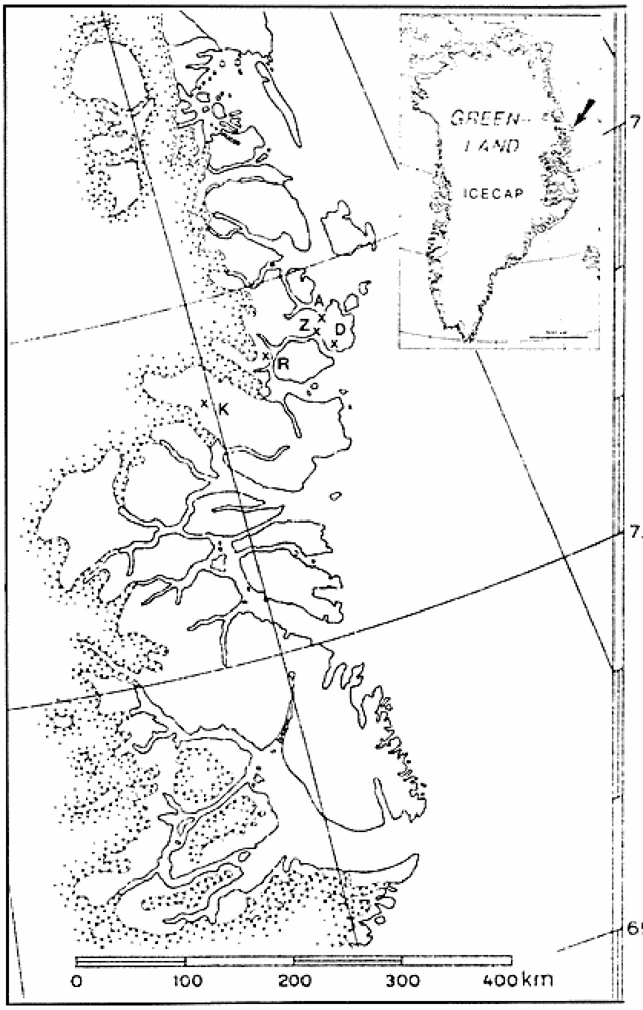

Fig. 1. The location of the research area in north-east Greenland. D: Daneborg, A: Albrecht Bay, Z: Zackenberg, R: Revet, and K: Krumme Langsø.

The geology of the region is composed of areas with gneissic and granitic bedrock and other areas dominated by sedimentary bedrock. Especially in the Zackenberg area, both types of bedrock are widely distributed, which leads to a diversity of landforms and soils.

At higher altitudes the geomorphology is characterized by glacial erosion, and only sporadic thin layers of fine-grained deposits are found on the plateaus and valley bottoms. These areas are dominated by block fields, taluses, rock glaciers and shutes. The lowland areas are mainly characterized by sedimentary formations, being dominated by tills and glaciofluvial and fluvial deposits.

The advanced positions of terminal moraines from the Milne Land Stade characterize the region. In near coastal areas, these deposits are covered by estuarine and marine sediments. The upper marine limit, which generally decreases from the outer coast to the interior, reaches about 65 metres a.s.l. at Zackenberg Bay.

In this part of eastern Greenland the climate is high arctic. At Daneborg (D in fig. 1) meteorological observations (1961-1974) show a mean annual temperature of -10.3 °C. The mean temperatures of the warmest and coldest months - normally July and February - are +4.0 °C and -23.6 °C, respectively. Mean annual precipitation is 214 mm, which is probably an underestimation, due to the degree of accuracy. The summer period generally experiences a somewhat lower precipitation than the autumn and winter period. The soil temperature regime (Soil Taxonomy 1990) is pergelic. At present, only small amounts of water occasionally move down through the well-drained soil during most years, due to the rather low precipitation values. Weak leaching caused by this vertical movement of water is normally to take place during late spring and early summer, in June and July. Areas with impeded drainage have wet soils with accumulations of organic matter. In the interior the climate is more continental and soils are normally dry for long periods.

Generally, the outer coast areas are covered by a sparse vegetation of dwarf shrub heaths. Fell-fields are widespread. The sunnier and not too dry interior, lying at some distance from the outer coast, has a markedly longer growing season. Dense heath vegetation of different species composition, herb slopes on some of the south-facing areas, fens and saltmarshes dominate. Exposed sites such as raised fluvial terraces and moraine ridges are windswept, barren areas. At the heads of the fjords, extremely continental conditions have resulted in a steppe-like vegetation, with widespread salt encrustations on soil surfaces.

METHODS

The soils were described according to F.A.O. (1977). The following methods were used for analyzing the fine earth. The pH value was measured in 1:2.5 w/w soil:0.01 M $CaCl_2$ suspension. Organic carbon was determined by combustion in a LECO induction furnace, and total N was analyzed by Kjeldahl digestion. Phosphorus was determined spectrophotometrically after extraction with 12 N sulphuric acid. Total P was determined after extraction of soil heated to 550 °C, and inorganic P without heating the soil. Si was determined spectrophotometrically (Morrison and Wilson, 1963) after acid oxalate extraction (Mc Keague and Day, 1966). Iron and aluminium were determined by atomic absorption spectrophotometry (AAS) after being extracted by the dithionite-citrate method of Mehra and Jackson (1958), by the pyrophosphate method of McKeague (1967) and by the acid oxalate method of McKeague and Day (1966). Exchangeable bases (Ca, Mg, K and Na) were also analyzed by AAS after extraction by NH_4OOCCH_3. Exchangeable acidity (H and Al) was determined by titration after extraction with KCl. The cation exchange capacity, at the actual pH of the soil (ECEC), was calculated as the total of exchangeable cations determined by the above- mentioned methods.

THE SOILS OF THE AREA

The soils studied at the locations of Daneborg (D), Zackenberg (Z), Revet (R), and Krumme Langsø (K) are marked in fig. 1. They represent zonal soil development that occurs on vegetated, well-drained, almost level land areas. Permafrost is not found within the upper 100 cm of the soil, and cryoturbation processes have only slightly affected the pedogenetic horizontation of soil profiles. The soil at A (fig. 1) - Albrecht Bay - has developed on a vast heath-covered tundra plain in a valley bottom. Permafrost is reached at a depth of about 35 cm. The sandy, active layer is probably moist or wet throughout the summer period and strong mixing occurs due to cryoturbation. Outlines of soil profiles are given in fig. 2. All the well-drained soils show more or less morphologically distinct eluvial and illuvial characteristics. The colours of the soil horizons are given in table 1. Soils D and Z have developed in slightly gravelly, sandy material deposited by water, soil R in fine sandy till and soil K in sandy loess which covers coarse-textured, fluvial material.

Tundra soils of varying composition - as regards drainage and organic matter accumulation - dominate large areas in valley bottoms from the outer coast as far as to about half way to the present margin of the Ice Cap. Hummocky grounds and poorly-drained swamps with peat formation occur as inclusions. In the interior, the soils on fine-grained deposits are generally dry, and in some areas even desert-like. Wet soils are only found along lakes and water courses. Generally, barren landscapes, with bedrock and boulder fields, are found at high altitudes and on steep slopes.

SOIL FORMATION

Among the well-drained soils, the most pronounced soil formation is observed at Zackenberg. Morphologically, the soil profile is a Podzol with a strongly bleached E horizon, an upper, dark, humus-rich B horizon and a dark reddish brown lower B horizon. ECEC and %C values and the distribution of extractable Fe and Al confirm that translocation processes characteristic of Podzols have taken place in the soil profile (tables 1, 2 and 3). The distribution of the different fractions of extractable Fe and Al shows that metals combined in organic complexes

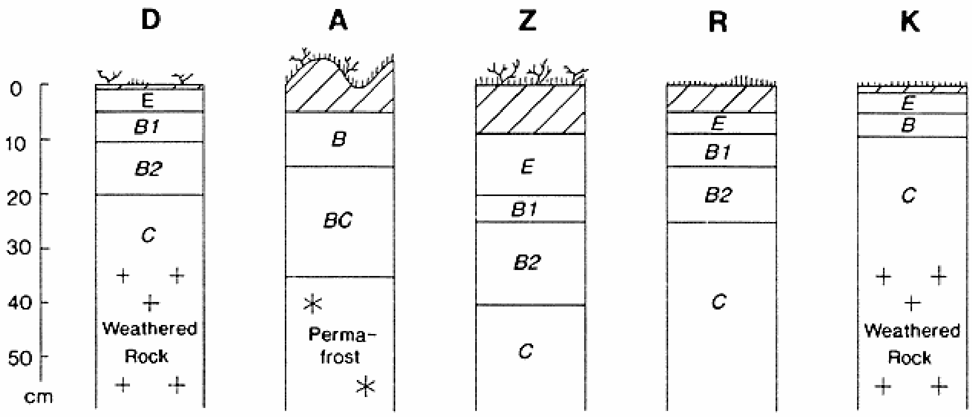

Fig. 2. Outlines of the five soil profiles.

dominate in the upper B horizon, whereas metals occur in inorganic forms in the lower B horizon, mostly in compounds containing Si. The values of the total of inorganic amorphous Al and Fe and extractable Si are highest in the lower B and in C horizons and lowest in the upper B horizon (table 3).

Thus, the profile characteristics give evidence of a multiple soil formation system, where, generally, the early process of inorganic Al(Fe)-Si translocation is followed by a translocation of metal-organic complexes. The latter process probably remobilizes Al(Fe)-Si rich, amorphous compounds in the B horizon whereby Si-rich material will be translocated into deeper horizons. The result of this sequence of processes is the observed difference in properties between the upper and lower B horizon. Changes in Podzol-forming processes over long periods and also short-term variations in process intensity have been reported by Milnes & Farmer (1987), Ugolini et al. (1987) and Stoner & Ugolini (1988). Subarctic Podzols in southern Greenland show similar characteristics of a sequence of pedogenetic processes (Jakobsen, 1991a, 1991b).

The Podzol at Zackenberg is only weakly acid. The pH values range from 6.0 to 6.5 and are lowest in the upper B horizon. A secondary accumulation of probably aeolian material has taken place on top of the soil (horizon A11).

Profile/ Horizon		Sample depth	Colour (moist)	pH ($CaCl_2$)	%C	%N	C/N	C/P	o.P ppm	io.P ppm
A	A	0- 2	7.5YR 4/2	5.28	4.10					
	Bv	5-10	5YR 3/4	5.41	5.37					
	C	15-20	5YR 4/1	5.17	3.52					
	C	25-30	5YR 4.1	5.20	3.40					
D	A	0- 1	10YR 3/2	6.64	4.32	0.31	14	469	92	168
	E	1- 5	10YR 5/2	6.59	2.15			112	192	142
	B1	5-10	7.5YR 4/4	7.33	3.66			66	250	133
	B2	12-17	7.5YR 3/4	7.20	2.01			58	344	78
	C	25-30	7.5YR 5/3	6.45	0.91			55	165	153
Z	A11	0- 5	10YR 5/3	6.22	1.57	0.11	14	102	154	196
	A12	10-15	10YR 3/3	6.18	2.62	0.18	15	181	145	243
	E	20-25	10YR 4/4	6.04	0.75			45	168	216
	B1	30-35	2.5YR 2/2	5.94	5.76			258	223	134
	B2	35-40	10YR 4/6	6.10	0.53			37	145	76
	C	50-55	10YR 5/4	6.09	0.16			12	132	176
	C	60-65	2.5Y 5/4	6.47	0.22			19	114	195
R	A	0- 5	7.5YR 4/2	6.13	11.71	0.56	21	420	279	382
	E	5-10	7.5YR 5/3	6.26	1.19			75	158	166
	B1	10-14	5YR 6/4	7.08	0.72			248	29	197
	B2	14-30	7.5YR 5/8	6.35	0.52			41	128	264
	C	35-40	7.5YR 6/3	6.33	0.46			58	79	327
K	A	0- 1	10YR 4/2	7.27	3.47	0.19	18	183	190	217
	E	1- 5	10YR 5/2	7.23	2.60			257	101	257
	B	5-10	10YR 5/3	6.58	2.79			127	220	203
	C	15-20	10YR 5/2	7.14	2.55			166	154	234
	C	25-30	10YR 5/2	7.09	2.65			104	255	86
	C	35-40	10YR 6/2	6.72	2.11			325	65	155

Table 1. Properties of the five soil profiles studied. Munsell soil colour, pH, %C, %N, C/N, C/P, organic P (o.P) and inorganic P (io.P). Underlined figures show maximum values.

Profile Horizon		Sample depth	Ca	Mg	K meq/100g	Na	H+Al	ECEC
D	A	0- 1	13.22	2.42	0.32	0.13	0.05	16.14
	E	1- 5	8.19	1.66	0.20	0.10	0.15	10.30
	B1	5-10	7.90	1.72	0.22	0.12	0.05	10.01
	B2	12-17	11.01	2.42	0.33	0.08	0.06	13.90
	C	25-30	5.93	1.32	0.15	0.15	0.03	7.58
Z	A11	0- 5	7.38	2.80	1.06	0.21	0.04	11.49
	A12	10-15	12.22	3.87	0.27	0.45	0.11	16.92
	E	20-25	5.41	2.07	0.14	0.22	0.09	7.93
	B1	30-35	10.07	4.10	0.12	10.09	0.23	24.61
	B2	35-40	3.48	1.76	0.08	0.97	0.24	6.53
	C	50-55	2.70	1.64	0.10	0.19	0.18	4.81
	C	60-65	4.71	2.67	0.20	0.29	0.29	8.16
R	A	0- 5	22.08	4.29	0.42	0.53	0.07	27.39
	E	5-10	5.86	1.83	0.15	1.78	0.06	9.68
	B1	10-14	7.66	2.74	0.20	0.29	0.04	10.93
	B2	14-30	4.45	1.53	0.11	7.03	0.03	13.15
	C	35-40	3.57	1.26	0.10	0.31	0.03	5.27
K	A	0- 1	37.21	4.62	0.28	0.07	0.04	42.22
	E	1- 5	25.54	3.11	0.20	0.12	0.13	29.10
	B	5-10	23.68	3.66	0.12	0.10	0.05	27.61
	C	15-20	33.51	4.38	0.09	0.07	0.06	39.11
	C	25-30	24.19	3.53	0.07	0.05	0.05	27.89
	C	35-40	14.92	1.56	0.04	0.15	0.05	16.72

Table 2. Exchangeable cations and cation exchange capacity at the actual pH of the soil (ECEC) for the well-drained soils. Underlined figures show maximum values.

Prof./ Hor.		D	Fe-d	Fe-o	Fe-p	Al-d	Al-o	Al-p	Si-o	Al*	Fe*
			per thousand								
A	A	0- 2	34.54	7.87	2.43	2.08	1.11	1.31	0.63	<0	5.44
	Bv	5-10	26.73	7.21	3.76	3.03	1.74	1.62	1.04	0.12	3.45
	C	15-20	28.79	7.09	1.42	1.40	0.77	0.81	0.33	<0	5.67
	C	25-30	37.77	8.01	1.41	1.84	0.93	0.58	0.63	0.35	6.60
D	A	0- 1	9.21	2.49	1.31	2.35	1.61	1.08	0.96	0.53	1.18
	E	1- 5	9.42	2.82	1.79	2.05	1.52	0.91	0.84	0.61	1.03
	B1	5-10	10.25	2.96	1.86	3.02	1.61	1.73	0.87	<0	1.10
	B2	12-17	8.72	3.00	3.09	2.93	2.02	1.51	0.85	0.51	<0
	C	25-30	8.15	1.67	1.12	1.65	1.16	0.56	0.88	0.60	0.55
Z	A11	0- 5	7.75	2.73	0.61	1.40	1.13	0.26	1.17	0.87	2.12
	A12	10-15	8.93	3.27	1.27	1.67	1.30	0.47	1.07	0.83	2.00
	E	20-25	8.89	3.49	1.57	1.71	1.31	0.54	1.06	0.77	1.92
	B1	30-35	7.69	4.51	3.59	2.32	1.97	1.64	0.83	0.33	0.92
	B2	35-40	11.90	6.40	3.05	2.43	1.57	0.64	1.14	0.93	3.35
	C	50-55	5.23	2.94	0.89	1.22	1.25	0.33	1.04	0.92	2.05
	C	60-65	7.25	3.33	1.08	1.48	1.47	0.28	1.47	1.19	2.25
R	A	0- 5	6.16	3.98	2.29	1.93	1.51	1.00	1.04	0.51	1.68
	E	5-10	3.29	1.20	1.03	1.15	0.98	1.10	0.50	<0	0.17
	B1	10-14	5.90	2.01	1.15	1.10	1.21	0.35	1.02	0.86	0.86
	B2	14-30	9.85	3.57	3.51	1.43	1.03	0.72	0.77	0.31	0.06
	C	35-40	4.84	1.96	0.97	1.11	0.98	0.54	1.27	0.44	0.99
K	A	0- 1	2.58	0.88	0.38	0.88	0.65	0.23	0.73	0.42	0.50
	E	1- 5	2.43	0.91	0.30	0.82	0.70	0.21	0.69	0.49	0.61
	B	5-10	3.53	1.30	0.49	1.04	0.96	0.38	1.03	0.58	0.81
	C	15-20	3.09	1.18	0.35	1.05	0.95	0.31	1.22	0.64	0.83
	C	25-30	3.38	1.26	0.48	0.91	1.06	0.50	1.39	0.56	0.78
	C	35-40	1.41	1.00	0.19	0.70	0.85	0.20	0.26	0.65	0.81

Table 3. Contents of iron, aluminium and silicon in soil profiles. Dithionite-citrate extractable (d), acid oxalate extractable (o) and pyrophosphate extractable (p). Al* and Fe* values are (o)-values minus (p)-values and therefore primarily show the content of amorphous, inorganic aluminium and iron. Underlined figures show maximum values.

Additionally, a secondary enrichment of Na is observed in the B horizons.

The well-drained soils at Daneborg (D), close to the outer coast, and at Revet (R) and Krumme Langsø (K) in the interior show a markedly weaker profile development. Soil D has been weakly podzolized, with an accumulation of translocated Al, Fe and C in the B horizons. In soil R and K, there is no observed accumulation of organic carbon in the B horizons. Translocation characteristics of Al and Fe are weak, especially in soil K, in the most continental part of the research area. In the latter profile (K), translocation processes have probably been dominated at an early stage by the translocation of inorganic, Si-rich material. These initial stages of soil formation are also observed in Podzols in southern Greenland (Jakobsen, 1989). At Revet (R) too, a probably secondarily formed maximum of adsorbed Na is observed in the lower B horizon.

The pH-profiles of the studied soils (fig. 3), clearly reflect the varying intensity of soil leaching. In Albrecht Bay, the soil is depleted of bases compared to the other four soils, due to the outer coast climate and the dense lowland heath vegetation. The horizon-mixing cryoturbation processes are intense and a nearly constant pH of about 5.2-5.4 has been recorded throughout the active layer.

Generally the pH-values of soils increase inland, reflecting the still drier moisture regime. The soil at Daneborg -

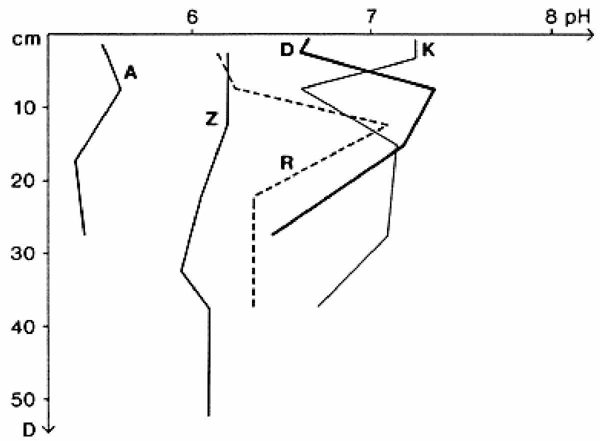

Fig. 3. Graph showing the pH-profiles for the five soils.

on the south-western coast of Wollastone Forland - immediately shows unexpectedly high pH-values. Yet, the combination of a extremely sparse, heath vegetation that covers these upland soils and the overall dry high-arctic climate has resulted in low leaching intensities. Pedogenetically, the Daneborg profile hereby shows more similarities with the soils of the continental interior than with those of the more luxuriant, intermediate zone at e.g. Zackenberg. Thus, the intensity of horizon differentiating soil forming processes in well-drained soils generally increases as one progresses from the outer coast to the land areas somewhat inland. From here on, a marked decrease is once again observed going inland. The combined effect of greater warmth (length of growing season) and accessible water for biological processes, such as plant growth, explains the luxuriance and the intense soil formation at Zackenberg compared to those inland and in the outer coast localities.

SOILS AS PALAEOCLIMATIC INDICATORS

The present climate and vegetation at Zackenberg cannot explain the occurrence of a well-developed Podzol. The soil is found under a dry, low Kobresia-Willow-Mountain Avens heath in well-drained fluvial deposits. The enrichment of basic ions in the soil, especially of Na, presumably by wind brought into the area from the fjord, also indicates weak leaching processes and the alkalization of subsurface horizons. The Podzol would indicate a period with a markedly warmer and moister climate. During this period, a dense shrub vegetation presumably covered the land.

The existence of a warm Holocene phase in Greenland, in this part of Greenland probably from about 7000-5000 B.P., has been proved on the basis of the analysis of pollen and deep Inland Ice cores. During the warm Holocene phase, a strong climatic gradient prevailed similar to that observed today, ranging from the cool, moist, outer coast to the warmer and drier continental interior. Such conditions have presumably characterized the ice-free land. Since then, the climatic cooling and decrease in precipitation have fossilized the morphology and most of the chemical characteristics from the soil profile formed in the warm period. Present soil forming potential is weak and a change in the composition of the adsorbed elements in the soil seems to be the most dramatic change affecting the soil characteristics during the course of the last five cold and dry millennia.

As indicated by the thin cover of aeolian material on top of 'the warm period soil profile' at Zackenberg, and because no noticeable aeolic activity can be seen to have taken place during the warm period Podzol formation, the climatic cooling that ended the Holocene warm period probably also started the sporadic erosion of soils. This erosion of exposed sites, mostly by wind but probably also due to increased sheet flow and soil creep, was presumably partly triggered by a serious ower-grazing of the open shrub heath when the region cooled.

CONCLUSIONS

A reconnaissance group of Danish geo- and bioscientists has visited the Young Sound area in the National Park of North and East Greenland. Due to the important role of high-arctic Greenland in relation to Global Change, and the extraordinary high variability of ecosystems at this latitude in East Greenland, the group recommends the establishment of an internationally-coordinated, comprehensive arctic system research programme for the area and the establishment of research station facilities.

The geography of soils reflects the present dry, cool conditions of the region. The climatic gradient reveals a markedly more continental climate in the interior of the ice-free land area. The highest intensity of soil-forming processes is to be observed at some distance from the outer coast due to the combined effect of maximum warmth and accessible water. Both inland and outer coast localities have weaker soil development. At present, only weak leaching processes take place and the alkalization of subsurface horizons may be observed.

Strongly developed Podzols, with secondary alkalization features, found in the most luxuriant, intermediate part of the ice-free land area, indicate a previous, Holocene, climatic optimum with markedly higher temperatures and higher precipitation. The subsequent climatic cooling, probably resulting in the overgrazing of the shrub vegetation by i.a. reindeer and musk ox, triggered the first erosion of the vegetated soils that has been identified during the Holocene. The climatic cooling in high-arctic Greenland is known to have started about 5000 B.P., and was therefore presumably rather unique and dramatic.

As indicated by the pronounced change in soil-forming processes, the Holocene climatic variation must have significantly influenced the circulation of sediments and nutrients in the high-arctic ecosystem. Basic research on previous and present soil formation in the High Arctic is therefore a prior condition for the correct interpretation of chemical and physical evidence obtainable from the geochemical and sedimentological examination of arctic lakes and estuaries. A combined study of the soils and the chemical and physical sedimentation that occurs in ecosystems in the Arctic will provide valuable regional information on the ecosystem response to changes in climatic controls similar in magnitude and scope to those projected for the future.

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CONCLUSIONS

A reconnaissance group of Danish geo- and bioscientists has visited the Young Sound area in the National Park of North and East Greenland. Due to the important role of high-arctic Greenland in relation to Global Change, and the extraordinary high variability of ecosystems at this latitude in East Greenland, the group recommends the establishment of an internationally-coordinated, comprehensive arctic system research programme for the area and the establishment of research station facilities.

The geography of soils reflects the present dry, cool conditions of the region. The climatic gradient reveals a markedly more continental climate in the interior of the ice-free land area. The highest intensity of soil-forming processes is to be observed at some distance from the outer coast due to the combined effect of maximum warmth and accessible water. Both inland and outer coast localities have weaker soil development. At present, only weak leaching processes take place and the alkalization of subsurface horizons may be observed.

Strongly developed Podzols, with secondary alkalization features, found in the most luxuriant, intermediate part of the ice-free land area, indicate a previous, Holocene, climatic optimum with markedly higher temperatures and higher precipitation. The subsequent climatic cooling, probably resulting in the overgrazing of the shrub vegetation by i.a. reindeer and musk ox, triggered the first erosion of the vegetated soils that has been identified during the Holocene. The climatic cooling in high-arctic Greenland is known to have started about 5000 B.P., and was therefore presumably rather unique and dramatic.

As indicated by the pronounced change in soil-forming processes, the Holocene climatic variation must have significantly influenced the circulation of sediments and nutrients in the high-arctic ecosystem. Basic research on previous and present soil formation in the High Arctic is therefore a prior condition for the correct interpretation of chemical and physical evidence obtainable from the geochemical and sedimentological examination of arctic lakes and estuaries. A combined study of the soils and the chemical and physical sedimentation that occurs in ecosystems in the Arctic will provide valuable regional information on the ecosystem response to changes in climatic controls similar in magnitude and scope to those projected for the future.

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