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Geological Modeling and Facies Analysis in Sanand Field, Cambay Basin, India

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Summary

Sanand field lying in the northwest of Ahmedabad is located on the southern part of Mehsana-South Kadi-Jhalora-Sanand high trend in north Cambay Basin. It is an elongated doubly plunging anticline trending NNW-SSE direction.

Sanand field is known for accumulation of oil and gas in Kalol, Cambay Shale, and Olpad formations. Within Kalol Formation, K-III, K - IV and K-IX+X have been found to be prospective and are producing hydrocarbons. K - III pay zone is the main producer in northern part of the field and Jhalora, whereas in the southern part, K-IV is the main producing layer along with reservoir layers of Chhatral member as secondary pay. Till date 155 exploratory and development wells have been drilled in the field. Cumulative oil production is more than 3 MMT from the field.

Study of the area was taken up with a view to prepare exploration model of K-IV layer in southern part of Sanand field incorporating new geological, well & log data. The main emphasis was given on the analysis of development of reservoir facies and its relationship with hydrocarbon distribution. The studies of log and geological data have re-affirmed that the direction of major sedimentary input is from NNW and north of the study area. Net to gross thickness ratio along with log characteristics in the drilled wells indicate better reservoir facies around well Sanand-57. The channel orientation and shape of sand lobes are the major guides for stepping out towards NNW direction. Stratigraphic nature of entrapment is visualized for Chhatral member while strati-structural influence on entrapment of hydrocarbon is envisaged for K-IV reservoir unit. The dominant facies in Chhatral member is argillaceous where numerous ultra-thin irresolvable siltstone layers containing hydrocarbons are found within large thicknesses of shaly section. K-IV layer, however, indicates better reservoir characteristics as compared to Chhatral, yet it may require hydro-fracturing or suitable stimulation techniques to exploit relatively higher API density oil from the layer.

The study revealed that the areas of good reservoir facies are likely to develop on a major structural high trend axis at K-IV level in the area. Thus it is imperative to test the hydrocarbon potential of K-IV sands in northwestern part of the area under study.

Introduction

Discovered in 1962, Sanand field has been producing oil and gas since 1969 (first oil producer-well #15) from K-III, K-IV, K-IX+X units of Kalol-, Cambay Shale- (Chhatral member) and Olpad- formations. The field is located approximately 25 km northwest of Ahmedabad (**Fig-1**). In the northern part, K-III unit is the main producer where as in the southern part; K-IV is the main pay layer. Till date, 155 wells have been drilled on Sanand prospect. In the

southern part of the Sanand Field, the present study area, thirty five wells have been drilled so far where the main pay zone is sand/siltstone of K-IV unit. A few wells in this part have also penetrated Younger Cambay Shale- (including Chhatral member) and Olpad- formations. Out of these thirty five wells, fifteen wells have been declared oil bearing while two wells are gas bearing. The main reservoir rock is silt/sand of K-IV unit (Wavel member) of Kalol Formation. Additionally, sands/siltstone of Chhatral and Olpad- formations have also been found to be



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hydrocarbon bearing and are oil and gas producer in a few wells. Shale layers within Cambay Shale Formation are the main source rocks in the area. In addition to this, thin shale sections in Olpad Formation have also contributed in oil and gas generation as proved by geochemical studies of a few wells.

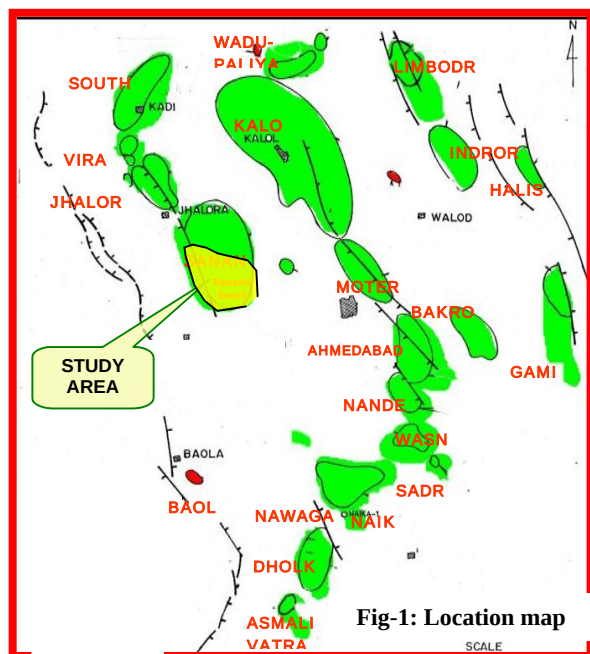


Fig-1: Location map

The present study area comprises the southern part of Sanand Field. An integrated analysis of geological and geophysical data was carried out to understand the depositional set up of K-IV unit of Kalol Formation. Habitat for oil and gas and their distribution have also been analyzed during the course of study.

Objectives and Methodology:

1. To review and refine the geological model of Sanand Field with special reference to K- IV pay unit and
2. To assess the prospectivity of K-IV and Chhatral reservoirs in the area. The following methodology was adapted:
 - Study of log correlation profiles in dip and strike directions for Kalol- and upper part of Cambay Shale- (Chhatral) formations
 - Preparation of structure contour maps on K-IV Top and Chhatral Top based on time structure patterns on the top of K-III+ K-IV and Chhatral units, after well data analysis and log correlation

- Computation of thicknesses of K-IV unit in wells and preparation of isopach map of the unit
- Analysis of sand/silt, shale and coal content of K-IV unit and preparation of triangular diagram and facies map
- Study of sand-shale ratios
- Analysis of laboratory data generated on the cores to understand depositional setting
- Preparation and study of sand/silt isolith maps and depositional model for K-IV unit
- Assessment of prospectivity of K-IV and Chhatral member

Geology of the area:

Cambay Basin has been characterized as a narrow elongated intra-cratonic rift-graben surrounded by Saurashtra Uplift in the west, Aravalli-Delhi Fold Belt in northeast, and Deccan Craton in the southeast. The major tectonic trend is roughly N-S, extending from Sanchor in the north to Gulf of Cambay in the south and further opening up into Arabian Sea. The basin is about 425 km long and having width varying between 40 and 80 km. About 5 to 7 km of sedimentary thickness is envisaged in the basin (Pandey et al., 1992). The major trend of the lineament in North Cambay Basin is NNW-SSE and NE-SW. In the southern part, however, the main trend is ENE-WSW (Chandra et al., 1969). The basin is divided into discrete tectonic blocks based on major lineament trends.

Sanand Field forms a part of Mehsana-Ahmedabad tectonic block. The field lies in the western part of Ahmedabad sub-block. Tectonically, Sanand field is the southern most part of the western high axial trend starting from South Kadi passing through Viraj and Jhalora and extended up to Sanand. It is confined by Wamaj low in east and western syncline in the west. Jetalpur Low lies further southward.

As mentioned earlier the study area lies in the southern part of Sanand Field. Structurally, it is an elongated doubly plunging anticline trending NNW-SSE. The plunge is gentle in the northern part as compared to steeper plunge in southern part. Two major fault trends viz., NNW-SSE (parallel to the fold axis) and WNW-ESE (oblique to the fold axis) have been mapped in the area

Regionally, a better reservoir facies development in the northern part is observed as compared to the area in the south. This may be due to dominant northern entry of the sediments. The K-III sand is well developed in Jhalora area and also in the northern part of Sanand Field. The southern portion, however, became more argillaceous and fast deterioration of reservoir facies from north to south is evident from the data analysis. The depositional environments have played a major role in distribution of reservoir facies.

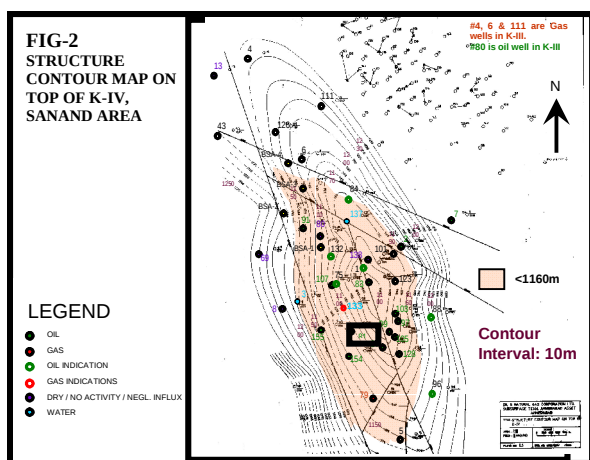


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Kalol Formation is the main reservoir in the field. However, sands/silts within Chhatral/Younger Cambay Shale- and Olpad- formations have also been found to be hydrocarbon bearing in a few wells of the area. The entrapment style is mainly strati-structural for the Kalol units. Cambay Shale is the major source rock in the area. Additionally, thin shale bands in Olpad Formation have also generated oil and gas hence is considered effective source rocks. Wamaj Depression lies in the east and a prominent low (Western Syncline) lies to the west of Sanand structure. These depressions are known for the generation potentials of hydrocarbons. The thickness of sediments within oil window ($R_o > 0.5$) is more than 1800m in Wamaj Low. Srivastava et. al, 1992, based on geochemical studies, brought out the presence of rich source rocks within Wamaj Depression. Excellent source rock characteristics in the low, up dip migration and entrapment of hydrocarbons in the strati-structural/stratigraphic targets in arenaceous reservoirs of Chhatral & Kalol Formations make the area very promising for exploration.

Structure Map on Top of K-IV Unit:

The area is represented by a doubly plunging anticline (Fig-2). The dip on the western limb of the anticline is steeper as compared to the eastern side. The structure is dissected by a set of two longitudinal faults trending NNW-SSE direction. One of the faults is passing through the crestal portion of the anticline dissecting the structure in to two fault closures on either side. The other longitudinal fault is located on the western limb of the anticline. The throw of this fault varies from 30-35 m.



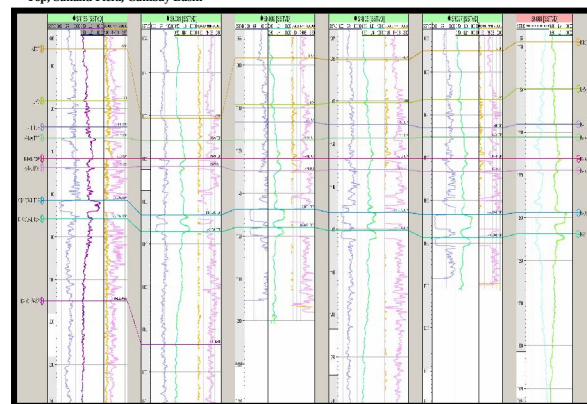
Two major WNW-SSE trending faults have also been mapped in the northern part of the plunging anticline. The down thrown side of both the faults is towards NE direction. The throw is negligible to 5m on the fault located

in the south and around 25-30m of the northern-most fault. In addition to these faults, there are two minor transverse faults trending NE-SW and are mapped in the extreme southern part near well #79. The throw of these minor faults is around 5 m towards SE direction. These two faults divide the southern tip of the plunge into two different blocks i.e. block of wells #79 and #5. This part seems to have undergone active tectonic disturbance after deposition of Kalol units. Well #79 is gas bearing in this part, while well # 5 drilled in the adjacent block is abandoned.

Lithological Variations:

The gross lithological variations in K-IV unit among the drilled wells are comparable. The unit is represented by shale, silt/sand and coal. The high argillaceous content of the unit is observed in the drilled wells (Fig-3). Silt/sands are not very clean and at places are highly shaly. The K-IV unit has been divided into two sub-units viz., K-IVA (upper) and K-IVB (lower). Distinct coal layers are developed at the bottom of K-IVB sub-unit in a majority of the wells. Another coal layer marks top of K-IVB sub-unit in many wells located on the main Sanand structure. In general, K-IVB sub-unit has poor reservoir facies development in most of the wells. On the contrary, K-IVA sub-unit has better reservoir facies development in the form of silt/sand. Intervening thin/thick shale separates the reservoir silt/sand layers of K-IVA.

Fig-3 Stratigraphic Correlation Profile Along Wells SN#155, #81, #99, #105, #97 and #88. Datum: K-IVB Top, Sanand Field, Cambay Basin

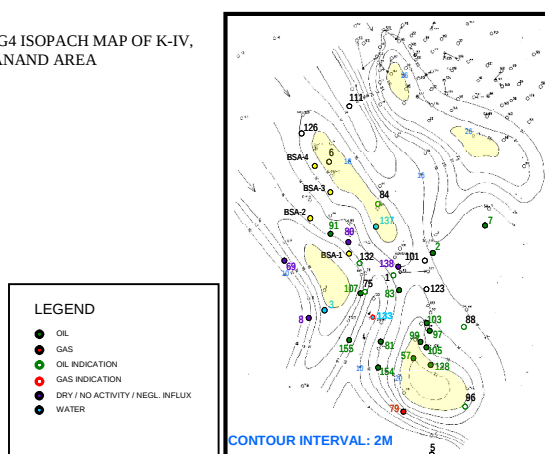


Isopach Map K-IV Pay:

Isopach map (Fig-4) indicates that thickness is better in northeast and southeast portions of the study area. Four sediment maxima viz., central, northeast, southeast and western have been mapped. The maximum thickness of 26m is observed in northeast lobe in and around wells #74, #68 and #6.



FIG4 ISOPACH MAP OF K-IV, SANAND AREA



The central maxima which is also the crestal portion of plunging anticline around well #137 shows a thickness of 18 m. Many wells in this area have been found to be hydrocarbon bearing in K-IV.

The western maxima which also shows deterioration of thickness around wells #3, #8 and #69 is in the down thrown side of the longitudinal fault. This area is not very encouraging from hydrocarbon accumulation point of view. However, well #155 is located in the outer circle of the maxima and has yielded oil from K-IV.

The southeastern maxima around wells #79 and #96 show a thickness of 22 m in the centre. Wells drilled on northern portion of the lobe have been found to be hydrocarbon bearing.

On the basis of the isopach map it can be inferred that three main channels of transportation of sediments existed during this time and it may have converged further southeast or south.

The thickness on the crestal portion of plunging anticline indicate that upliftment of structure might have taken place post-deposition period.

The entry of the sediments is mainly from the north, northwest and locally northeast. The thickness of southeastern lobe indicates that a relative low area in the southeast associated with the probably higher rate of sedimentation/subsidence. The direction of sedimentary input is envisaged from north to south and the main depocentre was around Jetapur low. The depositional pattern on western and eastern side of the anticline indicates that faults have got activated only during post – depositional time.

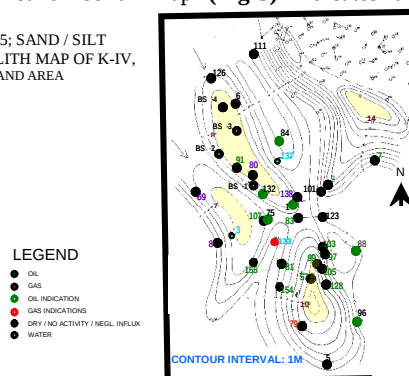


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Sand/Silt Isolith Maps of K-IV:

The sand isolith map (Fig-5) indicates that the entry

FIG-5: SAND / SILT ISOLITH MAP OF K-IV, SANAND AREA



of sand from north, northeast and northwest directions. The maximum thickness of sand/silt is observed in northeast lobe (about 14m) while it is around 11m in southeast lobe. Thickness of 7 to 8m is observed on the western flank. In general, an improvement of sand/silt is seen from west to east. Sand/silt thickness around the crest is around 5 to 6m. The area in south east lobe also shows better facies development and many oil bearing wells are located in this lobe at K-IV level. At Chhatral level this lobe is prospective and wells #154 , #79 and #105 have been found to be oil bearing while well # 57 has been re-interpreted to be hydrocarbon bearing.

Reservoir Distribution Pattern and Facies:

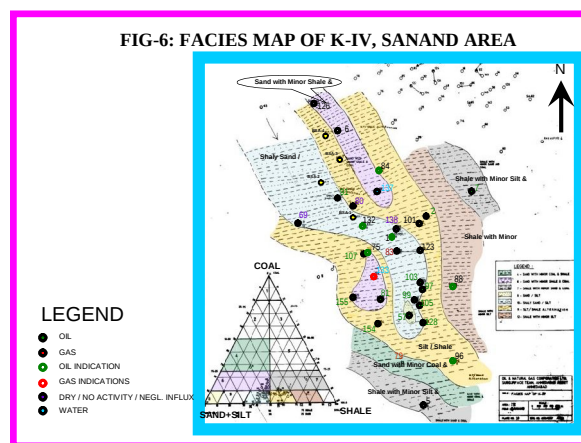
Kalol Formation:

Kalol Formation was deposited in paralic environment under unstable shelf conditions with alternating regressive and transgressive conditions. The oscillating conditions gave rise to incomplete coal cyclothems (Pandey et al, 1992). The coarser clastics of Wavel and Sertha members were deposited when the conditions were regressive while the marine shale of Kansari member was deposited under transgressive environments. The K-IV pay unit forms a part of the Wavel Formation. The coal / sandstone / siltstone units of this member as also those of the Sertha member were deposited in paludal environment with wide fluctuations of shore line.

Deposition of K-IV began within a regressive phase, right after the deposition of a coal unit that marks the base of K-IV and is found to exist in almost all the wells of Sanand area. The swampy, stagnating conditions changed to those of a flood plain / channels on a gentle slope. The sediment entry has been envisaged from NNW direction with minor influence from NNE to northerly directions. Gross thickness as well as silt-sand maxima has been mapped



Sonic-Resistivity overlay technique identified oil producing layers and has been used for assessment of hydrocarbon pay thickness of the wells in the area. (K. Rai et al, 2006).





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Hydrocarbon Plays:

The study on distribution of reservoir facies in the depositional model of K-IV unit indicates inputs from NNW to NNE directions. The reservoir facies distribution as well as faults, have played important roles in the entrapment of hydrocarbons in this area, thus a strati-structural model of entrapment has been envisaged for K-IV unit. Oil entrapment in Cambay Shale (Chhatral) Formation, however, is governed by stratigraphic plays related to areas of better facies development.

Prospectivity Analysis:

The area under study has been established as the area of high prospectivity due to its geological setting. Sanand field is currently on production from Kalol and Chhatral formations. Prominent anticlines are mapped at Kalol and Chhatral Top levels. The structure was subdued during Kalol deposition but became prominent post-Kalol deposition. Thick shale of Cambay Shale Formation along with thin shale layers within Olpad Formation have been established as excellent effective source rocks for Sanand Field. These rocks have been deposited in the adjacent Wamaj Depression, Jetalpur Low and Western Syncline. Rocks of Tarapur Formation constitute regional cap rocks. Thin or thick shale layers within Tarapur, Kalol, and Chhatral and Olpad formations are found to be effective cap rocks locally. The oil generated from the source rocks migrated up dip and got entrapped mainly in the reservoir facies of Kalol and Chhatral formations. The entrapment style is mainly strati-structural or stratigraphic in nature.

Sanand area is highly prospective in view of the availability of the various elements of the petroleum system(s) and associated processes responsible for generation, migration and accumulation of hydrocarbons in the area.

Conclusions

- In Sanand Field oil and gas have been entrapped mainly in the silt/sandstone reservoir facies of K-IV and K-III units of Kalol Formation along with silty layers of Chhatral Member. The entrapment style is strati-structural for Kalol pays and stratigraphic for Chhatral pays.
- Sanand structure is a well defined doubly plunging anticline at Kalol and Chhatral levels.
- Two sets of faults have been mapped on Chhatral and Kalol levels. These faults trend in NNW-SSE and WNW-ESE directions with varying throws.
- With reference to the present day adjacent lows, Sanand structure also existed at the time of Kalol deposition. However, this was quite subdued as compared to today's prominent high.
- Lithological variation indicates that silty/sandy facies of Kalol Formation have better reservoir characteristics towards north and northwest and along the axis of the channels.
- Silt/sand, shale and coal constitute K-IV unit of Kalol Formation. Overall argillaceous content of the unit is high.
- Log correlation studies suggest that individual sub-units are well correlatable along and across the structure with a little variation in thicknesses and facies. It also brings out that crestal part has better thicknesses especially, along the channel lobe which suggests that locally there were the areas of better deposition and more subsidence on this structure.
- Isopach map indicates that thickness is better in northeast and southeast portions of the study area. Four sediment maxima viz., central, northeast, southeast and west have been mapped.
- On the basis of the Isopach map and sand Isolith map it can be inferred that three main channels of transportation of sediments existed during this time and they might have converged in further southeast or south.
- Facies is predominantly argillaceous with varying amount of sand and silt. The best facies development is seen around well # 57. The most of the wells are located in shaly sand/silt and silt/shale alternations facies. Third facies type is sand/silt with minor shale and coal.
- The overall reservoir facies development is poor in the area for unit K-IV. The reservoir silt/sand tends to be argillaceous in nature. Better facies development is, however, seen along the channel course and also towards north due to nearness of the provenance.
- Tidal channel, tidal flat and locally swampy environments were interpreted for K-IV unit.
- The isopach and sand/silt isolith maps suggest that the main entry for the sediments was from the north and northwest.
- Better reservoir facies and thickness development are observed along the axis of the channel lobes.
- Facies maps indicate dominance of argillaceous content and short supply of coarser clastics in relatively low energy environment of deposition.
- Sanand area is highly prospective in view of the availability of the various elements of the petroleum system(s) and associated processes responsible for generation, migration and accumulation of hydrocarbon in the area. The area has better prospectivity in the north and northwest directions



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