

Geoscientific analysis for exploring the prospectivity in Tharad block, Cambay basin, Gujarat

Anil K Kaul*, K.P.Singh, A. Bhattacharya, K.Viswanath, & Arun Kumar

*kaul_ak1@ongc.co.in

Keywords

Intracratonic rift, breached structures, playfairway

Summary

Tharad block is situated at the junction between two producing subbasins Barmer towards the north and Cambay to the south within the composite Cambay – Barmer intra-cratonic rift basin. It is thus imperative to envisage hydrocarbon prospectivity in Tharad block akin to Barmer & Cambay basins. However during the course of the study in the Tharad block, it is established that the absence and or facies change of Early Eocene principal source rock (Cambay Shale) in the subsurface, attributes for a low confidence in defining, determining the play fairway in the area similar to the Mehsana area or for that matter to the Thumbli plays towards the north in the Barmer basin. Further the principal structures formed on the rift shoulders within and in the vicinity of Tharad block, some of which have been heitherto drilled have been formed after the critical moment due to post Miocene inversion and the same is so severe that the footwall breach has occurred up to surface vertically as well as laterally. Middle Eocene (Tharad Formation) level unconventional play fairway is established in the CBM wells but yet to be commercialised as a conventional hydrocarbon play. Further the extension of Paleocene (Olpad/Balutri Formation) level play fairway present towards the north (Fategarh play) in the Barmer Basin and (Olpad Play) in the South Patan-Cambay basin is to be established. Drilling of the proposed wells in the NELP block CB-ONN-2010/1 is expected to break the jinx.

Introduction

Earliest exploration activities in the Cambay basin commenced in the Tharad block with the first exploratory well Tharad-1. Subsequently through joint Indo-Russian collaboration, more exploratory efforts were supplemented but without success. Currently only one NELP-IX block CB-ONN-2010/1 located in the northern most part of the Cambay basin in the tectonically designated Patan-Tharad block

(Kundu & Wani, 1993), is actively being pursued for exploration activities by ONGC The block is conspicuous by the stratigraphic presence of the pre-rift fill (Late Cretaceous? encountered to the north of the block in Serau East-1 well) and older syn-rift fill (Paleocene? encountered to the north of the block in Balutri-1/ Serau East-1/Sanchore-1/Tharad-1 & 2P well). (Fig.1)

GENERALISED STRATIGRAPHIC COLUMN OF BARMER-SANCHOR BASIN

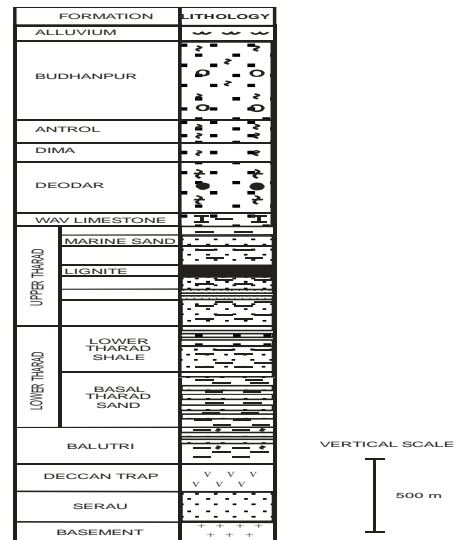


Figure 1: Representative Lithostratigraphic column in the vicinity of the Tharad block.

Contiguous to the NELP block, CB-ONN-2010/1, ONGC has drilled eight (8) wells Tharad-1 (1969); Serau East-1 (1970); Varsada-1 (1970); Deodar-1 (1970); Delvada-1 (1971); Balutri-1 (1972); Wara-1 (1974); Sampara-2 (1976). After a drilling holiday of nearly twelve (12) years ONGC drilled three parametric wells under Russian collaboration: Banas-1 (1988) Tharad-2P (1988) & Sanchore-1 (1989). ONGC-GSPC combine drilled eight (8) core wells and two (2) test wells in the block BS(3)-CBM-

Prospectivity perception in Tharad Block, Cambay basin

2003/II (area 790 km²) and relinquished the same after phase-I.

RIL has drilled four wells CB-ON-C1 (June, 2008); CB-ON-G1 (August, 2008); CB-ON-F1 (Sept, 2008); CB-ON-A1 (August,2009) in the vicinity of the block boundaries in Pre-NELP block CB-ON-1.(Block awarded in 1998, 6133 Km², PEL grant on 05-09-2003 and the same was surrendered after Phase-I).

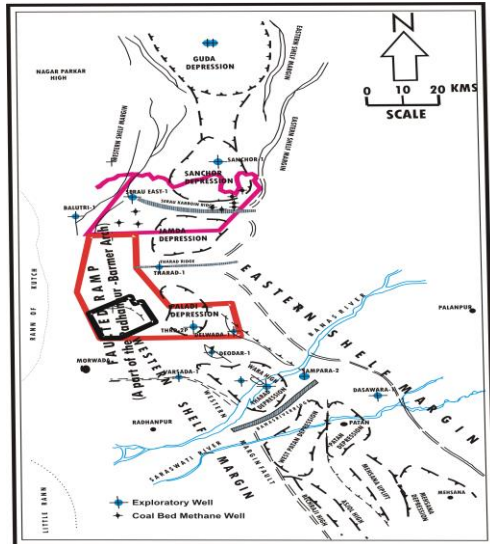


Figure 2: Tectonic map of the Tharad block showing the presently operated block CB-ONN-2010/1 & adjoining CBM block BS(3)-CBM-2003/II

The exploration in Tharad block is currently active in NELP-IX block CB-ONN-2010/1 carved out of the above surrendered block CB-ON-1 and a majority of the area within the block falls in the rift shoulder (Radhanpur-Barmer High/Arch) with not so significant adjoining lows to the east (southern Paladi depression and the northern Jamda Depression). (Fig.2)

Regional Geological Setup contiguous to the Tharad block

A seismo-geological cross-section from Guda low in the north to Tharad block in the south displays the rift architecture comprising of various highs and adjoining lows in a crooked yet dominantly strike section (Fig.3). Towards north of the Tharad block, Dharvi Dungar and Thumbli Formations have tested commercial oil on the central basin high in the Guda

and Raageshwri fields. Similarly DST tested presence of gas is confirmed in the well Tharad-1 within the Tharad block. Additionally CBM desorbed gas was confirmed in the cores of ten (10) wells drilled in the block BS (3)-CBM-2003/II.

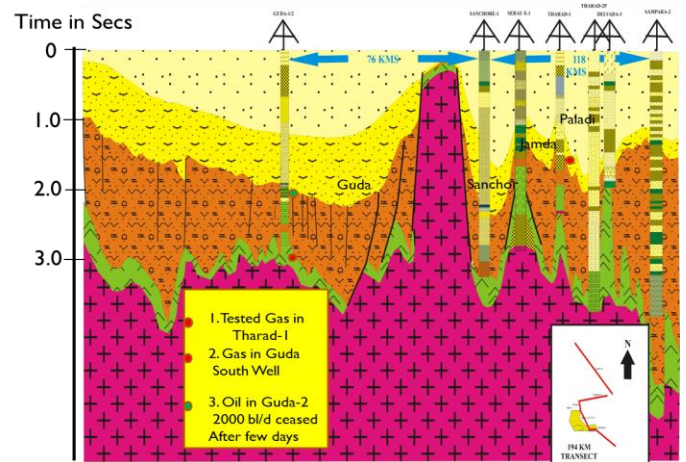


Figure 3: Seismo-geological section from Guda low (Barmer Basin) to Tharad-Sanchore block (Cambay Basin)

Description of envisaged Petroleum system

Resource Base:

A prognosticated reserve of 37 MmtoE in Paleocene to Mid/Late Eocene sequences is envisaged in the Patan-Tharad block. In the CBM block BS(3)-CBM-2003/II, producible reserves of a minimum 7 BCM (0.24 TCF), Mean 18.5 BCM (0.65 TCF) & Maximum 33.7 BCM (1.189 TCF) has been envisaged for the block area 790 km². (NDR data)

However, in the study area, owing to the absence of any successful play other than the Tharad level TST (presence of gas in Tharad levels at well Tharad-1, Guda-2), the other envisaged plays like Basement play (Raageshwari Deep) Fategarh/Olpad (Aishwariya & Mangala) are significant to be foreseen but are yet to be proven in the block. The possibility of a large stratigraphic play system within the deeper syn-rift environment may be considered subject to the imaging issues.

Towards the north in the Barmer basin, the Dharvi Dungar and Thumbli Formations have generally tested commercial oil only on the Central Basin High

Prospectivity perception in Tharad Block, Cambay basin

in the Raageshwari and Guda fields. Both formations are sand poor, where proven productive, with reservoirs being restricted to fine grained, low-sinuosity channels and crevasse splays. These reservoirs seldom reach more than 10 m in thickness and are commonly only 3-4 m thick with high porosity but low permeability

Source Rocks:

After the drilling of the first well Tharad-1, a dominantly arenaceous section has been generated in the subsurface. Further, the presence of gas was confirmed in the Sugary sandstone section and the same was not met with in Serau East-1 drilled north west of the Tharad-1 well and a facies change was envisaged for the same. The drilling of the well also confirmed the presence of volcanic basement at shallow depths and the basement was met early in the subsequently drilled well Deodar-1. However in the Tharad-Sanchore block, the subsurface data obtained in the Delwada-1, which is situated within the south-eastern part of the NELP block boundary, show that the black shales of the Mehasana area, are absent here too except for the thin intercalation of grey shale in the sugary sandstone section (perceived to be within Tharad Formation and the equivalent present in the well Tharad-1 too). Thus in the absence of principal source rock (Cambay Shale) the intervening shales of Barmer Hill/ Tharad Formation acts as a source rock type-II and III kerogen, immature lignite (Sanchore basin), aquatic and woody (South Barmer/ Guda low) in the area. However, owing to its deposition in lacustrine setting (Deep embayment lake) the shales of Barmer Hill Fm. consist of Type-I Kerogen with high HI and low OI. Dharvi-Dungar comparable to Tharad Fm of our area consists of Type-II kerogen. Balutri/Olpad level source rock is yet to be confirmed as an effective source rock in Tharad-Sanchore block but the same cannot be summarily ruled out due to its efficacy in Barmer basin.

Reservoir:

In the Tharad block and its vicinity, Early rift sandstones and conglomerates of the Olpad Formation which were deposited in alluvial, fluvial and lacustrine settings can form reasonably good reservoirs. Further in the coal/ shale reservoirs within the Tharad Formation sandstone member is a proven play in Tharad-1, Guda-2 & CBM wells to the east and north of the block boundary.

Seals:

Shales of Late Eocene–Oligocene age (Tarapur / Wav Formation) act as a regional seal in the North Cambay Basin. However in the Tharad block and the vicinity, the interfingering shales, coals within the Tharad Formation may act both as a seal and the reservoir.

Entrapment Model:

During the Early Cretaceous, the first sedimentation cycle commenced with the deposition of oldest Pre-Rift fill encountered in the well Serau East-1. Late Cretaceous-Paleocene witnessed the destruction of the pre-rift floor and widespread outpouring of lava on an uneven surface. Concomitant with the thermal cooling and shoulder / Foot wall uplifts the early rift fill comprising the clastic fills with intermediaries in the form of granitic / volcanic clasts (Balutri Formation) was deposited within the block boundaries. Consequent to the above, a syn-rift phase within largely lacustrine setting was deposited (cyclothem of Barmer Hill/Tharad/Dharvi Dungar in the progressively subsiding lows which is more apparent in the Barmer Basin & in Tharad-Sanchore area.

In the Barmer basin, local charging of individual structures from adjacent graben lows is typical in the northern part of the basin. However, in the southern part, the basement highs adjoining the lows constitute the entrapment model (Guda-2).

Geochemical Characterization of Clastic Reservoir within Tharad/Olpad Fm.:

The clastics within the Banaskantha/Balutri/Olpad Formation levels and the clastics/coal units of Tharad Formation are the established reservoirs in the study area. The coals are high in moisture (9-23%), very low in ash (2-9%) content with high volatile matter (30-55%) with low calorific value and are assigned Lignite Rank as per ASTM Coal Classification. From desorbed data the %age of CO₂ is varying from 29-49%. Higher %age of CO₂ again indicates the generation of methane by Aceticlastic Methanogenesis, whereby acetate transform in to methane and CO₂ and points towards the immaturity of coal i.e. immature lignite. Methane production potential of coal is directly related to the amount of Lipinite maceral in the sample. The Maceral % (Oxygen rich Huminite 47.7 to 81.2%; Lipinite 2.4 to 17.7%) The V_{ro}% values of these coals are observed to vary between 0.28 to just below 0.4 indicating a

Prospectivity perception in Tharad Block, Cambay basin

very low thermal maturity. Huminite/Vitrinite Content% is of the order of 62-92 with a reservoir pressure of 1600-2000 psi. The gas content of the lignites in the Antrol area varies mainly from 2-4 gm/cc in the lower coal unit and 2-3.5 gm/cc in the upper coal unit. Higher gas content of 8-10 cc/gm has been reported in coal seams encountered at depths beyond 1440 in one of the test wells in the CBM block BS(3)-CBM-2003/II just north of the NELP block boundary. All published data indicate that CBM production from lignite with Vro% of less than 0.4 is not happening.

In the clastics of Olpad, the vitrinite reflectance of 0.37-0.54% (Tharad-2P) 0.42-0.46% (Banas-1) points towards the presence of predominantly dry gas. Even the younger horizons in the stratigraphic column, display a vitrinite reflectance between 0.41-0.55 (Tharad-2P) and 0.39-51 (Banas-1) which points towards the gas prone kerogen.

Geochemical Source Rock analysis:

Geochemical Studies conducted on the samples from well Sanchore-1, Wara-1 and Sampara-2 indicate that the organic carbon percentage ranges from 1.2 to 27% and its percentage is higher towards the depressions. Vitrinite reflectance data suggests that the sediments below 1500 m are matured. The Tmax values for Tharad equivalent formation range between 435°C and 441°C. Ro for Lower Tharad level is 0.64 and for the Upper Tharad levels it is around 0.45. This suggests that the sedimentary section is fairly close to threshold value of hydrocarbon generation. The HI-Tmax plot at Sanchore-1 has revealed that the organic matter from Shale layers within the Lower Tharad formation is mainly of Type-II. In Paleocene section at 3146 mts the organic content of 0.98% shows fair richness. The HI value of 45 shows presence of type-III kerogen with a moderate quality organic matter capable of generating gas at Palaeocene levels.

In the Barmer basin towards the north of the study area, gas shows and gas fields are almost exclusively confined to the southern portion of the basin.(Guda and Raageshwari)

Geochemical Microseep analysis in the area:

A Microseep survey was undertaken in NELP Block CB-ONN-2010/1 as a pre-requisition for providing

exploration leads by identifying areas of high concentration of hydrocarbon in the surface soil (microseep anomaly) emanating from the sub surface petroleum deposits.(Fig.4)

The survey has shown the presence of Five distinct hydrocarbon anomaly clusters of high concentration of hydrocarbons (C1 to C6) in the surface soil at several locales. These hydrocarbons are catagenetic in origin, petroliferous in nature and indicate their association with oil/ gas.

The anomaly clusters are:

1. Dharadhara- Tithgam anomaly cluster
2. Rantila- Changvada anomaly cluster
3. Mera- Sanesda anomaly cluster
4. Vasarda anomaly cluster
5. Kunvata- Sardarpura anomaly cluster

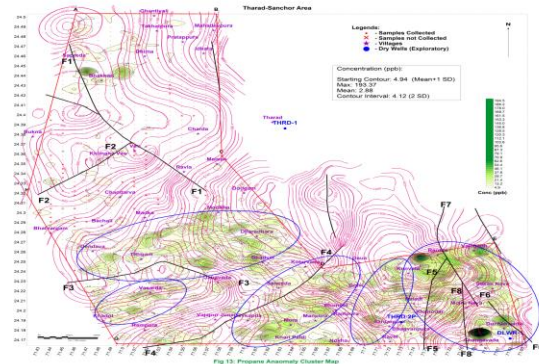


Figure 4: Five distinct hydrocarbon anomaly clusters have been identified in the microseep anomaly map.

In the well CB-ON-1-G1 sulfur species, H2S in this case, of probable bacterial origin are noted intermittently at 595-725m which indicate micro seepage or migration of petroleum from depth followed by bacterial sulphate reduction at temperatures below 650C.

Further, the anomalies are concentrated in the areas containing fresh structures and along the faults which have suffered recent severe inversion and thus are favourable for their seepage to surface.

Electrolog correlation-Stratigraphic analysis:

The electrolog correlation profiles, whose scheme is shown in Fig.5 a, b & c clearly bring out the stratigraphic architecture.

Prospectivity perception in Tharad Block, Cambay basin

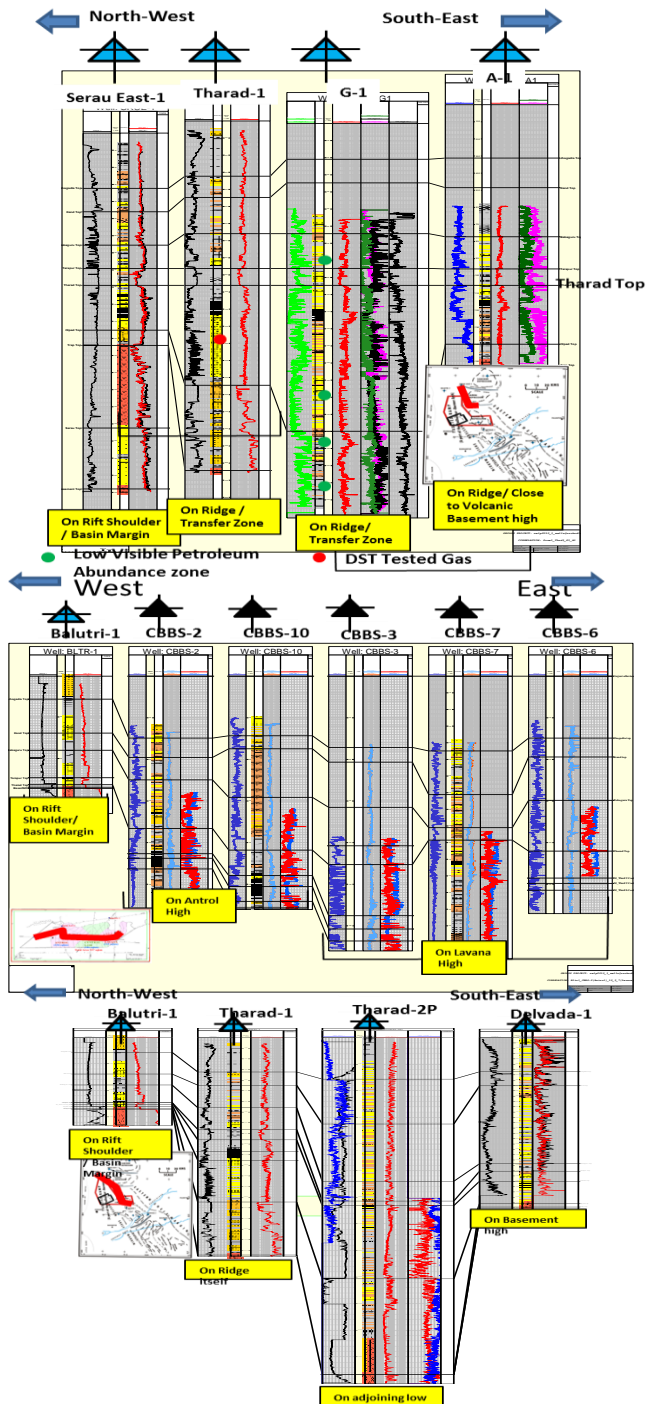


Figure:5a,b&c: Electrolog correlation across the exploratory wells and CBM wells in the Tharad area NELP & CBM block.

Structural Analysis – Regional trends

On the basis of maps prepared on horizons on Tertiary Formations (Babaguru Top, Tharad Top & Olpad Top), the area shows variable structural grains with many sub-divisions. To the east/southeast of NELP block extensional faults are discernible in the NNW-SSE direction at the deeper Syn-rift levels. Owing to transfer of extensional stress another faultset in E-W direction is formed which is dormant in the syn-rift level stage. Owing to post-Miocene inversion in the area concomitant with the Himalayan orogeny, the inversion of this E-W transfer zones becomes more pronounced in the area and demarcates the area in to various sub-basinal lows. As a matter of fact the severity of inversion is so severe in the rift shoulder/flanks that even extensional faults reverse their motion and infact the shortening is then accommodated by a thrust that cuts the footwall at lower angle.

Envisaged play description

In analysing the prospectivity perception in the block, categorization of various identifiable play description in the currently active NELP block will definitely help augmenting the cause of future exploration in the area.

Type-I (Strati-structural play) A large prospect area lies to the west-southwest of the Tharad-1 well in which solitary gas presence has been tested through cased hole DST with higher fractions of gaseous hydrocarbon fraction with calorific value more than 10,000 Kcal/m³ in the Tharad sandstone member.

- The proposed prospect area expects the westward pinchout of the sugary sandstone member updip which is absent in Serau East-1 and whose seismic presence in the form of wedgeouts/pinchouts is confirmed.

- The thin sections prepared for reconstruction of Bulk volatile chemistry from fluid inclusion study, from five depths in the well CB-ON-1-G1 i.e., 595m, 825m, 1615m, 1875m & 2115m in which rare white fluorescent, upper low gravity petroleum inclusions are noted in fractured detrital quartz at 595 m, 825m, and 1615m. Low visible petroleum inclusion abundance suggests migration of liquid petroleum without accumulation at the wellbore location.

- Paleo-tectonic analysis of the prospect area show a distinct high at the critical moment and it is envisaged that the already emergent high could have

Prospectivity perception in Tharad Block, Cambay basin

been charged due to its proximity with the adjoining lows containing not only the Tharad level wedgeouts but the older Olpad/Balutri level as well as the Mesozoic? Whose presence is met in well Serau East-1

- In the proposed prospect area, all the probable plays envisaged and met in Barmer basin can be envisioned with considerable level of confidence.

Type-II (Stratigraphic play)

- This prospect area on the hanging / footwalls of the rifted blocks away from the lows will test the updip pinchout of the Tharad lithosome, the envisaged play may confirm the presence of updip wedgeouts of older syn-rift Olpad/Balutri which is condensed in the well Balutri-1.

- Owing to not so very well resolved deeper syn-rift seismic imaging issues, usually prevalent in such area, the location carries inherent wildcat / parametric elements of exploration component.

Type-III (Purely Structural play)

- A series of structural prospective areas are located amidst the micro seepage anomaly concentration area.

- The prospect area is attractive prime-facie but the structures are very recent and on paleo-tectonic analysis, the structuration is not available at the critical moment.

- The structural prospective areas carry the risk due to tectonic footwall breach whose footprint can be perceived up to surface vertically as well as laterally in many identified structures within the identifiable area.

- Further any remigration in the area and particularly in the envisaged structural prospective areas is to be understood well and thus the prospective area also carries the parametric component with it.

The envisaged plays if converted in to drillable prospects would be parametric in nature and any accretion envisaged, will carry a huge bias for any effective decision making.

Conclusions

In the Tharad block, the absence and or facies change of Early Eocene principal source rock (Cambay Shale) in the subsurface, envisages a somewhat low confidence in defining, determining the play fairway in the area similar to the Mehsana area. Middle Eocene (Tharad Formation) level play fairway is

established but yet to be commercialised as a conventional hydrocarbon play. The Paleocene (Olpad/Balutri Formation) level play fairway is yet to be established in the area even though both towards the north (Fategarh play) in the Barmer Basin and (Olpad Play) in the South Patan-Cambay basin is established.

Further the principal structures formed on the rift shoulder have been formed after the critical moment due to post Miocene inversion and the same is so severe that the footwall breach has occurred up to surface vertically as well as laterally.

Thus the efficacy of northward continuity of Kalol/Kadi or even Cambay Shale from southern parts, as the effective reservoir/source in such similarities as is normally evident in Mehsana area has been discounted by the earlier workers. Further, during the course of the present study, the presence of Thumbli/Dharvi Dungar equivalent coals of Barmer basin and their seismic continuity with the Tharad coals in CBM/Sanchor wells has been documented which constructs the late syn-rift fill more analogous to Barmer basin. Thus the tectonostratigraphy of the block is more akin to the Barmer basin than with the Cambay basin even though the tectonics possibly will be analogous to the main Cambay rift.

References

Chakraborty, Amitava, P. K. Tiwari, and A. K. Singh., 2011., Coalbed Methane Exploration in A Tertiary Lignite Basin, North Gujarat, India., GEO India 12-14th Jan, 2011

Raju, S.V and Mathur, N., 2013, Rajasthan lignite as a source of unconventional oil Current Science, Vol.104 no.6 pp. 752-757.

Singh, N.P., Koshal, V.N., Srivastava, D.C and Rao, V.K., 1980, Paleogene Stratigraphy, Biozonation and Paleocology of the sub-surface sediments in the area lying north of Saraswati river, Gujarat. Journal of Paleontological Society of India Vol. 23 & 24, pp. 118-128.

Surface Geochemical prospecting, source rock & well completion reports related to the area under discussion

https://www.ndrdgh.gov.in/NDR/?page_id=1251

Acknowledgments

The authors express their deep gratitude to Shri. A.K. Dwivedi, Director (Exploration), ONGC for granting permission to publish this paper in SPG 2017. The views expressed by the authors in this paper are their own and may not be the view of company they belong to.