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4D seismic for identification of potential unswept areas for development in a producing field with water injection support: A case study of the Ravva Field, east coast of India

Sivasankar Josyula, Rao, C.G, Swarup Sarkar, Kondal Reddy, Menal Gupta, Kausik Saikia, CARIN*

Summary

The Ravva Field is a mature oil field in the shallow offshore KG Basin, Andhra Pradesh, which has been producing from Middle Miocene reservoirs since 1993. Pressure support by water injection was provided in the early stages of production life (1997). Water injection sustained a plateau production of 50000 bopd for ~ 9 years. The field is currently on decline with increasing water cut. Reservoir simulation and history matching data suggest additional recovery from the unswept zones in the crestal part of the structure are present, together with by-passed zones of commercial value contained within the assumed swept zone up-dip of the original oil-water contact (OWC). A feasibility study was carried out to model the expected seismic response resulting from oil production and water injection between 2000 and 2010. From the modeling it is estimated that an acoustic impedance change of 3 – 12% in the reservoir occurs due to saturation changes and expansion of solution gas. This is observed to be sufficient to map the advancing water front in the reservoir sands. An OBC survey was acquired in 2000 (the Base survey) with a Monitor survey being subsequently acquired in 2010. Base and Monitor data sets were processed in a 4D sense to map time lapse seismic effects caused by production and water injection. Initial 4D interpretation studies reveal areas of reservoir sweep, potential unswept areas and probable intra-reservoir heterogeneities. Hydrocarbon saturations were confirmed at the crestal part of the structure. An infill drilling campaign was executed during 2010-11 and the drilling results are in line with 4D interpretations. Several potential unswept areas have been identified in the Ravva Field and further work is on-going to assess their value. 4D seismic has provided key data which is being used to optimize well placement and generate additional value by way of extracting increased recovery from this mature field.

***Keywords**: 4D seismic, Acoustic Impedance changes (AIC), Water injection (WI), Reservoir modeling, unswept areas, oil water contacts (OWC), Base and Monitor surveys, by-pass zones.*

Introduction

Cairn India's Ravva Field is located in shallow waters off Kakinada, on the east coast of India in the KG Basin (Figure.1). The field was discovered in 1983, and consists of two main blocks; RAD and REFB separated by shale-filled erosional cut of Pliocene age. The main reservoirs are high Darcy sands of Middle Miocene age. The field was put on production in 1993 and water injection started in 1997 and to date has achieved an oil recovery of 47%. Currently production in the field is declining with increasing water cut. Reservoir simulation studies based on the existing static model, and incorporating stochastic inversion models, derived reservoir parameters from the 2000 OBC 3D. These indicate potential undrained areas in the crestal part of the structure. An incremental recovery of 4% over the initial estimate of 51% of OIIP was predicted following a 5 well infill drilling campaign in 2011.

4D seismic technology was applied as a field development strategy to arrest the production decline and add incremental reserves, The objective of the 4D project was to confirm the model predictions and map the reservoir

CAIRN INDIA LIMITED
3rd Floor, Vipul Plaza, Sun City, Sector 54, Gurgaon 122 002
Sivasankar.Josyula@cairnindia.com

sweep, as well as define associated heterogeneities, flow barriers and pressure compartments. The results of the project would be used to up-date the reservoir model for optimal reservoir management and development of an unswept oil strategy going forward.

Methodology

The Ravva implementation of 4D seismic technology was carried out in several planned, inter-related stages, namely: feasibility study, survey design, acquisition, processing, and interpretation.

Feasibility study

To assess the Acoustic Impedance Change (AIC) and seismic response caused by production and water injection in the reservoir, a feasibility study was carried out. The changes in water saturation, expansion of solution gas etc. were estimated at the production periods 2000, 2003 and 2005 from the Reservoir Simulation Model (Figure. 2). Rock physics modeling and fluid substitution studies on well logs were carried out and AIC in the reservoirs was estimated to be of the order, from 2% to around 10% – 12% (Ghosh at al., 2007). This AIC range enables the 4D seismic data set to be used for mapping reservoir details, e.g. advancing water front, unswept zones, and other production and WI related heterogeneities in the reservoir sands.

Survey design, acquisition and processing

The first OBC 3D seismic was acquired in 2000 and considered as the Base survey. A Monitor OBC 3D survey was shot in 2010, with a dual objective of high resolution and high degree of repeatability with the Base. The Monitor survey was designed and executed with a position accuracy of <5m. To obtain the required coverage near the new platform facilities extra lines were shot.

Processing of the Base and Monitor surveys includes analysis of trace pairs for repeatability and only those trace pairs, with minimum source & receiver distance error, were selected as the input to the 4D processing sequence.

Processing of the OBC data made full use of established best practice processing sequences customized and supported by robust data conditioning through crossequalization and spatial matching of both datasets. This ensured seismic data repeatability and time-lapse integrity to enhance the production-related reservoir anomalies in the difference volumes. The processing sequence also included pre- and post-stack cross-equalization processes which incorporated amplitude, phase and frequency balancing, local and global static shifting and spatial crosscorrelation to correct for possible systematic positioning errors, as well as design of full spectrum global matching operator to balance amplitude and spectral composition of the embedded seismic wavelets.

Interpretation

The Ravva Field 4D interpretation studies, undertaken by Cairn India involved mapping of reservoirs in time and depth and extraction of seismic amplitude attributes together with time shift volumes on both the Base and Monitor data sets. The observed differences in seismic attributes are linked with changes in reservoir properties as interpreted from model and actual data. The Ravva Field reservoirs exhibit a classic Class II AVO response and fluid effects are more pronounced at far angles. Integrated study of all attributes with production data and geology aids in reservoir characterization and interpretation of dynamic changes in the reservoir between 2000 and 2010. Far angle minimum amplitude attribute of Base and Monitor indicate the movement of OWC from the original 1707m to 1650m subsea (Figure. 2). High amplitudes at the crestal part of the structure in RAD and REFB blocks confirm the un drained areas as predicted by the model (Figures 3 and 4). The movement of the water front is clear in the REFB area which is corroborated by well data. Interpretations suggest the presence of flow barriers and compartments that were not were considered in the earlier interpretations and dynamic reservoir models. However, the 4D response is the result of a combination of changes in saturation and pressures and hence requires discrete separation of the pressure and saturation components of the 4D effect to enable quantitative interpretation. Whilst the reservoir pressure has been maintained in the RAD block, the REFB block has undergone pressure reduction by 400 psi due to inadequate initial water injection support. This lack of pressure maintenance resulted in solution gas expansion and therefore has contributed to the 4D signal. To decouple the pressure and saturation effects and estimate the current saturation levels 4D AVO Simultaneous Inversion was carried out on the Base and Monitor datasets. Currently further interpretation work is ongoing.

Conclusions

The 4D seismic studies in the Ravva Field have provided key information that reveals the position and extent of the current OWC and reveals potential undrained areas in the crestal region of the RAD and REFB blocks of the field. Basic 4D interpretations undertaken so far have enabled description of the geometry of the reservoir sweep and our preliminary view is that this may reveal more details of reservoir continuity than previously recognised in the previous data sets. The 4D seismic data has already been used to optimize sub-surface targets, and underpinned Cairn India's 2011 infill drilling campaign on the field which was instrumental in reducing the rate of production decline on the field. On-going studies are aimed at adding incremental reserves through the quantitative definition of by-passed oil zones.

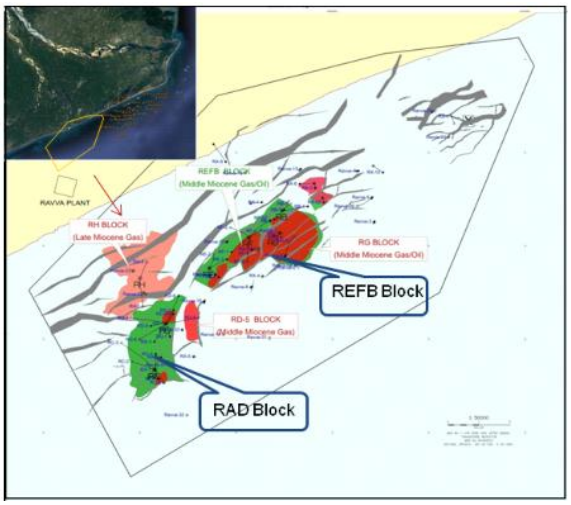

Figure 1: Location map of Ravva field showing RAD and REFB areas.

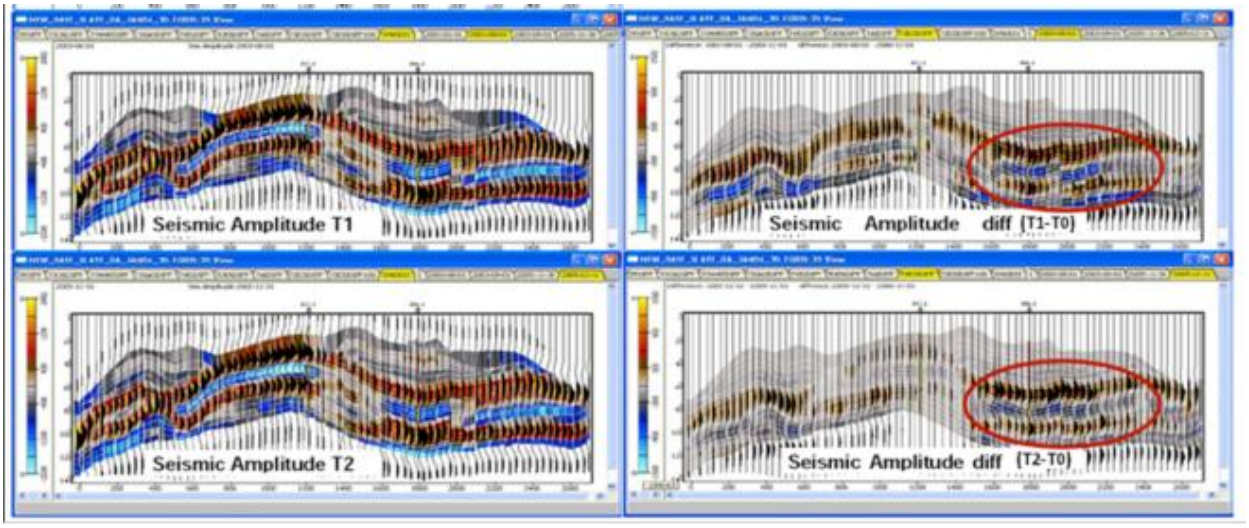

Figure 2: Synthetic seismic amplitudes from the feasibility study. Figures on the left show the modeled seismic amplitudes at the production period 2003 (T1) & 2005 (T2). Figures on the right show the seismic amplitudes between 2000 (T0) & 2003 (T1) and 2000 (T0) & 2005 (T2). 4D signal is observed at both T1 & T2 time-stamps with increasing production (shown in ellipse).

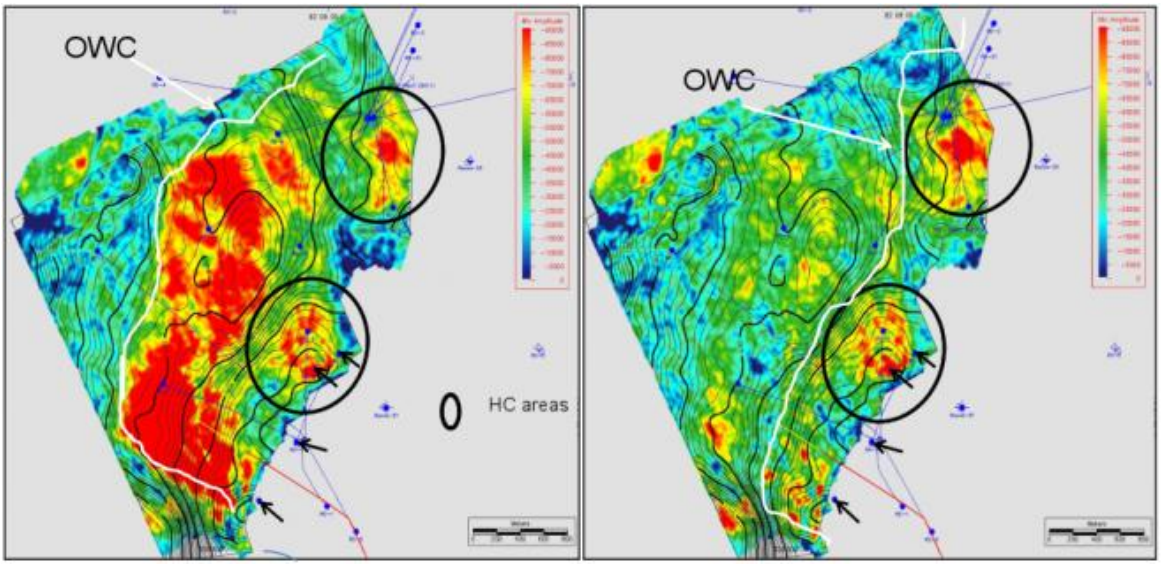

Figure 3: Far angle mimimum amplitude attribute showing the movement of OWC between 2000 & 2010. Areas marked in circle shows the undrained areas in the crestal part of the structure.

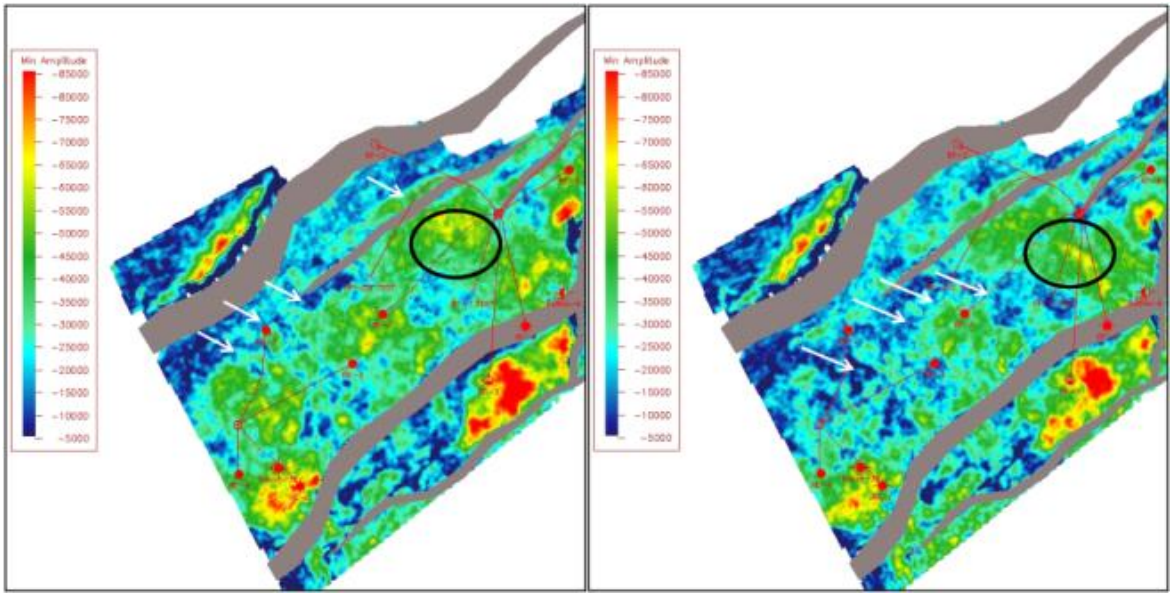

Figure 4: Far angle mimimum amplitude attribute showing the movement of injected water (white arrows) in REFB block. Area marked in black circle shows the undrained areas which were proved by drilling..

References

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