Age of oils in West Greenland: was there a Mesozoic seaway between Greenland and Canada?

Jørgen A. Bojesen-Koefoed, Hans Peter Nytoft and Flemming G. Christiansen

For many years the existence of an oil-prone source rock off West Greenland was challenged by industry. But since 1992 when active oil seeps were found onshore West Greenland on the Nuussuaq peninsula (Fig. 1; Christiansen *et al.* 1996; Bojesen-Koefoed *et al.* 1999), the question has changed focus to the age, distribution and potential of the source rock. Five different oils – each with their own characteristics – have been reported by the Geological Survey of Denmark and Greenland (GEUS). One of these, a typical marine shale-derived oil with a possible regional distribution, is known as the Itilli oil. Geochemical analysis suggests that it may have been generated from Cenomanian–Turonian age marine shales, equivalent to prolific source rocks known from Ellesmere Island, Nunavut, Canada. Three of the other oils were generated from deltaic source rocks of Albian, Campanian and Paleocene ages, while one is of unknown origin (Bojesen-Koefoed *et al.* 1999).

The presence of a regional marine source rock is important to petroleum exploration; GEUS has therefore investigated the possible existence of Mesozoic, in particular Cenomanian–Turonian, petroleum source rocks in West Greenland offshore areas. Since sediments older than the Santonian are not known from any of the six wells drilled offshore West Greenland (Fig. 1), assessment of oil-prone source rocks in older sedimentary successions must rely on circumstantial evidence offered by oil chemistry data and analogy studies. Petroleum in quantities amenable to chemical analysis has so far not been recovered from offshore. However, oil-bearing fluid inclusions are known from the Ikermiut-1 well (unpublished data 2001, Phillips Petroleum and GEUS), a gas-kick was recorded during drilling of the Kangâmiut-1 well (Bate 1997), and seismic data indicate hydrocarbons in many areas (cross-cutting reflectors, bright spots, smearing of seismic).

Petroleum exploration offshore West Greenland suffered for many years under the misconception that oceanic crust covered vast areas, rendering the region unattractive. However, the presence of thick sedimentary successions and rotated fault blocks in Cretaceous basins have been demonstrated to be present in areas previously believed to be underlain by Cretaceous–Tertiary oceanic crust (cf. Chalmers & Pulvertaft 2001). New high-quality seismic data, acquired by the seismic company TGS-NOPEC over recent years, combined with gravimetric data, have further demonstrated the presence of deep basins containing thick sedimentary successions in other areas (e.g. Christiansen *et al.* 2002). Despite the progress made over the past few years, the geological evolution of the Davis Strait region in general remains poorly understood, but new data on oil chemistry may shed some light on the history of this region.

Fig. 1. Map showing location of wells drilled offshore West Greenland. The onshore oil seepage area in the Disko–Nuussuaq–Svartenhuk Halvø region is **framed** and includes the onshore exploration well GRO#3.

The Itilli oil type

Based on its chemical characteristics, the Itilli oil type is presumed to have been generated from marine shales of Cenomanian–Turonian age, but no known source rocks are

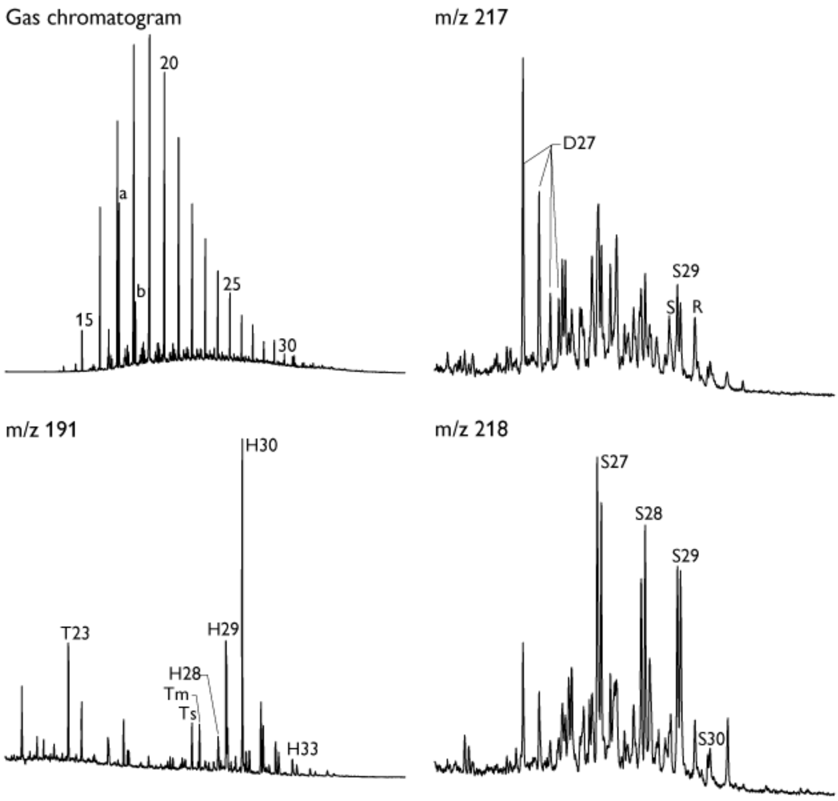

Fig. 2. Characteristics of the Itilli oil type (modified from Bojesen-Koefoed *et al.* 1999). Gas chromatogram shows light-end skewed *n*-alkane distribution and pristane/phytane < 2 (numbers: *n*-alkane carbon number, **a**: pristane, **b**: phytane). Triterpanes monitored by the *m/z 191* fragmentogram show abundant tricyclics (**T23**: C_{23} tricyclic triterpane) and notable proportions of 28,30-bisnorhopane (**H28**). **Ts**: trisnorneohopane; **Tm**: trisnorhopane; **H29**: norhopane; **H30**: hopane; **H33**: trishomohopane. Steranes monitored by the *m/z 217* and *m/z 218* fragmentograms show a high abundance of diasteranes (**D27**) at moderate levels of thermal maturity indicated by C_{29} sterane S/(S+R) epimerisation ratio of approximately 0.50 (C_{29} sterane: **S29**; **S**: 20S epimer; **R**: 20R epimer), and a relatively high abundance of C_{28} steranes (**S28**) compared to C_{27} (**S27**), C_{29} (**S29**) and C_{30} (**S30**) steranes.

exposed or have been drilled in West Greenland. However, on Ellesmere Island, the lower part of the Kanguk Formation comprises excellent, highly oil-prone marine shale source rocks of presumed Cenomanian–Turonian age (Núñez-Betelu 1993). The deposits are, however, thermally immature and cannot be directly compared to the Itilli oil from onshore West Greenland more than 1000 km to the south. However, artificial maturation by hydrous pyrolysis of samples of the Kanguk Formation generates bitumen that shares a number of important characteristics with the Itilli oil type. These characteristics include: light-end skewed *n*-alkane distribution, pristane/phytane ratio less than 2, abundant tricyclic triterpanes, abundant 28,30-bisnorhopane and diasteranes, plus a predominance of C_{27} steranes while maintaining relatively high proportions of C_{28} steranes (Fig. 2).

A Mesozoic seaway between Greenland and Canada?

The recent demonstration of more or less continuous deep sedimentary basins offshore West Greenland (Christiansen *et al.* 2002), the occurrence of reworked marine Upper Jurassic palynomorphs in the Qulleq-1 well (Christiansen *et al.* 2001) together with the apparent relationship between the Itilli oil and pyrolysates of the lower Kanguk Formation, open possibilities for the existence of regional Mesozoic marine source rocks in the offshore areas. This implies the existence of a seaway between Greenland and Canada during the Mesozoic, connecting the proto-Atlantic to the proto-Arctic Ocean – a palaeo-Davis Strait, partly analogous to the 'Cretaceous Western Interior Seaway' (CWIS) of North America (Caldwell & Kauffman 1993; Dean & Arthur 1998). The CWIS developed as a foreland basin east of the rising Cordillera along the western margin of the North American continent, whereas the Davis Strait is a product of rifting and strike-slip movements, albeit without sea-floor spreading. This is noteworthy since many published palaeogeographic maps feature a spreading ridge along the axial part of the Davis Strait. Despite the differences in origin, the morphological analogy between a palaeo-Davis Strait and the CWIS is clear and the potential for deposition of similar types of sediments in both settings exists. The evolution of the CWIS is relatively well constrained, and petroleum accumulations, derived from Cenomanian–Turonian age marine source rocks, are known more or less throughout the entire extent of the seaway – from the southern part of the USA to the Canadian Arctic. A series of marine oils of Cenomanian–Turonian age from the CWIS, plus a number of other oils (Table 1), have been collected and analysed to serve as a reference for comparison with Itilli oils from West

Greenland. In addition to Cenomanian–Turonian derived marine oils from the CWIS, the reference sample database includes oils generated from Upper Jurassic source rocks in the Jeanne d'Arc Basin (Newfoundland, eastern Canada) and in the North Sea, the Cretaceous age Heron H-73 oil from offshore eastern Canada, and the Cambro-Ordovician Shoal Point crude from western Newfoundland (Fig. 3).

The distribution of a series of diatom-derived oil constituents known as 24-norcholestanes has proven to be age-diagnostic, and a standard plot for assessment of oil source rock maximum age has been devised by Holba *et al.* (1998). Using this plot, the reference samples show an N–S trend among the CWIS oils of Cenomanian–Turonian age (Fig. 4). The single Cretaceous oil from offshore eastern Canada plots between the Denver and Alberta Basin oils, as expected from its geographical position. Upper Jurassic oils from the Jeanne d'Arc Basin and the North Sea groups occur in a narrow band at the expected position, whereas the Cambro-Ordovician oil yields a 'Palaeozoic' age. Superimposing data from West Greenland Itilli oils onto the reference oil plot shows that samples in which admixture of oil from other sources can be recognised all yield rather young ages, whereas pure Itilli oil samples show Cretaceous or even Late Jurassic source rock ages (Fig. 4). Hence, age-diagnostic biological marker data support the existence of a regional Cretaceous age marine petroleum source rock, in addition perhaps to an Upper Jurassic source rock. A characteristic feature of Cenomanian–Turonian age oils from the Canadian Arctic is a relatively high abundance of C_{28} regular steranes, compared to C_{27} and C_{29} regular steranes, whereas Upper Jurassic oils generally show a rather low abundance of C_{28} regular steranes. Some Itilli oils from West Greenland show sterane distributions very similar to Cenomanian–Turonian age oils from the Canadian Arctic, others may show distributions rather similar to Upper Jurassic oils, and some may show intermediate distributions. Hence, regular sterane data further support the notion of a Cretaceous plus perhaps an additional Upper Jurassic marine petroleum source rock in the Davis Strait region, and thus the existence of a Mesozoic seaway between Greenland and Canada.

Table 1. Analysed oil samples

Region	No. of samples	Source rock age
Denver Basin*	3	Cenomanian–Turonian
WCSB†, Alberta*	3	Cenomanian–Turonian
Arctic Canada*	4	Cenomanian–Turonian
W. Greenland	40	Jurassic(?), Cretaceous(?) Paleocene
E. Canada offshore/onshore	4	Upper Jurassic, Cretaceous, Cambro-Ordovician
North Sea	3	Upper Jurassic

* Cretaceous Western Interior Seaway
† Western Canadian Sedimentary Basin

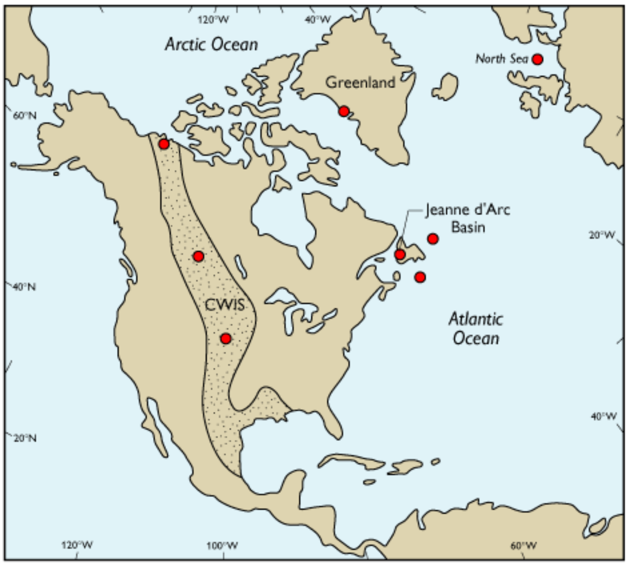

Fig. 3. Cretaceous Western Interior Seaway (**CWIS**) of North America and the North Atlantic. **Red dots**: approximate positions of analysed oil samples.

Conclusions

The Itilli oil type from onshore central West Greenland is an oil derived from marine shale, and shows clear similarities to pyrolysates of immature Cenomanian–Turonian age oil-prone source rocks from the Canadian Arctic.

Analysis of age-diagnostic biological markers and the distribution of regular steranes indicate a source rock age similar to that of Cenomanian–Turonian age oils from the Canadian Arctic or of older Upper Jurassic oils from the Jeanne d'Arc Basin.

Geochemical data, combined with other indications of petroleum in West Greenland offshore areas, support the existence of one or more Mesozoic marine petroleum source rocks in the larger Davis Strait area, and hence the notion of a Mesozoic seaway between Greenland and Canada.

Acknowledgements

Analyses of samples were financed by the Bureau of Minerals and Petroleum, Government of Greenland (CENTUR Project, grant no. 69.41.06). Samples provided by the United States Geological Survey (Denver), the Geological Survey of Canada (Calgary and Halifax), and the Canadian New-foundland Offshore Petroleum Board (St. John's) are gratefully acknowledged.

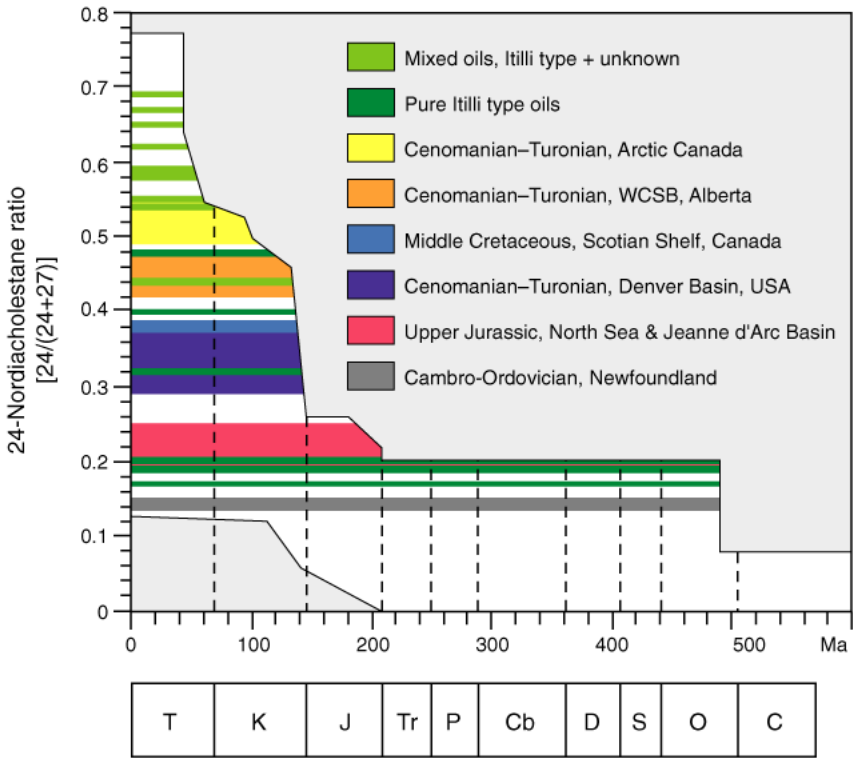

Fig. 4. Standard diagram for assessment of oil source rock maximum age using the nordiacholestane ratio (modified from Holba *et al.* 1998). Note N–S trend among Cenomanian–Turonian from the Cretaceous Western Interior Sea-way. Mixed oils yield young source rock ages whereas pure Itilli oils show Cretaceous or even Jurassic source rock ages. **WCSB**: Western Canadian Sedimentary Basin.

References

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**, 24 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, 305–314. London: Geological Society.

Caldwell, W.G.E. & Kauffman, E.G. 1993: Evolution of the Western Interior Basin. Geological Association of Canada Special Paper **39**, 679 pp.

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 Publication (London) **187**, 77–105.

Christiansen, F.G., Bojesen-Koefoed, J.A., Dam, G., Nytoft, H.P., Larsen, L.M., Pedersen, A.K. & Pulvertaft, T.C.R. 1996: The Marraat oil discovery on Nuussuaq, West Greenland: evidence for a latest Cretaceous – earliest Tertiary oil prone source rock in the Labrador Sea – Melville Bay region. Bulletin of Canadian Petroleum Geology **44**, 39–54.

Christiansen, F.G. *et al.* 2001: Petroleum geological activities in West Greenland in 2000. Geology of Greenland Survey Bulletin **189**, 24–33.

Christiansen, F.G., Bojesen-Koefoed, J.A., Chalmers, J.A., Dalhoff, F., Marcussen, C., Nielsen, T., Nøhr-Hansen, H. & Sønderholm, M. 2002: Petroleum geological activities in West Greenland in 2001. Geology of Greenland Survey Bulletin **191**, 84–89.

Dean, W.E. & Arthur, M.A. 1998: Stratigraphy and paleoenvironments of the Cretaceous Western Interior Seaway, USA. SEPM Concepts in Sedimentology and Paleontology **6**, 255 pp.

Holba, A.G., Dzou, L.I.P., Masterson, W.D., Hughes, W.B., Huizinga, B.J., Singletary, M.S., Moldowan, J.M., Mello, M.R. & Tegelaar, E. 1998: Application of 24-norcholestanes for constraining source age of petroleum. Organic Geochemistry **29**, 1269–1283.

Núñez-Betelu, L.K. 1993: Rock-Eval/TOC pyrolysis data from the Kanguk Formation (Upper Cretaceous), Axel Heiberg and Ellesmere Islands, Canadian Arctic. Geological Survey of Canada Open File **2727**, 30 pp.

Authors' address

Geological Survey of Denmark and Greenland, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark. E-mail*: jbk@geus.dk*