Reservoir Risk Reduction by Accurate Characterisation of a Complex Permian Gas Reservoir in Ghawar Field of Saudi Arabia

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Summary

The Permian Khuff-C carbonate reservoir in IJthmaniyah area over the Ghawar field in Saudi Arabia was discovered in exploratory drilling in 1982 and is a prolific producer of gas and condensate. The reservoir porosity distribution is complex and is influenced by syn-depositional diagenesis. The Khuff-C rocks were deposited on tidal flat where slight changes in sea level created local islands that were sub-areally exposed. In these islands the pores were occluded with evaporite cement.

The recently acquired 3D seismic data in the area has been integrated with borehole information and reservoir simulation history match results. This has permitted us to define the local tight porosity areas. Amplitude inversion of the 3D seismic data has computed high acoustic impedance near the crest of the Khuff-C structural flanks, low acoustic impedance values corresponding to porous, gas saturated reservoir, were derived from seismic inversion. Based on these results, the previously interpreted stratigraphic porosity edge to the east flank of Khuff-C reservoir has been revised. This could potentially add 20% to the delineated gas and condensate reserves in the Khuff-C reservoir in the Uthmaniyah area.

Geological Setting

The Khuff Formation is the earliest period of major carbonate sedimentation in the Ghawar Field area, resulting from a late Permian transgression of the Tethys Sea over the Arabian craton. Four major depositional cycles are recognized within the Khuff Formation. These are, in descending order, Khuff-A, B, C and D. These cycles in the Khuff Formation are correlatable with the global upper Permain eustatic cycles. Khuff-C was deposited during a major transgressive cycle, which culminated in an arid sabkha environment. The Khuff-C reservoir falls with in one of these major cycles and is in a sequence of cyclic carbonate-evaporite deposits of the Khuff Formation. The reservoir interval is comprised of interbedded, tight and porous limestone and dolomite beds sandwiched between thicker anhydrite rich intervals. Syndepositional stratiform diagenetic changes influenced by the depositional environment were responsible for the complex Khuff-C reservoir facies. Minor sea level changes over short periods together with alternating evaporite carbonate deposition are believed to be the cause of the complexity. Several wells in the north-central field area penetrate the Khuff-C reservoir. Two of these wells, A and B, encountered tight Khuff-C reservoir interval. Cores form Khuff-C in these wells show anhydrite cement filling the grainstone matrix and layers of fine-grained dolomite. From these, results, a stratigraphic zero porosity edge was originally interpreted to the east ofthesetwo wells. Based on this original interpretation the eastern flank of the structure was condemned for further Khuff-C reservoir development.

Core Analysis

The cores from the Khuff-C reservoir interval from several wells in ‘Uthmaniyah area were slabbed and examined for composition, texture, grain types, porosity type and cementation history. Thin sections from the cores were also

examined fortextural details and also for diagenetic overprints. Cores from porous Khuff-C reservoir show porous limestone and dolomite. The depositional facies is usually obscured by the prominent syndepositional.diagenesis. Diagenetic changes played a dominant role in the porosity distribution of the reservoir—dolomitization, leaching and dissolution enhanced the porosity while cementation destroyed the reservoir porosity. Microscopic examination of thin section from Khuff-C core from one of the tight wells indicate evaporite cement occluding the integranular pores.

Seismic Evaluation

3D seismic data were acquired in the study area in order to understand the reservoir framework, delineate the reservoir complexity, and to map the porosity distribution. The survey parameters were designed to better image the deeper Khuffand Pre-Khuff objective down to 16,000 feet. Five vibrators were used at each source point, with a 12 second up-sweep and a sweep frequency of 8-80 Hz. The cable length was 3600 meters. The field geometry created a 24 fold in-line and 6 fold cross line. The surface coverage was 200 source points per square kilometre and the CDP bin size was 25 by 25 meters. The total seismic survey area was over 800 square kilometres. The data were processed through a stratigraphic flow in order to preserve the relative amplitudes. The Final DM0 time migrated seismic stack volume was loaded for interactive interpretation on the workstation.

Sonic and density logs from wells were processed for petrophysical analysis and fieldwide calibration and correction. Seismic markers near the objective reservoir for these wells were also identified and converted to two-way time to aid the interpretation of seismic data. Synthetic seismograms generated from the well logs indicate a sharp waveform contrast and amplitude associated with wells with porous Khuff-C. Wells with tight Khuff-C interval correspond to low acoustic impedance and diminishing amplitude or in some cases, a reversal of polarity. The sharp waveform contrast observed in the synthetic seismograms from porous to tight Khuff-C reservoir provide a basis for delineating porosity variations within the reservoir.

Seismic Inversion Results

The Khuff-C reservoir thickness in the area varies between 170 to 250 feet at a depth of 12,000 feet. This is within the resolution of the 30 Hz dominant frequency of the seismic data. Interpretations of seismic events corresponding to Khuff-C reservoir show an abrupt termination of amplitude in the vicinity of the two wells that encountered tight reservoir. Model based seismic amplitude inverse modelling was performed on the data using the calibrated wells as initial model. The initial model assigns an impedance log for every CDP in the seismic volume by interpolating impedance values between the well control points. The model is then updated in the inversion process to match the amplitudes for each trace in the seismic volume time window. The amplitude inversion was thus target oriented, iterative and was constrained by acoustic impedance computed at the wells. The wells were calibrated to tie the picked geological markers with seismic horizons and a wavelet was derived form the seismic data to generate synthetic seismogram for calibration at well location. These results indicate an increase in acoustic impedance from known, porous, gas filled, Khuff-C reservoir to tight Khuff-C interval. From the seismic amplitude section, corresponding acoustic impedence section, was generated using inversion technique. The amplitude termination is seen to the east of porous well 2, before it reaches the tight well A. The impedance section shows an abrupt increase of impedance east of well 2. Beyond well A in the east flank, the amplitudes reappear and also lower impedance values, or porous Khuff-C are observed. Here the Khuff-C amplitude is continuous and the acoustic impedance is also low throughout the section. This shows that the original porosity edge interpreted to be at the east of well 6 on this line does not exist. On the 3D data the high impedance is seen only in the vicinity of the wells A and B. The higher acoustic impedance or tight porosity is localized near wells A and B. These results of seismic amplitude in-

version conclude that Khuff-C porosity extends to the entire eastern flank of 'Uthmaniyah and thus opens up a large fairway for porous Khuff-C reservoir delineation. The 3D Seismic data indicates that the gas, condensate reservoir volume in the area is significantly large than was originally interpreted based on the well data alone.

Reservoir Simulation

Reservoir simulation study of Khuff-C gas reservoir in the area was performed using a geological model with zero porosity-thickness to the east of the two wells that encountered tight reservoir. The other wells in the area penetrated porous Khuff-C and most of them are prolific producers of gas. The history match results from the reservoir simulation model study at the initiation of gas production in 1984 to 1997 indicate measured pressures are consistently 700-800 psi higher than the modelled pressured. This additional pressure suggests extra sources of Khuff-C reservoir energy. In order to achieve a history match the observed pressure at the well, the gas saturated porosity thickness (q-h* Sg) of the reservoir need to be increased by 40%. This can be explained with more pore volume or large reserves and water invasion from the aquifer.

Conclusions

The present study conducted by integrating 3D seismic interpretation, well log data, core analysis and reservoir simulation history match results have redefined the stratigraphy in the Khuff-C reservoir over 'Uthmaniyah area in Ghawar field. The integration of observations from various disciplines has resulted in a synergy that has reduced, if not eliminated, the ambiguity in the interpretation of results form each individual discipline. The stratigraphic porosity edge, interpreted from the well data, in the east flank of the field, has been revised. In this revised interpretation the tight Khuff-C is localized near the wells A and B. These results conclude that the Khuff-C porosity extends to the entire eastern flank of the Khuff anticline. This improved characterization of the reservoir has increased the pore volume of the Khuff-C reservoir in the area and has added significantly to the gas and condensate reserves. The geocellular reservoir pore volumes, updated as a result of this study will improve the production history match and provide a more accurate prediction of the reservoir performance.

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