Geological Attributes and Depositional History of Becharaji Inversion Structure in the Western Depression of Mehsana Block North Cambay Basin

S.C.Sonare, G.N. Rao*, P.S. Wakekar & Vinod Kumar

ONGC, Mehsana

Summary

Becharaji field located in North Cambay Basin is an inversion structure located in the Asjol Low to the west of the prominent paleaostructural high "Mehsana Horst". This elongate asymmetrical anticline discovered in 1988 is under production from Kalol pays. A re-look of the anatomy of structure and reevaluation of the reservoir dispersal pattern through a holistic approach for assessment of geological evolution of structure in time-space continuum was necessitated to streamline the ongoing In-situ combustion process. The results obtained so far from the process analysed in the light of reservoir characterization can lead to improved monitoring of the pilot.

Kalol Formation in Becharaji field has hitherto been considered a single large stratigraphic package. However, detailed stratigraphic analysis reveals that four reservoir units separated by persistent shale markers constitute Kalol Pay. Integration of Seismic, Flow unit characterization, porosity and saturation, distribution and Sediments dispersal pattern has indicated inversion of Becharaji structure. A depositional low axis with fines at the lowest point accommodated channel deposits of a river system during Eocene time. Miocene structural inversion inverted the incised valley into an elongate antiformal feature. Migration that took place in the post inversion period resulted in the accumulation of hydrocarbons. The spatial knowledge of the structural anatomy of an inversion structure encompassing fines in the crestal part and coarse sediments on the flanks is crucial from the point of view of exploitation strategy. The new refined model will facilitate in re-designing the ongoing In–Situ Combustion Pilot. This is of utmost significance for the programme to improve ultimate recovery of this heavy oil field.

Introduction

Becharaji field located to the west of Mehsana Horst in Northern Block of Cambay Basin produces from Kalol pays of Middle Eocene age (Figs.1&1a). The field discovered in 1987 produces at the rate of 300 tons/day. The oil is highly viscous (viscosity 250 cps at 70^{o}C) with low API gravity (15^{o} API) and falls under the category of heavy oil field. The primary recovery is likely to be low (10-15%). Therefore, it is a candidate field for enhanced oil recovery process to improve ultimate recovery. In-situ combustion pilot was designed to produce additional oil of 0.26MMT with the design of four injectors, nine direct producers, fifteen offset producers and other near by wells. The efficacy of the process got established by the end of the year 2002 as all direct and offset producers indicated presence of flue gases and showed tendency to come on self flow. However, the oil production as envisaged could not be realized for almost a year and remains below expectation. The effect started spreading to far offset wells than envisaged. A comprehensive layer wise analysis of In-situ combustion pilot area was carried out and communication between injectors and producers was re-confirmed. However, it was

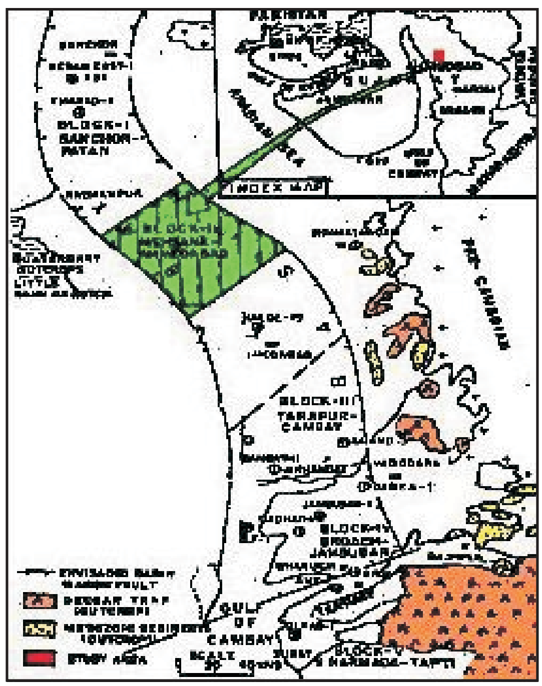

Fig. 1: Index map of Cambay Basin showing Mehsana Block,

observed that effect of enhance oil recovery processes was wide spread and affected more number of wells than predicted earlier. The entire geoscientific data involving seismics, electro-logs, reservoir and production data have been reviewed and a refined geological model which reflects the inversion phenomena has been conceptualized. The study designated to understand the performance, movement of fire front, extension of in-situ combustion effect, production optimization in producers taking into account refined geological model as basis has also been completed.

Geological set up

Mehsana Block, the northern block of Cambay Basin is bounded by Kutch uplift in the west and Aravali Hills in the east. The Cambay Basin is an N-S trending rift bounded on eastern and western margins by N-S trending faults Northern part of Cambay basin is mainly affected by extensional tectonics. The major structural element, which divides the block into two distinct regimes with series of parallel horst and graben in eastern part and while major depression in the centre with prominent eastern and western rising flanks. Two major NE-SW trending transfer faults form the northern and southern boundary of the Mehsana Block. Becharaji structure is bounded to the east by a fault bound graben and to west by Mehsana Horst. There is a low towards east of Becharaji High and the structure gradually rising towards Mehsana Horst where sands deposited in Kalol and Kadi formation pinches out. There is another low towards north of Becharaji High and again structure rises to the NE.

Reservoir plumbing

The geological setting of the reservoir involves important aspects of sediment types and distribution, and diagenesis. These processes combine to establish present day “plumbing”. Reservoir plumbing is a combination of variables, like porosity and permeability, together with reservoir continuity trends and fluid barriers and seals. Such geological conditions in turn exert major controls on the distribution of gas, oil and water across the reservoir. Mutual interrelationship between the reservoir fluid distribution and reservoir rock geometry needs to be addressed for better reservoir management.

Recognition of two interacting fluvial systems is fundamental to developing proper understanding of the resultant reservoir plumbing patterns. The In-situ combustion dynamics are influenced by the fluid flow of injected and produced gases, the heat transfer in the porous medium and the surroundings, the rate of combustion reaction(s), and the heterogeneity of the porous medium. It is imperative that the effect of the porous-medium heterogeneity on the sustained propagation of combustion fronts is continually evaluated. A simple representation of heterogeneity is the use of layers.

Work flow

The geological, seismic, electro-log, reservoir and production data of the field was re-examined threadbare. Electro-log correlations prepared afresh (Fig. 2) revealed that the main pay sand of Kalol Formation can be subdivided into four layers. Sand relief, effective sand and porosity maps were generated on the four identified reservoir sub units and forms the basis of assessment. Similarly effect of the ongoing In-situ combustion pilot in the limited area of the field was studied. Fresh geological maps were prepared in the context of sediment dispersal, sand geometry and structural anatomy

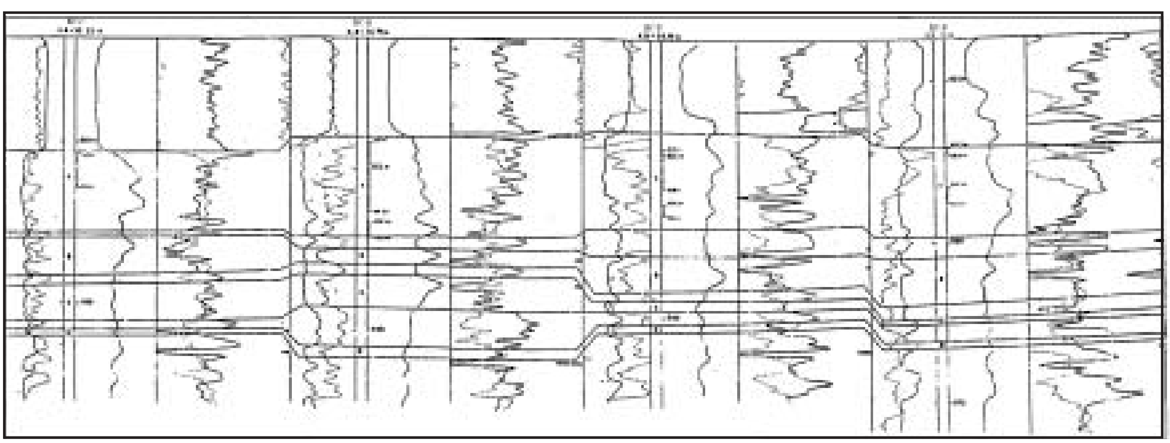

Fig. 2: NW-SE Electro-log profile along the wells Becharaji C, D, E & F

of the entire field. The whole gamut of the aforesaid studies was integrated to evaluate the movement of the combustion front, movement of flue gases and the resultant effect on oil production in the specific area of In-situ combustion pilot and around it.

Reservoir heterogeneity

The lithological units encountered in Kalol Pays are argillaceous sandstones, silty and sandy claystone / shale and coal. Sedimentological studies reveal the deposition of sandy reservoir facies in distributary channels affected by tides resulting in the formation of tidal bars in some parts of the field. Log motifs in the crestal part present a fining upward signature. The anastomosing distributary channel network of the drainage system criss-crossing the area characteristically reveals conspicuous decrease in porosity towards crestal areas of the antiform. The overall poor sorting and argillaceous nature of the sands has affected the reservoir characteristics. The reservoir sands are further divided in layers A, B, C and D. These layers are separated by persistent shales. However, they are hydro-dynamically interconnected with a common aquifer. In view of this a development strategy has been chalked out considering all the layers as one development unit. The classification, however, will help in recovering left over oil from less permeable layers in future as better permeable layers will be flooded preferentially early in the life of the field.

Sand dispersal pattern

Sand A: This layer widespread across the length and breadth of the field is with entry from NNW and NE. Maximum sand thickness is of the order of 10-12 m and spread is indicative of distributary channels. The porosity distribution indicates, in general, low porosities varying from 20 to 25 percent in the crestal part and relatively higher porosity on the flanks in the range of 25 to 30 percent. However, in areas wherever the sand input is dual, both from major NNW and minor NE direction the porosity pods with higher porosity range of 25 to 30 percent are also observed in the crestal part. Reservoir characteristics deteriorating on crestal parts due to shaliness can be seen (Figs. : 3, 4, & 5).

Sand B: The sand is widespread with ribbon type distributary channel sand bodies. Average sand thickness ranges from 4 to 6m. The sand entry is from NNW and NE. The porosity distribution indicates, in general, low porosities in the range of 20 to 25 percent in the crestal part except in the southern culmination where porosity, both in the flanks and crestal part are in the range of 25 to 30 percent. However,

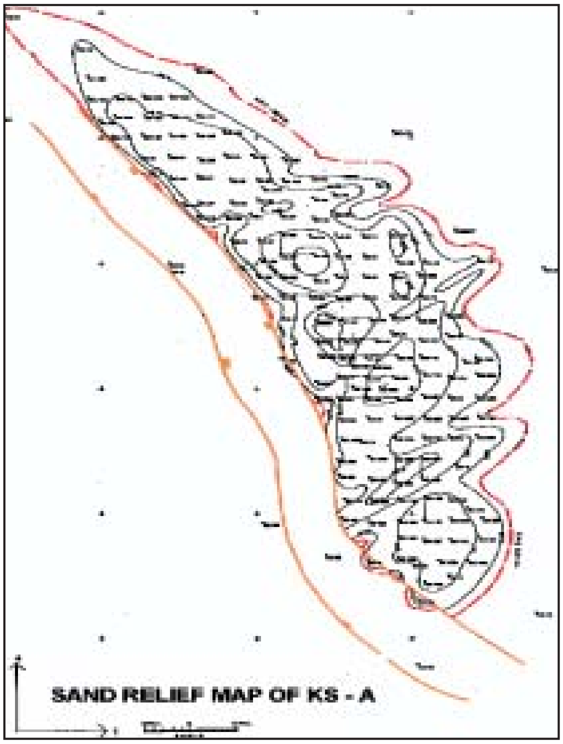

Fig 3 : Sand Relief map KS-A.

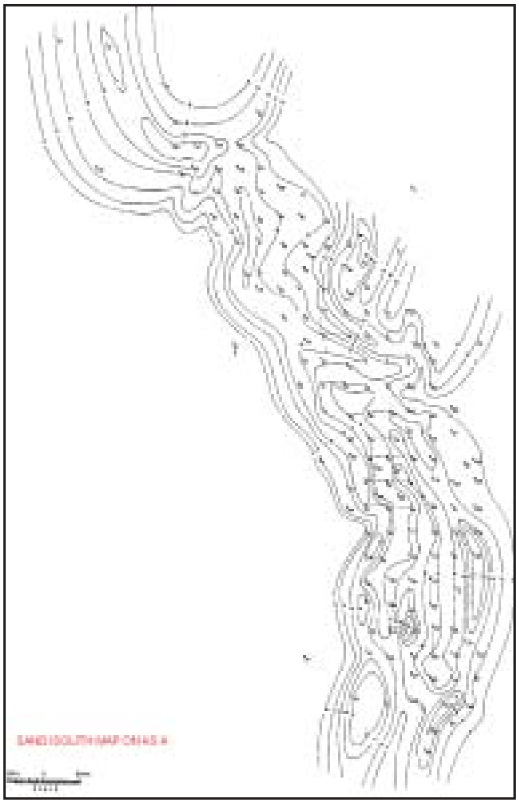

Fig .4 : Isolith map KS-A

there are porosity pods of higher porosity in crestal areas where the sand input is dual, from major NW and minor NE directions. (Figs. 6 & 7)

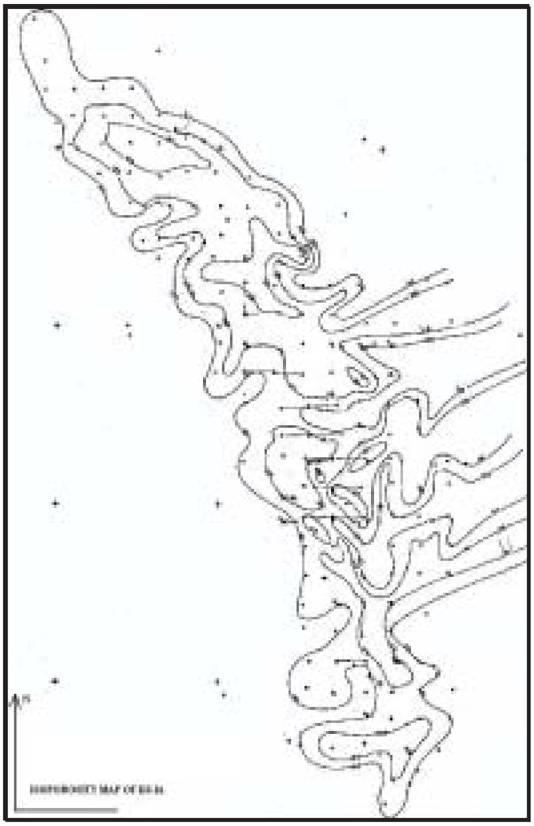

Fig. 5: Isoporosity KS-A.

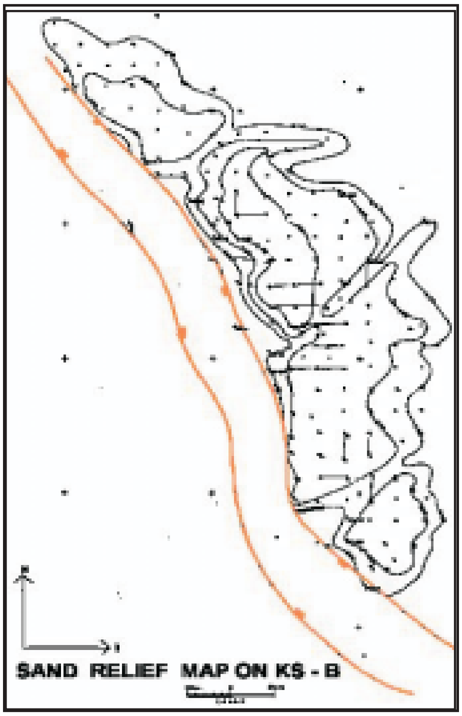

Fig .6: Sand Relief map KS-B

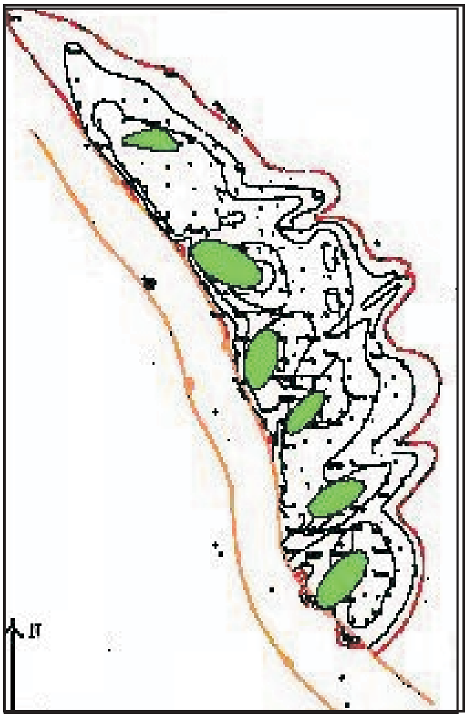

Fig. Sand Relief map KS-A

Fig. 7: Isoporosity KS-B

Sand C: The pay sand distribution even as it is widespread but thicknesses are only 2 to 4 m (average). The sand geometry conforms to distributary channel regime. The porosity distribution indicates low porosity in the rage of 20 to 25 percent on the flanks and high porosities in the range of 25 to 30 percent in the crestal part and in areas where sand input is dual equally from NW and NE. (Figs. 8, 9 & 10)

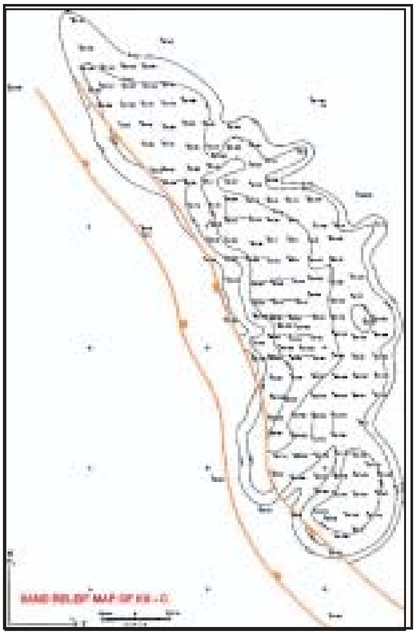

Fig. 8 : Sand Relief map KS-C

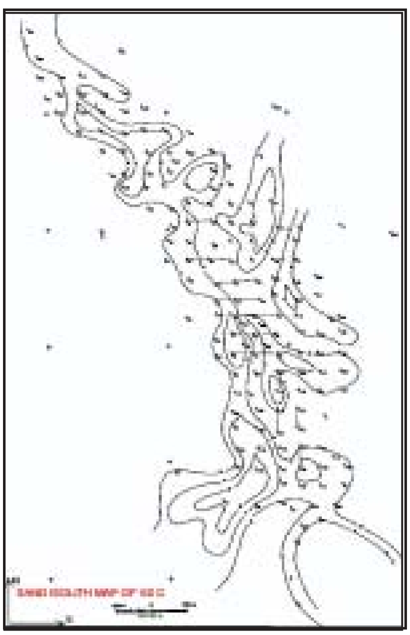

Fig. 9 : Isolith map KS-C

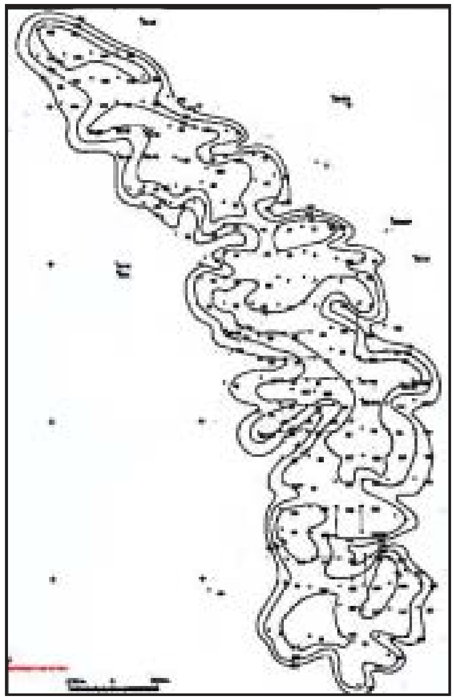

Fig. 10: Isoporosity KS-C

Sand D: This layer sand distribution is sporadic due to quick waxing and wanning of sands with bird foot imprint in a distributary channel mode. Thicknesses are less, averaging 3m only. Porosity pods are present in the entire field with porosity ranging from 25 to 30 percent. Similarly there are low porosity areas all around with porosity in the range of 20 to 25 percent. Since most of the area including crestal part has got thickness of around 1 metre only the trend are not clearly discernible and does not set to any set pattern. (Figs. 11, 12 & 13)

Structural architecture

Becharaji field is an inversion structure, a prominent NNW-SSE to N-S trending antiform with numerous culminations all along the length of the field. There are three prominent NE-SW to E-W dislocations which cut across the field possibly indicative of cross faults. However, this is not corroborated by the available 2D seismic data. As and when closely spaced 3D seismic surveys are carried out in this field these faults may be identified and precisely mapped. The field is limited to the west by a NNW-SSE to NW-SE fault bound graben which limits the extension of the field.

Interpretation of the available 2D seismic data in WSW-ENE (Dip oriented) and NW-SE (Strike oriented)

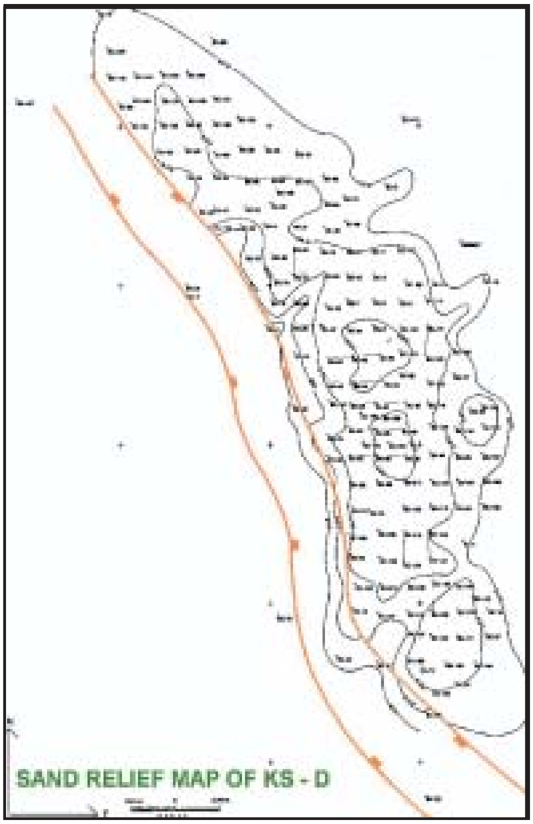

Fig. 11: Sand Relief map KS-D

Fig 12 : Isolith map KS-D

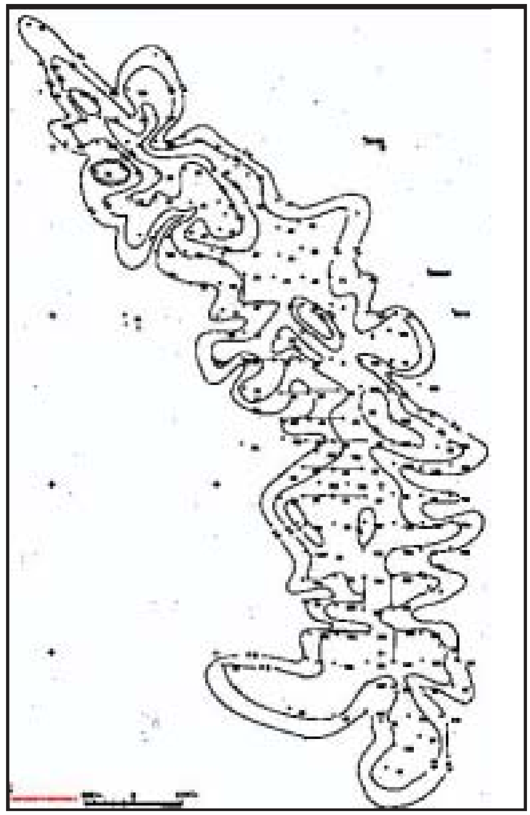

Fig. 13: Isoporosity KS-D

directions has brought out structural configuration of the field. At Kalol top level, Bechraji field is a narrow, low relief antiformal feature trending NW-SE, bounded by fault towards west (F1-F1) hading west. Another fault F2-F2, west of a fault (F1-F1) hading east is prominent. The structure seems to be formed by a number of smaller culminations within an overall NW-SE longitudinal alignment. (Fig.14)

Depositional history

Proto –Saraswati River flowed from the North during Middle Eocene times. As Mehsana Horst was a positive element present at that time the river got bifurcated. The major distributary flowed towards east of the Mehsana Horst where reservoir sands were deposited in Lanwa, Balol, Santhal, Jotana and North Kadi areas. The minor distributary flowing west of the Mehsana Horst deposited reservoir sands in Modhera and Bechraji fields besides adjoining areas. Besides these water flows across Mehsana Horst also re-distributed some of the sediments down slope on both sides of the Horst. Water run-off from Mehsana Horst eventually joined a NNW-SSE flowing braided rivers system which transported both water and sediments from the Proto-Saraswati and Mehsana Horst in a direction more or less

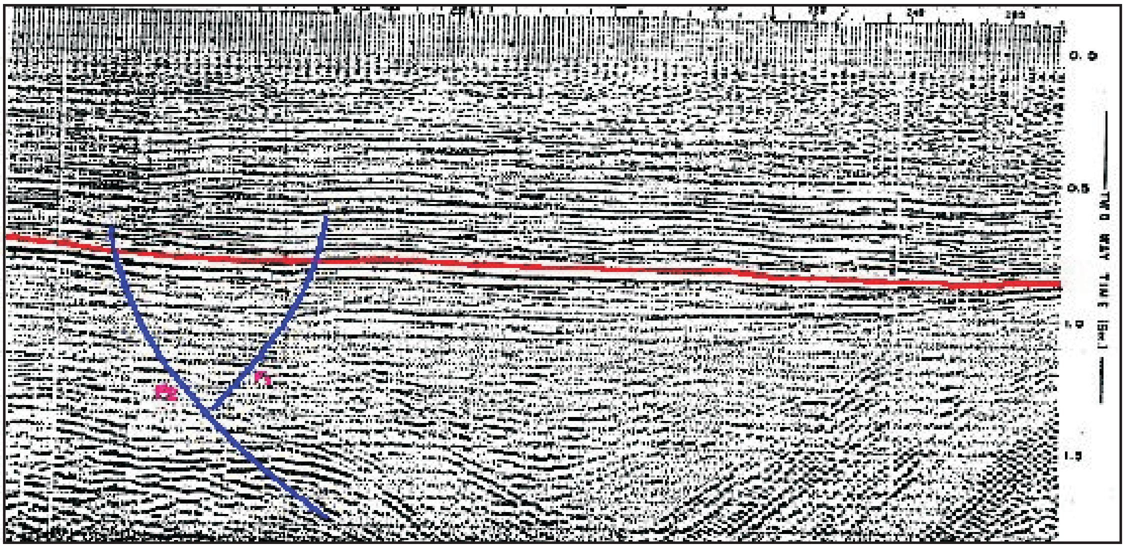

Fig. 14 : Seismic expression depicting inversion in Becharaji Field.

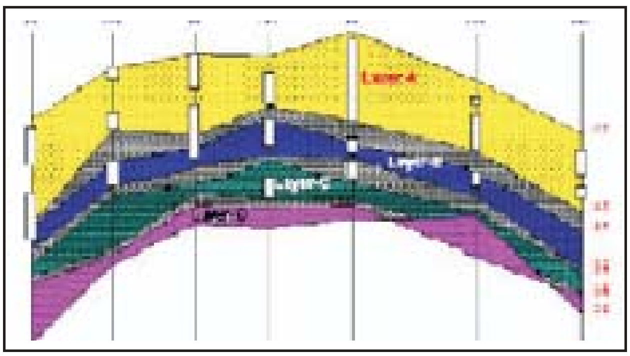

Fig. 15: Geological Cross-section across Pilot Area

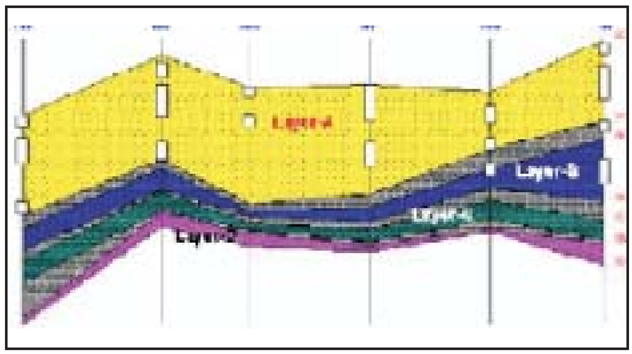

Fig. 17: Geological Transect along Pilot Area

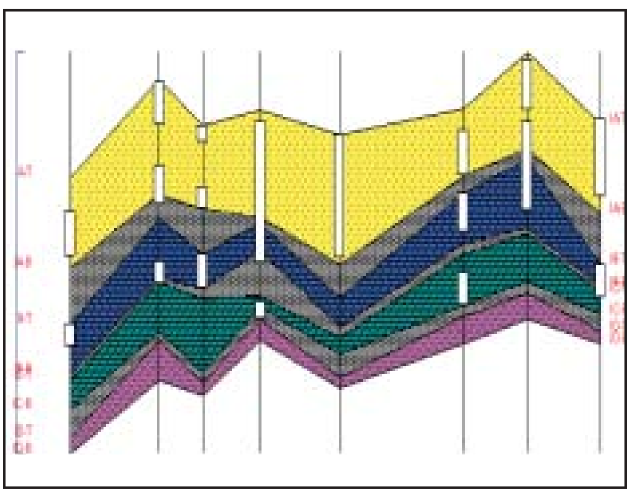

Fig. 16: Geological Cross-section across Pilot Area

parallel to the horst. The river was no doubt controlled in its position and direction of flow by topography and structural activity of the basin at the time. Thus, the clastic reservoir units were deposited by a south flowing river system draining through Khambel-Kamboi area onto Becharaji along an axial depositional axis with minor input from Mehsana Horst and flows further into Asjol area down South.

A depositional low axis with clay smears at the lowest point accommodated channel deposits of a river system during Eocene times. Evolutionary history of the accumulation has been conceived and its impact on fluid accumulation forms the major input for future redesigning of re-development plan of the field to augment heavy oil production. Sedimentological studies reveals sandy reservoir facies in distributary channel environment which is affected by tidal influence resulting in formation of tidal bars in some parts of the field.

Original oil saturation towards the crest is comparatively low. Oil accumulation in the field is governed by common oil-water contact. This interface occurs in more than one flow unit at more or less comparable depths which reveals connection with a common aquifer. It is therefore, inferred that vertical communication did exist between the flow units at the time of accumulation but subsequently hydrodynamic discontinuity has been created due to differential withdrawal from the individual layers.

Performance of pilot

The In-situ pilot project was initiated with four injectors, nine direct producers, fifteen offset producers and other near by well. (Fig. 18).

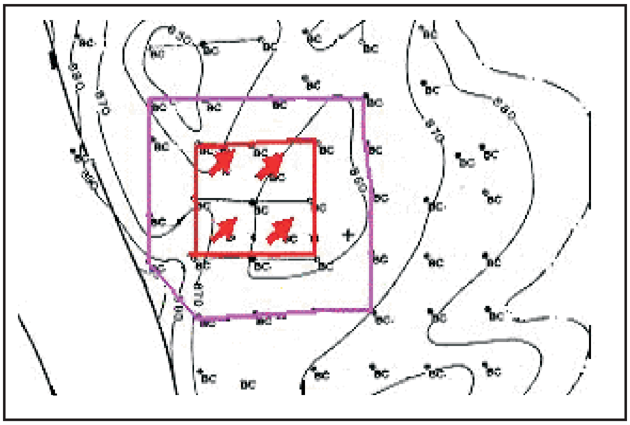

Fig. 18 : Part of KS-A map showing In-situ combustion Pilot Area

Geological cross-sections across the Pilot area have been prepared and indicate the present status of the wells completion and different layers (Figs: 15, 16 and17).

Presently 24 producers (9 direct + 15 offset) are affected by In-situ combustion process against the envisaged 9 direct and 6 offset producers. Out of these 24 producers, 9 direct producers and 7 offset producers have come on self flow. In all the 9 direct producers, the CO_2 % level is in the range of 13% to 15% indicating full-fledged high temperature combustion in this zone. The CO_2% in the 15 offset producers is less than 10%, the impact of combustion front is upto the offset producers.

The plots of production performance of 9 direct producers, 15 offset producers are shown in Figs.:19 & 20 respectively.

The In-situ combustion affected producers which are on western flanks and structurally down dip are usually having higher porosity values against prospective pays and thus are performing better.

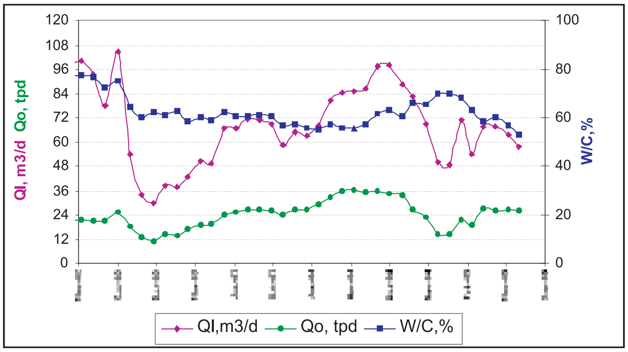

Fig. 19: Production performance of 9 direct producers

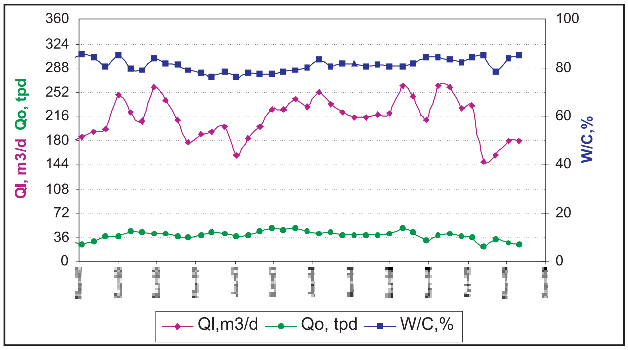

Fig.20 : Production performance of 15 offset producers

There is ample scope for improvement in oil production from 9 direct producers in the Pilot area from a level of 23 m^3/ day to 37 m^3/ day (gain of 14 m^3/ day) with drastic reduction in water cut from 77% to 56%. The production from 15 offset producers improved from a level of 29 m3 / day to 41 m3 / day (gain of 12 m3 / day) with marginal reduction in water cut from 84% to 82%. This may be attributed to poor reservoir characteristics.

Exploitation strategy

A depositional low axis with fines at the lowest point accommodated channel deposits of a river system during Eocene time. Miocene structural inversion inverted the incised valley in to an elongate antiformal feature. Migration that took place in the post inversion period resulted in the accumulation of hydrocarbons. In view of the identification of four vertical flow units and considerable water encroachment having occurred in the course of exploitation since 1988, it is suggested to suitably place high angle-high drift wells in preference over horizontal wells to drain oil from areas hitherto undrained. This will also enable landing the well appropriately avoiding the crestal areas with least porosity into better porosity pod areas. It will also tackle coning and cusping to enable obtain better primary recoveries. This will be in addition to the ongoing pilot pending commercialization of in-situ combustion process for enhanced oil recovery.

Conclusion

Refined geological model clearly indicates the antiform to be an inversion structure with a number of culminations in main pay of Kalol Formation. The pay sand is subdivided into layers A, B, C & D, separated by persistent shale. The reservoirs are hydro dynamically interconnected with common aquifer. The field is limited towards west by a NNW – SSE to NW – SE fault bounded graben. The field is under active bottom water drive operating from eastern side. Meticulous data analysis reveals existence of three cross trends in the field.

On the basis of this model mid-course correction and commercialization of In-situ combustion scheme can be designed. Placement of Injectors should be preferably on each separate culmination and producers are located where down dip areas are expected to be better producers due to high effective porosities as against that on the crest. Before modification / expansion of In-situ combustion pilot into commercialization in future, it is necessary to give serious thought to layerwise completions. Layer-wise oil production is suggested to avoid bypassed reserves. A change in exploitation strategy is suggested to suitably drill high angle –high drift wells in place of conventional vertical wells.

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