An integrated approach to develop a self-sourcing, self-sealing stratigraphic prospect for the Hanifa Formation, offshore Bahrain

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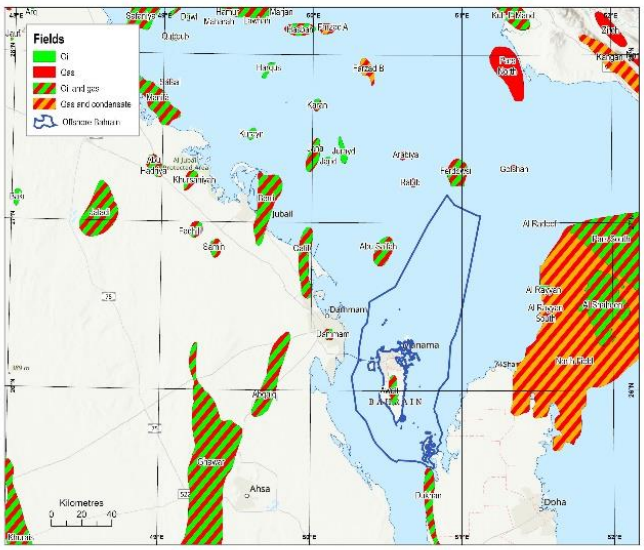

Figure 1 Location map outlining the offshore extent of the territorial waters of the Kingdom of Bahrain. Regional oil and gas field locations, including the Bahrain Field, Ghawar Field, and South Pars/North Dome Field, are shown.

Summary

Targeting of stratigraphic traps is rapidly becoming a successful exploration strategy, especially in relatively mature basins where a high proportion of structural traps have been tested. The development of robust geological and trap models, integrated with the results of seismic inversion, are key steps in mitigating the larger uncertainty and risk associated with exploration for stratigraphic traps.

This study demonstrates the benefit of a fully integrated workflow, involving the interpretation and analysis of geophysical and geological data, to ensure the development of a robust prospect model. In this case, a new stratigraphic trapping concept has been developed within the Upper Jurassic Hanifa Formation – a unit which is generally considered to consist of low porosities based on existing well control.

Introduction

The Bahrain Field (formerly Awali Field), located within the Rub al-Khali basin on the island of Bahrain (Figure 1), was discovered in 1932 and is one of the oldest producing fields in the Middle East region. The Rub al-Khali basin is a world-class hydrocarbon province and hosts the largest oil and gas fields, in Ghawar Field and South Pars/North Dome Field, respectively.

Data set

The study data set consists of approximately 390 linear kilometers of 2D post-stack time migrated seismic, acquired during various campaigns between 1981 and 2009. The variable quality of the different lines, especially in terms of seismic character, motivated the application of a conditioning sequence with the objective to enhance the regional coherency of the dataset. The most recent seismic data, acquired in 2019, were used as a reference amplitude and frequency balancing. In the absence of pre-stack seismic information over most of the lines, post-stack processing steps, including linear noise removal, multiple attenuation and spatial amplitude compensation, were considered to increase the interpretability of each individual line.

Wireline logs and various historical well reports for three key wells within the study area that penetrate the Hanifa Formation were also utilized for sedimentological analysis. Interpreted horizons for key stratigraphic intervals were correlated across the study area and subsequently used as a guide to build the elastic inversion framework.

Acoustic inversion was applied to 10 key seismic lines within the study area, generating a set of acoustic impedances. An impedance-to-porosity relationship (Figure 2), calibrated to well data (blue points), was then used to produce realistic porosity predictions away from the well locations.

reservoir model for a cross-bedded grainstone reservoir was proposed.

Interpretation of the 2D seismic data set, tied to key wells via well synthetics and constrained by the depositional model, provided a framework from which to identify and define areas where stratigraphic trapping mechanisms were possible. Furthermore, porosity predictions, derived from elastic inversion attributes, support the presence of a porous package within the Hanifa Formation, and informed an understanding of reservoir architecture and distribution (Figure 4).

Critical components of a trap model are also identified from the predicted porosity data, where low-porosity zones encompassing the postulated grainstone reservoir suggest that tighter facies of the Hanifa, likely to be composed of tight lime muds, may provide an effective top and lateral seal (Figure 5).

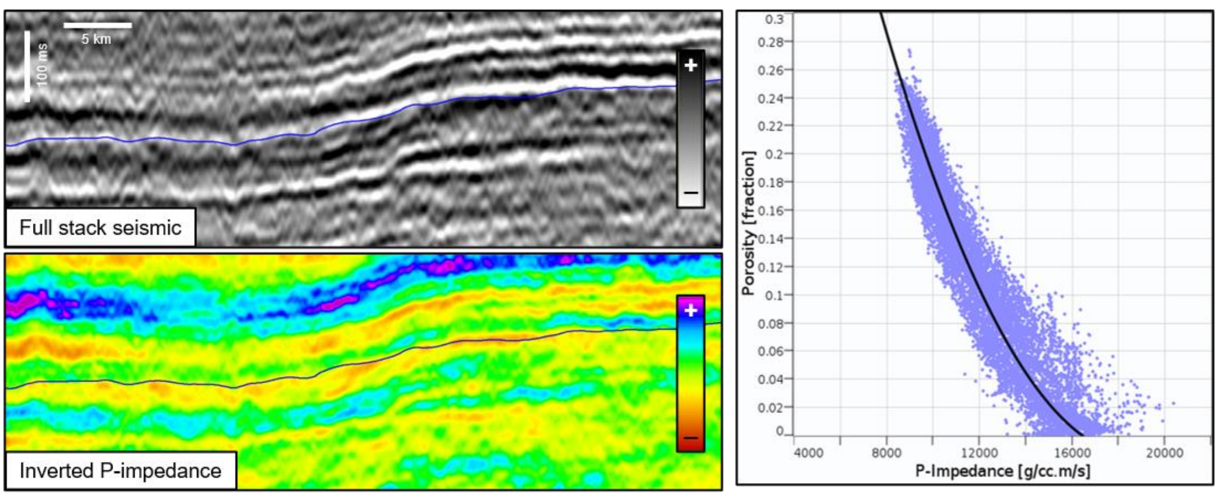

Figure 2 Top left: Example full stack seismic section. Bottom left: Inverted P-impedance section. Right: an impedance-to-porosity cross plot derived for the Hanifa Formation.

Development of the Hanifa Prospect

Initial sedimentological analysis of all relevant well data provided a better understanding of depositional trends within the study area, and suggested the greatest potential for reservoir quality would be associated with a previously undrilled high-energy facies belt within the Hanifa Formation. Observations from analogues within the Rub al-Khali basin were also incorporated (Figure 3), and a

A change in depositional environment, from the distal ramp to the intrashelf basin, has facilitated the development of organic-rich limestones with potential source rock quality (Figure 4). Petroleum system analysis and modeling, conducted to better understand and confirm the quality and distribution of this potential source, predict significant expulsion and migration of hydrocarbons from the Hanifa Formation and support a valid charge mechanism.

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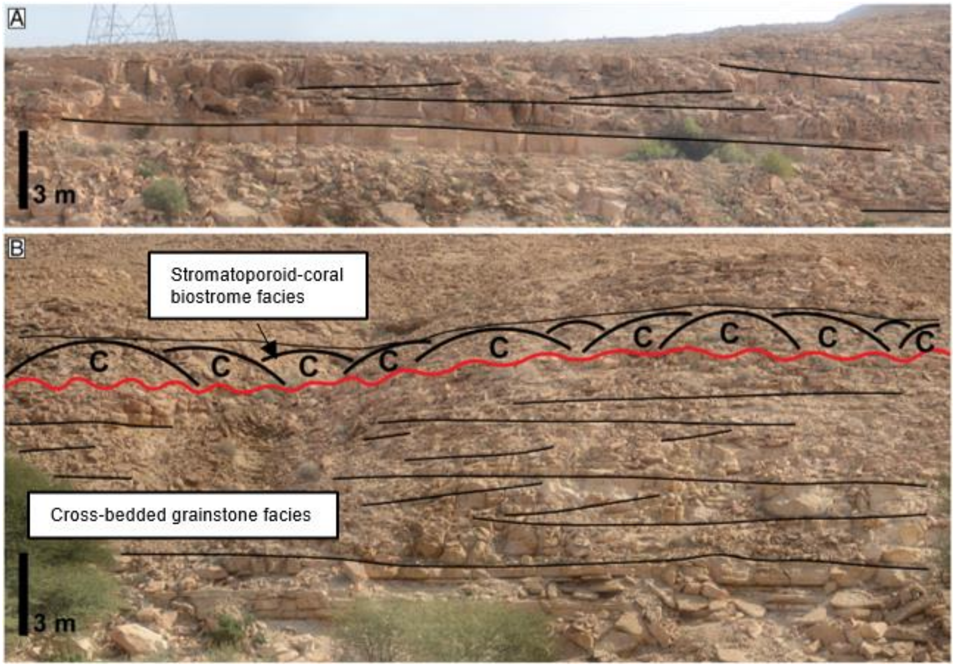

Figure 3 Outcrop analogues from the Rub al-Khali basin showing the development of a) cross-bedded grainstone and b) biostrome facies of the Hanifa Formation (Fallatah and Kerans, 2018).

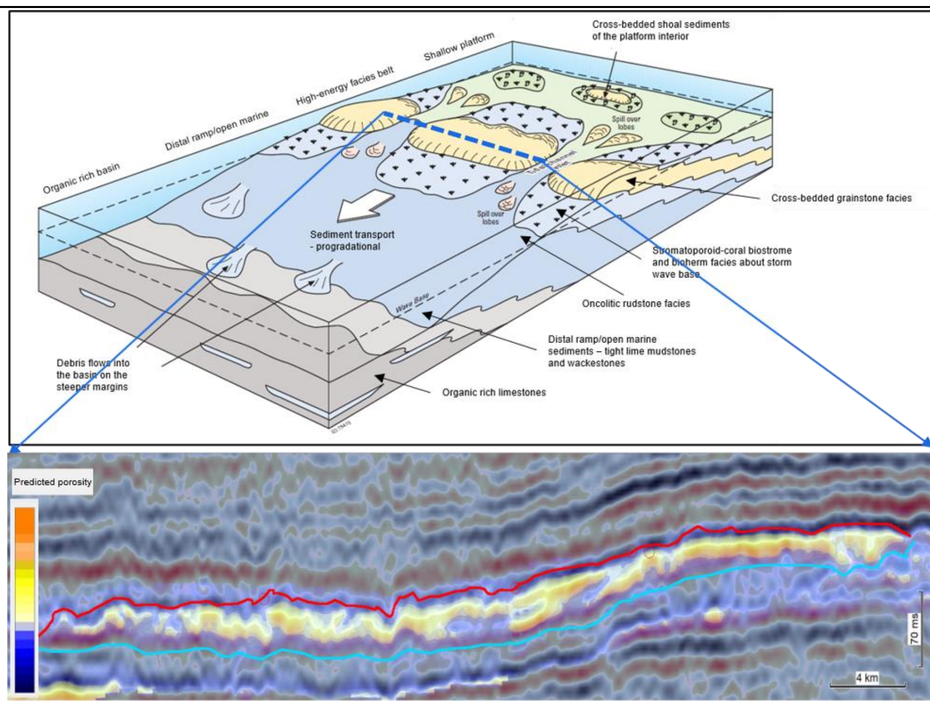

Figure 4 Top: A depositional environment block diagram; Bottom: Example seismic section co-rendered with predicted porosity values along the long axis of the postulated grainstone facies belt.

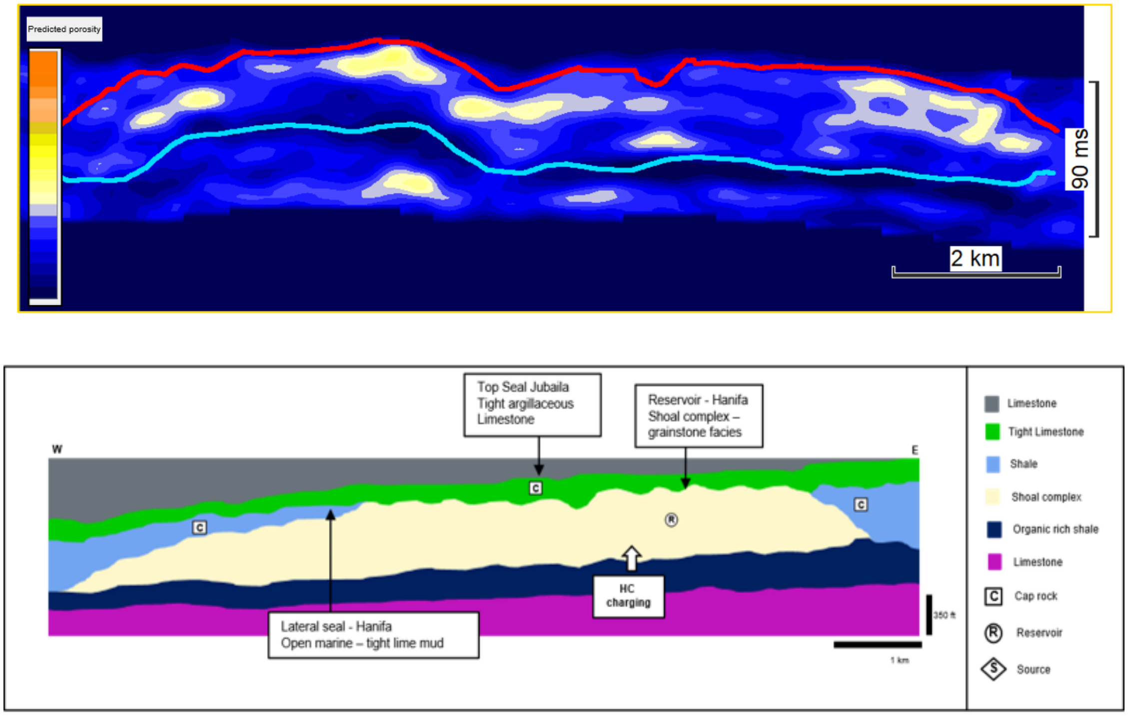

Figure 5 Top: A predicted porosity section along the short axis of the grainstone belt, demonstrating a mounded morphology. Bottom: Prospect concept diagram for the Hanifa prospect, with key petroleum system elements labeled.

Conclusions

The true value of the insights provided by predicted porosity, as a product of seismic inversion, are only fully recognized when placed in their correct geological context and integrated with sedimentological analysis and seismic interpretation.

In this case study, an acoustic inversion was performed over a large and diverse 2D seismic dataset which received a careful harmonization to optimize its regional coherency. The resulting predicted porosity data supported reservoir development, and a robust geological and trap model (Figure 5). This in turn has highlighted the stratigraphic trapping potential of a previously unidentified reservoir-with a local charge mechanism and effective top and lateral seals.

Acknowledgments

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Fallatah, M. I., and C. Kerans, 2018, Stratigraphic evolution of the Late Jurassic Hanifa Formation along the Tuwaiq Escarpment, Saudi Arabia: Evidence for a carbonate ramp system: Sedimentary Geology, **363**, 152–180, doi: https://doi.org/10.1016/j.sedgeo.2017.10.008.