DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2011/42

# West Greenland petroleum systems

## An overview of source rocks and oil seepages and their implications for offshore petroleum exploration

Jørgen A. Bojesen-Koefoed

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF CLIMATE AND ENERGY

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# Preface

This report has been prepared further to numerous contacts with the petroleum industry that all, in one way or another, have concerned West Greenland petroleum systems.

Hence, the aim of the report is to fullfill an apparent need for a brief and reasonably comprehensive overview of  current insight into West Greenland petroleum systems.

The report will essentially review and summarise data that have previously been published in print or presented orally whereas new and unknown information is largely absent.

# 1. Introduction

The West Greenland offshore is a large, Mesozoic or perhaps older system of rift basins that in places host at least 13 kilometres of syn- and post-rift sediments of Cretaceous (? pre-Cretaceous) to recent sediments. The area is situated in the Arctic or even high Arctic, bordered by the craton areas of northwest Greenland and northeast Canada (Nunavut), (fig. 1.1).

Relatively little is known about the nature of the basin-fill, since most of the basins are untested by wells and except for a few isolated occurrences, the country-rock of the bordering land-areas consists of  metamorphic basement essentially devoid of exposed sedimentary rocks. In total only seven exploration wells have been drilled in the entire west Greenland region (fig. 1.2). Hence, most of our current knowledge relies on geophysical data such as potential field data (geomagnetic and gravimetry data) in combination with seismics available in a rather open grid, although the number of line-kilometres and the grid-density are steadily growing.

Petroleum systems do not lend themselves to assessment based on geophysical data, but require samples for proper evaluation. In the absence of samples an assessment of the portential petroleum systems of the West Greenland offshore must rely on analogies and extrapolation of information gathered from neighbouring regions, some of which may seem rather far afield. Moreover, the basin configuration and the connections to neighbouring basins during both the Paleozoic and the Mesozoic are poorly known, adding further to the uncertainty.

The assessment of potential petroleum systems reportered here relies primarily on information from central West Greenland that constitutes a key area where extensive seepage of petroleum has been documented (Christiansen et al., 1996, Bojesen-Koefoed et al., 1999 and references therein). Additional information has been derived from Nunavut (Canada): Ellesmere Island, Bylot Island, Baffin Island, and from seabed sampling in the Davis Strait.

Compilation of information from these regions leads to the conclusions that petroleum source rocks of Cretaceous and Paleogene age can be expected to be present. In addition, the presence of Ordovician age petroleum source rocks should not be ruled out.  Principal reservoirs are presumably syn-rift sandstones of Cretaceous-Tertiary age, but perhaps also older units such as Ordovician carbonates and Proterozoic sandstones.

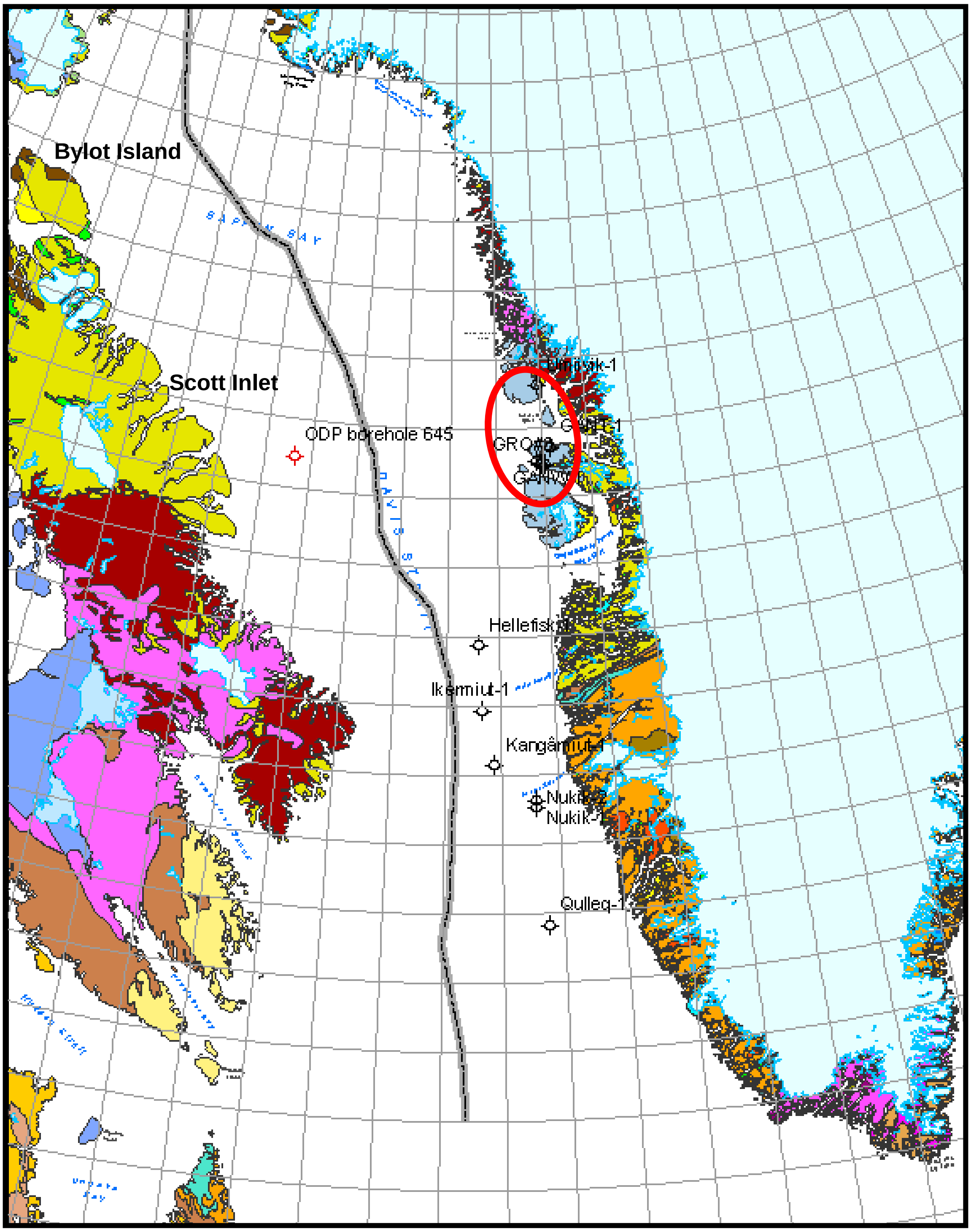

Fig. 1.1 Overall study area. Seepage area in central West Greenland encircled.

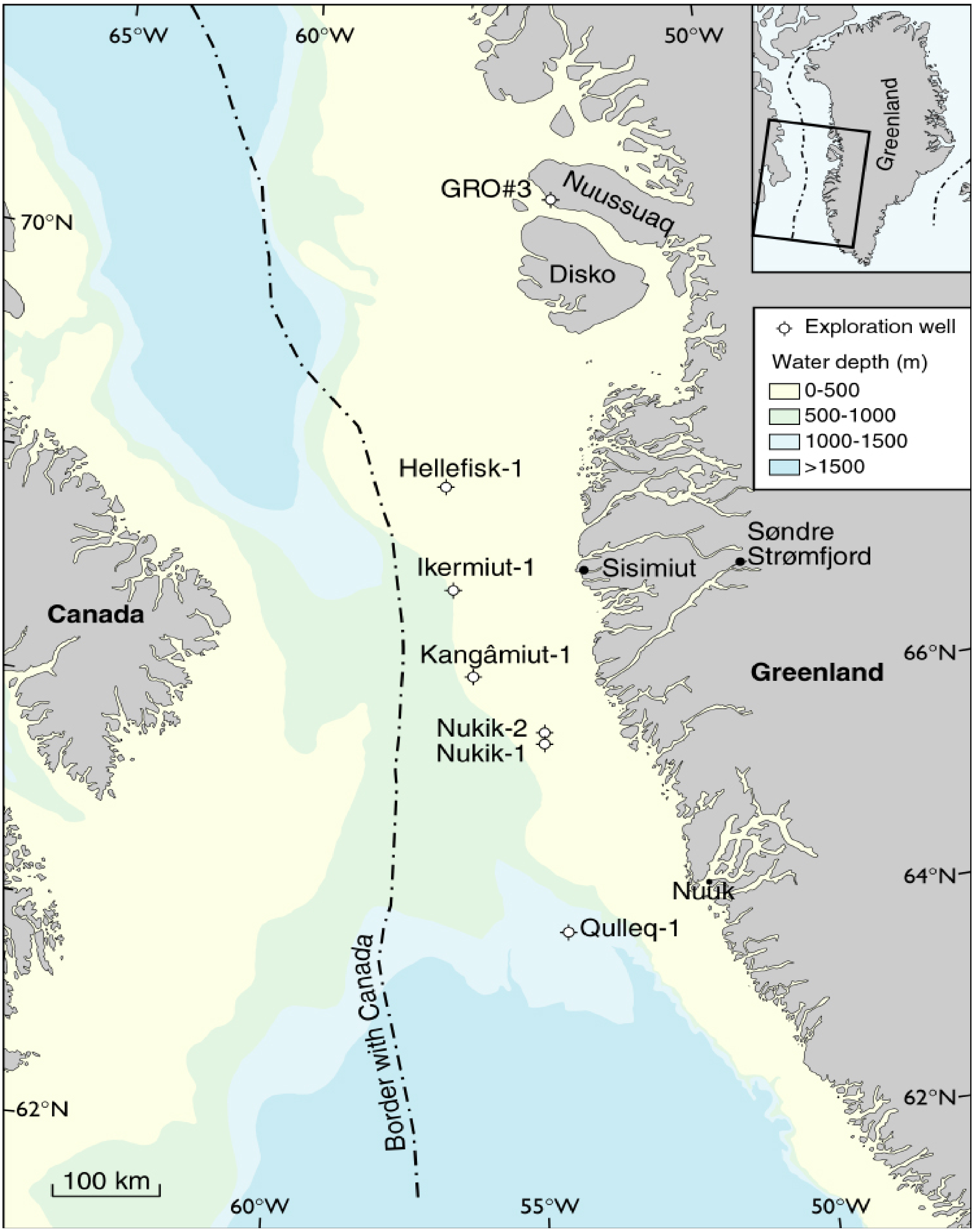


Fig. 1.2 Location of exploration wells in West Greenland.

# 2. Petroleum seepages in Central West Greenland: characteristics of oil types and their sources

## 2.1 Introduction

The central West Greenland Basin is a Mesozoic – Tertiary basin hosting at least 6 kilometres of Cretaceous – Tertiary sediments, overlain by Paleogene plateau basalts reaching a thickness of up to approximately 2 kilometres (Chalmers et al. 1999).
Widespread seepage and staining of petroleum has been documented in the region. Petroleum is mainly found plugging available porosity in picritic lavas or hyaloclastites, but petroleum has also been found in sand/sandstones and as fine inclusions in carbonate veins in lavas and along dyke-contacts. Based on biological marker analyses five different oil types have been identified, in addition to mixtures (key references: Christiansen et al. 1994, 1996; Bojesen-Koefoed et al. 1997, 1999, 2004, 2007) (fig. 2.1.1).
Further to the initial discovery of oil seepage, five shallow (up to ca. 700 metres) core wells were drilled on the Nuusuaq peninsula, several of which recovered oil-stained rocks (Christiansen et al. 1996; 1997b)(fig. 2.1.2).
In addition, one exploration well proper (GRO#3) was drilled. This well was dry (Bojesen-Koefoed et al. 1997), but later petrophysical evaluation suggested that a payzone with high oil saturation was bypassed unnoticed and cased, probably due the the use of heavy drilling mud as a precaution towards overpressure problems in the environmentally highly sensitive region (Kristensen & Dam 1997).
In addition to the wells drilled on Nuussuaq, the Umiivik corehole, a stratigraphic well reaching approximately 1200m was drilled on the Svartenhuk peninsula (Dam 1997; Dam et al. 1998). The well penetrated a succession of marine, Turonian age (?) black shales, but due to the presence of thick intrusions, both biostratigraphic and petroleum geochemical analyses were severely hampered (Nøhr-Hansen 1997; Christiansen et al. 1997a).
In the following the seep oil types known from central West Greenland are briefly reviewed and their bearing on the offshore exploration potential is assessed.


Fig. 2.1.1 Location of samples analysed for oil staining. Colour-coding refers to petroleum types


Fig. 2.1.2 Location of coreholes and a single exploration well, GRO#3 onshore central West Greenland

## *2.2 Marraat type*

**Key references:** Christiansen et al. (1994, 1996); Bojesen-Koefoed et al. (1997, 1999); Nytoft et al. (2002)

### 2.2.1. General

The Marraat oil type owes its name to the place where it was first discovered. Marraat is a locality on southern Nuussuaq, well-known among sailors in the region due a nearby well-sheltered anchorage.
The Marraat oil type is widespread, often present in relatively large volumes, plugging available porosity in the volcanics of the area. The seepage is active, albeit slow, since new tarry encrustations of seeping oil seem to emerge gradually over time. This has been demonstrated by the fact that revisits to the same locations separated by periods of one or more years reveal the emergence of additional conspicuous outflows of viscous oil from the volcanics (fig. 2.2.1).

Fig. 2.2.1 Marrat-type oil bleeding from volcanics at Marraat on southern Nuussuaq. Hammer-handle to the left as scale.
(Photo: F.G. Christiansen).

## 2.2.2. Characteristics:

The Marraat oil-type is a high-wax oil, rich in long-chain normal alkanes and saturated components in general. Pristane/phytane ratios are high, generally 4-6, acyclic isoprenoids relatively scarce (fig. 2.2.2). Unresolved Complex Mixture (UCM) is virtually absent in undegraded samples, and not very prominent even in biodegraded samples. Tricyclic triterpanes are scarce relative to pentacyclics. The distribution of pentacyclic triterpanes is characterized by presence of appreciable proportions of several isomers of bisnorlupanes, coeluting oleanane and lupane, occasional taraxastane, clear predominance of hopane over norhopane, abundant Tm and moretanes. Extended hopanes decrease rapidly in abundance with increasing carbon number along a distinctly concave-up trend (fig. 2.2.3). Regular steranes are strongly dominated by $C_{29}$-components. $C_{30}$-steranes (n-propylcholestanes) are not detected. Diasteranes are less abundant than regular steranes (fig. 2.2.4). Hopane to sterane ratios are high, generally estimated at 10-20.

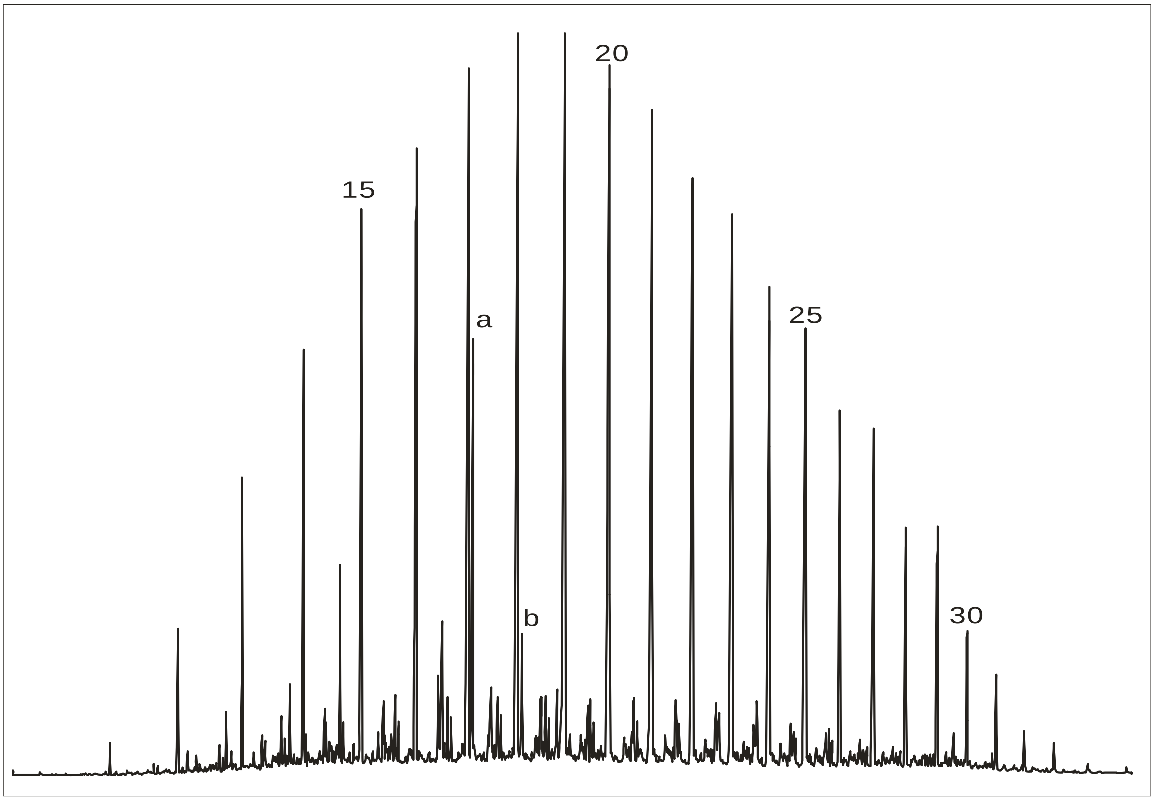


Fig. 2.2.2 Gas Chromatogram, Marraat oil type. Numbers refer to n-alkane Carbon-number, a, b: pristane and phytane, respectively. Note modest degree of front-end evaporation and high proportions of ”waxy n-alkanes” ($nC_{22+}$)

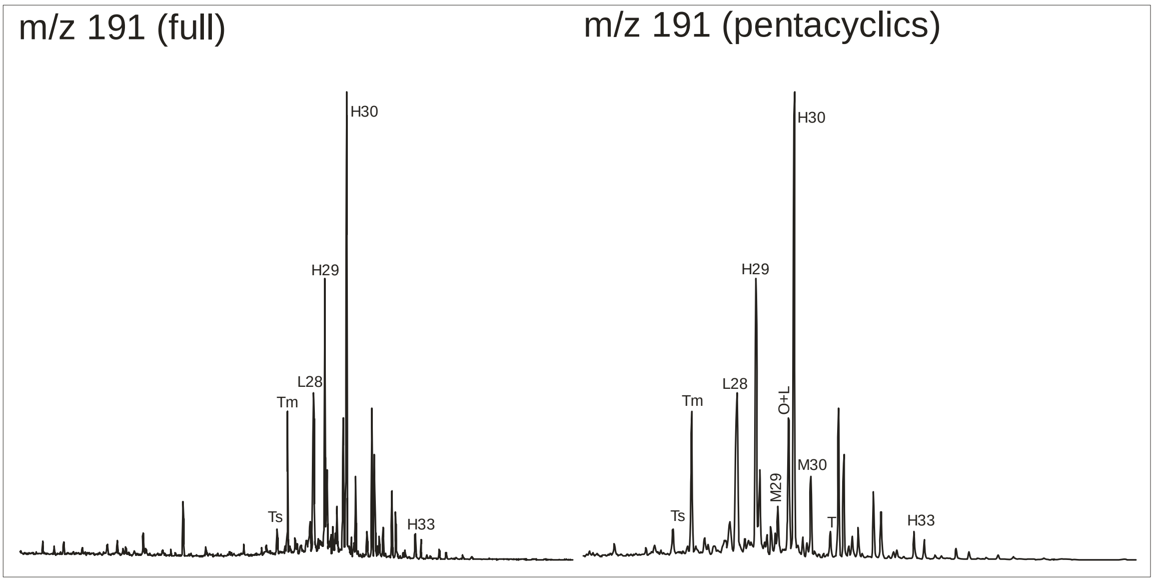


Fig. 2.2.3. M/z 191 ion fragmentogram, Marraat oil type. Left: fullsize, note near absence of tricyclic terpanes. Right: pentacyclics enlarged, note abundant angiosperm higher landplant markers such as oleanane and lupane (O+L, coeluting see Nytoft et al. 2002), bisnorlupanes (L28) and taraxastane (T).

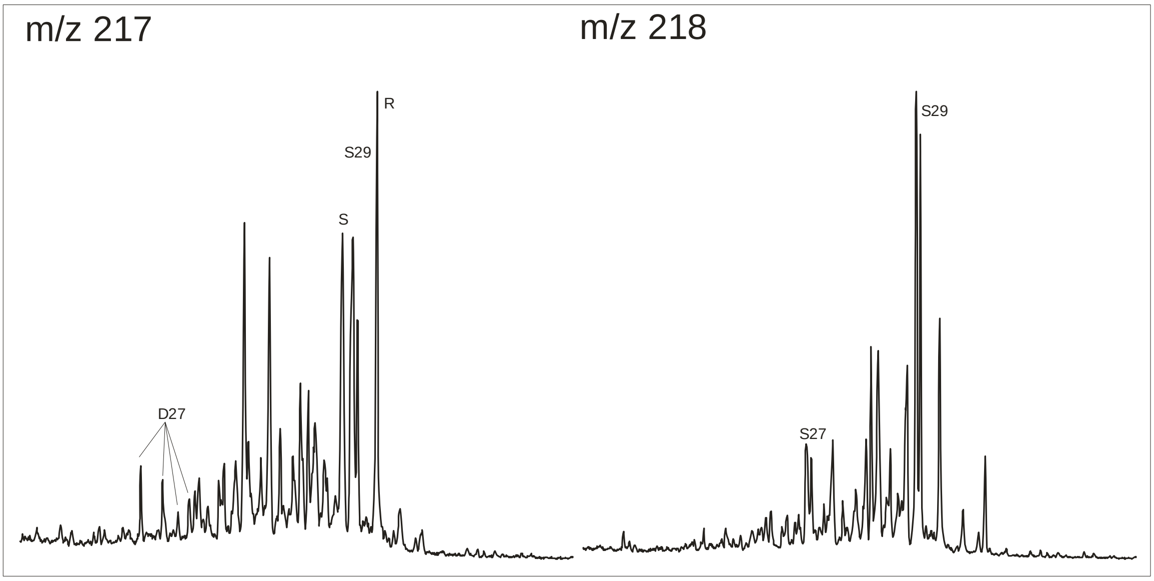


Fig. 2.2.4. Left: m/z 217 ion fragmentogram, Marraat oil type. Note predominance of $C_{29}$ regular steranes (S29), moderate proportions of diasteranes (D27, $C_{27}$-diasteranes) and absence of $C_{30}$ n-propylcholestanes. The level of thermal maturity as indicated by the $S_{29}$ (S/S+R) epimer ratio is relatively low. Right: m/z 218 ion fragmentogram. The predominance of $C_{29}$-steranes relative to $C_{27}$- and $C_{28}$- steranesis expressed even more clearly than by the m/z 217 fragmentogram.

## 2.2.3. Distribution:

The Marraat oil is observed plugging available porosity in numerous basalt layers in the Marraat-1, the GANW-1, and the GANE-1 wells. Furthermore, abundant in surface seeps over the Marraat area, and filling pores, cracks, and veins in  specific basalt beds, which may be followed for several kilometers along strike. I addition, surface seeps of the Maraat oil-type have been recorded on the north coast  of Disko, on Hareøen and on a small skerry off the coast of Hareøen (fig. 2.2.5). Moreover, some seeps may consist predominantly of Marraat-type oil mixed with variable proportions of other oil types. The Maraat-type oil and mixtures are usually not biodegraded, although front-end evaporation may be prominent. When biodegradation is observed the level is generally modest.

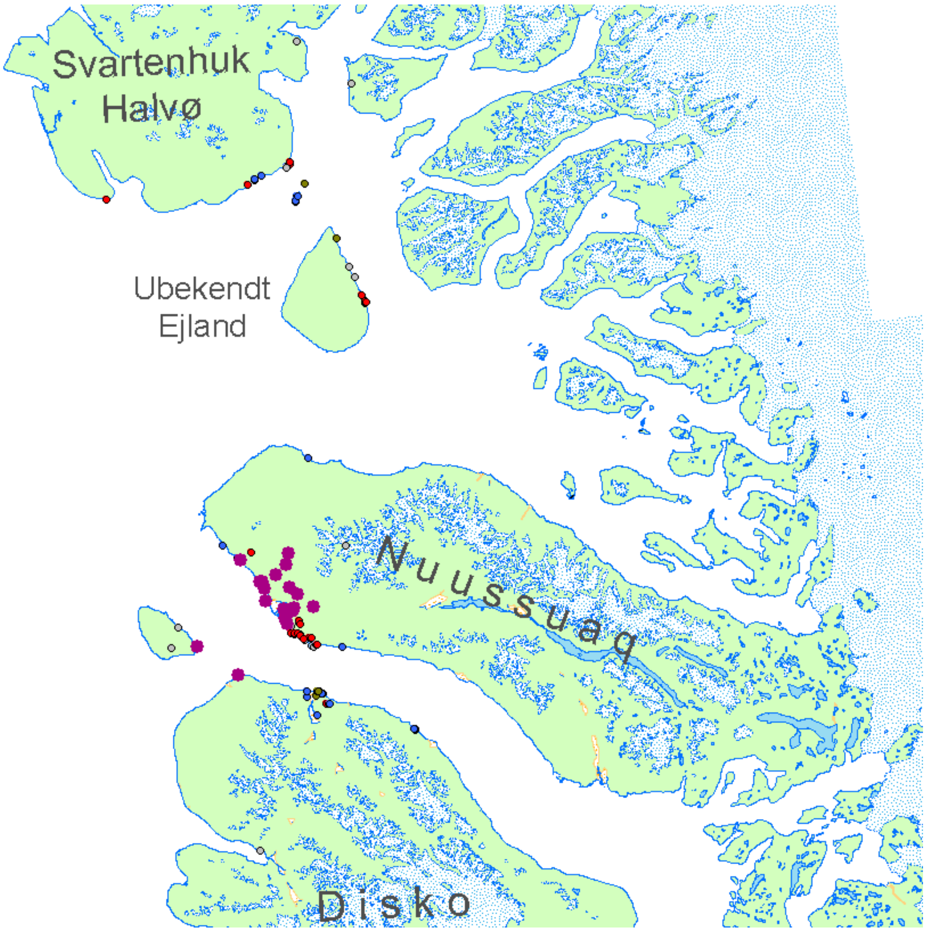


Fig. 2.2.5. Distribution of the Marrat oil type (purple highlighting, mixtures not included)

## 2.2.4. Interpretation:

The Marraat oil-type is a typical “deltaic oil”, generated from sediments containing abundant terrigenous organic debris. Although the generative kerogen is predominantly terrigenous, the source rock is a marine deposit, Based the presence of oleanane, lupane, bisnorlupanes, and taraxastane, the source rock is not likely to predate the latest part of the Upper Cretaceous. A close correlation to extracts of thermally immature Paleocene-age shales drilled by the GRO#3 well near the south coast of Nuusuaq suggests generation from lateral equivalents in more deeply buried kitchen areas, possibly situated in subbasins in the western Vaigat and Maligat area, the existence of which is suggested by interpretation of seismic and gravimetric data. The age-equivalent Reindeer Supersequence is acknowledged as a source for oil in the Beaufort MacKenzie area (Arctic Canada), and the Paleocene shales of Central West Greenland seem very similar in quality (fig. 2.2.6).

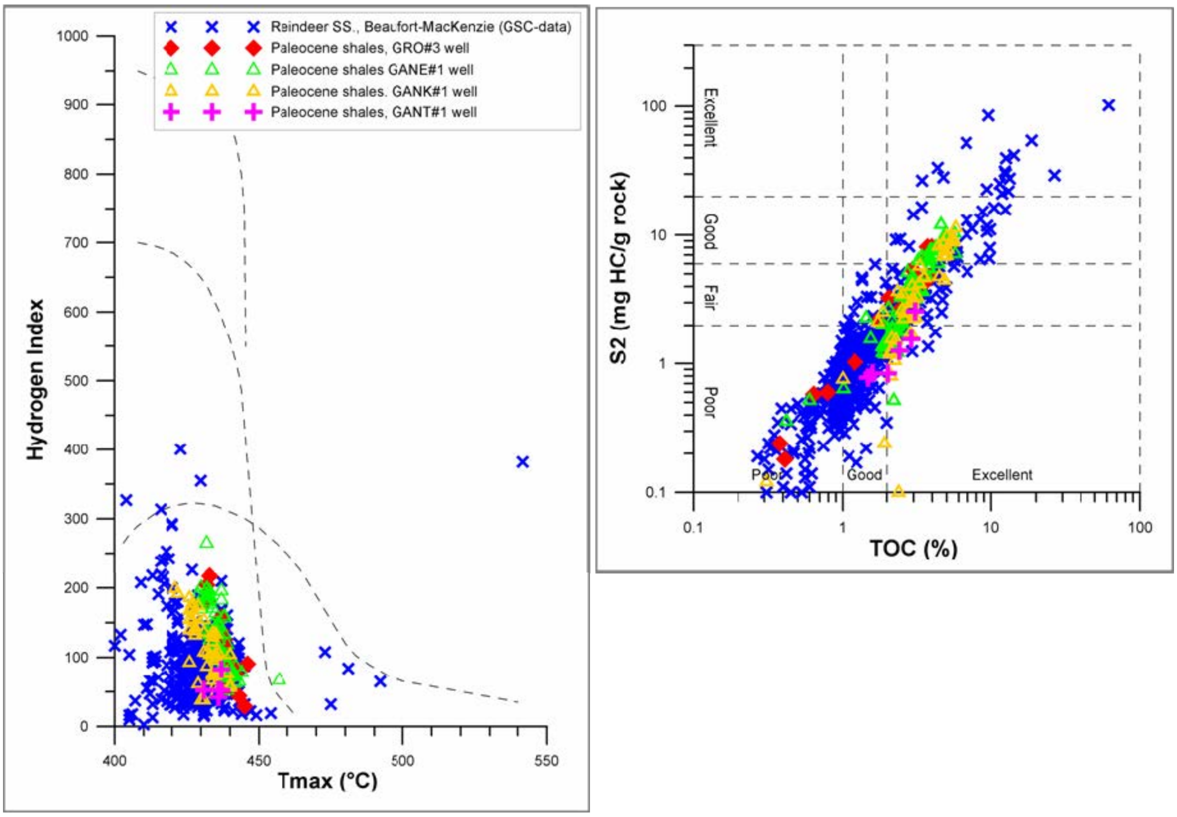


Fig. 2.2.6. Rock-Eval/TOC screening data for Palecene shales from West Greenland (Marraat oil type source rocks) compared to data on age-equivalent shales of the Reindeer Supergroup of Canada (data on the Reindeer Supergroup compiled from various publicatiuons issued by the Geological Survey of Canada)

## 2.2.5. Implications for exploration in the offshore

The Maarrat oil type and mixed oils containing contributions from oils similar to the Marraat type are widely distributed in central West Greenland. Including such mixed oils, Marraat oil type seepages can be traced over an area of roughly 50 by 150 kilometres, suggesting that the. Marraat oil source rock or equivalent deposits are distributed over a similarly large area. Hence, the common notion that West Greenland is exclusively gas prone is thoroughly discredited since all available evidence points to an oil prone source rock in the Paleocene. In this respect the region differs from the Labador shelf where the Markland Formation is regarded as predominantly gas-prone. In a wider perspective, the widespread occurrence of Marraat-type or Marraat-like oils suggests that regional conditions during the Paleocene were conducive to the deposition of oil-prone deltaic source rocks in the northern part of the present-day Davis Strait. Hence, similar source rocks may exist elsewhere in the region.

## *2.3. Eqalulik type*

**Key references:** Christiansen et al. (1996); Bojesen-Koefoed et al. (1997, 1999), Nytoft et al. (2000)

### 2.3.1. General

The Eqalulik oil type owes its name to the place where the GANE-1 well (GANE-1: **G**røn**A**rctic **N**uussuaq **E**qalulik**-1**) was drilled since the Eqalulik oil type is only known in its "pure state" from staining in sandstones in the deepest of this well (approximately 600-700 metres). Gas was flared off from the same depth during drilling. The Eqalulik oil type shows unique compositional characteristics, that allow the detection of even minute contributions of this oil type to other oils. Hende while the oil is only known in its pure state from the GANE-1 well, mixtures with other oils are fairly widespread.

### 2.3.2. Characteristics:

The Eqalulik oil-type is a highly unusual and easily recognizable oil-type. The wax content is but moderate, but the oil is rich in acyclic isoprenoids, sesquiterpanes, and pentacyclic triterpane and sterane biomarkers. Pristane/phytane ratios are variable, 1.3-4. Unresolved Complex Mixture (UCM) is not very prominent, but shows a bimodal distribution with maxima in the sesquiterpane and the triterpane regions (fig. 2.3.1). Tricyclic triterpanes are virtually absent. The distribution of pentacyclic triterpanes is characterized by presence of appreciable proportions of 28,30-bisnorhopane as well as a homologous series of hitherto unknown extended 28-norhopanes, with may be monitored in the m/z 355 ion fragmentogram. Angiosperm-derived biological markers such as oleanane, lupane, taraxastane, etc. are not detected. Extended hopanes show a remarkable distribution comprising a very minor decrease in abundance from $C_{31}$ to $C_{33}$, followed by a sudden decrease from $C_{33}$ to $C_{34}$, and a slight decrease from $C_{34}$ to $C_{35}$ (Fig. 2.3.2). Regular steranes are very scarce, but $C_{28}$ ring-A methylated steranes are very abundant and hamper evaluation of the distribution of regular steranes by the m/z 217 and 218 ion fragmentograms. Diasteranes are scarce (fig. 2.3.3).

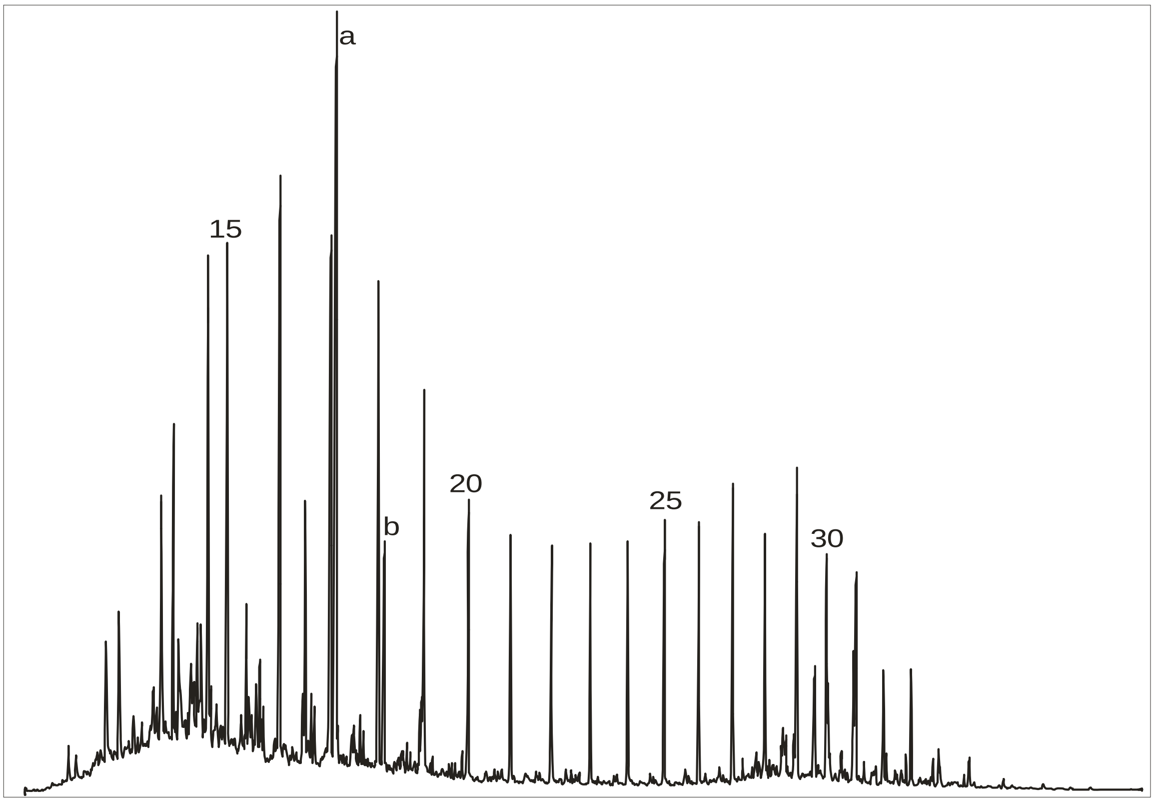


Fig. 2.3.1 Gas Chromatogram, Eqalulik oil type. Numbers refer to n-alkane Carbon-number, a, b: pristane and phytane, respectively. Note unusual n-alkane distribution and bimodaldistribution of UCM

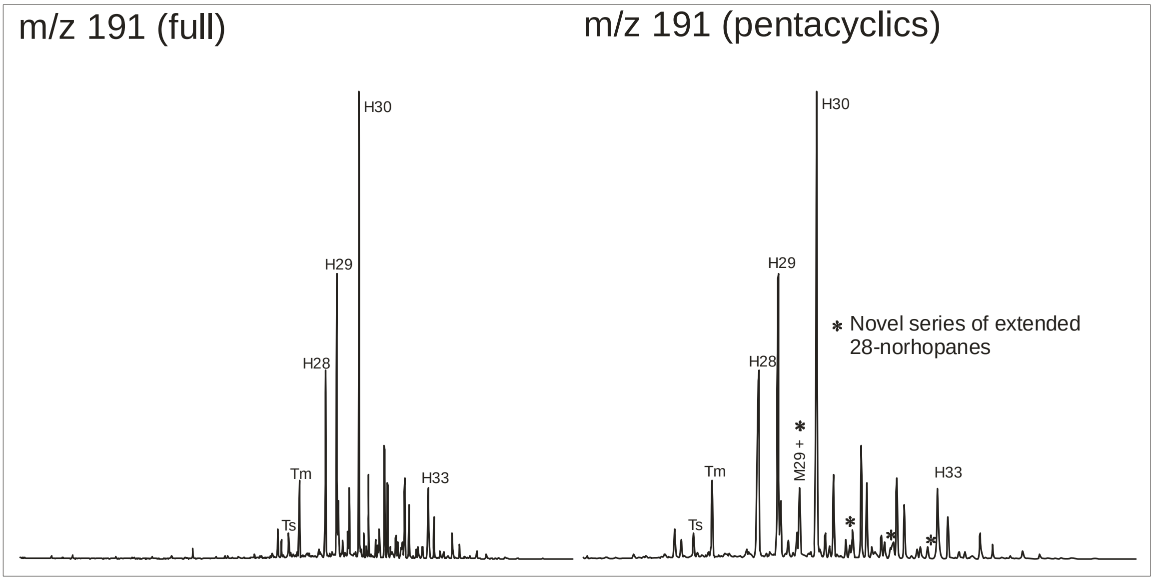


Fig. 2.3.2. M/z 191 ion fragmentogram, Eqalulik oil type. Left: fullsize, note absence of tricyclic terpanes. Right: pentacyclics enlarged, note absence of angiosperm higher landplant markers and presence of previously unknown series of extended 28-norhopanes (indicated by asterisks, Nytoft et al. 2000).

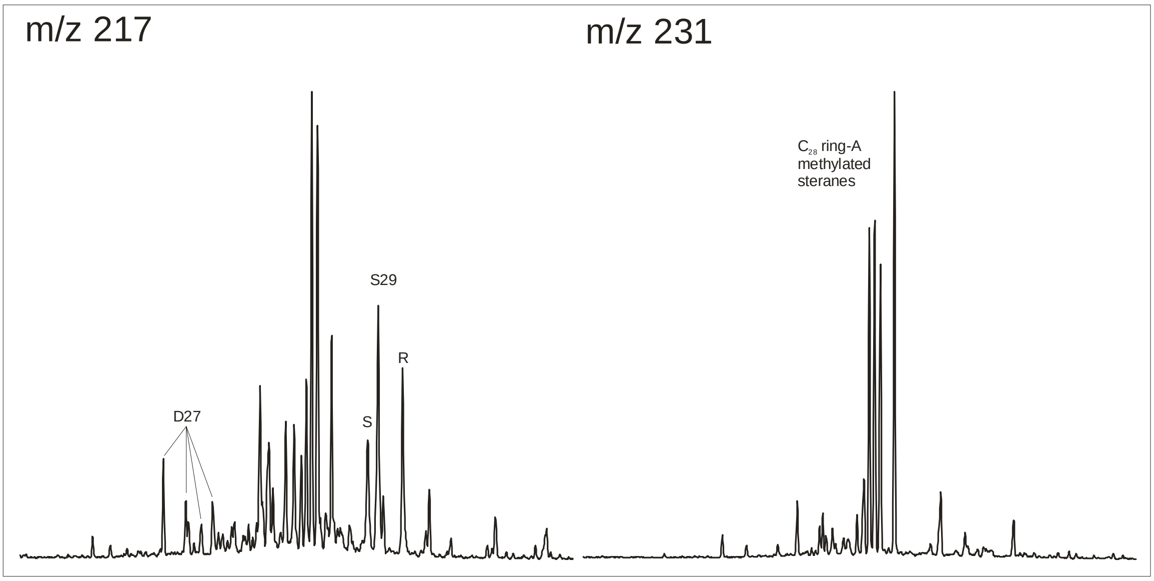


Fig. 2.3.3. Left: m/z 217 ion fragmentogram, Eqalulik oil type. Note very low concentrations of regular steranes and diasteranes, more or less masked by overwhelmingly abundant C28-methyl-steranes. Right: m/z 218 ion fragmentogram. The predominance of $C_{28}$-methylsteranes is striking.

## 2.3.3. Distribution:

In its pure state, the Eqalulik oil-type is only known from sandstones of the Agatdalen Formation (Dam et al. 2009) in the deepest interval of the GANE-1 well on Nuussuaq, where it occurs separated from the Marraat-type oil, which is present in the upper parts of the succession penetrated by the well (fig. 2.3.4). Mixtures of the Marrraat-oil type and the Eqalulik oil-type in varying proportions are found as surface seeps in a comparatively well-defined and confined area west of the Niaqornarssuk areas on the south coast of Nuussuaq, but the Eqalulik oil type can also be traced in oil seepages further to the north on Ubekjendt Ejland and Svartenhuk Halvø.

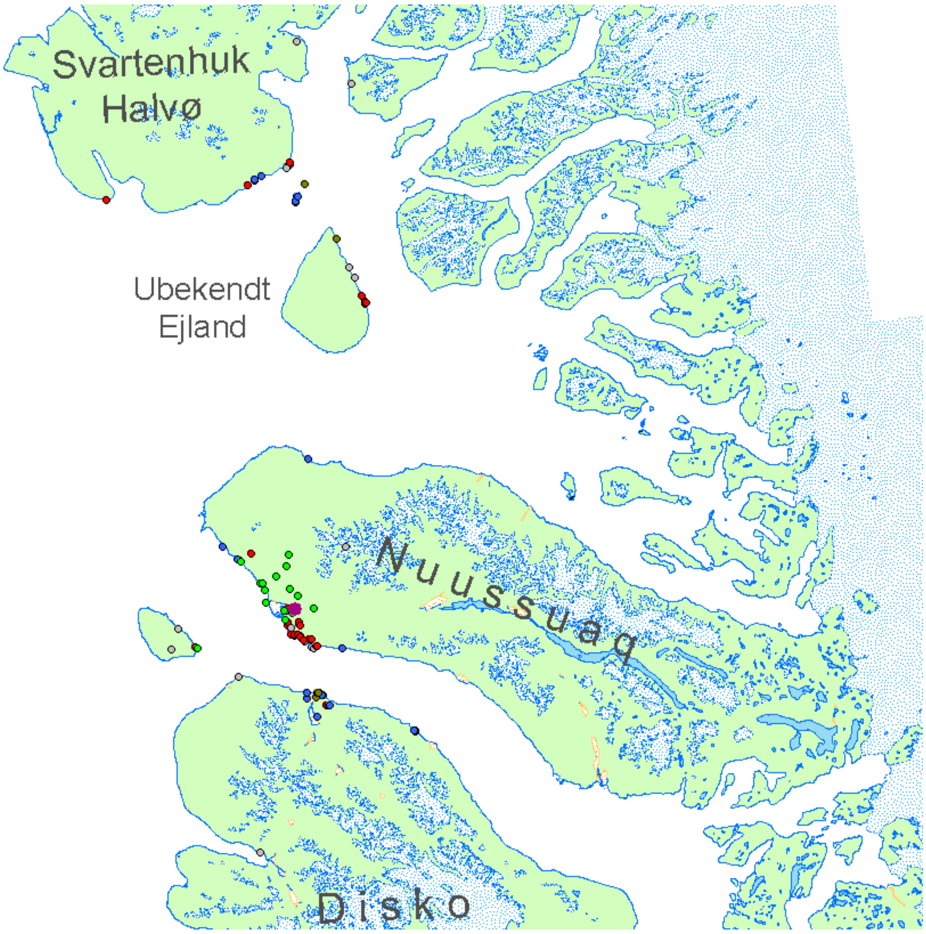


Fig. 2.3.4. Distribution of the Eqalulik oil type (purple highlighting, mixtures not included)

## 2.3.4. Interpretation:

The origin of the Eqalulik oil-type is enigmatic. 28,30-bisnorhopane is generally held to indicate deposition under highly anoxic marine conditions (e.g. Volkman 1986, 1988), but the significance of the unusual series of extended 28-norhopanes characteristic of the Eqalulik oil (Nytoft et al.,2000) is not known. Ring-A methylated steranes are held to be associated with microalgae, and may be found in sediments of both freshwater, normal marine and hypersaline environments. Occasionally, these compounds are particularly abundant in lacustrine deposits, and usually a distribution comprising predominance of the $C_{29}$ and $C_{30}$ and inferior proportions of $C_{28}$ homologoues is observed (Fu Jiamo 1990). However, a distribution comprising exclusively $C_{28}$ homologoues has to the best of our knowledge not been described before. Although, these compounds are probably mainly derived from algae, precursors of $C_{28}$ 4-methyl-steranes have been observed in the methane-oxidizing bacterium *Methylococcus capsulatus* (Bouvier et al. 1976). Nothing conclusive can be said about the origin of the Eqalulik oil-type. Previously a saline lacustrine/lagunal origin was favoured, but the relative abuncdance of traces of the Eqalulik oil type in other seepage oils seems to make this interpretation less attractive. Based on the total absence of angiosperm higher land plant markers, the age of the source rocks is probably not younger than the Santonian.

## 2.3.5. Implications for exploration in the offshore

The Eqalulik oil type may at present be viewed upon as a curiosity of limited significance for exploration. The imperfect understanding of the origin of the oil type precludes assessment of its potential importance for exploration.

## *2.4. Niaqornaarsuk type*

**Key references:** Christiansen et al. (1996); Bojesen-Koefoed et al. (1997, 1999)

### 2.4.1. General

The Niaqornaarsuk (a.k.a.Niaqornarssuq) oil type owes its name to the place on the south coast of Nuussuaq where the oil type is found. Note that "Niaqornaarsuk" is a commonly used name for small capes or promontory-like features on the coast.

### 2.4.2 Characteristics:

The Niaqornarssuq oil-type is a high-wax oil, rich in long-chain normal alkanes and saturated components in general. Pristane/phytane ratios are moderate, generally 2.6-3.8, and acyclic isoprenoids are scarce. Unresolved Complex Mixture (UCM) is largely absent (fig. 2.4.1). Tricyclic triterpanes are very scarce relative to pentacyclics, but a $C_{24}$ tetracyclicterpane is comparatively prominent. The distribution of pentacyclic triterpanes is characterized by presence of both significant proportions of 28,30-bisnorhopane and small proportions of angiosperm-derived biological markers such as coeluting oleanane and lupane. However, bisnorlupanes and taraxastane are not observed. Norhopane is but slightly less abundant than hopane. Extended hopanes decrease rapidly in abundance with increasing carbon number along a distinctly concave-up trend (fig. 2.4.2). Regular steranes are strongly dominated by $C_{29}$-components. $C_{30}$-steranes are not detected. Diasteranes are approximately equally abundant as regular steranes. Hopane to sterane ratios are variable, estimated at 2-10.

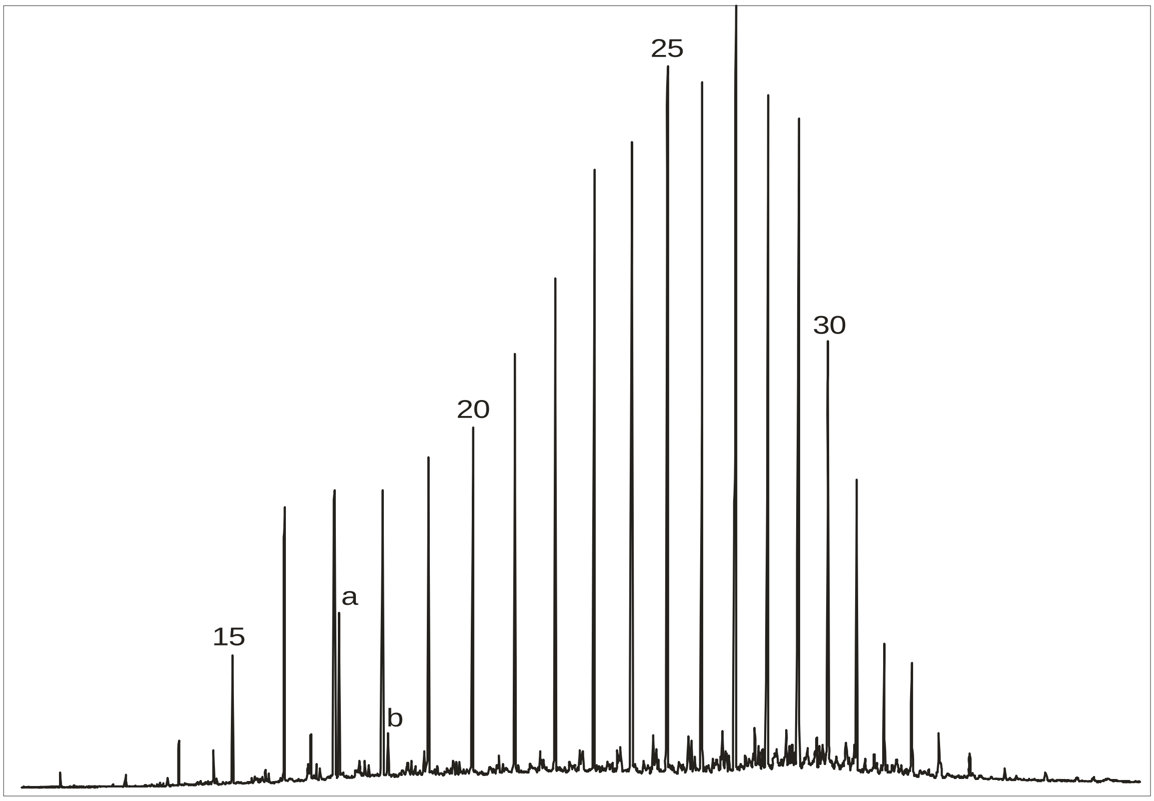


Fig. 2.4.1 Gas Chromatogram, Niaqornaarsuk oil type. Numbers refer to n-alkane Carbon-number, a, b: pristane and phytane, respectively. Note front-end evaporation and high abundance of ”waxy” ($nC_{22+}$) n-alkanes

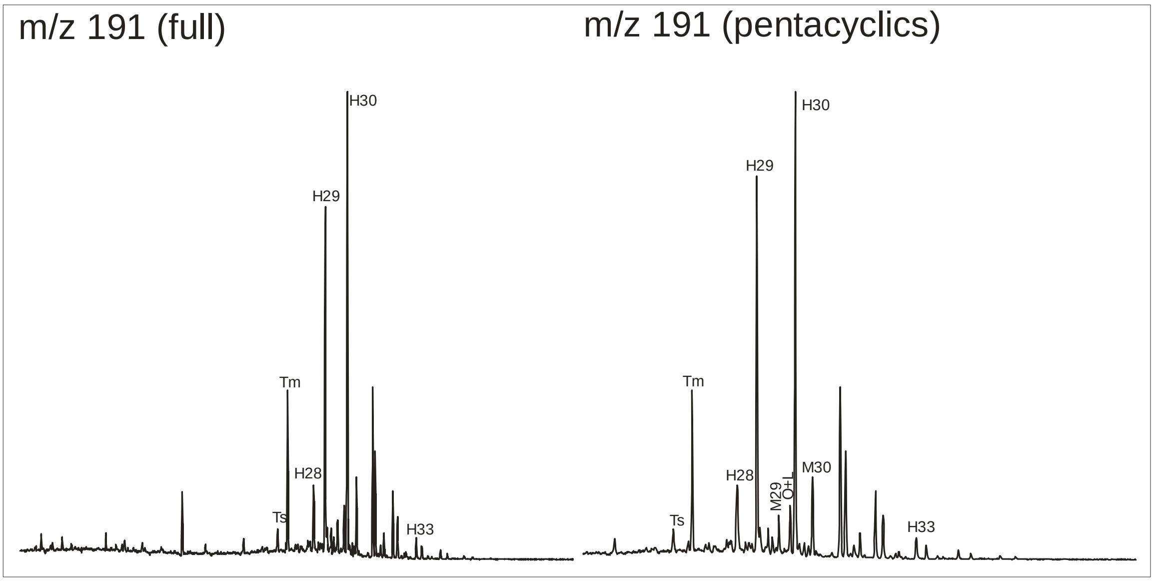


Fig. 2.4.2. M/z 191 ion fragmentogram, Niaqornaarsuk oil type. Left: fullsize, note near-absence of tricyclic terpanes relatively high concentrations of a $C_{24}$-tetracyclic terpane (largest peak left of ”Ts”). Right: pentacyclics enlarged, note presence of angiosperm higher landplant markers oleanane and lupane (O+L) and absence of their demethylated derivatives in combination with relatively high concentrations of 28,30-bisnorhopane and absence of extended 28-norhopanes.

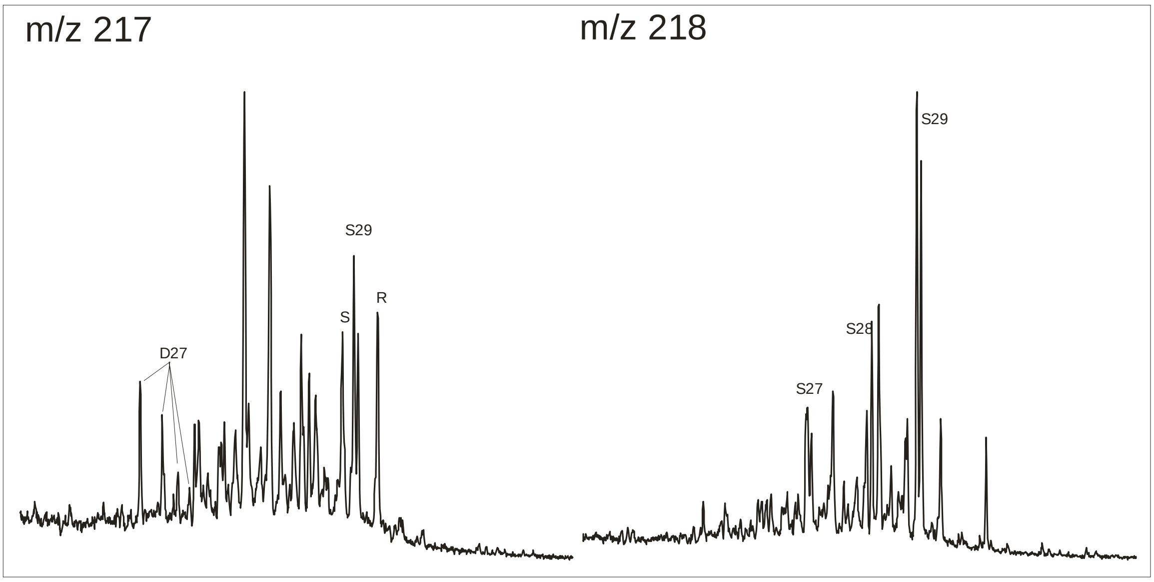


Fig. 2.4.3. Left: m/z 217 ion fragmentogram, Niaqornaarsuk oil type. Note strong predominance of $C_{29}$ regular steranes (S29), relatively high proportions of diasteranes (D27, $C_{27}$-diasteranes) and absence of $C_{30}$ n-propylcholestanes. Right: m/z 218 ion fragmentogram. The predominance of $C_{29}$-steranes relative to $C_{27}$- and $C_{28}$- steranes is expressed even more clearly than by the m/z 217 fragmentogram.

## 2.4.3. Distribution:

The Niaqornarssuk oil-type is found as surface seeps in a small fracture or fault-zone area west of the Kuugannguaq-Qunnilik fracture-zone near Niaqornaarsuk on the south coast of Nussuaq (fig. 2.4.4). However, one sample from the GANT-1 well in the northern/central part of Nuussuaq yields a biomarker distribution closely resembling that of the seeps at Niaqornaarsuk. Mixtures with a recognised Niaqornaarsuk oil type contribution are scarce.

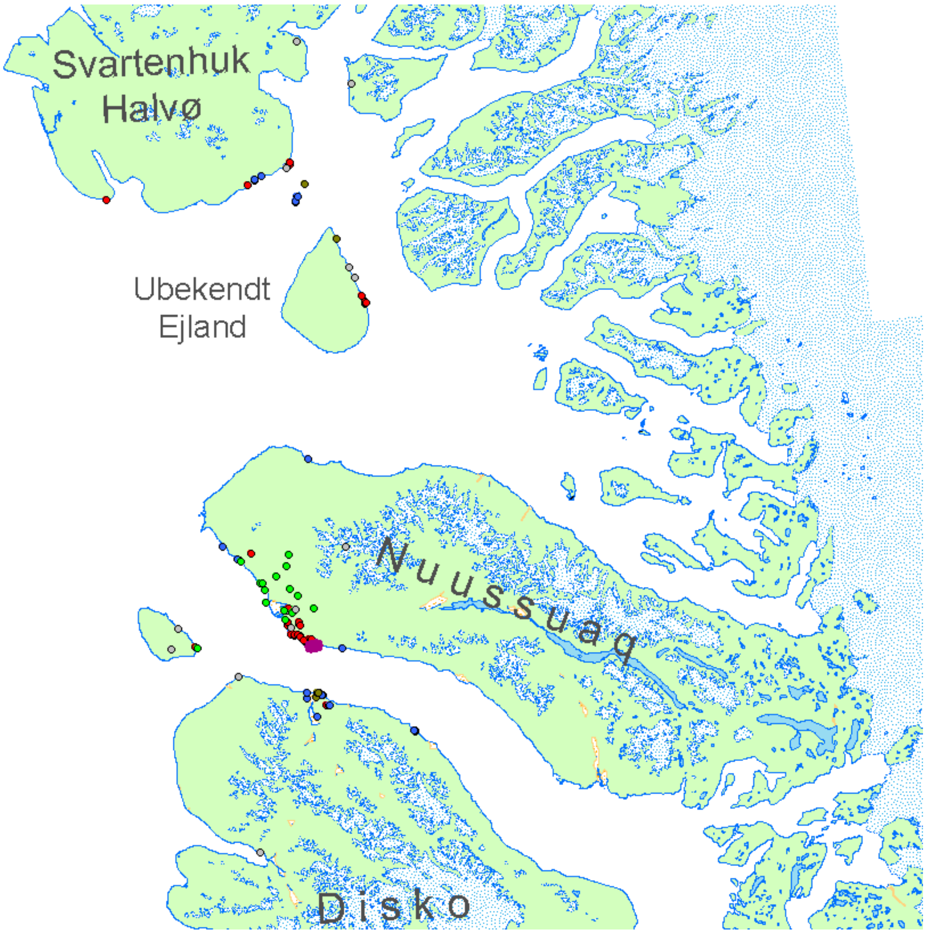


Fig. 2.4.4. Distribution of the Niaqornaarsuk oil type (purple highlighting, mixtures not included)

## 2.4.4. Interpretation:

The Niaqornaarsuk oil type was probably generated by a deltaic source rock, *i.e.* a marine shale source-rock, which contain high proportions of terrigenous organic matter. Based on a close correlation of biological marker characteristics of Niaqornaarsuk seep oils and solvent extracts of Campanian-age shales sampled in the GANT-1 well, generation from such deposits is suggested. These Campanian-age shales are otherwise thermally immature where they may be accessed, but presumably the deposits have locally reached oil-window maturity near the fault-zone at Niaqornaarsuk where the oil type is found.

## 2.4.5. Implications for exploration in the offshore

The Niaqornaarsuk oil type may at present be viewed upon as having limited importance for exploration in the offshore. Although the same line of reasoning followed for the Marraat oil type source rock may be employed with respect to the Niaqornaarsuk oil type source rock, the scarcity of oil stains with a Niaqornaarsuk-type signature suggests that the source rock is restricted in distribution. Hence, although the existence of Campanian age deltaic source rocks in the offshore cannot be ruled out, the putative existence of such deposits cannot form the basis of exploration until their presence is eventually demonstrated by drilling.

# *2.5. Kuugannguaq type*

**Key references:** Christiansen et al. (1996); Bojesen-Koefoed et al. (1997, 1999), Petersen et al. (2006)

## 2.5.1. General

The Kuugannguaq oil type owes its name to the place on the north coast of Disko where the oil was initially found and where the oil has its most conspicuous occurrence. “Kuugannguaq” roughly translates into the “the lesser big valley”, and the Kuugannguaq oil type is fairly common on the eastern side of the mouth of the valley.

## 2.5.2. Characteristics:

The Kuugannguaq oil-type is a high-wax oil, rich in long-chain normal alkanes and saturated components in general. Pristane/phytane ratios are moderate, generally 1.4-3.6, occasionally affected by front-end evaporation. Acyclic isoprenoids in general are scarce (fig. 2.5.1). Tricyclic triterpanes are very scarce relative to pentacyclics, but the presence of $C_{24}$ tetracyclic terpane is noted. The distribution of pentacyclic triterpanes is characterized by a moderate predominance of hopane over norhopane, abundant Tm and moretanes. Angiosperm-derived biological markers, 28,30-bisnorhopane, and ring-A methylated steranes are absent. Extended hopanes decrease rapidly in abundance with increasing carbon number along a distinctly concave-up trend (fig. 2.5.2). Regular steranes show a very pronounced predominance by $C_{29}$-components and absence of $C_{30}$-steranes. Diasteranes are generally scarce relative to regular steranes (fig. 2.5.3). Hopane to sterane ratios are high, generally estimated at 10-20.

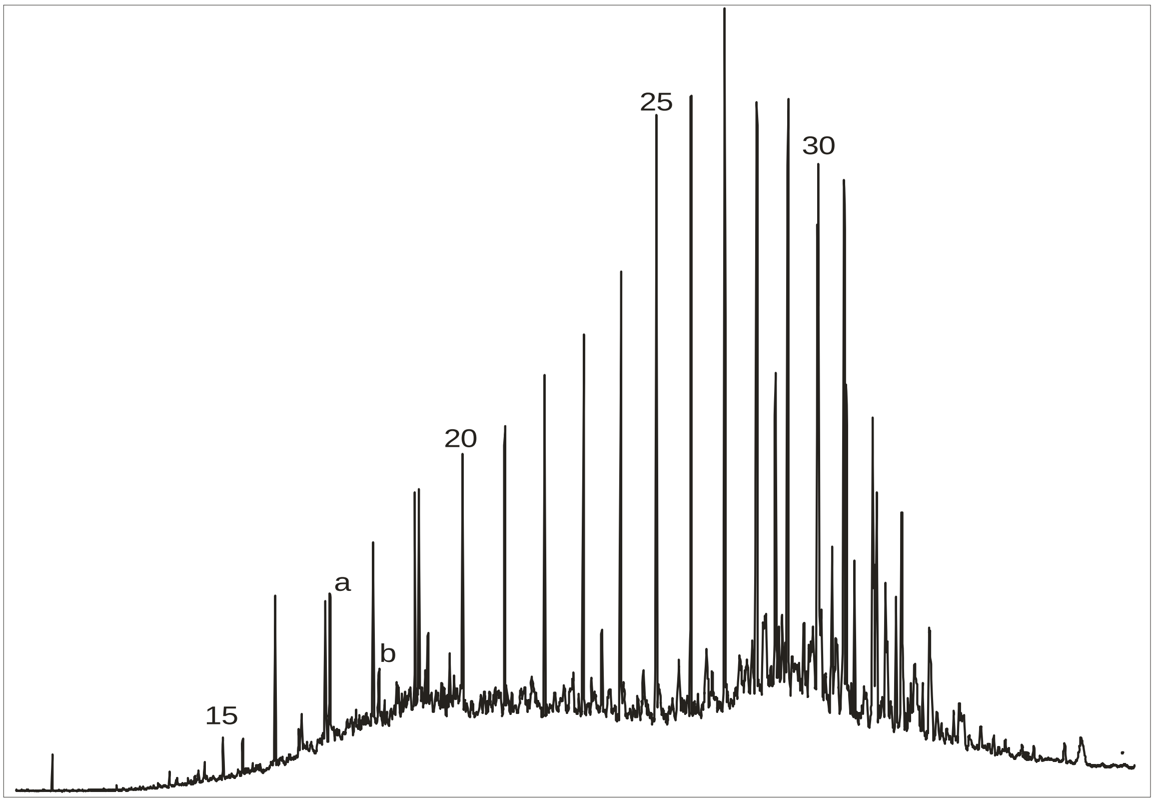


Fig. 2.5.1 Gas Chromatogram, Kuugannguaq oil type. Numbers refer to n-alkane Carbon-number, a, b: pristane and phytane, respectively. Note front-end evaporation and high abundance of ”waxy” ($nC_{22+}$) n-alkanes

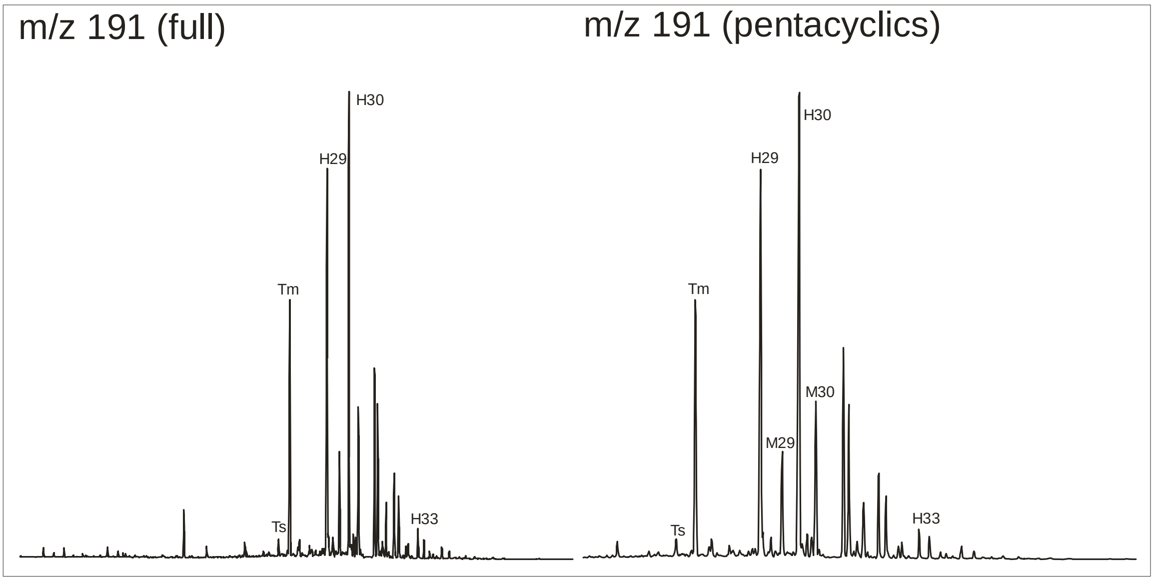


Fig. 2.5.2. M/z 191 ion fragmentogram, Kuugannguaq oil type. Left: fullsize, note near-absence of tricyclic terpanes relatively high concentrations of a $C_{24}$-tetracyclic terpane (largest peak left of ”Ts”). Right: pentacyclics enlarged, note absence of angiosperm higher landplant markers as well as of 28,30-bisnorhopane.

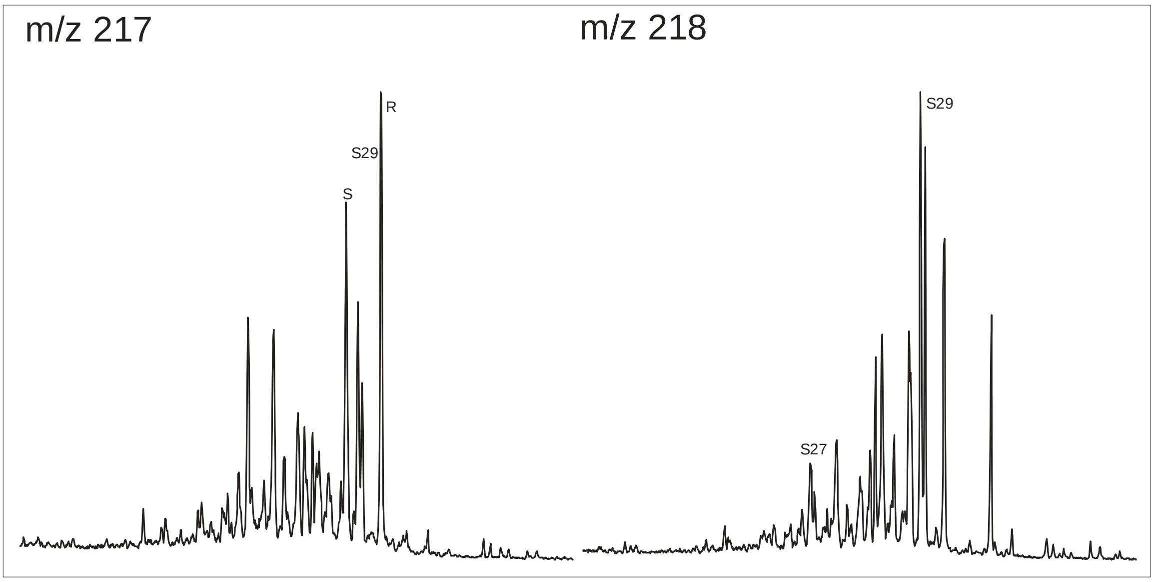


Fig. 2.5.3. Left: m/z 217 ion fragmentogram, Kuugannguaq oil type. Note strong predominance of $C_{29}$ regular steranes (S29), scarcity of diasteranes and absence of $C_{30}$ n-propylcholestanes. Right: m/z 218 ion fragmentogram. The predominance of $C_{29}$-steranes relative to $C_{27}$- and $C_{28}$- steranes is expressed even more clearly than by the m/z 217 fragmentogram.

## 2.5.3. Distribution:

The Kuugannguaq oil-type is found as surface seeps at a few localities east of the Kuugannguaq fault zone, near the mouth of the Kuugannguaq valley on the north coast of Disko (fig. 2.5.4). In addition, a few samples collected in the northern part of the seepage area, *i.e.* Ubekjendt Ejland and Schade Øer, show Kuugannguaq-type characteristics. The Kuuganguaq oil type is principally recognised by negative criteria, *i.e.* a characteristic absence of certain compounds that are present in the other “deltaic” oil types of the area, and mixtures with contributions from the Kuugannguaq oil type may thus be difficult to detect.

## 2.5.4. Interpretation:

The Kuugannguaq oil bears all the characteristics of a terrigenous oil. Due to the absence of any trace of Angiosperm-derived biological markers, the source rock is probably older than the Santonian. Hence, sourcing from coals and carbonaceous shales of the Lower Cretaceous Atane Formation is favoured.

## 2.5.5. Implications for exploration in the offshore

The Kuugannguaq oil type may at present be viewed upon as having limited importance for exploration in the offshore. Although the same line of reasoning followed for the Marraat oil type source rock may be employed with respect to the Kuugannguaq oil type source rock, the scarcity of oil stains with a Kuugannguaq-type signature suggests that the source rock is restricted in distribution. However, it should be noted that a few samples collected in the northern part of the seepage area, *i.e.* Ubekjendt Ejland and Schade Øer, show Kuugannguaq-type characteristics suggesting a relatively wide distribution of a Kuugannguaq-type source rock, and the existence of similar deltaic source rocks in the offshore cannot be ruled out. However, the putative existence of such deposits cannot form the basis of exploration until their presence is eventually demonstrated by drilling.

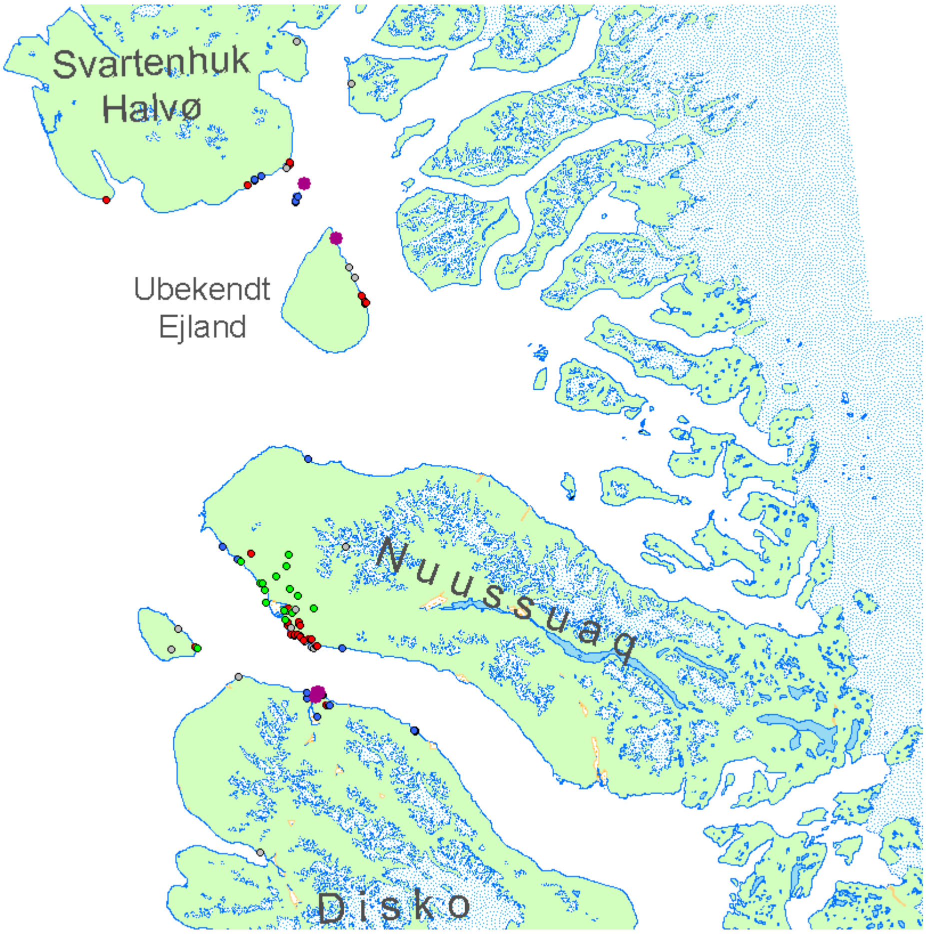


Fig. 2.5.4. Distribution of the Kuugannguaq oil type (purple highlighting, mixtures not included)

## *2.6. Itilli type*

**Key references:** Bojesen-Koefoed et al. (1997a, 1999, 2004, 2007),

### 2.6.1. General

The Itilli oil type owes its name to the Itilli Valley in western Nuussuaq, where the oil was first found.

### 2.6.2. Characteristics:

The Itilli oil-type is a low-wax oil, showing a light end-skewed distribution of n-alkanes. The abundance of long chain n-alkanes decreases rapidly with increasing carbon number along a distinctly "concave-up" trend. Pristane/phytane ratios are variable, 0.8-3.0, and the proportion of acyclic isoprenoids is moderate. However, it should be noted that unusually low values of the pristane/phytane ratios recorded in some samples may be artefacts produced by evaporative losses (fig. 2.6.1). Tricyclic triterpanes are comparatively abundant relative to pentacyclics, and $C_{24}$ tetracyclicterpane is present. The distribution of pentacyclic triterpanes is characterized by the presence of notable proportions of 28,30-bisnorhopane and absence (or near absence) of angiosperm-derived biological markers such as oleanane, lupane, bisnorlupanes and taraxastane. Although presence of relatively high proporstions of 28,30-bisnorhopane is a ditinctive characteristic of the Itilli oil type does not show presence of the series of extended 28-norhopanes that is charcteristic of the Eqalulik oil type (see Nyftoft et al. 2000) Norhopane varies in abundance, probably in response to source facies, from significantly less abundant than hopane to almost equal in abundance. Extended hopanes decrease in abundance with increasing carbon number along a smooth concave-up trend (fig. 2.6.2). Regular steranes are strongly dominated by $C_{27}$-components, and $C_{30}$-steranes are present. Diasteranes are comparatively abundant relative to regular steranes (fig. 2.6.3).

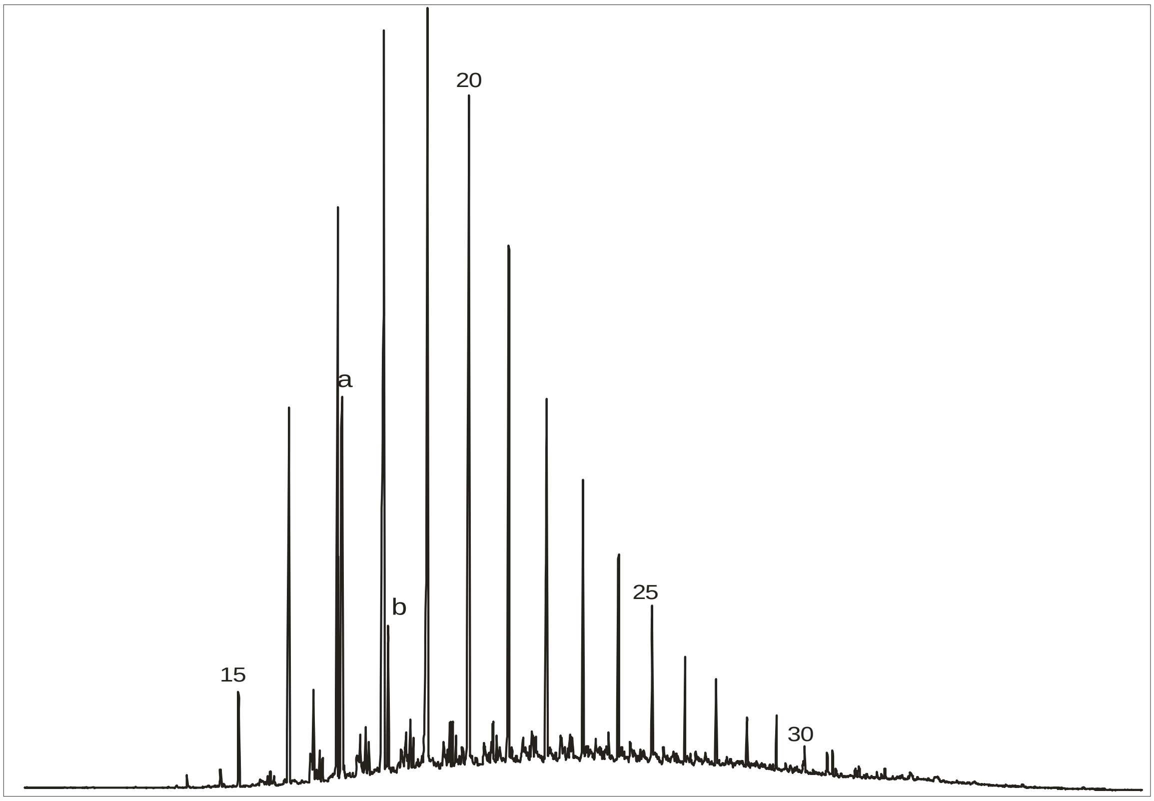


Fig. 2.6.1 Gas Chromatogram, Itilli oil type. Numbers refer to n-alkane Carbon-number, a, b: pristane and phytane, respectively. Note front-end evaporation and light-end skewed, low-wax distribution of n-alkanes

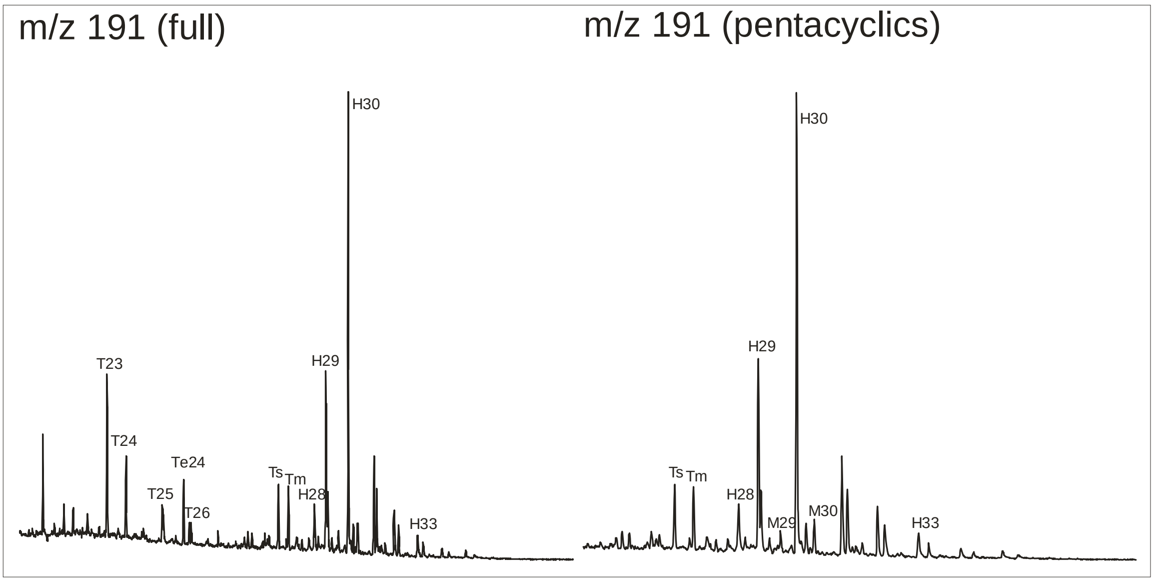


Fig. 2.6.2. M/z 191 ion fragmentogram, Itilli oil type. Left: fullsize, note high abundance of tricyclic terpanes relatively high concentrations of a $C_{24}$-tetracyclic terpane (Te24). Right: pentacyclics enlarged, note abundant 28,30-bisnorhopane (H28) and absence of extended 28-norhopanes known from the Eqalulik oil.

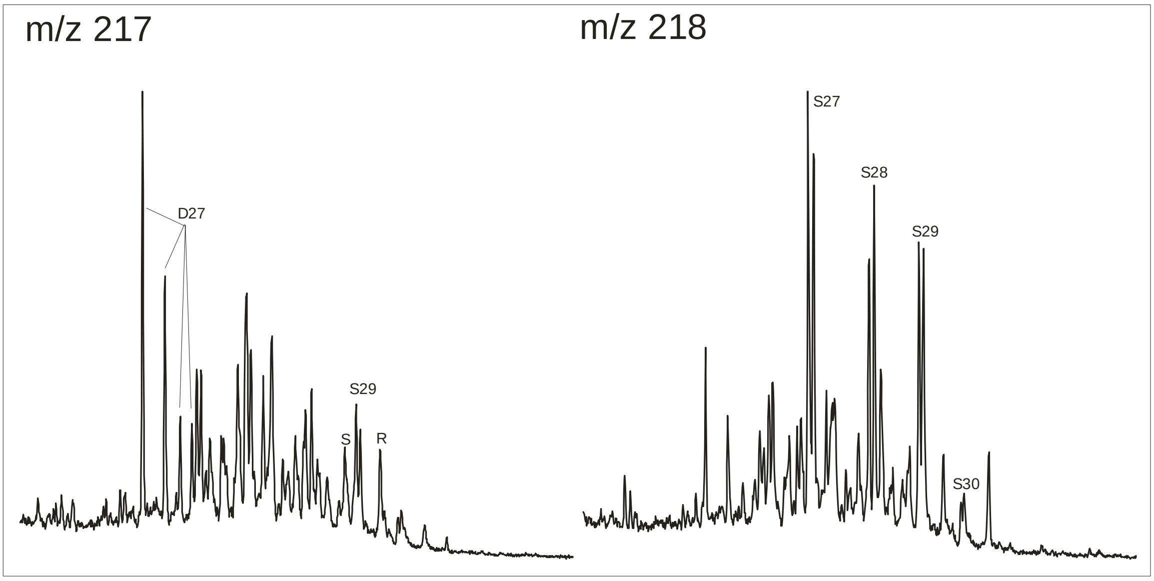


Fig. 2.5.3. Left: m/z 217 ion fragmentogram, Itilli oil type. Note strong predominance of $C_{27}$ regular steranes (S27), abundance of diasteranes and presence of $C_{30}$ n-propylcholestanes. Right: m/z 218 ion fragmentogram. The predominance of $C_{27}$-steranes relative to $C_{28}$- and $C_{29}$-steranes is expressed even more clearly than by the m/z 217 fragmentogram.

## 2.6.3. Distribution:

Seepages of the Itilli oil-type are widespread, but the individual samples generally only show traces oil. Hence, samples showing Itilli oil type characteristics are known from Disko and Nuussuaq northwards to Svartenhuk Halvø via Ubekjendt Ejland and Schade øer (fig. 2.6.4). The low concentration of oil in the samples is related to the most common mode of occurrence displayed by the Itilli oil, which contrasts markedly with that of the other oil types observed in the region. The Itilli oil type is generally associated with carbonate veins in the basalts and carbonate fillings along dyke contacts, in which the oil is found as minute inclusion in the carbonates. Occasionally a slight brownish tinge can be observed in the carbonate that is tentatively attributed to oil inclusions. An exception to this is the seepages at Asuk on the north coast of Disko, where a biodegraded facies-variety of the Itilli oil is found in sands of Albian-Cenomanian age. The Asuk seepages have been extensively discussed by Bojesen-Koefoed et al. (2004, 2007).

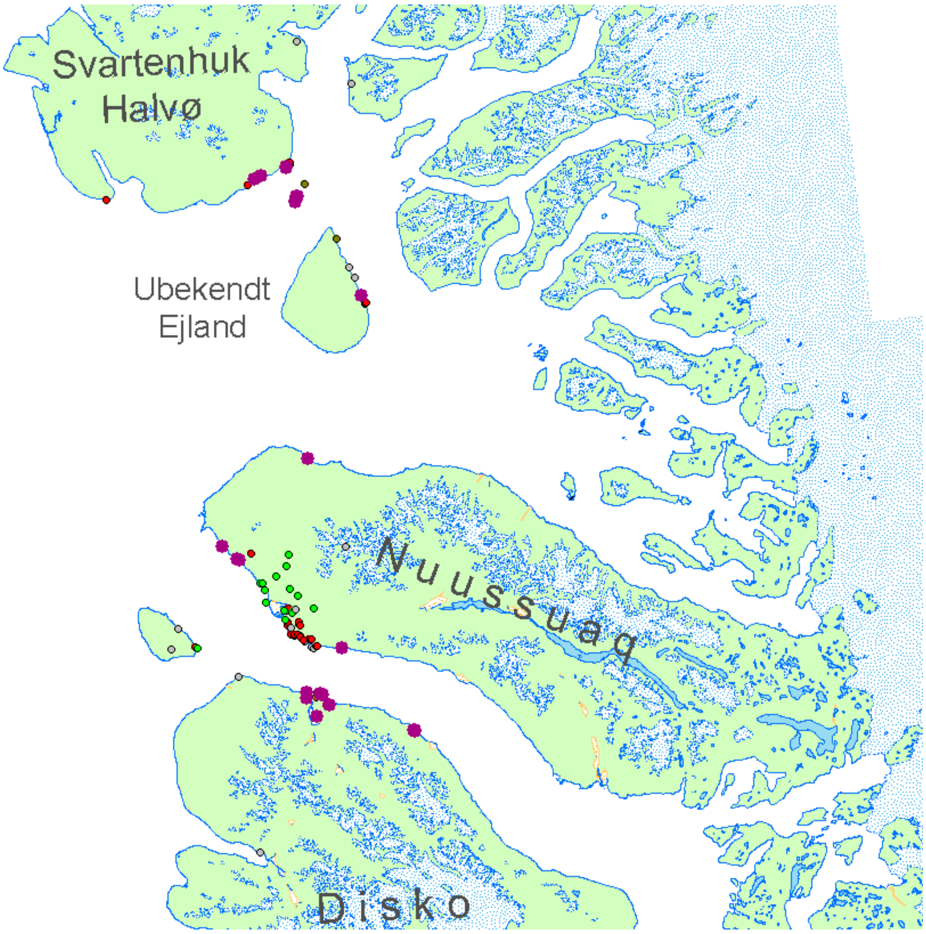


Fig. 2.6.4. Distribution of the Itilli oil type (purple highlighting, mixtures not included)

## 2.6.4. Interpretation:

The Itilli oil-type bears all the characteristics of an oil generated from a marine black shale source rock. No obvious source-rock candidates are known from the area, but the Cenomanian-Turonian-age Bituminous Member (informal) of the Kanguk Formation on Ellesmere Island, arctic Canada, contains rich marine source rocks with characteristics comparable to the assumed Itilli source rock (Nunez-Betulu 1993, 1994, Bojesen-Koefoed et al. unpubl. manuscript). The Umiivik stratigraphic corehole on Svartenhuk Halvø penetrated a thick succession of organic-rich marine Turonian-age shales that due to excess heating by a number of magmatic intrusions did not lend themselves to organic geochemical analyses that would allow assessment of their original petroleum potential and biological marker signature (Dam 1997; Dam et al. 1998; Nøhr-Hansen 1997; Christiansen et al. 1997a). However, samples showed very high concentrations of wet hydrocarbon gases, and analyses of mixed layer clays including ammonium-illites in samples of the shales demonstrate that petroleum

generation did indeed take place during the course of maturation of the deposits, thus providing circumstantial evidence for an original petroleum potential (Drits et at. 2005; 2007). Biological marker evidence, including age-specific markers suggest an origin of the Itilli oil type from a Cretaceous age source rock, and Cenomanian-Turonian marine shales equivalent to those known from the Kanguk Formation on Ellesmere Island or perhaps Cretaceous-age deposits that are slightly older are favoured as candicates for an Itilli oil type source. Although such deposits have not been sampled in the region, their widespread presence can reasonably be assumed. This assumption is further substantiated by data from Baffin Island and Bylot Island, see section 3.1 below. In addition, Cenomanian–Turonian source rocks are known from the Canadian arctic as well as from the “Cretaceous Western Interior Seaway” (CWIS) of the United States and Canada (Feinstein et al. 1988; Pancost et al. 1998; Bojesen-Koefoed and Nytoft 2003). Conceivably a marine connection to a “proto-Davis Strait” existed during the Cretaceous, either to the North or through the Hudson Bay, or perhaps even both ways (Bojesen-Koefoed et al 2004; White et al. 2000).
Although the Itilli oils bear notable similarity to Upper Jurassic oils generated Kimmeridge Clay Formation-type source rocks, the presence of Upper Jurassic source rocks in Central West Greenland is considered unlikely for paleogeographic reasons.

### 2.6.5. Implications for exploration in the offshore

The Itilli oil type and its wide distribution prove the existence of a marine shale source rock in the region, and with any likelihood this source rock is indeed present in the offshore. Its detailed distribution, thichkness and petroleum potential are, however, unknown and this lack of knowledge adds to the source rock risk associated with exploration in the offshore. However, a marine shale source rock of Aptian to Turonian age is still the most important candidate for a regionally distributed oilprone source rock.

## *2.7. Mixtures*

Mixed oils, *i.e.* oils in which contributions from two or more of the established oil types from west Greenland can be recognised are common (fig. 2.7.1).

Mixtures of the Marraat and Eqalulik oil types are fairly common over a large part of the region and in the area east of Marraat, a tentative mixing trend may even be seen.

Mixtures of the Itilli and Eqalulik oil types are also fairly common, notably on the east coast of Ubekjendt Ejland.

Other mixed oils combinations include Itilli/Marraat, and Niaqornaarsuk/Eqalulik.

In addition to regular mixtures, oils that show “migration contamination” are sometimes observed. For instance a number of Itilli oil samples from the north coast of Disko may show notable discrepancies with respect to thermal maturity based on sterane 20S/(20S+20R) epimer ratio when calculated for $C_{27}$ and $C_{29}$ steranes, respectively. Hence, the sterane epimer ratio may suggest significantly higher level of thermal maturity when calculated for $C_{27}$ steranes than when calculated for $C_{29}$ steranes in the same sample. This corresponds to migration contamination of a mature $C_{27}$ sterane-dominated charge of marine oil by terrestrial, $C_{29}$ sterane-dominated material of lower thermal maturity.

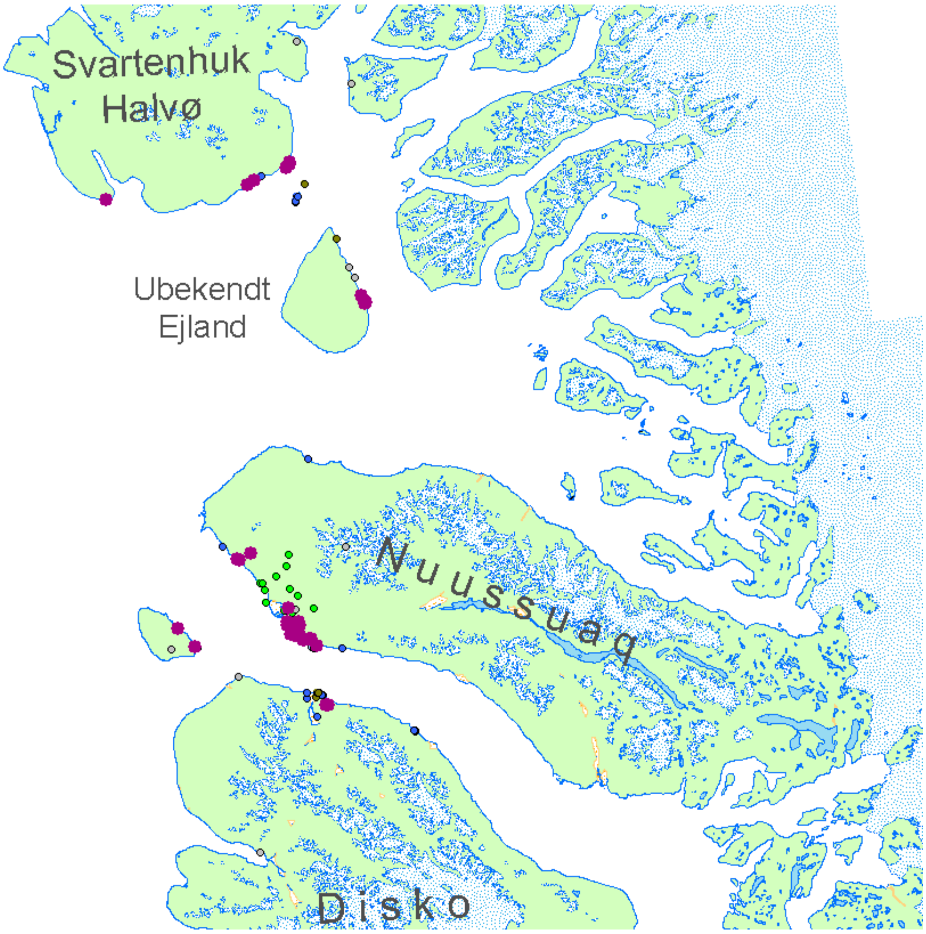


Fig. 2.7.1. Distribution of mixed oils (purple highlighting)

# 3. Other indications of petroleum systems

## *3.1. Scott Inlet seepage (Baffin Island) and the Cretaceous – Palaeogene on Bylot Island and Baffin Island (Canada)*

Scott Inlet is a small embayment on the eastern coast of Baffin Island where seepage of petroleum has been alleged to take place (see Levy and Ehrhardt (1981) and references therein; Burden & Langille,1990; Burden & Halloway, 1985). The occurrences have been much debated, although little has been published, and no decisive data seem to have been available. However, recent analyses by the Canadian Geological Survey indicate that petroleum seepage is indeed taking place, and biomarker data suggest that the seeping oil is biodegraded, originating from a marine shale source rock, probably of Cretaceous age (Fowler et al. 2005). Hence, the Scott Inlet seep may share its origin with the Itilli oil type known from West Greenland, which is very encouraging for exploration in the West Greenland offshore, where the presence of a Cretaceous marine shale source rock is a major risk.

On the southwestern part of Bylot Island and on the northern and northeastern part of Baffin Island Cretaceous-Tertiary age sediments are exposed. No information on the presence of petroleum source rocks on Baffin and Bylot Islands seems to be available in the public realm. However, unpublished preliminary results of recent fieldwork suggest the presence of shale petroleum source rocks within both the Cretaceous and Tertiary successions exposed in the southwestern and also the northern part of Bylot Island, juxtaposed to the Lancaster Sound (H. Wielens, pers. comm 2010).

Aptian – Cenomanian sediments (Qauqaluit Formation), developed in essentially terrestrial facies, and Paleocene sandy sediments (Cape Searle Formation) are preserved in half-graben on Baffin Island near Cape Dyer and nearby small islands (Burden & Langille, 1990).

## *3.2. The Silurian*

Silurian deposits developed in shale facies with petroleum source rock potential are widespread in North Greenland. Stratigraphically, such deposits are referred to the Lafayette Bugt Formation and to the Tors Fjord Member of the Wullf Land Formation (Christiansen, 1989; Christiansen & Nøhr-Hansen, 1989). The extent of these deposits towards the West and the South is unknown, and possibly Silurian shales may be preserved in offshore basins. Moreover, Silurian age shale source rocks are widespread on the North American craton.

## *3.3. The Ordovician*

Several indications of the presence of Ordovician oils and source rocks have been found in the greater Davis Strait – Baffin Bay region (Fig 3.3.1.), *viz*:

- Oil stain at the Fossilik inlier
- Source rock from Canyon A (offshore)
- Source rock from Aleqatsiaq Fjord Fm, (North Greenland)
- Oil stain, Davis Strait High (offshore)
- Source rocks and oil shales from Hudson Bay – Foxe Basin (Canada)

The Fossilik inlier is a small remnant of Ordovician carbonate rocks situated in the basement area north of Nuuk. In a grey carbonate of Upper Ordovician age small droplets of oil can be found. The oil is undegraded and, based on biological marker data, generated from a highly anoxic carbonate source rock (figs. 3.3.2, 3.3.3, 3.3.4). The precise origin of this oil is not known, since no deposits having petroleum source potential are found in the Fossilik inlier. The composition of the Fossilik oil is unique and shows little compositional similarity to any known Ordovician source rock or oil in the region.

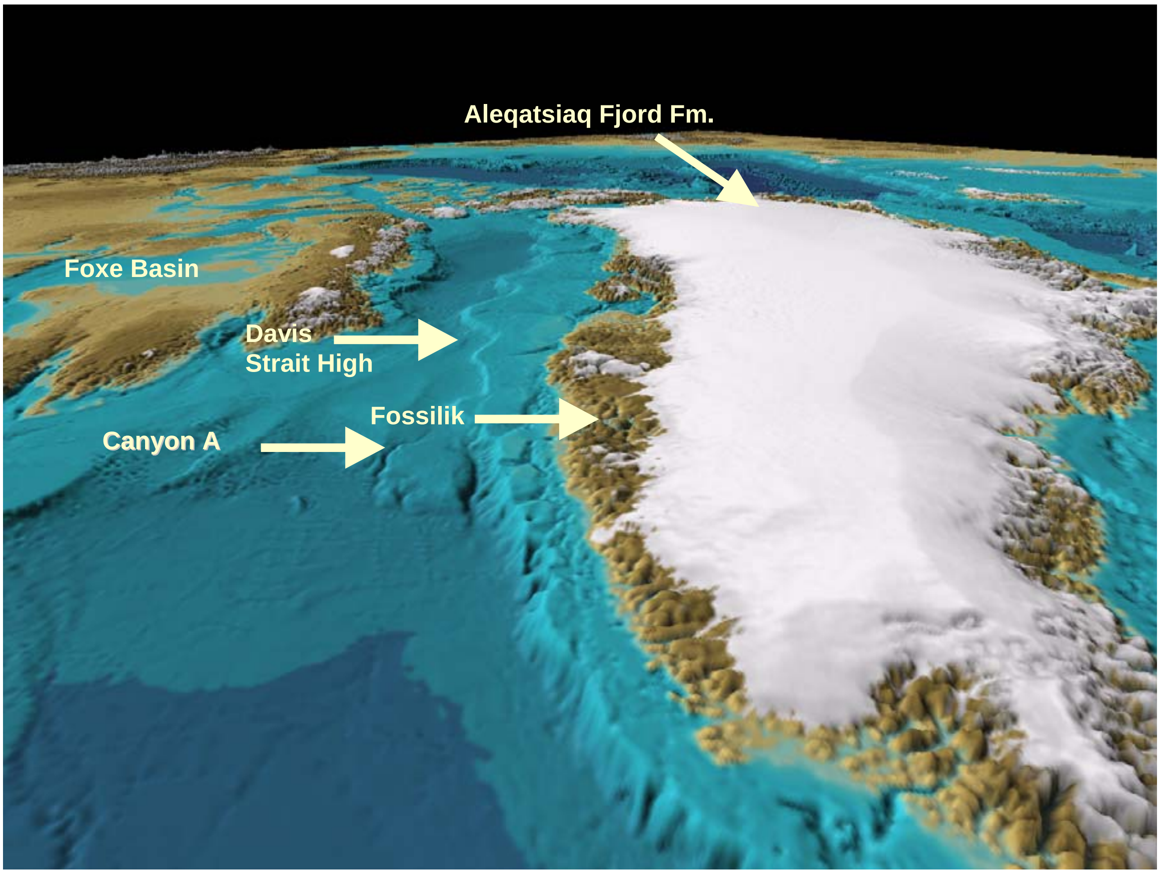


Fig 3.3.1. Location of Ordovician samples with oil staining or source potential, “airial view” of the Davis Strait towards the North

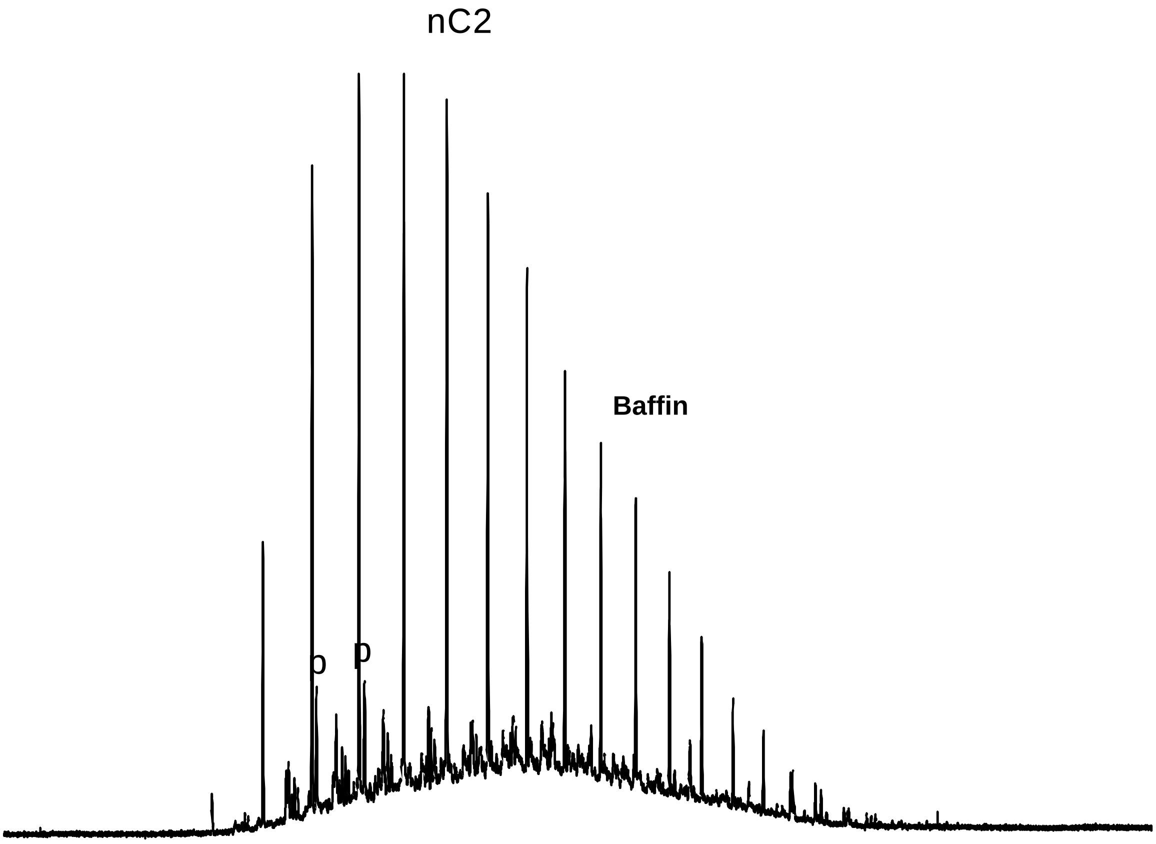


Fig. 3.3.2 Gas Chromatogram, Fossilik oil. Numbers refer to n-alkane Carbon-number, a, b: pristane and phytane, respectively. Note pristane/phytane ratio close to unity and light-end skewed, low-wax distribution of n-alkanes

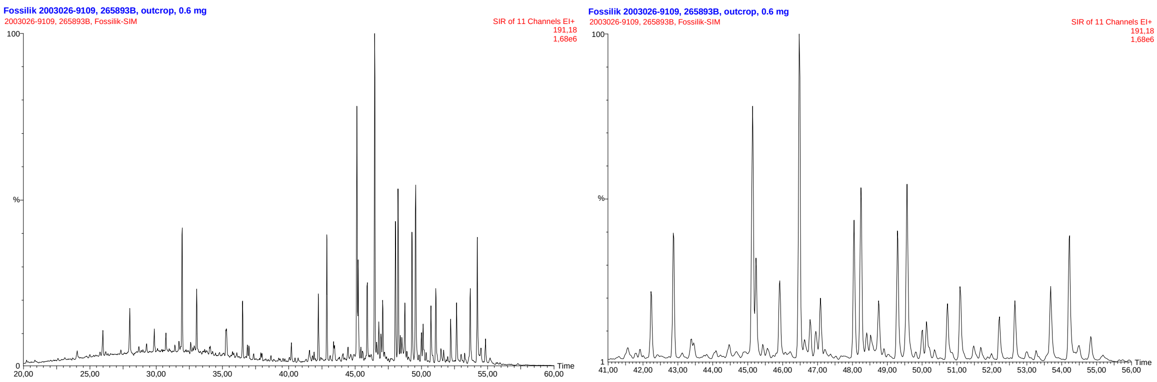


Fig. 3.3.3. M/z 191 ion fragmentogram, Fossilik oil. Left: fullsize, note relatively high abundance of tricyclic terpanes. Right: pentacyclics enlarged, note unusual distribution of extended hopanes

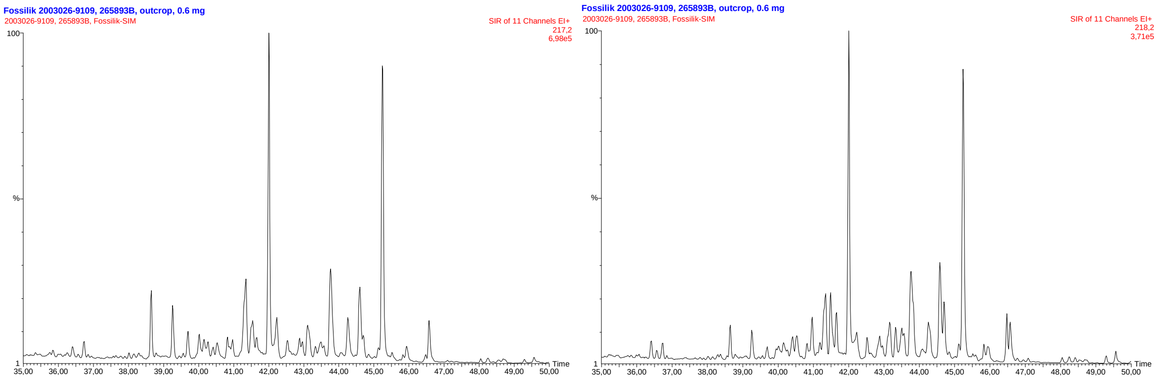


Fig. 3.3.4. Fossilik oil. Left: m/z 217 ion fragmentogram. Note near-equal proportions of $C_{27}$ and $C_{29}$ regular steranes and low abundance of diasteranes. Right: m/z 218 ion fragmentogram.

During the TTR-cruise in the Davis Strait in 2003 a dredge sample of the seabed collected in the “Canyon A” in the Davis Strait recovered a roughly fist-sized lump of brownish-black finely laminated carbonate of late Ordovician age. Analyses of 5 subsamples (fig. 3.3.5) showed that the rock was organic rich and could be classified as a good oilprone source rock with TOC generally close to 2% and Hydrogen Indices 400-500 (fig. 3.3.6). A sample of the Aleqatsiaq Fjord Formation (North Greenland) of identical age shows very similar characteristics, although its petroleum source potential is somewhat lower.
Biological marker analyses showed several unusual features, among these high concentrations of gammacerane, 28-norspergulanes (Nytoft et al. 2006), and rather high concentrations of tetracyclic polyprenoids (Holba et al. 2003), that are otherwise characteristic of lacustrine deposits, despite the marine origin of the “Canyon A”-sample. These characteristics are essentially recurring in the sample collected from the Aleqatsiaq Fjord Formation (North Greenland), referred to above (figs. 3.3.7, 3.3.8).

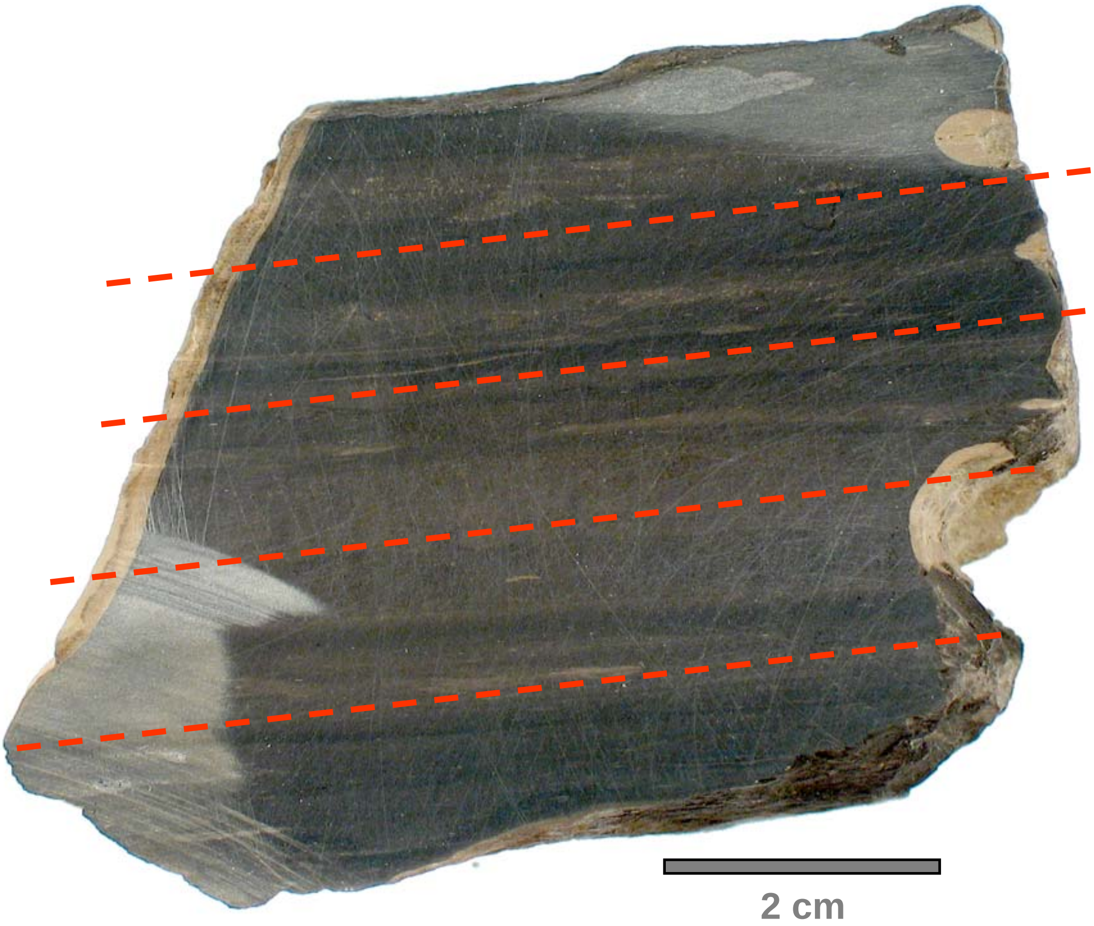


Fig. 3.3.5. Ordovician laminated carbonate recovered by dredging in the Canyon A, Davis Strait. Red dotted lines show approximate split into subsamples.

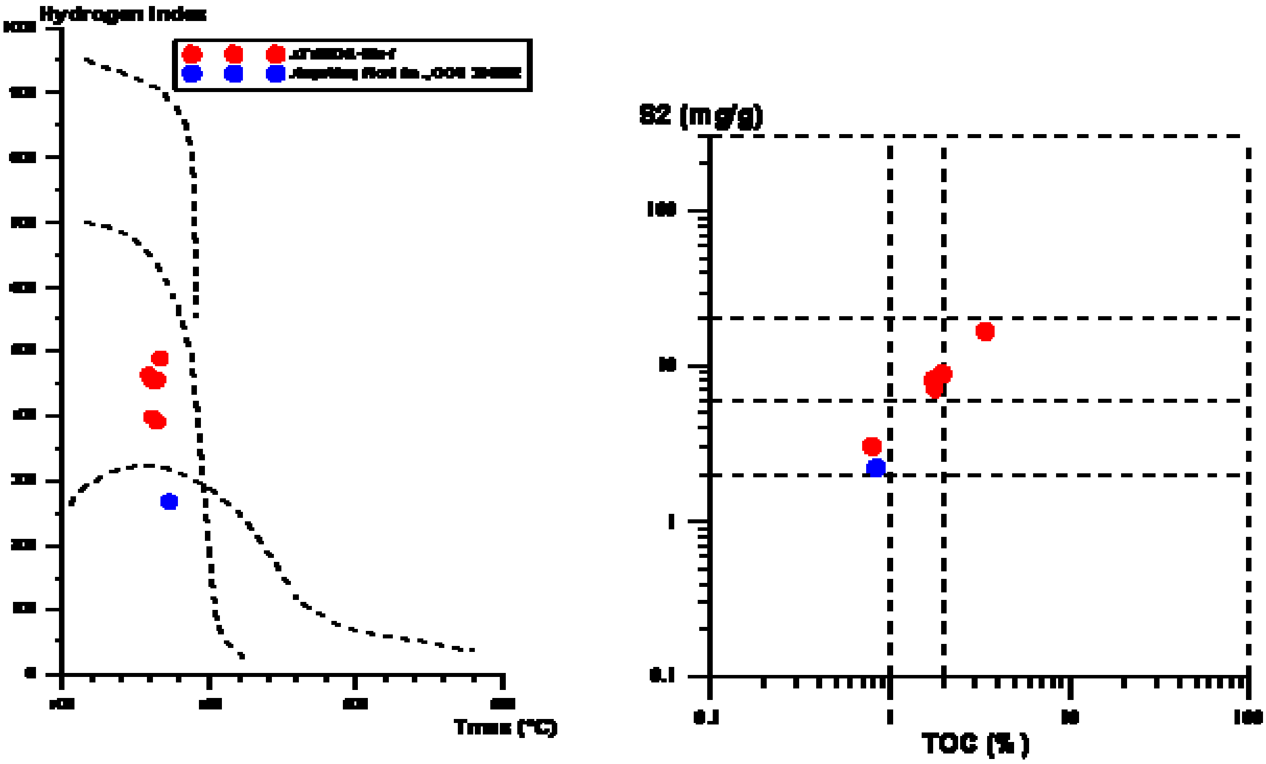


Fig. 3.3.6. Standard Rock-Eval/TOC screening data, Ordovician carbonate collected from the Canyon A, Davis Strait (red symbols) and similar age Aleqatsiaq Fjord Formation (North Greenland) sample.

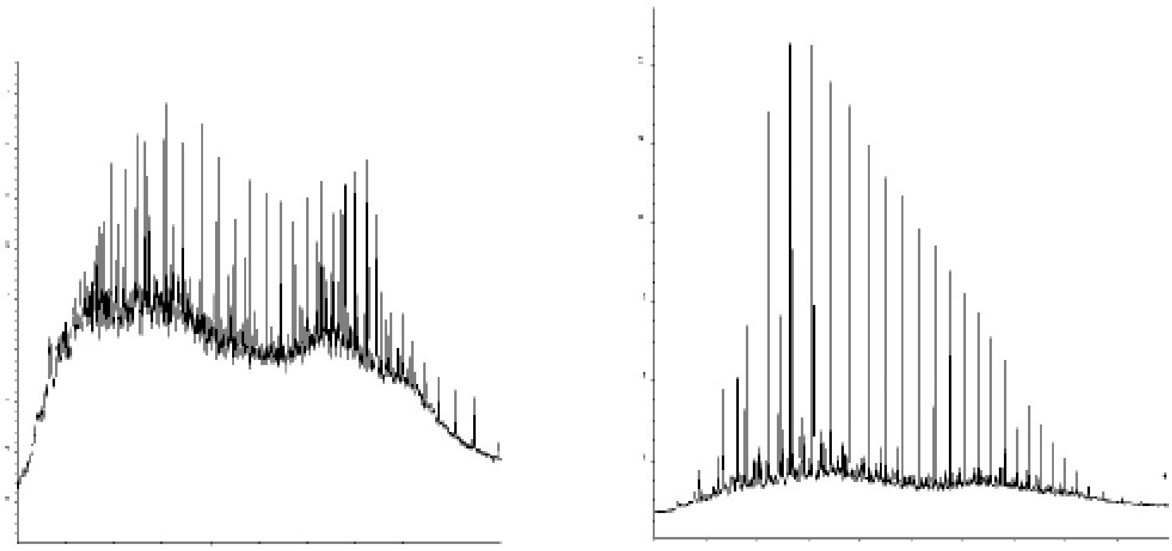

Fig. 3.3.7 Gas Chromatograms, Ordovician carbonate collected by dredging, Canyon A, Davis Strait (left) and Aleqatsiaq Fjord Formation, North Greenland (right). The GC data yielded by the Canyon A sample (left) are somewhat unusual, apparently biodegradation has affected the distribution of normal alkanes – this is rarely observed in source-rock samples.

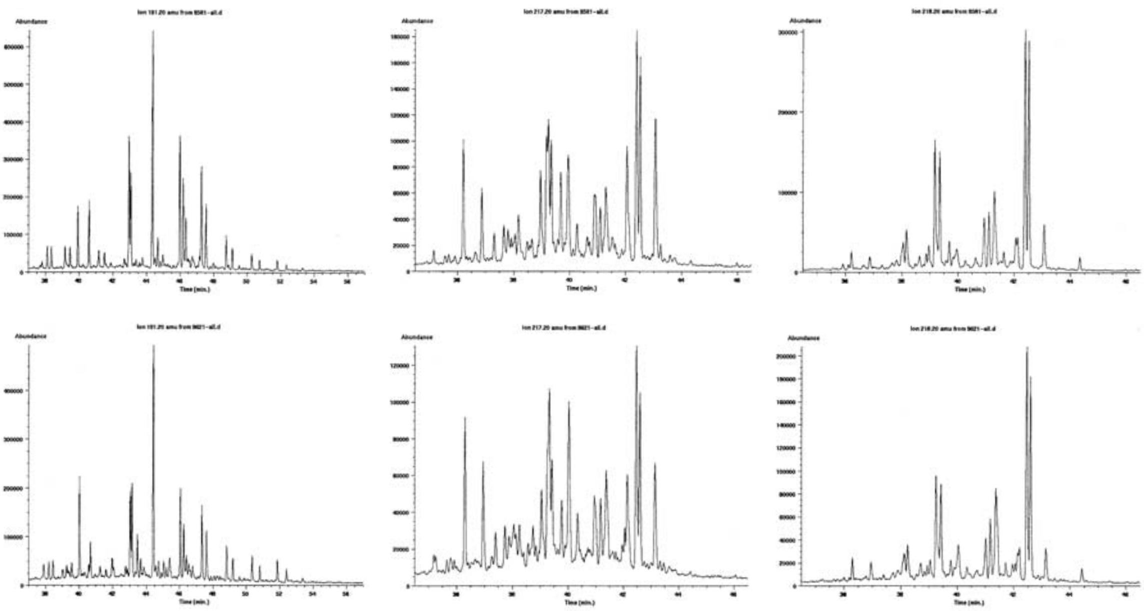

Fig. 3.3.8 Biological marker data for “Canyon A” source rock sample (upper row) and similar age Aleqatsiaq Fjord Formation sample (lower row) (left to right: m/z 191 (hopanes), m/z 217 (steranes) and m/z 218 (steranes)). Note nearly identical biological marker signatures – despite the somewhat higher level of thermal maturity of the Aleqatsiaq Fjord Formation sample

An oil-stained chunk of Ordovician carbonate was recovered by dredging at the Davis Strait High. The staining was not conspicous, but did lend itself to analysis. The oil shows a relatively wax-rich distribution of normal alkanes, but pristane/phytane ratio less than unity (fig. 3.3.9). The triterpane distribution shows scarcity of tricyclics, abundance of a $C_{24}$ tetracyclic terpane and high realtive abundance of homohopanes, showing increased propotions of $C_{34}$-homohopanes (fig. 3.3.10). Gammacerane is not present in appreciable quantities. The sterane distribution shows relatively high proportions of diasteranes on no obvious $C_{27}$ or $C_{29}$ carbon-number predominance (fig. 3.3.11).
Except for low pristane/phytane ratio, the oil stain does not show obvious “carbonate”-characteristics, and its composition seems dissimilar to that of the Fossilik oil stain as well as to the Canyon A and Aleqatsiaq Fjord Formation source rocks.

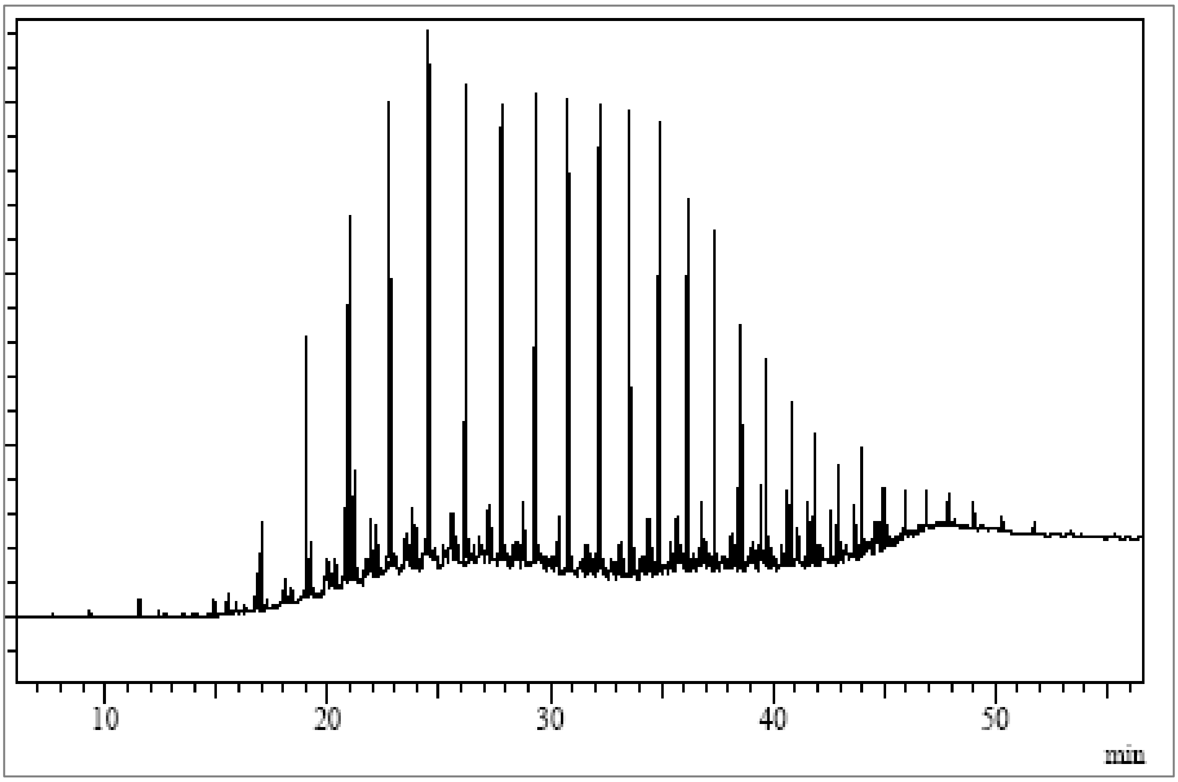


Fig. 3.3.9 Gas Chromatogram, Davis Strait High oil stain. Note relatively high proportions of long-chain (waxy) normal alkanes.

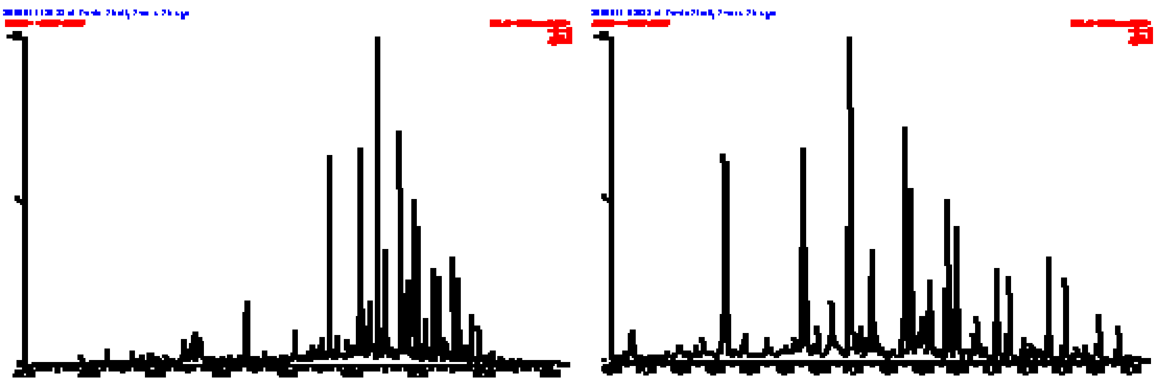

Fig. 3.3.10. M/z 191 ion fragmentogram, Davis Strait High oil stain. Left: fullsize, note low abundance of tricyclic terpanes. Right: pentacyclics enlarged, note irregular distribution of extended hopanes and absence of gammacerane.

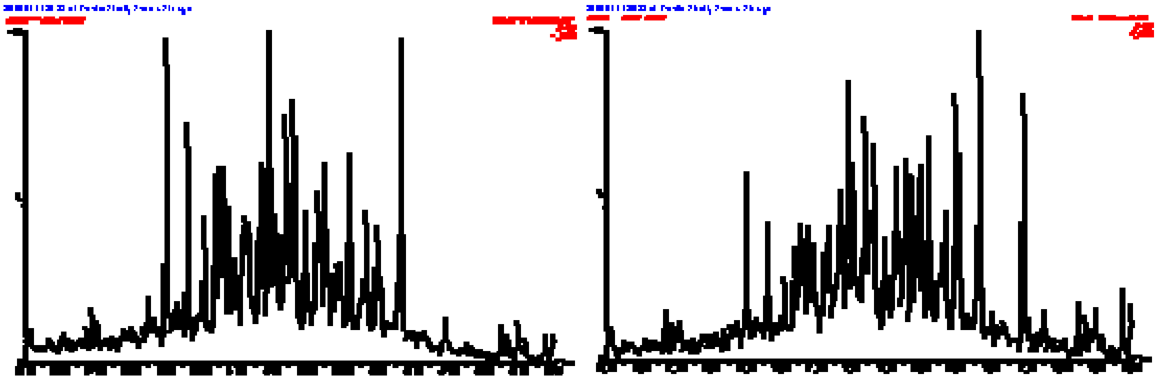

Fig. 3.3.11. Davis Strait High oil stain. Left: m/z 217 ion fragmentogram. Note near-equal proportions of $C_{27}$ and $C_{29}$ regular steranes and high abundance of diasteranes. Right: m/z 218 ion fragmentogram.

Rocks of late Ordovician age showing petroleum source potential are widespread over large portions of the Hudson Bay and Foxe Basin (Macauley et al., 1990). The deposits are generally referred to the Boas River Formation. The Boas River Formation includes oil shales and exposures are found from Southampton in the southwest to Akpatok Island in the southeast, northwards via southwestern Baffin Island, Baird Peninsula to Rowley Island and Hall Beach on Melville Island in the northern part of the Foxe Basin (fig. 3.3.12). The most easterly exposures known are on Blunt Peninsula that forms the northeastern coast of Frobisher Bay. Although there may be up to 1000 kilometres to the type section, all of these depostis are referred to the Boas River Fomation. The age of these deposits roughly corresponds to that of the various Ordovician deposits known from the West Greenland on- and offshore (Stouge et al. 2007) (fig. 3.3.13).

According to Macauley (1990) considerable variation in both age and nature of these deposits are observed, although they also have several features in common. Occasionally, thin (up to app. 30 cm) organic rich layers are found, showing TOC's in the range 10-16 % and Hydrogen Indices of approximately 600. In addition, the formation includes heterolithic units that consist of light-coloured carbonates without petroleum potential alternating with thin layers of dark-coloured carbonates with petroleum potential similar to that of the sample collected in the "Canyon A" referred to above, *i.e.* TOC 1-4% and Hydrogen Index close to 400. The heterolithic units range in thickness from a few metres (Boas River, Southampton Island) via 16–17 metres (Gore Point, Sixteen Mile Brook, Southampton Island to 35 metres (Akpatok Island). Biological marker data on the deposits do not seem to be available in the public realm, but they seem to show characteristics essentially identical to those of the sample collected in the "Canyon A" referred to above (M. Fowler, pers. comm. 2004), rather than showing the characteristic *Gloecapsomorpha prisca* fingerprint that is otherwise common in many Ordovician source rocks. The relative abundance of source versus non-source carbonates in the heterolithic units does not seem to be well known but is held to be largely equal.

Equivalent Ordovician-age source units in neighbouring regions include the Yeoman Shale of Sascatchewan (Williston Basin - a kukersite proper, containing large amounts of *Gloecapsomopha prisca*), the Collingwood Shale of Ontario, Point Bleu Formation of Quebec, units in the Green Point Group of Newfoundland plus various units in the Franklinian Basin in the High Arctic, including the Aleqatsiaq Fjord Formation of North Greenland.


Fig. 3.3.12. Distribution and thermal maturity (based on Conodont Alteration Index, CAI) of Ordovician deposits in Greenland and eastern Canada

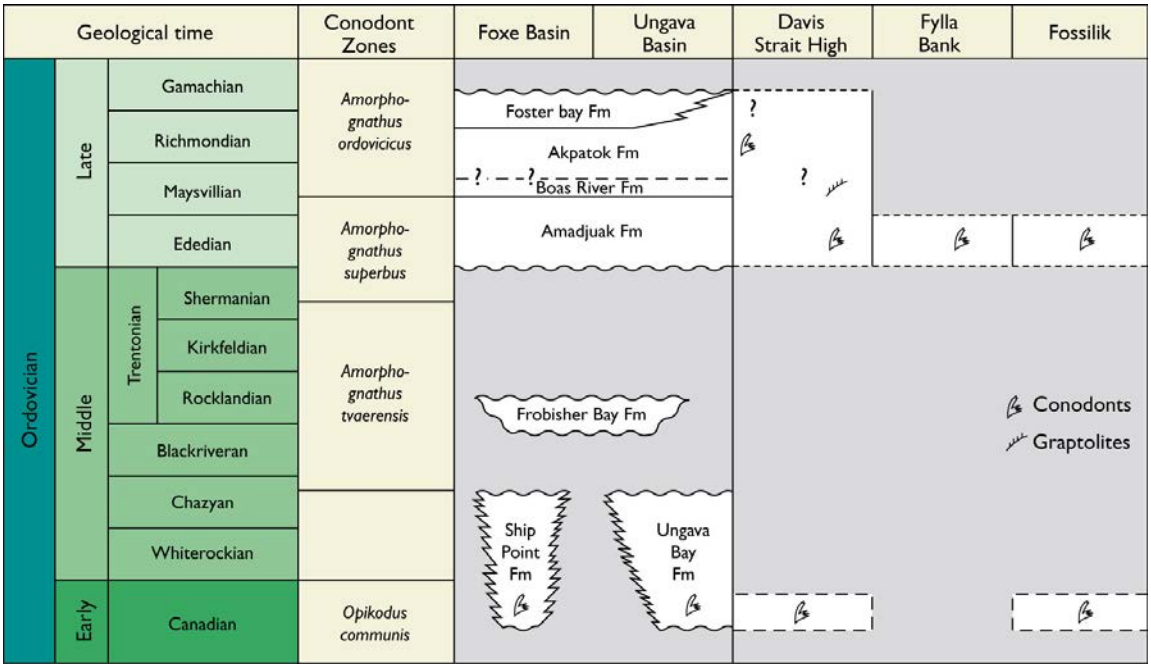


Fig. 3.3.13. Schematic correlation chart showing the chronostratigraphic position of the Ordovician in eastern Canada relative to samples from the west Greenland on- and offshore (Stouge et al. 2007, modified from McCracken (2000))

## *3.4. The Proterozoic Thule Supergroup*

The intracratonic Thule Basin of the northern Baffin Bay region hosts an approximately 6 kilometres thick succession of of largely undeformed and unmetamorphosed strata that are referred to the Thule Supergroup (Dawes, 1997). The rocks of the supergroup crop out in northern west Greenland and on Ellesmere Island (Canada), whereas their distribution in the offshore is not known. The succession is in general dominated by various clastics with minor carbonates and evaporities in places in combination with basaltic volanics represented by flows as well as by sills and dykes.

The essentially unmetamophosed nature of the Thule Supergroup strata, their unknown distribution in the offshore in combination with the abundance of coarse-grained clastics may call for some interest with respect to the reservoir rock potential of the sandstones, whereas the offshore mudstones present in parts of the succession may do so with respect to petroleum source potential.

No porosity or permeability data on the sandstones seem to exist. A number of mudstones/shales have shown the presence of recognisable palynomorphs (Samuelsson et al., 1999).

# 4. Summary

- The West Greenland offshore is a vast area with essentially no hard evidence existing regarding petroleum systems
- Any assessment of potential petroleum systems in the offshore must rely on information from neighbouring regions, principally the West Greenland Basin
- Based on such information Ordovician, Cretaceous, and Paleogene age source rocks are expected
- Reservoirs: primarily Cretaceous–Tertiary age sandstones but perhaps also older units such as Ordovician carbonates and Proterozoic sandstones
- Oil seepage and staining are widespread in Central West Greenland
- Five different types of seepage oil have been identified in the Disko–Nuussuaq–Svartenhuk Halvø region
- Three oil types derived from terrestrial source rocks of Cretaceous–Palaeogene age
- One oil type is of unknown origin
- One oil type is derived from Cretaceous marine shales, presumably of Cenomanian–Turonian or older age
- Two of these petroleum source rocks are expected to show regional distribution: Paleocene deltaic shales and Cretaceous marine shales
- A marine paleo-Davis Strait between Greenland and Canada existed during the Mesozoic, perhaps extending northwards to link with marine basins in the Arctic or southwestwards to link with the Cretaceous Western Interior Seaway of the USA
- This seaway was the locale of deposition for potential petroleum source rocks that later gave rise to the Itilli oil type known from seepages onshore central West Greenland
- Additional oil stains and source rocks are known from the Ordovician
- Ordovician deposits may constitute supplementary sources of hydrocarbons
- It may be speculated if Silurian shales equivalent to those known from North Greenland locally could constitute a supplementary source for hydrocarbons in the Baffin Bay and perhaps elsewhere.
- The Proterozoic Thule Group is essentially unmetamorphosed and includes both sandstones that may possible serve as reservoirs and shales with unknown petroleum potential.

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