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Identification and Evaluation of CCS Sweet Spots in the West Netherlands Basin

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SUMMARY

Carbon Capture and Sequestration (CCS) is expected to become a serious CO2-emission reduction technology in the Netherlands, for example in the mature West Netherlands Basin (WNB). This study aims to identify and evaluate potential CO2-storage reservoirs based on geological boundary conditions. These criteria are applied to a basin-scale structural model of the WNB in combination with a literature review on lithology and petrophysical parameters of the targeted Triassic and Upper Jurassic to Lower Cretaceous intervals. Selected 'sweet spots' are evaluated through the construction of high-resolution 3D static reservoir models. These serve as the basis for estimations of CO2-storage capacity, dynamic flow modelling and overburden studies.

The results of this study are not only important for the selection of locations for future CCS projects, but they also serve to assess the proposed workflow, showing that reservoir structure, facies architecture and petrophysical properties play a major role in calculating storage potential. Furthermore, the conventional approach to calculating CO2-storage capacity from average petrophysical values is found to significantly overestimate injectable volumes when compared to the results of this study. This emphasises the need for an accurate facies distribution model in estimating the CO2-storage potential.

Introduction

Carbon capture and sequestration (CCS) is expected to become a serious CO_2-emission reduction technology in the Netherlands. The industry- and government-supported national research programme *CATO-2* is tasked to investigate the opportunities and feasibility of CCS projects, both onshore and offshore in the Dutch territory. To this end, demand-driven research is performed with focus on facilitating and enabling integrated development along the entire CCS chain.

An example of geological CO_2-storage opportunities are the deep aquifers and (soon-to-be) depleted gas reservoirs in the West Netherlands Basin (WNB), conveniently situated near CO_2-emitting sources in the Rotterdam industrial area and a future >1,000MW coal-fired power station. The WNB is a mature area with a declining production of predominantly natural gas, but also oil. Production started in the 1950's and is mainly from Triassic and Upper Jurassic to Lower Cretaceous intervals (De Jager & Geluk, 2007).

As part of the *CATO-2* research, an identification and evaluation study of *sweet spots* for CO_2-storage in the WNB was performed to assess the opportunities for future CCS development. In this paper, the results of this study and their implications for assessing the storage potential are briefly elucidated.

Basin geological setting

The regional geology of the WNB has been extensively described in earlier publications (e.g. Racero-Baena & Drake, 1996, and Wong et al. 2007); therefore only a summary will be presented here. The WNB is a basin (150 by 60 km; Fig. 1) with a complex geological history, involving phases of rifting, regional peneplanisation and basin inversion, causing several angular unconformities (Fig. 2).

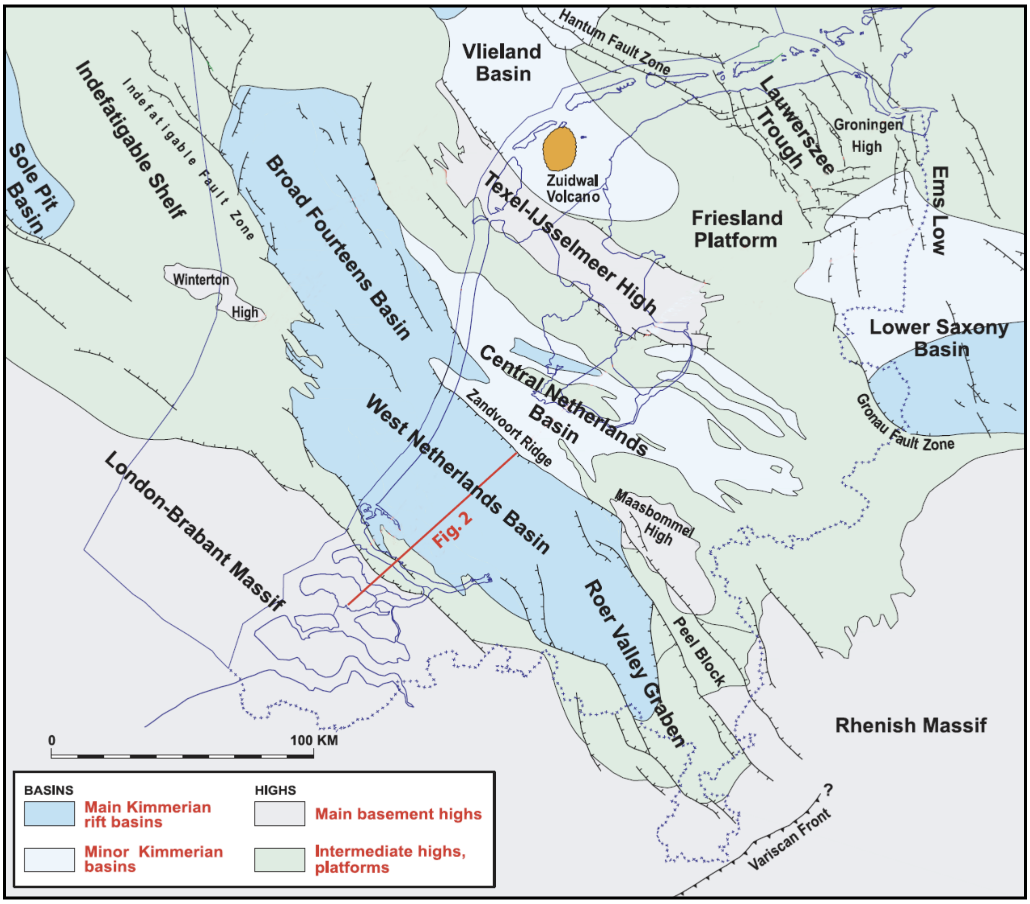

Figure 1 *Structural map of the Dutch subsurface showing Jurassic and Early Cretaceous basins, highs and platforms, including the West Netherlands Basin (modified from De Jager, 2007).*

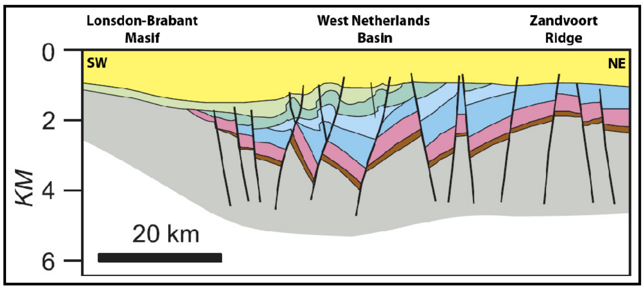

Figure 2 *Regional cross-section of the West Netherlands Basin (Fig. 1); colour legend in Fig. 3 (modified from De Jager, 2007).*

A thin package of Lower Permian *Rotliegend* clastics were laid down on the Variscan unconformity, followed by Upper Permian *Zechstein* clastics and carbonates. Unlike in the rest of the Northwest European Gas Province, salt deposits are absent. Due to their proximity to the London-Brabant Massif in the south, Triassic *Buntsandstein* clastics adjacent to this structural high are thicker and sandier when compared to parts of the basin further to the north. Lower and Middle Jurassic rocks are mainly marine shales, including the prolific *Posidonia Shale* oil source rock (Fig. 3).

During the Late Jurassic and Early Cretaceous, the WNB was subjected to phases of intense rifting. Initially, only terrestrial clastics of the *Delfland Subgroup* and *Vlieland Sandstone* were deposited (Fig. 3), but subsequent sediments were laid down in marine environments.

In the Late Cretaceous, a thick package of Chalk was deposited over the WNB (Fig. 3). Later on in the Cretaceous, structural inversion of the basin started and large sections of older rocks were eroded below a Paleogene unconformity, particularly in the centre and the eastern part of the basin (Fig. 2). During most of the Cenozoic, slow subsidence and clastic deposition took place and faults became inactive.

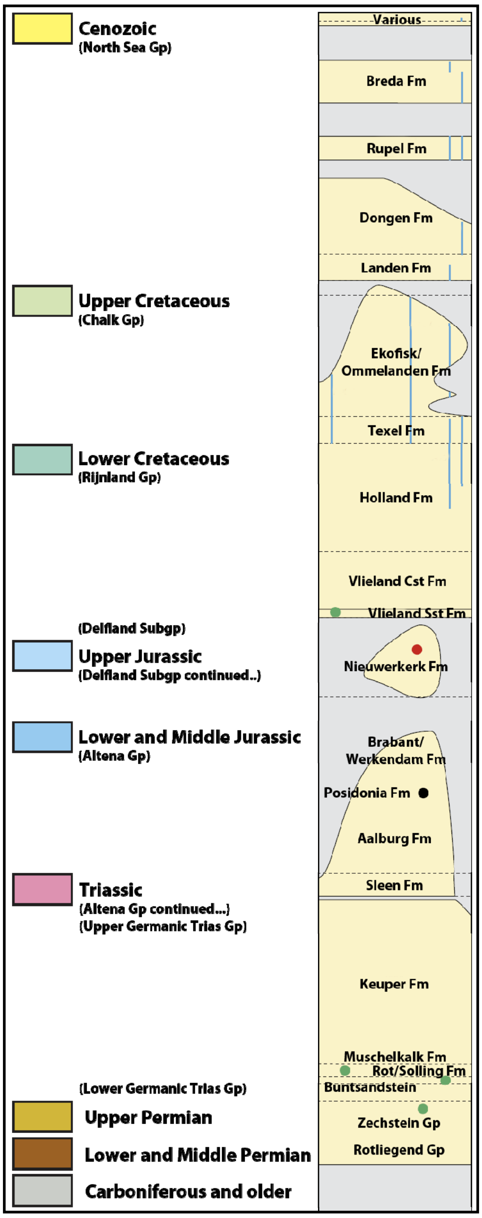

Figure 3 *Tectono-stratigraphic chart of the West Netherlands Basin (modified from De Jager, 2007, and TNO, 2011).*

Basin model and sweet spot identification

The identification of *sweet spots* for CO_2 storage is based on pre-defined geological boundary conditions, including trap type, geological and petrophysical reservoir architecture, top-seal and fault-seal quality, CO_2-storage capacity and reservoir depth, contributing to a cost-efficient reservoir (re)development at low environmental impact. These criteria are applied to a basin-scale structural model, in combination with a literature study on the lithology and petrophysical properties of the targeted stratigraphic intervals. The procedure used to do this is similar to that conducted by Bachu (2003) to assess and rank sedimentary basins for CO_2 sequestration.

The data required for the construction of a basin-scale structural model of the WNB are gathered from a public database, along with a selection of models from earlier regional studies:

- A representative selection exploration and development wells, including deviation tables and well completion logs.
- All available 3D seismic data.
- The *VelMod-2* regional velocity model (Van Dalfsen et al. 2007).
- Regional mapping of major faults (Duin et al. 2006).

Based on this dataset, a new tectono-stratigraphic framework is developed for the targeted Triassic and Upper Jurassic to Lower Cretaceous intervals to correlate the wells over the entire basin. Nine discernible horizons are interpreted from the available seismic data and correlated accordingly. These are then converted from time to depth using the velocity model and the corresponding well tops. Next, a fault model is created from the regional fault maps and all seismic and non-seismic horizons are reconstructed, honouring both well correlation and fault offset.

Thickness maps are derived from the structural model and combined with depth maps to identify geological structures suitable for CO_2 storage. Lithology and petrophysical properties of the targeted intervals are then derived from literature. Based on this information, the suitability of each potential reservoir for CO_2 sequestration is assessed.

Sweet spot reservoir models and storage potential

Based on the analysis and correlation of comprehensive subsurface datasets, provided by *CATO-2* partners, high-resolution 3D static reservoir models are constructed for identified CO_2-storage *sweet spots*. The higher density and completeness of the data allow for an accurate time-to-depth conversion, reconstruction of the structural architecture and modelling of the reservoir facies distribution. The models are populated with known petrophysical properties from the targeted intervals in the area and core tests (Fig. 4), in close correlation with the facies architecture.

The static models serve as the basis for CO_2-storage capacity estimations, dynamic flow modelling and overburden studies. The various uncertainties in e.g. structural architecture, facies distribution and petrophysical properties are quantified through Monte Carlo simulation and their effects are evaluated. The results show that all of these factors have a significant influence on volumetric calculations.

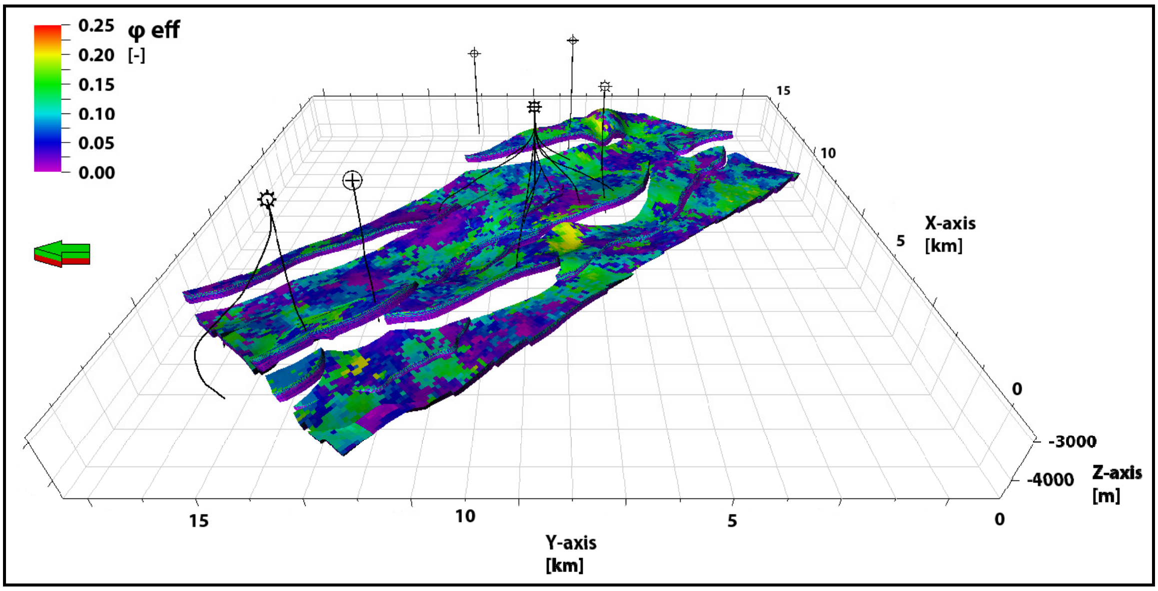

Figure 4 *Modelled distribution of effective porosity (φ_{eff}) in the Lower Triassic P18 offshore gas field. Existing wells are shown in black; arrow indicates the North.*

In case of the nearly-depleted P18 offshore gas field, a *Buntsandstein* (Lower Triassic) fluvial sandstone reservoir (Fig. 4), production data provide a solid baseline for validation of CO_2-storage capacity estimations. Furthermore, the estimated CO_2-storage capacity is compared with conventional estimates, which are based on anisotropic averaging of petrophysical properties without considering heterogeneity in the facies architecture. It is shown that, whilst the approach in this study still leaves a substantial uncertainty in the estimated storage capacity, the conventional estimates significantly overestimate injectable volumes and have an equal or greater uncertainty. Results from *Vlieland Sandstone* (Lower Cretaceous) shallow marine, coastal and fluvial reservoirs confirm this observation.

Conclusions

Through this study, important knowledge was obtained on the CO_2-storage potential of Lower Triassic and Lower Cretaceous reservoirs in the WNB. Not only are these results important for selection of locations for future CCS projects, but they also serve to assess the proposed workflow, showing that reservoir structure, facies architecture and petrophysical properties play a major role in calculating storage potential and cause a considerable uncertainty. In addition, the conventional approach to estimating CO_2-storage capacity from average petrophysical values is found to significantly overestimate injectable volumes when compared to the results of the approach in this study. This emphasises the need for an accurate facies distribution model and correlation of petrophysical properties in estimating the CO_2-storage potential.

Acknowledgements

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