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Glacial History of East Greenland Explored

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To study the glacial and environmental history of East Greenland dating back to late Quaternary time, the polar research vessel *Polarstern* took its third cruise to the East Greenland Sea from August 17 to October 6, 1994, where it served as a platform for shipboard investigations and field observations. A variety of techniques were employed: sediment coring and seismic profiling were carried out in the fjords as well as on the continental shelf and slope. And, for the first time, these investigations were supplemented by profiling and coring in periglacial lakes.

Preliminary analysis of the data gathered has already resulted in several noteworthy findings. A submarine morainic ridge was discovered at the entrance of Davy Sund/Kong Oscar Fjord, which probably indicates the greatest extent of the Greenland Ice Sheet during the last glacial maximum. Complete postglacial sediment sequences were recovered both offshore and onshore. Study of these sequences will lead to a basic understanding of the marine and lacustrine sediment formation with respect to late Pleistocene and Holocene ice margin variations. Annual meltwater layers---varves---throughout the postglacial history of one of the periglacial lakes were also discovered; they promise to be useful as a source of high-resolution temperature record for East Greenland.

Marine Geological Investigations

The main goal of the marine geology program of the *Polarstern* cruise was to study sedimentary and biogenic processes within the major fjord systems and along the continental margin of East Greenland. Sedimentary and biogenic processes are strongly affected by factors controlled by the Earth's climate, including the cold East Greenland Current, the extent of the Greenland Ice Sheet, the permanent or seasonal sea ice cover, calving of icebergs, and meltwater input. Detailed sedimentological, geochemical, mineralogical, and micropaleontological investigations will help researchers reconstruct the late Quaternary glacial history of the East Greenland margin and find correlations among the terrestrial and marine records.

To study the sedimentary and biogenic processes of East Greenland, comprehensive geological sampling was performed at 43 stations using a giant box corer and a gravity corer (Figure 1). All coring positions were selected based on sediment echo sounding using a parametric frequency of 4 kHz, which allowed subbottom penetration up to 100 m with a vertical resolution of 30 cm. Excellent, undisturbed near-surface samples and sediment cores more than 11 m in length were recovered. Study of most of the sediment cores began aboard the ship. Also performed aboard the ship were the first microscopic investigations of smear slides and coarse fractions, and determinations of magnetic susceptibility, density, and acoustic compressional wave velocity. These first investigations have already led to a fairly accurate picture of the depositional environment and how it has changed since the last glacial maximum.

The distinct changes in composition, texture, and grain size of the sediment sequences from cores taken on a west-east profile of the inner Kejser Franz Josef Fjord system via the shelf to the lower continental slope (Figure 1), and the variations of these parameters throughout the sequences (Figure 2) indicate two important points. Different mechanisms have controlled the sedimentation, and the relative importance of these mechanisms has changed through time. The sedimentary sequences can be divided into four main lithological units---A, B, C, and D---which can also be identified in the magnetic susceptibility and density records. The open ocean cores show that the clay of unit A is silty, dark grayish-brown, and bioturbated. It also contains an abundance of foraminifera and nannofossils. Unit B is characterized by abundant 0.2--0.8-cm-thick sand layers intercalated every 0.5 to 2 cm with the silty clay lithology. Coarse-grained, ice-rafted detritus is absent. Unit C consists of olive, dark olive-gray, and dark grayish-brown silty clay, intercalated with layers/horizons of dark olive-gray and dark reddish-gray, sandy, silty clay with common ice transported dropstones and mudclasts (diamicton).

Unit D is a diamicton, composed of dark olive-gray, sandy, silty clay with common to abundant dropstones. The dropstones may

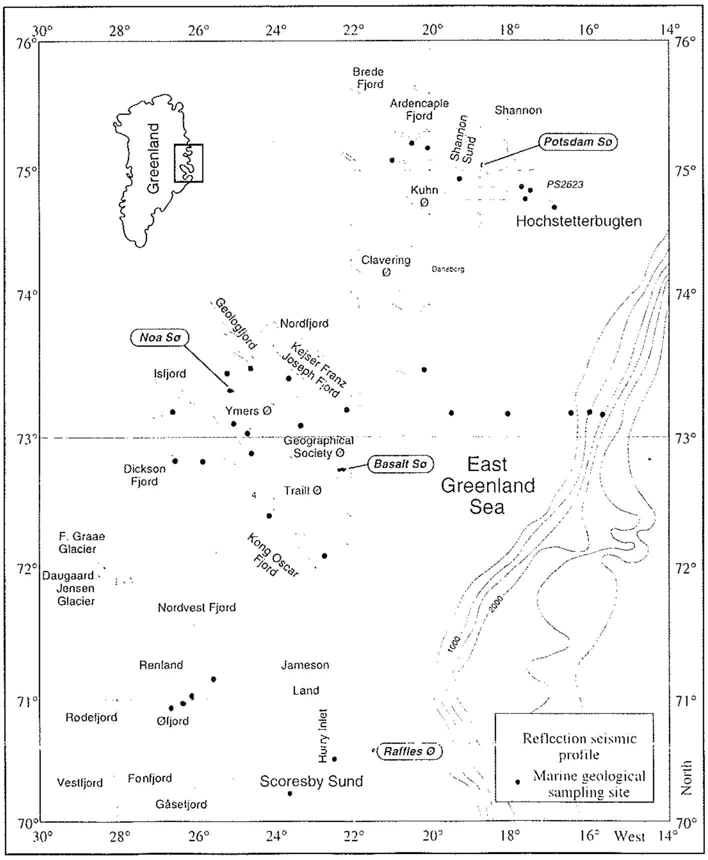

Fig. 1 Working area of RV Polarstern cruise ARK-X/2 at East Greenland showing the marine geological sampling sites, the lakes studied during the expedition, as well as the reflection seismic profiles.

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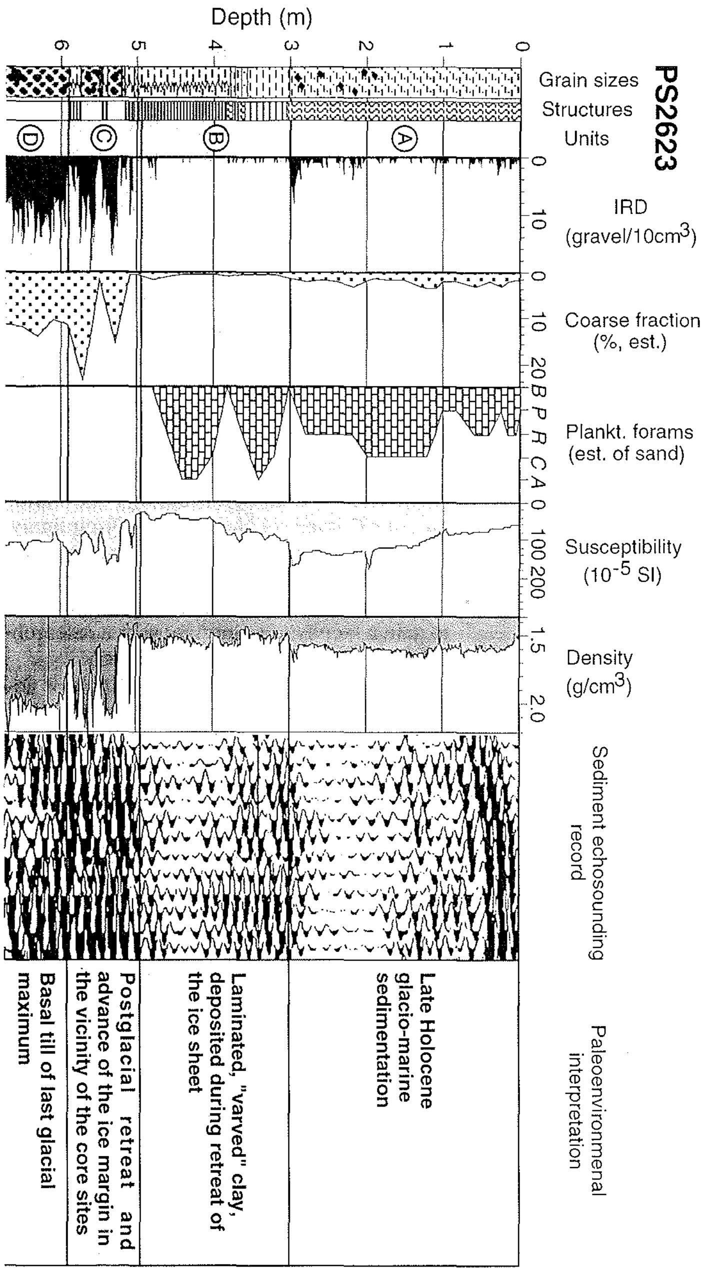

Fig. 2 Lithology, IRD content, coarse fraction abundance, content of planktonic foraminifera in the coarse fraction (B = barren, P = present, R = rare, C = common), susceptibility and density, and sediment echo sounding record of core PS2623-4.

reach diameters of >10 cm. Trace amounts of planktonic foraminifera occur throughout unit D. The variations of the Greenland Ice Sheet during the last glacial-interglacial cycle—that is, the transition from the last glacial maximum to the Holocene—is best documented in the sedimentary sequence of core PS2623, which was taken from the shelf south of Shannon Island (Figures 1 and 2). The overconsolidated, stiff diamicton recovered in the lowermost part of this core (unit D) suggests that the glaciers of the East Greenland continental ice sheet probably reached the shelf south of Shannon Island and extended to the east to at least 17°30'W during the last glacial maximum. This interpretation is supported by the occurrence of a similar diamicton with a ^{14}C age slightly older than 15,000 yr BP on the East Greenland shelf at 65°N [*Mienert et al.*, 1992], and the maximum occurrence of ice-rafted detritus recorded on the East Greenland continental slope between 69°N and 75°N at about 16–22 Ka [*Nam et al.*, 1995].

The retreat of the glaciers from the shelf at the end of the last glacial—that is, deglaciation—is recorded in the finely laminated silty clay lithology (unit B) deposited in a proglacial environment. The retreat of the glaciers was gradual, interrupted by several readvances as indicated in the intercalated diamictons in the lower part of the laminated sequence. The diamicton intervals are clearly indicated by maximum susceptibility and density values and maxima for the terrigeneous coarse fraction (>63 mm); foraminifera are absent (unit C). The Holocene is documented in the bioturbated glaciomarine sediments characterized by minor but significant amounts of ice-rafted detritus and foraminifers (unit A). Dark olive gray and very dark gray sediment colors and the abundance of black spots representative of high amounts of iron sulphides indicate reducing conditions, probably caused by the decomposition of marine organic matter by the activity of sulfate-reducing bacteria. High sedimentation rates and somewhat increased surface water productivity resulting from the reduced Holocene sea ice cover may explain the increased flux and preservation of marine organic matter in these sediments.

Seismic Reflection

The extent of the Greenland Ice Sheet during the last glacial maximum is only poorly understood. But relicts of this glacial period, such as moraines, should be found on- and offshore. Several onshore geological expeditions have included the mapping of such structures in their programs. In 1994 a seismic reflection program was conducted to investigate glacial structures that indicate the greatest extent of the Greenland ice sheet during the last glacial period.

A total of about 1100 km of reflection seismic lines were measured at the mouths of three big fjord systems: Brede-/Ardencaple Fjord-Hochstetterbugten, Kejser Franz Josef Fjord, and Kong Oscar Fjord/Davy Sund (Figure 1). Although glacial features were observed onshore, moraine structures were not detected in the Brede/Ardencaple Fjord-Hochstetterbugten or at the entrance of the Kejser Franz Josef Fjord. In contrast, a large morainic feature has been partially delineated offshore from Kap Simpson at the Davy Sund/Kong Oscars Fjord entrance. The morainic ridge shows a hummocky surface and is approximately 75 m high and 7 km long. It occurs about 3 km to the south of Kap Simpson, decreases in amplitude toward the center of the fjord, and becomes a fairly uniform layer of deposits about 45 m thick with a flat top surface.

Subsurface Profiling and Sediment Coring in Periglacial Lakes

Sediment sequences from periglacial lakes are one of the best natural data archives in high-latitude areas for reconstructing Late Pleistocene and Holocene environmental and climatic history. In polar regions, lake sediments are mostly laminated and free from any disturbance by bioturbation. Furthermore, commonly occurring high organic carbon contents often enable detailed age determinations via radiocarbon dating. Thus through comparisons of the paleolimnological results to marine geological investigations on the continental margin, and to glaciological investigations from ice coring, new information concerning both the late Quaternary environmental history of East Greenland and the correlation of the land and ocean records is expected.

Sediment coring was carried out in six lakes in four different areas of the East Greenland coast: a small lake on Shannon Island; Noa Lake and a small lake north of it on Ymers Island; Basalt Lake and a small lake south of it on Geographical Society Island; and a small lake on Raffles Island offshore of Jameson Land (Figure 1). On Potsdam, Noa, and Basalt Lakes, the three largest, the coring locations were selected for their large-scale sedimentary architecture, which was investigated by subsurface profiling with a sediment echo sounder.

The lake sediment sequences were sampled using gravity corers and piston corers, from a platform positioned over open water or lake ice. In the six lakes investigated, a total of 66 m of sediment were recovered from 27 sampling sites. The longest sequences were obtained from Noa Lake (9.6 m), from the small lake south of it (7.3 m), and from Basalt Lake (9.9 m, Figure 1). The lacustrine sediment basis was reached at least at three sites in Noa Lake, where it probably directly overlays basement rocks, and at one site in Basalt Lake, where a moraine was recovered at the sediment basis. These sequences comprise the complete glacial and postglacial lake histories.

First results, based on subsurface profiling and sediment description, indicate that in the major portion of Noa Lake a varve sedimentation took place throughout more or less the entire history of the lake. This varve sedimentation results from an annual terrigeneous sediment supply from an ice cap in the nearby southern lake and from a depression in front of the main inflow, which functions as a trap for coarse-grained sediments. Also, the complete coverage of the lake by ice in wintertime favors accumulation of the fine-grained suspension load following Stokes-Law. From the sequences recovered from Noa Lake, we expect to find a very long-ranging varve chronology for East Greenland. All other lakes sampled during the expedition are characterized by a much lower terrigeneous sediment input, at least in modern times, resulting in higher contents of biogenic components and organic carbon. The samples of the other lakes also differ in that sediment composition changes are more pronounced in grain-sized distribution, sediment color, and physical properties. Three unconsolidated sediment units are obvious in the susceptibility, density, and *P* wave velocity variations, as well as in the subsurface profile (Figure 3). One of these units is probably a moraine. It lies below ~9.8 m and ~5.5 m in an irregularly stratified and partially graded unit that probably represents the initial lake stage and its rapid sedimentation. A well-stratified unit, which may result from a highly energetic, rhythmic sedimentation, lies between ~5.5 m and ~3, and a massive unit that probably represents the quiet, pelagic sedimentation of modern times is present in the uppermost ~3 m.

The paleoclimatic program was complemented by a deep seismic survey to investigate the crustal structure and composition up to 76°N. Refraction seismic studies carried out in 1988 and 1990 as well as earlier gravimetric data [*Forsberg*, 1991], suggested a crustal thickness of 45--60 km for the East Greenland Caledonides in the Scoresby Sund area, indicating the occurrence of a crustal root, which is typical only of young mountains. During this cruise, automatic recording stations were deployed on nunataks as far west as possible to receive signals from the westernmost deep gradient area at approximately 26°W along the Kong Oscar/Kejser Franz Joseph fjord systems. Eight deep seismic sounding profiles, with a total length of 1750 km, were shot in three different areas.

Results of laboratory investigations of the cores (for example, stable isotope investigations on foraminifera, palynological and sedimentological studies), carried out since the expedition, suggest that the material and data recovered can be used to construct a deglaciation model of East Greenland in the near future.

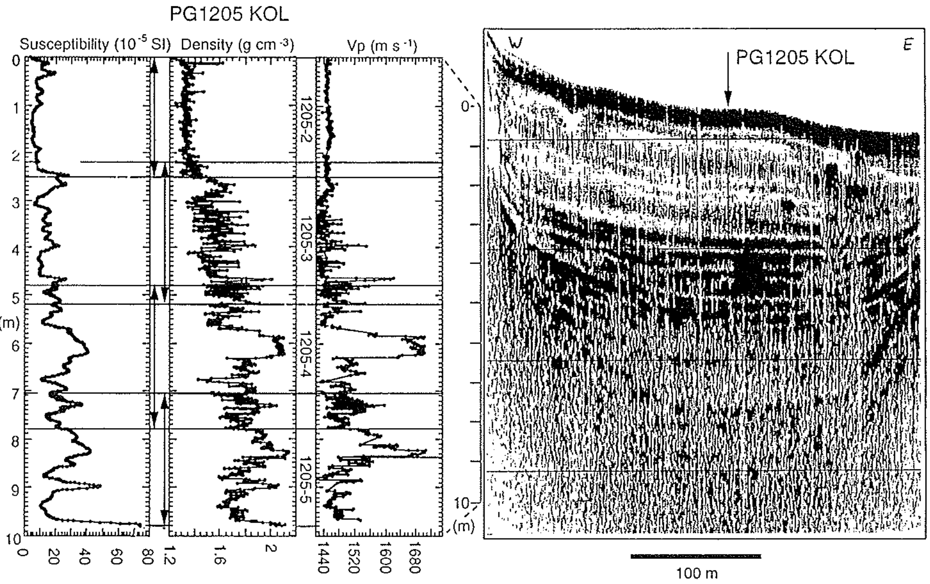

Fig. 3 Susceptibility, density, and P *wave velocity of lake sediment core PG1205 (left), compared to the subbottom seismic profile at the coring locality (right).*

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