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Utilising borehole image logs to interpret delta to estuarine system: A case study of the subsurface Lower Jurassic Cook Formation in the Norwegian northern North Sea

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ABSTRACT

The Lower Jurassic Cook Formation forms a regressive and transgressive sandstone wedge of shallow marine reservoir sandstones. It is distributed mainly in the Norwegian sector of the northern North Sea and the formation has proven to be hydrocarbon bearing. A case study of this formation from the Tampen Spur area presents a methodology for reconstructing depositional environments in areas of scarce data coverage and poor seismic quality using limited core-coverage, wire-line logs and borehole image logs. The core material and image logs are from different wells. The latter offer interesting opportunities for sedimentological descriptions and interpretations both in cored and uncored sections, particularly as the resolution of the tool (mm-scale under optimal conditions) enables identification of sedimentary structures. In order to avoid over-interpretation, a system of descriptive, simple and robust image facies was established for this study. These include: horizontal lamination, low-angle lamination, cross-stratification, as well as mottled and deformed strata.

The Cook Formation is interpreted here as a regressive tidal-fluvial delta to transgressive wave-dominated estuary couplet with offshore shale above and below. The tidal-fluvial delta of the regressive part seems to be at odds with the regional context as the regressive part of the Cook Formation in the Tampen Spur area is interpreted as a wave-dominated delta system. Internally, the regressive part of the Cook Formation thickens westwards with 68% which is unusual for the otherwise tabular regressive Cook Formation in the Tampen Spur area. Both the thickness and depositional environment difference of the regressive part of the Cook Formation can be explained with temporary fault movement of a blind fault located basinward during basin infill. This could have created a fault-induced monocline that led to wave sheltering of the tidal-fluvial delta system. A spit-barrier system was probably associated with the monocline sourced by longshore drift from the otherwise wave-dominated coast of the regressive Cook Formation. After basin infill and removal of basin relief, the subsequent transgression resulted in the formation of a wave-dominated estuary.

1. Introduction

The Kvitebjørn Field and the adjacent Valemon area, located 20 km southeast of the Gullfaks Field and 130 km off the West Norwegian coast (Fig. 1), lie on a down-faulted terrace adjacent to the deeply subsided Viking Graben to the east (Odinsen et al., 2000). It is situated in a structurally complex area as a result of several rift phases. The Cook Formation varies in thickness from about 65 m to 87 m over a distance of 13 km in the study area.

The Kvitebjørn Field produces gas and condensate from the Brent Group and also from now the Cook Formation (Toarcian age) following the discovery of gas in the 34/11-A - 6 well. In order to aid the future and ongoing gas production of the Cook Formation a sedimentological study was initiated to provide input to reservoir characterisation and reserve estimates for both the Kvitebjørn Field (production license 193) and Valemon area (production license 050). The database consists of five wells (34/10 - 23, 34/10 - 35, 34/11 - 1, 34/11 - A - 6 and 34/11 - A - 10) with wire-line logs, one partly cored Cook Formation well (34/10 - 35) and two wells (34/11 - A - 6 and 34/11 - A - 10) with borehole image logs (Formation Micro Image log – FMI). The base of the Cook Formation is set at the level

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where the gamma-log values decrease upwards in comparison to the continuous high values of the underlying Burton Formation. This break in gamma-ray log response is easily identified in the other wells and is a pragmatic approach to define the base of the Cook Formation.

Seismic interpretation of the Cook Formation in the Tampen Spur area is difficult due to the weak impedance contrast of the shales above and below, and the relatively low frequencies at these great depths of reservoir (in this case from about 3930 m (below sea floor) in 34/10 - 35 to about 4380 m in 34/10 - 23). As a result no surfaces of the Cook Formation or the Dunlin Group are recognisable in seismic data. With this limited database it was important to take full advantage of the available data. The aim of this study is to describe and interpret the borehole image logs, wire-line logs and the available cores and combine them to establish depositional environments, palaeo sediment transport directions within these environments, and the stratigraphic development of the formation based on sequence stratigraphic principles within a biostratigraphically calibrated framework. The results were used as input for reservoir evaluation purposes, however this aspect is not discussed here.

2. Geological setting

The Cook Formation belongs to the Dunlin Group (Pliensbachian – Toarcian; Vollset and Doré, 1984; Charnock et al., 2001) and is bound by the offshore Burton Formation below and the offshore Drake Formation above in the Tampen Spur area. It has been described as a succession of relatively shallow marine deposits (Ager, 1975; Gage and Doré, 1986; Dreyer and Wiig, 1995; Marjanac and Steel, 1997). In the study area, the Cook Formation is of Toarcian age and is time-equivalent with the Cook Formation found in the Gullfaks Field (Fig. 2). The formation was sourced from the eastern basin margin and prograded westwards due to the Late Pliensbachian rift margin uplift (Charnock et al., 2001; Husmo et al., 2003) and shows a maximum westerly extent into the Statfjord Field (33/12) (Dreyer and Wiig, 1995) (see Husmo et al. (2003) for palaeogeographical maps of the Cook Formation in the northern North Sea). The Cook Formation was deposited at a time when marine waters had transgressed over parts of the Triassic and Lower Jurassic sediments mainly fluvial Statfjord Formation in the northern North Sea (Steel, 1993) and formed a narrow seaway (Husmo et al., 2003). The Cook Formation can be divided into two distinct units, a lower (regressive) and an upper (transgressive) unit of the Cook Formation (Steel, 1993) and this study also uses this nomenclature.

The northern North Sea experienced rifting and extension in the Late Permian to Early Triassic epoch with development of north–south trending faults (Fig. 1), and was followed by general post-rift thermal cooling and subsidence (Gabrielsen et al., 1990; Yielding et al., 1992; Steel, 1993). These Permo – Triassic faults are also

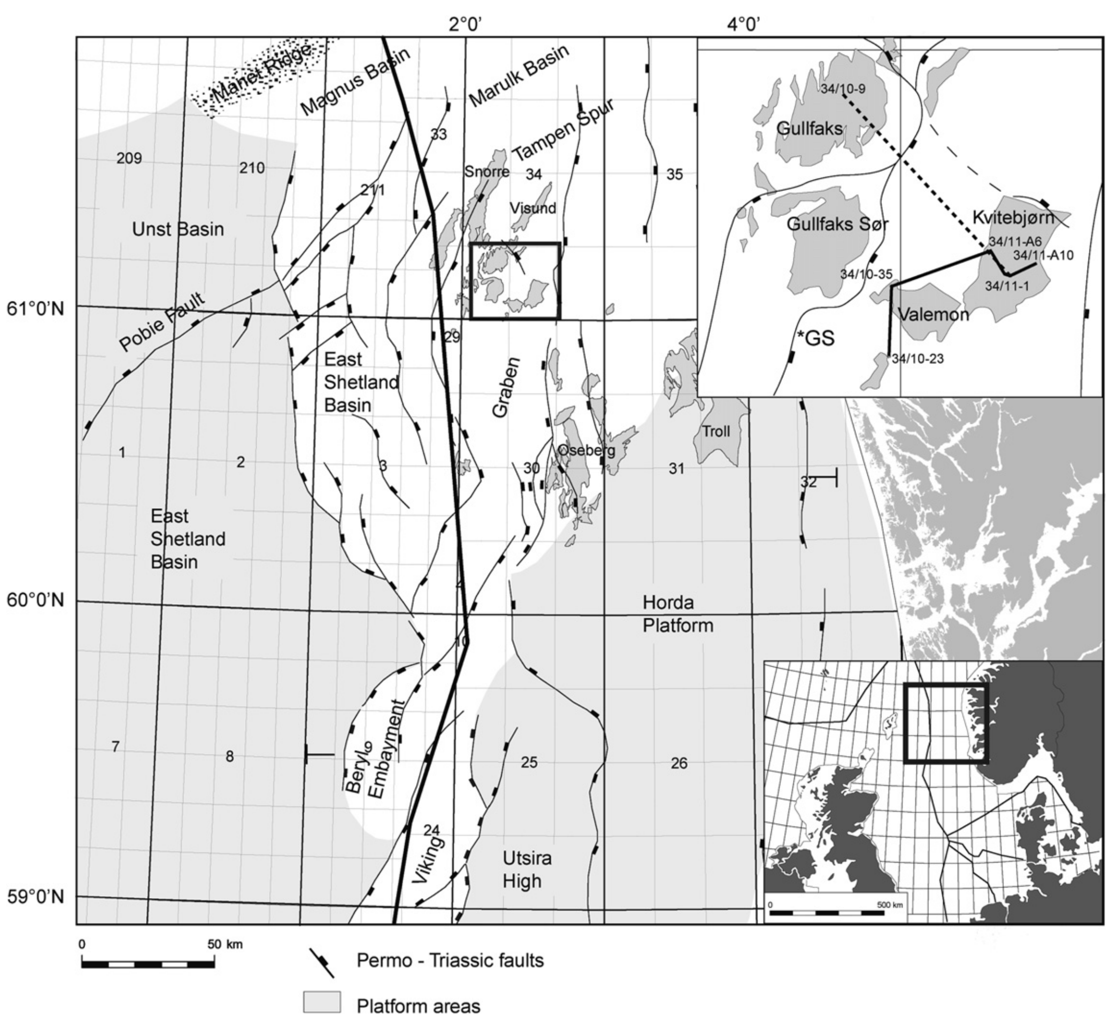

Figure 1. Basin configuration map of the northern North Sea, modified from Færseth (1996). Indent map show the study area with blocks 34/10 and 34/11 and Permo – Triassic fault pattern (modified from Rouby et al., 1996) with the position of the well-correlation panel in Fig. 16 and the seismic cross-section in Fig. 17. Dashed line indicates the well correlation shown in Fig. 2. Note the indicated Gullfaks Sør (GS) fault which is discussed later in the text.