

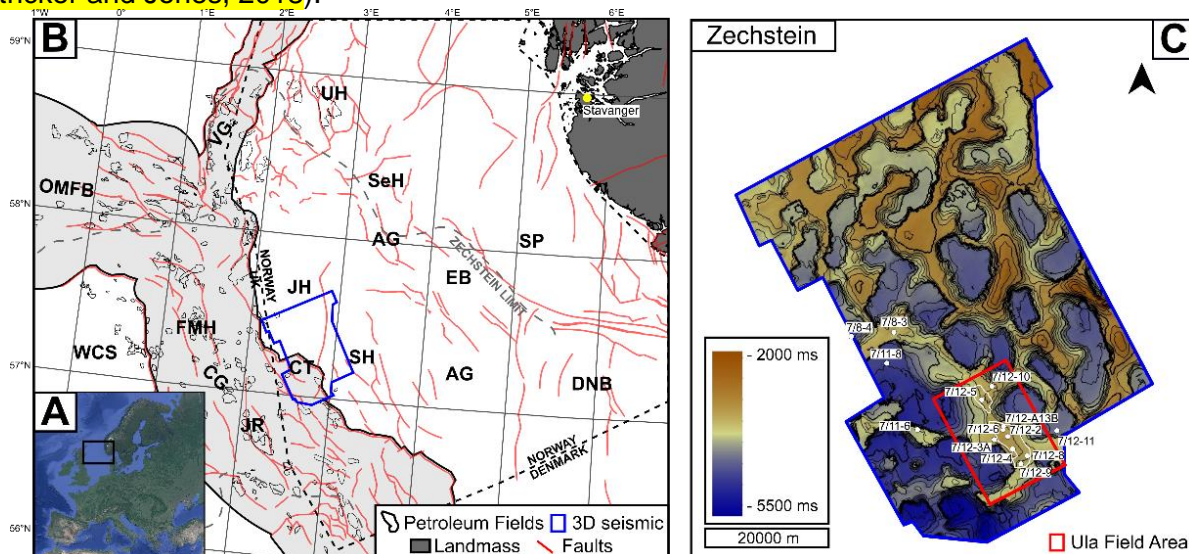
Effect of salt tectonics on Triassic sedimentology and reservoir quality

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Summary

The surging global demand for energy and the pressing need for energy transition have highlighted the significance of underexplored geological formations. These formations can potentially be considered as new sources of energy or storage options, and exploiting them could significantly enhance the quality of life by providing affordable and reliable energy while meeting low-carbon emission goals. To address this need, we have focused on the North Sea basin, which is situated between the UK, Norway, Denmark, Germany and the Netherlands. Although this basin has been considered a mature hydrocarbon province, it contains geological formations that are considered potential targets for hydrocarbon exploration and CO₂ storage. Examples of underexplored formation targets are the Smith Bank Formation and the Skagerrak Formation. The Smith Bank Formation consist of Early Triassic fluvio-lacustrine and aeolian sedimentary rocks (Wilkins et al., 2018). The Skagerrak Formation consists of an alternation of three sandstone and three mudstone-dominated members Middle - Late in age (Burgess et al., 2021). The Skagerrak Formation sediments are deposited by a series of distributive fluvial systems (DFS) (McKie, 2014). Each sandstone-dominated member represents the maximum extension phase of DFS while each mudstone-dominated member represents stages of DFS retreat. For a long time, the investigation of these geological formations has been restricted and hindered due to great burial depth, overpressure, sedimentological complexity related to the depositional environment (McKie, 2014), structural complexity including halokinesis (cf. Banham and Mountney, 2014), post-depositional erosion (Burgess et al., 2021; Archer et al., 2022) and diagenesis (Grant et al., 2014; Stricker and Jones, 2018).



AG, Åsta Graben; CG, Central Graben; CT, Cod Terrace; DNB, Danish-Norwegian Basin; EB, Egersund Basin; FMH, Forties Montrose High; JH, Jæren High; JR, Josephine Ridge; OMF, Outer Moray Firth Basin; SeH, Sele High; SH, Sørvestlandet High; SP, Stavanger Platform; UH, Utsira High; VK, Viking Graben; WCS, West Central Shelf (modified after Goldsmith et al. 2003). Stippled line delineates offshore Norway border; blue outline highlights area shown in B. (c) Top salt surface with location of the studied wells and minibasins, red outline shows the Ula Field Area.

A multidisciplinary approach was used to investigate the Triassic interval in the Central North Sea, using a complete subsurface data package from the region around the Ula Field in the Norwegian sector. The package includes a 3D seismic reflection survey, standard well-logs, and Triassic core. The study aims to determine how halokinesis affects sedimentology and stratigraphy and its impact on reservoir quality. The techniques and methodologies used in this study can be replicated in other basins worldwide.

Methods

To attain our objectives, we relied on a seismic facies approach (Mitchum et al., 1977) for interpreting seismic data. For well-log interpretation, we followed the guidelines laid out by Di Lauro et al. (in rev.). For core interpretation, we used seven sedimentary facies that were grouped into three sedimentary facies associations: Channel-Fill (CFA), Splay (SFA), and Floodplain (FFA) (cf. Gray et al., 2022). Dating and age estimates were based on Burgess et al. (2021). We used core data and core interpretation to identify primary factors controlling reservoir properties. We then created a neural network by combining core interpretation with well-log interpretation to predict facies association and thus reservoir quality along uncored intervals. This methodology provided insight into horizontal and vertical variations of reservoir quality. We merged well-log interpretation and petrophysical analysis with seismic interpretation to obtain a three-dimensional insight into the geological interpretation. The integration of multiple datasets allowed us to reconstruct the palaeogeography throughout the Triassic time.

Results

Integration of core data and core interpretation revealed that CFA bears the best reservoir properties whereas FFA the poorest. The neural network used for predicting facies association showed that reservoir quality increases upwards, as evidenced by the abundance of CFA. As matter of fact, the Joanne Sandstone Member has more CFA (37 %) compared to the underlying Judy Sandstone Member (23 %) and thus better reservoir quality.

The palaeogeographic reconstruction revealed the presence of multiple entry points for sediments during the deposition of the Smith Bank and Skagerrak Formation. During the deposition of the Smith Bank Formation, the area was covered by floodplain sediments but over time, more channel sediments were deposited. During the deposition of the Skagerrak Formation, there was evidence of both progradation and retrogradation of the DFSs.

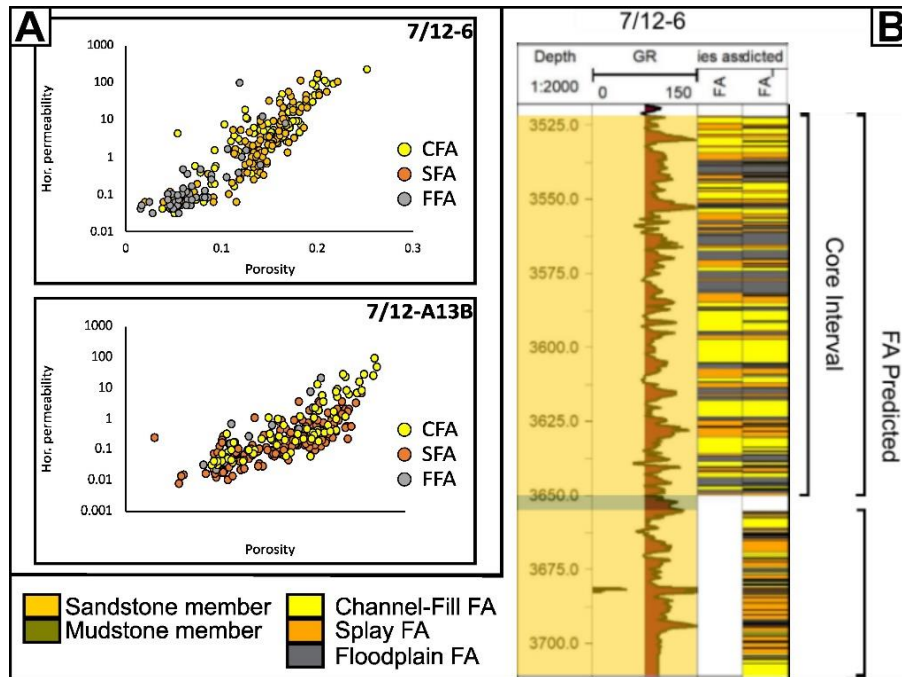


Figure 2 - A) Example of core porosity and core permeability analysis in two of the available wells; B) Example of Facies Association (FA) predicted along the uncored Judy Sandstone Member of the well 7/12-6.

Discussions

Through core data analysis, a correlation was found between core porosity and permeability. When integrated with facies associations, the results revealed that the primary control for reservoir quality is the depositional environment and facies. These findings are consistent with previous regional studies in the area (Grant et al., 2014; Gray et al., 2022). However, these studies also show that the Joanne Sandstone Member has high permeability, while in the same interval of the study area, we observed reduced values of permeability (< 200 mD, commonly <10 mD). These low values are a result of diagenetic processes that have altered reservoir quality in the area.

Our observations have led to the interpretation that the Judy Sandstone Member was deposited as part of the distal part of the DFS, whereas the Joanne Sandstone Member was interpreted as part of the medial zone of the DFS. This interpretation is supported by the abundance of channel deposits predicted and by the width of channel belts measured in the core.

The integration of data allowed the construction of four palaeogeographies representative of the Triassic time. During the initial stages of the deposition of the Smith Bank Formation, which is equivalent to the Induan time, we observed that salt was moving, but it did not create any topographic relief. This indicates that the distribution of fluvial sediments was not controlled by halokinesis. We observed a constant direction of sediment supply over time and we also noticed that the fluvial system prograded without any influence of the ongoing halokinesis. During Middle-Late Triassic, halokinesis proceeded and deposition was not influenced by salt movement. The deposition of sandstone members was characterized by an expansion and progradation of the DFSs whereas the deposition of the mudstone-dominated members was characterized by the

retreat of the DFSs. The proposed model is supported by the presence of the full Triassic section and by channel deposits in wells located on top of the salt highs and in minibasins. In the available dataset, it seemed that channel deposits were able to migrate freely across the area and were not impacted by the salt structures that were growing. This is a significant discovery as it shows that halokinesis did not influence the distribution of facies or the quality of the reservoir.

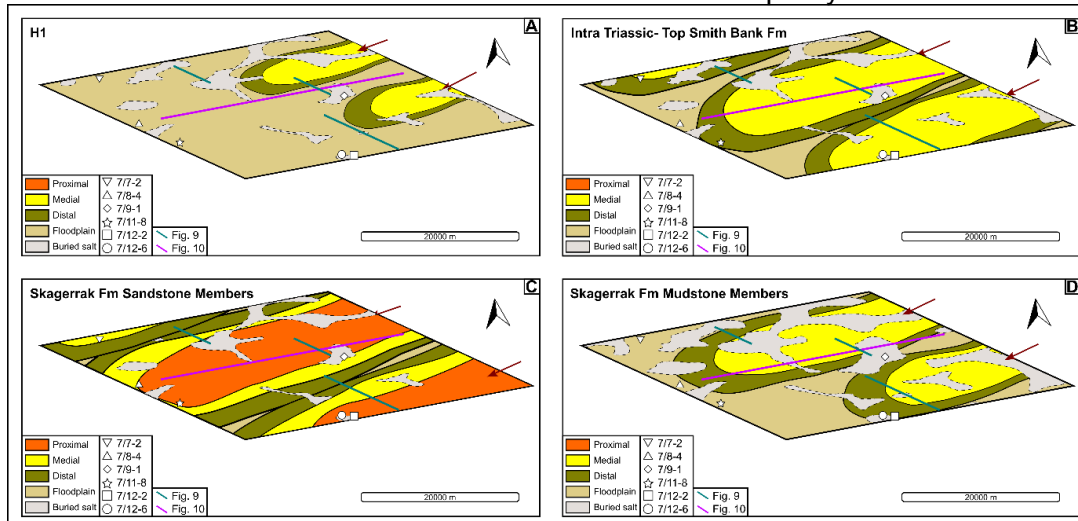


Figure 2 - A) Example of core porosity and core permeability analysis in two of the available wells; B) Example of Facies Association (FA) predicted along the uncored Judy Sandstone Member of the well 7/12-6.

Conclusions

This study demonstrated that porosity and permeability are linked and controlled by the Facies Association observed in core. Samples from the Channel-Fill Facies Association had the highest values of porosity and permeability while low permeability values were due to diagenetic processes in the Skagerrak Formation. By integrating core interpretation and well-log profiles, a neural network was created to predict Facies Association along uncored intervals, revealing an increase in reservoir quality upwards, indicating more channel deposits in the Joanne Sandstone Member than the Judy Sandstone Member.

The integration of the seismic interpretation with core and well-log interpretation showed that halokinesis occurred during the deposition of both Smith Bank and Skagerrak Formation. However, halokinesis did not have an imprint on the topography, suggesting that channel belts were free to migrate across the area, allowing sedimentation both on salt highs and in minibasins. Thus, salt mobilization did not affect facies distribution and consequently reservoir quality.

Novel Information

This study demonstrates that multidisciplinary approaches with the integration of different datasets at different scale can overcome exploration challenges. While this work was carried out in a portion of the North Sea, the concepts, methodologies, and techniques can be extended to other parts of the North Sea and replicated in other basins worldwide to increase knowledge and understanding while reducing exploration costs and risks. Furthermore, this study demonstrates for the first time the interaction between salt tectonics and sedimentation, revealing that the

sedimentology of the Triassic interval under investigation is not affected by salt tectonics. Moreover, this is the first time such a high-resolution study has been conducted on the Triassic in the North Sea. This study has enabled a full comprehension of the controlling factors for reservoir quality in the area.

Acknowledgements

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