A multidisciplinary study of the Palaeogene succession offshore southern West Greenland

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A project with the aim of amalgamating an interpretation of reflection seismic data from offshore southern West Greenland with a new interpretation of well data was finalised at the Geological Survey of Denmark and Greenland (GEUS) in 2001 (Chalmers *et al.* 2001b). As part of this study, seismic and depositional sequences between major regional unconformities of Danian and mid-Eocene age were delineated and dated.

New palaeoenvironmental and sedimentological interpretations using dinoflagellate cyst, microfossil and nannoplankton stratigraphies and palaeoenvironmental interpretations from the five exploration wells drilled offshore West Greenland in the 1970s have been combined with a revised interpretation of lithology and correlated with the aid of seismic stratigraphy. The Qulleq-1 well drilled in 2000 was relinquished late in the project period (Christiansen *et al.* 2002, this volume), and it has therefore only been possible to incorporate biostratigraphic information from this well into the project.

The results show that the region offshore southern West Greenland (Fig. 1) was subject to major uplift and erosion during the Danian, when uppermost Cretaceous sediments were removed. Sedimentation resumed in the late Danian, and was coeval with major volcanism in central West Greenland and the start of sea-floor spreading in the Labrador Sea. Upper Paleocene sediments were deposited in a predominantly extensional tectonic environment. The extensional stresses continued in most areas during the Early Eocene, but in the northern and north-western part of the region, a transtensional system developed along a major strike-slip fault system that transferred sea-floor spreading movements between the Labrador Sea and Baffin Bay.

A stratigraphic framework for the basins offshore southern West Greenland has been erected based on knowledge from the six drilled exploration wells and the onshore exposures of sediments and volcanic rocks in the Nuussuaq Basin and at Cape Dyer, Canada (Rolle 1985; Nøhr-Hansen 1998; Nøhr-Hansen *et al.* 2000; Chalmers *et al.* 2001b; Christiansen *et al.* 2001). Furthermore, seismic sequence studies have been carried out in the southern West Greenland basins (Chalmers *et al.* 1993, 1995, 2001a; Chalmers & Pulvertaft 2001) and these have been compared with the drilled successions offshore Labrador (Balkwill 1987).

Of the five wells drilled in the 1970s, three penetrated only Cenozoic sediments before terminating in Paleocene basalts (Hellefisk-1, Nukik-2) or Precambrian basement (Nukik-1). The Kangâmiut-1 well drilled through an Eocene and younger, sand-dominated succession, then Lower Eocene and Paleocene mudstones, below which the well penetrated a coarse arkosic sand interleaved with mudstone before terminating in Precambrian basement. Only one well from the 1970s (Ikermiut-1) drilled a significant section of pre-Cenozoic sediments, sampling an 850 m mudstone section of Santonian–?Campanian age (unpublished data, H. Nøhr-Hansen 2002) before drilling was stopped. However, the well drilled in 2000 (Qulleq-1), also penetrated thick Campanian mudstones below a Neogene and a thin Palaeogene succession, and terminated in sandstones of Santonian age (Nøhr-Hansen *et al.* 2000; Christiansen *et al.* 2001; Pegrum *et al.* 2001).

The sediments forming the subject of this study lie above a major, regional unconformity of Danian age. The package is bounded above by an unconformity that can be traced over the whole of the southern West Greenland basin (Fig. 1; Chalmers *et al.* 2001a), here referred to as the mid-Eocene unconformity. The sediments immediately above the mid-Eocene unconformity are of middle to late Lutetian age (Nøhr-Hansen 1998, 2001), which coincides with the time at which sea-floor spreading slowed abruptly in the Labrador Sea (magnetochrons 20–21; Roest & Srivastava 1989; Chalmers & Pulvertaft 2001). The package of sediments forming the subject of this report was thus deposited during active sea-floor spreading in the Labrador Sea between magnetochrons 27n and 20r.

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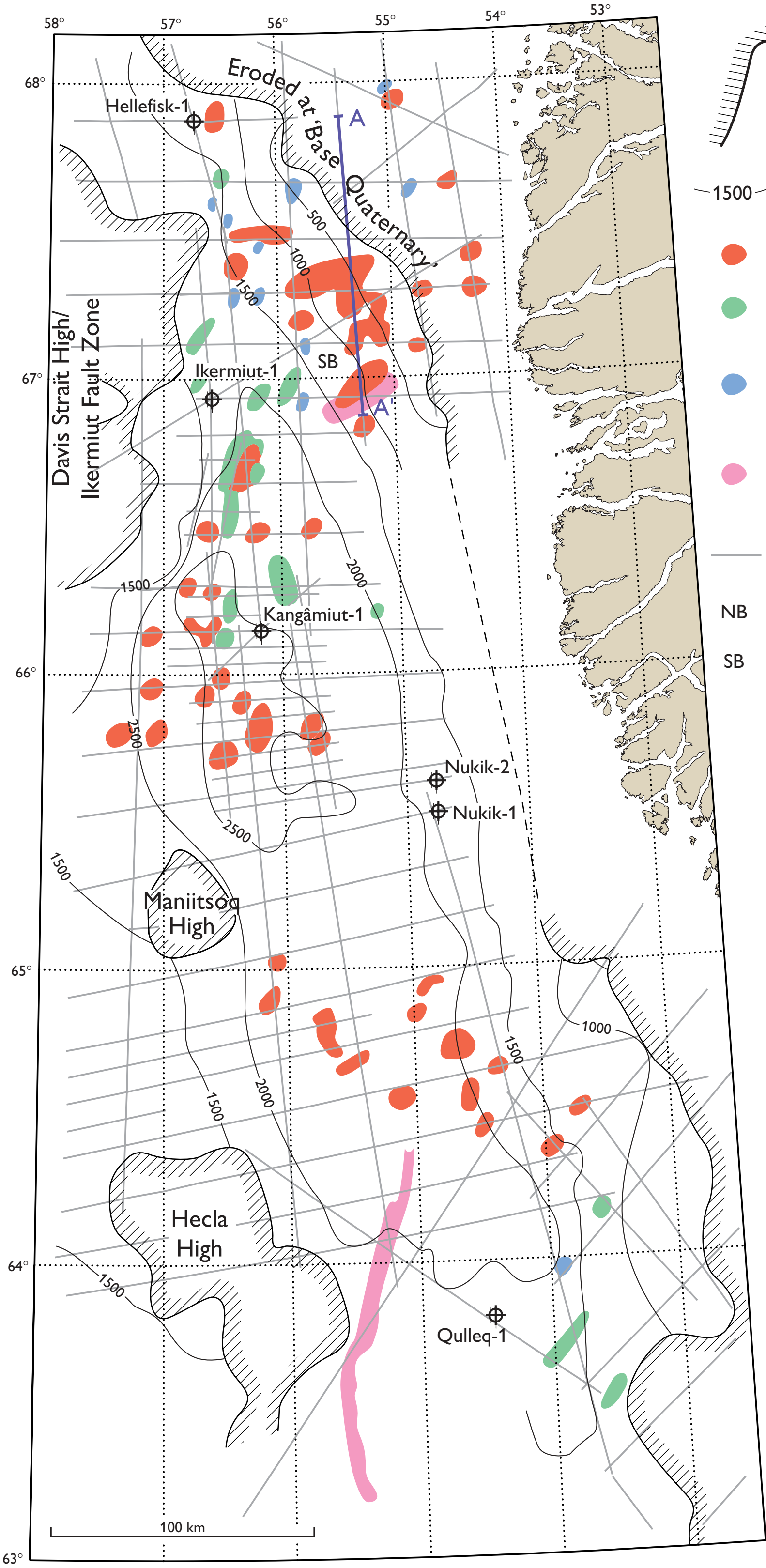

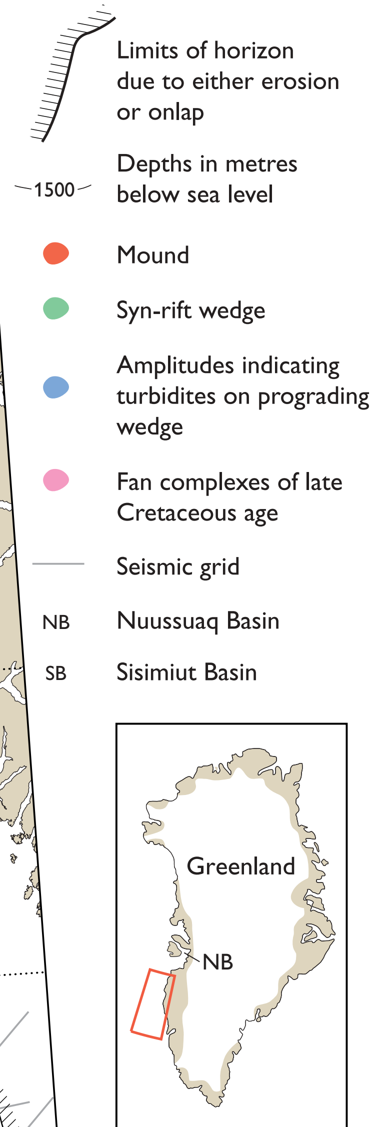

Fig. 1. Locality map showing the extent of the investigated region and the positions of the wells and the seismic lines used to interpret the seismic sequences in this study. The contours show the depths in metres below sea level to the mid-Eocene unconformity. The described Paleocene to mid-Eocene seismic sequences lie under this unconformity, and their distribution shows the maximum extent of the Paleocene to mid-Eocene succession. The map also indicates the distribution of seismic facies representing possible hydrocarbon reservoirs. Seismic line **A–A'** is shown in Fig. 2.

Seismic interpretation

The grid of seismic reflection data used in this interpretation is shown in Fig. 1. The data are all multichannel lines, acquired in 1990, 1991, 1992 and 1995, with the addition of some reprocessed regional lines acquired in 1977. Twenty-nine seismic sequences have been recognised within the studied sediment package, and these seismic sequences have been grouped into 11 third-order depositional sequences (Chalmers *et al.* 2001a). The seismic stratigraphic interpretations have been used to infer two distinct episodes of tectonism. During the Late Paleocene, coinciding with the stage of sea-floor spreading in the Labrador Sea between magnetochrons 27 and 25, tectonism was predominantly extensional. During the Early to Middle Eocene, extension continued in most of the region, but became transpressional along the Ikermiut Fault Zone. Major tectonism ceased during the Middle Eocene at the same time as sea-floor spreading in the Labrador Sea slowed substantially (Chalmers *et al.* 2001a).

A seismic sequence has been identified that is equivalent in age to the sediments that include the Marraat source rock in the Nuussuaq Basin (Bojesen-Koefoed *et al.* 1999). If this seismic sequence also includes a source rock facies, it will be mature for oil generation in the region between the Maniitsoq High and the Kangâmiut-1 well (Chalmers *et al.* 2001a).

In the distal parts of many of the seismic sequences, it is possible to recognise and map discrete seismic facies interpreted as basin-floor fans, syn-tectonic wedges and turbidite channel complexes that could act as hydro-

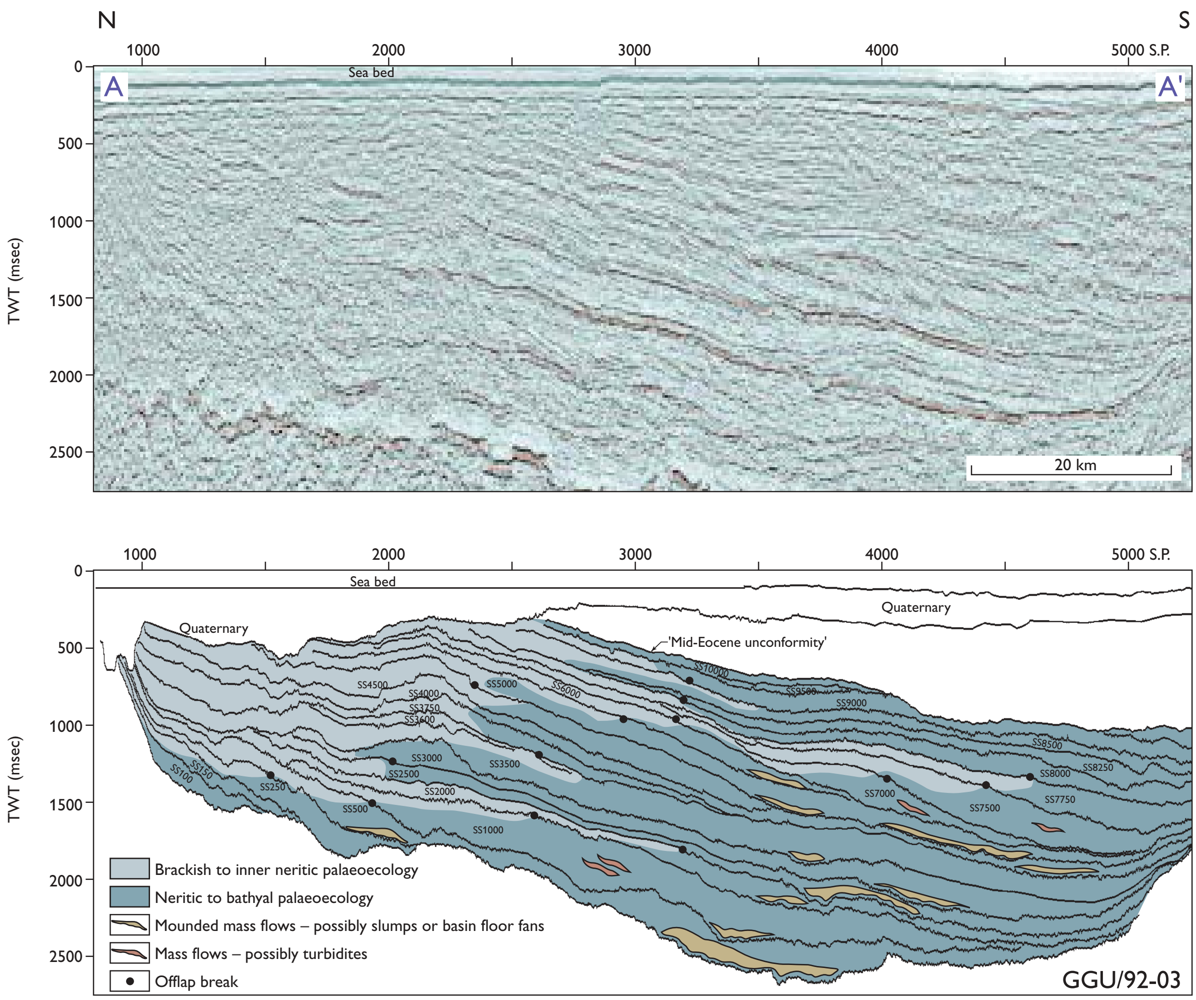

Fig. 2. North–south seismic line GGU/92-03 across the Sisimiut Basin showing the maximum thickness of the seismic sequences. This line illustrates many of the relationships between the seismic sequences, their internal seismic facies and interpretation of palaeoenvironments. For location, see Fig. 1.

carbon reservoirs, sealed by surrounding mudstone (Figs 1, 2). Based on thickness variation throughout the basin it is suggested that sediment input was dominantly from the north, probably representing a continuation of the Cretaceous drainage system from the Nuussuaq Basin, as described by Pedersen & Pulvertaft (1992). Lesser amounts of sediments came from the mainland of Greenland to the east and minor amounts from highs to the west. The sediments were deposited in environments that ranged from freshwater/marginal marine to upper bathyal. Proximal environments are probably generally sand-prone, whereas distal environments probably contain larger amounts of mud, some of which could contain a mature source rock for oil.

Well log interpretation

Sedimentological and palaeoenvironmental interpretations are based on well log interpretation, cuttings and sidewall core descriptions, and palynological and microfossil studies. A lithostratigraphic and biostratigraphic correlation of the five wells from the 1970s offshore West Greenland has been achieved and a log panel displaying correlation of the palyno- and microfossil zonation and seismic sequences is presented here (Fig. 3). Sixteen sequences have been described and dated using log motifs, lithology, microfossils and palynomorphs, and a depositional environment has been suggested for each.

The sediments are predominantly sandstones in the basin-marginal wells (Hellefisk-1, Nukik-1, Nukik-2) and shales in the basin-centre wells (Ikermiut-1, Kangâmiut-1). Based on the re-interpretation of the log data, the sand/shale ratio and facies distributions have been modified from that presented by Rolle (1985). Most of the Palaeogene sediments in Hellefisk-1, Nukik-1, and to a certain degree Nukik-2, were deposited in a littoral to inner neritic environment, whereas most Palaeogene sediments in Kangâmiut-1 and Ikermiut-1 were deposited in an outer neritic to bathyal turbiditic environment (Dalhoff *et al.* 2001).

Biostratigraphy

A new Palaeogene dinoflagellate cyst stratigraphy from offshore West Greenland has been described based on data from the Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1, Nukik-2 and Qulleq-1 wells (Nøhr-Hansen 2001). The dinoflagellate cyst stratigraphy has been correlated with the microfossil zonation and previously established zonations in the North Sea. Twenty-one stratigraphic intervals are defined from the upper Lower Paleocene to the Upper Eocene. The stratigraphy and well correlation are based on last appearance datum events and abundances of stratigraphically important species from 355 samples, 148 of which are sidewall core samples.

A nannofossil study has been carried out in the Kangâmiut-1 and Nukik-2 wells (Sheldon 2001). The stratigraphy has been correlated with previously established nannofossil zonation schemes and, where possible, used to indicate palaeoenvironmental changes during the Early and Middle Eocene. The stratigraphy and dating are based on stratigraphically important species, and palaeoenvironmental signals are based on species influxes. A total of 69 samples (26 sidewall cores and 43 ditch cuttings samples) were examined and compared with findings from nearby DSDP and ODP sites.

A microfossil-based biostratigraphy of the Paleocene and Lower Eocene sediments of the Hellefisk-1, Ikermiut-1, Kangâmiut-1, Nukik-1 and Nukik-2 wells has been established (Rasmussen & Sheldon 2001). In general, the five wells contain fairly well-preserved, diverse microfossil faunas and floras consisting mainly of foraminifera, radiolaria, ostracods, bivalves and fish remains, together with diatom and palynomorph floras. Nannofloras (mainly coccoliths) occur in relatively low numbers (Sheldon 2001). The biozones are more easily recognised in the two basinal wells (Ikermiut-1 and Kangâmiut-1) than in the three more nearshore wells (Nukik-1, Nukik-2 and Hellefisk-1) due to a higher microfossil diversity and abundance.

The Middle Eocene and upper Lower Eocene intervals of the Hellefisk-1 well in particular are poorly represented by microfauna, with samples often being barren or only containing coal fragments.

Concluding remarks

The new interpretation of seismic and well data suggests that an equivalent to the Marraat oil source rock may be present – and mature – in large parts of the Sisimiut Basin. The Marraat oil, one of the oils that have been discovered seeping to the surface in the Nuussuaq Basin, has been attributed to a source rock not older than the latest Cretaceous (Bojesen-Koefoed *et al.* 1999). The source rock appears to have been encountered in the GRO#3 well (Christiansen *et al.* 1999), and this interval is dated as belonging to the Early Paleocene (Nøhr-Hansen *et al.* in press). Only the lower part of sequence

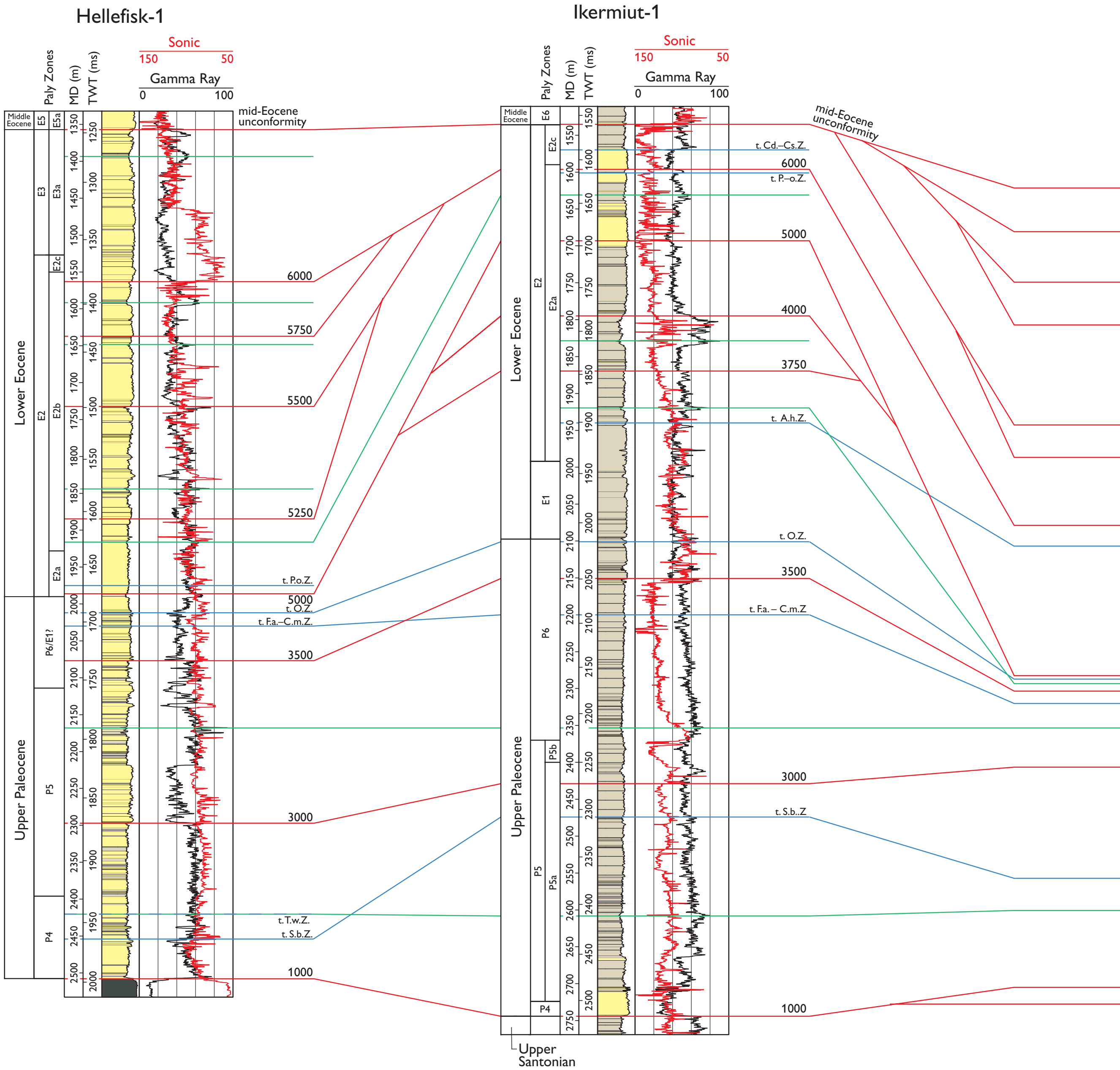

Fig. 3. Log panel showing the correlation of the Palaeogene succession in the five wells from offshore West Greenland drilled in the 1970s. The seismic sequences are numbered sequentially (500–10 000); the marine flooding surface within sequence 3000 is used as the datum. It should be noticed that some sequences are very local, especially above Sequence 6000 in the Kangâmiut-1 well. The crossing between the *A. hirtus* Zone correlation line and the seismic sequence boundaries between Ikermiut-1 and Kangâmiut-1 may be explained by a lower resolution of the former. The palynological zonation adopted here is based on that of Bujak & Mudge (1994) and Mudge & Bujak (1996a, b). Modified from Dalhoff *et al.* (2001).

SS500 and older seismic sequences are as old as this, and the extent of an equivalent to the Marraat oil source rock is restricted to the extent of SS500 (Chalmers *et al.* 2001a, figs 8, 31).

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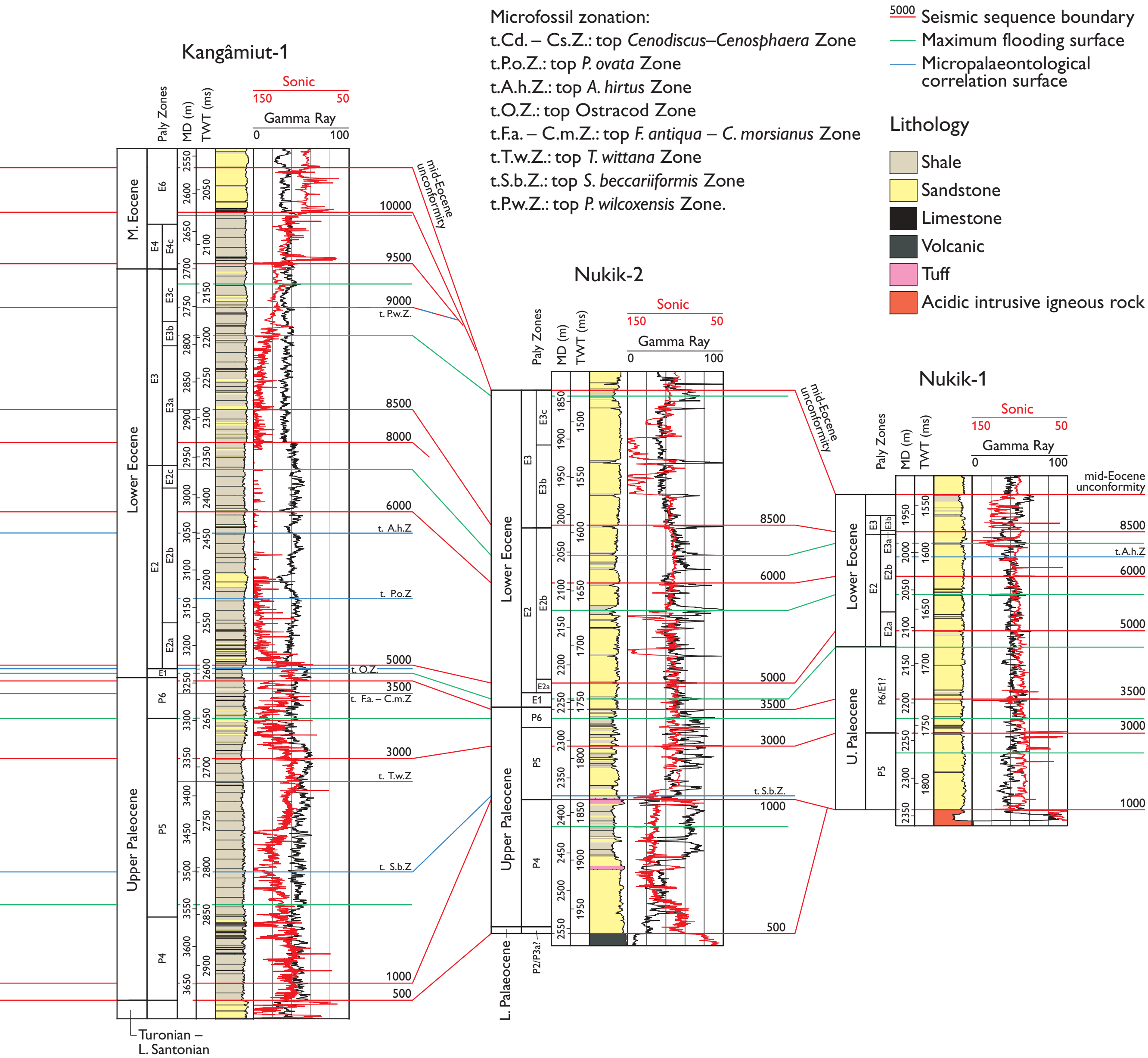

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