Palaeo-oil field in a Silurian carbonate buildup, Wulff Land, North Greenland: project 'Resources of the sedimentary basins of North and East Greenland'

Lars Stemmerik, Martin Sønderholm and Jørgen A. Bojesen-Koefoed

The multi-disciplinary research project 'Resources of the sedimentary basins of North and East Greenland' was initiated in 1995 with financial support from the Danish Research Councils (Stemmerik *et al.*, 1996). During the 1996 field season, hydrocarbon-related studies within the project were focused on the sedimentary basins of East Greenland (Stemmerik *et al.*, 1997), while field work in the Franklinian Basin of North Greenland from which the observations reported here derive, was limited to two weeks in early August. The project also includes research related to the ore geology of North Greenland, especially focused on the zinc-lead deposit at Citronen Fjord (Fig. 1). This aspect of the project is covered by Langdahl & Elberling (1997) and Kragh *et al.* (1997).

The work on the Franklinian Basin succession was based at Apollo Sø in eastern Wulff Land (Fig. 1), with the main emphasis on sedimentological and sequence stratigraphic studies of carbonates of the Cambrian portion of the Ryder Gletscher Group and the Silurian Washington Land Group. These two carbonate-dominated shelf successions are equivalent in age to the main source rocks for liquid hydrocarbons in the basin, and have been suggested as potential reservoir units in the conceptual reservoir models proposed for the basin (Christiansen, 1989). Earlier investigations in the region have shown that small occurrences of bitumen are widespread in western North Greenland, although typically closely associated with nearby source rocks (Christiansen *et al.*, 1989a). Notable exceptions are the asphalt seepages in southern Warming Land and southern Wulff Land (Fig. 1); in these cases, long distance migration of the order of 75–100 km is envisaged (Christiansen *et al.*, 1989a).

During the 1996 field season, a palaeo-oil field was identified in a carbonate buildup in eastern Wulff Land (Victoria Fjord buildup), thus demonstrating for the first time that Silurian buildups have formed large-scale reservoirs for generated hydrocarbons in the geological past.

Silurian buildups of the Franklinian Basin

Silurian carbonate buildups are preserved within an approximately 850 km long reef belt extending in North Greenland from Kronprins Christian Land in the east to Washington Land in the west (Fig. 1), and continuing westwards into Arctic Canada (Sønderholm & Harland, 1988; Trettin, 1991). The reef belt developed along the southern margin of the Franklinian Basin during the latest stages of basin evolution.

In the late Ordovician to earliest Silurian, open marine to slightly restricted platform carbonates accumulated on an extensive, essentially flat carbonate shelf which was separated by an escarpment from the deep water trough to the north (Higgins *et al.*, 1991; Sønderholm & Harland, 1988). Later, during the Early Silurian, deepening of the outer part of the shelf resulted in southerly retreat of the shelf margin in the western parts of North Greenland. Reef and reef-related sediments including slope buildups, referred to the Washington Land Group, developed in a reef belt conformably overlying the lowermost Silurian platform carbonates, and interfingering with slope and basin clastic sediments of the Peary Land Group.

Victoria Fjord buildup

The carbonate buildup in which the palaeo-oil field has been located crops out in the east of Wulff Land on the coast of Victoria Fjord (Fig. 1). The buildup is situated in an upper slope position, approximately 5 km north of the Early Silurian platform margin and is draped by Silurian shales and turbidites of the Peary Land Group (Fig. 2). It is more than 260 m high and extends for *c.* 1200 m along the north–south trending fjord; a comparable nearby buildup in southern Nares Land (Fig. 1) has an approximately circular shape in plan view.

Geology of Greenland Survey Bulletin 176, 24–28 (1997)

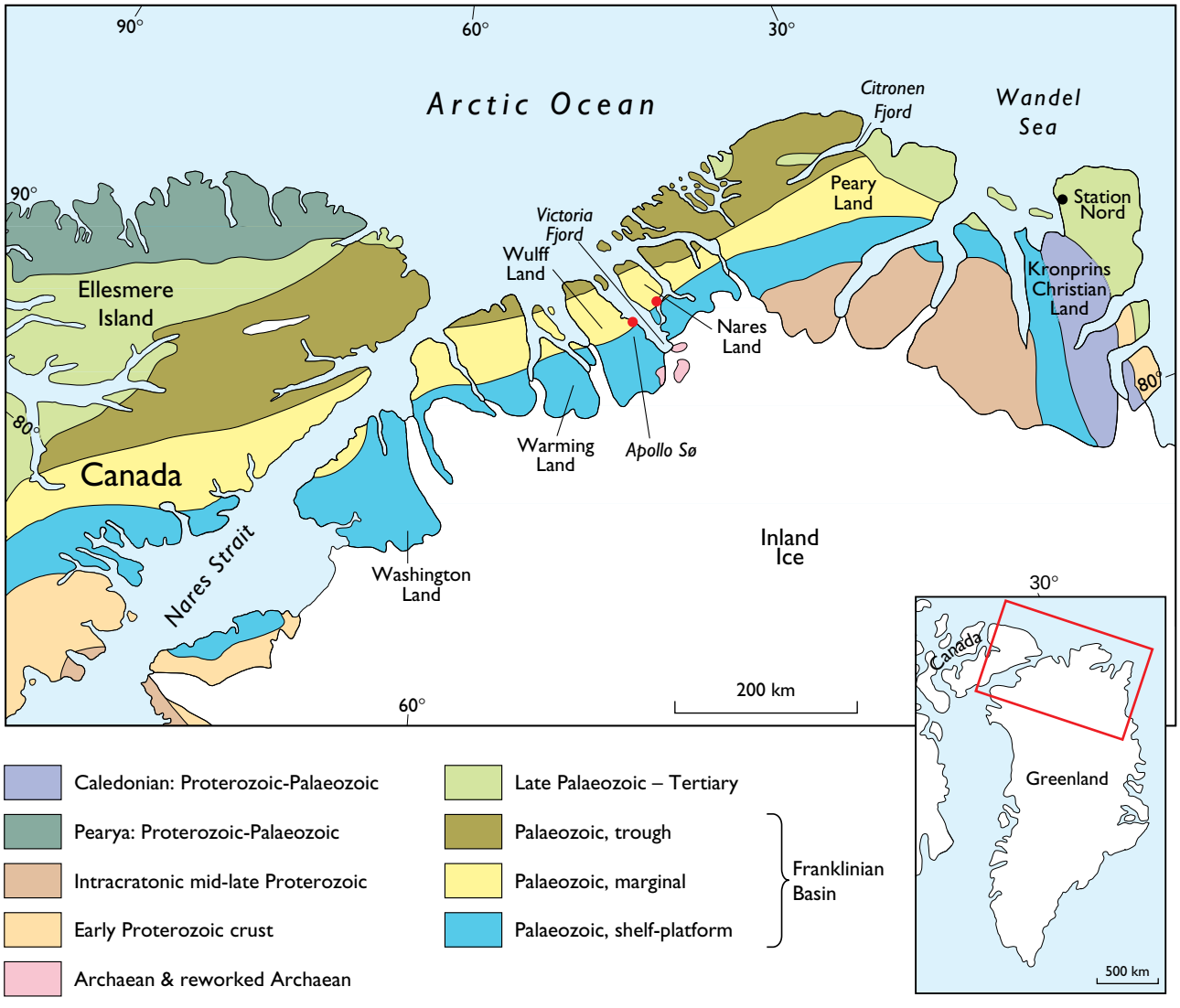

Fig. 1. Simplified geological map of North Greenland and adjacent Ellesmere Island, Canada, showing the location (red dots) of the carbonate buildups in eastern Wulff Land and southern Nares Land discussed in the text. Modified from Dawes (1994).

The core of the Victoria Fjord slope buildup is similar to that of other buildups in the region (Sønderholm & Harland, 1988), and comprises stromatactis-rich lime mudstone, marine cementstone and wackestone. Stromatoporoids and corals are also present in the core and in flanking biostromal deposits, and probably played a major role in stabilising the steep slopes of the buildup. Crinoidal grainstones typically form steeply dipping aprons wedging out into siliciclastic slope deposits.

In the upper *c.* 120 m of the buildup, all available pore space appears to be filled with bitumen (Fig. 3). Visual estimates of porosities are in the range 10–20 %. Based on these estimates, the total pore-volume of the reef is in the order of 10–15 million m^3 (60–100 million bbl), of which *c.* 4 million m^3 (25 million bbl) are filled with bitumen. Previous estimates of the generative potential of the source rocks in contact with an isolated Silurian reef were in the order of approximately 100 million bbl (Christiansen, 1989); this estimate involved a drainage area of 400 km^2. For a reef in an upper slope setting, the source rocks are mainly located on the basinward side; a comparable drainage area would thus necessitate migration paths of up to 15 km, which are considered unlikely. More feasible migration paths of the order of 5–10 km result in drainage areas of 40–150 km^2. In this case, the generative potential of the source rocks within the drainage area would be 10–50 million bbl. The fact that only the upper part of the reef is filled suggests that migration paths were either relatively short (i.e. a restricted drainage area as noted above) or

Fig. 2. The Silurian carbonate buildup at Victoria Fjord, eastern Wulff Land. The 260 m high isolated carbonate buildup is draped by shales and turbidites of the Peary Land Group.

that the generative efficiency or other source rock parameters are lower in this setting than originally anticipated by Christiansen (1989).

Bitumen composition

Although the Victoria Fjord buildup is located in a position where Silurian shales are post-mature with respect to hydrocarbon generation (cf. Christiansen *et al.*, 1989b), it was possible to prepare solvent extracts of all 10 bitumen-stained samples collected during field work (Fig. 4). The composition of these extracts is broadly similar; generally speaking the analysed oils are well-preserved.

The asphaltene contents are somewhat variable (4–44%), and maltene fractions are predominantly aliphatic. Saturated components constitute 54–70%, whereas the proportions of aromatic components are very low (0–12%); the proportions of heteroatomic compounds (NSOs) are moderate (29–46%). One sample (GGU 444069) shows very high proportions of asphaltenes (82.4%), and a strong predominance of NSO-components in the maltene fraction.

The *n*-alkane distributions are generally convex-up, unimodal, with apices in the interval $nC_{16–24}$, or more or less distinctly bimodal with maxima in the intervals

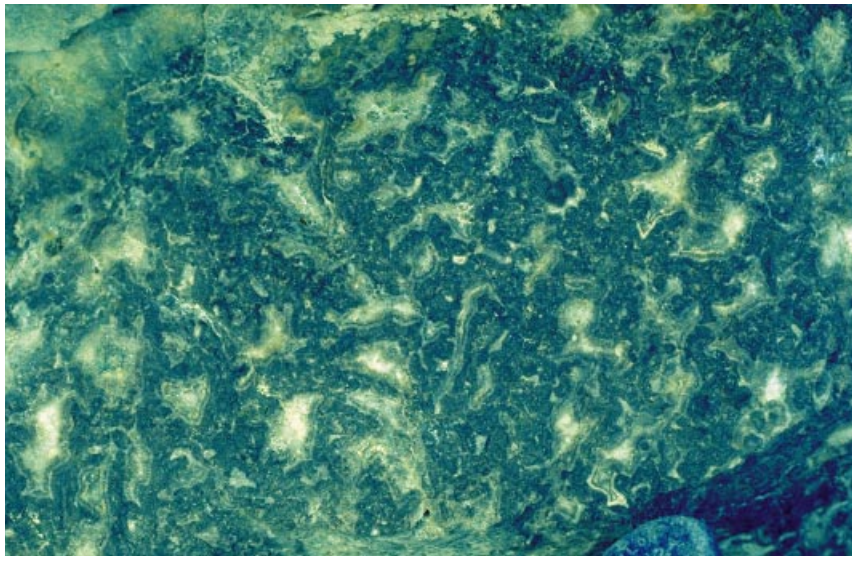

Fig. 3. Bitumen-stained marine cement from the upper part of the Victoria Fjord buildup. Field of view is approximately 30 cm across.

$nC_{16–18}$ and $nC_{27–33}$. The *n*-alkanes range from C_{12} to C_{38} or more, with high proportions of 'waxy' (nC_{22+}) components. No clear even- or odd-number predominance is present. In a few samples, slight depletion in the lower carbon number range is observed. Acyclic isoprenoids are not very abundant, and pristane/phytane ratios are close to 1. The proportions of 'Unresolved Complex Mixture' (UCM) are low. Hence, although light-end evaporation has clearly affected a few samples, the distributions of *n*-alkanes do not indicate significant biodegradation.

The youngest known potential source rocks in the region are shales of the Lower Silurian Thors Fjord Member (Wulff Land Formation). Thus the distribution of *n*-alkanes is remarkable since high proportions of waxy components and bimodal *n*-alkane distributions in oils and rock extracts are generally held to indicate significant contributions of higher plant cuticular waxes to the parent kerogen (e.g. Peters & Moldowan, 1993).

The biological marker concentrations and distributions generally conform to those observed in solvent extracts of marine Palaeozoic shales and oils generated from such sources, although the proportion of tricyclic triterpanes are lower than might be expected (cf. Dahl *et al.*, 1989; Kanev *et al.*, 1994). Triterpane and sterane biological markers are only present in very low concentrations. The distributions of pentacyclic compounds are rather featureless, showing Ts/Tm>1, predominance of hopane, and low abundance of homohopanes. However, the presence of 28,30-bisnorhopane is noted. Regular steranes are dominated by C_{27} components, and diasteranes are abundant relative to regular steranes. Both hopane and sterane isomerisation ratios have reached equilibrium. Hopane/sterane ratios are estimated at approximately 2:1.

The analysed oils are well-preserved, and largely unaffected by biodegradation as indicated by the presence of a full range of *n*-alkanes and a general predominance of saturated components in the maltene fraction. This observation combined with occasionally high proportions of asphaltenes may indicate continuous and ongoing replenishment of the reservoir. From a geochemical point of view therefore, it is unlikely that the petroleum-impregnated carbonates are the uplifted remains of a 'fossil oil-filled reservoir' since the petroleum would have been unlikely to survive uplift and erosion unaltered. This contradicts the established models for the region, which suggest pre-Devonian migration and entrapment, and further work is needed to fully understand this bitumen occurrence.

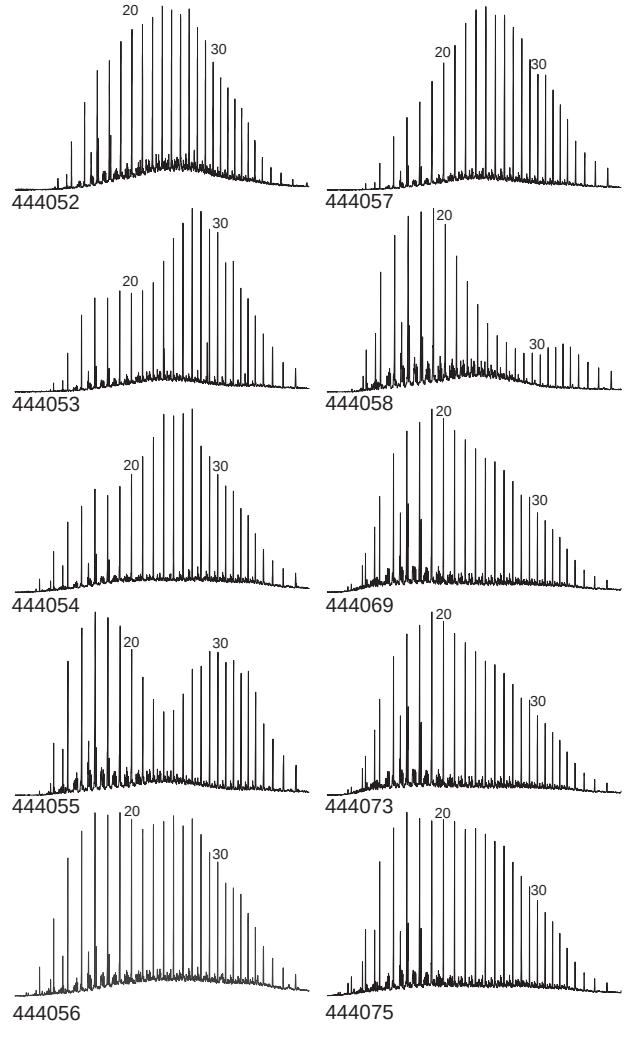

Fig. 4. Gas chromatograms of saturate extract fractions. Sample numbers are indicated below each chromatogram. Small numbers refer to *n*-alkane carbon numbers. Note high proportions of long-chain *n*-alkanes and convex-up, occasionally bimodal, distributions which are generally held to indicate higher plant contributions to the parent kerogen.

References

Christiansen, F. G. 1989: Quantitative aspects and economic implications. *In* Christiansen, F. G. (ed.) Petroleum geology of North Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **158**, 78–84.

Christiansen, F. G., Buchardt, B., Jensenius, J., Jepsen, H. F., Nøhr-Hansen, H., Thomsen, E. & Østfeldt, P. 1989a: Bitumen occurrences. *In* Christiansen, F. G. (ed.) Petroleum geology of North Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **158**, 61–72.

Christiansen, F. G., Koch, C. J. W., Nøhr-Hansen, H., Stouge, S., Thomsen, E. & Østfeldt, P. 1989b: Thermal maturity. *In* Christiansen, F. G. (ed.) Petroleum geology of North Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **158**, 40–60.

Dahl, J., Chen, R. T. & Kaplan, I. R. 1989: Alum shale bitumen maturation and migration: implications for Gotland's oil. *Journal of Petroleum Geology* **12**, 465–476.

Dawes, P. R. 1994: Themes in the promotion of Greenland's mineral resource potential. *Rapport Grønlands Geologiske Undersøgelse* **160**, 22–27.

Langdahl, B. R., & Elberling, B. 1997: The role of bacteria in degradation of exposed massive sulphides at Citronen Fjord, North Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. *Geology of Greenland Survey Bulletin* **176** (this volume).

Higgins, A. K., Ineson, J. R., Peel, J. S., Surlyk, F. & Sønderholm, M. 1991: Lower Palaeozoic Franklinian Basin of North Greenland. *In* Peel, J. S. & Sønderholm, M. (ed.) Sedimentary basins of North Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **160**, 71–139.

Kanev, S., Margulis, L., Bojesen-Koefoed, J. A., Weil, W. A., Merta, H. & Zdanaviciute, O. 1994: Oils and hydrocarbon source rocks of the Baltic syneclise. *Oil & Gas Journal* **92**(8), 69–73.

Kragh, K., Jensen, S. M. & Fougt, H. 1997: Ore geological studies of the Citronen Fjord zinc deposit, North Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. *Geology of Greenland Survey Bulletin* **176** (this volume).

Peters, K. E. & Moldowan, J. M. 1993: *The biomarker guide. Interpreting molecular fossils in petroleum and ancient sediments*. Englewood Cliffs, New Jersey: Prentice Hall, 363 pp.

Sønderholm, M. & Harland, T. L. 1988: Franklinian reef belt, Silurian, North Greenland. *In* Geldsetzer, H. H. J., James, N. P. & Tebbutt, G. E. (ed.) Reefs, Canada and adjacent areas. *Canadian Society of Petroleum Geologists Memoir* **13**, 356–366. (Issued 1989).

Stemmerik, L., Jensen, S. M., Korstgård, J., Schønwandt, H. K., Surlyk, F., Clausen, O. R., Fougt, H., Kragh, K., Langdahl, B. R. & Therkelsen, J. 1996: Resources of the sedimentary basins of North and East Greenland – an integrated petroleum and ore geological research project. *Bulletin Grønlands Geologiske Undersøgelse* **172**, 32–36.

Stemmerik, L., Clausen, O. R., Korstgård, J., Larsen, M., Piasecki, S., Seidler, L., Surlyk, F. & Therkelsen, J. 1997: Petroleum geological investigations in East Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. *Geology of Greenland Survey Bulletin* **176** (this volume).

Trettin, H. P. (ed.) 1991: Geology of the Innuitian orogen and arctic platform of Canada and Greenland. *Geology of Canada* **3,** 569 pp. Ottawa: Geological Survey of Canada. (Also *The geology of North America* **E**, Geological Society of America).

Authors' address:
Geological Survey of Denmark and Greenland, Thoravej 8, DK-2400 Copenhagen NV, Denmark.