

Regional correlation of Mesozoic–Palaeogene sequences across the Greenland–Canada boundary

Regionalgeologisk korrelation af mesozoiske–palæogene sekvenser
i det canadisk–grønlandske sokkelområde

Final report for EFP-2001 project
ENS 1313/01-0022

Martin Sønderholm, Henrik Nøhr-Hansen,
Jørgen Bojesen-Koefoed, Finn Dalhoff
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Executive summary

The separation of Canada and Greenland is normally regarded as a consequence of the opening of the Labrador Sea in late Mesozoic to early Cenozoic time resulting in a complex of linked rift basins stretching from the Labrador Sea to northern Baffin Bay. Two main phases of rifting and basin development have been documented during this time in the area; an episode of Early Cretaceous rifting, and a Late Cretaceous – Early Paleocene episode before sea-floor spreading started in mid-Paleocene time. However, recently acquired seismic data across the Davis Strait and northern Labrador Sea combined with modelling of gravity and magnetic data have shown that deep sedimentary basins with unknown stratigraphy are widespread in the region, suggesting that initial rifting in the region may have occurred significantly earlier.

Biostratigraphy

This study describes and correlates the palynology of the Cretaceous to Palaeogene succession from four selected wells offshore eastern Canada and six West Greenland on- and offshore wells. Twenty new palynological intervals are proposed here for the Cretaceous whereas the twenty-one palynological intervals from the Early Paleocene to the Late Eocene have been described earlier.

Data from the Canadian offshore wells have provided important new information leading to refinement and improving previous interpretations of the Cretaceous and Palaeogene successions in West Greenland.

The new, non-marine to brackish succession of Aptian to Cenomanian age described from the Canadian Ogmund E-72 well is important for further correlation with similar deposits onshore Nuussuaq.

The new data from the 1500 m thick continuous Lower Campanian to Upper Maastrichtian and lowermost Palaeogene marine succession in Skolp E-07 has provided new information to re-evaluate the dating of the youngest Cretaceous successions in the Greenland Ikermiut-1 and Qulleq-1 wells that both seem to be of Early Campanian age. A hiatus spanning the Late Campanian to early Paleocene is present in these two wells and is probably related to uplift during latest Maastrichtian or earliest Paleocene time. This event has been recorded in large parts of the areas offshore West Greenland but is only recorded as a minor hiatus onshore Nuussuaq, West Greenland. On parts of the Labrador Shelf the Upper Campanian to Maastrichtian succession is more or less complete.

In contrast to the onshore deposits on Nuussuaq in West Greenland, the Lower Paleocene (Danian) succession is generally thin or absent in the offshore Canadian and Greenland wells. The $^{40}\text{Ar}/^{39}\text{Ar}$ dating of the basaltic rocks overlying the Danian on Nuussuaq shows that the volcanism commenced in West Greenland between 60.9 and 61.3 Ma. This compares well with ages on basalts in the Gjoa G-37 well where basaltic rock have yielded 57.9 and 60.4 Ma, respectively. The Upper Paleocene is absent on Nuussuaq, whereas it is well represented in the Ikermiut-1 well and between the basalts in the lower part of the Gjoa G-37 and Hekja O-71 wells.

A limited number of microfossil samples were examined with the purpose to enhance the stratigraphic resolution of the palynological zonation. The microfossil content (foraminifera, diatoms and radiolarians) was, however, extremely low and of limited value both stratigraphically and palaeo-environmentally.

Well log correlation

A preliminary correlation of the seven selected exploration wells on the Labrador and South-East Baffin Island shelves and offshore and onshore West Greenland has been carried out. The lithological interpretation of the four Canadian wells is done on information from log data and the Master Log prepared by the mud logger. The log correlation is based on biostratigraphic data, and the biostratigraphic events are placed disregarding the log pattern.

Source rock evaluation

The knowledge on especially marine oil-prone source rock intervals in the northern Labrador Sea – Baffin Bay region is relatively sparse since source rock intervals have only been drilled in a few wells. However, both direct and indirect evidence of their presence exists from seeping oil in West Greenland and from some of the Canadian discovery wells.

A geochemical analysis of five Canadian wells (Ogmund E-72, Skolp E-07, Raleigh N-18, Hekja O-71 and Gjoa G-3) and eight Greenland wells (Qulleq-1, Nukik-1 and 2, Kangâmiut-1, Ikermiut-1, Hellefisk-1, GR0#3 and Umiivik-1) has been carried out in order to characterise possible source rocks intervals. However, only little or no petroleum source potential has been recorded with the possible exceptions of the Hekja O-71 and Umiivik-1 wells. Furthermore, the analyses of the five Canadian wells could not confirm that the organic rich marine mudstones of the Markland Formation and the Lower Cretaceous lignites and coals of the Bjarni Formation represent regional source rocks. It has earlier been proposed that the petroleum accumulations found in the Hekja O-71 well are sourced from surrounding Paleocene organic rich marine mudstones. This could not be confirmed since the mudstones are thermally immature in the area around the well.

Nevertheless, the presence of active hydrocarbon systems in the region shows that mature, oil-prone source rocks exist. The hydrocarbons are therefore probably generated from an as yet unknown source. Geochemical evidence from seeping oil in Greenland and from the stratigraphically deep Umiivik-1 well suggests that a marine source rocks of possible Cenomanian–Turonian age, comparable to the prolific source rock in the Kanguk Formation on Ellesmere Island, is present in West Greenland. However, knowledge on this – or maybe even older – source rock is still very sparse and depends on either results from stratigraphically deep exploration wells or from sea bed sampling of structurally inverted regions.

Introduction

Martin S nderholm

Petroleum exploration activity in the Labrador Sea and Davis Strait has been carried out both on the Canadian and on the Greenland side. In Canada, exploration was carried out from 1971 to 1985 and during this time 28 exploration wells were drilled and more than 80,000 km of reflection seismic data were acquired. Several large gas discoveries were reported, mainly in Lower Cretaceous syn-rift reservoirs; however, none were put into production and all data are now open file.

In Greenland, the first phase of exploration was contemporaneous with exploration in Canada. In the mid-1970s, five exploration wells were drilled and approximately 40,000 km of reflection seismic data acquired. All wells were at that time declared dry, and exploration came to a stop in 1979 when all licences were relinquished. In 1987 the Survey initiated a re-evaluation of the seismic data and based on these results a major publicly financed seismic acquisition programme was carried out supplemented by detailed petroleum geological studies in the onshore areas during 1991–1995. These efforts led to the signing of three licences: one onshore licence and two offshore. In 1995, an onshore licence on Disko and Nuussuaq was awarded to a small Canadian company (gr nArctic Energy) that drilled a deep exploration well (GRO#3) in 1996 which was declared dry by the company. In 1996, an offshore licence was awarded to a group of companies headed by Statoil and in 1998 another to a group headed by Phillips Petroleum. The renewed industry interest in Greenland resulted in further seismic acquisition by private companies (more than 30,000 km since 1995) and in the drilling of one new exploration well in the Statoil licence in the year 2000 (Qulleq-1). Although dry, the Qulleq-1 well provided a wealth of new stratigraphic data important to the evaluation of the petroleum geology of West Greenland. All these licences are now relinquished and data are open file. Exploration activities have, however, not ceased in West Greenland; following a licensing round in 2002 a new offshore exploration licence was awarded to EnCana and both public and private data acquisition is still being carried out, especially in the border region between Greenland and Canada.

Since the Canadian exploration licences were relinquished in the mid-1980s neither well data nor seismic data have been re-examined in any systematic way. In Greenland, however, the major public effort in promoting West Greenland to the industry since 1990 and the following exploration activities have created a wealth of new data resulting in major revisions in the interpretation of the geological evolution of the West Greenland offshore basins (cf. Chalmers & Pulvertaft 2001).

The combination of the huge amounts of data on the Canadian side combined with the new knowledge obtained in recent years in Greenland it seems pertinent to re-evaluate the geology of the entire Labrador Sea – Davis Strait – Baffin Bay region.

The main purpose of the present project is to establish an up-to-date correlation between the wells drilled offshore Greenland and Canada in the Labrador Sea and Davis Strait area as

a first step in generating a revised regional geological and geotectonic model. The correlation is based on both new seismic and well data from Greenland and a new biostratigraphic processing and analysis of selected Canadian (Ogmund E-72, Skolp E-07, Hekja O-71, Gjoa G-37) and Greenland wells (Qulleq-1, Kangâmiut-1, Ikermiut-1, GR0#3 and Umiivik-1) and to compare this with known onshore successions in the Nuussuaq Basin, West Greenland. If feasible, the project should also try to explain the regional distribution of any possible source and reservoir intervals in the succession. For this purpose, a geochemical analysis of the wells has been carried out in order to characterise possible source rock intervals.

The project is closely linked to a regional geological reconstruction project and a geochemical source rock analysis project, both financed by the Bureau of Minerals and Petroleum, Government of Greenland.

The EFP-2001 project 'Regional correlation of Mesozoic–Palaeogene sequences across the Greenland–Canada boundary' was co-funded by the Geological Survey of Denmark and Greenland, the Bureau of Minerals and Petroleum, Government of Greenland, and Phillips Petroleum, Norway. This final report summarises the studies carried out under this heading but includes also related reports made under other projects (see list of contents).

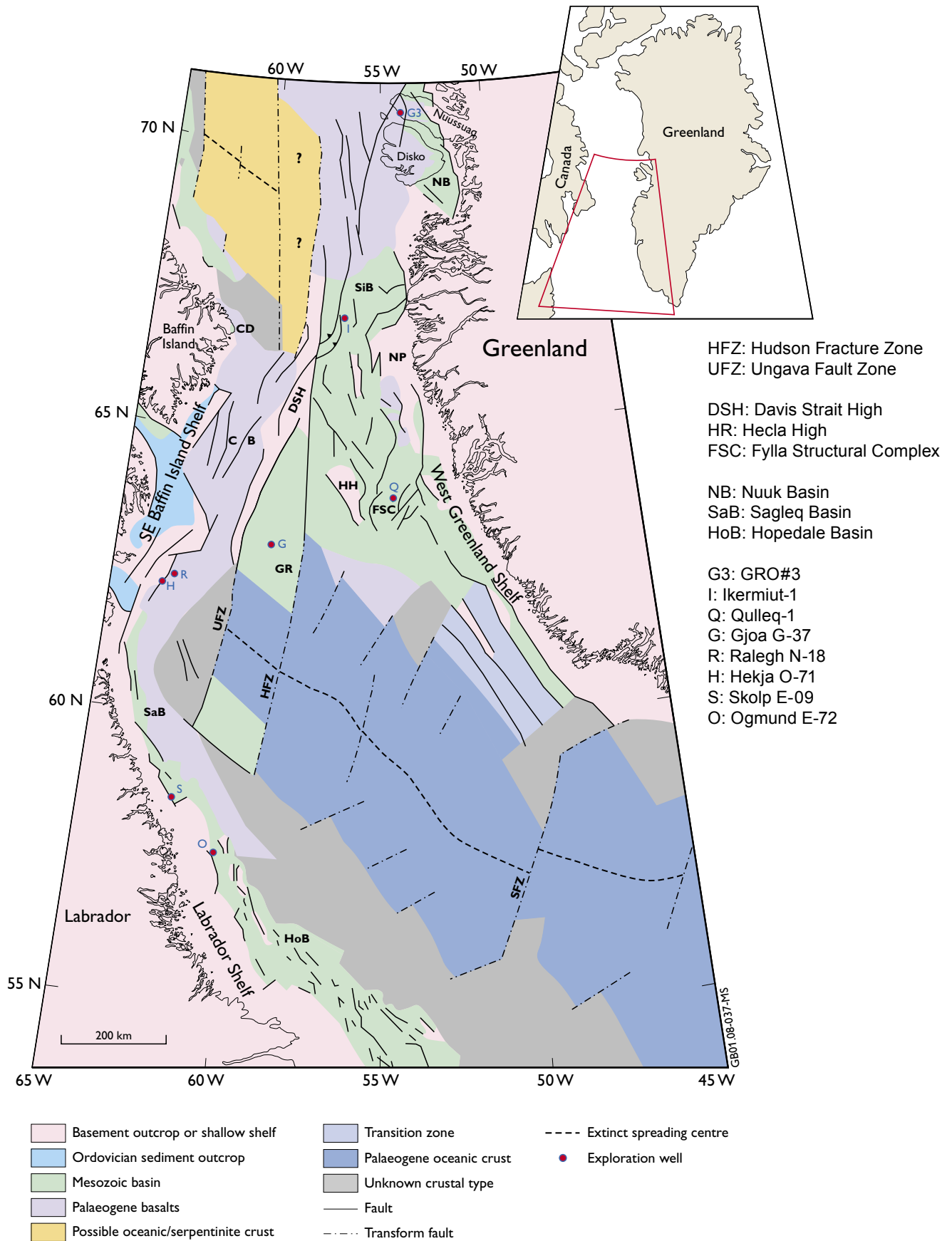


Fig. 1. Simplified geological map of the Labrador Sea – Davis Strait region. Modified from Chalmers & Pulvertaft (2001).

Geological setting and general stratigraphy

Martin Sønderholm

The Labrador Sea is an oceanic basin, approximately 900 km wide, that opens into the North Atlantic Ocean to the south-east. To the north it passes into the Davis Strait, a relatively shallow seaway approximately 300 km wide leading into Baffin Bay. The Labrador Sea is flanked by typical shallow Arctic shelves: the Labrador and South-East Baffin Island shelves to the west and the southern West Greenland shelf to the east (Fig. 1).

The separation of Canada and Greenland is normally regarded as a consequence of the opening of the Labrador Sea in late Mesozoic to early Cenozoic time (Chalmers & Pulvertaft 2001). This resulted in a complex of linked rift basins stretching from the Labrador Sea to northern Baffin Bay (Fig. 1). Two main phases of rifting and basin development have been documented during this time in the area; (1) an episode of Early Cretaceous rifting, and (2) a Late Cretaceous – Early Paleocene episode before sea-floor spreading started in mid-Paleocene time (Chalmers & Pulvertaft 2001). However, recently acquired seismic data across the Davis Strait and northern Labrador Sea combined with modelling of gravity and magnetic data have shown that deep sedimentary basins with unknown stratigraphy are widespread in the region (Chalmers *et al.* 2001), suggesting that initial rifting in the region may have occurred as early as during Jurassic or even Triassic time.

The geological history is best known from the sedimentary basins under or close to the continental shelves where petroleum exploration has taken place and from studies of the relatively sparse outcrops in the Nuussuaq Basin, West Greenland and at Cape Dyer, eastern Baffin Island. Outcrops of Cretaceous – Palaeogene sediments are also seen further north in Arctic Canada on Bylot Island (Miall *et al.* 1980; Miall 1986) and on Ellesmere Island (Núñez-Betelu 1994).

Over the Labrador shelf extensive seismic surveys were carried out in from 1971 to 1983 and 25 wells were completed (Fig. 2). Six discoveries of gas were made, but none of them have been exploited. On the South-East Baffin Island shelf three wells were drilled in the early 1980s, one of which (Hekja O-71) recovered condensate (see summary by Balkwill *et al.* 1990; Bell & Campbell 1990).

Cretaceous–Palaeogene stratigraphy

Labrador and South-East Baffin Island shelves

On the Labrador Shelf the initiation of the Early Cretaceous rifting episode is recorded by a major volcanic phase represented by the Alexis Formation of Valanginian – Early Aptian age (approx. 131–104 Ma; Umpleby 1979; Balkwill *et al.* 1990). The Alexis Formation is overlain by the Barremian–Albian Bjarni Formation which is recognised both on the Labrador Shelf (Hopedale Basin) and on the South-East Baffin Island Shelf (Saglek Basin; Fig. 3); it is dominated by nonmarine sandstone and argillaceous sandstone and coal beds (Balkwill *et*

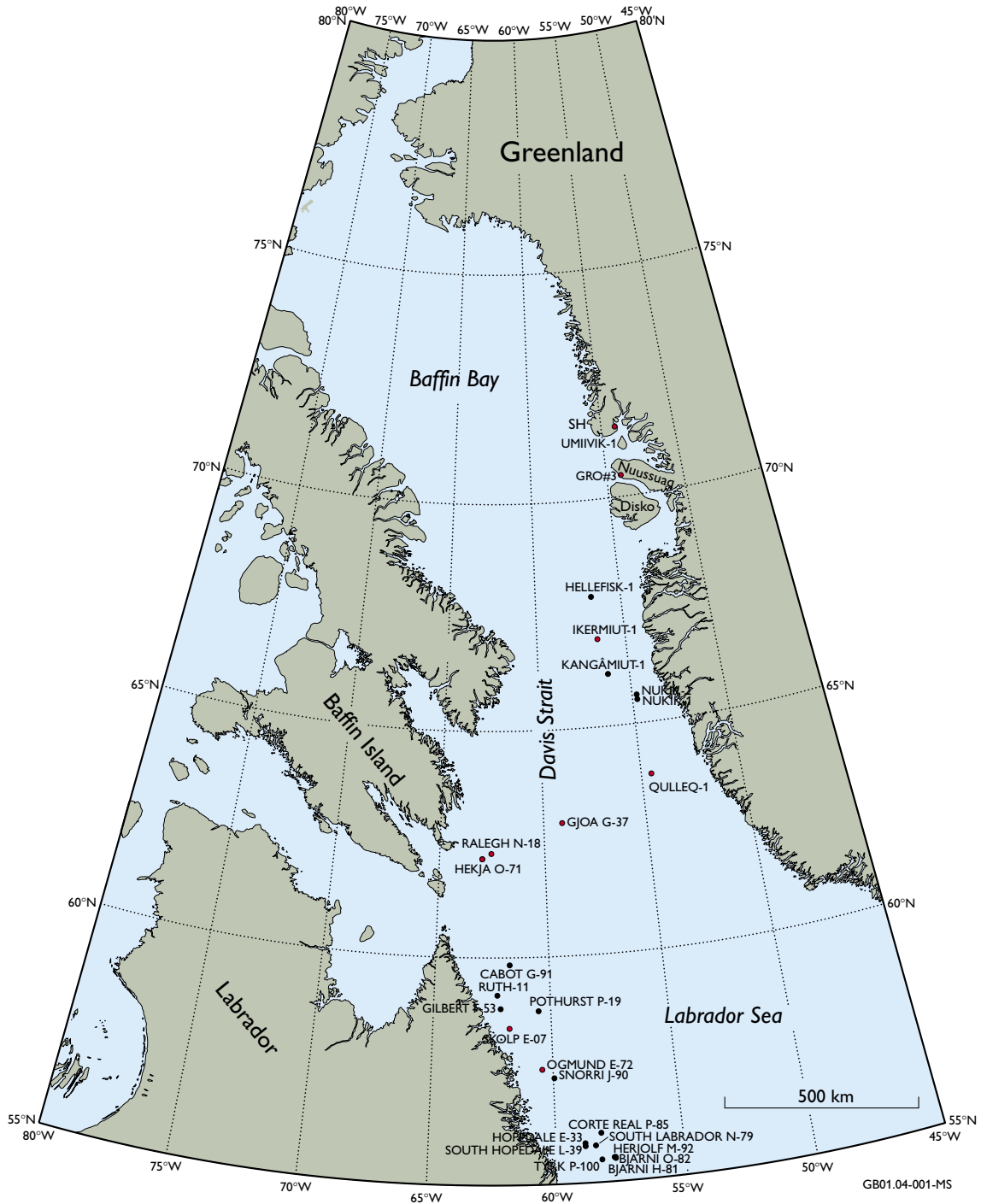


Fig. 2. Exploration wells drilled on the Labrador and South-East Baffin Island shelves and off- and onshore West Greenland.

al. 1990) and around Cape Dyer similar sandstone deposits of the same age are assigned to the Quqaluit Formation (Burden & Langille 1990). The Bjarni Formation is the most common hydrocarbon objective in the Labrador Shelf wells.

The Late Cretaceous – Early Paleocene rifting event is recorded by the Markland Formation in both the Hopedale and Saglek basins. The Markland Formation comprises marine shelf mudstone; more proximal sandstone-dominated facies are referred to the Freydis Member and lower Gudrid member of Cenomanian–Campanian age and Early Paleocene (Danian)

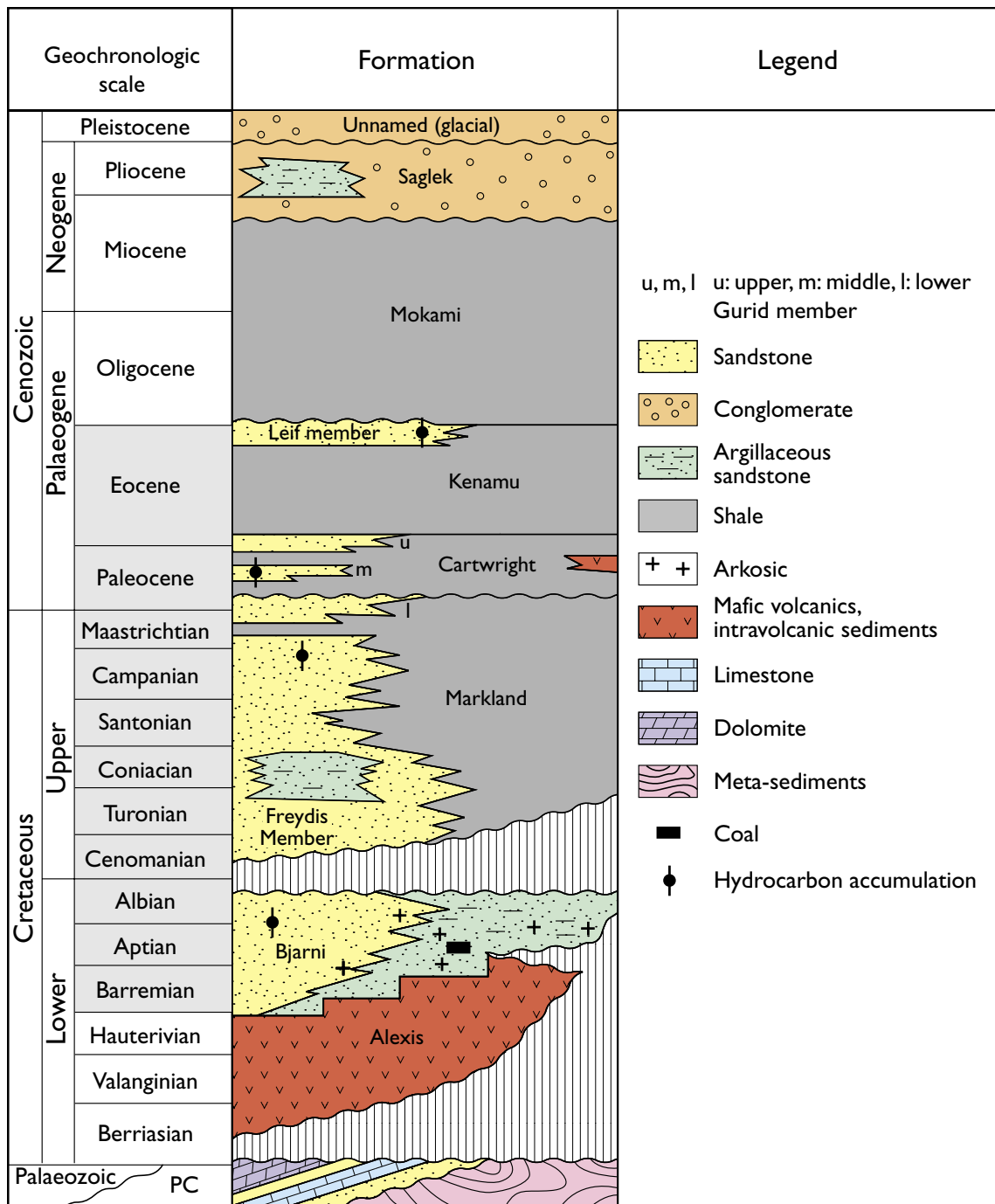
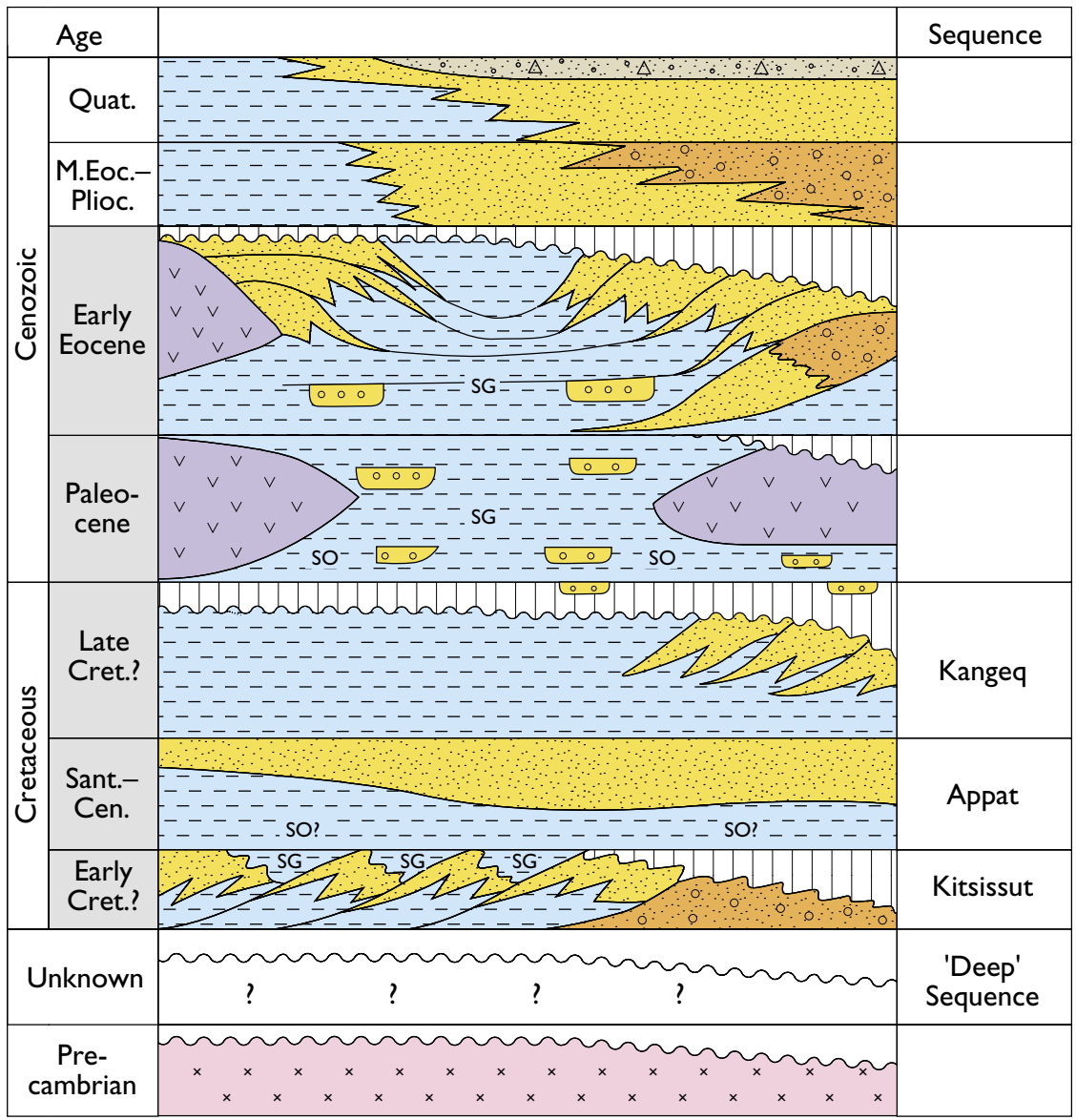


Fig. 3. Generalised stratigraphy of the Labrador and South-East Baffin Island shelves. Based on Balkwill *et al.* (1990). Grey shading denotes stratigraphy covered in this report.

age, respectively (Fig.3; Balkwill *et al.* 1990). At Cape Dyer this phase is probably not represented.

During Palaeogene sea-floor spreading, sedimentation in the Hopedale and Saglek basins is recorded by the Cartwright and Kenamu Formations which are dominated by marine mudstone. In the Saglek Basin, the Cartwright Formation is commonly interbedded with thick basaltic flows. Proximal shallow marine deltaic sandstones have, however, been recognised in both formations (Fig. 3) and are referred to the middle and upper Gudrid mem-



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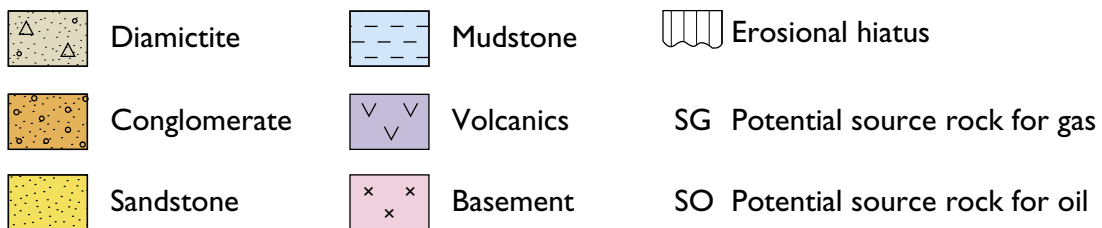


Fig. 4. Generalised stratigraphy of the West Greenland basins Modified from GEUS (2002) and Chalmes & Pulvertaft (2001). Grey shading denotes stratigraphy covered in this report.

bers (Cartwright Formation) and to the Leif member (Kenamu Formation; for discussion on these informal units, see Balkwill *et al.* 1990). The Leif member contains the most important Palaeogene hydrocarbon reservoirs in the region and are especially well developed in the Hopedale Basin. At Cape Dyer, a very thin (<10 m) succession of alluvial sandstones of Early Paleocene age (Cape Searle Formation) underlies a several hundred metres thick succession of basalt breccias (Burden & Langille 1990).

West Greenland shelf

The earliest manifestations of Early Cretaceous rifting in West Greenland is characterised by a volcanic phase represented by a 380 km long coast-parallel basaltic dyke swarm yielding ages between 138 and 133 Ma (Berriasian – Valanginian; Larsen *et al.* 1999) – ages that are comparable to the Alexis Formation on the Labrador Shelf. Offshore West Greenland, sedimentary successions of this phase have not been drilled, but are recognised as the Kitsissut seismic sequence (Fig. 4; cf. Chalmers & Pulvertaft 2001). Coeval sediments may be found onshore northern Nuussuaq where outcrops of fluvial and shallow marine sandstones of possible Albian age and unconformably overlain by younger deposits are referred to the Kome (cf. Pulvertaft 1979; Nøhr-Hansen 1992; Midtgaard 1996).

The Late Cretaceous – Early Paleocene rifting event is represented by the Appat and Kangeq seismic sequences offshore West Greenland (Fig. 4; cf. Chalmers & Pulvertaft 2001). Rolle (1985) proposed a lithostratigraphy for the basins offshore West Greenland based on cuttings and logs from the five exploration wells drilled in the mid-1970s, but only two of these (Ikermiut-1 and Kangâmiut-1) reached Cretaceous strata. In the lowermost part of the Kangâmiut-1 well, Upper Cretaceous to Lower Paleocene syn-tectonic fan deposits were assigned to the Narssarmiut Formation and correlated with the Freydis Member of the Markland Formation on the Labrador Shelf (Rolle 1985; Bate 1997). Basinal deposits comprising mainly mudstone were assigned to the Ikermiut Formation of Campanian to Middle Eocene age (Rolle 1985). However, new biostratigraphic data from the Ikermiut-1 well and the Qulleq-1 well (drilled in 2000) have shown that a major hiatus, possibly spanning the Late Campanian to earliest Paleocene, is present in both wells (see below). Onshore West Greenland, Cenomanian to earliest Paleocene (early Danian) sediments are included in the Nuussuaq Group (Dam *et al.* 1998a; Dam & Nøhr-Hansen 2001; Dam & *et al.* in prep.) which includes fluvial, shallow marine and deep marine deposits. Uplift is also recorded in the onshore sediments by a system of deeply incised valleys which were filled during the following phase of sedimentation (Dam *et al.* 1998a; Dam & Søndersholm 1998).

Onset of Paleocene sea-floor spreading in West Greenland is marked by the extrusion of extensive flood basalts and coincided with a phase of rapid subsidence (Dam *et al.* 1998a) resulting in a thick and varied succession of sediments in the offshore basins (Fig. 4). These were assigned to the Hellefisk, Ikermiut and Nukik Formations and correlated with the Cartwright and Kenamu Formations on the Labrador Shelf (Rolle 1985). Onshore Nuussuaq, the uppermost part of the Nuussuaq Group comprises sandy fluvial valley fills overlain by estuarine deposits eventually followed by offshore mudstones before the eruption of hyaloclastic breccias filled the basin (Dam *et al.* 1998a; Dam & Søndersholm 1998).

Table 1: Technical data of the Canadian and Greenland wells used in the palynological studies

	Drilled/ Operator	Position	Formation at TD/ Reference	Palynological study
Ogmund E-72	1980 Petro Canada	Hopedale Basin, Labrador Shelf, offshore eastern Canada 57.525028°N; 60.442825°W (NAD83) Water depth: 156.2 m Rotary table: 12.8 m Total depth: 3094.0 m b.R.T.	Lower Cretaceous sandstones and conglomerates (Bujak Davies Group 1987c; Miller & d'Eon 1987)	Interval: 790–3090 m Eocene – ?Aptian Samples: 134 cutting samples 20 sidewall core samples
Skolp E-07	1978 Total Eastcan	Saglek Basin, Labrador Shelf, offshore eastern Canada 58.440322 °N; 61.768175°W (NAD83) Water depth: 166.5 m Rotary table: 12.0m Total depth: 2992 m b.R.T.	Precambrian gneiss (Miller & d'Eon 1987)	Interval: 925–2985 m L. Eocene – Albian Samples: 136 cutting samples
Hekja O-71	1979 Aquitaine	Saglek Basin, Davis Strait, offshore eastern Canada 62.181228° N; 62.978328°W (NAD83) Water depth: 350.8 m Rotary table: 12.5 m Total depth: 4566.0 m b.R.T.	?Upper Cretaceous shale (Bujak Davies Group 1987b; Miller & d'Eon 1987)	Interval 1465–4566 m U.Paleocene – U.Eocene Samples: 78 cutting samples 1 sidewall core sample
Gjoa G-37	1979 Esso H. B.	Davis Strait Basin, Davis Strait, offshore Eastern Canada 62.941275 °N; 59.106975°W (NAD83) Water depth: 1000 m Rotary table: 24.0 m Total depth: 3998 m b.R.T.	Lower Paleocene shales (Bujak Davies Group 1987a; Miller & d'Eon 1987)	Interval: 1510–3998 m M.Eocene – L.Paleocene Samples: 79 cutting samples 1 sidewall core sample
Qulleq-1	2000 Statoil	Fylla Structural Complex, offshore West Greenland 63° 48' 48.03" N; 54° 27' 06.61" W (WGS84) Water depth: 1152.3 m Rotary table: 36 m Total depth: 2973 m b.R.T.	?Upper Santonian sandstone (Nøhr-Hansen <i>et al.</i> 2000)	Interval 1862–2970 m L.Eocene – ?Santonian Samples: 30 cutting samples 50 sidewall core samples
Ikermiut-1	1979 Chevron Petroleum	Sisimiut Basin, close to the Ungava/Ikermiut Fault Zone offshore West Greenland 66° 56' 12" N; 56° 35' 26" W (WGS84) Water depth: 447 m Rotary table: 12 m Total depth: 3619 m b.R.T.	?Campanian shales (Rolle 1985; Nøhr-Hansen 1998)	Interval: 1049–3616 m M.Eocene – ?L.Campanian Samples: 104 cutting samples 75 sidewall core samples
GRO#3	1995 grønArctic Energy Inc.	Nuussuaq Basin, Nuussuaq, onshore West Greenland 70° 27.765' N ; 54° 05.227' W (WGS84) Rotary table: 22,5 m a.m.s.l. Total depth: 2998 m b.R.T.	Cretaceous shales (Nøhr-Hansen 1997a)	Interval: 300–2950 m U.Paleocene – ?Coniacian Samples: 70 cuttings samples

Palynological study: correlation Canada – West Greenland

Henrik Nøhr-Hansen

Palynological material

The present palynological study of the Cretaceous to Palaeogene succession in the Labrador Sea – Davis Strait area is based on samples from the eastern Canadian offshore wells Ogmund E-72, Skolp E-07, Hekja O-71 and Gjoa G-37, the West Greenland offshore wells Qulleq-1 and Ikermiut-1, the West Greenland onshore wells GRO#3 and Umiivik-1, and outcrop samples from Svartenhuk Halvø and Nuussuaq (Figs 1, 2; Table 1).

The analysis of surface samples from Svartenhuk Halvø and from Kangilia and Slibestensfjeldet on northern Nuussuaq have earlier been reported on by Nøhr-Hansen (1992, 1996) and Nøhr-Hansen *et al.* (2002). Most of the studied West Greenland samples were processed or re-processed in the 1990s. However, the majority of the sidewall core samples from the Ikermiut-1 well are only available as original slides produced in 1977 and are of variable – and generally low – quality. All the Canadian samples were processed in 2001 and 2002.

Methods

Palynological preparation and studies of the samples were carried out at the Geological Survey of Denmark and Greenland (GEUS). Palynomorphs were extracted from 20 g of sediment from each sample by modified standard preparation techniques including treatment with hydrochloric (HCl) and hydrofluoric (HF) acids, sieving using a 20 μ nylon mesh and oxidation (3–10 minutes) with concentrated nitric acid (HNO₃). Finally, palynomorphs were separated from coal particles and woody material in most samples, using the separation method described by Hansen & Gudmundsson (1978) or by swirling. After each of the steps mentioned above the organic residues were mounted in a solid medium (Eukitt®) or in glycerine gel. The palynological slides were studied with transmitted light using a Leitz Dialux 22 microscope (No. 512 742/057691). Dinoflagellate cysts, acritarchs and selected stratigraphically important spores and pollen species were recorded from the sieved, oxidised or gravity-separated slides. Approximately 100 specimens were counted whenever possible.

The sample depths and relative abundance of species referred to in the biostratigraphic section (below) are illustrated on range-charts of each well (Enclosures 1–8). The illustrations of dinoflagellate cysts from Ogmund E-72, Skolp E-07 and Gjoa G-37 (Plates 1–50) are marked with sample number, slide number and laser-video-record number (LVR) for later identification.

Series	Stage	Dinocyst zonation*	Palynological intervals present study	Last appearance events	Acmes		
Upper Eocene	Priabonian	E8	<i>A. diktyoplokum</i> (H)	← <i>A. diktyoplokum</i>	← <i>C. cf. guiseppiei</i> ● (H)		
				← <i>G. texta</i> , <i>E. fenestrata</i> , <i>R. longimanum</i> , <i>Phthanoperidinium</i> spp.	← <i>G. texta</i> ■ (H)		
Middle Eocene	Bartonian	E7b	<i>G. texta</i> (H)	← <i>W. spinula</i> , <i>R. draco</i>	← <i>L. machaerophorum</i> ● (H)		
				E7a	<i>G. semitecta</i> (I, K)	← <i>C. bartonensis</i> , <i>G. semitecta</i> , <i>H. porosa</i>	← <i>I. cf. insolitum</i> ■ (H)
						Lutetian	E6
	← <i>G. cf. spineta</i> , <i>E. pectiniformis</i>						
	← <i>A. cf. bicellulum</i>						
	← <i>P. regalis</i> , <i>T. magnifica</i> , <i>D. denticulata</i>						
	E5a	<i>P. regalis</i> (H)	← <i>C. tenuivirgula</i>				
			← <i>C. magna</i>				
	E4c	<i>C. magna</i> (K)	← <i>H. costae</i> , <i>H. tubiferum</i> , <i>W. cf. lineidentatum</i>				
			← <i>E. ursulae</i>	← <i>H. tenuispinosum</i> ■ (K)			
Lower Eocene	Ypresian	E3d-E3c	<i>E. ursulae</i> (K, N2)	← <i>C. columna</i> , <i>D. brevispinum</i> , <i>W. endocyst</i> , <i>D. aff. pseudocolligerum</i>			
				E3b	<i>C. columna</i> (K, N1, N2, Q)	← <i>E. furensis</i> , <i>A. medusettiformis</i>	← <i>H. tenuispinosum</i> ■, Fungal spp. ■ (N1)
		E3a	<i>E. furensis</i> (H, K, N1, Q)			← <i>A. medusettiformis</i> ●	← <i>A. cf. bicellulum</i> ■ (H)
				E2c	<i>A. medusettiformis</i> (I, K, N1, N2?)	← <i>D. condylos</i> , <i>D. politum</i> , <i>D. oebisfeldensis</i> , <i>Rhombodinium</i> sp. 1	← <i>A. medusettiformis</i> ● (H, I, K)
		E2b	<i>D. condylos</i> (H, K, N1, N2, Q)			← <i>F. bipolaris</i> , <i>Carpatella</i> sp. 1	← <i>W. lunaris</i> ■ (N2)
				E2a	<i>F. bipolaris</i> (H, I, K, N1, N2)	← <i>W. astra</i> , <i>S. septatus</i>	← <i>Spinidinium</i> spp. ■ (N2)
		E1	Spores & pollen (H) <i>P. in-dentata</i> acme (N1) <i>Apectodinium</i> acme (I, K, N2)			← <i>C. dartmoorium</i> (N2), <i>C. crassiramossa</i> (K)	← <i>S. aff. pseudofurcatus</i> ■ (H)
Upper Paleocene	Thanetian			P6	← <i>Apectodinium</i> spp. ●	← <i>A. homomorphum</i> ■ (H)	
		P5	<i>A. gippingensis</i> (H, I, K, N1, N2, Q)		← <i>A. gippingensis</i> , <i>A. margarita</i>	← <i>F. bipolaris</i> ■ (H, N1)	
					← <i>P. pyrophorum</i> consistent <i>P. bulliforme</i>	← <i>W. astra</i> ■ (K)	
Lower Paleocene	Danian	P2/P3a?	<i>C. kangiliense</i> (N2)	← <i>C. kangiliense</i> , <i>S. cf. iterlaense</i>	← <i>D. oebisfeldensis</i> ● <i>S. aff. sagittula</i> ● (I), <i>Glaphrocysta</i> spp. ■ (K)		

Fig. 5. Palaeogene palynological intervals and bioevents offshore West Greenland, correlated with the dinocyst zonations of Bujak & Mudge (1994) and Mudge & Bujak (1996a, b) and the foraminifera and microfossil intervals of Rasmussen & Sheldon (in press). From Nøhr-Hansen (in press).

Palynological results

Palynostratigraphic correlations of the Upper Cretaceous to Palaeogene West Greenland deposits have previously been presented by Nøhr-Hansen (1996, 1997a, 1997b, 1998), Dam *et al.* (1998b), Nøhr-Hansen & McIntyre (1998), Christiansen *et al.* (1999), Nøhr-Hansen *et al.* (2000, 2002) and Nøhr-Hansen (in press, see Appendix 3). There is no formal palynological zonation for the Cretaceous of the Labrador Shelf, but available data for the Cretaceous and Palaeogene have been summarised by Williams *et al.* (1990).

Paleocene	<i>T. evittii</i>	
U. Maastrichtian	<i>Palynodinium grallator</i> (S, GRO#3)	← <i>P. grallator</i> , W. sp. ← <i>I. majae</i>
	<i>Chatangiella biapatura</i> (S)	← <i>C. biapatura</i> ← <i>T. quinqueangula</i>
	<i>Isabelidium cooksoniae</i> (S, O, GRO#3)	← <i>I. cooksoniae</i> , H. j. ← <i>L. arcticum</i>
L. Maastrichtian	<i>Alterbidinium acutum</i> (S)	← <i>A. acutum</i> ← <i>H. quasicibrata</i> ← <i>C. aceras</i>
U. Campanian	<i>Odontochitina operculata</i> (S, GRO#3)	← <i>S. rotunda</i> , <i>T. cas</i> ← <i>O. operculata</i> , <i>H.</i> ← <i>X. wetzellii</i> ← <i>C. madura</i> , <i>R. fucc</i> ← <i>T. suspectum</i>
	<i>Callaiosphaeridium asymmetricum</i> (S)	← <i>A. cf. haromense</i> , ← <i>C. asymmetricum</i> ← <i>C. cf. nyei</i> , <i>C. whii</i> ← <i>S. obscurum</i> ← <i>O. costata</i> , <i>W. lur</i> ← <i>B. jaegeri</i> ← <i>P. infusorioides</i>
	<i>Fromea nicosia</i> (S & Q ?)	← <i>A. varium</i> ← <i>C. decorosa</i> ← <i>D. longicornis</i> ← <i>F. nicosia</i> ← <i>O. parosa</i> ← <i>X. ceratioides</i> ← <i>Fromea</i> sp. 1 ← <i>C. bondarenkoi</i>
? L. Campanian	<i>Dinocyst</i> sp. E. Ioannides 1986 (S, Q & I)	← <i>Dinocyst</i> sp. E. Io ← <i>I. microarmum</i>
U. Santonian ?	<i>Dinogymnium sibiricum</i> (Svartenhuk Halvø, Q ?)	← <i>D. cf. sibiricum</i>
L. Santonian	<i>Heterosphaeridium difficile</i> (Svartenhuk Halvø, Q ?)	← <i>H. difficile</i>
Coniacian	<i>Arvalidium scheii</i> (Svartenhuk Halvø, Umiivik-1)	← <i>A. scheii</i> , <i>C. mcint</i> ← <i>S. longifurcatum</i> ← <i>A. scheii</i> , <i>I. svartei</i> ← <i>C. cf. madura</i>
	<i>Chatangiella cf. madua</i> (Svartenhuk Halvø, Umiivik-1)	← <i>I. magnum</i> ← <i>C. aff. spectabilis</i>
	<i>Spinidium echinoideum</i> (Umiivik-1)	← <i>S. echinoideum</i> ■ ← <i>S. echinoideum</i>
U. Turonian	<i>Chatangiella cf. ditissima</i> (Umiivik-1)	← <i>C. cf. elegantulum</i> ← <i>C. cf. ditissima</i> , <i>S.</i>
	<i>Raphidodinium fucatum</i> (Umiivik-1)	← <i>R. fucatum</i> , <i>T. sus</i>
Cenomanian– Albian	<i>Rugubivesiculites</i> spp. (O)	← <i>H. difficile</i> ← <i>R. reductus</i> ← <i>Afropollis?</i> ← <i>R. rugosus</i>
Albian– Aptian	<i>Quantouendinium dictyophorum</i> (O)	← <i>Q. dictyophorum</i>
	<i>Nyctericysta davisii</i> (O, Nuussuaq)	← <i>N. davisii</i>
	<i>Vesperopsis</i> spp. (O.)	← <i>Vesperopsis</i> spp.
	<i>Vesperopsis cf. nebulosa</i> (O)	← <i>V. cf. nebulosa</i> ← <i>Balmula</i> spp.

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Fig. 6. Twenty preliminary Cretaceous palynological intervals and bioevents on- and offshore eastern Canada and West Greenland.

This study describes the palynology of the Cretaceous to Palaeogene succession of selected wells offshore eastern Canada and on- and offshore West Greenland. Twenty preliminary palynological intervals are proposed here for the Cretaceous (Fig. 5) and twenty-one palynological intervals have been erected from the Early Paleocene to the Late Eocene (Fig. 6; Nøhr-Hansen in press). The last appearance datum (LAD), first appearance datum (FAD) and abundance of stratigraphic marker species define the intervals.

The palynology of the Neogene offshore West Greenland is not included in this report but is described by Nøhr-Hansen *et al.* (2000) and Piasecki (in press).

Stratigraphic overview

In the present study new data from the Cretaceous successions in Ogmund E-72 and Skolp E-07 offshore eastern Canada are compared with data from the West Greenland exploration wells Qulleq-1, Ikermiut-1 and GRO#3 (Figs 7, 8), and from onshore exposures on Svartenhuk Halvø and Nuussuaq (Fig. 9). The Cretaceous dinoflagellate cyst stratigraphy presented here (Fig. 5) is mainly compared with the Cretaceous dinoflagellate cyst zonation from the North Sea described by Hansen (1977), Costa & Davey (1992) and Schiøler & Wilson (1993).

The new stratigraphy for the Cretaceous is preliminary mainly because several of the described intervals are only recorded from one well/locality and because some of the nonmarine to brackish intervals from Ogmund E-72 need correlation to fully marine sections. It is therefore strongly recommended that this preliminary stratigraphy should be tested and refined against other wells offshore eastern Canadian that contain Cretaceous marine successions (eg. North Leif I-05, Bjarni O-82 and Gilbert F-53) and onshore Cretaceous deposits on Bylot Island and Devon Island in the Canadian Arctic Archipelago.

A detailed dinoflagellate cyst stratigraphy for the Palaeogene succession offshore West Greenland has recently been established by Nøhr-Hansen (in press). Twenty-one palynological intervals were described from the Early Paleocene to the Late Eocene based on material from the Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1, Nukik-2 and Qulleq-1 wells (Fig. 6).

Furthermore, a detailed dinoflagellate cyst zonation for the pre-volcanic part of the Danian (lowermost Paleocene) has been established by Nøhr-Hansen *et al.* (2002) based on material from three outcrop successions on northern Nuussuaq (Kangilia, Danierygge and Anner-tuneq) and from four shallow, slim core wells (GANW#1, GRO#3, GANE#1 and GANK#1). Five zones and three subzones were described (Fig. 9).

The present study includes new data from the Palaeogene successions in the Ogmund E-72, Skolp E-07 and Gjoa G-37 wells offshore eastern Canada which have been correlated with the successions on- and offshore West Greenland (Fig. 10). The calibration to the Palaeogene dinocyst zones follows Bujak & Mudge (1994), Mudge & Bujak (1996a, b), Nøhr-Hansen *et al.* (2002) and Nøhr-Hansen (in press), see Figure 6.

In Ogmund E-72 (Enclosure 1) the lower 1170 m of the well consists of a nonmarine to brackish succession of Aptian to Albian age followed by a 130 m thick nonmarine succession of

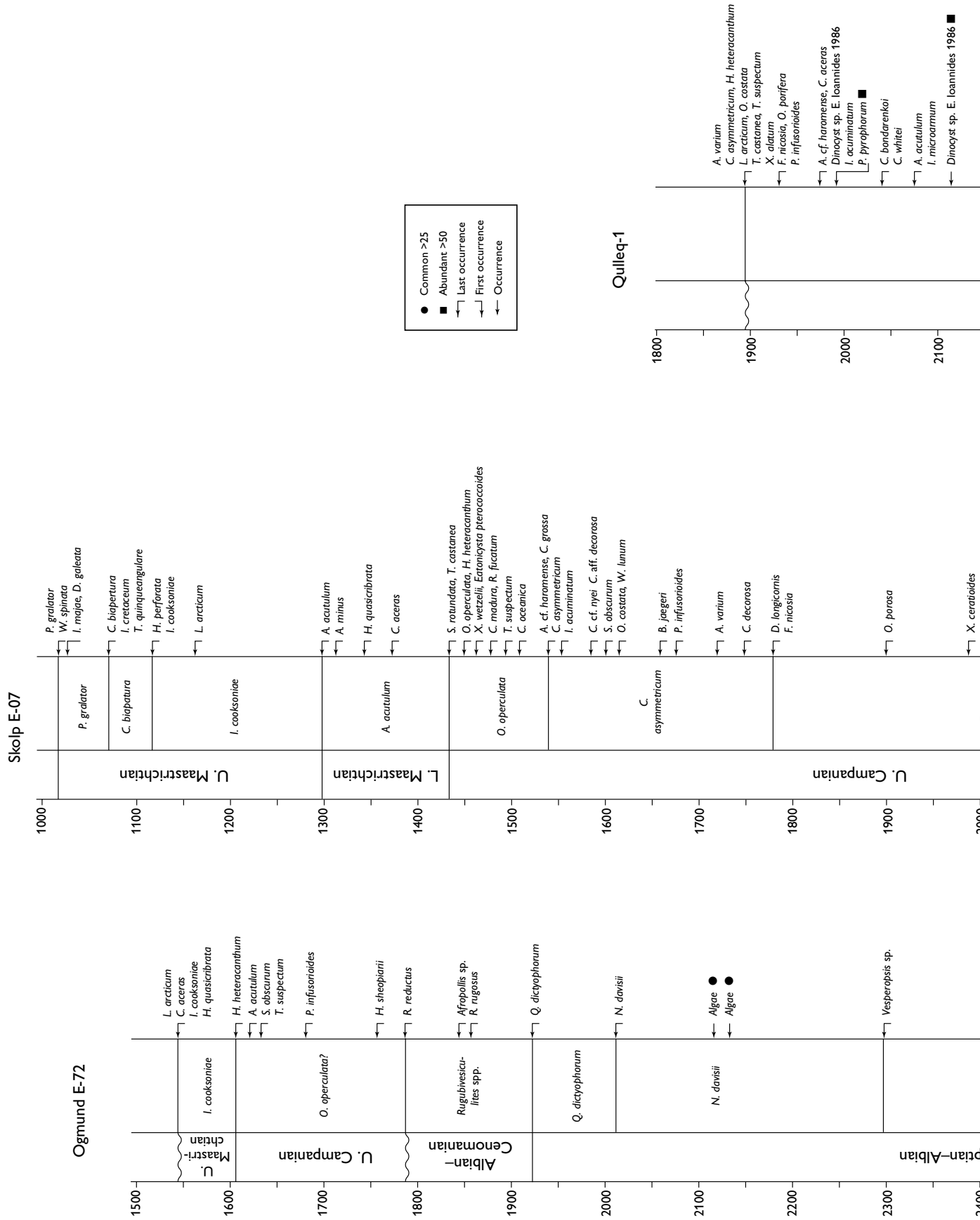
presumably Albian to Cenomanian age (Fig. 7). The nonmarine deposits are unconformably overlain by marine Upper Campanian and Upper Maastrichtian deposits (140 m) followed by a lowermost Paleocene succession age (Fig. 7). The Palaeogene is represented by a very thin (15 m) lowermost Paleocene succession (P1) which is unconformably overlain by a 225 m thick Upper Paleocene to Lower Eocene succession (P5–E3b; Fig. 10). However, no indication of the lowermost Eocene (E1) has been recorded which may suggest a very condensed interval or an unconformity between the uppermost Paleocene to Lower Eocene (P6–E2a). A possibly more than 300 m thick Middle Eocene succession (most likely Bathonian, E7) unconformably overlies the Lower Eocene (Fig. 10).

In Skolp E-07 (Enclosure 2) the deepest part of the well consists of a 490 m thick succession of nonmarine deposits of presumably Albian to Cenomanian age unconformably overlain by a 1500 m thick and apparently continuous Lower Campanian to Upper Maastrichtian and lowermost Palaeogene marine succession (Fig. 7). The Palaeogene is represented a 20 m thick lowermost Paleocene succession (P1) unconformably overlain by a 70 m thick (condensed?) Lower Eocene succession (?E2b–?E2c; Fig. 10).

In Hekja 0-71 (Enclosure 8) the palynological content – especially the marine – of most of the Palaeogene is of very low diversity and lacks stratigraphic marker species making a detailed zonation difficult. The Upper Paleocene (P4–P6) in Hekja 0-71 is 1425 m thick; however, it also includes more than 1000 m of volcanic rocks. An $^{40}\text{Ar}/^{39}\text{Ar}$ age dating of basaltic rocks is in conflict with the biostratigraphic data since it has yielded a late Early to early Middle Eocene age of 49.1 ± 1.3 Ma (Williamson *et al.* 2003). As in Skolp E-07, Gjoa G-37, Qulleq-1 and possibly also Ogmund E-72 the Upper Paleocene may be unconformably overlain by a Lower Eocene succession (?E2–?E3) which in Hekja 0-71 is approximately 700 m thick. This is followed by an approximately 1000 m thick Middle to Upper Eocene succession (Fig. 10).

In Gjoa G-37 (Enclosure 3) the Palaeogene succession is probably represented by a 1680 m thick Upper Paleocene succession (P4–P6) which, however, may include a 440 m thick lower Paleocene (P2) succession in the lower part of the well (Fig. 10). The Paleocene deposits are interbedded with volcanic rocks with a total thickness of more than 500 m. As in Skolp E-07, Qulleq-1 and possibly also Ogmund E-72 an unconformity is present between the uppermost Paleocene and an approximately 640 m thick Lower Eocene succession (E2a/E2b–E3c). The Lower Eocene is conformably overlain by approximately 60 m of Middle Eocene (Lutetian, E3d–E4) deposits (Fig. 10).

The interpretation of the Cretaceous dinocyst stratigraphy in the Ikermiut-1 well (Fig. 8, Enclosure 5) is complicated due to a combination of reworking and extensive caving (see below). Therefore, 25 critical samples have been re-processed and all data available have been carefully evaluated. This has resulted in a revised stratigraphy of the well suggesting that the youngest Cretaceous succession in Ikermiut-1 is of Early Campanian age, suggesting a hiatus related to uplift during latest Maastrichtian to earliest Paleocene time as seen in the Qulleq-1 well (Fig. 10, Enclosure 4; Christiansen *et al.* 2001). This event has been recorded in large parts of the areas offshore West Greenland (Chalmers & Pulvertaft 2001) but is only seen as a minor hiatus onshore Nuussuaq, West Greenland (Nøhr-Hansen *et al.* 2002). On parts of the Labrador Shelf the Upper Campanian to Maastrichtian succession is more or less complete.



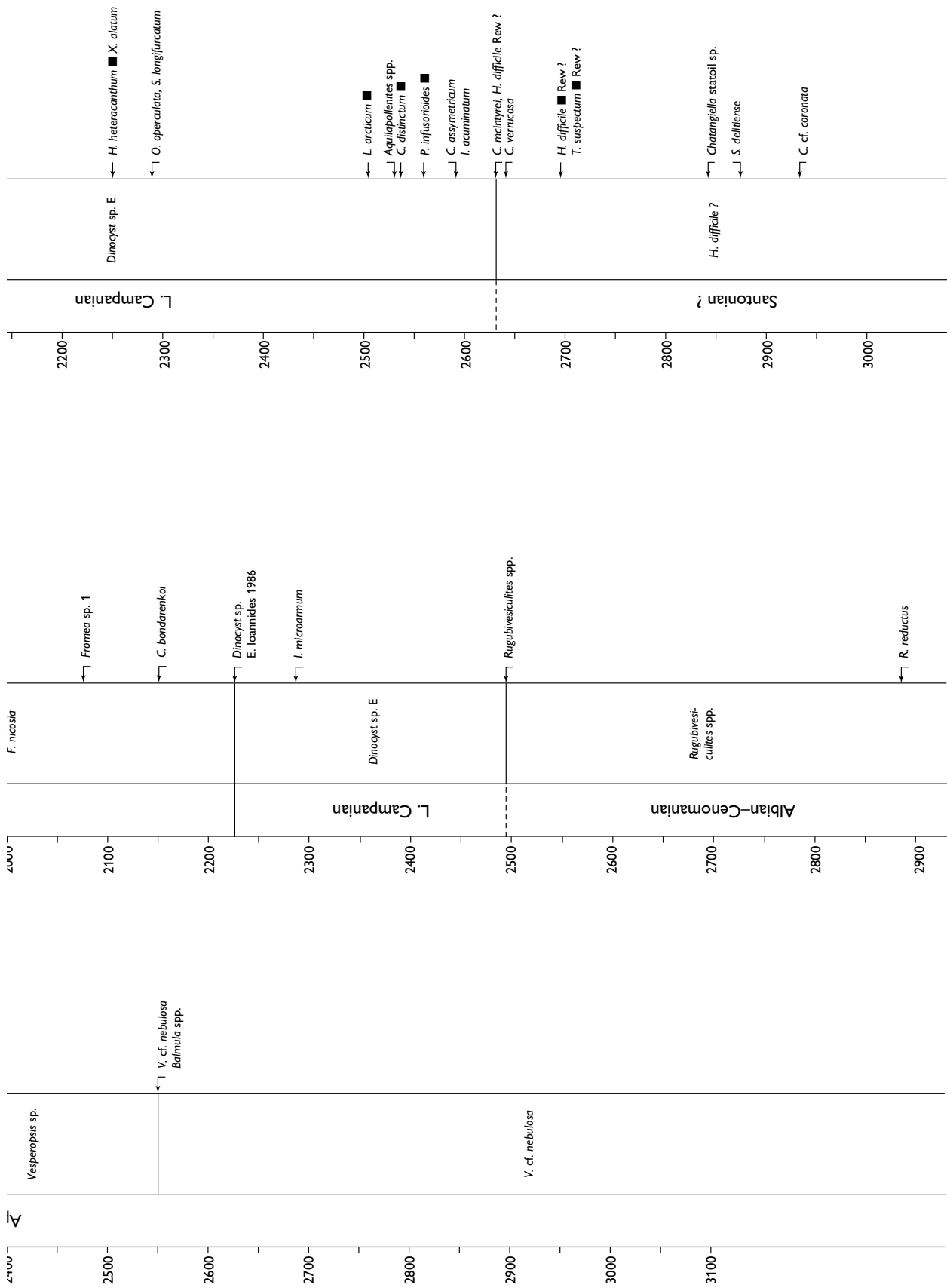
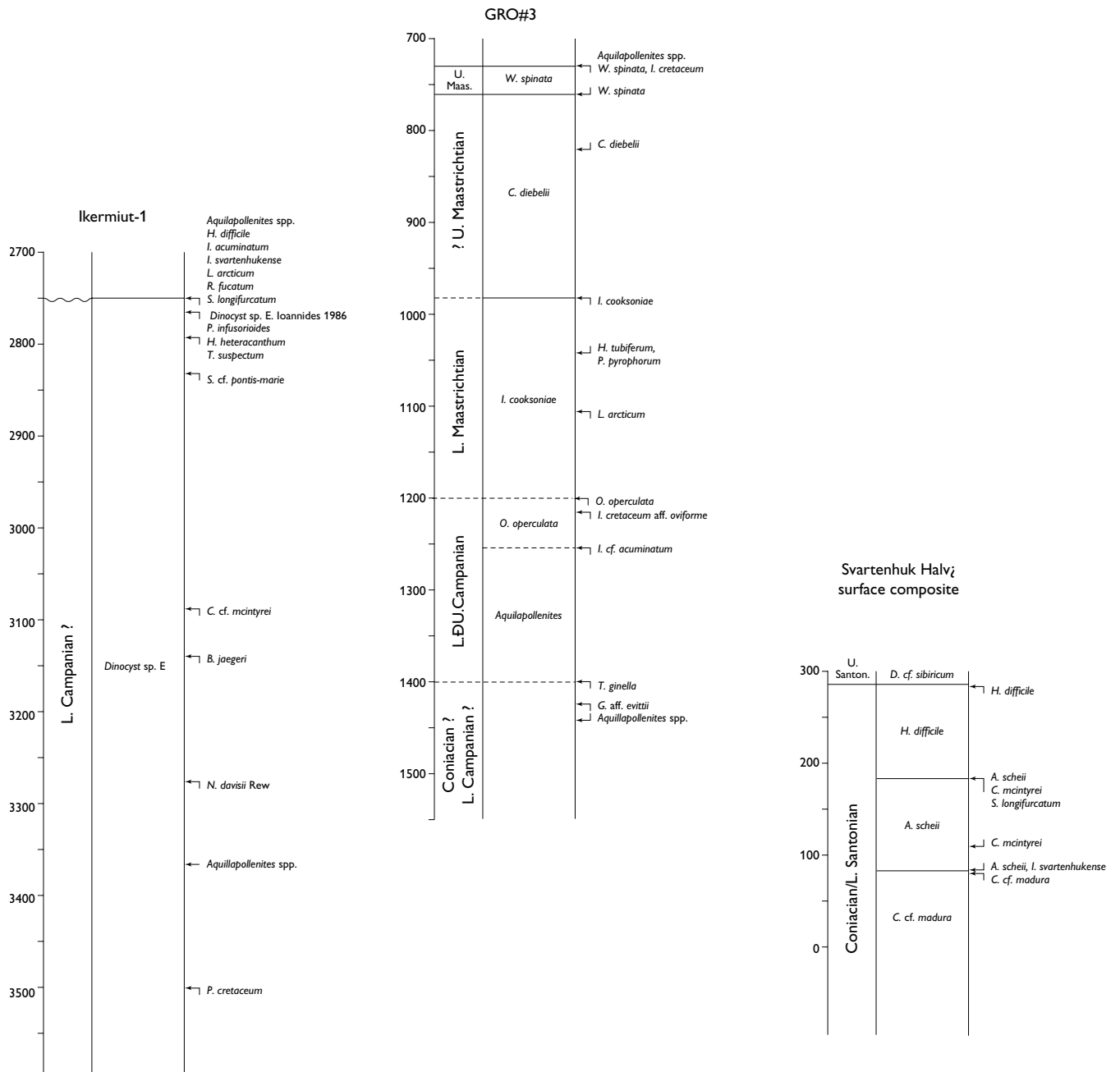


Fig. 7. Cretaceous palynological intervals and bioevents for the Ogmund E-72, Skolp E-07 and Qulleq-1 wells, offshore Eastern Canada and West Greenland. The stratigraphy is based on last appearance datum events, first appearance datum events and abundances of stratigraphically important species. Depth scales in metres.



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In contrast to the onshore deposits on Nuussuaq in West Greenland, the Lower Paleocene (P1–P2, Danian) succession is generally thin or absent in the offshore Canadian and Greenland wells (Fig. 10; Nøhr-Hansen *et al.* 2002). The $^{40}\text{Ar}/^{39}\text{Ar}$ dating of the basaltic rocks overlying the Danian on Nuussuaq shows that the volcanism commenced in West Greenland between 60.9 and 61.3 Ma and that ~80% of the Paleocene lava pile was erupted in 1 million years or less (Storey *et al.* 1998). This compares well with ages on basalts in the Gjoa G-37

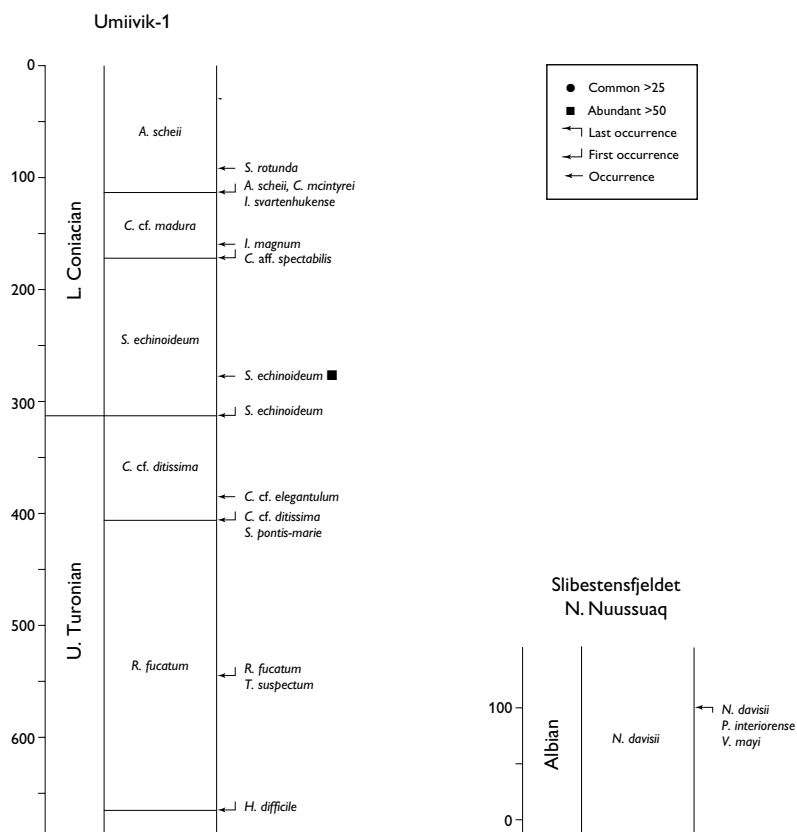


Fig. 8. Cretaceous palynological intervals and bioevents for the on- and offshore wells, and surface sections in West Greenland. The stratigraphy is based on last appearance datum events, first appearance datum events and abundances of stratigraphically important species. Depth scales in metres.

well where two samples of basaltic rock have yielded 57.9 ± 2.9 Ma and 60.4 ± 1.7 Ma, respectively (Williamson *et al.* 2003). The Upper Paleocene is absent on Nuussuaq, whereas it is well represented in the Ikermiut-1 well and between the basalts in the lower part of the Gjoa G-37 and Hekja O-71 wells.

Preliminary palynological zonation of the Cretaceous

Maastrichtian

Maastrichtian successions have been recorded from the Ogmund E-72, Skolp E-07 and GRO#3 wells and from outcrop sections on Nuussuaq (Figs 7, 8). Three Upper Maastrichtian and one Lower Maastrichtian intervals are proposed (Fig. 5).

The top of the uppermost *Palynodinium grallator* interval is characterised by the LAD of *Palynodinium grallator* and *Wodehouseia spinata*, whereas *Isabelidinium majae* has its LAD in the middle part of the interval. From the Danish North Sea Schiøler & Wilson (1993) also recognised the FAD of *P. grallator* in the uppermost Maastrichtian *Palynodinium grallator* Zone of Hansen (1977) whereas they only recorded *I. majae* from Hansen's (1977) *Tanyosphaeridium magdalinium* Subzone (lower part of the *P. grallator* Zone).

Discussion: Interval IV of the GRO#3 well (Enclosure 6), which Nøhr-Hansen (1997a) correlated with the *Wodehouseia spinata* interval of Nøhr-Hansen (1996), may be correlated with the *Palynodinium grallator* interval based on the LAD of *Wodehouseia spinata* which is seen in all three intervals.

The top of the Upper Maastrichtian *Chatangiella biapatura* interval is characterised by the LAD of *Chatangiella biapatura* and *Trithyrodinium quinqueangulare*. McIntyre (1975) described *C. biapatura* from the Upper Maastrichtian from the district of Mackenzie N.W.T., Canada.

Discussion: The stratigraphic position of the *Chatangiella biapatura* interval of this study suggests that it correlates with interval V of the GRO#3 well, which Nøhr-Hansen (1997a) correlated with the *Cerodinium diebelii* interval of Nøhr-Hansen (1996).

The top of the Upper–Lower Maastrichtian *Isabelidinium cooksoniae* interval is characterised by the LAD of *Hystriochosphaeropsis perforata* and *I. cooksoniae*, whereas *Laciniadinium arcticum* has its LAD in the upper part of the interval. Schiøler & Wilson (1993) also recognised the FAD of *H. perforata* in their lower Upper Maastrichtian *I. cooksoniae* Interval Zone from the North Sea.

Discussion: Nøhr-Hansen (1997a) correlated interval VI of the GRO#3 well with the Upper Campanian *Isabelidinium cooksoniae* interval of Nøhr-Hansen (1996). The *Isabelidinium cooksoniae* interval was, however, not defined on the LAD of *I. cooksoniae* but on the abundance of the species. A re-study of the data from interval VI in GRO#3 suggests that the upper part (980–1170 m) of interval VI correlates with the Upper Maastrichtian *Isabelidinium cooksoniae* interval of this study based on the LAD of *I. cooksoniae* at 980 m and the LAD of *Laciniadinium arcticum* at 1110 m in GRO#3. It is therefore suggested that the Upper Campanian *Isabelidinium cooksoniae* interval of Nøhr-Hansen (1996) is replaced by the Upper Campanian *Odontochitina operculata* interval of this study since an LAD of *Odontochitina operculata*

is also recognised at the top of the *Isabelidium cooksoniae* interval in the Kangilia section on northern Nuussuaq (see below).

The top of the Lower Maastrichtian *Alterbidinium acutululum* interval is characterised by the LAD of *A. acutululum*, whereas *Hystriospheraopsis quasicribrata* and *Caligodinium aceras* have their LAD in the middle part of the interval. Schiøler & Wilson (1993) also recognised the FAD of *A. acutululum* in their Lower Maastrichtian *Alterbidinium acutululum* Interval Zone from the North Sea.

Campanian

Campanian successions have been recorded from the Ogmund E-72, Skolp E-07, Qulleq-1 and GRO# 3 wells and from outcrop sections on Nuussuaq and possibly from the Ikermiut-1 well (Figs 7, 8; see discussion below). Three Upper to mid-Campanian and one Lower Campanian intervals are proposed (Fig. 5).

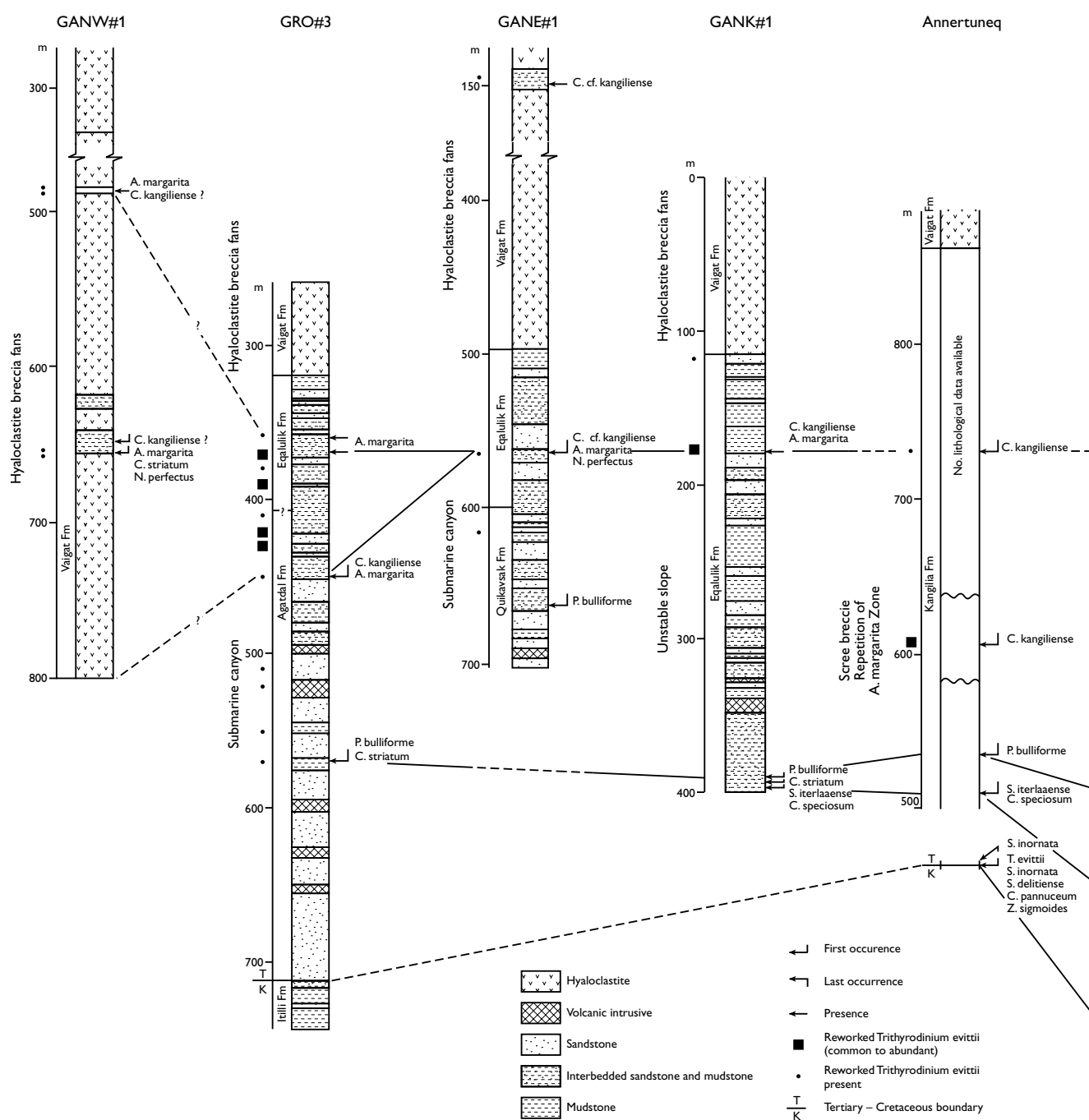
The upper part of the uppermost Campanian *Odontochitina operculata* interval is characterised by the LAD of *Heterosphaeridium heteracanthum*, *Odontochitina operculata*, *Senoniasphaera rotundata* and *Trichodinium castanea*, followed by the LADs of *Xenascus wetzellii*, *Eatonicysta pterococcoides*, *Raphidodinium fucatum* and *Trithyrodinium suspectum* in the middle to lower part of the interval. According to Schiøler & Wilson (2001) the last occurrence of the genera *Odontochitina* may be a good uppermost Campanian marker. Slimani (1996) described *Xenascus wetzellii* from Lower to Upper Campanian strata in Belgium and the Netherlands.

Discussion: Nøhr-Hansen (1997a) correlated interval VI from GRO#3 with the Late Campanian *Isabelidium cooksoniae* interval of Nøhr-Hansen (1996). A re-study of this interval suggests that the middle part of interval VI (1200–1250 m) correlates with the Upper Campanian *Odontochitina operculata* interval of this study based on the LAD of *Odontochitina operculata* in the top of the interval (1200 m) in the GRO#3 well (Fig. 8). As noted above it is suggested that the Upper Campanian *Isabelidium cooksoniae* interval of Nøhr-Hansen (1996) is replaced by the Upper Campanian *Odontochitina operculata* interval of this study.

The top of the Upper to mid-Campanian *Callaiosphaeridium asymmetricum* interval is characterised by the LAD of *Atopodinium* cf. *haromense*, *Callaiosphaeridium asymmetricum*, *Chlamydophorella grossa*, *Chlamydophorella* cf. *neyi* and *Cometodinium whitei*. These are followed by the LADs of *Scriniodinium obscurum*, *Odontichitina costata*, *Wallodinium lunum*, *Batioladinium jaegeri*, *Palaeohystriochophora infusorioides*, *Alterbidinium varium* and *Chatangiella decorosa* in the middle to lower part of the interval. The LAD of *Callaiosphaeridium asymmetricum* is an intra-Campanian event close to the Lower–Upper Campanian boundary according to Costa & Davey (1992).

The top of the mid- or Lower Campanian *Fromea nicosia* interval is characterised by the LAD of *F. nicosia* and *Dinogymnium longicornis*, followed by the LADs of *Odontochitina porifera*, *Xenascus ceratioides*, *Fromea* sp. 1 and *Chatangiella bondarenkoi* in the middle to lower part

WELLS



of the interval. Nøhr-Hansen (1996) recorded *C. bondarenkoi* from the Lower or mid-Campanian on West Greenland; Lentin & Vozzhennikova (1990) recorded the species from the Santonian to Campanian of Arctic Canada.

The top of the Lower Campanian Dinocyst sp. E. loannides 1986 interval is characterised by the LAD of Dinocyst sp. E. loannides 1986, followed by the LAD of *Isabellidinium micro-*

OUTCROPS

Kangilia

Danien-rygge

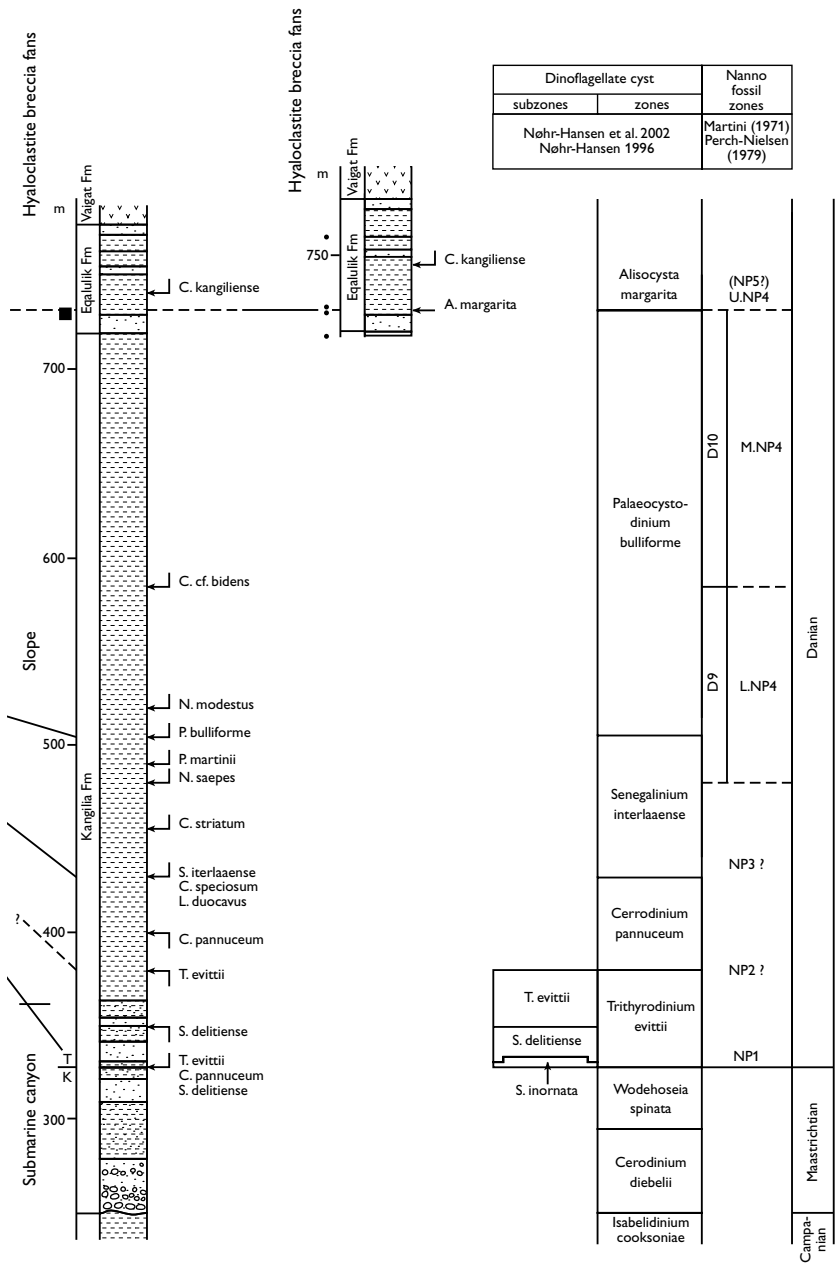


Fig. 9. Biostratigraphic correlation, dating and lithostratigraphy of the studied Palaeogene outcrops sections and wells from Nuussuaq, West Greenland, based on dinoflagellate cysts and nannofossils (figure 4 in Nøhr-Hansen et al. 2002).

armum in the middle part of the interval. Ioannides (1986) recorded his *Dinocyst* sp. E. from a possible Maastrichtian interval situated between a Santonian–Campanian interval and a Maastrichtian interval on Bylot Island, Canada. *Dinocyst* sp. E. Ioannides 1986 has its LAD in the Lower Campanian and *Isabellidinium microarmanum* has its LAD in the lowermost Lower Campanian according to B. Tocher (personal communication 2000).

Discussion: Parts of the Lower to mid-Campanian *Aquilapollenites* interval of Nøhr-Hansen (1996) may be correlated with the Lower Campanian Dinocyst sp. E. Ioanides 1986 interval of this study based on the LAD of *Isabellidium microarmum* seen in the top of the *Aquilapollenites* interval on Nuussuaq (Nøhr-Hansen 1996). Nøhr-Hansen (1997a) correlated the lower part of interval VI from GRO#3 (1250–1400 m) with the Lower to mid-Campanian *Aquilapollenites* interval of Nøhr-Hansen (1996) based on the presence of *Aquilapollenites* spp. (Fig. 8); however, the palynological assemblage in the GRO#3 well is of low diversity and poorly preserved due to thermal alteration.

Santonian–Coniacian

Five Santonian to Coniacian intervals have been described based on outcrop sections and the stratigraphical well Umiivik-1 onshore Svartenhuk Halvø, West Greenland (Fig. 5, Enclosure 7; Nøhr-Hansen 1996, 1997b). Marine Coniacian to Santonian successions may – if not reworked – be recognised in the lower part of Qulleq-1 well (Fig. 7).

The base of the Upper Santonian or Lower Campanian *Dinogymnium* cf. *sibiricum* interval of Nøhr-Hansen (1996) is defined by the LAD of *Heterosphaeridium difficile* and the top by the LAD of *Dinogymnium* cf. *sibiricum*. *Dinogymnium sibiricum* has a Coniacian to Lower Santonian range according to Costa & Davey (1992), whereas McIntyre (1974) reported an Upper Santonian to Upper Campanian range for the almost identical species *Dinogymnium* cf. *sibiricum*. The absence of *Heterosphaeridium difficile* and the presence of *Spinidinium echinoideum* suggest a Late Santonian to Early Campanian age.

The top of the Coniacian to Lower Santonian *Heterosphaeridium difficile* interval of Nøhr-Hansen (1996) is defined by the LAD of *Heterosphaeridium difficile*. The interval is characterised by a poorly preserved, low diversity palynomorph assemblage. The frequency of *Chatangiella* specimens is very low but species such as *Chatangiella* cf. *ditissima*, *Heterosphaeridium difficile*, *Laciniadinium arcticum*, *Odontochitina striatoperforata*, *Palaeohystrichophora infusorioides* and *Spinidinium echinoideum* are present throughout the interval, whereas *Surculosphaeridium longifurcatum* has its LAD in the lowermost part of the interval. The last occurrences of *Heterosphaeridium difficile* and *Surculosphaeridium longifurcatum* indicate an age not younger than Early Santonian in agreement with the range given by Costa & Davey (1992). Based on the last occurrence of *H. difficile*, the interval may be correlated with the lower part of the Upper Coniacian to Lower Campanian Zone 3 described from the Kanguk Formation in Arctic Canada by Núñez-Betelu (1994).

Nøhr-Hansen (1996) proposed a *Laciniadinium arcticum* interval of Early Coniacian age. The base of this interval was defined by the FAD of *Laciniadinium arcticum* and the top by the LAD of *Arvalidinium scheii*. The FAD of *Laciniadinium arcticum* was later recorded from much older sediments in the Umiivik-1 (Fig. 8; Nøhr-Hansen 1997b). It is therefore suggested that the *Laciniadinium arcticum* interval of Nøhr-Hansen (1996) is withdrawn and that the succession is included in an extended *Arvalidinium scheii* interval (see below).

The *Arvalidinium scheii* interval has been dated as Early Coniacian since it has been recorded

below *in situ* ammonites of Early Coniacian age in the core hole GGU 400712 (Nøhr-Hansen 1996). The base of the interval was defined by the first occurrence of *Arvaldinium scheii* and *Isabelidinium svartenhukense* and the top was immediately below the FAD of *Laciniadinium arcticum*. As mentioned above, this definition is no longer valid and it is therefore suggested that the *Arvaldinium scheii* interval ranges from the LAD of *Arvaldinium scheii* to the FAD of *Arvaldinium scheii*, which expands the upper part of the *Arvaldinium scheii* interval of Nøhr-Hansen (1996) with the *Laciniadinium arcticum* interval of Nøhr-Hansen (1996). The interval is characterised by the presence of abundant *Arvaldinium* and *Chatangiella* specimens and common *Odontochitina striatoperforata*. The interval is also characterised by the incoming of the species *Chatangiella mcintyreii*, *Isabelidinium svartenhukense* and *Palaeotetradinium sillicorum*.

Discussion: Manum (1963) described *Arvaldinium scheii* (as *Deflandrea scheii*) from Graham Island, Arctic Canada. The dinoflagellate cyst assemblage reported by Manum & Cookson (1964) from Graham Island is quite similar to the assemblage recorded from the *A. scheii* interval on Svartehuk Halvø. Manum (1963) and Manum & Cookson (1964) indicated that the samples were collected from the Upper Albian – Lower Cenomanian Hassel Formation, but Felix & Burbridge (1976) have argued that it is more likely that Manum's samples are from the Kanguk Formation of Late Cenomanian to Early Campanian age. Núñez-Betelu (1994) described some forms resembling *A. scheii*, from the base of his Upper Coniacian to Lower Campanian Zone 3; the level is dated Late Coniacian by the presence of the ammonite *Scaphites depressus* (Hills *et al.* 1994).

Nøhr-Hansen (1996) has proposed a Coniacian *Spinidinium echinoideum* interval. The base of this interval was defined by the FAD of *Spinidinium echinoideum* and the top was immediately below the FAD of *Arvaldinium scheii*. However, the FAD of *Spinidinium echinoideum* has later been recorded from much older sediments in the Umiivik-1 well (Fig. 8; Nøhr-Hansen 1997b) and it is therefore suggested here that the use of the *Spinidinium echinoideum* interval is withdrawn and that the succession is included in an extended *Chatangiella cf. madura* interval (see below).

The *Chatangiella cf. madura* interval is described as Coniacian but a Late Turonian or Early Santonian age can not be excluded (Nøhr-Hansen 1996). The interval was originally characterised by the occurrence of *Chatangiella cf. madura*, its upper limit being the FAD of *Spinidinium echinoideum*. As mentioned above, this definition is no longer valid and it is therefore suggested that the top of the *Chatangiella cf. madura* interval is now defined by the LAD of *Chatangiella cf. madura* immediately below the FAD of *Arvaldinium scheii*, which expands the upper part of the *Chatangiella cf. madura* interval of Nøhr-Hansen (1996) with the *Spinidinium echinoideum* interval of Nøhr-Hansen (1996). The genera *Chatangiella*, *Isabelidinium* and *Heterosphaeridium* dominate the assemblages and the following stratigraphically important species have been recorded: *Chatangiella cf. madura*, *Chatangiella aff. spectabilis*, *Florentinia aff. deanei*, *Heterosphaeridium difficile*, *Spinidinium echinoideum*, *Surculosphaeridium? longifurcatum*, and *Trigonopyxidia ginella*. Furthermore, the stratigraphically important species *Isabelidinium magnum* is recorded from the middle part of the interval in the Umiivik-1 well (Fig. 8; Nøhr-Hansen 1997b). The absence of species with a last occurrence in the Turonian suggests that this interval may be of Coniacian age.

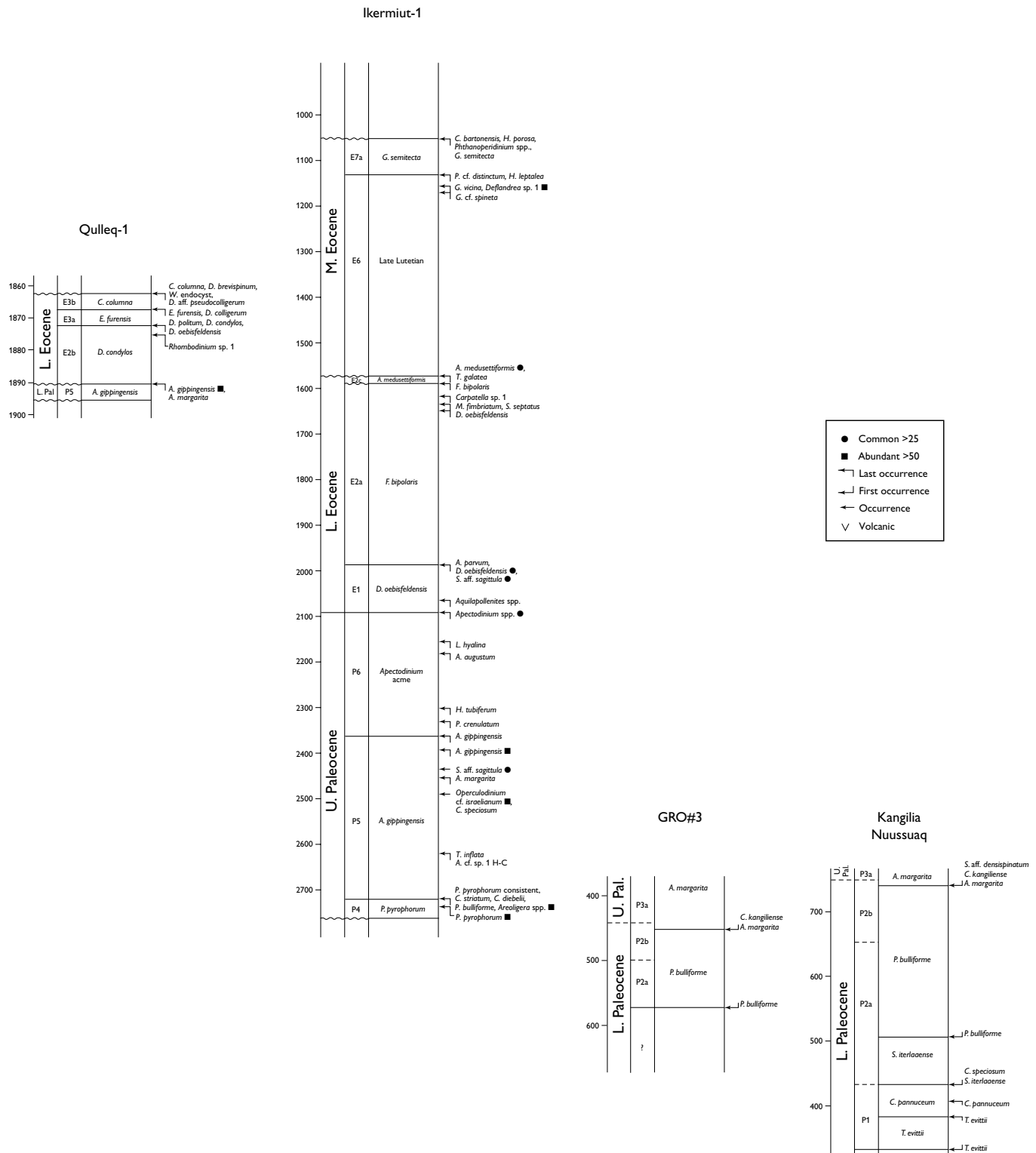


Fig. 10. Palaeogene palynological intervals and bioevents for the on- and offshore wells Eastern Canada and West Greenland correlated with the dinocyst zonation of Bujak & Mudge (1994) and Mudge & Bujak (1996a, b). The stratigraphy is based on last appearance datum, first appearance datum events and abundances of stratigraphically important species. Depth scales in metres.

Discussion: According to the observations by Costa & Davey (1992) from the North Sea region, the presence of *Heterosphaeridium difficile* and *Surculosphaeridium? longifurcatum* throughout the interval indicates an age not younger than Early Santonian. *Florentinia deanei* and *Isabelidinium magnum* has its last occurrence in the latest Coniacian in Europe (Foucher 1979; Costa & Davey 1992). *Chatangiella madura* is described by Cookson & Eisenack (1970) from the Senonian (Upper Cretaceous) of Australia. Ioannides (1986) recorded *C. madura* from the lower part of his Santonian–Campanian palynological interval I on Bylot Island, Arctic Canada. Núñez-Betelu (1994) recorded the species from his Zone 2 (Upper Turonian to Upper Coniacian) and Zone 3 (Upper Coniacian to Lower Campanian) at Glacier Fjord, Arctic Canada. Kirsch (1991) reported *C. madura* from the lower part of his Coniacian to Santonian *Raetiaedinium truncigerum* Zone and from his Campanian *Areoligera coronata* Zone in Oberbayern, Germany.

Coniacian – Turonian

The *Spinidinium echinoideum* interval was described as interval III from the Umiivik-1 well (Nøhr-Hansen 1997b) and dated as ?Early Coniacian to latest Turonian (Fig. 8). The lower boundary of the interval is placed at the FAD of *Spinidinium echinoideum*. The species *Heterosphaeridium difficile* and *Circulodinium distinctum* are common in the upper part of the interval. *Spinidinium echinoideum* has an acme within the lower part of the interval, whereas *Raphidodinium fucatum* has an acme in the upper part. According to observations from the Paris Basin, France (Foucher 1979) the presence of *Raphidodinium fucatum* and *Spinidinium echinoideum* suggests an age not older than latest Turonian. The interval thus comprises deposits of latest Turonian to ?Early Coniacian age.

The *Chatangiella cf. ditissima* interval was described as interval IV from the Umiivik-1 well (Fig. 8; Nøhr-Hansen 1997b) and dated as Late Turonian. The lower boundary of the interval is placed by the incoming of *Subtilisphaera pontis-mariae*, *Chatangiella cf. ditissima* and *Isabelidinium* sp. nov. The species *Heterosphaeridium difficile*, and *Isabelidinium* sp. nov. are common in the interval. Within the interval the following stratigraphically important species have been recorded: *Chatangiella cf. ditissima*, *C. granulifera*, *Ctenidodinium aff. elegantulum*, *Florentinia* sp., *Heterosphaeridium difficile*, *Isabelidinium* sp. nov., *Raphidodinium fucatum*, *Odontochitina striatoperforata*, *Subtilisphaera pontis-mariae*, *Surculosphaeridium longifurcatum*, *Tanyosphaeridium cf. variecalamus* and *Trithyrodinium suspectum*.

Discussion: According to observations from the Paris Basin, France (Foucher 1979) the presence of *Raphidodinium fucatum* and *Subtilisphaera pontis-mariae* suggest an age not older than Late Turonian. Foucher (1979) recorded the FAD of *Raphidodinium fucatum* and *Spinidinium echinoideum* from the uppermost Turonian and the FAD of *Subtilisphaera pontis-mariae* from the base of Upper Turonian in the Paris Basin. The presence of *Tanyosphaeridium cf. variecalamus* and *Raphidodinium fucatum* throughout the interval suggest an age not older than middle Turonian (Costa & Davey 1992).

The *Raphidodinium fucatum* interval was described as interval V from the Umiivik-1 well (Nøhr-Hansen 1997b) and dated as Turonian, possibly Upper Turonian (Fig. 8). The dinoflagel-

late specimens are all strongly thermally altered and in a poor state of preservation. It has been possible to identify black specimens of *Chatangiella* spp., possible *Heterosphaeridium difficile* and *Trithyrodinium suspectum* which according Costa & Davey (1992) date the interval not older than latest Cenomanian to Early Turonian. A questionable occurrence of *Raphidodinium fucatum* and *Heterosphaeridium difficile* may suggest an age not older than middle Turonian according to Costa & Davey (1992) and not older than latest Turonian according to Foucher (1979). However, the very sparse content of dinoflagellate cysts precludes a more precise dating and definition of the interval.

?Cenomanian to ?Late Albian

A possible Cenomanian to Upper Albian nonmarine succession has been recorded from the Ogmund E-72 and Skolp E-07 wells (Fig. 7).

The upper part of the ?Cenomanian to ?Late Albian *Rugubivesiculites* spp. interval is characterised by the LAD of *Rugubivesiculites rugosus*; within the interval the LAD's of *Ornamentifera baculata* and *Afropollis?* spp. is recorded (Fig. 5). Singh (1983) reported the LAD of *Rugubivesiculites rugosus* and *Ornamentifera baculatus* from the Cenomanian and Late Albian.

Discussion: Williams (1975) proposed an Upper Albian *Rugubivesiculites rugosus* Assemblage Subzone from wells on the Scotian Shelf and the Grand Banks offshore, eastern Canada. The subzone was characterised by the presence of *Rugubivesiculites rugosus* and tricolpate pollen.

Albian to ? Aptian

Four brackish-water to nonmarine Albian to ?Aptian intervals are recorded in the Ogmund E-72 well (Fig. 7) one of which is also recognised from surface sections onshore northern Nuussuaq (Fig. 8). The species diversity of these intervals is, however, very low.

The top of the *Quantouendinium dictyophorum* interval is characterised by the LAD of the presumed brackish-water species *Quantouendinium dictyophorum*. Mao *et al.* (1999) described *Q. dictyophorum* from Aptian to Albian brackish-water deposits in China.

The top of the *Nyktericysta davisii* interval is characterised by the LAD of the presumed brackish-water species *Nyktericysta davisii* and the presence of *Quantouendinium dictyophorum*. *N. davisii* has been recorded from upper Middle to lower Upper Albian brackish-water deposits in the Western Interior, USA by Bint (1986) and from mid-Upper Albian successions onshore East and West Greenland, and Arctic Canada by Nøhr-Hansen (1992, 1993) and Nøhr-Hansen & McIntyre (1998).

The top of the *Vesperopsis* spp. interval is characterised by the LAD of the presumed brackish-water genera *Vesperopsis* and the presence of *Quantouendinium dictyophorum*. *Ves-*

perosis species are described from Upper Albian brackish-water deposits in the Western Interior by Bint (1986) and the genus *Vesperopsis* has been recorded from Middle and Upper Albian successions onshore East and West Greenland, and Arctic Canada by Nøhr-Hansen (1992) and Nøhr-Hansen & McIntyre (1998).

The top of the *Vesperopsis* cf. *nebulosa* interval is characterised by the LAD of the presumed brackish-water genera *Vesperopsis* cf. *nebulosa*, *Balmula* spp. and the presence of *Quantouendinium dictyophorum*. *Vesperopsis nebulosa* and *Balmula* species have been recorded from lower Upper Albian brackish-water deposits in the Western Interior by Bint (1986) and from the Middle and Upper Albian successions onshore East and West Greenland, and Arctic Canada by Nøhr-Hansen (1992) and Nøhr-Hansen & McIntyre (1998).

Discussion of the ages of the Cretaceous successions in Ikermiut-1

The interpretation of the Cretaceous dinocyst stratigraphy in the Ikermiut-1 well is complicated due to a combination of reworking, extensive caving, and the generally poor preservation of the organic material.

Toxwinius (1986) dated the interval 2755–?2814m as ?Maastrichtian based on the presence of a an *Aquillapollenites* spp. from 2755 m (side wall core; SWC) and common *Palynodinium grallator* from three ditch cuttin samples (DCS) at 2763 m, 2814 m, and 2889 m. Nøhr-Hansen (1998) did not recognise any of these species; the dating was therefore based on the records of Santonian marker species such as *Heterosphaeridium difficile* and *Surculosphaeridium longifurcatum*. However, the present study has revealed new data that changes the previous interpretations.

The thirty sidewall cores taken in the Cretaceous interval of the Ikermiut-1 well were processed by Chevron in 1977 and the palynological slides are now held at GEUS. Apart from Cretaceous species, Paleocene species also occur, e.g. *Cerodinium striatum* which has been recorded from 2850 m, 2975 m, 3114 m, 3120 m, 3150 m, 3184 m, 3275m, 3301 m and 3487 m, *A. gippingensis* recorded from 3184 m, 3275 m and 3281 m, and a single specimen of *Alisocysta margarita* from 2850 m. This is interpreted as being the result of remaining drilling mud due to inadequate cleaning of the sidewall cores before processing of the samples.

Caved specimens of the Paleocene species such as *Areoligera* spp., *Glaphyrocysta* spp., *Cerodinium* spp. *Palaeoperidinium* spp. and *Allisocysta* spp. dominate the assemblages in most ditch cutting samples but Upper Cretaceous species are, nevertheless, present in the majority of these samples.

The first sample below the Paleocene in Ikermiut-1 is a sidewall core sample from 2755 m. A re-study of three slides from this sample revealed a single *Aquilapollenites* specimen together with *Heterosphaeridium difficile*, *Surculosphaeridium longifurcatum*, *Raphidodinium fucatum*, *Chatangiella granulifera*, *Isabelidinium acuminatum* and a single *Odontochitina* operculum. In addition, a single specimen may be recognised as *Palaeohystrichophora*

infusorioides (Fig. 8). The presence of *Aquilapollenites* suggests a maximum age of latest Santonian/earliest Campanian according to Nichols & Sweet (1993). The first downhole appearance (FDA) of *Wallodinium lunum* is recorded at 2760 m (DCS) suggesting an age not younger than Late Campanian.

Toxwinius (1986) reported the Maastrichtian marker species *Palynodinium grallator* as common at 2763 m (DCS). In the present study an effort has been made to try to identify this species; however, the only common chorate specimens found that could be mistaken as *P. grallator* are some caved *Glaphyrocysta* specimens that also are common in the succession above the Cretaceous. The LAD of reasonably well preserved *P. infusorioides* and the Dinocyst sp. E loannides 1986 was recorded at 2772 m (DCS). The new record of Dinocyst sp. E loannides 1986 is important, since this species has its LAD below the well documented Upper Campanian succession in Skolp E-07 (Fig. 7), indicating an Early Campanian age for the upper part of the Cretaceous succession in Ikermiut-1 (Fig. 8).

The re-study of the palynomorphs from 2805 m (DCS) revealed a confusing record of a very poorly preserved specimen that may resemble a *Wodehouseia* specimen suggesting a Maastrichtian age which could confirm the dating by Toxwinius (1986). Alternatively, the single record of a *Wodehouseia* specimen could be explained as a result of reworking of Maastrichtian strata into the Paleocene – as seen in the Qulleq-1 well (Nøhr-Hansen *et al.* 2000) – followed by caving into the Campanian during drilling. The very poor *Wodehouseia* specimen is the only Maastrichtian marker species that has been recorded from the Ikermiut-1 well.

Aquilapollenites specimens have been recorded in the Cretaceous succession from SWCs at 2755 m, 2835 m, 3366 m and from DCSs at 2784 m and 2976 m (Fig. 8). Possible reworked *Aquilapollenites* specimens have been recorded at 2070 m (SWC) and 2492 m (SWC) in the Palaeogene succession. The presence of Dinocyst sp. E loannides 1986 and the presence of the few *Aquilapollenites* spp. suggest an Early Campanian age for the succession below 2755 m; the presence of the Santonian marker species *Heterosphaeridium difficile* and *Surculosphaeridium longifurcatum* is considered to be a result of reworking.

It therefore seems probable that a major unconformity separates the Lower Campanian strata from the Upper Paleocene (Figs 8, 10); this is supported by the maturity trend of the organic material observed in the well (see below).

Microfossils of the Ogmund E-72 and Skolp E-07 wells, Labrador Sea

Jan Audun Rasmussen

A limited number of microfossil samples were examined with the purpose to enhance the stratigraphic resolution of the biostratigraphic zonation of Nøhr-Hansen (this report). The microfossil content, both foraminifera, diatoms and radiolarians, was extremely low, and subsequently three nannofossil slides were prepared to test if this fossil group occurred in greater numbers than microfossils.

Samples and methods

Seventeen microfossil samples were prepared at GEUS during autumn 2002. The samples were wet-sieved, and the 0.063 – 0.5 mm fractions were subsequently separated in heavy liquid ($\delta=1.8 \text{ g/cm}^3$), which increases the microfossil concentration within the light fraction. Seven samples from Ogmund E-72 and nine samples from Skolp E-07 were investigated for their microfossil content. In addition, three nannofossil samples were prepared from Skolp E-07 by use of the smear slide method as described in Bown & Young (1998). All sample numbers refer to depths in metres measured from the rotary table.

The following samples were analysed.

Ogmund E-72 (7 microfossil samples): 1530 m, 1545 m, 1755 m, 1935 m, 2250 m, 2535 m, 3075 m

Skolp E-07 (9 microfossil samples): 995 m, 1295 m, 1445 m, 1520 m, 1760 m, 2075 m, 2330 m, 2600 m, 2975 m

Skolp E-07 (3 nannofossil samples): 1445 m, 2600 m, 2975 m

Stratigraphy

Microfossils

The number of microfossils was extremely low and many samples were barren. However, siliceous sponge spicules and ovate spheroids of unknown affinity (calcispheres?) are relatively common in Skolp-E07, while coal fragments are common in both wells (Fig. 11). The biostratigraphically non-diagnostic benthic foraminifer *Lenticulina* sp. and a specimen of an indeterminable triserial, calcareous benthic foraminifer was recorded from the uppermost part of Ogmund E-72.

Calcispheres? and sponge spicules are common throughout the Mesozoic succession of Qulleq-1 (Santonian – Early Campanian; Fig. 11); in Skolp E-07 they only occur in small numbers in the upper part of the Mesozoic section of (Late Campanian and Maastrichtian), while they are virtually absent in Ogmund E-72 (Albian, Early Turonian and Late Campanian?). The stratigraphical significance of these fossil groups is not clear with the limited data at hand.

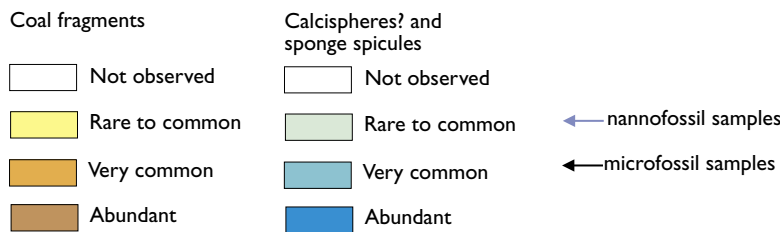
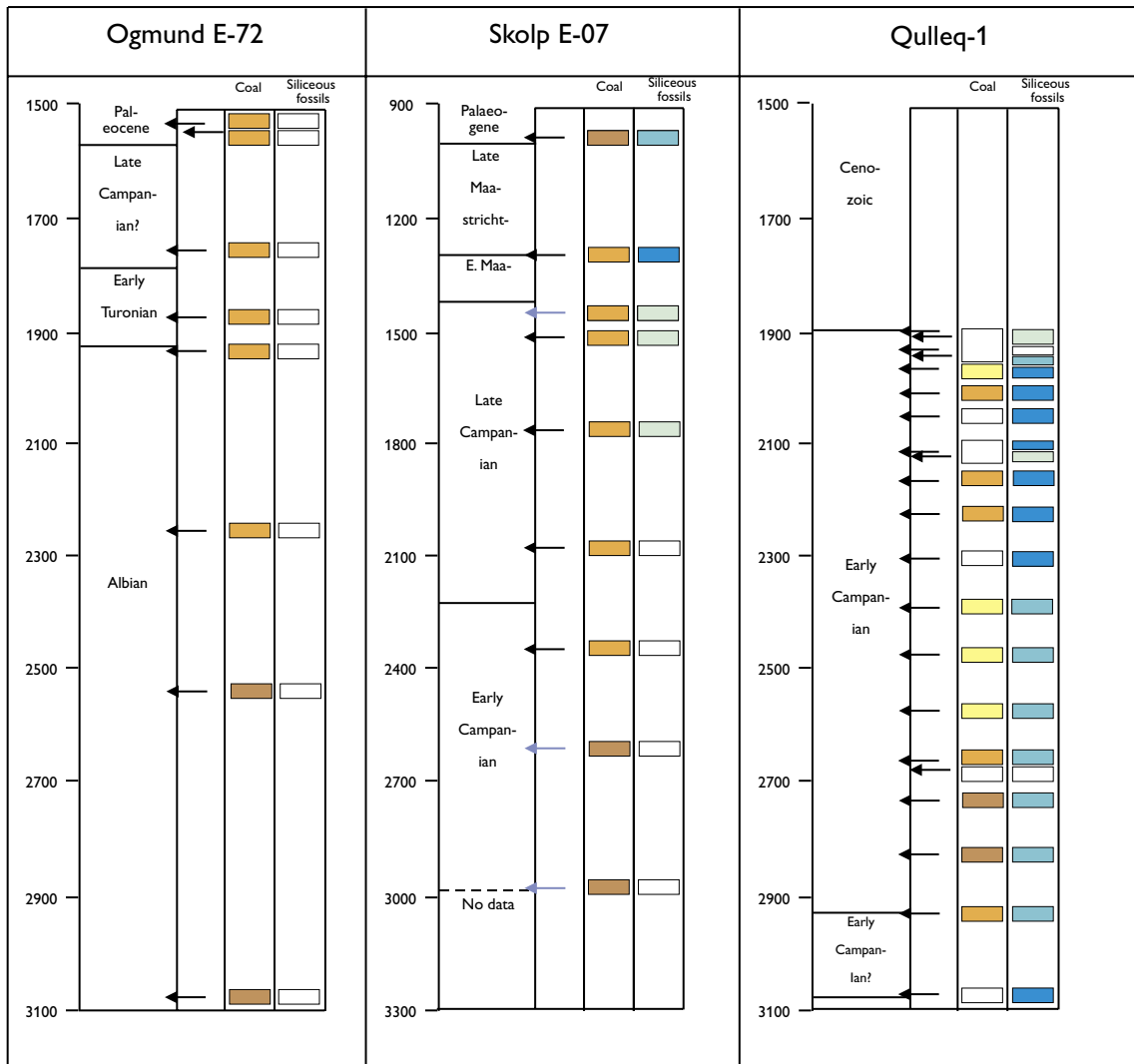


Fig. 11. Relative abundance of selected microfossil groups in the Ogmund E-72 and Skolp E-07 wells from the Labrador Shelf and from the Qulleq-1 well, West Greenland.

Nannofossils

Arkhangelskiella cymbiformis and other Upper Cretaceous nannofossils were found in the sample collected at 2975 m in the Skolp E-07 well indicating a Campanian to Maastrichtian age. The other samples did not contain stratigraphically diagnostic nannofossils.

Depositional setting

It is very difficult to interpret the depositional setting from the very few samples and parameters analysed here. Coal fragments are generally common in the Ogmund and Skolp wells, and this together with the low number of marine microfossils may, however, suggest a near-shore palaeoenvironment, possibly littoral or inner neritic.

Well log correlation

Finn Dalhoff

A correlation of the seven selected exploration wells on the Labrador and South-East Baffin Island shelves and offshore and onshore West Greenland is displayed in Enclosure 9. For location of wells, see Figure 2.

The log correlation is based on biostratigraphic data, and the biostratigraphic events are placed disregarding the log pattern. Digital uncorrected well log data of the four Canadian wells were obtained from the Canadian authorities and are tabulated below. Some of the petrophysical logs are in very bad shape and are in places unreliable or the baseline of the curve is drifting which make it impossible to compare specific lithological values from within the well.

The lithological interpretation of the four Canadian wells is done on information from log data and the Master Log prepared by the mud logger. It is primarily the Gamma Ray curve in combination with the density log curve (RHOB) and the Sonic log (DT) that has been used in the interpretation. The lithological column was calculated using well log characteristics and user-defined baselines (see tables in Appendix 2) combined with the Master Log and are displayed on Enclosure 9 together with the biostratigraphic correlation.

Table 2 : Available geophysical log data from four Canadian exploration wells

Ogmund E-72

Curve Name	Top Depth	Base Depth	Log Max	Log Min
DT	401.00	3068.60	676.5600	108.6400
GR	397.00	3076.80	408.4950	23.2800
ILD	401.00	3081.00	2235.7844	0.8626
ILM	401.00	3081.00	2107.8022	0.8200
NPFI	401.00	3078.80	0.7596	-0.0052
RHOB	401.00	3082.60	2.6390	1.2092
SFLU	401.00	3081.00	1500.4789	0.2030
SP	401.00	3070.60	280.3600	-38.5800
CAX	401.00	3082.60	777.3500	303.5250

Skolp E-07

Curve Name	Top Depth	Base Depth	Log Max	Log Min
CALI	505.00	2982.00	422.1250	166.6500
GR	169.00	2982.00	118.7500	7.5000
ILD	505.00	2989.00	39.8685	0.9467
ILM	505.00	2989.00	2336.8447	0.9329
RHOB	505.00	2982.00	2.7020	1.0959
SP	509.00	2989.00	0.3200	-88.4300

Hekja O-71

Curve Name	Top Depth	Base Depth	Log Max	Log Min
DT	721.00	4527.40	294.9733	45.8175
GR	368.00	721.00	20.8650	4.8450
ILD	711.00	3613.00	1904.7146	0.6948
ILM	721.00	3613.00	1438.2352	0.7103
NPHI	3253.00	4527.20	0.5644	-0.0373
RHOB	722.00	4530.00	3.0085	1.3980
SFLU	721.00	3613.00	2088.4780	0.2067
SP	711.00	3613.00	-0.8900	-113.5800
NPSS	750.00	3253.00	0.7223	0.0614
GR1	722.20	4523.60	87.1200	4.1250

Gjoa G-37

Curve Name	Top Depth	Base Depth	Log Max	Log Min
DT	1402.20	3984.00	206.3190	50.4681
GR	970.00	3984.00	88.5271	5.4756
ILD	1404.00	3991.80	1993.0481	0.8616
ILM	1404.00	3991.80	2080.8640	0.8277
RHOB	1852.60	3995.00	2.9415	1.5379
SFLU	1404.00	3991.80	292.3303	0.4705
SP	1404.00	3991.80	-3.0182	-60.1275
NPSS	1857.80	3991.00	0.6441	-0.0261

Geochemical data – source rock evaluation

Jørgen A. Bojesen-Koefoed and Martin Sønderholm

Introduction

Although source rock intervals have only been drilled in a few wells in the northern Labrador Sea – Baffin Bay region, both direct and indirect evidence of their presence exist from seeping oil in West Greenland and from Canadian discovery wells.

On the Labrador Shelf two source rock sequences have been reported: (1) a Lower Cretaceous lignite and coal-bearing succession (Bjarni Formation), and (2) Upper Cretaceous – Paleocene organic rich mudstones (Fig. 3, Markland Formation; Bell & Campbell 1990). The Bjarni Formation lignites and coals have only been encountered in seven wells; in Skolp E-07 lignite beds account for 30–50 m of the Lower Cretaceous succession (Bell & Campbell 1990). However, this postulated source rock interval could not be confirmed in the Skolp E-07 and Ogmund E-72 wells analysed by GEUS and reported on below (for further details, see Bojesen-Koefoed 2002, Appendix 4). The Markland Formation contains mainly terrestrial organic matter (Balkwill *et al.* 1990; Bell & Campbell 1990), but Bujak *et al.* 1977a, b) have recorded high contents of amorphous kerogen. Nor could this source rock interval be confirmed in the wells mentioned above.

In the Davis Strait it is suggested that the gas and condensate pool at Hekja O-71 was sourced by Paleocene shales both overlying and underlying the reservoir section in the well (Klose *et al.* 1982). Although some source rock potential of these intervals in the Hekja O-71 well has been documented by the GEUS analyses, they are also shown to be thermally immature, and it is therefore unlikely that they are the actual source for the hydrocarbons found in the well.

In West Greenland, several source rocks have been inferred on the basis of geochemical analysis of onshore oil seeps in the Disko – Nuussuaq – Svartenhuk Halvø region (Bojesen-Koefoed *et al.* 1999, 2003). Five distinct oil types have been documented. One oil type is of unknown origin and three are generated from deltaic source rocks with ages ranging probably from the Albian to the Paleocene; the Paleocene source rock has been documented by drilling of the GRO#3 well, whereas a Campanian-age source rock is known from the GANK-1 well. Furthermore, a low to moderately waxy oil type occurs showing a characteristic biomarker composition very similar to that shown by the prolific source rocks in the Kanguk Formation of Cenomanian–Turonian age on Ellesmere Island (Bojesen-Koefoed *et al.* 1999).

Geochemical analyses of wells

A geochemical analysis of five Canadian wells (Ogmund E-72, Skolp E-07, Raleigh N-18, Hekja O-71, Gjoa G-37) and eight Greenland wells (Qulleq-1, Nukik-1 and 2, Kangâmiut-1,

Ikermiut-1, Hellefisk-1, GR0#3 and Umiivik-1) has been carried out in order to characterise possible source rocks intervals. The results are, however, generally disappointing regarding both the Canadian and Greenland wells since only little or no petroleum source potential has been recorded with the possible exceptions of the Hekja O-71 and Umiivik-1 wells. T_{max} -values generally vary between 415 and 440 indicating that they are predominantly thermally immature, even at great depth. This indicates a low geothermal gradient in most of the region.

A short summary of the results of each well is given below (see Table 3).

Ogmund E-72

134 samples have been analysed in the interval between 724 and 3090 m (Eocene – Aptian/Albian). Total organic carbon (TOC) contents are very variable showing values between 0.1% and 37.5% (average 3.1%). S_2 pyrolysis yields show wide variations with an average of 1.7 mg/g. Hydrogen Indices (HI) are, however, consistently low with a recorded maximum of 113. T_{max} -data show a rather irregular maturation trend with values between 420°C and 430°C. Although some coaly intervals in the lower part of the well show fairly high S_2 -values, no potential petroleum source rock is present.

Skolp E-09

136 samples have been analysed in the interval between 925 and 2985 m (L. Eocene – Aptian/Cenomanian). TOC contents are variable showing values between 0.5% and 36.7% (average 5.3%). S_2 pyrolysis yields show wide variation with an average of 7.5 mg/g. Consequently, Hydrogen Indices (HI) range from 14 to 277. T_{max} -data show a rather irregular maturation trend with values between 420°C and 435°C. Based on Rock-Eval data minor petroleum source potential may be present in several intervals.

Raleigh N-18

76 samples have been analysed in the interval between 1365 and 3840 m (strat). TOC contents are very variable showing values between 0.1% and 25.0% (average 2.5%). S_2 pyrolysis yields show wide variation with an average of 3.7 mg/g. Consequently, Hydrogen Indices (HI) are very variable with a maximum of 427. T_{max} -data show a rather irregular maturation trend with values between 420°C and 435°C. Although HI-values are generally below 100, several intervals, albeit immature, may possess some petroleum source potential.

Hekja O-71

69 samples have been analysed in the interval between 1465 and 4566 m (U. Eocene – U. Paleocene). TOC contents are very variable showing values between 0.0% and 25.7% (average 5.8%). S_2 pyrolysis yields show wide variation with an average of 8.6 mg/g. Consequently, Hydrogen Indices are also very variable, ranging from 0 to approximately 225. T_{max} -data show a rather irregular maturation trend with values between 415°C and 440°C. Although

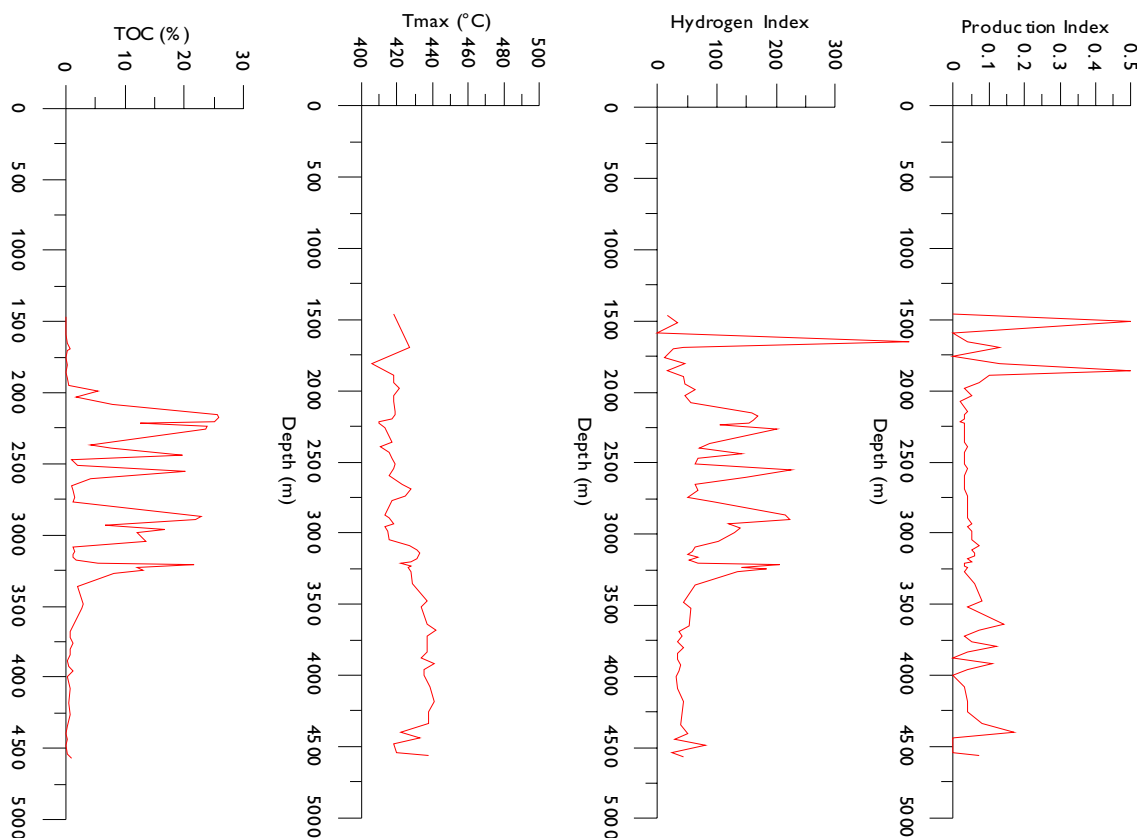


Fig. 12. Simple geochemical log of the Hekja O-71 well, Saglek Basin, South-East Baffin Island Shelf.

generally immature, several intervals within the 2100 – 3300 m interval may possess some petroleum source potential (Fig. 12).

Gjoa G-37

78 samples have been analysed in the interval between 1510 and 3998 m (U. Eocene – L. Paleocene). TOC contents are generally low (0.1% – 2.5%; average 1.1%). Hydrogen Indices never exceed 100. T_{max} -data are very variable but a depth trend varying between c. 430°C to c. 440°C may tentatively be identified. No petroleum source potential has been recorded.

Qulleq-1

149 samples have been analysed in the interval between 1282 and 2970 m (Cenozoic – U. Santonian). Organic geochemical analysis was hampered by the extensive use of polyethyleneglycol (PEG) as a mud additive; thus, geochemical data from the well are largely useless (Bojesen-Koefoed *et al.* 2000b). The data show, however, that no prolific source rock exists in the drilled succession. Vitrinite reflectance data show that the penetrated succession is immature with respect to petroleum generation ($R_0 < 0.4\%$).

Nukik-1 and 2

42 prewashed samples (washed on rig) have been analysed in the interval between 1402 and 2557 m (M. Miocene – U. Paleocene). Organic geochemical analysis is difficult due to the very poor sample quality; extraction data suggest that many samples are contaminated and therefore data are not very reliable. TOC-values vary between 0.12% and 11.06%. S₂ pyrolysis yields are variable, occasionally high, with values between 0 mg/g and 21 mg/g. Hydrogen Indices are in the range 15–500. T_{max}-data show a wide scatter; although a reliable maturity trend cannot be constructed there is no doubt that maturity is low. No petroleum source potential can be inferred from the samples available.

Kangâmiut-1

43 prewashed samples (washed on rig) have been analysed in the interval between 1956 and 3600 m (M. Miocene – U. Paleocene). The upper, mid-Eocene part of the well (above 2780 m) shows TOC-values in the range 0.25% and 1.5% whereas the deeper part shows values up to 3.5%. S₂ pyrolysis yields are invariably low to very low (<3 mg/g, generally < 1 mg/g) and Hydrogen Indices are <100. T_{max}-data show a generally well-constrained maturation trend with values between 415°C and 438°C. Seven samples have been analysed for biological markers; however, interpretation of data is strongly hampered by contamination and an overall low maturity. No petroleum source potential has been recorded.

During drilling of the Kangâmiut-1 well, high pressures were encountered in the section below 3706 m that necessitated the use of very heavy control mud. Gas-chromatograph readings of up to 9% were recorded with the gas consisting of C1 to C4 in measurable amounts and a trace of C5 (Bate 1997). Such readings commonly indicate that the well has penetrated an oil field, or at least a gas condensate field. A Drill-Stem Test (DST) performed over the interval 3674 to 3705 m which, however, only flowed water. Later testing of the water showed that it had the same chemistry as the drilling-mud fluids indicating that only drilling-mud liquids were produced during the DST. The evidence therefore strongly suggests that Kangâmiut-1 drilled through an oil or condensate accumulation with a so far unknown source (Bate 1997).

Ikermiut-1

77 prewashed samples (washed on rig) have been analysed in the interval between 1551 and 3607 m (U. Eocene – L. Campanian). The Eocene part of the succession (above 2075 m) shows low TOC (<1%), very low S₂ pyrolysis yields (<0.5 mg/g) and Hydrogen Indices <50. The Upper Paleocene part of the succession (2075 m – 2755 m) shows somewhat higher TOC (0.5–2%), low S₂ pyrolysis yields (<1.5 mg/g) and Hydrogen Indices <100. The Lower Campanian part shows relatively high TOC-values (generally >2%), but low S₂ pyrolysis yields (1.5–4 mg/g) and HI-values (50–150). Twelve samples have been analysed for biological marker and they seem to represent marine mudstone carrying variable proportions of terrigenous organic matter. The Campanian rocks show a very high proportion of 28,30-bisnorhopane suggesting a marine anoxic depositional environment. However, no petroleum source potential has been recorded.

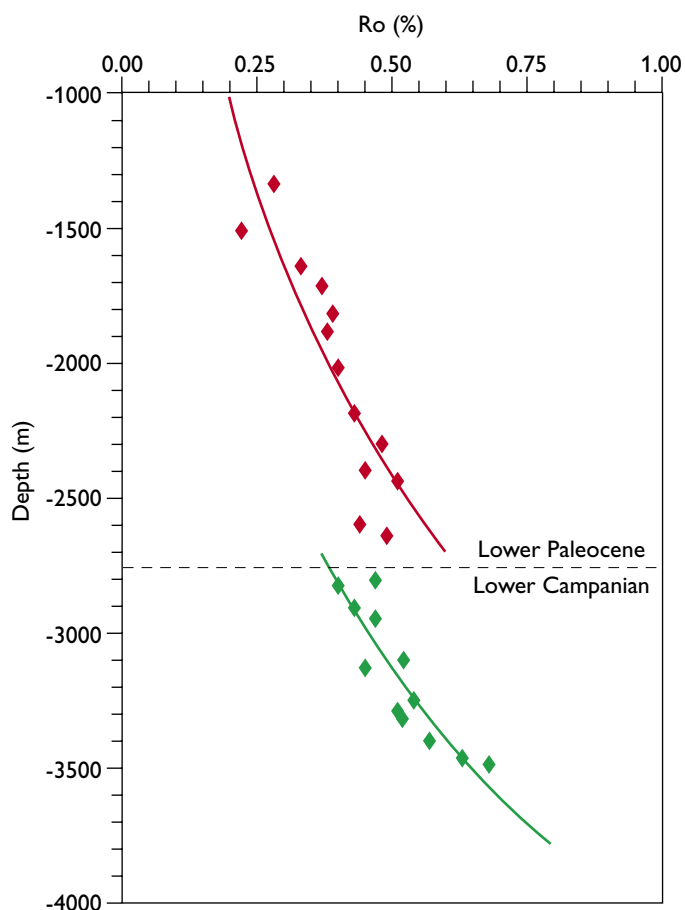


Fig. 13. Selected vitrinite reflectance data from the Ikermiut-1 well, offshore West Greenland

T_{max} -values are in the range 420–445°C showing a rather irregular maturation trend including a possible reversal around 2700 m. This observation is supported by vitrinite reflectance data (Fig. 13) and the biomarker maturity trend. The complex maturity gradient in the Ikermiut-1 well may either be a result of major uplift during the latest Maastrichtian or earliest

Paleocene or of repetition of strata due to thrusting since the well is situated in an area with flower structures (cf. Chalmers & Pulvertaft 2001). The biostratigraphic data indicate a major unconformity at 2755 m separating Lower Campanian and Upper Paleocene strata, but no indication of repetition of strata can be seen.

Hellefisk-1

26 prewashed samples (washed on rig) have been analysed in the interval between 1902 and 2515 m (L. Eocene). TOC-values are generally <1% with a few samples showing values up to 6.08%. S_2 pyrolysis yields are low throughout (<6mg/g; generally <1mg/g) and HI-values are <100). T_{max} -values range from 420°C to 433°C showing a fairly regular increasing trend with depth. Biological marker data are not very informative, but the 3 analysed samples seem to represent marine mudstone carrying some terrigenous organic matter. No petroleum source potential has been recorded.

GRO#3

114 samples have been analysed in the interval between 320–2990 m (Cenozoic – Coniacian and older). T_{max} -values range from 431°C to 575°C showing a regular increasing trend with depth. Vitrinite reflectance shows a similar trend with values between 0.71% and 2.63%. TOC-values vary between 1.14% and 6.55% (average 4.46%) with a tendency for TOC to be slightly higher in the deeper part of the succession than in the Paleocene part. S_2 py-

rolysis yields are very variable ranging from 0.04 mg/g to 8.08 mg/g. Values greater than 2 mg/g are restricted to the upper 1700 m. Hydrogen Indices vary between 4 and 217 (average 50) showing a fairly regular decrease with depth. A shale succession at approximately 400 m b. rotary table has been identified as representing the source of the Marraat oil type, seeps of which are widespread on Nuussuaq.

Table 3: Summary of geochemical results from selected Canadian and Greenland wells

	# of samples	sample interval m	TOC %	S ₂ mg/g	HI	T _{max} °C
Ogmund E-72 ¹	134	724 – 3090	0.1 – 37.5 average 3.1	<22.9 average 1.7	< 113 average 46	420 – 430
Skolp E-07 ¹	136	925 – 2985	0.5 – 36.7 average 5.3	0.2 – 101.2 average 7.5	14 – 277 generally low	420 – 435
Raleigh N-18 ¹	76	1365 – 3840	0.1 – 25.0 average 2.5	<107.0 average 3.7	<427 generally low	420 – 435
Hekja O-71 ¹	69	1465 – 4566	0.0 – 25.7 average 5.8	<49.4 average 8.6	<225 generally low	415 – 440
Gjoa G-37 ¹	78	1510 – 3998	0.1 – 2.5 average 1.1	<2.1 average 0.4	<100	430 – 440
Qulleq-1 ²	149	1282 – 2970	< 7 recalculated data	<8 recalculated data	<120 recalculated data	no reliable data R ₀ <0.4%
Nukik-1 and 2 ³	42	1402 – 2557	0,12 – 11,06	<21 very variable	15 – 516 very variable	no reliable data
Kångamiut-1 ³	43	1956 – 3600	0,25 – 3,5	<3 generally <1	<100	415 – 440
Ikermiut-1 ³	77	1551 – 3607	0,24 – 2,92	<4 generally <	<150	420 – 445
Hellefisk-1 ³	26	1902 – 2515	0,07 – 6,08 generally <1	<6 generally <1	<100	420 – 435
GRO#3 ⁴	114	320 – 2990	1.15 – 6.55 average 4.5	0.04 – 8.08 average 2.06	<217 average 50	431 – 575 regular trend
Umiivik-1 ⁵	98	50 – 1200	<6 average 3.4	<6.3	<136	427 – >560

¹: Bojesen-Koefoed (2002); ²: Bojesen-Koefoed *et al.* (2000b); ³: Bojesen-Koefoed *et al.* (2000a); ⁴: Bojesen-Koefoed *et al.* (1997); ⁵: Christiansen *et al.* (1997), Dam *et al.* (1998b)

Umiivik-1

98 samples have been analysed in the interval between 50 and 1200 m (L. Coniacian – U.Turonian). T_{max}-values in the upper part of the well range from 427°C to 441°C (average 434°C) with a high scatter. Vitrinite reflectance values in this interval are between 0.55% and 0.63%. Although a marine depositional environment is suggested for these mudstones, biomarker data suggest a significant contribution of terrestrial organic matter.

Below 405 m T_{max}-values are, however, very high, in most cases between 500°C and 560°C or even higher and controlled by the position of sills. In the lower part of the well vitrinite re-

flectance values are between 1.7% and 4.3%. TOC contents are moderate to high (2 – 6%; average 3.4%) in the upper 390 m of the well, whereas the deeper and thermally post-mature part shows significantly lower values (average 2.85%). This variation may be primary and not only be controlled by maturity level. S₂ pyrolysis yields are very variable ranging from 0 mg/g to 6.32 mg/g but are generally >3 mg/g in the upper part of the core. Hydrogen Indices are between 63 and 136 in the upper part of the well, but very low – typically <25 – in the lower part suggesting that all potential hydrocarbons have been generated and thermally cracked to gas (Christiansen *et al.* 1997). Head space analysis of gas containing core samples from the lower part of the well show that considerable amounts of gas were released from some intervals. Methane is the most abundant hydrocarbon gas but wet gases containing both normal and isobutane and pentane also occur (Dam *et al.* 1998b). Thus, the organic geochemical results suggest that a possible source rock is present in the deeper part of the Umiivik-1 well. Due to the high thermal maturity this possible Cenomanian–Turonian source rock cannot be dated in detail and it is not possible to document the detailed composition of the generated products and the generative potential (Dam *et al.* 1998b).

Conclusion

One of the aims of the present study was to try to explain the regional distribution of any possible source rock intervals in the Cretaceous – Palaeogene succession in the Labrador Sea – Baffin Bay area. However, the geochemical analyses of the five Canadian wells have not documented hitherto unknown source rock intervals nor could it be confirmed that the organic rich mudstones of the Markland Formation and the Lower Cretaceous lignites and coals of the Bjarni Formation represent regional source rocks. Furthermore, the geochemical analyses could not support that the Paleocene organic rich mudstones are the actual source for the petroleum accumulations found in the Hekja O-71 well since the mudstones are probably thermally immature in the area around the well. The hydrocarbons may therefore be generated from a deeper and as yet unknown source. Marine source rocks in West Greenland are so far only known indirectly and can thus not be regionally mapped.

References

Balkwill, H.R., McMillan, N.J., MacLean, B., Williams, G.L. & Srivastava, S.P. 1990: Geology of the Labrador Shelf, Baffin Bay, and Davis Strait. Chapter 7. In: Keen, M.J. & Williams, G.L. (eds): Geology of the continental margin of eastern Canada. *Geology of Canada* **2**, 295–348. Ottawa: Geological Survey of Canada. (also *The geology of North America I-2*, Geological Society of America).

Bate, K.J. 1997: Interpretation of the basal section of well Kangâmiut-1, offshore southern West Greenland. *Danmarks og Grønlands Geologiske Undersøgelse Rapport*, **1997/76**, 26 pp.

Bell, J.S. & Campbell, G.R. 1990: Petroleum resources. Chapter 12. In: Keen, M.J. & Williams, G.L. (eds): Geology of the continental margin of eastern Canada. *Geology of Canada* **2**, 679–720. Ottawa: Geological Survey of Canada. (also *The geology of North America I-2*, Geological Society of America).

Bint, A.N. 1986: Fossil Ceratiaceae: a restudy and new taxa from the mid-Cretaceous of the Western Interior, USA. *Palynology* **10**, 135–180.

Bojesen-Koefoed, J.A. 2002: Petroleum geochemistry: selected wells from the eastern Canada offshore area. Data report: Gjoa G-37, Hekja O-1, Ogmund E-72, Raleigh N-18 and Skolp E-09 wells. *Danmarks og Grønlands Geologiske Undersøgelse Rapport* **2002/114**, 57 pp.

Bojesen-Koefoed, J.A., Christiansen, F.G., Guvad, C. & Nytoft, H.P. 2000a: Evaluation of thermal maturity data from wells offshore West Greenland – recommendations for basin modelling. *Danmarks og Grønlands Geologiske Undersøgelse Rapport* **2000/32**, 18 pp.

Bojesen-Koefoed, J.A., Christiansen, F.G., Mathiasen, A., Nytoft, H.P., Pedersen, A.K. & Skaarup, N. 2003: Petroleum geochemistry of seep oils in central West Greenland – concepts for sub-basalt exploration. 7th Nordic Symposium on Petrophysics, Akureyri, Iceland, August 2003. Proceedings, (CD-ROM publication).

Bojesen-Koefoed, J.A., Christiansen, F.G., Nytoft, H.P. & Dalhoff, F. 1997: Organic geochemistry and thermal maturity of sediments in the GRO#3 well, Nuussuaq, West Greenland. *Danmarks og Grønlands Geologiske Undersøgelse Rapport* **1997/143**, 18 pp.

Bojesen-Koefoed, J.A., Christiansen, F.G., Nytoft, H.P. & Pedersen, A.K. 1999: Oil seepage onshore West Greenland: evidence of multiple source rocks and oil mixing. In: Fleet, A.J. & Boldy, S.A.R. (eds): *Petroleum geology of Northwest Europe: Proceedings of the 5th conference on petroleum geology of NW Europe*, 305–314. London: Geological Society.

Bojesen-Koefoed, J.A., Nytoft, H.P. & Rosenberg, P. 2000b: Qulleq-1 (6354/4-1): petroleum geochemistry. *Danmarks og Grønlands Geologiske Undersøgelse Rapport* **2000/83**, 14 pp.

Bown, P.R. & Young, J.R. 1998: Introduction. In: Bown, P.R. (ed.): Calcareous nannofossil biostratigraphy, 1–15. London: British Micropalaeontological Society Series, Chapman & Hall/Kluwer Academic.

Bujak Davies Group 1987a: Biostratigraphy and Maturation of 17 Labrador and Baffin Island Shelf wells. Volume 3: Gilbert F-53 and Gjoa G-37. Geological Survey of Canada Open File Report **1931**, 65 pp.

Bujak Davies Group 1987b: Biostratigraphy and Maturation of 17 Labrador and Baffin Island Shelf wells. Volume 4: Hekja O-71 and Hopedale E-33. Geological Survey of Canada Open File Report **1932**, 54 pp.

Bujak Davies Group 1987c: Biostratigraphy and Maturation of 17 Labrador and Baffin Island Shelf wells. Volume 6: North Leif I-05 and Ogmund E-72. Geological Survey of Canada Open File Report **1934**, 72 pp.

Bujak, J.P., Barss, M.S. & Williams, G.L. 1977b: Offshore eastern Canada: organic type and colour and hydrocarbon potential. *Oil and Gas Journal* **75**(15), 96–100.

Bujak, J.P., Barss, M.S. & Williams, G.L. 1977a: Offshore eastern Canada: organic type and colour and hydrocarbon potential. *Oil and Gas Journal* **75**(14), 198–202.

Bujak, J.P. & Mudge, D. 1994: A high-resolution North Sea Eocene dinocyst zonation. *Journal of the Geological Society of London* **151**, 449–462.

Burden, E.T. & Langille, A.B. 1990: Stratigraphy and sedimentology of Cretaceous and Paleocene strata in half-grabens on the southeast coast of Baffin Island, Northwest Territories. *Bulletin of Canadian Petroleum Geology* **38**(2), 185–196.

Chalmers, J.A., Christiansen, F.G., Sønnderholm, M., Olsen, J.C., Myklebust, R. & Schønwardt, H.K. 2001: Geological information base growing on North Atlantic rift basins. Data developed for Greenland licensing. *Offshore* **61**(11), 87–89, 100.

Chalmers, J.A. & Pulvertaft, T.C.R. 2001: Development of the continental margins of the Labrador Sea: a review. In: Wilson, R.C.L. *et al.* (eds): Non-volcanic rifting of continental margins: a comparison of evidence from land and sea. Geological Society Special Publications (London) **167**, 77–105.

Christiansen, F.G. *et al.* 1999: Petroleum geological activities in West Greenland in 1998. *Geology of Greenland Survey Bulletin* **183**, 46–56.

Christiansen, F.G., Bojesen-Koefoed, J. & Laier, T. 1997: Organic geochemistry of sediments and gases in the borehole Umiivik-1, Svartenhuk Halvø, West Greenland. *Danmarks og Grønlands Geologiske Undersøgelse Rapport* **1997/33**, 16 pp.

- Christiansen, F.G. *et al.* 2001: Petroleum geological activities in West Greenland in 2000. *Geology of Greenland Survey Bulletin* **189**, 24–33.
- Cookson, I.C. & Eisenack, A. 1970: Cretaceous microplankton from the Eucla Basin, Western Australia. *Proceedings of the Royal Society of Victoria* **83**, 137–157.
- Costa, L.I. & Davey, R.J. 1992: Dinoflagellate cysts of the Cretaceous System. In: Powell, A.J. (ed.): *A stratigraphic index of dinoflagellate cysts*, 99–131. London: Chapman & Hall (British Micropalaeontological Society).
- Dam, G. & *et al.* in prep.: Lithostratigraphy of the Cretaceous–Paleocene Nuussuaq Group, Nuussuaq Basin, West Greenland. *Geology of Greenland Survey Bulletin*.
- Dam, G., Larsen, M. & Søndersholm, M. 1998a: Sedimentary response to mantle plumes: Implications from Paleocene onshore successions, West and East Greenland. *Geology* **26**(3), 207–210.
- Dam, G. & Nøhr-Hansen, H. 2001: Mantle plumes and sequence stratigraphy; Late Maastrichtian – Early Paleocene of West Greenland. *Bulletin of the Geological Society of Denmark* **48**, 189–207.
- Dam, G., Nøhr-Hansen, H., Christiansen, F.G., Bojesen-Kofoed, J.A. & Laier, T. 1998b: The oldest marine Cretaceous sediments in West Greenland (Umiivik-1 borehole) – record of the Cenomanian–Turonian Anoxic Event? *Geology of Greenland Survey Bulletin* **180**, 128–137.
- Dam, G. & Søndersholm, M. 1998: Sedimentological evolution of a fault-controlled Early Paleocene incised-valley system, Nuussuaq Basin, West Greenland. In: Shanley, K.W. & McCabe, P.J. (eds): *Relative role of eustasy, climate, and tectonism in continental rocks*. Society of Economic Paleontologists and Mineralogists Special Publication **59**, 109–121.
- Felix, C.J. & Burbridge, P.P. 1976: Age of microplankton studied by Manum and Cookson from Graham and Ellef Ringnes Islands. *Geoscience and Man* **15**, 83–86.
- Foucher, J.-C. 1979: Distribution stratigraphique des kystes de dinoflagellés et des acritarches dans le crétacé supérieur du bassin de Paris et de l'Europe septentrionale. *Palaeontographica* **B 169**, 78–105.
- GEUS 2002: West Greenland 2002 licensing round. Exploration information. Copenhagen: Danmarks og Grønlands Geologiske Undersøgelse (CD-ROM).
- Hansen, J.M. 1977: Dinoflagellate stratigraphy and echinoid distribution in Upper Maastrichtian and Danian deposits from Denmark. *Bulletin of the Geological Society of Denmark* **26**, 1–26.
- Hansen, J.M. & Gudmundsson, L. 1978: A method for separation of acid insoluble microfossils from organic debris. *Micropalaeontology* **25**, 113–117.

Hills, L.V., Braunberger, W.F., Núñez-Betelu, L.K. & Hall, R.L. 1994: Paleogeographic significance of *Scaphites depressus* in the Kanguk Formation (Upper Cretaceous), Axel Heiberg Island, Canadian Arctic. *Canadian Journal of Earth Sciences* **31**, 733–736.

Ioannides, N.S. 1986: Dinoflagellate cysts from Upper Cretaceous–Lower Tertiary sections, Bylot and Devon Islands, Arctic Archipelago. *Geological Survey of Canada Bulletin* **371**, 1–99.

Kirsch, K.-H. 1991: Dinoflagellatenzysten aus der Oberkreide des Helvetikums und Nordultrahelvetikums von Oberbayern. *Münchner Geowissenschaftliche Abhandlungen A* **22**, 306 pp.

Klose, G.W., Malterre, E., McMillan, N.J. & Zinkan, C.G. 1982: Petroleum exploration offshore southern Baffin Island, northern Labrador Sea, Canada. In: Embry, A.F. & Balkwill, H.R. (eds): *Arctic geology and geophysics*. *Canadian Society of Petroleum Geologists Memoir* **8**, 233–244.

Larsen, L.M., Rex, D.C., Watt, W.S. & Guise, P.G. 1999: ^{40}Ar - ^{39}Ar dating of alkali basaltic dykes along the south-west coast of Greenland: Cretaceous and Tertiary igneous activity along the eastern margin of the Labrador Sea. *Geology of Greenland Survey Bulletin* **184**, 19–29.

Lentin, J.K. & Vozzhennikova, T.F. 1990: Fossil dinoflagellates from the Jurassic, Cretaceous and Palaeogene deposits of the USSR – a re-study. *American Association of Stratigraphic Palynologists Foundation, Contributions Series* **23**, 211 pp.

Manum, S. 1963: Some new species of *Deflandrea* and their probable affinity with *Peridinium*. *Norsk Polarinstitut Årbok* 1962, 55–67.

Manum, S. & Cookson, I.C. 1964: Cretaceous microplankton in a sample from Graham Island, Arctic Canada, collected during the second 'Fram'-expedition (1898–1902) with notes on microplankton from the Hassel Formation, Ellef Ringnes Island, 1–36. Oslo: Universitetsforlaget.

Mao, S.-Z., Wan, C.-B. & Qiao, X.-Y. 1999: Cretaceous nonmarine dinoflagellates from northeast China. *Grana* **38**, 144–161.

Martini, E. 1971: Standard Tertiary and Quaternary calcareous nannoplankton zonation Proceedings of the II Planktonic Conference, Roma 1970 **2**, 739–785.

McIntyre, D.J. 1974: Palynology of an Upper Cretaceous section, Horton River, District of Mackenzie, N.W.T. *Geological Survey of Canada Paper* **74-14**, 1–57.

McIntyre, D.J. 1975: Morphologic changes in *Deflandrea* from a Campanian section, District of Mackenzie, N.W.T., Canada. *Geoscience and Man* **11**, 61–76.

Miall, A.D. 1986: The Eureka Sound Group (Upper Cretaceous – Oligocene), Canadian Arctic Islands. *Bulletin of Canadian Petroleum Geology* **34**, 240–270.

- Miall, A.D., Balkwill, H.R. & Hopkins, W.S., Jr. 1980: Cretaceous and Tertiary sediments of Eclipse Trough, Bylot Island area, Arctic Canada, and their regional setting. Geological Survey of Canada Paper **79-23**, 20 pp.
- Midtgaard, H.H. 1996: Sedimentology and sequence stratigraphy of coalbearing synrift sediments on Nuussuaq and Upernivik Ø (U. Albian – L. Cenomanian), central West Greenland, 175 pp. Unpublished Ph. D. thesis, University of Copenhagen, Copenhagen.
- Miller, P.E. & d'Eon, G.J. 1987: Labrador Shelf – Paleoenvironments. GSC Open File **1722**, 186 pp.
- Mudge, D.C. & Bujak, J.P. 1996a: An integrated stratigraphy for the Paleocene and Eocene of the North Sea. In: Knox, R.W.O.B., Corfield, R.M. & Dunay, R.E. (eds): Correlation of the early Paleogene in Northwest Europe. Geological Society Special Publications (London) **101**, 91–113.
- Mudge, D.C. & Bujak, J.P. 1996b: Paleocene biostratigraphy and sequence stratigraphy of the UK central North Sea. *Marine and Petroleum Geology* **13**, 295–312.
- Nichols, D.J. & Sweet, A.R. 1993: Biostratigraphy of the Upper Cretaceous non-marine palynofloras in a north–south transect of the Western Interior Basin. In: Caldwell, W.G.E. & Kauffman, E.G. (eds): Evolution of the Western Interior Basin. Geological Association of Canada Special Paper **39**, 539–584.
- Núñez-Betelu, L.K. 1994: Sequence stratigraphy of a coastal to offshore transition, Upper Cretaceous Kanguk Formation: a palynological, sedimentological and Rock-Eval characterisation of a depositional sequence, northeastern Sverdrup Basin, Canadian Arctic, 569 pp. pp. Unpublished Ph. D. thesis, Department of Geology and Geophysics, University of Calgary, Calgary, Canada.
- Nøhr-Hansen, H. 1992: Cretaceous marine and brackish(?) dinoflagellate cysts, West Greenland. 8th International Palynological Congress, Aix-en-Provence, France, 6–12 September, 1992. Abstract, .
- Nøhr-Hansen, H. 1993: Upper Maastrichtian? – lower Paleocene dinoflagellate cysts and pollen from turbidites in the Itilli region, Nuussuaq central West Greenland – first dating of the sediments. Rapport Grønlands geologiske Undersøgelse **159**, 81–87.
- Nøhr-Hansen, H. 1996: Upper Cretaceous dinoflagellate cyst stratigraphy, onshore West Greenland. Grønlands Geologiske Undersøgelse Bulletin **170**, 104 pp.
- Nøhr-Hansen, H. 1997a: Palynology of the GRO#3 well, Nuussuaq, West Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1997/151**, 19 pp.
- Nøhr-Hansen, H. 1997b: Palynology of the Umiivik-1 borehole, Svartenhuk Halvø, West Greenland. Danmarks og Grønlands Geologiske Undersøgelse Rapport **1997/32**, 12 pp.

Nøhr-Hansen, H. 1998: Dinoflagellate cyst stratigraphy of the Upper Cretaceous to Paleogene strata from the Hellefisk-1, Ikermiut-1, Kangâmiut-1 and Nukik-1 wells, offshore central West Greenland. *Danmarks og Grønlands Geologiske Undersøgelse Rapport* **1998/54**, 58 pp.

Nøhr-Hansen, H. in press: 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. *Marine and Petroleum Geology*.

Nøhr-Hansen, H. & McIntyre, D.J. 1998: Upper Barremian to Upper Albian (Lower Cretaceous) dinoflagellate cyst assemblages, Canadian Arctic Archipelago. *Palynology* **22**, 143–166.

Nøhr-Hansen, H., Piasecki, S., Rasmussen, J.A. & Sheldon, E. 2000: Biostratigraphy of well 6354/4-1 (Qulleq-1), West Greenland. *Danmarks og Grønlands Geologiske Undersøgelse Rapport* **2000/101**, 81 pp.

Nøhr-Hansen, H., Sheldon, E. & Dam, G. 2002: A new biostratigraphic scheme for the Paleocene onshore West Greenland and its implications for the timing of the pre-volcanic evolution. In: Jolley, D.W. & Bell, B.R. (eds): *The North Atlantic Igneous Province: stratigraphy, tectonic, volcanic and magmatic processes*. Geological Society Special Publication (London) **197**, 111–156.

Perch-Nielsen, K. 1979: Calcareous nannofossil zonation at the Cretaceous/Tertiary boundary in Denmark. In: Birkelund, T. & Bromley, R.G. (eds): *The Maastrichtian and Danian of Denmark. Symposium on Cretaceous–Tertiary boundary events* **1**, Copenhagen, Denmark, 18–24 September, 1979, 115–135. University of Copenhagen.

Piasecki, P. in press: Neogene dinoflagellate cysts from Davis Strait, offshore West Greenland. *Marine and Petroleum Geology*.

Pulvertaft, T.C.R. 1979: Lower Cretaceous fluvial-deltaic sediments at Kûk, Nûgssuaq, West Greenland. *Bulletin of the Geological Society of Denmark* **28**, 57–72.

Rolle, F. 1985: Late Cretaceous – Tertiary sediments offshore central West Greenland: lithostratigraphy, sedimentary evolution, and petroleum potential. *Canadian Journal of Earth Sciences* **22**, 1001–1019.

Schiøler, P. & Wilson, G.J. 1993: Maastrichtian dinoflagellate zonation in the Dan Field, Danish North Sea. *Review of Palaeobotany and Palynology* **78**, 321–351.

Schiøler, P. & Wilson, G.J. 2001: Dinoflagellate biostratigraphy around the Campanian–Maastrichtian boundary at Tercis les Bains, southwest France. In: Odin, G. (ed.): *Campanian–Maastrichtian stage boundary; characterisation at Tercis les Bains (France) and correlation with Europe and other continents*. *Developments in Palaeontology and Stratigraphy* **19**, 221–234. Amsterdam: Elsevier.

Singh, C. 1983: Cenomanian microfloras of the Peace River area, northwestern Alberta. *Bulletin Alberta Research Council* **44**, 322 pp.

Slimani, H. 1996: Les dinokystes des craies du Campanien–Danien a Hallembaye et Turnhout (Belgique) et a Beutenaken (Pays-Bas); supplement de systematique. Annales de la Société géologique de Belgique **117**(2), 371–391.

Storey, M., Duncan, R.A., Pedersen, A.K., Larsen, L.M. & Larsen, H.C. 1998: $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology of the West Greenland Tertiary volcanic province. Earth and Planetary Science Letters **160**, 569–586.

Toxwenius, B.B. 1986: Compilation of Late Cretaceous – Tertiary biostratigraphic data and correlation of five wells, offshore central West Greenland, 69 pp. Unpublished report, Geological Survey of Greenland, Copenhagen, Denmark (now Geological Survey of Denmark and Greenland).

Umpleby, D.C. 1979: Geology of the Labrador Shelf. Geological Survey of Canada Paper **79-13**, 34 pp.

Williams, G.L. 1975: Dinoflagellate and spore stratigraphy of the Mesozoic–Cenozoic, offshore Eastern Canada. In: van der Linden, W.J.M. & Wade, J.A. (eds): Offshore Geology of Eastern Canada, volume 2. Geological Survey of Canada Paper **74-30**, 107–161.

Williams, G.L., Ascoli, P., Barss, M.S., Bujak, J.P., Davies, E.H., Fensome, R.A. & Williamson, M.A. 1990: Biostratigraphy and related studies. Chapter 3. In: Keen, M. & Williams, G. (eds): Geology of the continental margin of eastern Canada. Geology of Canada **2**, 87–137.: Geological Survey of Canada. (also The geology of North America **I-2**, Geological Society of America).

Williamson, M.-C., Villeneuve, M., Jackson, H.R. & MacLean, B. 2003: Argon geochronology of basaltic rocks recovered from drilling on the Baffin Island Shelf and in the Davis Strait, eastern Canada. Fourth International Conference on Arctic Margins, Dartmouth, Nova Scotia, Canada, 30 September – 3 October, 2003. Abstract.

