DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2001/103

Stratigraphy, seismic sequences and depositional evolution of the Paleocene – Eocene Succession, offshore southern West Greenland

James A. Chalmers, Ulrik Gregersen, Finn Dalhoff,
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MINISTRY OF ENVIRONMENT AND ENERGY

GEUS

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Final Report. EFP-Project 1313/99-0025

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G E U S

Contents

Description of the Project

In the 1970s the continental shelf offshore southern west Greenland was explored for hydrocarbons by the oil industry. A total of around 40 000 km of 2-D seismic data were acquired and 5 exploration wells were drilled in 1976 and 1977. All of these licences were relinquished by 1979, because at that time the industry interpreted the results of the exploration to indicate that the southern West Greenland basin either lacked hydrocarbons or at best contained only gas. The results of this phase of exploration were summarised in a series of papers from both Grønlands Geologiske Undersøgelse, GGU and some of the oil companies.

In 1987 GGU (Danmarks og Grønlands Geologiske Undersøgelse, GEUS, after 1995 when GGU was integrated with Danmarks Geologiske Undersøgelse, DGU, to form GEUS) started a new investigation of the structure, development and hydrocarbon potential of the areas offshore southern and central West Greenland and onshore central West Greenland using new techniques of processing and interpretation of seismic data that had been developed during the 1980s. This work was supported by Råstofforvaltning for Grønland, who, in 1990, 1991 and 1992 provided funds to GGU for the acquisition and processing of seismic data. Additional seismic data were acquired and processed in 1995 by GGU/GEUS with funds provided by the Government of Greenland, Bureau of Minerals and Petroleum and the Danish State through the Mineral Resources Administration for Greenland. As a direct result of GGU/GEUS' work, licences to explore for hydrocarbons were granted to oil exploration offshore in the so-called Fylla (1996) and Vest Sisimiut (1998) areas. An exploration well (Qulleq-1) was drilled in the Fylla licence in 2000.

New work was also started in the late 1980s in the so-called Nuussuaq Basin, onshore central West Greenland, where Mesozoic and Tertiary sediments are exposed. Initially the work onshore was expected to provide analogues for interpreting the sediments offshore that were being investigated using the seismic data. When, however, in 1992 bitumen was discovered in vugs in basalts, attention began to focus on the petroleum potential of the Nuussuaq Basin itself. Since the original discovery, oil and bitumen have been found in surface outcrops over a wide area in western Nuussuaq and also on the north side of Disko and on the southeast corner of Svartenhuk Halvø. Furthermore, oil bled freely from the cores of two of the five slim core wells drilled in western Nuussuaq in 1993–95 drilled by both by GGU and by grønArctic Energy Inc., a Canadian company that held a concession in western Nuussuaq from 1994 to 1998. A conventional well was also drilled by grønArctic Energy Inc. in western Nuussuaq in 1996 (GRO#3). As part of GGU/GEUS' work, the existence of a potential hydrocarbon reservoir system was recognised in the so-called Itilli Formation in western Nuussuaq, a deep-water turbidite fan complex.

The Fylla and Vest Sisimiut licences are over structural prospects, i.e. situations where it is hoped that hydrocarbons may be trapped because of the structural configuration of the sediments. However, during regional structural interpretation of seismic data acquired by GGU/GEUS in 1990, 1991, 1992 and 1995 offshore southern West Greenland, the existence of complex high-stand and low-stand fan systems that could be stratigraphic traps for hydrocarbons was recognised. The Itilli Formation in Western Nuussuaq may be an onshore analogue for some of these units. Such traps are well-known from other parts of the world, for example the North Sea and the Faeroe-Shetland Channel.

In the present project, this type of trap was investigated using an integrated sequence stratigraphic approach based on interpretation of the seismic data acquired by GGU/GEUS in 1990, 1991, 1992 and 1995, supplemented by industry data acquired by Halliburton Geophysical Servise (HGS) in 1990, that was confidential when acquired, but is now old enough to be open-file and academic data acquired by Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) in 1977 and reprocessed by GGU in 1989 and 1990 with financial support from efp (efp projects 1313/89-5 and 1313/90-0013). The seismic interpretation was controlled by new lithostratigraphic, sequence stratigraphic and biostratigraphic interpretations of the data from the 5 wells drilled in the 1970s. Data from Qulleq-1 has been used to control the southern parts of the interpretation. Qulleq-1 was drilled in 2000 and data from the well became open-file in early 2001.

Work carried out

Work carried out in 1999

Seismic Interpretation

A grid of seismic lines that cover the whole of the West Greenland basin south of 68ºN was assembled on a 'Landmark' workstation. The grid consisted of all the seismic lines acquired by GGU and GEUS in the 1990s plus lines acquired by Halliburton Geophysical Service (HGS, now Western Geophysical) in 1990 that are now open-file. The total available grid of digital data amounts to 9694.4 km. These data have been supplemented by use of some regional lines from the 1970s which are now open file and are available on paper.

An interpretation has been made of the interval between the 'Kangeq' Sequence (Upper Cretaceous) that was defined by Chalmers et al. (1993) and the regional unconformity that now appears to be of mid-Eocene age defined by Chalmers et al. (1995). At the end of 1999, the interpretation was complete on all of the data on the Landmark work-station.

A total of 28 seismic sequences were defined, i.e. units that are bounded above and below by disconformities. Many of these seismic sequences are local and may consist of delta or fan lobes of limited lateral extent. Only about a third of the sequences could be tied to the wells.

Interpretation of lithology from petrophysical logs

Interpretation of the petrophysical logs was started on a "Landmark" workstation during the autumn of 1999 by checking the quality of the data. The data were produced in the early 1990s by digitising the original analogue paper copies, scale 1:200, after which they were entered into GEUS' database.

By the end of 1999, a lithological interpretation of Hellefisk-1 had been completed. Six different lithologies have been defined: sandstone, silty medium sandstone, silty fine sandstone, clay, mudstone and volcanic rocks. This interpretation of the lithologies is tentative, and may be altered during interpretation of the other wells.

The lithological interpretation was done by first dividing the well into intervals within which the curve patterns fall into the same maximum and minimum values to define "baselines", which are lines that define 100% mudstone or 100% sandstone. Information about the lithology is thereafter obtained from the log data and from the "mud log" produced during the actual boring of the well. "Mud logs" are, among other information, descriptions of the cuttings returned to the surface in the drilling mud.

On completion of the lithological interpretation, a preliminary sequence stratigraphic interpretation was made, and a report was started to document the interpretation of the Hellefisk-1 data.

Biostratigraphy

Palynomorphs

Dinoflagellate cysts from Nukik-2 have been restudied in detail in order to refine the zonation of Toxwenius (1986).

Palynological processing of 86 samples was carried out by GEUS´s palynological laboratory in 1999:

From Hellefisk-1, 18 SWC (sidewall core) samples have been processed.
From Kangamiut-1, 19 SWC samples have been processed.
From Nukik-1, 10 SWC samples have been processed.
From Nukik-2, 9 SWC samples and 30 ditch cutting samples have been processed.

75 samples from Nukik-2 were restudied and analysed during 1999, and range charts were plotted. Most of these samples were processed at the Geological Survey of Greenland (GGU) and by Mobil during the 1970's and the early 1980's.

Microfossils

Microfossils from selected intervals in the wells Kangamiut-1, Nukik-1 and Nukik-2 were studied in detail in order to refine the microfossil zonation of Toxwenius (1986).

123 samples from Kangmiut-1, 109 samples from Nukik-1 and 86 samples from Nukik-2 were studied and analysed during 1999, and range charts were plotted. Several of the samples were prepared and sorted at the Geological Survey of Greenland during the early 1980's. These samples were restudied. The remaining samples were prepared at GEUS by

wet-sieving of the 63-1000 µm sediment fraction followed by drying and picking. If the microfossil content was very low, the 63 - 500 µm fraction of the samples were gravity-separated in bromoform (δ = 1.8 g/cm3) after the sieving. This process tends to concentrate the foraminifera and radiolaria in the light fraction, while pyritized diatoms will sink to the bottom as part of the heavy fraction. The technique is more time-consuming in the laboratory, but normally reduces the picking-time considerably.

Nannofossils

A nannofossil analysis was carried out on the interval 1844m-2301m in the Nukik-2 well. Mobil Exploration Greenland Inc. undertook an earlier study on the nannoflora from this well. The present study aimed to refine these results.

43 samples from Nukik-2 were examined for nannofossils. In the time available, it was considered sensible to work with one length of the slide coverslip and record every nannofossil occurrence. This method ensures that reasonable coverage of the slide is made, accounting for 'clustering' of sediment grains (thereby concentrating any nannofossil occurrences) or 'barren spots' (where sediment did not adhere to the slide or where a bubble may have formed in the mounting medium). In general, nannofossil occurrence was very rare and several samples were barren. Any specimens that were present were very poorly preserved. The fossils had been badly overgrown and the calcite that usually comprises nannofossils had been diagenetically changed. Whereas nannofossil identification is usually made with reference to optical properties using bright field and cross polarised light, the poor preservation of the fossils in Nukik-2 meant that identification was made almost solely upon shape and size.

Work carried out in 2000

Seismic interpretation

In 2000, "seismic facies analysis", i.e. describing and interpreting the patterns of reflections within each of the seismic sequences defined in 1999, was initiated. The analysis focuses on the description of the internal reflection configurations, distinguishing morphological features (e.g. mounds and progradational units) and the amplitude level. By the end of the year, a third of the sequences had been described and mapped. Correlation of the sequences to the wells in the area was initiated.

Interpretation of lithology from petrophysical logs

Interpretation of the petrophysical logs on a "Landmark" workstation continued during 2000. All depths and descriptions of 550 sidewall cores were loaded to use during the lithological interpretation.

By the end of 2000, lithological interpretations of Hellefisk-1, Ikermiut-1 and Kangamiut-1 were complete and tentative correlations with the seismic sequence stratigraphy and the biostratigraphy of dinoflagellates had been made.

Biostratigraphy

Palynomorphs

Dinoflagellate cysts from the Ikermiut-1, Hellefisk-1, Kangamiut-1 Nukik-1 and Nukik-2 wells were restudied in detail in order to refine the zonation of Toxwenius (1986) and the dinoflagellate cyst stratigraphy of Nøhr-Hansen (1998).

Palynological processing of 20 DCS (ditch cutting samples) samples from Hellefisk-1 has been carried out by GEUS´s palynological laboratory in 2000.

The 106 palynological samples (Hellefisk-1: 18 SWC, 20 DCS; Kangamiut-1: 19 SWC; Nukik-1: 10 SWC; Nukik-2: 9 SWC and 30 DCS) that GEUS´s laboratory processed in 1999 and 2000 have been studied. The data has been included to fill in gaps, where previously studied samples have yielded little or no biostratigraphic information.

The new results from the Nukik-2 samples indicate that dinoflagellate cysts are very rare in the Oligocene and Neogene upper part of the well, whereas they are relatively common in the lower part of the well dated as Early Paleocene to middle Eocene.

1798m-1972m has been dated as middle Eocene
1990m-2237m have been dated as Early Eocene
2256m-2521m have been dated as Late Paleocene and
2548m-2575m have been dated as Early Paleocene

The new results from the Hellefisk-1, Kangamiut-1 and Nukik-1 samples improve and support the previously established zonations.

At end 2000, the palynological events data and palynological zones from the five offshore wells were in the process of being described and correlated with the micropalaeontology zones, petrophysical logs and seismic data in order to establish a sequence stratigraphic model for the Palaeogene successions.

Microfossils

Microfossils from selected intervals in the Hellefisk-1, Ikermiut-1, Kangamiut-1, Nukik-1 and Nukik-2 wells were studied in detail in order to refine the microfossil zonation of Toxwenius (1986).

In total the following amount of samples have been studied and analysed during 1999 and 2000:

Hellefisk-1 (1106 m - 3194 m): 166 samples.
Ikermiut-1 (789 m - 2970 m): 186 samples.
Kangamiut-1 (530 m - 3690 m): 170 samples.
Nukik-1 (415 m - 2362 m): 82 samples.
Nukik-2 (1341 m - 2688 m): 110 samples.

Range charts were plotted for all wells. Several of the samples were prepared and sorted at the Geological Survey of Greenland during the early 1980's. These samples were restudied. The remaining samples were prepared at GEUS by wet-sieving of the 63-1000 μm sediment fraction followed by drying and picking. If the microfossil content was very low, the 63 - 500 μm fraction of the samples were gravity-separated in bromoform (δ = 1.8 g/cm3) after the sieving. This process tends to concentrate the foraminifera and radiolaria in the light fraction, while pyritized diatoms will sink to the bottom as part of the heavy fraction. The technique is more time-consuming in the laboratory, but usually reduces the picking-time considerably.

Work carried out in 2001

Integration of interpretations

During the early part of 2001, all preliminary seismic interpretation, litholog interpretation and biostratigraphic interpretations were completed. The biostratigraphic data were loaded into the same "Landmark" program that was used to interpret the lithology in the wells, and the seismic data were tied to the lithology and biostratigraphy interpretations.

The initial integration showed that there was generally good agreement between the three methods. There was general agreement between seismic and biostratigraphic correlations of the wells. Because the seismic method is of limited resolution, it was necessary to refine the initial seismic ties to the wells using both the biostratigraphic and lithology interpretations.

Sequence boundaries and maximum flooding surfaces were picked on the well data, and these were then used to refine the seismic ties, and the seismic ties were used to refine the interpretations of the well data. This process was iterated several times until agreement between all interpetations was reached.

The lithological and palaeo-environmental data were then used to calibrate the seismic facies interpretations and isopach maps of each seismic sequence was produced, onto which was plotted both seismic facies and palaeo-environmental data as interpreted from the seismic data.

Five papers have been written that give details of the work carried out. These will be submitted to the journal 'Marine and Petroleum Geology'. Copies of the manuscripts are included as appendices to this report.

Summary of Results

The detailed results are described in the manuscripts attached as appendices to the report. These consist of five papers on each aspect of the work. Only a summary of the results is presented here.

The new interpretations of data from the boreholes and reflection seismic data offshore southern West Greenland have been used to delineate 28 seismic sequences within the Paleocene to mid-Eocene interval. The package of sequences is bounded above and below by major regioanl unconformities.

Dinoflagellate cyst, microfossil and nannoplankton stratigraphies and palaeoenvironmental interpretations and a revised lithostratigraphy have been established from the 5 wells drilled offshore southern west Greenland during the 1970s, and results from the Qulleq-1, which was drilled during 2000 and became publically available during the early part of 2001, have been used to check the interpretations in the southern part of the area. The well data have been combined with the seismic stratigraphy to establish new palaeoenvironmental and sedimentological interpretations of the intervals of Paleocene to middle Eocene age.

The results show that the area offshore southern West Greenland was subject to major uplift and erosion during the Danian when latest Cretaceous sediments were removed. Sedimentation restarted in the late Danian, coevally with major volcanism in central West Greenland and the start of sea-floor spreading in the Labrador Sea. Late Paleocene sediments were deposited in a predominantly extensional tectonic environment. The extensional stresses continued in most areas during the early Eocene, but in the northern and northwestern part of the basins, a transtensional system developed along the strike-slip faults that transferred sea-floor spreading movements between the Labrador Sea and Baffin Bay.

Sediment input to the basins was predominantly from the north, possibly from a major river system flowing out of central Greenland. Lesser amounts of sediment came from the east, from the mainland of Greenland, and minor amounts from the west. The thickness of total sediment decreases substantially from north to south. The sediments were deposited in environments that ranged from fresh-water/marginal marine to upper bathyal. Proximal environments are probably generally sand-prone, but distal environments probably contain larger amounts of mud, some of which could contain a mature source rock for oil. Basin-floor fans, syn-tectonic wedges and turbidite channel complexes, that could act as hydrocarbon reservoirs sealed by surrounding muds, have been identified in the distal parts of many of the seismic sequences.

The results are detailed in the manuscripts attached as appendices to this report.
They are:

Mapping and facies analysis of Paleocene–mid-Eocene seismic sequences, offshore southern west Greenland by James A. Chalmers, Ulrik Gregersen, Finn Dalhoff, Hernrik Nøhr-Hansen, Jan Audun Rasmussen and Emma Sheldon

Abstract
Reflection seismic data, tied to lithology and biostratigraphy data from boreholes, have been used to delineate seismic sequences of Paleocene to mid-Eocene age offshore southern West Greenland. The interpreted seismic sequences lie between major regional unconformities of Danian and mid-Eocene age.

The area offshore southern West Greenland was subject to major uplift and erosion during the Danian when latest Cretaceous sediments were removed. Sedimentation restarted in the late Danian, coevally with major volcanism in central West Greenland and the start of sea-floor spreading in the Labrador Sea. Late Paleocene sediments were deposited in a predominantly extensional tectonic environment. The extensional stresses continued in most areas during the early Eocene, but in the northern and northwestern part of the basins, a transtensional system developed along the strike-slip faults that transferred sea-floor spreading movements between the Labrador Sea and Baffin Bay.

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Revised sedimentology and palaeoenvironmental interpretation of the Palaeogene sediments drilled offshore southern West Greenland by F. Dalhoff, H. Nøhr-Hansen, J. A. Rasmussen, E. Sheldon, J: A. Chalmers, J. A. & U. Gregersen.

Abstract
Sedimentological and palaeoenvironmental interpretation of the Palaeogene offshore southern West Greenland from the boreholes: Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1 and Nukik-2. The study is based on well log interpretation, cutting and sidewall core de-

scriptions, revised palynology and microfossil studies, and an extensive seismic mapping and facies analysis. A log panel with correlation of the paly- and microfossil zonation and seismic sequences has been established. The base of the studied stratigraphic sequence is Upper Cretaceous sediment for the basinal boreholes and volcanic or crystalline basement for the basin marginal boreholes and with the regional "mid-Eocene unconformity" as the upper boundary.

Dinoflagellate cyst stratigraphy of the Palaeogene strata from the wells Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1, Nukik-2 and Qulleq-1, offshore West Greenland by Henrik Nøhr-Hansen

Abstract
A new Palaeogene dinoflagellate cyst stratigraphy from offshore West Greenland has been described based on the strata from the wells Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1, Nukik-2 and Qulleq-1.Twenty one strartigraphic intervals are defined from the Late Eocene to the late Early Paleocene. The new stratigraphy has been correlated with a new microfossil zonation and previous established North Sea zonations. The stratigraphy and well correlation is based on last appearence datum events and abundances of stratigraphically important species from 355 samples, 148 of which are side wall core samples. A major mid Eocene hiatus spanning the early Lutetian and a major Early Paleocene hiatus spanning the early Danian to the Late Santonian, Late Cretaceous have been recognised from the offshore deposits.

Palaeogene nannofossil biostratigraphy of the Kangâmiut-1 and Nukik-2 wells, offshore West Greenland by Emma Sheldon

Abstract
A new Palaeogene nannofossil study has been made of the Kangâmiut-1 and Nukik-2 wells, offshore West Greenland. The stratigraphy presented herein has been correlated with previously established nannofossil zonation schemes and where possible used to indicate palaeoenvironmental changes during the Early and Middle Eocene. The stratigraphy and dating is based upon stratigraphically important species and palaeoenvironmental signals are based upon species influxes. A total of 69 samples (26 side wall cores and 43 ditch cuttings samples) were examined and where possible, were compared with findings from closely situated DSDP and ODP sites.

Microfossil biostratigraphy of the Palaeogene succession in the Davis Strait, offshore West Greenland by Jan Audun Rasmussen and Emma Sheldon

Abstract

A microfossil-based biostratigraphy of the Paleocene and Lower Eocene sediments of the Hellefisk-1, Ikermiut-1, Kangamiut-1, Nukik-1, and Nukik-2 wells offshore West Greenland has been established. The five wells in general contain fairly well-preserved, diverse microfossil faunas and floras consisting mainly of foraminifera, radiolaria, ostracods and diatoms. The interval studied was subdivided into three foraminifera zones (the S. beccariiformis, P. ovata and P. wilcoxensis zones) and five zones based on additional microfossil groups (the T. wittiana, F. antiqua-C. morsianus, Ostracod, A. hirtus and Cenodiscus-Cenosphaera zones). Due to the higher microfossil diversity and abundance in the two most basinal wells, Ikermiut-1 and Kangamiut-1, the biozones are more easily recognised here than in the three more nearshore wells, Nukik-1, Nukik-2 and Hellefisk-1.

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Appendix 1

Mapping and facies analysis of Paleocene–mid-Eocene seismic sequences, offshore southern west Greenland

by

James A. Chalmers, Ulrik Gregersen, Finn Dalhoff, Hernrik Nøhr-Hansen, Jan Audun Rasmussen and Emma Sheldon

Mapping and facies analysis of Paleocene–mid-Eocene seismic sequences, offshore southern west Greenland James A. Chalmers, Ulrik Gregersen, Finn Dalhoff, Henrik Nøhr-Hansen, Jan Audun Rasmussen and Emma Sheldon. *Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen NV, Denmark*

Abstract

Reflection seismic data, tied to lithology and biostratigraphy data from boreholes, have been used to delineate seismic sequences of Paleocene to mid-Eocene age offshore southern West Greenland. The interpreted seismic sequences lie between major regional unconformities of Danian and mid-Eocene age.

The area offshore southern West Greenland was subject to major uplift and erosion during the Danian when latest Cretaceous sediments were removed. Sedimentation restarted in the late Danian, coevally with major volcanism in central West Greenland and the start of sea-floor spreading in the Labrador Sea. Late Paleocene sediments were deposited in a predominantly extensional tectonic environment. The extensional stresses continued in most areas during the early Eocene, but in the northern and northwestern part of the basins, a transtensional system developed along the strike-slip faults that transferred sea-floor spreading movements between the Labrador Sea and Baffin Bay.

Sediment input to the basins was predominantly from the north, possibly from a major river system flowing out of central Greenland. Lesser amounts of sediment came from the east, from the mainland of Greenland, and minor amounts from the west. The thickness of total sediment decreases substantially from north to south. The sediments were deposited in environments that ranged from fresh-water/marginal marine to upper bathyal. Proximal environments are probably generally sand-prone, but distal environments probably contain larger amounts of mud, some of which could contain a mature source rock for oil. Basin-floor fans, syn-tectonic wedges and turbidite channel complexes, that could act as hydrocarbon reservoirs sealed by surrounding muds, have been identified in many of the seismic sequences.

Introduction

The sedimentary basins offshore southern West Greenland (Fig. 1) are situated between the oceanic crust of the Labrador Sea to the southwest and the exposed Proterozoic rocks of Greenland to the northeast (Chalmers & Pulvertaft in press). The basins contain sediments and volcanic rocks of Mesozoic and Cenozoic age and the present description is limited to the area between approximately 63°N and 68°N. The southern limit is the southern limit of where the studied seismic sequences are present and the northern limit is a line of tectonic highs (Chalmers *et al.* 1995) near the southern limit of Palaeogene basalts. The tectonic ridge brings the top of the basalts to or close to the seabed, and it is not possible to correlate the Palaeogene succession across the ridge. The eastern limit of the study is either the eastern limit of the sequences or the eastern limit of modern coverage of seismic data. The western limit is the boundary between the territorial waters of Greenland and Canada.

Descriptions of the entire basin have been published by Manderscheid (1980), Henderson *et al.* (1981) and Chalmers *et al.* (1993, 1995). Chalmers & Pulvertaft (in press) provide a review of the regional geology of the entire Labrador Sea, Davis Strait and southern Baffin Bay area. Rolle (1985) first described the lithostratigraphy and biostratigraphy of five deep wells drilled in the basin in 1976 and 1977, and his account has been revised by Dalhoff *et al.* (this volume), Nøhr-Hansen (1998, this volume), Rasmussen & Sheldon (this volume) and Sheldon (this volume).

Bathymetry (Fig. 2)

The bathymetry of the area offshore southern West Greenland (Fig. 2) was first described by Henderson (1973). South of about 63°N, the continental shelf is narrow, less than 30 km wide, and is bounded to the southwest by a steep (up to 20°) slope to depths of 2500 metres, beyond which is the deep water of the Labrador Sea. The continental shelf is wider north of 63°N, reaching 200 km wide at 68°N. Between the shelf and the coast is a channel of deeper water (in places >500m) where basement is exposed at the sea bed, and this gives rise to rugged, complex topography. The shelf is separated into banks by channels within which water depths over 500 metres are again found.

North of 63°N and west of the continental shelf, water depths are between 500 and 1500 metres, the Davis Strait sill. Water depths increase from between 500–1500 metres to more than

2500 along a south-facing slope between 63°N and 64°N. Two large N–S-trending canyons cut this slope at 53°W and 55° 30'W.

Structural elements (Fig. 1)

The Nuussuaq Basin is exposed onshore on the island of Disko and the peninsulas of Nuussuaq and Svartenhuk. Cretaceous and Paleocene sediments are overlain by picrites and basalts of Paleocene and Eocene age (Chalmers *et al.* 1999). The basalts can be traced offshore to just south of 68°N and to around 73°N (Whittaker *et al.* 1997). The well Hellefisk-1 drilled through approximately 2500 metres of Cenozoic sediments into about 600 metres of these basalts in which it terminated (Rolle 1985, Hald & Larsen 1987, Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume). East of the Hellefisk-1 well is a tectonic ridge, the **Kangeq High**, whose southern flank plunges more than 5 km into the **Sisimiut Basin**, which extends between 66°30'N and 68°N.

The well Ikermiut-1 was drilled into a line of structures called the **Ikermiut Fault Complex** along the western margin of the Sisimiut Basin. These structures were interpreted by Henderson *et al.* (1981) as shale diapirs but Chalmers *et al.* (1995) and Chalmers & Pulvertaft (in press) have suggested that they may be caused by compression related to strike-slip faulting. This is discussed again below. Further west again, basement crops out at seabed on the **Davis Strait High**.

The southern margin of the Sisimiut Basin is an east–west striking fault zone, south of which is the **Nukik Platform**. The wells Nukik-1 and Nukik-2 were drilled into the southern part of this platform. Both wells penetrated between 2300 to 2500 metres of Cenozoic sediments. Nukik-1 terminated in Precambrian crystalline basement and Nukik-2 terminated in Paleocene basalts (Rolle 1985, Hald & Larsen 1987, Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume).

The Kangâmiut-1 well (Rolle 1985, Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume) was drilled on the west flank of the **Kangâmiut Ridge**, a north–south-trending basement ridge to the west of the Nukik Platform and separated from it by a graben. East of the Kangâmiut Ridge is the northern part of the **Nuuk Basin** in which basement lies deeper than 8 km in places.

The Nuuk Basin is bounded to the east by the Nukik Platform and, south of the Kangâmiut Ridge, by the **Atammik Structural Complex** and the **Fylla Structural Complex** (Bate *et al.* 1994, Aram 1999, Isaacsen & Neff 1999, Christiansen *et al.* in press).

The Nuuk Basin is bounded to the west by the **Maniitsoq Rise** and the **Hecla Rise** (Tucholke & Fry 1985). Recent unpublished work suggests that these two structures consist of lava domes over relatively shallow, block-faulted basement complexes, and may contain central intrusive complexes. The Maniitsoq and Hecla Rises are bounded to the west and southwest by the Lady Franklin Basin that contains thick Mesozoic sediments faulted into large fault-blocks and may be a northwesterly continuation of the transition zone between continental and oceanic crust (Chalmers & Pulvertaft in press).

The geology under the deep water south of the Fylla Structural complex is poorly known because of lack of data. What seismic data exists has revealed the presence of a volcanic continental margin (Chalmers & Laursen 1995, Chalmers & Pulvertaft in press), which may be part of the shallow volcanic area called the **Gjoa Rise** by Tucholke & Fry (1985) and which has been drilled in Canadian waters by the well Gjoa G-37 (Klose *et al.* 1982). Further south again, the oceanic crust of the Labrador Sea is separated from Greenland continental crust by a transition zone whose nature is unclear. This area is discussed in the review by Chalmers & Pulvertaft (in press).

Regional Stratigraphy

Onshore outcrops in central West Greenland (Nuussuaq Basin) and on Baffin Island

Cretaceous and Palaeogene sediments and Palaeogene volcanic rocks (Fig. 1) are exposed on the island of Disko and the peninsulas of Nuussuaq and Svartenhuk (69°–72°N) in West Greenland (the Nuussuaq Basin) and near Cape Dyer (67°N) in southeast Baffin Island (Chalmers *et al.* 1999; Burden & Langille 1990; Chalmers & Pulvertaft in press).

The Cretaceous sediments in the Nuussuaq Basin were deposited in a delta system that fanned out to the west and northwest from a point east of Disko island. This implies that there must have been a major river flowing westwards from central Greenland. In the southeast and east of the outcrop area, the sediments consist of fluvial-deltaic sandstones, mudstones and coal seams of Albian–early Campanian age which constitute the Atane Formation. The fluvio-deltaic sediments pass northwestwards into marine mudstones alternating with up to 50 m thick turbidite channel sandstones that were deposited on a submarine slope, the Itilli succession (Dam & Sønderholm 1994). The present-day eastern boundary of Cretaceous outcrops is a system of major faults. The occurrence of very coarse conglomerate in Cenomanian sediments adjacent to one of the faults indicates active faulting at that time (Rosenkrantz & Pulvertaft 1969), but elsewhere, Upper Albian–Cenomanian fluvial sands and shales are cut off by the boundary fault without any evidence of the proximity of syn-sedimentary fault scarps, suggesting that there was also post-Cenomanian fault movement (Pulvertaft 1979, 1989). The oldest Cretaceous sediments are exposed on the north side of Nuussuaq near the boundary fault system. These are of Late Albian age and constitute the Kome Formation (Midtgaard 1996). Midtgaard (1996) suggested that these sediments were deposited in an active half-graben with its bounding fault to the west. A low-angle unconformity separates these sediments from the overlying sediments of the Atane Formation (Midtgaard 1996).

Important faulting started in the mid-Campanian and was resumed in the mid-Maastrichtian (Dam & Sønderholm 1994, Dam *et al.* 1998). These movements resulted in both rotation and uplift of the Atane Formation sediments in fault blocks (Chalmers *et al.* 1999), and were followed by the incision of a series of large, deep channels which were filled by transgressive successions of coarse conglomerates and turbidites or by fluvial sandstones (Dam & Sønderholm 1994, 1998; Dam *et al.* 1998, 1999). An angular unconformity separates upper Campanian–Palaeocene sediments from the underlying Atane Formation in many parts of the area.

Palaeogene volcanism began in the Nuussuaq Basin with the eruption of the high-temperature, plume-related picrites of the Vaigat Formation (Clarke & Pedersen 1976; see also Gill *et al.* 1992; Holm *et al.* 1993 and Graham *et al.* 1998), followed by the eruption of the feldsparphyric tholeiites of the Maligât Formation (Hald & Pedersen, 1975). Six $^{40}Ar/^{39}Ar$ age determinations of samples from the Vaigat and Maligât formations yielded good plateau ages between 60.4±0.5 and 59.4±0.5 Ma (Storey *et al.*, 1998), equivalent to dinocyst zone P2 (Mudge & Bujak 1996) and also coeval with the start of sea-floor spreading in the Labrador Sea (Chalmers & Laursen 1995, Chalmers & Pulvertaft in press). Nøhr-Hansen *et al.* (in press) report that the youngest sediments under the picrites also yield dinocyst zone P2 dates.

At the northwest extremity of Nuussuaq peninsula, there is approximately 2 km of lower Eocene basalts. A comendite tuff within these basalts has yielded an age of 52.5±0.2 Ma corresponding to dinocyst zone E2a (Mudge & Bujak 1996). Younger rocks are represented only by minor intrusions and sediments laid down in very local features associated with minor volcanism (Chalmers *et al.* 1999).

Near Cape Dyer, on eastern Baffin Island, there are fluvial sediments of Late Aptian–Early Cenomanian age that appear to have been deposited during active faulting (Burden & Langille 1990). The sediments are overlain unconformably by lower Palaeocene mudstones, arkoses and conglomerates also deposited during an episode of active faulting. Here also sedimentation ended when picritic basalts were erupted (Clarke & Upton 1971).

Offshore southern West Greenland

The stratigraphy of the basins offshore southern West Greenland is known from the five exploration boreholes drilled in the 1970s (Rolle 1985, Nøhr-Hansen 1998, this volume, Dalhoff *et al.* this volume, Rasmussen & Sheldon this volume, Sheldon this volume) and well Qulleq-1 (6354/4-1) drilled in 2000 (Nøhr-Hansen *et al.* 2000, Pegrum *et al.* 2001, Christiansen *et al.* in press), by comparison of seismic sequences visible on seismic lines from the southern West Greenland basins (Chalmers *et al.* 1993, 1995, Chalmers & Pulvertaft in press) with those known and drilled offshore Labrador (Balkwill 1987), and by comparison with the sediments and volcanic rocks exposed in the Nuussuaq Basin and at Cape Dyer. Only a summary is given here and the reader is referred to a more detailed review in Chalmers & Pulvertaft (in press).

Of the five wells drilled offshore West Greenland in the 1970s (Rolle 1985, Nøhr-Hansen 1998, this volume, Dalhoff *et al.* this volume, Rasmussen & Sheldon this volume, Sheldon this volume), three penetrated only Cenozoic sediments before being terminated in Paleocene basalts (Hellefisk-1 and Nukik-2) or Precambrian basement (Nukik-1). Kangâmiut-1 drilled through an Eocene and younger, sand-dominated succession, then lower Eocene and Paleocene mudstones, below which the well penetrated a coarse arkosic sand interleaved with mudstone, before being terminated in Precambrian basement. Only one well drilled in the 1970s, Ikermiut-1, drilled a significant section of pre-Cenozoic sediments, sampling an 850-m section of Turonian–Santonian (Nøhr-Hansen 1998) mudstone before drilling was stopped. However, the well drilled in 2000, Qulleq-1, also penetrated thick Campanian mudstones below Neogene and thin Palaeogene sediments, and terminated in sandstones of Santonian age (Nøhr-Hansen *et al.* 2000, Pegrum *et al.* 2001, Christiansen *et al.* in press).

Four seismic sequences have been recognized below the Cenozoic succession offshore southern West Greenland called, in stratigraphic order downwards, the Kangeq, Appat, Kitsissut and 'deep' sequences (Chalmers *et al.* 1995, Chalmers & Pulvertaft in press). Only the uppermost of these, the Kangeq Sequence, has been penetrated, and that by only the Ikermiut-1 and Qulleq-1 wells. The pre-Cenozoic sediments have been defined on the basis of their seismic characteristics (Chalmers *et al.* 1995, Chalmers & Pulvertaft in press). The uppermost sequence, called the Kangeq sequence, is seismically transparent and this characteristic has been used to trace it around the entire basin complex south of 68°N and to distinguish it from the more reflective over- and underlying sequences. Ikermiut-1 penetrated the uppermost part of the Kangeq sequence which there is found to be of Turonian–Santonian age. The Campanian sediments penetrated by Qulleq-1 were also attributed to the Kangeq sequence prior to drilling of that well, but the underlying sediments dated as Santonian were formerly attributed to the Appat sequence. So there is a clear, as yet unresolved, correlation problem of the Mesozoic sediments.

Both Hellefisk-1 and Nukik-2 terminated in basaltic rocks (Rolle 1985, Hald & Larsen 1987). The flood basalts exposed in the Nuussuaq Basin have been traced offshore to the west from 73°N to south of 68°N (Whittaker *et al.* 1997, Chalmers & Pulvertaft in press) where they were penetrated by Hellefisk-1, a total area of around 75 000 km^2. The basalts around Nukik-2 are not geographically connected to those penetrated by Hellefisk-1 and occupy a much smaller area (Chalmers *et al.* 1993). Williamson *et al.* (2001) report an Ar/Ar data of 57.7±1.2 MA for the basalts penetrated by Hellefisk-1, equivalent to dinocyst zone P4, and consistent with the P4 dating reported by Nøhr-Hansen (this volume) for the immediately overlying sediments. No Ar/Ar dates have been reported from Nukik-2, but the sediments lying above the basalts are also reported by Nøhr-Hansen (this volume) to be of P4 age.

Ikermiut-1, Qulleq-1 and possibly Kangâmiut-1 all penetrated a substantial unconformity between Paleocene and Cretaceous sediments. In Ikermiut-1, Upper Paleocene sediments lie on Upper Santonian sediments (Nøhr-Hansen 1998, this volume). In Qulleq-1, Upper Paleocene sediments lie on Campanian sediments (Nøhr-Hansen *et al.* 2000, Pegrum *et al.* 2001, Christiansen *et al.* in press) and in Kangâmiut-1, Upper Paleocene sediments lie on a sandstone/conglomerate sequence that in turn lies on metamorphic basement. The sandstones and conglomerates in Kangâmiut-1 have been conjectured to be either of Santonian age (Nøhr-Hansen 1998) or Paleocene age (Bate 1997).

Above the basal Cenozoic unconformity is the package of reflective sediments that is the subject of the study reported here. The package is bounded above by an unconformity that can be traced over the whole of the southern West Greenland basin (Fig. 3), called in this paper the mid-Eocene Unconformity. Depths to this unconformity are shown in Fig. 4. Sediments immediately above the mid-Eocene Unconformity are of middle to late Lutetian age (Nøhr-Hansen 1998, this volume), which coincides with the time (magnetochrons 20–21) at which sea-floor spreading slowed abruptly in the Labrador Sea (Roest & Srivastava 1989, Chalmers & Pulvertaft in press), so the package of sediments that is the subject of this report was deposited during active sea-floor spreading in the Labrador Sea between magnetochrons 27n and 20r.

Tectonic activity can be seen within the package along the Ikermiut fault zone in Quadrants 6656 and 6756 (Fig. 3). The Ikermiut-1 well appears to have penetrated the easternmost fold of a flower structure, which may have been produced by a step-over on a strike-slip fault. Chalmers & Pulvertaft (in press) interpret this fault as part of the Ungava Fault complex, which is the main transform fault along which the Greenland and North American plates moved sinistrally relative to one another.

Sediments shallower than the mid-Cretaceous Unconformity have not yet been studied in detail, other than a suggestion by Chalmers (2000) that the eastern parts of the basin north of 67°N have been lifted by up to 2–3 kilometres and eroded during the Neogene. This uplift exposed the area known as the Nuussuaq Basin.

In summary, the sedimentary-tectonic history of the basins offshore southern West Greenland is thought to be as follows (see Chalmers & Pulvertaft in press):

(1) Pre- to early syn-rift deposition of the Kitsissut and 'deep' sequence in pre-Late Cretaceous time.

(2) Faulting and fault-block rotation and deposition of the Appat Sequence onto the hanging-walls of the fault-blocks during the mid-Cretaceous. This event may have been asynchronous in different parts of the basin system.

(3) Post-rift deposition of the Kangeq sequence during a phase of thermal subsidence during the Late Cretaceous.

(4) Extension and fault-block rotation in the Nuussuaq Basin onshore and Fylla area offshore and possibly elsewhere in the West Greenland basins in latest Campanian to early Palaeocene time. Uplift and erosion caused by impact of the Iceland plume slightly later in the Paleocene

(63 to 62 Ma) produced major channel systems in the Nuussuaq Basin and the effect of this event offshore is a subject of the present study.

(5) Volcanism during the Palaeocene between 61–57 Ma, and again in the early Eocene at 54.8–52.5 Ma.

(6) Sedimentation offshore that is the subject of this study during tectonism that includes both extension and strike-slip tectonism along the Ikermiut Ridge that ended during the middle Eocene.

(7) Regional subsidence and sedimentation from the middle Eocene to some time during the Neogene.

(8) Uplift of the eastern Sisimiut Basin and elsewhere during the Neogene to expose the Nuussuaq Basin.

Data and interpretation techniques

Seismic reflection data

The grid of seismic reflection data used in this interpretation is shown in Fig. 2. The data are all multichannel lines, acquired in 1990, 1991, 1992 and 1995 plus some regional lines acquired in 1977 (Hinz *et al.* 1979) (the BGR/77 lines) that were reprocessed in 1990 (Chalmers & Laursen 1995).

The BGR/77 lines were acquired using a 2400-metre, 48-channel receiver cable and a 23.45 litre airgun source. The data were stacked 24-fold and migrated after stack. All of the data acquired in the 1990s were acquired with 3000-metre cables, those in 1990, 1991 and 1992 with an analogue streamer with 120 channels and those in 1995 with a digital streamer with 240 channels. Sources were all airguns at 140 bar (2000 psi), 3616 cu. in. 1990, 5015 cu in. in 1991 and 1992 and 4100 cu. in. in 1995. All data were stacked 60-fold, various proprietary techniques were used to remove multiples, and the lines were all migrated after stack.

Interpretation techniques

The standard techniques of seismic stratigraphy interpretation were used (see e.g. Payton 1977, Bally 1988). The upper and lower boundaries of seismic sequences were determined by interpreting the locus of reflection terminations and tying these round the grid of lines. The boundaries were tied to the wells, within limits of uncertainty due to seismic resolution. More accurate ties were obtained by interpretation of the higher-resolution well data (Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume). The seismic interpretations were converted from two-way time to depth using data from the wells. An interval velocity of 2500 m/s was used for all the seismic sequences interpreted in this paper, an interval velocity of 1480 m/s was used for sea water and a velocity function $V=1808 + 0.698(T_e-T_w)$ was used to determine the interval velocity V (m/s) between the sea bed and the mid-Eocene Unconformity where T_e is the two-way time in milliseconds from the surface to the mid-Eocene unconformity and T_w is the two-way time in milliseconds from the surface to the sea bed.

Once a satisfactory interpretation of boundaries was obtained, the internal reflection pattern within each sequence was mapped. Interpretations from the wells were used to determine the lithology, depositional environment and Palaeo-environment of the patterns observed on the seismic lines at the well-ties. Elsewhere, interpretation of the internal reflection pattern was based on the principles of seismic and sequence stratigraphy (see e.g. Bally 1988, Emery & Myers 1996).

Nomenclature of the seismic sequences

A seismic sequence in this paper is named e.g. SS5000 and its base is referred to as e. g. SB5000. The numbers are in strict stratigraphic order with the lower numbers indicating stratigraphically lower seismic sequences. The first seismic sequences interpreted were numbered SS1000 to SS10000. As the interpretation progressed, it was found necessary to interpolate additional seismic sequences between those already interpreted, and they were given intermediate numbers, e.g. SS5500 and SS5250, with bases SB5500 and SB5250. Numbering in strict stratigraphic order was maintained.

Description of the seismic sequences

SS100 (Fig. 5)

SS100 has not been penetrated by any well. However its stratigraphic position above the Kangeq sequence and below SS500, which is the oldest Palaeogene seismic sequence that has been dated (see below), indicates an age between Late Santonian and Danian (P2). Regional considerations (see later) suggest that the likely age of SS100 is at the younger end of this range.

Information from seismic data

SS100 occurs in a limited area in the NE Sisimiut Basin.

Seismic facies. The lower boundary of SS100 is defined partly by onlaps and downlaps, especially in its central area, and partly by being the base of the first reflective interval above the seismically transparent Kangeq sequence. Its upper boundary is partly defined by truncations and partly by terminations of reflections in succeeding seismic sequences. SS100 has been removed erosionally to the east and north, locally by a Quaternary channel or valley (Fig. 6).

Internal reflections are sub-parallel and slightly wavy, downlapping but also chaotic, especially in central parts. Locally in the lowermost, deep northwestern part of the sequence, mounds are observed (Fig. 7).

Interpretation.

The reflection character suggests a shelf to basin environment. The mounds, which may be mass flows, fans or slumps, are probably derived from palaeohighs and support a shelf to basinal setting. The erosion and mounds may indicate lowered relative sea-level. A tectonic influence on erosion and sediment input in late Cretaceous and Danian sequences cannot be excluded.

Prospectivity.

The mounds may indicate the presence of fans or mass flows that could contain reservoirs. A local amplitude anomaly (Fig. 7) may indicate presence of shallow gas.

SS150 (Fig. 5)

SS150 has not been penetrated by any well. However its stratigraphic position above the Kangeq sequence and below SS500, which is the oldest Palaeogene seismic sequence that has been dated (see below), indicates an age between Late Santonian and Danian (P2). Regional considerations (see later) suggest that the likely age of SS150 is at the younger end of this range.

Information from seismic data.

SS150 is interpreted in two limited areas in the NE Sisimiut Basin and west of the Kangâmiut Ridge. It is not certain that these two units are necessarily the same sequence, but they lie within the same stratigraphic interval and it is convenient to treat them together.

Seismic facies. The lower boundary of SS150 is defined partly by onlaps and partly by being the first reflective interval above the seismically transparent Kangeq sequence. Its upper boundary is partly defined by truncations and partly by terminations of reflections in succeeding seismic sequences. The sequence has been removed by erosion to the east and north (Fig. 6).

Internal reflections are sub-parallel and in places chaotic, especially in central parts. In the lowermost part of the sequence in Quadrant 6754, a minor mound is observed.

Interpretation.

The reflection character suggests an outer shelf to deep basin environment. The mound, which may be a slump derived from palaeohighs or possibly contourites, supports a shelf to basin setting and the sub-parallel, onlapping facies suggests that SS150 was deposited during a transgression.

Prospectivity.

The slump or contourite mound could contain reservoir sands sealed stratigraphically by surrounding mudstones.

SS250 (Fig. 5)

SS250 has not been penetrated by any well. However its stratigraphic position above the Kangeq sequence and below SS500, which is the oldest Palaeogene seismic sequence that has been dated (see below), indicates an age between Late Santonian and Danian (P2). Regional considerations (see later) suggest that the likely age of SS250 is at the younger end of this range.

Information from seismic data.

SS250 occurs in a limited area in the NE Sisimiut Basin.

Seismic facies. The lower boundary of SS250 is defined partly by onlaps and downlaps and partly by truncations of reflections within underlying seismic sequences. Its upper boundary is partly defined by truncations and partly by terminations of reflections in succeeding seismic sequences. The sequence has been removed erosionally to the east and north (Fig. 6).

Internal reflections are sub-parallel and in places chaotic, especially in central parts. In Quadrant 6755, two areas of complex-sigmoid prograding reflections are observed, one towards the north and the other southwards. The progradations are on opposite sides of and away from a major fault. In the lowermost part of the sequence in Quadrant 6754, a minor mound is observed.

Interpretation.

The general reflection character and the mound, which may be a slump or possibly a contourite, support a shelf to basin setting. The bi-directional progradations suggest the presence of one or more highs around the major fault, and it is possible that the parts of SS250 to the north and south of the fault are not today in the same geographical relationship to one another as they were when deposition occurred, since there is evidence that sinistral strike-slip movement occurred on these faults during the Eocene (Chalmers & Pulvertaft, in press).

Prospectivity.

The slump or contourite mound could contain reservoir sands sealed stratigraphically by surrounding mudstones.

SS500 (Fig. 8)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume).

SS500 was penetrated by the Nukik-2 and Kangâmiut-1 wells.

Kangâmiut-1	3671–3649 m	2931-2917 msec TWT
Nukik-2	2557–2379 m	1974–1841 msec TWT

SS500 lies above conglomerates and sandstones of either Early Santonian or early Paleocene age in Kangâmiut-1 and above hyaloclastites in Nukik-2.

Biostratigraphy & Palaeoecology. Age: Late Danian (P2, late early Paleocene) to early Thanetian (P4, late Paleocene). A maximum-flooding surface has been interpreted in Nukik-2 at 2415 m.

The overall depositional environment is inner to outer neritic in Nukik-2, but outer neritic to upper bathyal in Kangâmiut-1. Thin sand layers with sharp bases containing near-shore palynomorphs are probably turbidites or storm-sand layers, indicating transport from nearby shore areas.

Lithology. In Nukik-2, SS500 is dominated by thick, fining-upwards, sandy deposits, succeeded by claystones with fining-upward log trends containing minor sand layers. The palaeoecology data also indicate that shallower layers were redeposited in deeper water. In Kangâmiut-1, SS500 contains probably shelf mudstones.

Information from seismic data.

SS500 is widespread from the northern part of the Sisimiut Basin (68°N) to the Kangâmiut Ridge and in an area south of the Nukik wells.

Seismic facies. The lower boundary of SS500 is partly defined by onlaps and partly by downlaps. Its upper boundary has been interpreted by the termination of reflections within the succeeding seismic sequences. In the northern part of Quadrant 6754, SS500 has been removed by erosion during Neogene times (Fig. 6).

Syn-tectonic wedges can be seen in several places associated with the major faults in Quadrants 6655, 6656, 6755 and 6756 and on the boundary between Quadrants 6454 and 6554. One of these wedges forms the thickest part of SS500. In the Sisimiut Basin, in Quadrants 6754 and 6755, major mounds are observed. Strongly reflecting units may show the presence of turbidites and/or storm sands. There are small areas of complex-sigmoid progradation towards the south in the Sisimiut Basin and towards the west from the Nukik Platform in Quadrant 6554 and east of the Hellefisk-1 well. Elsewhere internal reflections tend to be sub-parallel and locally chaotic.

Interpretation.

The well information and reflection character suggests a shelf environment. The sharp-based, fining-upwards sands encountered by Nukik-2 may be basin-marginal submarine channels, succeeded by marine claystones, indicative of ?lowstand to transgressive deposits. Minor sand layers in the transgressive deposits are probably turbidites or storm-sand layers. The major mounds in Quadrants 6754 and 6755 (Fig. 9) may be mass flows and or basin-floor fans. The high amplitudes at the foot of the slope of the progradational units (Fig. 10) may be turbidites. SS500 also contains thick synrift deposits, locally with stacked high amplitudes towards the fault-zone north and west of Ikermiut-1, indicating coarser clastic deposits. All these observations suggest a period of active tectonics, erosion and sand-dominated sediment supply.

The basin floor fans (mounds) in the Sisimiut Basin may indicate lowstand deposits, succeeded by transgressive and highstand deposits, which are thickest towards the margins of SS500, and the progradational units may have been deposited during late highstand times. Thick sands may have been deposited during the transgressive phase into channels eroded during the lowstand.

Prospectivity.

The interpreted high sand content indicates the presence of possible reservoirs as turbidites, channels and synrift talus. Sealing may be poor internally, especially towards the margins of the seismic sequence.

SS1000 (Fig. 8)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume).

SS1000 was penetrated by the Hellefisk-1, Ikermiut-1, Kangâmiut-1 and Nukik-1, and -2 wells.

Hellefisk-1	2508–2297 m	1998–1870 msec TWT
Kangâmiut-1	3649–3350 m	2917–2692 msec TWT
Nukik-1	2342–2240 m	1822–1758 msec TWT
Nukik-2	2379–2307 m	1841–1792 msec TWT

SS1000 lies above volcanic rocks in Hellefisk-1, Upper Santonian claystones in Ikermiut-1, claystones of SS500 in Kangâmiut-1, claystones of SS500 containing acid intrusives in Nukik-2 and metamorphic basement in Nukik-1.

Biostratigraphy & Palaeoecology. Age: late Paleocene (P4-P5, middle Thanetian).
A maximum flooding surface has been interpreted in Nukik-1 (2266 m) and Hellefisk-1 (2420 m). In Nukik-1, this coincides with a local maximum in diversity of dinoflagelates.

In Nukik-1, the palaeoenvironment of SS1000 is generally shallow marine to brackish or littoral at the base, shallowing upward above the maximum flooding surface. The sediments penetrated by Hellefisk-1 and Nukik-2 were deposited in deeper water, with upward shallowing outer- to inner neritic conditions. The base of SS1000 in Hellefisk-1 probably represents an erosive ravinement surface. Ikermiut-1 and Kangâmiut-1 both penetrated sediments that probably represent upper bathyal to inner neritic (shallowing upward) conditions, mudstone-dominated but with thin sandy, possibly turbiditic or storm-sand, layers containing reworked fresh to brackish-water algae.

Lithology. Nukik-1 and -2 and Hellefisk-1 all contain sandy intervals with sharp-based, blocky gamma-log signals, possibly indicating submarine channels. Kangâmiut-1 and Ikermiut-1 are both mudstone dominated with thin sandstone layers, possibly turbidites or storm sand layers. Inner neritic conditions in the basal sand in Ikermiut-1 are replaced upwards by more offshore conditions, indicating a mass-flow, possibly a turbidite or basin-floor fan.

Information from seismic data.

Sequence 1000 is widespread; from north of Hellefisk-1 in the north to Qulleq-1 in the south, a distance of over 500 km.

Seismic facies. The lower boundary of SS1000 is partly defined by onlaps and partly by downlaps. Its upper boundary has been interpreted in places from the termination of sigmoid-oblique reflections and in other places by the termination of reflections within the succeeding seismic sequences. In the northern parts of Quadrants 6754 and 6755, SS1000 has been removed by erosion during Neogene times (Fig. 6 and Chalmers 2000).

Sigmoid-oblique reflections in Quadrants 6754, 6755 and 6756 define a southerly prograding wedge separating a probably marginal marine environment to its north from an inner–outer neritic environment to its south. Water depths of up to about 250 metres are indicated by the height of the foresets. SS1000 is over 400 metres thick in places in this area, and other locally thick areas are associated with south-southwesterly progradations in Quadrants 6554 and 6553.

Other areas where SS1000 is thick, to over 600 metres, lie along and are clearly associated with the faults in Quadrants 6656 and 6756. Active faulting contemporaneous with sedimentation probably produced these patterns, and indeed characteristic syn-tectonic wedges of sediment can be seen in several places in this area.

Over much of the area where SS1000 is between 0 and 200 m thick, internal reflections are sub-parallel. However there are places of chaotic pattern, especially in thicker parts of the sequence, and major mounds are observed especially along the foot of the progradations in Quadrants 6754, 6755 and 6756 and in Quadrants 6655 and 6656.

Interpretation.

The well information, seismic facies character and clinoform height of around 200 ms (~250 m) suggests a neritic–bathyal environment in the central part of SS1000's area. The major mounds may be mass-flows. The high amplitudes at the foot of the slope of the progradational units (Fig. 6) may be slumps or turbidites (see e.g. Gregersen & Skaarup, this volume). Furthermore, SS1000 contains thick synrift deposits, with stacked high amplitudes in places towards the fault, indicating coarser clastic deposits. The thick sands in the basin marginal wells have sharp-based, blocky gamma-log signals, containing reworked marine to brackish fossils, indicating shallow-marine channels. All these observations suggest a period of active tectonics, erosion and high, sand-dominated sediment supply.

It is possible that SS1000 consists of a syn-tectonic depositional sequence containing lowstand basin-floor fans (mounds) and turbidites centrally in the area. There are indications of aggrading, transgressive patterns around the eastern margins of the sequence and progradational units where sediment input has been high compared to rate of subsidence.

In the Sisimiut Basin, SS1000 may be divided locally into at least two seismic units by an onlap or downlap surface of moderate to high amplitude (Fig. 6). High amplitudes observed downdip, basinward, on this line may be mass-flows. It is unlikely that this observation indicates that SS1000 should be divided into more than one seismic sequence as this internal boundary is present clearly only over a limited area. SS1000 can be interpreted as an undivided syn-tectonic seismic sequence, dominated by low-stand deposition but with evidence for transgressive and high-stand influences in its eastern and especially northeastern parts. SS1000 may be a 3rd order lowstand systems tract containing 4th order lowstand, transgressive and highstand systems tracts.

Prospectivity.

The interpreted turbidites, basin-floor fans and synrift talus may contain sands sealed by surrounding claystones, which can act as stratigraphic traps.

SS2000 (Fig. 11)

SS2000 has not been penetrated by any well. However its stratigraphical position between SS1000 and SS3000 indicates a late Paleocene age (P5).

Information from seismic data.

SS2000 occurs in the Sisimiut Basin only.

Seismic facies. The lower boundary is defined partly by onlaps, partly by downlaps and partly by truncation of reflections in underlying seismic sequences. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the northeast, SS2000 has been removed by Neogene erosion (Fig. 6).

In the north and south, internal reflections are sub-parallel and in places chaotic, especially towards the south. A zone of sigmoid-oblique reflections occurs in the central area of the seismic sequence indicating progradation towards the south and southwest. Minor mounds are observed in the lowermost part of the sequence in the south.

Interpretation.

The reflection character suggests a shelf environment. The sequence erodes into SS1000 and SS500 towards the north indicating a relative sea-level fall. The progradational unit probably indicates a transition from littoral or brackish conditions to its north to neritic further south, and the mounds to its south may be slumps or possibly contourites. The high amplitudes on the foresets of the progradational units (Fig. 12) may indicate the presence of turbidites. A continuous, high amplitude and widespread reflection in the uppermost part of SS2000 (Fig. 6) may indicate a maximum flooding surface with high organic content or clastic mass-flow deposits.

SS2000 may represent either a shelf-margin systems tract or a lowstand systems tract with basin floor fans (mounds) and turbidites centrally in its area, succeeded by transgressive deposits. The progradational unit is displaced slightly basinward of the progradational unit of the preceding sequence and its offlap break is slightly more distal and deeper than that of SS1000. This indicates a minor decrease in the accommodation space, if any, compared with SS1000.

Prospectivity.

Reservoirs of limited extent could exist within the prograding section, but these would rely on seal within another seismic sequence. SS2000 is probably mud-dominated.

SS2500 (Fig. 11)

SS2500 has not been penetrated by any well. However, its stratigraphical position between SS1000 and SS3000 indicates a late Paleocene age (P5). The sequence occurs in the Sisimiut Basin only.

Information from seismic data

Seismic facies. The lower boundary of SS2500 is defined partly by onlaps, partly by downlaps and partly by truncation of reflections in underlying seismic sequences. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the northeast, SS2500 has been removed by Neogene erosion (Fig. 6). Internal reflections are sub-parallel and in places chaotic, especially towards the southwest. Major mounds (Fig. 13) and areas of high amplitude occur in the central area SS2500.

Interpretation.

The reflection character suggests a shelf environment, with a change from marginal marine in the northeast (where internal reflections are generally sub-parallel) to more neritic further southwest in the area of generally chaotic reflections. The latter may represent mudstones, possibly disturbed by dewatering. The mounds in this area may be mass flows and may have been deposited during a relative lowstand of the relative sea level. SS2500 is probably predominantly a major lowstand systems tract.

Prospectivity

Reservoirs may exist within the mass flow deposits and be sealed by the possibly overpressured mudstones above them.

SS3000 (Fig. 11)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume).

SS3000 is present in the Hellefisk-1, Ikermiut-1, Kangâmiut-1 and the Nukik-1 and -2 wells.

Hellefisk-1	2297–2077 m	1870–1733 msec TWT
Ikermiut-1	2429–2151 m	2272-2050 msec TWT
Kangâmiut-1	3350–3247 m	2692–2611 msec TWT
Nukik-1	2240–2195 m	1758–1728 msec TWT
Nukik-2	2307–2259 m	1792–1761 msec TWT

SS3000 lies above SS1000 in all 5 wells.

Biostratigraphy & Palaeoecology. Age: late Paleocene age (P5–P6, middle to late Thanetian).

A maximum flooding surface has been interpreted in Hellefisk-1 (2168 m), Ikermiut-1 (2353 m), Kangâmiut-1 (3297 m), Nukik-1 (2221 m) and Nukik-2 (2271 m).

In Hellefisk-1 and Nukik-1 and -2 the environment of deposition is generally shallow marine to brackish or littoral while in Ikermiut-1 and Kangâmiut-1, the depositional environment is generally outer neritic. Palynomorphs show peaks in bio-diversity near or at the maximum flooding surface in the latter two wells, which in general also have a higher bio-diversity than the other three. Microfossils from the Hellefisk-1 and Nukik-2 wells show significantly less diversity in SS3000 than in older seismic sequences and only coal particles are common. Shallowing upward is recognised in the lower part of SS3000, but fining upward log trends in all wells except Ikermiut-1 suggest that the upper part of the SS3000 is transgressive.

Lithology. Hellefisk-1, Nukik-1 and Nukik-2 penetrated sands with sharp-based, blocky gamma-log signals, possibly indicating channels. The other two wells, Ikermiut-1 and Kangâmiut-1, are both mudstone dominated with thin sandstones, possibly turbidites or storm-sand layers containing reworked fresh- to brackish-water algae.

Information from seismic data.

SS 3000 is widespread offshore southern West Greenland and is up to over 400 m thick.

Seismic facies. The lower boundary of SS3000 is defined partly by onlaps, partly by downlaps and partly by truncation of reflections in underlying seismic sequences. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the northeast, SS3000 has been removed by Neogene erosion (Fig. 6)

Internal reflections are mostly sub-parallel and in places chaotic, especially away from the margins of SS3000, where large mounds (Fig. 14) are observed in the lower part of SS3000. In places along the Ikermiut fault complex, SS3000 has a wedge-shaped cross-sections containing facies patterns that can be interpreted as syn-rift wedges (Fig. 15).

Most of SS3000 probably consists of neritic to possibly upper bathyal mudstones with minor turbidites. The large mounds observed in the Sisimiut Basin in Quadrant 6755 and high amplitudes along the major fault system in Quadrants 6656 and 6756 may be slumps, mass flows or basin floor fans, possibly derived from highs to the west of the faults.

Southeast of Hellefisk-1 and south from Nukik-1 and -2, marginal marine to brackish sediments are preserved. These have higher sand contents than elsewhere in SS3000, and much of the sand may have been deposited as channel-fill.

SS3000 probably contains basin floor fans (mounds) and turbidites centrally in its area, succeeded by transgressive deposits, but it seems that highstand deposits are missing. No progradational unit is observed, though coarsening-upward trends are observed in the basinal wells. The rapid variations in thickness of SS3000 in Quadrants 6656 and 6756 near the major faults may indicate that the faults were active during deposition of the sequence. The observations may indicate syn-tectonic lowstand conditions followed by transgression.

Prospectivity

Reservoir-quality sands may be present in the many slumps, mass flows or basin floor fans indicated by the large mounds observed in Quadrant 6755 and along the major fault system in Quadrants 6656 and 6756. The reservoirs may be sealed stratigraphically by surrounding mudstones.

SS3500 (Fig. 16)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume).

SS3500 is present in the Hellefisk-1, Ikermiut-1, Kangâmiut-1 and Nukik-1 and -2 wells.

Hellefisk-1	2077–1986	1733–1677 msec TWT
Ikermiut-1	2151–1870	2050–1848 msec TWT
Kangâmiut-1	3247–3225	2611–2596 msec TWT
Nukik-1	2195–2105	1728–1669 msec TWT
Nukik-2	2259–2224	1761–1739 msec TWT

SS3500 lies directly on SS3000 in all wells.

Biostratigraphy & Palaeoecology. Age: latest Paleocene to early Eocene (P6 to E2a, latest Thanetian to early Ypresian). A maximum flooding surface has been interpreted in Ikermiut-1 (1920 m), Kangâmiut-1 (3237 m), Nukik-1 (2125 m) and Nukik-2 (2245 m).

Inner neritic to brackish conditions from dinoflagellate cysts, plant material and palynomorphs occur at levels interpreted as channels on logs in Nukik-1, Nukik-2 and Hellefisk-1, while inner to outer neritic conditions are found in the other two wells. Dinoflagellate diversity is higher at the maximum flooding surface and just above in Kangâmiut-1, Ikermiut-1 and Nukik-2, and especially at a calcareous interval in Kangâmiut-1 which probably represents a condensed section. Deepening upward is recorded above1940 m in Ikermiut-1.

Lithology. Hellefisk-1, Nukik-1 and Nukik-2 penetrated sands with sharp-based, blocky gamma-log signals, possibly indicating channels. Ikermiut-1 and Kangâmiut-1 are both mud-/siltstone-dominated with thin sandstone layers, which possibly represent turbidites or storm-sand layers.

Information from seismic data.

SS3500 occurs over most of offshore southern West Greenland, but has been eroded locally in the south, west and northeast.

Seismic facies. The lower boundary of SS3500 is defined partly by onlaps, partly by downlaps and partly by truncation of reflections in underlying seismic sequences. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the northeast, SS3000 has been removed by Neogene erosion (Fig. 6). Significant erosion at the base of SS3500 appears to have removed significant parts of the preceding three sequences, particularly towards the margins (Fig. 6).

SS3500 is thickest just east of the major faults in Quadrants 6657, 6656 and 6756, over 600 metres in many places and over1 km in the southern part of Quadrant 6756. There are also large local variations in thickness in this area, probably indicating syn-tectonic deposition during high sediment influxes.

SS3500 laps onto the basalts over the Maniitsoq Rise in Quadrants 6556, 6557 and the Hecla Rise in Quadrants 6456, 6457 (Fig. 17), indicating that the basalts in this area are of latest Paleocene or younger age. SS3500 appears to have been eroded over fault-blocks in the Fylla area of Quadrants 6554 and 6455 and does not extend south of approx. 63°30' N in the syncline east of the Fylla Structural Complex.

Internal reflections are mostly sub-parallel and in places chaotic, especially away from the margins. Complex-sigmoid reflections (Fig. 18), indicating prograding sediments, are found in many areas; prograding southwards in the central parts of the Sisimiut Basin and westwards at many places along the margin of the Nukik Platform.

In the lowermost part of SS3500 away from its margins, mounds are observed, some of which are stacked.

Interpretation.

The thick sands in Hellefisk-1 and Nukik-1 and -2 have sharp-based, blocky gamma-log signals, containing reworked brackish fossils, indicating shallow marine channels. These calibrate the seismic character in this area showing that marginal marine conditions existed in the northern Sisimiut Basin and along the margin of the Nukik Platform. Elsewhere, the well data and seismic reflection character, together with clinoform heights of around 150 ms (approx. 200 m), suggest that the sub-parallel to chaotic seismic character over most of the area indicates a neritic environment. The major mounds may be mass flows or basin-floor fans, and the deformed mounds may be slumps. The high amplitudes at the foot of the slope of the prograding units (Fig. 6) may be slumps or turbidites. SS3500 contains thick syn-rift deposits (Fig. 15) along the Ikermiut fault complex. All these observations suggest that SS3500 was deposited during a period of active extensional tectonism, erosion and high, sand-dominated sediment supply.

The observations indicate that SS3500 consists mostly of sediments deposited during lowstand conditions during active tectonism.

In part of the Sisimiut Basin, SS3500 may be divided locally into at least two seismic units – possibly a forced regressive systems tract and lowstand systems tract – by an onlap surface (Fig. 6, seismic line GGU/92-03; S.P. 3300) of moderate amplitude. High amplitudes observed downdip, basinward on this seismic line may be mass flows. That there are two units may also be supported by the bell-shaped gamma-log trends, which could be interpreted as lowstand deposits in the upper half of SS3500 in Ikermiut-1. However, as this internal boundary is clear only locally and that in an area of active tectonism, SS3500 has been interpreted and mapped as a single seismic sequence.

Prospectivity

The many mounded and syn-tectonic features within SS3500 indicated that reservoir sands could be present as turbidites, basin-floor fans and synrift talus in many places. Many of these features may be sealed by mudstones within SS3500, especially in the more basinal parts, so there are good possibilities of stratigraphic plays.

SS3600 (Fig. 19)

SS3600 has not been penetrated by any well. However, its stratigraphic position between SS3500 (P6 to E2a, late Thanetian to early Ypresian) and SS3750 (E2a, early Ypresian) suggests an early Eocene (E2a, early Ypresian) age for SS3600.

Information from seismic data

SS3600 occurs only in the northern Sisimiut Basin, with a maximum thickness between 100 and 200 metres.

Seismic facies. The lower boundary of SS3600 is defined by onlaps, and the upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the northeast, SS3600 has been removed by Neogene erosion (Fig. 6). Internal reflections are mostly sub-parallel but also in places chaotic.

SS3600 is thin and occurs only in a limited area in the northern part of the Sisimiut basin and updip (landward) of one of the areas of progradation in SS3500 (see Fig. 19 and Fig. 6). No mounded or sigmoid/oblique seismic facies are found in SS3600, indicating little erosional activity.

Interpretation.

The palaeogeographical location and configuration of internal reflections of SS3600 indicate that it was deposited during a period of rising sea-level and transgression, i.e. that SS3600 represents a transgressive systems tract.

Prospectivity.

Sands deposited during the transgression could form a reservoir, but neither internal nor external sealing is likely, since SS3600 dips steadily southwestwards from eroded Quaternary subcrop to the northeast.

SS3750 (Fig. 19)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume).

SS3750 is present in the Ikermiut-1 well.

Ikermiut-1	1870–1795 m	1848–1784 msec TWT

SS3750 lies above SS3500 in Ikermiut-1.

Biostratigraphy & Palaeoecology. Age: early Eocene (E2a, early Ypresian).

Outer neritic conditions with no marginal-marine fossils. A maximum flooding surface has been interpreted at 1829 m in Ikermiut-1.

Lithology. Predominantly claystone with thin sand layers in the lowermost part of the sequence, possibly turbidites or storm sand layers.

Information from seismic data.

The sequence occurs from the Sisimiut Basin in the north, to west of the Kangâmiut Ridge in the south.

Seismic facies. The lower boundary of SS3750 is defined partly by onlaps, partly by downlaps and erosion at its base has removed the landward parts of the preceding sequence. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the north, west and southeast, SS3750 has been removed by Neogene erosion (Fig. 6).

There is a local depocentre in the Sisimiut Basin. Complex variations in thickness along the fault system in Quadrants 6657, 6656 and 6756 with syn-rift wedges indicate syn-tectonic deposition.

Internal reflections are generally sub-parallel but chaotic in places, especially in the basinal parts, and a few mounds, probably indicating slumps or basin-floor fans, are also present in the Sisimiut Basin.

Interpretation

The well information and reflection characters suggest an outer neritic environment mainly during a relative highstand of sea level.

Prospectivity

Some of the mounds in the Sisimiut Basin could contain sands with reservoir properties, sealed under mudstones.

SS4000 (Fig. 19)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume).

SS4000 is present in the Ikermiut-1 well.

Ikermiut-1	1795–1693 m	1784–1694 msec TWT

SS4000 lies above SS3750 in Ikermiut-1.

Biostratigraphy and Palaeoecology. Age: early Eocene (E2a, early Ypresian).

Dinoflagelates indicate outer neritic conditions, although (probably reworked) fresh to brackish-water algae are also found at e.g. 1710 m in thin sands. Microfossils indicate a shallowing trend in the upper part of the seismic sequence from a deep outer neritic to a shallower outer neritic environment.

Lithology. Ikermiut-1 penetrated sand layers with abrupt bases followed by upwardly increasing (bell-shaped) gamma-log values, indicating turbidites or storm-sand layers, within outer neritic claystones.

Information from seismic data

SS4000 occurs in the Sisimiut Basin in the north to west of the Kangâmiut Ridge in the south.

Seismic facies. The lower boundary of SS4000 is defined partly by onlaps and partly by downlaps. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the north, west and southeast, SS4000 has been removed by Neogene erosion (Fig. 6).

Internal reflections are sub-parallel and chaotic, especially in the thicker parts. Very strong amplitudes are observed in the deep central part of the western Sisimiut basin and towards the basin highs, south of Hellefisk-1. Mounds are observed locally in the lowermost part of SS4000 away from its margins and synrift deposits can be seen northeast of the Kangâmiut Ridge.

Interpretation

The well data and reflection character suggest an outer shelf environment. The mounds, which may be mass flows, support a basinal setting. The turbidites or storm sand layers may be a local input during the tectonically disturbed, generally highstand conditions or SS4000 may be a 3rd order highstand systems tract containing elements of 4th order lowstand and transgressive upward-fining deposits.

The more proximal parts of SS4000 appear to thicken towards the Kangeq High, east of Hellefisk-1. This may be due to proximal transgressive-highstand development, or may alternatively be due to a synrift wedge, subsequently inverted.

The very high amplitudes uppermost in SS4000 in the central Sisimiut Basin could indicate mass flow sands, or they could be due to high organic contents at a condensed section.

Prospectivity

Mounds, the syn-tectonic wedge and, if they are due to sands, the large area of high amplitudes in the central Sisimiut Basin could contain reservoirs, sealed by surrounding claystones.

SS4500 (Fig. 19)

SS4500 has not been penetrated by any well. However its stratigraphic position between SS4000 and SS5000 indicates an early Eocene age (E2a, early Ypresian).

Information from seismic data

SS4500 occurs in the Sisimiut Basin with an isolated outlier to the northwest of the Kangâmiut Ridge. While there is no unambiguous tie between the two areas, SS4500 is the only seismic sequence between SS4000 and SS5000.

Seismic facies. The lower boundary of SS4500 is defined partly by onlaps, partly by downlaps and partly by truncation of preceding sequences. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the north and northeast, SS4500 has been removed by Neogene erosion (Fig. 6). Significant erosion by SB4500 appears to have removed landward parts of the preceding sequence.

Internal reflections are sub-parallel but also chaotic in places, especially away from the margins. Sigmoid-oblique reflections, indicating units prograding towards the south, are observed in places in the Sisimiut Basin. A mound and two areas of high amplitude reflections are observed locally in the lowermost part of SS4500.

Interpretation

The reflection character suggests an outer shelf environment. The mounds, which may be mass flows, support a basinal setting.

The very high amplitudes uppermost in SS4500 in the central Sisimiut Basin could indicate mass flow sands, or they could be due to high organic contents at a condensed section.

SS4500 has the characteristics of a highstand systems tract, if the mound is due to a mass-flow on an unstable slope.

Prospectivity

The mound, and, if they are due to sands, the large areas of high amplitudes in the central Sisimiut Basin could contain reservoirs, sealed by surrounding claystones.

SS5000 (Fig. 20)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume).

SS5000 is present in the Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1 and Nukik-2 wells.

Hellefisk-1	1986–1884	1677–1607 msec TWT
Ikermiut-1	1693–1596	1694–1611 msec TWT
Kangâmiut-1	3225–3022	2596–2417 msec TWT
Nukik-1	2105–2031	1669–1622 msec TWT
Nukik-2	2224–2091	1739–1646 msec TWT

SS5000 lies above SS3500 in Hellefisk-1, Kangâmiut-1, Nukik-1 and Nukik-2 and above SS4000 in Ikermiut-1.

Biostratigraphy & Palaeoecology. Age: early Eocene (E2a–E2b, early to middle Ypresian). A maximum flooding surface has been interpreted in Hellefisk-1 (1916 m), Ikermiut-1 (1631 m), Nukik-1 (2056 m) and Nukik-2 (2127 m).

Marginal marine to brackish dinoflagellate cysts (in Hellefisk-1 and Nukik-1) and plant material (especially in Nukik-2 and Hellefisk-1) occur at levels interpreted as channels on logs, followed upwards by littoral to inner neritic conditions in Hellefisk-1. Microfossils indicate an inner to outer neritic environment in Nukik-1 and Ikermiut-1, and an outer neritic to upper bathyal environment with high biodiversities in Kangâmiut-1.

Lithology. Hellefisk-1, Nukik-1 and Nukik-2 contain sandy sediments with sharp-based, blocky gamma-log signals, possibly indicating channels. Ikermiut-1 and Kangâmiut-1 both encountered mud-/siltstones with thin sandstone layers, possibly turbidites or storm sand layers.

Information from seismic data.

SS5000 occurs widespread over the whole of offshore southern West Greenland, from north of Hellefisk-1 to 63°N in the south, but is absent over most of the western part of the area and between 65°N and 65° 30'N.

Seismic facies. The lower boundary of SS5000 is defined partly by onlaps, partly by downlaps and partly by truncation of preceding sequences. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the north and northeast, SS5000 has been removed by Neogene erosion (Fig. 6). Significant erosion by SB5000 appears to have removed landward parts of preceding sequences.

Internal reflections are sub-parallel and in places chaotic, especially in the thicker parts. Moderate to high amplitudes are observed, especially in a major area in the deep part of the basin in and around Quadrant 6455. Complex sigmoid oblique patterns are observed locally, indicating progradation to the southwest in Quadrant 6754 and to the southeast away from the fault in Quadrant 6657. Mounds are common in the lower part of SS5000.

Changes in the thickness of SS5000 across faults are seen in Quadrant 6656 along the Kangâmiut Ridge, and small rotated fault-blocks have been created, indicating active syn-depositional tectonism (Fig. 21).

Interpretation.

SB5000 erodes into preceding sequences. The basinward seismic facies contains many mounds, which may be mass flows - possibly either turbidites or slumps. Between the two areas are clinoforms, around 150 ms (ca. 200 m) high. Together with the well data, these observations suggest littoral to marginal-marine environments around the margins of SS5000 and a neritic to upper bathyal environment farther basinward.

SS5000 was deposited during active tectonism (Fig. 21). However, it is possible that SS5000 may form the lowstand part of a syn-tectonic 3rd order sequence, although 4th order transgressive and highstand deposits may be present.

Prospectivity

The many large mounds may contain turbidite or basin floor fan sands, which may be surrounded and sealed by claystones.

SS5250 (Fig. 20)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume).

SS5250 was penetrated only by Hellefisk-1.

Hellefisk-1 1884–1732 m 1607–1499 msec TWT

A maximum flooding surface has been interpreted at 1844 m.

SS5250 lies above SS5000 in Hellefisk-1.

Biostratigraphy & Palaeoecology. Age: early Eocene (E2b, middle Ypresian).

Inner to outer neritic dinoflagellates dominate the lower part and marginal marine to brackish dinoflagellate cysts occur in the upper part at levels interpreted as channels on logs. No microfossils were observed but abundant coal fragments indicate a very nearshore environment in the upper part.

Lithology. Sandstone with minor to moderate interbeds of claystone and occasional siltstone.

Information from seismic data

SS5250 is interpreted only in a small area around Hellefisk-1. Internal seismic facies are sub-parallel.

Interpretation

The very local occurrence of SS5250 suggests that its presence is due to tectonic activity in the Hellefisk High area. Tectonic activity may have created short-lived accommodation space in a time of relatively high sediment input, or SS5250 may consist of slumps or slides. It is difficult to relate this small area to any conventional system tract. The 'maximum flooding surface' interpreted in the well may be due to sediment by-passing during active tectonism.

SS5500 (Fig. 22)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume)

SS5500 was penetrated only by Hellefisk-1.

Hellefisk-1	1732–1637 m	1499–1434 msec TWT

A maximum flooding surface has been interpreted in Hellefisk-1 (1649m).
SS5500 lies above SS5250 in Hellefisk-1.

Biostratigraphy & Palaeoecology. Age: early Eocene (E2b, middle Ypresian).

Dinoflagellates suggest inner neritic conditions in the lower part and brackish conditions at a level interpreted as a channel on logs.

Lithology. Glauconitic sandstone with interbedded claystone, more argillaceous towards the base.

Information from seismic data

SS5500 occurs in three isolated areas, and the only justification for considering these to be parts of the same sequence is that they occur within same stratigraphic interval between seismic sequences that have been correlated with more confidence. It is possible that the two more southerly areas could be correlated with SS5250 or SS5750 rather than SS5500. There is no evidence either way.

Seismic facies. Sub-parallel to chaotic with small mounds in the more basinal parts.

Interpretation

SS5500 may consist of erosional remnants of a previously more extensive sequence, or, especially the northern area, sediments deposited during active movements of the faults near Hellefisk-1. Sediment input rates do not appear to be particularly high. It is difficult to relate these small areas to any conventional system tract. The 'maximum flooding surface' interpreted in the well may be due to sediment by-passing during active tectonism.

SS5750 (Fig. 22)

Information from well data (from Dalhoff *et al.*, this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume)

SS5750 is present only in Hellefisk-1.

Hellefisk-1	1637–1563 m	1434–1378 msec TWT

SS5750 lies above SS5500 in Hellefisk-1.

Biostratigraphy and Palaeoecology:

Age: early Eocene (E2b–E2c, middle Ypresian).

A maximum flooding surface is interpreted in Hellefisk-1 at 1592 m.

Brackish dinoflagellate cysts occur at two levels interpreted as channels on logs.

Lithology. Glauconitic sandstone with interbedded claystone.

Information from seismic data

SS5750 is interpreted only in a small area around Hellefisk-1.

Seismic facies. Sub-parallel with a single mound at the location of Hellefisk-1.

Interpretation

The presence of a mound in a sandy marginal marine environment suggests that it may be a channel or shore-face sand or mass flow within an otherwise more mud-prone environment. It is difficult to relate this small area to any conventional system tract.

SS6000 (Fig. 23)

Information from wells (from Dalhoff *et al.*, this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume)

SS6000 is present in the Hellefisk-1, Ikermiut-1, Kangâmiut-1 and Nukik-1 and -2 wells.

Hellefisk-1	1563–1357 m	1378–1246 msec TWT
Ikermiut-1	1596–1536 m	1611–1559 msec TWT
Kangâmiut-1	3022–2930 m	2417–2330 msec TWT
Nukuk-1	2031–1973 m	1622–1580 msec TWT
Nukik-2	2091–2015 m	1646–1597 msec TWT

A maximum flooding surface is interpreted in Hellefisk-1 at 1393 m, Kangâmiut-1 at 2966 m, Nukik-1 at 1988 m and Nukik-2 at 2054 m. SS6000 lies above SS5750 in Hellefisk-1 and SS5000 in Ikermiut-1, Kangâmiut-1 and Nukik-1 and Nukik-2.

Biostratigraphy & Palaeoecology. Age: early Eocene (E2b–E3a, middle to late Ypresian).

Inner neritic to brackish dinoflagellate cysts and no marine microfossils occur in Nukik-2 and in Hellefisk-1. The inner neritic to littoral conditions at Nukik-2 are dominated by channels in the lower part and a change to deeper-water conditions above is marked by a diversity increase and an increase in the abundance of tubular agglutinating foraminifera. The lower part of the sequence in Hellefisk-1 indicates inner neritic conditions, while its middle part contains high amounts of terrestrial plant material and saccate pollen. Inner to outer neritic conditions are suggested upwards from the maximum flooding surface in Nukik-1. Outer neritic to upper bathyal conditions and highest diversities are found in the lower part of Kangâmiut-1 well, whereas a change to inner neritic conditions occurs above the maximum flooding surface.

Lithology. Hellefisk-1, Nukik-1 and Nukik-2 penetrated sandy sediments with sharp-based, blocky gamma-log signals, possibly indicating channels. Ikermiut-1 and Kangâmiut-1 both penetrated mud/siltstones with thin sandstone layers, possibly turbidites or storm sand layers.

Information from seismic data

SS6000 is widespread over much of southern West Greenland.

Seismic facies. The lower boundary of SS6000 is defined partly by onlaps, partly by downlaps and partly by truncation of preceding sequences. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the north and northeast, SS6000 has been removed by Neogene erosion (Fig. 6).

Internal reflections are sub-parallel and in places chaotic, especially in the thicker parts. Complex sigmoid oblique patterns are observed in Quadrants 6654, 6754 and 6755, indicating progradation to the southwest, and in Quadrants 6557 and 6657, indicating progradation towards the east. Mounds are observed in places in the lowermost, most basinward parts of SS6000.

In Quadrants 6555, 6556, 6655 and 6656, changes in the thickness of SS6000 across faults are seen (Fig. 21) and SB6000 erodes underlying fault blocks, and in the deeper part of the basin it truncates sequences down to SS3750, indicating that the syn-depositional tectonism observed during deposition of SS6000 continued during SS6000 time.

Interpretation

The tectonic movements active from SS5000 to SS6000 time appears to have formed high areas near the Hellefisk-1, Ikermiut-1, Kangâmiut-1 wells, as well as other areas around the Maniitsoq, and Hecla Rises and at the southwest margin of the Nukik Platform. Progradation from the northeast and west indicates substantial sediment input to the basin at this time. The mounds that are found close to and distally from the foot of the progradations are probably mass flows or turbidite fans. Elsewhere in the basin, the data indicate a neritic shelf environment.

SS6000 is very extensive and probably represents either a transgressive systems tract or a highstand systems tract or a combination of both.

Prospectivity.

If the mounds consist of sands embedded in mudstones, they could form stratigraphic traps.

SS7000 (Fig. 23)

SS7000 has not been penetrated by any well, however its stratigraphic position between SS6000 and SS8000 indicates an early Eocene age (E3a, late Ypresian).

Information from seismic data

SS7000 occurs only in the Sisimiut Basin.

Seismic facies. The lower boundary of SS7000 is defined partly by onlaps, partly by downlaps and partly by truncation of preceding sequences. It erodes into preceding sequences at highs. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the north and northeast, SS7000 has been removed by Neogene erosion (Fig. 6). Erosion by SB7000 appears to have removed landward parts of preceding sequences.

Internal reflections over most of the area of SS7000 are sigmoid-oblique indicating progradation towards the south-southwest, with sub-parallel reflections to the north (landward) and south (basinward) of the prograding unit. Moderate to high amplitudes are seen, especially near the offlap break and at the toes of the progradational system. High amplitude reflections that may indicate a mass flow such as a turbidite are found at the toe of the prograding system.

Interpretation

Landward, SB7000 erodes into preceding sequences at highs, and further basinward it consists mainly of prograding units near the centre of the Sisimiut Basin. The palaeo-sub-horizontal, moderate to high amplitudes at the offlap break may represent a transition from marine near-shore sands to marine clays, and may thus mark a base-level. SS7000 may represent progradation during a fall or lowstand in relative sea-level and may be either a lowstand prograding wedge or a forced regressive wedge, more probably the latter since its offlap break lies considerably basinward and below the offlap break of the preceding SS6000 (Fig. 24). SS7000 is thus probably either a lowstand wedge or possibly an entire major lowstand systems tract.

The high amplitudes at the toes of the prograding reflections may be mass flow deposits, possibly turbidite sands.

Prospectivity

The small turbidite fans at the toe of the progradations could contain hydrocarbons if they are sealed.

SS7500 (Fig. 23)

SS7500 has not been penetrated by any well. However its stratigraphic location between SS6000 and SS8000 indicates an early Eocene age (E3a, late Ypresian).

Information from seismic data.

SS7500 occurs only in the Sisimiut Basin.

Seismic facies. The lower boundary of SS7500 is defined partly by onlaps, partly by downlaps and partly by truncation of preceding sequences. It erodes into preceding sequences at highs. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the north and northeast, SS7500 has been removed by Neogene erosion (Fig. 6).

Internal reflections over most of the area of SS7000 are sigmoid-oblique (Fig. 24) indicating progradation towards the southwest, with sub-parallel reflections to the north (landward) and south (basinward) of the prograding unit. Moderate to high amplitudes are seen especially near the offlap break (Fig. 24) and at the toes of the progradational system.

Interpretation

SS7500 consists predominantly of progradations in a restricted area of the Sisimiut Basin. The moderate to high reflection amplitudes at the offlap break may represent a transition from marine near-shore sands to marine clays and the amplitudes at the toes of the slopes may be mass flow deposits, possibly turbidite sands. These characters are typical of a submarine shelf–prodeltaic environment. The progradations in SS7500 are displaced to a more distal position than those in the preceding SS7000 and sediment bypass and/or erosion may have removed the more proximal parts of SS7500. The seismic sequence may represent progradation during a lowstand in relative sea-level. SS7500 lies in what may be regarded as the 'fore-deep' of the transpressional Ikermiut fault complex possibly during a period of significant tectonic activity along them. This may have created the accommodation space for these sediments.

Prospectivity

Turbidite fans at the toe of the progradations could contain hydrocarbons if they are sealed.

SS7750 (Fig. 23)

SS7750 has not been penetrated by any well. However its stratigraphic location between SS6000 and SS8000 indicates an early Eocene age (E3a, late Ypresian).

Information from seismic data.

SS7750 occurs in the southern Sisimiut Basin only.

Seismic facies. The lower boundary of SS7500 is defined partly by onlaps, partly by downlaps and partly by truncation of preceding sequences. Significant erosion at its base may have removed major landward parts of the preceding sequence. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the north and northeast, SS7500 has been removed by Neogene erosion (Fig. 6).

Internal reflections over most of the area of SS7000 are sigmoid-oblique indicating progradation towards the southwest, with sub-parallel reflections to the north (landward) and south (basinward) of the prograding unit (Fig. 24). Moderate to high amplitudes are seen especially near the offlap break and at the toes of the progradational system. Elsewhere, internal reflections are sub-parallel and chaotic, especially in the basinal parts. Mounds are found in the deepest basinal parts at the toe of the prograding system.

Interpretation.

SS7750 consists predominantly of progradations in a restricted area of the Sisimiut Basin. The moderate to high reflection amplitudes at the offlap break may represent a transition from marine near-shore sands to marine clays and the amplitudes at the toes of the slopes may be mass flow deposits, possibly turbidite sands. These characters are typical of a submarine shelf–prodeltaic environment. The sequence, especially its progradational part, is very well confined to the deepest part of the Sisimiut Basin but the level of the sub-horizontal, moderate to high amplitudes, probably representing facies transition near offlap break, has been displaced to a more basinward but slightly higher position than that in the preceding SS7500, indicating that lowstand conditions persisted during the time of SS7750, but that sea level was constant or beginning to rise. As was the case for SS7500, continued tectonic activity along the Ikermiut Fault Complex may have created the accommodation space for SS7750 in the 'fore-deep' to the transpressional faults.

Prospectivity

Turbidite fans at the toe of the progradations could contain hydrocarbons if they are sealed.

SS8000 (Fig. 25)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume)

SS8000 has been penetrated only by the Kangâmiut-1 well.

Kangâmiut-1	2930–2887 m	2330–2290 msec TWT

SS8000 lies above SS6000 in Kangâmiut-1.

Biostratigraphy & Palaeoecology. Age: early Eocene (E3a, late Ypresian).

The sediments penetrated by Kangâmiut-1 were deposited in upper bathyal conditions and are dominated by "flysch-type", tubular agglutinating foraminifera.

Lithology. Silty mudstone

Information from seismic data

SS8000 extends from the Sisimiut Basin to south approximately 65° 40'N with an isolated small area in Quadrants 6357 and 6457. There is no unambiguous connections between these two separated areas other than that they occupy the same stratigraphic interval.

Seismic facies. The lower boundary of SS8000 is defined partly by onlaps, partly by downlaps and partly by truncation of preceding sequences. In one area, SB8000 truncates preceding sequences down to SS3500.

Internal reflections are sub-parallel and in places chaotic, especially in the thicker parts. Sigmoid oblique patterns are observed in Quadrants 6654 and 6755, indicating progradation to the south-southwest and in Quadrants 6557 and 6657 indicating progradation to the east. Mounds are observed basinward of the toes of the progradations.

Interpretation

Possible back-stepping of internal reflections, updip and landward of the progradations in SS7750, indicate a relative rise in sea level, and that SS8000 consists mostly of a major transgressive systems tract. The progradations may be due to local sediment input being higher than the local increase in accommodation space during the transgression. Alternatively, but perhaps less likely, it may be due to regression during a sea-level high-stand. The mounds are probably basin-floor fans deposited by turbidites flowing down across the prograding fronts.

Prospectivity

Marginal marine sands deposited during the transgression may be preserved, but would need to be sealed by mudstones in the upper part of SS8000 or a later sequence. The mounds in the more basinal parts of SS8000 could contain reservoirs sealed by mudstones within the sequence.

SS8250 (Fig. 25)

SS8250 has not been penetrated by any well. However its stratigraphic location between SS8000 and SS8500 indicates an early Eocene age (E3a, late Ypresian).

Information from seismic data

The sequence occurs only in a limited area of the Sisimiut Basin.

Seismic facies. Sub-parallel to chaotic with one mound and one small area of high amplitude.

Interpretation

The depositional environment of SS8250 is unclear, but it could consist of a remnant of the more distal areas of a lowstand systems tract, whose more proximal areas may have been removed by subsequent erosion.

SS8500 (Fig. 26)

Information from wells (from Dalhoff *et al.*, this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume)

SS8500 has been penetrated by Kangâmiut-1, Nukik-1 and Nukik-2.

Kangâmiut-1	2887–2751 m	2290–2166 msec TWT
Nukik-1	1973–1923 m	1580–1541 msec TWT
Nukik-2	2015–1835 m	1597–1475 msec TWT

A maximum flooding surface is interpreted in Kangâmiut-1 at 2788 m and Nukik-2 at 1843 m.

SS8500 lies above SS8000 in Kangâmiut-1 and SS6000 in Nukik-1 and Nukik-2.

Biostratigraphy & Palaeoecology. Age: early Eocene (late E3a–E3c, late Ypresian)

Palynomorphs and microfossils indicate deepening-upwards, littoral to outer neritic conditions in the Nukik-1 and -2 wells and shallowing-upwards, upper bathyal to outer neritic conditions in Kangâmiut-1.

Lithology. Kangâmiut-1 penetrated silty mudstone with minor sandstone layers, while Nukik-1 and Nukik-2 found predominantly sandstone with interbeds of claystone.

Information from seismic data

SS8500 occurs widespread over most of offshore southern West Greenland.

Seismic facies. Many areas of sigmoid-oblique internal reflections are observed; in the Sisimiut Basin, where they indicate progradation to the southwest, and in several places along and west of the western margin of the Nukik Platform, where they indicate progradation in a generally westwards direction. Reflections in the Sisimiut Basin, both proximally and distally of the progradations are high amplitude, possibly indicating the influx of large amounts of sand. Elsewhere, internal reflections are sub-parallel to chaotic, probably indicating mud-dominated neritic environments distal to the progradations and marginal marine environments proximal of them. SS8500 was affected by faulting along the flanks of the Kangâmiut Ridge (Fig. 21).

Interpretation

The evidence from Kangâmiut-1 that the environment of deposition of SS8500 'deepened upwards' suggests that the sequence was deposited during a period of overall transgression. This may be the most likely interpretation of SS8500, despite the substantial amount of progradation observed, because SS8500 was probably deposited during continuing movement on the Ikermiut fault zone, which was undergoing transpression and uplift in Quadrants 6656, 6657, 6756 and 6757, and possibly creating some form of 'fore-deep' in the Sisimiut Basin. This effect may have enhanced the accommodation space available for sedimentation, and high sediment supply rates may have outpaced the overall transgression and created local regression around the eastern margins of the sequence and in the Sisimiut Basin.

Prospectivity

There may be significant amounts of sand in the eastern marginal areas of SS8500 and in the Sisimiut Basin, but this would need to be sealed by shallower sediments. There seems little evidence of the presence of distal sand.

SS9000 (Fig. 27)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume)

SS9000 was penetrated by Kangâmiut-1.

Kangâmiut-1	2751–2693 m	2166–2188 msec TWT

A maximum flooding surface is interpreted in Kangâmiut-1 at 2720 m. SS9000 lies above SS8500 in Kangâmiut-1.

Biostratigraphy & Palaeoecology. Age: early to middle Eocene (E3c?–E3d, late Ypresian to early Lutetian).

The depositional environment in Kangâmiut-1 is interpreted to be inner neritic to upper bathyal, shallowing upwards, although marginal marine to brackish dinoflagellates dominate just below the maximum flooding surface.

Lithology. Predominantly mudstone.

Information from seismic data

SS9000 is found in three separate areas. It is not necessary that the areas south of 65°N form part of the same seismic sequence as those north of 65°N, but the occupy the same stratigraphic interval, and it is natural to treat them are the same seismic sequence.

Seismic facies. The lower boundary of SS9000 is defined partly by onlaps, partly by downlaps and partly by truncation of preceding sequences. The faulting along the margins of the Kangâmiut Ridge ceased after deposition of SS8500 (Fig. 21) and SS9000 and later sequences drape the Ridge. Thus significant faulting, whose location along the Kangâmiut Ridge shifted with time, took place during the period from the deposition of SS5000 to the deposition of SS8500, but not later. In the deeper parts of the basin SS9000 truncates sequences to SS3750. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the north and northeast, SS9000 has been removed by Neogene erosion (see Fig. 6).

An area of sigmoid-oblique reflections in the Sisimiut Basin indicates progradation towards the southwest. Elsewhere, internal reflections are sub-parallel and also chaotic with mounds west of the Kangâmiut Ridge. They probably represent basin floor fans.

Interpretation

The sediments from the sequence boundary to the maximum flooding surface probably represents a transgressional systems tract and the interval above the maximum flooding surface a highstand systems tract. The maximum flooding surface is not apparent on the seismic data.

Prospectivity

The mounds west of the Kangâmiut Ridge could indicate the presence of reservoirs in basin floor fans, sealed by surrounding overpressured mudstones.

SS9500 (Fig. 27)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume)

SS9500 was penetrated by Kangâmiut-1.

Kangâmiut-1	2693–2625 m	2118–2069 msec TWT

A maximum flooding surface is interpreted in Kangâmiut-1 at 2628 m. SS9500 lies above SS9000 in Kangâmiut-1.

Biostratigraphy & Palaeoecology. Age: middle Eocene (E4c, early Lutetian).

Outer neritic to upper bathyal conditions in Kangâmiut-1.

Lithology. Silty mudstone in Kangâmiut-1

Information from seismic data

SS9500 is found from the southern Sisimiut Basin to the areas east and west of the Kangâmiut Ridge.

Seismic facies. The lower boundary of SS9500 is defined partly by onlaps, partly by downlaps and partly by truncation of preceding sequences. It erodes into preceding sequences at highs. The upper boundary is defined partly by truncation of internal reflections and partly by termination of reflections in overlying seismic sequences. Towards the north and northeast, SS9500 has been removed by Neogene erosion. An area of sigmoid-oblique internal reflections in northern quadrant 6653 indicates progradation to the west. Elsewhere internal reflections are sub-parallel and chaotic. Mounds are observed in two places.

Interpretation

SS9500 is probably the erosional remnant of a lowstand systems tract. The sub-parallel and chaotic internal reflections may indicate the presence of upper bathyal to outer neritic muds and the progradations may be a shelf margin prograding wedge. The mounds indicate the possible presence of basin-floor fans.

Prospectivity

The mounds may indicate the presence of basin floor fan reservoirs within an otherwise muddy environment.

SS10000 (Fig. 28)

Information from wells (from Dalhoff *et al.* this volume, Nøhr-Hansen this volume, Rasmussen & Sheldon this volume, Sheldon this volume)

SS10000 was penetrated by Kangâmiut-1.

Kangâmiut-1	2625–2565 m	2069–2031 msec TWT

SS10000 lies above SS9500 and below the mid-Eocene Unconformity in Kangâmiut-1. It is the shallowest sequence interpreted in this study penetrated by any well.

Biostratigraphy & Palaeoecology. Age: middle Eocene (E4c, early Lutetian)

Inner to outer neritic conditions in Kangâmiut-1.

Lithology. Fine-grained, massive sandstone with a sandy limestone at the base.

Information from seismic data

SS10000 is widespread over offshore southern West Greenland.

Seismic facies. The lower boundary of SS10000 is defined partly by onlaps and partly by truncation of preceding sequences. The upper boundary is mostly the mid-Eocene Unconformity, which is mainly defined by truncation of internal reflections within overlying seismic sequences. Towards the north and northeast, SS10000 has been removed by Neogene erosion.

Over much of the area of SS10000, including where the sequence was penetrated by the Kangâmiut-1 well, internal reflections are strong and parallel (Fig. 21). Elsewhere, internal reflections are weaker and sub-parallel.

Interpretation

Kangâmiut-1 indicates that the strong, parallel seismic facies is due to the presence of sandstones, which in turn may have been deposited in submarine dunes migrating over a shelf. In which case, the areas of less reflectivity would be due a more mud-prone facies. SS10000 is widespread and probably indicates a transgression. SS10000 may have been deposited when the whole of the area offshore southern West Greenland was entirely marine for the first time.

Prospectivity

The widespread sands of SS10000 would probably form an excellent reservoir, however, over much of the area there is probably no adequate seal, since conditions later than SS10000 time seem to have been predominantly sandy (Rolle 1985).

SS11000 (Fig. 28)

SS11000 has not been penetrated by any well. However its stratigraphic location between SS10000 and the mid-Eocene Unconformity indicates a middle Eocene age (E4c–E5a, early Lutetian).

Information from seismic data.

SS11000 occurs only in the southwestern Sisimiut Basin and as tiny areas east and west of the Kangâmiut Ridge. There is no necessary connection between these areas other than that they occupy similar stratigraphic positions between SS10000 and the mid-Eocene Unconformity.

Seismic facies. The two southern areas are thin and more or less transparent, without internal character. Sigmoid-oblique internal reflections in the northern area indicate progradation towards the southwest, and high amplitudes along the offlap breaks probably indicate the presence of sand above and to the northeast of slope mudstones.

Interpretation

SS11000 is probably the erosional remnant of either a lowstand systems tract or a highstand systems tract, eroded by the mid-Eocene Unconformity except for its remaining limited extent.

SS12000 (Fig. 28)

SS12 000 has not been penetrated by any well. However its stratigraphic location between SS10000 and the mid-Eocene Unconformity indicates a middle Eocene age (E4c–E5a, early Lutetian).

Information from seismic data.

SS12000 occurs only as a small area in the southwestern Sisimiut Basin.

Seismic facies. SS12 000 is thin and more or less transparent with one small internal high-amplitude internal reflection.

Interpretation

SS12 000 is probably an erosional remnant of a previously more extensive sequence. Its remains are now so limited that it is difficult to interpret the depositional environment from seismic data.

Third-order Depositional Sequences

Reliable dates are available for the 21 seismic sequences from SS500 to SS10000. Their stratigraphic (dinoflagellate zone) ages range from P3 to E4c; a total of approximately 13 million years from 60 Ma to 47 Ma. Examination of Fig. 29 shows that the duration of deposition of individual seismic sequences varies considerably, from nearly 2 million years for SS3000 to very short periods for several of the seismic sequences between SS7000 and SS8000. However the mean time of deposition of a seismic sequence is about 0.6 million years. Emery and Myers (1996, p. 18) consider that 3rd order sequence cycles are in the time range 0.5 to 3 million years and 4th order cycles are in the time range 0.1 to 0.5 million years. Miall (1997, p. 51) reports ranges of 0.01 to 10 million years for 3rd to 5th order cycles and

0.01 to 2 million years for 4th to 5th order cycles. Brink *et al.*'s (1993) cycles lasted an average of 0.12 million years and they regarded them as 4th order.

Table 1 shows a summary of the interpretations of the seismic sequences described in this paper, including attribution of systems tracts where appropriate. Inspection of Table 1 suggests that several of the seismic sequences can be grouped into successions that commence with a lowstand systems tract succeeded by a transgressive systems tract and a highstand systems tract. Such groupings indicate deposition during a 3rd-order cycle of relative sea-level, and their constituent seismic sequences may be 4th-order sequences. Other seismic sequences seem to contain entire 3rd-order cycles of relative sea-level. The groupings suggest the presence of 11 third-order sequences, of average duration slightly over 1 million years.

Discussion

Early Paleocene uplift and erosion

The evidence presented in this paper suggests that lower Danian and possibly uppermost Cretaceous sediments are missing from offshore southern West Greenland south of 68°N. SS500 and SS1000 are widespread over southern West Greenland (Fig. 8) and they are dated as late Danian to early Thanetian (P3 to P4) and middle Thanetian (P4 to P5) respectively. Over most of southern West Greenland, these sequences are underlain directly by the Kangeq sequence, which has been penetrated only twice, in Ikermiut, where its uppermost sediments are dated as Late Santonian (Nøhr-Hansen 1998), and in Qulleq-1, where Campanian sediments lie directly under Paleocene sediments. Only undated seismic sequences SS100, SS150 and SS250 have been interpreted from the interval between the Kangeq sequence and SS500 and SS1000, and they are restricted to a limited area of the northeast Sisimiut Basin (Fig. 6).

The lowermost part of SS500 may have been deposited contemporaneously with the Danian volcanic rocks exposed in the Nuussuaq Basin (Magnetochrons 27N to 26R, Riisager & Abrahamsen 1999, equivalent to Dinozone P2, Nøhr-Hansen *et al.* in press). Dam & Sønderholm (1994) and Dam *et al.* (1998) have described episodes of faulting in the Nuussuaq Basin that started in Campanian time and resumed in mid-Maastrichtian time. These movements resulted in both rotation and uplift of the Upper Cretaceous Atane Formation sediments in fault blocks (Chalmers *et al.* 1999), and were followed by the incision of a series of large, deep channels which were filled by transgressive successions of coarse conglomerates and turbidites or by fluvial sandstones (Dam & Sønderholm 1994, 1998; Dam *et al.* 1998). An angular unconformity separates upper Campanian–Palaeocene sediments from the underlying Atane Formation in many parts of the area. Dam *et al.* (1998) and Dam *et al.* (1999) suggested that the rapid uplift and subsequent rapid subsidence during the Danian revealed by these sediments may have been due to a very-short (<5 m.y.) period of plume-related uplift prior to the eruption of the volcanic rocks.

Dam *et al.* (1998, 1999), following Campbell & Griffiths (1992) interpret the uplift in the Nuussuaq Basin to be due to the combined mechanical and thermal effects of an impinging plume head and the subsidence due to the combined effects of plume spreading, magma escape and consequent loading of the lithosphere. The lack of lowermost Danian sediments offshore may be explained if the entire area had been subjected to the same episode of uplift described by Dam *et al.* (1998, 1999), but without the subsequent subsidence, suggesting that magma escape may be an important factor in inducing subsidence.

Only SS100, SS150 and SS250 were deposited offshore during or prior to P2 time, and they may be the distal equivalents of the latest channel/valley erosion and subsequent refill episodes described by Dam & Sønderholm (1994), which took place during early Danian (P2) time. SS500 was deposited during the period of igneous eruption, most of which took place during P2 time onshore but as late as P4 time in the area penetrated by Hellefisk-1.

Tectonism

Many of the seismic sequences discussed in this paper were deposited during active tectonism. There is evidence for at least two distinct patterns of tectonism; extension during the Paleocene and early Eocene and compression/transpression during the early Eocene.

Evidence for extension can be seen in SS500, SS1000, SS2000, SS3000 and SS3500 (Figs 8, 11 and 16) in all of which syn-tectonic wedges can be seen indicating extensional down-to-the-east movement on faults in Quadrants 6656 and 6657, along the line of the Ikermiut Fault Complex (Fig. 15). There is no clear evidence for the persistence of this extensional movement in seismic sequences younger than SS3500, which is dated as latest Paleocene to earliest Eocene.

Seismic sequences near the Ikermiut fault zone have clearly been compressed. Clear evidence of folding and overthrusting is visible on many seismic lines (e.g. Figs 3 and 15), and Chalmers *et al.* (1993, 1995) and Chalmers & Pulvertaft (in press) have interpreted the

Ikermiut fault zone as a flower-structure caused by left-lateral step-over in a sinistral strike-slip zone. That interpretation is consistent with the evidence presented here for seismic sequences younger than SS3500.

The change in structural style between eastwards-directed extension to transpression took place just after the Paleocene–Eocene boundary. This is the same time that sea-floor spreading started in the northern North Atlantic, and when the direction of sea-floor spreading in the Labrador Sea rotated by about 13° (Srivastava 1978, Roest & Srivastava 1989, Chalmers & Pulvertaft in press).

Evidence for extension during the early Eocene is present in other parts of southern West Greenland basins. Seismic sequences SS5000, SS6000, SS8500 and SS9000 are broken by faults in the Fylla Structural Complex between about 64°N and 65°N that do not seem to persist later than the mid-Eocene Unconformity. Extensional activity along the Kangâmiut Ridge took place during the late Paleocene and persisted during the Eocene, particularly during the period that included the deposition of seismic sequences SS5000 to SS8500 inclusive.

Sediment supply directions

An approximately north-south section (located on Fig. 1) showing thicknesses of the Paleocene–Lower Eocene sediments offshore southern West Greenland is shown in Fig. 30. It is immediately obvious that the thickness of sediment in the Sisimiut Basin is approximately three times what it is south of the Kangâmiut Ridge. Closure inspection of Fig. 30 and comparison of the isopach maps shows that this discrepancy is mostly because many more seismic sequences are interpreted in the Sisimiut Basin than further south. The presence of only SS1000, SS6000, SS8000 and SS8500 in the Qulleq-1 well (Figs 29 and 30) suggests that this is likely to be a reflection of the true state of affairs and not just due to lack of resolution of seismic data.

Examination of the seismic data and maps for evidence for this state of affairs suggests that the most likely explanation is that most sediment entered the basin system from the north. Evidence for progradation towards the south and southwest, and to a lesser extent to the west, in the Sisimiut Basin can be seen in seismic sequence after seismic sequence; SS100, SS150, SS250, SS500, SS1000, SS2000, SS3500, SS4500, SS5000, SS6000, SS7000, SS7500, SS8000, SS8500, SS9000 and SS10 000. Progradation is also observed in other areas, although none so persistent as in the Sisimiut Basin. Progradation towards the west and southwest is observed in Quadrant 6554, south of the Nukik-1 and –2 wells, in SS1000, SS3000, SS3500 and SS8500. In SS3500 and SS8500, the area of progradation observed in Quadrant 6554 extends southwards into Quadrants 6454 and 6453. Downlapping reflections, evidence of sediment movement towards the east and southeast and south, can be seen in Quadrants 6656 and 6657 in SS3500, SS6000 and SS8000.

The sediment that moved eastwards and was deposited in Quadrants 6656 and 6657 may have originated on the footwall of active faults along the Ikermiut fault zone, moved across the faults and been deposited on the hanging wall. The sediment that moved westwards and was deposited in Quadrants 6554, 6454 and 6453 appears to have moved across the Nukik Platform and been deposited at the edge of the platform, where accommodation space was being created by differential compaction of older sediments, possibly assisted by some active tectonic movements.

The large amounts of sediment preserved in the Sisimiut Basin originated from the north and northeast. There is no evidence in any of the wells that erosion of the flood basalts (Fig. 1) was a major source of sediment, so these sediments probably have originated beyond them. During the Late Cretaceous, thick sediments were deposited in the Nuussuaq Basin in a delta from a major river flowing westwards from the interior of Greenland. During the Maastrichtian and Danian, deep channels, both subaerial and submarine, were cut across the Nuussuaq Basin (Dam & Sønderholm 1994), indicating the persistence to the east of a large source of flowing water and sediment at this time. This source seems to have been switched off or diverted during the active phase of volcanism in the late Danian, when the volcanic pile dammed a lake on its landward side (Pedersen *et al.* 1998). There is no reason to suppose that the river in the interior of Greenland disappeared at this time, merely that its outflow was diverted elsewhere. The large amounts of sediment moving into the Sisimiut Basin from the north and northeast could have originated from this river. If so, it is possible that the volcanic pile diverted it to the south in the mid-Paleocene, to flow across southern Disko Bay along the eastern margin of the basalts to an estuary/delta in the Sisimiut Basin.

An additional reason for the preservation of large thicknesses of sediment in the Sisimiut Basin compared to elsewhere may be because of movements on the Ikermiut fault zone. During the Paleocene and earliest Eocene (SS3500 and older), the Ikermiut fault zone may have been acting as an extensional fault system with the area to the east as the hanging wall.

Movements on the faults along the Kangâmiut Ridge and that bound the Sisimiut Basin to the east complicate the picture, but it seems that the combined effects of these movements was to create more accommodation space in the Sisimiut Basin than elsewhere at this time. During the rest of the early Eocene and early middle Eocene, the Ikermiut fault zone was in transpression, and the Sisimiut Basin appears to have acted as a downwarping foreland basin, which again created more accommodation space here than elsewhere.

Petroleum Prospectivity

Marraat oil source rock equivalent

The Maraat oil, one of the oils that have been discovered seeping to the surface in the Nuussuaq Basin, has been attributed to a source rock "not likely to pre-date the latest part of the Late Cretaceous" (Bojesen-Kofoed *et al.* 1999). This source rock appears to have been encountered in the GRO#3 well where there is ".. a remarkable similarity in geochemistry between the mudstones from the interval from 320 m to 510 m ... and the Marraat oil type" (Christiansen *et al.* 1999). This interval is dated as P2 by Nøhr-Hansen *et al.* (in press).

Offshore south of 68°N, only the lower part of SS500 and older seismic sequences SS100, SS150 and SS250 are as old as this, so any extension of the Marraat source rock into the offshore is limited in extent to a maximum shown by the extent of SS500 (Fig. 8). Fig. 31 shows a map of depths to SB500. Unpublished calculations of maturity by A. Mathiessen (personal communication) based on data from Ikermiut-1 and Kangâmiut-1 suggest that the distribution of maturity of any source rock at this horizon is likely to as shown by tone on Fig. 31, i.e. that there is an area northeast of Ikermiut-1 where such a source rock may be in the main oil window at the present-day, and a much larger area where it may be in the early oil window. The Sisimiut Basin was tilted upwards towards the east or northeast at some time during the Neogene (Chalmers 2000). It is therefore likely that, prior to Neogene uplift, the area of maturity of any source rock in SS500 extended farther east than shown in Fig. 31.

Reservoirs, seals and traps

Many potential stratigraphic traps are present, consisting of fans of various types encased in basin mudstones. Inspection of the maps in Figs 8, 11, 16, 19, 20, 23, 25 and 27 will show where such fans are located. The fans consist of two main types, basin floor fans and syn-rift wedges. No detailed mapping of these features has been possible on the widely-spaced seismic grid used in this project. To map these features in detail and identify any structural traps needs a much denser grid of lines. Such a grid of commercial, in-confidence data is becoming available at the time of writing, but it could not be used in this publication because of its confidentiality.

Conclusions

The techniques of seismic stratigraphy interpretation have been used successfully to interpret Paleocene and Lower to Middle Eocene sediments on a regional grid of seismic lines offshore southern West Greenland.

Twenty nine seismic sequences have been interpreted and their internal seismic facies described and interpreted.

The twenty nine seismic sequences have been grouped into eleven third-order depositional sequences.

Successful seismic, biostratigraphic and lithostratigraphic correlations have been achieved between the six deep boreholes offshore southern West Greenland.

The seismic stratigraphic interpretations have been used to suggest two distinct episodes of tectonism. During the late Paleocene, and coinciding with the stage of sea-floor spreading in the Labrador Sea between magnetochrons 27 to 25, tectonism was predominantly extensional. During the early to middle Eocene extension continued in most of the area, but became transpressional along the Ikermiut fault complex, where flower structures formed. Major tectonism ceased during the middle Eocene at the same time as sea-floor spreading in the Labrador Sea slowed substantially.

During the Paleocene and early to middle Eocene, sediment input to the southern West Greenland basins was predominantly from the north, possibly from a major river system diverted by volcanism farther north. Areas of lesser sediment input were from the east over the Nukik Platform and, much less, from the west over the tectonically active Ikermiut faults.

A seismic sequence has been identified that is equivalent in age to the sediments containing the Marraat source rock in the Nuussuaq Basin. If this seismic sequence also contains a source rock, it will be mature for oil generation in the western Sisimiut Basin north of about 65° 30'N.

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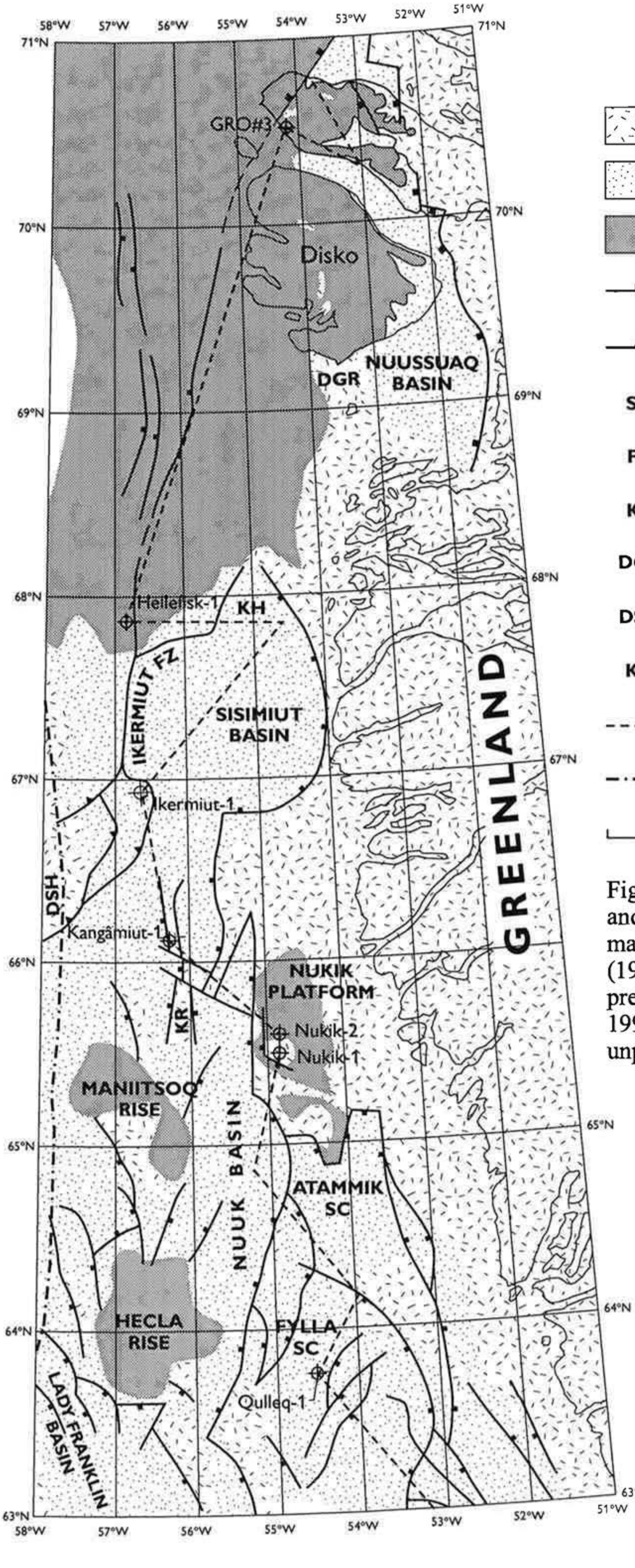
Table 1

Summary of seismic sequences and their system tract attributions

Seismic Sequence	Systems tract(s)	Third-order Sequence
SS100	LST	
SS150	TST	
SS250	LST or HST	WGPG I
SS500	LST + TST + HST	WGPG II
SS1000	LST + TST + HST	WGPG III
SS2000	LST + HST	WGPG IV
SS2500	LST	
SS3000	(LST? +) TST	WGPG V
SS3500	LST (+FRWST?)	
SS3600	TST	
SS3750	HST	WGPG VI
SS4000	TST + HST?	
SS4500	HST	WGPG VII
SS5000	LST	
SS5250	)	
SS5500	) syn-tectonic units	
SS5750	)	
SS6000	TST + HST	WGPG VIII
SS7000	FRWST or LST	
SS7500	LST (pw)	
SS7750	LST (pw)	
SS8000	TST	WGPG IX
SS8250	LST?	
SS8500	TST?	
SS9000	TST + HST	WGPG X
SS9500	LST?	
SS10000	TST	
SS11000	(LST or) HST	
SS12000	?	WGPG XI

Definition of acronyms

HST	High-stand Systems Tract
TST	Transgressive Systems Tract
LST	Low-stand Systems Tract
FRWST	Forced Regressive Wedge Systems Tract
pw	prograding wedge



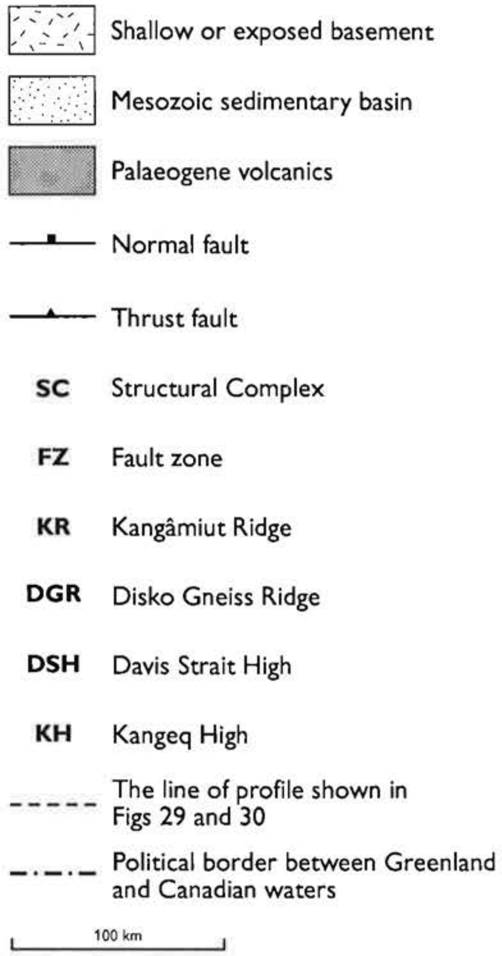


Fig. 1 : Structural elements of central and southern West Greenland. The map is based on Chalmers & Laursen (1995), Chalmers & Pulvertaft (in press), Chalmers et al. (1993, 1995, 1999), Whittaker et al. (1997) and unpublished work. See text for details.

GB01.08-034-JAC

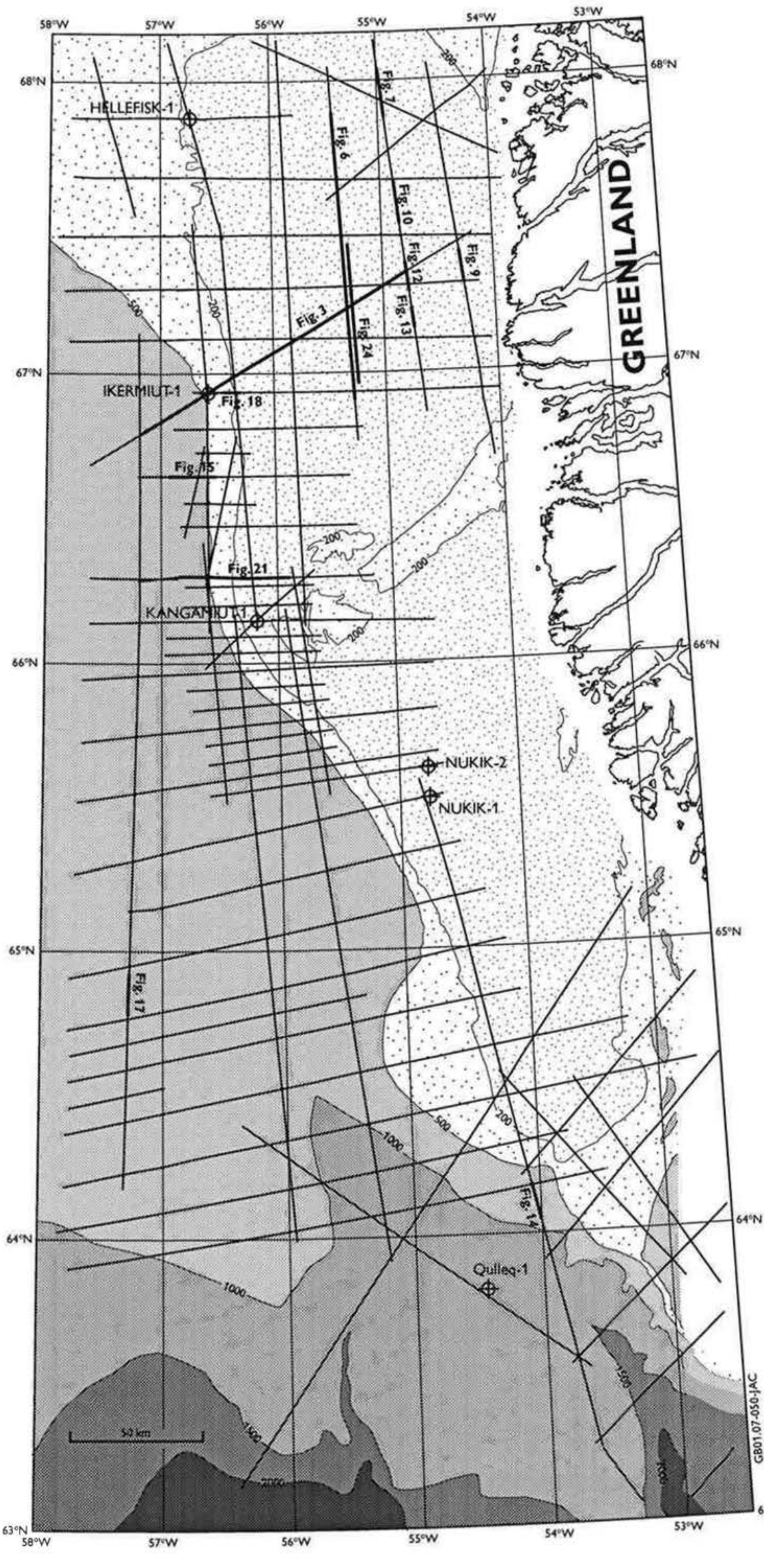


Fig. 2: Bathymetry offshore southern West Greenland and the location of the multichannel reflection seismic lines used to interpret the seismic sequences.

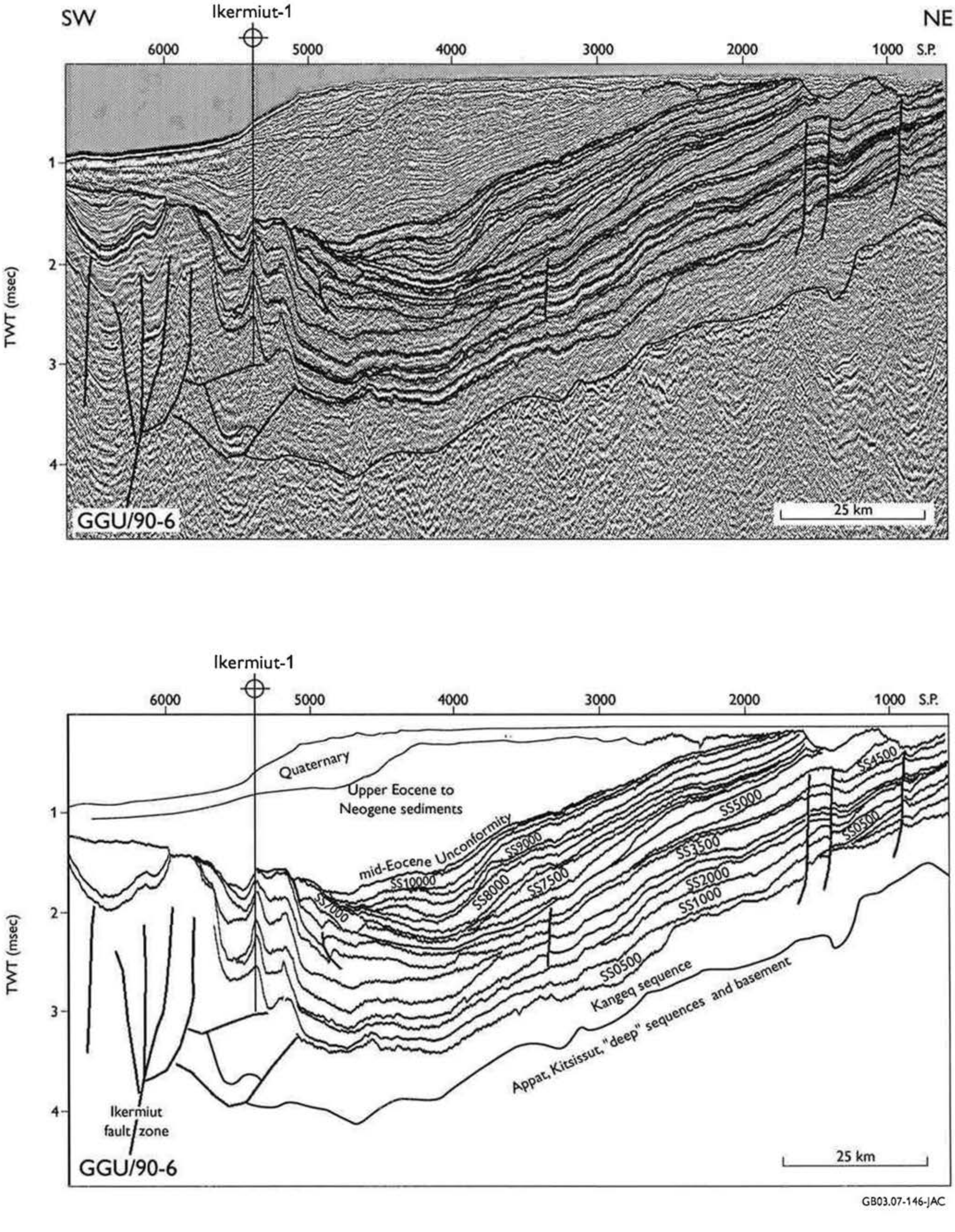


Fig. 3: Seismic line GGU/90-6 through the Sisimiut Basin and well Ikermiut-1. The line illustrates the entire succession of seismic sequences interpreted in this paper. The Paleocene to mid-Eocene seismic sequences lie unconformably on the seismically transparent Kangeq sequence of Late Cretaceous age and are truncated above by the 'mid-Eocene Unconformity. The Ikermiut-1 well is interpreted as being on the eastern flank of a flower structure, the Ikermiut fault zone, caused by leftward overstepping of a sinistral strike-slip fault. All the Palaeogene seismic sequences have been tilted to the southwest during the Neogene (Chalmers 2000) and are terminated updip to the northeast by a channeled unconformity at the base of Quaternary sediments. See Fig. 2 for location

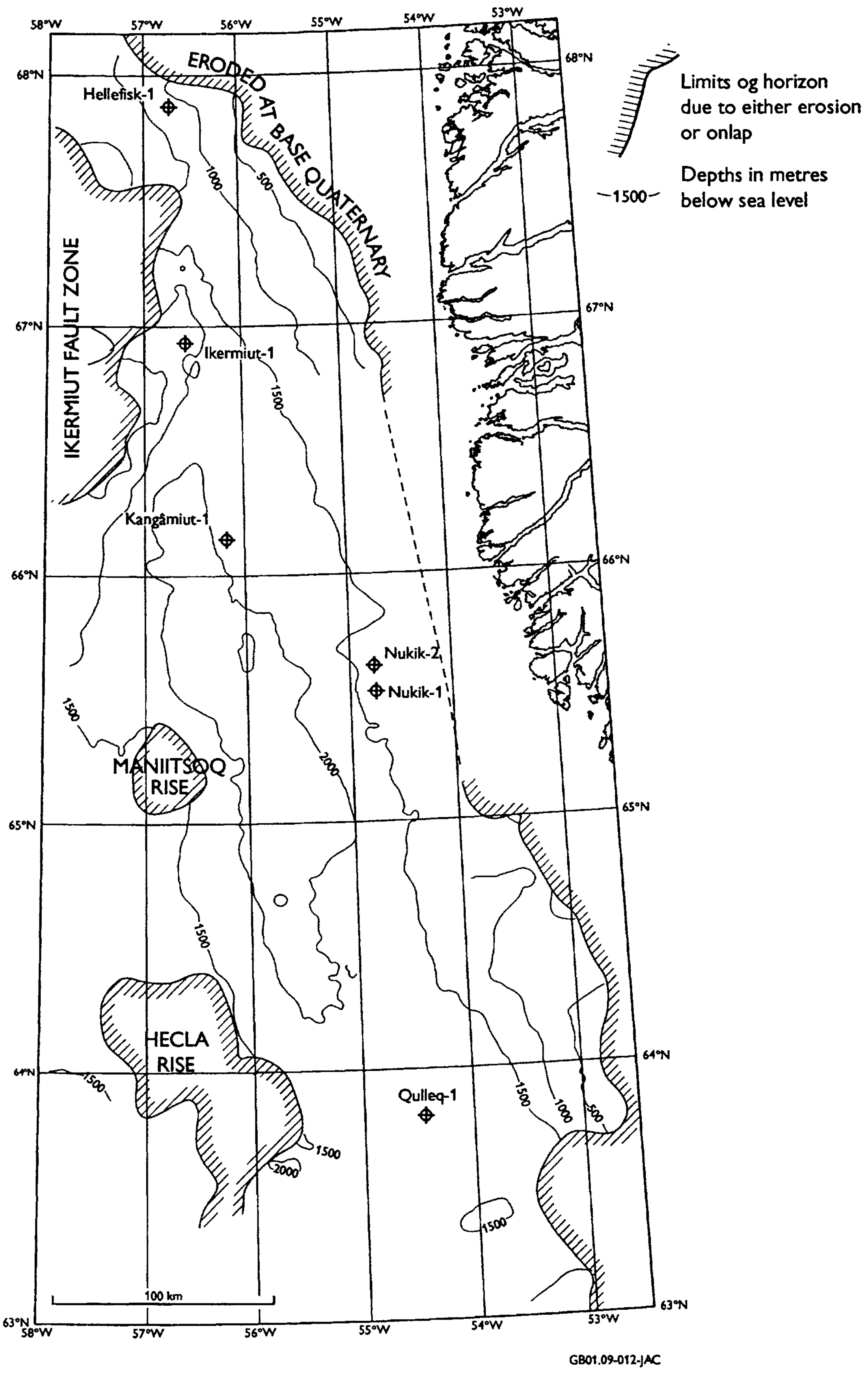


Fig. 4: Depths in metres below sea-level to the mid-Eocene Unconformity. The Paleocene to mid-Eocene seismic sequences described in this paper lie under this unconformity, and its extent shows the maximum extent of the Paleocene to mid-Eocene succession.

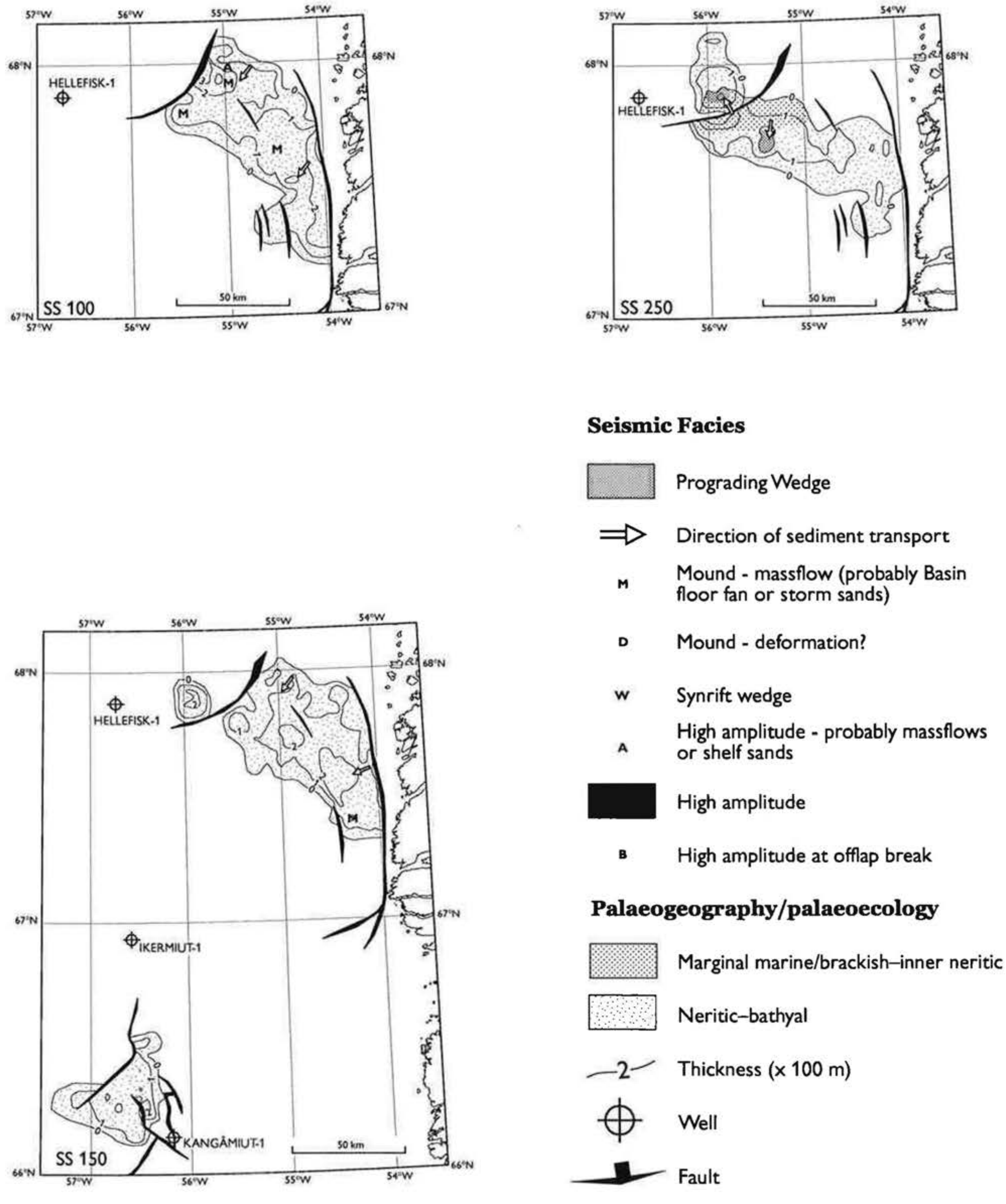


Fig. 5: Isopach maps (thickness in hundreds of metres) of seismic sequences SS100, SS200 and SS250 and their seismic facies and palaeoenvironmental interpretations as described in the text.

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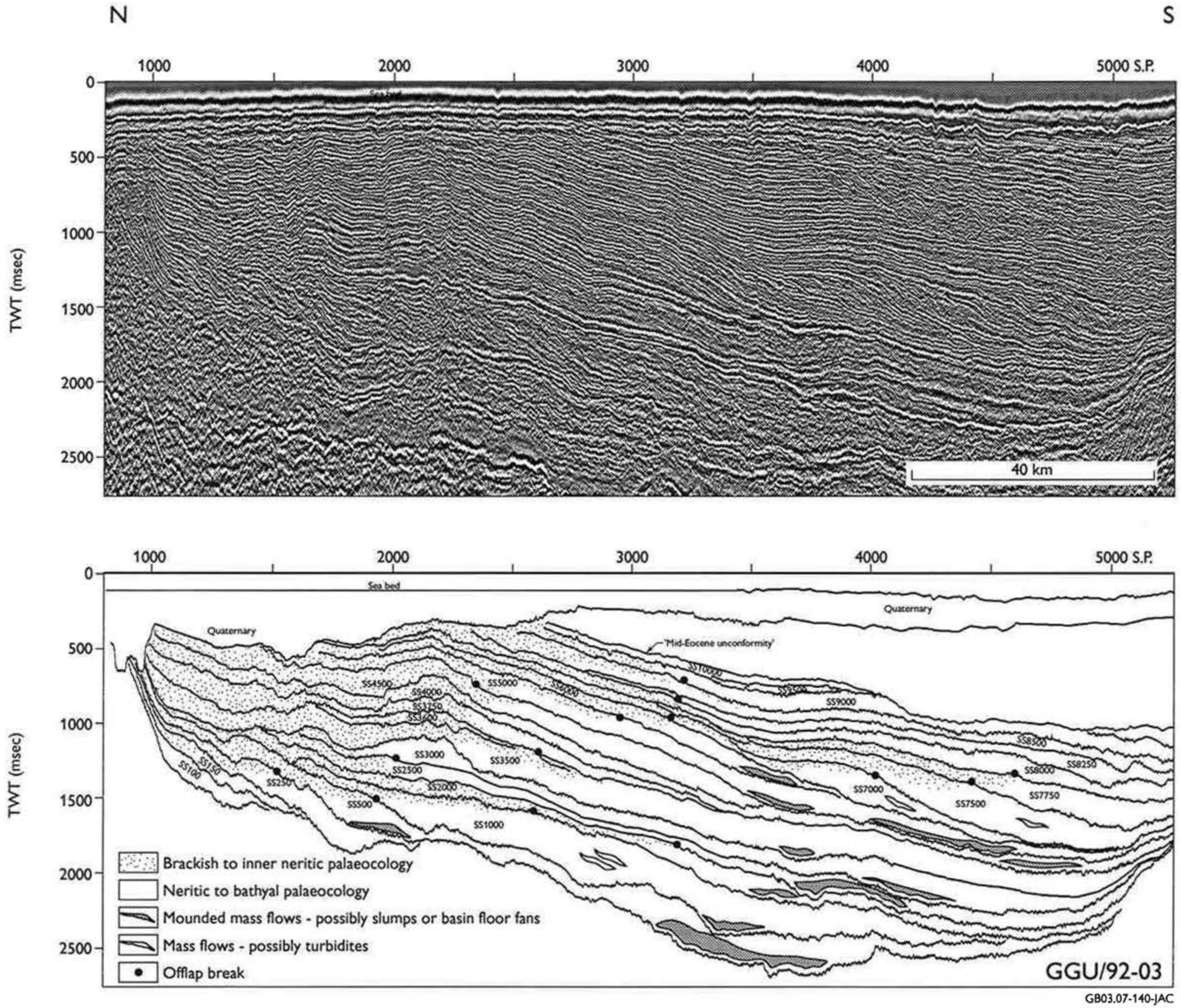


Fig. 6: North–South seismic line GGU/92-03 across the Sisimiut Basin showing the maximum thickness of the seismic sequences described in this paper. This line illustrates many of the relationships between the seismic sequences, their internal seismic facies and our interpretation of palaeoenvironments. See Fig. 2 for location.

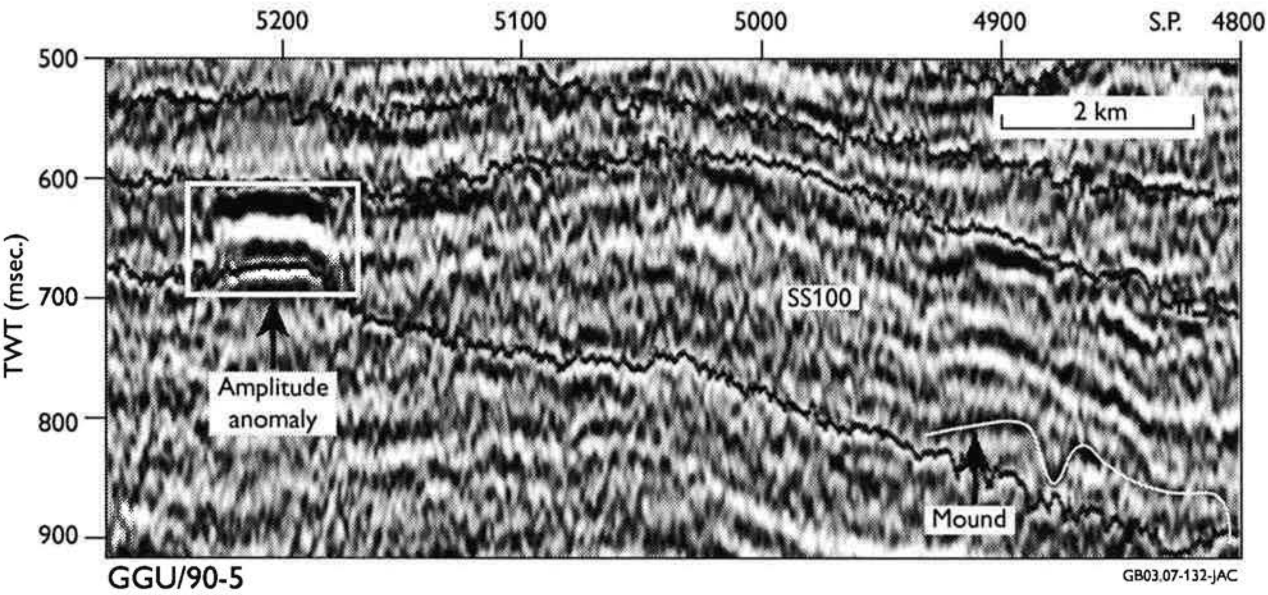


Fig. 7: Part of seismic line GGU/90-5 showing mounds in SS100 and an amplitude anomaly that could indicate the presence of shallow gas. See Fig. 2 for location.

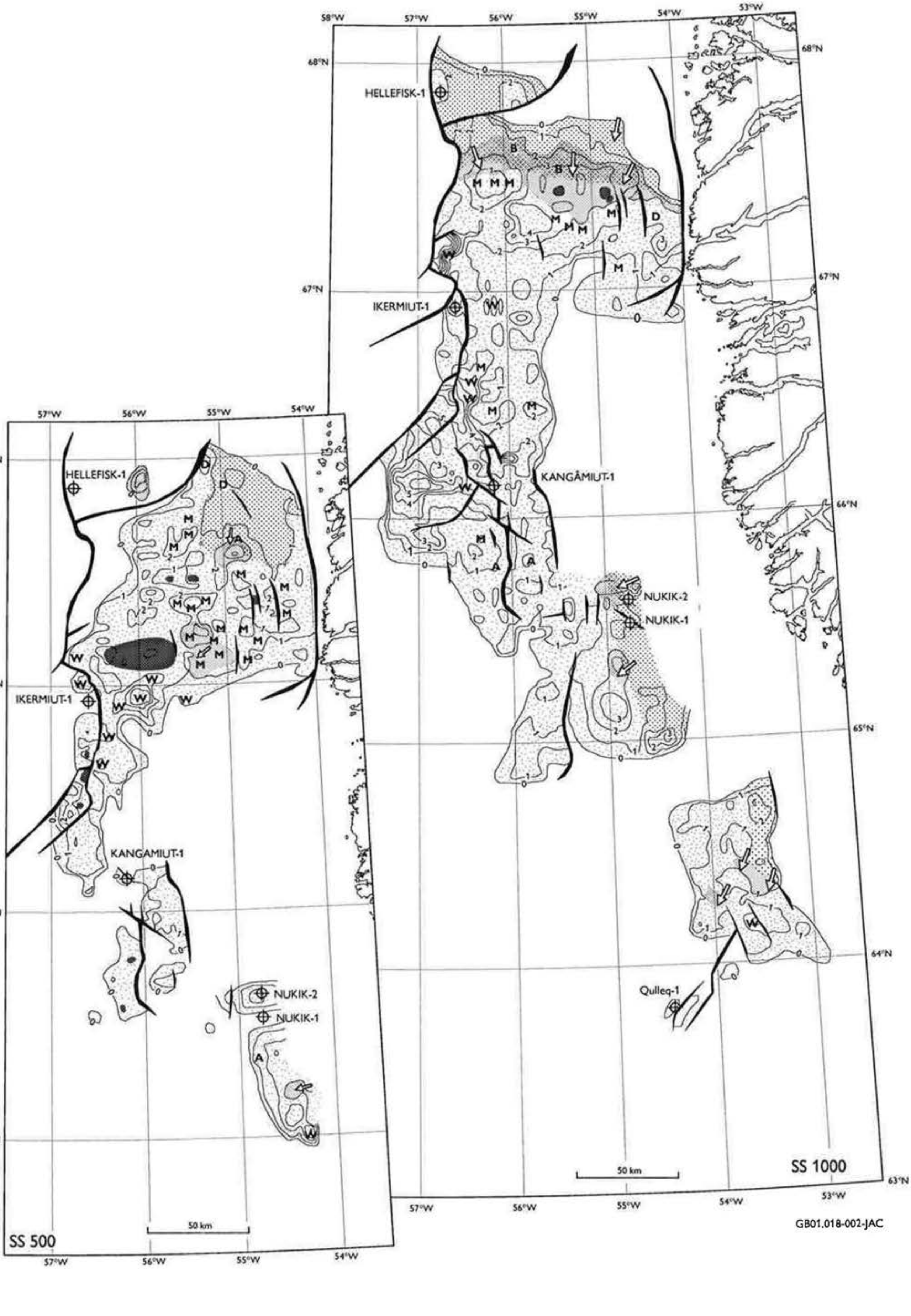


Fig. 8.: Isopach maps (thickness in hundreds of metres) of seismic sequences SS500 and SS1000 and their seismic facies and palaeoenvironmental interpretations as described in the text. See Fig. 5 for the key to this figure

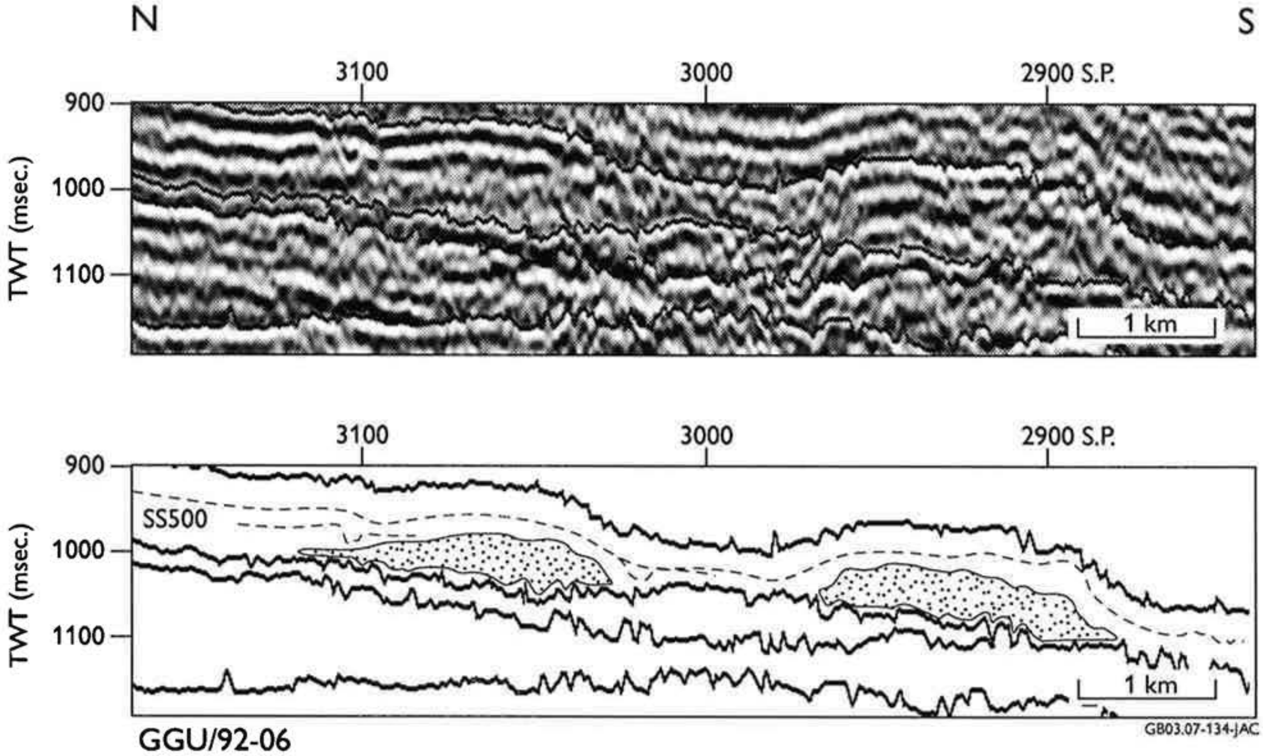


Fig. 9: Part of seismic line GGU/92-06 showing large mounds in SS500 that may indicate the presence of mass flows and or basin-floor fans. See Fig. 2 for location.

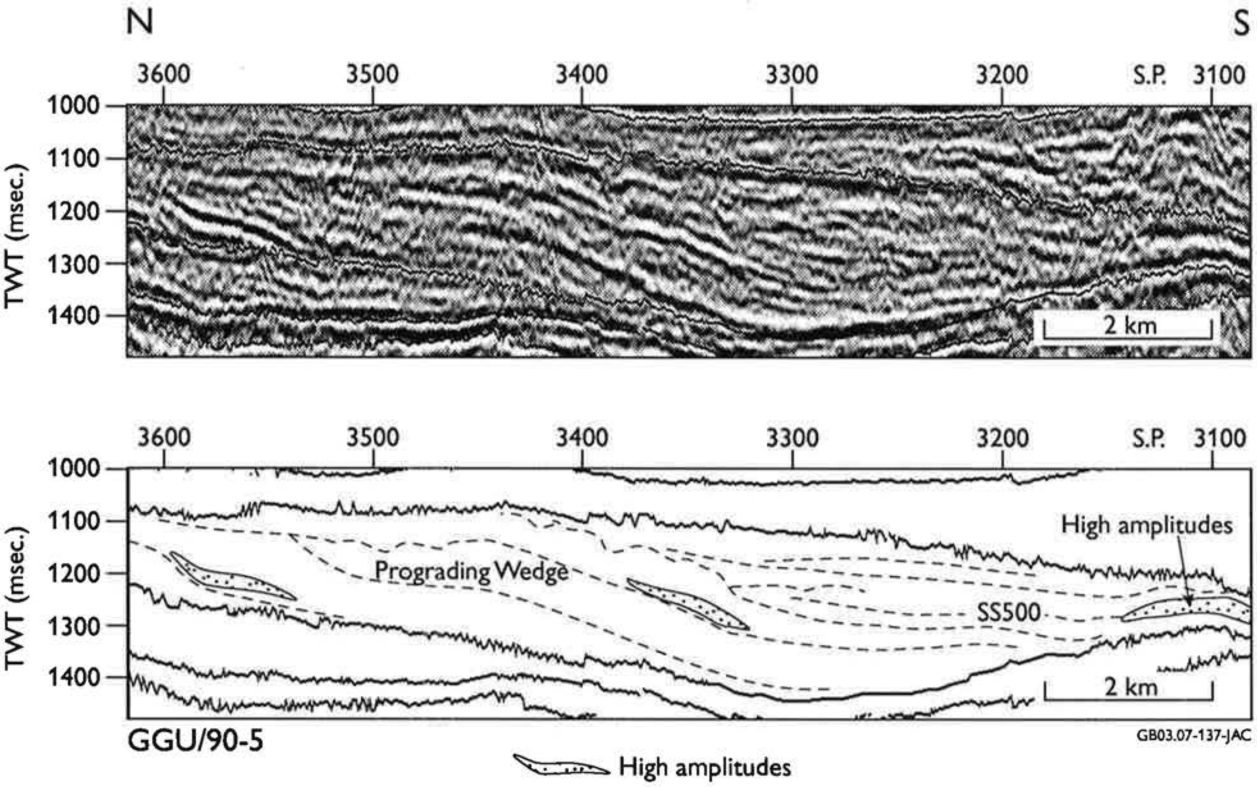


Fig. 10: Part of seismic line GGU/90-5 showing a prograding wedge in SS500. A high amplitude reflection at the toe of the prograding wedge may indicate the presence of turbidites. See Fig. 2 for location.

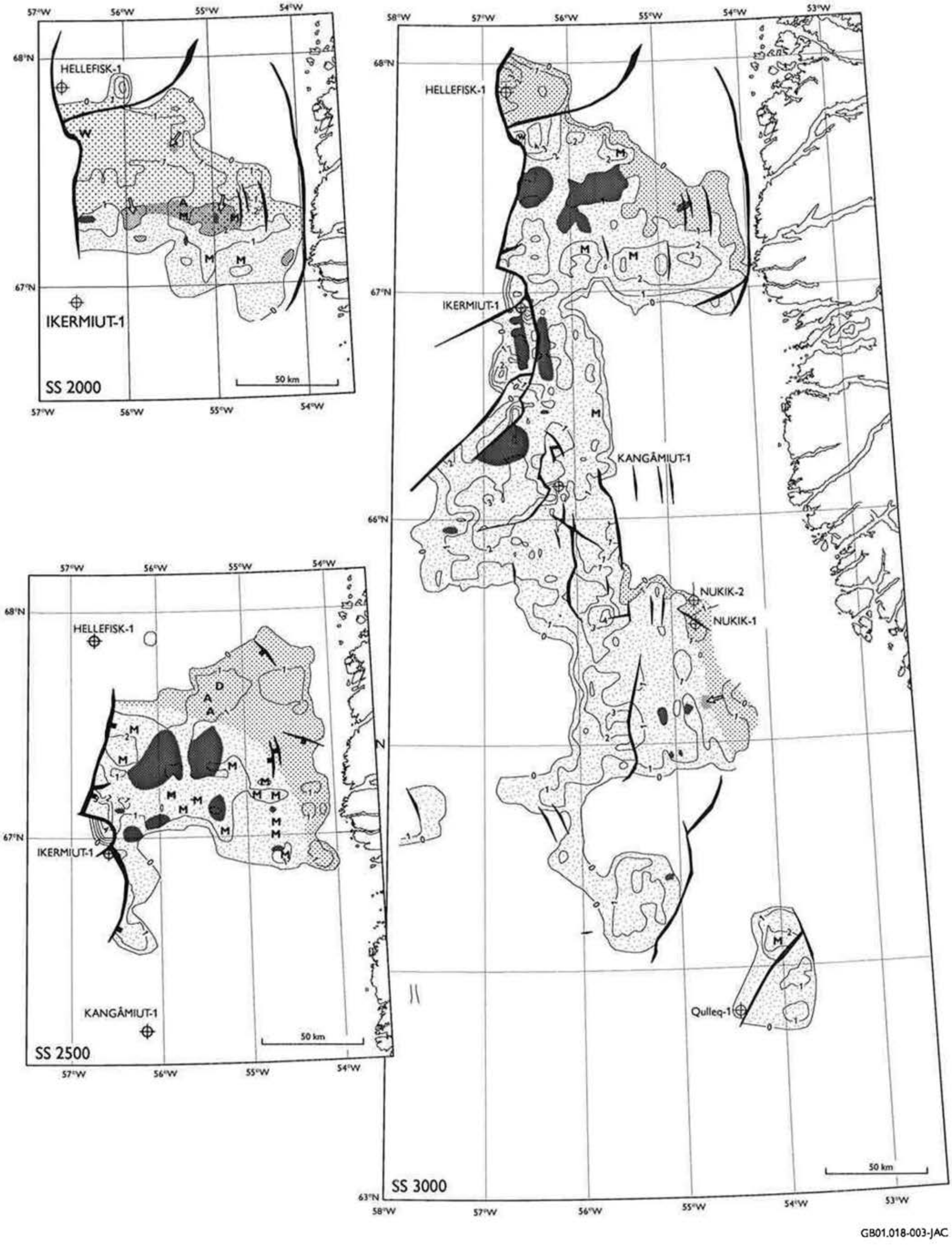


Fig. 11: Isopach maps (thickness in hundreds of metres) of seismic sequences SS2000, SS2500 and SS3000 and their seismic facies and palaeoenvironmental interpretations as described in the text. See Fig. 5 for the key to this figure.

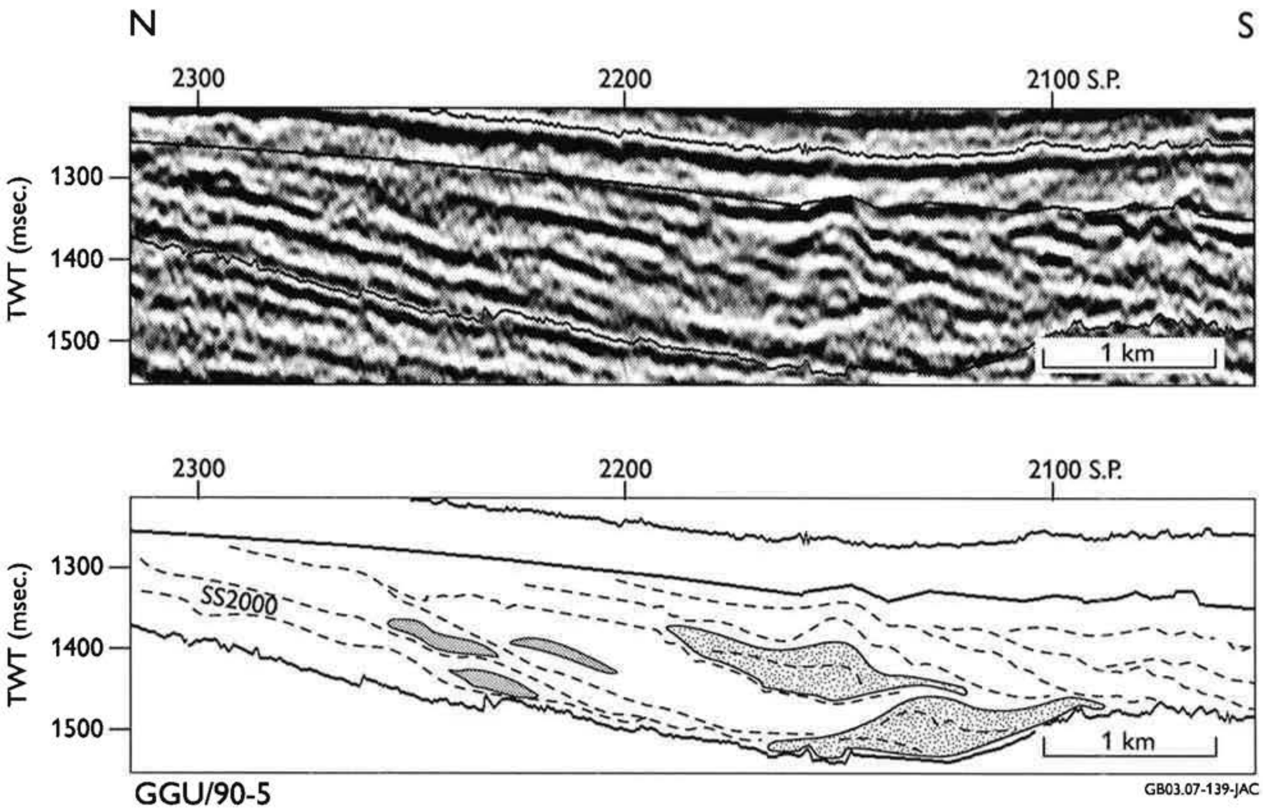


Fig. 12: Part of seismic line GGU/90-5 showing high amplitude reflections that may indicate the presence of turbidite channels on the foresets of a prograding unit, and large mounds at the toe of and distal from the foresets that may indicate the presence of basin floor fans or mass flow deposits. See Fig. 2 for location.

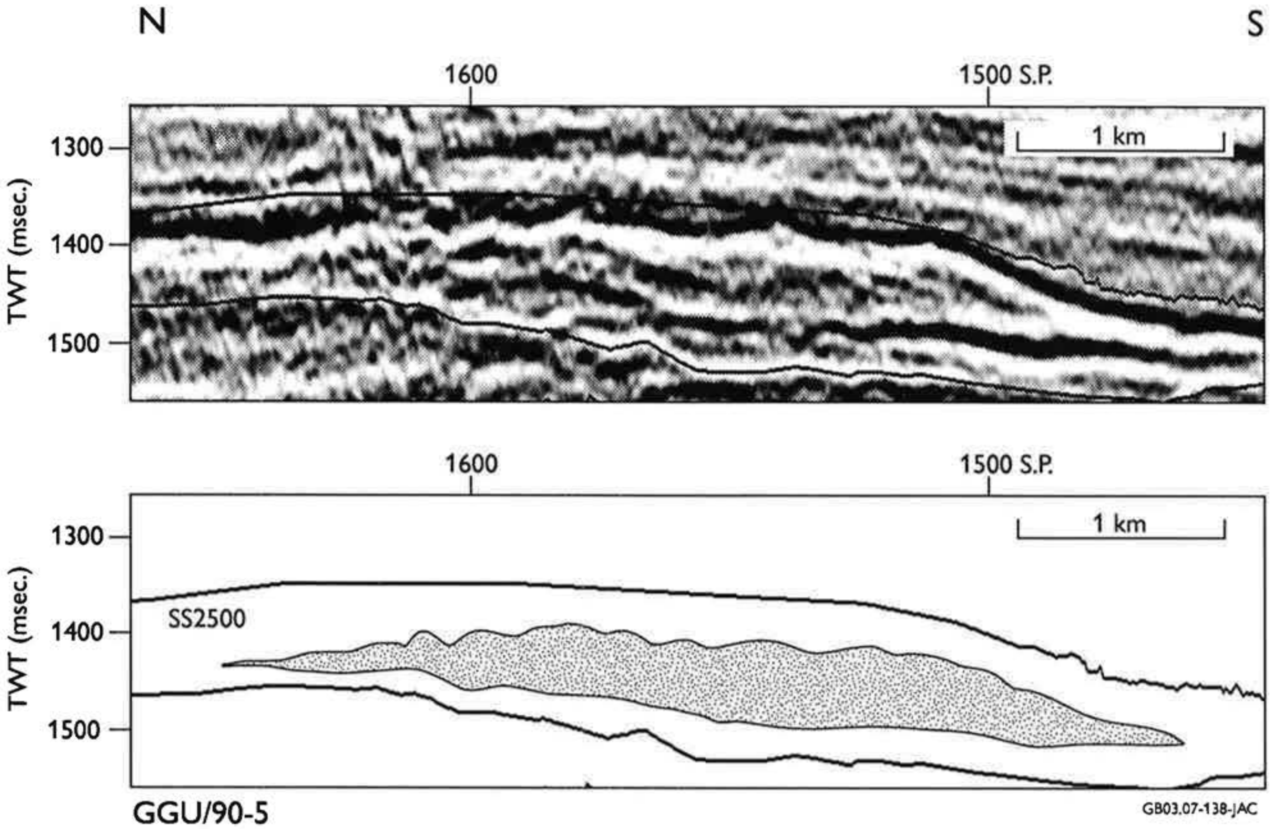


Fig. 13: Part of seismic line GGU/90-5 showing the presence of a large mound in SS2500 that may indicate the presence of mass flows. See Fig. 2 for location.

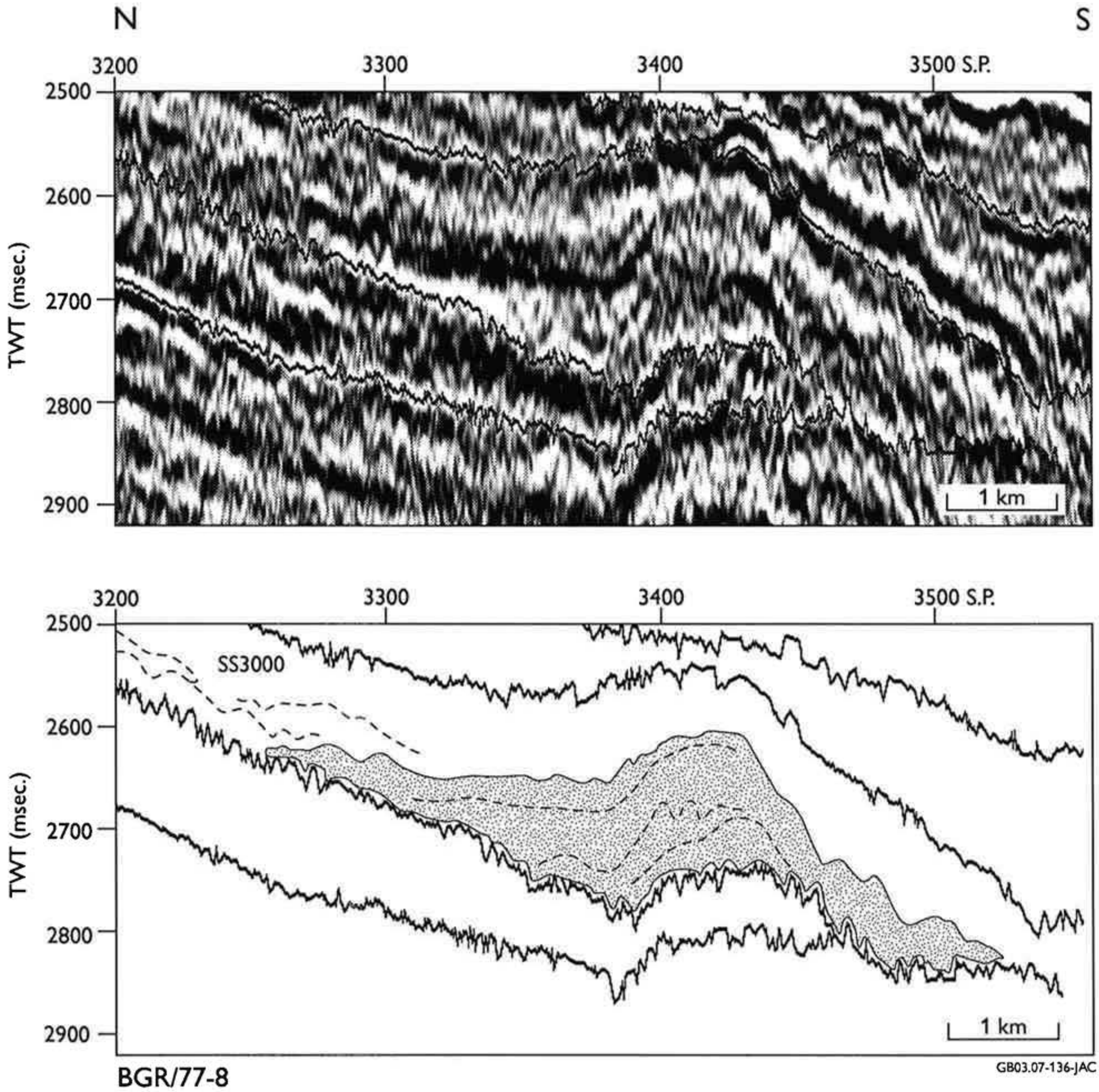


Fig. 14. Part of seismic line BGR/77-8 showing a large mound that may indicate the presence of a basin-floor fan in SS3000. See Fig. 2 for location.

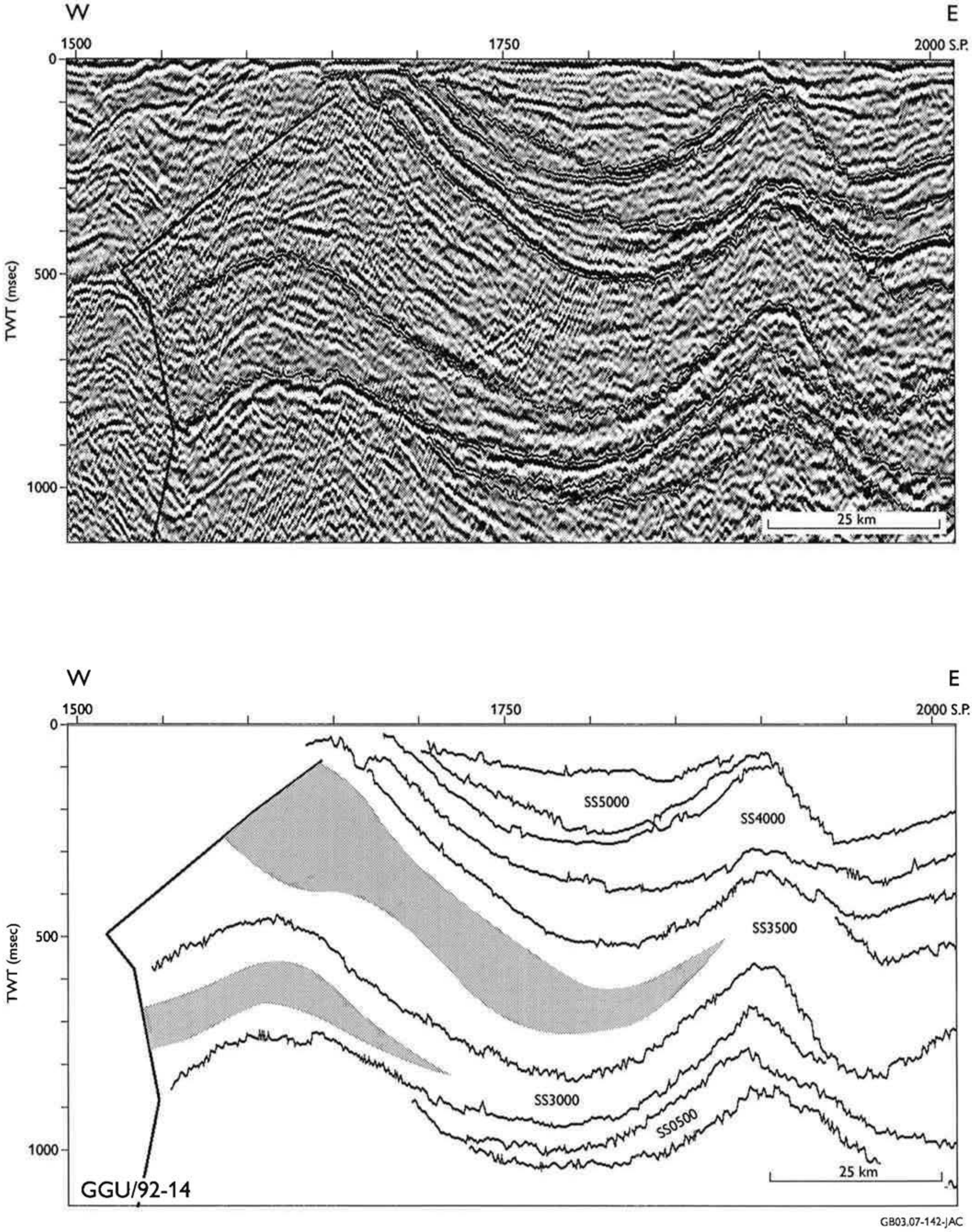


Fig. 15. Part of seismic line GGU/92-14 showing wedge-shaped cross-sections of SS3000 and SS3500 and internal facies patterns that may indicate syn-tectonic wedges. If so, these sequences may have been deposited during extension along the Ikermiut fault complex during the Paleocene. SS3000, SS3500 and preceding seismic sequences were subsequently folded during transpressional movements of the Ikermiut fault system during the early to middle Eocene. See Fig. 2 for location.

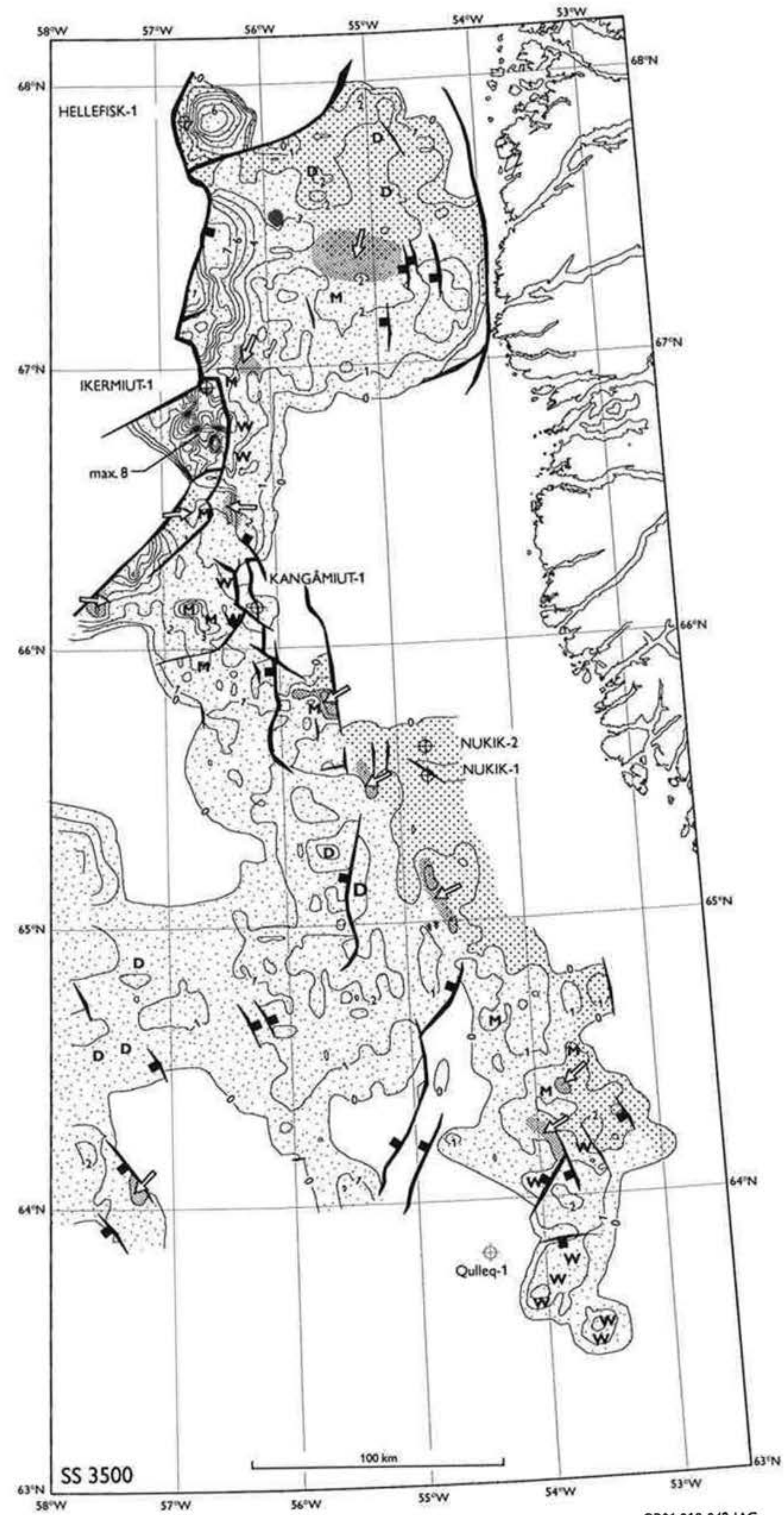


Fig. 16: Isopach map (thickness in hundreds of metres) of seismic sequence SS3500, and its seismic facies and palaeoenvironmental interpretations as described in the text. See Fig. 5 for the key to this figure.

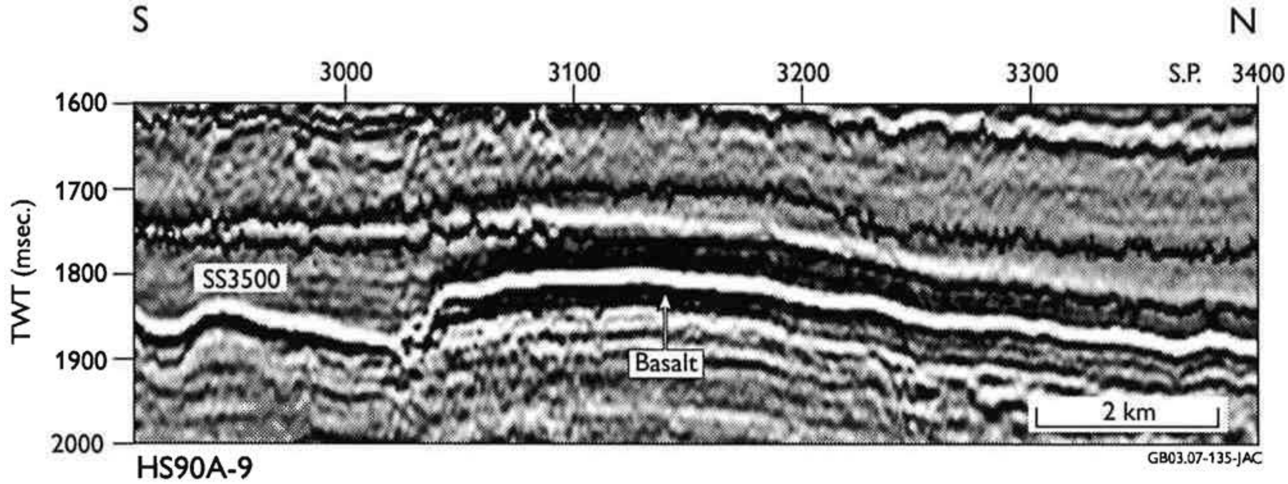


Fig. 17: Part of seismic line HS90A-9 over a basalt escarpment on the margin of the Hecla Rise. SS3500 overlaps the basalts in this area indicating that they were erupted no later than the end of the Paleocene. See Fig. 2 for location.

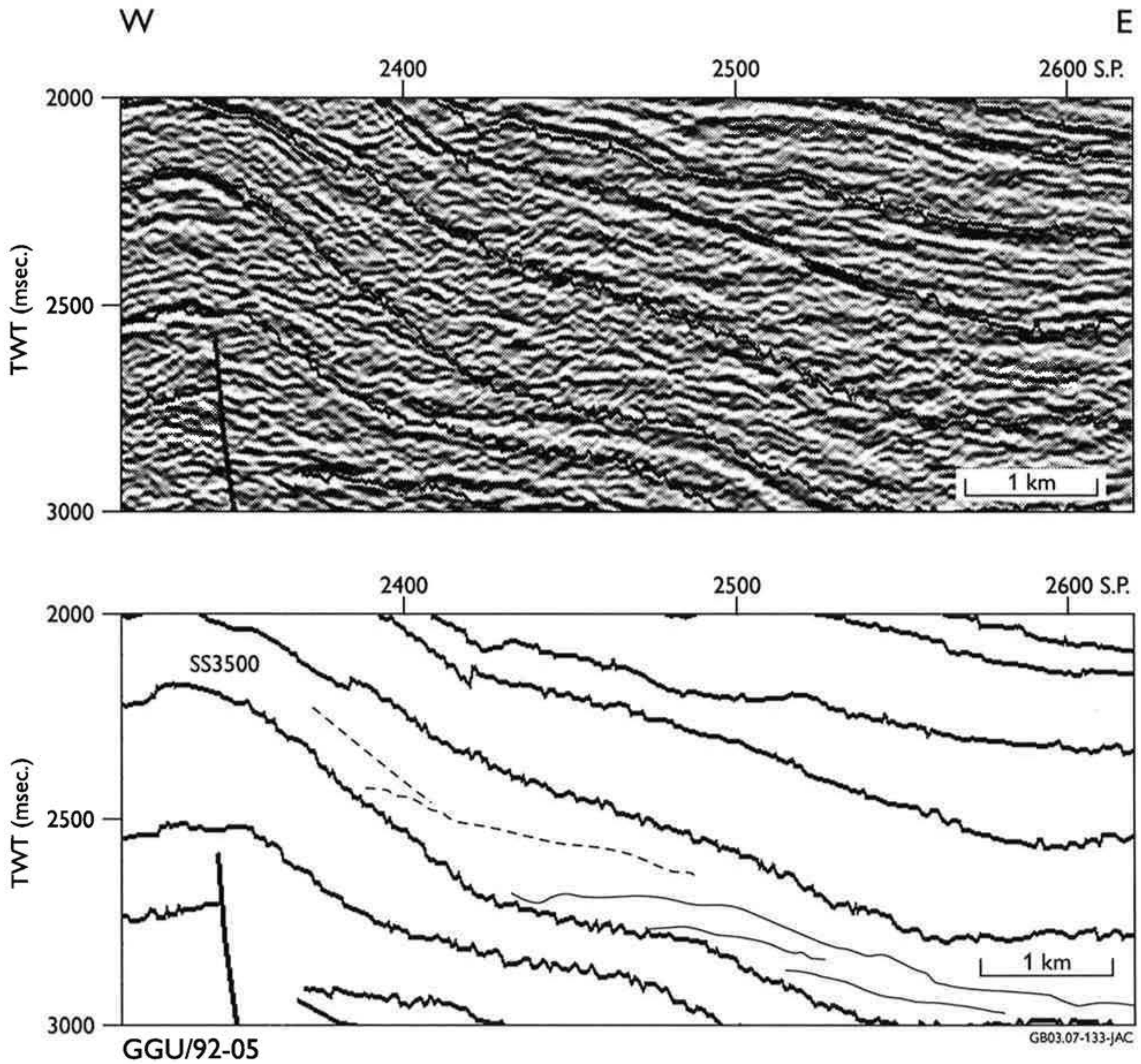
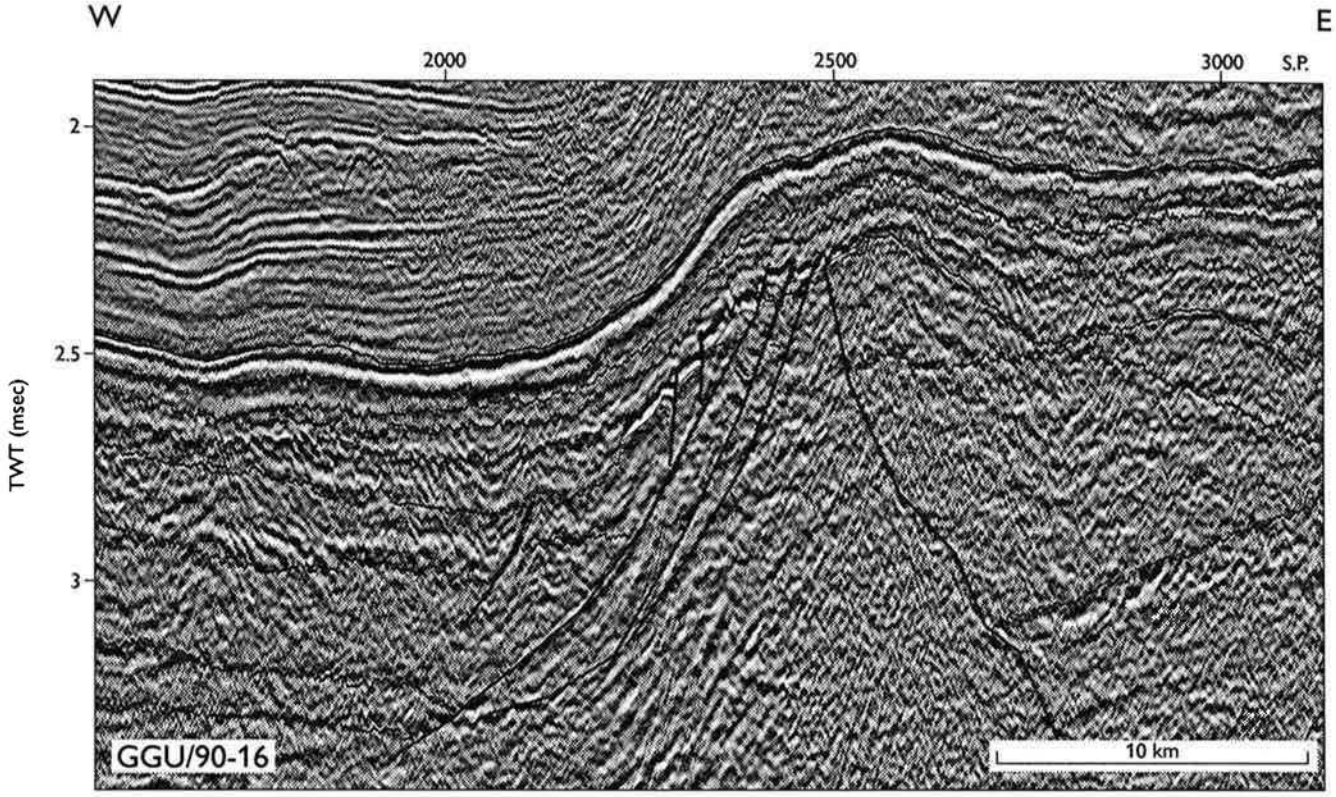


Fig. 18: Part of seismic line GGU/92-05 showing an example of complex-sigmoid reflections indicating prograding sediments within SS3500. See Fig. 2 for location.

Fig. 19: Isopach maps (thickness in hundreds of metres) of seismic sequences SS3600, SS3750, SS4000 and SS4500 and their seismic facies and palaeoenvironmental interpretations as described in the text. See Fig. 5 for the key to this figure.

Fig. 20: Isopach maps (thickness in hundreds of metres) of seismic sequences SS5000 and SS5250 and their seismic facies and palaeoenvironmental interpretations as described in the text. See Fig. 5 for the key to this figure.



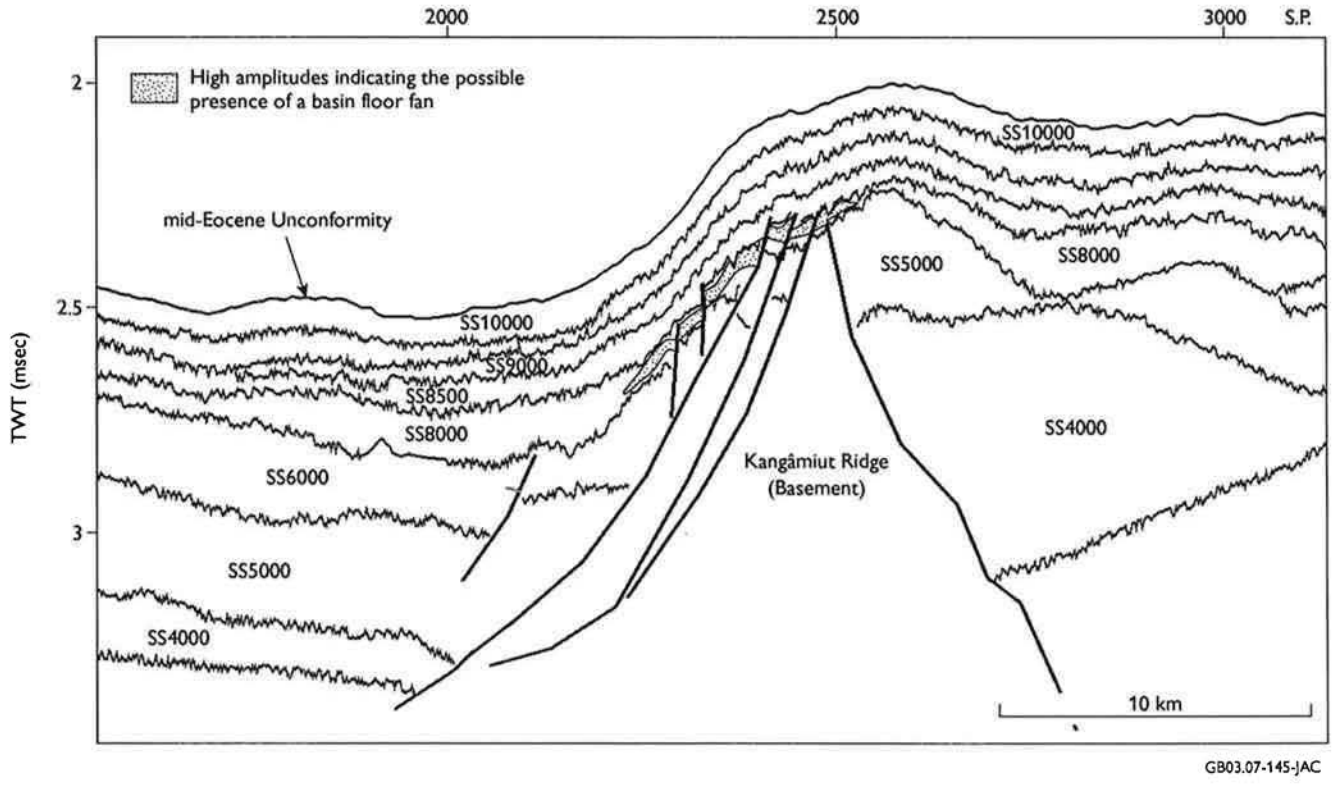


Fig. 21: Part of seismic line GGU/92-16 showing faulting on the east and west flanks of the Kangâmiut Ridge and the high amplitude of SS10000 in contrast to more mud-prone, underlying seismic sequences. High amplitudes indicating the probable presence of a basin floor fan can be seen within SS 8000 on the west flank of the Ridge. See Fig. 2 for location.

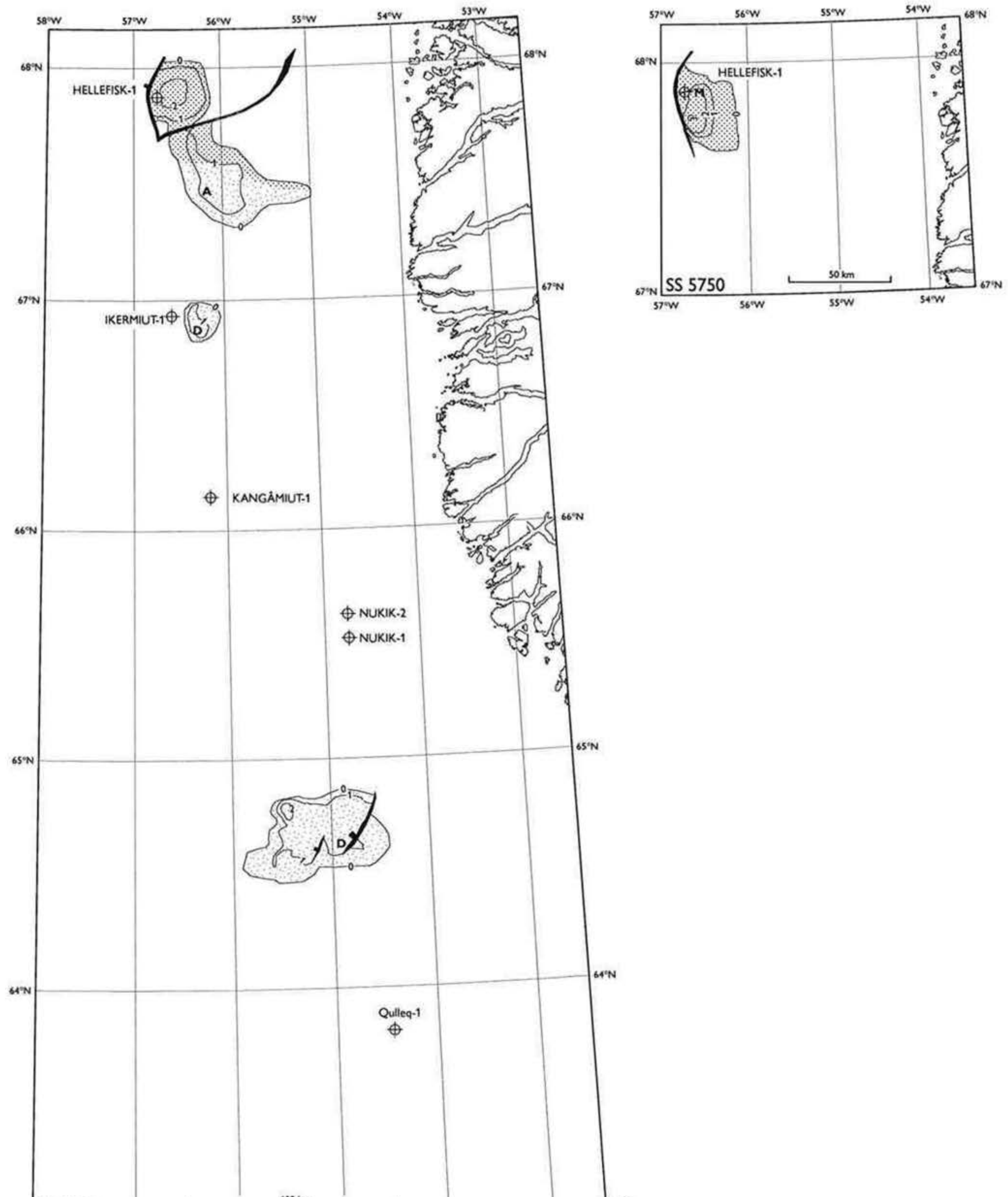


Fig. 22: Isopach maps (thickness in hundreds of metres) of seismic sequences SS5500 and SS5750 and their seismic facies and palaeoenvironmental interpretations as described in the text. See Fig. 5 for the key to this figure.

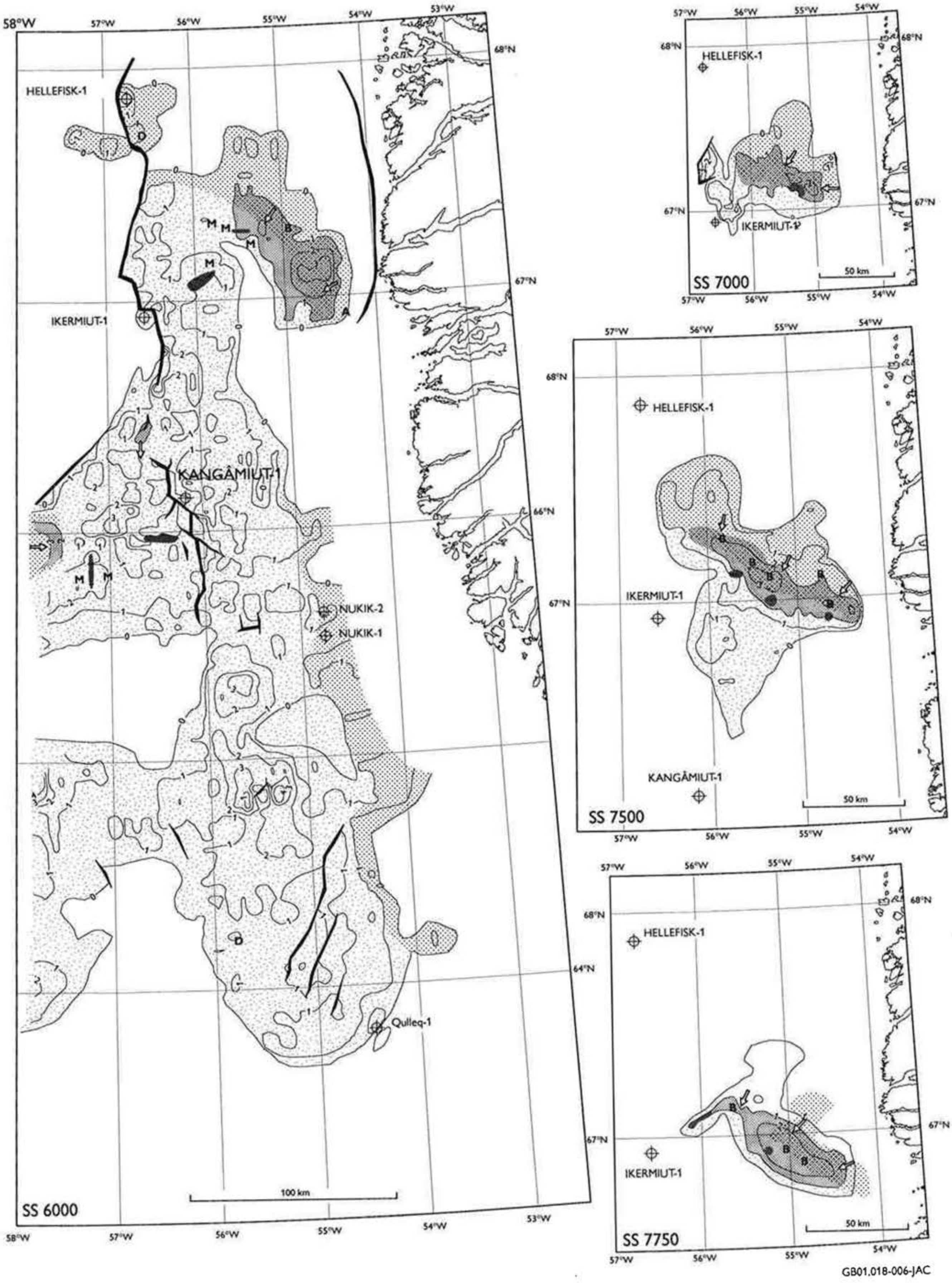


Fig. 23: Isopach maps (thickness in hundreds of metres) of seismic sequences SS6000, SS7000, SS7500 and SS7750 and their seismic facies and palaeoenvironmental

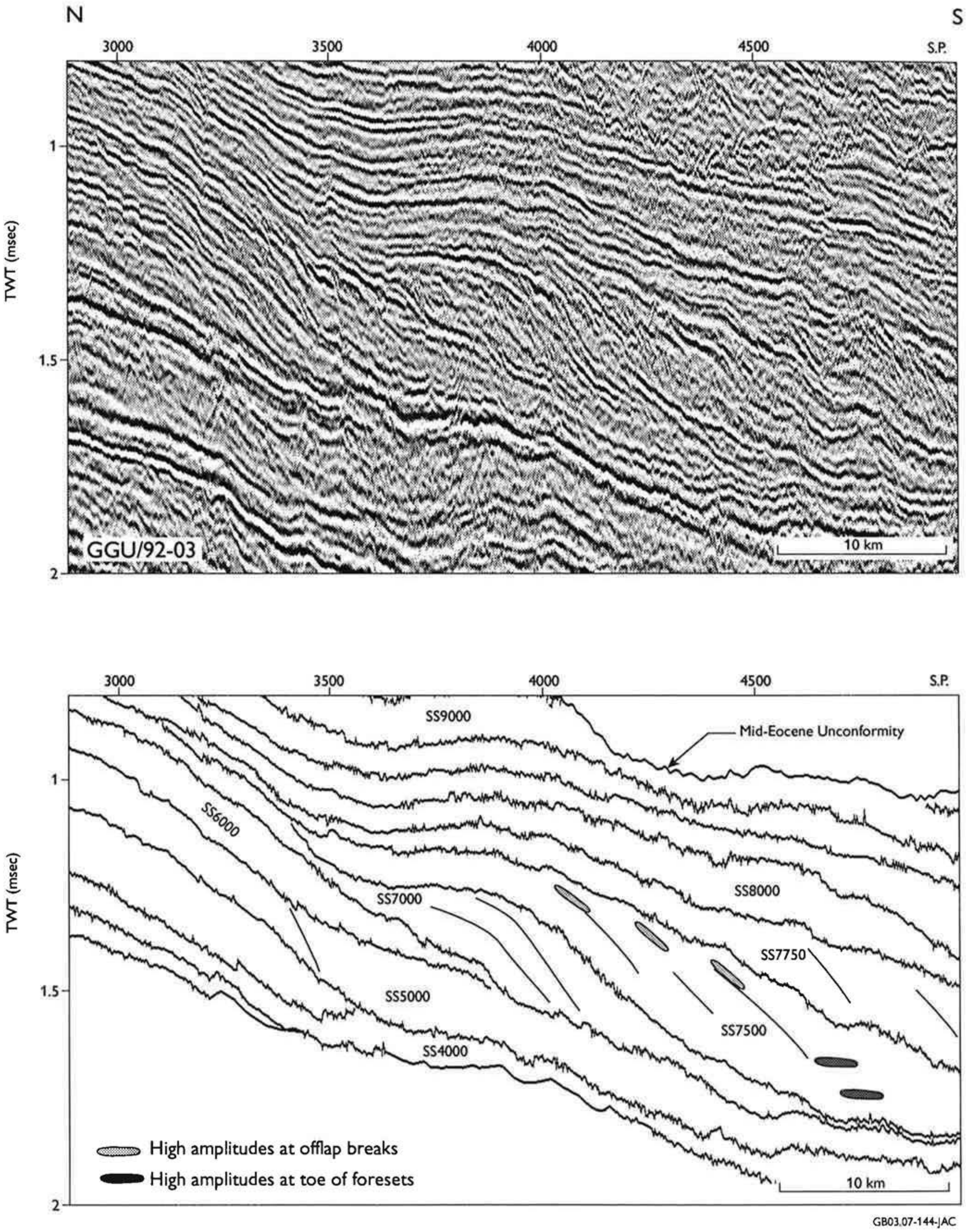


Fig. 24: Part of seismic line GGU/92-03 showing stacked progradations in lower Eocene seismic sequences SS6000, SS7000, SS7500 and SS7750 in the Sisimiut Basin. Note the high amplitudes at the offlap breaks and at the toes of the foresets in SS7500. Note also the relative positions of the offlap breaks from seismic sequence to seismic sequence. See Fig. 2 for location.

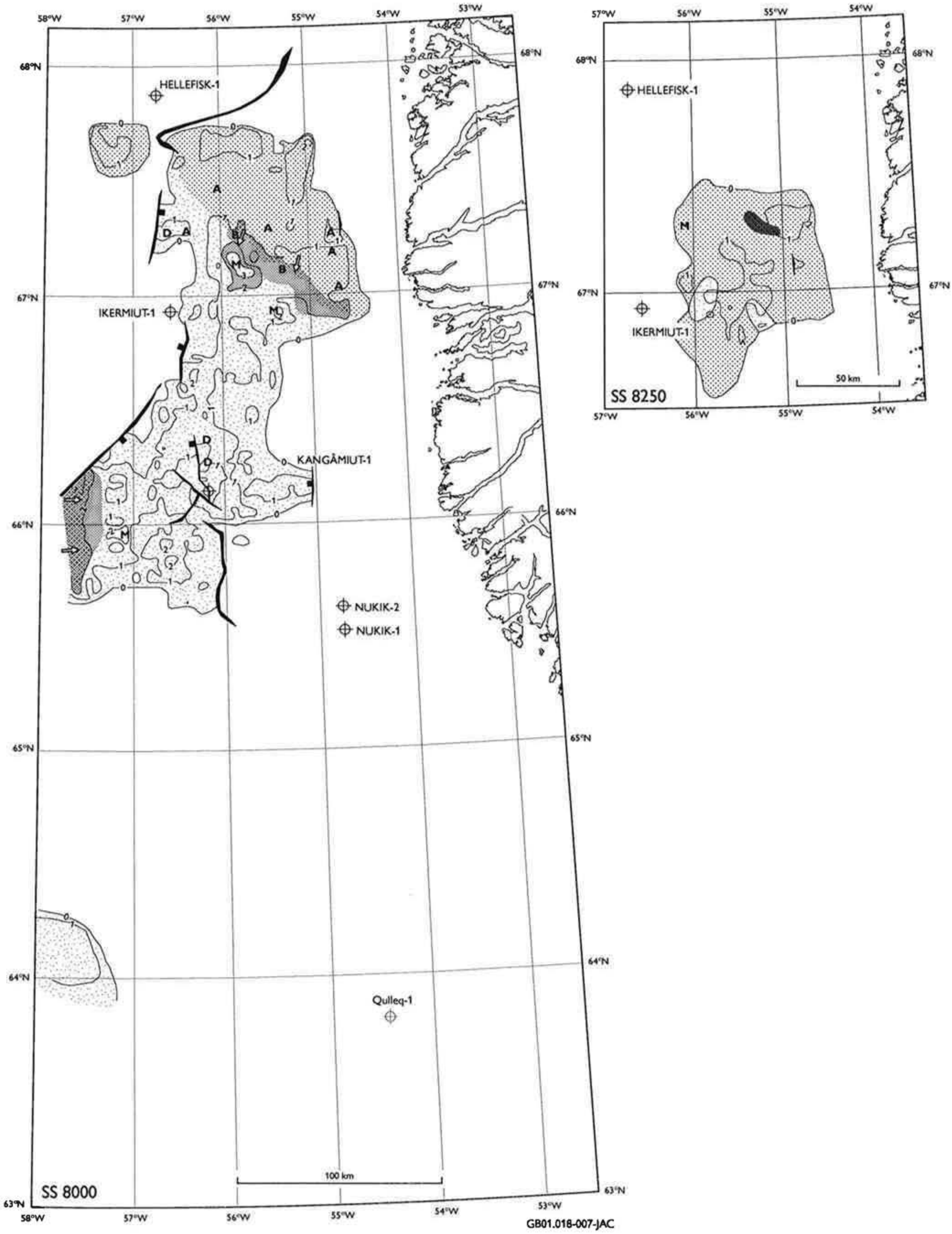


Fig. 25: Isopach maps (thickness in hundreds of metres) of seismic sequences SS8000 and SS8250 and their seismic facies and palaeoenvironmental interpretations as described in the text. See Fig. 5 for the key to this figure.

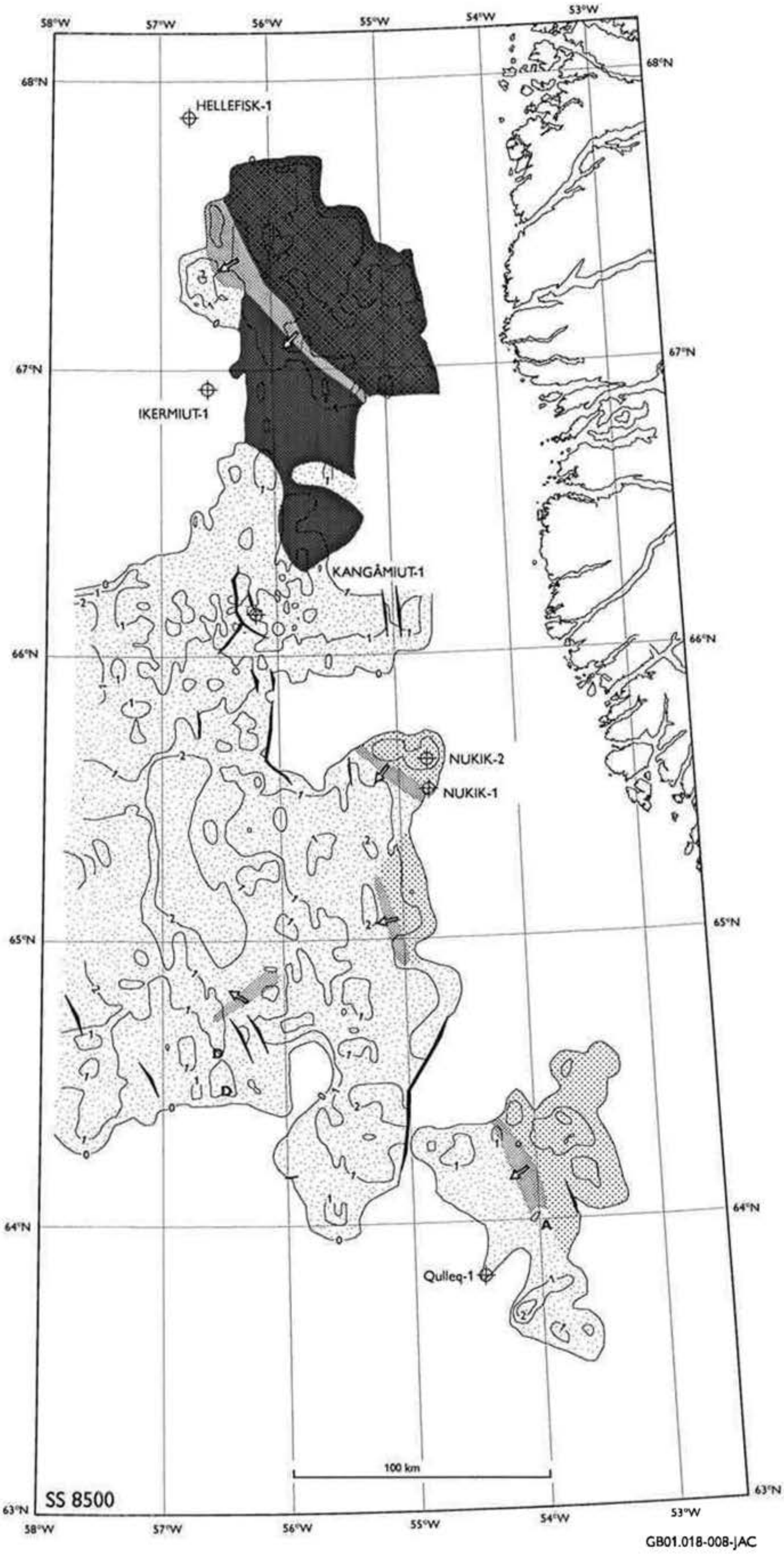


Fig. 26: Isopach map (thickness in hundreds of metres) of seismic sequence SS8500 and its seismic facies and palaeoenvironmental interpretations as described in the text. See Fig. 5 for the key to this figure

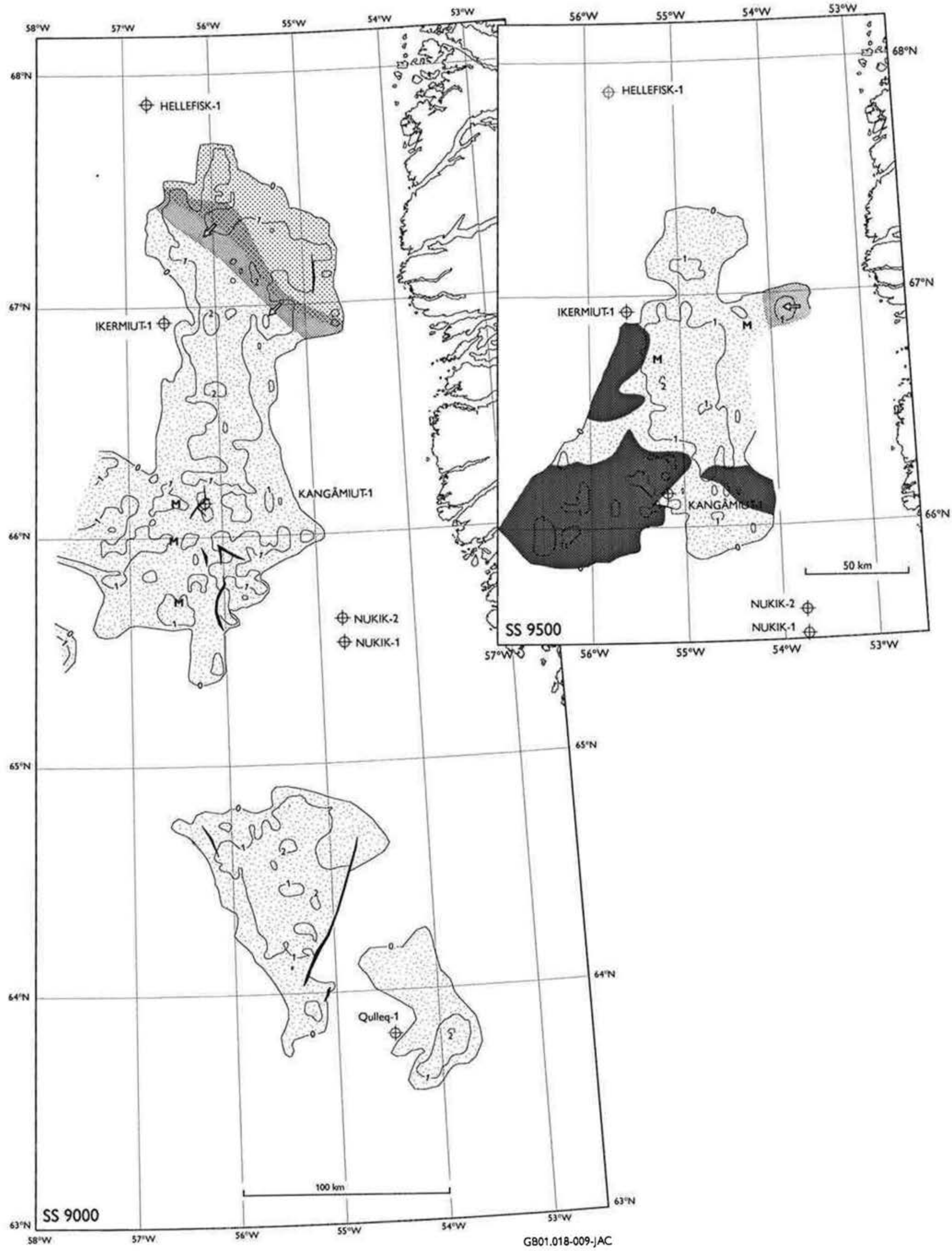


Fig. 27 : Isopach maps (thickness in hundreds of metres) of seismic sequences SS9000 and SS9500 and their seismic facies and palaeoenvironmental interpretations as described in the text. See Fig. 5 for the key to this figure.

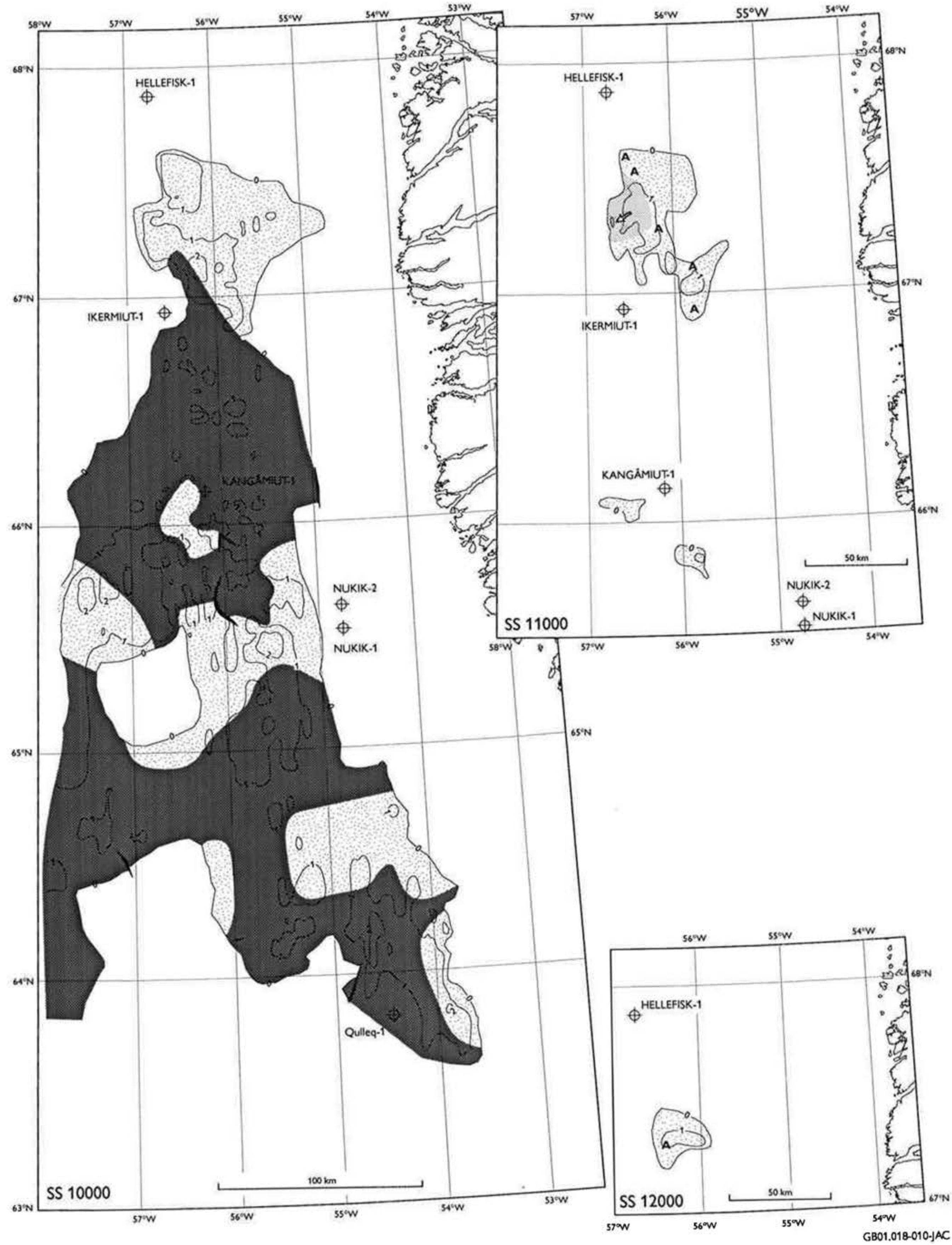


Fig. 28: Isopach maps (thickness in hundreds of metres) of seismic sequences SS10000, SS11000 and SS12000 and their seismic facies and palaeoenvironmental interpretations as described in the text. See Fig. 5 for the key to this figure.

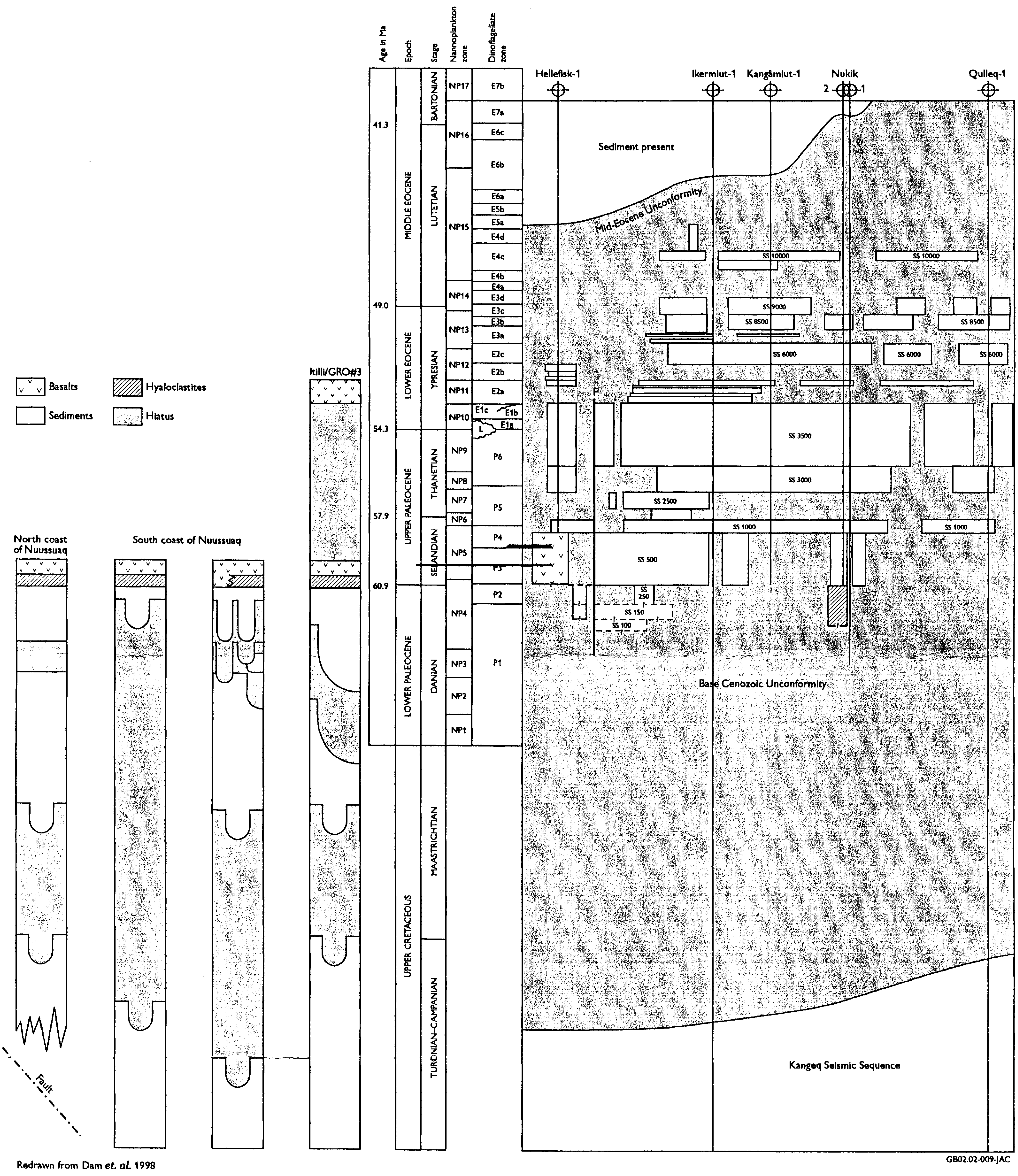


Fig. 29: Stratigraphic correlation of the seismic sequences described in this paper and the Cretaceous and Palaeogene sediments and volcanic rocks in the Nuussuaq Basin described by Dam et al. 1998. The correlation is along the profile shown in Fig. 1. Note that the unconformity separating Paleocene–Eocene sediments from underlying Upper Cretaceous sediments offshore (to the right of the scale) corresponds to the unconformity interpreted by Dam et al. 1998 onshore and was interpreted by them as due to extensional faulting followed by uplift and then subsidence from the impact of the Iceland plume head. There appears to be now equivalent unit offshore to the Maastrictian–lower Danian channel units interpreted by Dam et al. 1998, bit SS100, SS150 and SS250 may be the equivalent of their upper Danian sediments, deposited just prior to the onset of volcanism. The onshore sections (left of the scale) are redrawn from Dam et al. (1999).

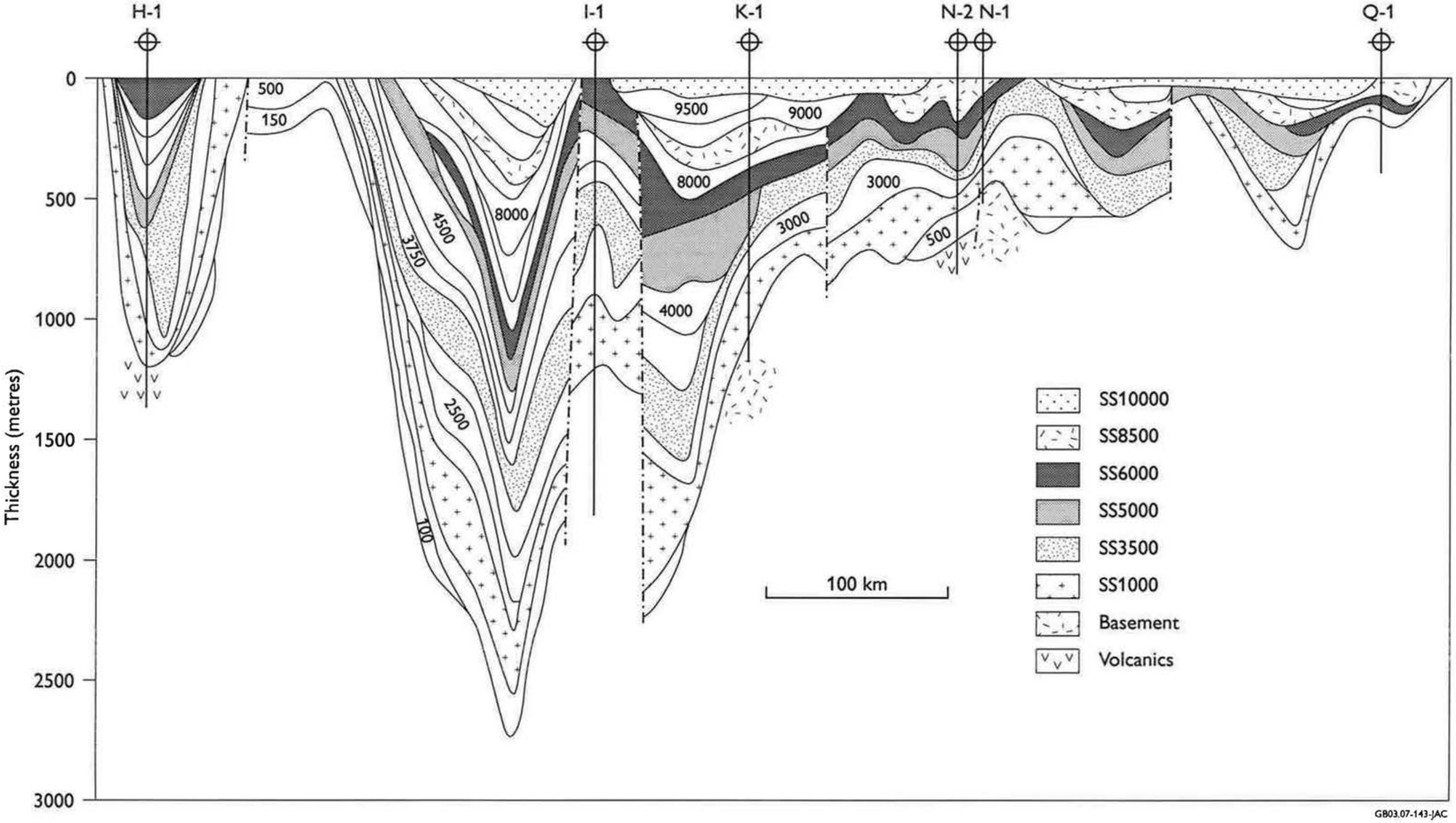


Fig. 30: Thicknesses of Paleocene and lower and middle Eocene sediments drawn with the mid-Eocene Unconformity as base line. The section is drawn along the line of profile shown in Fig. 1, east and south of the Hellefisk-1 well.

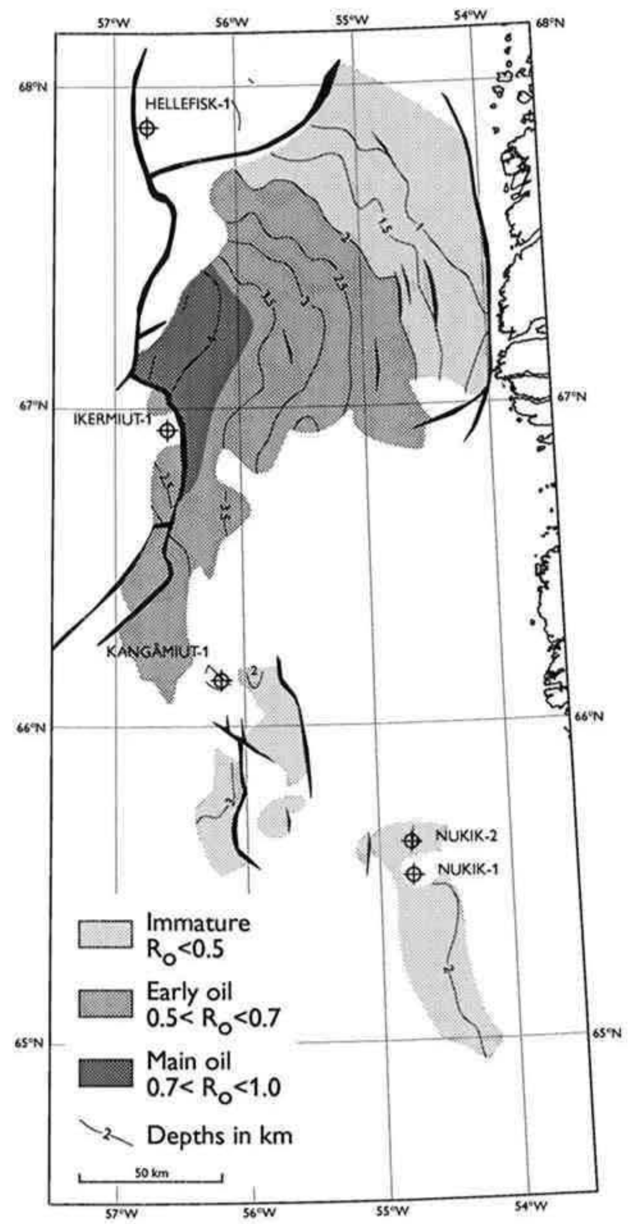


Fig. 31: Map of depths below sea level to SB500. Unpublished calculations of maturity by A. Mathiessen (personal communication) based on data from Ikermiut-1 and Kangâmiut-1 suggest that the distribution of maturity of any source rock at this horizon is likely to as shown by the tones, i.e. that there is an area northeast of Ikermiut-1 where such a source rock may be in the main oil window, and a much larger area where it may be in the early oil window. See text for discussion.

Appendix 2

Revised sedimentology and palaeoenvironmental interpretation of the Palaeogene sediments drilled offshore southern West Greenland

by

F. Dalhoff, H. Nøhr-Hansen, J. A. Rasmussen, E. Sheldon, J: A. Chalmers, J. A. & U. Gregersen.

Revised sedimentology and palaeoenvironmental interpretation of the Palaeogene sediments drilled offshore southern West Greenland

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Abstract

Sedimentological and palaeoenvironmental interpretation of the Palaeogene offshore southern West Greenland from the boreholes: Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1 and Nukik-2. The study is based on well log interpretation, cutting and side wall core descriptions, revised palynology and microfossil studies, and an extensive seismic mapping and facies analysis. A log panel with correlation of the paly- and microfossil zonation and seismic sequences has been established. The base of the studied stratigraphic sequence is Upper Cretaceous sediment for the basinal boreholes and volcanic or crystalline basement for the basin marginal boreholes and with the regional "mid-Eocene unconformity" as the upper boundary.

Introduction

In 1996 two licences were granted offshore West Greenland, the Fylla licence and the Sisimiut West licence, to two groups of companies (Fig. 1). On the Fylla licence, with Statoil as operator, a single well, Qulleq-1, was completed in the summer of 2000. Qulleq-1 terminated at a total depth of 2937 m below sea level in sandstones of Late Cretaceous age. Unfortunately the well was dry and is now permanently plugged and abandoned. The granting of the licences in 1996 followed a period of almost 20 years with no or very little industrial interest in the West Greenland offshore areas. In 1975, 13 exclusive concessions covering 19082 km^2 were granted to four groups of companies, followed by the drilling of five wildcat boreholes from 1976–1977 (Fig. 1). All five boreholes were dry, and all concessions were relinquished in 1979.

This study continues the palynological stratigraphic study of these boreholes by Nøhr-Hansen (1998; this volume) combined with a new microfossil study, Rasmussen & Sheldon (this volume), a nannofossil study Sheldon (this volume) and a reinterpretation of the lithology and sedimentology first published by Rolle (1985). Toxwenius (1986) carried out by an earlier correlation of the five boreholes using palynomorphs, foraminifera, calcareous nannoplankton and diatoms. The lithological interpretation is based on cutting and side wall core descriptions of completion reports (Arco, 1978; Chevron, 1977; Manderscheid & Quin, 1977; Mobil, 1978a; Mobil, 1978b) and from Henderson (1979) in combination with well log interpretation. This new information is compared with the seismic sequences of Chalmers, Gregersen, Dalhoff, Nøhr-Hansen, Rasmussen & Sheldon (this volume) and placed into a seismic stratigraphic frame.

Geological setting

The oldest known sediments from West Greenland comprise a small outcrop of carbonates in the Maniitsoq area (Fossilik) (Fig. 1.) and dredged dropstones dated as Late Ordovician in age (Poulsen, 1966; Stouge & Peel, 1979; Stouge & Sønderholm, in press). These findings and the fact that reworked Carboniferous palynomorphs are observed in Qulleq-1 (Piasecki, pers. comm.) imply that a sedimentary basin existed between Greenland and Canada during the Middle to Late Palaeozoic time. In Qulleq-1, reworked Jurassic palynomorphs were observed in the Neogene section (Nøhr-Hansen, pers. comm.) but otherwise, pre-Cretaceous sediments are unknown from the West Greenland basin, although the regional presence of deep successions of unknown sediments is indicated from seismics (Chalmers, Dahl, Bate & Whittaker, 1995; Chalmers & Pulvertaft, 1993; Chalmers, Pulvertaft, Christiansen, Larsen, Laursen & Ottesen, 1993).

Chalmers & Pulvertaft (in press) summarise the tectonic and sedimentary history of the southern West Greenland basin as a period of active sea-floor spreading in the Labrador Sea during the Palaeogene preceded by deposition of pre- to early syn-rift sediments, the Kitsissut and 'deep' sequences, in pre-Late Cretaceous time. Mid-Cretaceous faulting and fault-block rotation and deposition of the Appat Sequence onto the hanging-walls followed that. This was followed by a period of thermal subsidence during Late Cretaceous and post-rift deposition of the Kangeq Sequence. The latest Campanian to Paleocene time were characterised by extension and fault-block rotation in the Nuussuaq Basin onshore and in the Fylla area offshore and probably elsewhere in the West Greenland basin. Later in Paleocene time, a plume-related uplift caused extensive erosion, and produced major channel systems in the Nuussuaq Basin (Dam, Nøhr-Hansen, Pedersen & Sønderholm, 2000; Dam & Sønderholm, 1998). The Late Paleocene and the Early Eocene were characterised by volcanism in some parts of the area and with offshore sedimentation associated with strike-slip tectonism that ended during the Middle Eocene. From the Middle Eocene to Neogene time, regional subsidence and sedimentation prevailed followed by uplift of the basin margins to expose the Nuussuaq Basin. For a much more comprehensive and detailed description of the tectonism in the West Greenland Basin the reader is referred to (Chalmers et al., 1995; Chalmers et al., this volume; Chalmers & Pulvertaft, 1993; Chalmers & Pulvertaft, in press; Chalmers et al., 1993).

Borehole physics and sample conditions

The boreholes were spudded at water depths between c. 100 m and 450 m and with a total depth of 2360–3870 m. A normal suite of wire line logging were carried out and in Kangâmiut-1 a Drill Stem Test in the interval 3674–3705 m was also performed, unfortunately with inconclusive results (Bate, 1997; Chalmers, 1992). The reliability of the wire line logging from the boreholes is to some extent controversial duo to extensive caving in some intervals. A large zone of overpressure in the Kangâmiut-1 *c.* 2775–3225 m (Fig. 2) is also blurring the information from the interval transit time from this borehole. All the log traces were recorded analogue and are later digitised and loaded on workstations.

It should be noticed that the major palaeoenvironmental interpretation are based on data from ditch cutting samples (DCS), therefore caved specimens in the samples are to some extent common due to the extensive caving in some parts of the boreholes (Fig. 2) and may account for differences between palynological and micropalaeontological interpretations.

Sequence stratigraphy

The number of sequences, their boundaries and correlation is a result of an integrated study between seismic interpretation, well log interpretation and biostratigraphy. In this paper the sequence stratigraphic definitions first published by the Exxon group is adopted and Mitchum (1977) defined a sequence as a unit of relative conformable strata deposited during one relative sea-level cycle. However, the majority of the identified and correlated sequences in this work are seismic sequences and the standard techniques of seismic stratigraphy interpretation has been used (Chalmers et al., this volume). Several of the seismic sequences can be grouped into successions that commence with an lowstand stystem tract (LST) succeeded by a transgressive system tract (TST) and highstand system tract (HST). Such groupings indicate deposition during a 3rd order cycle of relative sea-level, and their constituent seismic sequences may be 4th order sequences.

Palaeoecological significance and relative sea-level fluctuations

A tentative palaeoenvironmental analysis for the Paleocene and Eocene microfossil and palynological assemblages of the Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1 and Nukik-2 boreholes has been achieved during the present study (Figs. 3–7), and the results of the two biostratigraphic methods have been compared with data from the sedimentological and seismic investigations. The micropalaeontological palaeoenvironmental interpretations are primarily based on foraminiferal groups, which have been documented as occuring in a restricted range of palaeoenvironments. Other microfossil groups included in the interpretations are diatoms, radiolaria, gastropods, bivalves, ostracods, calcareous nannofossils and coal fragments. The palaeoenvironmental interpretations of palynomorphs are primarily based on dinoflagellate cysts, however signals from fresh water algae, fungal spores, pollen and plant tissues have also been included.

Dinoflagellates

Lagoonal and littoral palaeoenvironment

Both *Alterbidinium* cf. *bicellulum* and *Fibrocysta bipolaris* are regarded as littoral to inner neritic indicators. In the present study these species were not found to co-occur in abundance with *Cordosphaeridium* spp. and *Spiniferites* spp. (both regarded as outer neritic species). The abundance of the genus *Homotryblium* is suggested to represent restricted marine to inner neritic, maybe lagoonal water masses (Brinkhuis, 1994; Köthe, 1990). The presence of *Paralecaniella* spp. is suggested to be most abundant in marginal marine successions, indicating a tolerance for inner-neritic, probably brackish conditions or indicating transport from such deposits (Brinkhuis & Schiøler, 1996; Elsik, 1977; Powell, Brinkhuis & Bujak, 1996). According to Brinkhuis & Schiøler (1996) is *Paralecanilla*-dominated assemblages deposited during hydrodynamically high-energy conditions, under which most clay-sized particles remained in suspension, leading to an impoverished palynological assemblage. *Pediastrum* spp. indicate a fresh to brackish-water origin or transport from such deposits (Batten, 1996; Powell et al., 1996). *Spiniferites* cf. *pseudofurcatus* is interpreted as being an opportunistic species as it is only recorded from a narrow level in the Hellefisk-1 well, where it dominates. Brinkhuis (1994) notes that *S. pseudofurcatus* is more common in marginal marine settings than in offshore settings in Italy.

Littoral to inner neritic palaeoenvironment

An almost monospecific assemblage of *Apectodinium* spp. indicates a tolerance for high-energy shallow marine conditions (Powell et al., 1996). Bujak & Brinkhuis (1998) described Late Paleocene *Apectodinium* spp. blooms and indicated that they were related to a world wide global warming which led to increased surface water temperatures (possibly associated with nutrient availability) permitting the possibly holozoic *Apectodinium* spp. to migrate into mid and high latitudes. Bujak & Brinkhuis (1998) stated that there is no evidence suggesting that *Apectodinium* were not fully marine and that the species *Apectodinium augustum* probably indicates more offshore conditions, as it is not known from nearshore marine sections. *Apectodinium homomorphum* represents near shore conditions with low salinity according to Costa & Downie (1976) and De Coninck (1990). The genera *Cerodinium* and *Deflandrea* are supposedly represent heterotrophic peridinoid cysts. Abundance of heterotrophic cysts are suggested to reflect areas with high primary productivity related to increased nutrient availability such as upwelling areas and river mouths (indicating near shore conditions), or may indicate transport from such deposits (Brinkhuis, 1994; Heilmann-Clausen, 1994; Nøhr-Hansen & Heilmann-Clausen, 2000; Powell et al., 1996). *Lingulodinium machaeophorum* in recent cyst assemblages is believed to indicate near shore coastal or estuarine waters with a lower than normal salinity (Goodman, 1979; Islam, 1984; Wall, Dale, Lohmann & Smith, 1977).

Operculodinium centrocarpum are suggested to represent restricted marine to open marine neritic water masses (Brinkhuis, 1994; Islam, 1984). The *Wetzeliellaceae* are grouped together with *Deflandrea* by some authors (e.g. Downie, Hussain & Williams, 1971; Goodman, 1979; Jan Du Chêne & Adedian, 1984; Köthe, 1990) and are considered to indicate lagoonal, estuarine or brackish conditions. Van Mourik, Brinkhuis & Williams (2001) described the genus *Wetzeliella* as an inner neritic indicator.

Outer neritic to bathyal palaeoenvironment

Assemblages characterised by rich and relatively high diversity dinoflagellate associations probably reflect outer neritic conditions or hydrodynamically lower energy deposits (Schiøler, Brinkhuis, Roncaglia & Wilson, 1997). The species *Areoligera gippingensis* is probably indicative of offshore conditions (Heilmann-Clausen, 1994), whereas *Areoligera* spp. and *Glaphyrocysta* spp. are thought to represent open marine, inner-neritic conditions (Brinkhuis, 1994; Powell et al., 1996). *Charlesdowniea coleothrypta* was tentatively interpreted as a middle neritic to oceanic indicator based on cluster analysis by Jaramillo & Oboh-Ikuenobe (1999) who also mention that *Charlesdowniea* is more abundant than *Wetzeliella* in offshore areas of the Hampshire and London basins. *Cordosphaeridium* spp. is regarded as representing open marine water masses (Brinkhuis, 1994). Other indicators of oceanic influence are *Hystrichokolpoma* spp. according to Van Mourik (2001) and *Impagidinium* spp. according to Dale (1996). *Spiniferites* spp., like *Cordosphaeridium* spp. are regarded as representing open marine neritic water masses (Brinkhuis, 1994; Wall et al., 1977). *Thalassiphora pelagica* may be a stress tolerant species, occurring in abundance in low-oxygen environments (Köthe, 1990). However new studies by Pross (2001) indicate that this species changes morphology with fluctuating oxygen levels. New observations by Van Mourik (2001) described the genus *Thalassiphora* as an outer neritic indicator.

Microfossils

The palaeoenvironmental interpretation is based on a number of different groups of foraminifera and other microfossil groups, which are believed to have represented certain palaeoenvironments. It should be emphasised again, however, that the majority of samples included in this study are ditch cutting samples, meaning that the relative abundance of fossils in each sample may have been distorted by caving from higher levels in the wells. This implies that the palaeoenvironmental interpretations should only be regarded as very tentative.

The following non-foraminiferid microfossil groups have been included in the abundance schemes in this study (e.g. Fig. 4): coal fragments, microgastropods, ostracodes, bivalves, radiolaria (*Cenodiscus* spp. and *Cenosphaera* spp.) and aulacodiscid diatoms (*Aulacodiscus* spp.). The majority of microfossils are foraminiferids represented by the following groups: Midway Fauna taxa including e.g. *Anomalinoides* spp., *Gavelinella danica*, *Cibicidoides alleni* and other *Cibicidoides* species, *Cibicidina* spp., *Gyroidinoides subangulata*, *Osangularia plummerae* (see Plummer, 1926; Brotzen, 1948 and Berggren & Aubert, 1975 for additional taxa); striated nodosariids (*Nodosaria latejugata*, *N. elegantissima*, *N. torsicostata*), polymorphinids (e.g. *Globulina* spp. and *Guttulina* spp.), miliolids, *Allomorphina* spp., Vaginulinidae and Lagenidae (including e.g. *Lenticulina* spp. and *Marginulinopsis* spp.), buliminids (including infaunal calcareous benthic genera such as *Bulimina*, *Praeglobobulimina*, *Turrilina* and *Uvigerina*), planktic foraminifera, and *Nuttalides* spp. Four groups of agglutinated foraminifera have been included, following the subdivision of Jones and Charnock (1985): Agglutinated foraminifera Morphogroup A (tubular, erect genera including *Rhabdammina* spp. and *Bathysiphon* spp.), Agglutinated foraminifera Morphogroup B (mainly epifaunal genera including e.g. *Ammodiscus* spp., *Glomospira* spp., *Saccammina* spp., *Haplophragmoides* spp.), Agglutinated foraminifera Morphogroup C (infaunal, torpedo-shaped genera such as *Hormosina* spp., *Dorothia* spp., *Textularia* spp., *Rzehakina epigona*), and Agglutinated foraminifera Morphogroup D (epifaunal, trochospiral genera including most trochamminids).

Lagoonal and littoral palaeoenvironment

Recent marine lagoons are characterised by foraminiferal assemblages with a high porcellaneous content (order Miliolida). The miliolids include e.g. the genera *Quinqueloculina* and *Triloculina*. Paleocene coastal deposits of Tunisia were shown to contain a relatively high number of e.g. *Bulimina trigonalis* (Saint-Marc & Berggren, 1988). Jones & Charnock (1985) showed that agglutinated foraminifera of Morphogroups B (epifaunal), C2 (infaunal, *Miliammina*) and D (epifaunal attached, most trochamminids) are approximately equally common in marsh and marginal environments. Ostracods, gastropods and coal fragments may be common in these shallow water environments.

Inner neritic palaeoenvironment

Paleocene neritic foraminiferal faunas have been described from the Midway Formation, Texas (Plummer, 1926; 1931), Denmark (Franke, 1927), Scania, Sweden (Brotzen, 1948) and several other places (see review by Berggren & Aubert, 1975), and have been named the Midway-type Fauna. The Midway-type fauna comprises a diverse calcareous, benthic fauna including e.g. *Bulimina* ex gr. *trigonalis* (restricted to inner neritic and littoral environments), *Gavelinella danica*, *Gavelinella lellingensis*, *Cibicidoides alleni*, *Anomalinoides midwayensis*, *Cibicidoides* spp., *Cibicides* spp. and polymorphinids (e.g. *Guttulina* and *Globulina*). Saint-Marc & Berggren (1988) noted also that *Allomorphina trigona* and lenticulinids were common in this environment. *Praeglobobulimina ovata*, which is common in the Ikermiut-1 and Kangâmiut-1 boreholes, was interpreted as characterising the slightly brackish, inner neritic palaeoenvironment (Murray, Curry, Heynes & King, 1989).

Elongate with an infaunal life position (Morphogroup C1 of Jones & Charnock, 1985) are relatively common in this environment. Agglutinated foraminifera of Morphogroup C1 includes e.g. textulariids, uncoiling lituolids and hormosinids. The benthic diatom genus *Aulacodiscus* indicates inner neritic conditions, and it has been suggested that increased diatom productivity was related to high surface water productivity with increased nutrient levels and oxygen depletion in the lower water column (Nagy, Kaminski, Johnsen & Mitlehner, 1997; Thomas & Gradstein, 1981). Ostracods and molluscs (especially gastropods and bivalves) may be common in the inner neritic environment. Calcareous nannoplankton assemblages dominated by *Reticulofenestra* spp., *Chiasmolithus* spp., *Transversopontis pulcher* and *Coccolithus* spp. indicate a relatively deep-water environment (Firth, 1989) but it is difficult to differentiate between inner and outer neritic palaeoenvironments using nannofossils.

Outer neritic palaeoenvironment

The outer neritic palaeoenvironment commonly contains a relatively high proportion of the Midway-type Fauna during the Early Palaeogene (see above). *Bulimina* ex gr. *trigonalis* and *Gavelinella danica* occur in relatively lower numbers than in the inner neritic environment. Planispiral and lenticular trochospiral epifaunal agglutinated foraminifera (Morphogroup B3 of Jones & Charnock, 1985) are relatively common (including most lituolids such as *Haplophragmoides* and *Cyclammina*).

Bathyal palaeoenvironments

The Velasco-type fauna, which includes e.g. *Nuttalides truempyi*, *Pullenia coryelli*, *Cibicidoides dayi*, *Angulogavelinelli avnimelechi*, *Gaudryina* spp. and *Dorothia oxycona* were relatively common in bathyal environments during the Paleocene. The boreholes described herein contain only few of these species (e.g. *Nuttalides truempyi*, *Stensioeina beccariiformis* and *Cibicidoides dayi*) but tubular agglutinated; suspension-feeding foraminifera (Morphogroup A of Jones & Charnock, 1985) are very common in certain levels. Epifaunal suspension feeders are adapted to life in areas of low organic influx (Nagy et al., 1997). Planktic foraminifera are much more common in the bathyal environment than in the neritic. For instance *Subbotina* ex gr. *patagonica* is common in the Early Eocene in both Ikermiut-1 and Kangâmiut-1. Radiolaria are occasionally abundant in this environment. It is difficult to distinguish between the upper, middle and lower bathyal environments in the offshore West Greenland area on a qualitative basis, but as there is a relative decrease in the number of benthic species (e.g. Midway-type elements) down slope, a tentative segregation can be made on a semi-quantitative basis.

Sequence description

Sequence 500

Presence

Kangâmiut-1, 3671–3649 m (22 m)

Nukik-2, 2557–2379 m (178 m), maximum flooding surface (mfs) 2414 m

Palynozone

P2 –P4 (Mudge & Bujak, 1996), mfs in P4. Stratigraphically significant dinoflagellate cyst species are *Areoligera* spp., *Cerodinium speciosum*, *C. striatum*, and *Palaeoperidinium pyrophorum* in addition to *Cerodinium kangiliense* and *Senegalinium iterlaaense* in the lower part (Nøhr-Hansen, this volume).

Microzone

S. beccariiformis foraminifera Zone (Rasmussen & Sheldon, this volume).

Age

Late Danian (late Early Paleocene) to early Thanetian (Late Paleocene).

Kangâmiut-1

Boundaries

Sequence boundary (SB) 500 is placed at a pronounced shift on all the e-logs (Fig. 2). It marks the boundary from Turonian–Lower Santonian sandstones to Upper Paleocene mudstones. The upper boundary is defined by seismic interpretation and is placed with respect to the seismic resolution.

Log motif

Sequence (S) 500 is characterised by small 2–6 m thick stacked fining-upwards and thinning-upwards parasequences with a back-stepping log motif (Fig. 2).

Lithology

The sequence is interpreted as a shale dominated unit, described as a dark grey to brown soft shale with silty limestone streaks and traces of pyrite, glauconite and calcite (Manderscheid & Quin, 1977)

Dinoflagellate cyst assemblage

Only one sample from S500 in Kangâmiut-1 has been studied. It contains a moderately diverse assemblage including *Spiniferites* spp., *Cordosphaeridium* spp., *Impagidinium* spp. and frequent *Pediastrum* spp.

Microfossil assemblage

Only one DCS sample was studied from this interval. It contains a diverse foraminiferal fauna including abundant *Praeglobobulimina ovata*, *Haplophragmoides/Cribrostomoides* spp. (agglutinated foraminifera of Morphogroup B3) and *Rhabdammina discreta* (agglutinated foraminifera of Morphogroup A) and common *Lenticulina* spp. (lageniid) and nodosariids. The diatom *Fenestrella antiqua* is abundant.

Depositional environment

The palynological content of the one studied sample suggests outer neritic to bathyal conditions, however, the presence of frequent freshwater algae suggests supply from freshwater environments, probably redeposited sediments (Fig.3). The microfossil content and the scarcity of shallow water indicators such as *Midway Fauna* elements and ostracods and gastropods indicate an upper bathyal depositional environment with an estimated palaeodepth of 200–500 m (Fig. 4).

Nukik-2

Boundaries

The lower boundary has a sharp base lying conformably upon possible subaqueous basaltic flows of Late Paleocene age. The age of the basaltic flows encountered in Nukik-2 and Hellefisk-1 have been discussed in some detail by Mobil (1978b), Hald (1987), Rolle (1985) and Williamson, Villeneuve, Larsen, Jackson, Oakey & MacLean (2001). A decrease in interval transit times and an abrupt decrease in gamma ray readings mark the upper boundary in Nukik-2 at 2386 m (Fig. 2).

Log-motif

In Nukik-2 the gamma ray log shows an overall fining-upwards trend whereas the sonic log displays a slight decrease. In the lower part of the sequence the gamma ray log shows minor fining-upwards log motifs of 10–20 m thickness. At 2497m, 2470 m and 2385 m an abrupt fall in the gamma readings is combined with a decrease in the sonic values, whereas in other parts of the sequence a similar drop in the gamma readings is not combined with similar changes on the sonic log (Fig. 2).

Lithology

In Nukik-2 S500 is dominated by a thick lower sandstone unit, which gradually passes into a siltstone / shale dominated unit upwards. The sandstone is described as a medium grained, subangular quartz sandstone with abundant volcanic fragments and the siltstone / shale unit as a soft to medium hard, very argillaceous and in part very calcareous, micaceous siltstone with common pyrite grading into a brown blocky subfissile shale (Mobil, 1978b). The sandstone unit is interpreted as stacked fining-upwards submarine channels with intercalated volcanics. The minor sandstone layers in the upper shale dominated unit are probably turbidites or storm sand layers. Three minor volcanic beds occur where falls in the gamma readings are combined with decreases on the sonic log (Fig. 2).

Dinoflagellate cyst assemblage

Spores and pollen dominate the assemblage in Nukik-2. Frequent *Cerodinium* spp. are recorded from a thin sandy layer in the side wall core sample (SWC) at 2429 m (Fig. 5). The significant dinoflagellate species are *Cerodinium* spp., *Palaeoperidinium pyrophorum* and *Areoligera* spp. The almost complete absence of *Spiniferites* spp. is conspicuous. Few *Cordosphaeridium* spp. are recorded from the upper part of the sequence. The mfs at 2414 m is marked by a slight increase in species diversity and by superabundant *Areoligera* spp. The base of the uppermost sandstone unit of S500 is marked by a relatively high dinoflagellate cyst diversity, of *in situ* species, of which there are 13, however reworked species are also common at that level.

Microfossil assemblages

Microfossil diversity is moderate to high in the samples in the lower c. 30 m of S500 (Fig. 6). The foraminiferal fauna includes common *R. discreta* (agglutinated foraminifera of Morphogroup A) and *Usbekistania charoides* (agglutinated foraminifera of Morphogroup B3) together with more sparse *Praeglobobulimina ovata* and *Midway Fauna* elements. Radiolaria of the *Cenodiscus* and *Cenosphaera* groups and smooth ostracods are common. Planktic foraminifera were not observed in S500. The middle part of the sequence contains abundant *R. discreta* and radiolaria (especially *Cenodiscus* spp.) and common *U. charoides*. The upper part of the sequence is dominated by agglutinated foraminifera, especially *Haplophragmoides* spp. and *Rhabdammina discreta* and common diatoms (*Fenestrella microtrias*). Calcareous benthic foraminifera of the *Midway Fauna* occur sporadically.

Depositional environment

The dinoflagellate cysts indicate near shore inner neritic conditions for most of the sequence, this is supported by a dominance of spores and pollen. The presence of a few outer neritic indicators in the upper part of the sequence suggests a deepening upwards. Common *Cerodinium* spp. recorded from a thin sandy layer at 2429 m may indicate near shore conditions, or transport from such deposits e.g. by turbidites (Fig. 5).

The microfossil content indicates an inner neritic depositional environment in the lower part of the sequence, a deep outer neritic environment in the middle part, and a more shallow outer neritic environment in the upper part with an estimated palaeodepth of less than 200 m (Fig. 6).

Systems tracts

Based on the palynomorph and microfossil data is S500 from the Kangâmiut-1 thought to represent a part of a lowstand system tract (LST) that passes onward into the subsequent sequence. In the Nukik-2 borehole S500 is interpreted to represent almost a full depositional sequence. The sandstone comprising the lower half is referred to LST overlain by a transgressive surface (TS) followed by a mudstone dominated transgressive system tract (TST) comprising minor sandstone layers and from the major flooding surface (mfs) a mudstone dominated highstand system tract (HST). The palynomorphs and microfossils support this interpretation.

Sequence 1000

Presence

Hellefisk-1, 2508–2297 m (211 m), mfs 2420 m

Ikermiut-1, 2744–2429 m, (315 m), mfs 2608 m

Kangâmiut-1, 3648–3350 m (298 m), mfs 3545 m

Nukik-1, 2342–2240 m, (102 m), mfs 2266 m

Nukik-2, 2379–2307 m (72 m), mfs not recognised

Palynozone

Upper P4–upper P5 (Mudge & Bujak, 1996), mfs in P5. Stratigraphically significant dinoflagellate cyst species are *Alisocysta margarita*, *Areoligera gippingensis* and *Palaeoperidinium pyrophorum* with the addition of *Cerodinium speciosum* and *C. striatum* in the lower part of the sequence (Nøhr-Hansen, this volume).

Microzone

S. beccariiformis to lower *P. ovata* foraminifera zones and *T. wittiana* to lower *F. antiqua–C. morsianus* microfossil zones (Rasmussen & Sheldon, this volume).

Age

Middle Thanetian (Late Paleocene).

Hellefisk-1

<u>Boundaries</u>

The lower boundary is marked by an abrupt shift in the e-log readings where S1000 rests upon basalt. The upper boundary is placed at the base of a marked basin-ward shift on the gamma log.

Log motif

Hellefisk-1 is characterised by an aggrading slightly back-stepping logpattern comprising 5–20 m of thick parasequences of both fining- and coarsening-upwards trends (Fig. 2).

Lithology

S1000 contains interbedded clay, sandstone and siltstone and becomes more clay rich / silty upwards. The clay is light to medium grey, soft, occasionally silty and sandy, very argillaceous, calcareous, glauconitic and soft to firm. The sandstone is white, fine-grained, friable to hard and very calcareous. Some minor layers comprise green to grey green, very fine-grained, glauconitic and friable sandstone. The siltstone is medium grey to green grey to brown, very argillaceous, slightly to very calcareous, soft to firm and becomes very silty, sandy and very glauconitic at the base (Arco, 1978).

Dinoflagellate cyst assemblage

In the lowermost part of the sequence abundant *Areoligera gippingensis* is found together with frequent *Cordosphaeridium* spp. and *Spiniferites* spp. Further up sequence abundant *Cerodinium* spp. are recorded within thin sandy layers (2463 m and 2438–40 m). Above the mfs (2420 m) *Glaphyrocysta* spp. become frequent. The species diversity is moderate (1–11) (Fig. 7).

Microfossil assemblages

A high diversity, low abundance assemblage is present from 2505 m to 2435 m. Fauna and flora include the buliminid group (particularly *Praeglobobulimina ovata* and *Bulimina trigonalis*), *Aulacodiscus* spp., *Thalassiosiropsis wittiana*, *Aulacodiscus* sp. 3 GEUS, *Midway Fauna*; taxa Vaginulinidae and Lagenidae, polymorphinids, *Haplophragmoides* spp. / *Cribrostomoides* spp., Nodosaria (striated), *Cyclammina* spp. and agglutinated foraminifera Morphogroups A-D (*Rhabdammina discreta* and *Trochammina* spp., respectively) in relatively equal amounts (Fig. 8).

A noticeable increase in abundance of several groups between 2426 m and 2414 m, especially peaks in *Aulacodiscus* spp., *Midway Fauna* (including *Anomalinoides welleri* and *A. midwayensis*) and agglutinated foraminifera Morphogroup D, indicates a change in depositional environment.

From 2405 m to 2295 m at the top of the sequence, a drop in faunal and floral abundance and diversity occurs until only coal fragments and rare ostracods and bivalves are present.

Depositional environment

The dinoflagellate cyst assemblage indicates outer neritic / offshore conditions for the lower part of the sequence. The abundant *Cerodinium* spp. recorded within thin sandy layers in the lower part suggest near shore conditions, or transport from such deposits by turdidites. Above the mfs (2420 m) the outer neritic indicators are almost absent and the inner neritic indicators frequent (Fig. 7).

The microfossils indicate an outer neritic, open marine depositional environment with a palaeodepth of between 100 m and 200m in the lower part of S1000 due to the presence of a mixed diatom, calcareous benthic and agglutinated foraminiferal flora and fauna (Fig. 8). At around 2400 m, influxes of *Midway Fauna* taxa, agglutinated foraminifera of Morphogroup D and *Aulacodiscus* spp. indicate a temporary shallowing to an inner neritic environment, with an estimated palaeodepth of less than 100 m. This is immediately followed by a fall in faunal and floral abundance and diversity, suggesting a return to more open marine conditions again. Above this a shallowing to a very shallow marine to littoral/lagoonal environment is indicated by a sharp decrease in floral and faunal abundance and diversity; a palaeodepth of less than 50 m is suggested for the upper part of this sequence.

Ikermiut-1

Boundaries

SB1000 is marked with an abrupt shift in the e-log readings, which marks a facies change from Upper Santonian claystone towards Upper Paleocene sandstone. The upper boundary is defined by seismic.

Log motif

In Ikermiut-1 the gamma log indicates a fining-upwards trend from the base to 2608 m, and from the mfs a coarsening-upwards trend to SB3000. The log pattern shows minor fining-upwards and coarsening-upwards parasequences of 5 to 20 meters in thickness.

Lithology

Ikermiut-1 is dominated by shale / claystone, silty in places with the presence of silty limestone streaks, very fine-grained glauconitic sandstones and traces of pyrite (Chevron, 1977).

Dinoflagellate cyst assemblage

Ikermiut-1 contains a diverse (6-19) dinoflagellate cyst assemblage around the sequence boundary (2744 m) dominated by *Cerodinium* spp., *Glaphyrocysta* spp., *Palaeoperidinium pyrophorum* and *Thalassiphora delilcata* (Fig. 9). This changes rapidly upwards where the assemblage is dominated *Areoligera gippingensis* and *Spiniferites* spp. *Cordosphaeridium* spp. are present at the levels where *Spiniferites* spp. are abundant.

The algae *Pediastrum* spp. occur frequently in samples from the sandy intervals and often at the base of these intervals. *Pediastrum* spp. is only recorded from this sequence in Ikermiut-1 and Kangâmiut-1. In the uppermost part of Ikermiut-1 *Cerodinium* spp., *Deflandrea* spp. and *Spinidinium* aff. *sagittula* are common to abundant, whereas the abundance of *Spiniferites* spp. decrease.

Microfossil assemblages

S1000 in Ikermiut-1 contains a rich microfauna dominated by agglutinated foraminifera (Fig. 10). It contains common foraminifera of agglutinated Morphogroup A (*Rhabdammina discreta*), keeled members of Morphogroup C (*Spiroplectammina spectabilis*) and B3 (especially *Haplophragmoides - Cribrostomoides* complex). Calcareous benthic foraminifera (buliminids, nodosariids) are also present in many samples. Planktic foraminifera are rare. The microfaunal assemblages of the basal sandstone unit and the overlying shale interval are very similar. Ostracods are common in only one sample in the upper part of the sequence (2474 m) together with e.g. *Praeglobobulimina ovata* and *Allomorphina* spp. but otherwise are rare or missing.

Depositional environment

The dinoflagellate cyst assemblage around the SB1000 (2744 m) indicates inner neritic near shore conditions, however, this changes rapidly upward in the major mudstone succession where outer neritic dinoflagellate assemblages dominate (Fig. 9). The intercalated sandy intervals contain the alga *Pediastrum* spp. suggesting fresh to brackish-water environments or more likely transport from such deposits by turbidites. In the uppermost part of the sequence inner neritic indicators are common to abundant, whereas the abundance of outer neritic indicators decreases. This may result in an influx of inner neritic environmental indicators just below SB3000.

The microfauna indicates an overall outer neritic palaeoenvironment with a palaeodepth of 100–200 m in most parts of sequence (Fig. 10), possibly interrupted by an interval representing an upper bathyal environment in the middle part of the sequence where a depth of 200–500 m may have occurred (c. 2500 m – 2650 m).

Kangâmiut-1

Boundaries

SB1000 in Kangâmiut-1 is only well defined on seismic sections (Chalmers et al., this volume) and lies unconformably on the Late Danian to early Thanetian claystones of S500.

Log-motif

The gamma log from Kangâmiut-1 displays an overall fining-upwards tendency indicating a backstepping motif comprising minor sharp-based 5–20 m thick fining-upwards and coarsening-upwards parasequences (Fig. 2)

Lithology

Kangâmiut-1 is dominated by partly silty shale / claystone with the presence of very thin silty limestone streaks, very fine-grained glauconitic sandstones and traces of pyrite (Manderscheid & Quin, 1977).

Dinoflagellate cyst assemblage

As in Ikermiut-1, the major mudstone succession in Kangâmiut-1 is dominated by *Areoligera gippingensis* together with frequent *Spiniferites* spp. and *Cordosphaeridium* spp. in the lower part. *Pediastrum* spp. are frequent in the middle of the sequence (Fig. 3). The species diversity is moderate (7–12).

Microfossil assemblages

Kangâmiut-1 contains a rich microfauna in S1000 (Fig. 4). It is dominated by agglutinated foraminifera of Morphogroup A and Morphogroup B3 (*Haplophragmoides/Cribrostomoides*) in the lower part, but diatoms are also abundant (*Fenestrella antiqua*). *Nutallides truempyi* is rare. The middle and upper parts of the sequence are dominated by buliminids (*Praeglobobulimina ovata*), Morphogroup A agglutinated foraminifera, diatoms (including *Aulacodiscus* spp. and *Thalassiosiropsis wittiana*) and with more common Midway Fauna species and ostracods.

Depositional environment

The major mudstone succession is dominated by outer neritic dinoflagellate assemblages (Fig. 3). Due to the content of reworked brackish water alga *Pediastrum* spp., the sandy layers are interpreted as turbidites bringing near shore sediments offshore. The microfossil content indicates an upper bathyal palaeoenvironment in the lower part of the sequence developing into a mainly outer neritic setting in the middle and upper parts (Fig. 4). The microfossil assemblage indicates a palaeodepth of 200–500 m for the lower part and less than 200 m for the middle and upper parts.

Nukik-1

Boundaries

In Nukik-1 the lower boundary is marked by an abrupt shift in the e-log readings and S1000 rests on intrusive acidic rocks.

Log motif

Nukik-1 is characterised by an aggrading slightly back-stepping logpattern comprising 5–20 m thick parasequences of both fining- and coarsening-upwards trends (Fig. 2)

Lithology

S1000 is dominated by a clear to translucent, unconsolidated, generally medium-grained, subangular to subrounded, poorly sorted sandstone with abundant weathered metamorphic grains, traces of glauconite and traces of carbonaceous material becoming more indurated towards the base (Mobil, 1978a).

Dinoflagellate cyst assemblage

In Nukik-1, *Paralecaniella indentata* occurs frequently to commonly in samples from the sandy intervals, especially at the base of these intervals (Fig. 11). *Paralecaniella indentata* is only recorded from this sequence in Nukik-1and Nukik-2. *Glaphyrocysta* spp., *Impagidinium* spp., *Spiniferites* spp. and *Thalassiphora pelagica* occur frequently at levels with no or few specimens of *P. indentata*. The species diversity is higher in the muddy intervals (13–16), whereas it is low (1–4) in the sandy intervals.

Microfossil assemblages

Nukik-1 contains a very sparse microfauna dominated by agglutinated foraminifera. Accordingly, the palaeoecological interpretation is tentative and based on poor fossil evidence (Fig. 12). S1000 only contains microfossils in the upper part, where sparse *Rhabdammina discreta* and *Bathysiphon* spp. (agglutinated foraminifera Morphogroup A) occurs together with *Spiroplectammina spectabilis* (agglutinated foraminifera Morphogroup C1) and *Haplophragmoides* spp. (agglutinated foraminifera Morphogroup B3). Coal fragments are rare or occasionally common.

Depositional environment

The overall palynological content of the studied samples from Nukik-1 suggest that the low diversity assemblages from the sandy intervals represent marginal marine to brackish water depositional environments (Fig. 11), whereas the moderately high diversity assemblages represent inner to outer neritic environments.

The very poor microfossil content and the presence of coal fragments together with the relatively coarse clastic sediments indicate an inner neritic depositional environment (Fig. 12), although the setting is difficult to interpret due to the poor microfossil yield. An estimated palaeodepth of 100–200 m is suggested for S1000.

Nukik-2

Boundaries

The sequence boundary rests on the upper mudstone dominated unit of S500 and is marked by an abrupt shift on the e-log readings.

Log motif

The gamma log from Nukik-2 displays an overall fining-upwards tendency. The log pattern shows minor fining- and coarsening-upwards parasequences of 5–20 m in thickness with an aggrading and back-stepping motif.

Lithology

S1000 in Nukik-2 is dominated by interbedded, very fine to medium grained, poorly sorted, occasionally slightly calcareous and glauconitic sandstone units (Mobil, 1978b).

Dinoflagellate cyst assemblage

In the lowermost sample *Areoligera* spp. occurs frequently together with few specimens of *Areoligera gippingensis*, *Cordosphaeridium* spp. and *Spiniferites* spp. (Fig. 5). These genera are absent in the middle and upper part of the sequence where *Paralecaniella indentata* becomes frequent. The species diversity is low (1–6).

Microfossil assemblages

Nukik-2 contains a sparse microfauna in S1000 (Fig. 6). Only the lowermost studied sample (2374 m) contained a relatively rich fauna, comprising entirely of agglutinated foraminifera. Agglutinated foraminifera of Morphogroups A and B3 are common, while those from Morphogroup C1 occur in lower numbers. All the samples in the upper part of the sequence were barren, apart from one sample that contained a single specimen of agglutinated foraminifera of Morphogroup A.

Depositional environment

The dinoflagellate cyst assemblage in this sequence suggests an inner to outer neritic depositional environment for the lower part (Fig. 5), whereas the content of the samples from the upper part suggests marginal marine to brackish water depositional environment.

The low microfossil content indicates a shallow outer neritic or inner neritic depositional environment for the lower part of the sequence (Fig. 6), altering to an inner neritic and / or littoral palaeoenvironment in the upper part. An estimated palaeodepth of less than 200 m at the base of the sequence to less than 50 m for the upper part is suggested.

Systems tracts

The three basin margin boreholes (Hellefisk-1, Nukik-1 and Nukik-2) all contain sandy intervals with sharp based, blocky gamma-log signals, possibly indicating submarine channels as suggested by the palaeoecological interpretation. The two more basin central boreholes (Ikermiut-1 and Kangâmiut-1) are mudstone dominated with thin sandstone layers; possibly turbidites or storm sand layers. Inner neritic, nearshore conditions as interpreted from the basinal sand (Ikermiut-1) are upwardly rapidly replaced by more offshore conditions, indicated by a massflow, possibly turbidite/BFF. S1000 is interpreted to comprise LST, TST and HST.

Sequence 3000

Presence

Hellefisk-1, 2297–2077 m (220 m), mfs 2168 m

Ikermiut-1, 2429–2150 m (279 m), mfs 2353 m

Kangâmiut-1, 3350–3247 (103 m), mfs 3297 m

Nukik-2, 2307–2259 m (48 m), mfs 2271 m

Nukik-1, 2240–2195 m (45 m), mfs 2221 m

Palynozone

Upper P5–P6 / ?E1 (Bujak & Mudge, 1994; Mudge & Bujak, 1996), mfs upper P5 (only in Hellefisk-1) and lower P6 / E1. Stratigraphically significant dinoflagellate cyst species are *Apectodinium* spp., *Apectodinium augustum, Lejeunecysta hyalina* and in the lower part *Areoligera gippingensis* (Nøhr-Hansen, this volume).

Microzone

P. ovata foraminifera Zone, and *F. antiqua-C. morsianus* to Ostracod microfossil zones (Rasmussen & Sheldon, this volume).

Age

Middle to late Thanetian (Late Paleocene).

Hellefisk-1

Boundaries

The lower boundary of S3000 has a sharp base and rests unconformably on S1000. The mfs is picked at the highest gamma reading.

Log motif

At the base of the sequence the gamma log is marked by an abrupt shift towards lower readings, causing a blocky log motif with internal minor parasequences. The overall log pattern of Hellefisk-1 is characterised by retrogradational parasequence sets below the mfs and progradational parasequence sets comprising flat-based fining-upwards parasequences above the mfs (Fig. 2).

Lithology

The sequence predominantly contains sandstone with minor to moderate interbeds of siltstone and claystone. The sandstone is white with clear, loose, fine to very coarse, angular to subrounded quartz grains and is rarely glauconitic and occasionally very pyritic, and below 2249 m calcareous. The siltstone is light to medium grey, very argillaceous, soft to firm and occasionally carbonaceous. The claystone is light to medium grey, silty, generally soft and sticky (Arco, 1978).

Dinoflagellate cyst assemblage

Paralecaniella indentata is generally rare in the sequence, except from a narrow interval at 2114 m where it occurs frequently together with *Areoligera gippingensis* (Fig. 7). Only few *Glaphyrocysta* spp. and *Spiniferites* spp. are recorded from the sequence. Terrestrial plant material is abundant at the top and base of the sequence. The diversity is generally low (less than 6).

Microfossil assemblages

From 2295 m (the bottom of the sequence) to 2075 m (the top of the sequence), the very low diversity and abundance assemblage includes low numbers of ostracods, bivalves and *Aulacodiscus* spp., but is dominated by coal fragments (Fig. 8).

Depositional environment

The palynological contents of the studied samples from Hellefisk-1 indicate inner neritic conditions in the lower part and more brackish conditions for the upper part, as suggested by the frequent occurrence of freshwater algae (Fig. 7).

The low abundance and diversity microfossil assemblages and the dominance of coal fragments indicate a shallow marine to littoral or lagoonal environment for this sequence,with an estimated palaeodepth of less than 50 m (Fig. 8).

Ikermiut-1

Boundaries

SB3000 in Ikermiut-1 is determined from the seismic interpretation (Chalmers et al., this volume) and rests unconformably on S1000. The mfs is picked at the highest gamma reading and is marked by evident changes in the gamma and sonic readings.

Log motif

The log motif of Ikermiut-1 is very similar to that described from Hellefisk-1 with a characteristically retrogradational set of parasequences below the mfs and a progradational parasequence set above the mfs comprising flat-based fining-upwards parasequences.

Lithology

The silty to sandy claystones are interbedded with dark grey to black, pyritic, locally very carbonaceous, well indurated shales occasionally with calcite-filled fractures. Minor siltstones and very fine-grained, glauconitic sandstones occur as lenses in the claystone. Thin limestone and dolomite beds are minor elements. From 2357–2388 m a soft orange-red clay with anhydrite inclusions and hard, red-brown claystones are interbedded with light grey, calcareous siltstones which grade into very fine-grained arkosic and glauconitic sandstones (Chevron, 1977).

Dinoflagellate cyst assemblage

Two peaks of *Deflandrea* spp. occur in the lower part of the sequence (Fig. 9). The base of the sequence is dominated by *Areoligera gippingensis*, and is upwardly followed by a dominance of *Apectodinium* spp. and *Spiniferites* spp. This situation is changes in the upper part of the sequence where *Apectodinium* spp. and the fresh to brackish water alga *Pediastrum* spp. dominates and *Spiniferites* spp. are less common (except from 2190 m, where it dominates). Apart from in Ikermiut-1, only one specimen of *Pediastrum* spp. is recorded in S3000 from both Nukik-2 and Kangâmiut-1. In these boreholes it occurs at the base of the influx of *Apectodinium* spp. (Powell et al., 1996) also recorded common *Pediastrum* spp. just below an *Apectodinium* spp. influx from the Lower Upnor section in south-east England.

Apectodinium spp. is common to very abundant in the major part of S3000 in Ikermiut-1 and in the upper part of the sequence in Kangâmiut-1 and Nukik-2. There is a noteble decrease in the thickness of sections containing the *Apectodinium* spp. acme, from more than 100 m in Ikermiut-1 to 30 m in Kangâmiut-1 and 10 m in Nukik-2. No *Apectodinium* spp. have been observed from Nukik-1 and Hellefisk-1. The possible offshore indicator *Apectodinium augustum* is very rare in West Greenland. The species diversity is the highest for S3000 (4–23).

<u>Microfossil assemblage</u>

S3000 contains a less abundant microfauna than the neighbouring sequences (Fig. 10). *Allomorphina* spp. and diatoms are common in most of the sequence, while planktic foraminifera are present in small numbers in the lower and upper parts. Ostracods and buliminids (*Praeglobobulimina ovata*) are restricted to the upper part of the sequence. The abundance of agglutinated foraminifera is notably lower than in S1000.

<u>Depositional environment</u>

The overall palynological content of the studied samples from Ikermiut-1 suggests an outer neritic depositional environment (Fig. 9). According to (Powell et al., 1996) an almost monotypic assemblage of *Apectodinium* spp. indicates tolerance for high-energy shallow marine conditions indicative of a transgressive system tract (TST). The frequent to common occurrences of the fresh to brackish water alga *Pediastrum* spp. throughout the sequence, and the peaks of *Deflandrea* spp. in the lower part suggest turbidite re-deposition.

The microfauna content indicates an outer neritic palaeoenvironment in the lower part of S3000 and an inner neritic palaeoenvironment in the upper part (Fig. 10). The species diversity is intermediate and an estimated palaeodepth of 100–200 m in the lower part and probably less than 100 m in the upper part is suggested for S3000.

Kangâmiut-1

<u>Boundaries</u>

SB3000 in Kangâmiut-1 is determined from the seismic interpretation (Chalmers et al., this volume) and rests unconformably on S1000. The mfs is located at a dinoflagellate diversity peak and just 10 m above a peak in foraminifera, ostracods and diatoms (Fig. 2)

<u>Log motif</u>

The e-logs are characterised by a back-stepping coarsening-upwards motif from the sequence boundary toward the mfs containing 5–10 m thick thickening-upwards parasequences. From the mfs towards the top of the sequence, the log motif represents an aggrading and slightly fining-upwards tendency.

Lithology

The lithology is described as a dark grey to brown shale, occasionally grading into soft silty clay with silty limestone streaks. Traces of pyrite, glauconite, calcite and quartz grains are present in thin layers (Manderscheid & Quin, 1977).

Dinoflagellate cyst assemblage

Palynological samples do not represent the lower part of the sequence. *Areoligera gippingensis* and *Spiniferites* spp. are frequent in the middle part, whereas *Apectodinium* spp. and *Spiniferites* spp. are common in the upper part of the sequence (Fig. 3). Only one specimen of *Pediastrum* spp. is recorded from the base of the influx of *Apectodinium* spp.

Microfossil assemblages

S3000 is characterised by a high diversity and abundance assemblage and is dominated by common lageniids (*Lenticulina*), *Cyclammina* and ostracods together with *Midway Fauna* elements and nodosariids (Fig. 4). Diatoms, especially *Fenestrella antiqua*, are abundant whereas tubular suspension feeders of agglutinated foraminifera of Morphogroup A are rare.

Depositional environment

The palynological content of the studied samples from Kangâmiut-1 suggests an outer neritic depositional environment (Fig. 3). The occurrences of a few fresh- to brackish water indicators in the middle part of the sequence suggest turbidite re-deposition. The species diversity is moderately high (12–16). The mfs may indicate a condensed section, as suggested by the peaks of palynomorphs and microfossils.

The microfossil content indicates an inner neritic palaeoenvironment with an estimated palaeodepth of probably less than 100 m (Fig. 4).

Nukik-1

Boundaries

In Nukik-1 the boundary is defined from seismic interpretation (Chalmers et al., this volume). It is sharp based and rests unconformably on S1000. The mfs is placed at the highest gamma reading.

Log motif

The log motif of S3000 is characterised by an overall aggrading motif comprising upward coarsening parasequences of 5–10 m thickness.

Lithology

The lithology in S3000 in Nukik-1and Nukik-2 is very similar and is described as interbedded sand, clay and siltstone with minor shale. The sand is light grey, clear / translucent, medium-grained, moderately to poorly sorted, partly unconsolidated with abundant weathered metamorphic grains, traces of glauconite and slightly carbonaceous. The clay is light to dark grey, soft to firm, silty, kaolinitic, calcareous and micaceous, with rare glauconite, common pyrite and occasional quartz grains. The siltstone is light to dark grey, very argillaceous, slightly calcareous, micaceous, medium hard, partly grading into silty shale with common scattered very fine to fine-grained quartz grains (Mobil, 1978a; Mobil, 1978b).

Dinoflagellate cyst assemblage

Paralecaniella indentata is common to abundant in the sandy intervals in the lower and uppermost parts of the sequence (Fig. 11). *Spiniferites* spp., *Thalasiphora pelagica* and *Wetzeliella* spp. are present to frequent in the upper part. The species diversity is generally low (1–12)

Microfossil assemblages

Extremely few microfossils were recovered from S3000, indicating that the palaeoenvironmental interpretation should be regarded as tentative. Tubular suspension feeders of agglutinated foraminifera of Morphogroup A are present (*Bathysiphon*, *Rhabdammina*), and only single specimens of ostracods and *Haplophragmoides kirki* were observed. Coal fragments are common. Both microfossil diversity and abundance are very low (Fig. 12).

Depositional environment

In Nukik-1 the sandy intervals in the lower and uppermost parts of the sequence are interpreted as being deposited under brackish water conditions or representing re-deposition by submarine channels. The palynological assemblage from 2198 m in the upper part of the sequence suggests inner to outer neritic conditions (Fig. 11).

Despite the occurrence of tubular suspension feeders, the very low fossil content, the common coal fragments and the coarse-grained clastic sediments indicate a (inner?) neritic palaeoenvironment with a palaeodepth of probably less then 200 m (Fig. 12).

Nukik-2

Boundaries

S3000 in Nukik-2 is defined from seismic interpretation (Chalmers et al., this volume) and SB3000 is placed within limits of uncertainty due to seismic resolution at a basin-ward shift on the e-logs (Fig. 2). The boundary rests unconformably on sediments from S1000 and the mfs is placed at the highest gamma reading.

Log motif

The log motif of S3000 is characterised by a very serrate log pattern interpreted as an retrogradational motif from the base to the mfs comprising minor flat based parasequences. From the mfs towards SB3500 the motif is progradational.

Lithology

The lithology is the same as described for S3000 in Nukik-1.

Dinoflagellate cyst assemblage

As in Nukik-1 and Hellefisk-1, *Paralecaniella indentata* is recorded throughout the sequence, however its abundance is low in Nukik-2 (Fig. 5). The amount of terrestrial plant material is general high. Only one specimen of *Pediastrum* spp. is recorded from the base of the influx of *Apectodinium* spp. *Areoligera* spp. are common in the lower part, whereas the group decreases in number in the upper part, where *Apectodinium* spp., *Cordosphaeridium* spp., *Spiniferites* spp. and *Thalassiphora pelagica* are present. *Deflandrea oebisfeldensis* is common to abundant within a thin sandy layer (at 2301 m) in the lower part of sequence. The species diversity is intermediate (2–15).

Microfossil assemblages

Microfossil diversity and abundance is extremely low (Fig. 6). Only one specimen of agglutinated foraminifera of Morphogroup A (*Rhabdammina discreta*) was observed from S3000 (2301 m). Coal fragments, however, are abundant.

Depositional environment

The palynological content in the basal part of the sequence indicates a near shore to brackish palaeoenvironment and for the lower part, inner neritic conditions are suggested. A shift towards inner to outer neritic palaeoenvironment occurs in the upper part of the sequence (Fig. 5).

The lack of marine microfossils together with abundant coal fragments indicates a shallow littoral or lagoonal palaeoenvironment and a palaeodepth of probably less than 10 m (Fig. 6).

Systems tracts

At the base of S3000 in Hellefisk-1 the gamma log is marked by an abrupt shift towards lower readings causing a blocky log motif with internal minor parasequences. This pronounced 80 m thick log motif with very low gamma readings may be interpreted as a large incised valley comparable to those described from Nuussuaq by Dam (2000) and Dam (1998) and may in Hellefisk-1 represent the LST. Central in the basin the sequence is developed as a depositional sequence comprising lowstand basin floor fans (mounds) and turbidites succeeded by transgressive deposits (Chalmers et al., this volume). Progradational units are not observed (Chalmers et al., this volume), though coarsening-upwards trends are observed in the basinal boreholes and it seems that HST deposits are missing. S3000 is interpreted to be e associated with lowstand progradation followed by transgressive conditions.

Sequence 3500

Presence

Hellefisk-1, 2077–1986 m (91m), mfs 1990 m

Ikermiut-1, 2151–1870m (281 m), mfs 1920 m

Kangâmiut-1, 3247–3226 m (21 m), mfs 3237 m

Nukik-1, 2195–2104 m (91 m), mfs 2125 m

Nukik-2, 2259–2224 m (35 m), mfs 2245 m

Palynozone

Upper P6–E1–E2a (Bujak & Mudge, 1994; Mudge & Bujak, 1996), mfs E1, E2a in Ikermiut-1. Stratigraphically significant dinoflagellate cyst species are *Apectodinium parvum, Cerodinium dartmoorium, Deflandrea oebisfeldensis* and *Spinidinium* aff. *Saggittula* (Nøhr-Hansen, this volume).

Microzone

P. ovata foraminifera Zone and upper *F. antiqua-C. morsianus* – Ostracod microfossil zones. The *A. hirtus* microfossil zone is observed in S3500 only in Ikermiut-1 (Rasmussen & Sheldon, this volume).

Age

Late Thanetian (Late Paleocene) to early Ypresian (Early Eocene).

Hellefisk-1

Boundaries

S3500 rests unconformably on S3000 in all five boreholes. In Hellefisk-1 the sequence boundary is placed were a pronounced shift on the gamma log and sonic log is located (Fig. 2). The sequence boundary is sharp and is marked by a shift in lithology from a siltstone / claystone to sandstone. A mfs is not suggested for this sequence since it is interpreted as being part of a greater depositional sequence.

Log motif

The log motif is aggradational and retrogradational with minor sharp based, blocky gamma-log signals representing fining-upwards parasequences.

Lithology

S3500 comprises interbedded sandstone, siltstone and claystone with sandstone as the dominant lithology downwards. The sandstone is loose, fine to very coarse-grained and subangular to subrounded. From 2067 m upwards the interval is predominantly claystone and siltstone with rare sand beds. The siltstone is light grey to grey-brown, very argillaceous, varyingly carbonaceous and micaceous, soft to firm and occasionally sandy. The claystone is grey to grey-brown, soft, sticky, varyingly silty, slightly carbonaceous and micaceous. A black, shiny, conchoidal to hackly fracturing thin coal bed containing pyrite nodules is reported from 2024 m (Arco, 1978; Henderson, 1979).

Dinoflagellate cyst assemblage

Only a few specimens of *Areoligera* spp. and *Glaphyrocysta* spp. have been recorded from S3500 in Hellefisk-1 (Fig. 7).

Microfossil assemblages

Aulacodiscus spp. (a group of diatoms indicative of a shallow or inner neritic environment), *Aulacodiscus* sp. 3 GEUS, *Aulacodiscus hirtus*, and ostracods are the dominant components of this sequence with a peak in abundance between 2054 m and 2012 m (Fig. 8). Coal fragments are common throughout the sequence and other components comprise rare buliminids, radiolaria, *Midway Fauna*, Vaginulinidae and Lagenidae and polymorphinids.

The assemblages become less diverse toward the top of the sequence, with ostracod and diatom abundances falling. The middle of the sequence is punctuated by a high abundance and diversity calcareous benthic foraminiferal assemblage, which is caved from the Pliocene / Pleistocene strata.

Depositional environment

Based on the very low amount of palynomorph data, a brackish to inner neritic depositional environment has been suggested (Fig. 7).

A slight marine incursion to an inner neritic environment is indicated by the microfossils in the middle of the sequence by a proliferation of *Aulacodiscus* spp., ostracods and the calcareous benthic groups mentioned above. However the other groups (*Midway Fauna*, nodosariids, agglutinated foraminifera Morphogroup D) which were present in the S1000 are absent or present in reduced numbers here, indicating that the depositional environment in S3500 was probably marine (with an estimated palaeodepth of less than 100 m), but not as 'open marine' as in the S1000. The fall in abundance of all these groups at the top of the sequence indicates a return to shallower waters, probably below 50 m palaeodepth (Fig. 8).

Ikermiut-1

Boundaries

The sequence boundary is placed were a pronounced shift on the e-logs is located (Fig. 2). The sequence boundary is sharp and is marked by a shift in lithology from a siltstone / claystone to sandstone. The mfs is placed were the highest gamma reading is identical or very close to a diversity peak in foraminifera.

Log motif

In Ikermiut-1 the log motif has an overall retrogradational trend from the base to the mfs. The lower part of the sequence is characterised by flat-based bell shaped or blocky parasequences (Fig. 2). From the mfs to the top of S3500 the log motif is progradational with minor fining-upwards and coarsening-upwards parasequences.

Lithology

The lithology is predominantly claystone and siltstone. The claystone is light grey to grey-brown and is locally very silty to sandy, soft to firm, slightly calcareous, finely micaceous and interbedded with medium to dark grey, subfissile silty shale. Thin beds and stringers of siltstone and very fine to fine-grained arkosic sandstones with black minerals and glauconite are scattered throughout the interval. A 30 m thick fine to medium-grained, poorly sorted, arkosic, glauconitic sandstone is located from 1975–1945 m (Chevron, 1977; Henderson, 1979).

Dinoflagellate cyst assemblage

Spiniferites spp and *Cordosphaeridium* spp. are frequent throughout the sequence, whereas *Spiniferites* spp. becomes common at the mfs (1919 m). *Apectodinium* spp. is common to very abundant in the lowermost part of the sequence (Fig. 9). *Apectodinium* spp. has not been recorded from Nukik-1 and Hellefisk-1. *Areoligera* spp. are also present throughout the sequence but become more frequent in the middle part. *Deflandrea* spp. is common to abundant in a thin sandy layer in the middle part of the sequence (1992 m) where it co-occurs with common *Cerodinium* spp., *Spinidinium* aff. *sagittula* and *Pediastrum* spp. *Paralecaniella indentata* is frequent just above (1977 m). The diversity is moderate (2–18).

Microfossil assemblage

S3500 contains an abundant and diverse microfauna with abundant buliminids (*Praeglobobulimina ovata*) and *Allomorphina* spp. Smooth ostracods are common in the lower part and rarer in the upper part. Striated nodosariids, lageniids, polymorphinids, tubular agglutinated foraminifera of Morphogroup A and aulacodiscid diatoms are present through most of the sequence. Planktic foraminifera and *Midway Fauna* species are present in the upper half of the sequence (fig. 10).

Depositional environment

The palynological assemblage indicates an inner neritic depositional environment below the mfs, whereas a shift occurs to outer neritic conditions in the upper part of the sequence (Fig. 9). The presence of brackish to inner neritic indicators in the middle of the sequence point to near shore conditions, or transport from such deposits by turbidites.

The microfaunal content indicates an inner neritic palaeoenvironment in the lower part of the sequence and an outer neritic palaeoenvironment in the upper part. The palaeodepth is interpreted as being less than 100 m in the lower part and probably 100 – 200 m in the upper part (Fig. 10).

Kangâmiut-1

Boundaries

SB3500 in Kangâmiut-1 is based on seismic interpretation (Chalmers et al., this volume) since no marked change in log response or lithology is observed. The mfs is placed were the highest gamma reading is identical or very close to a diversity peak in foraminifera. The upper boundary is defined by marked changes on all the e-logs (Fig. 2)

Log motif

S3500 in Kangâmiut-1 is very thin and is characterised by rather high gamma readings comprising a progradational log motif (Fig. 2). The density and porosity curves display a pronounced separation.

Lithology

The lithology comprises interbedded shale and sandstones becoming sand dominated towards the top. The shale is grey to brownish grey, slightly silty, occasionally very calcareous, slightly carbonaceous, occasionally slightly pyritic and glauconitic and with traces of anhydrite. The sandstone is quartzose, very fine-grained and loose. Abundant stringers of fibrous calcite are seen throughout (Henderson, 1979).

Dinoflagellate cyst assemblage

Spiniferites spp. and *Cordosphaeridium* spp. are common to abundant in the sequence. *Apectodinium* spp. is common in the lowermost part of the sequence and *Paralecaniella indentata* is present throughout the sequence. This sequence in Kangâmiut-1 represents the highest (12–25) palynological diversity of all the boreholes (Fig. 3).

Microfossil assemblages

Only one sample, 3231 m comprising a microfauna of medium diversity and abundance, was studied from S3500 (Fig. 4). It contains common planktic foraminifera and ostracods together with rare *Midway Fauna* species, agglutinated foraminifera of Morphogroup A, and diatoms (*Aulacodiscus*).

Depositional environment

The palynological assemblage suggests an outer neritic depositional environment with turbiditic re-depositions of brackish to inner neritic indicators (Fig. 3).

The microfossil content indicates an outer neritic palaeoenvironment relatively close to the shelf-slope transition with a palaeodepth of approximately 200 m (Fig. 4).

Nukik-1

Boundaries

SB3500 is defined from seismic interpretation and the boundary is placed at a marked change on all the e-logs, within limits of uncertainty due to seismic resolution. The mfs is placed at the highest gamma readings (Fig. 2) and the upper boundary is again defined by seismic interpretation.

Log motif

The log motif is aggradational from base to top with minor sharp based, blocky and coarsening-upwards parasequences.

Lithology

Lithologically, S3500 is similar to S3000 with interbedded sand, siltstone and clay / claystone.

Dinoflagellate cyst assemblage

Palynological samples from the lowermost part of the sequence have not been studied. The lowermost studied sample yielded a highly diverse assemblage with abundant *Thalassiphora pelagica*, common *Spiniferites* spp. and some *Impagidinium* spp. (Fig. 11). *Paralecaniella indentata* is present to frequent in the middle part. A few specimens of *Thalassiphora pelagica*, and *Spiniferites* spp. occur in the uppermost part of the sequence. Diversity is generally low (1–5) apart from the one sample mentioned above (29).

Microfossil assemblages

Very few microfossils were recovered from S3500. Agglutinated foraminifera are rare and only one buliminid (calcareous benthic foraminifera) was observed. Tubular suspension feeders of agglutinated foraminifera of Morphogroup A (*Bathysiphon*, *Rhabdammina*) are present together with *Haplophragmoides* and *Cyclammina* in the lower half of the sequence. Coal fragments occur sporadically in the upper half of the sequence. Both the diversity and abundance are very low (Fig. 12).

Depositional environment

The palynological assemblage from the lowermost studied sample indicates outer neritic conditions, this changes rapidly upwards to marginal marine to brackish water conditions for the middle part, whereas the presence of a few indicators may suggest inner neritic conditions for the upper part (Fig. 11).

The few agglutinated foraminifera observed in the lower half of the sequence indicate an outer neritic palaeoenvironment with a palaeodepth of 100–200 m. The coal fragments and coarse grained clastic sediments indicate a slightly shallower, probably inner neritic palaeoenvironment in the upper half of the sequence and with a palaeodepth of less than 100 m (Fig. 12).

Nukik-2

Boundaries

The sequence boundary is defined from seismic (Chalmers et al., this volume) and placed, were a prominent shift on the gamma log and sonic log is located (Fig. 2). The sequence boundary is sharp based and is marked by a shift in lithology from a siltstone / claystone to sandstone. The mfs is placed were the highest gamma reading pick is identical or very close to a diversity peak in foraminifera. The upper boundary is defined by seismic interpretation.

Log motif

From the sequence boundary towards the mfs, the log motif is retrogradational comprising small, few metres thick parasequences and from the mfs towards the top the logs display a progradational motif of small coarsening-upwards parasequences.

Lithology

S3500 is lithologically similar to S3000 with interbedded sand, siltstone and clay / claystone.

Dinoflagellate cyst assemblage

Areoligera spp., *Cordosphaeridium* spp., *Impagidinium* spp., *Spiniferites* spp. and *Wetzeliella* spp. are all present in low numbers in the sequence. *Apectodinium* spp. are frequent in the lowermost part. The amount of terrestrial plant material is high and a single specimen of *Paralecaniella indentata* has been recorded from the middle part (Fig. 5). Species diversity is generally high (7–17).

Microfossil assemblages

Marine microfossils were not observed but common to abundant coal fragments were present (Fig. 6).

Depositional environment

The overall palynological content of the studied samples suggests an inner to outer neritic depositional environment. The occurrence of a single brackish-water specimen in the middle part of the sequence suggests re-deposition by turbidites (Fig. 5).

The lack of marine microfossils together with the common occurrence of coal fragments indicates a shallow littoral or lagoonal palaeoenvironment (Fig. 6).

Systems tracts

This sequence is possibly developed as a depositional sequence with lowstand basin floor fans (mounds) and turbidites central to the area (Chalmers et al., this volume), succeeded by transgressive and highstand deposits, which are thickest in more marginal areas with stacked shallow marine channels and highstand progradational units. The three basin marginal wells, Hellefisk-1, Nukik-1 and Nukik-2 are sandy with sharp based, blocky gamma-log signals, possibly indicating sub-marine channels interpreted as part of the HST (Fig. 2). The two more basin central boreholes, Ikermiut-1 and Kangâmiut-1 are both shale dominated with thin sandstone layers; possibly turbidites or stormsand layers. This unit is interpreted as the LST and TST. Major bio diversity peaks coincides with clayey to calcaceous layers indicating mfs, succeeded by upward coarsening lithology of a highstand. However the palaeontology indicate an upward deepening which may lead to an alternative interpretation, that the mfs instead represent an earlier transgressive surface and that the sediments of S3000 is deposited as a LST.

Sequence 3750

Presence

Ikermiut-1, 1870–1795 m (75 m), mfs 1829 m.

Palynozone

E2a, mfs E2a. Stratigraphically significant dinoflagellate cysts species are *Apectodinium* spp. and *Spiniferites septatus* (Nøhr-Hansen, this volume).

Microzone

P. ovata foraminifera Zone (Rasmussen & Sheldon, this volume).

Age

Early Ypresian (Early Eocene).

Ikermiut-1

Boundaries

SB3750 is defined from seismic interpretation by an onlap surface (Chalmers et al., this volume). The wire line logging and the lithological interpretation show no clear evidence for SB3750. On the log panel the sequence boundary is picked within the range of uncertainty given by the seismic resolution where the gamma log shows the most pronounced basin-wards shift. The mfs is picked at the highest gamma log value (Fig. 2).

Log motif

The sequence displays an almost symmetrical gamma – sonic log profile with an abrupt shift at c. 1835 m towards higher gamma readings and increased interval transit time. In the upper half of the sequence the gamma log displays a log pattern of coarsening-upwards cycles separated by gamma peaks, combined with an overall retrogradational log motif.

Lithology

S3750 is predominantly a light to medium grey and grey-brown, soft and soluble to firm, slightly calcareous, finely micaceous claystone, locally with dark mineral grains, interbedded with medium to dark grey, subfissile and grey–brown, silty shale. Stringers and thin beds of siltstone and very fine to fine-grained arkosic sandstone with abundant dark-green and black heavy minerals are scattered throughout. A few thin limestones are present. (Chevron, 1977).

Dinoflagellate cysts assemblage

Areoligera senonensis, *Cordosphaeridium* spp. and *Spiniferites* spp. are present to frequent, however no marginal marine to brackish water indicators have been recorded from the sequence (Fig. 9). The species diversity is generally low (less than 10).

Microfossil assemblages

Abundant lageniids (*Lenticulina*) and buliminids (*Praeglobobulimina ovata*) dominate the very rich microfauna. Agglutinated foraminifera are rare. Buliminids are especially numerous in the lower part of the sequence together with *Midway Fauna* species, radiolaria and the diatom genus *Aulacodiscus*. Gastropods occur in low numbers throughout the sequence. The upper part of S3750 contains common planktic foraminifera (e.g. *Subbotina* ex gr. *patagonica*) and the benthic genus *Allomorphina*. Both abundance and diversity are very high (Fig. 10).

Depositional environment

The palynological assemblage indicates outer neritic depositional conditions for this sequence (Fig. 9).

The microfossil assemblages indicate an outer neritic environment close to the shelf-slope transition, with relatively common planktic foraminifera. The estimated palaeodepth is between 100–200 m, probably shallower in the lower part of the sequence than in the upper part. The relatively high sea level continues from the preceding sequence, where the deepening starts in the upper most part of S3500 (Fig. 10).

Systems tracts

The thin sandstone layers found in the lowermost part of the sequence are interpreted as turbidites or storm sand layers and S3750 is interpreted as a HST. As previously described, there is no clear evidence of a sequence boundary on the wire line logs and the sequence could be interpreted as a continuation of the highstand conditions found in S3500.

Sequence 4000

Presence

Ikermiut-1, 1795–1693 m (102 m)

Palynozone

E2a. The only stratigraphically significant dinoflagellate cyst species are a few specimens of *Apectodinium* spp (Nøhr-Hansen, this volume).

Microzone

P. ovata foraminifera Zone (Rasmussen & Sheldon, this volume).

Age

Early Ypresian (Early Eocene).

Ikermiut-1

Boundaries

SB4000 is defined by a combination of seismic reflectors indicating an onlap surface and basinward shift on the gamma log. The sequence boundary is also characterised by a change in lithology from claystone / shale towards siltstone.

Log motif

The log motif indicates two major fining-upwards cycles containing secondary fining-upwards units. By interpreting the log motif, a clearer candidate for the sequence boundary would be *c.* 15 m further up the borehole, at 1780 m where a marked shift in lithology from siltstone to sandstone is located. However, the seismic resolution can not justify the sequence boundary at that level (Chalmers et al., this volume).

Lithology

S4000 is a part of the same claystone / shale unit as S3750 and may lithologically be described as the preceding sequence (Chevron, 1977).

Dinoflagellate cyst assemblage

As in S3750, *Areoligera senonensis*, *Cordosphaeridium* spp. and *Spiniferites* spp. are present to frequent in this sequence. Only few specimens of the algae *Pediastrum* spp. have been recorded from samples in thin sandstone layers (Fig. 9). The species diversity is generally low (less than 10).

Microfossil assemblages

Midway Fauna species (especially *Gavelinella* ex gr. *danica*), planktic foraminifera and *Allomorphina* spp. are abundant in the lower part of the sequence while diatoms (e.g. *Aulacodiscus*) together with rare *Midway Fauna* elements dominate the upper part. The abundance and diversity is medium to high in the lower part changing to low in the upper part of the sequence (Fig. 10).

Depositional environment

The palynological assemblage suggests outer neritic depositional conditions for this sequence. The presence of the algae *Pediastrum* spp. at the base of thin sandstone layers (e.g. 1710 m) suggests transport by turbidites from freshwater deposits (Fig. 9).

Microfossils indicate an outer neritic environment in the lower part of the sequence and an inner neritic environment in the upper part. The estimated palaeodepth is less than 200 m in the lower part and probably less than 100 m in the upper part the sequence (Fig. 10).

Systems tracts

S4000 is interpreted to represent 3rd order HST deposits and the turbidites or storm sand layers may be local input during tectonically disturbance. This 3rd order HST might contain elements of 4th order lowstand and transgressive fining-upwards deposits indicated by the log motifs (Fig. 2).

Sequence 5000

Presence

Hellefisk-1, 1986–1884 m (102 m), mfs 1916 m

Ikermiut-1, 1693–1596 m (98 m), mfs 1631 m

Kangâmiut-1, 3226–3022 m (204 m)

Nukik-2, 2224–2091 m (133 m), mfs 2127 m

Nukik-1, 2104–2031 m (73 m), mfs 2056 m

Palynozone

E2a–E2b, mfs E2a and possibly E2b in Ikermiut-1. Stratigraphically significant dinoflagellate cyst species are *Carpatella* sp. 1., *Deflandrea oebisfeldensis*, *Fibrocysta bipolaris* and *Wetzeliella astra* (Nøhr-Hansen, this volume).

Microzone

Uppermost *P. ovata* to lower *P. wilcoxensis* foraminifera Zones, and the *A. hirtus* to *Cenodiscus-Cenosphaera* microfossil zones (Rasmussen & Sheldon, this volume).

Age

Early to middle Ypresian (Early Eocene).

Hellefisk-1

Boundaries

SB5000 in Hellefisk-1 is marked by a shift on the gamma log from relatively high readings towards somewhat lower readings combined with a lithological change from a shale / mudstone to sandstone (Fig. 2).

Log motif

The sonic and gamma log displays an asymmetrical log motif in the lowermost part of the sequence, whereas the Compensated Neutron Log (CNL) and Compensated Formation Density (FDC) logs display an almost symmetrical log motif. The gamma log indicates minor progradational units of 20–30 m thicknesses at the base of the sequence. In Hellefisk-1 the mfs is picked at a clay / mudstone interval and just below an influx of marine dinoflagellates.

Lithology

Predominantly clay / claystone with minor to moderate interbeds of siltstone, sandstone and coal. The clay / claystone is light to medium greenish grey, varyingly silty and sandy, soft, sticky, carbonaceous and micaceous. The sandstone is light to medium grey, very fine to fine-grained occasionally medium-grained, slightly micaceous, slightly to moderately glauconitic and occasionally slightly calcareous. At the top of the sequence the sandstone is green-grey to light brown, very fine to fine-grained, argillaceous, silty, soft to friable, glauconitic, micaceous and has a poor porosity. The siltstone is light to medium grey, very argillaceous, soft to firm, varyingly carbonaceous and micaceous. The coal is black to brown, sub-bituminous, firm to brittle with associated nodular pyrite and traces of sparry calcite (Arco, 1978).

Dinoflagellate cyst assemblage

Fibrocysta bipolaris is, as in Nukik-1, abundant to dominant in the lower part of the sequence. The species is regarded as a littoral to inner neritic indicator. *Glaphyrocysta* spp. are common at the mfs level and *Cordosphaeridium* spp. are present in the upper part of the sequence. A single specimen of *Paralecaniella indentata* is recorded from the middle part of the sequence (Fig. 7). The species diversity is low (less than 7).

Microfossil assemblages

This sequence displays a low abundance and diversity assemblage of calcareous benthic foraminifera and a fairly high abundance of diatoms prevail in the lower part of this sequence. Above this (1878 m – 1926 m) the samples are barren of microfauna/flora. From 1990 m (the bottom of the sequence) to 1975 m, small numbers of ostracods and buliminids are present. From 1951 m until the top of this sequence at 1870 m, the assemblage is almost completely dominated by coal fragments, apart from an abundance of diatoms between 1945 m and 1935 m (Fig. 8).

Depositional environment

The palynological assemblage for the lower part of the sequence is suggested as representing a restricted brackish to inner neritic depositional environment, whereas a change towards more inner neritic conditions occurs around the mfs level (Fig. 7).

A shallowing from an inner neritic to a littoral / lagoonal palaeoenvironment is indicated by an impoverished calcareous benthic foraminiferal fauna at the bottom of the sequence. This is replaced up-sequence by an assemblage almost dominated by coal fragments (Fig. 8).

Ikermiut-1

Boundaries

In Ikermiut-1 is SB5000 marked by a shift on the gamma log from relatively high readings towards somewhat lower readings combined with a lithological change from a shale / mudstone to sandstone. The mfs is picked using a combination of micropaleontological data and the log pattern.

Log motif

The gamma and sonic logs display an overall symmetrical log pattern with a fining-upwards log motif from the sequence boundary towards the mfs and a coarsening-upwards trend from the mfs towards SB6000. The wire line logging is somewhat disturbed by rather prominent caving.

Lithology

The lithology comprises a claystone / shale unit of a light grey to grey-brown, soft to firm, slightly calcareous and micaceous claystone interbedded with medium to dark grey, subfissile silty shale. Also present are stringers and thin beds of siltstone and very fine to fine-grained arkosic sandstones with abundant dark-green and black heavy minerals. A few thin limestone beds are present (Chevron, 1977).

Dinoflagellate cyst assemblage

Glaphyrocysta spp. are frequent in the lower part of the sequence. *Spiniferites* spp. and *Cordosphaeridium* spp. are present throughout the sequence and become frequent around the mfs in the upper part. *Fibrocysta bipolaris* are present in low numbers throughout the sequence (Fig. 9). The species diversity through the sequence is generally high (3–19).

Microfossil assemblages

The microfossil abundance and diversity is intermediate and diatoms (*Aulacodiscus* spp.) together with common *Midway Fauna* species dominate the lower part of S5000. Radiolaria, agglutinated foraminifera of Morphogroup A, buliminids (*P. ovata*) and *Midway Fauna* species are common in the upper part together with rare planktic foraminifera (Fig. 10).

Depositional environment

The palynological assemblage indicates inner neritic conditions for the lower part of the sequence shifting towards outer neritic conditions around the mfs, continuing into the upper part of the sequence (Fig. 9).

The microfossils indicate an inner neritic palaeoenvironment in the lower part and an outer neritic palaeoenvironment in the upper part of the sequence with an estimated palaeodepth of less than 100 m in the lower part shifting to 100–200 m in the upper part (Fig. 10).

Kangâmiut-1

Boundaries

SB5000 is well defined from both e-logs and from seismic interpretation. On the e-logs the boundary is evident with a basin ward shift on the gamma log and marked changes on both the FDC and CNL logs. The sonic log also displays changes; however these are somewhat unreliable in that SB5000 marks the base of an overpressure zone with rather high interval transit times. On the seismic interpretation the sequence boundary is defined by onlaps toward highs and downlaps towards the basin centre (Chalmers et al., this volume).

Log motif

S5000 in Kangâmiut-1 is characterised by the onset of a large interval, stretching over several sequences, with an increase in interval transit time reflecting a zone of overpressure. The wire line readings are therefore somewhat unreliable. However, the gamma log displays a retrogradational motif, comprising small, less than 10 m thick, parasequences and one major coarsening-upwards unit from 3130–3105 m (Fig. 2).

Lithology

The lithology is predominantly shale with sandstone stringers and one prominent sandstone unit in the middle of the sequence. The shale is grey to brown, occasionally slightly silty, occasionally very calcareous, slightly micaceous, occasionally pyritic and glauconitic and fossiliferous. Coal fragments are present in the lower half of the sequence (Henderson, 1979).

Dinoflagellate cyst assemblage

Spiniferites spp. and *Cordosphaeridium* spp. are frequent to common throughout the sequence; in the lowermost part they occur together with common *Wetzeliella astra* and in the lower part they co-occur together with common *Glaphyrocysta* spp. Frequent *Fibrocysta bipolaris* also occurs in the lower part. *Charlesdowniea coleothrypta* is frequent in the middle part of the sequence and frequent *Deflandrea* spp. and *Cordosphaeridium* spp. occur just below the mfs level. Palynological samples have not been analysed from the uppermost part of the sequence (Fig. 3). The species diversity is the high (12–29).

Microfossil assemblages

Planktic foraminifera (especially *Subbotina* ex gr. *patagonica*), agglutinated foraminifera of Morphogroup A (*Rhabdammina discreta*) and diatoms (*Aulacodiscus* spp., *Fenestrella antiqua*) are abundant while buliminids (*Praeglobobulimina ovata*) are common. Polymorphinids, *Midway Fauna* elements and lageniids (*Lenticulina* spp.) are relatively common in the lower half part of S5000, while the bathyal marker *Nutallides truempyi* is restricted to the upper part. *Aulacodiscus* spp. is super-abundant in a single sample (3138 m), probably in relation to a significant regressive event. The diversity and abundance are high throughout the sequence (Fig. 4).

Depositional environment

The palynological assemblage for the sequence is suggested to represent outer neritic to bathyal conditions, even if a mixture of inner and outer neritic indicators in the lower part of the sequence may indicate that this part of the sequence could represent inner neritic conditions (Fig. 3).

The microfossils indicate an outer neritic palaeoenvironment during the lower and middle part of the sequence, while the uppermost part probably represents an upper bathyal palaeoenvironment. The estimated palaeodepth is 100–200 m in the lower and middle parts of S5000, and 200–500 m in the uppermost part (Fig. 4).

Nukik-1

Boundaries

The boundary in Nukik-1 is marked by a shift on the gamma log from relatively high readings towards somewhat lower readings combined with a lithological change from a shale / mudstone to sandstone.

Log motif

The log motif is retrogradational from the sequence boundary towards the mfs comprising 5–20 m thick parasequences. From the mfs towards SB6000 the log motif is progradational with c. 5 m thick parasequences. The gamma log contains some high gamma readings and the mfs is placed at one such reading considering the palynological and microfossil data.

Lithology

The lithology of S5000 in Nukik-1 is the same as that described in S3000.

Dinoflagellate cyst assemblage

As in Hellefisk-1, *Fibrocysta bipolaris* is dominant in the middle part of the sequence and a single specimen of *Paralecaniella indentata* is also recorded from this part of the sequence. *Cordosphaeridium* spp. and *Spiniferites* spp. are absent, whereas a few *Impagidinium* spp. have been recorded from the lower and upper parts of the sequence (Fig. 11). The species diversity is low in the middle part (less than 5) and moderately high in the lower and upper part (11–16).

Microfossil assemblages

The very sparse microfauna and -flora include scattered occurrences of *Haplophragmoides- Cribrostomoides, Cyclammina amplectens* and *Bathysiphon*. The diatom *Aulacodiscus hirtus* occurs in the upper part of the sequence together with rare coal fragments (Fig. 12).

Depositional environment

The palynological assemblage for the lower part of the sequence is suggested to represent inner neritic conditions. A restricted brackish depositional environment is suggested for the middle part, whereas a change to more inner neritic conditions occurs around and above the mfs level (Fig. 11).

The few present marine microfossils and coal fragments indicate a neritic palaeoenvironment, possibly outer neritic in the lower and middle parts of the sequence, and inner neritic in the uppermost part. An estimated palaeodepth of less than 200 m is suggested (Fig. 12).

Nukik-2

Boundaries

SB5000 is not well defined on e-logs. Within limits of uncertainty due to seismic resolution, the boundary is placed at the most suitable depth according the log motif.

Log motif

The log pattern in Nukik-2 is very similar to that seen in Nukik-1 with rather constant readings, though some high gamma readings are present. The gamma picks indicate a marine influx and the mfs coincides with an influx of foraminifera, marine fungal spores and with maximum readings on the gamma log.

Lithology

The lithology of S5000 in Nukik-2 is equivalent to that described in S3000.

Dinoflagellate cyst assemblage

Spiniferites spp., *Cordosphaeridium* spp., *Thalassiphora pelagica* and *Wetzeliella* spp. are frequent throughout the sequence. *Areoligera* spp. are also frequent but become common in the upper part together with the presence of *Impagidinium* spp. *Fibrocysta bipolaris* has only been recorded in low numbers from the uppermost part of the sequence. Abundant *Spinidinium* spp. occur in all DCS but have not been recorded from any of the SWCs, suggesting either caving or contamination from the drilling mud (Fig. 5). The amount of terrestrial plant material is high in Nukik-2. The species diversity for the majority of the samples is high (10–22).

Microfossil assemblages

Marine microfossils were not observed but the sequence contains abundant coal fragments (Fig. 6).

Depositional environment

The palynological assemblage is suggested to represent inner to outer neritic conditions (Fig. 5). However, the large amount of terrestrial material and the presence of assumed dinoflagellate contamination from the drilling mud makes it difficult to interpret the palaeoenvironment.

The lack of marine microfossils together with common coal fragments indicates a shallow littoral or lagoonal palaeoenvironment (Fig. 6).

Systems tracts

It is suggested that this sequence is developed as a depositional sequence with lowstand basin floor fans (mounds) and turbidites central to the area (Chalmers et al., this volume), succeeded by lowstand progradational units basinward of the preceding sequence. These are succeeded by transgressive and highstand deposits.

The three basin marginal boreholes Hellefisk-1, Nukik-1 and Nukik-2 are sandy with sharp based, blocky or coarsening-upwards gamma-log signals, possibly indicating channels or prograding shoreface sands. The two more basin central boreholes Ikermiut-1 and Kangâmiut-1 are shale dominated with thin sandstone layers, possibly turbidites or storm sand layers. However, in the lower part of the sequence in Hellefisk-1, dinoflagellates indicate inner neritic conditions, but further upwards (1935 m) foraminifera and diatoms suddenly become very rare and may indicate a regression.

Sequence 5250

Presence

Hellefisk-1, 1884–1732 m (152 m), mfs 1844 m

Palynozone

Middle E2b, mfs E2b. Stratigraphically significant dinoflagellate cyst species are *Spiniferites* aff. *pseudofurcatus* and *Wetzeliella lunaris* (Nøhr-Hansen, this volume).

Microzone

A microfossil zonation has not been established for this sequence.

Age

Middle Ypresian (Early Eocene).

Hellefisk-1

Boundaries

On the log panel SB5250 is picked at the base of a minor coarsening-upwards sequence and at the same level a slight increase in interval transit time is observed. From the seismic interpretation the sequence boundary is defined at an unconformity surface (Chalmers et al., this volume). The mfs is picked *c.* 40 m below a distinct influx of dinoflagellates but due to the lack of good sample material, has the mfs been placed at the level with the highest gamma reading.

Log motif

The log motif shows a series of fining-upwards and coarsening-upwards parasequences, especially above the mfs where the gamma log illustrates a prograding and aggrading log pattern.

Lithology

The interval is predominantly sandstone with minor to moderate interbeds of claystone and occasional siltstone. The sandstone is white, clear, light grey, quartzose, loose, very fine to fine-grained with some coarse grains, subangular to subrounded and has a fair to good porosity (Arco, 1978).

Dinoflagellate cyst assemblage

Paralecaniella indentata is present to frequent in the lower and upper parts of the sequence. *Glaphyrocysta* spp. dominantes at three levels; in the lowermost, middle and upper parts and *Apectodinium homomorphum* dominates in a narrow interval in the lowermost part of the sequence. *Spiniferites* aff. *pseudofurcatus* dominates in a narrow level at the top of the sequence; this species is interpreted as a opportunistic species. *Spiniferites* spp. and *Cordosphaeridium* spp. are present in most samples, however they are absent in the sample from the middle of the sequence where *P. indentata* is frequent (Fig. 7). *Spiniferites* spp. has a peak occurrence at 1806 m (SWC). The species diversity is intermediate (2–15).

Micropalaeontological assemblages

The microflora / fauna in S5250 is very similar to that in S5000. The assemblage is completely dominated by coal fragments and the sequence is almost barren of microfauna and –flora (Fig. 8).

Depositional environment

The palynological assemblages from this interval are all taken from SWC samples. The assemblages suggest inner neritic conditions for the lower part, shifting to outer neritic conditions in the middle part. An abrupt change to brackish conditions occurs upwards, this is followed by inner neritic conditions, whereas the uppermost part of the sequence is suggested to represent brackish to inner neritic conditions (Fig. 7).

The microfossil assemblage indicates a littoral / lagoonal environment with an estimated palaeodepth of less than 50 m throughout the sequence, due to an almost total dominance of coal fragments (Fig. 8).

Systems tracts

This sequence is interpreted as comprising an almost complete sequence with a TST composed of a back-stepping wedge below the mfs and a HST above the mfs containing a fore-stepping wedge (Fig. 2). However, S5250 may also be interpreted as a continuation of the HST prevailing from S5000, comprising a 4th or 5th order ciclicity.

Sequence 5500

Presence

Hellefisk-1, 1732–1637 m (95m), mfs 1649 m

Palynozone

Upper E2b, mfs E2b. There are no stratigraphically significant dinoflagellate cyst species (Nøhr-Hansen, this volume).

Microzone

A microfossil zonation has not been established for this sequence.

Age

Middle Ypresian (Early Eocene).

Hellefisk-1

Boundaries

On the log panel readings the sequence boundary is picked at a marked shift on the gamma log from a spike with high gamma readings towards rather low readings. There are no significant changes on the sonic log and the FDC and CNL logs have not been recorded from 1771 m towards the top. The sequence is only recognised in Hellefisk-1 and is confirmed by the seismic interpretation (Chalmers et al., this volume). There are no palynological or microfossil indicators for the mfs, it is picked from the highest readings on the gamma log and may represent a higher order of depositional cycles.

Log motif

The log motif is very similar to that of the preceding sequence with back-stepping and fore-stepping fining-upwards and coarsening-upwards parasequences although here the gamma and sonic logs are more asymmetrical than in S5250 (Fig. 2).

Lithology

The lithology in S5500 is predominantly medium grey green, fine to medium-grained, argillaceous, glauconitic sandstone, becoming more argillaceous towards the base. The interbedded claystone is dark brown to dark grey, very sandy, silty and soft (Arco, 1978).

Dinoflagellate cyst assemblage

From this sequence only two samples from the lower part have been studied, apart from frequent *Glaphyrocysta* spp. only a few specimens of *Cordosphaeridium* spp., *Spiniferites* spp. and *Paralecaniella indentata* are recorded (Fig. 7). The species diversity is low (6).

Micropalaeontological assemblages

A very impoverished assemblage comprising only coal fragments and very rare buliminids (Fig. 8).

Depositional environment

The palynological assemblages from this interval indicate inner neritic conditions for the lower part of the sequence (Fig. 7). Micropalaeontological studies indicate a littoral / lagoonal environment, with a continued estimated palaeodepth of less than 50 m, indicated by assemblages dominated by fragments. The depositional process is interpreted to be of prograding shore face deposits and submarine channels transporting coal fragments and brackish foraminifera offshore (Fig. 8).

Systems tracts

S5000 is interpreted to be of higher order cyclicity, 4th or 5th order cycles.

Sequence 5750

Presence

Hellefisk-1, 1637–1563 m (74m), mfs 1592 m

Palynozone

Upper E2b – lower E2c, mfs E2b. *Dracodinium condylos* is stratigraphic significant (Nøhr-Hansen, this volume).

Microzone

A microfossil zonation has not been established for this sequence.

Age

Middle Ypresian (Early Eocene)

Hellefisk-1

<u>Boundaries</u>

SB5750 is defined from seismic interpretation by an onlap surface (Chalmers et al., this volume). The wire line logging and the lithological interpretation do not clearly support a sequence boundary at this interval. The boundary is placed within the range of uncertainty given by the seismic resolution combined with the most basin-ward shift on the gamma log. The mfs is picked at an interval of high gamma readings (Fig. 2).

<u>Log motif</u>

The log motif is very much like the one from the preceding sequence with back-stepping fining-upwards and blocky parasequences below the mfs and a fore-stepping log pattern above.

<u>Lithology</u>

The lithology is equivalent to that described in S5500 becoming slightly better sorted towards the top with a fair to good porosity (Arco, 1978).

<u>Dinoflagellate cyst assemblage</u>

Glaphyrocysta spp. is frequent at the base of the sequence. A few *Spiniferites* spp. and *Cordosphaeridium* spp. are recorded around the mfs level and *Paralecaniella indentata* is present just above the mfs (Fig. 7). The species diversity is low (5–10).

<u>Micropalaeontological assemblages</u>

From 1640 m (the bottom of the sequence) to 1591 m, coal fragments are the sole component of the assemblage. A peak in coal fragment abundance occurs at 1579 m, just before the top of the sequence. The assemblage is very impoverished (Fig. 8).

Depositional environment

The palynological assemblages from this interval indicate inner neritic conditions (Fig. 7), while a littoral / lagoonal environment with a palaeodepth of less than 50 m is suggested by a continued lack of microfauna / flora and complete dominance by coal fragments (Fig. 8).

Systems tracts

S5750 is interpreted to be of higher order cyclicity, 4th or 5th order cycles, comprising retrogradational parasequences and a progradational and aggradational parasequences.

Sequence 6000

Presence

Hellefisk-1, 1563–1357 m (206 m), mfs 1393 m

Ikermiut-1 1596–1536 m (60 m)

Kangâmiut-1, 3022–2930 m (92 m), mfs 2966 m

Nukik-1, 2031–1973 m (58 m), mfs 1988 m

Nukik-2, 2091–2015 m (76 m), mfs 2054 m

Palynozone

Upper E2b–E3a, mfs E2b and E2c. Stratigraphically significant dinoflagellate cyst species are *Areoligera medusettiformis, Muratodinium fimbriatum* and *Wetzeliella lunaris* (Nøhr-Hansen, this volume).

Microzone

Cenodiscus-Cenosphaera microfossil Zone (observed only in Ikermiut-1), and the *P. wilcoxensis* foraminifera Zone (Kangâmiut-1).

Age

Middle to late Ypresian (Early Eocene).

Hellefisk-1

Boundaries

SB6000 is well defined by a marked shift on both the gamma and sonic logs; the only available logs from this sequence. The gamma log displays a basin-ward shift in facies and the sonic log shows a dramatic decrease in interval transit time (Fig. 2). The boundary is also defined by a basin wide seismic onlap surface. S6000 is upwardly terminated by the mid-Eocene unconformity. The mfs is picked on the basis of palynological and microfossil data.

Log motif

In Hellefisk-1 the log motif for S6000 is the onset of an interval with asymmetrical gamma and sonic log patterns. The sonic log displays an interval with rather low interval transit times in the lower half of the sequence (Fig. 2) and is interpreted as an interval with calcite or dolomite cementation. The gamma log indicates coarsening-upwards and fining-upwards parasequences with an overall fining-upwards trend from the base to the mfs. The log interpretation of this interval in Hellefisk-1 is hampered by the lack of other wire line logs apart from the gamma ray and sonic logs.

Lithology

S6000 predominantly comprises a white to light tan coloured fine to medium-grained at the base grading into coarse-grained towards the top, subangular to subrounded, fair to well sorted glauconite sandstone. At the base abundant heavy minerals and dolomite cement are present and a fair to good porosity exits throughout the sequence (Arco, 1978).

Dinoflagellate cyst assemblage

Paralecaniella indentata is recorded only in low numbers from S6000 in Hellefisk-1 and Nukik-2. *Glaphyrocysta* spp. is abundant in the lower part of the sequence (Fig. 7). As in Nukik-2, *Wetzeliella* spp. are common in the middle part of the sequence where they occur together with few specimens of *Homotryblium* spp. *Alterbidinium* cf. *bicellulum* dominates the upper part of the sequence together with frequent *Deflandrea* spp. The amount of terrestrial plant material and saccate pollen is high in the middle part of the sequence. The species diversity is low in the lower part (1–8), and moderate to high in the upper part (6–19).

Micropalaeontological assemblages

From the bottom of the sequence at 1560 m to 1362 m the assemblage comprises very low numbers of coal fragments and diatoms (Fig. 8).

Depositional environment

The palynological assemblage from the present sequence suggests inner neritic conditions changing to brackish conditions in the uppermost part (Fig. 7), whereas the microfossil assemblage for the majority of this sequence indicates deposition during continued lagoonal / littoral conditions as suggested by the lack of marine species. Assemblage dominated by coal fragments suggests a continued palaeodepth of less than 50 m for S6000 (Fig. 8).

Ikermiut-1

Boundaries

SB6000 is picked at a combined decrease in interval transit time and decrease in gamma readings. The FDC and CNL logs together with the resistivety logs also mark the boundary. From seismic interpretation the boundary is interpreted as a basin wide onlap surface (Chalmers et al., this volume) although the e-log interpretation may indicate 4th or 5th order sequences. The upper boundary is the mid-Eocene unconformity.

Log motif

The log motif in Ikermiut-1 is characterised by somewhat asymmetrical gamma and sonic logs with high interval transit times and a maximum in the upper shale dominated part, also showing the highest gamma readings. The CNL and FDC logs show a symmetrical log pattern although they are separated in the lower sand dominated interval and display a slight cross over at the lithological shift towards shale. The gamma log displays a flat based blocky unit in the lower half of the sequence and a prograding unit in the upper half.

Lithology

The interval comprises a claystone / shale unit of a light grey to grey-brown, soft to firm, slightly calcareous and micaceous claystone interbedded with medium to dark grey, subfissile silty shale. Thin beds and stringers of siltstone and very fine to fine-grained arkosic sandstones are present with abundant dark-green and black heavy minerals. A few thin limestones are present (Chevron, 1977).

Dinoflagellate cyst assemblage

Glaphyrocysta spp. are only frequent in the lower part of the sequence, whereas few *Cordosphaeridium* spp. and *Spiniferites* spp. are the main environmental indicators in the upper part (Fig. 9). The species diversity is moderately high (3–15).

Microfossil assemblage

Abundant tabular agglutinated foraminifera of Morphogroup A and radiolaria, especially *Cenodiscus* spp. and *Cenosphaera* spp., dominate the sequence (Fig. 10).

Depositional environment

The palynological assemblages from this sequence suggest inner neritic conditions for the lower part, whereas outer neritic conditions are suggested for the upper part. The microfossil assemblage indicates slightly deeper conditions, probably an upper bathyal palaeoenvironment.

Kangâmiut-1

Boundaries

The sequence boundary is defined by the most pronounced basin-ward shift on the wire line logs (Fig. 2) and the mfs is picked by a combination of biostratigraphic data and wire line data. Using only wire line logs there is no distinctive evidence for a sequence boundary at this level however, SB6000 is defined by a seismic onlap surface and the boundary is placed within the uncertainty of seismic resolution.

Log motif

S6000 in Kangâmiut-1 is characterised by very high interval transit times due to an overpressured zone that cover the interval S5000 to S8500. The gamma log display retrogradation, below the mfs and aggradational and progradational parasequences above the mfs.

Lithology

The sequence is predominantly a grey to brown-grey, in places slightly silty, slightly to moderately calcareous, carbonaceous, micaceous, and occasionally dolomitic and calcitic shale. Stringers of a light brown argillaceous limestone are occasionally present (Henderson, 1979).

Dinoflagellate cyst assemblage

Charlesdowniea coleothrypta and *Cordosphaeridium* spp. are frequent to common, occuring together with a single specimen of *Impagidinium* spp. in the lower part of the sequence (Fig. 3). Common *Deflandrea phosphoritica* from the same level (DCS 2991 m) are conflicting but may be explained by turbidite redeposition. The outer neritic indicators disappear above the mfs and *Areoligera* spp. become common. The species diversity is high in the lower part (16–23) and low in the upper part (6) of the sequence.

Microfossil assemblages

The sequence contains a rich agglutinated foraminiferal fauna with common agglutinated foraminifera of Morphogroup A and *Cyclammina* spp. *Nutallides truempyi* occurs in the upper part with planktic foraminifera (*Subbotina* spp.) and chorate dinoflagellate cysts. The diversity and abundance is high throughout the sequence (Fig. 4).

Depositional environment

The palynological assemblages from this sequence indicate outer neritic conditions for the lower part, with possible turbiditic redeposition of inner neritic indicators. Above the mfs a change to inner neritic conditions is suggested (Fig. 3).

The microfossils indicate an upper bathyal setting with an estimated palaeodepth of 200–500 m (Fig. 4).

Nukik-1

Boundaries

Again the boundary is defined from seismic interpretation and is placed within limits of uncertainty due to seismic resolution by the most pronounced basin-ward shift on the wire line logs

(Fig. 2), but as seen in Kangâmiut-1 there is no clear evidence of a sequence boundary at this level. The mfs is picked using a combination of biostratigraphic and wire line data.

Log motif

The log motifs in Nukik-1 display similar parasequences to those described earlier although the position of the mfs is recognised from the complete log suite, with an increase in both the gamma and sonic values, an increase in the CNL and a decrease in the FDC combined with a fall on the resistivity curves (Fig. 2).

Lithology

The sequence comprises unconsolidated sand interbedded with minor clay / silt. The sand is clear, white, fine to medium grained, subangular to subrounded, poorly to fairly sorted with a clay matrix. The clay is light grey to white, silty, kaolinitic and soft with occasional scattered quartz grains. Thin dark grey to grey green, silty shale streaks are present. Very fine disseminated pyrite and scattered dark minerals are present (Mobil, 1978a).

Dinoflagellate cyst assemblage

A few *Homotryblium* spp. are present below and above the mfs level. *Glaphyrocysta* spp. and *Spiniferites* spp. are present throughout the sequence. *Thalassiphora pelagica* are frequent just above the mfs level (Fig. 11). The species diversity is moderately high (4–13).

Microfossil assemblages

This sequence within Nukik-1 contains only very sparse microfossils (Fig. 12). Rare coal fragments occur with rare specimens of agglutinated foraminifera of Morphogroup A (*Bathysiphon* spp.) and diatoms (*Aulacodiscus* spp. and *Fenestrella antiqua*) in the lower part of the sequence. The upper part is characterised by common *Bathysiphon* spp. and rare *Cyclammina amplectens.*

Depositional environment

The palynological assemblages from this sequence suggest inner neritic conditions for the lower part, shifting to outer neritic conditions just above the mfs. A return to inner neritic conditions is suggested for the uppermost part of the sequence (Fig. 11).

The few marine microfossils and coal fragments indicate a neritic palaeoenvironment, probably inner neritic in the lower part of the sequence, and outer neritic in the upper part, which contains more common *Bathysiphon* spp. The estimated palaeodepth is probably less than 100 m in the lower part and between 100 m and 200 m or slightly deeper in the upper part (Fig. 12).

Nukik-2

Boundaries

On the e-logs the boundary is defined at the base of a fining-upwards unit with a basin-ward shift in facies and a cross over on the CNL and FDC logs. This position is selected taking seismic resolution into consideration, which shows a basin-wide onlap surface for this sequence boundary (Fig. 2). The mfs is picked by a combination of biostratigraphic and wire line data.

Log motif

Below the mfs the log motifs in Nukik-2 are display a fining-upwards and a coarsening-upwards pattern combined with an over all retrogradational motif. The interval from the mfs to the top of the sequence comprises an upward coarsening unit with a fine-grained unit at the top (Fig. 2).

Lithology

Nukik-2 is characterised by unconsolidated sand interbedded with minor clay / silt. The sand is clear, white, fine to medium grained, subangular to subrounded, poorly to fairly sorted with a clay matrix. The clay is light grey to white, silty, kaolinitic and soft with occasional scattered quartz grains. Thin dark grey to grey green, silty shale streaks are present. Very fine disseminated pyrite and scattered dark minerals are present (Mobil, 1978b)

Dinoflagellate cyst assemblage

Wetzeliella spp. are common in the middle and upper parts of the sequence where they occur together with few specimens of *Homotryblium* spp., *Paralecaniella indentata* is only recorded in low numbers from one sample also from the middle part of the sequence. Few specimens of *Cordosphaeridium* spp., *Impagidinium* spp., *Spiniferites* spp. and *Thalassiphora pelagica* are recorded from the upper part (Fig. 5). The species diversity, as in S6000 in Hellefisk -1, is low in the lower part (0–3), and moderately high in the upper part (4–22).

Microfossil assemblages

The sequence contains common coal fragments and a single chorate dinocyst at 2063 m. Marine microfaunas were not observed (Fig. 6).

Depositional environment

The palynological assemblages from this sequence suggest inner neritic to brackish conditions for the channel dominated lower part. The conditions change just below the mfs level where the diversity increases suggesting outer neritic environment. A shift to low diversity brackish conditions occurs just above the mfs level, whereas the moderately high diversity assemblages from the upper part suggest inner to outer neritic conditions (Fig. 5).

A lack of marine microfaunas together with common coal fragments indicates a shallow littoral or lagoonal palaeoenvirnment with a palaeodepth of less than 10 m (Fig. 6).

Systems tracts

S6000 in Hellefisk-1, Kangâmiut-1, Nukik-1, and Nukik-2 is interpreted as exposing a complete cycle of LST, TST and HST. The LST and TST are contained in the retrogradational parasequences located from the base to the mfs. In the basin marginal boreholes; Hellefisk-1, Nukik-1 and Nukik–2, the sandstone is interpreted as representing deposition from channels and prograding shore face deposits (Fig. 2). LST and TST in Kangâmiut-1 are interpreted as representing turbidite deposits (Fig. 2). The HST is contained within the aggradational and progradational parasequences situated above the mfs. The parasequences are interpreted as representing the same sedimentation processes as in the LST and HST although some deepening is seen from the biostratigraphy above the mfs in Nukik-2. In Kangâmiut-1 a shallowing is recognised from the mfs upwards.

In Ikermiut-1 S6000 is interpreted as representing a LST were the sandstones are stacked submarine channels and turbidite sands.

Sequence 8000

Presence

Kangâmiut-1, 2930–2887 m (43 m).

Palynozone

E3a. There are no stratigraphically significant dinoflagellate cyst species.

Microzone

P. wilcoxensis foraminifera Zone (Rasmussen & Sheldon, this volume).

Age

Late Ypresian (Early Eocene).

Kangâmiut-1

<u>Boundaries</u>

SB8000 is defined from seismic interpretation by an onlap surface (Chalmers et al., this volume). Although there is a marked drop in the gamma readings where the sequence boundary is placed, the drop is taken to be an artefact and not indicative of a sequence boundary as the fall in readings coincides with a casing point. This contradicts the fact that the logging was supposedly undertaken in the open hole.

Log motif

The sequence displays an almost symmetrical log motif between gamma – sonic, CNL – FDC, and the resistivity logs. The gamma log indicates small, less than 5 meters thick, fining-upwards trends, indicative of turbidites or storm sand layers, combined with an aggradational to slightly retrogradational log motif.

Lithology

S8000 predominantly comprises shale and is described from a SWC sample at 2922 m as a "brown silty and micaceous shale with fine laminated sections of nodosriids and *Bathysiphon*, some glauconitic grains and patches" (Manderscheid & Quin, 1977).

Dinoflagellate cyst assemblage

Only one sample has been examined from this sequence, containing a low diversity (4) assemblage with single specimens of both *Spiniferites* spp. and *Hystrichokolpoma* spp (Fig. 3).

Microfossil assemblages

The single sample studied from this interval at 2901 m contains super-abundant agglutinated foraminifera of Morphogroup A (*Rhabdammina discreta*) together with common *Cyclammina* and *Recurvoides* spp. of Morphogroup B3. Calcareous benthic and planktic foraminifera, diatoms and chorate dinoflagellate cysts are rare. The abundance and diversity are high. One nannofossil sample was analysed from this interval (2922 m), and contained high numbers of *Toweius occulatus*, *Coccolithus pelagicus* and *Transversopontis pulcher* (Fig. 4).

Depositional environment

The low diversity palynological assemblages from this sequence suggest outer neritic conditions (Fig. 3).

The microfossil assemblage reflects deeper conditions, with an upper bathyal palaeoenvironment with an estimated palaeodepth of 200–500 m (Fig. 4). The presence of the common nannofossils *T. pulcher, C. pelagicus* and *Toweius* spp. suggests a neritic palaeoenvironment with the possibility of a warm water incursion (Firth, 1989; Gradstein & Srivastava, 1980)

Systems tracts

This sequence is interpreted as a TST, with the back-stepping fining-upwards log motif.

Sequence 8500

Presence

Kangâmiut-1 2887–2751 m (136 m), mfs 2788 m.

Nukik-1 1973–1923 m (50 m).

Nukik-2 2015–1835 m (180 m), mfs 1843 m.

Palynozone

Upper E3a–E3c / ?d, mfs E3b. Strartigraphic significant dinoflagellate cyst species are *Charles-downiea columna, Diphyes brevispinum* and *Eatonicysta* cf. *Furiensis* (Nøhr-Hansen, this volume).

Microzone

P. wilcoxensis foraminifer Zone (Rasmussen & Sheldon, this volume).

Age

Late Ypresian (Early Eocene).

Kangâmiut-1

Boundaries

SB8500 in Kangâmiut-1 is confirmed from the seismic interpretation (Chalmers et al., this volume) and is placed within limits of uncertainty due to seismic resolution at a decrease in both the gamma ray readings and the interval transit time combined with a pronounced peak on the FDC log.

Log motif

In Kangâmiut-1 the gamma log displays an aggrading and slightly retrogradational motif from the sequence boundary towards the mfs. From the mfs towards SB9000 the gamma log displays a prograding log motif. From the base towards the mfs the log pattern indicates minor parasequences of flat-based fining-upwards units. The CNL and FDC logs display a very symmetrical log motif except at the very top of the sequence from 2780 m towards SB9000.

Lithology

The lithology is predominantly a brown silty and micaceous shale with fine laminated sections (Manderscheid & Quin, 1977), minor sandstone layers and a recrystallised micritic limestone at 2777 m.

Dinoflagellate cyst assemblage

The lower part of the sequence is represented by frequent *Homotryblium* spp. and frequent *Wetzeliella* spp., however the more basin-ward indicators *Spiniferites* spp. and *Thalassiphora* *pelagica* are also frequent together with the presence of a few *Hystrichokolpoma* spp. and *Impagidinium* spp (Fig. 3). The middle part of the sequence, represented by a SWC at 2802 m, contains common *Eatonicysta* cf. *furiensis*, common *Wetzeliella* spp. and frequent *Spiniferites* spp. together with single specimens of *Impagidinium* spp. and *Paralecaniella indentata*. In the upper part *Alterbidinium* cf. *bicellulum* and *Deflandrea phosphoritica* are frequent and *Wetzeliella* spp. common. However a few *Hystrichokolpoma* spp., *Impagidinium* spp. and *Spiniferites* spp. are also recorded from the upper part of the sequence. Of all the boreholes, Kangâmiut-1 contains the highest dinoflagellate diversity for this sequence (up to 33).

Microfossil assemblages

The microfossil abundance and diversity are high, with assemblages dominated by agglutinated foraminifera of Morphogroup A (*Rhabdammina discreta*), *Cyclammina* spp. and *Haplophragmoides* spp. Planktic foraminifera are common in the lower part, where the bathyal indicators *Cibicidoides praemundulus* and *Bulimina trinitatensis* (van Morkhoven, Berggren & Edwards, 1986) are also present (Fig. 4). Agglutinated foraminifera of Morphogroup A are dominant in the upper part of the sequence.

Two nannofossil samples were examined from this sequence, one at 2844 m containing dominant *C. pelagicus* and *T. pulcher* as in the previous sequence, and one at 2776.5 m with a fairly high diversity but low abundance assemblage containing *Chiasmolithus* spp., *Neococcolithes* spp., *Reticulofenestra* spp., *Toweius* spp. and *Transversopontis* spp.

Depositional environment

The palynological assemblages from the lower part of the sequence are a mixture of inner neritic and more basin-ward indicators. Together with the micropalaeontological data, the palynological signals may indicate an outer neritic/upper bathyal environment with turbidites. The upper part of the sequence may represent relatively more shallow water and an inner to outer neritic environment (Fig. 3).

The microfauna indicate a bathyal palaeoenvironment, probably upper or middle bathyal with a palaeodepth of between 200–1000 m. The nannofossils from the sample at 2844 m suggest a neritic palaeoenvironment as in S8000, while those from 2776.5 m suggest a slightly shallower palaeoenvironment (Fig. 4).

Nukik-1

Boundaries

In Nukik-1 the sequence boundary is placed taking seismic interpretation and the seismic resolution into account. A good candidate for a sequence boundary cannot be recognised using wire line logs.

Log motif

The gamma log in Nukik-1 displays a retrogradational motif from SB8500 towards the mid-Eocene unconformity while the sonic log pattern is very serrate. The FDC log displays very constant values with the preceding sequence whereas the CNL log shows a slight increase.

Lithology

The lithology of Nukik-1 comprises interbedded sandstone and siltstone. The sandstone is dark grey to yellow brown, fine to medium grained, subangular to subrounded, abundant biotite, amphibole, glauconite and pyrite and a good porosity. The siltstone is dark brown, micaceous, laminated, firm and has a poor porosity (Mobil, 1978a).

Dinoflagellate cyst assemblage

Homotryblium spp. and fungal species dominate the base of the sequence together with frequent *Deflandrea* spp. In the upper part of the sequence *Wetzeliella* spp. is common together with frequent *Spiniferites* spp. and *Thalassiphora pelagica* (Fig. 11). The species diversity is relatively high (6–22).

Microfossil assemblages

Agglutinated foraminifera of Morphogroup A (especially *Bathysiphon* spp.) dominate the sequence, but *Cyclammina* spp. and *Haplophragmoides-Cribrostomoides* are also relatively common. The foraminiferal diversity and abundance are low, and diatoms and coal fragments are rare throughout the sequence (Fig. 12).

Depositional environment

The palynological assemblages from this sequence indicate littoral or possibly lagoonal conditions in the lower part. A change towards inner to outer neritic conditions is suggested for the upper part of the sequence (Fig. 11).

The microfossil assemblages indicate an outer neritic palaeoenvironment and an estimated palaeodepth of 100–200 m is suggested for sequence (Fig. 12).

Nukik-2

Boundaries

Taking seismic interpretation and seismic resolution into account, the sequence boundary in Nukik-2 is placed at a basin-ward shift on the gamma log, as in Nukik-1. The upper boundary is the mid-Eocene unconformity.

Log motif

Nukik-2 is characterised by almost symmetrical gamma and sonic log motifs although they are very blocky and rather high gamma spikes divide each unit. Overall the gamma log displays a retrogradational log motif and the blocky parasequences contain minor upward coarsening and upward fining units. Again the CNL and FDC logs are very symmetrical although a tendency to a cross over pattern is seen simultaneously with the high gamma readings.

Lithology

The lithology is predominantly a light grey to yellow brown, loose, fine to medium occasionally coarse-grained, moderately sorted, partly argillaceous, subangular to subrounded sandstone with abundant biotite. Glauconite increases upwards. Interbeds of light grey to light brown, slightly calcareous in part, micaceous, silty, partly sandy and medium hard claystone are present (Mobil, 1978b).

Dinoflagellate cyst assemblage

In the lower part of the sequence *Deflandrea phosphoritica, Homotryblium* spp. and *Wetzeliella* spp. are frequent, whereas *Cordosphaeridium* spp. *Spiniferites* spp. and *Thalassiphora pelagica* are rare. In the upper part of the sequence *Spiniferites* spp. is frequent. *Cordosphaeridium* spp., *Hystrichokolpoma* spp. and *Impagidinium* spp. are present throughout the sequence (Fig. 5). The species diversity is relatively high for the most of the sequence (5–25).

Microfossil assemblages

The diversity and abundance are extremely low, and the only microfossils that were observed were very rare sponge spicules, gastropod fragments, unidentifiable foraminifera and probable calcispheres (Fig. 6).

Depositional environment

The palynological assemblages from this sequence suggest inner to outer neritic conditions for the lower part of the sequence. This changes in the upper part of the sequence where the inner neritic indicator species almost disappear and a slight increase in outer neritic species indicates more offshore conditions (Fig. 5).

Due to the very low microfossil content it is difficult to interpret the palaeoenvironment, but a littoral or neritic setting is probable (Fig. 6).

Systems tracts

In Nukik-1 the back-stepping and fining-upwards log motif of S8500 is interpreted as a TST. This interpretation is supported by the biostratigraphically data. S8500 in Nukik-2 and Kangâmiut-1 comprises retrogradational log motifs from the sequence boundary to the mfs and is interpreted as a TST followed by a small part of a HST.

Sequence 9000

Presence

Kangâmiut-1 2751–2693 m (58 m), mfs 2720 m

Palynozone

E3c–E4c, mfs E3c or E3d?. *Eatonicysta ursulae* is stratigraphically significant (Nøhr-Hansen, this volume).

Microzone

A microfossil zonation has not been established for this sequence.

Age

Late Ypresian (Early Eocene) to early Lutetian (middle Early Eocene).

Boundaries

As there is no direct evidence from the wire line logs, SB9000 is defined using seismic data (Chalmers et al., this volume).

Log motif

The wire line logs; gamma – sonic and CNL – FDC, mutually display very symmetrical log motifs. The gamma log displays a retrogradational log pattern from the sequence boundary towards the mfs and a progradational pattern from the mfs towards the next sequence boundary (Fig. 2).

Lithology

The interval predominantly comprises shale and the side wall cores have been described as a "brown silty and micaceous shale with fine laminated sections of nodosariids and *Bathysiphon* with carbonate nodules (siderite) and abundant Lituolids" (Manderscheid & Quin, 1977).

Dinoflagellate cyst assemblage

In the lower part of the sequence *Wetzeliella* spp. are common, *Spiniferites* spp. frequent and *Charlesdowniea coleothrypta* present. Just below the mfs in the middle part *Homotryblium* spp. is abundant. In the upper part *Deflandrea phosphoritica* are common and *Spiniferites* spp. frequent (Fig. 3). The species diversity is high (10-21).

Microfossil assemblages

Only one sample was studied from this sequence (2718 m). It is dominated by agglutinated foraminifera of Morphogroup A (*Rhabdammina discreta*), *Cyclammina* spp. and *Haplophragmoides* spp. *Cibicidoides praemundulus* is rare together with agglutinated foraminifera of Morphogroup B2 (*Ammodiscus latus*), *Nodosaria latejugata*, and unidentifiable diatoms and fish teeth. The diversity and abundance are moderate.

The single nannofossil sample at 2725 m contains a fairly high abundace and diversity assemblage with commen *T. occulatus*, *C. pelagicus*, *Chiasmolithus eograndis* and *C. medius*, and rare *Cruciplacolithus* spp. and *Reticulofenestra* spp (Fig. 4).

Depositional environment

The palynological assemblages from the lower part of the sequence suggest inner to outer neritic conditions. A change to littoral or maybe lagoonal conditions occurs just below the mfs, however, the abundant brackish water indicators could also have been re-deposited by turbidites. In the upper part a return to an inner neritic environment is suggested.

The microfauna indicate deeper conditions, more precisely an upper bathyal palaeoenvironment and a palaeodepth of probably 200 m–500 m. It is difficult to suggest a palaeoenvironment with the mixed nannofossil assemblage from this single sample (Fig. 4).

Systems tracts

The interval from the sequence boundary towards the mfs is interpreted to represent a TST with the back-stepping upward thinning log pattern, comprising minor higher order parasequences. The interval from the mfs to SB9500 represents HST deposits with a fore-stepping and upward thickening log pattern.

Sequence 9500

Presence

Kangâmiut-1 2693–2625 m (68 m), mfs 2628 m

Palynozone

E4c, mfs E6c. Stratigraphically significant dinoflagellate cyst species are *Cerebrocysta magna*, *Diphyes ficusoides* and *Hystrichosphaeropsis costae* (Nøhr-Hansen, this volume).

Microzone

A microfossil zonation has not been established for this sequence.

Age

Late Ypresian (Early Eocene) to Lutetian (Middle Eocene).

Boundaries

S9500 is defined using seismic interpretation and the sequence boundary is placed at the base of a thin interval containing limestone stringers.

Log motif

The gamma and sonic logs are very constant and almost symmetrical except for an interval containing limestone stringers were the interval transit time decreases abruptly. The gamma log displays an aggradational log pattern from the sequence boundary towards the mfs. The porosity and density logs and resistivety logs are also very constant and symmetrical (Fig. 2).

Lithology

Again the lithology is predominantly "brown silty and micaceous shale with fine laminated sections containing nodosariids and *Bathysiphon*" (Manderscheid & Quin, 1977). Stringers of recrystallised micritic limestone with some organic debris are present near the base of the sequence.

Dinoflagellate cyst assemblage

In the lower part of the sequence a few *Wetzeliella* spp. and *Glaphyrocysta* spp. are recorded. In the middle part *Cordosphaeridium* spp. *Spiniferites* spp. and *Thalassiphora pelagica* are present to frequent (Fig. 3). Palynological samples from the uppermost part have not been examined. The species diversity is low (3) at the base and increases upwards (11-25).

Microfossil assemblages

Abundant agglutinated foraminifera of Morphogroup A (*Rhabdammina discreta, Bathysiphon* spp.) and *Cyclammina* spp. occur together with common *Haplophragmoides* spp., *Kareriella conversa* (agglutinated foraminifera of Morphogroup C1) and diatoms in the lower part of the sequence. The same taxa dominate the upper part of the sequence, but in lower abundances. The overall diversity and abundance are moderate (Fig. 4).

The single nannofossil sample analysed at 2656.5 m is dominated by *Cibrocentrum* spp. with common *T. pulcher, C. pelagicus, Chiasmolithus medius* and *Reticulofenestra dictyoda*.

Depositional environment

The palynological assemblages from the lower part of the sequence suggest inner neritic conditions and outer neritic conditions for the middle part (Fig. 3). The microfauna indicate an upper bathyal environment and an estimated palaeodepth of 200–500 m. A more neritic palaeoenvironment than in S9000 is suggested by nannofossils, as indicated by an increase in *T. pulcher* and *C. pelagicus* (Fig. 4).

Systems tracts

The aggradational and slightly back-stepping log motif is interpreted to represent LST and TST deposists followed by very avery thin HST.

Sequence 10000

Presence

Kangâmiut-1 2625–2565 m (60 m)

Palynozone

E6c. *Cerebrocysta magna* is a stratigraphically significant dinoflagellate cyst (Nøhr-Hansen, this volume).

Microzone

A microfossil zonation has not been established for this sequence.

Age

Lutetian (Middle Eocene)

Boundaries

SB10000 is placed were the wire line logs display marked shifts in the readings (Fig. 2). The simultaneous decrease in gamma and sonic log readings combined with a cross over in the CNL and FDC log readings picks the boundary clearly. The resistivity logs have some very high readings at and across the boundary.

Log motifs

The gamma and sonic logs display asymmetrical log motifs; the gamma log overall displaying a blocky fining-upwards log pattern.

Lithology

S10000 marks a basin-ward shift in facies with the incoming of massive sandstone. The sandstone is described as fine-grained, shaly and feldspathic sandstone; with very abundant and very altered ferruginised debris and minerals; mostly micas. Fresh garnets and chlorite nodules and some limy rock fragments and thin layers of black organic matter are present. At the base of the interval the sandstone is described as sandy limestone with a coarse recrystallised sparite cement (Manderscheid & Quin, 1977).

Dinoflagellate cyst assemblage

Only two low diversity samples with no characteristic species assemblages have been studied from the middle part of this sequence. A few specimens of *Spiniferites* spp. are the only palaeoenvironmental indicators (Fig. 3). The species diversity is low (2–3)

Microfossil assemblages

Microfossil diversity and abundance are very low. Agglutinated foraminifera of Morphogroup A (*Rhabdammina discreta*) occur together with *Cibicidoides* spp., *Uvigerina* spp., gastropod fragments and echinoderm fragments. Nannofossil samples analysed from this sequence were barren (Fig. 4).

Depositional environment

The palynological assemblages from the middle part of the sequence might suggest outer neritic conditions (Fig. 3). The microfauna indicate an outer (lower part) to inner neritic palaeoenvironment and an estimated palaeodepth of less than 200 m (Fig. 4).

Systems tracts

S10000 is interpreted to represent part of a TST due to the slightly retrogradational log motif.

Conclusion

Lithostratigraphic and biostratigraphic correlations of the 5 boreholes offshore West Greenland have been achieved.

Sixteen sequences have been described using log pattern, lithology, microfossils and palynomorphs. The sixteen sequences have been dated using palynological and microfossil zonations and a depositional environment have been suggested for each sequence.

The sediments are predominantly sandstones in the basin-marginal boreholes (Hellefisk-1, Nukik-1 and Nukik-2) and shales in the basin-central boreholes (Ikermiut-1 and Kangâmiut-1).

The depositional environment is primarily inner to outer neritic for all five boreholes although both littoral / lagoonal and bathyal environments are recorded in some parts of the studied successions.

A sequence stratigraphic framework based on the integration of petrophysical logs, biostratigraphic data and regional seismic interpretation has been established for the Palaeogene succession offshore West Greenland.

Dating and duration of the regional correlated unconformities have been accomplished.

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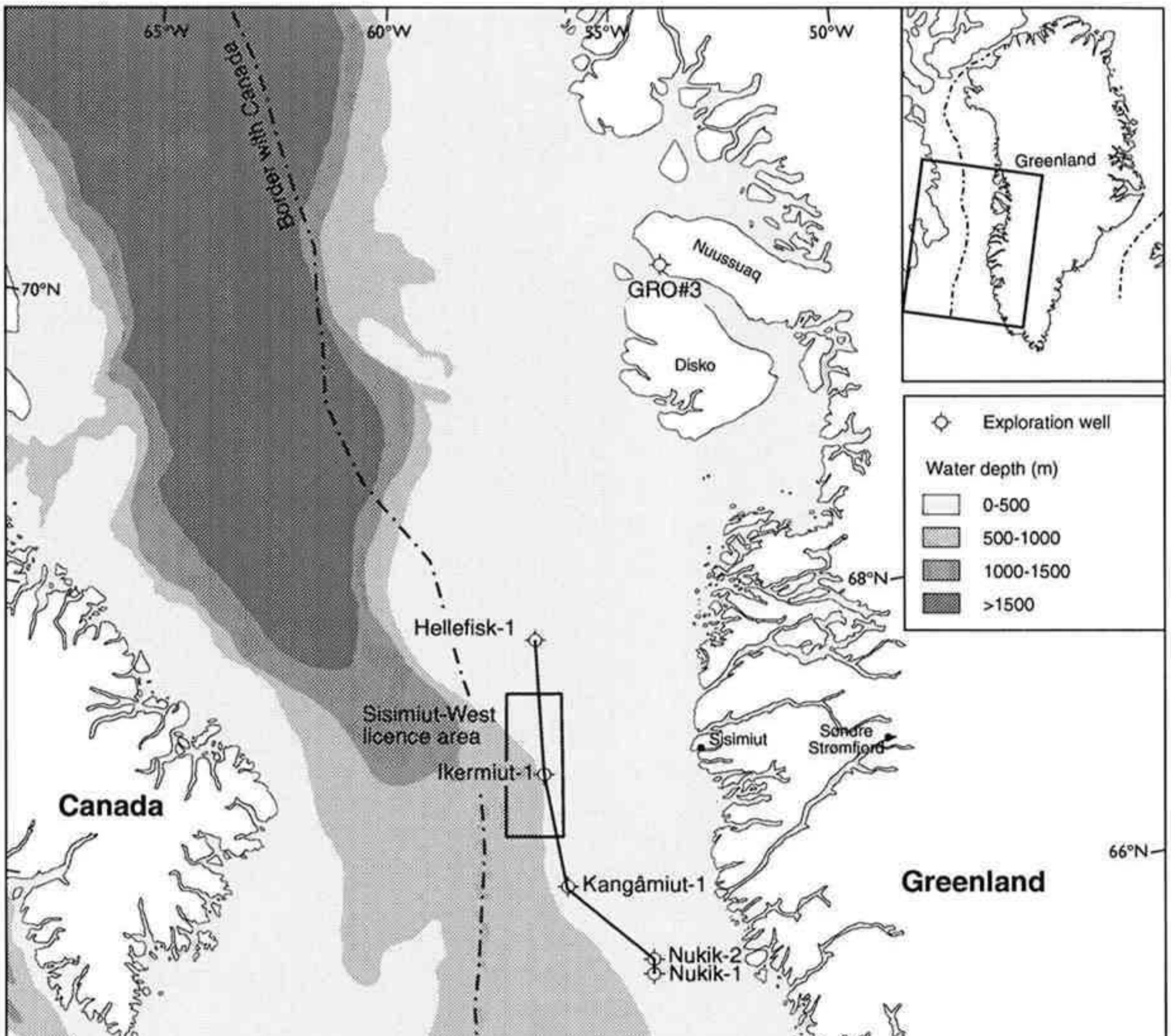

Fig. 1. Locality map showing location of the deep boreholes offshore West Greenland, bathymetry and the line of secdtion illustrated on Fig. 2. The two licences, the Sisimiut-West licence and the Fylla licence granted to Phillips and Statoil respectively are also indicated. The GRO#3 and Qulleq-1 boreholes are not covered by this work.

Fig. 2

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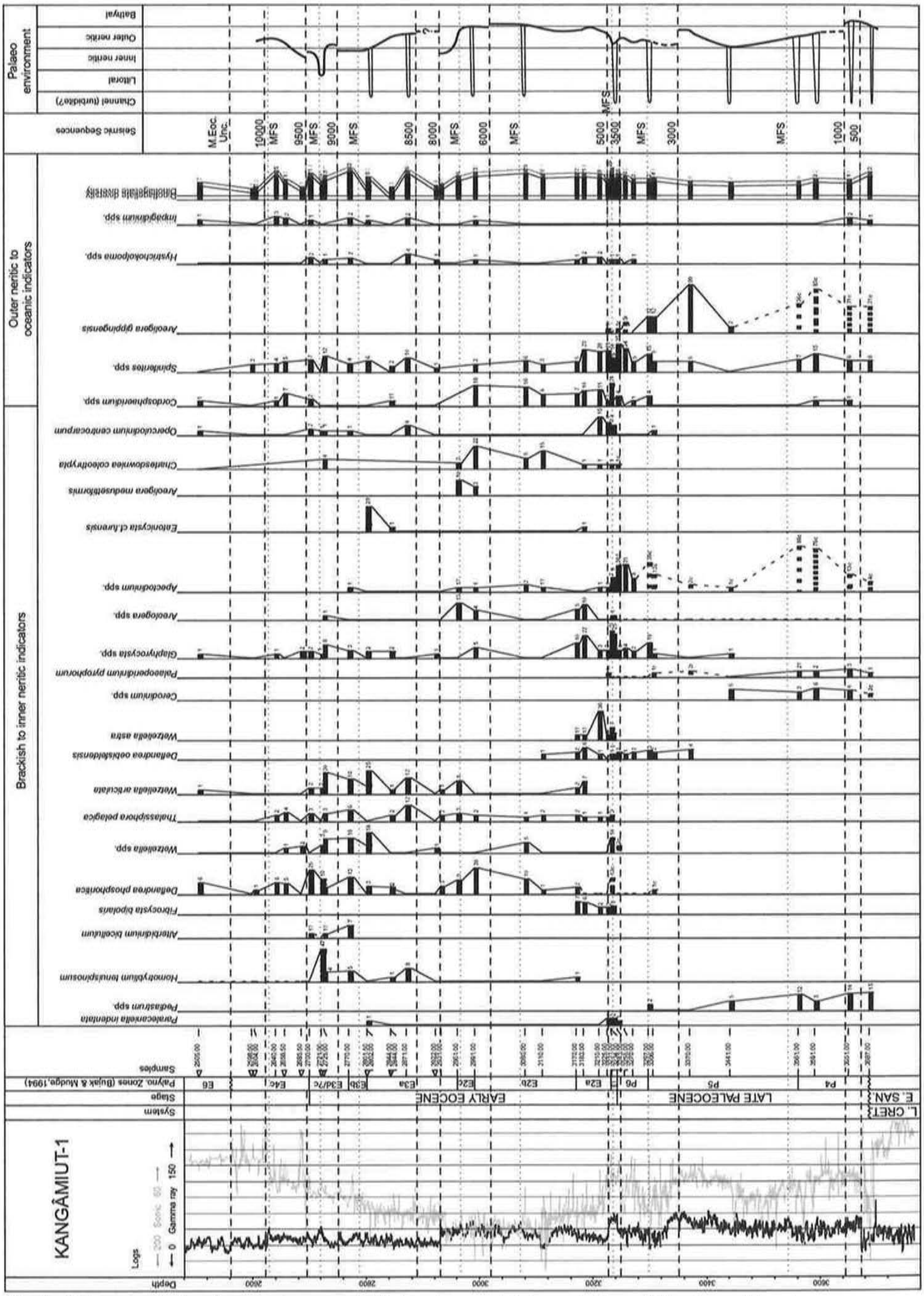

Fig.3. Palynological palaeoenvironmental indicators and interpretation of the depositional palaeoenvironment in Kangâmiut-1.

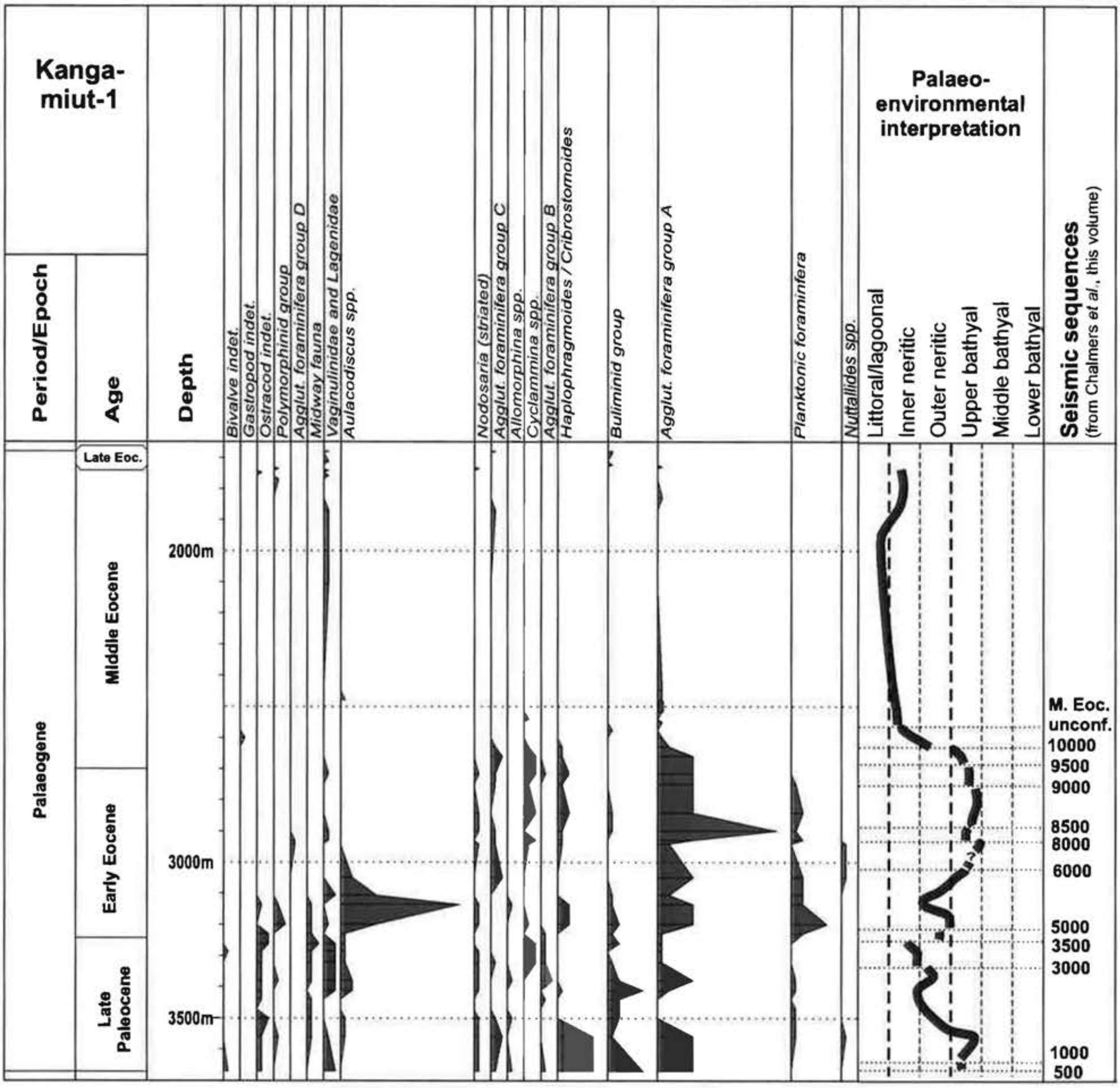

Fig. 4. Micropalaeontological palaeoenvironmental indicators and interpretation of the depositional palaeoenvironment in Kangâmiut-1. The more nearshore fossil groups are shown to the left and the more basinal groups to the right.

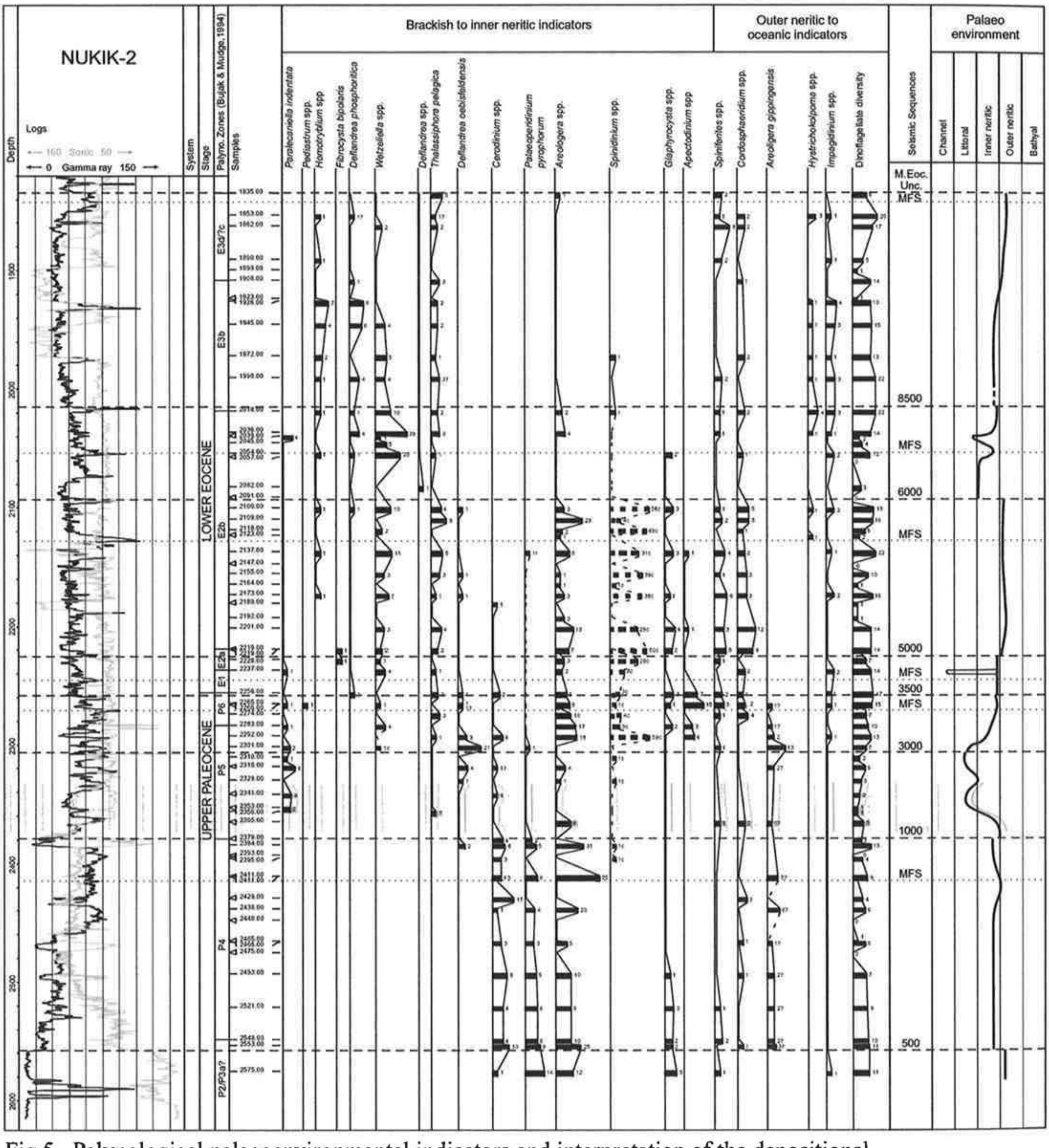

Fig.5. Palynological palaeoenvironmental indicators and interpretation of the depositional palaeoenvironment in Nukik-2.

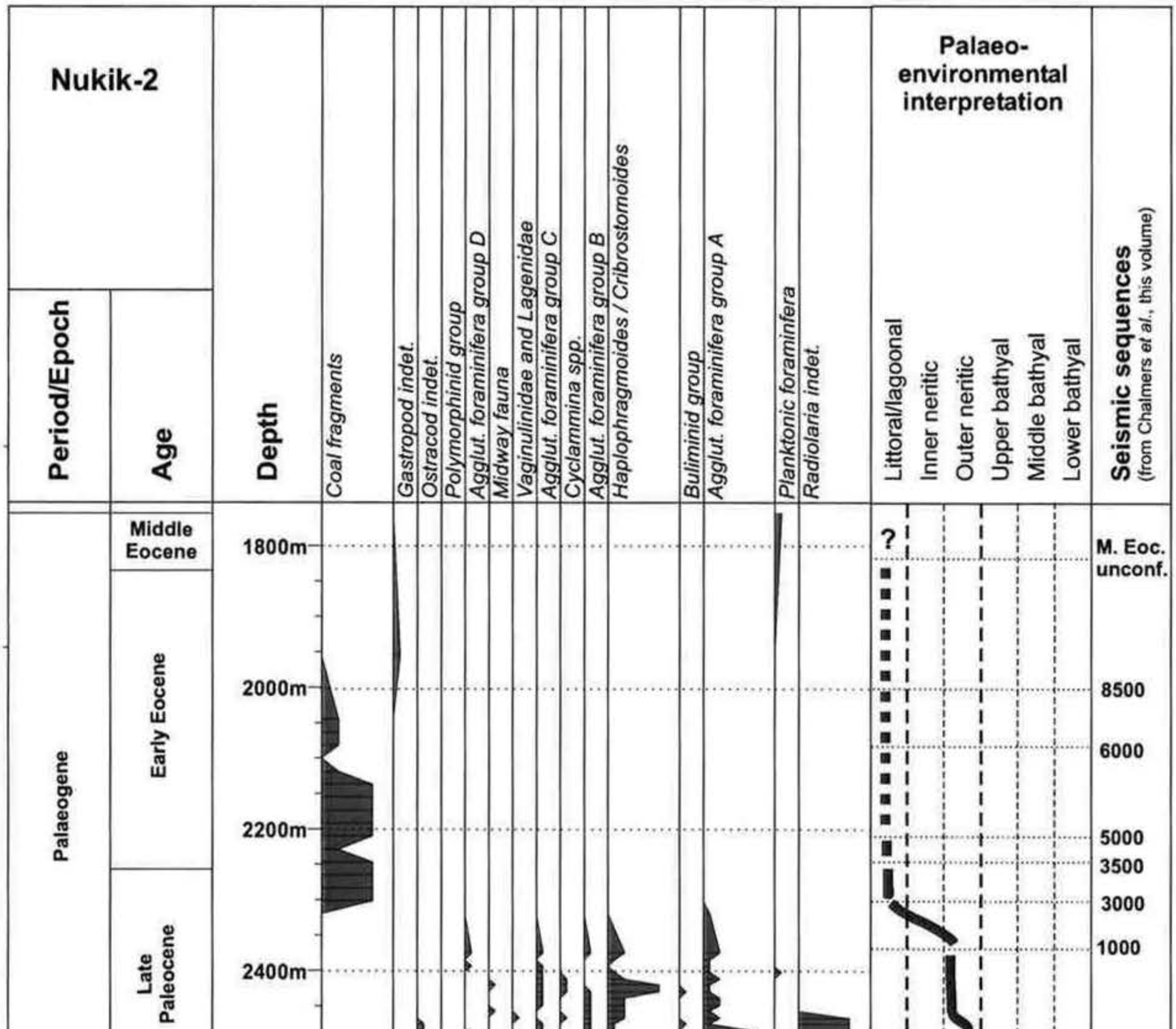

Fig. 6. Micropalaeontological palaeoenvironmental indicators and interpretation of the depositional palaeoenvironment in Nukik-2. The more nearshore fossil groups are shown to the left and the more basinal groups to the right.

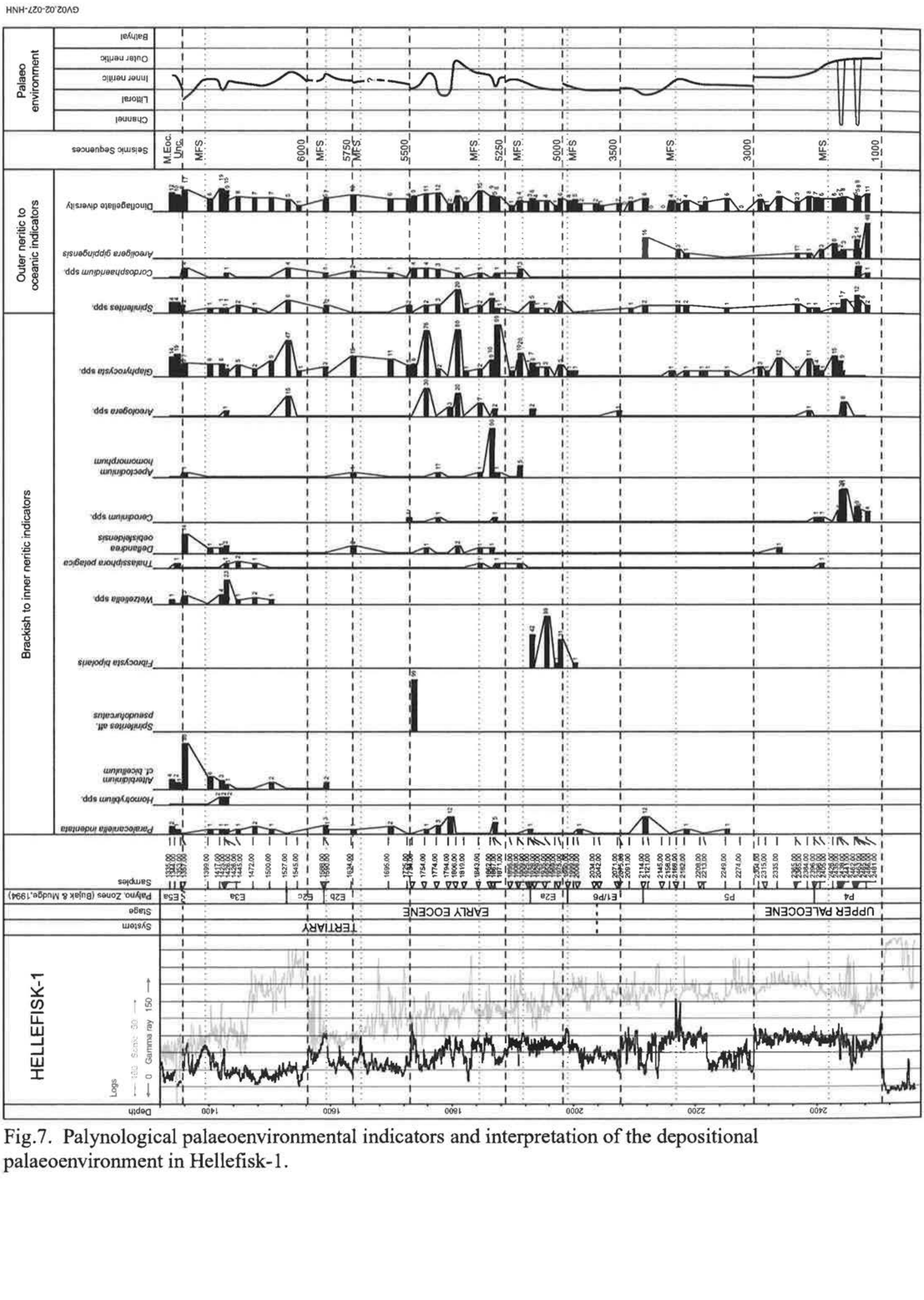

Fig.7. Palynological palaeoenvironmental indicators and interpretation of the depositional palaeoenvironment in Hellefisk-1.

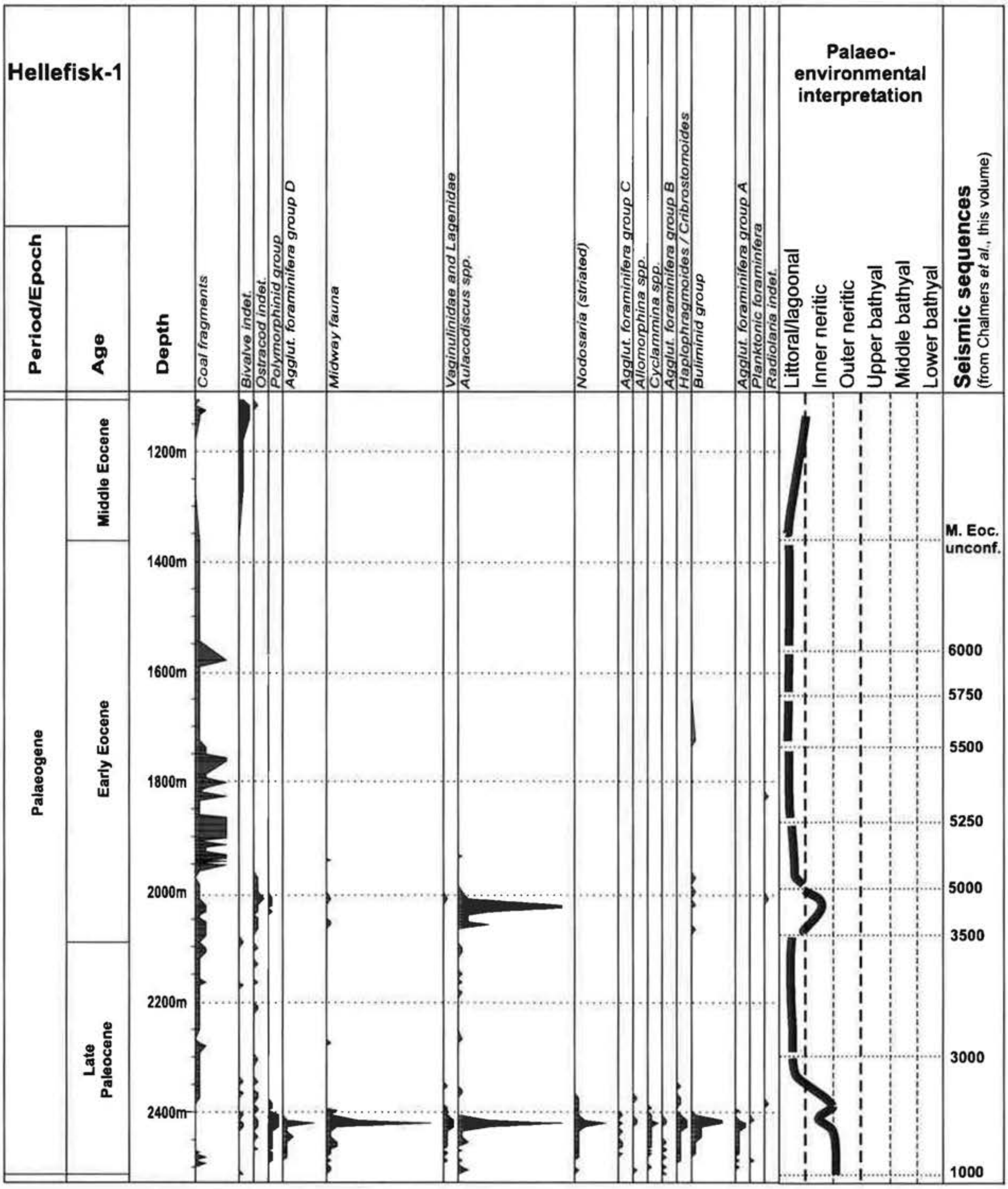

Fig. 8. Micropalaeontological palaeoenvironmental indicators and interpretation of the depositional palaeoenvironment in Hellefisk-1. The more nearshore fossil groups are shown to the left and the more basinal groups to the right.

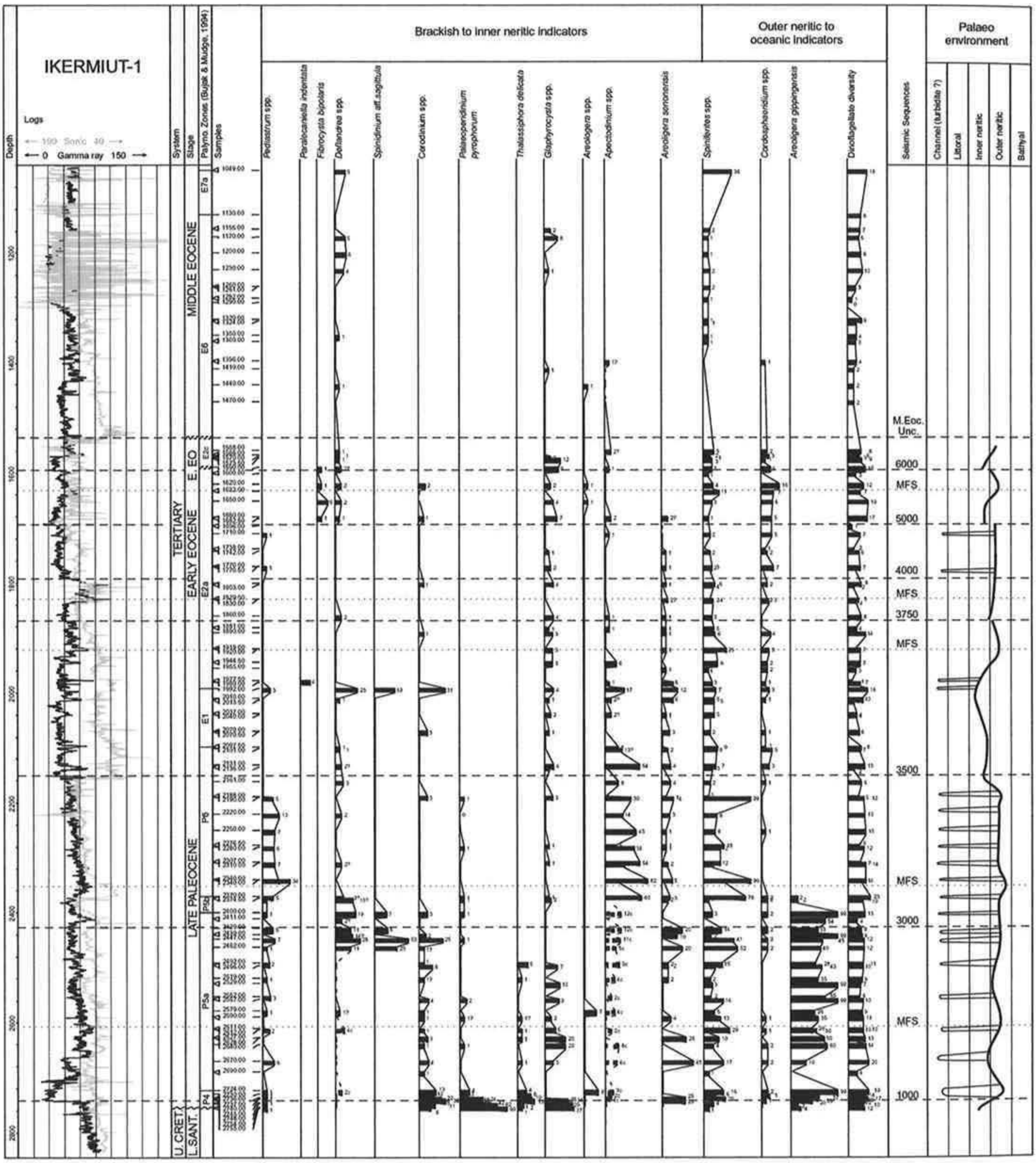

Fig.9. Palynological palaeoenvironmental indicators and interpretation of the depositional palaeoenvironment in Ikermiut-1.

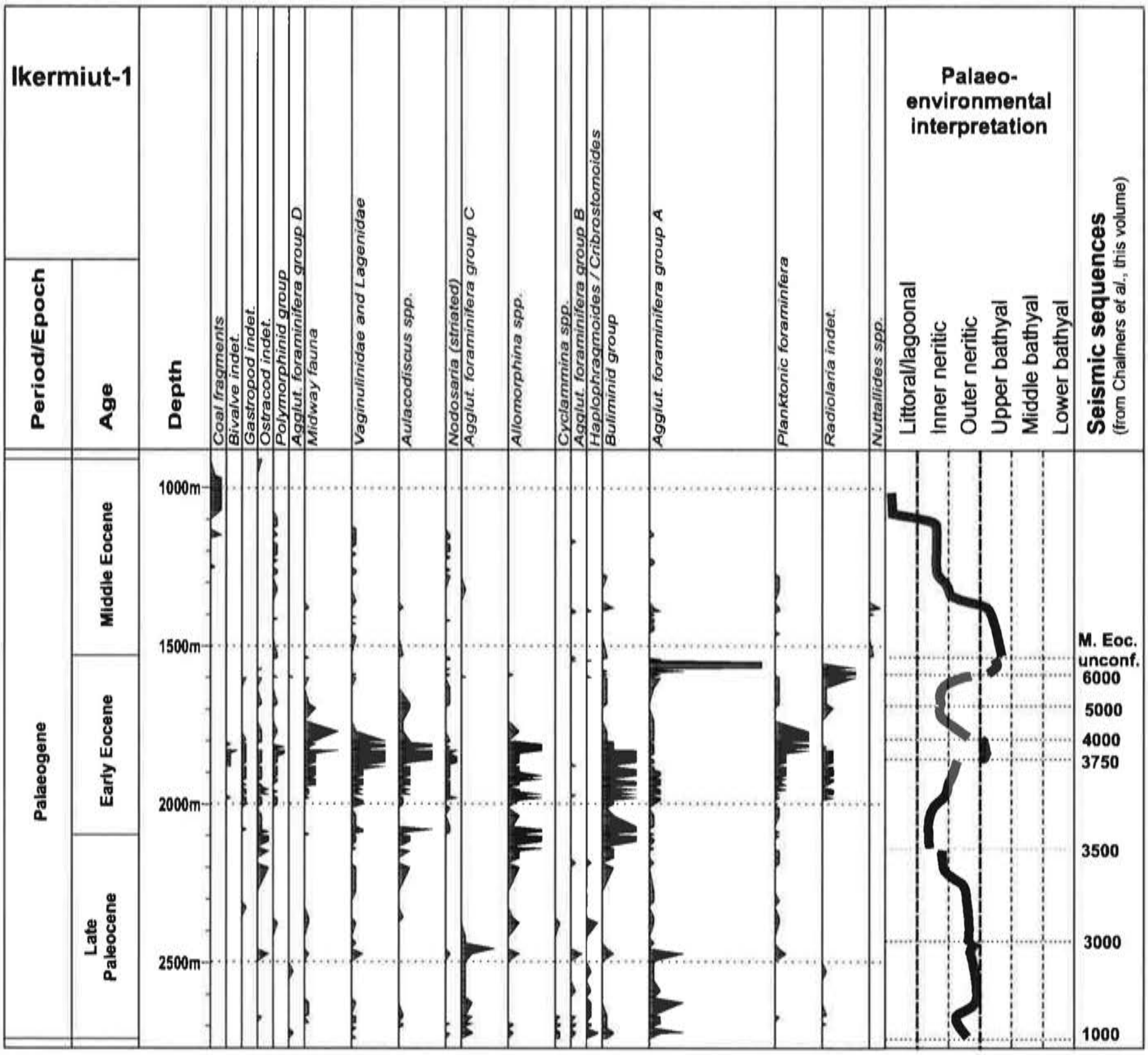

Fig. 10. Micropalaeontological palaeoenvironmental indicators and interpretation of the depositional palaeoenvironment in Ikermiut-1. The more nearshore fossil groups are shown to the left and the more basinal groups to the right.

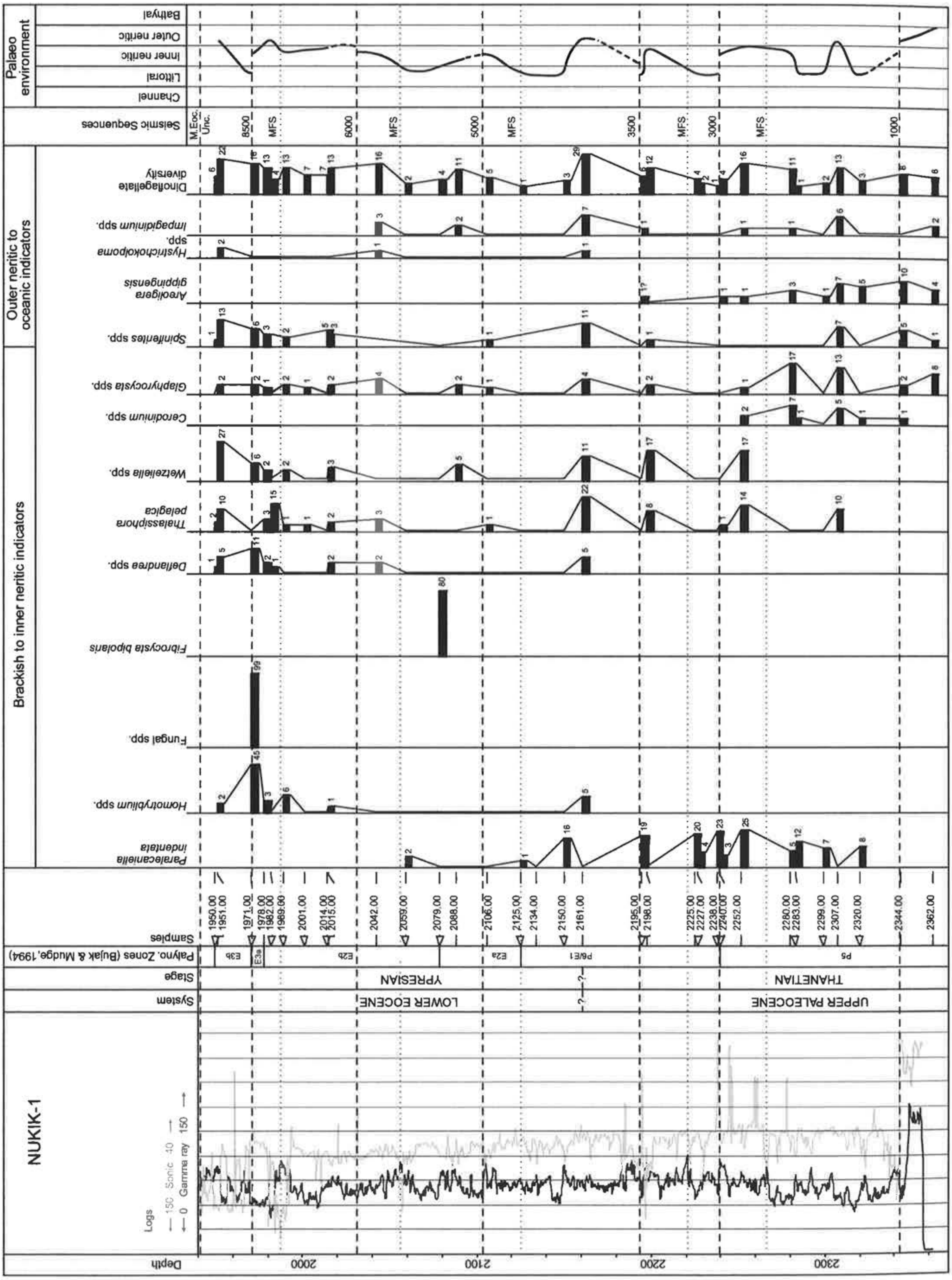

Fig.11. Palynological palaeoenvironmental indicators and interpretation of the depositional palaeoenvironment in Nukik-1.

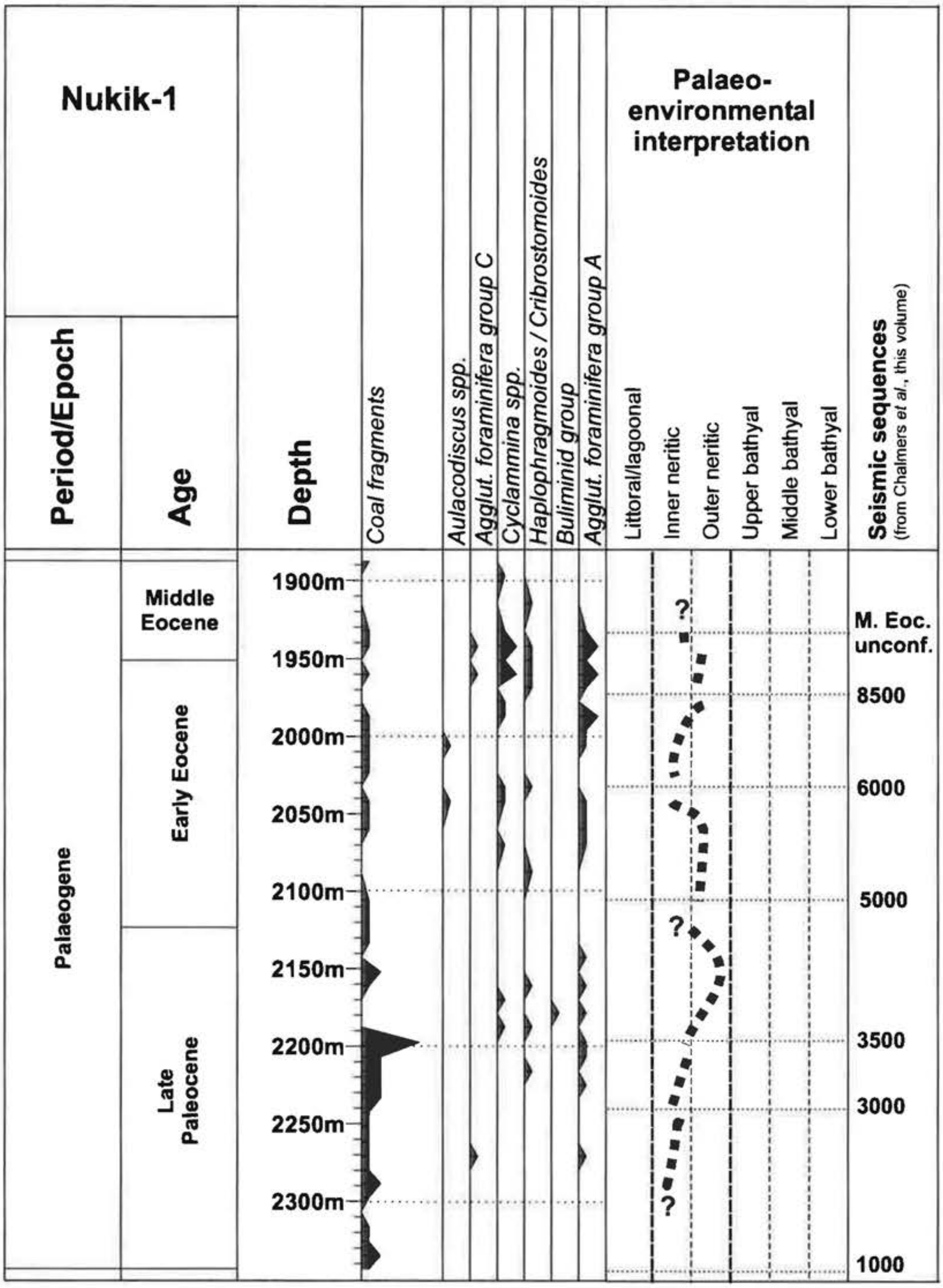

Fig. 12. Micropalaeontological palaeoenvironmental indicators and interpretation of the depositional palaeoenvironment in Nukik-1. The more nearshore fossil groups are shown to the left and the more basinal groups to the right.

Appendix 3

Dinoflagellate cyst stratigraphy of the Palaeogene strata from the wells Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1, Nukik-2 and Qulleq-1, offshore West Greenland

by

Henrik Nøhr-Hansen

Dinoflagellate cyst stratigraphy of the Palaeogene strata from the wells Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1, Nukik-2 and Qulleq-1, offshore West Greenland.

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Abstract

A new Palaeogene dinoflagellate cyst stratigraphy from offshore West Greenland has been described based on the strata from the wells Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1, Nukik-2 and Qulleq-1.Twenty one strartigraphic intervals are defined from the Late Eocene to the late Early Paleocene. The new stratigraphy has been correlated with a new microfossil zonation and previous established North Sea zonations. The stratigraphy and well correlation is based on last appearence datum events and abundances of stratigraphically important species from 355 samples, 148 of which are side wall core samples. A major mid Eocene hiatus spanning the early Lutetian and a major Early Paleocene hiatus spanning the early Danian to the Late Santonian, Late Cretaceous have been recognised from the offshore deposits.

Introduction

During 1976 and 1977 five dry exploration wells (Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1 and Nukik-2) were drilled through Tertiary and Upper Cretaceous shelf sediments offshore central West Greenland between 65° N and 68° N (Fig. 1; Henderson 1978, 1979, Henderson, Scheiner, Risum, Croxton & Andersen (1981). Rolle (1985) described the lithostratigraphy, sedimentary evolution and petroleum potential of the five wells. The ages of Rolle's (1985) lithostratigraphic formations were based on palynological datings by Croxton (1981a, b, c, d & e) and Costa (1982). Later, Toxwenius (1986) compiled the Upper Cretaceous–Tertiary biostratigraphic data and correlated the five wells. During the summer 2000, the exploration well Qulleq- 1 was drilled further to the south at the Fylla Banke (63,5° N). The biostratigraphic dating of Qulleq-1 has been described by Nøhr-Hansen, Piasecki, Rasmussen & Sheldon (2000).

New exploration licences and renewed geophysical interpretation of both older and newly acquired seismic data from offshore West Greenland (Chalmers, 1991; Chalmers, Pulvertaft, Christiansen, Larsen, Laursen & Ottesen, 1993; Chalmers & Pulvertaft, 1993; Chalmers &

Laursen, 1995; Chalmers, Dahl-Jensen, Bate & Whittaker, 1995; Bate, Whittaker, Chalmers & Dahl-Jensen, 1995) prompted the need for a reinvestigation of the biostratigraphy of the previously drilled wells as major problems correlating seismic sequences to the wells were encountered.

The present dinoflagellate cyst biostratigraphy, together with microfossil studies (Rasmusen & Sheldon, this volume) and nannofossil studies (Sheldon, this volume), has been very important for the seismic sequence correlation study (Chalmers, Gregersen, Dalhoff, Nøhr-Hansen, Rasmussen & Sheldon this volume) and the log correlation and palaeoenvironment interpretation (Dalhoff, Nøhr-Hansen, Rasmussen Sheldon, Chalmers & Gregersen, this volume).

Technical data

Hellefisk-1

Hellefisk-1 was drilled in 1977 by Arco Greenland Inc. at 67° 52' 41" N and 56° 44' 21" W (Fig.1). The well was drilled at a water depth of 163 m (536 ft). The rotary table was 12 m (38 ft) above sea level, and the well total depth was 3201 m (10502 ft) below rotary table where Paleocene? Basalts were encountered (Rolle, 1985). All sample depths are measured from rotary table datum.

Ikermiut-1

Ikermiut-1 was drilled in 1997 by Chevron Petroleum Co. of Greenland at 66° 56' 12" N and 56° 35' 26" W (Fig.1). The well was drilled at a water depth of 447 m (1468 ft). The rotary table was 12 m (41 ft) above sea level, and the well total depth was 3619 m (11874 ft) below rotary table where ?Campanian shales were encountered (Rolle, 1985). All sample depths are measured from rotary table datum.

Kangâmiut-1

Kangâmiut-1 was drilled in 1976 by Total Grønland Olie A/S. The position of the well was 66° 09' 01" N and 56° 11' 24" W (Fig.1). The well was drilled at a water depth of 180 m (590 ft). The rotary table was 12 m (41 ft) above sea level, and the well total depth was 3874 m

(12710 ft) below rotary table where Precambrian basement were encountered (Rolle, 1985). All sample depths given in this paper are measured from rotary table datum.

Nukik-1

Nukik-1 was drilled in 1977 by Mobil Exploration Greenland Inc. The position of the well was 65° 31' 36" N and 54° 45' 38" W (Fig. 1). The well was drilled at a water depth of 104 m (342 ft) The rotary table was 24 m (80 ft) above sea level, and the well total depth was 2363 m (7754 ft) below rotary table where Precambrian basement were encountered (Rolle, 1985). All sample depth given in this paper are measured from rotary table datum.

Nukik-2

Nukik-2 was drilled in 1977 by Mobil Exploration Greenland Inc. The position of the well was 65° 37' 54" N and 54° 46' 01" W (Fig. 1). The well was drilled at a water depth of 117 m (383 ft) The rotary table was 24 m (80 ft) above sea level, and the well total depth was 2694 m (8838 ft) below rotary table where Maastrichtian basalt were encountered (Rolle, 1985). All sample depth given in this paper are measured from rotary table datum.

Qulleq-1

The Qulleq-1 (6354/4-1) well was drilled in the summer of 2000 by Statoil at a position of 63° 48' 03" N and 54° 27' 61" at Fylla Banke, offshore West Greenland. The well was drilled at a water depth of 1152.3 m, the rotary table was 36 m above sea level, and the total depth was 2973 m below rotary table. The well terminated in Upper Santonian? Sandstones (Nøhr-Hansen *et al.* 2000). All sample depths are measured from rotary table datum.

Palynological samples and methods

The present biostratigraphic study of dinoflagellate cysts from the wells Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1, Nukik-2 and Qulleq-1, offshore West Greenland is based on 355 samples of which 207 are ditch cutting samples (DCS) and 148 are side wall core samples (SWC). The Palynological analysis of the interval 1335–2481 m in Hellefisk-1 was based on 45 cutting samples and 53 side wall core samples. In Ikermiut-1 was the analysis of the interval 1049–2455 m was based on 58 cutting samples and 43 side wall core samples. In Kangâmiut-1 the analysis of the interval 2505–3687 m was based on 39 cutting samples and 16 side wall core samples. In Nukik-1 the analysis of the interval 1950–2362 m was based on 15 cutting samples and 17 side wall core samples. In Nukik-2 the analysis of the interval 1835–2575 m was based on 46 cutting samples and 15 side wall core samples and in Qulleq-1 the interval 1862–1893 m was based on the analysis of 4 cutting samples and 4 side wall core samples. Most of the studied samples were re-processed in the nineties for this study, however many of the SWC samples are represented by oil company slides produced in the late seventies and are of variable quality. The previous palynostratigraphic correlation of the Neogene to Late Cretaceous offshore deposits presented by Toxwenius (1986) was based on data from studies by Croxton (1981a, b, c, d & e; approximately 1000 samples), Hansen (1978; 10 samples), Costa (1982; 46 reprocessed samples) and Toxwenius (1986; 177 samples). In his correlation study Toxwenius (1986) used the dinoflagellate cyst D zonation, this was later used by Costa & Manum (1988) to describe the palynostratigraphy of the wells. It should, however, be noted that the calibration of Costa & Manum's (1988) D zones to nannoplankton zones (NP zones) has since changed. In this study the calibration to NP zones follows Powell (1992) and Bujak & Mudge (1994, Mudge & Bujak, 1996b; Fig. 2).

The present study describes the palynology of the Palaeogene succession only. Twenty one stratigraphic intervals are defined from the Late Eocene to the late Early Paleocene (Fig. 3). The Palynology of the Neogene is described by Nøhr-Hansen *et al.* (2000) and Piasecki (in prep), the palynology of the upper Cretaceous has been described Nøhr-Hansen (1998), Christiansen, Boesen, Bojesen-Koefoed, Chalmers, Dalhoff, Dam *et al.* (1999) and by Nøhr-Hansen *et al.* (2000).

The new dinoflagellate cysts stratigraphy presented here is mainly correllated to the Paleocene and Eocene dinoflagellate cyst zonation from the North Sea (Fig. 3) described by Bujak & Mudge (1994) and Mudge & Bujak (1996a, b). However some intervals have also been correlated with earlier observations and zones described from North Western Europe by Bujak, Downie, Eaton & Williams (1980), Costa & Manum (1988), Hansen (1977, 1980), Heilmann-Clausen (1985, 1988, 1994), Powell (1992) and Powell, Brinkhuis & Bujak (1996, Fig. 2). Some intervals have been correlated with earlier observations from offshore Eastern Canada by Williams & Brideaux (1975), Ioakim (1979), Head & Norris (1989) and with observations from New Zealand by Wilson (1984, 1988). The new dinoflagellate cyst stratigraphy has also been correlated with the new microfossil stratigraphy (Rasmussen & Sheldon, this volume) and the new nannoplankton stratigraphy (Sheldon, this volume) established from offshore West Greenland.

Palynological results

The present study has revealed dinoflagellate cyst species of stratigraphic value from several samples that were previously reported as being poor or barren of dinoflagellate cysts by Toxwenius (1986). The new observations have changed the previous biostratigraphic dating of the sedimentary succession recorded in Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1 and Nukik-2 radically, especially in the upper parts of the Palaeogene successions, where the base middle Eocene has been moved upward by approximately 600 m in Hellefisk-1 and by 400 m in Ikermiut-1.

The dinoflagellate cyst based correlation of the four wells shows that the most complete middle Eocene to mid Lower Eocene succession occurs in the Kangâmiut-1 well, and the most complete middle Lower Eocene to Upper Paleocene succession is represented in Ikermiut-1 (Fig. 4).

A major middle Eocene hiatus spanning the early Lutetian and late Ypresian (Early Eocene) occurs in Hellefisk-1 and Ikermiut-1 (Figs 4, 5). The middle Eocene hiatus only spans the middle Lutetian in Kangâmiut-1 (Figs 4, 5). A mid Early Eocene hiatus is probably also present in Ikermiut-1 and a major Early Paleocene hiatus spanning the early Danian to the Late Santonian, Late Cretaceous occurs in Ikermiut-1 and Kangâmiut-1, whereas the major Early Paleocene hiatus spans the early Danian to the Early Campanian, Late Cretaceous in Qulleq-1 (Figs 4, 5). It is noteable that the thick palynologically dated early Danian and Maastrichtian prebasaltic succession described from onshore West Greenland (Nøhr-Hansen, 1996; Nøhr-Hansen & Dam, 1997, Nøhr-Hansen, Sheldon & Dam, in press) has only been recorded offshore from the lowermost part of the Nukik-2 well.

Caved specimens are common in the Paleocene in all the wells. Caved specimens occur in ditch cutting samples, and are recognised by being less thermally mature and stratigraphically younger than the main assemblage.

Reworked specimens occur scattered at all levels in all wells but are never dominant. Reworked specimens are recognised by being more thermally mature and stratigraphically older than the main assemblage.

The presence of the Cretaceous species *Ovoidinium verrucosum* in most of the DCS in Hellefisk-1 and Nukik-2 is considered to be a result of pollution from drilling mud, probably a Cenomanian bentonite.

Palynological and micropalaeontological palaeoenvironmental interpretations of the five old wells are described in Dalhoff *et al.* (this volume). The general trends of the palaeoenvironmental study indicate that the majority of the sediments representing the Palaeogene of Hellefisk-1, Nukik-1and to a certain degree Nukik-2 were deposited in a littoral to inner neritic environment, whereas most sediments representing the Palaeogene of Kangâmiut-1 and Ikermiut-1 were deposited in an outer neritic to bathyal turbiditic environment.

The sample depths and relative abundance of species referred to in the biostratigraphic section (below) are illustrated on range-charts of each well reported in Nøhr-Hansen (in press). From each sample 100 specimens have been counted if possible. The stratigraphic distribution and relative abundance of environmentally significant species and genera are presented in Dalhoff *et al.* (this volume, figs x, x, x, x, x).

The illustrations of dinoflagellate cysts (Figs. xx-xx) are marked with sample number, slide number, data base number (MicroImage; MI) and laser-video-record number (LVR) for later identification. The illustrated dinoflagellate cysts are also marked with MGUH numbers and are stored in the type collection of the Geological Museum of the University of Copenhagen, Øster Voldgade 5–7, DK 1350, Copenhagen K, Denmark.

Biostratigraphy

Twenty one palynological Palaeogene intervals have been defined and used to correlate the Palaeogene succession offshore southwest Greenland (Fig. 3). The intervals are defined by the last appearence datum (LAD) and abundance of stratigraphic marker species (Figs 3, 4).

Figure 2 along with the authours correlation and interpretation of previously established North Sea area dinoflagellate cysts zonations is shown to facilitate the understanding of the discussion and correlation below.

1) *Areosphaeridium diktyoplokum* Interval

Age. Late Eocene, Priabonian

Occurrence. Hellefisk-1, 715–1025 m

Definition. The *Areosphaeridium diktyoplokum* interval is defined by the last appearence datum (LAD) of *Areosphaeridium diktyoplokum*. The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Hellefisk-1are the LAD of *Areosphaeridium diktyoplokum*, *Areosphaeridium arcuatum* and *Cribroperidinium* cf. *giuseppei* at 723 m (SWC), LAD of *Charlesdowniea coleothrypta* at 849 m (SWC), LAD of *Corrudinium incompositum* and *Lentinia* cf. *serrata* at 857 m (SWC) and the LAD of *Svalbardella* cf. *cooksoniae* and *Apectodinium homomorphum* at 862 m (SWC).

Common to abundant species within the interval. Fragments and opercula of *Cribroperidinium* cf. *giuseppei* are abundant at 857 m (SWC). Dinoflagellate diversity and density are gernerally low. Saccate pollen and spores dominate the interval from 910 to 1025 m.

Reworked species. *Chatangiella* spp., *Nyktericysta* cf. *davisii*, *Palaeoperidinium pyrophorum* and *Wetzeliella astra* (723–751 m). *Deflandrea* spp. at 884 m. One specimen of *Wetzeliella spinula* at 1025 m.

Discussion. The presence of *Areosphaeridium diktyoplokum* suggests an age of no younger than the latest Priabonian, Late Eocene (Bujak & Mudge, 1994; Brinkhuis & Visscher, 1995). The presence of the species *Areosphaeridium diktyoplokum*, *Cribroperidinium* cf. *giuseppei*, *Corrudinium incompositum* and *Lentinia* cf. *serrata* all suggest an earliest Oligocene age according to Brinkhuis & Biffi (1993). The same authors recorded the LAD of *A. diktyoplokum* from the *Areosphaeridium diktyoplokum* Interval Zone at the Global Stratotype Section and Point for the Eocene/Oligocene (mid NP 21) boundary at Massignanoin, Italy. The Eocene/Oligocene stage boundary problems have later been discussed by Bujak & Mudge (1994); Brinkhuis & Visscher (1995) and Aubry, Berggren, Van Couvering & Steininger (1999), and palynologists now tend to use the LAD of *Areosphaeridium diktyoplokum* to define the latest Eocene.

The presence of *Areosphaeridium arcuatum* and *Apectodinium homomorphum* suggest an age of not younger than earliest Oligocene (top D12), correlating with the *Rhombodinium perforatum* (Rpe) Interval Biozone of Powell (1992; Fig. 2). *Cribroperidinium giuseppei* has been recorded from the London Clay (Zone LC-3) to the Barton Beds (Zone Bar-5, Fig. 2) by Bujak *et al.* (1980), correlating with the base of D8 to the top of D11 (Powell, 1992). As mentioned above Brinkhuis & Biffi (1993) recorded *C. giuseppei* up to the earliest Oligocene (NP21, Fig. 2) in Italy.

Corrudinium incompositum and *Lentinia serrata* have been recorded from the Barton Beds (Bar-1–Bar-5) by Bujak *et al.* (1980) which according to Powell (1992) correlate with the upper part of D10 to the top of D11. *Corrudinium incompositum* was originally described by Drugg (1970) from Oligocene sediments of the Gulf Coast, USA. Williams, Stover & Kidson (1993) reported an Early Oligocene (Rupelian) to Middle Eocene (Bartonian) range for the species in the northern hemisphere, whereas Brinkhuis & Biffi (1993) recorded *C. incompositum* from the earliest Oligocene (NP21) in Italy. *Lentinia serrata* was described from the upper Barton Beds by Bujak (1980), and Williams *et al.* (1993) recorded the LAD of *L. serrata* from the middle Priabonian (D12; Fig. 2).

Correlation. The observations suggest a correlation with the Late Eocene *Rhombodinium perforatum* (Rpe) Interval Biozone (Powell, 1992) and the *Areosphaeridium diktyoplokum* Zone (E8) of Bujak & Mudge (1994).

2) *Glaphyrocysta texta* Interval

Age. Middle Eocene, mid to late Bartonian

Occurrence. Hellefisk-1, 1045–1155 m

Definition. The *Glaphyrocysta texta* interval is defined by the LAD of *Rhombodinium longimanum*. The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Hellefisk-1 are the LAD of *Areosphaeridium fenestratum*, *Areosphaeridium* sp. 1, *Glaphyrocysta texta*, *Rhombodinium longimanum*, *Phthanoperidinium echinatum*, *P. geminatum* and *P. multispinum* at 1045 m (SWC), LAD of *Aranosphaera araneosa* at 1074 m (SWC), LAD of *Rhombodinium draco* and *Wetzeliella spinula* at 1142 m (SWC) and the first appearence datum (FAD) of *Glaphyrocysta texta* and *Wetzeliella spinula* in a SWC sample at 1155 m.
Common to abundant species within the interval. *Glaphyrocysta texta* (1045–1095 m), *Lingulodinium machaerophorum*, *Wetzeliella spinula* (1142–1155 m), *Phthanoperidinium echinatum* and *Implektosphaeridium* cf. *insolitum* (1152 m).

Discussion. According to Costa & Manum's (1988) definition of their D11 Zone, *Glaphyrocysta texta* becomes extinct at the top of the zone. Powell (1992) correlated D11 with the two interval biozones: *Wetzeliella simplex* (Wsi) and *Rhombodinium porosum* (Rpo) and correlated the lower zone (Rpo) with Bar-3 and the higher zone (Wsi) with the Bar-4 and Bar-5 zones of Bujak *et al.* (1980; Fig. 2). The base of Bar-3 is defined by the first occurrence of *G. texta* and the base of Bar-4 is defined by the first occurrence of *W. spinula* amongst other species, whereas the top of Bar-5 is defined by the last occurrence of *G. texta*, *R. longimanum* and *W. spinula* (Bujak *et al.*; 1980).

Correlation. The observations suggest a correlation with the *Wetzeliella simplex* (Wsi) and *Rhombodinium porosum* (Rpo) interval zones of Powell (1992) and the *Heteraulacacysta porosa* Subzone (E7b) of Bujak & Mudge (1994).

3) *Glaphyrocysta semitecta* Interval

Age: Middle Eocene, early Bartonian.

Occurrence. Ikermiut-1, 1049 m and Kangâmiut-1, 1725–1845 m.

Definition. The *Glaphyrocysta semitecta* interval is defined by the LAD of *Cerebrocysta bartonensis* and the LAD of *Glaphyrocysta semitecta.* The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Ikermiut-1 are the LAD of *Cerebrocysta bartonensis, Lentinia serrata, Phthanoperidinium echinatum* and *P. comatum* at 1049 m (SWC). The species *Glaphyrocysta semitecta, Heteraulacacysta porosa* and *Phthanoperidinium geminatum* both have their LAD and FAD at 1049 m (SWC). Common to abundant species in Ikermiut-1 are *Glaphyrocysta semitecta, Operculodinium centrocarpum* and *P. geminatum.*
Diagnostic species events in Kangâmiut-1 are the LAD of *Cerebrocysta bartonensis, Membranophoridium* aff. *aspinatum, Phthanoperidinium echinatum, P. geminatum* and *P. multispinum* at 1725 m (DCS). The LAD of *Glaphyrocysta semitecta* is recorded at 1747 m (SWC).

Discussion. The presence of *Cerebrocysta bartonensis* suggests a level of not higher than D11 (Bujak *et al.* 1980; Powell 1992) or not higher than the *Areoligera tauloma* Subzone (E7a) (Bujak 1994; Bujak & Mudge 1994) correlating with upper part of D10 (Fig. 2). According to Bujak *et al.* (1980) and Powell (1992) *H. porosa* is only recorded from D10 and the lower part of D11. However, Bujak & Mudge (1994) extended the range for *H. porosa* in the North Sea upward to the top of their subzone E7b correlating with the top of D11 (Fig. 2). Bujak (1980) described *G. semitecta, L. serrata* and *P. geminatum* from the Barton Beds in southern England (Bar-1 to Bar-5) corresponding to upper D10 and D11 (Fig. 2). The absence of *G. texta, R. longimanum* and *W. spinula*, which amongst others were recorded from the younger *Glaphyrocysta texta* interval in Hellefisk-1, suggest a late D10 age. The presence of *C. bartonensis* and *H. porosa* together with *G. semitecta, L. serrata* and *P. geminatum* also suggests a D10 age.

Correlation. The observations suggest a correlation with the uppermost part of D10, which correlates with the *Rhombodinium draco* (Rdr) Interval Biozone (Fig. 2; Powell 1992) and the *Areoligera tauloma* Subzone (E7a) of Bujak & Mudge (1994).
This interval in Kangâmiut-1 is dated as NP 16–18 using nannofossils (Sheldon, this volume).

4) Late Lutetian Interval (E6)

Age. Middle Eocene, late Lutetian.

Occurrence. Hellefisk-1, 1170–1270 m, Ikermiut-1, 1130–1470 m and Kangâmiut-1, 1871–2505 m.

Definition. The dinoflagellate assemblages in this interval are very poor in the three wells and direct correlation between the wells based on a single stratigraphic marker species has not been possible, instead the characteristic species are discussed for each well. The base of the interval is bounded by the Mid Eocene unconformity (Chalmers *et al.*, this volume)

Hellefisk-1

Diagnostic events in Hellefisk-1 are the LAD of *Alterbidinium* cf. *bicellulum* at 1170 m (DCS) and the LAD of *Areoligera* cf. *tauloma* at 1216 m (DCS). Common to abundant species within the interval, *Implektosphaeridium* cf. *insolitum* (1170–1216 m), *Alterbidinium* cf. *bicellulum* (1216–1262 m).

Discussion. *Alterbidinium bicellulum* has previously only been recorded by Islam (1983a, b) who described the species and its range from the Bracklesham Beds zones B-4, B-3 and B-2 in southern England. These beds correlate with D9 and D8 and E6b to E2c (Powell 1992; Mudge & Bujak 1996a; Fig. 2).

Correlation. The observations from the present interval in Hellefisk-1 suggest a correlation with the upper part of the *Areosphaeridium arcuatum* (Aar) interval zone of Powell (1992) and the lower part of the *Diphyes colligerum* Zone (E6) of Bujak & Mudge (1994).

Ikermiut-1

Diagnostic events in Ikermiut-1 are the LAD of *Phthanoperidinium* aff. *distinctum*, *Heteraulacacysta leptalea* at 1130 m (DCS), LAD of *Glaphyrocysta vicina* at 1155 m (SWC), LAD of *Glaphyrocysta* cf. *spineta* at 1170 m (DCS) and the LAD and FAD of *Areosphaeridium pectiniforme* at 1320 m (DCS). *Areosphaeridium acuatum* is recorded from 1155 m to 1360 m (both SWC). *Phthanoperidinium comatum* is recorded from 1230 m to 1470 m (both DCS). The informal species *Deflandrea* sp. 1 A is common at 1155 m (SWC). Dinoflagellate cysts are rare in the lower part of the interval.

Discussion. Bujak & Mudge (1994) reported *P. distinctum* as ranging from their North Sea *Diphyes pseudoficusoides* Subzone (E6a) to and including the *Phthanoperidinium distinctum* Subzone (E6b), which correlates with the upper part of the Middle Eocene D9 Zone (Fig. 2). Bujak *et al.* (1980) recorded the LAD of *G. spineta* and the FAD of *Areosphaeridium pectiniforme* (as *A. multicornutum)* from the lower part of the Bracklesham Beds (B-5) correlating with the upper part of D9 and the middle part of E6 (Bujak & Mudge 1994; Fig. 2). Heilmann-Clausen & Costa (1989) recorded the LAD of *G. spineta* from the uppermost part of D9 in north-west Germany.

Correlation. The sparse assemblage recorded suggests a late Lutetian age, correlating with the middle part E6 (Bujak & Mudge, 1994); possibly the *Phthanoperidinium distinctum* Subzone (E6b).

Kangâmiut-1

Diagnostic species events in Kangâmiut-1 are the LAD of *Areosphaeridium arcuatum* and *A. pectiniforme* at 1871 m (SWC), FAD of *Areosphaeridium pectiniforme* and *Phthanoperidinium geminatum* at 2004 m (DCS) and the FAD of *Phthanoperidinium comatum* at 2159 m (SWC).

Discussion and correlation. According to Powell (1992) *Phthanoperidinium comatum* has its FAD at the base of D9, *Areosphaeridium arcuatum* has its FAD in the lower part of D9 and *A. pectiniforme* and *P. geminatum* have their FAD at the base of D10. The sparse assemblage recorded in the upper part of the interval suggests a possible late Lutetian age, correlating with E6 (Bujak & Mudge, 1994). Stratigraphic marker species were not recorded from the poor abundance assemblages from 2217 m to 2505 m, however nannoplankton dating of SWC samples from 2387 m and 2422 m (Sheldon, this volume) also suggests a late Lutetian age (NP 16).

5) *Phthanoperidinium regalis* Interval

Age. Middle Eocene, early Lutetian.

Occurrence. Hellefisk-1, 1289–1344 m,

Definition. The *Phthanoperidinium regalis* interval is defined by the LAD of *Phthanoperidinium regalis.* The base of the interval is defined by the top of the underlying interval.

Diagnostic species events in Hellefisk-1 are the LAD of *Deflandres denticulata*, *Phthanoperidinium regalis* (rare) and*Turbiosphaera magnifica* at 1289 m (DCS) and the LAD of *Charlesdownia teniuvirgula* at 1344 m (DCS). Saccate pollen are common to abundant within the inetrval, whereas dinoflagellate cysts are rare.

Discussion. According to Bujak (1994) and Bujak & Mudge (1994) *Phthanoperidinium regalis* only occurs in the early Lutetian, and they note that the species has not been recorded beyond the North Sea. Bujak & Mudge (1994) recorded the range of *P. regalis* from top of the *Phthanoperidinium clithridium* Subzone (E5a) down to their *Cerebrocysta magna* Subzone (E4c), however none of the marker species from subzones E4d and E4c have been recorded from the *Phthanoperidinium regalis* Interval. Powell (1992) also recorded the LAD of *Deflandres denticulata* from the early Lutetian (lower part of D9). Bujak *et al.* (1980) recorded the LAD of *Charlesdownia tenuivirgula* in the middle to upper part of Bracklesham Beds B-4, which correlates with the upper part of zone D9 and the lower part of E6 or E5 (Bujak & Mudge, 1994). However Powell (1992) noted that Costa & Downie (1976) indicate that *C. tenuivirgula* range up to the upper Eocene.

Correlation. The sparse assemblage recorded shows precise age, however an early Lutetian age is suggested, correlating with the E5a to E4c subzones of Bujak & Mudge (1994); possibly their *Phthanoperidinium clithridium* Subzone (E5a).

6) *Cerebrocysta magna* Interval

Age: Middle Eocene, early Lutetian.

Occurrence. Kangâmiut-1, 2598–2685 m.

Definition. The *Cerebrocysta magna* Interval is defined by the LAD of *Cerebrocysta magna* and the middle part of the interval is defined by the LAD of *Hystrichosphaeropsis costae.* The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Kangâmiut-1 are the LAD of *Cerebrocysta magna* at 2598m, the LAD of *Diphyes ficusoides*, *Hystrichosphaeropsis costae*, *Hystrichosphaeridium tubiferum* and *Wilsonidinium* cf. *lineidentatum* Williams & Brideaux 1975 at 2640 m (DCS).

Discussion. The presence of *Cerebrocysta magna* suggests a level of not higher than the upper part of the *Cerebrocysta magna* Subzone (E4c) of Bujak & Mudge (1994) and the presence of *Hystrichosphaeridium tubiferum* and *Hystrichosphaeropsis costae* suggests a level of not higher than the middle part of the *Cerebrocysta magna* Subzone (E4c) of Bujak & Mudge (1994). *Wilsonidinium* cf. *lineidentatum* Williams & Brideaux 1975 was first reported from a single sample in the lower part of the middle Eocene in Corehole no. 16, situated on Grand Banks, Atlantic Continental Margin by Williams & Brideaux (1975). Later Ioakim (1979) observed the same species in a single sample of Lutetian age from the Labrador well Freydis B 87. The range of *Wilsonidinium echinosuturatum* in New Zealand corellate with the middle to lower Eocene (Porangan to basal Bortonian) *Wilsonidinium echinosuturatum* Zone of Wilson (1984).

Correlation. The observations indicate correlation with the early Lutetian *Diphyes ficusoides* Biozone E4 of Bujak & Mudge (1994) and possibly the *Cerebrocysta magna* Subzone (E4c).

7) *Eatonicysta ursulae* Interval

Age: Middle Eocene, earliest Lutetian/early Eocene, latest Ypresian.

Occurrence. Kangâmiut-1, 2700–2725 m and possibly Nukik-2, 1835–1889 m.

Definition. The *Eatonicysta ursulae* Interval is defined by the LAD of *Eatonicysta ursulae.* The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Kangâmiut-1 are the LAD of *Eatonicysta ursulae*, *Cerodinium depressum* and *Wilsonidinium echinosuturatum* at 2700 m (DCS) and the LAD of *Homotryblium tenuispinosum* at 2721 m (SWC).
Common species within the interval in Kangâmiut-1. *Deflandrea phosphoritica* and *Palaeocystodinium golzowense* are common at 2700 m (DCS). *Homotryblium tenuispinosum* is abundant and *D. phosphoritica* is common at 2721 m (SWC). *Spiniferites* spp. and *Wetzeliella* spp. are common at 2725 m (SWC).
Diagnostic species events in Nukik-2 are the LAD of *Diphyes ficusoides* at 1835 m (DCS), LAD of *Eatonicysta ursulae*, *Deflandrea denticulata, Homotryblium tenuispinosum* at 1853 m (DCS), LAD of *Wilsonidinium echinosuturatum* and the LAD of the possibly caved *Wilsonidinium* cf. *lineidentatum* Williams & Brideaux 1975 at 1862 m (DCS).

Discussion. Bujak *et al.* (1980) and Powell (1992) reported the LAD of *Eatonicysta ursulae* from the middle part of the *Areosphaeridium arcuatum* (Aar) Interval Biozone (correlating with the middle part of NP15). However, Bujak & Mudge (1994) strongly indicate that *E. ursulae* has its LAD in their E3d Subzone (correlating with NP14), which correlates with the *Phthanoperidinium comatum* (Pco) Interval Biozone of Powell (1992). Bujak & Mudge (1994) recorded *Homotryblium tenuispinosum* as being abundant from their E4c Subzone down to their E3b Subzone and superabundant in their underlying E3a Subzone (mid NP14; Fig. 2). Powell (1992) recorded the LAD of *Cerodinium depressum* from the upper part of his Pco Interval Biozone (NP14), whereas Bujak & Mudge (1994) described the LAD of *C. depressum* from their E4d Subzone (mid NP15).

Correlation. The observations suggest a correlation with the lower Lutetian *Eatonicysta ursulae* Subzone (E3d) and maybe the upper Ypresian *Eatonicysta ursulae* Acme Subzone (E3c) of Bujak & Mudge (1994).

8) *Charlesdowniea columna* Interval

Age: Early Eocene, late Ypresian.

Occurrence. Kangâmiut-1, one sample at 2770 m, Nukik-1, 1950–1951 m, Nukik-2, at 1908–1990 m and Qulleq-1, at 1862–1866 m.

Definition. The *Charlesdowniea columna* Interval is defined by the LAD of *Charlesdowniea columna, Diphyes brevispinum* and *Dapsilidinium* aff. *pseudocolligerum.* The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Kangâmiut-1 are the LAD of *Charlesdowniea columna* and *Diphyes brevispinum* at 2770 m (DCS). *Wetzeliella* spp. are common at the same level.
The diagnostic event in Nukik-1 is the LAD of *Charlesdowniea columna, Dapsilidinium* aff. *pseudocolligerum* and *Wetzeliella* endocyst at 1942 m (DCS). *Thalasiphora pelagica* and *Wetzeliella arrticulata* are common at 1951 (DCS).
Diagnostic species events in Nukik-2 are the LAD of *Charlesdowniea columna* at 1908 m (DCS).
Diagnostic species events in Qulleq-1 are the LAD of *Charlesdowniea columna, Deflandrea* aff. *spinulosa, Diphyes brevispinum* and *Wetzeliella* endocyst at 1861 m (SWC) and the LAD of *Dapsilidinium* aff. *pseudocolligerum* at 1866 m (DCS). *Deflandrea* aff. *spinulosa, Phthanoperidinium echinatum* and *Systematophora placacantha* are common within the interval in Qulleq-1.

Discussion. Bujak & Mudge (1994) defined their late Ypresian *Charlesdowniea columna* Subzone (E3b) by the LAD of *Charlesdowniea columna.* Mudge & Bujak (1996a) illustrate that *C. columna* only occurs in their two subzones E3b and E3a, the same range as Bujak (1994) describe for *Diphyes brevispinum.*

Correlation. The present observations and records from the interval below in Kangâmiut-1, Nukik-1 and Qulleq-1 indicate a correlation with the late Ypresian *Charlesdowniea columna* Subzone (E3b) of Bujak & Mudge (1994).
The *Charlesdowniea columna* Interval correlates with the upper part of the *Pseudohastigerina wilcoxensis* foraminifera Zone in Kangâmiut-1 suggesting an Ypresian age (Rasmussen & Sheldon, this volume).

9) *Eatonicysta furiensis* Interval

Age: Early Eocene, late Ypresian.

Occurrence. Hellefisk-1?, 1357–1500 m, Kangâmiut-1, 2801–2931 m, Nukik-1, one sample at 1971 m and Qulleq-1, one sample at 1867 m.

Definition. The *Eatonicysta furiensis* Interval is defined by the LAD of *Eatonicysta furiensis* and by abundant *Homotryblium tenuispinosum.* The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Hellefisk-1 are the LAD of *Areoligera medusettiformis*, the FAD of *Areosphaeridium dictyoplokum* and FAD of *Alterbia* cf. *bicellulum* at 1357 m (SWC). Also the LAD of *Eatonicysta* cf. *furiensis* at 1417 m and the LAD of *Charlesdowniea columna* at 1472 m. *Alterbia* cf. *bicellulum* is abundant and *Deflandrea phosphoritica* is frequent at 1357 m (SWC) and *Wetzeliella* spp. are abundant at 1426 m (SWC).

Diagnostic species events in Kangâmiut-1 are the LAD of *Eatonicysta furiensis* at 2801 m (SWC). Also *Eatonicysta furiensis* is abundant at 2801 m (SWC) and *Wetzeliella* spp. are abundant in the upper part of the interval.
Diagnostic species events in Nukik-1 are the LAD and occurrence of abundant *Homotryblium tenuispinosum* and the occurrence of abundant Fungal spores at 1971 m (SWC).
Diagnostic species events in Qulleq-1 are the presence of *Charlesdowniea columna,* the LAD of *Eatonicysta furiensis* and *Areoligera medusettiformis* at 1867 m (SWC). *Dapsilidinium* aff. *pseudocolligerum* and *Impagidinium* spp. are common in the same level.

Discussion. Bujak & Mudge (1994) defined their late Ypresian *Membranilarnacia compressa* Subzone (E3a) by the last occurrence of frequent *Areoligera medusettiformis*, superabundant *Homotryblium tenuispinosum* and the LAD of *Eatonicysta furiensis*. Bujak & Mudge (1994) noted that subzone E3a from the North Sea can be seperated into three parts. The upper part is defined by the LAD of *Membranilarnacia compressa,* the middle part is characterised by the LAD of *Eatonicysta furiensis* and the lower part is characterised by the last occurrences of frequent *Areoligera medusettiformis* and superabundant *Homotryblium tenuispinosum*. Mudge & Bujak (1996a) recorded the FAD of *Areosphaeridium dictyoplokum* from E2c, and Islam (1983b) recorded the FAD of *Alterbidinium bicellulum* from the Bracklesham Beds zone B-2 in southern England. This bed correlates with D8 and E2c (Powell 1992; Mudge & Bujak 1996a; Fig. 2).

Correlation. The present observations from the interval in Kangâmiut-1, Nukik-1 and Qulleq-1 and possibly Hellefisk-1 indicate a correlation with the middle and lower part of the late Ypresian *Membranilarnacia compressa* Subzone (E3a) of Bujak & Mudge (1994).
The *Eatonicysta furiensis* Interval correlates with the middle part of the *Pseudohastigerina wilcoxensis* foraminifera Zone in Kangâmiut-1 suggesting an Ypresian age (Rasmussen & Sheldon, this volume). The *Eatonicysta furiensis* Interval in Kangâmiut-1 is dated as NP 12 using nannofossils (Sheldon, this volume).

10) *Areoligera medusettiformis* acme Interval

Age: Early Eocene, middle Ypresian.

Occurrence. Hellefisk-1, 1527–1545 m, Ikermiut-1, 1535–1573 m, Kangâmiut-1, one sample at 2961 m.

Definition. The *Areoligera medusettiformis* acme Interval is defined by the LAD of common to abundant *Areoligera medusettiformis*. The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Hellefisk-1, Ikermiut-1 and Kangâmiut-1 are the LAD of common to abundant *Areoligera medusettiformis* and common to abundant *Areoligera* spp. It should be noted that the LAD of common *Areoligera medusettiformis* in Ikermiut-1 occurs 38 m below the top of the interval, which in this well is defined by the middle Eocene unconformity.

Discussion. Bujak & Mudge (1994) defined their middle Ypresian *Areoligera medusettiformis* acme Subzone (E2c) by the last occurrence of superabundant *Areoligera medusettiformis* and common *Areoligera* spp.

Correlation. The present observations from the interval in Ikermiut-1 and Kangâmiut-1 indicate a correlation with the middle Ypresian *Areoligera medusettiformis* acme Subzone (E2c) of Bujak & Mudge (1994).
The *Areoligera medusettiformis* acme Interval correlates with the *Cenodiscus – Cenosphaera* microfossil Zone in Ikermiut-1 suggesting a late Ypresian age (Rasmussen & Sheldon, this volume).

11) *Dracodinium condylos* Interval

Age: Early Eocene, middle Ypresian.

Occurrence. Hellefisk-1, 1588–1925 m, Kangâmiut-1, 2991–3110 m, Nukik-1, 1978–2059 m, Nukik-2, 2018–2201 m and Qulleq-1, 1872–1884m.

Definition. The *Dracodinium condylos* Interval is defined by the LAD of *Dracodinium condylos* and/or by the LAD of *Dracodinium politum*, *Rhombodinium* sp. 1 and *Deflandrea oebisfeldensis*. The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Hellefisk-1 are the LAD of *Deflandrea oebisfeldensis* at 1357 m (SWC), LAD of *D. condylos* at 1588 m (SWC), LAD of *Hystrichosphaeridium tubiferum* and *Thalassiphora delicata* at 1843 m (SWC). *Alterbidinium* cf. *bicellulum* is abundant and *Deflandrea oebisfeldensis* is frequent at 1357 m (SWC), *Spiniferites* aff. *pseudofurcatus* is abundant at 1734 m (SWC) and *Apectodinium homomorphum* are abundant at 1862 m (SWC). Diagnostic species events in Kangâmiut-1 are the LAD of *D. condylos* and *D. politum* at 2991 m (DCS), the LAD of *Deflandrea oebisfeldensis* and *Spiniferites septatus* at 3110 m (DCS), and the LAD of *Thalassiphora delicata* at 3080 m (DSC). *Deflandrea phosphoritica*, *Charlesdowneia coleothrypta* and *Cordosphaeridium* spp. are common in cutting samples in the upper part of the interval in Kangâmiut-1.

Diagnostic species events in Nukik-1 are the LAD of *Dracodinium politum* at 1978 m (DCS), LAD of *D. condylos* at 2015 m (DCS) and the LAD of *Deflandrea oebisfeldensis* at 2042 m (DCS).
Diagnostic species events in Nukik-2 are the LAD of *Rhombodinium* sp. 1 and *Wetzeliella lunaris* at 2018 m (DCS), LAD of *D. condylos* at 2054 m (DCS), and the LAD of *Deflandrea oebisfeldensis* at 2100 m (DCS). *Wetzeliella lunaris* is common from 2018–2054 m (DCS). *Spinidinium* spp. and *Areosphaeridium* spp. are common in all DCS from 2100–2201 m, however none have been recorded from SWC samples suggesting that they may be caved or be a result of polution from the drilling mud. Plant fragment are common to dominant within the interval in Nukik-2 and *Paralecanilla indentata* specimens are frequent at 2039 m (SWC).
Diagnostic species events in Qulleq-1 are the LAD of *Dracodinium condylos* at 1872 m (SWC), LAD of *Rhombodinium* sp. 1, *Deflandrea oebisfeldensis*, Dinocyst sp. F Head & Norris 1989 at 1978 m (DCS), and the LAD of *Dracodinium politum* at 1884 m (DCS). *Operculodinium centrocarpum* and *Spiniferites* spp. are common in the interval in Qulleq-1.

Discussion. Bujak & Mudge (1994) defined the middle Ypresian of their *Dracodinium politum* Subzone (E2b) by the last occurrence of consistent *Dracodinium condylos* and consistent and locally common *D. politum*, and correlated it with the lower part of nannofossil zone NP 12 . The LAD of Dinocyst sp. F Head & Norris 1989 and *Rhombodinium* sp. 1 support this dating. Head & Norris (1989) recorded Dinocyst sp. F and *Rhombodinium* spp. together with *D. condylos* from a narrow interval correlating with NP 12 from the ODP hole 647A in the Labrador Sea. According to Mudge & Bujak (1996a) *Deflandrea oebisfeldensis* has a sporadic LAD in the *Dracodinium politum* Subzone (E2b). *Alterbidinium bicellulum* has previously only been recorded by Islam (1983a, b) who described the species and its range from the Bracklesham Beds zones B-4, B-3 and B-2 in southern England. These beds correlate with D9 and D8 and E6b to E2c (Powell 1992; Mudge & Bujak 1996a; Fig. 2).

According to Powell (1992) *Spiniferites septatus* has its LAD in the upper part of his *Dracodinium varielongitudum* Interval Biozone, correllating with upper NP 11. The few records of *S. septatus* from the late Lutetian Lillebælt Clay Formation in Denmark by Nielsen, Baumann, Deyu, Heilmann-Clausen & Larsen (1986), were considered to be reworked (Powell, 1992). The presence of *S. septatus*, if not reworked may suggest that the lower part of the interval in Kangâmiut-1 might belong to the older *Fibrocysta bipolaris* Interval described below.

Correlation. The present observations from the interval in Hellefisk-1, Kangâmiut-1, Nukik-1, Nukik-2 and Qulleq-1 indicate a correlation with the middle Ypresian *Dracodinium politum* Subzone (E2b) of Bujak & Mudge (1994).
The *Dracodinium condylos* Interval correlates with the *Aulacodiscus hirtus* microfossil Zone in Kangâmiut-1 and Nukik-1 suggesting an early Ypresian age (Rasmussen & Sheldon, this volume).

12) *Fibrocysta bipolaris* Interval

Age: Early Eocene, early Ypresian.

Occurrence. Hellefisk-1, 1928–1975 m, Ikermiut-1, 1590–1980 m, Kangâmiut-1, 3170–3183 m, Nukik-1, 2079–2206 m and Nukik-2, 2219–2228 m.

Definition. The *Fibrocysta bipolaris* Interval is defined by the LAD of *Fibrocysta bipolaris*. The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Hellefisk-1 are the LAD of *Fibrocysta bipolaris* and *Wetzeliella meckelfeldensis* at 1928 m (SWC) and the LAD of *Spiniferites septatus* at 1975 m (SWC). *Fibrocysta bipolaris* is abundant from 1928 m (SWC)–1975 m (SWC) and *Operculodinium centrocarpum* is common at 1975 m (SWC).
Diagnostic species events in Nukik-1 are the LAD of *Fibrocysta bipolaris* and *Carpatella* sp. 1 at 2079 m (SWC), in this sample *F. bipolaris* is abundant whereas *Carpatella* sp. 1 and *Operculodinium centrocarpum* are common.
Diagnostic species events in Ikermiut-1 are the LAD of *Fibrocysta bipolaris* and *Wetzeliella meckelfeldensis* at 1590 m (DCS), LAD of *Carpatella* sp. 1 at 1620 m (DCS), and the LAD of *Spiniferites septatus* at 1632 m (SWC). *Spiniferites* spp. are common at 1919 m (SWC).
Diagnostic species events in Kangâmiut-1 are the LAD of *Fibrocysta bipolaris* at 3170 m (DCS), and the occurrence of common *Spiniferites* spp. at 3183 m (DCS).

Diagnostic species events in Nukik-2 are the LAD of *Fibrocysta bipolaris* and *Carpatella* sp. 1 at 2219 m (DCS) and the LAD of *Spiniferites septatus* at 2228 m (DCS). Plant fragment are common to dominant within this interval in Nukik-2.

Discussion. *Fibrocysta bipolaris* was described (as *Cordosphaeridium bipolare*) from the Paleocene Dartmoor Formation by Cookson & Eisenack (1965). Brown & Downie (1984) recorded *F. bipolaris* from the Early Eocene in DSDP holes 553A and 555 on the Rockall Plateau, where they correlated the LAD of *F. bipolaris* with NP 10, whereas the LAD of *Wetzeliella astra* was recorded stratigraphically lower in DSDP Hole 555. Wilson (1988) recorded the LAD of *F. bipolaris* from the upper part of his Early Eocene *Wetzeliella spinulosa* Zone.

Fibrocysta aff. *essentialis* was reported from 374.5 m in the Kallo borehole and from 284 m in the Knokke boreholes. The interval was dated as early Ypresian by De Coninck (1999), who in his species remarks considered the species to be a junior synonym of *F. bipolaris.* Costa & Downie (1976) included the interval from 377–357 m in the Kallo borehole in their *Wetzeliella meckelfeldensis* Zone which Powell (1992) correllated with the upper part of NP 10 and lower part of NP11. *Fibrocysta bipolaris* is very common in a narrow interval within Nukik-1 and Hellefisk-1, where it supposedly represents a restricted marine environment (Dalhoff *et al.*, this volume). The species is rare in this interval in Nukik-2, Ikermiut-1 and Kangâmiut-1, which where supposed to represent more neritic conditions. According to Powell (1992) *Spiniferites septatus* has its LAD in the upper part of his *Dracodinium varielongitudum* Interval Biozone, correllating with upper NP 11.

Correlation. The present observations from this interval in Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1 and Nukik-2 indicate no clear age. A correlation with the early Ypresian *Wetzeliella meckelfeldensis* Interval Biozone of Powell (1992) is suggested, corresponding to the lower part of the *Dracodinium solidum* Subzone (E2a) of Bujak & Mudge (1994).

The *Fibrocysta bipolaris* Interval correlates with the *Praeglobobulimina ovata* foraminifera Zone in Hellefisk-1, Ikermiut-1and Kangâmiut-1suggesting an early Ypresian to Thanetian age (Rasmussen & Sheldon, this volume). Moreover the *Fibrocysta bipolaris* Interval correlates with an interval above the Ostracod Zone the in Hellefisk-1, Ikermiut-1, Kangâmiut-1 and

Nukik-1 suggesting an early Ypresian rather than a Thanetian age for the *Fibrocysta bipolaris* Interval (Rasmussen & Sheldon, this volume).

13) *Wetzelliella astra* Interval

Age: Earliest Eocene, earliest Ypresian.

Occurrence. Kangâmiut-1, 3210–3225 m.

Definition. The *Wetzelliella astra* Interval is defined by the LAD of *Wetzelliella astra*. The base of the interval is defined by the top of the underlying interval

Diagnostic events in Kangâmiut-1 are the LAD of *Wetzelliella astra* and a single *Apectodinium paniculatum* specimen at 3210 m (DCS). *Deflandrea oebisfeldensis* are present but not frequent in this interval. *Wetzelliella astra* is common at 3210 m (DCS) and *Spiniferites* spp. are common at 3210 m (DCS) and 3225 m (DCS).

Discussion. Powell (1992) reported the LAD of *Wetzeliella astra* and *Apectodinium paniculatum* from the lower part of the *Wetzeliella meckelfeldensis* Interval Biozone and the FAD at the base of the *Wetzeliella astra* Interval Biozone (lower part of D6b to the base of D6a, Fig. 2).

Correlation. The present observations from this interval in Kangâmiut-1 suggests correlation with the lower part of the early Ypresian *Wetzeliella meckelfeldensis* Interval Biozone or the *Wetzeliella astra* Interval Biozone of Powell (1992), which Bujak & Brinkhuis (1998) correlated with the *Dracodinium solidum* Subzone (E2a) of Bujak & Mudge (1994).
The *Wetzelliella astra* Interval correaltes with the *Praeglobobulimina ovata* foraminifera Zone and the Ostracod Zone in Kangâmiut-1 (Rasmussen & Sheldon, this volume).

14) Earliest Ypresian (earliest Eocene) /latest Thanetian (latest Paleocene)

The succession spanning the earliest Ypresian (earliest Eocene) and latest Thanetian (latest Paleocene) time interval has been described by several palynological intervals below.

14a) *Deflandrea oebisfeldensis* acme Interval

Age: Earliest Eocene, earliest Ypresian.

Occurrence. Ikermiut-1, 1992–2070 m and Kangâmiut-1, 3231–3234 m.

Definition. The *Deflandrea oebisfeldensis* acme Interval is defined by the LAD of common *Deflandrea oebisfeldensis* in Ikermiut-1 and by the LAD of common *Glaphyrocysta* spp. in Kangâmiut-1.The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Ikermiut-1are the LAD of common *Deflandrea oebisfeldensis* and common *Spinidinium* aff. *sagittula* at 1992 m (DCS).
Diagnostic species events in Kangâmiut-1are the LAD of common *Glaphyrocysta* spp. at 3231 m (DCS) and the LAD of *Charlersdowneia crassiramosa* at 3231 m (DCS). *Glaphyrocysta* spp. are common in this interval, whereas *Deflandrea oebisfeldensis* is present but not frequent. A few specimens of *Paralecaniella indentata* are recorded at 3234 m (DCS).

Discussion. Powell (1992) and Powell *et al.* (1996) reported the LAD of common *Glaphyrocysta ordinata* from the *Glaphyrocysta ordinata* Interval Biozone (D5b; Fig.2). Bujak & Mudge (1994) also defined their lower Eocene *Deflandrea oebisfeldensis* Acme Subzone (E1b) by the LAD of common *Glaphyrocysta ordinata* together with the LAD of consistent *Cerodinium wardenense* and frequent to abundant *Deflandrea oebisfeldensis*.
Drugg (1970) described *Spinidinium sagittula* from the Lower Eocene from the Gulf Coast of USA.

Correlation. The present observations from this interval in Ikermiut-1 and Kangâmiut-1 suggest correlation with the earliest Eocene *Deflandrea oebisfeldensis* Acme Subzone (E1b) of Bujak & Mudge (1994) which corresponds to the upper part of the *Glaphyrocysta ordinata* Interval Biozone of Powell (1992).

The lower part of the *Deflandrea oebisfeldensis* acme Interval correlates with part of the Ostracod Zone in Kangâmiut-1 suggesting an earliest Eocene to latest Palaeocene (basal Ypresian to Thanetian) age (Rasmussen & Sheldon, this volume).

14b) *Cerodinium dartmoorium* Interval

Age: Earliest Eocene, earliest Ypresian.

Occurrence. Nukik-2, one sample at 2237 m.

Definition. The *Cerodinium dartmoorium* Interval is defined by the LAD of *Cerodinium dartmoorium*. The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Nukik-2 include the LAD of *Cerodinium dartmoorium* common at 2237 m (DCS). Plant fragment are common to dominant within the interval, and a single *Paralecaniella indenta* specimen is recorded at 2237 m (DCS).

Discussion. Bujak & Mudge (1994) defined their lowermost Eocene *Cerodinium wardenense* Acme Subzone (E1a) by the LAD of *Cerodinium dartmoorium* and frequent *Cerodinium wardenense*.

Correlation. The present observations from this interval in Nuklik-2 suggests correlation with the earliest Eocene *Cerodinium wardenense* Acme Subzone (E1a) of Bujak & Mudge (1994) which corespond to the lower part of the *Glaphyrocysta ordinata* Interval Biozone of Powell (1992).

14c) Spores and pollen Interval

Age: Earliest Eocene, earliest Ypresian/latest Paleocene latest Thanetian.

Occurrence. Hellefisk-1, 1990–2091 m.

Definition. The Spores and pollen interval is characterised by being dominated by spores, pollen and plant fragments and containsalmost no marine palynomorphs. The base of the interval is defined by the top of the underlying interval.

Diagnostic events in Nukik-2. The dominance of spores, pollen, plant fragments and a single *Paralecaniella indenta* specimen at 2006 m (SWC) characterised this interval.

Discussion. Bujak & Mudge (1994) reported abundant pollen and abundant degraded herbaceous and amorphous kerogen from their earliest Eocene *Cerodinium wardenense* Acme Subzone (E1a). They suggested that the palyno composition could be explained by deposits in a shallow, restricted lake-like sea, corresponding to the palaeoenvironment described from the North Sea in the Early Eocene by Bonde (1974). The absence of frequent *Cerodinium* spp., *Deflandrea* spp. and *Glaphyrocysta* spp. and the total absence of *Apectodinium* spp. indicates that the spores and pollen interval represents shallow marine to brackish deposits of earliest Eocene, earliest Ypresian to latest Paleocene, latest Thanetian age.

Correlation. The present observations from the interval in Hellefisk-1 suggests correlation with the earliest Eocene *Hystrichosphaeridium tubiferum* Acme Biozone (E1) of Bujak & Mudge (1994) and the *Apectodinium augustum* Zone (P6) of Mudge & Bujak (1996).
Microfossil dating for Hellefisk-1 (1975–2012 m) suggest an early Ypresian age represented by the *Praeglobobulimina ovata* Zone of Rasmussen & Sheldon (this volume). The upper part of the Spores and pollen interval correlates with the Ostracod Zone in
Hellefisk- 1 suggesting an earliest Eocene to latest Paleocene (basal Ypresian to Thanetian) age (Rasmussen & Sheldon, this volume). Moreover the lower part of the Spores and pollen interval correlates with the *Fenestrella antiqua – Coscinodiscus morsianus* microfossil Zone in Hellefisk-1 suggesting a late Paleocene (Thanetian) age (Rasmussen & Sheldon, this volume).

14d) *Paralecaniella indenta* acme Interval

Age: Earliest Eocene, earliest Ypresian/latest Paleocene latest Thanetian.

Occurrence. Nukik-1, 2125–2238 m.

Definition. The *Paralecaniella indenta* acme interval is characterised by common *Paralecaniella indenta* and plant fragments with almost no *in situ* marine panynomorphs. The base of the interval is defined by the top of the underlying interval.

Diagnostic events. There are no diagnostic species events in Nukik-2 except for common *Paralecaniella indenta*, spores, pollen and plant fragments.

Discussion. Bujak & Mudge (1994) reported a late Paleocene to early Eocene *Leiosphaeridia* biofacies characterised by abundant *Pterospermella* alga, and probable brackish to freshwater or restricted marine cysts of unknown affinity assigned to *Leiosphaeridia.* They noted that the biofacies may be present in assemblages with low-diversity marine dinoflagellate populations, or within sections containing extremely few or no dinoflagellates. Powell *et al.* (1996) also recorded abundant *Paralecaniella* spp. and *Leiosphaeridia* spp. from their earliest Ypresian sequence 1 at Lower Upnor in southeast England. They noted that the abundant *Paralecaniella* spp. were recorded together with a mixture of taxa, which typically tolerate restricted marine conditions, and suggested that the assemblage reflected an early transgressive phase. The absence of frequent *Cerodinium* spp., *Deflandrea* spp. and *Glaphyrocysta* spp. and the total absence of *Apectodinium* spp. indicates that the present *Paralecaniella indenta* acme represents shallow marine to brackish deposits of earliest Eocene, earliest Ypresian to latest Paleocene, latest Thanetian age.

Correlation. The present observations from this interval in Nukik-1 suggests correlation with the earliest Eocene *Hystrichosphaeridium tubiferum* Acme Biozone (E1) of Bujak & Mudge (1994) and the *Apectodinium augustum* Zone (P6) of Mudge & Bujak (1996b).
The spores and pollen interval represents shallow marine to brackish deposits of earliest Eocene, earliest Ypresian to latest Paleocene, latest Thanetian age.
The present observations from this interval in Hellefisk-1 suggests correlation with the earliest Eocene *Hystrichosphaeridium tubiferum* Acme Biozone (E1) of Bujak & Mudge (1994) and the *Apectodinium augustum* Zone (P6) of Mudge & Bujak (1996b).

The last occurrence of Ostracods in 2198 m in Nukik-1 indicates that the *Paralecaniella indenta* acme interval correlates with the earliest Eocene to latest Palaeocene Ostrcod Zone of Rasmussen & Sheldon, this volume).

14e) *Apectodinium* spp. Acme Interval

Age: Latest Paleocene, latest Thanetian.

Occurrence. Ikermiut-1, 2097–2340 m, Kangâmiut-1, 3243–3270 m and Nukik-2, 2256–2274 m.

Definition. The *Apectodinium* spp. Acme Interval is defined by the LAD of common to abundant *Apectodinium* spp. The base of the interval is defined by the top of the underlying interval

Diagnostic events in Ikermiut-1are the LAD of frequent *Apectodinium* spp. at 2097 m (SWC), LAD of *Adnatosphaeridium robustum* at 2101 m (DCS), LAD of *Apectodinium augustum* and Gen. et sp. indet. Piasecki, Larsen, Pedersen & Pedersen 1992 at 2190 m (DCS). The FAD of *Apectodinium augustum* is recorded at 2340 m (DCS), just below the FAD of abundant *Apectodinium* spp. in a SWC sample (at 2307 m). *Apectodinium* spp. are common throughout the interval and abundant at 2131 m (DCS), 2250 m (DCS), 2307 m (SWC) and at 2340 m (DCS). *Spiniferites* spp. are present throughout the interval and abundant at 2190 m (DCS) and 2340 m (DSC). The alga *Pediastrum*, with a fresh to brackish water origin, is present in the lower part of the interval 2190 m to 2340 m and common in the lowermost part at 2340 m (SWC).
Diagnostic species events in Kangâmiut-1are the LAD of abundant *Apectodinium* spp. at 3243 m (DCS), and the LAD of *Apectodinium augustum* at 3255 m (DCS). A single specimen of *Paralecaniella indentata* is recorded from the upper part of the interval at 3243 m (DSC).
Diagnostic species events in Nukik-2 are the LAD of several *Apectodinium* spp. at 2256 m (DCS) and the occurrence of few *Paralecaniella indentata* and *Pediastrum* spp. recorded at 2265 m (DCS). Plant fragments are common to dominant within this interval in Nukik-2.

Discussion. Bujak & Mudge (1994) defined their late Paleocene *Apectodinium augustum* Biozone (P6) by the LAD of *Apectodinium augustum* and noted that several other *Apectodinium* spp. are common to abundant within the zone. Later Mudge & Bujak (1996b) subdivided the *Apectodinium augustum* Biozone (P6) into an upper *Apectodinium augustum* Subzone (P6b) defined by the range of *A. augustum* and the range of abundant *Apectodinium* spp. and a lower *Glaphyrocysta ordinata* Subzone (P6a), characterised by the absence of *A. augustum*, *Areoligera gippingensis* and *Alisocysta margarita* and by the presence of a low diversity assemblage of long-ranging species. As in Ikermiut-1, several pulses of *Apectodinium* spp. have been reported from the North Sea Basin (Powell *et al.* 1996, Bujak & Brinkhuis, 1998). Each of these *Apectodinium* spp. pulses was coincident with a third order sea level maximum (Bujak & Brinkhuis, 1998) and the youngest interval, defining the P6b Biozone of Mudge & Bujak (1996b) was coincident with superabundant *Apectodinium* spp. and the range of *Apectodinium augustum*. Biozone P6b has been correlated with the late Thanetian thermal maximum by Bujak & Brinkhuis (1998). New data from Kazakhstan (Iakovleva Brinkhuis & Cavagnetto, 2001) show that several pulses of common to abundant *Apectodinium* spp. occur both above the LAD and below the FAD of *Apectodinium augustum*. Iakovleva *et al.* (2001) correllated the oldest *Apectodinium* spp. peak below the FAD of *Apectodinium augustum* with P6a and the younger *Apectodinium* spp. peaks coincident with and above the LAD of *Apectodinium augustum* with P6b. The suggestion by Bujak & Brinkhuis (1998) that *Apectodinium augustum* is a more offshore species may suggest that its occurrence does not necessarily reflect the total range of the species in all areas (Iakovleva *et al.*, 2001).
Powell *et al.* (1996) also recorded common *Pediastrum* spp. and *Leiosphaeridium* spp. from an impoverished interzone just below the *A. augustum* biozone at Lower Upnor, southeast England. Heilmann- Clausen (1985) reported *Adnatosphaeridium robustum* from the Palaeocene Thanetian Viborg zone 5, which Heilmann-Clausen (1994) correllated with the *Apectodinium hyperacanthum* Interval Biozone of Powell (1992).
Bujak & Brinkhuis (1998) regarded *Apectodinium* spp. as a warm water holozoic group, that migrated from the Tethys into mid and high latitudes during a late Thanetian warming period, resulting in a nearly worldwide *Apectodinium* acme.

Correlation. The present observations from this interval in Ikermiut-1, Kangâmiut-1 and Nukik-2 suggests correlation with the latest Thanetian latest Paleocene *Apectodinium augustum*

Biozone (P6) and most likely the *Apectodinium augustum* Subzone (P6b) of Bujak & Mudge (1994).

The *Apectodinium* spp. Acme Interval correlates with parts of the *Praeglobobulimina ovata* foraminifera Zone in Hellefisk-1, Ikermiut-1 and Kangâmiut-1and with the Ostracod Zone and/or the *Fenestrella antiqua – Coscinodiscus morsianus* microfossil Zone in Hellefisk-1, Ikermiut-1, Kangâmiut-1 and probably Nukik-1 suggesting a latest Paleocene age (Rasmussen & Sheldon, this volume).

15) *Areoligera gippingensis* Interval

Age: Late Paleocene, late Thanetian.

Occurrence. Hellefisk-1, 2114–2484 m, Ikermiut-1, 2370–2690 m, Kangâmiut-1, 3297–3441 m, Nukik-1, 2240–2362 m (total depth), Nukik-2, 2283–2365 m and in Qulleq-1, 1890–1893 m.

Definition. The *Areoligera gippingensis* Interval is defined by the LAD of *Areoligera gippingensis* and the LAD of *Alisocysta margarita.* The lower part of the interval is characterised by abundant *Areoligera gippingensis*. The base of the interval is defined by the top of the underlying interval.

Diagnostic events. The LAD of *Areoligera gippingensis* and the LAD of *Alisocysta margarita* are the diagnostic species events at the top of the interval in all the studied wells, however an *Areoligera gippingensis* acme has only been recorded from the more basin-ward wells where the acme has its LAD in Ikermiut-1 at 2400 m, at 3370 m in Kangâmiut-1 and in Qulleq-1 at 1890 m.

Additional diagnostic species events in Hellefisk-1 are few except for the presence of *Paralecaniella indentata* in the upper part (2114–2249 m).

Diagnostic species events in Ikermiut-1 are common to abundant *Areoligera gippingensis* in both SWC and DCS from 2400–2670 m, LAD of *Cerodinium speciosum glabrum* at 2400 m (DCS), LAD of *Cerodinium speciosum* and *Thalassiphora delicata* at 2492 m (DCS), common *Cerodinium speciosum glabrum* at 2747 m (DCS), common to abundant *Spinidinium* aff.

sagittula and *Spiniferites* spp. at 2747 m (DCS) and 2462 m (DCS), common *Tenua* aff. *hystrix* at 2496 m (SWC), and the LAD of *Thalassiphora inflata* and *Alisocysta* cf. sp. 1 Heilmann-Clausen 1985 at 2627 m (SWC) and present *Pediastrum* spp. in most DCS in this interval. Diagnostic species events in Kangâmiut-1are the LAD of *Cerodinium speciosum glabrum* at 3370 m (DCS), and the LAD of *Cerodinium speciosum* and *C. striatum* at 3441 m (DCS). Diagnostic species events in Nukik-1are the LAD of *Cerodinium speciosum glabrum* at 2283 m (SWC), *Paralecaniella indentata* are present in both SWC and DCS in the interval. Diagnostic species events in Nukik-2 are the LAD of *Alisocysta* cf. sp. 1 Heilmann-Clausen 1985 at 2301 m (DCS) and present *Paralecaniella indentata* in both SWC and DCS in this interval. The LAD of superabundant *Areoligera gippingensis* at 1890 m (SWC) is diagnostic in Qulleq-1.

Discussion. Mudge & Bujak (1996b) subdivided their late Paleocene *Alisocysta margarita* Zone (P5) into an upper *Alisocysta margarita* Subzone (P5b) defined by the LAD of *Alisocysta margarita* and the LAD of consistent *Areoligera gippingensis* and a lower *Areoligera gippingensis* acme Subzone (P5a), characterisd by the LAD of abundant *Areoligera gippingensis*. The LAD of *Alisocysta* cf. sp. 1 Heilmann-Clausen 1985, *Cerodinium speciosum*, *C. striatum* and *Thalassiphora delicata* occur at the top of the *Palaeoperidinium pyrophorum* Interval Biozone of Powell (1992) corresponding to the Viborg zone 3 of Heilmann-Clausen (1985). The species *Alisocysta* cf. sp. 1 Heilmann-Clausen 1985 from Ikermiut-1 differs from *A.* sp. 1 Heilmann-Clausen 1985 by having a slightly less pronounced reticulum composed of large and small luminae and by its low (less than 5μm) penitabular membranes. The LAD in Ikermiut-1 of *Alisocysta* cf. sp. 1 Heilmann-Clausen 1985 is recorded stratigraphically higher than the LAD of *A.* sp. 1 which Heilmann-Clausen (1985) recorded from the top of Zone 3. Bujak & Mudge (1994) described the LAD of *Cerodinium speciosum* from the earliest Eocene. According to Heilmann-Clausen (1985) *Cerodinium speciosum glabrum* is restricted to Viborg zones 5 and 6 in Denmark.

Correlation. The present observations from the interval in the six wells suggests correlation with the lateThanetian late Paleocene *Alisocysta margarita* Zone (P5). Whereas the lower part of the interval in Ikermiut-1, Kangâmiut-1 and the entire interval in Qulleq-1 correlate with the *Areoligera gippingensis* acme Subzone (P5a) of Mudge& Bujak (1996).

The *Areoligera gippingensis* Interval correlates with the lower part of the *Fenestrella antiqua – Coscinodiscus morsianus* microfossil Zone and the upper part of the *Thalassiosiropsis wittiana* microfossil Zone in Kangâmiut-1 suggesting a Late Paleocene age (Rasmussen & Sheldon, this volume). Moreover the *Areoligera gippingensis* Interval correlates with the *Stensioeina beccariiformis* foraminifera Zone in Ikermiut-1 suggesting an ?Early to Late Paleocene age (Rasmussen & Sheldon, this volume).

16) *Palaeoperidinium pyrophorum* Interval

Age: Late Paleocene late Thanetian.

Occurrence. Hellefisk-1, 2396–2481 m (total depth), Ikermiut-1, 2724–2754 m, Kangâmiut-1, 3561–3651 m and Nukik-2, 2379–2521 m.

Definition. The *Palaeoperidinium pyrophorum* Interval is defined by the LAD of consistent *Palaeoperidinium pyrophorum.* The base of the interval is not defined in the present study where the interval is bounded by a hiatus.

Diagnostic events in Hellefisk-1 are the LAD of a few *Palaeoperidinium pyrophorum* specimens at 2396 m (DCS), LAD of *Cerodinium speciosum* at 2435 m (DCS), LAD of *Cerodinium striatum* at 2438 m (SWC) and common *Cerodinium speciosum* at 2438 and 2441 m (both SWC).
Diagnostic species events in Ikermiut-1 are the LAD of consistent *Palaeoperidinium pyrophorum*, the LAD of *Palaeocystodinium bulliforme* at 2724 m (DCS) and the LAD of *Cerodinium diebelii* at 2730 m (DCS). *Palaeoperidinium pyrophorum* are common to abundant and *Alisocysta margarita, Cerodinium speciosum, C. striatum* and *Thalassiphora delicata* are frequent within this interval in Ikermiut-1.
Diagnostic species events in Kangâmiut-1 are the LAD of *Palaeoperidinium pyrophorum, Cerodinium speciosum* and *C. striatum* at 3561 m (SWC). *Pediastrum* spp. frequently occurs within this interval.
Diagnostic species events in Nukik-2 are the LAD of *Cerodinium speciosum, Palaeocystodinium australinum* and *Palaeoperidinium pyrophorum* at 2379 m (SWC) and the

LAD of *Cerodinium diebelii* and *C. striatum* at 2384 m (DCS). *Palynodinium grallator*, *Spongodinium delitiense* and *Trithyrodinium evittii* are recorded from the same level (2384 m) indicating reworking from the uppermost Cretaceous/lowermost Palaeocene according to Nøhr-Hansen & Dam (1997; 1999).

Discussion. Mudge & Bujak (1996b) subdivided their late Paleocene *Palaeoperidinium pyrophorum* Zone (P4) into an upper *Palaeoperidinium pyrophorum* Subzone (P4b) defined by the LAD of consistent *Palaeoperidinium pyrophorum* and a lower *Palaeoperidinium pyrophorum* acme Subzone (P4a) defined by the LAD of abundant *Palaeoperidinium pyrophorum*. Mudge & Bujak (1996b) suggested that their *Palaeoperidinium pyrophorum* Zone (P4) correlated with the middle and upper parts of the Viborg zone 3 of Heilmann-Clausen (1985). According to Heilmann-Clausen (1985; 1994) the top of the Viborg zone 3 is defined by the LAD of *Cerodinium speciosum*, *Palaeocystodinium australinum* and *Palaeoperidinium pyrophorum*.

Correlation. The present observations from the interval in Hellefisk-1, Ikermiut-1, Kangâmiut-1 and Nukik-2 suggests correlation with the lateThanetian, Late Paleocene *Palaeoperidinium pyrophorum* Zone (P4) of Mudge & Bujak (1996b). The lower part of the interval in Ikermiut-1 correlates with the *Palaeoperidinium pyrophorum* acme Subzone (P4a) of Mudge & Bujak (1996b).
The *Palaeoperidinium pyrophorum* Interval correlates with the *Thalassiosiropsis wittiana* microfossil Zone in Hellefisk-1 and Kangâmiut-1 suggesting a late Paleocene (early Thanetian and Selandian) age (Rasmussen & Sheldon, this volume). Moreover the *Palaeoperidinium pyrophorum* Interval correlates with the *Stensioeina beccariiformis* foraminifera Zone in Hellefisk-1, Ikermiut-1, Kangâmiut-1and probably Nukik-2 suggesting an ?Early to Late Paleocene age (Rasmussen & Sheldon, this volume).

17) *Cerodinium kangiliense* Interval

Age: Early Paleocene, late Danian.

Occurrence. Nukik-2, 2548–2575 m.

Definition. The *Cerodinium kangiliense* Interval is defined by the LAD of consistent *Cerodinium kangiliense*. The base of the interval is not defined in the present study as the termination of the interval is represented by the total depth of the well Nukik-2.

Diagnostic events. Diagnostic species events in Nukik-2 are the LAD of *Cerodinium kangiliense* at 2548 m (DCS) and the LAD of *Senegalinium* cf. *iterlaaense* at 2553 m (DSC). *Palaeoperidinium pyrophorum* is frequent to common within the interval. *Palynodinium grallator*, *Spongodinium delitiense* and *Trithyrodinium evittii* are recorded in the lowermost sample at 2575 m indicating reworking from the uppermost Cretaceous/lowermost Palaeocene according to Nøhr-Hansen & Dam (1997; 1999).

Discussion and correlation. Nøhr-Hansen & Heilmann-Clausen (2001) described the range of *Cerodinium kangiliense* from the middle Danian to lower Selandian and the range of *Senegalinium iterlaaense* from the middle and upper Danian in West Greenland and Denmark. Nøhr-Hansen *et al.* (in press) recorded the FAD of *Cerodinium kangiliense* together with the FAD of *Alisocysta margarita* from their middle to late Danian *Alisocysta margarita* Zone. The zone was correlated with the upper part of NP4, which may correlate with the late Danian, Early Paleocene *Spiniferites magnificus* Subzone (P2b) or the *Thalassiphora* cf. *delicata* Subzone (P3a) of Mudge & Bujak (1996b).

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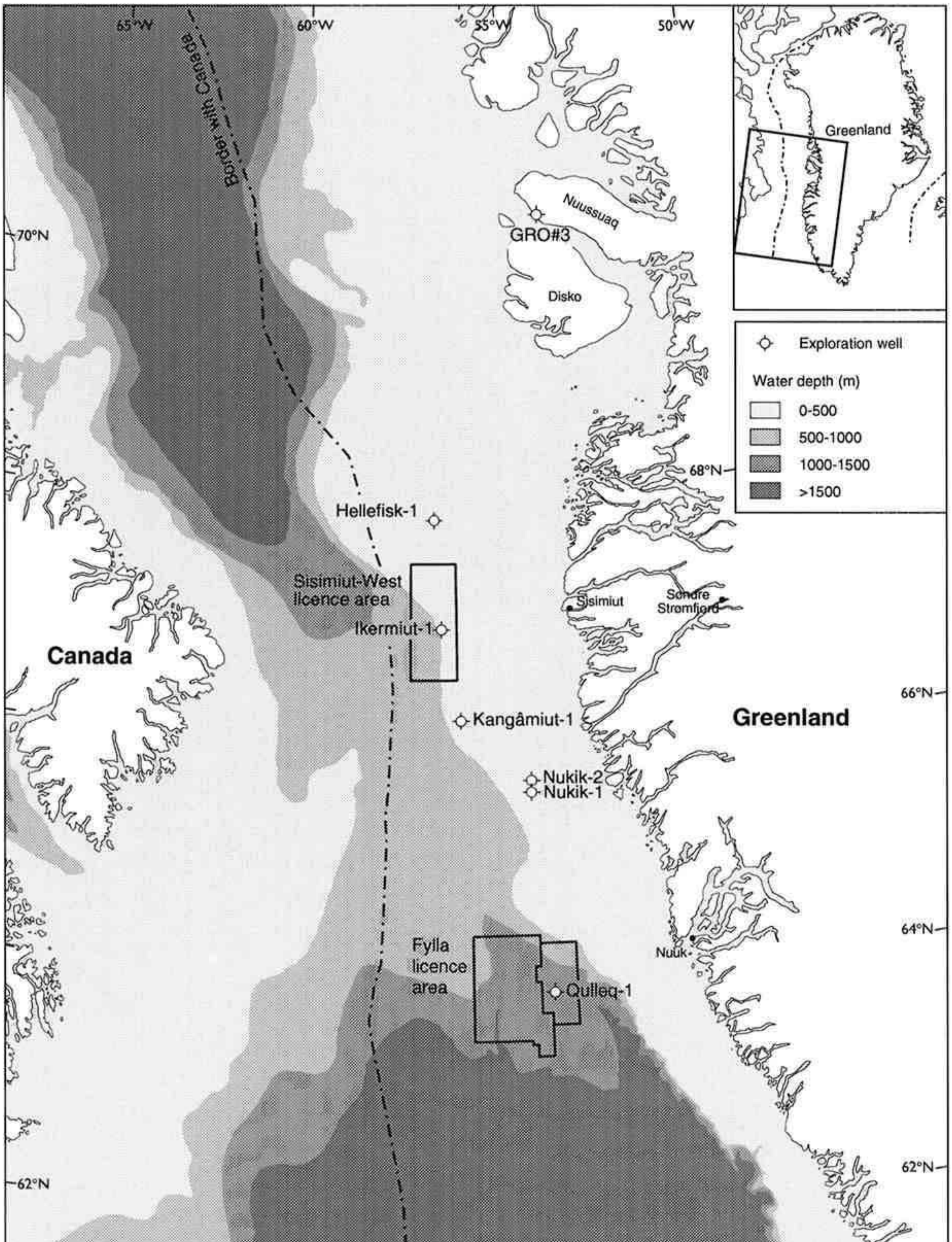

Fig. 1. Locations of the offshore Wells.

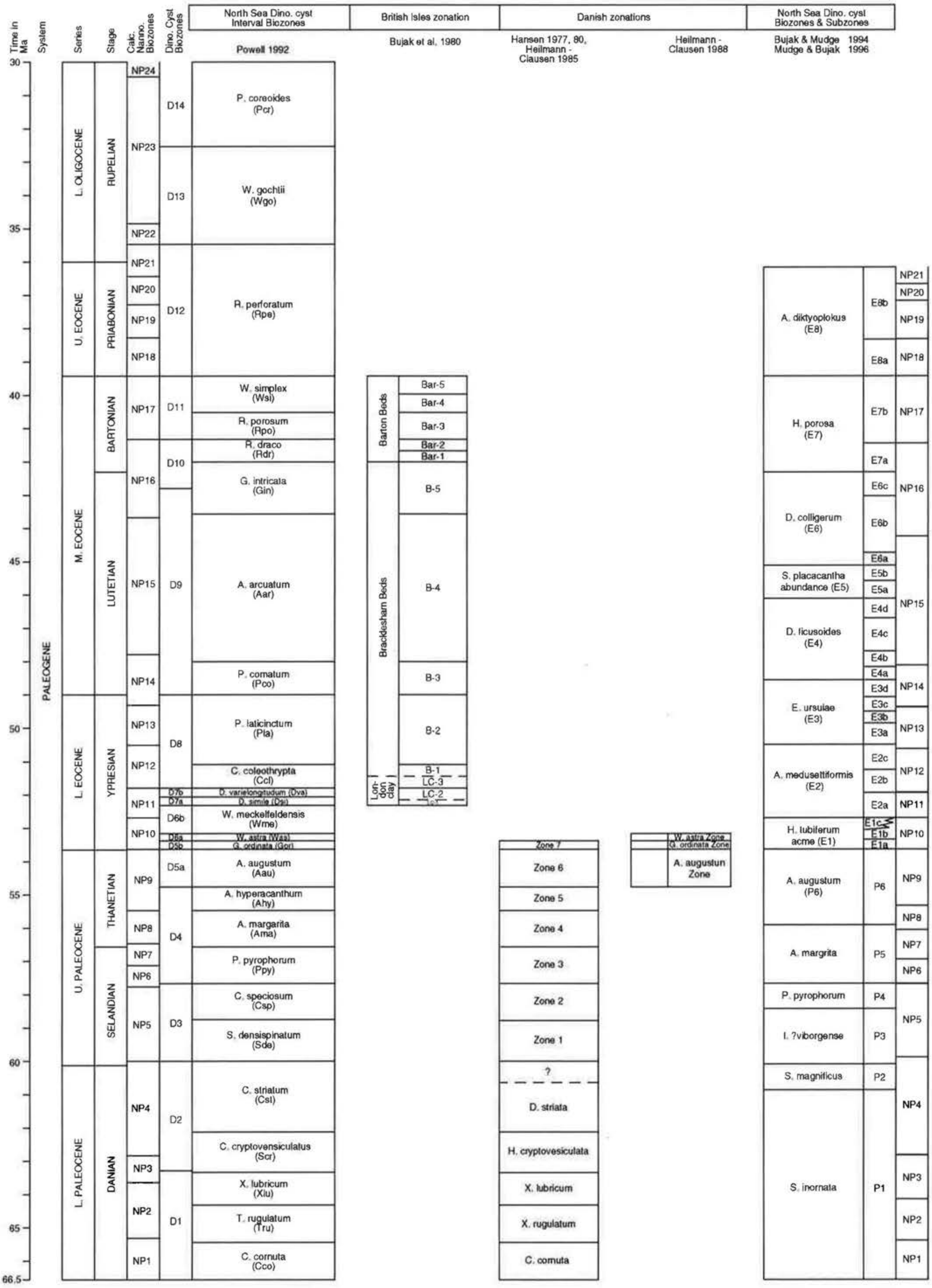

Fig. 2. Previous published dinoflagellate cyst zonations interval biozones from the North Sea region. The position of the Selandian/Thanetian boundary is according to Powell et al. (1996) situated at the base of the Alisocysta margarita (Ama) dinoflagellate cyst Interval Biozones (Powell, 1992) from the North Sea region, whereas Berggren et al. (1995) correlates the Selandian/Thanetian boundary with the middle part of NP 6.

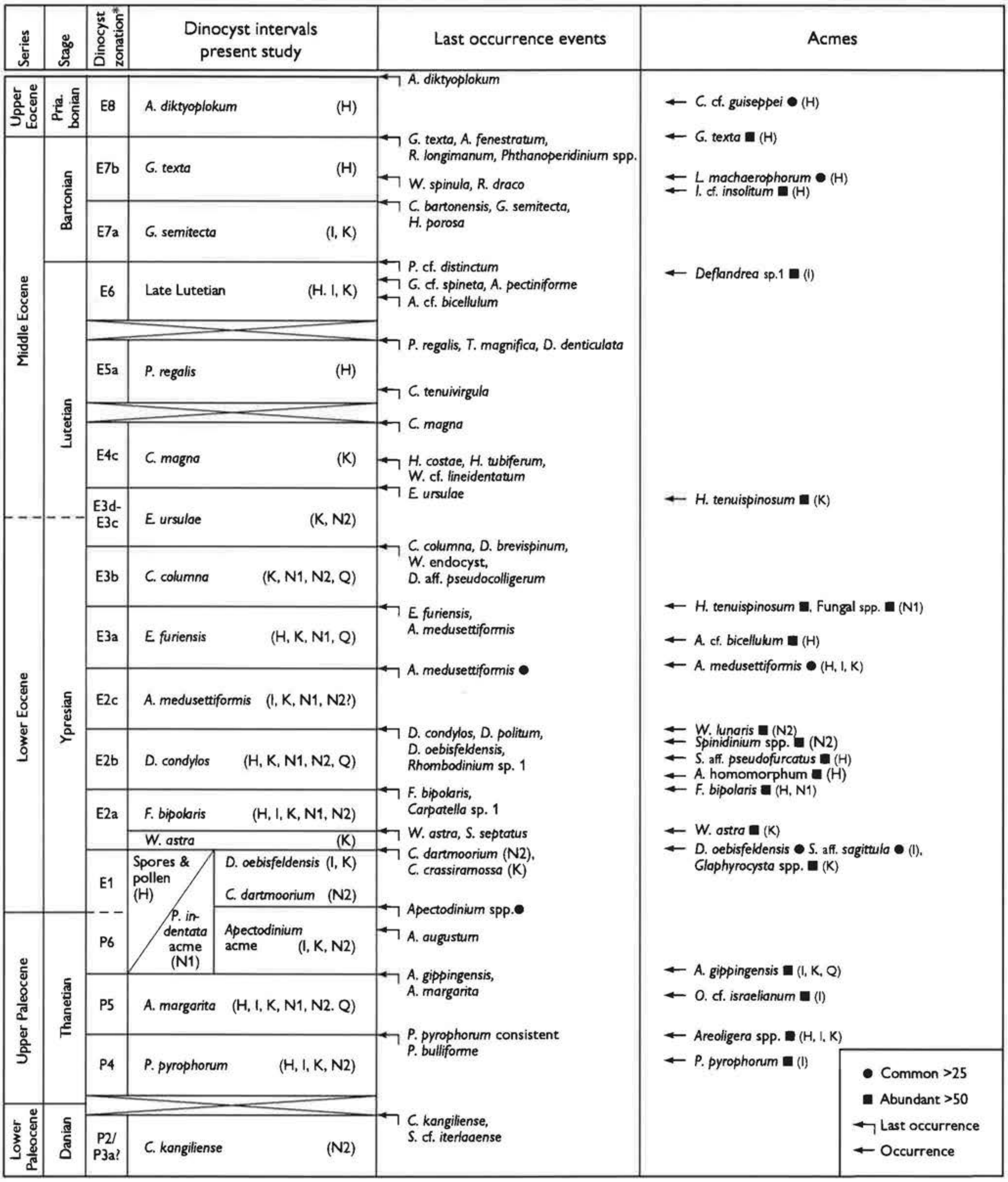

Fig. 3. Palaeogene dinocyst intervals and event offshore West Greenland, correlated with the dinocyst zonations* of Bujak & Mudge (1994) and Mudge& Bujak (1996a, b).

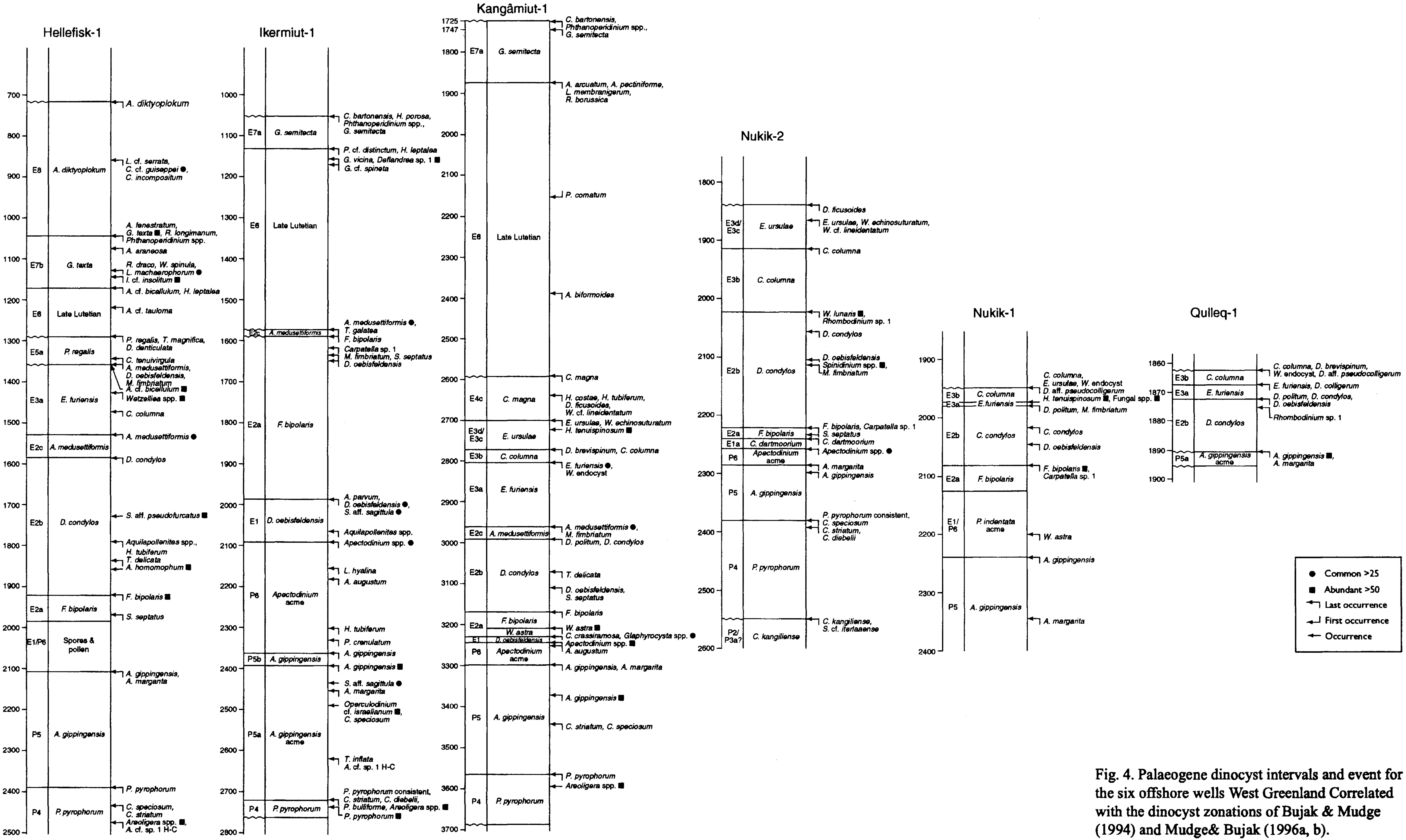

Fig. 4. Palaeogene dinocyst intervals and event for the six offshore wells West Greenland Correlated with the dinocyst zonations of Bujak & Mudge (1994) and Mudge& Bujak (1996a, b).

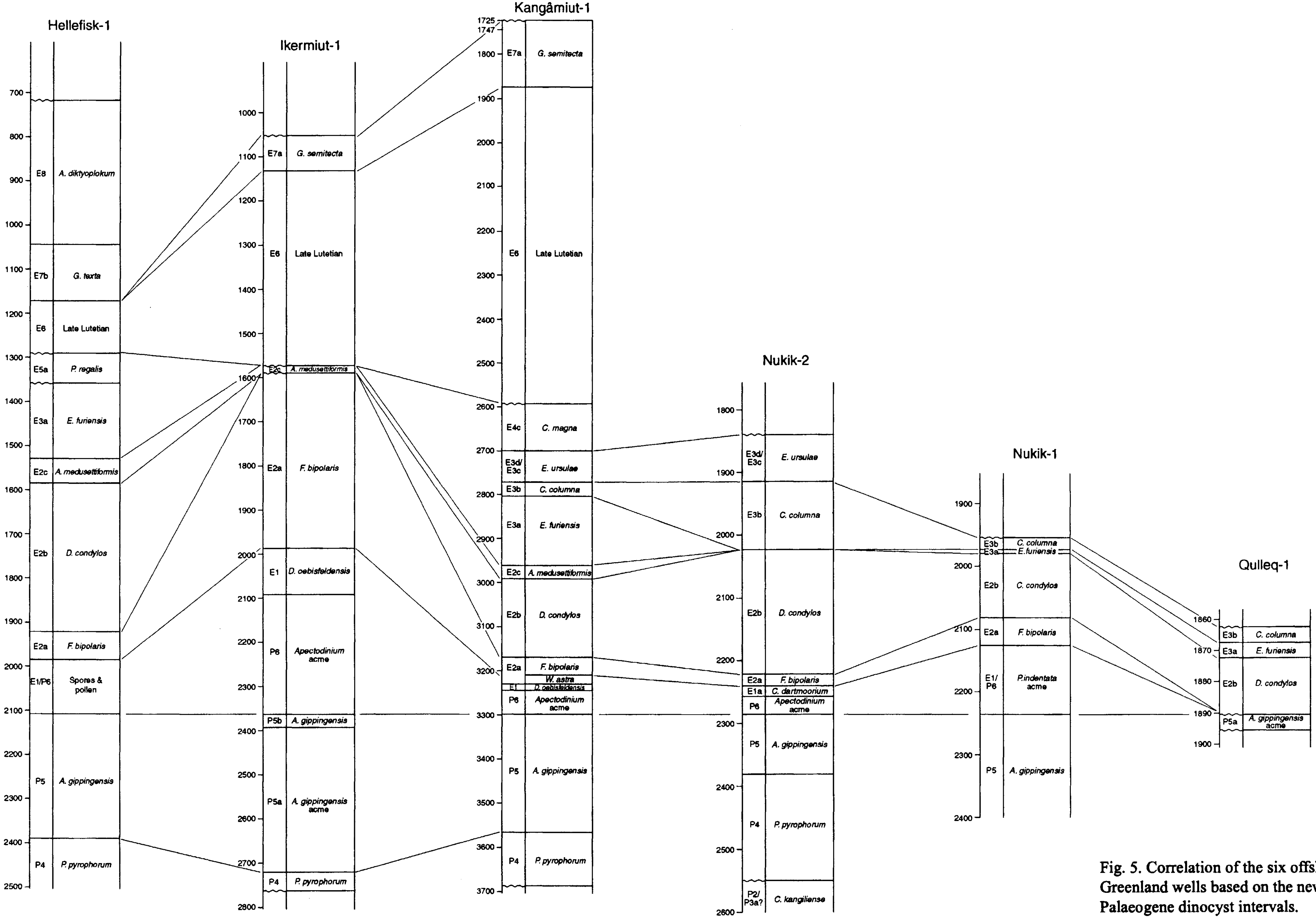

Fig. 5. Correlation of the six offshore West Greenland wells based on the new described Palaeogene dinocyst intervals.

Appendix 4

Palaeogene nannofossil biostratigraphy of the Kangâmiut-1 and Nukik-2 wells, offshore West Greenland

by

Emma Sheldon

Palaeogene nannofossil biostratigraphy of the Kangâmiut-1 and Nukik-2 wells, offshore West Greenland

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Abstract

A new Palaeogene nannofossil study has been made of the Kangâmiut-1 and Nukik-2 wells, offshore West Greenland. The stratigraphy presented herein has been correlated with previously established nannofossil zonation schemes and where possible used to indicate palaeoenvironmental changes during the Early and Middle Eocene. The stratigraphy and dating is based upon stratigraphically important species and palaeoenvironmental signals are based upon species influxes. A total of 69 samples (26 side wall cores and 43 ditch cuttings samples) were examined and where possible, were compared with findings from closely situated DSDP and ODP sites.

Keywords

Palaeogene, West Greenland, nannofossils

Introduction

Five exploration wells (Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1 and Nukik-2) were drilled offshore West Greenland (Fig. 1; Henderson, 1978, 1979, Henderson *et al.*, 1981) during 1976 and 1977 through Tertiary and Upper Cretaceous sediments. The lithostratigraphy, sedimentology and petroleum potential were described by Rolle (1985) and biostratigraphic studies were undertaken by Croxton (1981 a, b, c, d & e), Costa (1982) and Toxwenius (1986). The next exploration well to be drilled offshore West Greenland, Qulleq-1, was completed during the summer of 2000; with biostratigraphic studies undertaken by Nøhr-Hansen *et al.* (2000).

Following new geophysical interpretation of old and new seismic data from the area (Chalmers, 1991, Chalmers et al., 1993; Chalmers & Pulvertaft, 1993; Chalmers & Laursen, 1995, Chalmers et al., 1995; Bate et al., 1995), new micropalaeontological, palynological and nannofossil analyses were considered necessary as problems were encountered with the correlation of seismic sequences to the exploration wells.

The present nannofossil study of 2 of the wells; Kangâmiut-1 and Nukik-2, adds to dinoflagellate studies (Nøhr-Hansen, this volume), microfossil studies (Rasmussen & Sheldon, this volume), seismic sequence correlation (Chalmers *et al.*, this volume) and log correlation and palaeoenvironmental interpretaion (Dalhoff et al., this volume).

Technical data

Kangâmiut-1

Kangâmiut-1 was drilled by Total Grønland Olie A/S in 1976 at a position of 66^0 09' 01'' N and 56^0 11' 24'' W, in a water depth of 180 m (590'). The rotary table was positioned 12 m (41') above sea level and the well reached a terminal depth of 3874 m (12710') below rotary table in Precambrian basement. All depths in this paper are quoted in metres and are measured depth from the rotary table (MDRT).

Nukik-2

Nukik-2 was drilled by Mobil Exploration Greenland in 1977 at a position of 65^0 37' 54'' N and 54^0 46' 01'' W, in a water depth of 117 m (383'). The rotary table was positioned 24 m (80') above sea level and the well reached a terminal depth of 2694 m (8838') below rotary table in Maastrichtian basalt.

The results of the study have been compared with findings from DSDP sites 111, 112 and 113 and ODP sites 645, 646 and 647 which were situated in relatively close proximity to the afore-mentioned wells (Fig.1).

Materials and methods

The nannofossil samples were prepared using the pipette strew slide method described in Bown & Young, (1998); that is, by crushing approximately 1 cm^3 of sediment and adding it to distilled water, centrifuging and decanting. After shaking and allowing the suspension to settle, a few drops were pipetted from the middle of the liquid fraction, placed on a glass coverslip, spread evenly and allowed to dry. The coverslip was mounted, smear side down using *Norland Optical Adhesive* ® and allowed to cure in daylight for 24 hours. The nannofossil slides were studied with transmitted light using a Leitz Orthoplan microscope (No. 851318).

Number of samples analysed:	Kangâmiut-1	26 sidewall cores
	Nukik-2	43 ditch cutting samples

A full sample list is given in Appendix 1.

As a standard nannofossil zonation scheme has not been erected for the higher latitudes, reference has mainly been made in this report to the widely accepted schemes of the northern hemisphere of Martini (1971); (NP zonation), Okada & Buckry (1980) (CP zonation) and Varol (1998) (NNTp/NNTe/NNTo zonation). Where necessary, the dinoflagellate cyst schemes of Bujak & Mudge (1994) and Mudge & Bujak, (1996) (E zones), have been used. A zonal correlation can be seen in Fig. 2.

Nannofossil Biostratigraphy

Kangâmiut-1

The stratigraphic distribution of nannofossils in Kangâmiut-1 is found in Fig. 3 and the combined nannofossil/palynological biostratigraphy is found in Fig. 4. Note: shaded areas are samples barren of nannofossils and annotated samples are those with age indicative species. All other samples contain long ranging nannofossils. Of the 26 sidewall core samples examined, 9 were found to be barren of nannoflora.

1730–1192 m: Middle Eocene (NP16–18)

The sample at 1730 m contained a low abundance, high diversity nannofossil assemblage comprising *Cribrocentrum reticulatum*, *Markalius inversus*, *Neococcolithes dubius*, *Pontosphaera* spp., *Reticulofenestra minutula, Reticulofenestra ?pseudoumbilica, Reticulofenestra* cf. *umbilica*, *Toweius occulatus, Transversopontis pseudopulcher* and *Transversopontis pygmaea.*

Discussion:

The co-occurrence of *C. reticulatum* (NP15–21, CP14a–CP15B, NNTe9b–NNTe13), *N. dubius* (NP12–18, CP13c–15a, NNTe2–NNTe12a) and *R. umbilica* (NP16–22, CP14–16, NNTe10a–NNTe14) indicates the presence of Middle to Late Eocene nannofossil zones NP16–18.

The presence of longer ranging species such as *M. inversus* which ranges from the Cretaceous to the Middle Eocene (Perch-Nielsen 1985) suggests that the youngest age for this section is Middle Eocene. Other long ranging species include *Pontosphaera* which reach their maximum diversity during the Early and Middle Eocene (Perch-Nielsen 1985) and *T. pseudopulcher* (NP7–25, CP6–19, NNTp11b–NNTo12).

The nannofossil dating of this section supports the work of Nøhr-Hansen (this volume), which suggests that the age at this level is upper Middle Eocene; dinoflagellate zone E7a (Bujak & Mudge 1994), correlating with upper nannofossil zone NP16, (CP14a, NNTe10B).

Samples 1770–1992 m only included the long ranging species *Helicosphaera* spp., *Coccolithus pelagicus* and the calcareous dinoflagellate *Thoracosphaera* spp.

2025–2776.5 m: Early to Middle Eocene (NP10–16)

Apart from one sample at 2025 m, samples 2057–2339.5 m only yielded the long ranging species of calcareous dinoflagellate *Thoracosphaera* spp. Sample 2025 m, included *Chiasmolithus eograndis* and the long ranging *Markalius inversus* and is dated as NP10–13 (16). The presence of a single specimen of *C. eograndis* (NP10–NP13, CP9–11, NNTe1–NNTe7a) indicates an Early Eocene age according to most authors, however *C. eograndis* is not necessarily confined to the Early Eocene, as Firth (1989) recorded specimens in sediments of NP16 age in hole 647A of ODP Leg 105.

Based upon dinoflagellate cysts, Nøhr-Hansen (this volume) suggests an age of middle Middle Eocene (dinoflagellate zone E6, which correlates with nannofossil zones NP15–16, CP13b–14A, NNTe9a–NNTe10b) for this level.

The samples at 2386.5 m and 2422.5 m both contain specimens of *Reticulofenestra bisecta.* This species ranges throughout the Eocene and Oligocene (NP10–NN1, CP9a–CN1a, NNTe–NNTo12).

Samples 2467.5–2576 m do not contain any species useful for dating.

Samples 2656.5 m, 2725 m and 2776.5 m contain relatively high abundance and diversity assemblages including *Chiasmolithus ?edentulus*, *C. eograndis*, *C. grandis*, *C. medius, C. solitus*, *Coccolithus pelagicus*, *Cribrocentrum* spp., *Cruciplacolithus cribellum*, *C. cruciformis*, *Cruciplacolithus spp.*, *Neococcolithes dubius, N. minutus*, *Pontosphaera distincta, Pontosphaera* spp., *Reticulofenestra dictyoda*, *Reticulofenestra* spp., *Toweius occulatus, T. pertusus, Toweius spp.* and *Transversopontis pulcher*.

Discussion:

The presence of *C. eograndis* (NP10–NP13 (16), CP9–11 (13c–14a), NNTe1A–NNTeA (10)), *C. grandis* (NP11–17, CP9b–14b, NNTe1– NNTe11a), *R. dictyoda* (NP12–16, CP11–14a, NNTe2–NNTe10b), *P. distincta* (NP10–17, CP9–14, NNTe1–NNTe11a) and *C. solitus* (NP10–16, CP9a–CP14a, NNTe1–NNTe10) is indicative of an Early to Middle Eocene age.

C. medius (NP15, CP13b, NNTe8–NNTe9) indicates a Middle Eocene age, whereas occurrences of *Cruciplacolithus cruciformis* (NP10–14, CP9–12a, NNTe1–NNTe7b), *C. cribellum* (NP9–11, CP8b–9b, NTp16 – NNTe1, *Toweius occulatus* (NP12–13, CP10–11, NNTe2–NNTe7a), and *T. pertusus* (NP6 –12, CP5–10, NTp10 – NNTe5), point to an Early Eocene age. Also, while *Chiasmolithus edentulus* is dated as Early Paleocene to Early Eocene (NP4–11, CP3–9b, NNTp4D–NNTe1D) by Perch-Nielsen (1985) & Okada & Buckry (1980), Varol (1998) suggests it ranges from NNTp4F–NNTp10 (NP4 – NP5, CP3 – CP4); Early to Middle Paleocene.

Specimens of *Neococcolithes dubius* (NP12–18, CP10–15a, NNTe2–NNTe12a) and *N. minutus* (NP13–19, CP11–15b, NNTe6–NNTe12b) are indicative of an Early to Late Eocene age.

Long ranging species include *C. pelagicus, Pontosphaera* spp*., Reticulofenestra* spp., and *T. pulcher*.

The nannofloral assemblages in these samples indicate an Early to Middle Eocene age. It is possible that the Early Eocene indicative specimens could be reworked into younger, Middle Eocene sediments. This would support the work of Nøhr-Hansen (this volume) who correlates the lower part of the interval 2640-2770 m with dinoflagellate subzones E3c–E4c?, Bujak & Mudge (1994), and the lowest part with upper E3a–E3c, (correlating with nannofossil zones NP14–15, CP12a–13a, NNTe7B–NNTe8B).
The zonation scheme of Varol (1989b) has been included here as that of Varol (1998) is incomplete at upper Paleocene level.

2844–2922 m: Early Eocene (NP12)

Samples 2844 m and 2922 m once again contain fairly high abundance and diversity assemblages including *Chiasmolithus expansus*, *Coccolithus pelagicus*, *Cribrocentrum* spp*., Cruciplacolithus ?latipons, Neococcolithes dubius, N. minutus, Pontosphaera* spp., *Reticulofenestra dictyoda*, *Toweius occulatus*, *T. pertusus*, *Transversopontis exilis*, and *Transversopontis pulcher*.

Discussion:

R. dictyoda (NP12–16, CP11–14a, NNTe2–NNTe10b) and *Chiasmolithus expansus* (NP12–16, CP10–16a, NNTe2–NNTe10b) range from the Early to Middle Eocene, however the occurrence of *T. occulatus* (NP12–13, CP10–11, NNTe2–NNTe7a) and *T. pertusus* (NP6–12, CP5–10, NTp10–NNTe5 point to an Early Eocene age.

Specimens of *N. dubius* (NP12–18, CP10–15a, NNTe2–NNTe12a) and *N. minutus* (NP13–19, CP11–15b, NNTe6–NNTe12b) are indicative of an Early to Late Eocene age. This correlates with palynology Subzone 3a (Nøhr-Hansen, this volume). Longer ranging species include *C. pelagicus*, *Pontosphaera* spp., *T. pulcher* and *T. exilis.*

According to Perch-Nielsen (1985) and Okada & Buckry (1980) *C. latipons* ranges from the Middle to uppermost Paleocene (NP4–NP9 and CP3–8b); this correlates with zones NTp7–NTp20. It is possible that this species has been reworked into younger, Eocene sediments.

The zonation scheme of Varol (1989b) has once again been included here as that of Varol (1998) is incomplete at upper Paleocene level.

Samples 3694.5 m and 3744 m do not contain any useful marker species.

Nukik-2

The stratigraphic distribution of nannofossils in Nukik-2 is found in Fig. 5 and the combined nannofossil/palynological biostratigraphy is found in Fig. 6. Note: shaded areas are samples barren of nannofossils and annotated samples are those with age indicative species. All other samples contain long ranging nannofossils. Of the 43 ditch cutting samples examined, 22 were found to be barren of nannoflora.

1753 m: Early – Middle Eocene (NP12–16)

The presence of *H. seminulum* (NP 12–16, CP10–14a, NNTe2–NNTe10B) indicates an Early to Middle Eocene age and the presence of the long ranging *M. decussata* (CC14–NP15, CC14–CP13c, UC10–NNTe10A) supports this dating. However the low abundance of nannofossils in this sample prevents accurate dating.

1762–1817 m: Middle – Late Eocene

Assemblages include only very few specimens of *Sphenolithus pseudoradians* and possible *S. radians* .

Discussion:

The presence of *S. pseudoradians* (NP 15–24, CP15–19, NNTe8B–NNTo8) indicates a Middle Eocene to Late Oligocene age according to Perch-Nielsen (1985b) and a Late Eocene to Late Oligocene age according to Okada & Buckry (1980). The poor preservation of the calcareous component of the sample at 1817m prevented a definate species identification, however, the presence of *P. radians* (NP 11–19, CP9–15, NNTe1–NNTe12B) would indicate an Early to Late Eocene age.

1826 m: Middle Eocene NP 14–16

The presence of *D. wemmelensis* (NP14–16, CP12b–14a, NNTe8A–NNTe10B) indicates a Middle Eocene age.

1844 m–1999 m: Early – Middle Eocene (NP10–16)

The very low abundance and diversity assemblages include specimens of *Chiasmolithus solitus, Chiasmolithus* spp., *Discoaster germanicus, Discoaster* spp,. *D. wemmelensis, Helicosphaera seminulum, Sphenolithus pseudoradians, S. radians, Sphenolithus* spp., and *Thoacosphaera* spp.

Discussion:

The nannopalaeontology only acts as a support for the palynological dating of Subzones E3b-d, Nøhr-Hansen (this volume) as most nannofossil specimens are relatively long ranging.

The presence of *Ch. solitus* (NP10–16, CP9a–CP14a, NNTe1–NNTe10), *D. germanicus* (NP12–16, CP10–14a, NNTe2–NNTe10B) and *H. seminulum* (NP 12–16, CP10–14a, NNTe2–NNTe10B) indicate an Early to Middle Eocene age.

The occurrence of *D. wemmelensis* (NP14–16, CP12b–14a, NNTe8B–NNTe10B) indicates a Middle Eocene age, while the presence of *S. radians* (NP 11–19, CP9–15, NNTe1–NNTe12B) indicates an Early to Late Eocene age.

The co-occurrence of *S. radians* (NP 11–19, CP9–15, NNTe1–NNTe12B) and *S. pseudoradians* (NP 15–24, CP15–19, NNTe8B–NNTo8) would indicate a Middle to Late Eocene age.

2018–2219 m: Early Eocene (NP12 – 13)

The assemblages once again show very low abundance and diversity, and comprise *Chiasmolithus ?consuetus*, *Chiasmolithus* spp., *Discoaster barbadiensis, D. wemmelensis, Helicosphaera seminulum, Helicosphaera* spp., *Markalius inversus, Pontosphaera* spp., *Thoracosphaera ?operculata,* and *Thoracosphaera* spp.

Discussion:

Due to their low abundance and diverstiy, nannofossils were only used to supplement the palynological dating (Nøhr-Hansen, this volume) in this section.
The presence of *Ch. consuetus* (NP4–19, CP4–15b, NNTp4d–NNTe12b) indicates a Middle Paleocene to Late Eocene age. The presence of *H. seminulum* (NP 12–16, CP10–14a, NNTe2–NNTe10b) indicates an Early to Middle Eocene age, while that of *D. barbadiensis* (NP10–20, CP9a–15b, NNTe1–NNTe12B) indicates an Early to Late Eocene age.

The occurrence of *D. wemmelensis* (NP14–16, CP12b–14a, NNTe8A–NNTe10B) indicates a Middle Eocene age, but it is possible that this is caved from higher up section.

The presence of the long ranging species *M. inversus* which ranges from the Cretaceous to the middle Eocene (Perch-Nielsen 1985), suggests a youngest age of Middle Eocene for this section. *Helicosphaera* and *Pontosphaera* are also long ranging genera, and due to their poor preservation in this sample, could not be identified down to species level. *Helicosphaera* are common from the Early Eocene to the present and *Pontosphaera* reach their maximum diversity during the Early and Middle Eocene (Perch-Nielsen 1985).

2237–2301m: Late Paleocene – Early Eocene (NP9–NP11)

The presence of single specimens of *Thoracospahera* spp. and *D. bifax* (NP16, CP14a, NNTe7B–NNTe10B) indicates a Middle Eocene age. However, poor preservation renders the dating tentative. Also the fact that the samples from Nukik-2 are ditch cuttings samples means that material could have been caved from higher up section. Palynological analysis dates this section as zones P5–E2a of Bujak & Mudge (1994), which correlates with nannofossil zones NP 9–11 (CP8-CP9b, -NNTe1D).

Previous work:

DSDP Leg 12

This DSDP leg was undertaken in 1970, with sites 111 (Orphan Knoll, north-east of Newfoundland),112 (Southern Labrador Sea) and 113 (Labrador Sea Axis) drilled relatively close to Kangâmiut-1 and Nukik-2 (Fig 1). Eocene sediments were encountered in each of the three sites and were examined by Perch-Nielsen & Buckry (1972). Nannofossil zonation schemes for the lower latitiudes were utilised instead of erecting a new high latitude scheme, as in this leg nannofossils were primarily used to obtain approximate absolute ages of the sediments in order to calculate sedimentation rates.

In DSDP Leg 12, the Early to Middle Eocene (the equivalent sections that were encountered in Kangâmiut-1 and Nukik-2) were divided into calcareous nannofossil zones NP10–16 (Martini 1971). Fig. 7 shows selected nannofossil species found in Leg 12 and can be compared with Kangâmiut-1 and Nukik-2 (Figs. 3, 4, 5 and 6).

Discussion and Palaeoecology:

It was noted in Leg 12 that certain nannofossil species have palaeoecological significance in the Early and Middle Eocene. Buckry (1972) noted the lack of species of *Discoaster* in high latitude assemblages and as these are one of the most solution resistant groups, he concluded that their absence has palaeoecological significance; primarily reduced ocean-surface temperatures. Nukik-2 does have a few *Discoaster* species, but these are too few to be significant. They were not found in Kangâmiut-1.

ODP Leg 105

ODP Sites 645 (Baffin Bay), 646 (West of the Eirik Ridge, Central Labrador Sea) and 647 (Southern Labrador Sea) from Leg 105 were also drilled relatively close to Kangâmiut-1 and Nukik-2 in 1985. Only Site 647A will be discussed here as Site 645 and 646 did not encounter any sediments older than Miocene age.

The Early to Middle Eocene (Zones NP11–NP18) biostratigraphy from Site 647A can be seen in Fig. 8. Note the barren interval spanning NP14. This can be compared to the biostratigraphy of Kangâmiut-1 and Nukik-2 (Figs. 3 ,4, 6 and 7).
According to Firth (1989), the sediments from Leg 105 contained a diverse, well-preserved, high latitude nannoflora; this is in contrast to the Nukik-2 well in particular, where nannofossil abundance and diversity was very poor, with many samples being completely barren of flora. Kangâmiut-1 yielded a more diverse and abundant nannoflora.

Discussion and Palaeoecology:

It was also noted at site 647A that certain nannofossil species have palaeoecological significance in the Middle Eocene (Firth 1989).

Mid to high latitude indicators such as *Reticulofenestra* spp., *Chiasmolithus* spp. and *Coccolithus* spp. dominate in the Middle Eocene of Site 647A, although nearshore, shallow water indicators such as *Transversopontis* spp., *Pontosphaera* spp. and *Helicosphaera* spp. show high diversity but low abundance assemblages, indicating a relatively deep water paleoenvironment. This also appears to be the case in Kangâmiut-1 where specimens of *Reticulofenestra*, *Chiasmolithus* and *Coccolithus* are fairly common in the Middle Eocene (Figs. 3 and 4) and *Transversopontis exilis, Transversopontis pulcher, Transversopontis pygmaea, Transversopontis pseudopulcher, Pontosphaera distincta* and *Pontosphaera* spp. are present, although not in high numbers.

At site 647A, common *Toweius pertusus* and *C. pelagicus* were found together in the lowermost Eocene samples. This assemblage occured in the lower latitudes in the Paleocene and is thought to have migrated to higher latitudes during the Early and Middle Eocene (Firth 1989) as a warm water incursion. Kangâmiut-1 shows a similar relationship in the Early Eocene with common *Toweius occulatus* occurring simultaneously with *C. pelagicus*.
At site 647A, the Early Eocene assemblages were dominated by *Transversopontis pulcher* (a neritic environmental indicator) and by *C. pelagicus*, *T. occulatus* and *Discoaster* spp. The same pattern (apart from an absence of *Discoaster* spp.) occurs in the Early Eocene of Kangâmiut-1 and is thought to another warm water indicator (see also Gradstein & Srivastava 1980) who used planktonic foraminifera to indicate warm surafce waters in the Labrador Sea during the Early to Middle Eocene. The data from Kangâmiut-1 appears to support indicatations of warmer temperatures in the Early Eocene and more temperate conditions in the rest of the Middle Eocene.

Unfortunately the scarceity of nannofossils in Nukik-2 prevents useful palaeoecological interpretation.

Acknowledgements

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Appendix 1

Samples analysed for micropalaeontology

Kangâmiut-1 (all sidewall cores)

1730 m

1770 m

1834 m

1892.5 m

1942 m

1992 m

2025 m

2057 m

2097 m

2159 m

2251 m

2290 m

2339.5 m

2386.5 m

2422.5 m

2467.5 m

2505 m

2558 m

2576 m

2656.5 m

2725 m

2776.5 m

2844 m

2922 m

3694.5 m

3744 m

Nukik-2 (all ditch cuttings samples)

1753 m

1762 m

1771 m

1780 m

1789 m

1798 m

1807 m

1817 m

1826 m

1835 m

1844 m

1853 m

1862 m

1871 m

1881 m

1890 m

1899 m

1908 m

1917 m

1926 m

1935 m

1945 m

1954 m

1963 m

1981 m

1999 m

2018 m

2036 m

2054 m

2073 m

2091 m

2109 m

2128 m

2146 m

2164 m

2182 m

2201 m

2219 m

2237 m

2256 m

2274 m

2292 m

2301 m

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Figure captions

Fig. 1 Locality map showing exploration wells, offshore West Greenland, ODP sites (Leg 105) and DSDP sites (Leg 12)

Fig. 2. Correlation of nannofossil and palynology zones

Fig. 3. Kangâmiut-1: nannofossil range chart

Fig. 4. Kangâmiut-1: nannofossil and palynological dating

Fig. 5. Nukik-2: nannofossil range chart

Fig. 6. Nukik-2: nannofossil and palynological dating

Fig. 7. Ranges of selected nannofossil species from DSDP Leg 12 also encountered in the present study

Fig. 8. Ranges of selected nannofossil species from ODP Leg 105, Site 647A also encountered inthis study

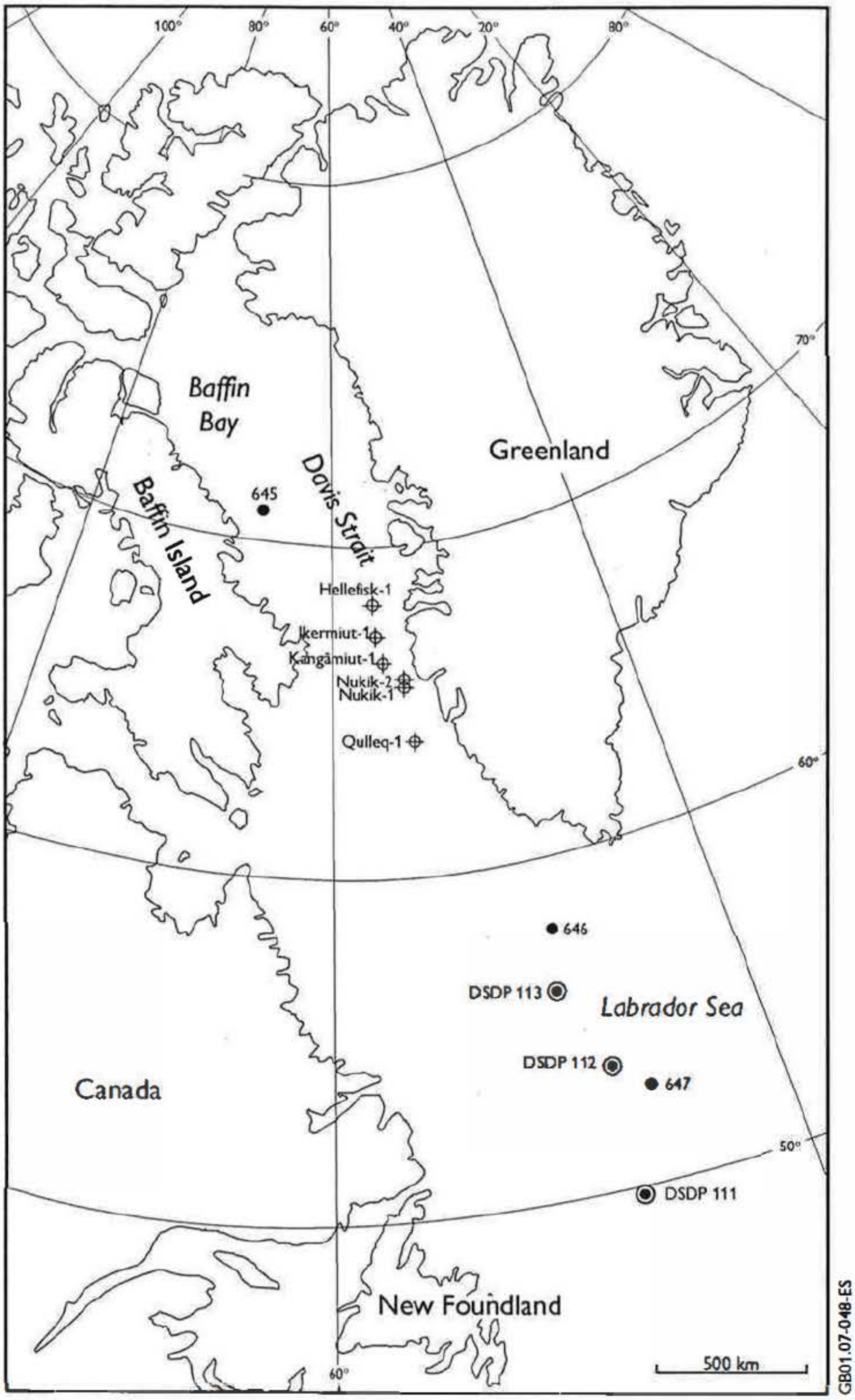

Fig 1. Locality map showing exploration wells, offshore West Greenland, ODP sites (leg 105) and DSDP sites (leg 12).

Series	Stage	Nannofossil zonations: Martini 1971	Nannofossil zonations: Okada & Bukry1980	Nannofossil zonations: Varol 1998		Dinocyst zonation: Bujak & Mudge1994	
U. Eocene	Priab.	NP21	CP16 pars.	NNTe14		E8	b
				NNTe13			
		NP20-NP19	CP15 b	NNTe12	B		
		NP18	CP15 a		A		a
Middle Eocene	Bart.			NNTe11	B		
		NP17	CP14 b		A	E7	b
		NP16	CP14 a	NNTe10	B		a
	Lutetian					E6	c
			CP13 c		A		b
		NP15		NNTe9	B		a
			CP13 b		A	E5	b
							a
				NNTe8	B	E4	d
			CP13 a				c
		NP14	CP12 b		A		b
							a
Lower Eocene	Ypresian		CP12 a	NNTe7	B	E3	d
							c
					A		b
		NP13	CP11				a
				NNTe6		E2	c
		NP12	CP10	NNTe5			
				NNTe4			b
				NNTe3			
				NNTe2			a
		NP11-NP10	CP9 b	NNTe1	D		
					C		
					B		
			CP9 a		A	E1	b
				Not zoned			a

Figure 2. Correlation of nannofossil and palynology zones

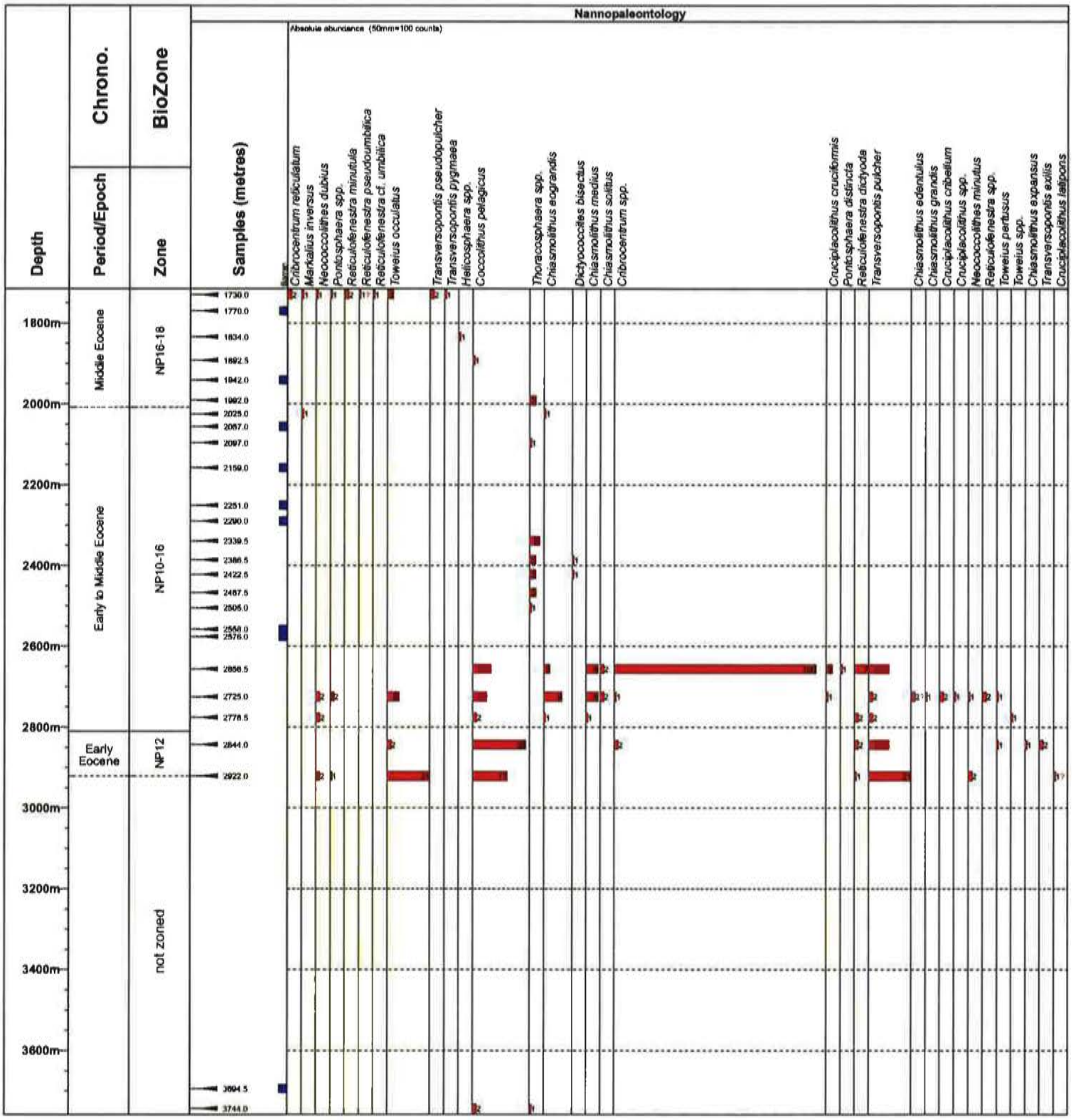

Figure 3. Kangamiut-1: nannofossil range chart.

Age	Sample depth (m)	Nannofossil Age	Martini 1971	Okada & Bukry 1980	Varol 1998	Palynological age Nøhr-Hansen (this volume)	Bujak & Mudge 1994 Mudge & Bujak 1996
Middle	1730	Middle Eocene	NP 16-18	CP13c-15a	NNTe10A-NNTe12A		
Eocene	1770					Upper Middle Eocene	E7a
	1834						
NP16-18	1892.5						
	1942						
	1992						
	2025	Middle Eocene	NP 10-13 (16)	CP9a-CP11 (13c-14a)	NNTe1-NNTe7a (10)		
	2057						
	2097						
Early	2159						
	2251						
to	2290					Middle Middle Eocene	E6
	2339.5						
Middle	2386.5	Early Eocene-(Late Oligocene)	NP10-NN1	CP9a-CN1a	NNTe1-?		
	2422.5	Early Eocene-(Late Oligocene)	NP10-NN1	CP9a-CN1a	NNTe1-?		
Eocene	2467.5						
	2505						
	2558						
NP10-16	2576						
	2656.5	Early-Middle Eocene	NP10-NP16	CP9a-CP14a	NNTe1A-NNTe10B	Latest Early Eocene-Lower Middle Eocene	E3d-E4c?
	2725	Early-Middle Eocene	NP10-NP16	CP9a-CP14a	NNTe1A-NNTe10B	Latest Early Eocene-Lower Middle Eocene	E3c-E3d?
	2776.5	Early-Middle Eocene	NP10-NP16	CP9a-CP14a	NNTe1A-NNTe10B	Late Early Eocene	upper E3a-E3c
Ey. Eoc.	2844	Early Eocene	NP12	CP10	NNTe2-NNTe5		
NP12	2922	Early Eocene	NP12	CP10	NNTe2-NNTe5	Early Eocene	E3a
	3694.5						
	3744						

Figure 4. Kangamiut-1: nannofossil and palynological dating (hashed areas indicate samples barren of nannofossils)

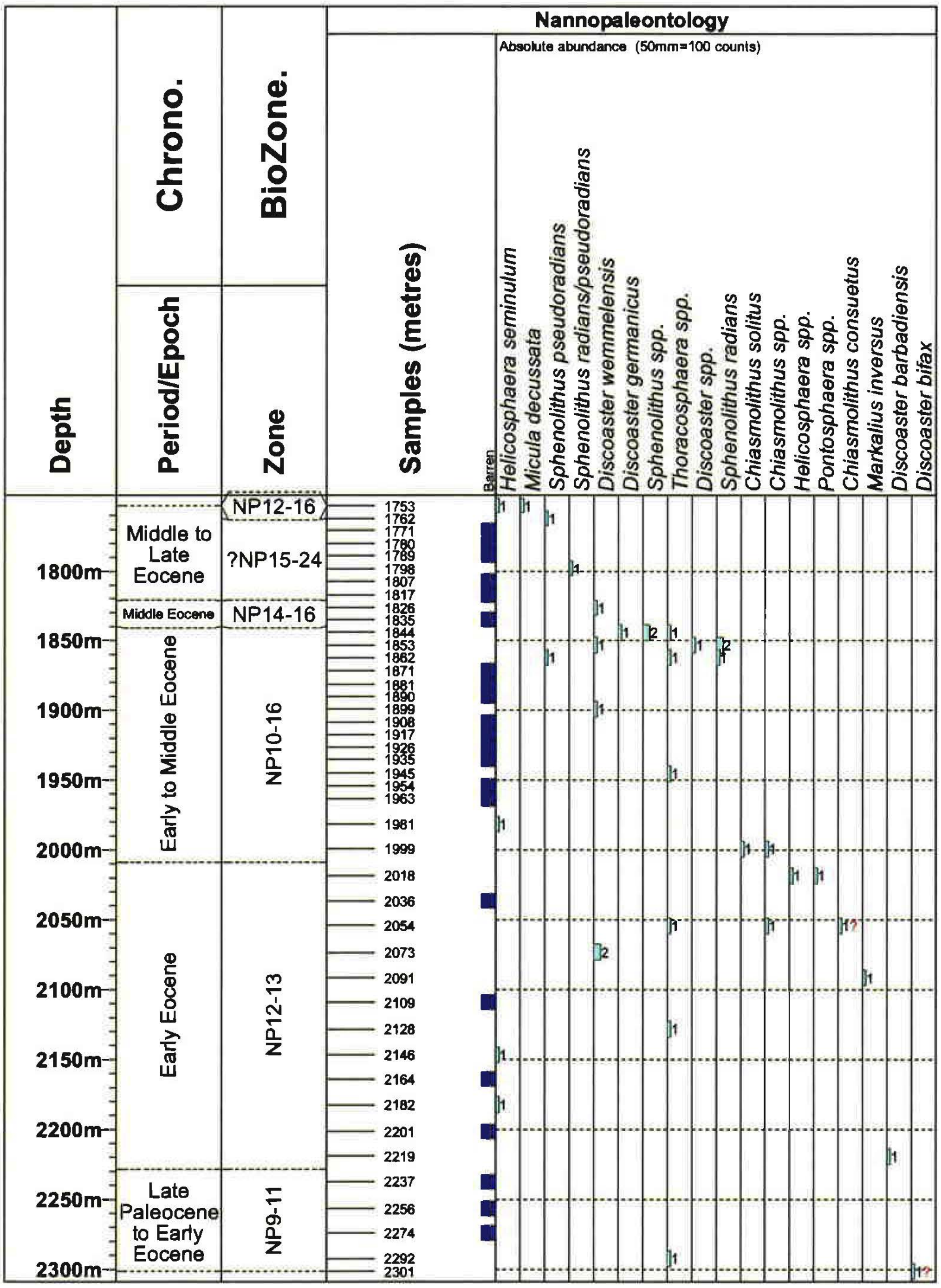

Figure 5. Nukik-2: nannofossil range chart.

Age	Sample depth (m)	Nannofossil Age	Martini 1971	Okada & Bukry 1980	Varol 1998	Palynological age Nøhr-Hansen (this volume)	Bujak & Mudge 1994 Mudge & Bujak 1996
	1753	Early-Middle Eocene	NP12-16	CP10-14a	NNTe2-NNTe10B		
	1762	Middle-Late Eocene	NP15-(24)	CP 13a-(19)	NNTe8B-NNTo8		
Middle	1771						
to	1780						
Late	1789						
Eocene	1798	Middle-Late Eocene	NP15-(24)	CP 13a-(19)	NNTe8B-NNTo8		
NP??	1807						
	1817						
Mid. Eoc.	1826	Middle Eocene	NP14-16	CP12b-14a	NNTe12A-NNTe10B		
NP14-16	1835						
	1844	Early-Middle Eocene	NP12-16	CP10-14a	NNTe2-NNTe10B		
	1853	Early-Middle Eocene	NP11-19	CP9-15	NNTe1-NNTe12B		
	1862	Middle-Late Eocene	NP11-24	CP9-19	NNTe1-NNTo8		
Early	1871					Upper Ypresian-Lower Lutetian	E3c-E3d
	1881						
to	1890						
	1899	Middle Eocene	NP14-16	CP12b-14a	NNTe12A-NNTe10B		
Middle	1908						
	1917						
Eocene	1926						
	1935						
	1945						
NP10-16	1954					Upper Ypresian	E3b
	1963						
	1981	Early-Middle Eocene	NP12-16	CP10-14a	NNTe2-NNTe10B		
	1999	Early-Middle Eocene	NP10-16	CP 9a-14a	NNTe1-NNTe10		
	2018						
	2036						
	2054						
Early	2073	Early-Middle Eocene (d.wemel)	Chech DSDP Leg 12				
	2091						
Eocene	2109					Middle-Upper Ypresian (Early Eocene)	
	2128						E2b
	2146	Early-Middle Eocene	NP12-16	CP10-14a	NNTe2-NNTe10B		
NP12-13	2164						
	2182	Early-Middle Eocene	NP12-16	CP10-14a	NNTe2-NNTe10B		
	2201						
	2219	Early-Late Eocene	NP10-20	CP9a-15b	NNTe1-NNTe12B		
	2237					Upper Thanetian-Lower Ypresian (Upper Paleocene-Lower Eocen	P6-E1-E2a
Late Pal.-	2256						
Ey. Eoc.	2274					Middle-Upper Thanetian (Upper Paleocene)	P5-P6
NP9-11	2292						
	2301						

Figure 6. Nukik-2: nannofossil and palynological dating (hashed areas indicate samples barren of nannofossils)

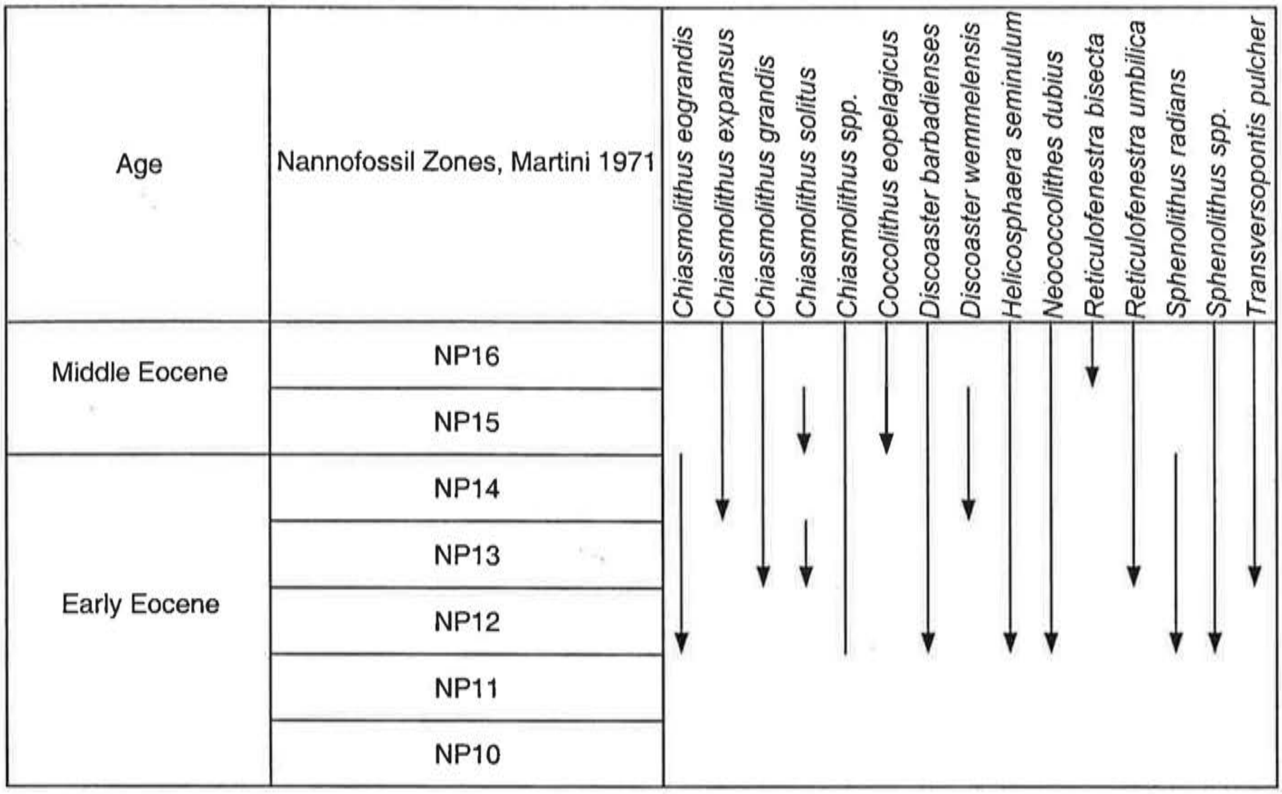

Figure 7. Ranges of selected nannofossil species from DSDP Leg 12 also encountered in this study

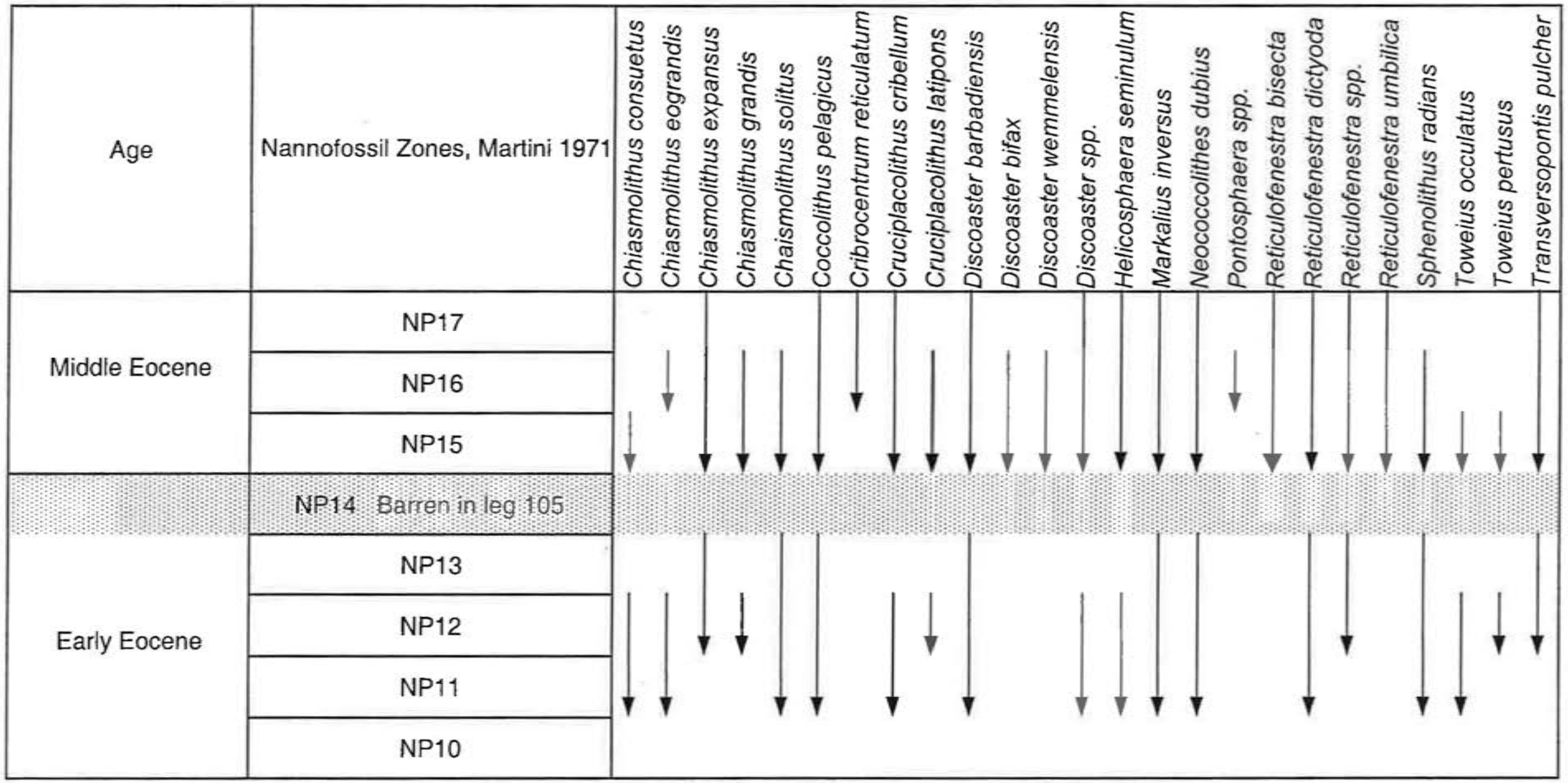

Figure 8. Ranges of selected nannofossil species from ODP Leg 105, Site 647A also encountered in this study

Appendix 5

Microfossil biostratigraphy of the Palaeogene succession in the Davis Strait, offshore West Greenland

by

Jan Audun Rasmussen and Emma Sheldon

Microfossil biostratigraphy of the Palaeogene succession in the Davis Strait, offshore West Greenland

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Abstract

A microfossil based biostratigraphy of the Paleocene and Lower Eocene sediments of the Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1, and Nukik-2 wells offshore West Greenland has been established. In general, the five wells contain fairly well-preserved, diverse microfossil faunas and floras consisting mainly of foraminifera, radiolaria, ostracods and diatoms. The studied interval was subdivided into three foraminifera zones (the *Stensioeina beccariiformis*, *Praeglobobulimina ovata* and *Pseudohastigerina wilcoxensis* zones) and five zones based on additional microfossil groups (the *Thalassiosiropsis wittiana*, *Fenestrella antiqua-Coscinodiscus morsianus*, Ostracod, *Aulacodiscus hirtus* and *Cenodiscus-Cenosphaera* zones). The biozones are more easily recognised in the two basinal wells, Ikermiut-1 and Kangâmiut-1, than in the three more nearshore wells, Nukik-1, Nukik-2 and Hellefisk-1, due to a higher microfossil diversity and abundance.

Key words

North Atlantic, Palaeogene, Biostratigraphy

Introduction

The present study is based on samples from five dry exploration wells, Hellefisk-1 (Arco Greenland Inc.), Ikermiut-1 (Chevron Petroleum Co.), Kangâmiut-1 (Total Grønland Olie A/S), Nukik-1 and Nukik-2 (Mobil Exploration Greenland Inc.), which were drilled during 1976 and 1977 (e.g. Henderson, Schiener, Risum, Croxton & Andersen, 1981; Rolle, 1985). All wells were plugged and abandoned. The technical data for the five wells have been published by Rolle (1985) and Nøhr-Hansen (this volume).

The five wells are situated on the West Greenland margin between 65–68° N, and 54–57° W in the Davis Strait between southern West Greenland and Baffin Island of the eastern margin of

Canada (Fig. 1). The Davis Strait is an about 300 km wide seaway, connecting Baffin Bay to the north with the Labrador Sea to the south.

The discovery of seeping oil onshore Nuussuaq in 1992 (Christiansen, Bojesen-Koefoed, Dam, Nytoft, Larsen, Pedersen, & Pulvertaft, 1996; Bojesen-Koefoed, Christiansen, Nytoft, & Pedersen, 1999) together with new results from the reinterpretation of older seismic data (e.g. Chalmers, Pulvertaft, Christiansen, Larsen, Laursen & Ottesen, 1993) has greatly increased the interest in West Greenland as a petroleum province. This has led to new licenses and acquisition of new seismic data from offshore West Greenland, which has subsequently revealed the need for an improved stratigraphic framework. Microfossils from the Palaeogene succession onshore West Greenland (Nuussuaq Basin) were first recorded by Ravn (1918) who mentioned the occurrence of two foraminifera species in burned shales from Atâ at southern Nuussuaq. Subsequently, the foraminiferal fauna was described by Hansen (1970), molluscs by Rosenkrantz (1970), nannofossils by Jürgensen & Mikkelsen (1974), Nøhr-Hansen & Sheldon (2000), Nøhr-Hansen, Sheldon & Dam (in press) and Sheldon (this volume), and dinoflagellates by Hansen (1980), Nøhr-Hansen & Dam (1997), Nøhr-Hansen (1998, this volume) and Nøhr-Hansen, Sheldon & Dam (in press).

The microfauna and biostratigraphy of Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1 and Nukik-2 were described by Toxwenius (1986a, b). Toxwenius compiled microfossil data from earlier company reports and unpublished papers and added it to a new study of the foraminifera fauna of the five wells. He adopted the benthic micropalaeontological stratigraphical assemblages proposed by Gradstein & Agterberg (1982), which were based on material from the Labrador Shelf and northern Grand Banks (Fig. 2). It was shown by Nøhr-Hansen (1998) and Christiansen, Boesen, Bojesen-Kofoed, Chalmers, Dalhoff, Dam *et al.*, (1999) that significant differences occur between the palynostratigraphical interpretations of Toxwenius (1986a) and that of Nøhr-Hansen (1998). As well as attempting to erect a detailed biostratigraphic zonation of the lower Palaeogene succession, one of the goals of the present study is to demonstrate whether a new biostratigraphic interpretation of the microfossil faunas will shed further light on the newly revised palynostratigraphy of Nøhr-Hansen (1998).

Palaeogene sediments are also known from the Qulleq-1 (6354/4-1) well drilled by Statoil in 2000 (Nøhr-Hansen, Piasecki, Rasmussen & Sheldon, 2000; Pegrum, Ødegård, Bonde, & Hamann, 2001; Christiansen, Bojesen-Koefoed, Chalmers, Dalhoff, Mathiesen, Sønderholm, *et al.,* 2001; Nøhr-Hansen, this volume) approximately 300 km south of Nukik-1 and 150 km west of Nuuk.

Very limited amount of microfossil biostratigraphic information on the Palaeogene succession is available from the area offshore West Greenland, whereas more detailed information is available from the Canadian margin of the Labrador Sea (e.g. Gradstein & Berggren, 1981; Gradstein & Agterberg, 1982; Williams, Ascoli, Barss, Bujak, Davies, Fensome & Williamson, 1990; Gradstein, Kaminski, Berggren, Kristiansen & D'Iorio, 1994).
During Ocean Drilling Program Leg 105 undertaken in 1985, three sites were positioned between Greenland and Canada. Site 645 was situated in the southern part of Baffin Bay, offshore Baffin Island, about 500 km NW of Hellefisk-1, while sites 646 and 647 were situated in the Labrador Sea; site 646 between southwestern Greenland and central Labrador. The southernmost site, 647, was situated to the south of Greenland and east of southern Labrador, more than 700 km from both coastlines. The drill holes at sites 645 and 646 did not penetrate sediments of older than Miocene age (Srivastava, Arthur, Clement *et al.*, 1989), while drill hole 647A terminated in Early Eocene sediments. Early

Geological setting

The geological setting of the investigated area is described thoroughly by Chalmers, Gregersen, Dalhoff, Nøhr-Hansen, Rasmussen & Sheldon (this volume), and only a very brief summary is given here. The West Greenland margin is a rifted continental margin, which was formed in relation to the opening of the Labrador Sea in late Mesozoic–early Cenozoic time (Chalmers *et al.*, 1993; Chalmers, Pulvertaft, Marcussen & Pedersen, 1999). Extension was followed by sea floor spreading in the Paleocene (Chalmers & Laursen, 1995), and several linked rift basins were formed along the West Greenland margin from Baffin Bay to the Labrador Sea (Chalmers *et al.*, 1993, 1999). The sedimentary basins offshore West Greenland are bordered by the oceanic crust of the Labrador Sea to the southwest and the exposed Proterozoic rocks of Greenland to the northeast (Chalmers & Pulvertaft in press).
Three of the five investigated wells only penetrated Cenozoic sediments (mainly sandstones) before they terminated in Paleocene basalts (Hellefisk-1), Paleocene basalts and hyaloclastites (Nukik-2) or Precambrian basement (Nukik-1). Kangâmiut-1 was drilled through Neogene to Middle Eocene sandstones, followed by lower Eocene and Paleocene mudstones, below which the well penetrated a coarse sandstone of possible Santonian age (Nøhr-Hansen, 1998), before being terminated in Precambrian basement. Ikermiut-1 penetrated Neogene to Middle Eocene sandstone-dominated sediments in the upper part, followed downhole by Lower

Eocene to Paleocene mudstones, and a significant section of Cretaceous (Turonian?–Santonian) mudstones (Nøhr-Hansen 1998) before drilling was terminated.

Microfossil distribution

The Upper Paleocene and Lower Eocene sediments of the five investigated wells generally contain fairly well-preserved, diverse microfossil faunas consisting of foraminifera, radiolaria, ostracods, gastropods, bivalves and fish remains together with diatom and palynomorph floras. Nannofloras (mainly coccoliths) occur in relatively low numbers (Sheldon, this volume). Microfossils are most abundant in the Kangâmiut-1 and Ikermiut-1 wells, which consist of mainly clastic mud- and siltstones with interbedded sandstone beds deposited in a generally open, marine palaeoenvironment during this time interval. The sediments penetrated by the other three wells, Hellefisk-1, Nukik-1 and Nukik-2, are less fosilliferous. The Paleocene and Lower Eocene sediments are mainly composed of clastic sandstones interfingering with thin mudstone beds, which were deposited in a primarily nearshore, marginal marine palaeoenvironment (Dalhoff, Nøhr-Hansen, Rasmussen Sheldon, Chalmers & Gregersen, this volume). Due to the higher microfossil diversity and abundance in the two most basinal wells, Ikermiut-1 and Kangâmiut-1, the biozones are more easily recognised here than in the three more nearshore wells, Nukik-1, Nukik-2 and Hellefisk-1.

Hellefisk-1

The Middle Eocene and upper Lower Eocene intervals are poorly represented by microfauna, with samples often being barren or only containing coal fragments. The middle part of the Lower Eocene is punctuated by a rich diatom flora and caved calcareous benthic foraminifera, while the Lower part of the Eocene is once again characterised by poor abundance and diversity microfaunal assemblages, with common coal fragments. In comparison, the Upper Paleocene is marked by a rich mixed assemblage of agglutinating and calcareous benthic foraminifera, diatoms, and ostracods.

Ikermiut-1

Sediments from Ikermiut-1 are characterised by containing a larger amount of calcareous benthic foraminifera than any of the other four investigated wells during the Eocene and uppermost Paleocene interval (1100 m – 2374 m). Only in the lower part of the Late Paleocene (*Stensioeina beccariiformis* Zone) do agglutinating foraminifera become the most abundant group. The early Ypresian time interval is represented by a thick sedimentary succession (approximately the interval from the top of the *Praeglobobulimina ovata* Zone to the top of the Ostracod Zone), while the remaining part of the Ypresian is very thin (approximately the interval from the top of the *Cenodiscus–Cenosphaera* Zone to the top of the *P. ovata* Zone).

Kangâmiut-1

The Paleocene and Lower Eocene (Ypresian) sediments of Kangâmiut-1 contain a rich mixture of agglutinating, calcareous benthic and planktic foraminifera together with diatoms and occasionally common ostracods. The Middle Eocene and younger sedimentary succession is generally less fossiliferous. Agglutinating foraminifera were dominant during Paleocene and late Ypresian times, while calcareous benthic and planktic foraminifera and diatoms were more common in the early Ypresian.

Nukik-1 and Nukik-2

Microfossils are generally rare in Nukik-1, while the lowermost part of Nukik-2 (2374 m–2688 m interval) contains an abundant, Paleocene microfauna and -flora. Agglutinating foraminifera are by far the dominating foraminiferal group in the two Nukik wells in both Paleocene (Nukik-2) and Eocene (especially Nukik-1) sediments. Calcareous benthic and planktic foraminifera are very rare in the two wells. Coal particles are particularly abundant in the uppermost Paleocene and early Eocene sediments of Nukik-2. Other fossils include radiolaria, ostracods and diatoms, which occur in large numbers in the Paleocene interval of Nukik-2.

Method

In total 714 samples have been studied and analysed in the present study: Hellefisk-1 (1106 m - 3194 m) 166 samples, Ikermiut-1 (789 m - 2970 m) 186 samples, Kangâmiut-1 (530 m - 3690 m) 170 samples, Nukik-1 (415 m - 2362 m) 82 samples and Nukik-2 (1341 m - 2688 m) 110 samples. Several of the samples were prepared and sorted at the Geological Survey of Greenland during the early 1980's and served as the base for the stratigraphic compilation carried out by Toxwenius (1986a, b). These samples were restudied. The remaining samples were prepared at GEUS by wet-sieving of the 63-1000 μm sediment fraction followed by drying and picking. If the microfossil content was very low, the 63 - 500 μm fraction of the samples was gravity-separated in bromoform ($\delta = 1.8$ g/cm3) after the sieving. This process tends to concentrate the foraminifera and radiolaria in the light fraction, while pyritized diatoms will sink to the bottom as part of the heavy fraction. The technique is time-consuming in the laboratory, but usually reduces the picking-time considerably.

Microfossil zonation

As the vast majority of the investigated samples are ditch cutting samples, the zonation and faunal and floral events are described from the top downwards. Eight biozones are recognised (Fig. 2).

***Cenodiscus - Cenosphaera* Zone**

Definition.– The interval between the last common occurrence of the radiolaria *Cenodiscus* spp. and *Cenosphaera* spp. and the last occurrence of the foraminifera *Praeglobobulimina ovata.*

Characteristics.– The interval is characterised by a radiolarian influx dominated by the genera *Cenodiscus* and *Cenosphaera*. Diatoms and tubular agglutinating foraminifera, especially *Rhabdammina discreta* (Plate 1, Fig. 1), are very common.

Reference well and range. – Ikermiut-1, 1570–1601 m (Fig. 3).

Distribution in the study area. – The *Cenodiscus - Cenosphaera* Zone was only observed in Ikermiut-1.

Age.– Late Early Eocene, late Ypresian.

Remarks.– The *Cenodiscus - Cenosphaera* assemblage was described from the North Sea as the "Eocene radiolarian flood" by Gradstein *et al.* (1994), who dated the event as early Middle Eocene (RASC Interval Zone NSR 5). The same event was recorded by Kaminski, Gradstein, Goll & Greig (1990) from ODP site 643 on the Vøring slope north of Jan Mayen. King (1989) defined the top of planktic zone NSP6 by the last occurrence of abundant large spherical radiolaria (*Cenosphaera* spp.), and dated it as basal Lutetian (Middle Eocene) in the North Sea. Subsequently, the last occurrence of common *Cenosphaera* spp. was dated as basal Lutetian by Bujak & Mudge (1994), who distinguished the event from the stratigraphically younger last occurrence of abundant *Cenodiscus* spp. (middle Lutetian). Correlation with other North Atlantic sites indicates that the *Cenodiscus - Cenosphaera* event is basal Lutetian. Dinoflagellate datings from Ikermiut-1, however, suggest a late Ypresian age (Zone E2c, Nøhr-Hansen this volume) for the event in the Ikermiut-1 area.

***Pseudohastigerina wilcoxensis* Zone**

Definition.– The interval between the last occurrence of *Pseudohastigerina wilcoxensis* and the last occurrence of *Praeglobobulimina ovata.*

Characteristics.– The assemblage is characterised by abundant tubular agglutinating foraminifera dominated by *Rhabdammina discreta* and *Bathysiphon* spp. and common diatoms together with sparse calcareous foraminifera, e.g. *Cibicidoides praemundulus, C. eocaenus, Pseudohastigerina wilcoxensis, Globorotalia wilcoxensis* and *Subbotina* spp..

Reference well.– Kangâmiut-1, 2751–3138 m (Fig. 3).

Distribution in the study area.– The *P. wilcoxensis* Zone was only observed in Kangâmiut-1.

Age.– Early Eocene, Ypresian.

Remarks.– The co-occurrence of *P. wilcoxensis* and *G. wilcoxensis* in the upper part of the *P. wilcoxensis* Zone indicates correlation with planktic foraminifera zone P7 or P8 according to Blow (1979). *Globorotalia wilcoxensis* and *Pseudohastigerina wilcoxensis* co-occur in the Lower Eocene Wittering Formation of the Hampshire Basin, England (Murray *et al.* 1989), correlating with Nannofossilzone NP13 (Martini, 1971). Both Nannofossilzone NP13 and palynozones E3a-b correlate with the uppermost part of the planktonic foraminifera Zone P8 (Bujak & Mudge 1994), which favours a P8 Zone age instead of Zone P7. *Pseudohastigerina wilcoxensis* and *Globorotalia wilcoxensis* (reported as *Acarinina wilcoxensis*) have common last occurrences in Early Eocene strata in the South Tempest G-88 well off the northern Grand Banks area (Gradstein *et al.* 1994). The *Pseudohastigerina wilcoxensis* Zone, as defined herein, correlates partly with the Early to early Middle Eocene *P. wilcoxensis* Zone of the North Atlantic (Berggren 1972), and the Labrador Shelf (Gradstein & Agterberg 1982), and with the interval from the lower part of Palynozone E3c to the lower part of E2b (Nøhr-Hansen, this volume) in Kangâmiut-1. The actual stratigraphic range of *P. wilcoxensis* in Kangâmiut-1, however, is delimited to the interval from lower E3c to upper E3a.

***Praeglobobulimina ovata* Zone**

Definition.– The interval between the last occurrence of *Praeglobobulimina ovata* (Plate 1, Fig. 2). and the last occurrence of *Stensioeina beccariiformis.*

Characteristics.– The *Praeglobobulimina ovata* Zone is characterised by common or abundant *P. ovata, Allomorphina subtriangularis, A. trigona, Subbotina* ex. gr. *patagonica* (Plate 1, Fig. 4) and common diatoms and radiolaria.

Reference well.– Ikermiut-1, 1601–2474 m (Fig. 3).
Distribution in the study area.– Hellefisk-1 (1975–2454 m), Kangâmiut-1 (3138–3501 m).
Age.– Early Eocene, (early Ypresian) to Late Paleocene (Thanetian).
Remarks.– *Praeglobobulimina ovata* has its last occurrence in the Early Eocene *Subbotina patagonica* Zone of Gradstein *et al.* (1994) in the eastern Canadian offshore area (reported as *Bulimina ovata*). The last common occurrence of *P. ovata* is slightly older than the last common occurrence of *Subbotina* ex gr. *patagonica* in Kangâmiut-1 (palynozone E2b *versus* palynozone E3a *sensu* Nøhr-Hansen, this volume), while it is slightly younger in Ikermiut-1 (both events occur in Palynozone E2a).

***Aulacodiscus hirtus* Zone**
Definition.– The interval between the last common occurrence of *Aulacodiscus hirtus* (Plate 1, Fig. 6, 7) and the first common occurrence of *A. hirtus*.
Characteristics.– The *Aulacodiscus hirtus* Zone is charcterised by abundant diatoms (e.g. *A. hirtus*) together with common foraminifera, especially *Subbotina* ex gr. *patagonica*, *Spiroplectammina spectabilis*, *Rhabdammina discreta*, *Bathysiphon* spp., *Allomorphina* spp. and *Praeglobobulimina ovata*.
Reference well.– Ikermiut-1, 1940–1960 m (Fig. 3).
Distribution in the study area.– Kangâmiut-1 (3051–3138 m), possibly Nukik-1 (possibly 2006–2042 m). The last common occurrence of *A. hirtus* appears at the same level as the last common occurrence of ostracods in Hellefisk-1, indicating the presence of a hiatus during the *A. hirtus* Zone time interval in this well.
Age.– Early Eocene, early Ypresian.
Remarks.– The *Aulacodiscus hirtus* Zone correlates with Palynozone E2a in Kangâmiut-1 and E2b in Ikermiut-1 (Nøhr-Hansen, this volume). *A. hirtus* is very rare in Nukik-1, where it occurs in Palynozone E2b. *Aulacodiscus hirtus* was documented from the Labrador Sea, the Northern and Southern Grand Banks and the Scotian Shelf by Thomas & Gradstein (1981). They demonstrated a Middle Eocene to Oligocene acme off the Northern Grand Banks (Cumberland B-55, Dominion O-23) and a late Paleocene to early Eocene acme in the Labrador Sea (Karlsefni H-13). The diachronous acmes indicate that the *Aulacodiscus* diatom blooms were dependent on local palaeooceanic conditions and nutrient levels, and that the species may be difficult to use in regional correlations. The top of the *A. hirtus* Zone, however, is situated in the lower Ypresian in three of the investigated offshore West

Greenland wells, and thus correlates with the acme event in the Karlsefni H-13 well of the Labrador Sea.

Ostracod Zone

Definition.– The interval between the last common occurrence of ostracods (Plate 1, Fig. 5) and the last occurrence of the diatom *Thalassiosiropsis wittiana.*

Characteristics.– The ostracod Zone is an acme zone, characterised by common ostracods together with common foraminifera, e.g. *Subbotina* ex gr. *patagonica, Rhabdammina discreta, Praeglobobulimina ovata, Allomorphina* spp. and radiolaria. In Hellefisk-1, the assemblage is characterised by common ostracods, *Aulacodiscus hirtus* and *Aulacodiscus* sp. 3 GEUS.

Reference well.– Kangâmiut-1, 3231–3264 m (Fig. 3).

Distribution in the study area.– Ikermiut-1 (2089–2200 m), Hellefisk-1 (2012–2030 m), and possibly Nukik 1 (2198–? m).

Age.– Earliest Eocene to Late Paleocene (basal Ypresian to Thanetian).

Remarks.– The common occurrence of ostracods in this zone is probably related to a shallowing during the latest Paleocene. This event is recognised in all wells except in the Nukik-2 well. A second, but less significant, ostracod influx is observed in the Early Eocene of Ikermiut-1 (last appearance datum 1970 m). The ostracod Zone correlates with palynozones E1 and P6 in Hellefisk-1, Ikermiut-1, and Kangâmiut-1 (Nøhr-Hansen this volume). It is doubtful that the Ostracod Zone is useful for correlation outside the study area, as ostracod acmes may be related to both local and global palaeoenvironmental changes.

***Fenestrella antiqua* - *Coscinodiscus morsianus* Zone**

Definition.– The interval between the last occurrence of *Thalassiosiropsis wittiana* (Plate 1, Fig. 8) and the last common occurrence of *Thalassiosiropsis wittiana.*

Characteristics.– The *Fenestrella antiqua - Coscinodiscus morsianus* Zone is characterised by common to abundant diatoms dominated by *Fenestrella antiqua, Aulacodiscus* sp. 3 GEUS, and *Stellarima microtrias*. Associated diatoms include *Coscinodiscus moelleri* and rare *Thalassiosiropsis wittiana*. Coal fragments dominate the main part of the zone in Hellefisk-1 along with rare but consistent ostracods, while foraminifera are common only in the lower part of the zone.

Reference well.– Kangâmiut-1, 3264–3381 m (Fig. 3).

Distribution in the study area.– Hellefisk-1 (2030–2420 m), Ikermiut-1 (2200–? m).
Age.– Late Paleocene (Thanetian).
Remarks.– The *Fenestrella antiqua - Coscinodiscus morsianus* assemblage was documented from the latest Paleocene of the Torsk Formation, southwestern Barents Sea (Nagy *et al.* 1997). The assemblage was characterised by common diatoms dominated by *Fenestrella antiqua*, associated with *Stellarima microtrias*, *Coscinodiscus morsianus*, *Trinacria regina*, *Aulacodiscus hirtus* and rare *Thalassiosiropsis wittiana*. Although the diatom flora from offshore West Greenland is less diverse, a correlation between the two events seems reasonable. The *Fenestrella antiqua - Coscinodiscus morsianus* Zone correlates with Palynozone P6 to uppermost P4 of Nøhr-Hansen (this volume). This agrees with the occurrence of the dinoflagellate *Apectodinium augustum* in the *Fenestrella antiqua - Coscinodiscus morsianus* assemblage interval in the Torsk Formation offshore western North Norway (Nagy *et al.* 1997), indicating a correlation with Thanetian strata in the North Sea (Zone DP6b of Mudge and Bujak 2001). *Thalassiosiropsis wittiana* is very rare in Ikermiut-1 (observed only in 2200 m), and therefore it was not possible to detect the upper boundary of the stratigraphically older *T. wittiana* Zone in this well.

***Thalassiosiropsis wittiana* Zone**

Definition.– The interval between the last common occurrence of *Thalassiosiropsis wittiana* and the last occurrence of Cretaceous microfossils.
Characteristics.– The *Thalassiosiropsis wittiana* Zone is characterised by common *T. wittiana* associated with common foraminifera, e.g. *Praeglobobulimina ovata*, *Bulimina midwayensis*, *B. paleocenica* and *Rhabdammina discreta*. Midway fauna taxa, for example *Anomalinoides welleri*, nodosariids, *Bulimina trigonalis* and *Lenticulina* spp. are common together with the agglutinating genera *Haplophragmoides*, *Recurvoides*, *Cyclammina* and *Rhabdammina* and diatoms in Hellefisk-1.
Reference well.– Hellefisk-1, 2420–2505 m (Fig. 3).
Distribution in the study area.– Kangâmiut-1 (3381–3672 m).
Age.– Late Paleocene (lower Thanetian and probably Selandian).
Remarks.– The *Thalassiosiropsis wittiana* assemblage was described by Nagy *et al.* (1997) from the middle Late Paleocene of the Torsk Formation, from well 7119/9-1 in the southwestern Barents Sea. *T. wittiana* is also known from the Knudeklint Member of the Fur Formation in northern Jutland, Denmark, where it occurs at ash layer -20 (Mitlehner, 1996),

which is very close to the Paleocene-Eocene boundary. *T. wittiana*, however, has a wider range extending from the Late Cretaceous to the Early Eocene (Hasle & Syvertsen 1985). The last occurrence of the dinoflagellate species *Palaeoperidinium pyrophorum* was observed at 1020 m in well 7119/9-1 by Nagy *et al.* (1997), which according to the range of this species in the North Sea demonstrated by Mudge & Bujak (2001), indicates a Selandian age for the *Thalassiosiropsis wittiana* assemblage. The *T. wittiana* Zone herein, correlates with Palynozones P5 and P4 of Nøhr-Hansen (this volume), indicating a range of early Thanetian to upper Selandian in the offshore West Greenland area.

***Stensioeina beccariiformis* Zone**

Definition.– The interval between the last occurrence of *Stensioeina beccariiformis* and the last occurrence of Cretaceous microfossils.

Characteristics.– The *S. beccariiformis* Zone is characterised by diverse microfaunal and microfloral assemblages in all wells it occurs in. A diverse agglutinating foraminiferal fauna including very common *Rhabdammina* spp. and *Bathysiphon* spp. occurs in all wells, while calcareous benthic foraminifera are especially common in the two northernmost wells, Hellefisk-1 and Ikermiut-1. Diatom floras including *Thalassiosiropsis wittiana*, *Fenestrella antiqua*, *Stellarima microtrias* are present but generally rare.

Reference well.– Ikermiut-1, 2474–2742 m (Fig. 3).

Distribution in the study area.– Hellefisk-1 (2454–2505 m), Kangâmiut-1 (3501–3672 m), ?Nukik-2 (probably 2374–2557 m).

Age.– Late–?Early Paleocene.

Remarks.– The last occurrence of *Stensioeina beccariiformis* is found in the Late Paleocene in the North Sea, while its last occurrence on the Canadian margin is in the early Middle Eocene (Gradstein *et al.* 1994).

S. beccariiformis has not been observed in Nukik-2, but the rich Paleocene agglutinating foraminiferal fauna including. e.g. *Usbekistania charoides*, *Dorothia oxycona* and *Rzehakina epigona*, indicates correlation with the *S. beccariiformis* Zone. Dinoflagellate data indicate that the *S. beccariiformis* Zone correlates with palynozones P5 (lower part), P5a, P4 and possibly P2/P3a (Nøhr-Hansen this volume).

Microfossil succession and correlation of bioevents

Hellefisk-1

The microfossil zones in Hellefisk-1 are not as easily recognised as in the other wells due to the low abundance and diversity microfaunal assemblages in most of the studied interval. The character of the assemblages means that microfossil zones are often based on only few specimens of the marker species, whereas in the two basinal wells (Ikermiut-1, Kangâmiut-1), some of the zonal boundaries have been marked by species acmes.

The *Pseudohasterigerina wilcoxensis* and *Cenodiscus-Cenosphaera* zones are not recognised in Hellefisk-1.

The *P. ovata* assemblage (1975 m – 2454 m) is poorly represented in Hellefisk-1 by a single (last occurrence) specimen of *P. ovata*. The other marker species in this zone, *Allomorphina* spp. and *Subbotina* ex gr. *patagonica*, are not present in this well. Otherwise, the zone is characterised by a low diversity assemblage including rare ostracods, *Stellarima microtrias* and coal fragments.

The zonal indicator *Aulacodiscus hirtus* has its last occurrence at the same level as the last common occurrence of ostracods (2012 m), and a hiatus probably spans the *A. hirtus* Zone interval in the Hellefisk-1 well. This indicates that the *A. hirtus* assemblage could be caved into the ostracod assemblage, but this is difficult to prove because the interval is only spanned by two samples. An alternative possibility is that the two zones are condensed as shown by the co-occurrence of common 'ribbed', 'spotty' and 'smooth' ostracods and influxes of *A. hirtus* and *Aulacodiscus* sp 3. GEUS.

The uppermost part of the *Fenestrella antiqua – Coscinodiscus morsianus* Zone (2030 m – 2420 m) in Hellefisk-1 is characterised by the last occurrence of the diatom *Thallassiosiropsis wittiana* coinciding with common diatoms. Ostracods are fairly common and occurrences of benthic foraminifera are sporadic but not useful for dating.

The interval between 2079 m and 2374 m is virtually devoid of microfauna, coal fragments being the only common component, and therefore is not included as part of this zone.

In Hellefisk-1, the *T. wittiana* Zone (2420 m - 2505 m) spans the interval from the last common occurrence of *T. wittiana* to the top of the Paleocene volcanics. This interval is characterised by a rich assemblage of calcareous benthic and agglutinating foraminifera, diatoms (including *T. wittiana*, *Stellarima microtrias* and *Fenestrella antiqua*) and ostracods. Most notable are the rich Midway-type Fauna (Berggren & Aubert, 1975) including *Bulimina trigonalis, Cibicides* spp. *Cibicidoides alleni*, *Globulina* spp., *Guttulina* spp., *Anomalinoides midwayensis* (Plate 1, Fig. 3) and *Gavelinella danica*, and the rich agglutinating foraminferal fauna (including *Haplophragmoides* spp. *Recurvoides* spp. *Cyclammina amplectens*,

Alveolophragmium spp., *Trochammina* spp. *Haplophragmoides walteri*, *Bathysiphon annulatus*, *Cyclammina rotundidorsata*, and *Rhabdammina robusta*).
The *Stensioiena beccariiformis* Zone (which is approximately coeval with the *T. wittiana* Zone) is represented in Hellefisk-1 by the occurrence of *S. beccariiformis* at 2454 m. This is supported by the occurrence of *Cibicidoides dayi* at 2420 m. *Rzehakina epigona* and *Hormosina ovulum* are other markers for this interval but are not present in Hellefisk-1.

Ikermiut-1

The uppermost probable Eocene microfossils recorded are sparse occurrences of *Glandulina laevigata*, *Cibicidoides tenellus*, *Nodosaria minor* and *Cibicidoides eocaenus* in the 1130 m – 1170 m interval, but it is not possible to correlate the assemblage to a specific foraminiferid zone. Probable Middle Eocene foraminfera occur from 1260–1280 m (*Globocassidulina subglobosa*, *Vulvulina pennatula*) to the *Cenodiscus-Cenosphaera* zonal top at 1570 m, but caving from younger beds is significant in certain parts of the interval. *Rhabdammina discreta* is common in the 1542 m – 1590 m interval, which overlaps with the upper part of the *Cenodiscus-Cenosphaera* Zone.
The early Ypresian interval from the top of the *P. ovata* Zone to the Ostracod Zone is characterised by a very diverse and abundant assemblage including *Praeglobobulimina ovata*, *Allomorphina subtriangularis*, *A. trigona*, *Subbottina* ex gr. *patagonica*, *Lenticulina* spp. together with common *Rhabdammina discreta*, diatoms and radiolaria. The underlying *A. hirtus* and Ostracod zones are less fossiliferrous, but still contain abundant *P. ovata*, *A. subtriangularis* and *Lenticulina* spp. together with the zonal indicators. A specimen of *Globanomalina compressa* was recorded from a side wall core sample at 2188 m, indicating that the lower part of the Ostracod Zone in Ikermiut-1 is of Paleocene (Selandian or Danian) age. This age, however, does not correlate with the palynomorph and additional microfossil datings, and indicates that *G. compressa* was reworked from an older stratigraphic level.
The late Paleocene *F. antiqua-C. morsianus* Zone is characterised by very sparse microfaunas and -floras. The top of the zone is marked by very rare *Thallassiosiropsis wittiana* and common *Stellarima microtrias* (both diatoms). The foraminifera *Bulimina paleocenica*, *Subbotina* aff. *triloculinoides* and *Trochammina subvesicularis* occur sparsely in the lower part of the zone. The underlying Paleocene *Stensioeina beccariiformis* Zone contains a relatively diverse microfauna dominated by agglutinating foraminifera, e.g. *S. beccariiformis*,

Rhabdammina discreta, Pseudoclavulina anglica, Usbekistania charoides, Hormosina ovula, and common *Spiroplectammina spectabilis.*

Kangâmiut-1

Kangâmiut-1 contains a relatively diverse calacareous benthic foraminiferal fauna of Middle Miocene to early Pleistocene age within the 500 m – 1100 m interval. Both diversity and abundance decrease significantly from 1100 m to 2600 m, although the last occurrence of e.g. *Karrerulina conversa* and *Kalamopsis grzybowskii* at about 1700 m indicates that Upper or Middle Eocene sediments were reached at this level. The last common occurrence of the agglutinating foraminifera *Rhabdammina discreta* and *Karrerulina conversa* and the last occurrence of *Cyclammina amplectens* and *Spiroplectammina spectabilis* in the 2631–2751 m interval, indicates a latest Ypresian or early Lutetian age for this part of the succession. The underlying *Pseudohastigerina wilcoxensis* Zone is characterised by an influx of planktic foraminifera including the zonal species together with *Globorotalia wilcoxensis, Subbotina* ex gr. *patagonica, S. inaequispira* and *S. hornibrooki.* This assemblage characterises the Lower Eocene succession of the northwestern Atlantic Margin (Gradstein & Agterberg 1982). Agglutinating foraminifera are common. A significant influx of the diatom *Aulacodiscus hirtus* defines the top of the *A. hirtus* Zone at 3051 m. In addition, the *A. hirtus* Zone is characterised by the last common occurrence of both the agglutinating foraminifera *Spiroplectammina spectabilis* and the diatom *Fenestrella antiqua.*
The uppermost part of the underlying *Praeglobobulimina ovata* Zone is characterised by the last occurrence of the calcareous benthic foraminifera *P. ovata, Allomorphina subtriangularis* and *A. trigona.* Other common or abundant species include the agglutinating taxa *Rhabdammina discreta* and species of the *Haplophragmoides-Cribrostomoides* group together with the planktic foraminifera *Subbotina* ex gr. *patagonica.* The diatom *Aulacodiscus* sp. 3 GEUS is abundant. The underlying Ostracod Zone (3231–3264 m) is characterised by an influx of ostracods, but *Subbotina* ex gr. *patagonica* is also common. *Bulimina* cf. *midwayensis* and *Chilostomella eocenica* have their last occurrence in this zone in Kangâmiut-1. Although the Ostracod Zone is believed to be useful mainly in local correlations because of its strong dependence on palaeoenvironmental factors, its occurrence in the uppermost Paleocene to lowermost Eocene beds in Hellefisk-1, Ikermiut-1 and Kangâmiut-1 show that it may have a potential in correlations from the marginal parts of the basin (Hellefisk-1) to the deeper parts (Ikermiut-1, Kangâmiut-1).

The last occurrence of *Thalassiosiropsis wittiana* marks the top of the *Fenestrella antiqua-Coscinodiscus morsianus* Zone at 3264 m. The zone is characterised by abundant *Lenticulina* spp. (calcareous benthic foraminifera) together with the agglutinating foraminifera species *Cyclammina amplectens* and the diatom *Fenestrella antiqua* in Kangâmiut-1. Abundant *Fenestrella antiqua* (the formal name of *Coscinodiscus* sp. 1, see synonymy in Bidgood, Mitlehner, Jones & Jutson, 1999) indicate that the *F. antiqua-C. morsianus* Zone correlates with zone NSP 4 of King (1989), which spans the uppermost Thanetian to lowermost Ypresian interval in the North Sea. The underlying *T. wittiana* Zone is characterised by the last common occurrence of the diatoms *Thalassiosiropsis wittiana*, *Fenestrella antiqua* and *Stellarima microtrias* at 3381 m. Agglutinating foraminifera are relatively common in the upper part of the zone, while calcareous benthic foraminifera dominate the lower part. *Praeglobobulimina ovata* is common throughout the interval. *Bulimina midwayensis* and *B.* ex gr. *paleocenica* have their last occurrence within this zone, which is also characterised by abundant *Praeglobobulimina ovata*.

The stratigraphically oldest microfossil zone that is recognised in Kangâmiut-1 is the *Stensioeina beccariiformis* Zone. The top of the zone is defined by the last occurrence of the nominate species at 3501 m, where *Hormosina ovula* also has its last occurrence. Agglutinating foraminifera, e.g. *Ammodiscus* spp. and *Haplophragmoides* are common in this zone. The calcareous benthic foraminifera *Anomalinoides welleri* and the planktic *Acarinina soldadoensis* have their last occurrence in the lowermost sample of the zone at 3672 m. It is probable that the common occurrence of *Praeglobobulimina ovata* and *Siphonodosaria* ex gr. *gracillima* in this level are caved from higher levels. The co-occurrence of *S. beccariformis*, *A. welleri* and *A. soldadoensis* indicates a Thanetian age for the *S. beccariiformis* Zone in Kangâmiut-1 (Gradstein *et al.* 1994; Olsson, Hemleben, Berggren, & Huber, 1999).

Nukik-1, Nukik-2

It was not possible to distinguish the Early Eocene and Paleocene microfossil zones with certainty in the Nukik wells, but a few correlative ties were recognised. The agglutinating foraminifera *Spiroplectammina spectabilis*, *Rhabdammina discreta*, *Karrerulina conversa* and *Cyclammina amplectens* have their last occurrence in the 1930–1960 m interval in Nukik-1 together with the diatoms *Fenestrella antiqua* and *Coscinodiscus morsianus*. The same species have their last occurrence, or last common occurrence, in the 2631–2751 m interval in

Kangâmiut-1, which is just above the *P. wilcoxensis* Zone and is probably of latest Ypresian to early Lutetian age. *Spiroplectammina spectabilis* and *Karrerulina conversa* have their last occurrence in the same time interval at ODP site 643 situated in the Barents Sea (Kaminski *et al.* 1990). Very rare specimens of the diatom species *Aulacodiscus hirtus* are present from 2006 m to 2042 m in Nukik-1, which may indicate correlation with the Early Eocene *A. hirtus* Zone. It should be noted, however, that the *A. hirtus* Zone of Ikermiut-1 and Kangâmiut-1 are characterised by an *A. hirtus* acme instead of the presence of only rare specimens.
The last appearence of the diatom *Stellarima microtrias* at 2271 m indicates correlation with the interval from the upper part of the *S. beccariformis* Zone to the lower part of the *P. ovata* Zone in Kangâmiut-1 and Ikermiut-1 suggesting a Thanetian age for this level in Nukik-1. The oldest possible correlative microfossil event in Nukik-1 is the last occurrence of common *Spiroplectammina spectabilis* at 2344 m. This event may indicate correlation with the Paleocene *S. beccariformis* Zone in Ikermiut-1, but the *S. spectabilis* specimens might also be caved from higher up. Palynomorph datings (Nøhr-Hansen, this volume) support a Paleocene age for this event in Nukik-1.

The Early Eocene and uppermost Paleocene succession in Nukik-2 is dominated by abundant coal particles and contains very few other microfossils. Biozonation of this interval has been established using palynomorphs (Nøhr-Hansen, this volume). The last common occurrence of (agglutinating) foraminifera is at 2374 m, which is coeval with the last occurrence of *Dorothia oxycona*, *Spiroplectammina spectabilis* and *Usbekistania charoides*. The calcareous benthic foraminifera *Bulimina midwayensis* and *Cibicidoides dayi* have their last occurrence just below this level. Although *Stensioeina beccariiformis* has not been recorded from this interval, it is very likely that the interval from 2374 m to 2557 m correlates with the *Stensioeina beccariiformis* Zone. It is noteworthy that the lower c. 130 m of Nukik-2 (2777 m – 2688 m), which consists of interbedded hyaloclastites and basalts, contains abundant microfaunas, several of which have not been observed higher up in the well.

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Plate 1.

Fig. 1. *Rhabdammina discreta* Brady. x150. Ikermiut-1, 2474 m. Top of the *Stensioeina beccariiformis* Zone.

Fig. 2. *Praeglobobulimina ovata* (d'Orbigny). x90. Ikermiut-1, 2549 m. *Stensioeina beccariiformis* Zone.

Fig. 3. *Anomalinoides midwayensis* (Plummer). x160. Ikermiut-1, 1800 m. *Praeglobobulimina ovata* Zone.

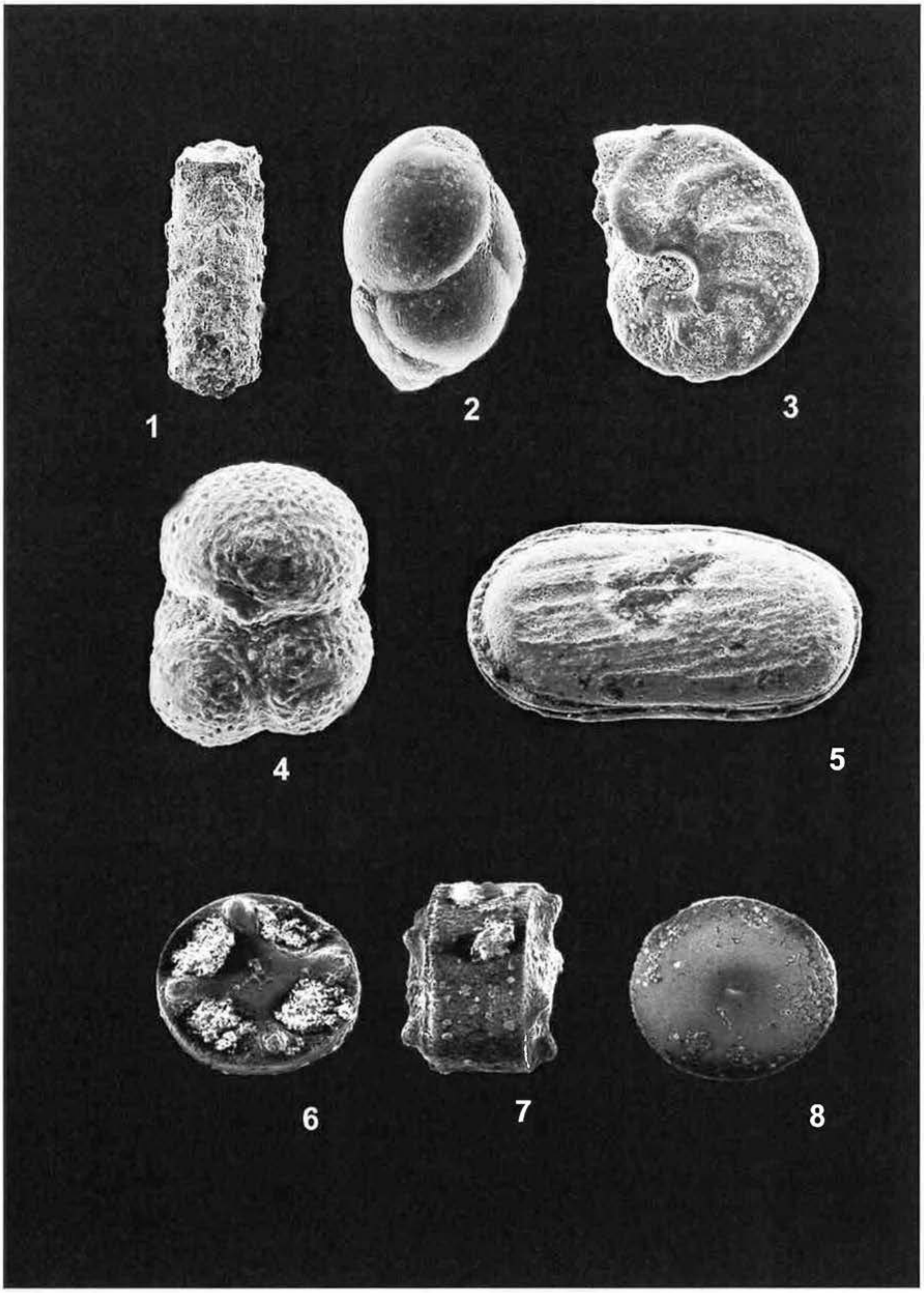
Fig. 4. *Subbotina* ex gr. *patagonica* (Todd & Kniker). x175. Ikermiut-1, 1800 m. *Praeglobobulimina ovata* Zone.

Fig. 5. Ostracod, indet. x100. Ikermiut-1, 2474 m. Top of the *Stensioeina beccariiformis* Zone.

Fig. 6. *Aulacodiscus hirtus* Barker &.Meakin. x165. Hellefisk-1, 2414 m. Lower part of the *Fenestrella antiqua-Coscinodiscus morsianus* Zone.

Fig. 7. *Aulacodiscus hirtus* Barker &.Meakin. x 210. Hellefisk-1, 2414 m. Lower part of the *Fenestrella antiqua-Coscinodiscus morsianus* Zone.

Fig. 8. *Thalassiosiropsis wittiana* (Pantocsek). x115. Hellefisk-1, 2420 m. Top of the *Thalassiosiropsis wittiana* Zone.



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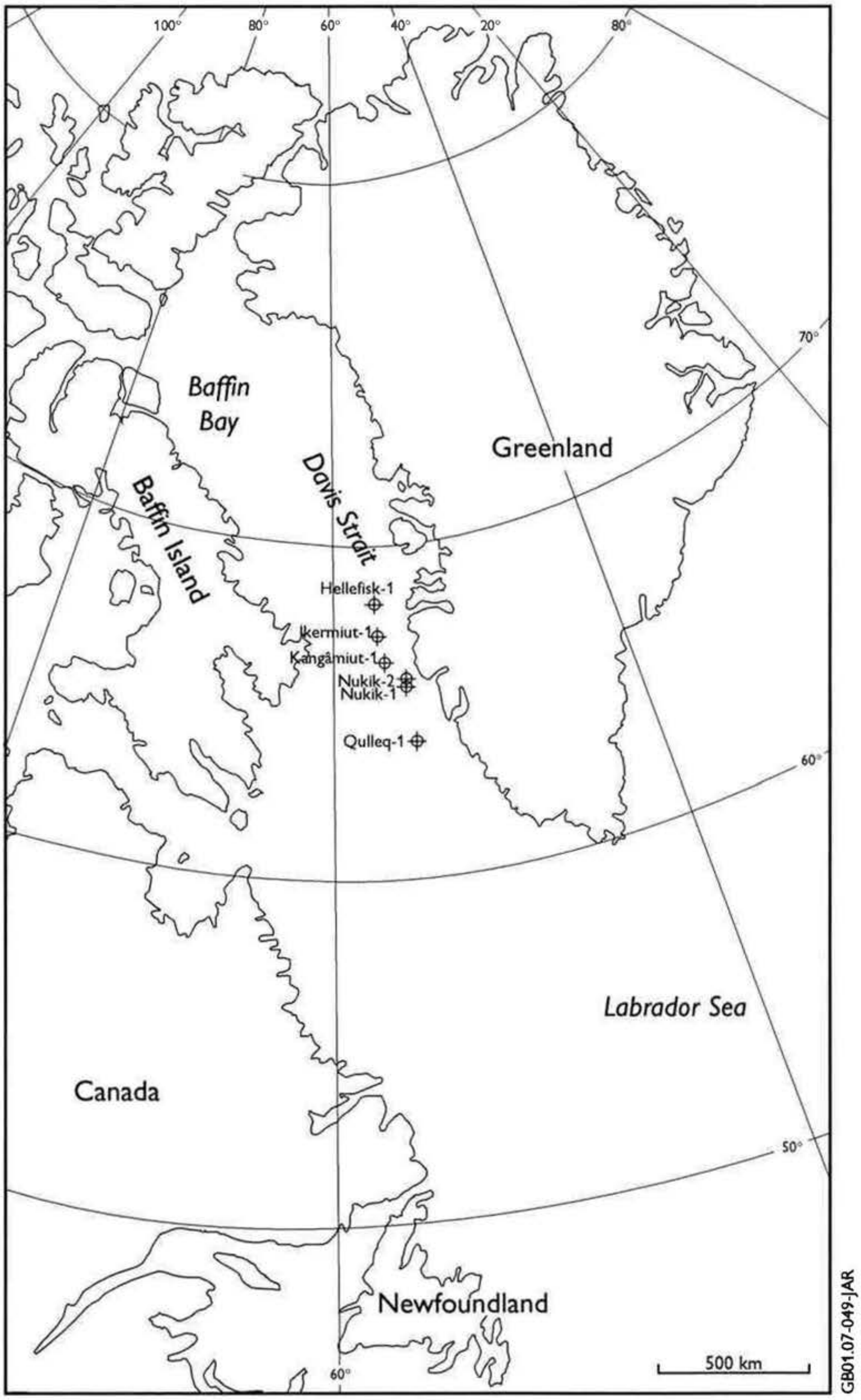

Fig 1. Locality map showing the investigated exploration wells, offshore West Greenland.

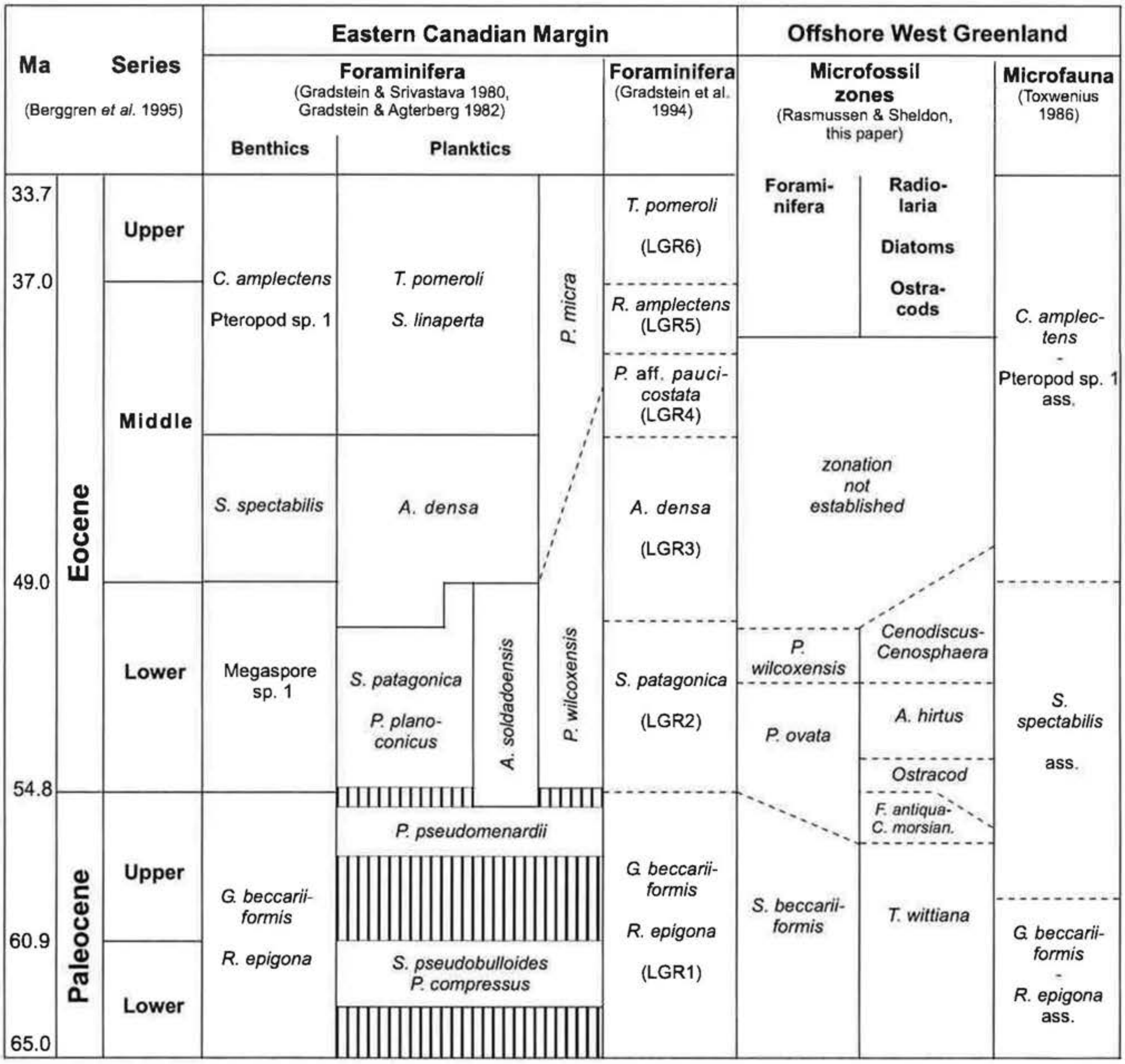

Fig. 2. Microfossil zones of the West Greenland offshore area and correlation with the zonations from the eastern Canadian margin.

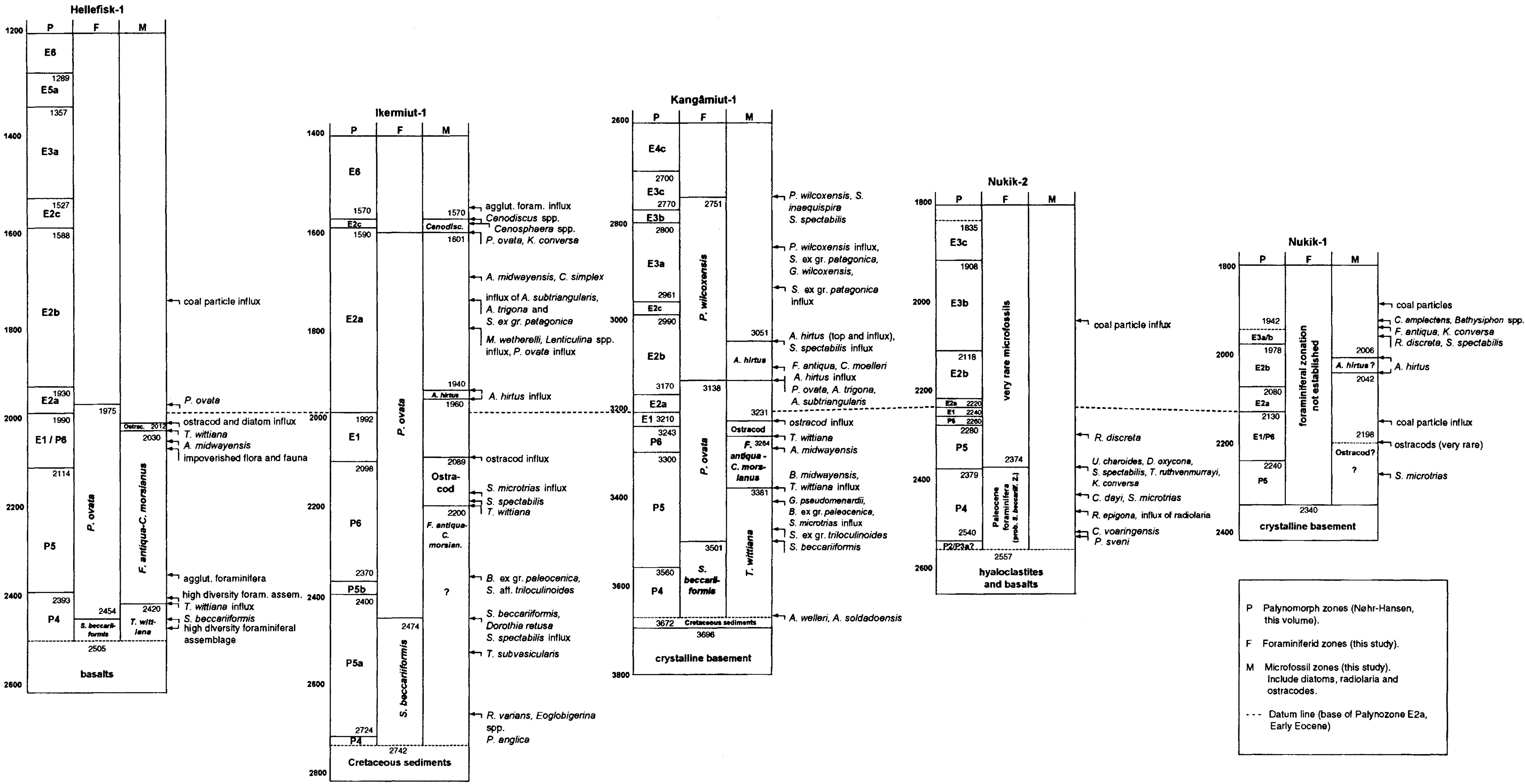

Fig. 3. Biostratigraphy of the Paleocene and Lower Eocene succession of the Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1 and Nukik-2 wells.