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Source rock prediction in deepwater frontier exploration areas: An integrated study of the Cretaceous in the Vøring Basin

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Generally, the upper Jurassic sequences are regarded as the main source rock intervals in the Norwegian Continental Shelf. Unfortunately, in large areas of the Vøring Basin, the upper Jurassic and even the lower Cretaceous sediments are deeply buried and hence extremely unlikely to be a source for liquid hydrocarbon accumulations. However, there exists evidence from organic geochemistry analyses that specific biomarker components encountered in hydrocarbon accumulations in the Vøring Basin are of post-Jurassic age. Having said this, the presence of a Cretaceous source rock that has generated hydrocarbons is unproven so far, probably due to the fact that very few wells have been drilled in the more central parts of the Vøring Basin where this source rock is most likely to have been deposited.

The Cretaceous was a time of widespread organic carbon deposition in marine environments during which the source rocks of over 60 % of the currently known large hydrocarbon accumulations were deposited (Thierstein 1989). Global boundary conditions particularly during the Cenomanian - Turonian (Oceanic Anoxic Event OAE II) may have favoured the preservation and deposition of vast amounts of organic material in the sediments (e.g. Stein et al. 1986, Thurow et al. 1992). However, these global conditions are likely to have been superimposed by more regional or local factors (variation in primary productivity, fluvial or upwelling induced nutrient supply, increased terrestrial supply, turbidity currents, etc.), which may result in complex system of black shale/source rock deposition. The Cretaceous interval in the Vøring Basin is very thick, suggesting high sedimentation rates, and often not further differentiated into individual sequences. This, together with the poorly constrained ages, increase uncertainty about the presence of a Cenomanian - Turonian source rock and whether or not it is in the oil window (Aram 1999).

An integrated study applying structural restoration, sedimentology and organic facies modelling techniques has been carried out to evaluate the source rock distribution and potential of the Upper Cretaceous (Cenomanian - Turonian) interval in the Vøring Basin.

Firstly, structural restorations of two cross sections across the Vøring Basin were performed. The restoration of the paleobathymetry along these transects were undertaken for three time steps: (1) present day (0 Ma), (2) Base Coniacian (89 Ma), and (3) Base Cenomanian (99 Ma). The reconstructions were based on seismic data, thermal history and stretching factors across the Norwegian margin. The lines were extrapolated to the estimated the palaeo-shorelines of Greenland and Norway. The resulting geometries were used as input for the ensuing depositional and organic facies modelling.

The DEMOSTRAT software was used for the depositional modelling. DEMOSTRAT is a 2D, process-based modelling tool (Rivenæs 1992, 1993). It employs a dual-lithology, depth-

dependent diffusion equation to model deposition and erosion of sand and mud. Thus, sediment transport and erosion are modelled as a function of sediment input, slope, and diffusion coefficients. The program takes into account the initial basin shape provided from structural restoration, compaction, tectonic and isostatic subsidence as well as eustatic sea level variations. Basement compaction and overload can also be incorporated.

The OF-Mod software was used for the organic facies modelling. OF-Mod has been recently developed at SINTEF Petroleum Research and is designed to constrain source-rock type and quality variations in basin kitchen areas during basin modelling studies (Mann and Zweigel, 1999, 2001). OF-Mod is also a 2D process-based modelling tool which takes into account all of the main factors controlling the deposition of organic carbon, as well as their interactions. OF-Mod is linked to the DEMOSTRAT program, which provides the model of the inorganic deposition needed as input for the organic modelling.

The modelling results clearly indicate that sedimentation rate was one of the most decisive parameters for the quantity and quality of organic matter in the Vøring Basin during Cenomanian - Turonian times. A second important factor, particularly for organic carbon quality, was the preservation conditions. As mentioned previously, the thickness of the Cretaceous in the central parts of the Vøring Basin suggests very high sedimentation rates (Aram 1999). These high sedimentation rates (on average approximately 140 cm/ka uncompacted) resulted in dilution of the modelled accumulated organic matter even when assuming a high organic carbon flux and good preservation (anoxic) conditions. However, well data shows variations in both sediment supply and amount of subsidence, indicating localised variations in sediment rates. These scenarios were modelled by varying sediment supply and reducing transport capacity (mimicking periods of submarine fan quiescence). These events of decreased sedimentation rate resulted in notably higher organic carbon contents. Modelling of various preservation scenarios mainly resulted in a significant increase of HI values with only a slight increase of organic carbon content. The results of the modelling were projected onto a map view based on the isochore map and water depth, which takes into account the sedimentation rate and the preservation factor.

Summary and conclusions

Structural restoration of two cross sections and the combined modelling of inorganic (DEMOSTRAT) and organic deposition (OF-Mod) along these cross sections were carried out in order to evaluate the probabilities of source-rock occurrence and associated quality in the Cenomanian - Turonian (Upper Cretaceous) interval in the Vøring Basin.

Sedimentation rates and, to some degree, preservation conditions seem to be the primary parameters controlling organic carbon quantity in the Vøring Basin. Preservation conditions appear to be the main control on organic carbon quality. The modelling showed that the development of high quality source rocks in the Cenomanian - Turonian of the Vøring Basin can only be expected locally in thin layers associated with reduced sediment input (e.g. due to temporal submarine fan quiescence), even if very good preservation conditions were present (Fig. 1 a and b). Furthermore, the modelling results show that the probability for oil and gas prone source rocks (with a bias to gas) is higher than that for oil prone source rocks.

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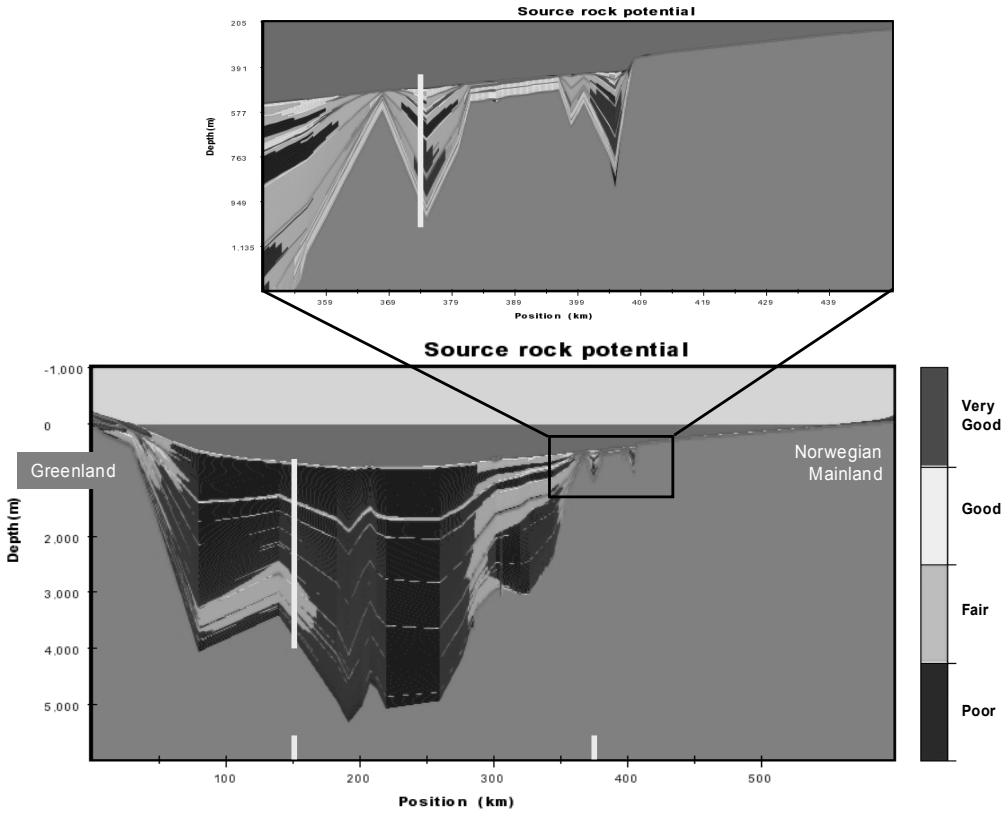

Fig. 1a Modelled source rock distribution (under immature conditions) along a cross section of the Vøring Basin during Cenomanian-Turonian times. The light bold lines indicate the locations of the two log profiles shown in Figure 1b.

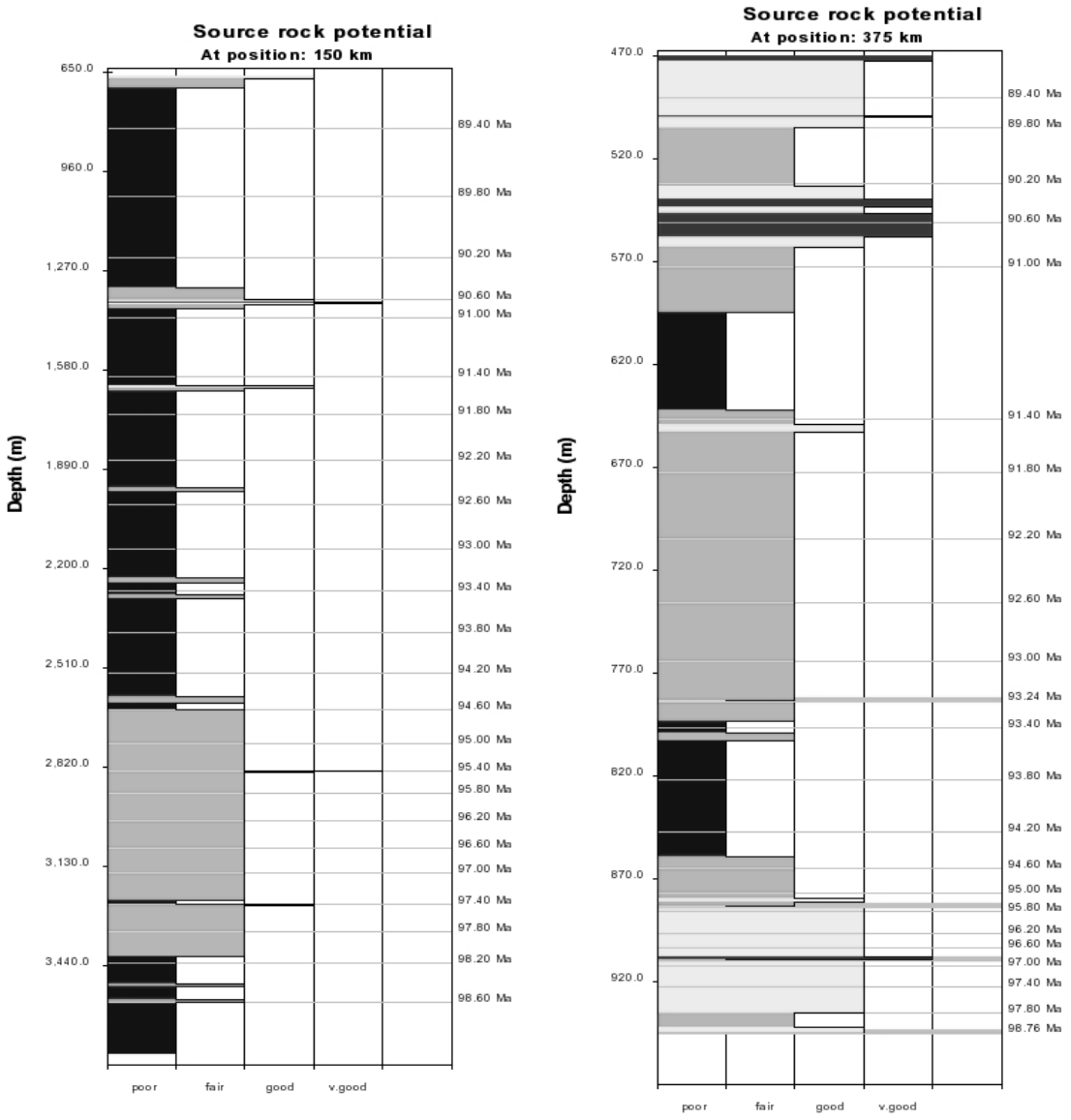

Fig. 1b Modelled source rock potential (under immature conditions) at a central (km150) and a more marginal (km 375) position of the Cretaceous Vøring Basin. The thick light grey lines indicate unconformities. The locations of the two log profiles at the cross section are shown in Figure 1a.