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High Resolution Stratigraphy and Reservoir Heterogeneity of Khartam Member of Khuff Formation from Outcrop, Saudi Arabia

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SUMMARY

The Permian-Triassic Khuff Formation is the most prolific for natural gas production in the Middle East. Understanding the Khuff reservoir heterogeneity is important to enhance the hydrocarbon production. Integrated study including sedimentology, stratigraphy and digital outcrop modelling is applied here. The studied Upper Khartam Member outcrop is an analog for the Khuff-A reservoir in the subsurface. Ten lithofacies were identified from the whole samples collected from the outcrop. These lithofacies were interpreted to have been deposited in 1) marine transgression, 2) foreshoal, 3) shoal complex, 4) shoal fringes, 5) back shoal, 6) tidal flat and 7) supratidal flat. The composite sequences of the Upper Khartam Member consist of five high frequency sequences. The results of this study also showed a distinct five potential reservoir units in the second and third high frequency sequences. The digital modelling been applied to these sequences to delineate the reservoir units in a more realistic and high precision environment. Outcomes of this study can be utilized to decrease uncertainty on reservoir continuity and architecture and lateral facies continuity within interwell spacing in equivalent Khuff reservoir models in the subsurface. Consequently this might enhance understanding and prediction of reservoir quality in the subsurface.

Introduction

The understanding of the reservoir properties and efficiency is playing a major role in the exploration and the development stages of oil and gas production. This has led to the development of the geological modelling to provide better understanding of reservoir heterogeneity and characterization. The Permian – Triassic carbonates of Khuff reservoirs in Saudi Arabia and equivalents in other Middle East countries are estimated to contain about 38.4% of the world's natural gas reserves. The deficiency of techniques and difficulty to define the accurate reservoir heterogeneity in the subsurface promote the utilization of surface outcrop analogs. Recently, terrestrial scanning LiDAR (Light Detection And Ranging) technique has become widely used in outcrop stratigraphic imaging and modelling. When combined with directly sampled data, digital modelling can create high-precision facies models (Hodgetts, 2013).

In central Saudi Arabia, the well exposed Permian – Triassic Khuff carbonates offer good outcrop analog to some of the subsurface Khuff reservoirs (Vaslet et al., 2005). Here, the focus will be on the Upper Khartam Member of Khuff Formation which is analog to the Khuff-A reservoir in the subsurface. The geological understanding of Khuff Formation in Saudi Arabia is vital and of great importance for exploration, development and management of its hydrocarbon resources. The study of the Khuff reservoirs has been a challenge due to the complexity of facies as a result of depositional and post-depositional controls. Therefore, detecting and defining the geological heterogeneity at outcrop micro- and macro-scale, facies and stratigraphic hierarchy will help to assess reservoir architecture and quality. The Khuff-A reservoir outcrop analog allowed examining and assessing geological heterogeneity that is hard to assess and evaluate from subsurface because of the limitations of data and methods of investigations. This study aims to conduct sedimentological and stratigraphical analysis as well as terrestrial LiDAR imaging, using strata in Qasim area in central Saudi Arabia which are equivalent outcrop analog for the Early Triassic Khuff-A reservoir.

Methodology

The Early Triassic Upper Khartam Member investigated here, cropping out as road cut in Qasim, Central Saudi Arabia. Sedimentological, stratigraphical and gamma ray analysis were conducted on five vertical stratigraphic sections in the field. Thin sections and plugs were prepared from the whole samples collected from the sections for micro-facies analysis and porosity and permeability measurements, respectively. Also, the whole outcrop extending 400 m long and 15 m high was scanned digitally using terrestrial LiDAR technique (Figure 1). The resulted high resolution stratigraphy interpretation was integrated and superimposed in the digital model for the final description and assessment of the heterogeneity in different scales.

Results and Discussion

Ten lithofacies (ranging from grainstone to graded pack to mudstone) were recognized from the whole samples studied in the study area. These lithofacies were interpreted to have been deposited in 1) marine transgression, 2) foreshoal, 3) shoal complex, 4) shoal fringes, 5) back shoal, 6) tidal flat and 7) supratidal flat. The composite sequences of the shallowing-upward Upper Khartam Member consist of five high frequency sequences. Based on the lithofacies and the petrophysical data potential reservoir units have been determined within the second and the third high frequency sequences (HFS-2 and HFS-3). The digital model has been constructed for HFS-2 and HFS-3 that contained clear potential reservoir units (Figure 2). The heterogeneity on the vertical scale is obvious than the lateral one because of the cyclicity in the deposition. The layer-cake type of the Khuff carbonates platform played a major role on the degree of heterogeneity especially on the lateral scale. The integrated digital model has revealed five potential reservoir units that extend laterally with a negligible thickness variation. The thickness of the reservoir units increases upward while the thickness of the barrier muddy beds decreases, this because of the cyclic deposition of the Khuff Formation.

Figure 1 This is a part of the studied outcrop in the study area. It shows clearly the cyclic deposition and the vertical variation in the facies and the thickness. Black lines indicate the beds variation. On the right, vertical stratigraphic section G: Grainstone, P: Packstone, W: Wackstone and M: Mudstone.

Figure 2 Digital outcrop model for HFS-2 of upper Khartam outcrop showing some measurements.

Conclusions

This integrated study helped to identify the detailed stratigraphy, define the lateral and vertical stacking pattern of the reservoir units and the reservoir heterogeneity at outcrop scale. The presence of potential reservoir units is robustly governed by stratigraphic position. Outcomes of this study can be utilized to decrease uncertainty on reservoir continuity and architecture and lateral facies continuity within interwell spacing in equivalent Khuff reservoir models in the subsurface. Consequently this might enhance understanding and prediction of reservoir quality in the subsurface.

References

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