Optimized Field Development Through Integrated Reservoir Characterization
Knowing our reservoirs - Optimized field development through integrated reservoir characterization

The subsurface is inherently complex and heterogeneous by its very nature. Oil and gas accumulations are trapped in porous rocks beneath the surface of the earth and their distribution is controlled by the geometry of the trap and the architecture of the depositional system in which they occur. However, revealing the details of this complexity is far from easy as seismic imaging techniques only provide a remote view of the subsurface reservoir and many important components are seismically invisible or below seismic resolution. Wells drilled into the reservoir only sample a tiny portion of the rock volume due to which producing hydrocarbons is always associated with uncertainty.

Cairn India takes pride in building a comprehensive understanding of its subsurface assets to reduce this uncertainty and maintain the Company’s history of low cost operations and high efficiency production. Leading-edge technology is employed wherever it reduces uncertainty and adds value. Whether it is the latest seismic processing technique, advanced geological model, long horizontal well or highest productivity index through sustained production optimization techniques, Cairn takes the extra step to understand its reservoirs with as much certainty as possible. Multi-disciplinary team working and data integration are vital (Fig.1).

Geocellular geological models are routinely built and updated for all subsurface assets of the Company using state-of-the-art software and integrated input data. Such 3D geocellular computer models are used to generate a realization of subsurface reservoirs, which represent rock properties such as lithofacies, porosity, permeability and hydrocarbon saturation in the context of the overall structure and architecture of

Fig. 1. Integration: From seismic to core sample to 3D immersive visualization, integration of critical data is characteristic of Cairn India’s field development philosophy

Fig. 2. Cairn India’s Producing Assets and Exploration Portfolio
the reservoir. These numerical models take the form of a network of 3D cells in which each grid cell is assigned rock properties completely controlled by well and seismic data. They attempt to represent true volumes of hydrocarbons in place, as well as the connectivity of the reservoir. Reservoir simulation is then performed on the geocellular model to predict reservoir performance and production history. This enables geoscientists and engineers to integrate a multitude of data from many different sources to calculate oil and gas volumetrics; perform efficient well planning; forecast reservoir performance; and optimize reservoir depletion schemes. Moreover, as the actual amount of data available from all sources is always small compared to the volume of the reservoir being modeled, stochastic simulation techniques are used to generate multiple realizations of the reservoir properties to capture the inherent uncertainties, all of which honor the input data. The differences among these realizations provide a quantitative envelope of the uncertainty due to the limited reservoir information and data for the subsurface.

Cairn India has production operations in three geographical areas within India (Fig. 2). Production was successfully increased in the Ravva Field in offshore Krishna Godavari basin, Andhra Pradesh, through the use of integrated seismic interpretation; subsurface mapping; geological modeling; and an understanding of oil and gas distributions in different stratigraphic intervals to create a focused development strategy. In the Ravva field, a rotated fault block structure with an Oligo-Miocene reservoir sequence, hydrocarbons are trapped in multiple stacked fluvial and coastal plain reservoirs that are highly compartmentalized (Fig. 3). The field has been on production for 20 yrs and under the operatorship of Cairn. The great success story here has been a production increase from around 3,500 bopd to a plateau of around 50,000 bopd. One of the remaining challenges is to extend and optimize production from this mature field. Our integrated approach to reservoir management with a state-of-the art 3D Ocean Bottom Cable (OBC) seismic volume, and the inverted elastic properties and reservoir surveillance has helped to sustain oil production from a mature field (Fig. 4). Cairn India has completed a 4D
The Mangala Field, in the Barmer Basin of Rajasthan, is an example of a subsurface reservoir in which the company has invested heavily to characterize both the reservoir and fluid systems. This effort has led to robust field development planning; very successful development wells; and an overall low development cost. This field, the largest onshore discovery in India in last three decades, came on production mid 2009, has more than billion barrels of crude. The field development plan comprises optimal placement of both, production and water injection wells, as well as designing subsequent enhanced oil recovery techniques.

From the discovery of this field to its current development, many types of data have been acquired to better characterize the reservoir and associated fluids. Several vintages of seismic acquisition have been performed which led to the discovery and development of the fields. The waxy crude contained in the reservoir has led to some innovative flow assurance techniques including the longest continuously heated and insulated pipeline in the world.

Modeling the distribution of hydrocarbons in the fluvial reservoir was essential to design the development plan for the field. The initial 2D vibroseis survey in 1996; Cairn’s unique regional grid in 2003; and an infill grid in 2004 led to the discovery of the Mangala, Bhagyam and Aishwarya fields. Although the Mangala structure was identified, the proper imaging of faults remained problematic. In 2004, a 455 km² 3D survey with an optimized shot and receiver interval of 25 m was acquired over the Mangala and Aishwarya fields. A Post Stack Time Migration (PSTM) volume was generated and used for preparing the initial Field Development Plan and revising our calculations of oil in place. Despite the acquisition parameterization, the data at the crest of the field remained poor, caused by the low seismic signal to noise ratio towards western bounding fault and associated scoop faults of the field. Subsequently in 2005, this data was reprocessed using PreSTM, and clearly provided better imaging and further identification of internal faults, though it suffered from poor vertical resolution. In pursuit of improving the seismic imaging, a high density (HD) 3D survey was designed, acquired and processed to PreSTM in 2007 and used for improved static model for better imaging for detailed reservoir characterization. The improved noise suppression and shallow velocity information resulted in significantly better resolution in terms of defining the lateral continuity of the primary reservoir packages and proper imaging of low angle gravity and internal faults (Fig.6).

In 2008, the information from earlier drilled wells and a further refined velocity model were used in controlled beam, Pre-Stack Depth Migration (PSDM) processing of the HD3D, which achieved even further improvements in imaging the structure and faults. The field development drilling campaign began early in 2009 and both of these HD3D volumes and the seismic inversion volume derived from
HD3D are extensively used in reservoir characterization and modeling, as well as in well planning. (Fig. 7).

In addition to the investment in seismic data and characterization, nearly 3000 m of core were taken during the early exploration and appraisal wells, subsequently supplemented with core from key development wells. The core acquisition program was designed to provide essential data on the reservoir units both stratigraphically and spatially around the field. Based on the geological studies of the core, a geocellular model of the field has been sub-divided into five major litho-stratigraphic units named FM1 to FM5. Vertical layering in the model was chosen at 1 m to capture the high degree of variability in these complex fluvial reservoirs (Fig. 8).

From the geocellular model, a reservoir simulation model was constructed to understand the flow and displacement efficiency of fluids within the reservoir. This enabled engineers to investigate the optimal placement of production and injection wells. For high net-to-gross reservoir units, a combination of horizontal production and peripheral water injection wells were selected, whilst the more discrete channelized reservoir units with moderate net-to-gross utilized a pattern flood of deviated producers and injectors. In view of the highly heterogeneous nature of the formation, the need for closer spacing was identified based on the study, and infill wells are being drilled to improve the sweep efficiency and extend the plateau production within Mangala field.

During the drilling phase, the model has been used in real-time to place horizontal wells by using the latest geosteering and rotary steerable drilling techniques to target zones of known connectivity and reservoir properties (Fig. 9). This demonstrates how important integrated models are to Cairn, incorporating seismic information and being used for planning initial development concepts right through to the drilling operations of deviated and horizontal wells. To date, 12 horizontal wells were successfully drilled and tested in the Mangala Field, and have delivered production rates of more than 10,000 bopd.

In our CB/OS-2 block in the Gulf of Cambay, one of our significant challenges was the development of thin, oil sands in a Miocene section beneath existing gas reservoirs. Due to the masking effect by overlying high amplitude gas sands, imaging and mapping of vertically stacked discrete and interbedded oil reservoir is difficult with conventional seismic techniques. Spectral decomposition techniques, especially Continuous Wavelet Transform (CWT) enabled the tuning responses of sands for varying thicknesses to be resolved at different frequencies and helped in delineating the geomorphology of individual sand reservoirs. (Fig. 10). Seismic facies guided object based geological modeling, followed by dynamic modeling helped in understanding the sand distribution and upside potential of the reservoirs, and contributed to optimized placement of development wells.

Successful development drilling of infill wells based on CWT studies and other seismic attributes validates the use and the reliability of these technologies that have
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Cairn India is one of the largest independent oil and gas exploration and production companies in India with a market capitalisation of ~US$ 10 billion and the fastest-growing energy company in the world as adjudged by the Platts 2012 and 2013 Rankings. Cairn India operates more than 25 per cent of India’s domestic crude oil production.

Through its affiliates, Cairn India has been operating for more than 15 years playing an active role in developing India’s oil and gas resources. To date, Cairn India has opened 4 frontier basins with over 40 discoveries, 28 in Rajasthan alone.

The Mangala field in Barmer, Rajasthan, discovered in January 2004, is the largest onshore oil discovery in India in more than two decades. Mangala, Bhagyam and Aishwariya fields – major discoveries in Rajasthan block – have gross ultimate oil recovery of over 1 billion barrels from primary, secondary and enhanced oil recovery (EOR) methods.

Cairn India has a portfolio of 9 blocks - one block in Rajasthan, two on the west coast and four on the east coast of India, and one each in Sri Lanka and South Africa. Oil and gas is currently being produced from Barmer, Ravva and Cambay.

Fig.9. The end result of data integration: targeted directional drilling in the Mangala field to maximize well exposure to the high quality FM3 reservoir unit

Fig.10. Spectral Decomposition Technique, especially continuous Wavelet Transform enabled delineating reservoir geometries

transformed an almost depleted gas asset into an oil asset producing over 10000 boepd. Reservoir characterization using advanced geophysical tools and reservoir modeling studies in a complex geological setting such as the Cambay fields enables the company to unlock remaining potential and good economic returns.

Wherever Cairn India produces hydrocarbons, a combination of targeted data acquisition, leading-edge technology, and a focus on low cost operations ensure we produce the most hydrocarbons for each dollar invested.

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