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Sub-Surface Understanding of an Oil Field in Cambay Basin

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Summary

It is based on the Sub-surface study of on oil field in Cambay basin. After a brief description of the Cambay basin's geology, the other aspects of exploration were discussed. It consists of the basic knowledge of the Geology of Cambay basin, basin analysis, petroleum geology, study of well logs, seismic data visualization, its interpretation, surface mapping and formation evaluation using Petrel 2010.1 and Kingdom 2009.

***Keywords**: Cambay basin, Ahmedabad – Mehsana Block, Ingoli field, Kadi, Kalol.*

Introduction

The basic workflow functioned/followed in an oil industry to explore an oil field is discussed and applied to an Oil field of Cambay basin named Ingoli Field. This procedure was also followed while working on software - Petrel 2010.1 and Kingdom 2009 and basic knowledge of software handling is discussed. This project has been made with help of software provided by Gujarat State Petroleum Corporation, Gandhinagar.

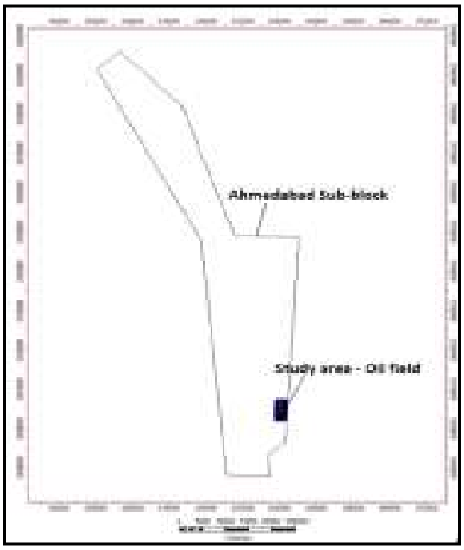

Figure 1: Block boundary and Study area – Ingoli Oil field.

Theory

1.Study Area

Cambay Basin, a narrow, elongated, intra-cratonic rift garben, came into existence at the close of Cretaceous. This linear NNW-SSE trending basin. The Deccan Basalt forms the technical basement over which more than 7-11 km thick piles of Tertiary sediments have been deposited during synrift and postrift phases of basin development.

Figure 2: 1 Location of Cambay basin, showing faults and Oil and Gas fields

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2. Ahmedabad-Mehsana Tectonic Block

This block lies between the Khari River in the north and the Vatrak River in the south. Major lineaments in this block trend in the NNW- SSE direction. Aerially, this is the lasrgest block in the basin, extending from Dholka-Nawagam in the south to Unawa in the north. The Mehsana horst is the prominent feature, which is an extension of the West Patan-Vansa horst. The apical part of this horst did not have the sedimentation in Eocene-Miocene. (Kundu and Wani, 1992)

3. Ahmedabad Sub-Block

This sub-block lies between Kadi in the north and Nawagam in the south, and is traversed by the Sabarmati River. The sedimentary sequence starts with the trap conglomerates succeeded by claystone, trap-wacke, sideritic marls. This constitutes the Lower Cambay shale. This sequence is sub-areally exposed from time to time, creating local development of reservoir facies with hydrocarbon accumulations in Nawagam. (Kundu and Wani, 1992)

4. Location of Study Area

Location: The southern part of exploratory block CB-ONN-2000/1 is located along the western margin of Mehsana-Ahmedabad tectonic bock. It extends from Longitude 72^{0} 17' 44'' to 72^{0} 30' 11'' and Latitude 23^{0} 00' 59" to 23^{0} 01' 42". The total block area is 1424 Km² (DGH, 2011).

The study area (Ingoli : 14.03 sq.km.) is located in southern part of CB-ONN-2000/1 which is limited to the south by the Nawagam – Wasana basement uplift. The NW-SE marginal fault located in SW portion of the block. The block is segmented longitudinally (NNW- SSE) into two major half grabens each associated with prominent faults (DGH, 2011).

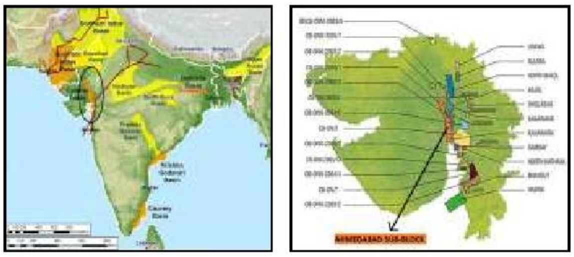


Figure 3: Location of Ahmedabad Sub-Block in Cambay Basin, Gujarat, India.

5. Tectonic Setting and Basin Evolution

The rift initiated at the end of Cretaceous. In the later part of Late Cretaceous, Seychelles islands were separated from the Indian Plate and the Indian sub-continent drifted northward. Rifting in the basin is marked by eruption of massive amount of flood basalt (Deccan Trap). The basalt constitutes the basement for subsequent tertiary sediments. The structural elements of the basin indicate influence of the tree major tectonic trends viz. Dharwar (NNW-SSE), Satpura (ENE- WSW) and Aravalli-Delhit (NE-SW) trends of Precambrian time. Several cross trends related to Satpura and Delhi-Aravalli tectonic trends are responsible for creation of tectonic blocks. The basin is divided into five tectonic blocks. They are (i) Sanchor-Patan (ii) Mehsana-Ahmedabad (iii) Tarapur-Cambay (iv) Broach-Jambusar (v) Narmada-Tapi blocks from north to south. (DGH, 2011)

The basin has two distinct fault systems: (i) N-S to NNW-SSE trending listric normal faults of Dharwarian trend and (ii) NE-SW to ENE-WSW trending faults of Aravalli-Delhi and Satpura trends.

The basin evolved in three different stages – (i) Synrift stage (extensional stage) during Paleocene-Early Eocene (ii) Postrift stage- I (thermal subsidence) during Middle Eocene-Early Miocene (iii) Postrift stage-II (structural inversion stage) during Middle Miocene- recent.

6. Stratigraphy of the Study area (Oil Field)

Tarapur Shale (Late Eocene to Oligocene)
Kalol Formation (Mid to Late Eocene)
Cambay Shale (Late Paleocene to Early Eocene)
Olpad Formation (Paleocene)
The technical basement – Deccan trap (Upper Cretaceous)

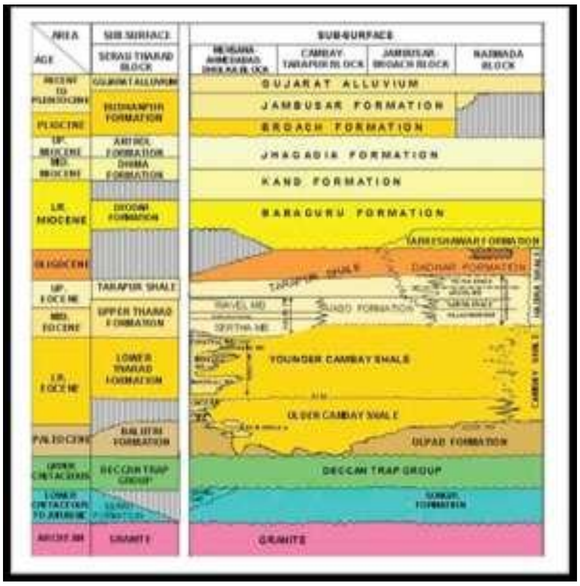


Figure 4: Stratigraphy of the Ingoli oil field and Generalized stratigraphy of Cambay Basin

Generalized stratigraphy of Cambay basin exhibits presence of rocks from Upper Cretaceous to Recent. Deccan Basalt constitutes the basement rock for the major part of the basin over which 8-11 km thick pile of tertiary sediments have been deposited in synrift and postrift phases.

7. Petroleum System of the Study Area – Oil field

Source Rock: Cambay Shale constitutes the major source rock.

Reservoir: Fractured Basement – Deccan trap being the reservoir marks it as an unconventional oil field. The major faults are running parallel to the ridge. Shear forces are parallel to the fractures, favorable for entrapment of hydrocarbons.

Migration: The NNE flank of the high area is believed to be on the migration path way from the kitchen located near to Nawagaam, northern part of study area.

Cap rock/ seal: Cambay shale act as regional seal.

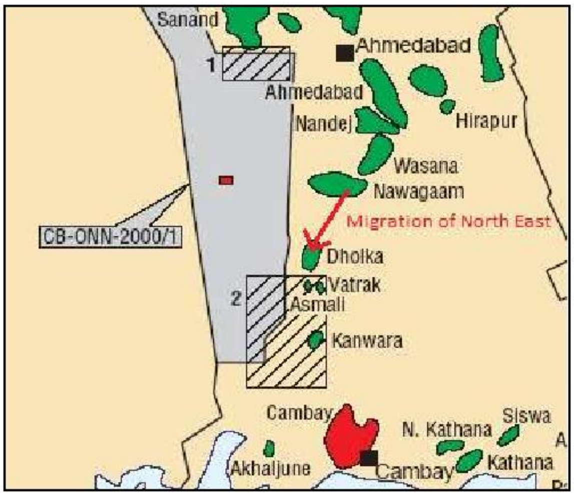


Figure 5: Migration pathway

Methodology

1. Seismic Data Visualization

2D and 3D Seismic Data visualization in Map view: Associate Lease Maps and Cultural data are imported to software – Kingdom 2009 to see the geological and geophysical data in Map view.

- The dotted area is representing the extent of 3D seismic data of the field.
- The black colored straight lines are representing the 2D seismic data of the field.
- The red block is our study area i.e. the south of Ahmedabad – Mehsana block (Ingoli Oil Field).
- The green block is the lease area allotted to GSPC in NELP II.
- To see the seismic data along inline, crossline and random line direction, we can select from Map view and open it in an Interpretation window (Seismic Data Visualization Window) for analysis.

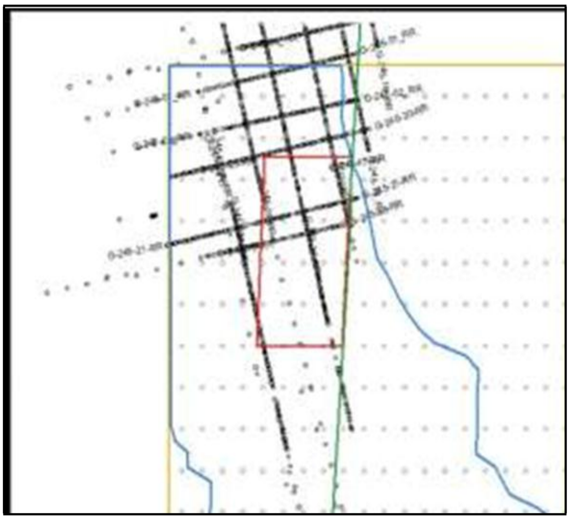


Figure 6: Extent of 2D and 3D seismic data in the study area

Seismic Reflector visualization from Seismic data:

Loading the seismic process data in SEG Y format. Prior to loading, we check the EBCEDIC header and BINARY header of SEGY data and get information about Seismic Survey Area and loading parameter like Line Sequence Number, Trace Sequence Number and UTM X and UTM Y. After successful loading of SEGY data, we will start to see the Inline (E-W direction), Cross line (N-S direction) and Arbitrary line (Random line). Also make Time slice in different time and visualize it thoroughly.

Observations from Inline Seismic Data:

- Shallow seismic reflector is dipping towards East.
- Deeper seismic reflector is dipping eastward. We can also see the middle part is structurally high and sides are dipping.
- Two faults are found forming a horst-graben structure.
- Below the deeper reflector, irregular and messy feature is representative fractured zone.

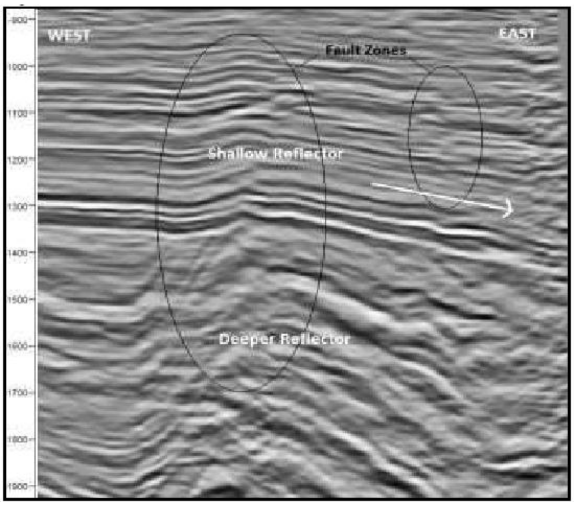


Figure 7: Seismic Data in Inline direction showing Seismic reflectors and Faults

Observation from Cross line Seismic data:

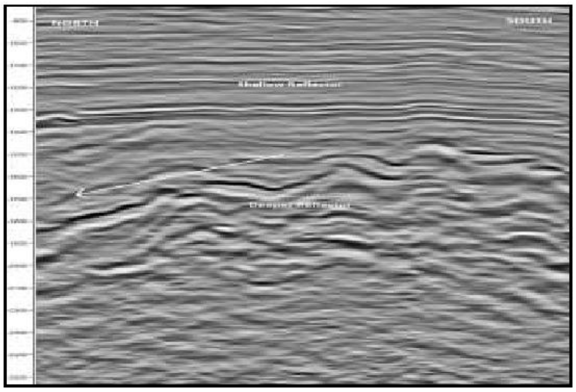


Figure 8: Seismic Data in Cross line direction showing Seismic reflectors

- Shallow seismic reflector is more or less horizontal.
- Below the deeper reflector, discontinuous and chaotic seismic feature indicating fractured zone.
- Deeper seismic reflector is dipping towards north. We can also see the middle part of deeper reflector is structurally high and both sides are dipping.

3D Seismic Data Visualization

- Here in 3D View, we collectively see 3D seismic data with inline section, cross line section, time slice and interpreted seismic horizon; 2 wells named Y and Z with their well log data and well tops in a 3D window are also showed. The green arrow in the bottom left corner is showing the North direction.

- During the course of visualization it has been noted that the data quality is fair to good in the study area.

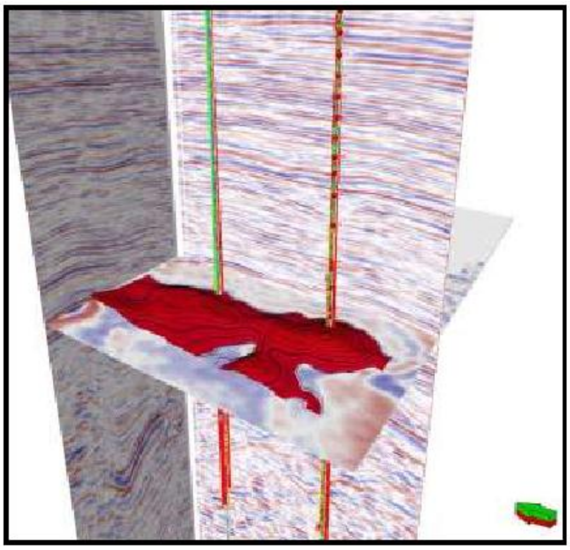


Figure 9: 3D seismic data visualization along with Inline, Cross line, Time slice, Well Y and Z and associate well tops and log data of both wells

2. Basic Seismic Interpretation

Seismic to Well Tie

- Well Seismic Tie is attempted to be generated from well logs (Y and Z wells) for correlation with the main seismic markers/reflectors. Check shot data is loaded for Y well to generate T-D curve. Same T- D curve is shared with other well Z.
- Well data is given in Depth domain. So to correlate it with seismic data we have to convert it into Time domain. This can be obtained either by velocity model or by available check shot data.
- T-D curve is generated using check shot data of Y well.

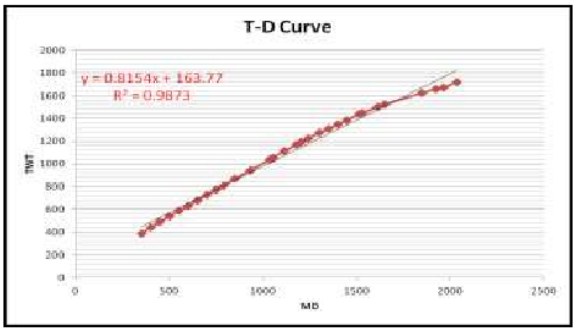


Figure 10: TWT versus MD curve (T-D curve) showing linear relationship

From above Fig, it is observed that velocity of the area is increased with depth.

- At the beginning, we loaded well data i.e Well coordinate, Measured depth and Log data (in LAS format) in study area. Check shot data also used in this method.
- Then well to seismic tie has been carried out for Y and Z wells. From well section view, it is observed that correlation of Seismic and well marker is much closed to each other. Associate seismic marker/reflector is identifying for Horizon picking.
- This method is useful to correlate well marker/stratigraphic marker with associate Seismic Reflector.

Marker Identification

Two wells (Y and Z) provided correlation points with the stratigraphy over the study area. Correlations were made on continuous coherent events of marker horizons in the area.

We have marked to horizons – (i) Seismic Horizon 1 at 1276 ms; (ii) Top CBSH at 1226 ms based on correlation points of well Y and Z.

Horizon picking or identification of seismic reflectors Seismic Horizon 1 and Top CBSH are more consistent because they are consistent reflectors of high amplitude throughout the area. But a reduction in amplitude, reflectivity strength and discontinuity of deeper reflector has been observed.

Marker Identification has been carried out using Petrel 2010.1 software, at every 5th line in crossline and inline directions.

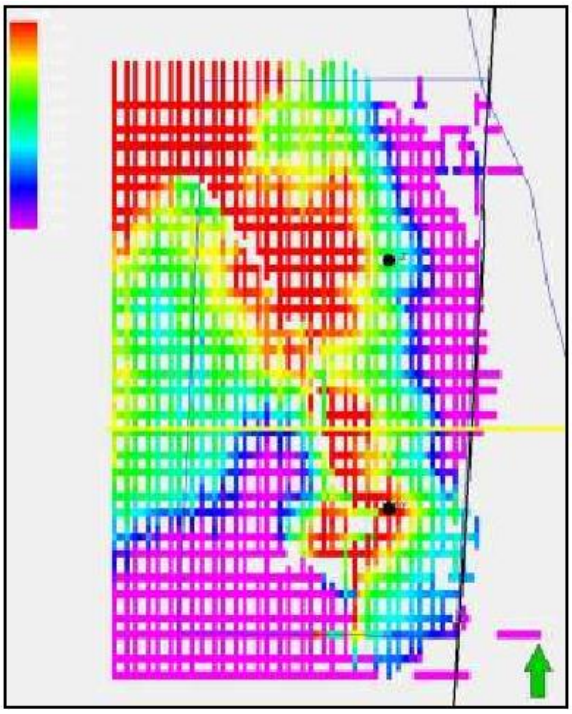


Figure 11: Seismic Horizon 1 showing in Map window (Grid Interval: 5 by 5)

- To mark a seismic horizon in software – Petrel 2010.1 we track horizon in Inline and cross line directions in an Interpretation window using the Geophysics module of the software – Petrel 2010.1.
- In interpretation window seismic horizon has been marked in both inline-crossline direction and with an interval of 5m between two consecutive inline - crossline. Manual Horizon picking mode is applied for track the horizon.
- The resulting image of the seismic horizon in the Map window and Interpretation window are shown in the figures.
- Color range can be changed manually to optimize the data and map observation method.
- The green colored arrow in the bottom left corner is showing north direction.
- Wells Y and Z can be seen in this interpretation window.
- Red is showing highest elevation and pink is showing lowest elevation in the map area.
- We can see that well Y is more structurally high area than well Z.

- Wiggles are showing the amplitude curve of the seismic data, yellow color filled in the wiggles with positive amplitude only. Well and logs are also shown, with Kalol and CBSH stratigraphy tops.

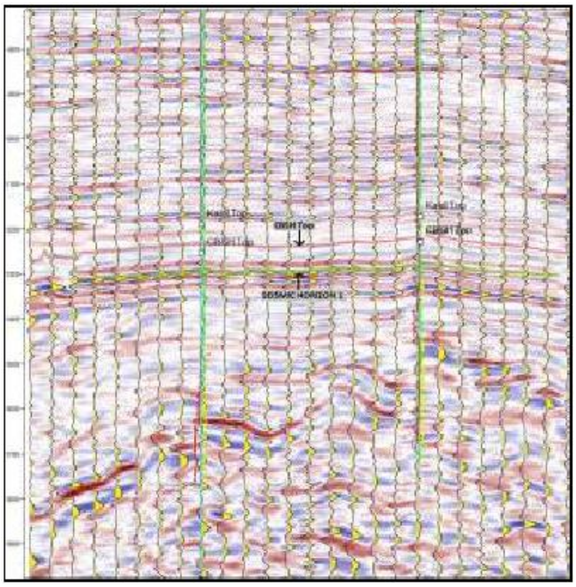


Figure 12: Seismic Markers showing in Interpretation Window

- Tracking of Seismic Horizon 1 and Top CBSH is done here in Cross line direction using the seismic interpretation tool.

Mapping

This aspect of mapping has been carried out to study the structural set up of the field. Surface Mapping procedure is the combination of gridding then contouring of a given seismic horizon.

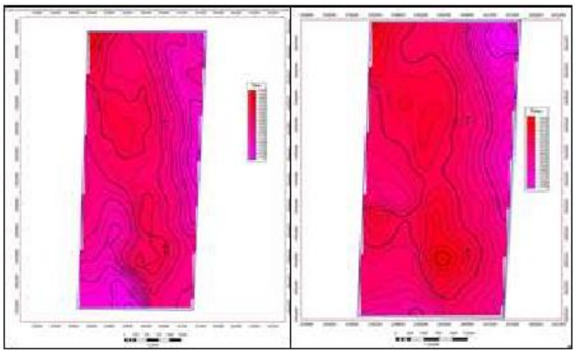


Figure 13: Surface mapping with contour for Seismic

Horizon 1 and Top CBSH

- Elevation is increasing from color pink to red.
- Well Y is present inside a close contour (TWT=1280 ms). Well Y and Z, both are structurally higher area. But Y well is much high than X well.
- In the southern part of the surface, slope is very steep as the contour lines are very closely spaced. We can interpret the feature as a fault in the southern portion of the map.
- We can make the contours smooth using the smooth operation (present in the settings of the surface generated).
- In the North-eastern part of the surface, slope is very steep as the contour lines are very closely spaced. We can interpret that fault is present is this area.
- We can make the contours smooth using the smooth operation (present in the settings of the surface generated).

3. Well Logging Interpretation and Correlation for Wells Y and Z of Ingoli Field.

Curves given to us are as follows:

a. Gamma Ray Log (0 to 150 GAPI)
b. Resistivity Log (2 to 2000 OHMM)
c. Neutron Porosity Log (-2.15 to 0.45 V/V)
d. Bulk Density Log (1.85 to 2.85 g/cc)

Well information i.e Longitude, Latitude, Kelly Busy(kb) and Depth values for 2 wells Y and Z are loaded in software – Petrel 2010.1. Logging data for both wells in LAS format are also loaded prior to the log interpretation. Loaded logs data (GR, Resistivity (LLD, LLS), Bulk Density (RHOB), and Neutron-Porosity (NPHIE)) are exhibit in Well Section window (Log Interpretation window). Stratigraphical marker Kalol, CBSH, Olpad and Trap has been marked for both the wells.

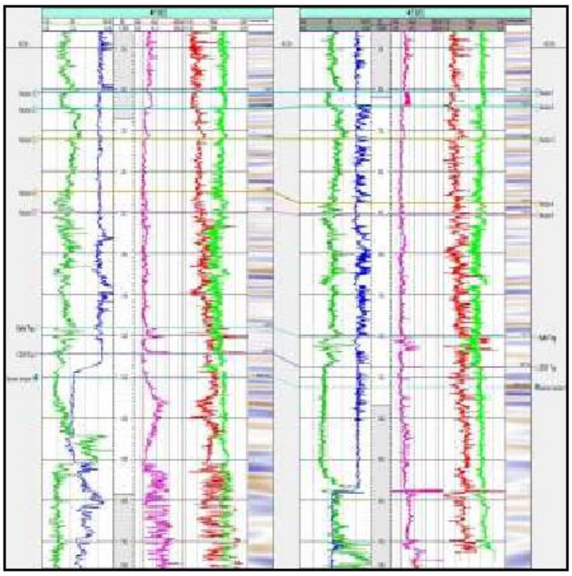


Figure 14: Well log correlation and Seismic to Well Tie Analysis of Wells Y(left) and Z(right).

WELL Y

- As discussed earlier, there are two hydrocarbon zones (Zone A and Zone B) are identified in well Y at measured depths 1196m-1205m and 1357m – 1364m respectively.
- Zone A is defined by Marker A top and Marker A bottom and Zone B is defined by Marker B top and Marker B bottom.
- Zone A is located within the Kalol formation whereas Zone B is located within the Lower Cambay Shale.

WELL Z

- There are two hydrocarbon zones (Zone C and Zone D) are identified in well Z at measured depths 1697m-1708m and 1715m –11754m respectively.
- Zone C is defined by Marker C Top and Marker C Bottom. Zone B is defined by Marker D Top and Marker D Bottom.
- Zone C and Zone D both are located nearby Olpad and Deccan trap Formation.

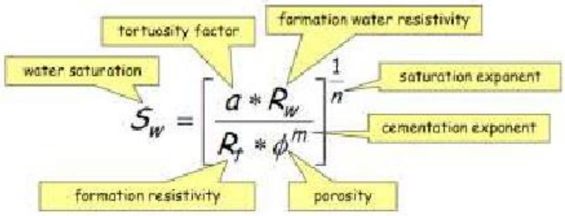
4. Formation Evaluation

Formation evaluation is used in the exploration, production, and development phases of the value chain to determine whether a potential oil and/or gas field is commercially viable. Tools such as wireline/well logs, well tests, and core samplers — used to detect oil and gas — return a myriad of data, including porosity, radioactivity, permeability, sonic velocity, bulk density, resistivity, etc., that are used to determine the economics of a reservoir.

Formation fluid saturation is an important quantity as it is necessary to determine the volume of fluids (Water and hydrocarbons) present. It may give us some indication as to what will be produced.

But for saturation calculation we have to estimate several parameters. On the basis of standard well logs: Gamma ray (GR), resistivity (LLD), neutron porosity and density porosity, water saturation and hydrocarbon saturation can be calculated.

Defining the terms in Archie's Equation:



Tortuosity factor (a): called the tortuosity factor, cementation intercept, lithology factor or, lithology coefficient is sometimes used. It is meant to correct for variation in compaction, pore structure and grain size.

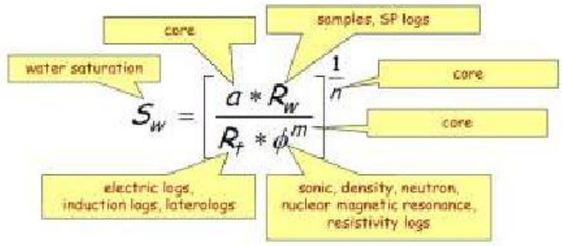
Saturation exponent (n): The saturation exponent n usually is fixed to values close to 2. The saturation exponent models the dependency on the presence of non-conductive fluid (hydrocarbons) in the pore-space, and is related to the wettability of the rock.

Cementation exponent (m): The cementation exponent models how much the pore network increases the resistivity, as the rock itself is assumed to be non-conductive. Cementation exponent is related to the permeability of the rock, increasing permeability decreases the cementation exponent.

Common values for this cementation exponent for consolidated sandstones are 1.8 < m < 2.0. Generally the value for constants a, m and n are taken 1, 2 and 2 respectively.
So, the equation reduces to,

$$\mathbf{S_w = [R_w/ (R_t{*}\ \Phi^2)]\ \text{^}1/2}$$

Traditional sources for variables in the equation:



The water saturation for different probable zones of hydrocarbon is calculated by using the Archie's equation and using the well log data. (O. Serra, Elsevier, 1984)

Procedure for calculation of Sw:

- The water saturation is calculated separately for $\Phi_{density}$, $\Phi_{neutron}$, Φ_{avg} and $\Phi_{effective}$.
- The values of Rt and Φneutron are directly read from the well log chart at points 1 m apart from each other.
- To calculate the Φdensity, following equation is used:
  $\mathbf{\Phi_{density} = (\rho_{matrix} - \rho_{log})/ (\rho_{matrix} - \rho_{fluid})}$
- To calculate the Φeffective, first the volume of shale has been calculated using the following equation:
  $\mathbf{V_{sh} = (G_{log} - G_{min})/(G_{max} - G_{min})}$
  Where, G_{log} = value of GR in the log observed.
  G_{min}= minimum value of GR in the probable area.
  G_{max}= maximum value of GR in the probable area.
  (O. Serra, Elsevier, 1984)
- After the Vsh has been found out, Φeffective is calculated by using following equation:
  $\mathbf{\Phi_{effective} = (X - V_{sh} * Y)}$
  Where, X = (ρmatrix - ρlog)/ (ρmatrix - ρfluid) And Y = (ρmatrix - ρshale)/ (ρmatrix - ρfluid)
- S_w is calculated with the help of Archie's Equation, with the constants value being a=1, m=2 and n=2. The value of Rw is known and is taken equal to 0.4.
- The values calculated are given below in the Table 1(Well X) and Table 2(Well Y).

Result and Discussion

- We studied an oil field near to the southern part of the Ahmedabad sub-block.
- In the study area both 2D and 3D seismic data are visualize and analyze. Data resolution of 3D data is more than 2D seismic data. Seismic features are prominently visible in both 2D-3D seismic data.
- From Seismic data visualization exercise it is noticeable that there are two-three prominent shallower and deeper reflectors in the study area. Faults and Horst-Graben structure has been visible in the study area. Some discontinuous and chaotic features are observed in deeper region in study area. Deeper reflector is structurally high in the middle part of the oil field.
- From Basic Seismic interpretation and mapping exercise, we observed that shallower seismic reflector is structurally high in SW part of the oil field whereas the NE part is structurally low. Y well is located more structurally high area than Z well.
- We studied three wells X, Y and Z. Well Y contains hydrocarbon zone at shallow depths (near to Kalol formation and Cambay Shale formation). Whereas well X and Z contain hydrocarbon bearing zone at deeper depths (near to Deccan Trap). From log data study it is obvious that there are two different Petroleum systems operated in the oil field area, one is shallow reservoir near to Kalol and Cambay Shale formation and another is deeper reservoir near to the Olpad and Deccan Trap formation.
- Hydrocarbon to be found in structurally high area in the oil field i.e. located in the middle part of the area.
- The Sw values indicate that the zones might be hydrocarbon- bearing (oil and/or gas).

Well X (Zone 1: 1761 m to 1775 m)	S_w range is from 13% to 71%
Well Y Zone 1 : 1180 m to 1186 m Zone 2: 1201 m to 1205 m Zone 3: 1238 m to 1242 m Zone 4: 1354 m to 1364 m	S_w range is from 47% to 83% S_w range is from 35% to 78% S_w range is from 19% to 58% S_w range is from 23% to 54%

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Views expressed in this paper are that of the authors only and may not necessarily be of GSPC.