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Studies of the onshore hydrocarbon potential in East Greenland 1986–87: field work from 72° to 74°N

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A study of the onshore hydrocarbon potential of central and northern East Greenland was initiated in 1986. Field work was carried out from early July to mid August covering the region between Kong Oscar Fjord and Kejser Franz Joseph Fjord (fig. 1). In 1987 field activities will continue further to the north, eventually reaching Danmarkshavn (77°N).

The programme is a continuation of the 1982–83 investigations in Jameson Land (Surlyk, 1983; Surlyk *et al.,* 1984a) and is part of a regional programme comprising petroleum geological studies of all sedimentary basins in Greenland (Larsen & Marcussen, 1985; Larsen, 1986).

The aim of the two-year field study followed by laboratory analyses is:

(1) to study the presence and distribution of potential hydrocarbon source rocks in the region;

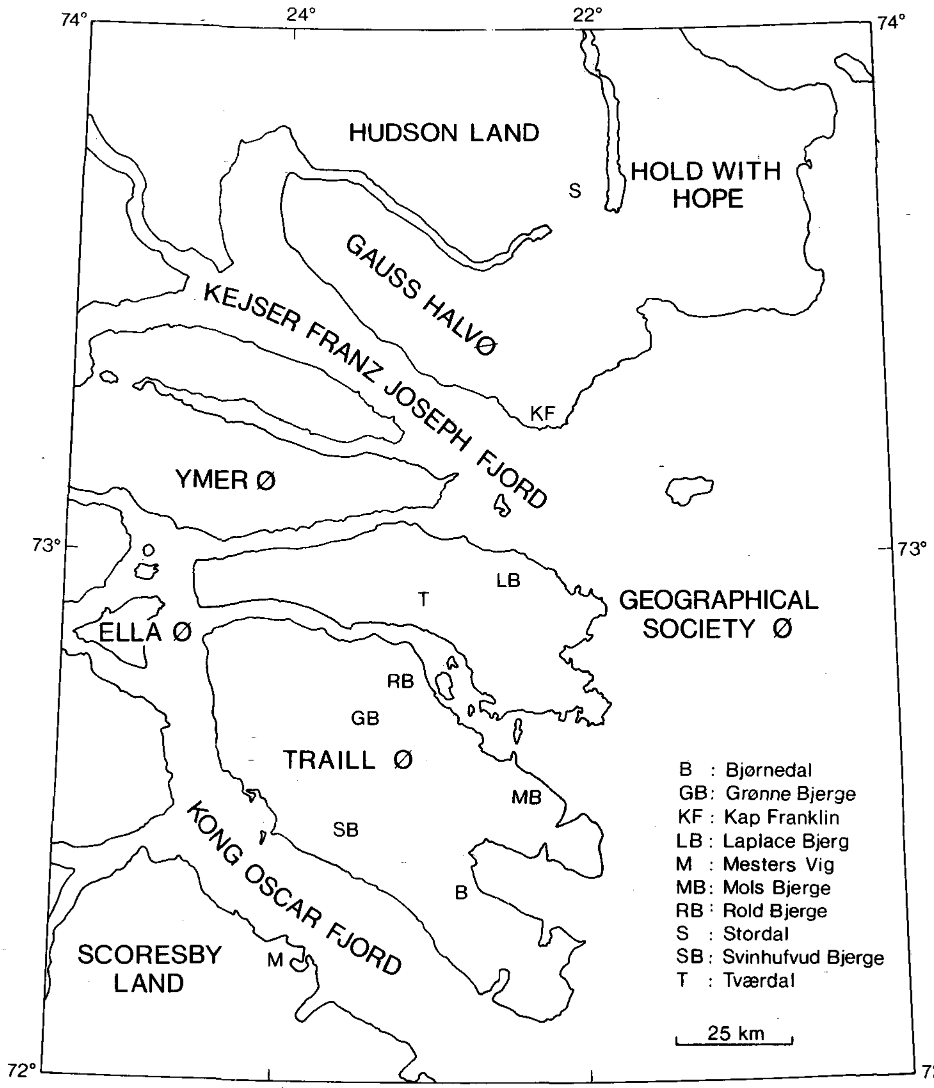

Fig. 1. The study region with localities mentioned in the text.

(2) to evaluate the thermal history and maturity pattern of the region including the thermal effect of Tertiary intrusions and volcanics;

(3) to make a stratigraphic, sedimentological and tectonic study of the region with special emphasis on subsidence history, reservoir formation and potential hydrocarbon traps.

The region was briefly visited during the 1985 field season (Piasecki & Marcussen, 1986) and preliminary laboratory data suggest the existence of several potential source rock horizons in the Carboniferous, Permian, Jurassic, and Cretaceous sequences (Piasecki, 1986).

Mesters Vig was used as base camp for the 1986 expedition. Stordal in Hudson Land (fig. 1) offering a natural landing strip for STOL aircraft will serve as the base in 1987, and a fuel depot has already been established. The expedition group numbered 19, comprising five two-person geological teams, a four-person drilling team and five supporting personnel, including a helicopter pilot and a helicopter mechanic. Two teams (led by P.-H. Larsen and H. Olsen) studied the Devonian succession with a tectonic and a sedimentological approach, respectively. One team (led by L. Stemmerik) investigated the Carboniferous, Permian and Lower Triassic sedimentology of the region. The Triassic, Jurassic and Cretaceous sequences were studied by two teams (led by F. G. Christiansen and S. Piasecki) with a structural and stratigraphical sedimentological approach, respectively. All teams collected material for source rock analyses and a large number of samples were also collected for determining reservoir rock properties. In addition, eight drill holes penetrated some of the more interesting source-rock horizons.

The drilling programme

The drilling unit used has been modified compared to the model previously employed in Jameson Land (Surlyk, 1983; Surlyk *et al.*, 1984a) and in North Greenland (Christiansen *et al.*, 1986). In order to reduce drilling time and to avoid problems with permafrost, the drill unit now operates with a wire-line system.

J. Boserup, A. Clausen and K. Villadsen worked as technical personnel on the drilling team, whilst J. Bojesen-Koefoed, S. Piasecki, F. G. Christiansen and L. Stemmerik alternated as drill site geologists.

In total, eight holes were drilled to depths of maximum 75 m with a cumulative length of approximately 295 m (Table 1). The black shale of the Permian Ravnefjeld Formation was the target of the first two holes. The third hole was in Lower Cretaceous shale, whereas the fourth and fifth holes were in shale of the Upper Jurassic Bernbjerg Formation and from the

Table 1. Geological description of the different drill sites

Drill site	Locality	Lithostratigraphy	Main lithology	Depth (m)	Drill time
303120	Grønne Bjerge	Ravnefjeld Fm	Shale	12.84	~ 7 h
303121	Rold Bjerge	Ravnefjeld Fm/ Wegener Halvø Fm	Silty shale and limestone	20.28	~ 8 h
303122	Rold Bjerge	'Berriasian(?) shale'	Silty shale	31.59	~ 17½ h
303123	Bjørnedal	Bernbjerg Fm	Silty shale	42.00	~ 17 h
303124	Bjørnedal	Sortehat Mb	Sandy shale	51.09	~ 14 h
303125	Svinhufvud Bjerge	'Albian-Cenomanian shale'	Shale	75.09	~ 24 h
303126	Svinhufvud Bjerge	'Albian-Cenomanian shale'	Shale	17.27	~ 10½ h
303127	Svinhufvud Bjerge	'Albian-Cenomanian shale'	Shale	44.34	~ 14 h

Middle Jurassic Sortehat Member, respectively. The last three holes were all drilled in black shale of Albian – Cenomanian age.

Devonian

Devonian sediments outcrop in the western part of the study area covering western Traill Ø, western Geographical Society Ø, and eastern Ymer Ø (figs 1 and 3).

Deposition of the Middle to Upper Devonian Kap Kolthoff Supergroup (Friend *et al.*, 1983) took place in a system of sandy braided rivers forming extensive braid plains in a rapidly subsiding intramontane basin. Occasionally periods of aeolian deposition prevailed resulting in thick successions of windblown sediments interfingering with the fluviatile succession. A system of alluvial fans formed along the main western border fault, and more than 1000 m of conglomerate were deposited in the Ella Ø area (fig. 2).

In the eastern part of the study area the Kap Kolthoff Supergroup is overlain by the Kap Graah Group (Friend *et al.*, 1983). This group is dominated by medium- to coarse-grained pebbly sandstone of braided river origin with local accumulations of aeolian and alluvial fan deposits. Towards the west interbedded siltstone and fine- to medium-grained sandstone of meandering stream and associated flood basin origins dominate.

The overlying Upper Devonian Mt. Celcius Supergroup (Friend *et al.*, 1983) is divided into the lower Remigolepis Group and the upper Grønlandaspis Group. The former is composed of siltstone and very fine sandstone formed in the depositional environment of a meandering stream system with extensive flood basins. The latter group consists mainly of medium-grained sandstone deposited from braided rivers.

The more than 6000 m thick succession of Devonian sediments was folded and thrusted in Carboniferous time against Lower Palaeozoic metamorphics and Precambrian basement to the west.

Except for a few metres of black shale in the Mt. Celcius Supergroup, potential source rock horizons have not been observed in the study area. In contrast, it is likely that the many kilometres thick succession of coarse clastics contains good potential reservoir rocks, especially in the aeolian deposits.

A reconnaissance study of the Middle Devonian Vilddal Supergroup (Friend *et al.*, 1983) at Kap Franklin, Gauss Halvø (fig. 1) showed that approximately 400 m of black to grey shale and siltstone are present. These fine-grained sediments which only occur north of Kejser Franz Joseph Fjord may have potential as a source rock.

Carboniferous – Lower Permian

Sediments of Carboniferous – Lower Permian age have been studied in northern Scoresby Land, Traill Ø, Geographical Society Ø and Ymer Ø (figs 1 and 3). This more than 1500 m thick succession (fig. 2) is subdivided into three major units which can be roughly correlated with the division of Witzig (1954) in northern Scoresby Land.

The lower, more than 700 m thick unit is composed of medium- to coarse-grained sandstone, red siltstone, organic-rich, black shale, and minor conglomerate and coal beds of fluviatile and lacustrine origin.

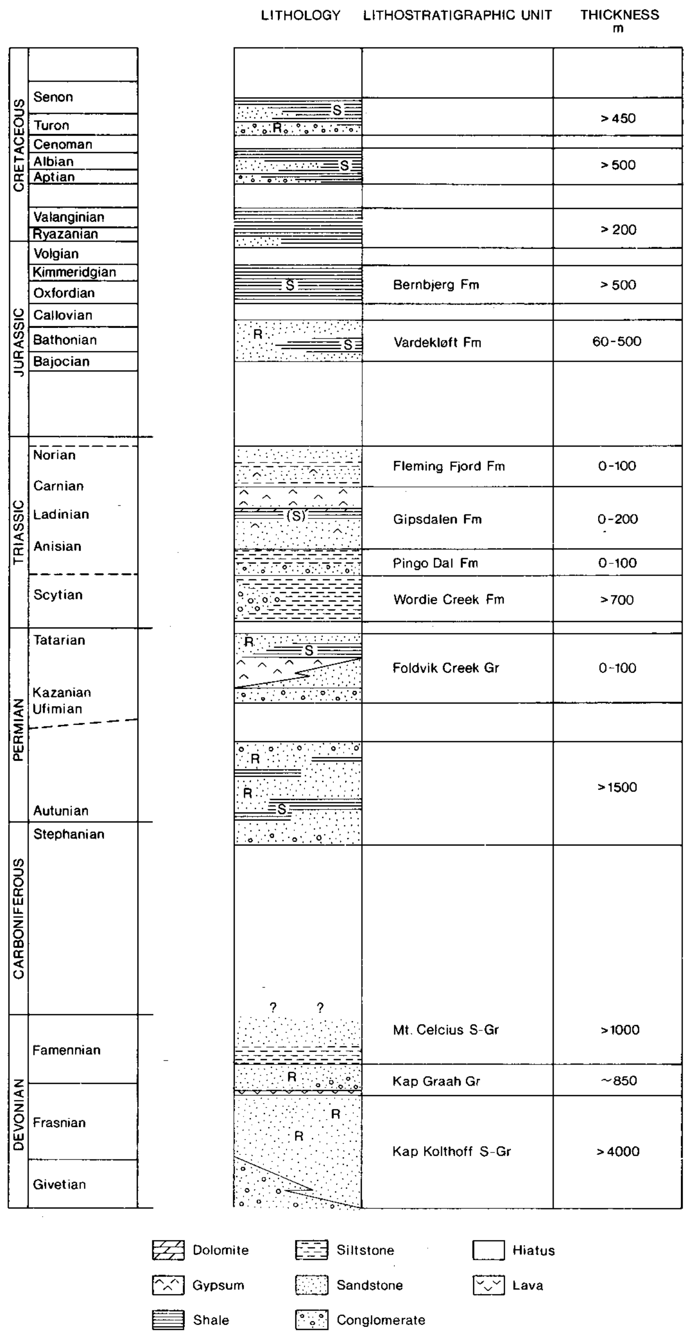

Fig. 2. Preliminary stratigraphic scheme of Traill Ø and Geographical Society Ø. Main lithology and maximum thickness are shown. S indicates potential source rocks, R indicates potential reservoirs.

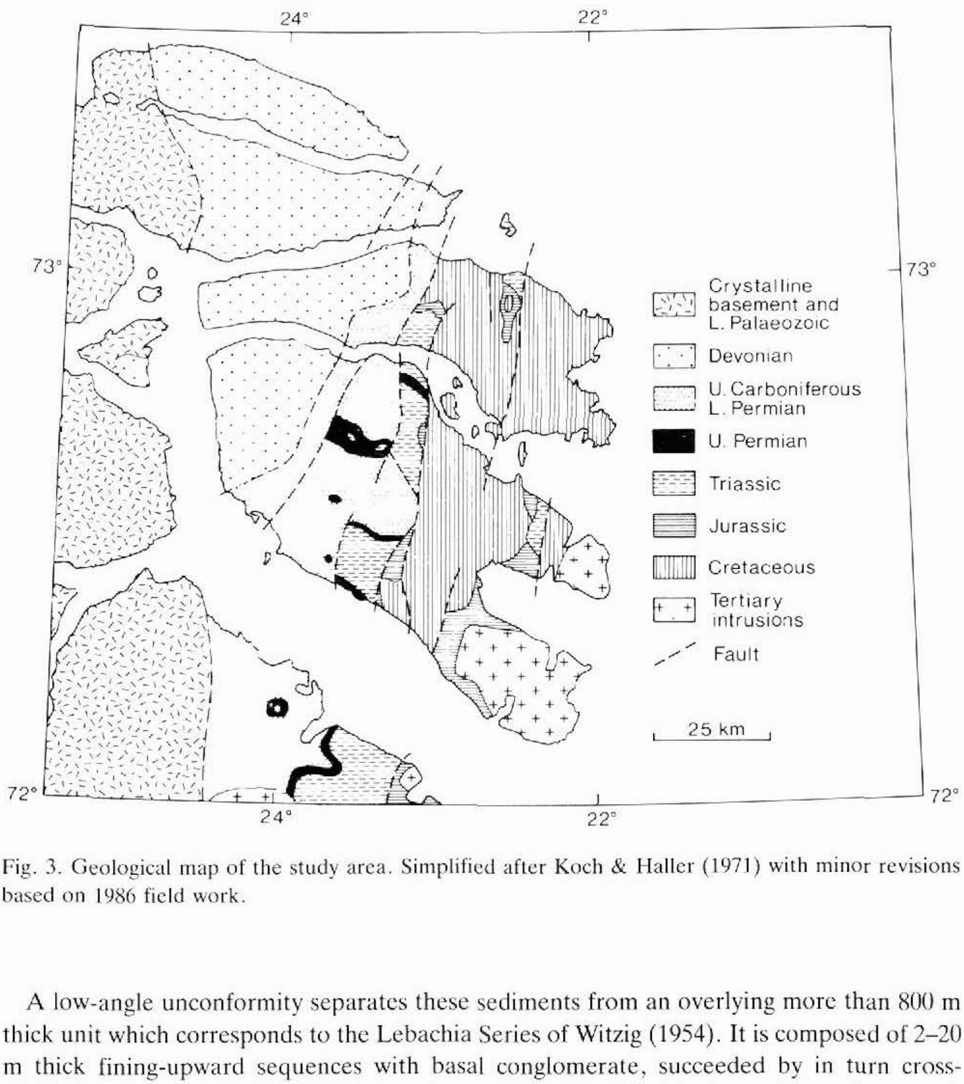

Fig. 3. Geological map of the study area. Simplified after Koch & Haller (1971) with minor revisions based on 1986 field work.

A low-angle unconformity separates these sediments from an overlying more than 800 m thick unit which corresponds to the Lebachia Series of Witzig (1954). It is composed of 2–20 m thick fining-upward sequences with basal conglomerate, succeeded by in turn cross-bedded coarse- and medium-grained sandstone, fine-grained sandstone and grey shale which are deposited by meandering streams. The proportion of sand to shale varies considerably from one sequence to the other.

The uppermost unit of conglomerates is equivalent to the Domkirken Series of Witzig (1954). It only occurs on Traill Ø where it is poorly exposed.

Potential source rocks are restricted to the lower unit. Several laterally extensive organic-rich shale units of lacustrine origin occur with a thickness up to 12 m. Preliminary analyses by Piasecki (1986) suggest that the shale is potentially a very good source rock for oil.

The Carboniferous – Lower Permian succession is dominated by fairly mature sandstone of fluviatile origin, known elsewhere to form good hydrocarbon reservoirs. Channel sand in the middle unit may act as stratigraphic traps whereas structural traps may have developed in relation to early(?) Permian faults.

Upper Permian – Triassic

The Upper Permian Foldvik Creek Group (Surlyk *et al.*, 1986b) is exposed on Traill Ø (fig. 3) with a thickness of approximately 200 m. It is dominated by sandstone, conglomerate and black shale with minor grey limestone and gypsum (fig. 2). The black shale of the Ravnefjeld Formation is described as having an excellent source rock quality in Jameson Land (Surlyk *et al.*, 1984b, 1986b), and is also likely to be a potential source rock further north. The sandstone is mainly of shallow marine origin and may form potential reservoirs sealed by overlying Upper Permian evaporite and shale.

The Lower Triassic Wordie Creek Formation (Perch-Nielsen *et al.*, 1974) has been cursorily examined in Svinhufvud Bjerge, Mols Bjerge, Tværdal, Rold Bjerge and Laplace Bjerg (fig. 1). This more than 500 m thick succession of finely laminated marine siltstone and sandstone does not contain any potential source rock horizons; the pebbly sandstone and conglomerate of the Svinhufvuds Bjerge Member (Clemmensen, 1980) are considered as potential reservoir rocks.

The Middle and Upper Triassic Pingo Dal, Gipsdalen and Fleming Fjord Formations (Clemmensen, 1980) only occur in Mols Bjerge within the studied region. These continental and shallow marine deposits are generally strongly cemented with calcareous and gypsiferous material with a low reservoir potential. The black lagoonal shale and limestone of the Gråklint Beds in the Gipsdalen Formation, previously suggested as a potential source rock (Henderson, 1976; Surlyk *et al.*, 1986a), is very poorly exposed. However, a one metre thick dolomite bed in the shale displays a secondary vuggy porosity which is partly filled with solid bitumen particles and millimetre- to centimetre-sized crystals of dolomite, calcite and quartz, suggesting that some hydrocarbon generation and migration has taken place.

Jurassic – Cretaceous

The Jurassic – Cretaceous succession is exposed in the central and eastern parts of Traill Ø and Geographical Society Ø (fig. 3). Towards the west the succession is bordered by synsedimentary faults, whereas the eastern part is intruded by Tertiary acid to intermediate plutonics and numerous dolorite dykes and sills. Locally, the intrusions comprise more than 50% of the total rock volume, especially in the eastern part and along the south coast of Traill Ø.

The basal Jurassic sediments observed on Traill Ø are the Middle Jurassic Vardekløft Formation (Surlyk, 1977), unconformably overlying the Triassic Wordie Creek Formation (in Tværdal and the Laplace Bjerg area) or the Fleming Fjord Formation in Mols Bjerge. In Bjørnedal the lower part of the formation encloses sandy, plant-rich, bioturbated black shales which can be correlated with the Sortehat Member in Jameson Land. Throughout Traill Ø and Geographical Society Ø, the Vardekløft Formation is characterized by coarse-grained pebbly sandstone which is rich in badly preserved plant remains, tree trunks and coal beds or debris.

The Upper Jurassic Bernbjerg Formation (Surlyk, 1977) with black, micaceous, silty shale overlies the Vardekløft Formation unconformably. This formation is only sporadically preserved in the studied region due to extensive postdepositional erosion, but it reaches a maximum thickness of approximately 500 m in Bjørnedal.

The Jurassic – Cretaceous boundary is marked by a hiatus and a significant angular unconformity (fig. 2). Many hundreds of metres of Jurassic sediments have been removed by Late Jurassic to Early Cretaceous erosion and locally a palaeotopography with reliefs of more than 100 m is observed (e.g. Laplace Bjerg, Svinhufvud Bjerge).

Lower Cretaceous deposits are rare and scattered in the region (see Donovan, 1953, 1955) and most of the often poorly exposed Cretaceous succession is dominated by at least 500 m of black silty shale of Aptian, Albian and Cenomanian age (fig. 2). The shales often contain thin beds of storm sand and metre-sized olistoliths of coarse clastic material, especially in the vicinity of the faults against the Permo-Triassic block. Supposed Turonian conglomerates (Donovan, 1953) are followed by black to grey, silty to sandy shale of Senonian age with a thickness of more than 450 m in Tværdal.

The Jurassic – Cretaceous sequence is interesting since it contains intervals of both potential source rocks and reservoir rocks. Potential source rocks include the Middle Jurassic Sortehat Member and the Upper Jurassic Bernbjerg Formation, and the Cretaceous shale of Aptian – Cenomanian and Senonian age. The Sortehat Member is preliminarily supposed to have a limited gas potential since it is dominated by terrestrial material and reflects oxygenated deposition conditions. In contrast, the Bernbjerg Formation seems more promising as it is a thick, fine-grained, laminated, organic-rich shale deposited under anoxic conditions. The lateral equivalent to this formation towards the south, the Hareelv Formation in Jameson Land, has very good source rock characteristics with a high content of organic matter with a hydrocarbon potential (Surlyk *et al.*, 1986a). The Cretaceous shale is interesting due to its great lateral extension and thickness. Large horizons are, however, bioturbated and sandy, suggesting oxic bottom conditions and low contents of organic carbon. Furthermore most of the Cretaceous shale is probably thermally postmature due to the heating effect of the Tertiary intrusions.

Both the coarse-grained sandstone of the Vardekløft Formation and the Turonian conglomerates are considered as potential reservoir rocks. The significant unconformities formed during the Jurassic – Cretaceous period, the variation in thickness of most units, and extensive faulting suggest good possibilities for both stratigraphic and structural hydrocarbon traps, in several cases with the source rock acting as seal.

Evidence of hydrocarbon generation in the Jurassic – Cretaceous sequence is restricted to the observation of coalified bitumen-impregnated sandstone. Close to Laplace Bjerg such sandstone occurs just below the Jurassic – Cretaceous unconformity. Here the Jurassic surface has a palaeotopography of more than 25 m with onlapping Cretaceous shales. The thickness of the 'palaeo oil field' is at least 35 m, probably approximately 60 m. Unfortunately, the hydrocarbons are completely thermally degraded to coal by an overlying dolorite sill more than 100 m thick. Furthermore, solid bitumen particles have been observed in Jurassic limestone and calcareous sandstone in Tværdal.

Laboratory work and future studies

The main objective of the basic geological studies and the planned laboratory programme is to obtain data for modelling the subsidence history of the basin and evaluating the hydrocarbon potential of the region.

The sedimentology and structures of the Devonian succession and the hitherto little-known Carboniferous – Lower Permian succession will be analysed in order to elucidate the origin and early history of the basin development. Detailed studies of the large new collection of Jurassic and Cretaceous fossils are necessary to reveal the chronology of the apparently complex Late Mesozoic history of the basin.

The thermal maturity and source-rock quality, especially of the previously mentioned Carboniferous – Lower Permian, Jurassic and Cretaceous shales, will be studied with the LECO/Rock Eval analyses followed by optical studies on both polished samples (fluorescence and vitrinite reflectance) and on palynological samples (Thermal Alteration Index and palynofacies). A limited number of source rocks will be studied in detail by gas chromatography and mass spectrometry.

The reservoir rock intervals will be studied by petrographic methods (stained thin sections) as well as petrophysical determinations of porosity and permeability.

Obviously, any conclusions about the hydrocarbon potential of the region must await the laboratory studies followed by field work in 1987. The field results of 1986 are, however, promising since most source and reservoir rock intervals from Jameson Land (e.g. Surlyk *et al.*, 1986a) can be traced northwards. In addition to the possible Upper Jurassic and Upper Permian hydrocarbon plays, the field data also suggest the possibility of an Upper Carboniferous – Lower Permian play. The Upper Jurassic play is probably non-prospective in the studied onshore areas as it occurs close to the topographic surface but it must be considered in the shelf area. In contrast, the Upper Palaeozoic plays are more interesting as this part of the succession is moderately deeply buried in the eastern part of the study area. It is, however, most likely that this area is strongly thermally affected by Tertiary igneous and volcanic activity.

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An ice-sampling programme in the Thule area, North Greenland

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A glaciological programme was carried out as part of the NORDQUA 86 expedition to the Thule area, North Greenland, from 7 to 24 August 1986.

The expedition included researchers from the five Nordic countries and Great Britain and was organised by the Geological Museum, Copenhagen (Funder, in press). The expedition had a Quaternary geological programme, as well as a glaciological programme dealing with the climatic history and ice-sheet dynamics before and during the last Ice Age in the area.

The glaciological programme involved collection of ice samples to be analysed for $\delta^{18}O$.

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