# 4D Seismic Application in Ravva Field: Methodology, Well Results and Key Learnings

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**Keywords**

Ravva, 4D seismic results, 4D seismic workflow, Learnings, Integrated reservoir modeling

**Summary**

Phase-5 infill drilling campaign executed in 2014-15 in Ravva field marked the successful application of first 4D OBC seismic project in India. This paper illustrates the methodology of the integrated reservoir modeling and interpretation that resulted in the identification of 4D infill drilling opportunities, final well results and highlights the key learnings in the process.

The project started in 2005 with a feasibility study (Ghosh et al., 2007) followed by a carefully planned and executed monitor OBC 3D survey in 2010 and integrated 4D simultaneous AVO inversion in 2011 (McClenaghan et al., 2012; Reddy et al., 2013a). 4D interpretation studies were carried out together with integrated reservoir modeling and fault seal analysis from 2011-13 and in-fill wells were drilled based on 4D response in the Phase-5 drilling campaign.

Well results demonstrated success of the 4D seismic technology in identifying bypassed oil in Ravva field. Additionally these wells have added ~ 5000 bopd to daily production and significant additional reserves to this mature field.

**Introduction**

Ravva field is located in the PKGM-1 block, offshore Godavari delta in the KG basin, East coast of India (Figure 1). The field is operated by Cairn India (22.5%) on behalf of its JV partners ONGC (40%), Videocon (25%) and Ravva Oil Singapore (12.5%). The field was discovered in 1987 and was brought to production in 1993. The main producing reservoirs are unconsolidated Miocene M30 and M20 sandstones deposited in a mixed wave and tide dominated delta. Oil production from Ravva was increased to reach a plateau of ~ 50,000 by 1999 with water injection for pressure maintenance. The oil production plateau rate was continued for 9 years till 2007 after which the field started declining due to increase in water cut in many producers.

The main Ravva producing reservoirs are contained within two areas (RAD and REFB) separated by a shale-filled erosional unconformity (Figure 1). The RAD area is further divided into two fault blocks RA and RD separated by a sealing fault.

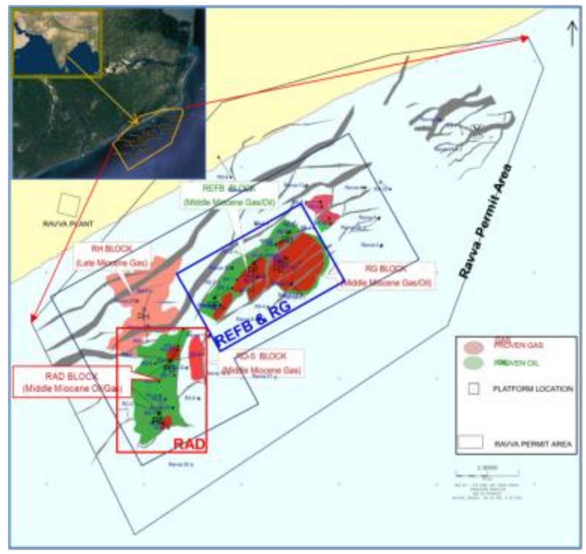


*Figure 1: Location map of Ravva field*

Pressure maintenance through downdip water injection was an integral part of the field management strategy. While reservoir pressure in the RAD area was maintained efficiently through peripheral water injection, the REFB area experienced a pressure depletion of ~ 400 psi.

As a consequence of significant volumes of water injection it was recognized early on that the injected water could eventually breakthrough at the producers, potentially leaving some areas of bypassed oil. In order to identify such areas of bypassed oil, a 4D seismic survey was carefully planned, executed, and interpreted at the Ravva field.

**Methodology**

The implementation of 4D seismic technology in the Ravva field was carried out in several planned inter-related stages. The first stage included feasibility study, survey design, acquisition, processing, rock physics modeling, qualitative and quantitative interpretation (Reddy et. al., 2013c). In this paper the authors illustrate the next stage of 4D comprising integrated reservoir modeling and interpretation that resulted in the identification of 4D infill drilling opportunities. Later results of wells drilled using the 4D seismic will also be discussed in detail, highlighting key learnings from the integrated 4D seismic workflow.

### 1. Integrated reservoir modeling

4D seismic interpretation was followed by an integrated reservoir modeling study to validate the identified 4D anomalies using other engineering and geological data. It involved structural framework building, property modeling, production history analysis, and reservoir simulation and history matching (Figure 2).

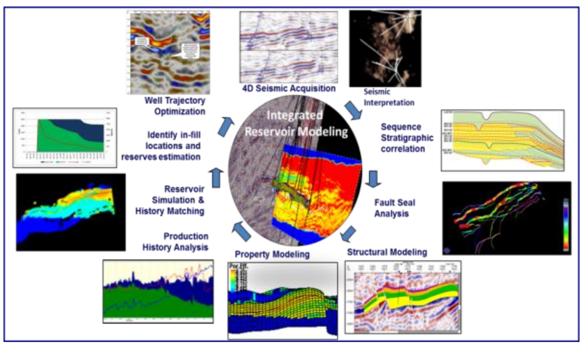


*Figure 2: Integrated reservoir modeling workflow*

Well locations were finalized based on the results of dynamic simulation, and further optimized by reviewing well trajectories in all available seismic volumes (Figure 3).

The Ravva reservoirs exhibit Class II AVO response and fluid effects are more pronounced at far angles. The 4D analysis of the far angle seismic sections clearly shows amplitudes dimming in the flank section of the main reflector and interpreted as water replacing oil (Blue ellipse in Figure 3). In the crestal portion, either no change in amplitude or brightening is observed, which is interpreted to indicate undrained areas oil (Red ellipse in Figure 3).

3rd party specialist sequence stratigraphic correlation and fault seal studies were also carried out to validate and de-risk the identified 4D anomalies. Fault mapping and fault seal analysis were combined with well and pressure data to investigate fault sealing characteristics of the main faults in the field. The 4D seismic signature in map and cross section views is shown in Figure 4. Interpretation of 2D seismic sections and maps reveal impact of an intra-block fault structuration on fluid flow. The waterflood had swept downdip areas, indicated by dim seismic amplitudes, whereas the crestal area where the attic oil was present showed as bright amplitude.

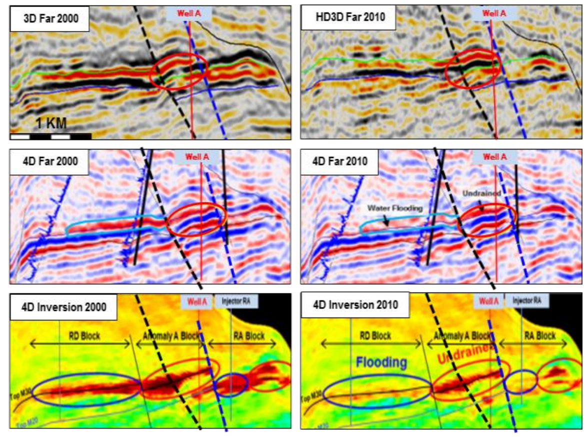


*Figure 3: Crosssection views of base (2000) vs monitor (2010) along Well-A in different seismic volumes (3D, HD3D, 4D and 4D inversion)*

### 2. Identification of in-fill opportunities

Three 4D anomalies were identified and drilled during the Ravva Phase 5 drilling campaign. Two of the in-fill drilling opportunities are described below and well results for the same are discussed in the next section

*Anomaly A* (Figures 3 & 4) was identified as a potentially upswept fault compartment between the RA and RD blocks, clearly seen in 3D, 4D and 4D inversion sections.

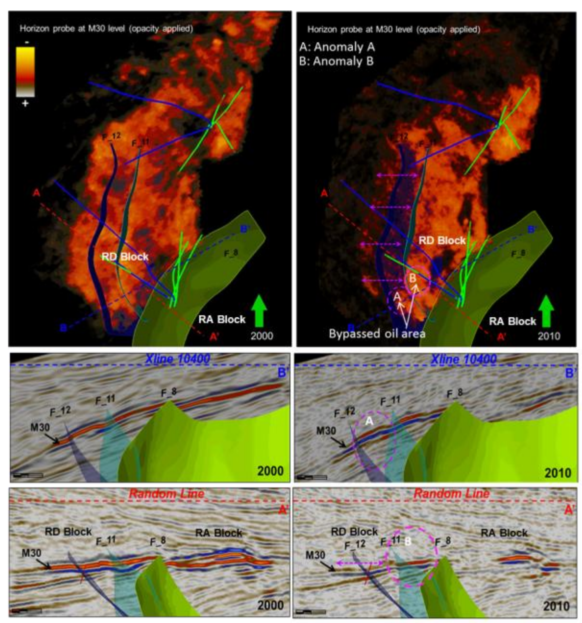


*Figure 4: Cross section and map view of base (2000) vs monitor (2010) data showing undrained response in Anomalies A and B.*

The 4D signal was found to be consistent with production data, and our understanding of the waterfront movement in the reservoir. This interpretation was also supported by fault seal studies based on shale gauge ratio. However, uncertainty remained in the expected column height, and so a well was placed at a structural high location to minimize risk. Low case column heights were estimated assuming that the area is connected to the RD area where the present OWC is at the top of highest water producing perforation. The high case column height was estimated as being up to the original OWC of the field, assuming that the area is completely isolated from both RA and RD blocks.

*Anomaly B* (Figure 4) was identified in the southwestern part of the RD block, bounded by faults in the south and northwest. 4D seismic maps showed water flooding signature to the west of fault F-11, and remaining oil east of the fault. This was also consistent with the fault seal study which suggested the faults to be sealing. Tracer breakthrough data also verified poor connectivity across this fault.

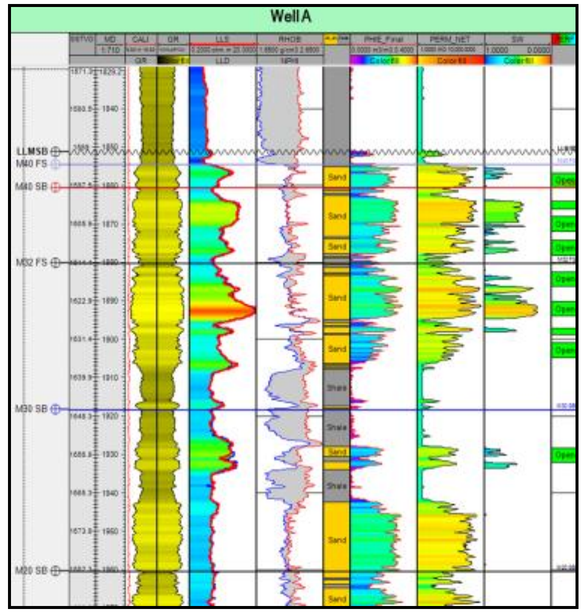


*Figure 5: Figure showing Well-A results*

**Well Results**

The infill well opportunities identified in the 4D seismic data (Reddy et. al,. 2013b) were drilled as part of the 2014-15 Ravva Phase 5 drilling campaign. The well results were predominantly encouraging. This section briefly describes results of two of the wells.

Well-A was drilled to test Anomaly A (Figure 3). It encountered ~40m of net oil column as expected in the base case scenario (Figure 5). MDT data acquired in Well-A showed depleted pressures, suggesting communication with the RD block. It also confirmed that Well-A is not connected to the RA block which is at ~100 psi higher pressure compared to RD. Well logs indicated a moved oil-water contact at 1660 m TVDSS which is ~20 m deeper than the topmost perforation in the water injector in RA. This clearly demonstrates the sealing nature of the fault separating the Well-A and the RA injector (Figure 3).

Well B was drilled to test Anomaly B. It encountered a 10 m oil column with a moved OWC at 1642 m (Figure 6). Pre drill modeling suggested an oil column of 15-25m. Post drill analysis suggested that the fault (F11) may be leaky and the area was drained during continued production from updip producers. The change in amplitude seen along the western fault (Figure 4) was interpreted as evidence for fault seal. It could also be considered a time lapse view of the waterfront in 2010 which would have moved further up, and seen in 4D seismic data if another monitor survey is done today.

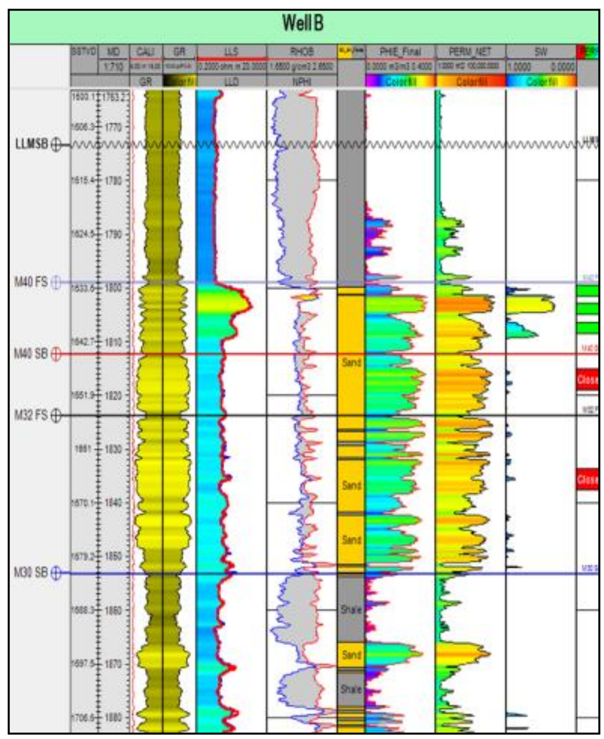


*Figure 6: Figure showing Well-B results*

**Key Learnings**

Key learnings from this study are:

1. 4D monitor seismic survey was designed, acquired and processed with same parameters. This ensured seismic data repeatability and time-lapse integrity to preserve production-related 4D signal in the difference volumes.

2. Decoupling of pressure and saturation effects in the 4D seismic data was critical in estimating of oil saturation changes in the reservoir and identifying by-passed oil areas.

3. Multi-disciplinary integration of various datasets helped in reducing uncertainty in the 4D datasets and in successfully placing new wells.

4. Fault seal analysis performed in the producing field was very challenging. Fault sealing can be predicted correctly when water flooded sands are juxtaposed on both sides of the fault (F12 in Figure 4), or when flooded sands occur on one side only (F8 in Figure 4). However when amplitudes indicating undrained areas are juxtaposed across the fault (F11 in Figure 4), it is difficult to assess the sealing nature of the fault.

5. The key lesson leant from results of the Well-B is that 4D seismic information alone may not confirm fault sealing quality, as hydrocarbons are present across Fault F11 (Figure 4). Predicting fault seal is more challenging I secondary information such as fault seal analysis from SGR and tracers do not work.

6. Future time lapse surveys, more closely spaced in time will accurately monitor the movement of hydrocarbons across faults and hence better predict the sealing nature of faults. However this is not economically feasible for the Ravva field.

**Conclusions**

Phase-5 infill drilling campaign executed in 2014-15 in Ravva field marked the successful application of first 4D OBC seismic project in India. The Middle Miocene reservoirs of the Ravva Field show a strong 4D signal in response to changes in dynamic reservoir parameters.

Three wells were drilled based on 4D information during the Phase-5 drilling campaign executed in 2014-15. Well results demonstrated success of the 4D seismic technology in identifying bypassed oil in Ravva field. This paper highlighted the key lessons learnt in the implementation of 4D seismic technology in Ravva. Further, the three 4D wells have increased daily production by ~5000 bopd, and added significant reserves to this mature field.

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**Acknowledgements**

The authors gratefully acknowledge the full support of the Ravva Field JV partners, Oil and Natural Gas Corporation, Videocon Limited and Ravva Oil (Singapore), in execution of 4D seismic studies and subsequent infill drilling campaign, and for their permission to publish this work