Reducing the uncertainty in 4D seismic interpretation through an integrated multi-disciplinary workflow: A case study from Ravva field, KG basin, India

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Abstract

A 4D seismic survey was carefully planned, executed and interpreted on the Ravva Field. The 4D studies include both qualitative and quantitative interpretation methods. The integration of geoscience, engineering and 4D seismic data have provided key information that defines fault compartments, position of the current OWC and reveals potential undrained areas. The preliminary results from the 4D seismic data has been used to optimize sub-surface targets, and underpinned Cairn India's infill drilling campaign, which was instrumental in arresting the production decline in the field. The infill drilling results, as well as on-going dynamic reservoir surveillance programs are in line with 4D interpretations. All these results are being used to update the reservoir model for optimal reservoir management and development. 4D seismic interpretations provide vital information about the dynamic changes in the reservoir. However, it also contains inherent uncertainty. In this paper, we will first discuss the qualitative and quantitative 4D seismic interpretation results, and the importance of pressure and saturation decoupling from the 4D signal in order to identify bypassed oil areas. Next, we will discuss the pitfalls and uncertainties in the 4D seismic interpretation and finally we will show how the integrated multi-disciplinary workflow helped us in reducing the uncertainty in the 4D seismic interpretation.

Introduction

The Cairn India operated Ravva Field is located off the shore of the Godavari Delta, within the KG Basin, on the east coast of India (Fig..1). The field was discovered in 1987, and consists of two main structural compartments; referred to as the 'RAD' and 'REFB' blocks, which are separated by a shale-filled erosional unconformity cut of Pliocene age. The field comprises a series of tilted and rollover fault blocks formed as the Pliocene Godavari delta edge collapsed, and these together with the overlying Pliocene shale provide the trapping mechanism in the field. The main reservoirs are multi Darcy sands of Middle Miocene age. The field was put on production in 1993 and the water injection started in 1997. Currently, production in the field is declining with increasing water cut.

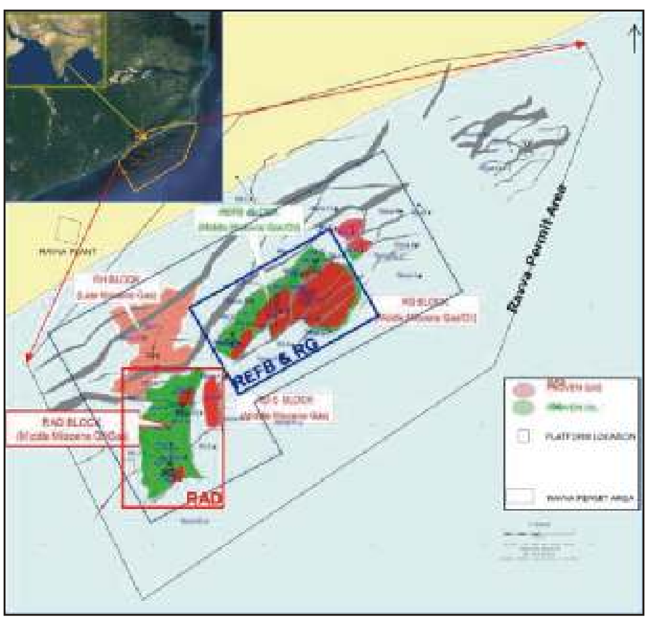

Fig. 1: Location map of Ravva Field.

To assess the Acoustic Impedance change (ΔIp) and seismic response caused by production and water injection in the reservoir, a feasibility study was carried out. Rock physics modeling and fluid substitution studies on well logs and 3D synthetic based on simulation model were carried out. The ΔIp in the reservoirs was estimated to be of the order 2% to around 12% discussed by Ghosh et al. (2007). The first survey, Baseline, was acquired during 2000-01 and a second survey, Monitor, was acquired during 2009-10. The Monitor survey was designed and executed with a position accuracy of <5m. Processing of the Baseline and Monitor surveys included 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 sequences are customized and supported by robust data conditioning through cross-equalization and spatial matching of both datasets. This ensured seismic data repeatability and 4D integrity to enhance the production-related reservoir anomalies in the difference volumes.

Methodology

The implementation of integrated multi-disciplinary workflow for reducing uncertainty in 4D seismic interpretation includes several planned inter-related stages: rock physics analysis, qualitative and quantitative 4D interpretations, detailed fault mapping and fault seal analysis, and reservoir production data and multi-disciplinary integration.

Rock physics modeling

4D rock physics modeling was carried out to predict 4D response in reservoirs under various production scenarios. Fig.1 shows the well based 4D fluid substitution and offset synthetic seismograms for the gas coming out of solution scenario. The model considered no gas cap in base case and 5m thick gas cap in monitor due to drop in the reservoir pressure. The top of the reservoir is red trough in offset gathers and the amplitude increased from base to monitor (Brightening/Softening). Offset difference gather shows greater magnitude of the 4D signal in far offsets compared to near offsets.

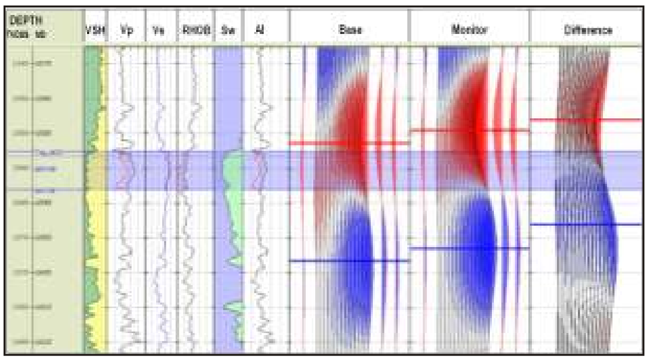

Fig. 2: 4D Fluid substitution and offset synthetic modeling.

4D qualitative interpretation

The integrated study of all attributes with field geology and production data has enabled detailed reservoir characterization and interpretation of dynamic changes in the reservoir between 2000 and 2010. The Ravva reservoirs exhibit Class II AVO response and fluid effects are more pronounced at far angles as seen in Fig. 3. The top of the reservoir is picked on a trough, represented as red, SEG Normal. The 4D analysis of the sections clearly shows amplitudes dimming in the upper reflector and interpreted as water replacing oil, proposed as a water flood response (Fig. 3).

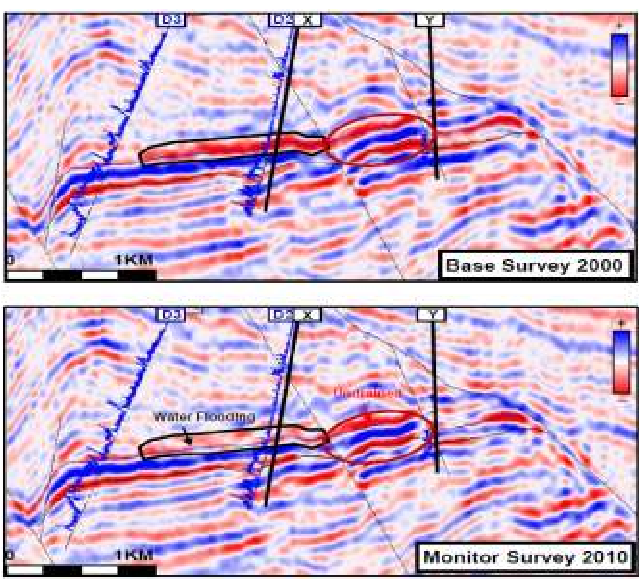

Fig. 3: Far angle 4D seismic sections showing the movement of waterfront between 2000 & 2010.

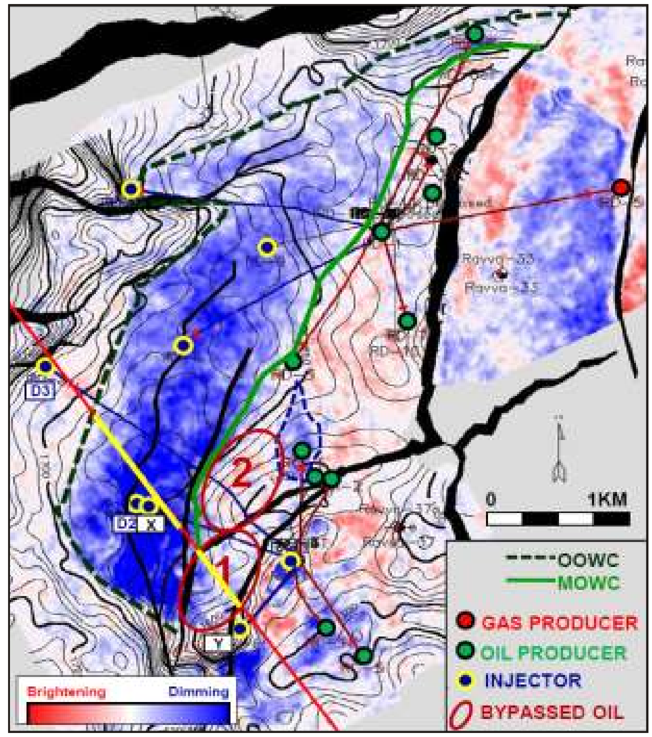

Fig. 4: Sum of negatives map showing brightening (red) and dimming (blue).

The 4D difference maps were generated using the sum of negative amplitudes attribute of baseline and monitor datasets. Brightening, represented by red, is modeled as gas coming out of solution, and an amplitude dimming, represented by blue, is modeled as a rise in water saturation. The far 4D difference map in RAD area is interpreted to show a strong water flooding signature in the western flank section of the structure indicating the movement of the waterfront from the original 1707m to present depth 1650m subsea. In the crestal portion, either no change in amplitude or brightening is observed, which is interpreted to indicate undrained areas (Fig..4). Movement of the water front in the RAD area is corroborated by subsequent development wells X and Y.

4D quantitative interpretation

A 4D Simultaneous AVO Inversion was carried out to derive the quantifiable elastic property changes in the reservoir. The ΔIp and ΔVp/Vs maps in RAD area show water flooding signature in flank portions of the structure indicating the movement of the OWC from the original 1707m to present depth 1650m subsea. The ΔIp is more sensitive to pressure changes and ΔVp/Vs is more sensitive to saturation changes, we should not neglect the fact that ΔIp and ΔVp/Vs can be sensitive to both pressure and saturation to variable degrees (Kondal et al 2013).

Pressure and Saturation decoupling

The 4D response in the Ravva Field is the result of a combination of changes in fluid saturation and pressures and hence requires discrete separation of the pressure and saturation components of the 4D signal to enable quantitative interpretation. The REFB block has undergone pressure reduction by more than 400 psi due to inadequate water injection support. Josyula et al. (2012) discussed that lack of pressure maintenance resulted in gas exsolution and therefore has contributed to the 4D signal.

The decoupling of 4D signal was done using a Petro-Elastic Model (PEM) to transform the 4D inversion derived elastic properties into Saturation (Sw) and Pressure (P) proxies (Fig. 5). PEM defined the relationship between the reservoir properties like porosity, pore fluid, effective pressure etc. and elastic properties (Kondal et.al 2013).

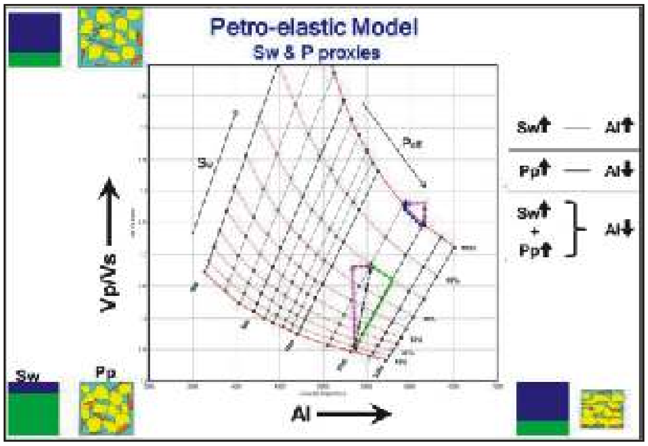

Fig. 5: Petro-elastic Model (PEM) was generated using forward modeling.

The estimated absolute saturation volumes of base and monitor surveys also shows water flooding signature in the flank side of the structure and undrained areas in the crestal portion (red ellipse in Fig. 6).

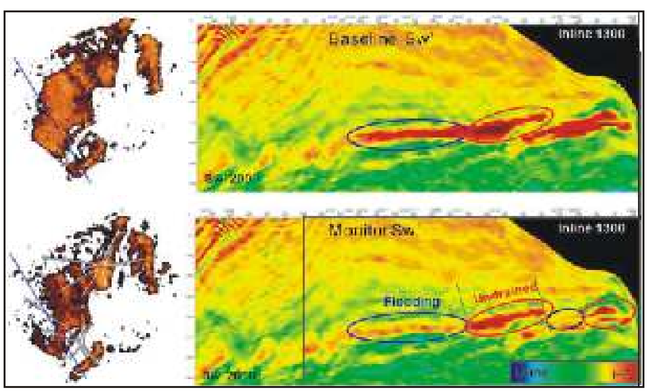

Fig. 6: 4D saturation sections shows flooding signature and undrained areas.

Fault Mapping and Fault Seal Analysis

The detailed 3D mapping of faults has provided a comprehensive understanding of 3D fault geometries and their linkages across the field. Mapping has revealed that the main faults that delineate and compartmentalize the Ravva Field are the result of early gravitational collapse of the shelf margin and two sets of rotational fault systems interact to produce the fault patterns observed today (McClenaghan et al., 2012).

Final fault and horizon models have been combined with well, tracer and pressure data to investigate fault sealing characteristics of the main faults in the field. Vertical sections across the key faults in the 4D volume and respective horizons reveal the impact of an intra-block fault structuration on fluid flow and show a potentially unswept fault compartment (red box in Fig. 7). 4D seismic amplitudes are restricted to the fault F2 due to the possible fault sealing in production time scales.

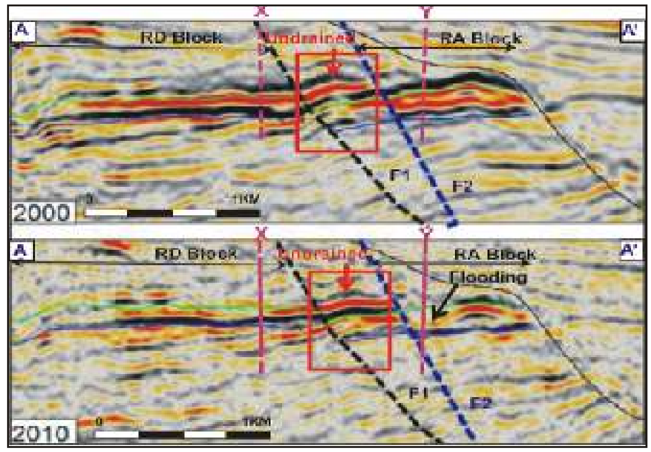

Fig. 7: 4D sections reveal the impact of an intra-block fault on fluid flow and shows a potentially unswept fault compartment.

Well production and injection activity

A strong correlation was observed when the 4D seismic difference maps are compared with the cumulative produced or injected volumes. The well production and injection activity at most of the wells is consistent with the observed and interpreted 4D response. The dynamic reservoir surveillance programs and the new infill drilling well logs are also in line with the 4D response.

Multi-disciplinary integration

Understanding and managing the uncertainty associated with the 4D seismic interpretation is critical for the infill drilling decisions. An integrated multi-disciplinary workflow was implemented for reducing uncertainty in 4D seismic interpretation (Fig. 8). This workflow includes several inter-related steps. The first step is the rock physics modeling to predict the 4D response and explain the 4D anomalies. The second step includes the use of qualitative 4D interpretation products such as 4D seismic sections and difference maps to identify the changes in reservoir due to production. However, the 4D differences are very sensitive to differences in porosity, thickness, saturation and pressure of the reservoir. The third step includes using the 4D inversion derived attributes to eliminate the thin bed related tuning issues. However, the inversion attributes are sensitive to both pressure and saturation at variable degrees. This issue is addressed in the fourth step, the decoupling the 4D signal in terms of pressure and saturation changes using PEM and inversion attributes described above.

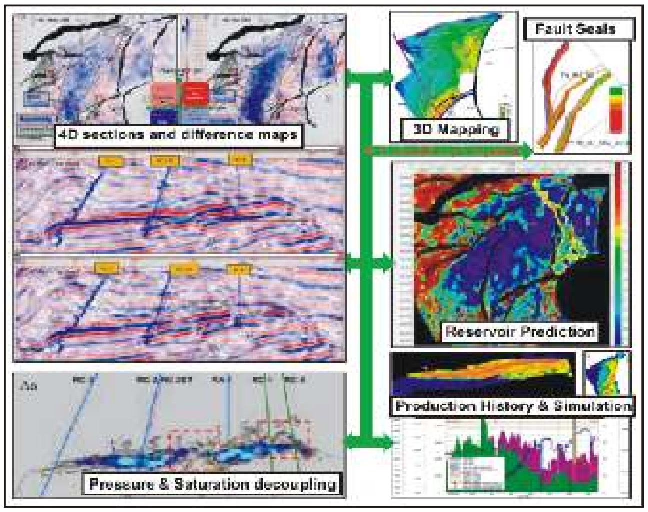

Fig. 8: Integrated multi-disciplinary workflow

After the saturation related 4D anomalies are identified using the above four steps of the workflow, then we integrated other geoscience and engineering datasets to validate the 4D anomalies. A detailed mapping of faults and horizons helped us identifying subtle structures and faults. Then fault seal analysis study revealed the nature of fault sealing, which is supported by 4D seismic sections and maps. The infill drilling results along with ongoing dynamic reservoir surveillance programs are in line with 4D interpretations.

Conclusions

A 4D seismic survey was carefully planned, executed and interpreted on the Ravva Field. An integrated multi-disciplinary workflow was successfully implemented for understanding and reducing uncertainty in 4D seismic interpretations. The qualitative and quantitative 4D interpretation has helped in identifying by-passed oil areas. The multi-disciplinary integration has reduced the uncertainty associated with locating and designing infill wells. All these results are being used to update the reservoir model for continued optimal reservoir management and development.

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