

Untapped Hydrocarbon Potential of Post Kalol pay sands of North Kadi-South Santhal Field, Cambay Basin, India

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Key words:

Miocene, Upper Suraj Pay, Lower Balol Pay, Siderite, Chamosite.

Summary

North Kadi field, lying in the Ahmedabad-Mehsana Tectonic Block (Fig.1) of Cambay Basin in India was discovered in 1968. Hydrocarbon accumulations in the area have been established mainly from Kalol pays of Middle Eocene age, with Linch, Mandhali & Mehsana pays, lying within Kadi and Cambay Shale of lower Eocene age, also contributing to hydrocarbon production. Accumulations in shallow, post-Kalol sands have also been established sporadically from Balol pay within Tarapur formation (Upper Eocene to Oligocene age) and from pays within Babaguru and Kand formations (Miocene age). However, their discovery has been largely by serendipity or half-hearted endeavours while probing Kalol and deeper pays rather than through any concerted effort to explore them. In earlier days of exploration, some zones in the shallow pays have been tested and flowed hydrocarbon, against which some reserves have been booked. Exploration efforts, so far, have focused primarily on Kalol and the deeper sands, considering their good producibility while the post-Kalol sands usually have not got the importance they merit in spite of their hydrocarbon potential. Very few of them have been tested properly, despite showing reasonably good log signatures, as majority of the interesting intervals fall behind double casing or are in presently producing wells. With the typically prolific Kalol sands now reaching a mature stage in the E&P cycle and only incremental accretions happening in recent years, it's imperative to look at new or relatively less explored pays. In this regard, the post-Kalol sands which are expected to hold good accumulations of untapped hydrocarbon merit attention for exploration.

The present study attempts to identify hydrocarbon potential of post-Kalol sands outside known limits, analyzing log response of drilled wells against shallow pays zones in tandem with G&G data and envisaged depositional model. As the accumulations are primarily structural, minute mapping of events

along the sand top helped in delineating possible pool limit also. These pools buried at depths of 1100m or less, making them techno-economically viable, even for smaller accumulations.

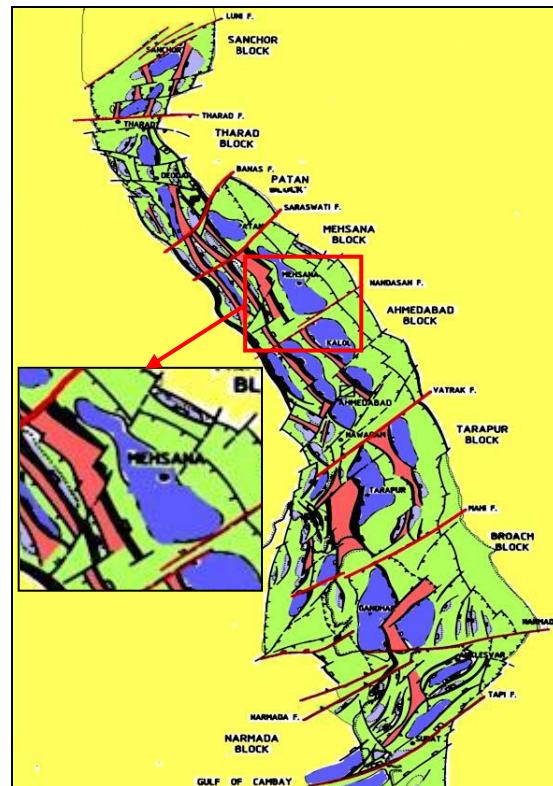


Fig. 1: Tectonic map of Cambay Basin (after J.Kundu et.al, 1996), with Mehsana-Ahmedabad Block in inset.

Introduction

North Kadi field (Fig.2), located 25 Km SW of Mehsana Town in the Ahmedabad-Mehsana Tectonic Block of Cambay Basin in India, is surrounded by Santhal field in the north and Linch field in the east, covering an area of more than 72 sq. km. North Kadi field was discovered in 1968 through discovery well X#1 and put on production since 1969 from Kalol sandstone reservoirs of Eocene age. Subsequent

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exploration/development efforts of the field indicated occurrence of hydrocarbon accumulations in sands,

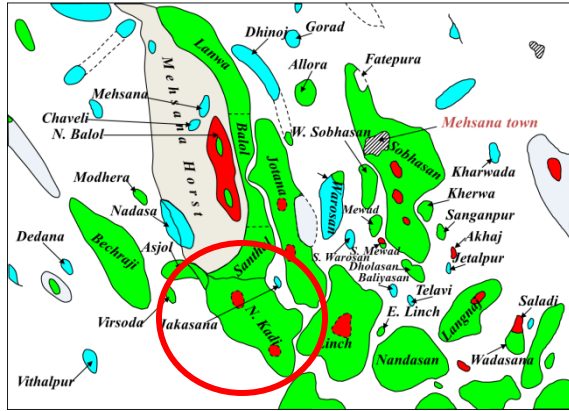


Fig.2: Prospect map showing hydrocarbon distribution of Mehsana Area and North Kadi field.

ranging in age from Upper Paleocene to Middle Eocene *i.e.* within Older Cambay Shale (Linch Pays), Kadi Formation (Mandhali, Mehsana & Chhatral pays) & Kalol Formations (KS-III to KS-IA pay & USP). Most of the in-place oil has been established within Kalol sands which are the most producers in the area. The underlying Linch, Mandhali & Mehsana pays of Lower Eocene age have also been good producers, particularly from south-eastern part of the field. Besides, hydrocarbon accumulations have been established in shallow pays within Tarapur Formation (Balol Pay) of Upper Eocene to Oligocene age and in sands within Babaguru and Kand Formation of Miocene age. However, their discovery has been mainly by providence while prospecting pays in Kalol & deeper levels. Reserve has been booked against these sands, but the present study suggests that the pay potential is much more.

Methodology

In the present study, an attempt has been made for the first time to prepare an integrated model covering South Santhal and N. Kadi field for shallow sands of Miocene age along with Balol Lower pay sands and USP sand.

More than 150 wells have been taken up for analysis of post Kalol pay sands in the area along with adjoining parts of Linch and Jotana field. The pay sands, which are differentiable from each other on the basis of prominent shales, were correlated in these wells. Analyses of log characters, available cutting samples & SWCs of drilled wells were carried out for facies determination and reservoir unit identification.

On basis of this, sand dispersal pattern of these pay sands were prepared. For identification of prospective zones for shallow pays, several wells were seen outside estimation limits which showed interesting log signatures (good resistivity and crossover at neutron porosity & density) in shallow untested zones. These may be interesting from the hydrocarbon point of view and need to be explored.

Litho-Stratigraphy of the Area

The Kalol sands of Middle Eocene Age which are the major producers here have been deposited extensively in the area. The Upper Suraj Pay (USP) sands were deposited at the top of Kalol Formation. Kalol Formation is overlain by marine Tarapur Shale of Late Eocene to Oligocene age. The overlying Balol pay sands (Late Eocene to Oligocene age) and the shallower Miocene sands are fairly wide-spread in the area.

Balol Lower & Upper pay sands are charged with free gas pools identified within Tarapur Shale. Subsequent tectonic activity in the basin resulted in the development of a widespread unconformity. The deposition of enormous thickness of Miocene sediments took place as the Babaguru, Kand and Jhagadia formations. Miocene sand-A, B, C, D & E are charged free gas pools within Babaguru & Kand formations. Sand and shale were deposited during the Pliocene, whereas during Pleistocene to Recent, the sedimentation was mainly fluvial represented by characteristic deposits of coarse sands, gravel, clays and *kankar* followed by finer sands and clays, comprising Gujarat Alluvium.

Sedimentology and Depositional Environment

The Miocene Section, differentiated as Miocene sands- B, C, D & E in Tarapur Formation and as Miocene sands- A1 & A2 in Kand Formation, was deposited as flood plain deposits with poor to fair reservoir facies.

Balol pay unit was also deposited as pro-gradational deltaic arenaceous sequence caused by sedimentation pulse within major transgressive Tarapur shale formation. Balol pay does not show classical sand stone/siltstone signatures in logs. It appears to be tight zone in log considering high density & resistivity peak; but ditch sample taken in these intervals reported in earlier drilled exploratory wells are documented as oolitic sand stone, showing high density nature due to presence of calcareous material within it.

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Oolites are developed in shallow marine environment, in a warm and wave agitated water.

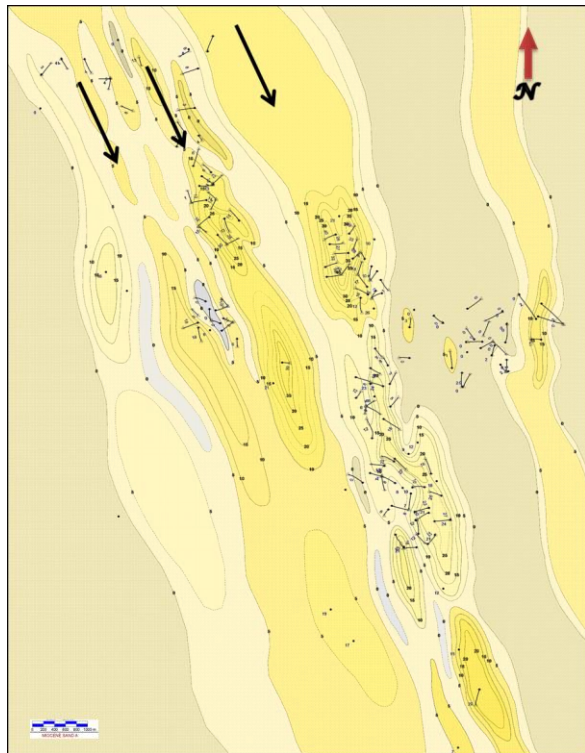


Fig.3: Sand isolith map of Miocene Sand -A of North Kadi field.

Warm water with low carbon di oxide concentration (lesser concentration of carbonic acid- H_2CO_3) in water enhances the precipitation rate of calcium carbonate. Most of the ooids are aragonitic in origin (a polymorph of calcite which crystallises in orthorhombic crystal system). Upper Suraj pay sand, developed just above the KS-I sand unit is a sideritic sand stone, also showing high density nature in log. Conventional core taken in wells, X-A, X-B in this interval reported presence of ferruginous material in sandstone. Available reports of sedimentological studies on Upper Suraj & Kalol sands also documented that in thin section slide (Fig.6), there is presence of Chamosite (Hydrous aluminum silicate of iron) with quartz nucleus embedded in Sideritic matrix.

Upper Suraj pay was deposited as distributary mouth bar and distributary channel in lower delta regime during constructive phase (progradation) of Delta. Presence of Siderite depicts development of reducing environment during deposition. There may be

colonized development of marshy areas causing development of organic rich water, leading to high

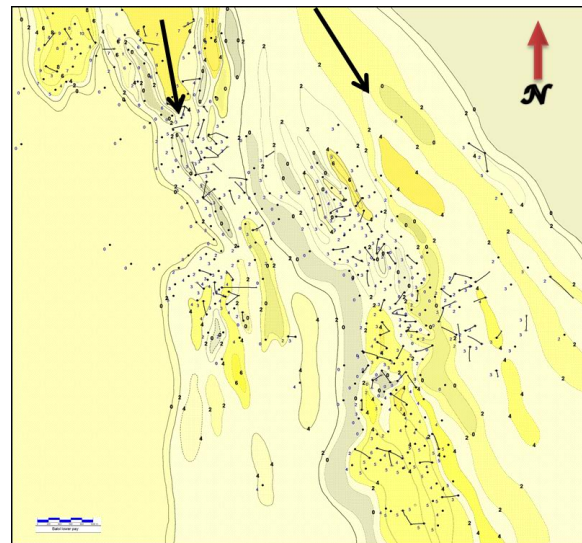


Fig.4: Sand isolith map of Balol Lower pay Sand of North Kadi field.

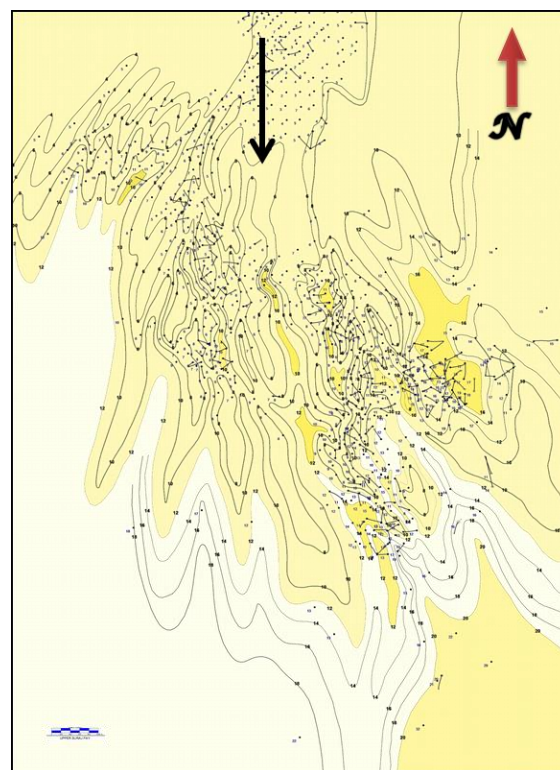
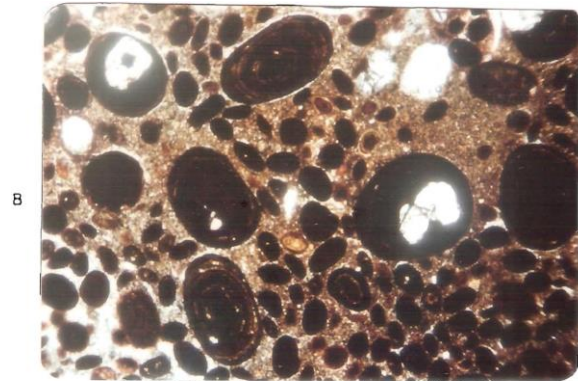


Fig.5: Sand isolith map of Upper Suraj Pay of North Kadi field.

concentration of ferriferous material in reducing condition. That led to mobilization of iron ions by organic acids. This could have been responsible for

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the ferruginization of carbonated oolites. High content of Siderite in Upper Suraj pay could have been deposited during such phase.



WELL , 1030.42 m, CHAMOSITE DOLITES WITH QUARTZ NUCLEUS, ROUNDED TO ELLIPTICAL, OCCUR IN TWO DISTINCT SIZES - ONE FINE GRAINED AND THE OTHER MEDIUM TO COARSE GRAINED, THESE ARE SET IN SIDERITE/CLAY (X 23, PP)

Fig.6: Thin section of Upper Suraj Pay of North Kadi field.

All the post Kalol pay units have been correlated all over the field and respective sand isolith maps have been prepared (Fig. 3 to 5). This is the first attempt to build up a depositional model for all of these shallow sands considering all available Geology & petrophysical data. All the shallow sands are having entry from north to north east direction & deposited in a very gentle slope.

Seismic Study

Available seismic data in and around the study area have been traditionally acquired and processed focusing Kalol and deeper objectives. Hence, the shallower zones are generally found to be affected by noise and data gaps, besides discontinuity of seismic events and wide variation in amplitudes. Advanced processing software, having better control over noise and data regularization, was used to reprocess the data for the shallower objectives. Appreciable improvement was seen in the re-processed data, particularly with respect to event continuity and amplitude strength (Fig.7). However, conventional seismic attributes failed to bring out any discernible depositional pattern or explain drill well data. Some sweet spots can be seen in the sweetness attribute map, though, which explain the drilled well data to a reasonable extent in localized zones (Fig. 8). Post Stack inversion, too failed to bring about any discrimination in lithology, ostensibly due to data quality.

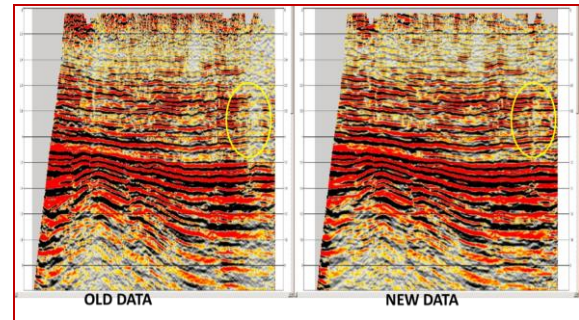


Fig.7: Discernible improvement seen in data quality of re-processed PSTM data

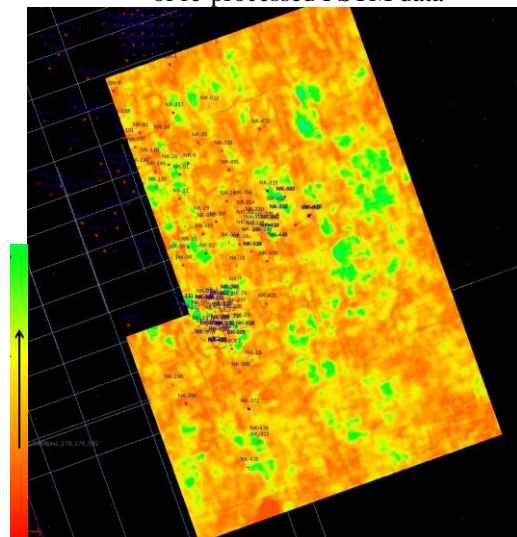


Fig.8: Time slice at 470ms of sweetness volume near Miocene Pay top.

Petrophysical Analysis

The Petrophysical Evaluation of the log response for shallow pays was carried out to identify hydrocarbon bearing zones in North Kadi Field. But many wells have vintage suite of logs, devoid of neutron-porosity logs. Even in some of the new wells logged with digital data logging system, porosity logs are not available, making facies determination very challenging. Hence, a qualitative approach has been used for identification of potential gas bearing zones. The characterization of shallow pays in North Kadi Field with available G &G data has been re-evaluated with production history of the wells. After detail log correlation at different formation levels, 90 wells were short listed for evaluation on basis of SP, Resistivity and Porosity logs. After fine-tuning the correlation, 17 wells, which had porous and permeable reservoirs ($> 10 \Omega\text{m}$ resistivity) were prioritized.

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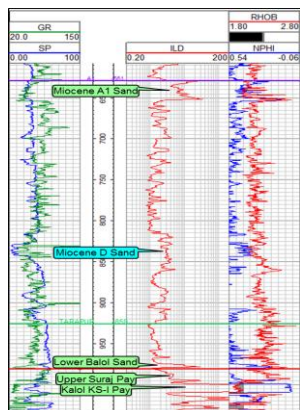


Fig.9: Log motif of well X-216 showing the shallower prospective sands.

The A sand which lies in the top part of Miocene is an established pay. These Miocene sands are characterized by high resistivity, Low gamma Ray of 40-50 API unit, good SP development, indicating good permeability and cross over on neutron and density log. Several wells were seen outside the estimation limit, showing interesting log character from the hydrocarbon point of view.

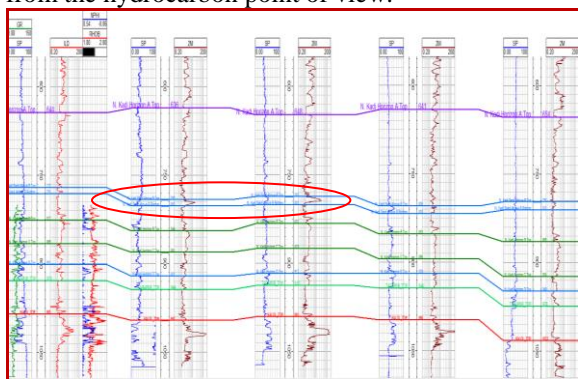


Fig.10: Log correlation profile showing untested zones within Miocene section.

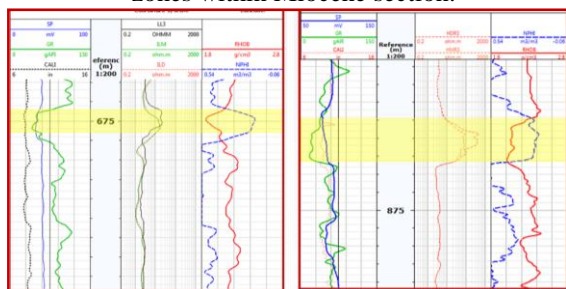


Fig.11A: Log motif of various wells showing the untested zones within Miocene section.

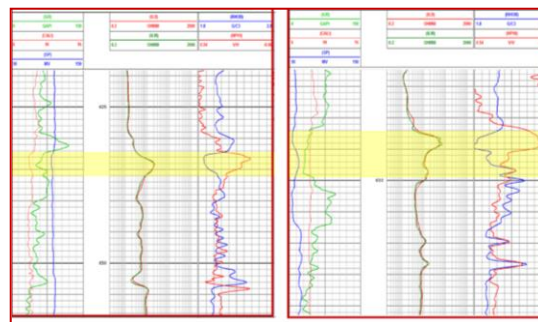


Fig.11B: Log motif of various wells showing the untested zones within Miocene section.

Log correlation profile of Miocene sand beyond estimation limits showing the zone of is given in profile (Fig-11A). Several such wells exhibit good resistivity and crossover at neutron porosity & density at Miocene level (Fig-11B). So far, these Miocene sands cumulatively flowed 44.73 MMm3 gas.

Oolitic Balol pay sand (rich in sideritic material) and ferruginous sand stone of Upper Suraj pay exhibits typical high density–high resistivity log character, looks like a tight zone, this type of intervals generally skipped considering the tight reservoir. But while tested properly these intervals flowed significant amount of hydrocarbon (more than 46 thousand ton oil from Upper Suraj pay & more than 172 MMm3 gas from Balol pay)

From the above analysis, it is clear that sands of Balol Pay and shallower Miocene pays have good hydrocarbon potential, which is yet to be tapped. Based on the study, good reservoir facies can be qualitatively inferred for following ranges of petrophysical parameters. Hydrocarbon accumulations are very likely in them, subject to suitable entrapment conditions.

Parameter	Range
Resistivity	>10 Ωm
Porosity	25-30%
Water Saturation	25-65%

Prospectivity Analysis

Prospectivity of shallow pay in north Kadi area has already been established in Wells X-C, X-D, X-E, which have produced from Kalol, Balol & USP pays. Suitable pay characters in the log at the Miocene levels (Jhagadia, Kand & Babaguru Formations) shows zones of interest with good porosity and resistivity (Fig. 9). Wells X-F & X-G which were earlier estimated as free gas reserves in Balol pay, are

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observed to be Oil bearing. Well X-H has produced Oil+ Gas from USP, although the well is outside estimated limit.

Wells X-M and X-N, lying outside the proven hydrocarbon limit, were identified during the study, showing resistivity of more than 10 ohm-m, as depicted in the log correlation profile (Fig. 10). Log motifs of later drilled wells outside estimation limit also show promising log signatures (Fig.11A).

As majority of the old wells are having casing corrosion problem, zone transfer to identified zone is not possible. Several such wells, appearing to be interesting in logs for the shallow pays, could not be tested as they are currently producing from Kalol pay or in some cases are abandoned. So new exploratory wells would be needed to probe these identified zones.

The shallow pays are expected to have primarily structural entrapment. Hence, the good reservoir facies identified in the area are likely to have accumulations of hydrocarbon, provided conducive entrapment situations like four-way closures or fault-bounded closure exists. The alternating shale intercalations separating the pays would expectedly provide the regional capping. Therefore, identifying and mapping reservoir prone zones with favourable structural disposition can give a fair assessment of untapped hydrocarbon pools.

The TWT structure map close to Miocene top (Fig. 12) shows several fault blocks alongside a few four-way closures of varying sizes. Some of these falling in the sand axial trend are potential hydrocarbon locales and hence, needs to be explored. In the present case, a large

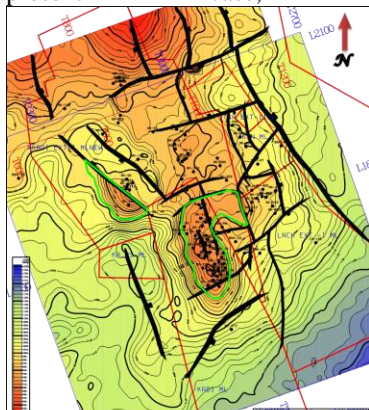


Fig.12: TWT map at Miocene top showing large four way closure.

four-way closure encompassing the wells X-M and X-N is seen, which needs to be.

Conclusions

- Drilled well data of more than 150 wells was used to build up a depositional model of the shallow sands, integrating all available geology & petrophysical data.
- Zones have been identified beyond estimation limits, where log response for shallow pays (Miocene level, Balol pay & USP) exhibit more than 10 Ω .m resistivity, 25-30% porosity and water saturation of 25-65%. These most likely indicate good reservoir facies having hydrocarbon accumulations, subject to favourable structural disposition. Probing new wells in such zones will help to delineate the extension of pool and accrete and produce good amount of hydrocarbon. As the new wells depth will be around 1100m, this new wells will be techno-economically viable enough.
- Absence of full suite of logs and inadequate availability of cutting samples in the post Kalol section was a constraint. But due to fairly good well control, it can be inferred that the present study has brought out a reasonable representation of the hydrocarbon potential of shallow pays.

Acknowledgements

The authors are grateful to Shri H. Madhavan, GGM -Basin Manager, WONB, ONGC, Vadodara for his valuable insights and guidance in this work. Suggestions given by Shri Bacheche Lal. CGM-Block Manager, Block-III, Mehsana Patan Block is thankfully acknowledged. The authors also record their appreciation towards all colleagues of Block-III for their direct or indirect help and contribution in this study. Authors express their gratitude to the ONGC Management to accord the permission to present this paper in SPG 2020.

N.B The opinions expressed in this paper are those of authors. They do not purport to reflect the opinions or views of the organization in which they are working.

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