Integration of technology & Geological understanding for reservoir characterization – A case study of Ahmedabad-Nandej-Wasna area of Cambay Basin, India

S. C. Malviya, Dhruvendra Singh, Rajeev Tandon, Anand Kumar, Rajiv Paul, Sanjay Kumar Singh, Ambrish Kumar Tripathi*
GEOPIC, Oil & Natural Gas Corporation Ltd., Dehradun
scmalvya@yahoo.co.in

Keywords

K-IX/K-X Parasequence, P-impedance

Summary

Nandej-Ahmedabad fields, located in southern part of Ahmedabad-Mehsana tectonic block of Cambay Basin are in active phase of development for Middle Eocene reservoir exploitation. The field is gradually approaching the mature phase and recent development activity for K-IX and K-X reservoirs have got setbacks and pose the challenges for future exploitation strategies.

Seismic mapping has brought out presence of three sets of faults trending NW-SE, WNW-ESE & NNE-SSW. These faults play very important role in hydrocarbon accumulation in the area. The structure maps clearly display the structural highs of Ahmedabad and Wasna Fields and the saddle between them as Nandej Field.

Integration of log response, lithological characters and laboratory analysis has led to preparation of litho-facies maps. The facies maps vividly bring out the sediment dispersal pattern in the study area. In Nandej Field, the K-IX & K-X reservoirs have been deposited under tide influence of Lower Delta Plain environment largely comprising of fine grained sandstone and siltstone facies. Within the K-IX unit, at least four channels are present with NE-SW orientation occurring as bottom sand unit and top sand unit.

The P-imp attribute maps along the stratal slices of the Impedance volume were generated on the basis of P-Impedance range classification, four dominant facies, viz. sandstone, siltstone, shale and coal have been identified and their distribution depicted in time and space. The sand distribution pattern inferred from this map corroborates fairly well with the sand-silt isolith trends and the drilled well data.

The findings have resulted into identification of areas for exploratory and development thrust.

Introduction

The fields of Ahmedabad-Nandej-Wasna located in the southern part of Ahmedabad-Mehsana tectonic Block of Cambay Basin (Fig.1) are gradually approaching the mature phase and poses the challenges for future exploitation from the thin and tight pay units of K-IX & K-X units of Sertha Member of Kalol Formation.

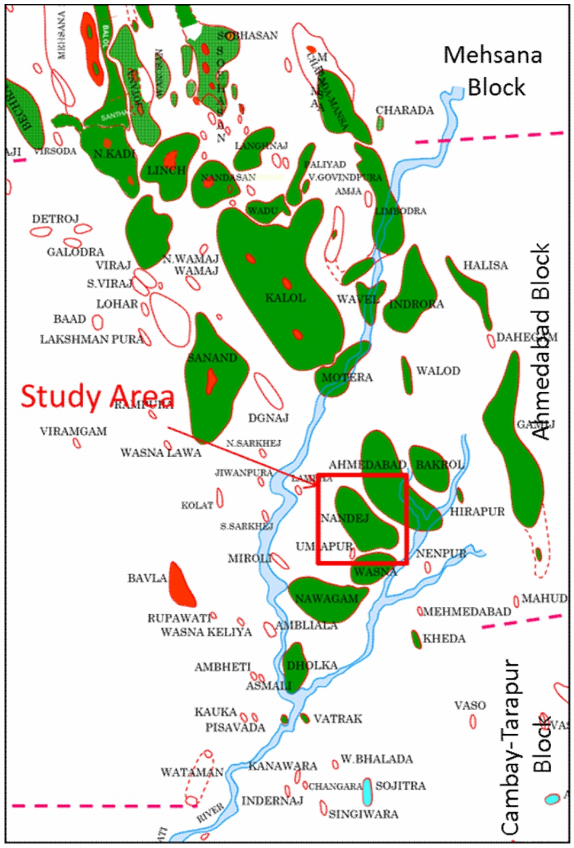

Figure 1: Prospect map of North Cambay Basin showing the area of study.

Workflow

To effectively understand and optimally derive the output from basic seismic data set workflow adopted is as displayed in the flowchart (Fig. 2). Interactive interpretive processing is carried out for improved imaging of the seismic data at pay level. Geological modelling of high order sequences together with petrophysical properties and

geophysical attributes are amalgamated with revised structural framework to reveal the intricacies of reservoir.

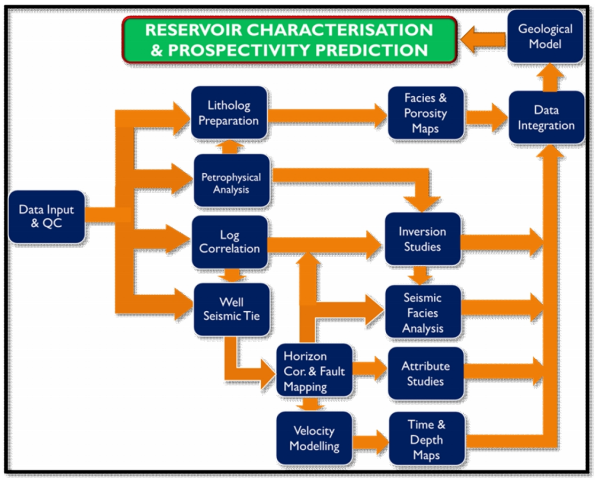

Figure 2: Description of flowchart here.

Geological History

The study area is a part of Ahmedabad-Mehsana tectonic block of Cambay Basin, an extensional basin and encompasses entire Tertiary sequence having mainly clastic sedimentation. The generalized stratigraphy of the entire succession from Middle Jurassic to Recent for the Cambay basin on the basis of outcrop and well data is shown in (Fig.3).

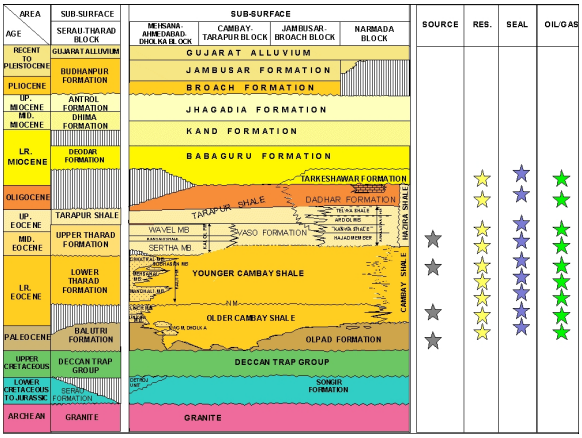

Figure 3 Generalized stratigraphy of Cambay Basin

The Deccan Trap forms the technical basement in the study area which is overlain by Paleocene syn-rift sediments of Olpad Formation. The Olpad Formation exhibits complex lithological association and basically a trap derivative. Petrographic study revealed the development of three lithofacies viz volcanic conglomerate, volcanic sandstone and claystone within this formation. The Olpad Formation, is overlain by transgressive Cambay Shale of lower Eocene age. Cambay shale is divided into Older Cambay shale (OCS) and younger Cambay shale Formations. The arenaceous reservoir facies developed within younger Cambay shale are Mandhali, Mehsana and Chhatral members. The younger Cambay shale is unconformably overlain by Kalol Formation of middle Eocene age.

Lithofacies and Depositional Framework

The Kalol Formation is divided into Sertha and Wavel members from bottom to top where the transgressive Kansari Shale occurs between the two. The Sertha member includes the pay horizons of K-X, K-IX and K-VIII while K-VI +VII horizons occur within Kansari Shale (Figure 4). The Kalol Formation is overlain by transgressive Tarapur Shale of Early Oligocene age.

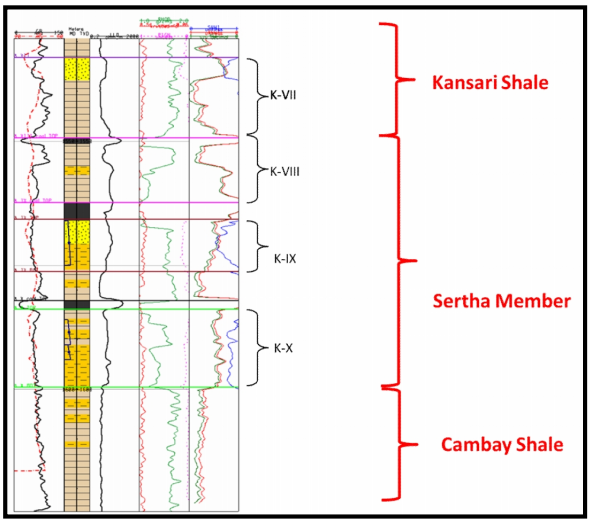

Figure 4 Log motif showing the reservoir units within Kalol Formation

The sequences of study area are in conformity with Regional Stratigraphy of the Cambay Basin. Kalol (K-IX & K-X) pay zones are well developed in the area. Both the horizons consists of fine grained sandstone/siltstone and silty shale / carbonaceous shale layers. Sideritic shales have also been reported in many core study reports.

The main producing sedimentary unit corresponding to the Kalol Formation K-IX and K-X (Sertha Member) consists of two parasequences representing two independent episodes that are separated from each other by a persistent transgressive shale. The K-IX parasequence is the prime target of the study as this is the major hydrocarbon contributor in this area

K-IX PARASEQUENCE

Deposition of K-IX parasequence started with marine transgressive shale which persists throughout the area. The sand isolith map (Figure 5) indicated depositional input from north and northeast direction in two different axes: one passing through high across the main Ahmedabad Field and the other lobe towards east of main field through Bakrol-Hirapur area. The western channel has been probed by drilling of number of wells of Nandej field and eastern channel has been confirmed by drilling of wells in Ahmedabad Field and needs further exploratory inputs for field growth. Redistribution of sediment along the cross faults can be seen in the southern part of Channel-2. The pre-existing east west oriented cross faults appear to have played the role in the sediment dispersal pattern.

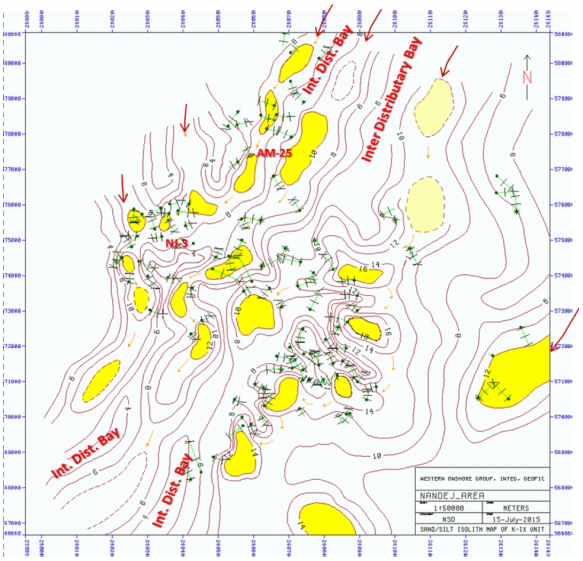

Figure 5 Sand/Silt Isolith map of K-IX unit

The unit is divisible into two units i.e. upper and lower (Figure 6). The facies of upper unit is lithologically characterised by fine quartzwacke with sideritic clay (kaolinite) occupying the intergranular pore space. The sedimentary structures include "wavy and flaser bedding, interlayer carbonaceous lamination of clays. This facies is also characterised by low volume clay content, good porosity, permeability and low water saturation. The facies is well developed in the central part of Nandej and south of Ahmedabad area and might have been deposited as tidal bars & channels.

The facies of lower unit is characterised by interlayered carbonaceous shale, sideritic claystone and occasionally siltstone. This facies is developed throughout and appears to have been deposited in tidal regime.

Four channels (1 to 4 from west) have been mapped in this area. These channel consist of two sand units. Out of these Channel-3 is described below. The upper sand unit of K-IX is largely persistent throughout whereas lower sand unit is absent in the Wasna area to the SW. Reservoir facies is expected to be better developed in the northeastern part where upper sand unit may not be present.

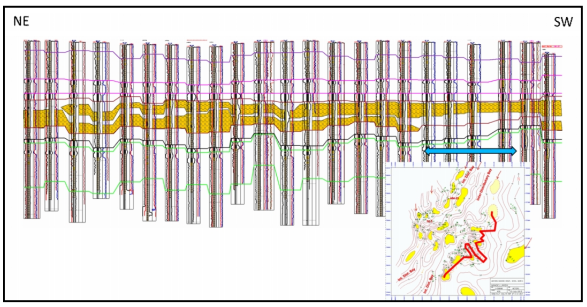

Figure 6 Electrolog correlation along channel-3 of K-IX unit

Inversion modelling and reservoir facies

To fine tune the attribute studies and to circumvent the limitations of conventional amplitude attributes due to masking effect of coal and low frequency content, post-stack inversion was carried out. To build the inversion model, elastic logs of 21 processed wells were used. Feasibility study for the same was carried out to evaluate possibility of discrimination of different lithologies. Different cross-plots were generated for the purpose. The GR Vs P-imp crossplot (Fig. 8) suggests separation of coal mainly, while other lithologies (sand/silt/shale) do not show discernible separation and even P-imp range from 4000 – 5000 g/cm^3 * m/s display mixing of some coal with the other lithologies.

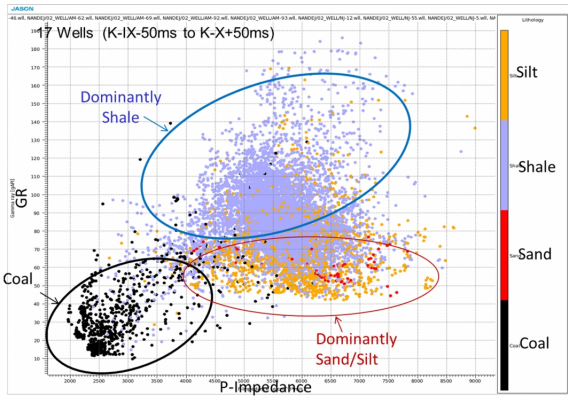

Fig. 8 Cross Plot (P-Impedance vs. GR)

The P-imp Histogram (Fig.9) also corroborate the same. However, from the skew of frequency (number of occurrences) of the different lithologies, as seen in the said histogram, it can be inferred that shale has mainly moderate P-impedances (4200 – 4800 g/cm^3 * m/s) while P-impedances of silt is mainly in the range of 4800 – 6200 g/cm^3 * m/s and that of sand is mainly in the range of 6200 – 7700 g/cm^3 * m/s. The possibility of partial overlapping of the said lithologies across the limits of the ranges mentioned cannot be ruled out, though.

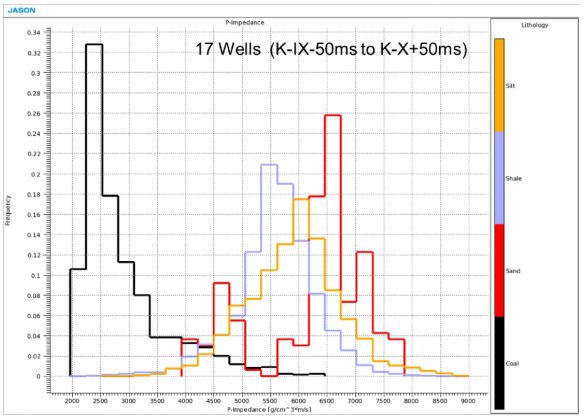

Figure 9 Histogram (P-Impedance)

On the basis of the broad P-impedance range classification, P-imp attribute maps were generated along stratal slices covering the K-IX pay window. After analyzing the individual slices, average P-imp maps for the full window corresponding to K-IX pay were extracted. The P-imp map corresponding to K-IX pay (Plate-10) depicts lateral spread of the lithologies (based on P-imp range) which may be fairly indicative of the likely clastic dispersal trends and reservoir distribution. The sand distribution pattern inferred from this map corroborates fairly well with the sand-silt isolith trends and the drilled well data.

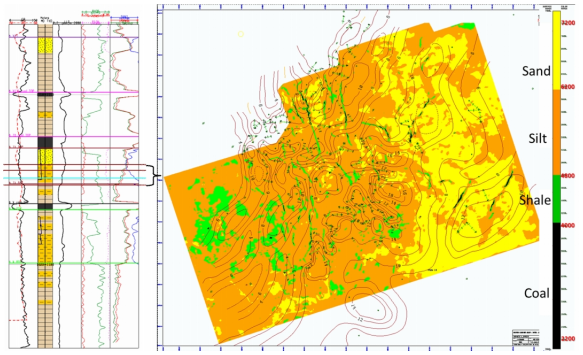

Figure10 Sand isolith map overlay on Impedance of K-IX Unit

Discussion and prospectivity analysis

The Cambay – Kalol petroleum system is a prolific system that occurs in the Ahmedabad-Mehsana block. The principal source of this system is the shale of the Cambay Formation, while the principal reservoirs are deltaic sandstones of the Kalol Formation.

Modeling of the generation histories of the source rock intervals within this petroleum system have been undertaken by various authors. Vitrinite reflectance values within Cambay Formation range from 0.5 - 2.2% Ro. Samanta (1993) suggests that the onset of generation within the Cambay Formation began in Late Oligocene / Early Miocene (approx., 25 ma), with peak generation occurring towards the end of the deposition of the Jhagadia Formation (approx. 6 Ma).

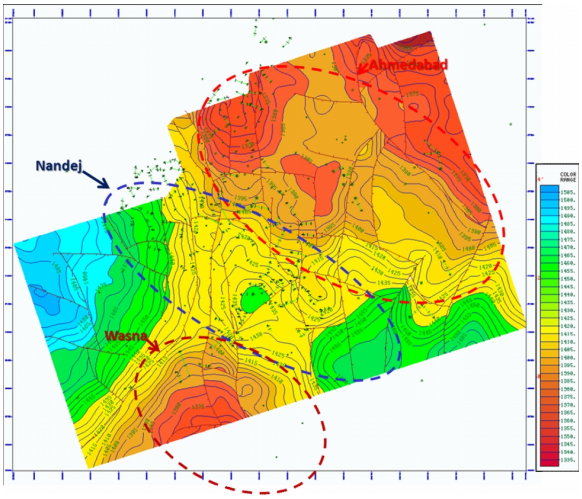

Figure11 Time structure map of K-IX Unit

The time maps close to K-IX have brought out the structural high features of Ahmedabad, Nandej and northern part of Wasna area with a low between Nandej and Wasna field (Figure11). These maps show the deepest part of the area to the west. The structure is gradually rising towards north and NE of the area. The map clearly displays the structural highs of Ahmedabad and Wasna Fields and the saddle between them as Nandej Field. Three sets of normal faults trending NW-SE, WNW-ESE & NNE-SSW have been brought out in the area. These faults play very important role in hydrocarbon accumulation in the area. These structures appear to have developed post Mid-Miocene compressional tectonics related to Himalayan orogeny and were available for entrapment at the time of peak hydrocarbon generation.

The hydrocarbon prospectivity of K-IX & K-X units in the study area has been identified by integrating all the G&G studies, viz. Sand / Silt isolith maps, Impedance attribute and GME model. The areas marked with green and pink in the Prospectivity map indicate the thrust areas for exploration and development activities respectively (Figure 12). Good reservoir facies in channel-3 & 4 is expected in these areas.

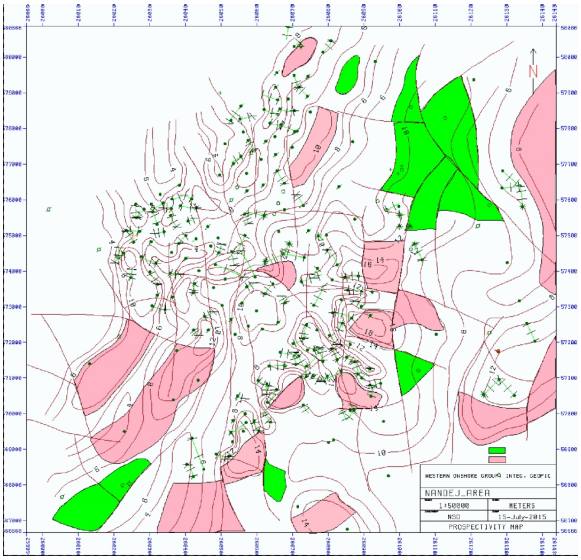

Fig. 12 Prospectivity map for K-IX sand

Conclusions

- Electrolog correlation displays structural variance differentiating the fields of Ahmedabad, Nandej and Wasna. It also displays the facies variation within K-IX parasequence. The reservoir facies developed just below the K-IX coal is better as compared to that developed in the lower part. Poor reservoir facies within K-IX is seen in the wells which are located in close proximity to the Inter distributary bay area.
- K-IX reservoirs have been deposited under tide influence environment of lower delta plain comprising fine grained sandstone and siltstone facies. Finer scale sand geometry depicting major channel axis have been delineated for these units. Within the K-IX unit, at least four channels are present with NE-SW orientation occurring as bottom sand unit and top sand unit.
- The P-imp attribute maps along the stratal slices of the Impedance volume were generated. On the basis of P-Impedance range classification four dominant facies, viz. sandstone, siltstone, shale and coal have been identified. The stratal slices within K-IX display widespread distribution of coal above the shale and siltstone/sandstone reservoir within the NE-SW oriented channels. Eastern part of the area display better reservoir facies as compared to western part.
- Based on the geological and geophysical inputs the areas have been identified for Development (marked in pink) and Exploration (marked in green) thrust.

References

1. Chandra, P.K., and Chowdhary, L.R. (1969): Stratigraphy of the Cambay Basin, ONGC Bull., 6(2), page 37-50.
2. Kundu, J. and Wani, M.R. (1993): Integrated geological studies and hydrocarbon prospect evaluation of Cambay Basin, unpublished report, ONGC, KDMIPE, Dehradun.
3. Pandey, J., Singh, N.P., Krishna, B.R., Sharma, D.D., Parakh, A.K. and Nath,S.S. (1993), Lithostratigraphy of Indian Petroliferous Basins: Document - III-Cambay Basin. KDMIPE Publication.
4. Parakh, A.K., Shau, S.K., Prakash, A., Ms. Negi, A., Pillai, S., Aswal, Srivastava, H.S., Ms. Niranjan, N. (2007) Sequence Stratigraphic Frame Work Cambay Basin, unpublished report, ONGC, WON, Baroda.

Acknowledgments

The authors are highly indebted to Shri Anil Sood, ED-Head of Institute, GEOPIC for being a constant source of inspiration during the course of this study. The suggestion made by Dr. Hari Lal, GM (GP), INTEG during the course of this study is also gratefully acknowledged.

The views expressed herein are entirely those of the authors and need not necessarily reflect the view of ONGC Ltd.