## 1. EXECUTIVE SUMMARY

Vedanta (erstwhile Cairn India Limited merged with Vedanta Limited w.e.f. April 11, 2017, pursuant to NCLT order dated March 23, 2017) is a globally diversified natural resources company with interest in Zinc, Iron Ore, Aluminum, Copper, Power and Oil & Gas. Through Cairn, its upstream Oil and Gas division, Vedanta is the operator of the Onshore RJ-ON-90/1 block and on behalf of itself and its Joint Venture (JV) partners Cairn Energy Hydrocarbons Limited (CEHL) and Oil and Natural Gas Corporation Limited (ONGC), hereby re-submits this approved development plan (RFDP-1 vide MCM 69) incorporating modifications in Surface Facility concept and associated changes in well trajectory as well as cost implication for Raageshwari-Oil Field situated within Development Area-1 (DA-1) (Figure 1.1), in accordance with the provisions of RJ-ON-90/1 Production Sharing Contract (PSC).

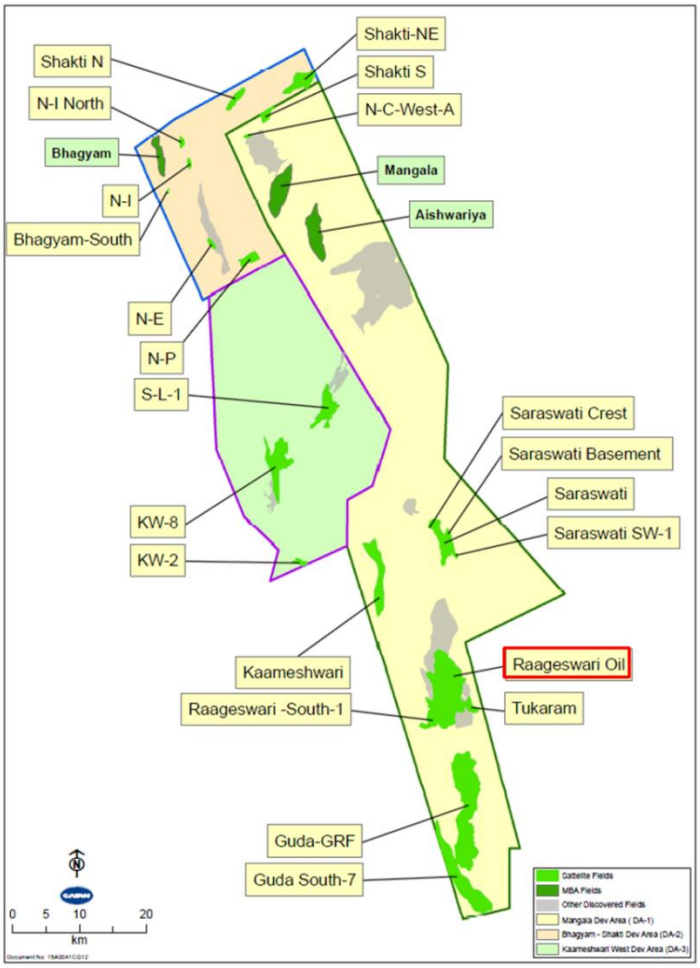


Figure 1.1: Raageshwari Oil Field Location Map

Raageshwari-Oil Field, a horst block structure situated in the southern part of Barmer Basin, was discovered in February 2003 through discovery well Raageshwari-1 (RJ-E-1). A Field Development Plan (FDP) for the oil-bearing Upper-Thumbli reservoirs was submitted in April 2005 and subsequently got approved in May 2006. The FDP approved program included field development in a phased manner. Phase-1 development had 2 existing and 6 new wells. There was in-principal agreement of drilling of additional wells in phase-2 based on the performance of phase-1 wells.



After the phase-1 FDP approval, five new wells (Raageshwari-8, -9, -10, -11 and -12) were drilled in the first phase of development in March/April 2007 to develop the Raag-3 block. Existing well Raageshwari-

3 along with 5 development wells was put on production since March 2012. Additionally, Raageshwari-3ST well was drilled immediately after submission of Raageshwari-Oil FDP to appraise the hydrocarbon potential of the fault-block east of Raageshwari-3 block. This well successfully tested oil from Upper Thumbli and was put on production in June 2016.

As per approved RFDP-1, Operator had proposed revised development of 4 fault blocks (Raag-3, Raag-3ST, Raag-Central and Raag-1ST) through drilling of additional producer and injector wells along with development of additional well pad (WP#2) and modification of existing Surface facility for handling additional HC as well as evacuation of the same. The broad scope was to drill 8 new producers from existing WP#1, 2 new producers from proposed WP#2 along with 4 new water injectors from the same pad. A Centralized Processing Facility (CPF) for handling oil, gas & water had been proposed at new WP#2 along with crude oil transfer to RDG via new heated pipeline. During execution of the FDP, Operator faced issue in acquisition of land for new pad (WP#2) location and decided to accommodate the wells and the surface facility planned in WP#2 to the existing wells pads of Raag-Oil (i.e. Raag oil WP-01 & 03) and Tukaram well pads.

Accordingly, 2 producer wells have been shifted to Tukaram-1Z well pad, 4 injectors with associated PW treatment, injection facilities have been shifted to Raag-Oil WP#3 and the centralized processing facility has been shifted to Raag-Oil WP#1. The necessary modifications were considered in the surface facility concept and evacuation plan along with changes in plan well trajectories maintaining the Subsurface development concept grossly unchanged.

Additionally, during drilling of RFDP-1 wells, Operator have faced operational issues in some high angle unsuccessful wells (>60 degree) including loss of well bore and loss in hole (LIH) of bottom hole assembly (BHA). Detailed study of the operational challenge reveals presence of unstable shale zone between Akli Lignite and Upper Thumbli reservoir in Raageshwari and this zone is prone to bore hole collapse for high angle wells. Accordingly, to de-risk the remaining wells, Operator has reduced the inclination of the planned wells which has also caused minor reduction in field EUR. During drilling of the lower inclination wells, some of the wells faced heavy mud-loss, ballooning issues which triggered a sizable cumulative mud volume lost and rig-time lost reported during the same. Due to uncontrolled loss, in one of the producer well, Operator had to abandon the original borehole and drill an operational sidetrack.

The current production from Raageshwari field is around ~550 boepd with 5 wells online however the full field capacity with all the 7 wells online is ~700 boepd. The reservoir pressure depletion is more than 1000 psi (in Raag-3 fault block). There is no water production from this field and the current GOR ~2000-2500 scf/stb. In line with MC approval (MCM 69), the operator proposes re-submission of RFDP-2 with certain modification in surface-facility design for development of 4 fault blocks (Raag-3, Raag-3ST, Raag-Central and Raag-1ST) with the estimated recovery of 7.5 MMSTB till 14$^{th}$ May 2030.

In the currently proposed development plan, Raag-Oil-WP-1 is planned to be developed with 8 new wells and Oil Processing Facility and Raag-Oil-WP-3 will have 4 new injectors and produced water treatment and Injection facility. All the produced crude and the associated natural gas (ANG), from Raag-Oil-WP-1 and Raag-Oil-WP-3 will be evacuated through pipelines. Crude is to be transported from Raag-Oil-WP-1 to AGI-5 through proposed heated pipeline. Post utilization of produced gas for internal consumption, additional gas would be transported to RGT through existing pipeline for sales consideration. The estimated EUR of gas from new wells is 5.9 BCF. The total sales gas volume estimated to be 3.7 BCF. 2 wells of Raag oil field are to be developed from Tuk-1Z pad, crude produced from these wells, along with

the Tukaram wells, to be evacuated through trucking to MPT and produced gas to be used for internal consumption and balance gas to be flared at the well pad only.

Key points of the proposed development plan are listed below:

- Production from 7 existing producer wells (6 well in Raag-3 Block & 1 well in Raag-3ST Block) to continue.
- 10 new deviated producer wells distributed in Raag-3, Raag-3ST, Raag-Central & Raag-1ST fault blocks (4 wells in Raag-3 Block, 4 wells in Raag-3ST Block, 1 well each in Raag-Central and Raag-1ST Blocks).
- Water injection proposed in Raag-3 block for pressure maintenance through 4 new deviated injectors.
- Two water source producer wells will be drilled for the supply of injection water.
- Peak oil production rate: ~3000 bopd
- Peak Field water Injection Rate (only in Raag-3 Block): ~9500 blpd
- Peak Field Liquid Production Rate: ~7000 blpd
- The cumulative oil production till 14$^{th}$ May 2030 is 7.5 MMSTB with an incremental production of 4.18 MMSTB above the existing development. The recovery factor till May 2030 is ~13% of the total STOIIP of all the 4 fault blocks of Raag-oil.
- The cumulative gas production till 14$^{th}$ May 2030 is 14.4 BCF with an incremental production of 5.9 BCF above the existing development. Post utilization of produced gas for internal consumption, additional gas would be transported to RGT through existing pipeline for sales consideration. The total sales gas volume estimated to be 3.7 BCF.
- The planned Central Processing Facility (CPF) at Raag Well-pad-2 has been moved to Raag-Oil-WP-1 (Oil Processing Facility) and Raag Well pad-3 (Water treatment and Injection facility). Produced crude from the field will be transported from Raag-WP-1 to AGI-5 through proposed heated oil pipeline. Crude produced in 2 producer wells planned in Tukaram-1Z pad, will be evacuated along with Tukaram wells through trucking to MPT.
- Revised FDP Capital Expenditure estimated at US$ 66.07 MM
- First oil from new wells to be delivered by Q3 of FY 2022-23 subject to timely project approvals.

The salient features of the FDP Revision are summarized in Table-1.1.

**Table 1. 1: Raageshwari Field Development Plan Summary**

| Key Field Parameters | Raageshwari-Oil Field |
|---|---|
| Reservoir Target | Upper Thumbli |
| 2P STOIIP – Upper Thumbli (MMSTB) | 53.64 |
| Field $EUR_{14\ May\ 2030}$ (MMSTB) | 7.5 |
| Field Recovery factor $_{14\ May\ 2030}$ (%) | ~14% |
| Incremental Field $EUR_{2030}$ (MMSTB) | 4.18 |
| Field $EUR_{14\ May\ 2030}$ -Gas(BCF) | 14.4 |
| Incremental Field $EUR_{2030}$ -Gas (BCF) | 5.9 |
| Incremental Gas sales volume (Bcf) | 3.7 |
| Number of Producers | 17 (7 Existing + 10 New) |
| Number of Injectors | 4 (All New) |
| Crude Evacuation Plan | Pipeline |
| Capital Expenditure (Million US$) | 66.07 |
| Production Commencement Date | Q3, FY 2023 |

It is recommended that the Field Development Plan FDP Revision-2 (Revised) for Raageshwari-Oil be approved in accordance with the RJ-ON-90/1 Production Sharing Contract provisions.

## 1.1. Conclusions and Recommendations

As per MC approved RFDP-1, 14 wells are proposed to be drilled in 4 fault blocks (10 producers and 4 water injectors). Out of the proposed 14 wells, 10 producers and 1 injector well has already been drilled successfully. Based on the land availability issue, the surface facility concept along with pad allocation of a number of producer and injector wells have been modified. As per the current execution schedule, the wells are expected to start coming online from Q3, FY 2022-23. Table 1.1.1 & Table 1.1.2 summarize the in-place volume and expected cumulative production till 14 May 2030. Expected production profile is shown in Figure 1.1.1. **Section 2.0** gives detail about the Hydrocarbons-in-place, reserves and production profiles with assumptions.

**Table 1.1. 1: Raageshwari-Oil Field STOIIP and GIIP**

| Raageshwari-Oil (Upper Thumbli) | 1P | | 2P | | 3P | |
|---|---|---|---|---|---|---|
| | GIIP | STOIIP | GIIP | STOIIP | GIIP | STOIIP |
| | *bcf* | *MMstb* | *bcf* | *MMstb* | *bcf* | *MMstb* |
| **FDP Revison-1*** | 11.69 | 43.41 | **13.27** | **53.64** | 6.30 | 89.03 |

*Note: Revised base case (2P) STOIIP of 53.64 MMstb has been considered for generating Base Case production profiles. 3P STOIIP considers all fault blocks.*

**Table 1.1. 2: Recovery Summary, Raageshwari-Oil till 14th May 2030**

| Scenario | Expected Cum Oil (14 May 2030) | Recovery Factor | Existing Producers | New Producers | New Injectors |
|---|---|---|---|---|---|
| | (MMstb) | (%) | | | |
| **Base Case*** | 3.3 | 6 | 7 | 0 | 0 |
| **FDP Revison-2*** | 7.5 | 14 | 7 | 10 | 4 |

** Base Case considers the production from existing 7 wells. Recovery factor calculated on the 2P STOIIP of 53.64 MMstb of all the fault blocks excluding North Raag-1 and raag-6 fault.*

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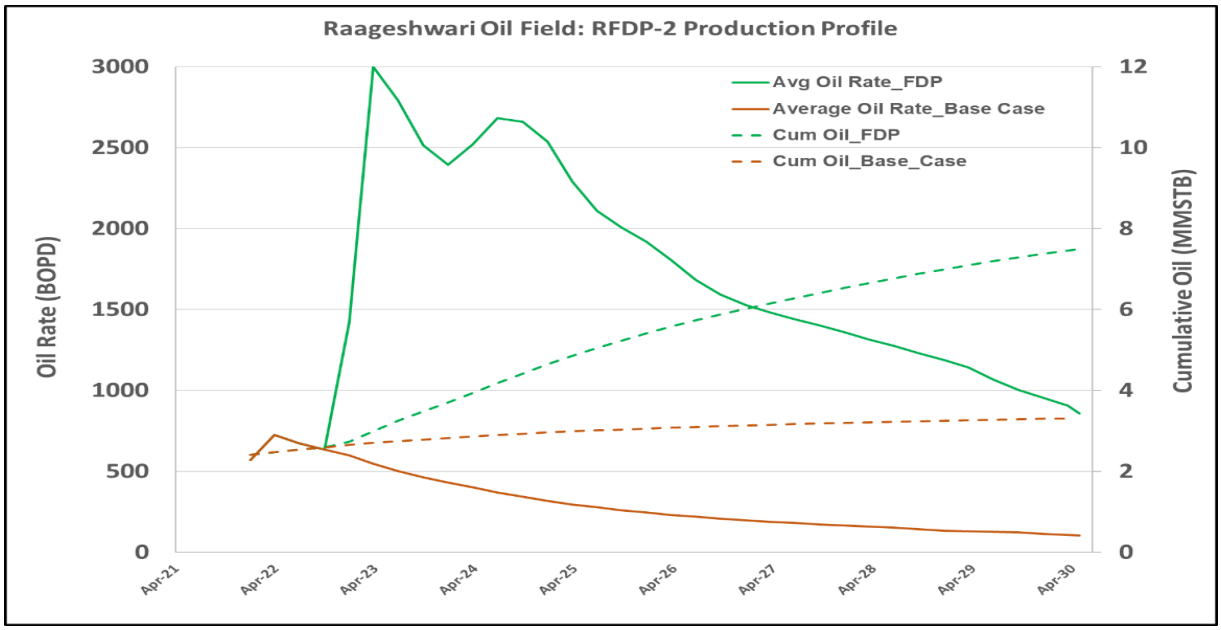


Figure 1.1.1: Raageshwari Oil Field Production Profile

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## 2. SUB-SURFACE

### 2.1. Introduction

After the discovery of Raageshwari-Oil Field through well Raageshwari-1 (RJ-E-1), the field was thoroughly appraised with 6 more wells out of which Raageshwari-2 and Raageshwari-3 were drilled in 2003-04 to appraise the Thumbli reservoir. The other wells Raageshwari-4, Raageshwari-5 and Raageshwari-6 were drilled to appraise the deeper Fatehgarh and volcanic formations as part of the Raageshwari Deep Gas appraisal program. Raageshwari-2 intersected the Thumbli reservoir in the water leg whereas Raageshwari-3 and Raageshwari-6 wells successfully tested oil from Upper Thumbli (UT) Formation. Additionally, five development wells in the Raageshwari-3 fault block were drilled during the Stage-I development along with one appraisal-cum-producer well (Raageshwari-3ST) in the adjacent fault block towards east of Raageshwari-3 fault block.

### 2.2. Geology

#### 2.2.1. Structural Setting

The Barmer Basin is a narrow NNW-SSE oriented rift basin that has undergone various episodes of rifting. The Raageshwari field is located on the Central Basin High (CBH), which is a structural high feature situated centrally in the Barmer Basin. The northern and the shallowest structural culmination include the Raageshwari Field. The Raageshwari structure is essentially an easterly dipping tilted fault block and develops horst block morphology due to an additional fault on the eastern side of the structure (Figure 2.2.1.1).

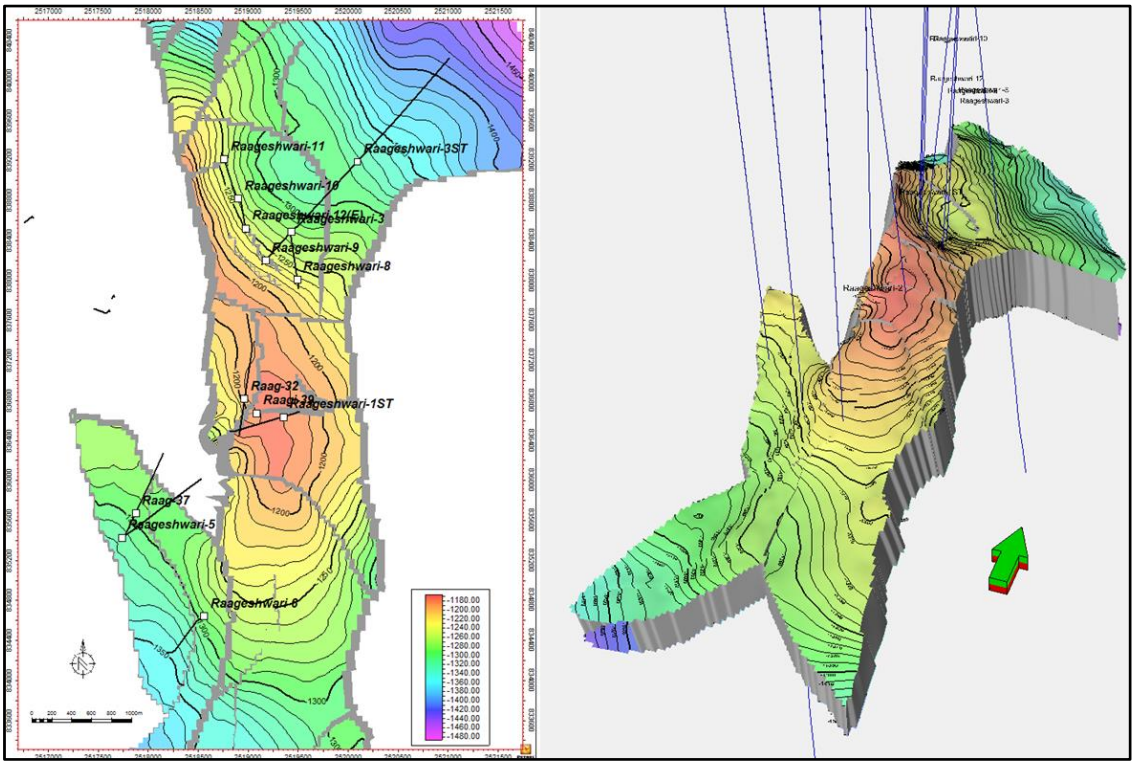


Figure 2.2.1. 1: Raageshwari Structural Setting

#### 2.2.2. Field Stratigraphy

The wells in the area including the Raageshwari Deep gas wells have encountered the entire stratigraphy of the Barmer Basin. Successful hydrocarbon discoveries have been made in, Upper Thumbli, Basal Thumbli, Fatehgarh and Pre-rift formations. This development plan is focussed on the oil bearing Upper Thumbli reservoir units of Thumbli Formation. The Thumbli Formation has been subdivided into the lowermost Basal Thumbli, Middle Thumbli and Upper Thumbli. This subdivision of the Thumbli Formation

is based primarily on well log data, lithological description of drill cuttings and gas chromatographic data. Based on the regional understanding and the regional depositional model, it is interpreted that the Basal Thumbli (BT) is deposited in a lacustrine environment, Middle Thumbli (MT) in a deep lake setting and Upper Thumbli (UT) in shallow lake margin environment with strong influence of fluvial channel systems.

The Upper Thumbli is further subdivided into 5 sub-units, UT5 to UT1, wherein UT1 is the deepest unit and UT5 is the shallowest. UT4, UT3 and UT1 units are hydrocarbon bearing whereas UT2 and UT5 are non-reservoir mudstones. Figure 2.2.2.1 represents the type stratigraphy of Raageshwari Field, Thumbli zonation and units of Upper Thumbli reservoir.

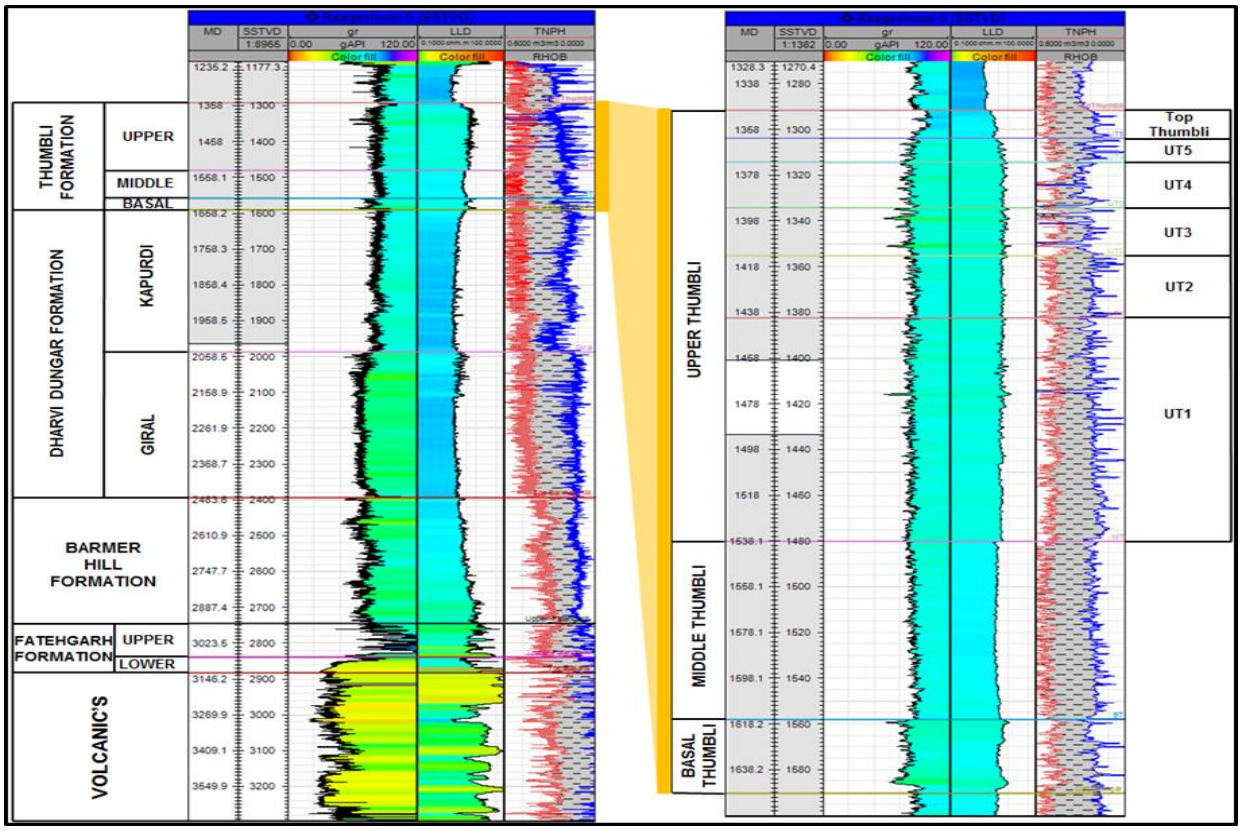


Figure 2.2.2. 1: Generalized Raageshwari Stratigraphy and Upper Thumbli units

### 2.2.3. Drilled Development Wells

As per the first FDP (2006), five producer wells were drilled in the Raageshwari-3 fault block. Raageshwari-8 and Raageshwari-9 were drilled from the Raageshwari-3 well pad and Raageshwari-10, Raageshwari-11 and Raageshwari-12 wells were drilled from Raag-Oil-1 well pad. After the submission of RFDP in 2018 (MCM 69), two more producer wells have been drilled in the field, with one well (Raag Oil-14) in Raag-1ST fault block from Tukaram-1Z well pad and the other (Raag Oil-16) in the Raag-3 fault block from Raag-Oil-1 well pad. (Figure 2.2.3.1). Table 2.2.3.1 summarizes development well data and logs acquired.

**Table 2.2.3. 1: Well Data summary for Raageshwari Development Wells**

| Well Name | Spud Date | TD (m) MDBRT/TVDSS | Full set of Basic Logs | Special Log Acquired |
|---|---|---|---|---|
| Raag-8 | 02-March-07 | 1620 /1363 | Yes | Dipole Sonic, RCI |
| Raag-9 | 13-March-07 | 1525 /1389 | Yes | NMR |
| Raag-10 | 26-March-07 | 1462 /1393 | Yes | Check shot |
| Raag-11 | 05-April-07 | 1553 /1388 | Yes | Dipole Sonic |

| | | | | |
|---|---|---|---|---|
| Raag-12 | 15-April-07 | 1458 /1395 | Yes | NMR |
| Raag Oil-14 | 21-December-2020 | 1819/1360 | Yes | N/A |
| Raag Oil-16 | 07-January-2020 | 1520/1359 | Yes | Formation Tester, Core |

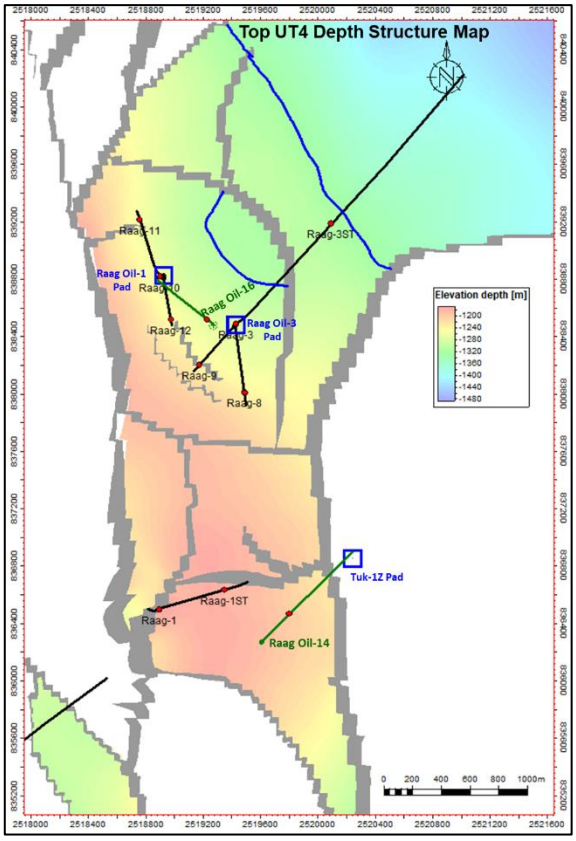


Figure 2.2.3. 1: Wells Drilled in Raag-Oil Field

### 2.2.4. Reservoir Characterization

The Thumbli Formation has been subdivided into the lowermost Basal Thumbli, Middle Thumbli and Upper Thumbli.

- **Basal Thumbli:** The interval is correlatable along the entire length of the CBH trend and is recognized at its base as the Dharvi Dungar unconformity. This formation is mainly characterized by siltstone.
- **Middle Thumbli:** A gradual prograding package of massive to laminated mudstone is representative of this formation.
- **Upper Thumbli:** This zone constitutes the primary hydrocarbon bearing interval (Figure 2.2.2.1) and has been subdivided into 5 zones (UT1 through UT5; older to younger). Among these five zones UT5 and UT2 are dominantly non-reservoirs and are characterized by predominantly mudstone and siltstone. The Upper Thumbli interval represents 2 primary cycles of sand deposition. The upper cycle is comprised of the UT4 and UT3 zones and non-reservoir UT2 separates the lower cycle comprising of UT1 reservoir zone. Non-reservoir UT2 zone most likely serves as a vertical barrier or baffle between upper (UT4/ UT3) and lower cycle (UT1) of sandstone reservoirs.

An integrated reservoir characterization study in Raageshwari has been performed and a geological model developed for the Upper Thumbli reservoir.



**Depositional environment**: Biostratigraphic analyses and sedimentological descriptions of conventional cores indicate that the Upper Thumbli interval of Raageshwari was most likely deposited in a delta plain lake margin environment. Based on the regional understanding, well log data, sand distribution maps

and trend of lignite thickness in Upper Thumbli, the orientation of lake margin is interpreted to be trending between NNW-SSE and NW-SE and channel orientations feeding into the lake margin are mostly NE-SW trending. The fine-grained sediments may represent sub-aqueous deposition in delta top lacustrine or delta plain marsh environments. The coarser grained siltstones and sandstones correspond to deposition in distributary channels and crevasse splay deposits associated with a fluvial delta plain system.

## 2.3. Geophysics

The current seismic interpretation of the Raageshwari fault bounded structure is carried out using pre-stack time migration (PSTM) 3D seismic volume of Central Basin High covering the Raageshwari field and all available well data with the objective of preparing a robust structural model. Faults were reinterpreted in the Raageshwari area with the help of different geometrical attributes. Most likely horizon time picks and faults polygons have been depth converted and used for the estimation of GRV.

### 2.3.1. Seismic Database and Data Quality

The Central Basin High 3D seismic data coverage over the Guda and Raageshwari Fields (Figure 2.3.1.1) comprises 450 km2 of 51/52 full fold, 4ms (acquired at 2ms), migrated data. Seismic data was acquired during 2000-2001 by Schlumberger and reprocessed by Veritas DGC in 2004 to pre-stack time migration (PSTM) to improve the signal/noise ratio and primary event imaging. This data, having moderate quality S/N ratio and imaging at Thumbli interval, has been used for the current seismic interpretation.

### 2.3.2. Well-to-Seismic Tie

Synthetic seismograms have been generated for Raag-3 and other surrounding appraisal wells which show a fair to good match with seismic events corresponding to the main stratigraphic markers (Akli Lignite, Thumbli UT4 and Top Giral Lignite) (Figure 2.3.2.1). In Raageshwari area, data have been interpreted to be SEG normal polarity with about zero phase such that an increase in acoustic impedance was recorded on tape as a more positive number. Top UT4 is correlated as the trough (-ve amplitude) on the seismic as there is decrease in impedance at the top of UT4.

### 2.3.3. Seismic Interpretation

The top of the Upper Thumbli reservoir, Top UT4, is interpreted as a trough (-ve seismic amplitude) in the 3D PSTM data based on the well to seismic tie. The presence of strong reflections corresponding to the overlying lignites, the seismic amplitude of the Top UT4 event is low to moderate (Figure 2.3.3.1). The faults were manually interpreted based on flexures and discontinuities in the seismic reflection events and were mapped aerially with the help of variance, illumination, dip angle and maximum curvature slices (Figure 2.3.3.2) along the top UT4 horizon. The horizon picks are gridded with the fault polygons to prepare time surface map (Figure 2.3.3.3).

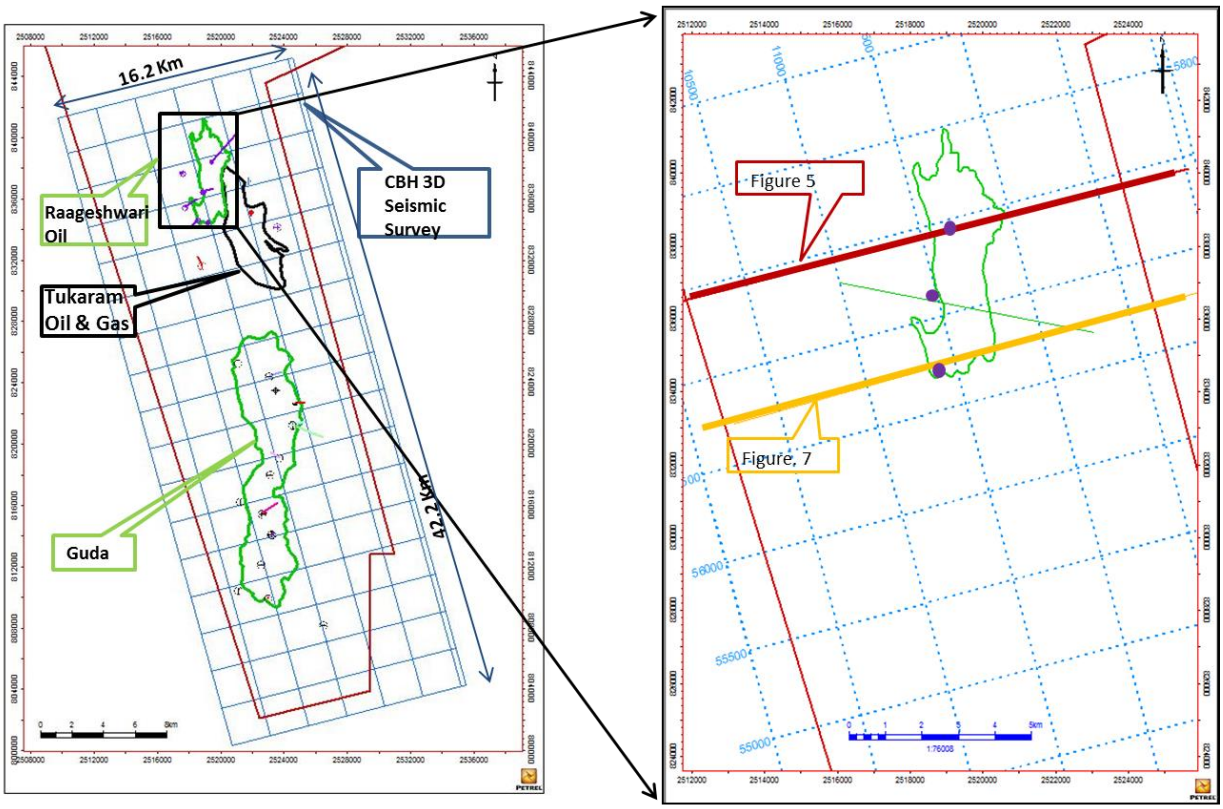


Figure 2.3.1. 1: CBH Seismic Survey and Detailed Raageshwari Field Seismic Base Map

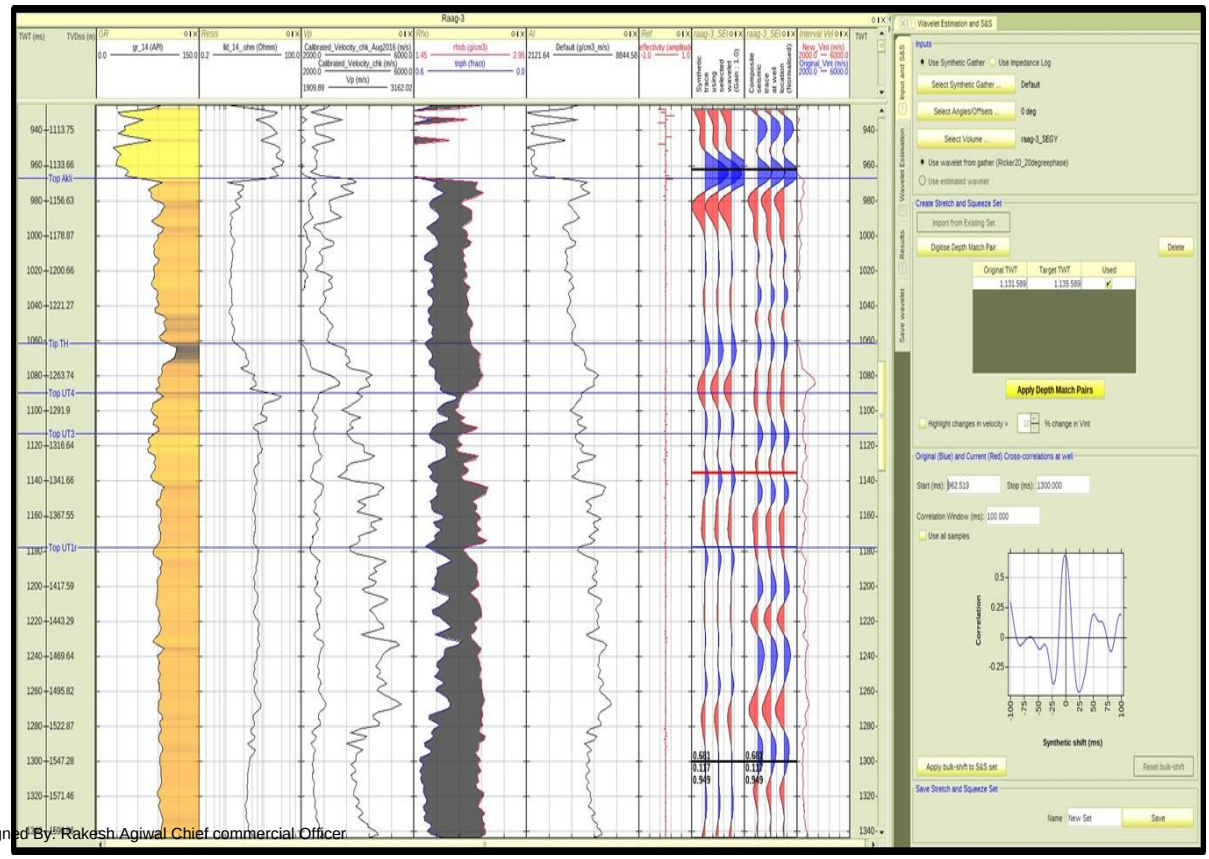


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Figure 2.3.2. 1: Synthetic Seismogram through Raageshwari-3

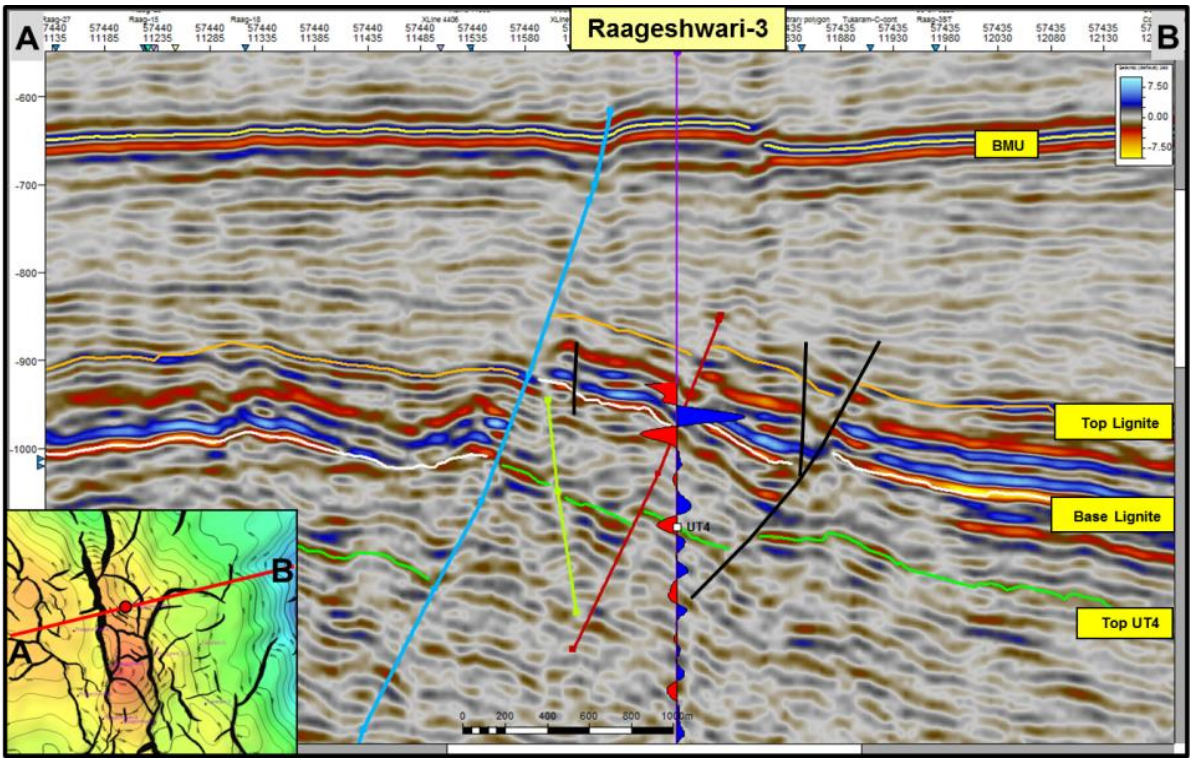


Figure 2.3.3. 1: Seismic Section along Raageshwari-3 Well

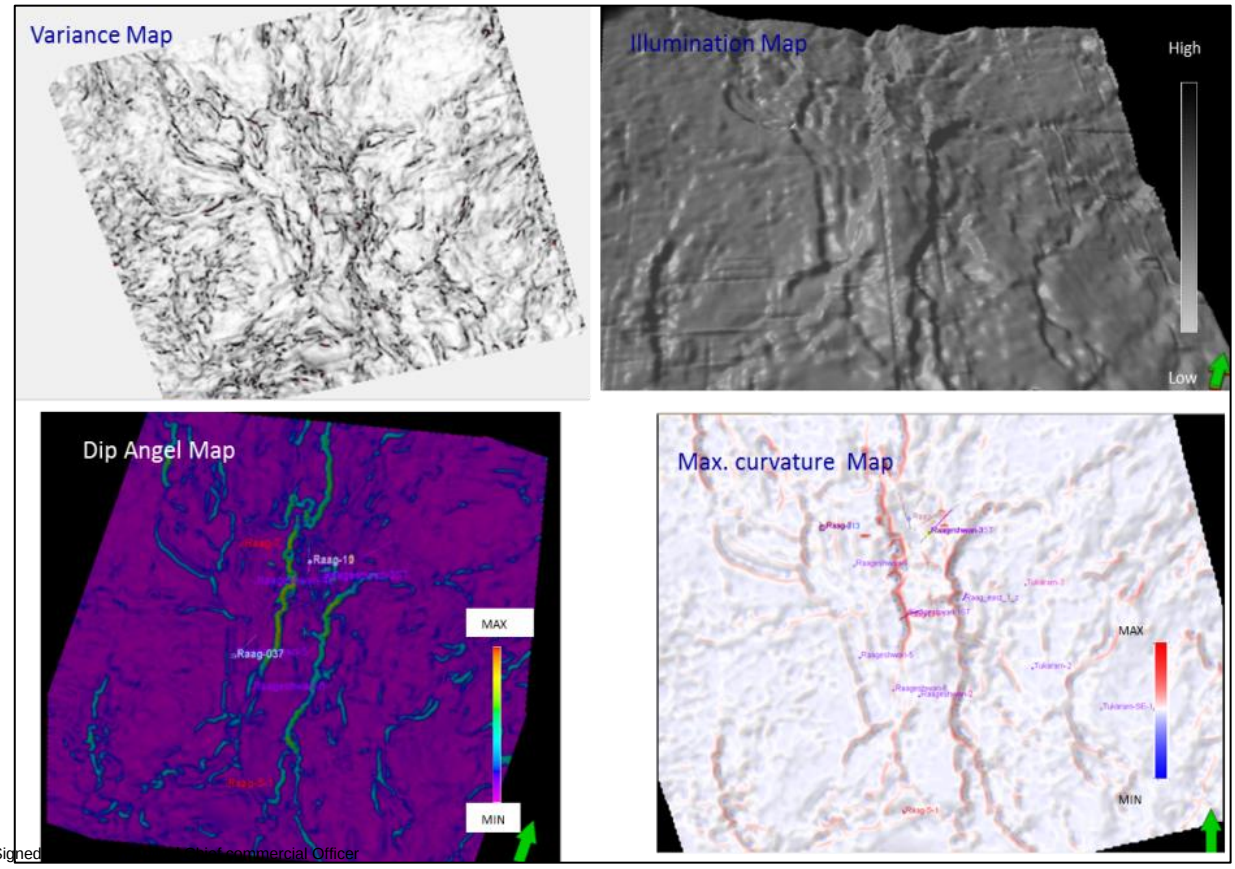


Figure 2.3.3. 2: Attributes used for Fault Interpretation

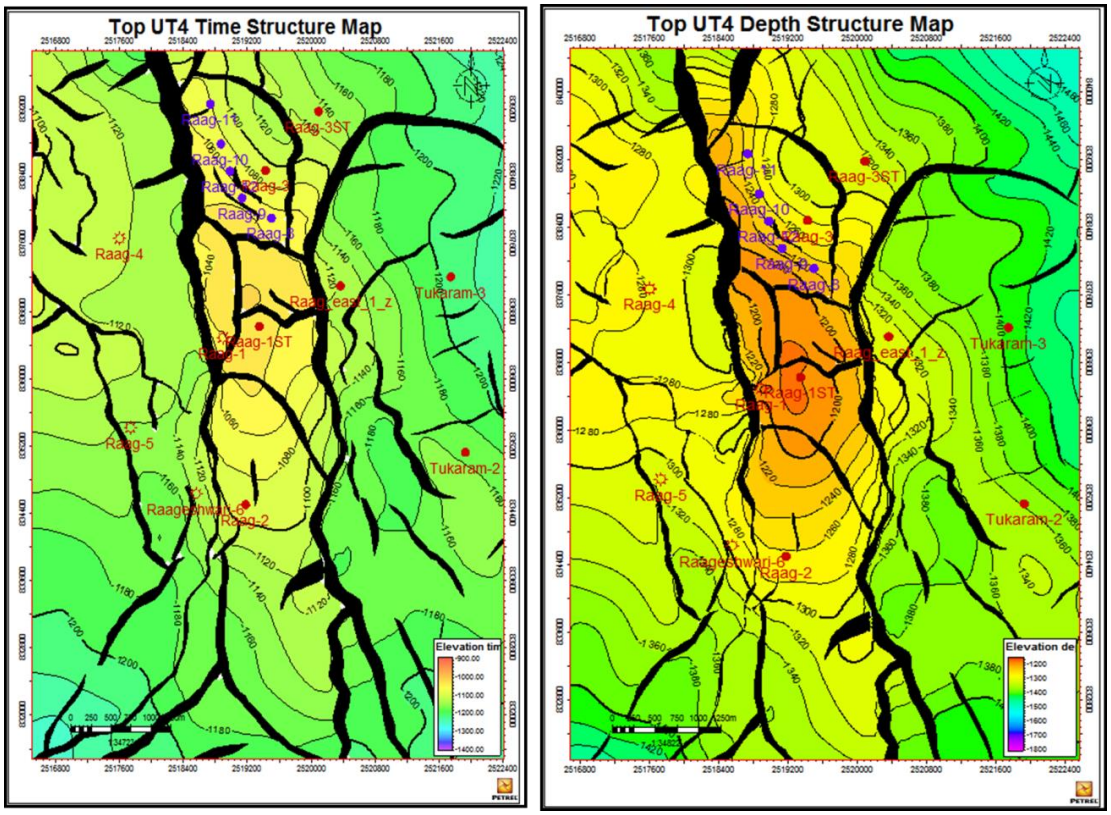


Figure 2.3.3. 3: Top UT4 TWT and Depth Structure Map

### 2.3.4. Time-Depth Conversion

Time to depth conversion has been carried out using polynomial function due to very little lateral velocity variations at the Upper Thumbli interval. Time and depth values for the Top UT4 stratigraphic marker are plotted and T-D polynomial function used for the depth conversion is shown in the Figure 2.3.4.1. The Top UT4 structure map after final correction to the formation tops is shown in Figure 2.3.3.4.

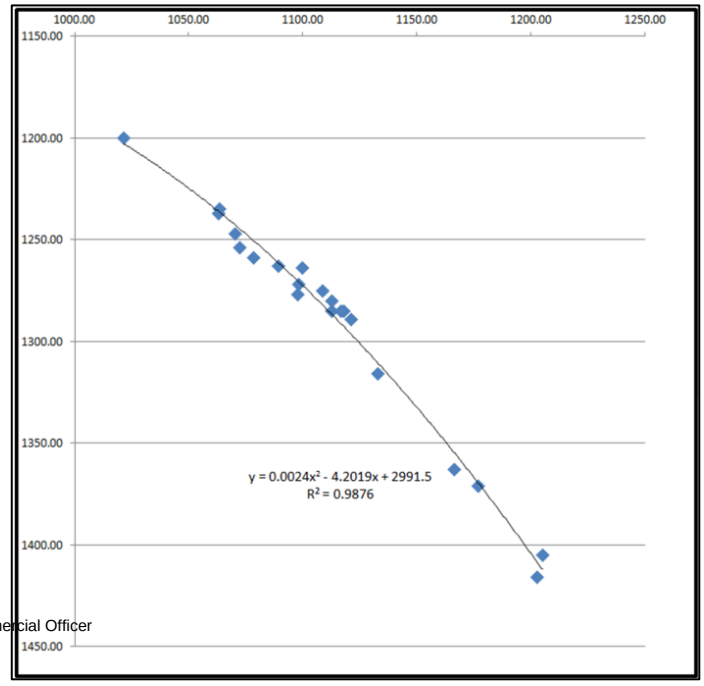


Figure 2.3.4. 1: Time Depth Relation

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### 2.3.5. Geophysical Uncertainty

The main source of geophysical uncertainty in the Raageshwari field relates to structural interpretation of top Thumbli (UT4). Compaction trend is uniform in the area at Thumbli level and hence velocity error within individual fault blocks is negligible. The TWT pick error based on the seismic data quality and velocity error contribute around 1% to the depth envelope uncertainty. Fault definitions at Thumbli level is based on the reflector discontinuity at the base of lignite interval reflections and therefore have lateral positioning uncertainty of ±50m.

## 2.4. Petrophysics

A deterministic petrophysical evaluation has been conducted on all the wells of Raageshwari shallow Oil field and output curves of clay volume, effective and total porosity, effective water saturation and permeability have been generated. These results were provided as input to the geo-cellular model.

Most of the new development wells such as Raag-9 and Raag-12 have modern logging suites such as NMR (CMR+) and Image data. The petrophysical model has been built by integrating all available data such as NMR and other modern logging suites.

### 2.4.1. Evaluation Methodology

A deterministic methodology was used for Raageshwari-Oil field petrophysical evaluation. There is no conventional core acquired in this field.

### 2.4.2. Available Data

All the available log data are summarized in Table 2.4.2.1.

**Table 2.4.2. 1: Available Well-log Data of the Raag-Oil Field**

| Wells | GR | Resistivity | Neutron | Density | Sonic | Image | NMR | MDT | DST | Core | Mud log |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Raag-1 | √ | √ | √ | √ | √ | | | | √ | | √ |
| Raag-3 | √ | √ | √ | | √ | | | √ | √ | | √ |
| Raag-8 | √ | √ | √ | √ | √ | | | √ | | | √ |
| Raag-9 | √ | √ | √ | √ | | √ | √ | | | | √ |
| Raag-10 | √ | √ | √ | √ | | | | | | | √ |
| Raag-11 | √ | √ | √ | √ | √ | | | | | | √ |
| Raag-12 | √ | √ | √ | √ | | √ | √ | | | | √ |
| Raag-32 | √ | √ | √ | √ | √ | | | √ | | | √ |
| Raag-39 | √ | √ | √ | √ | √ | | | √ | | | √ |
| Raag-1ST | √ | √ | √ | √ | √ | √ | √ | | | | √ |
| Raag-3ST | √ | √ | √ | √ | √ | | | | √ | | √ |
| Raag-6 | √ | √ | √ | √ | | | | | | | √ |
| Raag Oil-14 | √ | √ | √ | √ | | | | | | | √ |
| Raag Oil-16 | √ | √ | √ | √ | | | | √ | | √ | √ |

### 2.4.3. Log Evaluation

All the raw data were QC'd and processed prior to interpretation. Depth shifts were performed prior to the petrophysical evaluation using Gamma ray as reference.

**Clay Volume (Vcl)**



Shale in the study area has a very large volume of clay minerals (up to 50 – 70%). Estimates of clay volume are made using the gamma ray and neutron-density separation. It was assumed that clay volume

varies linearly to non-linearly in response to various logs. To arrive at a final shale volume, different factors of individual Vclay estimates were combined.

**Silt Volume ($V_{silt}$)**

The silt volume formula from Interactive Petrophysics used was:

$V_{silt} = 1 - V_{wetClay}$ - PhiE / PhiMax

**Pore Volumes and Fluid Saturations**

The neutron-density log was used for porosity estimation. Sandstone, shaly-sand and shale are the predominant lithologies in this field, and hence a grain density of 2.65 gm/cc was used for total porosity estimation (PhiT).

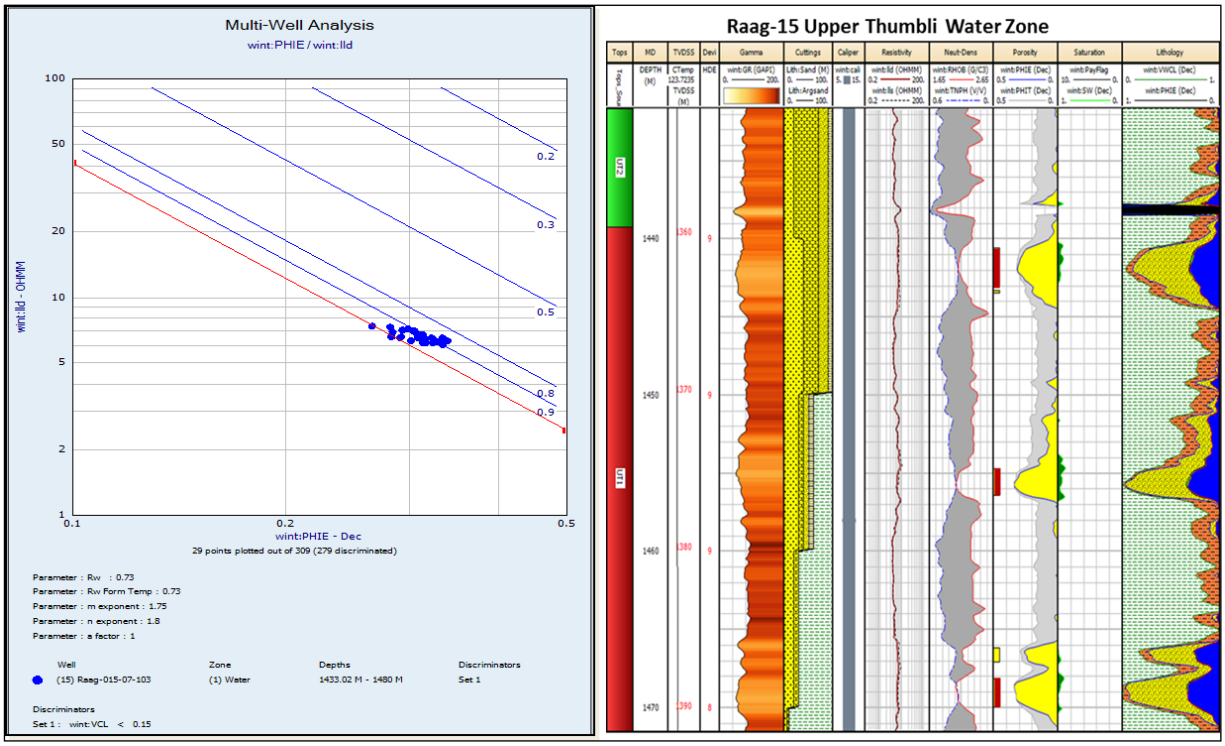


Figure 2.4.3. 1: The Pickett plot of water bearing zones in Raageshwari field

A fluid density of 0.85 gm/cc was used for the wells drilled with SOBM and 1 gm/cc for the wells drilled with WBM (older wells such as Raag-1, Raag-2, Raag-3, Raag-4 and Raag-5). As a calibration of porosity, NMR porosity (TCMR) was used to validate the total porosity (PhiT). Effective porosity (PhiE) was derived by subtracting the volume of clay-bound water from PhiT. Water saturation was calculated using Indonesian equations.

Raag-15 Upper Thumbli is good candidate for estimating "m" as these water bearing zones (Figure 2.4.3.1) are clean sand reservoirs and no Hydrocarbon shows were observed during drilling against these sands. By using Archie equation Sw^n = (a.Rw)/(Rt.phi^m), in water zone with Sw =1, Archie parameter "m" is estimated from (LogRw-LogRo)/LogPhi. It is not possible to estimate parameter "n" in absence of core data. The parameter "n" has been assumed to be closer to parameter "m" by rule of thumb. "n" parameter is about 1.8 in conventional reservoir in Barmer Basin (Fatehgarh core data from Mangala).



The parameters used in saturation equations are as follows:

'a' = 1; 'm' = 1.75; 'n' = 1.8

Rw = 1.34 ohmm at 30°C (equivalent salinity ≈ 3500mg/l which is in line with water sample analysis data) **(**Figure 2.4.3.1**)**

There are no capillary pressure curves available to generate saturation height functions. Hence, log-based saturation height model was established by using Harrison-Skelt saturation height function model. The well test data was used for estimating permeability.

### 2.4.4. Fluid Contacts

The reservoir pressure data is analysed to get the fluid contacts and found that the field has various pressure compartments. The gas-oil-contact (GOC) is found in Raageshwari Deep-Gas development well Raag-39 at 1195 mSS. The Fluid contacts based on pressure data and log based ODT are presented in Table 2.4.4.1.

**Raageshwari-39:** In UT4 zone where Raag-39 well falls under Raag-1 block, pressure data show gas-oil-contact at around 1195 mSS (Figure 2.4.4.1). The well goes into the Raag central block at UT3 level.
**Raageshwari-3:** In the Raag-3 well in Raag-3 block, pressure data shows free water level (FWL) at around 1310 mSS (Figure 2.4.4.1).

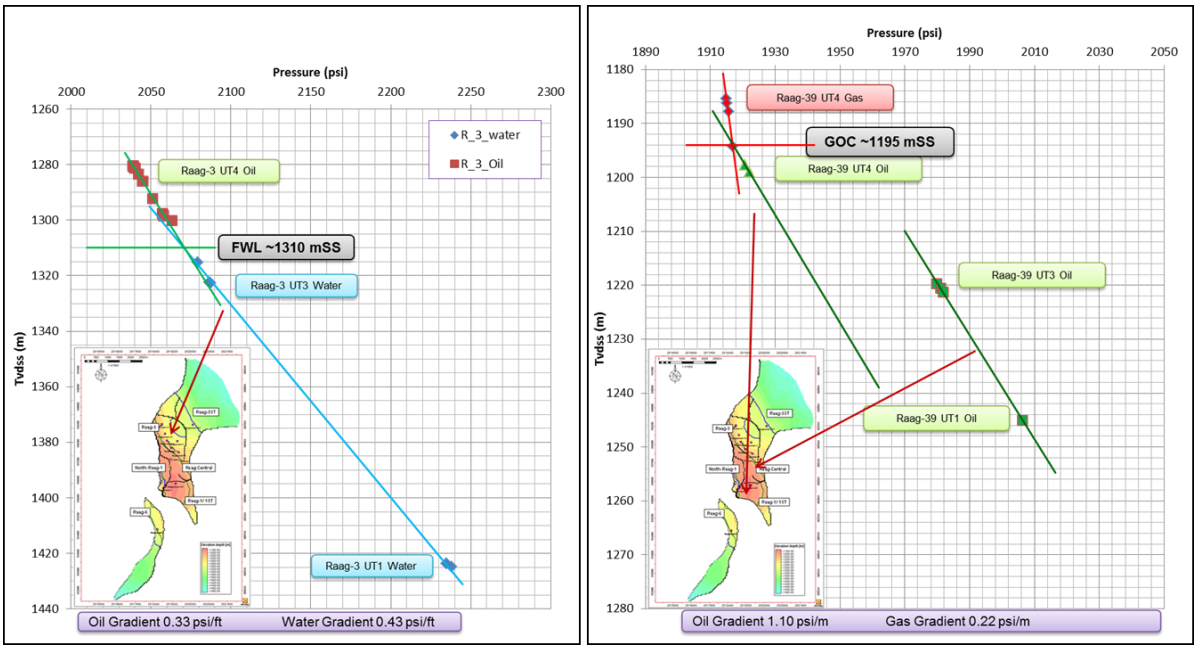


Figure 2.4.4. 1: The pressure vs depth plots for Raag-3, Raag-1&1ST and Raag Central

**Table 2.4.4. 1: Fluid Contacts Considered in Different Fault Blocks**

| Block | Fluid Contacts based on pressure data (m TVDSS) | | | Fluid Contacts used for Subsurface modeling (m TVDSS) | |
|---|---|---|---|---|---|
| | GOC/GDT | ODT | OWC | GOC | ODT |
| Raag 3 | - | - | 1310 (R-3) | 1211 | 1303 |
| Raag 1 & 1ST | GOC~1195 (R-39) | 1313 (R-1ST) | - | | 1313 |
| Raag Central | | | | | |
| N Raag 1 | - | 1220 (R-32) | - | | 1220 |
| Raag 3ST | - | 1326 (R-3ST) | - | | 1326 |
| Raag 6 | GDT~1296 | 1331 (R-6) | - | 1296 | 1331 |

### 2.4.5. Cut-offs: Net Reservoir and Net Pay Determination

Using the Interactive Petrophysics program built-in module, reservoir and pay sensitivity analysis was carried out for volume of clay, porosity and water saturation for the upper Thumbli Formation (Figure 2.4.5.1). Reservoir and pay cut-offs were decided based on sensitivity analysis and summarized below in Table 2.4.5.1.

**Table 2.4.5. 1: Reservoir and Pay Cut-offs**

| Cutoffs used | | | |
|---|---|---|---|
| Zone Name | Vcl | PhiE | Sw |
| Reservoir Summary | | | |
| Upper Thumbli | <= 0.5 | >=0.11 | |
| Pay Summary | | | |
| Upper Thumbli | <= 0.5 | >=0.11 | <= 0.6 |

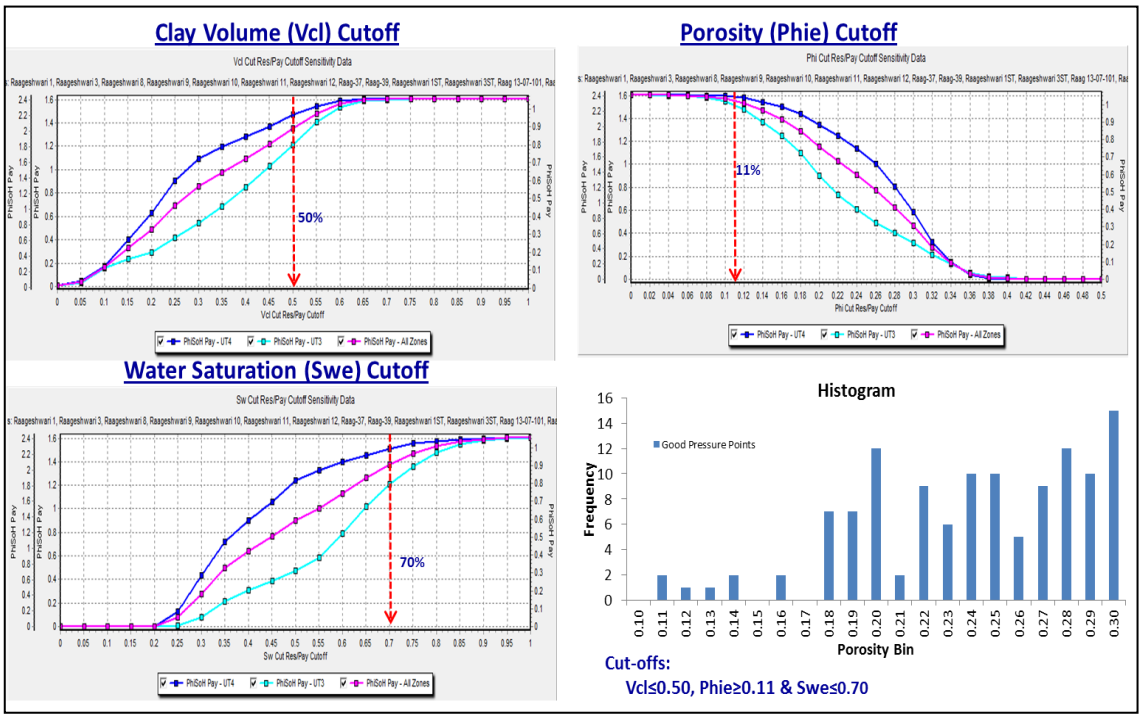


Figure 2.4.5. 1: Cut-offs: Net Reservoir and Net Pay Determination Plots

Reservoir and pay summaries for each well are shown below in Table 2.4.5.2.

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## Table 2.4.5. 2: Reservoir and Pay Summaries for individual wells

| Reservoir Summary | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Well | Zone | Top | Bottom | Top | Bottom | Gross | Net | N/G | Av Phi | Av Sw | Av Vcl |
| | | mMD | mMD | mTVDSS | mTVDSS | mTVDSS | mVDSS | TVDSS | v/v | v/v | v/v |
| Raag 3 | UT4 | 1341.73 | 1370.76 | 1278.97 | 1307.93 | 29.03 | 17.14 | 0.59 | 0.25 | 0.45 | 0.27 |
| Raag 3 | UT3 | 1370.76 | 1405.03 | 1307.93 | 1342.22 | 34.27 | 6.55 | 0.19 | 0.2 | 0.69 | 0.41 |
| Raag 8 | UT4 | 1402.5 | 1428.18 | 1237.64 | 1260.89 | 23.24 | 11.26 | 0.49 | 0.29 | 0.41 | 0.26 |
| Raag 8 | UT3 | 1428.18 | 1463.98 | 1260.89 | 1293.31 | 32.42 | 10.23 | 0.32 | 0.26 | 0.48 | 0.28 |
| Raag 9 | UT4 | 1361.77 | 1388.21 | 1235.47 | 1260.17 | 24.73 | 7.95 | 0.32 | 0.28 | 0.34 | 0.28 |
| Raag 9 | UT3 | 1388.21 | 1417.26 | 1260.17 | 1287.38 | 27.16 | 5.89 | 0.22 | 0.25 | 0.54 | 0.32 |
| Raag 10 | UT4 | 1326.66 | 1353.52 | 1260.97 | 1287.02 | 26.11 | 11.66 | 0.45 | 0.26 | 0.44 | 0.28 |
| Raag 10 | UT3 | 1353.52 | 1382.68 | 1287.02 | 1315.38 | 28.32 | 8.84 | 0.31 | 0.26 | 0.49 | 0.26 |
| Raag 11 | UT4 | 1403.86 | 1430.52 | 1253.96 | 1277.91 | 24.01 | 7.83 | 0.33 | 0.24 | 0.46 | 0.33 |
| Raag 11 | UT3 | 1430.52 | 1455.3 | 1277.91 | 1300.24 | 22.31 | 5.94 | 0.27 | 0.27 | 0.48 | 0.28 |
| Raag 12 | UT4 | 1352.29 | 1382.96 | 1247.85 | 1277.41 | 29.52 | 14.3 | 0.48 | 0.27 | 0.39 | 0.29 |
| Raag 12 | UT3 | 1382.96 | 1406.77 | 1277.41 | 1300.34 | 22.94 | 12.43 | 0.54 | 0.18 | 0.66 | 0.39 |
| Raag 3ST | UT4 | 1728.08 | 1757.5 | 1317.14 | 1338.93 | 21.8 | 8.05 | 0.37 | 0.25 | 0.46 | 0.33 |
| Raag 3ST | UT3 | 1757.5 | 1790.36 | 1338.93 | 1363.39 | 24.43 | 10.48 | 0.43 | 0.19 | 0.71 | 0.4 |
| Raag-32 | UT4 | 1319.08 | 1342.68 | 1193.91 | 1215.83 | 21.92 | 5.73 | 0.26 | 0.26 | 0.59 | 0.3 |
| Raag-32 | UT3 | 1342.68 | 1370.34 | 1215.83 | 1241.48 | 25.71 | 1.39 | 0.05 | 0.19 | 0.79 | 0.43 |
| Raag 1 | UT4 | 1241.73 | 1250.88 | 1181.81 | 1191.01 | 9.15 | 4.1 | 0.45 | 0.29 | 0.59 | 0.27 |
| Raag 1 | UT3 | 1250.88 | 1272.39 | 1191.01 | 1212.51 | 21.51 | 6 | 0.28 | 0.23 | 0.49 | 0.39 |
| Raag 1 | UT1 | 1301.9 | 1385.46 | 1242 | 1325.6 | 83.56 | 11.8 | 0.14 | 0.22 | 0.55 | 0.43 |
| Raag 1ST | UT4 | 1348.03 | 1369.33 | 1180.88 | 1199.75 | 18.86 | 11.27 | 0.6 | 0.21 | 0.52 | 0.27 |
| Raag 1ST | UT3 | 1369.33 | 1399 | 1199.75 | 1226.02 | 26.25 | 13.27 | 0.51 | 0.21 | 0.62 | 0.43 |
| Raag 1ST | UT1 | 1438.04 | 1619.8 | 1260.71 | 1427.72 | 166.98 | 11.22 | 0.07 | 0.2 | 0.61 | 0.39 |
| Raag 39 | UT4 | 1286.02 | 1302.04 | 1184.62 | 1199.98 | 15.24 | 7.83 | 0.51 | 0.25 | 0.36 | 0.29 |
| Raag 39 | UT3 | 1302.04 | 1325.84 | 1199.98 | 1222.59 | 22.64 | 5.94 | 0.26 | 0.23 | 0.48 | 0.37 |
| Raag 39 | UT1 | 1348.26 | 1480.37 | 1243.91 | 1369.48 | 125.55 | 1.89 | 0.02 | 0.15 | 0.66 | 0.48 |
| Raag 6 | UT4 | 1350.3 | 1367.91 | 1292.62 | 1310.09 | 17.48 | 6.75 | 0.39 | 0.22 | 0.48 | 0.31 |
| Raag 6 | UT3 | 1367.91 | 1390.45 | 1310.09 | 1332.39 | 22.33 | 8.82 | 0.4 | 0.2 | 0.66 | 0.38 |
| Raag Oil-14 | UT4 | 1513.18 | 1549.01 | 1220.20 | 1236.15 | 15.95 | 6.03 | 0.38 | 0.24 | 0.56 | 0.30 |
| Raag Oil-14 | UT3 | 1549.01 | 1596.25 | 1236.15 | 1257.65 | 21.50 | 4.43 | 0.21 | 0.18 | 0.58 | 0.45 |
| Raag Oil-14 | UT1 | 1642.20 | 1754.81 | 1278.79 | 1330.29 | 51.50 | 6.27 | 0.12 | 0.21 | 0.57 | 0.39 |
| Raag Oil-16 | UT4 | 1405.38 | 1442.38 | 1257.89 | 1290.60 | 32.82 | 14.08 | 0.43 | 0.27 | 0.41 | 0.25 |
| Raag Oil-16 | UT3 | 1442.38 | 1471.99 | 1290.60 | 1316.63 | 25.93 | 12.72 | 0.49 | 0.21 | 0.71 | 0.33 |

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| Pay Summary | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Well | Zone | Top | Bottom | Top | Bottom | Gross | Net | N/G | Av Phi | Av Sw | Av Vcl |
| | | mMD | mMD | mTVDSS | mTVDSS | mTVDSS | mVDSS | TVDSS | v/v | v/v | v/v |
| Raag 3 | UT4 | 1341.73 | 1370.76 | 1278.97 | 1307.93 | 29.03 | 15.93 | 0.55 | 0.26 | 0.44 | 0.26 |
| Raag 3 | UT3 | 1370.76 | 1405.03 | 1307.93 | 1342.22 | 34.27 | 3.2 | 0.09 | 0.23 | 0.62 | 0.39 |
| Raag 8 | UT4 | 1402.5 | 1428.18 | 1237.64 | 1260.89 | 23.24 | 10.72 | 0.46 | 0.3 | 0.4 | 0.25 |
| Raag 8 | UT3 | 1428.18 | 1463.98 | 1260.89 | 1293.31 | 32.42 | 9.42 | 0.29 | 0.26 | 0.47 | 0.27 |
| Raag 9 | UT4 | 1361.77 | 1388.21 | 1235.47 | 1260.17 | 24.73 | 7.67 | 0.31 | 0.29 | 0.33 | 0.27 |
| Raag 9 | UT3 | 1388.21 | 1417.26 | 1260.17 | 1287.38 | 27.16 | 5.8 | 0.21 | 0.25 | 0.54 | 0.32 |
| Raag 10 | UT4 | 1326.66 | 1353.52 | 1260.97 | 1287.02 | 26.11 | 10.5 | 0.4 | 0.27 | 0.41 | 0.26 |
| Raag 10 | UT3 | 1353.52 | 1382.68 | 1287.02 | 1315.38 | 28.32 | 8.16 | 0.29 | 0.26 | 0.48 | 0.25 |
| Raag 11 | UT4 | 1403.86 | 1430.52 | 1253.96 | 1277.91 | 24.01 | 6.21 | 0.26 | 0.26 | 0.41 | 0.3 |
| Raag 11 | UT3 | 1430.52 | 1455.3 | 1277.91 | 1300.24 | 22.31 | 5.94 | 0.27 | 0.27 | 0.48 | 0.28 |
| Raag 12 | UT4 | 1352.29 | 1382.96 | 1247.85 | 1277.41 | 29.52 | 12.8 | 0.43 | 0.28 | 0.36 | 0.26 |
| Raag 12 | UT3 | 1382.96 | 1406.77 | 1277.41 | 1300.34 | 22.94 | 6.65 | 0.29 | 0.21 | 0.59 | 0.34 |
| Raag 3ST | UT4 | 1728.08 | 1757.5 | 1317.14 | 1338.93 | 21.8 | 7.82 | 0.36 | 0.25 | 0.46 | 0.32 |
| Raag 3ST | UT3 | 1757.5 | 1790.36 | 1338.93 | 1363.39 | 24.43 | 3.94 | 0.16 | 0.22 | 0.65 | 0.38 |
| Raag-32 | UT4 | 1319.08 | 1342.68 | 1193.91 | 1215.83 | 21.92 | 3.34 | 0.15 | 0.29 | 0.45 | 0.25 |
| Raag-32 | UT3 | 1342.68 | 1370.34 | 1215.83 | 1241.48 | 25.71 | 0.19 | 0.01 | 0.21 | 0.62 | 0.31 |
| Raag 1 | UT4 | 1241.73 | 1250.88 | 1181.81 | 1191.01 | 9.15 | 3.9 | 0.43 | 0.3 | 0.58 | 0.26 |
| Raag 1 | UT3 | 1250.88 | 1272.39 | 1191.01 | 1212.51 | 21.51 | 5.3 | 0.25 | 0.24 | 0.47 | 0.39 |
| Raag 1 | UT1 | 1301.9 | 1385.46 | 1242 | 1325.6 | 83.56 | 10.7 | 0.13 | 0.22 | 0.54 | 0.42 |
| Raag 1ST | UT4 | 1348.03 | 1369.33 | 1180.88 | 1199.75 | 18.86 | 10.03 | 0.53 | 0.22 | 0.5 | 0.25 |
| Raag 1ST | UT3 | 1369.33 | 1399 | 1199.75 | 1226.02 | 26.25 | 12.65 | 0.48 | 0.21 | 0.61 | 0.43 |
| Raag 1ST | UT1 | 1438.04 | 1619.8 | 1260.71 | 1427.72 | 166.98 | 9.61 | 0.06 | 0.21 | 0.59 | 0.38 |
| Raag 39 | UT4 | 1286.02 | 1302.04 | 1184.62 | 1199.98 | 15.24 | 7.83 | 0.51 | 0.25 | 0.36 | 0.29 |
| Raag 39 | UT3 | 1302.04 | 1325.84 | 1199.98 | 1222.59 | 22.64 | 5.22 | 0.23 | 0.23 | 0.45 | 0.35 |
| Raag 39 | UT1 | 1348.26 | 1480.37 | 1243.91 | 1369.48 | 125.55 | 1.6 | 0.01 | 0.15 | 0.65 | 0.47 |
| Raag 6 | UT4 | 1350.3 | 1367.91 | 1292.62 | 1310.09 | 17.48 | 6.75 | 0.39 | 0.22 | 0.48 | 0.31 |
| Raag 6 | UT3 | 1367.91 | 1390.45 | 1310.09 | 1332.39 | 22.33 | 4.95 | 0.22 | 0.24 | 0.61 | 0.33 |
| Raag Oil-14 | UT4 | 1513.18 | 1549.01 | 1220.20 | 1236.15 | 15.95 | 4.87 | 0.31 | 0.25 | 0.55 | 0.28 |
| Raag Oil-14 | UT3 | 1549.01 | 1596.25 | 1236.15 | 1257.65 | 21.50 | 3.18 | 0.15 | 0.20 | 0.56 | 0.44 |
| Raag Oil-14 | UT1 | 1642.2 | 1754.81 | 1278.79 | 1330.29 | 51.50 | 3.77 | 0.07 | 0.23 | 0.54 | 0.37 |
| Raag Oil-16 | UT4 | 1405.38 | 1442.38 | 1257.89 | 1290.60 | 32.82 | 13.00 | 0.40 | 0.27 | 0.39 | 0.24 |
| Raag Oil-16 | UT3 | 1442.38 | 1471.99 | 1290.60 | 1316.63 | 25.93 | 1.07 | 0.04 | 0.29 | 0.56 | 0.27 |

### 2.4.6. Facies Definition

Due to absence of core data, the simplified binary facies scheme was applied based on the reservoir and non-reservoir definition from petrophysical cut-offs. The production data suggest consistent permeability distribution across the reservoir and this simplified binary facies definition also supports the same. The binary facies scheme has been tabulated in Table 2.4.6.1:

**Table 2.4.6. 1: Facies Definition**

| Facies | PhiE Cut-off Applied |
|---|---|
| Mudstone | PhiE ≤11% and V-shale ≥ 50% |
| Sandstone | PhiT ≥ 11% and V-shale ≤ 50% |

### 2.4.7. Permeability

Permeability was computed using the modified Coates & Dumanoir equation and calibrated with well test permeability.

### 2.4.8. Saturation Height Function

A log-based Harrison-Skelt saturation height function model was used to distribute water saturation in geo-cellular model. The Free Water Level (FWL) was established from Formation Pressure Tester data at wells (Figure 2.4.8.1). Log-derived water saturations were then used to calibrate the function and shown in Figure 2.4.8.1.

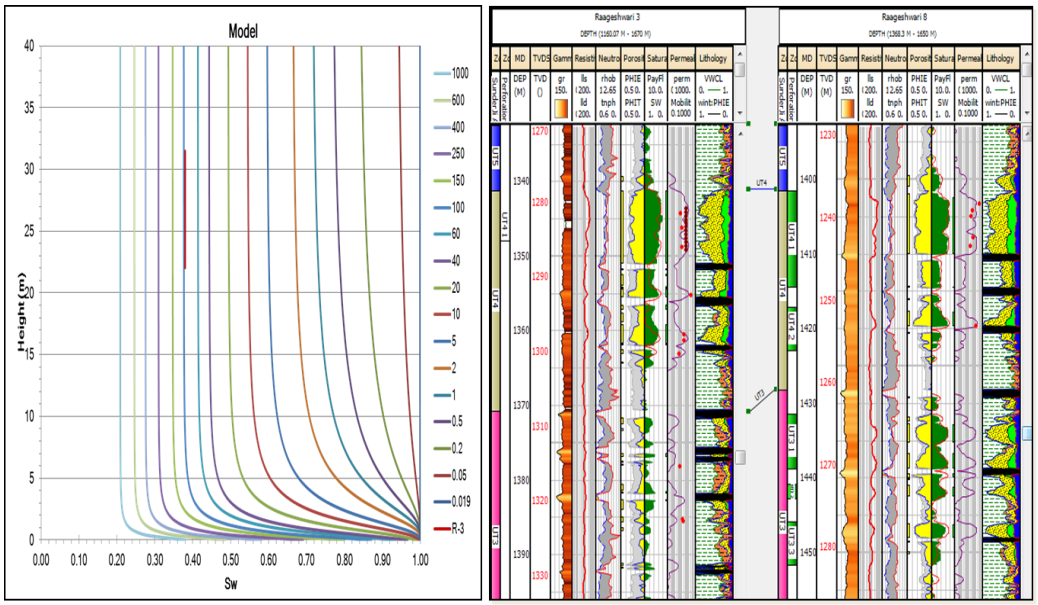


Figure 2.4.8. 1: Saturation Height function and its output comparison to calibrate the function

### 2.5. Fault Block consideration in 2P

Raag-3, N-Raag-1, Raag-1/1ST, Raag-Central, Raag-3ST fault blocks have been considered in 2P. Without any firm development plan of Raag-6 fault block, it has not been considered in 2P (Figure 2.5.1).

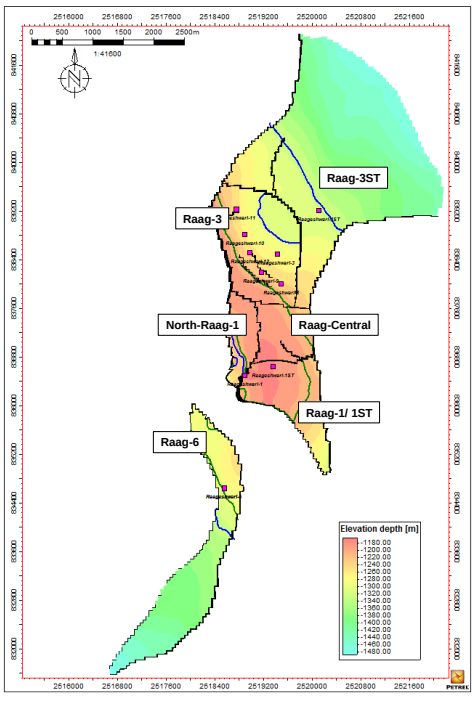


Figure 2.5. 1: 2P Fault Block Consideration

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## 2.6. Geocellular Modelling

Full-field reservoir studies have been carried out with the objective of preparing static and dynamic models for hydrocarbon bearing intervals of the Upper Thumbli formation and to identify development opportunities for the current stage of field development. The static model for Raageshwari-Oil has been prepared by integrating revised subsurface data and interpretations presented in the preceding sections. PETREL (Version 2014) suite has been used for building the static model with standard modelling work-flow as used in the existing FDP. The 2 wells drilled as part of execution of RFDP-1 has come more or less as per predicted in the static model. The updation of static model would be carried out after drilling of all the proposed wells of RFDP.

### 2.6.1. Structural Model

Structural framework has been created using best case structural interpretation of horizons and faults as discussed in **Section 2.3**. The input data considered for modelling are Top UT4 (reservoir top) depth surface and interpreted fault sticks. An array of structure bounding N-S trending normal faults and E-W trending internal faults have been modelled to define the individual fault blocks in the structural model (Figure 2.6.1.1). A 3D grid with 50 sq. m areal dimension has been prepared using conventional pillar gridding approach. Horizon modelling has been carried out incorporating well-tied Top UT4 surface and well based isochored surfaces for UT3, UT2 and UT1 (Figure 2.6.1.2). Layering sensitivity has been carried out considering the reservoir heterogeneity and in the four zones, 236 layers have been created proportionately. Separate fluid contacts for individual fault blocks have been considered as mentioned in Table 2.4.4.1.

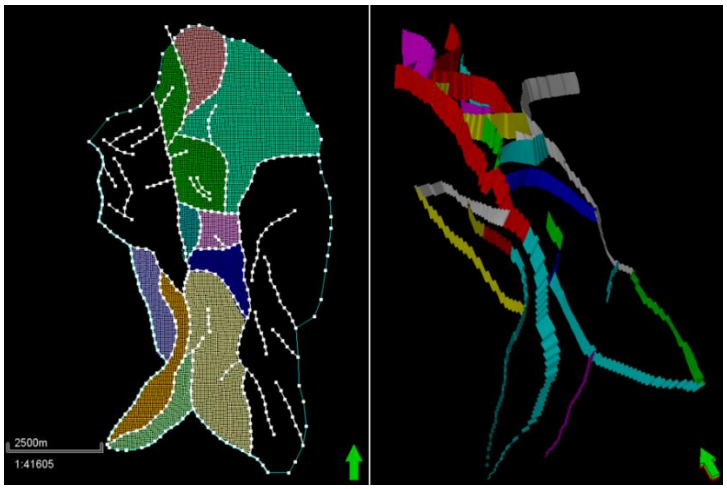


Figure 2.6.1. 1: Fault Model based on Revised Seismic Interpretation

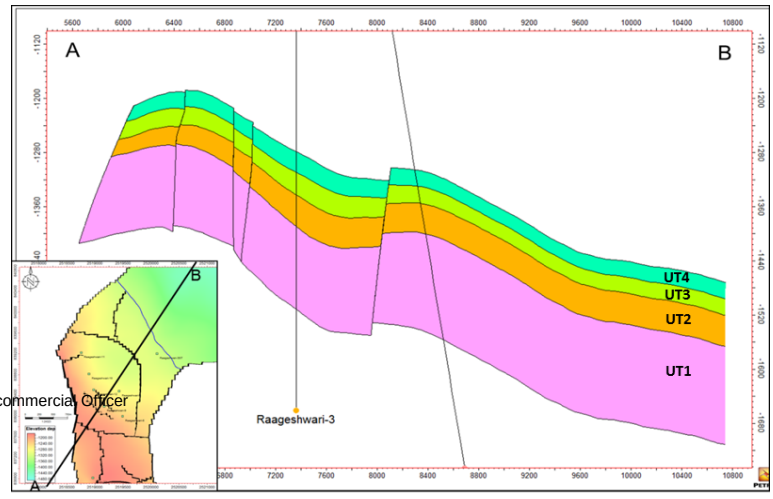


Figure 2.6.1. 2: Zone in Raag-Oil Model