Integrated Geoscience and 4D Technology Defines Reservoir Compartments to Extend Production Life of the Ravva Field, K-G Basin, India*

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Abstract

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. Oil and gas reserves were discovered in 1987 by the well R-2, which penetrated the then proposed middle Miocene sandstones. These Miocene sandstones were deposited in a NE-SW oriented, wave dominated and lower to upper shoreface, cut by fluvial distributary channels. During the Pliocene to recent times the basin underwent several episodes of tectonic movement which has re-activated pre-existing faults. As a result tilted and rollover fault blocks provide the trapping mechanism in the field. The exceptional quality Miocene reservoirs, comprising high porosity, multi-darcy sands, are sealed by overlying early Pliocene shales.

Within the initial phase of field development an extensive suite of litho-biostratigraphic, core, wireline log, and borehole image data together with structural dip data were used to construct a depositional and palaeogeographic model for the field, reflecting the wave-dominated deltaic environment. Reservoir management is via up-dip producer wells supported with pressure maintenance from associated injectors. Exploitation of the field was undertaken based on extensive simulation studies and an on-going dynamic reservoir surveillance program (comprising production logging, reservoir saturation monitoring, and tracer injection) to ensure that reservoir performance is optimized. The Ravva Field JV commitment to excellence in reservoir management is evident in the production performance of the field. Plateau production was significantly extended, and current 4D seismic results, when incorporated with new reservoir characterization studies described herein, will be used for future well planning and further extending field life. To date Cairn India and partners have produced in excess of 200 mm bbls from the Ravva Field.

4D seismic technology was applied as a field development strategy to arrest the production decline and add incremental reserves. A 4D seismic survey was carefully planned, executed, and interpreted on the Ravva Field. This was achieved with the systematic implementation of a 4D workflow described below from feasibility study to the multi-disciplinary interpretation. Initial 4D qualitative interpretation studies reveal areas of reservoir sweep, potential unswept areas, and probable intra-reservoir heterogeneities. An infill drilling campaign was executed during 2010-11 and the drilling results are in line with 4D interpretations. Hydrocarbon saturations were confirmed at the crestal part of the structure.

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 1987, and consists of two main blocks; 'RAD' and 'REFB' separated by a shale-filled erosional unconformity 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. Currently, production in the field is declining with increasing water cut. Reservoir simulation studies based on the existing static model, and incorporating stochastic inversion volumes, derived reservoir parameters from the 2000 OBC 3D survey. These indicate potential undrained areas in the crestal part of the structure.

Methodology

In this paper, we first describe the current geoscience studies undertaken on the field, emphasizing 4D seismic technology used to identify prospective areas. Next, we present the preliminary interpretation of the Ravva Field reservoirs using multi-disciplinary integration of geoscience studies and 4D seismic results in defining reservoir compartments to extend production life.

4D Seismic Workflow

The implementation of 4D seismic technology in the Ravva Field 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 and seismic response caused by production and water injection in the reservoir, a feasibility study was carried out. The changes in water saturation and expansion of solution gas 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 2% to around 12% (Ghosh et 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 is defined 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 survey. The Monitor survey was designed and executed with a position accuracy of <5 m. 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 and 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 cross-equalization 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 cross-correlation 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. The seismic sections show the production related time-lapse changes (Figure 2).

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 field geology and production data has enabled detailed reservoir characterization and interpretation of dynamic changes in the reservoir between 2000 and 2010. High amplitudes at the crestal part of the structure in RAD blocks confirm the undrained areas as predicted by the model (Figure 3). The far angle sum of negative attributes and 4D far difference map in the Base and Monitor surveys indicate that the movement of the OWC from the original 1707 m to present depth 1650 m subsea has not changed in the crestal portion but there is a strong flooding signature in flank portions of the structure (Figure 4). Movement of the water front in the RAD area is corroborated by infill drilling well data. These data 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 (Josyula et al., 2012). 4D AVO Simultaneous Inversion was carried out on the Base and Monitor datasets to decouple the pressure and saturation effects and estimated the current saturation levels.

Fault Mapping and Fault Seal Analysis

The HD3D seismic volume was instrumental in detailed 3D mapping of faults in the Ravva Field and 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 KG Basin shelf margin and two sets of rotational fault systems interact to produce the fault patterns observed today. Mapped and QC'd fault surface models have been combined with well and pressure data to investigate fault sealing characteristics of the main faults in the field. 2D sections across the key faults in the 4D volume and maps reveal the impact of an intra-block fault on fluid flow and show a potentially unswept fault compartment (red box in Figure 5). 4D seismic amplitudes are restricted to the fault F2 due to the possible fault sealing in production time scales (Figure 5). Pre-production 3D seismic may not reveal nature of fault sealing as fluid contacts across fault may appear continuous due to equilibrium conditions of fluids in geological time scales.

The Shale Gouge Ratio (SGR) predictions on several important faults separating the RA from the RD block have portions with less than 20% SGR values indicating potential for leaky behavior over geological time scales, especially in areas of sand-on-sand juxtapositions. However, these faults are considered to act as dynamic seals over the production time scale due to higher permeability contrast between fault zones and reservoir. The calculated fault zone permeabilities for all faults in the RAD and REFB areas are very low, often less than 0.001 mD. These faults are likely to act as impermeable barriers during production (Bretan et al., 2012). These fault property interpretations are being incorporated into the latest reservoir model to investigate their effects on production.

Multi-disciplinary Integration

A qualitative 4D interpretation and integration of multiple datasets was attempted to identify prospective 4D anomalies (Figure 6). The HD3D seismic volume helped in carrying out detailed mapping of faults and horizons. Fault seal analysis study revealed the nature of fault sealing, which is supported by 4D seismic sections and maps. Seismic attributes from HD3D cube delineated the better reservoir areas. 4D seismic analysis and inversion study helped in understanding the production related pressure and saturation changes in the reservoir. The 2010-11 infill drilling results along with on-going dynamic reservoir surveillance programs are in line with 4D interpretations. All these results are being used to up-date the reservoir model for optimal reservoir management and development.

Conclusions

The geoscience and 4D seismic studies in the Ravva Field have provided key information that defines fault compartments, position of the current OWC, and reveals potential undrained areas in the RAD and REFB blocks of the field. 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 multi-disciplinary interpretation and integration studies are aimed at adding incremental reserves through the quantitative definition of by-passed oil zones.

Acknowledgements

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

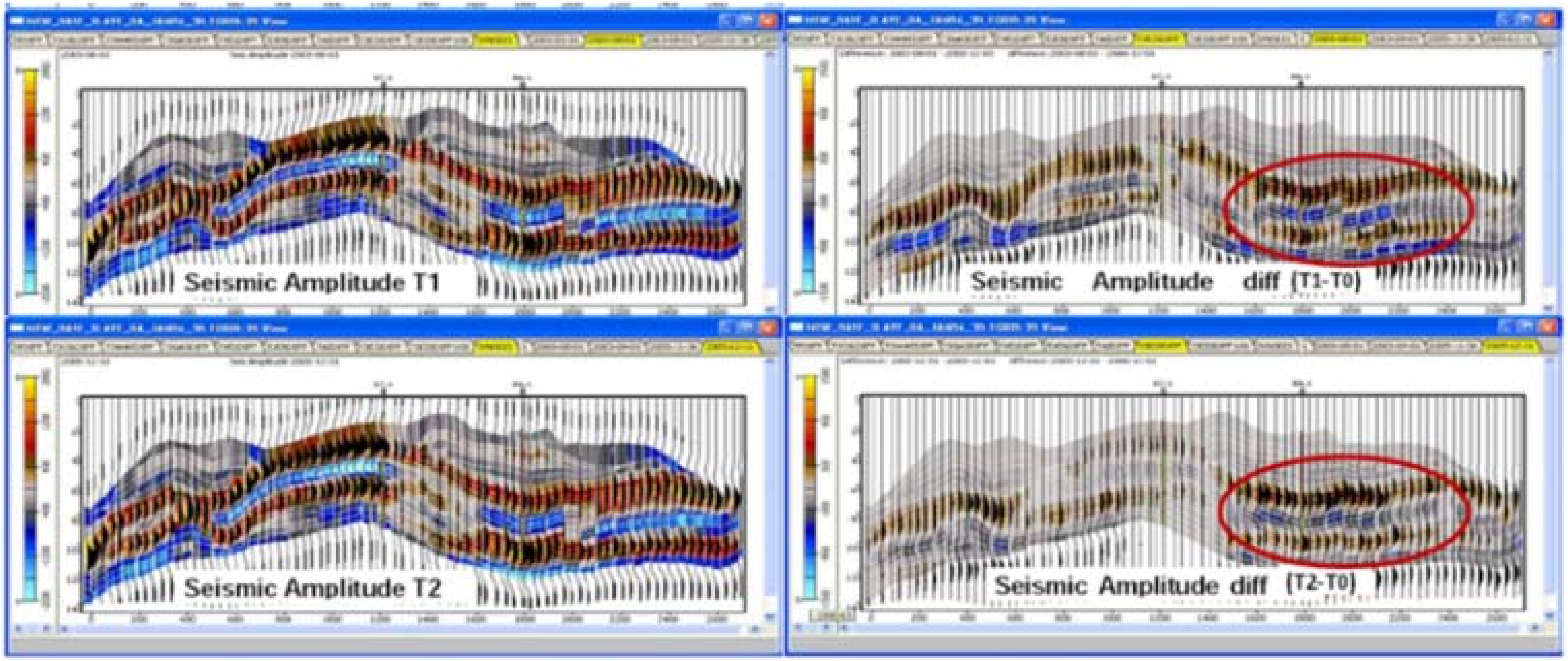

Figure 2. Synthetic seismic amplitudes from the feasibility study. Figures on the left show the modeled seismic amplitudes at the production period 2003 (T1) and 2005 (T2). Figures on the right show the modeled seismic amplitude differences between 2000 (T0) and 2003 (T1) and 2000 (T0) and 2005 (T2).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

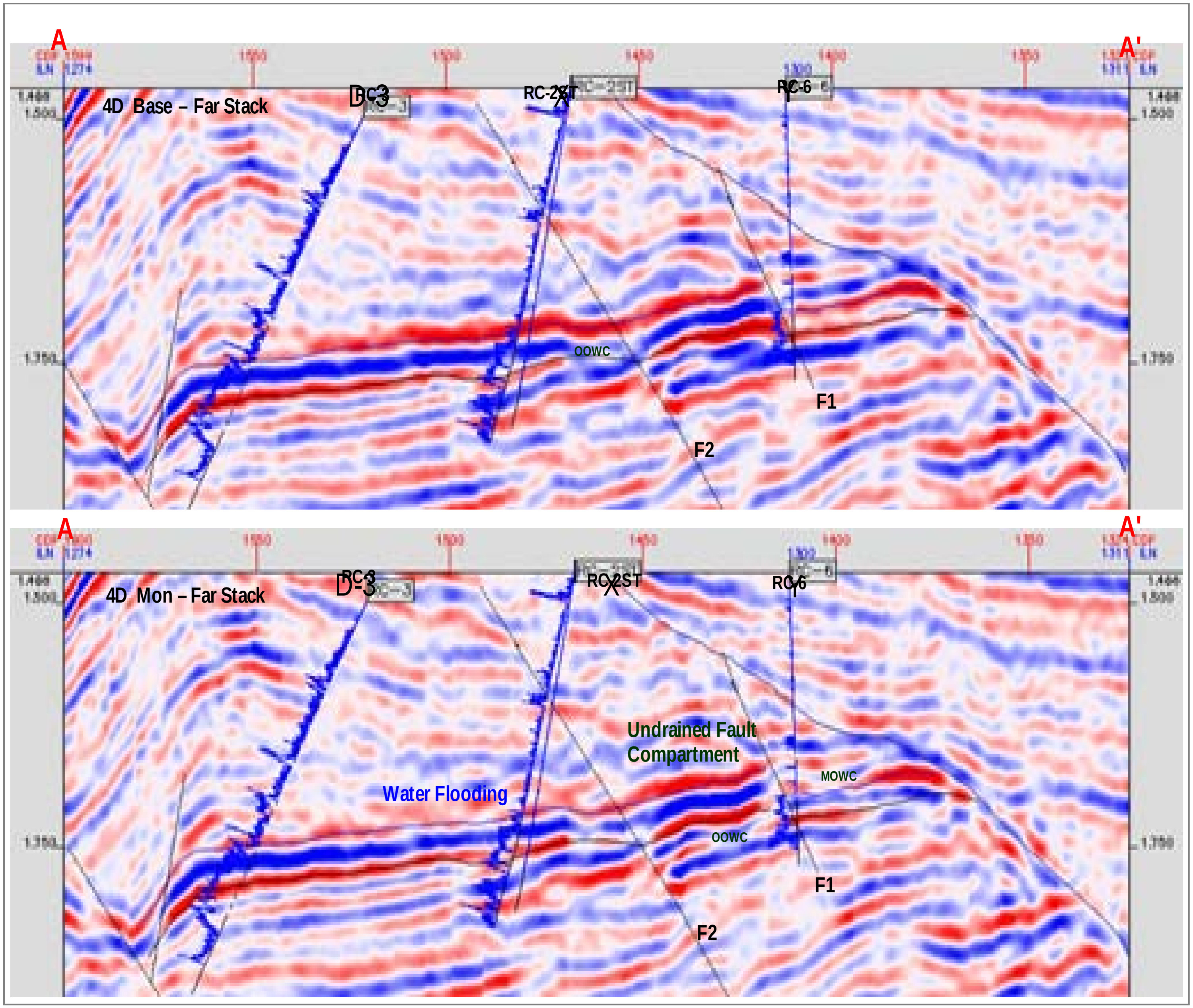

Figure 3. Far angle 4D seismic sections showing the movement of OWC between 2000 and 2010. Areas marked in green polygon shows the undrained areas in the crestal part of the structure. Areas marked in black polygon shows water flooding areas in the flank, which is corroborated with the 2010-01 drilled X and Y well results.

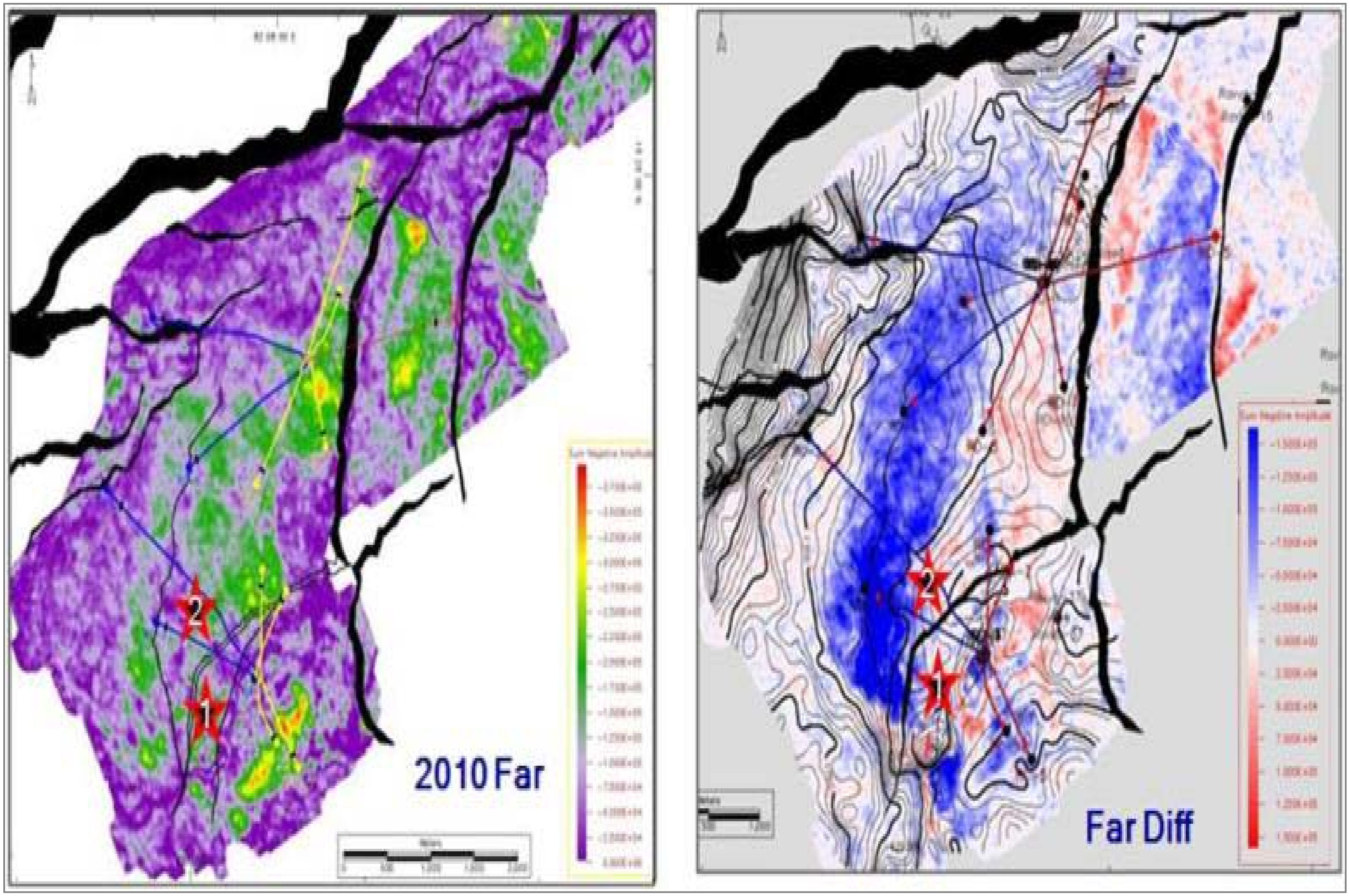

Figure 4. 2010 Far angle sum of negatives and Far 4D difference attribute maps showing the movement of OWC between 2000 and 2010. Blue areas in 4D difference map shows water flooding areas and white and red areas are undrained areas in the crestal part of the structure.

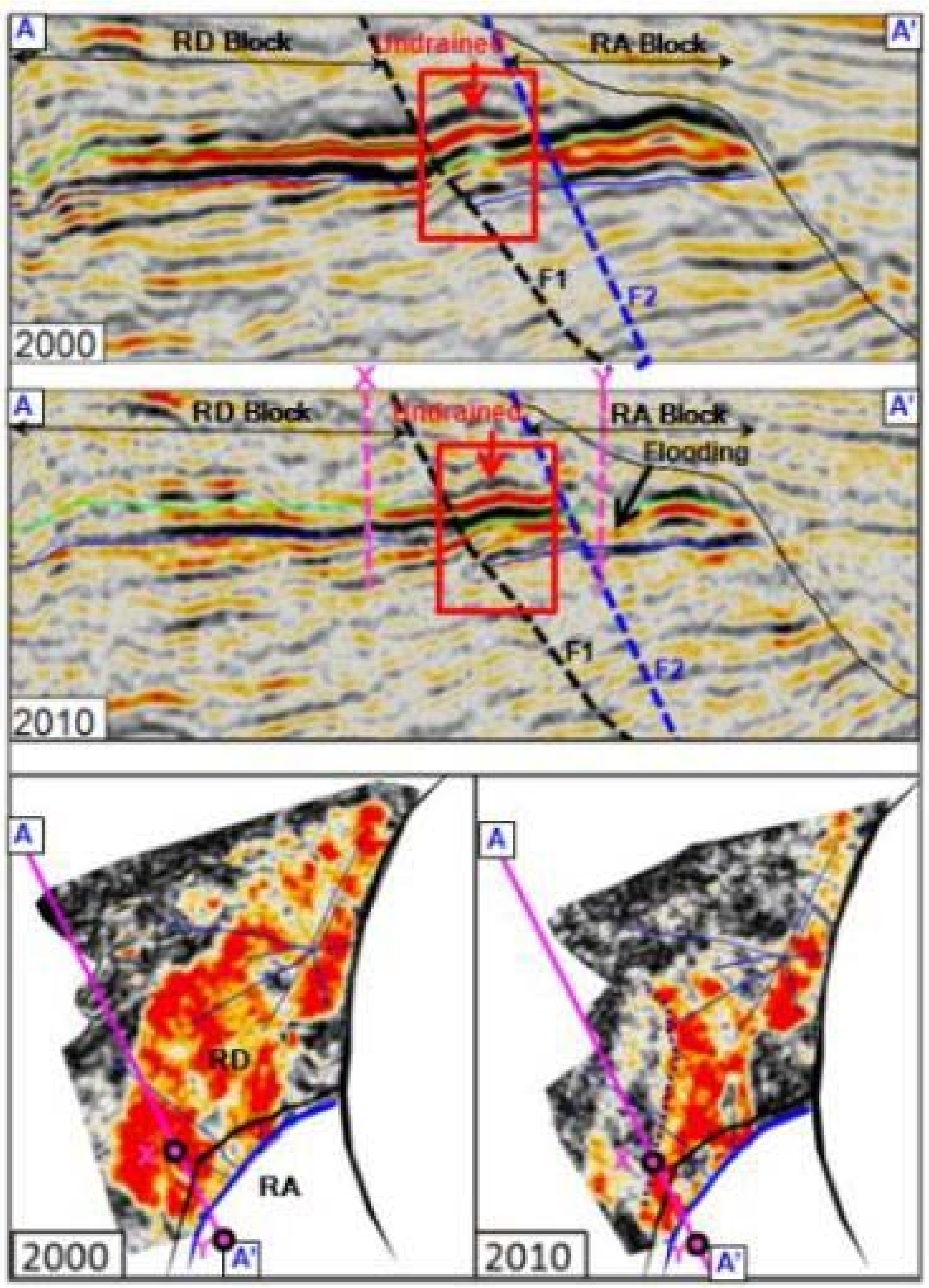

Figure 5. 4D sections and maps reveal the impact of an intra-block fault on fluid flow and shows a potentially unswept fault compartment (red box). 4D seismic amplitudes are restricted to the fault F2 due to the possible fault sealing in production time.

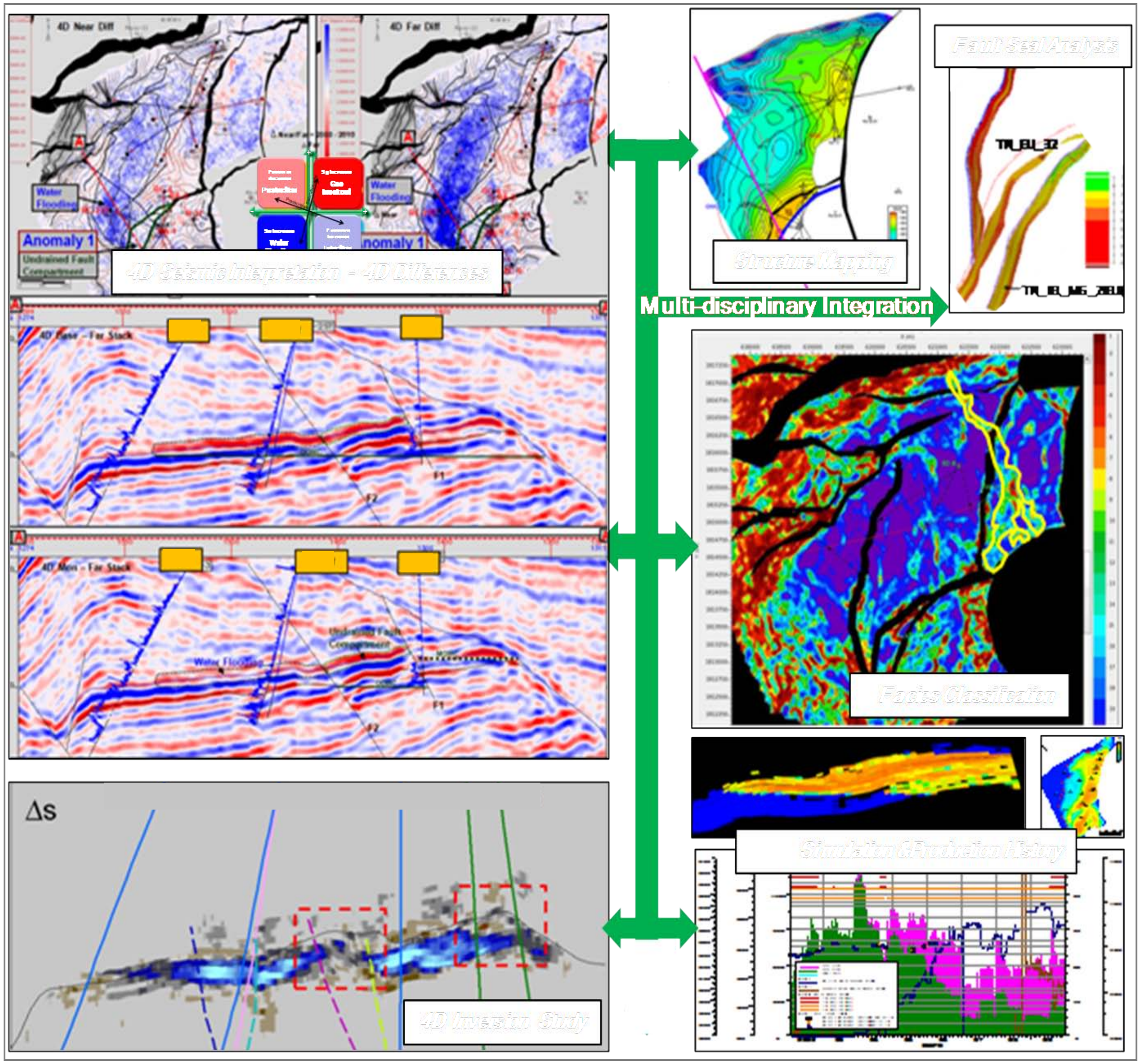

Figure 6. Multi-disciplinary integration: Integration of detailed mapping of faults and horizons using HD3D seismic, fault seal analysis, reservoir quality using seismic attributes, pressure and saturation decoupling using inversion studies, and calibration of 4D interpretations using infill well and dynamic reservoir surveillance results.