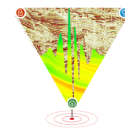




Biomarker evidence of coal bearing zones as oil producing source rock in Mumbai Offshore Basin

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Shweta Chauhan*, Nisha Choudhary, Ishita Dutta, Rashmi Anand, Sapna Sethi
Geochemistry Division, KDMIPE, ONGC, Dehradun, Email: chauhan_shweta@ongc.co.in*

Keywords

Coal source, Terrestrial biomarkers, Oil-Source Correlation, Bicinanes, Bisnorlupane, Oleanoids, Thermal maturity, Early mature, High-resolution spectroscopy

Abstract

Paleocene to Early Eocene coal rich Panna sediments of D-33 of Deep Continental Shelf (DCS), Bassein South East (BSE) and Central Graben (CG) area of Mumbai Offshore Basin have been geochemically analyzed using high-resolution spectroscopic techniques. Biomarker study in this basin reveals that coal within oil window show some peculiar pattern of triterpanes distribution. Higher plant related diagnostic biomarkers such as bicadinanes, bisnorlupane and oleanoids are exceptionally high and sometimes their abundance exceeds the usually most abundant C₃₀ triterpane. Homohopanes are generally low in these sediments. Similar biomarker signatures have been observed in Mukta oils of D-18 and Panna oils of D-33 Structure of DCS Block; Panna oils of A-10 and E-34-2 of Heera-Panna-Bassein (HPB) Block; Panna oils of C-1, E-105-4 and E-188-1 in north-west part of Mumbai High rendering these oils to be derived from coal source. Peak to late thermal maturity of these oils and positive oil-source correlation are suggestive of deep coal rich Panna sequences of their respective block as probable source of these oils. Good abundance of oleanoid triterpanes, high thermal maturity and occurrence of these oils near basinal lows suggest close proximity of these oils to their respective source. Early mature oils have also been observed in Oligocene reservoirs of wells F-13 and F-16 of South Bassein Field. Low API gravity (20.49° & 26.0°), high asphaltene content, biomarker and non-biomarker maturity parameters, all strongly suggest these oils to be generated locally by an early mature source rock. Moreover, positive oil-source correlation of these oils with Panna sediments, as observed in F-13 locale, further corroborates the later. Findings of the study suggest that the oils of Mumbai Offshore Basin are derived from different types of source rock viz., terrestrial shale, marine shale, carbonaceous shale and coal, generating hydrocarbons in entire maturity range (from early to late) of oil window. The oils are generated within their respective blocks and have not migrated from distant lows.

Introduction

Biomarkers present in crude oil and sediment extract play a crucial role in geochemical characterization, correlation, differentiation and source identification. Detailed geochemical analysis of the crude oils helps in understanding the characteristics of the source rock(s) from which these oils were generated thereby leading to fine-tuning of petroleum system(s) of a basin.

Whether, and to what extent generated liquid hydrocarbons are expelled by coal, has long been the subject of vigorous debate in 'oil from coal' studies. Unambiguous evidence of expulsion from coals is limited and in particular only a few commercial oil discoveries can be confidently correlated to coals. These include Upper Cretaceous Fruitland Formation coals in the USA, from which oil is produced; New Zealand Tertiary coals; and Middle Jurassic coals from the Danish North Sea. Coals have contributed to significant oil discoveries in the Gippsland Basin, Australia; in the Turpan Basin, China; and in the Kutei and Ardjuna Basins in Indonesia, but this remains unproven.

Present study utilizes high-resolution spectroscopic techniques viz., Gas chromatography-Mass Spectrometry (GCMS) and Gas chromatography-tandem mass spectrometry (GCMS/MS) for decoding various source organofacies related biomarkers in oils. Coal and coal bearing sediments have been critically examined and correlated with oils of Mumbai Offshore Basin. Tectonic blocks of Mumbai Offshore basin are shown in Figure 1.

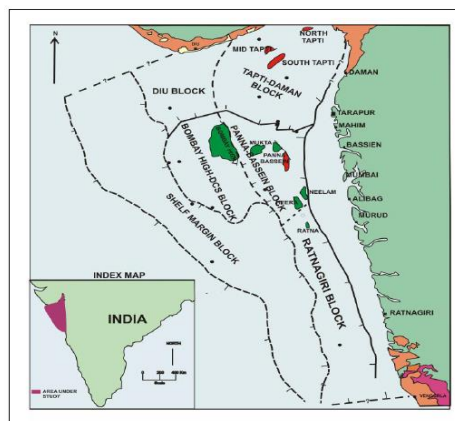
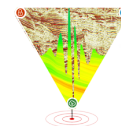


Figure 1: Tectonic blocks of Mumbai Offshore Basin



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Experimental

Crude oils and sediments: Oil samples were topped to 210°C and the residue was separated into asphaltene and maltene. Bitumen extraction of the sediment samples was done by Dichloromethane and Methanol mixture in the ratio 93:7 through Soxhlet extraction. The concentrated extractable organic matter (EOM) and the asphaltene free oils were fractionated into saturate and aromatic fractions through column chromatography using alumina:silica gel (1:1) column by successive elution with petroleum ether and toluene. The saturate fraction was further separated into normal alkanes and branched/cycloalkanes by urea adduction.

GC & GC-MS analysis: Saturate fraction of the oils were analyzed for normal alkanes and isoprenoids distribution on Gas Chromatograph (Shimadzu GC-2010 Plus) using 30 m x 0.25 mm x 0.25 µm fused silica capillary column (SH-RTx-1) programmed as follows: 80°C increased @ 4°C/min upto 300°C and final hold time of 30 minutes. Branched/cycloalkanes were analysed on GCMS Shimadzu QP2020 using fused silica capillary column RTx-1MS (30m x 0.25mm x 0.25µm) and Helium as carrier gas. Initial oven temperature was kept at 80°C with 2 minutes hold time, increased @ 3°C/min up to 300°C with final hold time of 15 minutes. The aromatic fractions were also analyzed for the distribution of phenanthrene and methyl isomers of phenanthrene on GC-MS (Shimadzu QP2020) using fused silica capillary column DB-5MS (30m x 0.25 mm x 0.25µm) and Helium as carrier gas. Initial oven temperature was kept at 60°C for 1 min, increased @ 2.5°C/min up to 260°C and then increased @ 3.5°C/min up to 300°C with final hold time of 5 minutes at 300°C.

GCMS/MS analysis: Branched/ cycloalkanes were analysed on Triple Quadrupole Mass Spectrometer (GC-MS/MS Shimadzu TQ8040) using fused silica capillary column RTx-1MS (30m x 0.25mm x 0.25µm) and Helium as carrier gas and Argon as collision gas. Initial oven temperature was kept at 80°C with 2 minutes hold time, increased @ 3°C/min up to 300°C with final hold time of 30 minutes.

Results and Discussions

The clastic sediments of Panna Formation, in the Paleocene to Early Eocene sequence, is the principal source rock of Mumbai offshore Basin spreading over the entire basin except the Paleo highs. It was deposited in a fluvio-deltaic environment, sometimes even in a restricted marine set-up. The heterogeneous nature of Panna in terms of shale source and coal source increased the

source potential of the formation drastically. With changes in geological history, its elevation difference created depocenters, rendering it as an excellent source not only at one point; in fact, it expelled hydrocarbons from varied source points at different maturity stages at varied geological time scale.

Biomarker analysis of source rock

Sediment samples from Panna Formation having effective source sequences were analysed for detailed geochemical and molecular level studies.

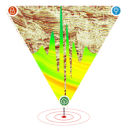
Sediment samples from wells H-33-5 and H-33-2 of DCS Block and wells P-1, A-10 and A-13 of HPB Block were analysed for biomarker studies. Abundance of coal in lithology of sediment samples has been observed from Master logs of drilled wells for correlation purpose.

The m/z 191 triterpane fragmentograms of studied sediments from wells H-33-5 and H-33-2 are characterized by good abundance of bicadinanes, 17β(H)-24,28-bisnorlupane (BNL) and oleanoids suggesting dominantly terrestrial higher plants related source input. BNL is common in extracts of coals and lignites (Armanios et al., 1995b; Stefanova et al., 1995). Bicadinanes are derived mostly from polycadinene, a resinous polymer produced by angiosperms such as the *Dipterocarpaceae* (Alam and Pearson, 1990; van Aarssen et al., 1990, 1992; Murray et al., 1994). Oleanoids also indicate terrigenous plant matter and are believed to be higher in oils reservoirs near the source (Murray 1998). The presence of oleanoid triterpanes may signal in situ, as opposed to allochthonous deposition of terrestrial organic matter. Sediments having high coal percent or 100% coal in lithology show somewhat different triterpane fingerprints than usual. Abundance of bicadinanes, BNL and oleanoids is quite high and sometimes exceeds the usually most abundant C₃₀ triterpane and homohopanes are low in abundance. This is the case in studied coaly Panna sequences of wells H-33-5 and H-33-2 (Figure 2). All the studied depth intervals of H-33-2 and H-33-5 are within oil window.

Organofacies variations have been observed vertically within the well in studied sediments of wells P-1, A-10 and A-13 of HPB Block. Studied upper Panna layers in these wells show low abundance of terrestrial biomarkers (bicadinane and bisnorlupane) despite of having coal in lithology. No signatures typical of coal have been observed in their mass chromatograms. This is because the sediment samples are immature and as soon as a rock sample having coal in lithology



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enters oil window, mass chromatograms typical of coaly signatures can be seen viz., increased abundance of resinous and angiosperm flowering plants derived biomarkers such as bicadinane (BCD), BNL, oleanoid, oleanane (OL) and taraxastane (T). Coal rich sediments are also characterized by $T_s > T_m$, sometimes high C_{30}

diahopane (C_{30}^*) and C_{28} steranes, high ratio values of $C_{19}TT/C_{23}TT$ and $C_{24}TeT/C_{30}H$. In studied lower Panna layers significant marine source input has been observed. Coal content and abundance of terrestrial biomarkers are very low in lower Panna layers as shown in Figure 3.

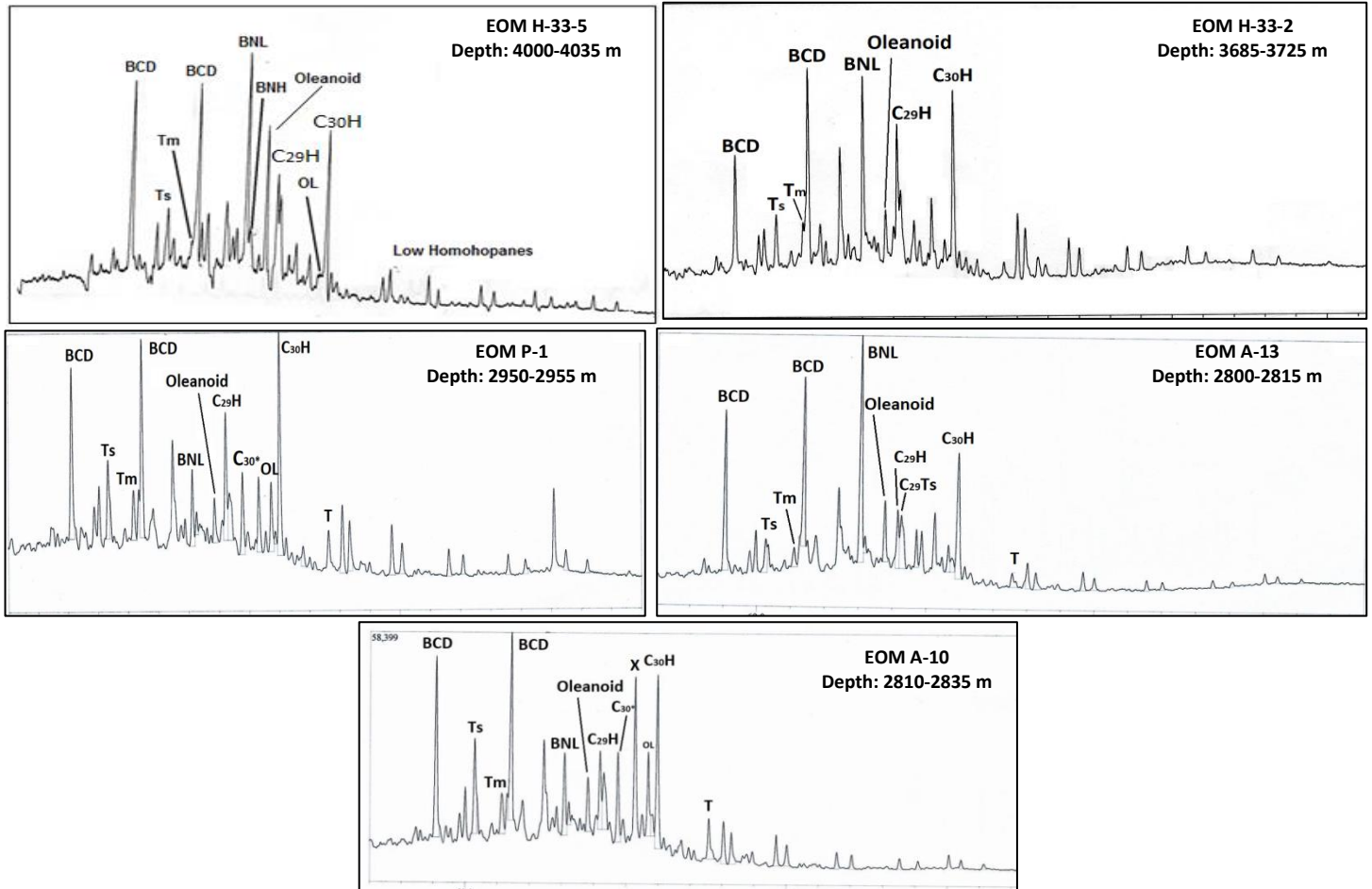


Figure 2: Triterpane fragmentograms (m/z 191) showing biomarker signatures of coaly source from studied wells of DCS and HPB Block

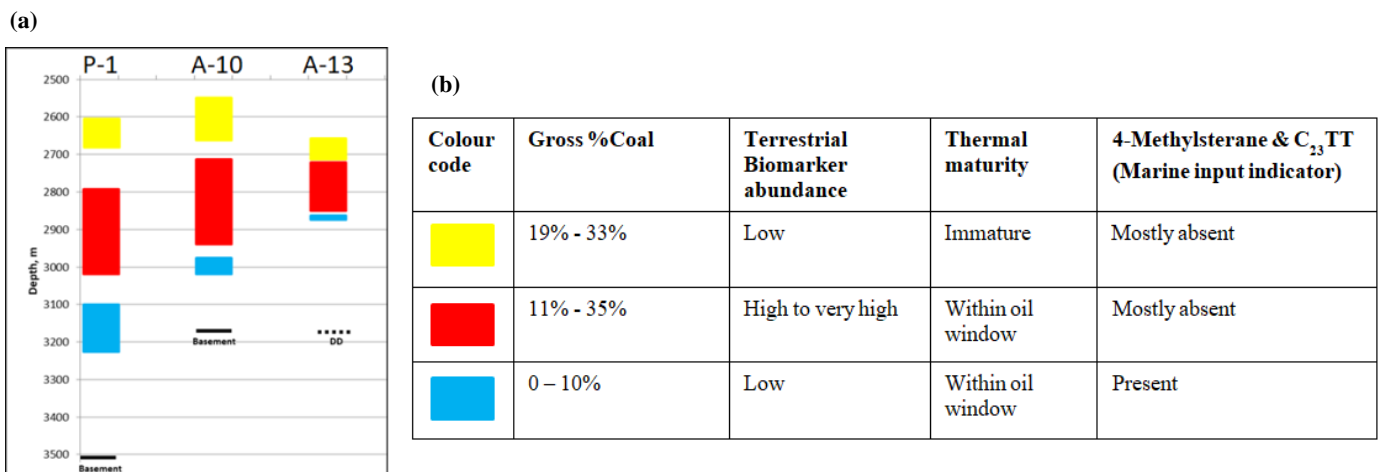
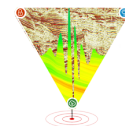


Figure 3: (a) Organofacies variation within Panna Formation vertically and laterally in BSE and CG area (b) Gross coal percent, biomarker characteristics and thermal maturity for studied depth intervals of Panna Formation shown in Figure 3(a)



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Biomarker analysis of crude oils

Oil samples from WO-DCS and HPB Block were geochemically analyzed to observe the coaly source imprints in crude oils. In DCS area, Mukta oils of D-18 and Panna oils of D-33 Structure are characterized by exceptionally high abundance of BNL, bicadinanes and absence/very low homohopanes suggesting resinitic coaly source rock(s) for these oils. This peculiar type of oils shows positive oil-source correlation with coal rich sequences of D-33 Field (Figure 2), rendering coal sequences of DCS area as oil-producing source rock. D-1 oils are also generated from coal/carbonaceous shale at earlier maturation (moderate thermal maturity) than typical coal-derived D-18 and D-33 oils. Similarly, in HPB Block, Panna oils of A-10 and E-34-2 indicate resinitic coaly source. A-10 oil is likely generated from coal rich Panna sequences as observed in wells of BSE and CG area (Figure 2). Oils from nearby fields of well E-34-2 viz., B-28/28A, B-23A and B-80 and from nearby wells of well A-10 viz., A-6 and A-11 oils are probably generated from carbonaceous shale. Oils generated from resinitic coaly source have also been observed in north-west part of Mumbai High viz., Panna oils of C-1, E-105-4 and E-188-1. Coal derived oils of this basin are thermally more mature (peak to late maturity) as compared to other oils (moderate to peak maturity) indicating that these oils are generated by deeper coaly Panna sequences highly rich in land plant input. High thermal maturity, good abundance of oleanoid triterpanes and occurrence of these oils near basinal lows suggest close proximity of these oils to their respective source. Triterpane fingerprints of oils from D-18, D-33, E-34-2 and A-10 are shown in Figure 4.

Geochemical analysis suggests that oils from Cluster 7 area (WO-24, B-192, B-203, B-45) exhibit geochemical similarity with oils from Mukta Field (B-57, B-59, B-126, B-127, B-147, B-149 & B-154 structures) and with majority oils of HPB Block viz., Neelam & Heera Fields oils, oils from wells A-2, A-3A, A-4A, N-1 (Obj-III), P-1, F-10, F-13 (Obj-I) and B-172, B-173/3A, B-174, B-178/178A, B-182, B-193 structure oils suggesting similar source organofacies and terrigenous source rock for these oils (Figure 5). These oils are generated at moderate to peak maturity of source rock. However, some marine source derived oils have also been observed in this basin as shown in Figure 5. Marine oils of HPB Block viz., N-1, E-172-9 and N-8-3, are likely generated from studied lower most Panna layer as shown in Figure 3. Few early maturity oils viz., Oligocene/Heera Formation oils of F-13 and F-16 (%VRc: 0.56 & 0.69 respectively) have also been observed in South Bassein Field. Low API gravity (20.49° & 26.0°), high asphaltene content, biomarker and non-biomarker maturity parameters, all strongly suggest these oils to be generated locally by an early mature source rock. The oils show positive oil-source correlation with Panna sequences as observed in F-13 locale. All these observations indicate local generation of these oils by early mature Panna source sequences.

All the above-mentioned geochemical findings in WO-DCS and HPB block of Mumbai High are depicted in Figure 5. Findings suggest that the oils of Mumbai Offshore Basin are derived from different types of source rock viz., terrestrial shale, marine shale, carbonaceous shale and coal generating hydrocarbons in entire maturity range (from early to late) of oil window. The oils are generated within their respective blocks and have not migrated from distant lows.

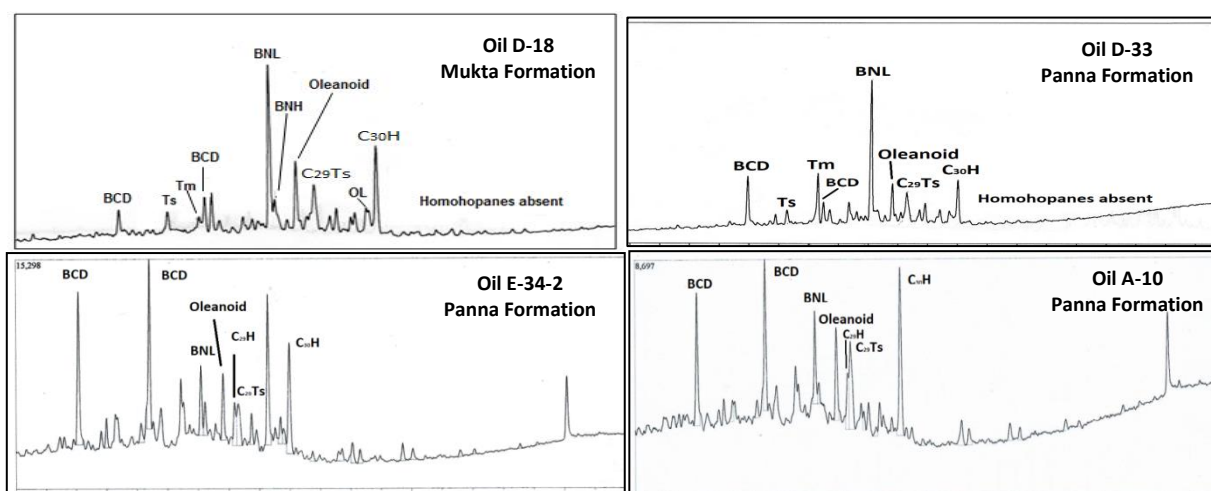


Figure 4: Triterpane fragmentograms (m/z 191) showing biomarker signatures of oils generated from coaly source

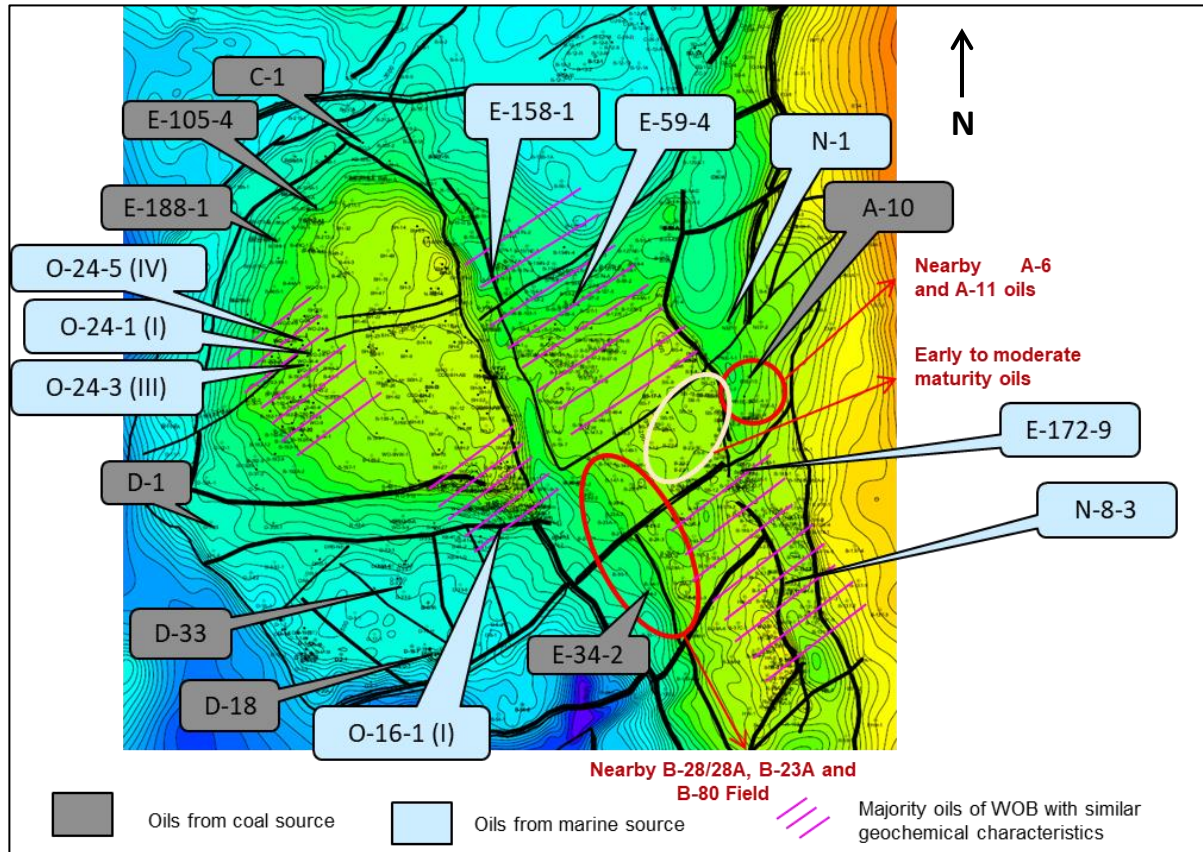


Figure 5: Geochemical findings in WO-DCS and HPB Block on structure map close to Panna (H4)

Conclusions

Only a few oil discoveries worldwide could be correlated to coal as source. Present detailed biomarker study on coal rich Panna sediments and crude oils of Mumbai Offshore Basin reveals resinitic coaly source for Mukta oils of D-18 and Panna oils of D-33 Structure of DCS Block; Panna oils of A-10 and E-34-2 of HPB Block; Panna oils of C-1, E-105-4 and E-188-1 in north-west part of Mumbai High. Coals and oils expelled by them show an unusual pattern of triterpanes distribution. These are quite rich in higher plants diagnostic biomarkers viz., bisnorlupane, bicadinanes, oleanoids while homohopanes are generally low. Peak to late thermal maturity, high abundance of oleanoid triterpanes and occurrence of these oils near basinal lows suggest close proximity of these oils to their respective source. Findings suggest deep coal rich Panna sequences of respective blocks as probable source for these oils. Few early mature oils have also been observed in South Bassein Field. It is likely that these oils are generated locally by an early mature Panna source.

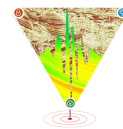
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