

# **Source Potential Evaluation of Paleogene-Neogene Sediments in Cambay-Tarapur Area, Cambay Basin, India\***

**M. Shanmukhappa<sup>1</sup>**

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<sup>1</sup>KDMIPE, Oil and Natural Gas Corporation Ltd., Kaulagarh Road, Dehradun, India ([drmsanmukhappa@hotmail.com](mailto:drmsanmukhappa@hotmail.com))

## **Abstract**

Source rock generation potential of Paleogene-Neogene sediments in the subsurface of Cambay-Tarapur area has been evaluated based on organic matter maturation studies to provide leads for hydrocarbon exploration. The study suggests that dispersed organic matter in the studied sediments is mainly land derived and the presence of phytoplanktons at different stratigraphic levels indicate a sizeable marine input also. Miocene sediments in the area are thermally immature (TAI 2.0) except in the central part from Kheda in the north to Watodara in the south and Ras in the east to West Bhalda in the west where marginal maturity (TAI 2.25) has been observed. The Oligocene sediments throughout the study area are marginally mature (TAI 2.25) and represents humic palynofacies, hence, modest generation of gaseous hydrocarbon is envisaged except in the western-most part of the area around Pisawada where these sediments are immature (TAI 2.0). The Middle-Late Eocene sediments in the area from Mahuda in the north to Kalamsar in the south, Ras in the east to Indernag in the west, are thermally mature (TAI 2.75) and the beginning of an intense generation phase for liquid hydrocarbon is inferred. The Early Eocene sediments showing top of oil window (TAI 2.75) and intense generation phase for liquid hydrocarbon has been envisaged in the west and south western part of the study area represented by Pisawada, Mitili and Akholjuni. The Early Eocene sediments showing retardation of liquid hydrocarbon generation phase (TAI 3.25) and intense generation phase for gaseous hydrocarbons (TAI 3.5) lies in the area bounded by Mahuda in the north to Ras in the east and Indernag in the west. The present study suggests that Early Eocene sediments in general are in intense generation phase for gaseous hydrocarbon except in western part where they are in the oil window. The Middle-Late Eocene sediments are optimally mature for generation of liquid hydrocarbon while Oligocene and Miocene sediments are immature to marginally mature and capable of generating gaseous hydrocarbon in the early stage of maturity.

## Introduction

The Tarapur block lies in the central part of Cambay Basin between Latitude 200° 30' and 220° 15' (Figure 1). In the north it is bounded by Mehsana-Ahmedabad block and in the south by the Broach block. The Cambay Basin is a narrow elongated rift graben type of basin, situated between the Saurashtra craton on the west, Aravallis on the northeast and Deccan craton to the southeast. On the west and east it is bounded by basin margin faults. It extends to Viramgam and Gogha in the west, while Himmatnagar-Baroda and Rajpipla lie near its eastern margin (Pandey et al., 1993).

This basin forms the northern inland extension of the Bombay Offshore Basin. The basin came into existence during the Late Mesozoic era with the development of major tensional faults along pre-existing basement trends in conjunction with widespread Deccan Trap basalt activity. The basaltic floor formed the basement for the deposition of about 3 km thick Tertiary-Quaternary sediments in this basin. The basin is longitudinally divided into five major tectonic blocks viz. Sanchor-Patan, Mehsana-Ahmedabad, Tarapur-Cambay, Jambusar-Broach and Narmada-Tapti blocks from north to south and bounded by transverse basement faults.

Previously exploration activities centered in the north of Mahisagar River at Cambay, Kathana, and Siswa fields and partly in the eastern and western flanks in Chaklasi, Vaso, Anand, Kanwara, Bhalada, Changara and Wataman area. Subsurface information is lacking in the central part as there are no drilled wells in this part. Hydrocarbon bearing fields in Tarapur Block are Cambay, Kathana and Kanwara producing from Tarapur Formation (Kathana and Siswa fields). In Kanwara the production is from Vaso Formation. Two exploratory wells, Indernag-A and B were drilled in the western part located in NNW of Cambay Field. The first well produced a little oil and the other well proved to be dry. It has now been accepted that the composition, concentration and maturation of organic matter are essential conditions for the generation of hydrocarbons. Present study has been carried out with the above objectives to provide lead and support for hydrocarbon exploration in this part of the basin.

## Stratigraphy

Stratigraphy, tectonics and sedimentation of Cambay Basin have been worked out by various authors, the more significant contributions being made by Sudhakar and Roy (1959), Zubov et al. (1966), Mathur et al. (1968), Chandra and Chaudhary (1969), Rao (1969), Sudhakar and Basu (1973), Bhandari and Choudhary (1975), and Raju et al. (1982). Lithostratigraphy work of Pandey et al. (1993) has been followed in this study. The Deccan Trap forms the basement in this area. The Deccan Traps are dark, greenish gray to brownish gray, melanocratic, microcrystalline, compact, porphyritic and fractured basalt with vesicles. The Trap is highly altered in the upper part. Alternations of dark gray, brownish gray, silty shale, greenish green weathered Traps and variegated tuff and clays of Olpad Formation overlie the Deccan Traps. The Olpad Formation is overlain by Cambay Shale. The lower part of Cambay Shale is designated as Older Cambay Shale and consists of dark gray to black shales with siltstone and fine sands. Probably an unconformity

marks the top of older Cambay Shale and is overlain by younger Cambay Shale, which consists mainly of shales that are dark gray to black, moderately compact and carbonaceous with occasional bands of siltstone. The Cambay Shale is overlain by the Kalol Formation, which is represented by the Sertha and Wavel members. These members consist of shales with alternate bands of siltstone and fine sandstone with thin coal bands. These two members contain the two lower Eocene pay zones. The Kalol Formation is overlain by Tarapur Shale, which is represented by the Balol and Lunej members. Dark gray shales, silty, carbonaceous, and occasionally calcareous with layers of greenish brown siltstone represent the Balol Member. The Upper Eocene pay zones have been found in this succession. The Lunej Member, probably representing Oligocene succession, consists of light to dark gray shale with medium to coarse-grained sand bands. Oil bearing Oligocene sands have been found in this section. The top portion is represented by the Babaguru and Kand formations of Miocene age that consist of dark gray to black shales with occasional coal bands and thin streaks of medium to coarse grained sands.

### **Material and Method**

The “Standard Laboratory Techniques and Procedures in Geology” (Pandey and Rao, 1991) has been followed for recovery of organic matter and source rock evaluation. The organic matter logging, i.e. volume percentage of organic matter types, palynofacies, TAI and source potential are depicted in [Figure 2](#), [Figure 3](#), and [Figure 4](#). The quantitative estimations are made by usual estimation method. The thermal alteration index (TAI) values based on spore-pollen colour are read on a one to five scale (Staplin, 1969). Three profiles AA’, BA’ and CC’ have been selected representing western flank wells, western and northwestern flank wells, and southeastern flank wells respectively.

### **Organic Matter Types, Palynofacies, Thermal Alteration Index Values and Source Potential**

The general characteristics of organic matter, palynofacies, thermal alteration index and prospect evaluation in the age wise sediments of different areas of the studied block have been discussed in the order of immature to mature sequences.

#### **1. Western Flank Wells: Profile AA’ Wells Pisawada-A, Mitli-A and Akholjuni-A**

#### **Miocene Prospects**

The dispersed organic matter of the Miocene sediments (1000-1113 m) in well Mitli-A contains structured terrestrial woody components, biodegraded terrestrial, amorphous and charcoal throughout the column in varying proportions. Presence of finely divided organic matter between 1036 m and 1045 m indicates microbial activity over organic matter. Spores/pollen and fungal

components are rare to common in occurrence. Total organic matter is poor in quantity. However, it indicates the dominance of humic palynofacies between 1000-1020 m and 1045-1090 m (60-80%) and sapropelic facies between 1036-1045 m. TAI value is ascertained as 2.0, which is indicative of immature facies.

Distribution of organic matter in Miocene sediments of well Akholjuni-A (900-1455 m) is fair to moderate. Structured terrestrial and biodegraded terrestrial are the major constituents of the organic matter. Amorphous organic matter, in general, is only 10-40%. Fungal components and spores/pollen are rare to common in occurrence. Palynofacies are dominantly humic (60-100%). Sapropelic constitutes 10-40% between 1130-1455 m interval only. Two TAI values, 2.0 and 2.25, have been delineated between 900-1175 m and 1175-1455 m, respectively. TAI of 2.0 indicates the immature facies and 2.25 as a marginal mature facies.

### **Oligocene Prospects**

The organic matter of the Oligocene sediments of well Pisawada-A (1075-1115 m) indicates the dominance of structured terrestrial and biodegraded terrestrial organic matter. Spores/pollen and fungal components are common and rare. Total dispersed organic matter in sediments indicates the dominance of humic palynofacies (80-100%). TAI value is ascertained as 2.0, which indicates immaturity of the organic matter. In well Mitli-A (1113-1165 m), Oligocene sediments contain poor organic matter.

Biodegraded terrestrial and structured terrestrial organic matters are the main constituents in the Oligocene sediments of well Akholjuni-A (1455-1520 m). Amorphous organic matter contributes 20-30% in total dispersed organic matter. Spores and pollen are rare in occurrence. Palynofacies are dominantly humic (70-80%) whereas sapropelic organic matter contributes 20-30% only. TAI value is ascertained as 2.25, which is indicative of marginal maturity of organic matter.

### **Eocene Prospects**

The upper part of Eocene sediments in well Pisawada-A (1115-1220 m) contain fair to moderate organic matter, whereas the lower part between 1220-1406 m contains inertinitic group of materials, i.e. Charcoal (10-60%) (Fusinite semifusinite). However, the sedimentary dispersed organic matter indicates that biodegraded terrestrial and structured terrestrial are major constituents being 10-40% between the 1115-1325 m levels. Spore-pollen and fungal components are rare to common in occurrence. Palynofacies are dominantly humic (60-90%) and sapropelic facies contributes 10-40% between the 1115-1325 m interval. The sediments between 1325 m and 1365 m contain poor organic matter. TAI values are ascertained as 2.0 and 2.25 between 1115-1325 m and 1325-1406 m, respectively. Eocene sediments in well Mitli-A (1165-1845 m) contain moderate to rich organic matter in which amorphous organic matter contributes 20-60%, structured terrestrial 10-30% and charcoal 10-20%. Finely divided organic matter is present in meager quantity and at certain places indicates microbial activity upon the organic matter. Sediments between the intervals 1165-1185 m,

1525-1545 m and 1735-1765 m contain poor organic matter. Total organic matter indicates the dominance of humic (50-80%), sapropelic (20-50%) palynofacies between 1185-1680 m and 1680-1845 m, respectively. TAI values are delineated as 2.25, 2.5 and 2.75 between 1185-1585 m, 1585-1815 m and 1815-1845 m, respectively. TAI value of 2.25 indicates the marginal maturity of organic matter whereas TAI 2.5 indicates the maturity of organic matter for onset of liquid hydrocarbons generation and 2.75, for intense generation of liquid hydrocarbons. Thus the threshold of liquid hydrocarbon generation is identified at around 1585 m and intense generation from 1815 m in this well.

In well Akholjuni-A the Eocene sediments between the intervals 1520-1575 m, 1645-1685 m, 1800-1820 m and 1855-1870 m have yielded poor organic matter. Dispersed organic matter indicate that the biodegraded terrestrial is the major constituent of sediments. Structured terrestrial woody and amorphous constituents are present in the Eocene sequence with the contribution of 10-40% each in the total organic matter except in the interval between 1715-1760 m where rich amorphous organic matter contributes 60-70%. Spore-pollen and fungal components are common at different intervals. Phytoplanktons are also recorded between 1715-1760 m. Palynofacies is dominantly humic (70-90%), whereas sapropelic dominates (60-70%) between 1715-1760 m. TAI values are ascertained as 2.5 and 2.75 between 1515-1905 m and 1905-1960 m respectively. Thus the oil generative window lies around 1515 m and intense generation of liquid hydrocarbons is around 1905 m in the sediments.

### **Paleocene to Lower Eocene Prospects**

Early Eocene sediments from well Pisawada-A (1406-1935 m) contain rich organic matter. Structured terrestrial, biodegraded terrestrial and amorphous organic matter are present throughout the sequence in varying percentages. Charcoal is also recorded between 1755-1925 m. Excellent preservation of amorphous (Sapropelic) organic matter has been observed between 1505-1825 m. Spore/Pollen are rare to abundant at different levels. Fungal components are rare to common. Organic resins are also recorded. The sediments between 1440-1555 m contain bitumen which is also confirmed by the fluorescence studies. Total organic matter indicates dominance of humic palynofacies between 1406-1460 m, 1745-1795 m and 1825-1870 m whereas, sapropelic facies dominates between the interval 1460-1745 m, 1795-1825 m and 1870-1935 m. TAI values are ascertained as 2.25, 2.5 and 2.75 between 1406-1455 m, 1455-1705 m and 1705-1935 m respectively. Onset of liquid hydrocarbons lies around 1455 m and peak stage at 1705 m in the sequence. In well Mitli-A (1845-2380 m), Paleocene- Early Eocene sediments contain moderate to rich organic matter at different levels. Structured terrestrial, biodegraded terrestrial, charcoal and amorphous organic matter is present in varying percentages. Finely divided organic matter shows meager presence at certain levels. Spore-pollen and fungal components are rare in occurrence. The sediments between 2060 m and 2095 m contain poor organic matter. In general total organic matter indicates the admixture of humic and sapropelic palynofacies with almost equal contribution from both. TAI value is ascertained as 2.75 which is indicative of intense generation of liquid hydrocarbons.

## **Source Potential**

Maturation levels are shown in profile AA' (Figure 5). Mature section of Pisawada-A, Mitli-A and Akholjuni-A indicates dominantly gas prone capability except Lower Eocene organic matter between 1505-1825 m in Pisawada-A. Eocene sediments between 1680-1845 m and 1715-1760 m in Mitli-A and Akholjuni-A respectively which suggests the oil and gas prone capability of organic matter. Lower Eocene sediments between 1440-1555 m contain accumulated hydrocarbons in Pisawada-A well.

### **2. Western and Northwestern Flank Wells: Profile BA' Wells Mahudha-A, Kheda-A, W. Bhalada-A, Indernaj-A and Akholjuni-A**

#### **Miocene Prospects**

Biodegraded terrestrial is the major constituent in the dispersed organic matter of the Miocene sediments in well Kheda-A (660-1208 m). Structured terrestrial, amorphous, charcoal and finely divided organic matter are present at certain intervals. Organic matter is meager in the sediments of this age. Palynofacies are dominantly humic (70-100%). TAI values are recorded as 2.0 and 2.25 between 660-1020 m and 1020-1208 m indicating immaturity and marginal maturity of the organic matter, respectively. Miocene sediments in well W. Balada-A (1000-1361 m) indicate moderate organic matter with main contribution from biodegraded terrestrial sources (60-70%). Structured terrestrial, charcoal and amorphous are present in minor quantities in the total dispersed organic matter. Spores-pollen are common in occurrence. Sediments between 1090-1200 m have poor organic matter. Palynofacies is dominantly humic (70-90%). TAI values are recorded as 2.0 and 2.25 which are indicative of immaturity and marginal maturity of the organic matter between 1000-1200 m and 1200-1361 m, respectively. Biodegraded terrestrial and structured terrestrial organic matter are the major constituents in the total organic matter of the Miocene sediments of well Indernaj-A (1200-1384 m) and amorphous organic matter is present in minor quantity. Spore-pollen and fungal components are common to abundant in occurrence. Palynofacies is dominantly humic 70-90%. TAI value is recorded as 2.0 which is indicative of inadequate maturity for hydrocarbon generation.

#### **Oligocene Prospects**

The boundary between Upper Eocene and Oligocene could not be identified in the well Mahuda-A (911-1082 m). Therefore Upper Eocene-Oligocene were dealt with together. Amorphous, biodegraded terrestrial and structured terrestrial of woody and cuticular remains are the main constituents in the rich dispersed organic matter of the sediments (Tarapur Formation). Spore-pollen, fungal components and dinoflagellates are recorded. Palynofacies are sapropelic-humic. TAI value is recorded as 2.25, which is indicative of marginal maturity of the organic matter. Biodegraded organic matter (40-70%) continues to dominate the total organic matter of the Oligocene sediments in well Kheda-A (1208-1300 m). Amorphous contribution is insignificant except at certain intervals.

Palynofacies is dominantly humic. Oligocene sediments encountered in well W. Bhalada-A (1361-1483 m) contain predominantly biodegraded terrestrial organic matter. Palynofacies are humic (80-90%). TAI value is recorded as 2.25. This TAI value indicates the marginal maturity of the organic matter. The dominance of biodegraded terrestrial organic matter along with a little contribution of amorphous organic matter indicate a minor generation of gaseous hydrocarbon.

Major constituents of the Oligocene sediments in well Indernag-A (1384-1440 m) are biodegraded terrestrial (40-60%) and structured terrestrial organic matter. Charcoal and amorphous organic matter are present in minor quantity. Spore and pollen are common in occurrence. Phytoplanktons are also recorded indicating the contribution of marine inputs in the total organic matter. Palynofacies is dominantly humic (70-80%). TAI value is recorded as 2.25 which is indicative of marginal maturity of the organic matter.

### **Eocene Prospects**

Amorphous and biodegraded terrestrial organic matter are the main constituents in the total organic matter of Early to Middle Eocene sediments in well Mahuda-A (1082-1767 m). Structured terrestrial and charcoal show scanty presence at different intervals. Total dispersed organic matter indicates the dominance of sapropelic palynofacies (70-100%) between 1280-1585 m and the humic facies in the rest of the sediments. TAI values are recorded as 2.25, 2.5 and 2.75 between 1082-1330 m, 1330-1600 m and 1600-1767 m, respectively. TAI value 2.5 indicates the onset of liquid hydrocarbons from 1330m onwards. TAI of 2.75 at the level of 1600m suggests the beginning of intense generation of liquid hydrocarbons.

In well Kheda-A (1300-2553 m), biodegraded terrestrial and amorphous are the main constituents of the total dispersed organic matter and dominate in the intervals 1300-1720 m and 1720-2300 m, respectively. Structured terrestrial, charcoal and finely divided organic matter are present in minor quantity. Sediments between 1320-1350 m, 2100-2160 m, 2180-2210 m and 2240-2300 m contain poor amount of organic matter. Palynofacies are humic-sapropelic and sapropelic-humic between 1300-1720 m and 1720-2300 m, respectively. TAI values are recorded as 2.25, 2.5 and 2.75 between 1300-1320 m, 1320-1740 m and 1740-2300 m respectively. TAI 2.5 lies at 1320 m indicating the onset of oil generation stage. TAI 2.75 lies at 1740 m suggesting the beginning of intense generation of liquid hydrocarbons. Amorphous, biodegraded terrestrial and finely divided organic matter of the Eocene sediments of well W. Bhalada-A (1483-2911 m) are the major constituents in the total dispersed organic matter of the sediments at different intervals. Sediments between 2380-2505 m and 2600-2685 m contain poor amount of organic matter. The total organic matter indicates that the humic and sapropelic palynofacies dominate over each other at different intervals. Humic palynofacies dominate between 1483-1945 m and 2705-2905 m, whereas sapropelic between 1945-2705 m. TAI values are recorded as 2.25, 2.5, 2.75 and 3.0 between 1500-1540 m, 1540-2005 m, 2005-2700 m and 2700-2911 m, respectively. Onset of oil generation corresponds to a depth of 1540 m. Thermal maturity of organic matter below 2005 m falls under intense stage of liquid hydrocarbon generation. Eocene sediments of well Indernag-A (1440-2260 m) cover Tarapur, Vaso and part of Cambay Shale Formations. All the organic matter constituents, i.e.

biodegraded terrestrial, amorphous, structured terrestrial, charcoal and finely divided are present in varying abundance. Biodegraded terrestrial (40-70%) dominates between 1440-1905 m and finely divided (40-70%) between 1905-2050 m intervals. Amorphous, charcoal and structured terrestrial organic matter are present in minor quantity. Spore, pollen and fungal components are rare to common in occurrence. Phytoplanktons are also recorded. Total dispersed organic matter in sediments suggest the dominance of humic facies between 1440-1905 m sapropelic-humic between 1905-2105 m and humic-sapropelic between 2105-2260 m intervals. TAI values are recorded as 2.25, 2.5 and 2.75 between 1440-1585 m, 1585-1950 m and 1950-2260 m, respectively. TAI 2.5 indicates that initiation of oil generation lies around 1585 m in the Tarapur Formation and active generation phase, corresponding to TAI of 2.75, occurs at 1950 m in Cambay Shale.

### **Paleocene Prospects**

Biodegraded terrestrial and amorphous are the main constituents in the total organic matter of the Paleocene sediments in well Mahudha-A (1767-2818 m). Structured terrestrial, charcoal and finely divided organic matter are present in varying abundance at certain intervals. Humic and sapropelic facies are dominating over each other at different intervals, i.e. sapropelic facies between 1900-2055 m, 2125-2180 m and 2530-2595 m and the humic facies in the rest of sediments. TAI values have been observed as 2.75, 3.0, 3.25 and 3.5 between the intervals 1767-1780 m, 1780-2360 m, 2360-2620 m and 2620-2818 m, respectively. TAI 3.5 indicates the terrestrial zone where in only gaseous hydrocarbons can be expected from the organic matter of this sequence.

Amorphous (50-80%) and finely divided (40-50%) organic matter are the major constituents in the total dispersed organic matter at different intervals of Cambay Shale and Olpad formations in the well Indernaj-A (2260-3000 m). Biodegraded terrestrial, structured terrestrial and charcoal present in minor quantities. Spore, Pollen and fungal components are common to abundant. Phytoplanktons are also recorded. Rich organic matter indicates the sapropelic-humic palynofacies with gas and oil prone capabilities. TAI values are recorded as 2.75, 3.0 and 3.25 between 2260-2600 m, 2600-2772 m and 2772-3000 m respectively. These TAI values suggest the adequate thermal maturity for the generation of hydrocarbons.

### **Source Potential**

Maturation levels are shown in profile BA' ([Figure 6](#)). Mature section of the well sediments suggests that good source potential for oil and gas lies between 1330-1585 m, 1908-2050 m, 2125-2205 m and 2530-2600 m in well Mahudha-A, 1740-2100 m in Kheda-A, 1940-2005 m and 2520-2600 m in W. Bhalada-A, and 1920-2085 m, 2200-2265 m, 2440-2665 m and 2720-2765 m in Indernaj-A with adequate thermal maturity (TAI 2.75-3.25). This thermal maturity suggests a significant oil and gas generation from these sediments. Rest of the mature section indicates dominantly gas prone capabilities of the organic matter.



### **3. Southeastern Flank Wells: Profile CC' Wells Ras-A, Uneli-A, Watadara-A and Kalamsar-A**

#### **Miocene Prospects**

Biodegraded terrestrial is the major constituent in the total organic matter in sediments of Miocene age in well Ras-A (1280-1459 m). Amorphous organic matter and charcoal are present throughout the sequence in minor quantity. Spores and pollen are rare in occurrence. Palynofacies is dominantly humic (70-90%). TAI value is ascertained as 2.25 which is indicative of marginal maturity of the organic matter.

Structured terrestrial of woody component and biodegraded terrestrial are present in significant quantity in the total organic matter of well Uneli-A (1075-1501 m). Amorphous contribution is poor in general and is only 10-20% in the total dispersed organic matter of the sediments. Spores-pollen and fungal components are rare to abundant in occurrence. Palynofacies is dominantly humic with the contribution 80-90% in the total organic matter. TAI values are recorded as 2.0 and 2.25 between 1075-1470 m and 1470-1501 m, respectively. TAI 2.25 indicates the marginal maturity of the organic matter. In well Watadara-A the Miocene sediments (1140-1578 m), contain rich organic matter of amorphous and biodegraded terrestrial origin between 1140-1205 m and 1205-1578 m, respectively. The sediments between 1205-1295 m indicate the microbial activity over the organic matter. Spore, pollen and fungal spores are rare, common and abundant at different levels. In general, sapropelic facies dominates between 1140-1205 m and humic between 1205-1578 m with the contribution of 60-70% and 60-90%, respectively. TAI values are recorded as 2.0 and 2.25 between 1140-1225 m and 1225-1578 m. Organic content between 1140-1225 m is lean in preservation and is also immature. Therefore, no hydrocarbon generation is expected from these sediments. TAI 2.25 indicate the marginal maturity of the organic matter but due to dominance of humic facies, these sediments do not have potential to generate liquid hydrocarbons. The Miocene sediments in well Kalamsar-A (880-1614 m) contain poor organic matter.

#### **Oligocene Prospects**

The Oligocene sediments in well Uneli-A (1501-1545 m) have yielded dominantly terrestrially sourced biodegraded organic matter. Palynofacies are dominantly humic. TAI value is recorded as 2.25. Poor preservation of organic matter indicates the poor source potential for generation of hydrocarbons.

In well Watadara-A the Oligocene sediments (1578-1618 m) contain rich organic matter with higher percentage of biodegraded terrestrial. Spore, pollen and fungal components are common in occurrence. Palynofacies is dominantly humic. TAI value is recorded as 2.25 indicating marginal maturity.

## **Eocene Prospects**

The studied sequence between 1620-1785 m in well Ras-A reveals a higher percentage of biodegraded terrestrial and inertinite group, i.e. charcoal in the total organic matter of the sediments. Palynofacies are dominantly humic in which charcoal contributes 40-60% indicating the poor source potential for liquid hydrocarbons of these sediments. TAI value 2.5 is recorded at the level of 1620 m. Ro 0.5% at 1570 m has been considered for onset of liquid hydrocarbon generation. The Eocene sediments (1545-2065 m) in well Uneli-A contains rich organic matter. Sediments between 1545-1835 m exhibit abundance of biodegraded terrestrial and structured terrestrial organic matter, whereas sediments between 1835-2065 m accumulate high percentage of amorphous organic matter. Spore-pollen and fungal components are common to abundant in occurrence. Organic resins are also recorded at certain places. Palynofacies is dominantly humic (70-90%) between 1545-1835 m and sapropelic-humic between 1935-2065 m. TAI values are recorded as 2.25, 2.5 and 2.75 between 1545-1650 m, 1650-1835 m and 1835-2065 m respectively. Threshold of oil generation is identified at 1650 m and intense generation at 1835 m. Zone of TAI 2.5 indicates poor potential for oil generation whereas zone of TAI 2.75 indicates good potential for oil generation. The Eocene sediments of well wata-dara-A (1618-1675 m) contain rich organic matter with higher quantity of biodegraded terrestrial organic matter. Spore-pollen and fungal components are common in occurrence. Palynofacies are dominantly humic (80-90%). TAI values are recorded as 2.25 and 2.5 between 1618-1635 m and 1645-1665 m, respectively. Onset of oil generation is identified at 1635 m. Dominance of humic facies in the mature section indicates the gas prone capability of the organic matter.

Charcoal, finely divided, biodegraded terrestrial and amorphous organic matter are present in the Eocene sediments of well Kalamsar-A (1644-2190 m). Presence of finely divided organic matter throughout the succession indicates the higher degradation of organic matter through microbial activity. Organic matter preservation between 1785-1860 m and 2085-2165 m is poor in quality as well as in quantity. Palynofacies is humic-sapropelic. TAI values are recorded as 2.25 and 2.5 between 1644-1700 m and 1700-2190 m, respectively. The onset of oil generation lies around 1700 m. The mature section 1700-2190 m indicates fair potential for gas/oil generation.

## **Paleocene Prospects**

Paleocene sediments (2065-2205 m) in well Uneli-A contain high percentage of amorphous organic matter (60-70%). Biodegraded terrestrial, structured terrestrial and finely divided organic matter are present in minor quantity. The sediments between 2300-2700 m have not been studied due to non-availability of samples. The samples between the interval 2940-2995 m are poor in organic matter. Charcoal is abundant (60-80%) between 2710-2920 m. Palynofacies is admixture of sapropelic and humic with the contribution of 60-100% and 30-40% respectively between the interval 2065-2305 m. Palynofacies encountered entirely humic between 2710-3000 m indicating the poor potential for liquid hydrocarbons. TAI values are recorded as 2.75, 3.0 and 3.25 between the intervals 2065-2155

m, 2155-2725 m and 2725-3000 m, respectively. Sediments of Olpad Formation between 2710-3000 m indicate a poor source potential for oil generation and only dry gas can be expected.

### **Source Potential**

Maturation levels are shown in profile CC' (Figure 7). Organic matter of Miocene and Oligocene sediments are immature and marginally mature respectively. Mature section of Eocene sediments indicates the gas prone capability except Uneli-A and Kalamsar-A between 1835-2200 m and 1700-2190 m indicating good and fair source rock potentials for gas/oil, respectively.

### **Conclusions**

- Dispersed organic matter in sediments is mainly land derived. The presence of phytoplanktons at different levels in the Tarapur block indicate the sizeable input of marine derivatives.
- Miocene sediments are thermally immature (TAI 2.0) throughout the block except in wells Akholjuni-A, Kheda-A, Ras-A, and Watadara-A indicating marginal maturity (TAI 2.25) between 1175-1455 m, 1020-1208 m, 1200-1361 m, 1280-1459 m and 1225-1578 m, respectively.
- Oligocene sediments throughout the Tarapur block are marginally mature (TAI 2.25) and dominated by humic palynofacies, hence little generation of gaseous hydrocarbons is expected, except the extreme western margin well Pisawada-A which is immature.
- Upper part of the Eocene sediments are mostly marginally mature. Top of the oil generative window (TAI 2.5) lies in the Eocene sediments except extreme western margin well Pisawada-A where it is in Early Eocene. Top of oil window in western margin wells Pisawada-A and Mitli-A and South-western well Akholjuni-A lies between 1455 m and 1565 m and beginning of intense generation phase of liquid hydrocarbons between 1705-1905 m.
- Top of the oil window in western and northwestern wells of Tarapur block, i.e., Mahudha-A, Kheda-A, W. Bhalada-A, Indernauj-A and Akholjuni-A lies around 1320-1585 m in Eocene sediments. Top phase of intense generation (TAI 2.75) lies around 1600-2005 m interval. Retardation of liquid hydrocarbon generation and intense generation of gases have been observed around 2360 m and 2772 m onwards in Mahudha-A and Indernauj-A respectively. Transitional zone TAI 3.5 have been observed in northern most well in Mahudha-A.

- Top of oil window in southeastern flank wells, i.e., Ras-A, Uneli-A, Watadara-A and Kalamsar-A lies between 1570-1700 m in Eocene sediments. Top of intense generation phase for liquid hydrocarbon (TAI 2.75) and retardation of liquid hydrocarbon generation phase (TAI 3.25) are identified around 1735 m and 2705 m respectively in well Uneli-A.
- Effective source rocks with oil and gas prone capabilities have been observed in Early Eocene sediments of Pisawada-A between 1505-1825 m and Eocene sediments between 1680-1845 m and 1715-1760 m in Mitli-A and Akholjuni-A, respectively. Otherwise whole of the mature sections are dominated by gas prone capabilities.
- Western and northwestern flank wells, e.g., Mahudha-A, Kheda-A, W. Bhalada-A and Indernaj-A indicate the oil and gas prone capabilities of the sediments between 1330-1585 m, 1900-2050 m, 2125-2205 m and 2530-2600 m in Mahudha-A, 1740-2100 m in Kheda-A, 1940-2005 m and 2520-2600 m in W. Bhalada-A, and 1920-2085 m, 2200-2265 m, 2440-2665 m and 2720-2765 m in Indernaj-A with adequate thermal maturity. TAI between 2.75-3.25 indicates a significant oil and gas generation from these sediments. The southeastern flank of the block indicates that the Eocene sediments are gas prone except the interval 1835-2200 m in Uneli-A which indicates good source rock development for oil and gas prone capabilities.
- Overall, organic matter maturation study indicates that a significant amount of liquid as well as gaseous hydrocarbons have been generated by the mature sections of this block.

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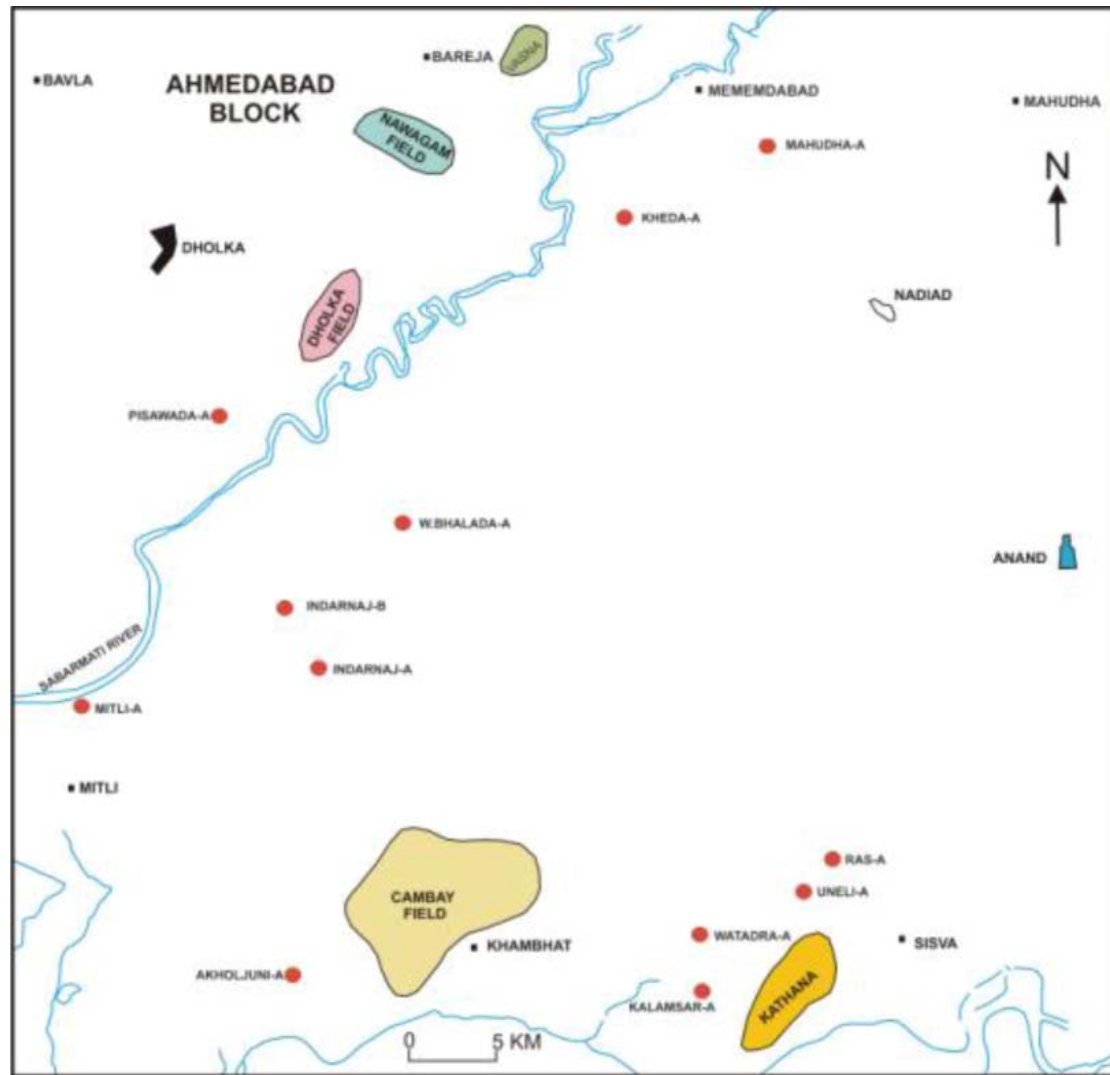


Figure 1. Map showing locations of studied wells in Tarapur block.

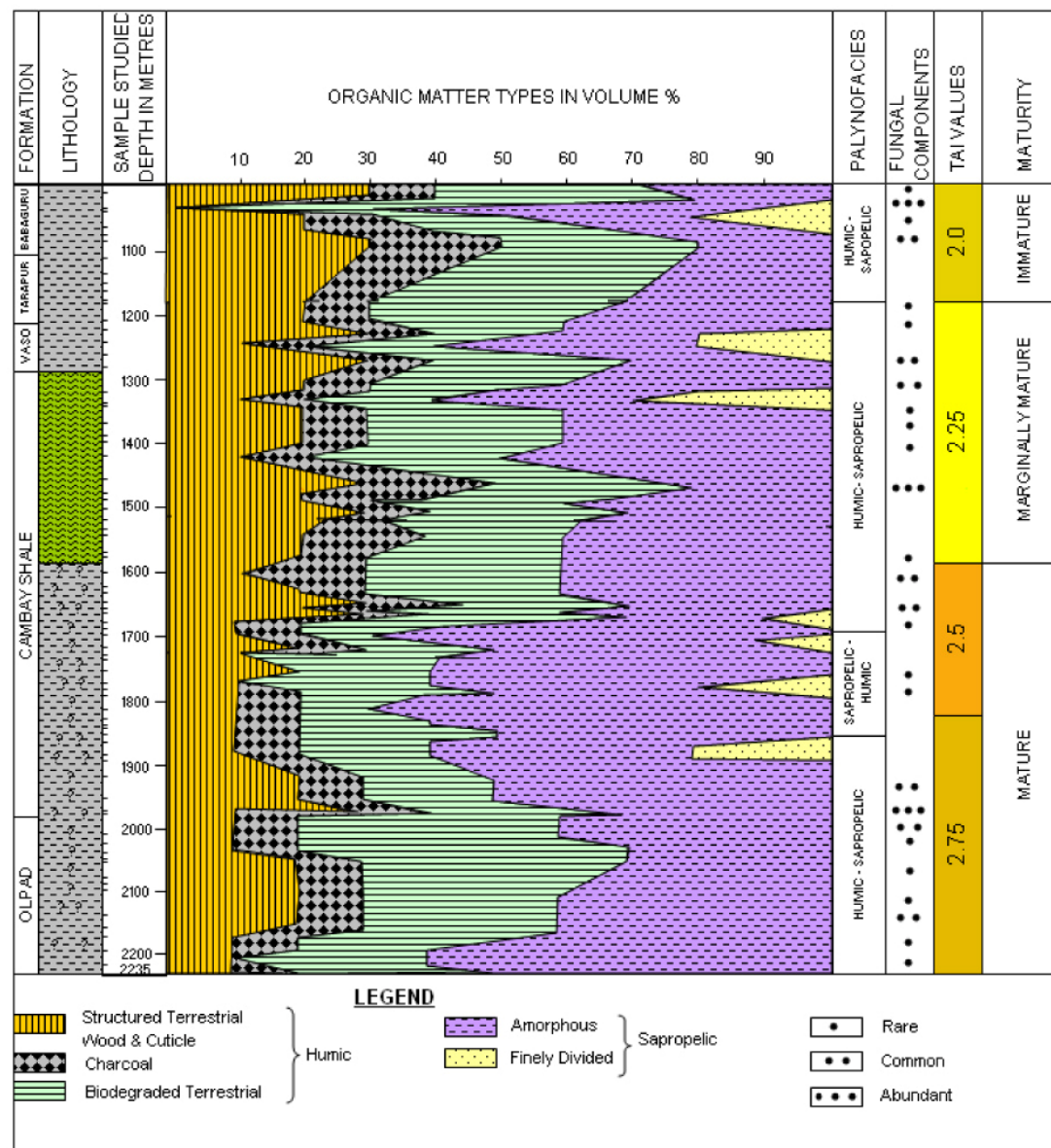


Figure 2. Organic matter types, palynofacies and thermal maturation index values in well Mitli-A, Tarapur Block, Cambay Basin.

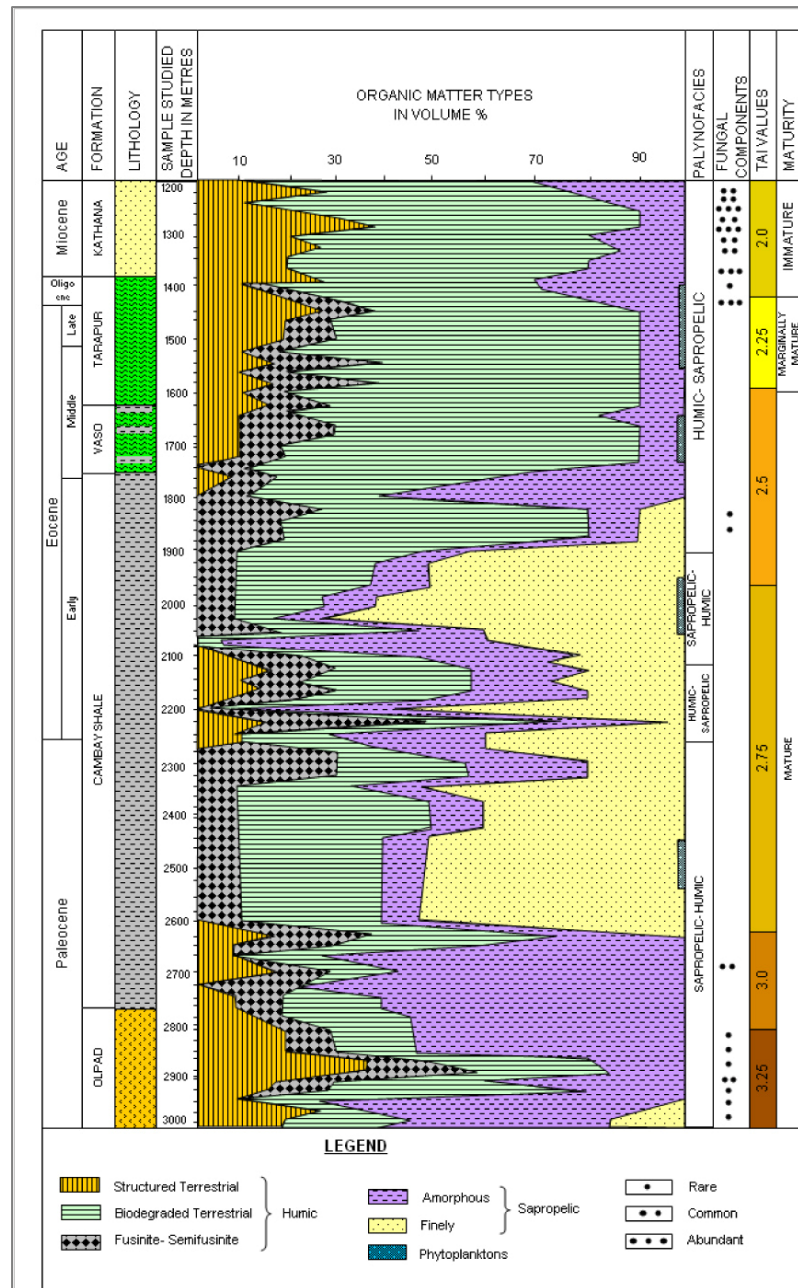


Figure 3. Organic matter types, palynofacies and thermal maturation index values in well Indernaja-A.



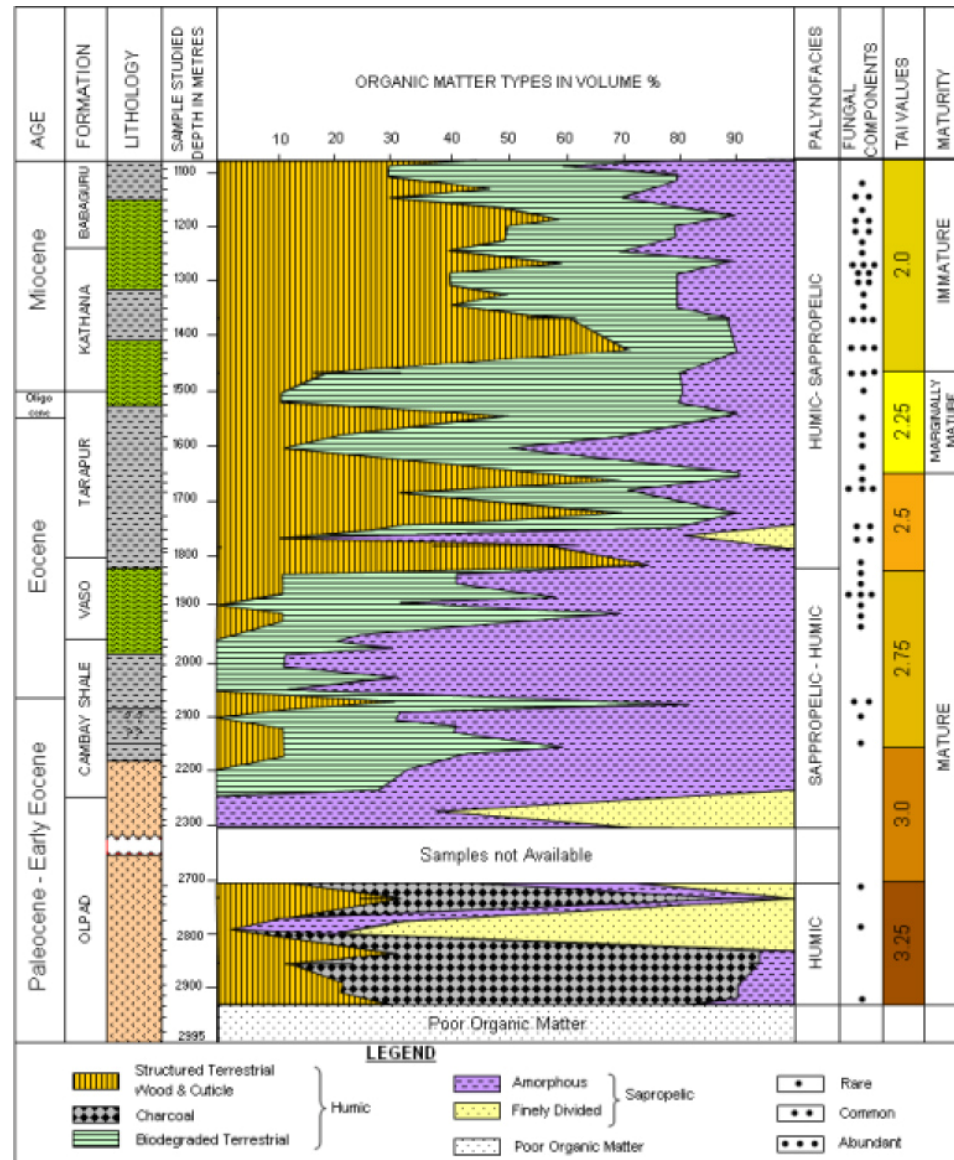


Figure 4. Organic matter types, palynofacies and thermal maturation index values in well Uneli-A.

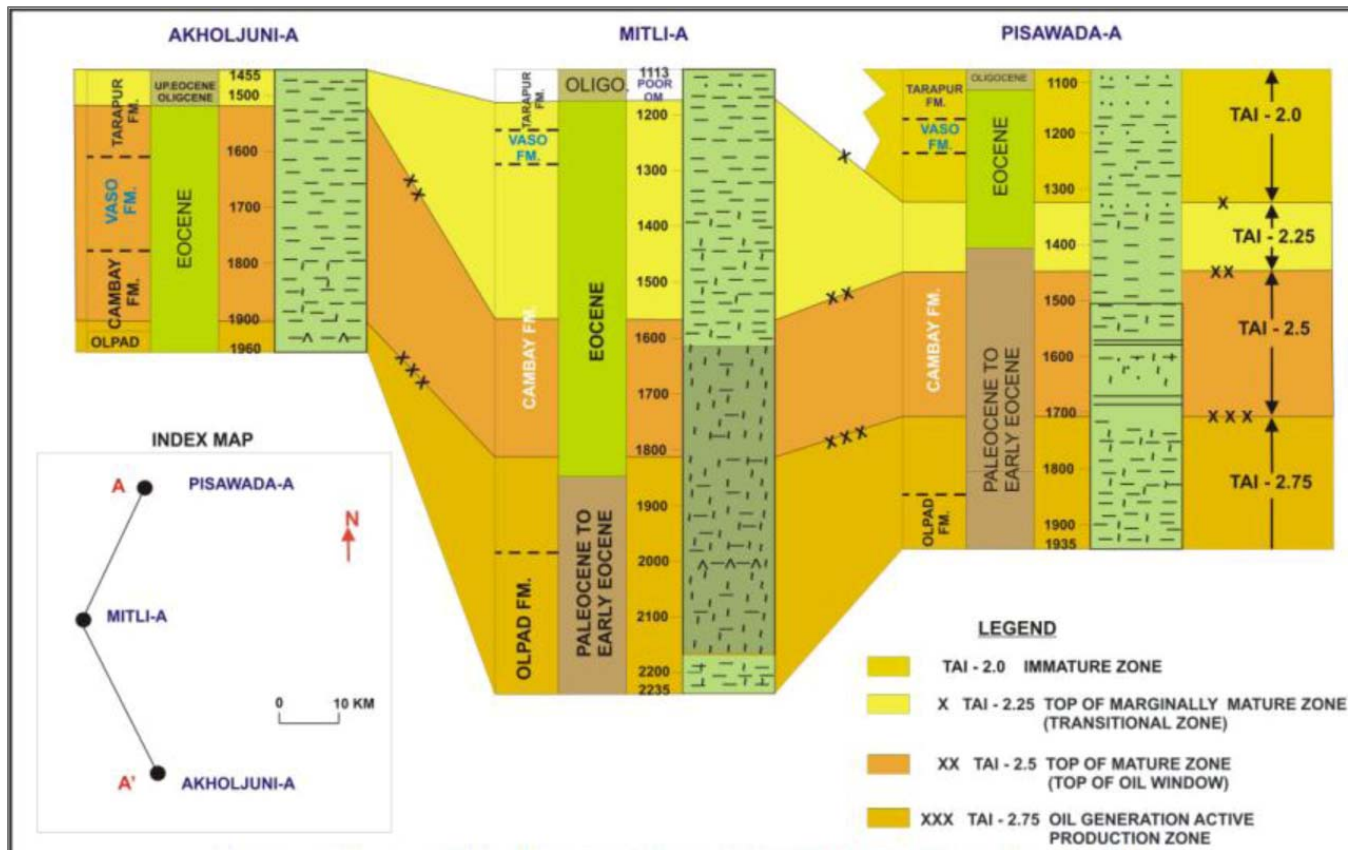


Figure 5. Level of thermal alteration index in Paleogene sequences along western margin of Tarapur block (Profile AA').

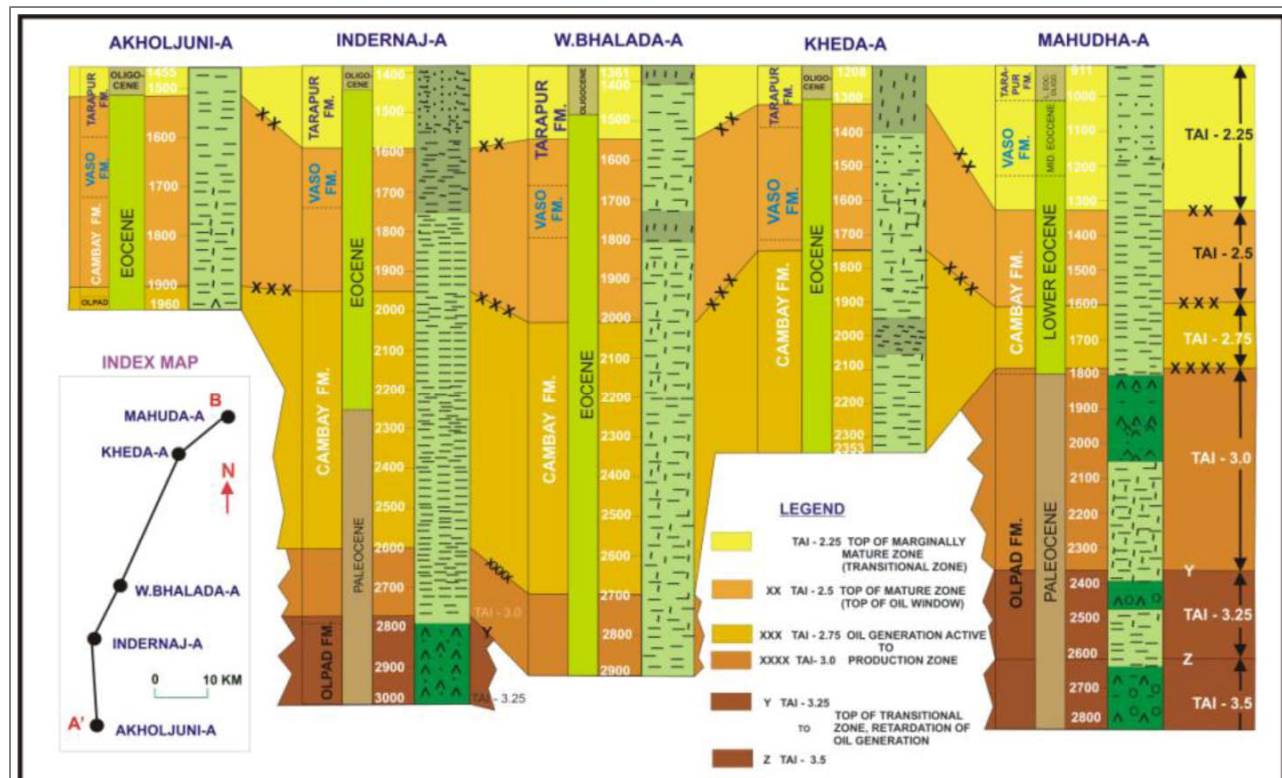


Figure 6. Level of thermal alteration index in Paleogene sequence along northwestern margin of Tarapur block (Profile BA').

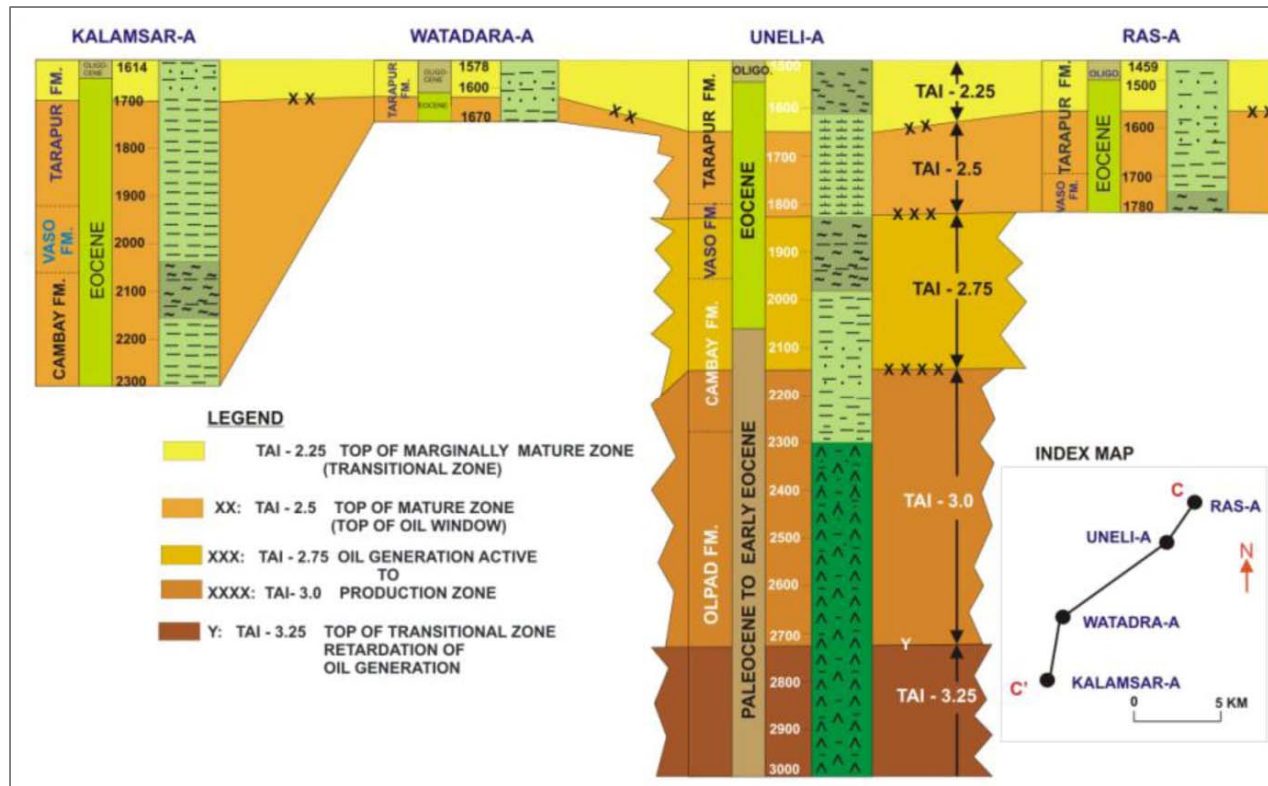


Figure 7. Level of thermal alteration index in Paleogene sequence along southeastern margin of Tarapur block (Profile CC').