

The Upper Carboniferous reservoir fairways over the Dutch offshore Cleaver Bank High: stratigraphy, sedimentary development and reservoir potential

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1) Introduction

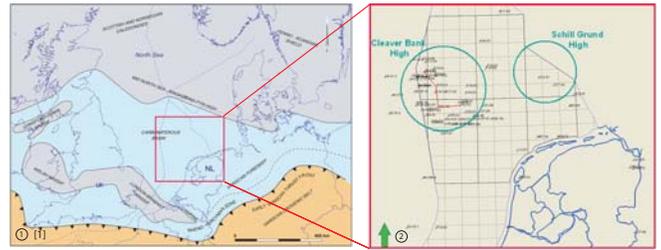
In this poster we report on the results of a regional geological study of the Upper Carboniferous in Dutch offshore. The study was performed by PanTerra Geoconsultants (Database management, seismic interpretation, geological modeling), TNO Geo-energy (project management, biostratigraphy, sedimentology, basin modeling) and ENRES International (Cyclog analysis, well correlation).

The aim of the study was to collect all relevant data of the offshore Upper Carboniferous gas play into one data-base and to construct a Petrel 3-D static geological model of the Upper Carboniferous. The Petrel model locates sand-prone Carboniferous intervals and thus assists and stimulates exploration for Carboniferous gas.

For this purpose all relevant geological and geophysical open-file data were loaded in Petrel. This was followed by seismic interpretation of the Carboniferous and a stratigraphic study of the wells based on wireline logs, palynology and sedimentology. The combined geophysical and stratigraphic data were used to build a regional static geological model in Petrel.

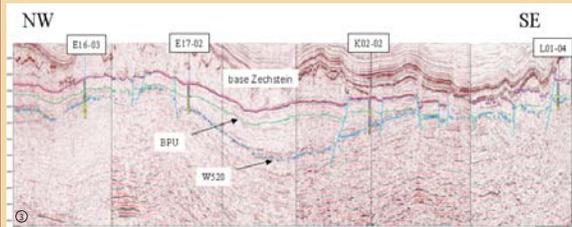
In addition, sedimentary analyses and basin modeling were carried out to increase understanding of reservoirs and hydrocarbon prospectivity. All this data were included into the Petrel database.

The study area is depicted in Figures 1-2 and covers two areas: the western Cleaver Bank area and the eastern Schill Grund High. Shown on this poster are the results of the Cleaverbank High only. Included in the project are 35 3D-seismic surveys and more than a hundred wells.



2) Seismic Interpretation

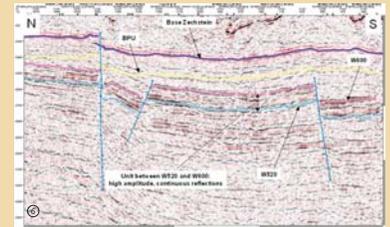
The Base Permian Unconformity (BPU, Figure 3 and 6) separates the Carboniferous from the overlying Permian Rotliegend (mostly the Silverpit Formation in the area of the Cleaver Bank High). Seismic interpretation of the Carboniferous is difficult due to poor seismic data quality in particular below thick Permian Zechstein salt accumulations and in areas of structural complexity. The BPU is indistinct on seismic data over large areas, but has been located by using well tops of about 81 wells.



In large parts of the Cleaver Bank High three seismic facies units can be recognized in the Upper Carboniferous, these are from top to bottom (Figure 6):

- 1) The upper seismic unit is relatively little reflective and has discontinuous reflections. This seismic unit can be correlated to the Westphalian B Coal Measures. Its upper boundary is the BPU; its lower boundary is the W 6000 seismic marker.
- 2) The middle seismic unit is highly reflective with high-amplitudes and continuous reflections. It is distinct from under- and overlying units that have lower reflectivity and discontinuous reflections. This seismic unit can be correlated to the Westphalian B Coal Measures. The distinctive seismic response is related to the alternation of thin coal beds with thin shale and sandstone layers. The coal beds generate primary reflections as well as strong inter-bed multiples. Due to constructive interference the amplitude reflectors cannot be correlated to individual coal beds. The base of this unit is seismic reflector W520. The W520 forms a good seismic marker and correlates to a distinct Cyclog well marker. The top of the unit, W600 is not interpreted as extensively as W520 (Figure 3), since it is truncated in many areas by the BPU and it is less clear on seismic data.

3) The lower seismic unit shows little reflectivity and has discontinuous reflections. Towards the South the lower unit changes in character with more continuous and higher amplitude reflectors. Most likely this is related to the increased coal content towards the South. The upper boundary separating the middle and the lower seismic units is the W520 Horizon. The lower boundary of the lower seismic unit is not defined in this study.



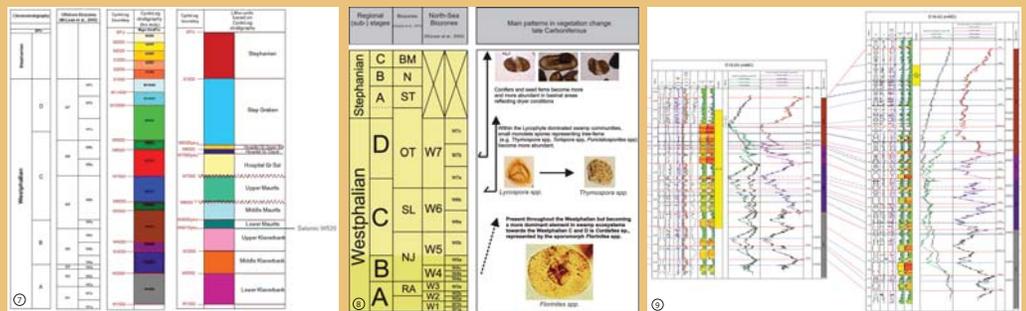
3) The Well Correlation Framework

A high-resolution stratigraphic well-to-well correlation framework was developed (Figure 7) using the log-based method of Climate Stratigraphy (Figure 9; see De Jong et al., 2007 and references therein) and integrated with the results from conventional wireline log correlation techniques and palynological (Figure 8) and seismic interpretations (Figures 3 and 6).

Climate Stratigraphy uses spectral trend analysis (waveform analysis Cyclog software) of GR logs to reveal trends and trend changes in the lithofacies succession (Figure 9). Guided and constrained by biostratigraphic and seismic data, time-equivalent depositional trends and trend changes have been identified and correlated between the wells. A high-resolution stratigraphic framework has been generated with 11 major stratigraphic packages in the Westphalian and 5 in the Stephanian (Figure 7); higher-order units have been differentiated within the major units.

Palynological biostratigraphical data of the Westphalian interval from selected wells were reviewed and updated to the latest biozone schemes. In addition a small selection of key-wells without publicly available palynological data were sampled and analysed.

The high-resolution stratigraphic subdivision was converted to a scheme of litho-units (Figure 7), which, in turn, were input to the geological model.

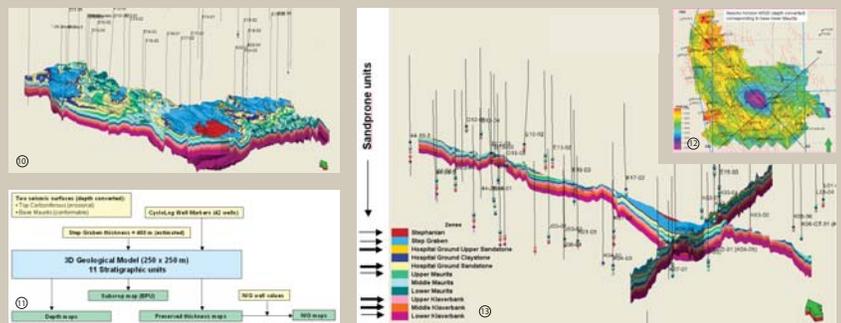


4) The Petrel Geological Model

The W520 seismic horizon corresponds to the W4210pbs Cyclog well markers and the base of the Lower Maurits and this provides the link between stratigraphic subdivision and well-based stratigraphic subdivision (Figure 7).

A 3D geological model for the Cleaver Bank High was created in Petrel (Figure 10), see the simplified workflow diagram (Figure 11). The model has been built from a 3D grid of 250x250 meter, in depth. Fault interpretation has not been included. Two depth oriented seismic horizons are the input: 1) top Carboniferous and 2) the base Lower Maurits (W520, Figure 12). The horizon top Carboniferous (=BPU) is defined in the Petrel model as erosional, it is the top of the 3D geological model. The base of the Lower Maurits is defined conformable. Input for the 11 stratigraphic units are the well-based stratigraphic markers. In the model all stratigraphic units (zones in Petrel terminology) were built conformable from the base Lower Maurits upward and downward (Figure 13).

The resulting geological model allows the generation of cross-sections through any point in the model (Figure 13), various maps (depth, thickness, subcrop, sand fraction), slices and block diagrams (Figures 16 - 19).



5) Sedimentary Development

Deposition in the study area took place in a basin between the Variscan orogenic chain in the south and faulted highs in the north. N/G sand values suggest a dominantly northern source during the Westphalian. There are indications for a possible sediment supply from the south in the southern part of the area, especially in the late Westphalian. The following sequence of events was reconstructed:

1) Deposition during Westphalian A and early B (Klaverbank litho-units) was in alluvial-fluvial depositional environments. Braided fluvial systems progressively built out southward across distal grey-coloured muds and peat-dominated sediments in large-scale cycles, followed by rapid retreat.

2) During the late Westphalian B to early C (Lower and Middle Maurits, Figure 15) the deposition of grey-coloured muds and coal was dominant, with little influence of fluvial systems. The fairly sudden inactivity of the early Westphalian fluvial system was possibly the result of widening of the basin, whereby sediment-supply areas were flooded and rivers were forced to retreat northward.

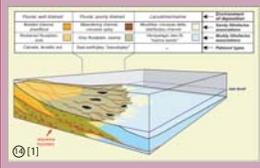
3) The upper Westphalian C (Upper Maurits, Figure 15) grey-beds show increased content of coarse-grained sediments and few coals, suggesting a reversal of the large-scale trend, back to an overall progradational fluvial setting, but sandstone percentage remains low. The base of this unit (W6000, Upper Maurits) may be a minor unconformity (Figure 15).

4) An unconformity occurs at the base of the Hospital Ground Sandstone (base W7000, Figure 15), possibly linked to a tectonic event. The overlying Westphalian C-D and Stephanian consist of alternating thin conglomeratic sandstones and fine-grained red-beds; coals and organic-rich shales are rare. Sandstone-dominated intervals alternate with mudstone-rich intervals on a large scale (Figures 16 - 19).

5) Following the deposition of Stephanian strata major tectonism occurred, with deformation and uplift, ultimately resulting in the formation of the BPU. Widespread erosion of primarily Stephanian and to a lesser extent Westphalian strata occurred.

Reservoir potential
Potential reservoir fairways are defined by the sand-prone intervals below the BPU. Major sand-prone units are the three Klaverbank litho-units, the Hospital Ground Sandstone, the Hospital Ground Upper Sandstone.

- References**
[1] J.M. van Buggenum & D.G. den Hartog Jager, 2007, Silisian. In: Wong, T.E., D.J. Bates and J. de Jager (eds), *Geology of the Netherlands*, p.43-62. (Figures 1 and 14)



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Please contact one of the authors for details on how to acquire this report and associated datasets and Petrel model.

