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P - 63

**Integrated Geological Modeling of a Mature Oil Field in
North Cambay Basin, India.**

*Debashis Chakravorty** ONGC Jorhat, Assam, *Kamleshwar Rai* ONGC , Ahmedabad,
Dr. M.C.Kandpal ONGC ,Jorhat, Assam & *Ram Avtar* ONGC , Mumbai
debashischakravorty@gmail.com

Summary

Development strategy of a mature oil field comprises a great amount of investment and involves a large number of parameters related to geological modeling and reservoir simulation. An oil Field in the western margin in Ahmedabad-Mehsana tectonic block of North Cambay Basin, India, is on production since 1977. It is a multi layered strati-structural sand stone reservoir with aquifer support. Oil production had started in 1977 and touched its peak in 1992. From 1992 onwards, oil production had started declining gradually mainly due to increase in water cut. In order to arrest declining oil production, hold back increasing water encroachment and maximize recovery, a systematic and Integrated geologic modeling & Reservoir simulation has been taken up to improve field-scale reservoir management in the field.

Effective Geological modeling adopted in the field included detailed electro log correlation & structural mapping and analysis of 3-D dynamic water encroachment trend. Once the distribution of pay was reliably mapped, the field has been simulated with 3-D 3-phase option and multi sensitivities tested to determine optimum placement of new wells. The simulation was performed to validate and improve the geological model. 2-D modeling involved creating structure contour and oil iso pay maps. Attempt was made to resolve prevailing gas-cap-anomaly and mapping of by-passed oil. The integration of geologic modeling and reservoir simulation has improved the understanding of the geology, sand geometry, and flow characteristics of the Field that has produced about 33% of its OIIP.

Although the field is under production for quite some time, it has not been covered by 3-D seismic, thus making it difficult for seismic modeling, to look for remnant or by passed oil and monitoring of reservoir front movement. Productivity of deeper pays has also not been thoroughly tested. Available 2-D data has been used for attribute studies, pseudo interval velocity transform studies & AVO etc to understand entrapment mechanism and also search for deeper pays. 3-D seismic data acquisition has been planned for the field, which in combination with simulation results will further refine placement of in fill wells. Acquisition of 4-D seismic data will further improve the productivity of this mature field and monitoring of reservoir.

Introduction:

Cambay Basin is a narrow elongated intra-cratonic rift graben, which came to existence towards the close of Mesozoic Era marked by Deccan Trap activity. It trends roughly N-S as a narrow depression with several N-S and E-W trending faults which has further subdivided the basin into five tectonic blocks (Fig-1). The major lineaments

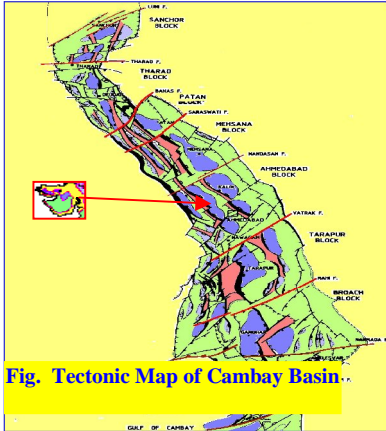


Fig. Tectonic Map of Cambay Basin.

control basin configuration and sedimentary pattern and to a large extent are related to basement faults. Sediments were mainly deposited during syn rift and post rift stages of basinal evolution.

Area of present study is Jhalora oil field, located in the western margin of Ahmedabad-Mehsana tectonic block of Cambay Basin in India. Main producer in this area are the Kalol sands K-A, K-B & K-C deposited in alternating regressive and transgressive environments. All the pay sands have aquifer support. Declining oil production has put forwarded a major challenge for field development. In order to optimize reservoir management, arrest production decline, improve recovery and extend field's economic life, an integrated Geological Modeling was conducted. The model is an integrated study of reinterpretation of existing 2D seismic data, reservoir simulation, 3D model of dynamic water encroachment trend & resolving of gas-cap-anomaly, recording of modern saturation logs for ascertaining by passed oil and generation of infill location for optimal exploitation.

Production Performance History:

Oil production started from the field in 1977. Up to 1982, 35 wells were drilled & oil production was 750m³/d with 5%

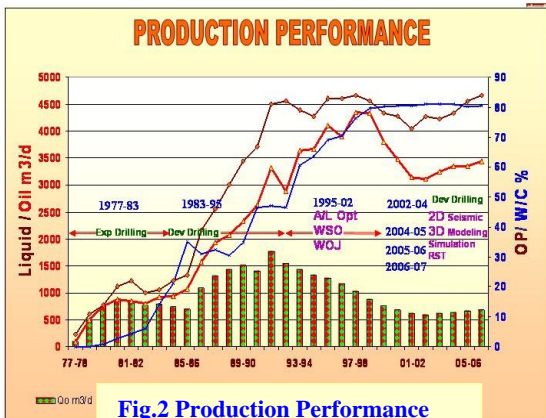


Fig.2 Production Performance

water cut. During 1982-1992, 80 more wells were drilled and production had touched its peak of 1850m³/d. Total liquid was 3400m³/d, but water cut had increased to 48%. By 1996, another 15 wells were drilled. Though liquid production was enhanced to 4200m³/d, but oil production had declined to 1200m³/d due to rise in water cut of 75%. Presently the field is producing oil @ 695m³/d with 88% water cut (Fig-2).

Net Pay Distribution & Reservoir Heterogeneity:

Net pay distribution map was prepared and revised after every new well data became available for each layer. The topmost K-A sand is best developed in the NW part, K-B sand is best developed in the central part where as K-C sand is well developed throughout the field with maximum

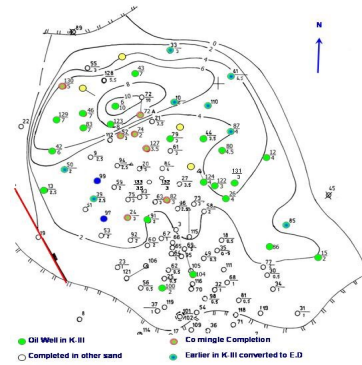


Fig.3 Net pay map of sand KA

sedimentation in the northern and central parts. (Fig- 3, 4, 5). Reservoir Heterogeneity in the field extends laterally as well as vertically. Lateral reservoir discontinuity scenario was also evaluated to confirm possible extension of channels. Porosity and permeability was found to vary in producing layers. The contrast in petro physical properties of various layers has resulted in obvious difference of production performance and water encroachment trend.

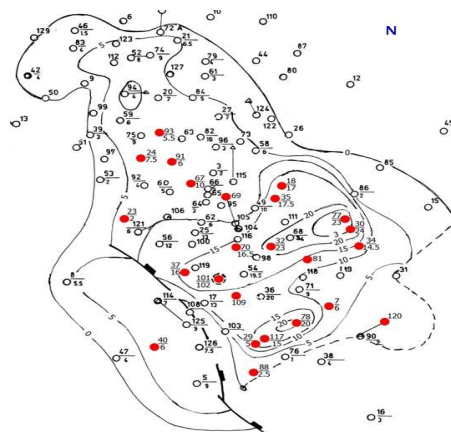


Fig.4 Net pay map of sand KB

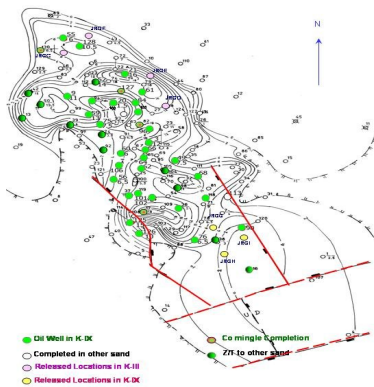
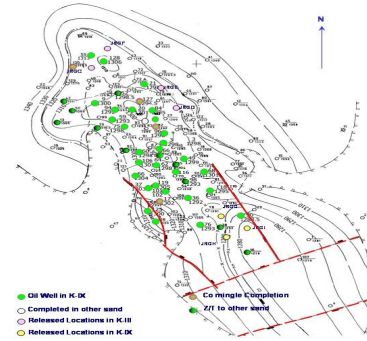


Fig.5 Net pay map of sand KC



Re-Interpretation of 2-D Seismic Data:

Present studies:

Various studies in the field were carried out with principal objectives of increasing the productivity and profitability from the mature Jhalora Field, thereby extending the economic life of this reservoir.

Structural Mapping:

Based on detailed reservoir correlation, structure maps at different levels were prepared and updated after each well was drilled. At K-A level the structure is an anticline with axes trending NNW-SSE. Central part of the field is flat, with western part dipping more steeply than the eastern part. For K-B sand, closure has been mapped in the central and southern part and at K-C level northern and southern parts are separated by a low. Small scale transverse and axial fault has also been mapped in the southern part (Fig-6,7, 8).

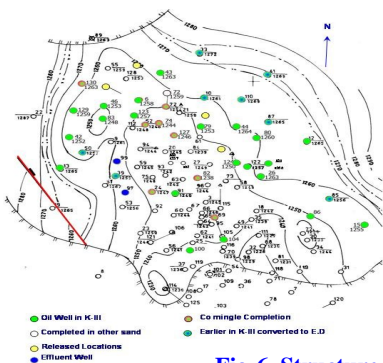


Fig-6. Structure map on top of K-A sand

An integrated study of the 2-D seismic data along with seismic attribute studies and pseudo interval velocity transform (PIVT) on selected lines was carried out in the western part of Jhalora area incorporating geological, reservoir and production data. Careful mapping of the western flank has indicated a NW-SE trending fault. An additional area on the up-thrown side of the fault was mapped (Fig-9) which was earlier thought to fall into structurally unfavorable area. Two locations were drilled on the up-thrown block, which has resulted in added reserves and substantial increase in production.

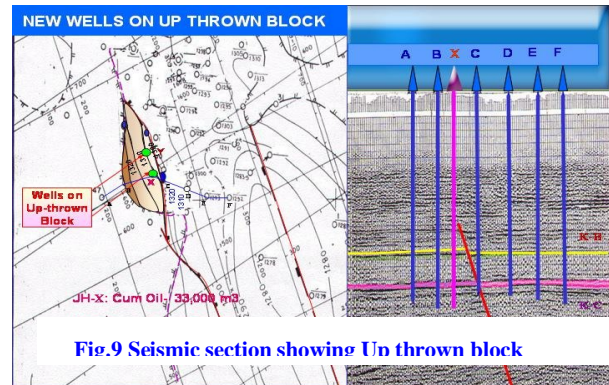


Fig.9 Seismic section showing Un thrown block

Discussions and Results:

Development of K-A Sand: A development plan was formulated for improving the recovery and augmenting oil production from upper most K-A sand which had produced 20% of OIIP. A Static and Dynamic reservoir model was prepared. On the basis of updated results of Reservoir models (Fig-10) along with production behavior, present day oil saturation, and net pay distribution. A series of year wise dynamic 3D water encroachment model was prepared (Fig-11). Results had indicated clear cut movement of water front mainly from the eastern flank with time and withdrawal. Based on water encroachment model, production

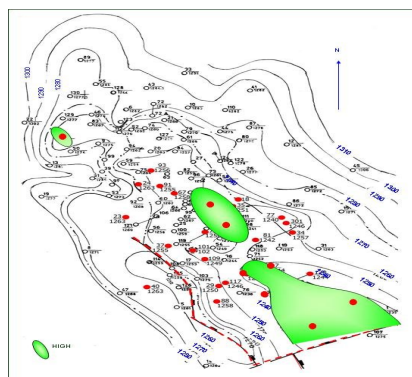
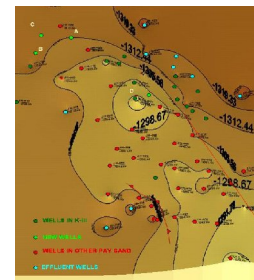


Fig-7. Structure map on top of K-B sand



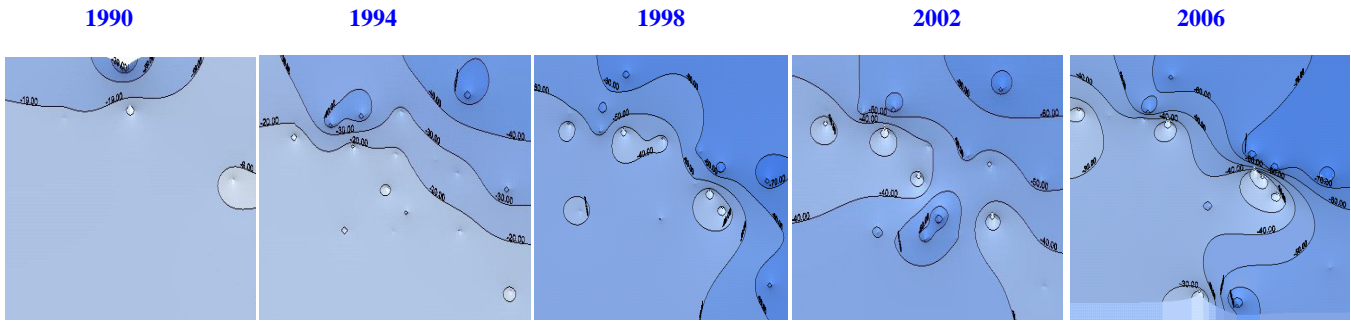


Fig.11 Dynamic water encroachment model

behavior, present day oil saturation, many new wells were planned and drilled. This has resulted in not only rise in production but also decline in average water cut.

Preparation of Static Model

Regional correlation has been firmed up after considering dip and strike line sections. Effective porosity has been taken up from formation evaluation of logs after appropriate thickness weighting. A layered geological model has been conceived for each layer with 5 set of property maps. The input data are continuously validated at various stages and finally a well conceived geological model has been put forth. Porosity 10% and Sw 80% has been uniformly taken as cut off values.

Revision of Geological Model:

Regional correlation has indicated a change in sand distribution pattern in the sand K-B & K-C (Fig-12).

Sand K-B: Based on revised correlation the sand is now envisaged as 3 layered reservoir and named as K-B-1, K-B-2, K-B-3. **Sand K-B-1** is developed as two N-S distributary channels separated by a median shale ridge. **Sand K-B-2** is developed as a thick continuous body in north with sand influx

from NW. The reservoir is limited to south central fringe by OWC. **Sand K-B-3** is the most widespread unit with influx mainly from NE and partly from restricted northern inlet. K-B-1 & 3, probably are in communication. During reservoir simulation interlayer communication has been studied and later combined to get better result.

Sand K-C: It is divided into 3 layers based on revised log correlation. **Sand K-C-1** is restricted to northern part with south central sand accretion. Highest relief is around 1310. **Sand K-C-2** is most extensively distributed with excellent production performance. Sand influx appears to be from north which chalk out main distributary path way. Sand accretion also noticed around SE part. **Sand K-C-3** is restricted to NW with low thickness and poor reservoir character.

Reservoir Simulation

Static model inputs are transferred at layer level on 200x200 grids in the form of 2 dimensional arrays for reservoir simulation. With oil rate as model input, model response of water cut has been attempted with the observed values from the fields. Good history match at field and sand level has been observed for 70% of wells. Oil saturation map at the end of the history were prepared (Fig-13, 14 & 15). Results had indicated remaining oil distribution in diverse layers of reservoirs and had provided sound base for optimized placement of in-fill locations and performance forecasting. Most of the layers are not in communication as indicated by water cut history match. Pressure production history suggests most of the layers operating under active edge water drive.

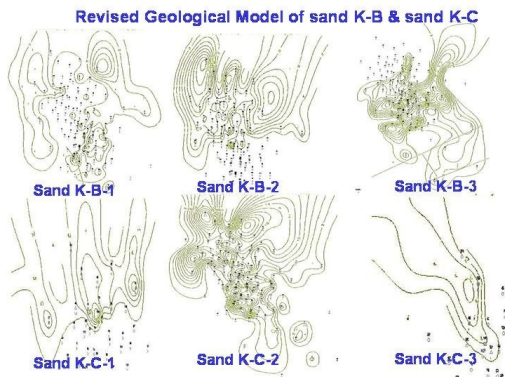


Fig. 12 Revised Geological Model

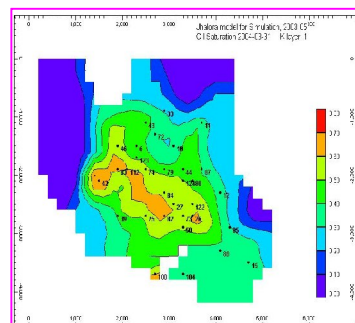


Fig. 13 Oil Iso saturation K-A



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23,810m³, due to well damage. Adjacent wells had encountered about 3-4m of K-A sand. The wells in the southern part are producing oil from K-C sand. Reservoir Simulation had indicated oil saturation of about 70% around well JB. Hence for optimal exploitation of K-A reservoir and to ascertain the extension of additional sand encountered in well JB, additional area was available SE of JB.

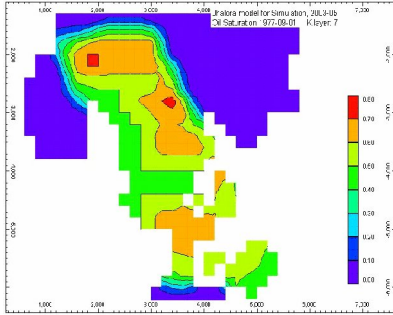


Fig. 14 Oil Iso saturation K-B

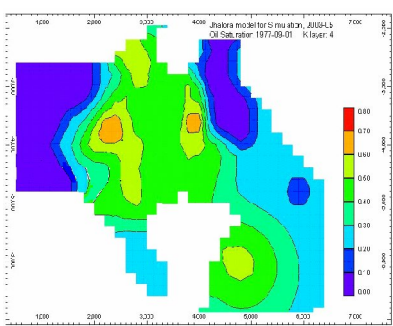


Fig. 15 Oil Iso saturation K-C

Implication of Geological modeling on field development:

Refinement of geological model has helped in placement of new wells for K-A & K-C pays, which has further enhanced the production from these pays. E-W Electrolog correlation in the northern part (Fig-16) shows behavior of different pay sands and disposition of additional sand. Well JB had encountered 3m of K-A sand & also additional oil bearing sand below K-A. This additional sand could not be traced south-wards or east-wards. The well JB was abandoned after cumulative oil production of

Gas-Cap Anomaly in K-C sand:

In the southern part of K-C layer, gas cap has been estimated on testing results of wells JA, J3 and JY and it has resulted in sufficient area left un-exploited. An integrated study was undertaken of the gas cap area in the southern part of Jhalora Field incorporating detailed well log correlation (Fig. 17), analysis of earlier test data, production performance, analysis of structural level (Fig. 18) and GOR for exploitation of this area. Detailed analyses of testing and electrolog data indicated that:

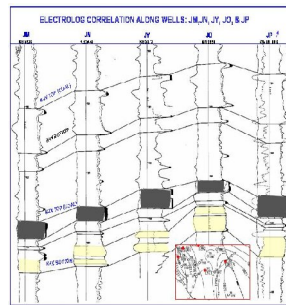


Fig.17 Electrolog Correlation Profile

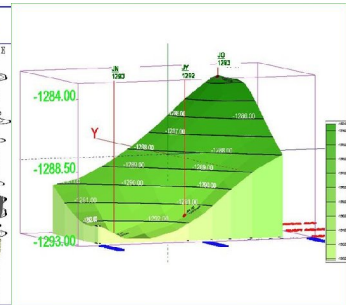


Fig. 18 Structural Level Analysis

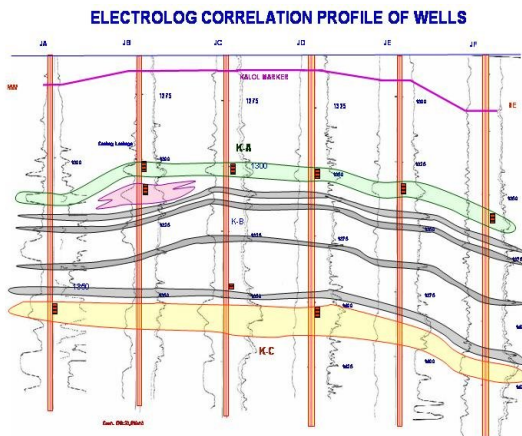


Fig 16 Electrolog correlation profile

In well JQ two hydrocarbon bearing sands were encountered in K-C layer. Cased hole N-N log had indicated higher API counts in both the layers indicating presence of gas. Top interval was perforated. The well produced gas @ 27,450m³/d through 5mm. In well JY, Two hydrocarbon bearing sands were encountered in K-C. Cased hole Neutron log indicated lower N-N API count in both the layers as compared to well JQ indicating presence of oil. Initially sand K-B was perforated. It had produced little oil and water. During subsequent work over, upper interval of K-C was perforated and on activation influx of oil & water was observed. PLT log was recorded had indicated, source of water from sand K-B. Adjacent well JN was tested in K-C. The well produced oil. Presently the well is flowing oil @ 12.55 m³/d and till date the well has produced 2,39,175m³ of oil and GOR has remained in the range of 10-20v/v. Similarly well JO was perforated in the K-C and produced oil 50 M³/Day and gas with initial GOR of 18 v/v. Presently the well is flowing oil @ 20 m³/d and till date the well has produced 65,000m³ of oil and GOR has remained in the range of 14-20 v/v.



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Electrlog correlation, production performance and GOR data had clearly indicated:

K-C sands in wells JN, JY and JO are all co relatable. In well JY, K-C sand encountered at 1292m has produced oil, water and gas during initial testing. In well JN, K-C was encountered at 1293m has produced oil since Sep'92 without any change in GOR. In well JO, K-C sand was encountered at 1283.5m has produced oil since March'99 without any change in GOR. Based on the above data it is inferred that: GOC if present is above the top of perforated interval of well JO. Sustained production performance of wells JN & JO indicate oil at least up to perforation top of well JO. Existing K-C sand maps around well JQ have been modified (Fig-19). Revision of maps resulted in increase in OIIP in sand KC by 0.51 MMt. The model was confirmed by drilling wells. One of the well is

producing @ 37m3/d on self. It has not only enhanced

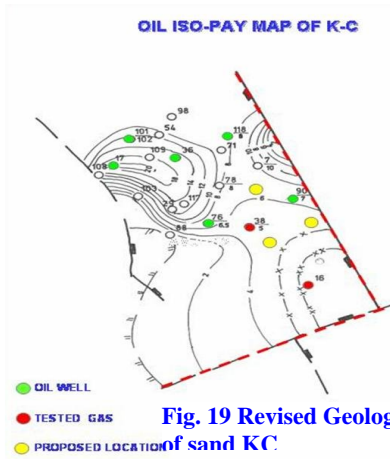


Fig. 19 Revised Geological Model of sand KC.

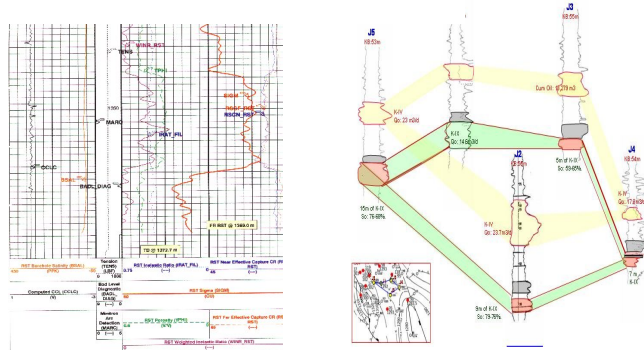
production, but has opened up new areas for development towards SW.

Mapping of by passed oil:

Ascertaining the status of residual oil saturation left in such a mature field that has produced more than 33% of it's in place reserve with aquifer support is of prime importance for healthy exploitation. A systematic campaign of recording of RST log was launched in carefully selected wells for targeting bypassed oil. Preliminary analysis of RST Sigma log recorded in well J-1

(Fig- 20) indicates by passed oil. C/O ratio shown in RST log also confirms similar observation. Well J-1 is on production

Fig.20 Revised Geological Model of sand KC



from sand K-C and is presently producing oil @ 15 m3/d where as near by wells J-2, 3 and J-5 is good producer from K-B sand. For optimal exploitation additional area was mapped.

Future Reservoir development strategy:

In view of proposed 3D seismic data acquisition in the area, the seismo geological models will need to be updated in regular intervals. 3D data will also help in looking for more by passed oil in the producing formations and also identifying deeper prospects. Integrating seismic with reservoir simulation will help in planning more wells in optimally located areas. Finally recording of time lapse 4D will help in identifying the least flooded areas after sustained production from the field.

Conclusions:

In order to optimize reservoir management, arrest production decline, improve recovery and extend the field's economic life, an integrated geological modeling was conducted. Revised pay zone correlation, reinterpretation of old 2D seismic data and dynamic water encroachment maps had helped in better understanding of the reservoir and further planning for field development. Reservoir simulation and recording of RST logs indicated present day oil saturation for better placement of in-fill wells. The effort has not only reversed the production declining trend but also has resulted in production enhancement from 620m3/d in 2003-04 to 695m3/d in 2006-07 from Jhalora Field that has produced about 33% of its OIIP.

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