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Soils of Some Norse Settlements in Southwestern Greenland

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ABSTRACT. Soils of some former Norse settlements in southwestern Greenland were investigated and found to have well-developed, brightly coloured soil profiles in spite of the high latitude. The soils are generally acidic, sandy, strongly organic and high in exchange cations. Iron extraction data suggest a moderate degree of pedologic activity. The presence of smectite and interstratified hydroxy-aluminum vermiculite is likely representative of an early stage of neomineral formation in an area which has probably been ice-free for at least 8000 years. In the areas visited, there was no evidence in the soil to suggest that extensive soil erosion was responsible for the abandonment of these settlements.

Key words: arctic soils, pedology, clay minerals, Greenland, Norse settlements

RÉSUMÉ. Lors de l'étude des sols de quelques sites primitifs de peuplement norois dans le sud-ouest du Groenland, on a trouvé des horizons pédologiques aux couleurs vives bien accumulés malgré la latitude élevée. Les sols sont en général acides, sableux, fortement organiques et riches en cations d'échange. Des données concernant l'extraction du fer suggèrent qu'il existe un degré moyen d'activité pédologique. La présence de smectite et de vermiculite d'hydroxyaluminium interstratifiée est probablement l'indice d'une formation néominérale à ses débuts, dans une région qui pourrait avoir été libre de glace pendant au moins 8000 ans. Dans les zones visitées, on n'a trouvé dans le sol aucune preuve portant àcroire qu'une importante érosion du sol aurait entraîné l'abandon de ces sites de peuplement.

Mots clés: sols arctiques, pédologie, minéraux argileux, Groenland, sites de peuplement norois

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INTRODUCTION

In 986 A.D., hundreds of Icelandic farmers settled in southwestern Greenland (Krogh, 1982). As population pressure increased, a new settlement was established about 800 km to the north in the environs of the present capital of Godthåb (Nuuk). This became known as the Western Settlement to distinguish it from the original or Eastern Settlement. There is reasonable agreement that at the height of maximum settlement, its total population may have been about 5000 (Krogh, 1982). The Western Settlement was abandoned about 1340, and by 1500 there was no evidence of active human settlement in the region (Berglund, 1986).

The disappearance of the colonies has been the cause of considerable speculation, and many explanations have been put forward (Berglund, 1986; Gribbin and Gribbin, 1990; Sandvig, 1990). Recently some Danish workers have suggested that the extinction of the settlements may have been caused by a combination of overgrazing and soil erosion (Jacobsen, 1987, 1989; Jacobsen and Jakobsen, 1986; Fredskild et al., 1988; Jakobsen, 1989a); but this view has been strongly challenged by local officials (Egede et al., 1988). Krogh (1982) drew attention to the present degradation of vegetation caused by grazing sheep in the Gardar (Igaliku) – Qasiarsuk area. He also provides evidence that the sedimentation in a tarn 300 m north of Brattahlid increased threefold during the time of Norse settlement and decreased suddenly when the settlement was abandoned.

This paper provides a pedologic account of the soils of some of the Norse settlements in southwestern Greenland and furnishes some basic information on the soils of this region. Some intimation of the role of fossil and recent aggravated soil erosion in pedologic processes is given.

THE PHYSICAL SETTING

The Norse settlements practising permanent agriculture were established in the inner fiords of southwestern Greenland. The more southerly Eastern Settlement is located at approximately 61˚N, 46˚W and the northern or Western Settlement at 64˚N, 52˚W. The relief varies from gently rolling to stark, steep fiord walls. The lithology of the whole settlement area consists of Archean and early Paleozoic intrusives, sediments and gneiss (Berthelsen et al., 1989). The present natural vegetation, which is probably similar to that in Norse times, comprises forest-like copses of birch (*Betula*) and willow (*Salix*) with dwarf shrub and heath cover. The yearly precipitation is approximately 600 mm, and mean temperatures of the coldest and warmest months are -8˚C and 10˚C respectively for the Eastern Settlement and -5˚C and 7˚C for the Western Settlement. Although there is no permafrost in

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the soils, the B and C horizons may not thaw until July. In some settlements, reasonably sophisticated arable agriculture is being carried out with tile drainage, cultivation, seeding and fertilization for improved pastures for sheep. A crop of barley, for example, will produce a similar weight of biomass as in Denmark but only exceptionally will the grain mature (Krogh, 1982).

Of major significance in any consideration of soil genesis is the nature of the milieu through which pedogenesis has progressed. It would not be unreasonable to expect that in southwestern Greenland, where the inland ice cap is so near to the present coastline, the period of soil development would have been much shorter than in southern Canada. The map (1703A) by Dyke and Prest (1987) suggests the Eastern Settlement to have been ice-free for 18 000 years. However Funden (1989), in a detailed study of the ice advances and retreats in this area, presents evidence that this area has been ice-free for about 8000 years. If so, soil development has proceeded for a similar period as in the Oslo area of southern Norway (60°N) and may well have been influenced by the same post-glacial climatic changes as in southern Norway (Hafsten, 1960). On the other hand, Funden (1989) suggests that most of the Western Settlement was not ice-free until approximately 4000 years ago.

MATERIALS AND METHODS

Sixty-three soil profiles were examined and described. Of these, sixteen were sampled in the Brattahlid, Narsarssuaq, Gardar, Hvalsey and Godthåb areas (Fig. 1).

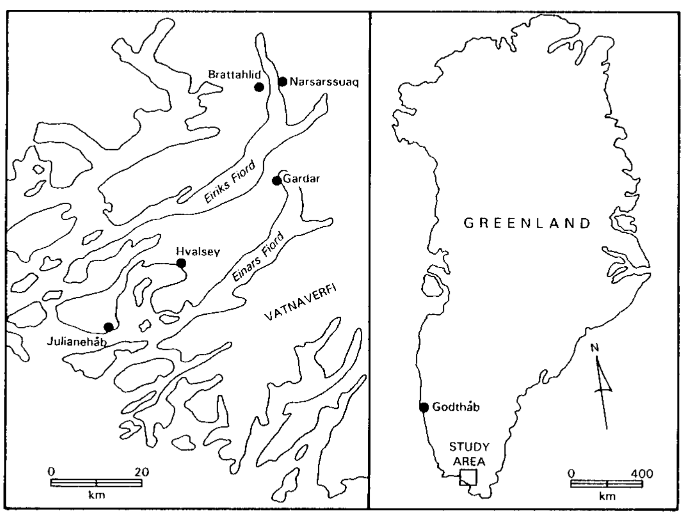

FIG. 1. Map of the study area.

The soil profile information in this text is derived from samples taken from the following profiles: Profile 4 from Narsarssuaq on the north side of Eriksfjord; Profile 7 from the south side of Eriksfjord near Brattahlid; Profile 18 from east of Brattahlid, showing soil development in shale saprolite; Profile 12 from Gardar, on a 15° slope above the cathedral site; Profile 15 from Hvalsey, on a gentle slope 400 m east of ruins; and Profile 20 from the west-facing slopes north of the airport at Godthåb.

Laboratory analyses included pH in 0.01 M $CaCl_2$, organic carbon by Leco furnace, particle size by hydrometer, and extractable Fe and Al by citrate-bicarbonate-dithonite (Fe_d), acid ammonium oxalate (Fe_o), and sodium pyrophosphate (Fe_p, Al_p) (Schuppli et al., 1983; Sheldrick, 1984). Exchange cations were determined after treatment with 1 M NH_4NO_3 (Stuanes et al., 1984). The results of all chemical analyses were checked against results from similar methods using standard soil samples. X-ray diffractograms of the < 2 μm, 10 – 15 μm and 100 – 150 μm fractions were prepared according to Gjems (1967). Diffractometer slides were prepared by deposition of known amounts of clay on a half microscope slide. To confirm the presence of vermiculite in the clay fractions, subset samples were K-saturated and heated at 25°C, 300°C and 500°C. However, to establish the presence of vermiculite in the silt-sized samples, each slide was heated to 550°C. All samples were run using Ni-filtered CuK radiation.

RESULTS AND DISCUSSION

The soil profile descriptions of some of the profiles examined are presented in Table 1, and the results of physical, chemical and mineralogical analyses are given in Tables 2 through 4. The hard rocks of the area give rise to sandy soil parent materials. The soils are generally sandy, the sand and silt fractions constitute more than 90% of the < 2 mm fraction. Surface horizons are high in organic matter, which is consistent with the short growing and decomposition periods, but some subsurface horizons are higher in organic matter than corresponding profiles in more southerly latitudes. The soil reaction is very strongly acidic but only slightly more so than on the southern portions of the Canadian Shield at latitude 44°N (Rutherford and Kemp, 1983). The unexpectedly high content of exchange cations is likely a function of high organic matter, although the levels do not seem to be essentially different from those recorded from the Northwest Territories (68°N) in Canada (Clayton et al., 1977). The high levels of exchangeable sodium in some profiles may be due to the proximity of sea water in the fiords.

The production of amorphous and crystalline iron and aluminum compounds is a major reaction of soil formation, and the activity ratio Fe_o/Fe_d is suggested as a relative measure of the degree of crystallinity of free iron oxides (Blume and Schwertmann, 1969; Torrent et al., 1980; Arduino et al., 1986). The Fe activity ratios, with few exceptions, are relatively high, which suggests at least a moderate degree of pedologic activity. The contents of amorphous iron compounds present further evidence for moderate pedologic activity at this northerly latitude. Fe_d-Fe_o is a measure of the soil's crystalline iron oxides, which are usually derived from the parent rocks. On the other hand, Fe_o-Fe_p indicates the content of amorphous iron oxide, which is usually formed by pedogenesis. Compared with soils formed at latitude 44°N in southern Canada (Rutherford and Kemp, 1983), the ratio

TABLE 1. Soil profile descriptions for southwestern Greenland.

Depth cm	Horizon[1]	Colour[2]	Texture[3]	Structure[3]
Eastern Settlement				
Profile 4; Narsarssuaq				
0 - 8	Ah	10YR4/1,2/1	sl	1msbk
8 - 10	Bfj	7.5YR5/3,3/3	l	0
10 - 12	Bf	10YR5/3,3/2	l	0
12 - 16	Bm	7.5YR3/3,4/3	sl	0
16 - 32+	C	10YR6/2,4/2	sl	0
Profile 7; Brattahlid				
0 - 7	Oh	10YR3/2,2/1	sl	2msbk
7 - 13	Bfj	10YR3/1,2/1	sl	1fsbk
13 - 60	Bhf	7.5YR4/4,3/3	sl	0
60 - 70	C	7.5YR4/6,3/4	sl	0
Profile 18; Brattahlid (saprolite on underlying shales)				
0 - 7	Ah	7.5YR6/3,3/3	sl	2fsbk; common shale frags
7 - 15	Bf	5YR5/4,3/2	ls	0 high shale frags
15 - 30	C	5YR5/2,3/2	ls	0 high shale frags
30+	Hard shale			
Profile 12; Gardar				
0 - 5	Ah	10YR4/2,2/1	sl	2msbk
5 - 8	Ah2	10YR4/1,2/1	sl	1cabk
8 - 9	Bf	10YR4/1,2/1	sl	charcoal
9 - 15	Bfj1	10YR5/3,3/2	ls	0
15 - 30	Bfj2	10YR5/4,3/2	ls	0
30 - 60	Bfj3	10YR4/3,3/2	ls	0
60 - 70	C	10YR5/3,3/2	ls	0
Profile 15; Hvalsey				
0 - 5	Oh	10YR3/1,2/1		2msbk
5 - 20	Bf1	7.5YR5/3,3/2	ls	0
20 - 31	Bf2	10YR5/3,3/2	sl	0
31 - 93	C	5YR6/3,3/3	l	0
Western Settlement				
Profile 20; Godthåb				
0 - 7	Oh	10YR5/2,3/2	ls	1cabk
7 - 11	Bfj	10YR5/2,3/2	sl	0
11 - 20	Bm	10YR6/1,4/2	sl	0
20 - 28	C	10YR4/3,3/2	ls	0

[1] (ACECSS, 1987)
[2] Munsell Colour Charts
[3] (Soil Survey Staff, 1951)

TABLE 2. Results of some chemical and physical analyses of soils from southwestern Greenland.

Sample Depth cm	Horizon	Particle Size Cl	Si %	Sa	OC %	pH	Exchangeable Cations Na	K	Mg meq/100g	Ca	Al
Eastern Settlement											
Profile 4; Narsarssuaq											
0 - 8	Ah	11	27	62	2.4	4.1	0.44	0.31	1.15	2.12	0.21
8 - 10	Bfj	12	43	45	1.3	4.1	0.26	0.15	1.05	3.03	0.28
10 - 12	Bfh	18	39	43	2.4	3.7	0.37	0.17	1.54	4.08	0.30
12 - 16	Bm	6	27	67	1.9	3.7	0.33	0.08	0.66	1.55	0.28
25 - 32	C	4	13	83	0.5	3.9	0.15	0.07	0.22	0.45	0.15
Profile 7; Brattahlid											
0 - 7	Oh	9	14	77	29.2	4.4	12.90	5.41	23.73	39.73	0.26
9 - 13	Bfj	15	30	55	16.1	3.9	7.87	2.00	8.29	10.34	0.34
20 - 23	BhfC	6	30	64	5.1	4.1	5.23	0.26	6.30	13.59	0.11
60 - 70	C	17	26	57	0.5	4.1	3.21	0.11	4.35	14.98	0.10
Profile 18; Brattahlid (saprolite)											
0 - 7	Ah	10	15	75	1.6	4.5	0.39	0.59	0.60	0.10	0.83
7 - 15	Bf	11	6	83	1.2	4.3	0.50	0.62	0.76	0.14	1.40
15 - 30	C	6	15	79	0.3	4.3	0.77	1.02	1.88	0.50	0.36
Profile 12; Gardar											
0 - 5	Ah	8	16	76	12.6	4.0	4.64	2.13	4.78	3.95	0.34
5 - 8	Ah2	6	28	66	8.7	3.8	2.27	0.53	2.82	1.16	1.40
8 - 9	Bf	10	31	59	8.2	3.7	2.91	0.58	1.73	1.28	1.20
9 - 15	Bfj1				1.7	3.6	0.49	0.21	0.85	0.34	0.71
20 - 25	Bfj2	3	18	79	1.9	3.6	1.04	0.23	1.05	0.51	0.98
40 - 45	Bfj3	3	16	81	2.0	3.7	1.03	0.15	0.87	0.36	0.73
65 - 70	C	8	18	74	1.1	3.8	1.21	0.14	1.15	0.87	0.66
Profile 15; Hvalsey											
0 - 5	Oh				19.8	4.1	2.40	2.18	12.97	23.76	0.41
8 - 12	Bfj	1	23	76	1.8	4.3	0.21	0.23	1.08	1.75	0.18
20 - 25	Bm	7	34	59	1.7	3.7	0.18	0.19	1.04	0.97	0.58
60 - 65	C	12	40	48	1.4	3.7	0.16	0.21	1.09	1.13	0.52
Western Settlement											
Profile 20; Godthåb											
0 - 7	O				31.5	3.4	0.90	1.10	5.01	9.00	2.66
7 - 11	Bfhj	15	23	62	4.4	3.4	0.18	0.07	0.17	0.40	0.62
11 - 20	Bm	11	18	71	2.4	3.0	0.18	0.07	0.17	0.19	0.50
20 - 28	C	9	11	80	0.4	3.5	0.14	0.06	0.12	0.14	1.08

Fe_d-Fe_o in the Greenland soils is substantially lower, whilst the Fe_o-Fe_p ratio is reasonably similar. Values for $Fe_p + Al_p$/clay are characteristic of B horizons (ACECSS, 1987). The levels of crystalline iron compounds are generally low except in the profiles at Brattahlid which are saprolitic at depth.

One problem in critically interpreting the results of clay mineral analyses is the uncertainty of differentiating between materials which occur in soils by mere inheritance from parent rocks (lithorelicts) and materials which are new formations generated by pedogenesis. The smectites and interlayered vermiculites and probably some illite in the surface horizons of Profile 4 are likely pedogenically derived. Across Eriksfjord at Brattahlid (Profile 7), a similar development of smectite and interlaid vermiculite is also evident (Table 4). At most sites, however, the vermiculite could be either pedogenic or lithorelict in origin.

Also at Brattahlid, where Profile 18 is developed on shale saprolite, the presence of high amounts of vermiculite and illite in all horizons suggests a lithologic origin; however, the absence of chlorite in the sand and silt fractions indicates that the vermiculite/chlorite is likely pedogenic. Profile 18 is in a strongly erosional site from which the upper horizons may have been removed by soil erosion in both recent and Norse times.

At Gardar in Profile 12, the low amounts of smectite and interstratified vermiculite in soils from high-mica rocks suggest a pedogenic origin. There seems to be ample source material in the associated chlorite content with depth (Gjems, 1967).

The Godthåb area is considered to be a much less active pedogenic area than the Eastern Settlement. Most of the mineral grains appear to be lithorelicts; the notable exception is the presence in the clay fraction of an interstratified hydroxy-aluminum vermiculite in all horizons. This interstratification may represent an early stage of soil neomineral formation.

TABLE 3. Results of analysis of soluble iron and aluminium in soil profiles in southwestern Greenland.

Sample Depth	Horizon	Fe_o/Fe_d	Fe_d-Fe_o	Fe_o-Fe_p	Fe_p+Al_p
Eastern Settlement					
Profile 4; Narsarssuaq					
0 - 8	Ah	0.90	0.04	0.30	0.24
8 - 10	Bfj	0.88	0.09	0.49	0.23
10 - 12	Bf	0.94	0.04	0.14	0.72
12 - 16	Bm	0.75	0.19	0.33	0.29
25 - 32	C	0.92	0.05	0.50	0.09
Profile 7; Brattahlid					
0 - 7	Oh	0.60	0.21	0.21	0.16
7 - 13	Bfj	0.40	1.11	0.28	0.19
20 - 23	Bhf	0.49	0.78	0.55	0.53
60 - 70	C	0.80	1.08	0.23	0.23
Profile 18; Brattahlid (saprolite)					
0 - 7	Ah	0.75	0.30	0.69	0.29
7 - 15	Bf	0.68	0.75	1.06	0.64
15 - 30	C	0.22	1.32	0.32	0.16
Profile 12; Gardar					
0 - 5	Ah	0.69	0.19	0.28	0.35
5 - 8	Ah2	0.56	0.30	0.21	0.29
8 - 9	Bf	0.88	0.09	0.22	0.67
9 - 15	Bfj1	0.84	0.12	0.38	0.41
20 - 25	Bfj2	0.83	0.15	0.44	0.45
40 - 45	Bfj3	0.80	0.12	0.26	0.40
65 - 70	C	0.57	0.19	0.21	0.21
Profile 15; Hvalsey					
0 - 5	Oh	0.90	0.04	0.15	0.57
8 - 12	Bfj	0.85	0.11	0.15	0.69
20 - 25	Bm	0.93	0.06	0.15	1.07
60 - 65	C	1.00	0.00	0.16	0.24
Western Settlement					
Profile 20; Godthåb					
0 - 7	Oh	0.77	0.06	0.01	0.37
7 - 11	Bfj	0.64	0.05	0.00	0.32
11 - 20	Bm	0.90	0.01	0.03	0.28
25 - 28	C	1.00	0.01	0.07	0.33

TABLE 4. Mineralogical composition[1] of some soil samples from soil profiles in southwestern Greenland.

Horizon	Fine Clay < 0.6 µm			Clay < 0.6 – 2.0. µm			Silt 10 – 15 µm			Sand 100 – 150 µm		
	high		low	high		low	high		low	high		low
Profile 4; Narsarssuaq												
A	VI		V/CCS	V	S	FACV/VI	QF		ACI	QF		AMC
B	VCV/C	I			VF	ACV/CI	QF		ACI	QF		AMC
C			FQCV/C			ACV/CI	QF		ACI	QF		AMC
Profile 7; Brattahlid												
A	I	VC	S		I	V/CVCFQA	FQ		CIA	FQ		AC
B	I	VC	S		I	VV/CFQAC	FQ		CIA	FQ		AC
C	I		VC			FQA	FQ		CA	FQ		AC
Profile 18; Brattahid												
A	F	IV		I		FVV/C	F		VAI	Q	IF	A
B	F	IV		I		FVV/C	F		IVA	Q	IF	A
C	I	V	F	I		VV/C	F		IVA	Q	IF	A
Profile 12; Gardar												
A	I	V/VC		I		FQAV/CVS			V/CCI	FQ	I	CA
B		V/CVCI				FQAV/CCVI			V/CCI	FQ	I	CA
C	V/C	V	IC			FQAV/CCVI			V/CC	FQ	I	CA
Profile 20; Godthåb												
A		CIF	H/VVC	I	C		FQ	A	IC	FQ		ACI
B		CIF	VH/VC	Q	IVV/I		FQ		AIC	Q	F	IAC
C		IV	CFCH/V	Q	IVV/I	C/M	Q	F	AIC	Q		IFAC

[1] A = amphibole, C = chlorite, F = feldspar, H = hydroxy-aluminum, I = illite, M = mica, Q = quartz, S = smectite, V = vermiculite, / = interstratification (e.g., V/C = interstratified vermiculite-chlorite).

CONCLUSIONS

Soils within a few kilometres of the present inland ice have developed profiles with bright colours and chemical properties typical of well-developed soils in areas free of ice for at least 9000 years at the same latitude, and up to 14 000 years at a latitude 16˚ farther south (Rutherford and Kemp, 1983). This is confirmation of the evidence for podzolization in southwestern Greenland presented by Jakobsen (1989b, 1991).

With respect to soil erosion as a cause of settlement abandonment, the Danish workers (Jacobsen and Jakobsen, 1986) on experience in the Vatnaverfi area, postulated that aggravated soil erosion was the major cause of general settlement abandonment. This author did not investigate soils in that area, but in the areas examined there was very little pedological evidence such as buried A and Bf horizons to indicate widespread soil degradation or deposition. Further, the chemical and physical evidence confirms the presence of monoperiodic soil formation. At the same time, sedimentation in the tarn near Brattahlid appears to have greatly increased during Norse occupation. This deposition could have resulted from normal human activities together with those of hard-hoofed animals rather than from widespread vegetation loss. From the chemical and mineralogical evidence presented, there is no reason to suspect that the soils could not have provided adequate nutrients for the subsistence grade of agriculture practised by the Norse settlers.

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