Erosion and Vegetational Changes in South Greenland Caused by Agriculture

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Pollen analyses and measurements of magnetic parameters in some lakes and ponds in sub-arctic South Greenland have shown, that after stable conditions through most of the Holocene drastic environmental, changes appeared as a result of the introduction of agriculture by the Norsemen c. A.D. 1000: the vegetation cover was broken by wood cutting and grazing, and soil erosion began. After c. five centuries the Norsemen died out, the vegetation began recovering and soil erosion decreased. After some centuries of stabilizing environmental conditions, the reintroduction of sheep breeding in the beginning of the 20th century has caused a new period of vegetational changes and increasing soil erosion.

Keywords: *Greenland, Holocene, pollen analysis, magnetic susceptibility, erosion.*

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Sheep and cattle grazing during the era of the Norsemen (A.D. 985-15th century) caused severe erosion and changes in the vegetation cover, undoubtedly among the major factors in the break-down of their community (Vebæk, 1943, Fredskild, 1973, 1978). Small-scale sheep-breeding, reintroduced in the beginning of the 20th century, was mainly based on year-round grazing in the nature. However, contemporarily with an increase in number of full-time breeders, some catastrophe winters in the 1960es, reduced the number of sheep from c. 48,000 to 20,000, the obvious signs of destruction of the plant cover, and of an increasing erosion, called for an alteration of the management. One of the many initiatives was the appointment and economic support in 1983 by the Greenland Home Rule Authorities and the then Danish Ministry for Greenland, a working group to follow the impact of sheep breeding on the environment. During its five years of existence, this group - a geographer, a botanist, a zoologist and an administrative chairman - initiated a number of investigations ranging from establishing of permanent fenced and unfenced reference areas (Feilberg, 1987) over pedological investigations (Jakobsen, 1991) to biomass measurements by remote sensing (Hansen, 1988). This paper shortly reports on another of the investigations, viz. botanical and magnetic analyses of lake sediments.

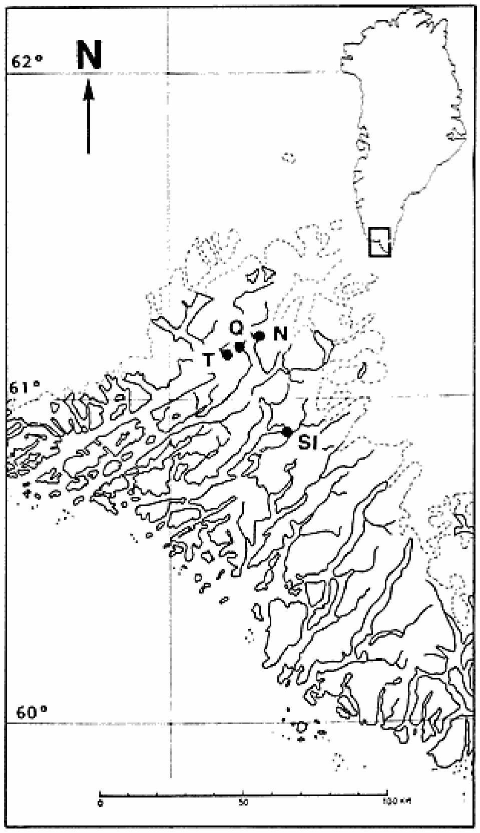

Fig. 1. Map of South Greenland. SI = Sdr. Igaliko, Q = Qassiarsuk, T = Tasiusaq, N = Narsarssuaq.

INVESTIGATION AREA

The interior S.Greenland has a sub-arctic, subcontinental climate with seven months above zero, peaking in July with 10-11° C, and a yearly precipitation about 600 mm. Strong, desiccating foehn winds from the Ice Cap are frequent all year round. Towards the outer coast the climate gradually changes to maritime, low-arctic. Here, sheep-breeding does not pay. Inland, ericaceous dwarf-shrub heaths of different species composition cover most of the ground from the sea to 5-700 m a.s.l. Below 200 m an open, 3-5 m high birch forest or, usually, a dense willow-birch copse covers the slopes on protected sites (Fredskild & Ødum, 1990). The fairly continental conditions are reflected in patchy, steppe-like communities dominated by i.a. Bellard's Kobresia and Three-leafed Rush.

METHODS

In 1988-89 corings with a 120 cm long Livingstone-sampler were undertaken from a raft in a lake (max. 325x175 m), 230 m a.s.l., east of Sdr. Igaliko (fig. 1). Samples for 14_C dating, magnetic measurements and macrofossil analyses, as well as 1 ml pollen samples were taken in the cores. To get undisturbed cores of the upper, very watery sediment, a 50 cm long Benoni-Enell sampler (Aaby & Digerfeldt, 1986) was used, some meters from the first coring site. The latter equipment, often containing c. 40 cm sediment from the gyttja-water interface downwards, was used from a tiny rubber dinghy in seven lakes and ponds. Pollen samples from these cores are not volumetrical. In the laboratory the pollen samples were processed by standard methods. At least 500 pollen of indigenous plants, excl. limnophytes, were counted in each sample. The sand in the 1 ml samples was decanted after acetolysis and weighed. The methods used, in measuring different kinds of magnetic susceptibility are described in Sandgren & Fredskild (1991). Some samples have been 14_C dated, and the contents of Cs-134 and Cs-137 were measured in 0.5 cm samples in the upper part of a Benoni-Enell core from the Sdr. Igaliko lake.

RESULTS

So far, magnetic measurements have been carried out in three, and pollen analyses in five of the recently cored waters. Magnetic measurements were made on stored samples from Galium Kær, taken in 1969. Pollen diagrams, 14_C datings and some botanical macrofossil analyses from this former pond are given in Fredskild (1973, 1978), which also contain palaeo-botanical analyses from one lake and five peat profiles at Qassiarsuk in the center of the Norse 'Eastern Settlement' (fig. 1). As the general trend in the pollen curves unambiguously points in the same direction, the Sdr. Igaliko lake will be used as an example. This lake, which has no inlet, is surrounded by gently undulating archaean bedrocks. Grassy, dry ground plant communities dominate; minor herb-slopes and low willow copses can be found on protected slopes. Southeast of the lake a 50 m high bedrock ridge has recently been severely eroded as indicated i.a. by a total lack of epilithic lichens. On the slope of this ridge towards the lake some vegetation-covered erosion remnants, 2-3 m high, indicate this erosion (fig. 2). Some of the sand is sedimentated in the nearest part of the lake where the bottom consists of almost pure sand. The corings, of which details are given in Sandgren & Fredskild (1991), were undertaken in the more protected NE corner. It should be noted that the pollen diagram (fig. 3) is based on the Livingstone cores as are the magnetic measurements of the deeper layers, whereas those of the upper layers were made on samples from a Benoni-Enell core from another site with a slower sedimentation rate (fig. 4). So, the depths in fig. 3 are not comparable to those in figs. 4 and 5.

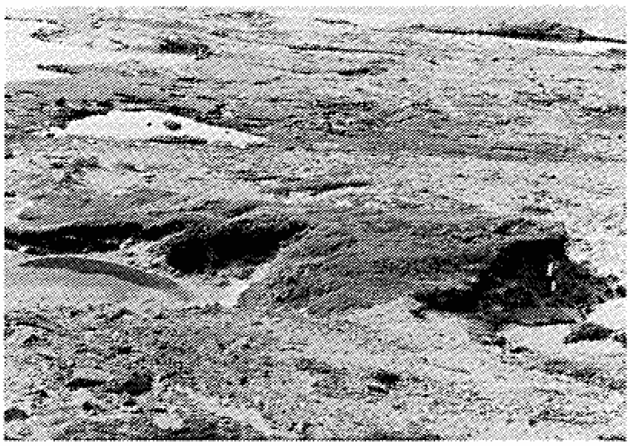

Fig. 2. Erosion at the south-east corner of the Sdr. Igaliko lake. Note person for scale.

Pollen Analysis

Sdr. Igaliko

In fig. 3 selected pollen curves are presented. Based on the terrestrial plants the diagram can be divided into six pollen assemblage zones:

a. Juniperus zone. The few Betula pollen, mainly of tree-birches as indicated by large pollen diameters (Fredskild, 1991) are long distance transported. Pteridophytes (ferns and clubmosses) are frequent.

b. Betula-Juniperus zone. First Betula glandulosa, shortly after B. pubescens immigrate. Gradually, the Betula-Salix copses with i.a. Angelica are spreading at the expense of Juniperus and other dry, open ground plants like Thalictrum and Botrychium. Besides being a result of competition among the plants, a climatic change around 4000-3500 14_C yrs B.P., registered all over S. and W.Greenland may be reflected. In the lake, a marked decrease in plankton productivity and a contemporary spreading of Myriophyllum alterniflorum and Isoëtes between the 89 and 81 cm samples, (not shown in fig. 3) most likely reflect the metachronous oligotrophication, common to most Greenland lakes (Fredskild, 1991). A sample 149-152 cm below lake bottom was dated at 4710 ± 75 14_C yrs B.P. (K-5197).

c. Betula-Salix zone. Judging from the pollen size the decrease in Betula is mainly caused by tree-birches. Salix remains at its highest level, Cyperaceae and Thalictrum increase. The amount of decanted sand (fig. 3) as well as the magnetic susceptibility (fig. 4) increase slightly. These evidences point to a change to more dry conditions as a result either of the temperature increase proved in the Ice Cap cores in the second half of the first millenium A.D., (Dansgaard et.al., 1975) or of the first indications of the

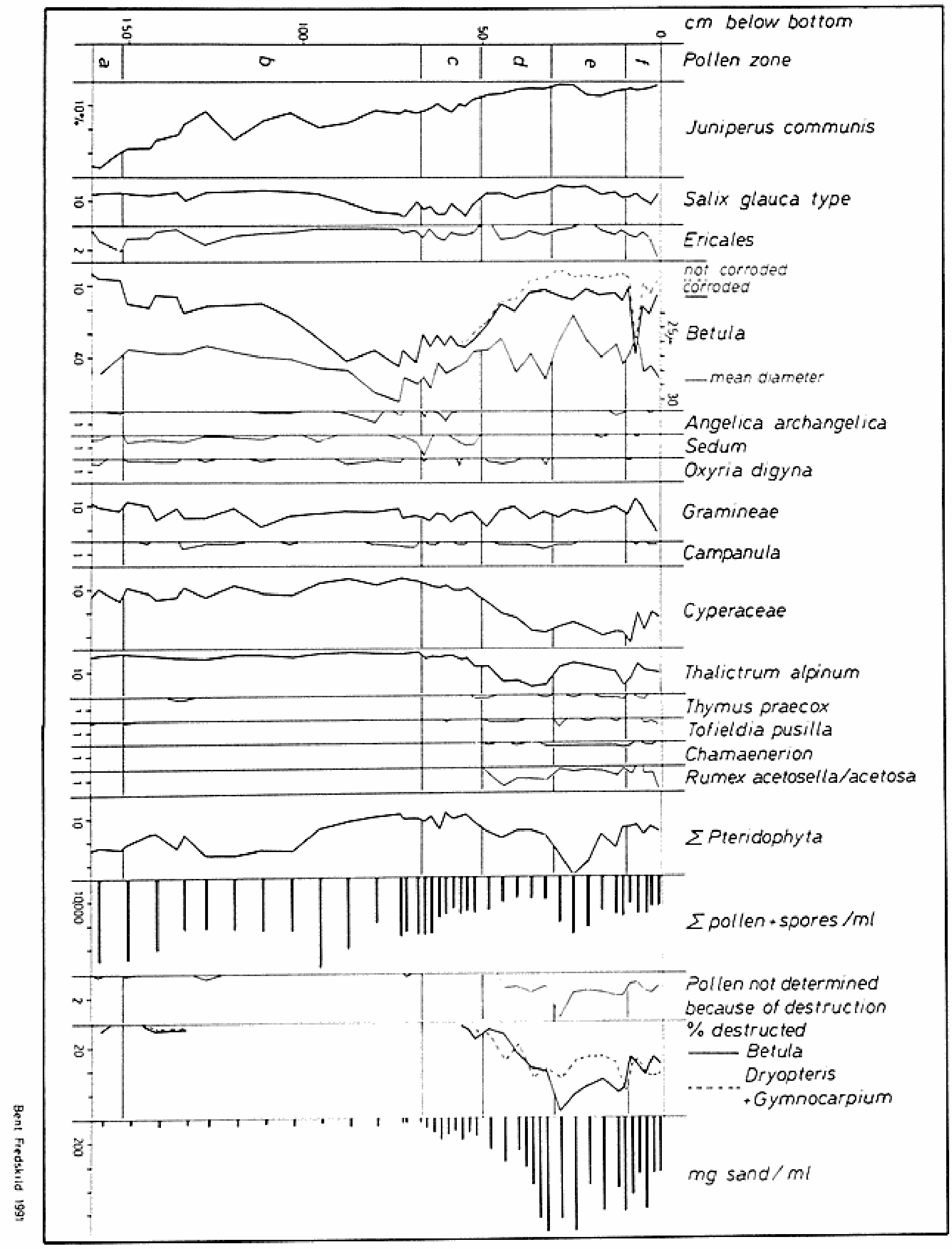

Fig. 3. Selected pollen curves from Sdr. Igaliko.

Norse landnam a couple of centuries later. The 14_C dating in the middle of the zone (59-62 cm: 1330±70 14_C yrs B.P., B-5311) does not immediately solve the problem as dating of gyttja usually is too old as a result of washing-in or blowing-in of old humus, and of a 'reservoir effect' caused by recycling within the lake of carbon. In Swedish lakes this usually gives a dating 3-400 years too old (Olsson, 1986). In two other Greenland lakes the dating of the landnam by limnic sediments is 2-300 years too old. As there are no indications of increasing supply of humus (see below) in this zone it is tempting to correct the dating by c. 300 years. If so, the changes at the beginning of the zone were climatically caused, accentuated during the later part by the landnam.

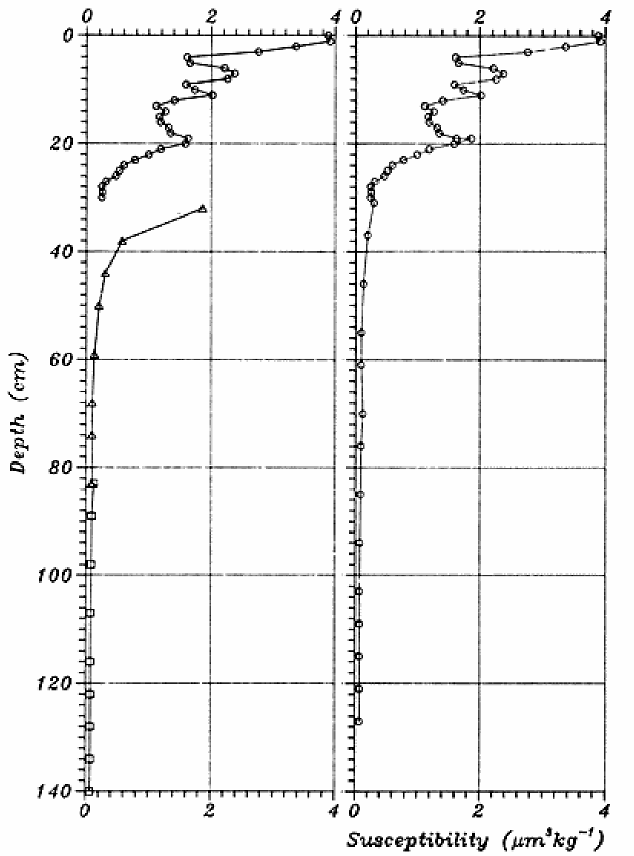

Fig. 4. Magnetic susceptibility of the Sdr. Igaliko sediment, related to original depths (left) in the Benoni-Enell core (circles) and Livingstone cores (triangles and squares). To the right a scale, 'corrected' by subtracting 13 cm from the Livingstone core depths. This scale is used in fig. 5.

d. Cyperaceae-Thalictrum-Rumex acetosella zone. By the opening of the zone the effect of the landnam is clearly reflected in the surroundings of the lake. Rumex acetosella and R. acetosa, both introduced by the Norsemen to S.Greenland spread, as did other dry, open soil plants like Thalictrum, Botrychium, Diphasiastrum and Selaginella. Cyperaceae, including fen plants like Eriophorum spp. and Carex saxatilis as well as dry soil plants like C. supina, and the today all dominating Kobresia myosuroides also increased. As there are no indications of increasing amount of fen plants, Kobresia most likely is the main supplier of Cyperaceae pollen. Juniperus, Salix and Betula, B. pubescens first, decrease as do Angelica and Sedum. In the middle of the zone the Betula pollen size increases, apparently indicating an increasing B. pubescens:B. glandulosa ratio. However, the drastic increase in destructed pollen at the same level proves that a still increasing part of the pollen and spores originates not from contemporaneous plants but from blown-in, older humus layers. During zones a-c only (0)2-5% of the pollen and spores showed any sign of destruction. Now a still increasing amount of the very resistant Betula pollen and Pteridophyte spores are destructed, often heavily, peaking at 76% of the Betula pollen in the 29 cm sample. In every sample several pollen were too badly preserved for a determination. If the destructed Betula pollen are excluded, the decrease in Betula percentages in this zone is even more drastic, as shown by the dashed curve.A sample 26-30 cm below lake bottom in the Benoni-Enell core was dated at 640 ± 50 14_C yrs B.P. (calibrated: 1281-1391 A.D., Lu-3145). By comparing the susceptibility curves (fig. 4), this corresponds to c. 40 cm in the pollen diagram. From around this level the amount of sand increases drastically as does that of destructed pollen. The sedimentation rate increases as a result of blown-in material, corroborated by a decrease in long distance pollen. Only exceptionally Cyperaceae pollen show signs of destruction indicating their being contemporary, presumably a result of the spreading of Kobresia to the freshly exposed, sandy soils.

e. Cyperaceae-zone. The transition d-e is marked by a decrease in some dry, open soil species like Thalictrum, Rumex (R. acetosella is and undoubtedly was far more common than R. acetosa), Campanula, Botrychium and Diphasiastrum. The increase in Juniperus, Chamaenerion and, towards the end, the reappearance of Angelica, all eagerly eaten by sheep, seem to indicate that sometime during this zone grazing was brought to an end. However, the many blown-in pollen blur the picture, illustrated by an AMS dating of a 16-18 cm sample in the Benoni-Enell core: 3520 ± 55 14_C yrs B.P. (ETH-6690), which tells that the sample mainly consists of a mixture of older, holocene material of any age. In order to date the most recent sediments, the contents of Cs-134 and Cs-137 were measured in 0.5 cm thick samples in the upper 10 cm of another Benoni-Enell core (fig. 6): The uppermost one centimeter was too loose to be divided. The Tjernobyl Cs-134 was only found in this sample, indicating that bioturbation at the water/gyttja interface is minimal. Thus, the upper c. 5 cm have been sedimented since 1945.

f. Gramineae-Rumex acetosella zone. A decrease in Juniperus and an increase in Rumex indicate the present grazing. The peak in Betula in the 7 cm sample, caused, beyond doubt, by macroscopically induced, contemporary B. glandulosa pollen is disregarded. However, the landnam is more pronounced in the magnetic measurements (figs. 4 and 5) and in pollen diagrams from other lakes, of which a couple shall be mentioned briefly.

Tasiusaq S

The decrease in Juniperus and in the Betula pollen size,

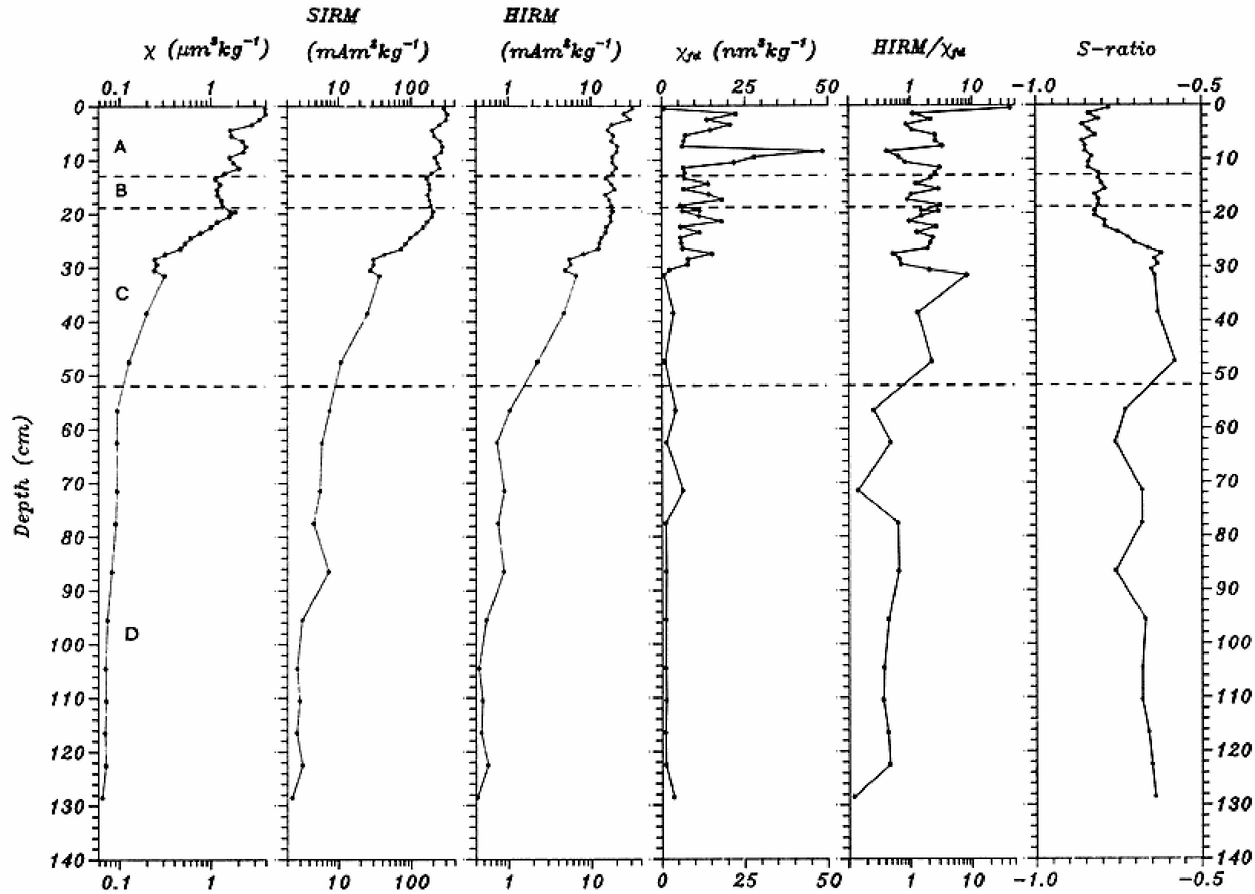

Fig. 5. Magnetic parameters of the Sdr. Igaliko sediment.

and the increase in charcoal at the 20 cm level (fig. 7) is taken as indications of the landnam. The Norse era ended at c. 10 cm, and the present century grazing is traced in the uppermost 3 cm, i.a. with the first Rumex pollen. Magnetic measurements were made on the sediments of this lake, which is further discussed in Sandgren & Fredskild (1991).

'Fåredam'
Benoni-Enell cores were taken in a 175x75 m pond northeast of Hestesporsø, southwest of Sdr. Igaliko. It is rich in limnophytes and the high productivity is illustrated by the fact that the last millennium since the Norse landnam is not even covered by the 46 cm gyttja obtained (fig. 8). In the middle of the diagram the gradual decrease in Rumex and Plantago maritima, and the increase in Juniperus and Angelica, supposedly reflect the close of the grazing period half a millennium ago. In the uppermost three cm reverse trends, reflect the present sheep grazing. Neither datings nor magnetic measurements are available.

Hestesporsø
This is the case, too, with a 36 cm core from the protected, northernmost creek of this more than two km long, narrow lake. At the east side, facing the valley towards Sdr. Igaliko, the lake bottom consisted of almost pure sand. The pollen curves are similar to those of the nearby pond ('Fåredam') with a gradual recovery of the scrubby plants and a decrease in Rumex beginning slightly above 30 cm. In this lake, the recent grazing is first registered around 7 cm below the bottom. In the nearby, even larger Skyggesø only a 25 cm core was obtained. Again, the uppermost three samples, covering 5 cm show a marked increase in Rumex and Thalictrum and a decrease in Juniperus and Betula.

Magnetic Measurements

As an example of the results of the performed magnetic analyses, some magnetic parameters from the Sdr. Igaliko lake sediments will be shortly presented (Figs 4-5). For references and detailed discussions of all the magnetically

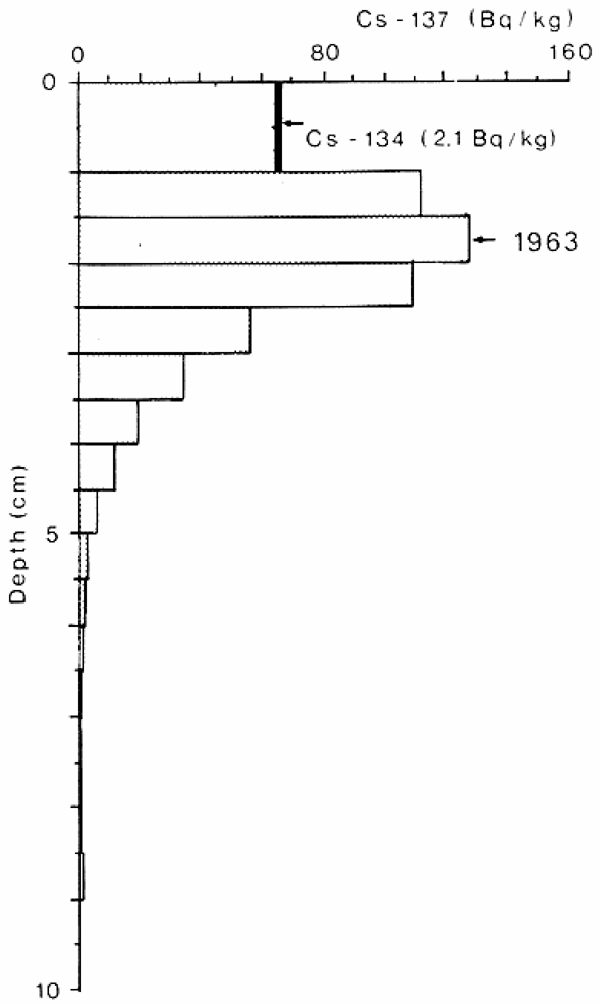

Fig. 6. Cs-diagram from the top 10 cm of the Sdr. Igaliko sediment.

investigated sites, see Sandgren & Fredskild (1991). The magnetic susceptibility (X) is largely a function of the amount of ferrimagnetic minerals in a sample, mainly magnetite and maghaemeite. Based on X values the Sdr. Igaliko lake sediment

succession has been separated into four units (fig. 5, A-D). Low and stable values characterize the lowermost unit D. From about the 50 cm level, values increase rapidly. The uppermost four samples in unit A, thus have the highest X values, being about 50 times higher than those in the lower part of unit D. The Saturated Isothermal Remanent Magnetization (SIRM) is an alternative measurement to X. This parameter is, however, influenced by somewhat different factors compared to the susceptibility. Similar to susceptibility, SIRM starts to increase significantly at about 50 cm. HIRM (High field Isothermal Remanent Magnetism) is a measure of the concentration of antiferromagnetic minerals (mainly haematite). This parameter also shows an increased concentration in the sediments from about the same level. Thus, all three concentration parameters (X, SIRM and HIRM) reflect an increased amount of magnetic particles in the sediment from about the 50 cm level. The S-ratio can be used as a first guide in discriminating between the relative proportions of ferrimagnetic versus antiferromagnetic mineralogies. In general the sediments in this basin are dominated by magnetite with a small admixture of haematite to about 25 cm, whereas the uppermost part seems to consist entirely of magnetite. The frequency dependent magnetic susceptibility (X_{fd}, the difference of magnetic susceptibility measured at two different frequencies) reflects magnetic grains of a very defined size. Whereas bedrock samples exhibit no frequency dependence, surficial soil layers often do. Two main processes are envisaged as leading to this so called top soil magnetic enhancement,

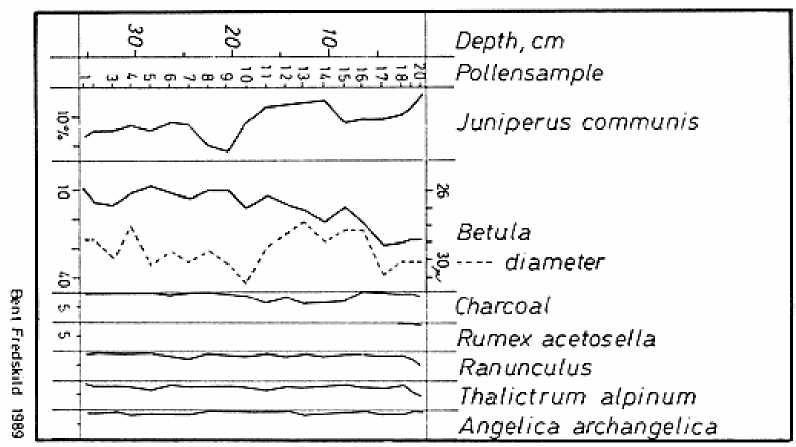

Fig. 7. Selected pollen curves from Tasiusaq, lake S.

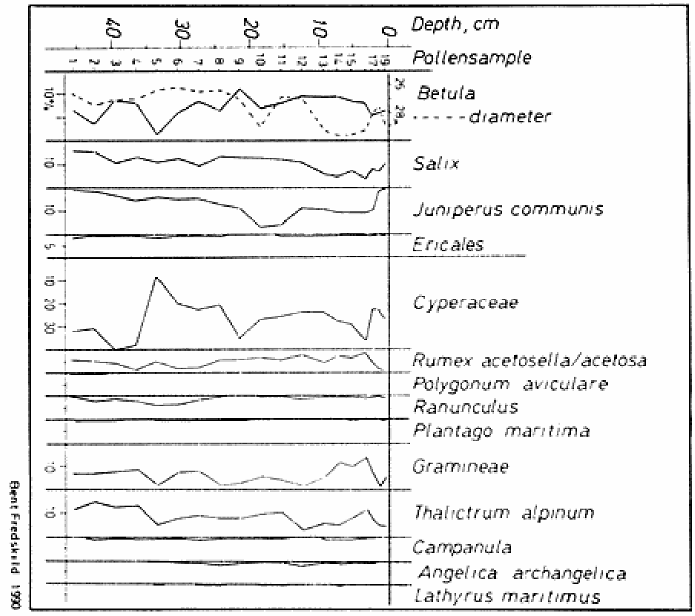

Fig. 8. Selected pollen curves from 'Fåredam'.

viz. a) pedogenic reduction-oxidation cycles, and b) burning. The presence of frequency dependent magnetic grains (or secondary formed ferrimagnetic grains) in a sediment succession thus points to an input of top soil material into the basin as a result of disturbance in the catchment. In the case of the Sdr. Igaliko lake sediments, a marked change takes place around the 30 cm level, in that the preceding period of low and stable values of less than 5 $\mu m^3 kg^{-1}$ are succeeded by far higher values. An even more clear picture of the dramatic change that obviously started in the landscape, documented at about the 50 cm level, is revealed by the HIRM/X_{fd} ratio. The increased ratio of antiferromagnetic to secondary ferrimagnetic grains along with the increased magnetic concentrations starting at the same level, indicate a clear top soil source of the material washed or blown into the basin.

CONCLUSION

All pollen analytically and magnetically analyzed sediment successions in this part of South Greenland, exhibit a similar development. Based on changes in the magnetic parameters the period since the deglaciation can be separated into six units (A-F, Sandgren & Fredskild, 1991), the upper four of which (A-D) are documented in the above presented site. The units, corroborated by pollen analyses, reflect periods of different conditions in the environment due to the establishment, spreading and successions of plant communities after the deglaciation and especially to periods of intense human activity by sheep grazing and forest clearance. During the local late-glacial period the open, unstable and exposed soils were sparsely covered by pioneer plants. Magnetically this oldest unit (F) is characterised by high concentrations of magnetic minerals, indicating high erosion rates. This development is seen as decreasing concentrations of magnetic minerals in the sediments (unit E). A period lasting for several millenia then followed, with well established vegetation cover and stable soil conditions. Erosion rates were at minimum indicated by the low concentrations of magnetic minerals in the sediments, characteristic of unit D. It is worth noting that neither lake sediments nor any of the many soil profiles investigated along a transect from close to the Ice Cap to the outer coast, show signs of increased aeolian sedimentation during this period (Jakobsen, 1991). This equilibrium between plant cover, climate, and soils was broken by the arrival of the Norsemen and their grazing animal (unit C). After some time erosion accelerated. Concentrations of magnetic minerals in the sediments show increasing values, along with a significant rise in the amount of secondary ferrimagnetic grain as evident in the Sdr.Igaliko lake. Close to the farmsteads in the Norse settlement at Sdr. Igaliko, there is evidence of erosion shortly after the landnam by dating of charcoal found on top of an original A-horizon, covered by more than half a meter of sand loess (Jacobsen and Jakobsen, 1986). In more distant areas the severe erosion began somewhat later, as e.g. in the Sdr.Igaliko lake sediments and in many soil profiles (Jakobsen, 1991). After the extinction of the Norsemen, the vegetation, as reflected in the pollen diagrams, indicates a renewed period of recovery and stabilisation (unit B). Decreasing erosion is also documented in the soil profiles and in the lower concentrations of magnetic minerals in the sediments. This period of renewed stabilisation was, however, interrupted by the present century landnam, which in inland areas has caused very severe erosion. This period is represented by unit A with magnetic concentration in the sediments, again in the same order of magnitude as during the late glacial period, accompanied in the top of the Sdr. Igaliko sediments with the highest HIRM/X ratio in the entire profile. Luckily this devastating development has now been realised by the authorities and the sheep-breeders' organisation who has started to change the management, i.a. to stable-feeding during winter when the vegetation is most sensitive to grazing, and by fencing of the most vulnerable areas.

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