Reservoir Delineation of Lower Kalol Pays and Field Growth in Wadu and Paliyad Areas, Cambay Basin, India

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Summary

The Lower Kalol pay zones (Kalol-X and Kalol-IX) in Wadu and Paliyad fields of Cambay Basin were remodeled. These pays are developed within Sertha Member of Kalol Formation of Middle Eocene age and are contributing fifty percent of total hydrocarbons produced from these fields. The objective was aimed at to demarcate the locales of yet-to-find hydrocarbons and delineate anticipated field growth areas for these pays; to recast future exploration/delineation strategy and also to reduce subjectivity of existing reservoir models posed constraint during exploration/delineation in these two fields since discovery to date.

The NNW-SSE trending Cambay rift basin, situated in the northwestern part of the Indian pre-Cambrian shield, is segmented into six different tectonic blocks by ENE-WSW trending transfer fault zones. The Wadu and Paliyad fields, located adjacently in the northern tip of Ahmedabad tectonic block, are proximal to the Ahmedabad-Mehsana transfer fault zone.

The Kalol Formation, deposited during post rift thermal subsidence stage, is the only producer of hydrocarbons in Wadu and Paliyad fields. The reservoirs within Kalol-X and Kalol-IX units (Kalol-X is overlain by Kalol-IX) vary from silty shale to siltstone to fine / medium-grained sandstone and sandwiched between coal at the top and shale at the bottom. The effective thickness of the reservoirs varies from 02 to 10 m. The reservoirs in Kalol-IX unit are developed in both Wadu and Paliyad areas unlike reservoirs in Kalol-X unit developed only in Wadu area. These two adjacent fields are heterogeneous in character by lateral and vertical discontinuity of aforesaid reservoirs and their variable fluid distribution. The pay zones have oil pool and operate on a depletion drive as evident from reservoir data and electrolog character.

The structural configuration of the area is brought out with the help of 3D seismic, time-thickness maps and drilled well data. Both the revised reservoir model and the inferred tectonic pattern are at variance with the existing ones.

The isochron and depth maps on enveloping surfaces near top of pay packages have been utilized for preparation of structure contour maps of respective pay units. Subsequently reservoir parameter maps were generated with the help of petrophysical parameters and production data of relevant wells. Petrophysical re-evaluation has established few wells to be hydrocarbon bearing on log and these reservoirs has been accounted. The shale out line of every pay package has been deciphered from seismic attribute character along with isopay thickness, isochronopach and well productivity. Seismic attribute maps were cross-correlated with reservoir parameter maps for delineation of pool limits of Kalol-X and Kalol-IX flow units.

The integrated analysis defines that in both Wadu and Paliyad areas, the channel axes for lower Kalol pays follow main high trends that correspond at depth to preexisting nosal features. The entrapment appears to be mainly strati-structural.

Each of the Kalol-X and Kalol-IX units displays an overall coarsening upward sediment distribution pattern that corroborated also by electrolog motifs. The combined study of facies types and association alongwith emerging reservoir geometry, under such tectonic regime, might suggest a fluvial-dominated progradational repetitive delta mouth bar cycles. Thick coal layer at the top of each unit marks the end of each deltaic cycle. Reservoir geometry suggests sediment input direction is from N and NW having swinging of lobes from west to east.

This study demarcates additional prospective areas for exploration of both new pools and delineation of existing ones in Kalol-X and Kalol-IX pays. Both the reservoirs are anticipated to have much more widely depositional limits much beyond the existing pool limits in these two fields. Substantial increase in IOIP (as both Kalol-X and Kalol-IX pays have only oil pool) is anticipated when compared with the existing reservoir limits of respective flow units.

Further exploration/delineation in light of revised reservoir models may improve production potential and may find “new oil in old place” from Kalol-X and Kalol-IX flow units unevenly distributed in Wadu and Paliyad fields.

Introduction

The search for hydrocarbons in the Cambay rift basin, situated in the northwestern part of the Indian pre-Cambrian shield, for the last four decades has resulted in considerable reserve accretion and a substantial amount of hydrocarbon resources have already been converted into initial in-place volume of hydrocarbons. Most of the structural prospects of this basin have already been probed for hydrocarbons. It is visualized that tapping a large portion of yet-to-find hydrocarbons vis-à-vis future field growth areas can be achieved from remodeling of reservoirs in a field where exploration is challenging because of inherent delineation problem of the field. The Wadu and Paliyad fields, lying adjacently in the north of Ahmedabad tectonic block (Fig.1), was chosen to remodel the lower Kalol pays (Kalol-X and Kalol-IX) as the field exhibits lateral and vertical inhomogeneity of the reservoirs and variable fluid distribution pattern posing constraint for successful exploration / delineation since discovery to date. The objective was also aimed at to demarcate the locales of yet-to-find hydrocarbons; to delineate anticipated field growth areas and to recast future exploration/delineation strategy.

Basin architecture and stratigraphy

The deposition in Cambay Basin was initiated during widespread rifting event in the Early Cretaceous. The first stage of rifting had extensional faulting, along Older Aravalli trend, generating series of half grabens in which deltaic clastics were deposited within the pre-Trappean sequence (Biswas, 1999). This was followed by transverse block faulting and widespread basalt volcanism forming technical basement of the Tertiary deposit in the second rift cycle. Tectonically, this NNW-SSE oriented linear graben is segmented into six different tectonic blocks by transfer fault zones. The Wadu and Paliyad fields, located adjacently in the northern part of Ahmedabad tectonic block, are proximal to the Ahmedabad-Mehsana transfer fault zone (Fig.1).

Pandey et. al (1993) standardized the lithostratigraphic framework of Ahmedabad Block of Cambay Basin and the same has been adopted here (Fig.2).

The Kalol-X and IX units are contained within Sertha Member (Lowermost Member of Kalol Formation) of Middle Eocene age where Kalol-X unit is overlain by Kalol-IX one with a coal layer in between. The Kalol-X and Kalol-IX pays are distributed unevenly in the study area

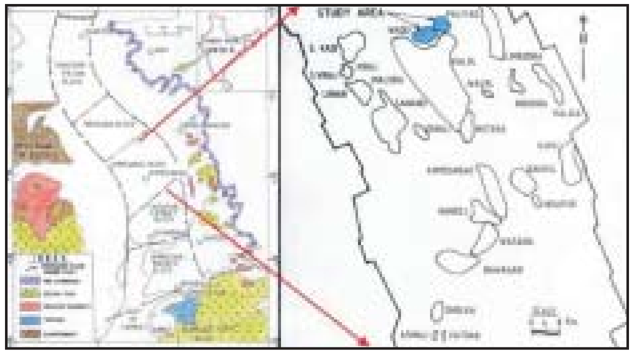

Fig.1 : Basin map showing study area

AGE	FORMATION	MEMBER	RIFT STAGES
RECENT	GUJARAT ALLUVIUM		LATE POSTRIFT (STRUCTURAL INVERSION)
PLEISTOCENE	JAMBUSAR		
PLIOCENE	BROACH		
LOWER MIOCENE TO UPPER MIOCENE	JHAGADIA		
	KAND		
	BABAGURU		
OLIGOCENE TO UP. MIDDLE EOCENE	TARAPUR		LATE SYNRIFT TO EARLY POSTRIFT (THERMAL SUBSIDENCE)
MIDDLE EOCENE	KALOL	WAVEL (KALOL-I-IV)	
		SANAND SHUBHAL (KALOL-V-VIII)	
		SERTHA (KALOL-IX-XI)	
LOWER EOCENE	YOUNGER CAMBAY SHALE	CHHATRAL	
		MEHSANA	
		MANDHALI	
UPPER PALEOCENE TO LOWER PALEOCENE	OLDER CAMBAY SHALE		
	OLPAD		
LOWER PALEOCENE TO UPPER CRETACEOUS	DECCAN TRAP		RIFTRELATED VOLCANISM

Fig.2 : Tectotno-stratigraphy of Ahmedabad Block

(Figs.3&4). The bottommost unit of Sertha Member is Kalol-XI and in Wadu and Paliyad areas only one well is on production from this particular unit (Fig.4). In rest part of the areas, this unit is represented by coal. Hence reservoir delineation is not attempted for this unit. The Kalol Formation, as a whole, was deposited during Late synrift to Early Postrift stage (thermal subsidence) of basin evolution (Kundu et. al, 1993). Characteristically the Lower Kalol Formation is represented by high amplitude alternations of seismic signals of which Kalol-X and Kalol-IX unit tops are prominent markers because of development of thick coals (Figs.3,4,5,6,7&8) both in Wadu and Paliyad areas. Time-structure contour maps near top of Kalol-X and IX units (Figs.9&10) exhibit that Wadu and Paliyad areas are characterized by NW-SE and NNW-SSE trending nosal features respectively. The structural relief and paleotectonic

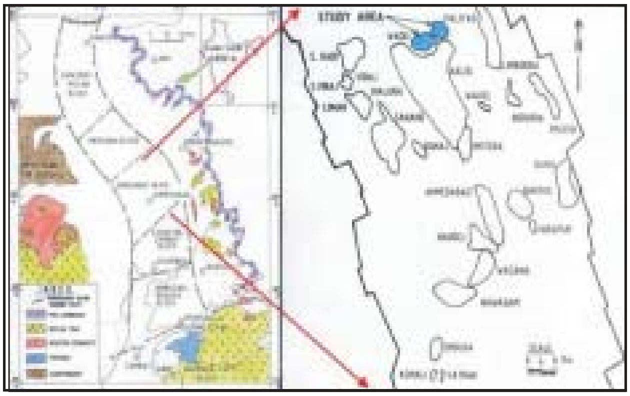

Fig.3 Lateral and vertical discontinuity of Kalol-X & IX reservoir facies

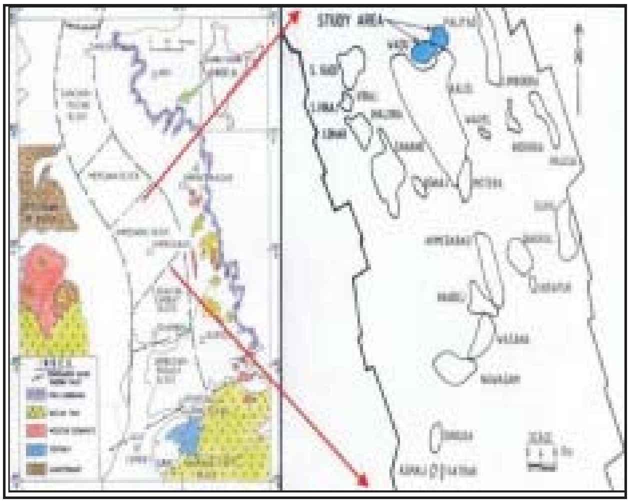

Fig.4 Lateral and vertical discontinuity of Kalol-X & IX reservoir facies and below

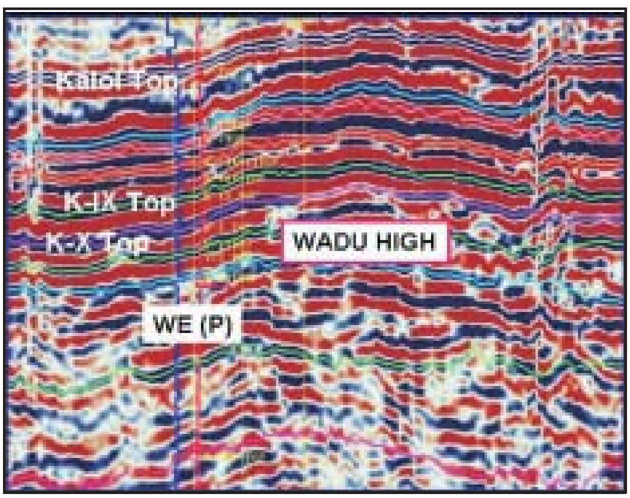

Fig.5 Calibrated enveloping surfaces of Kalol-X & IX units in Wadu area

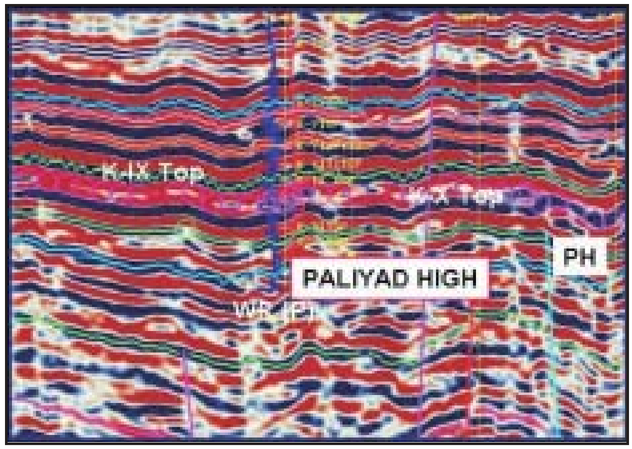

Fig.6 Calibrated enveloping surfaces of Kalol-X & IX units in Paliyad area

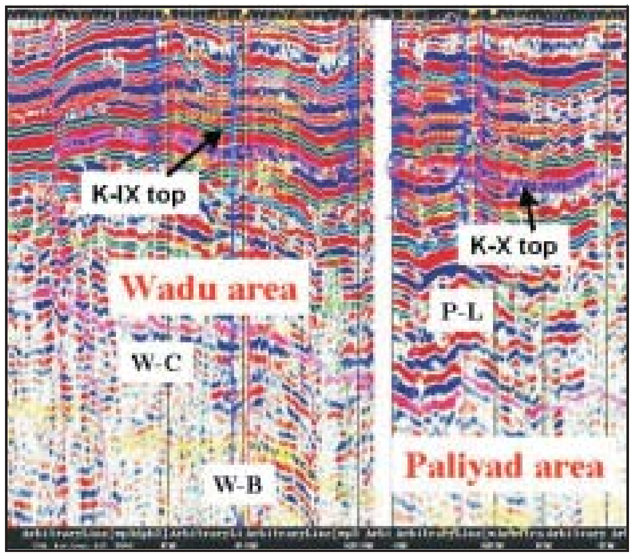

Fig.7 Arbitrary line and calibration joining Wadu and Paliyad areas .

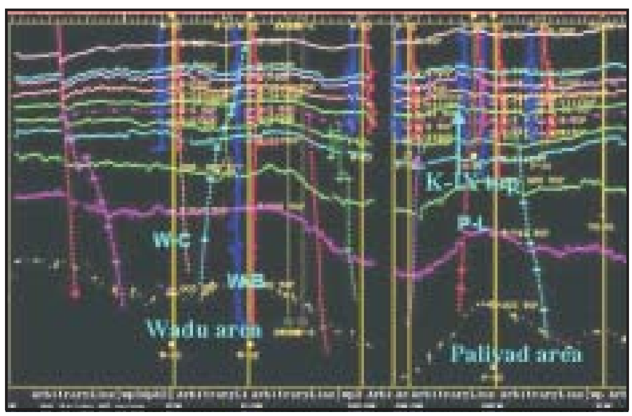

Fig.8 Depth section corresponding to Fig.7.

analysis indicated that these nosal features are pre-existing basement highs. The dominancy of EW trending transverse faults might be due to the proximal position of these two fields to the Ahmedabad-Mehsana transfer fault zone (Gupta, et. al, 2004). The inferred tectonic pattern of these areas is at variance with the existing one.

Geological constraints in exploration / delineation

The log correlation profiles (Figs.3&4) exhibit both vertical and lateral discontinuity of Kalol-X and Kalol-IX reservoirs and correspondingly their variable fluid distribution pattern. This led to final completion of wells in zones other than targeted objectives. The different phases of exploration / delineation in these two fields, though failed to have a target-oriented success but generated enough data utilized to prepare the envisaged models of respective reservoirs.

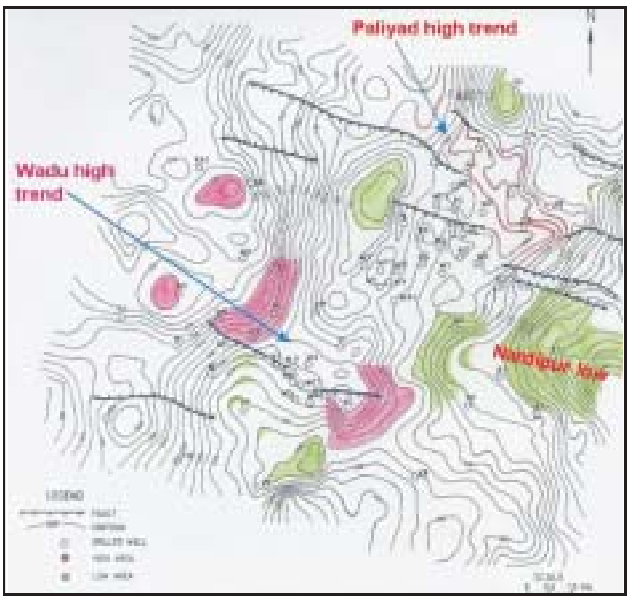

Fig.9 Time- structure contour map near top of Kalol-X coal

Reservoir delineation

Keeping this inherent reservoir heterogeneity in question, the recasting of delineation of pay zones of Kalol-X and IX was attempted utilizing 3D seismic data and attributes, petrophysical and well wise production performance data. The reservoirs have oil pools and electrolog and reservoir properties indicate a depletion drive mechanism.

Two way time-structure contour maps near top of coals (enveloping surfaces) of Kalol-X and Kalol-IX units

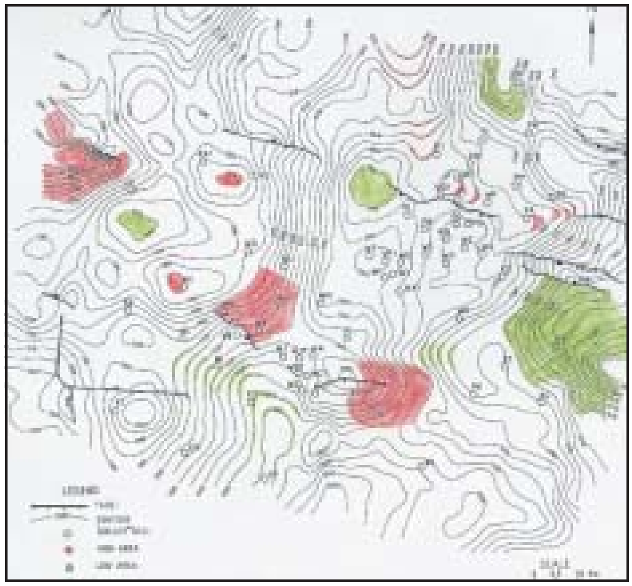

Fig.10 Time-structure contour map near top of Kalol-IX coal

(Figs.9&10) and corresponding depth maps (Figs.11&12) have been considered for depiction of geometry of respective reservoirs (Figs.13&14). The seismic attributes viz. average instantaneous amplitude and average

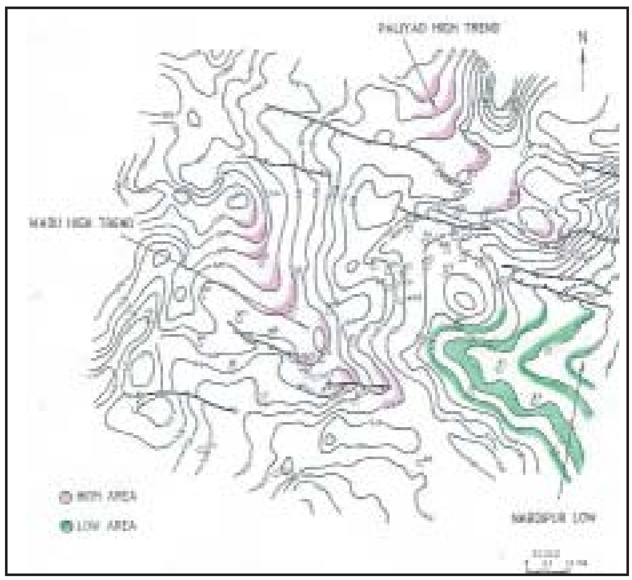

Fig.11 : Structure contour map near top of Kalol-X coal

instantaneous frequency were generated around Kalol-X and Kalol-IX pays within a specified time window and was calibrated at the well points with petro-physical properties. Average instantaneous amplitude shows loss of amplitude over the reservoir facies developed in Kalol-X and Kalol-IX layers. This is attributed to diminished impedance contrast generated from the shale-sand interface as

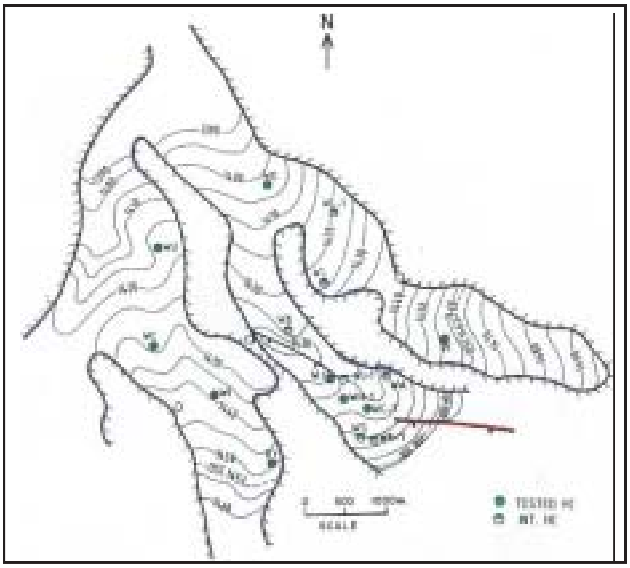

Fig.12 : Structure contour map near top of Kalol-IX coal and (below)

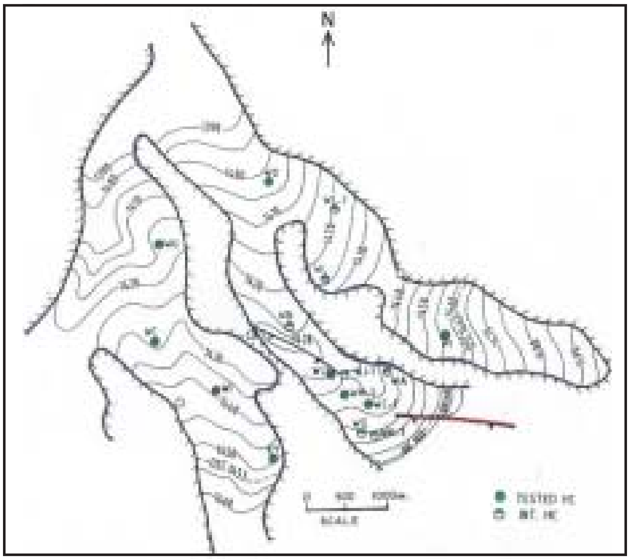

Fig.13 Reservoir geometry at the top of Kalol-X pay

compared to higher impedance contrast generated from shale-coal interface. In fact, the average instantaneous amplitude response of the reservoir facies was very subjective because of aforesaid reasons. The average instantaneous frequency analysis indicates zones of low frequency immediately beneath the Kalol-X and Kalol-IX reflectors top in areas of better reservoir facies development. This is attributed to loss of higher frequency in hydrocarbon saturated reservoir sand bodies.

The overall analysis indicated a broad match with the average instantaneous frequency distribution pattern rather than average instantaneous amplitude variation around every pay package. Hence average instantaneous frequency maps in consideration with depth maps were finally considered to infer channel orientation, geometry and likely areas of reservoir facies development (Figs.13&14). These maps were analysed to explain the likely extension of respective reservoir facies, beyond the estimated area, in consideration with the drilled well data. It was observed that the lowering of frequency anomaly is non-uniform across the Wadu and Paliyad fields (Figs.13&14) that probably indicate variations in reservoir type and thickness and fluid distribution. The reservoir limits in Kalol-X and Kalol-IX isopay maps has been deciphered in consideration with isopay thickness, isochronopach and well productivity data. The reservoir geometry of pay units has been deciphered from reevaluation of petrophysical data, production performance and frequency attribute.

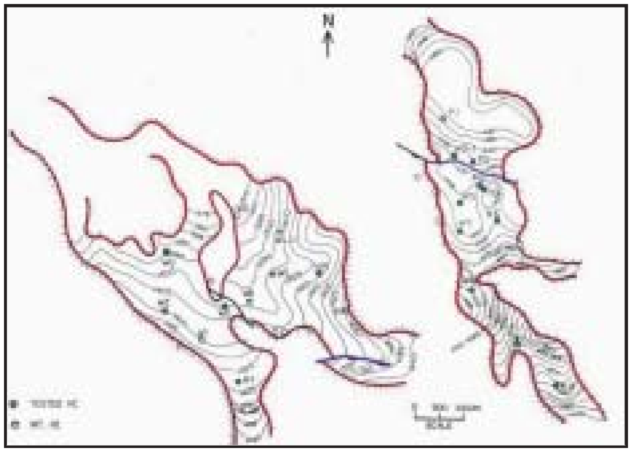

Fig.14 Reservoir geometry at the top of Kalol-IX pay

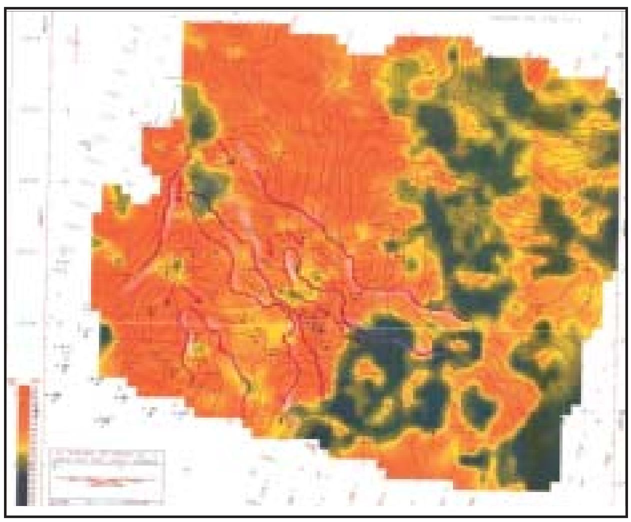

Fig.15 Average instantaneous frequency around Kalol-X pay (-10+20ms) superimposed on depth map showing channel direction and areal spread

Petrophysical re-evaluation has established few additional wells to be hydrocarbon bearing on log in these reservoirs and has been accounted for the revised models.

The pay unit wise reservoir description is enumerated as under.

Kalol-X pay

The Kalol-X pay unit occurs in between coal layer at the top and shale/silty shale at the bottom. The pay zone is developed only in Wadu area. Structure contour map at the top of flow unit (Fig.11) exhibits three isolated deltaic channel lobes trending NW-SE, intervened by interdistributaries, emanating from a trunk channel source from north. The OSC (Oil-Shale contact) for the easternmost channel has been deciphered to be at 1462m from well PI (Fig.11).

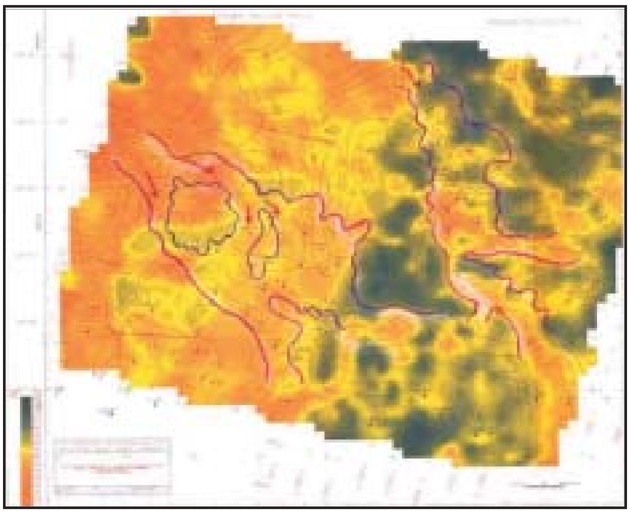

Fig.16 Average instantaneous frequency around Kalol-IX pay (-10+20ms) superimposed on depth map showing channel direction and areal spread

The central and western lobes have OSC at 1453m and inferred from wells WK1 and KY respectively. The westernmost lobe area has already been considered for Kalol field REC limit. Oil isopay map (Fig.17) exhibits the thickness range of reservoir from 02 to 08m.

Like Kalol-X, the Kalol-IX pay unit occurs in between coal layer at the top and shale/silty shale at the bottom. Sometimes additional development of pay unit is seen formed at the expense of bottommost shale but these are very local in extent (Fig.3). The areal extent of Kalol-IX pay is very wide and deposited in both Wadu and Paliyad

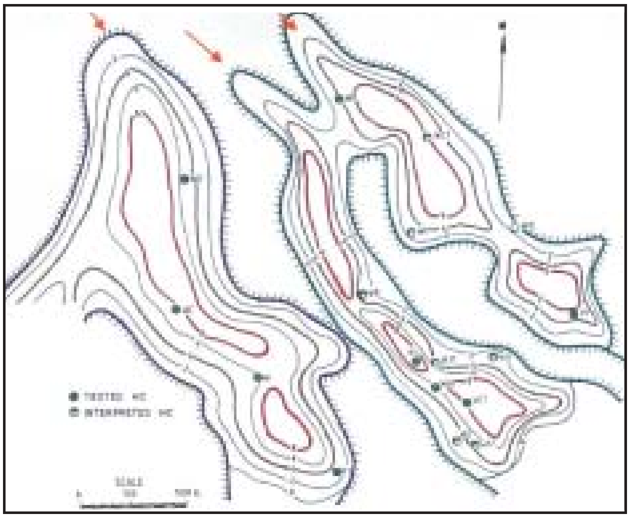

Fig.17 Oil isopay of Kalol-X showing wells reinterpreted to be hydrocarbon bearing

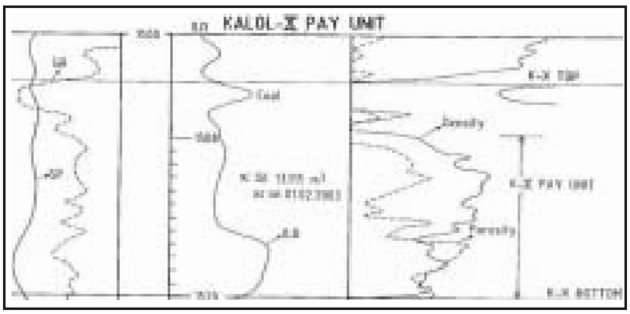

Fig.18: Log signatures of Kalol-X pay in flowing well WJ <u>Kalol-IX pay</u>

areas (Fig. 12). In Wadu area, two broad deltaic lobes, trending NNW-SSE, are mapped showing three separate input directions from north intervened by interdistributary areas. The eastern and western channels take a swing towards ESE and S respectively and join with the Kalol field. The OSC is deciphered to be at 1432m from well KY. The geometry of Kalol-IX reservoir in Paliyad area is exhibited by NNW-SSE trunk channel lobe getting bifurcated towards ESE and SSE in the south of K2 separated by an interdistributary. The ESE trending lobe gets abandoned in the south of K2 whereas the SSE trending lobe, passing through WR and K1, joins with Kalol REC limit. Three different oil pools have been inferred for the channel lobes trending towards west, south and SSE branching out from main entry from north. Three OSC have been established to be at 1477m, 1483m and 1513m from wells PD, WR and K1 respectively. The northern boundary of lobe is demarcated by shale out line and southern boundary is fixed by OSC. Oil isopay map (Fig.19) exhibits the thickness range of reservoir from 02 to 10m.

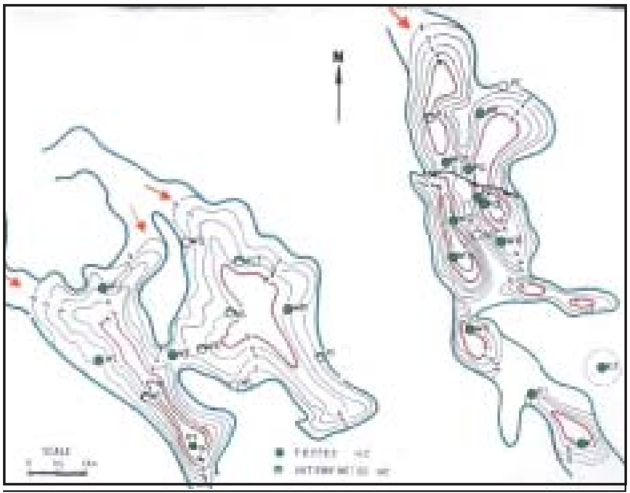

Fig.19 Oil isopay of Kalol-IX showing wells reinterpreted to be hydrocarbon bearing

Depositional milieu and entrapment

The Kalol-X and IX units likely represent deltaic deposits because “Deltaic systems are often a prominent component of passive margin settings, forming preferentially during the post-rift phase during which regional thermally induced subsidence prevails (Elliott, 1989)”. Each unit of Kalol-X and Kalol-IX records a passage from shale/ claystone (prodeltaic facies) upwards into a silty shale/ siltstone/fine to medium grained sandstones. This upward repetitive coarsening character is also reflected by electrolog motifs of these units (Figs.3,4,18&20). The low sinuosity of the mapped channels is probably indicative of distributaries. The facies association and character under such tectonic regime might be an indicative of delta mouth bar progradation from N and NW. As the axes of the mapped channel lobes (Figs.11,12,15&17) are parallel to the sediment input direction, the Kalol-X and Kalol-IX units may represent a fluvial-dominated repetitive delta mouth bar progradational cycles. Bordenave 1997 had also mapped NS oriented channels of lower Kalol sands in Wadu-Paliyad area and referred to those as fluvial channels. Kundu et. al 1993, reported vertically stacked distributary mouth bar system for Kalol-X and Kalol-IX units with sediment input from N and NW studied in the fields (Ahmedabad to Dholka, Fig.1) located in the south of present study area. Ahmed et. al 1993, in a study on Lower Kalol pays in the Kalol field (Fig.1) indicated fluvial dominated deltaic cycles. It indicates that Kalol-X and Kalol-IX units of Sertha Member were deposited under fluvial-dominated deltaic cycles in Ahmedabad Block of Cambay basin with major sediment input direction from N and NW. Coleman and Wright (1975) also reported the upward coarsening sequence formed by mouth bar progradation in fluvial-dominated Mississippi delta.

In the present case, the distributaries prograded, from N and NW towards south and southeast, over distal bar and prodelta generated coarsening upward sediment pattern. The elongated clastic lobes of silt/sand progressively filled the areas of maximum subsidence leading to stacking of fluvial-dominated delta mouth bar deposits. The gradual progradation led to the development of lower delta plain regime. Thick coal layer at the top of each unit indicates swampy areas and marks the end of each deltaic cycle. Occurrence of wavy and lenticular bedding, as reported from core data, indicates fluctuating supply of coarser and finer clastic facies from N and NW. The cause of switching of channel courses (Figs.17&19) from west to east, as revealed by reservoir geometry in Kalol-X and Kalol-IX, may be related to variable discharge of sediment types, slope change under thermally induced basin subsidence regime. This phenomenon probably developed variable geometries and distribution of Lower Kalol pays.

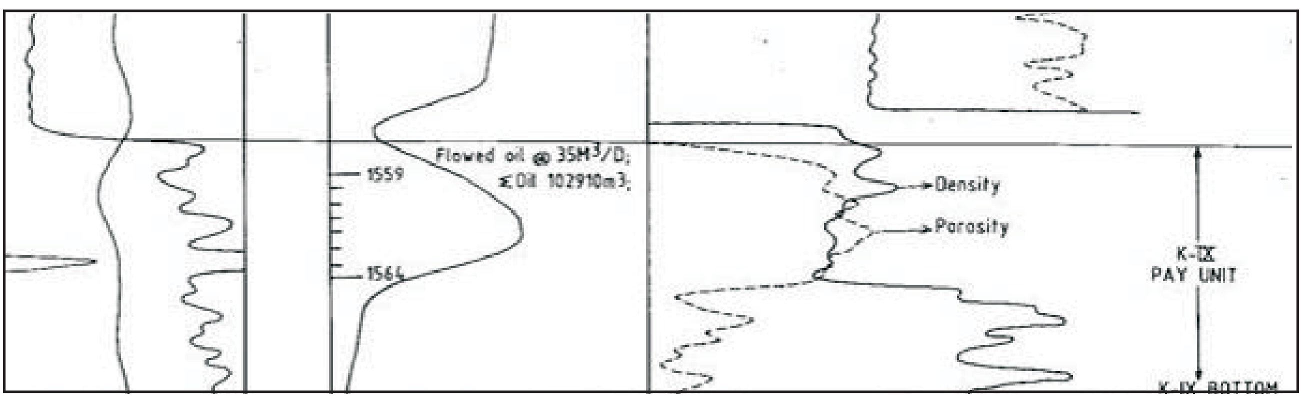

Fig.20 Log signature of Kalol-IX pay zone in flowing well PD

The integrated analysis defines that in both Wadu and Paliyad areas, the channel axes for Lower Kalol pays follow main high trends that correspond at depth to preexisting nosal features. The additional development of reservoir facies in Kalol-IX unit in well WU (Fig.3) corresponds to the location of the well along the high trend (Fig.10). It is also observed that wherever reservoir facies are present within Kalol-X and Kalol-IX units, they are hydrocarbon bearing. Till date, no oil water contact has been established in these sands in these fields. The entrapment appears to be mainly strati-structural under established Cambay-Kalol petroleum system.

Conclusions

The ultimate outcome of the present work relates to the anticipated future field growth areas arising out from revised reservoir models for both Kalol-X and Kalol-IX pay zones. Both the reservoirs are anticipated to have much more widely depositional limits much beyond the existing pool limits in these two fields. It demarcates additional prospective areas for exploration of both new pools and delineation of existing ones in these two pay zones. Substantial increase in IOIP (as both Kalol-X and Kalol-IX pays have only oil pool) is anticipated when compared with the existing reservoir limits of respective flow units (Figs.21&22).

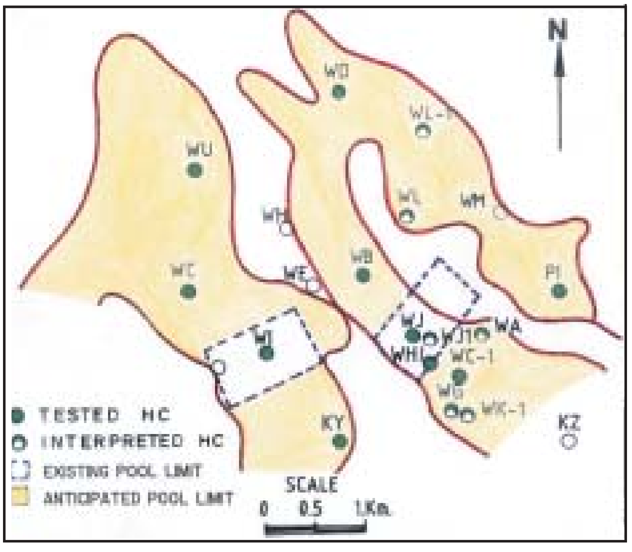

Fig.21 Envisaged field growth areas for Kalol-X pay unit

It is not impertinent to mention here that these new reservoir models can explain the lateral and vertical inhomogeneous distribution of these reservoirs and the production performance of producing wells in a more logical way.

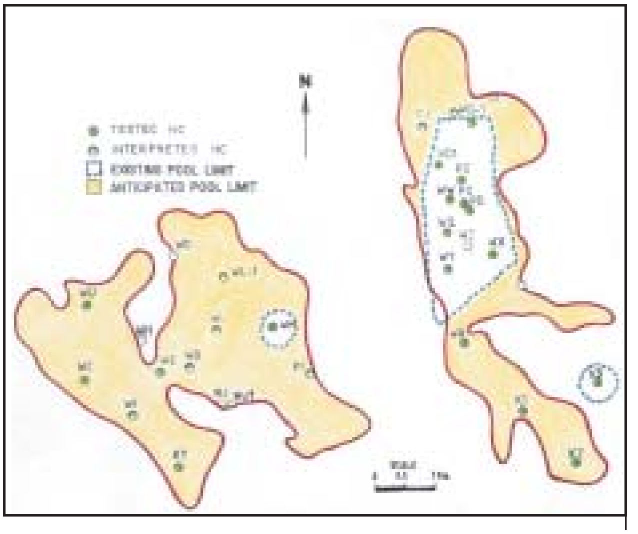

Fig.22 Envisaged field growth areas for Kalol-IX pay unit

Further exploration / delineation in light of these revised reservoir models may find "new oil in old place" from Kalol-X and Kalol-IX flow units unevenly distributed in Wadu and Paliyad fields.

The views expressed by the authors in this paper are absolutely personal and does not correspond to the view of the organization in which they belong.

Acknowledgement

The work was funded by ONGC. The authors express their sincere gratitude to Shri D. K. Pandey, Executive Director (Exploration), ONGC for providing opportunity to work in this area as well as for permitting to publish this work. The authors are also grateful to Dr. D. M. Kale, Executive Director and Head KDMIPE, Shri P. B. Pati, Shri A. K. Srivastava, GGM (Geol), KDMIPE, ONGC for critical review and valuable suggestions in accomplishing this task. Dr. O. P. Sharma, CG(w), Petrophysics Division, KDMIPE, ONGC is also acknowledged for time-to-time interactions.

Views expressed in this paper are that of the author(s) only and may not necessarily be of ONGC.

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