

Seismic in Understanding a Geological Model: Exploration in the UK Southern North Sea Rotliegend Transition Zone*

By

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Introduction

The Cleaver Bank High in Quad 49 in the Southern North Sea (SNS) is Shell Expro's and joint venture partner ExxonMobil's Rotliegend Transition Zone heartland and is located along the northern fringe of the conventional Rotliegend fairway (Figure 1). It contains several discoveries and fields that are being appraised and developed. The Carrack field is the JV's most significant discovery in the area and will be brought on stream in Q4 2003. Although the UK SNS Rotliegend creaming curve is flattening (Figure 2), new technology and closer cooperation between exploration and production continue to unlock relatively small but high-value volumes. The future Carrack hub and the recent success of the Cutter appraisal well (49/9a-7) have increased the attractiveness of the area for further exploration.

Our objective is to demonstrate that exploration in the Rotliegend Transition zone can be done more successfully by the application of depth migration followed by inversion since they can lead to a better understanding of the local intra-Rotliegend lithology.

The Geological Challenge

Since Tertiary charge is abundant and the Rotliegend reservoir is capped by a thick sequence of Zechstein evaporitic seals, the major risks and uncertainties are "structure" and the occurrence of "producible reservoir". Unlike some parts of the Dutch offshore sector, Top Rotliegend in Quad 49 is a fairly low-relief surface. Directly north of the Permian erg (Figure 1, the "100% sand line"), the Upper Rotliegend sediments (Silverpit Formation) form an interplay of fine-grained sabkha deposits and coarser grained sands of predominantly fluvial origin with minor aeolian input. Farther to the north this unit shales out and becomes interbedded with halite. There it forms a seal to the underlying Basal Leman Sandstone, examples of which can be found in Cutter (49/9a-3) and Markham (49/5-2) (Myres et al., 1995). The presence of this sandstone seems to be controlled by paleo-topography and/or syn-sedimentary faulting (Maynard et al., 2001; Geluk et al., 2002) and is therefore difficult to predict. In the area several wells that have

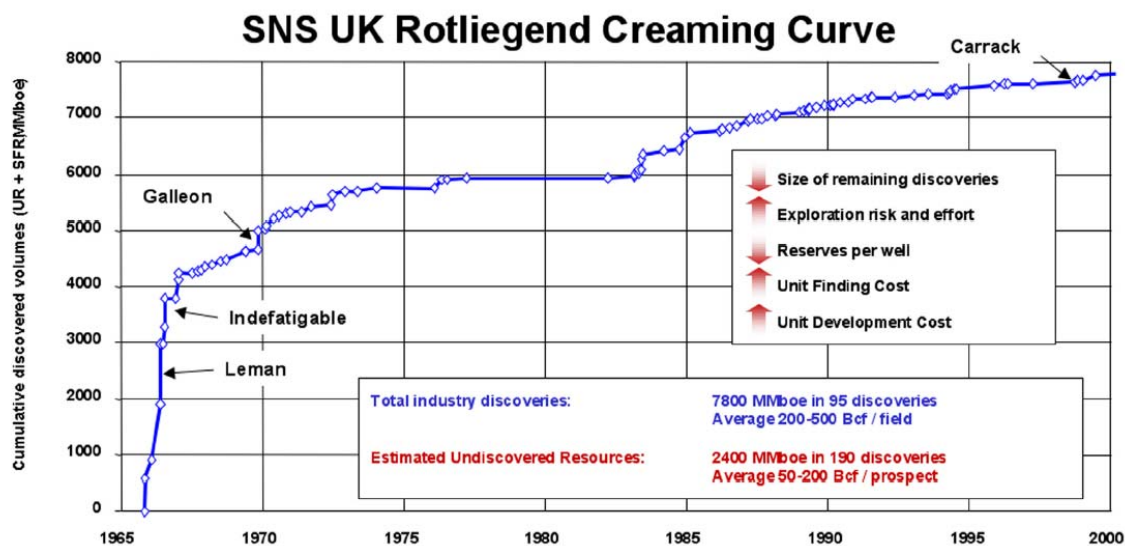


Figure 2. UK SNS Rotliegend creaming curve demonstrating the maturity of the play.

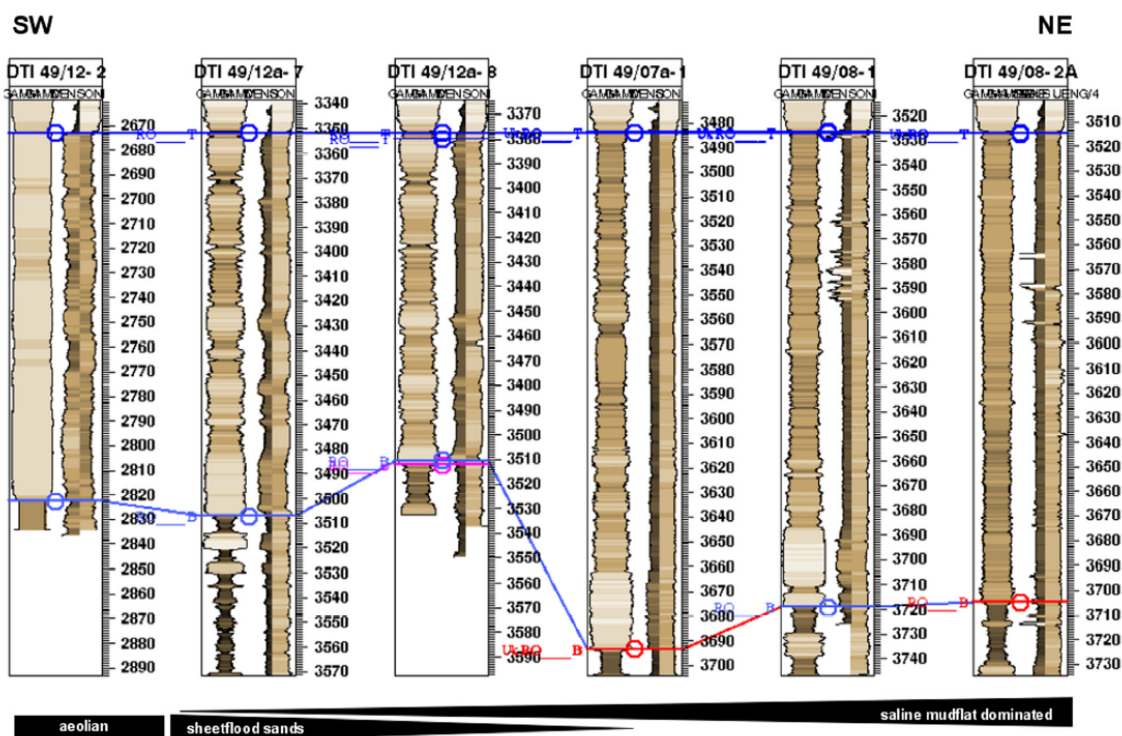


Figure 3. Well panel showing the Rotliegend (Silverpit Formation) transition from erg in the southwest to the shales in the northeast.

Method to Better Intra-Rotliegend Lithology Prediction

Below we will discuss our approach to better local intra-Rotliegend lithology prediction through the use of acoustic impedance data derived from depth-migrated seismic. Due to significant overburden complexities in this area, like the high-velocity-gradient Chalk and salt tectonics, imaging based on (anisotropic) velocity models is the preferred methodology. The results of this approach and impact on exploration potential will be illustrated on the basis of three examples.

Depth Migration Methodology and Inversion

To obtain optimal data quality and minimise costs, pre-stack data of different seismic surveys have been preprocessed and merged in order to have pre-stack input gathers available for depth migration. In parallel a large-scale 1600 km² initial anisotropic velocity/depth model has been generated on the basis of stacking velocities, well data, and horizons picked on various time-migrated data sets. Using this anisotropic velocity model, a post-stack depth migration (PostSDM) has been performed using a stack of the PreSDM input gathers. This approach has the following advantages:

1. In areas of relatively simple geology the imaging and positioning is better than that of the post-stack time migrated data.
2. The data allow a consistent interpretation on one seismic data set in depth that generally matches the wells (unlike any isotropic depth migration).
3. A calibrated structure map can be generated by interpretation of Top Rotliegend on the PostSDM in depth (no overburden horizon interpretation required) and by application of an error correction grid (the use of one anisotropy factor per layer in the velocity model prevents the interpretation in depth to match the wells exactly).

In case the imaging on the basis of the post-stack depth migration is not of sufficient quality, iterative pre-stack depth migration is required. Residual move-out analysis on common image gathers not only validates the correctness of the velocity model for imaging, but, in combination with the well matches, it can also improve the confidence in the anisotropic velocity model for depth conversion (assuming mild lateral variations in anisotropy within a layer and a target that is not too deep). If the model is of sufficient quality, selected 2D lines can be 3D migrated, and imaging enhancements can be evaluated prior to performing a full 3D PreSDM.

After availability of the depth migrated data set, of which the imaging can be improved further by application of post-migration image-enhancement filters, an inversion has been done. A good seismic-to-well match is critical for the inversion to be successful.

Examples

In our first example we show how an assumed Basal Leman prospect identified at Top Rotliegend level becomes less attractive after better imaging. Over this particular prospect the overburden geology is relatively simple, and as a result the imaging after the PostSDM has improved sufficiently to establish reliably the presence of the Basal Leman. Analysis of the fault based on the new Top and Base Basal Leman interpretation shows sand-sand juxtaposition (Figure 4). Although small-offset faults with sand-sand juxtaposition can seal via cataclasis, one would expect to find encouragement from Basal Leman amplitude anomalies, either related to gas fill or better preserved porosities due to early preserved charge, if the fault would be sealing. However, unlike at the gas-filled 49/9a-3 structure (Cutter), we do not see any amplitude anomaly. This example demonstrates the importance of intra-Rotliegend interpretation and attribute analysis when being in the Transition Zone. This can only be done when the imaging is of sufficient quality.

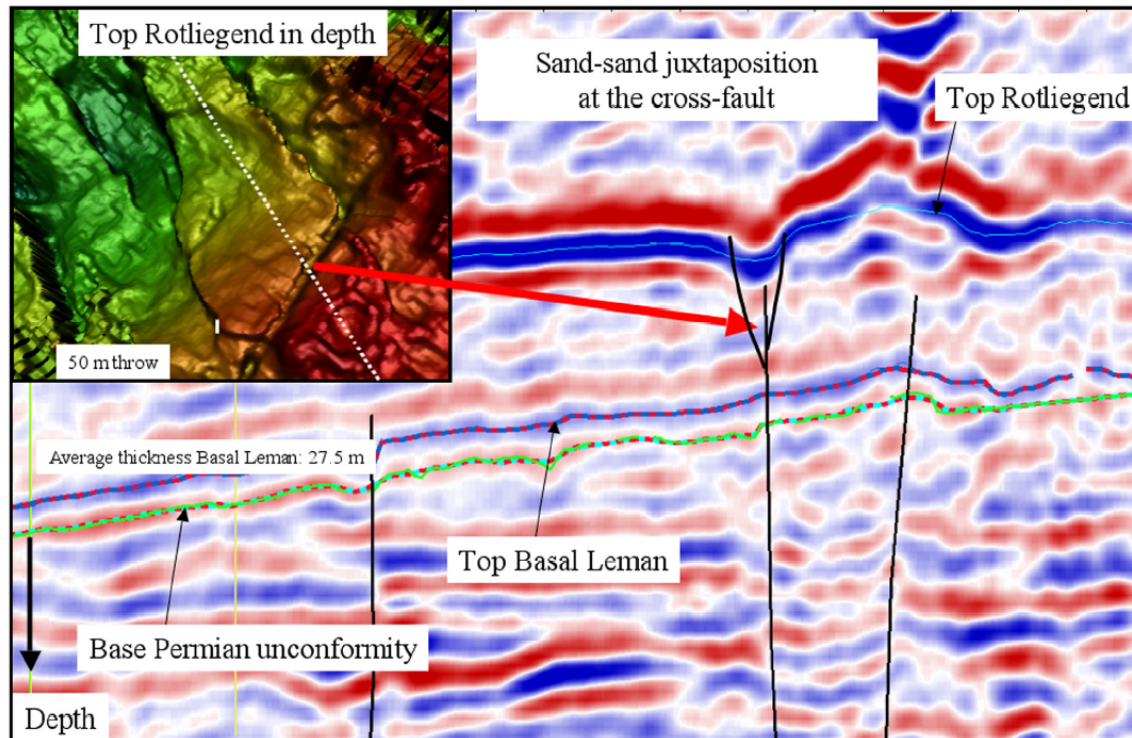


Figure 4. Although a cross-fault with 30+ m offset seems to be present at Top Rotliegend, the offset seems to die out when approaching the Base Permian. The interpretation of Top and Base of the Basal Leman Sandstone demonstrates sand-sand juxtaposition.

In our second example, a very low-relief structure, we show how a 3D-in-2D-out PreSDM test, a quick and low-cost exercise, has led to critical imaging improvements (Figure 5) and to more confidence in the velocity model for the depth conversion. On the PostSDM, and also on the post-stack time migration, the Basal Leman Sandstone is not well visible. It is unclear whether this is caused by an artifact or whether this is true

geology. Looking regionally, it could well be possible that we are dealing with a Carboniferous paleo-high on which no Basal Leman Sandstone was deposited. The results of the 3D-in-2D-out PreSDM test based on the PostSDM model tell a completely different story: although faulted, the Basal Leman Sandstone does seem to be present. As a result the local depositional model has been refined in between the well locations, and the probability of finding reservoir has been increased. In this case the flat common image gathers have also resulted in more confidence in the model for depth conversion over this low-relief structure.

The third example is from the 49/9a-3 (Cutter) area. After 3D PreSDM, a sparse spike inversion has been performed, the results of which are shown in Figure 6. Detailed examination of the inversion data set reveals a lot of information about the depositional model. In the top part of the Silverpit Formation a soft shale can be seen. Directly above the Base Permian unconformity, the Basal Leman Sandstone is present quite distinctly as a soft layer. Also, thickness variations that can be picked-up have been confirmed at the Cutter appraisal well. Above the Basal Leman there is a hard shale, most likely the equivalent of the Dutch "Ameland Shale". This shale can be interpreted over longer distances, and its continuity reduces the risk of having a thief zone in the Silverpit Formation.

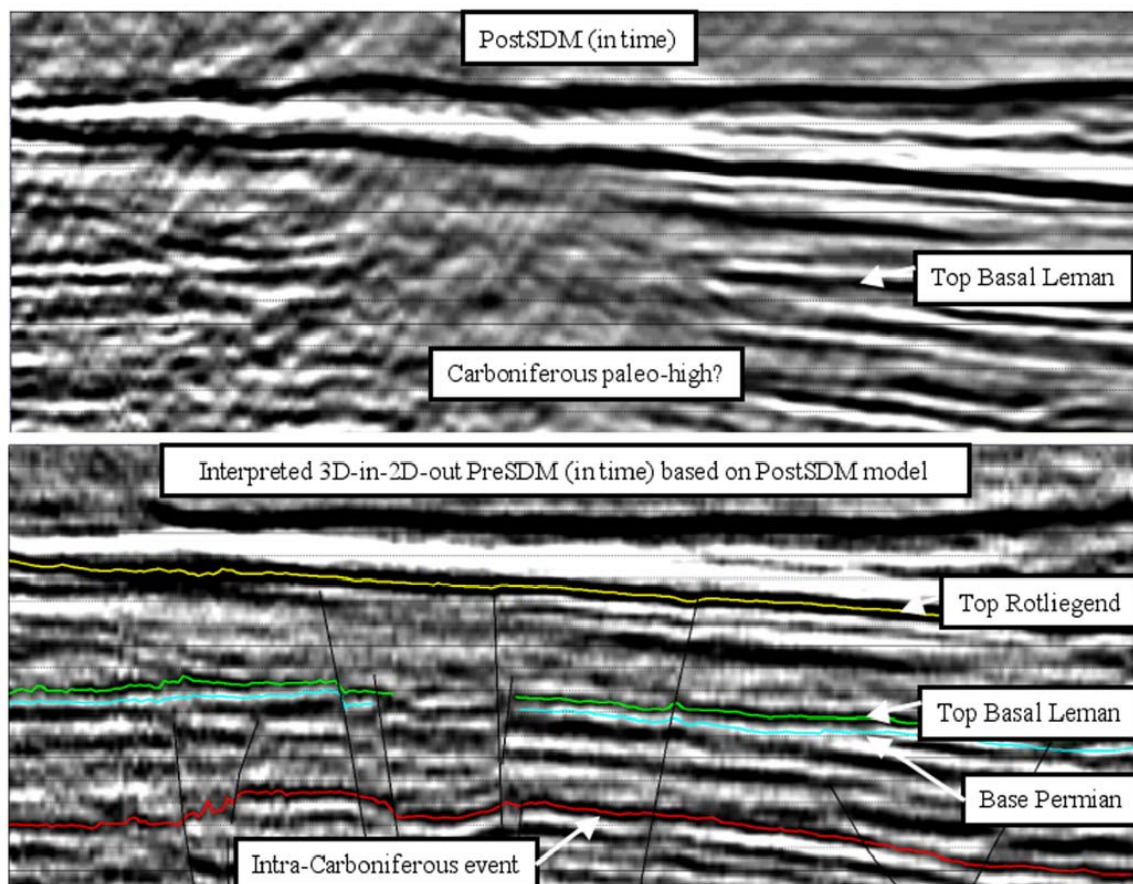


Figure 5. Example of imaging improvements through pre-stack depth migration (PreSDM). On the PostSDM in time (above) the Basal Leman seems to onlap on a Carboniferous paleo-high. On the PreSDM test based on the same model (below) the Basal Leman is clearly present.

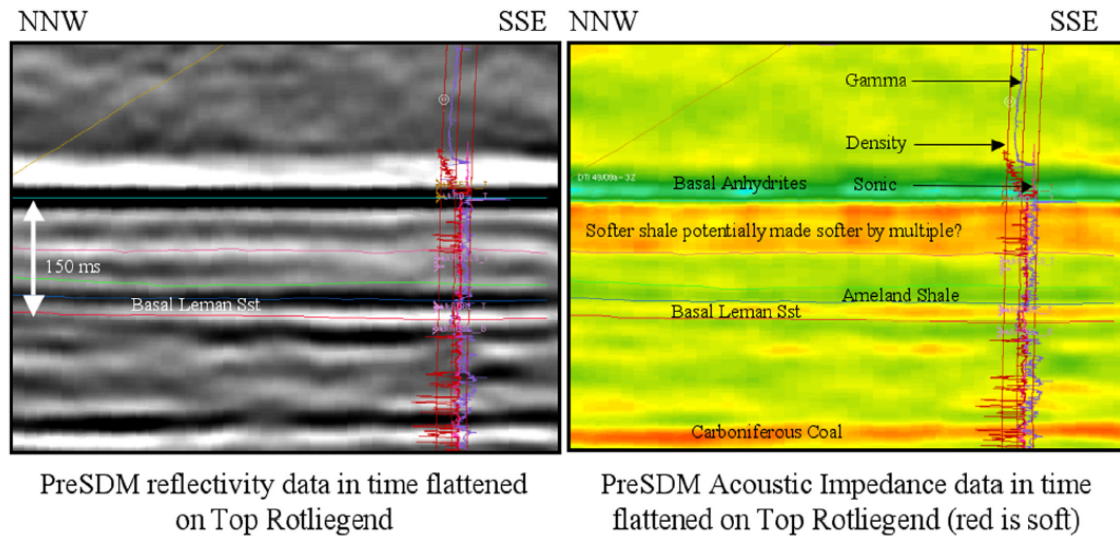


Figure 6. PreSDM reflectivity data (left) and acoustic impedance data (right) cross-section. Through the Cutter 49/91-3 well flattened on Top Rotliegend. Colour convention AI data: orange means soft; green means hard.

Conclusions

Exploration and development in the Rotliegend Transition Zone in Quad 49 can be done more successfully by intra- Rotliegend seismic interpretation and attribute analysis, both on depth migrated reflectivity and acoustic impedance data. The analysis of the different reservoir units in turn critically depends on the quality of the seismic image. The use of a combination of post- and (3D-in-2D-out) pre-stack depth migrations, preferably based on an anisotropic velocity model, has proven to be a cost effective and flexible means to address critical issues quickly for a sizeable exploration area. Once an interesting prospect has been identified, a full 3D PreSDM and inversion can further de-risk the local geological model. The approach requires very close cooperation between the geological and geophysical specialists in order to be most effective.

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