The Elly discovery, expected to be set in production in 1999, contains primarily gas (expected reserve: 5 billion Nm^3) and minor oil (expected reserve: 1 million m^3; Danish Energy Agency 1997).

The organic matter in the Falk-1 well has a similar level of thermal maturity as that observed in Elly-3. The maturity level infers exhaustion of the petroleum generative potential. However, high S_2 yields indicate that generative potential still remains (Table 24), and several HI values close to or above 200 indicate a good generative capacity (Fig. 46). Although petrography and Pr/Ph ratios generally above 3 support a classification of the organic matter as kerogen type III, the deposition in low-energy, open-water mires or lakes with restricted oxygen availability, as shown by the carbonaceous mudstones, and the presence of organo-mineral matrix and liptinitic terrestrial organic matter may account for the comparatively high HI values and the ability to generate petroleum at this level of maturity (Fig. 44; Tables 18, 23).

Several HI values between 100 and 200 obtained from core samples from Skjold Flank-1 and relatively high S_2 yields imply that the organic matter, constituted by kerogen type III and possibly type IIb, may possess the capability to generate condensate and gas even at the present level of thermal maturity (Fig. 46; Table 27). This is corroborated by computed petroleum generation depth trends for kerogen types II and III which show that in the Central Graben Group these kerogen types are within the condensate/gas window (GEUS, unpublished data). It is likely that the marine influenced coastal plain (as shown by dominance of C_{27} sterane, Fig. 47) with a variety of depositional environments, like lakes and lagoons, in places favoured the sedimentation and preservation of petroleum-prone organic matter.

The petrographic composition of the organic matter in the Alma-1x well is composed mainly of kerogen type III and some type IIb. However, although the organic matter with respect to thermal maturity is within the peak oil generation range the generally low HI values and S_2 yields suggest a rather poor petroleum generative potential (Fig. 46; Table 17). The overall floodplain environment seems in general to have been unfavourable for deposition of oil-prone organic matter.

The HI values from the Anne-3a and M-8 wells only in a few cases exceed 140 implying a limited petroleum generative capacity of the organic matter (Fig. 46; Tables 20, 25). The position of the cuttings in the HI versus T_{max} diagrams does not indicate a depth trend, but the presence of kerogen type II could be implicated. The comparatively low generative capacity, however, is probably related to a dominance of kerogen type III in the cuttings.

Conclusions

The coal seams of the Bryne Formation in the Søgne Basin

1. Peat accumulation occurred in coastal mires. Increased marine influence is observed in the Lulu-1 and Amalie-1 wells, where lagoonal, estuarine channel, shoreface and offshore siliciclastic sediments dominate.

2. The cumulative coal seam thickness decreases in a seaward direction from 5.05 m in the West Lulu-2 well, to 3.27 m in West Lulu-1 and 1.57 m in West Lulu-3, decreasing to 0.98 m in the Lulu-1 well, and to 0.60 m in the Amalie-1 well. This thinning of the seams towards the palaeo-shoreline is related to a more rapid outpacing of the rate of peat accumulation by the watertable rise linked to a relative sea-level rise.

3. A spatial coal seam distribution shows that the seams R1 and T4 are the most extensive; the precursor mires occupied the majority of the Danish part of the Søgne Basin. A seam split of seam R1, named R1a, is only present in the West Lulu-1 and West Lulu-3 wells. The precursor mire of seam T2 was also extensive, but did not reach the southern part (Amalie-1 well) of the basin. The mires represented by seams T1 and T3 had a limited extent and were restricted to the north-western part of the Danish Søgne Basin.

4. Petrographically the seams are characterised by low contents of liptinite (R-seams: 0.8–4.4 vol.%, T-seams: 1.6–7.8 vol.%), fluctuating but frequently important amounts of either allochthonous or *in situ* derived inertinite, and significant amounts of generally fluorescent vitrinite. The intimate association of the macerals creates a complex microlithotype composition. Towards the palaeo-coastline the coal facies generally represents a wet peat-forming environment due to a continuously high-standing watertable, whereas coal composition implies that the precursor peats may have been more subjected to a fluctuating watertable and desiccation landward of the palaeo-coastline. The presence of pyroinertinite, char and pyrolytic carbon in the seams is evidence for wildfires in the ancient mires, probably ignited by lightning. A stronger prolonged marine influence on the coastal reaches of the ancient mire systems is reflected by increased proportions of sterane C_{27} compared to sterane C_{29} and increased C_{35}-homohopane indices in all seams towards the palaeo-shoreline. This is supported by the recording of 28,30-bisnorhopane in seams R1, T2 and T4 in Lulu-1 and Amalie-1, which suggests marine-influenced anoxic conditions. In contrast, the seams in West Lulu-3 have the highest proportions of C_{29} sterane and the highest Pr/Ph ratios (average: 5.98) implying that this area of the precursor mires were least effected by the marine environment. Compared to the seams formed during a comparatively slow relative sea-level rise (seams R1, R1a and R2) the seams formed during an accelerated relative sea-level rise (seams T2, T3 and T4), which favours waterlogged, anoxic conditions due to a continuously high-standing watertable, have several characteristics suggesting an overall stronger marine influence on the precursor mires. These characteristics are: a) in general a higher content of pyrite in the T-seams, b) in general a higher proportion of C_{27} sterane in the T-seams in all well-sites, c) in a landward–seaward direction equal proportions of C_{27} and C_{29} steranes are obtained earlier (Lulu-1 well, seams T2 and T4, compared to Amalie-1 well, seam R1), and d) higher C_{35}-homohopane indices in the T-seams. Additionally, the C_{35}-homohopane index shows a vertical increase from the lowermost to the uppermost seam in each well reflecting the backstepping nature and overall transgressive trend of the coal-bearing succession. The depositional environment, in particular watertable (base-level) rise in the mires linked to relative sea-level rise, is thus recorded by the organic petrographic and geochemical composition of the coal seams.

5. The composition (macerals) of the organic matter in the coaly mudstones is similar to the composition of the coal seams.

6. Vitrinite reflectance values from the coals in the West Lulu-1, West Lulu-3 and Lulu-1 wells are in the range 0.75–0.89 $\%R_m$ indicating a high volatile bituminous B/A rank. Average T_{max} values in the wells range between 440°C and 444°C. Thus with respect to thermal maturity the coals are situated within the maturity range of peak oil generation in the oil window. The coals in the Amalie-1 well yield a vitrinite reflectance value of 1.3 $\%R_m$ indicating a medium volatile bituminous rank. The average T_{max} value is 468°C, and the coals with respect to thermal maturity are at the end of the oil window and are entering the late catagenesis maturation stage where mainly condensates and wet gas are formed. The organic matter in the Cleo-1 well has likewise a maturity level corresponding to the late oil window.

   The homohopane C_{31}–C_{35} epimer ratios between 0.57 and 0.67, the majority of the C_{29} sterane ratios between 0.45 and 0.50, and the majority of the $\alpha\beta\beta 20(S+R)/[\alpha\beta\beta 20(S+R)+\alpha\alpha\alpha 20(S+R)]$ ratios between 0.50 and 0.64, indicate that the transformation ratios of these organic geochemical parameters have reached equilibrium.

7. The average HI values from the coals in the West Lulu-3, West Lulu-1 and Lulu-1 wells are 178, 180 and 200 respectively; coaly mudstones yield average HI values of 172, 168 and 145 respectively. The highest average HI values (on seam basis) are generally obtained from the T-seams (in particular seams T3 and T4) as are the highest average S_1+S_2 contents, and for individual seams an increase in the average HI values is generally recorded in a seaward direction. The tendency to higher HI values and S_1+S_2 contents in the T-seams emplies an influence of the depositional environment on the generative potential of the seams. The deposition of the precursor peats of the T-seams during a comparatively faster relative sea-level rise may have: a) promoted a continuously high-standing watertable and the creation of an anoxic peat mire, b) favoured prolonged influence of saline water, particularly in the low-lying reaches of the mires towards the palaeo-coastline, and c) increased microbic activity of anaer-

obic bacteria. Such conditions will favour the preservation of hydrogen-enriched vitrinitic precursor material and lipid substances, which are important in petroleum generation. Thus, the general isolation from marine influence on the mire systems in the West Lulu-3 area may explain why low or the lowest HI values and S_1+S_2 yields are recorded in this location.

The coaly mudstones exhibit a lower generative potential or a similar potential as the coals. The organic matter in the Cleo-1 well has a general small generative potential, and is mainly gas-prone.

8. The coals are, despite their level of thermal maturity, capable of generating liquid and gaseous petroleum. About 13–30% of the carbon in the coals will participate in petroleum formation during maturation, and Py-GC data from the coals indicate that the generated petroleum will consist of 72.4–82.0% liquid petroleum and only 18.0–27.6% gas. Lower HI values and S_1+S_2 contents for the coals in Amalie-1 are caused by the significantly higher level of maturity, but Py-GC derived pyrolysates reveal that the coals are still capable of generating oil.

9. Multivariate statistical modelling of the data yielded a model explaining 71% of the variation in the remaining generative potential represented by S_2. The correlation coefficient is 0.85. However the low slope of 0.73 of the response line emphasises that other factors than petrographic composition and the TOC content influence S_2. Components with a significant positive influence on S_2 are the TOC content, the vitrinite maceral group, the vitrinite macerals collotelinite and telinite, the vitrinite-rich microlithotypes vitrite, clarite and duroclarite, and the liptinite maceral resinite. The small amount of liptinite macerals in the coals restricts the absolute importance of this maceral group in the model. Components with a negative influence on the generative potential are the fusinite, semifusinite, inertodetrinite and macrinite macerals, and the mineral-rich microlithotype carbominerite.

10. The coals from the West Lulu-3, West Lulu-1 and Lulu-1 wells yield migration index (S_1/TOC, cf. Hunt, 1996) values between 0.15 and 0.21, whereas the West Lulu-2 coals yield indices between 0.23 and 0.27. These values are very favourable according to the suggested 0.1–0.2 range for oil expulsion. The coaly mudstones yield lower or similar values.

11. The $C_{27–29}$ sterane distribution of three oil/condensate samples recovered from Bryne Formation sandstones in the West Lulu-1 and West Lulu-3 wells is typically terrestrial (dominance of C_{29} sterane) and it is very similar to the sterane distribution of the coal extracts. The oil/condensate samples are also of similar maturity and display typical terrestrial signatures like Pr/Ph ratios between 4.09 and 4.24 and bulk isotope $\delta^{13}C$ ratios of up to or greater than –26‰. A condensate from the Amalie-1 well has a bulk isotope $\delta^{13}C$ ratio of –25.26‰, and a maturation level corresponding to a vitrinite reflectance of 1.3 %R, which is similar to the vitrinite reflectance of the Amalie-1 coals.

12. The sum of the evidence implies that the Bryne Formation coals may act, and have acted, as a source for liquid and gaseous petroleum. No data support a better generative potential for the intervening carbonaceous mudstones.

Central Graben Group deposits

1. The examined deposits from the wells were generally deposited in a low-energy coastal plain environment with floodplains, lakes, lagoons and fluvial channels, which occasionally may have been tidally influenced.

2. The organic matter in the deposits is predominantly terrestrially derived and can be classified as kerogen type III or IIb. Pr/Ph ratios are typically greater than 2, with the highest ratio of 4.31. Except for Skjold Flank-1, where the distribution of $C_{27–29}$ steranes show a general dominance of C_{27}, the steranes are dominated by the C_{29} steranes.

3. Maturity parameters indicate that the kerogen in Alma-1x, Anne-3a and M-8 (Salt Dome Province) is close to or within the peak oil generation range in the oil window. With respect to thermal maturity the kerogen in Elly-3 and Falk-1 (Heno Plateau) is in the late oil window, whereas the kerogen in Skjold Flank-1 (Salt Dome Province) is close to the end of the oil window.

4. *Heno Plateau wells.* The kerogen in Elly-3 is depleted in hydrogen and only a limited generative potential remains. However, an initially good petroleum potential may have been present. A terrigenous oil

has been recovered from the nearby Elly-2 well. The organic matter in the Falk-1 well gives high S_2 yields and several HI values close to or above 200, implying that generative potential still remains.

Salt Dome Province wells: HI values between 100 and 200 and relatively high S_2 yields obtained from Skjold Flank-1 samples suggest that the kerogen may possess the capability to generate condensate and gas even at the present level of thermal maturity. The kerogen in the Alma-1x, Anne-3a and M-8 wells exhibits a generally poor petroleum generative capacity.

Acknowledgements

Stuart Watt (GEUS) and two referees, Walter Pickel (Lehrstuhl für Geologie, Geochemie und Lagerstätten des Erdöls und der Kohle, RWTH, Aachen, Germany) and Ger van Graas (Statoil, Norway), are thanked for constructive comments on the paper. Statoil is thanked for the permission to use unpublished data. Stefan Sølberg (GEUS) is thanked for providing technical support in preparation of figures. This study was financially supported by the Danish Energy Research programme (EFP-95), grant number 1313/95-0003.

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