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Identification of source pods using biomarkers as a tool for Mumbai High oils, India

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Summary

Biomarkers are used as a tool for predicting the source kitchens. About 40 oils of wells from the periphery and nearby Mumbai High were studied. The oils of this block are terrestrial in origin and have similar triterpane (m/z 191) and sterane (m/z 217) fingerprints in general. Yet, there are distinct signatures; Bisnorhopane, 4-Methyl C30 Sterane, Bicadinane etc, differentiating their source organic facies. Oil to oil correlation and oil to source correlation are used to predict the source kitchens.

South Mumbai depression has thick and effective rich source depositions in Panna clastics of Paleocene sequence especially in central part of Deep Continental Shelf. The wells NE of Mumbai High, Mukta area possess effective source rock in the Paleocene to Early Eocene and lower part of Middle Eocene sediments.

The variation in paleo environment of deposition of similar terrestrial organic matter in the sediments gives rise to the distinct biomarker signatures which differentiates the Mumbai High oils into three distinct groups. These oils may have been sourced from more than one source pods i.e C, B and NE of Mumbai in Mukta area.

Keywords: *South Mumbai depression, Bicadinane, Oleanane, Bisnorhopane, δC^{13} saturate.*

Introduction

Geological settings

Mumbai platform, a part of the shelf horst-graben complex, is bounded by Mumbai High main fault in the east, Miocene hinge in the west & south and Diu fault in the north. It comprises of Mumbai ridge including Mumbai High and a westerly dipping homocline surrounding the Mumbai High with 'B' series of structures, 'WO' series of wedge out prospects, Deep Continental Shelf with 'D' series of structures and south Mumbai depression.

The southern Mumbai depression occurs in the South West of DCS area which is a major depression and plunges towards South East. North East of Mumbai High (Mukta) dips down in N-157C-1. The N-55 structure in east of Mukta is in the ridge of Central graben & N-157C-1 low. Prospect map and general stratigraphy of Mumbai Offshore Basin are given in figures 1 & 2 respectively.

Petroleum Geology

The hydrocarbon bearing area of the Mumbai High field is about 1300 sq. km with a maximum vertical closure of about 200 m. A number of pay zones, ranging in age from Precambrian/Late Cretaceous Basement to Miocene, have been identified. L-III limestone, the main producer, is well developed all over the field and has a maximum hydrocarbon column of about 180 m. Other reservoirs, L-I, L-II, F-27, S- 1, La, Le, Lf, Lg, L-IV, L-V, L-VI, Basal sandstone and fractured Basement are also oil and gas bearing.

Fig.1 Prospect map of Mumbai Offshore Basin

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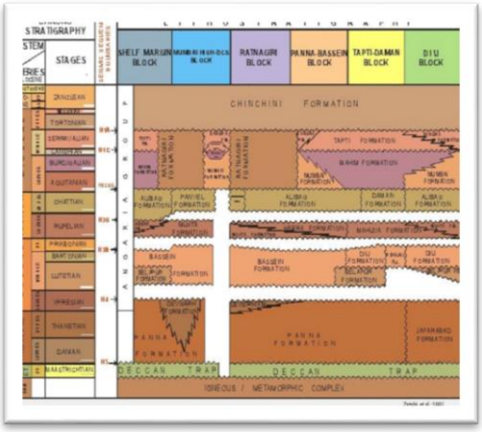

Fig.2 Stratigraphy of Mumbai Offshore Basin Methodology and Result

Experimental

Source rock analysis

Cuttings samples were processed for TOC analysis by grinding followed by their acidification, washing and drying. Approximately 150- 200 mg. of sample was taken for total organic content determination by using Carbon determinator instrument. The water washed dry cutting samples were finely crushed and screened through BSS-60 and retained over BSS-100 were analysed using RockEval-VI. Approx. 70 mg of the sample was taken in each analysis. Burial history and Maturity Modeling were carried out for some of the wells using Genex 1D software.

Oil/ bitumen analysis

Oils (topped to 210°C) and bitumens (Extracted OM from finely crushed Panna sediments) were fractionated on dual packed silica-alumina column using petroleum ether (40°C - 60°C), benzene and methanol as eluants sequentially to obtain saturate (saturated hydrocarbons), aromatic and NSO fractions, respectively. Iso- and cyclo-alkanes were separated from normal alkanes in the saturate fraction by the usual method of urea adduction.

Whole oils and saturate fractions of oils/bitumens were analyzed using Schimadzu 2010 on fused silica capillary column (WCOT DB-1, 30 m x 0.25 mm x 0.25 µm). Detector and injector were maintained at 310°C and column temperature was programmed from 50°C to 300°C @ 4°C/minute. Gas Chromatography-Mass Spectrometric (GC-MS) analyses (in total scan mode) of Branched / cyclic alkane fractions of saturate hydrocarbons of oils were analyzed on Perkin Elmer Clarus 500 Mass Spectrometer using DB-1MS (30m x 0.25mm x 0.25µm) fused silica capillary column. Initial column temperature was 80°C. Rest of the conditions for GC–MS analysis were the same as mentioned above for GC analysis.

Isotopic Analysis

Stable carbon isotopic study was carried out on VG Iso Prime Continuous Flow-Isotope Ratio Recording Mass Spectrometer interfaced with Euro EA elemental analyzer, equipped with a chromium oxide-silvered cobaltous-cobaltic oxide oxidation reactor at 1020°C and a copper reduction tube maintained at 650°C. Standard CO_2 gas is employed as reference to calibrate the measured carbon isotope ratios of samples. The mass spectrometer is standardized using an international standard NBS-22. Standard samples are also included in each run.

Results & Discussion

Regional source rock characterization

Paleocene - Early Eocene (Panna Formation) is the major source rock in Mumbai Offshore Basin. Development of source facies is witnessed in almost all the wells wherever Panna Formation has been encountered. The thickness of Panna sediments in wells of Western Offshore Basin (WOB) is given in figures 3a &b. Depletion in source rock quality and quantity, is inferred from geochemical data, from the South Mumbai depression to central part of Mumbai High. Sporadic development of source facies is observed in North of Mumbai High area. Thickening of mature source rock deposition in this succession is witnessed from central to southern part towards wedge out structure of Mumbai High, e.g. from 2m thin deposition in the well N-105-5 in the north to 30m in the well N-147-5 and 75m in well V-5-10. The Panna source rocks, is dominated by siliciclastic and carbonate rocks with intermittent beds of coal and carbonaceous shale in wells of the south Mumbai depression of Mumbai High in DCS area. The Panna sediments in central part of DCS area are rich in organic matter with excellent effective source rock in BA, M & C wells. The effective source thickness varies from streaks in E-1 & F, N-45-2(50 m), M-1 (50m), B-1/BA-1 (150m) that goes up to 300m in C in DCS area.

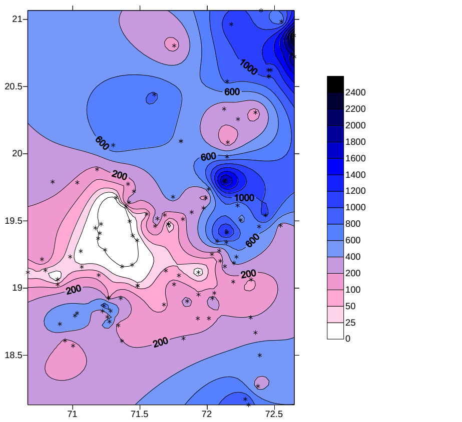

Fig.3a Thickness of Paleocene to Early Eocene sediments of wells of WOB.

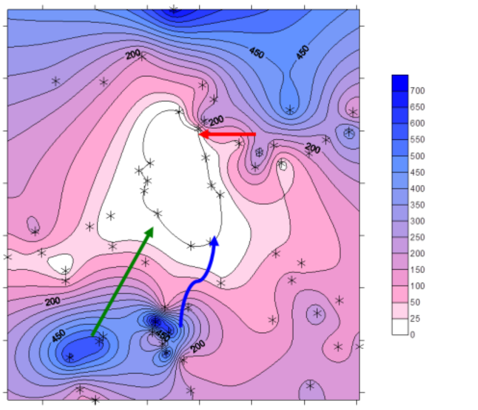

Fig.3b Thickness of Paleocene to Early Eocene sediments of wells around Mumbai High.

The rest of wells in DCS are devoid of effective source rock deposition. The organic matter in these wells are of Type III kerogen except in the well M-1 where it is kerogen of mixed type II+ III category.

The source rock quality and thickness of Paleocene to Early Eocene sediments in the NE of Mumbai High (Mukta area) increases from N-15A (poor) in the west, N-15B (fair), N-55 (50m) in the east, good in N-154-2 (100m), N-127-3(150m) in the south and good to excellent in the deepest well N-157C-1 (260m).

The bottom of the Middle Eocene, Bassein section (3340 - 85m) of N-157C-1 along with Panna section indicated effective good to excellent source rocks (305m). Wells of Mukta field viz. N-157C-1, N-55-2, N-153-1 and N-57-1 found to exhibit effective source rock development in Middle Eocene (Bassein Formation) also. Kerogen is mainly type II+III.

Maturity windows geohistory curves

Representative wells N-154-2, N-157C-1, BA-1 & C-4 from the area, have been selected for carrying out maturity modeling study using Genex 1D Software. The results indicate that oil window corresponding to 0.6 % VRc commences at ~2960m in Early Oligocene and at ~2850m in Late Oligocene sequence in wells BA-1 & C-5 respectively. The maximum maturity achieved at the Paleocene bottom is equivalent to 0.9 % VRo & 1.3 % VRo in BA-1 & C-5 wells respectively. Panna sediments of BA & C have generated liquid HC from Early Miocene age and are at present in catagenetic to metagenetic maturation stage especially in the well C-5. The onset of liquid HC generation is about 36 Mya & gas with liquid HC generation is about 26 Mya in N-157C-1 and the onset of liquid HC generation is about 8 Mya in N-154-2. Figures 4 & 5 depict the maturity & hydrocarbon windows geohistory curves of C-5 & N- 154-2 respectively.

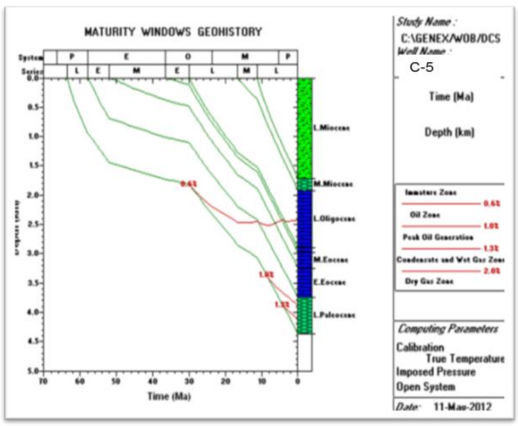

Fig.4 Maturity windows geohistory of C-5.

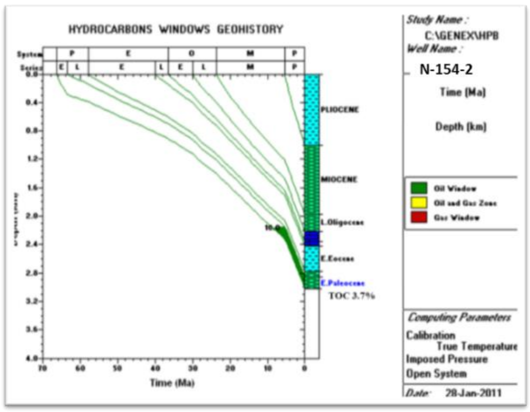

Fig.5 Hydrocarbon windows geohistory of N-154-2.

Geochemical Characterization of oils and EOM

Bulk & GC parameters

The oils are light (API 30-45), waxy, paraffinic in nature and the pour point of the oils are in general high (>18). The saturate /aromatic ratio of these oils ranges from 1-5. The GC profile shows the presence of higher n-alkanes which extends up to C35 indicating the contribution of terrigenous lipids and waxes.

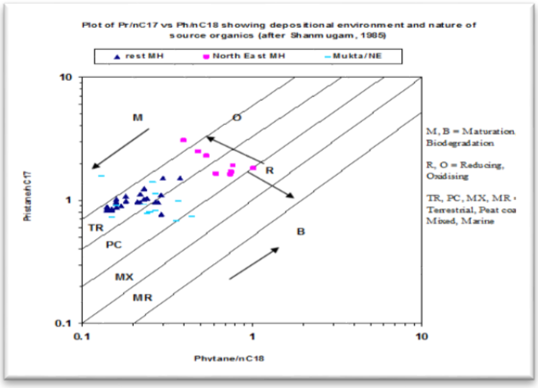

Fig.6 Plot of Pr/nC17 vs Ph/nC18 showing depositional environment and nature of source organics for oils of MH & nearby

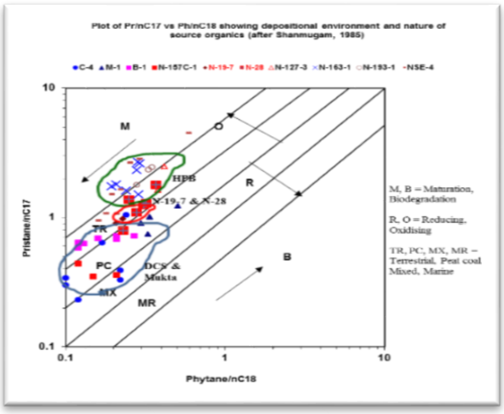

Fig.7 Plot of Pr/nC17 vs Ph/nC18 showing depositional environment and nature of source organics for EOM from Panna sediments of wells from south Mumbai depression,Mukta & Heera Panna bassein block

Biomarker Analysis of Oils & EOM

The triterpane & sterane fingerprints are shown in figures 8, 9 & 10. The triterpane fingerprints of oils/EOMs from sediments show the presence of usual hopane homologous series, i.e., C27 (Tm and Ts), C29 (hopane), C30 (hopane and moretane) and C31-C35 homohopanes (22S and 22R isomers). Oleanane(Ol) & Bicadinanes (BCD) are present indicating contribution from higher plant. The dominance of C29 steranes over C27 & C28 for the oils/EOM further confirms that they are terrestrial source organics. Thus it can be inferred that oils were generated from similar source organics.

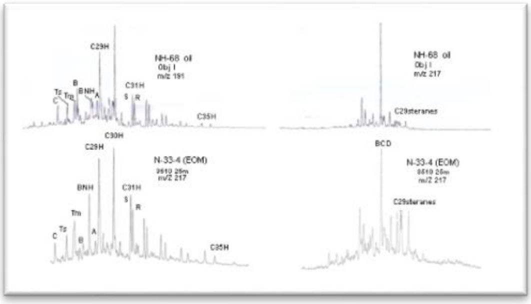

Fig.8 Mass chromatograms showing the triterpane (m/z 191) & sterane (m/z 217) distributions in NH-68 oil & EOM from Panna sediments of C-4.

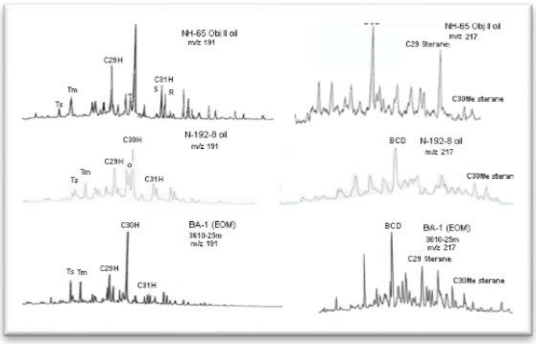

Fig.9 Mass chromatograms showing the triterpane (m/z 191) & sterane (m/z 217) distributions in NH-45 & N-192-8 oils & EOM from Panna sediments of BA-1.

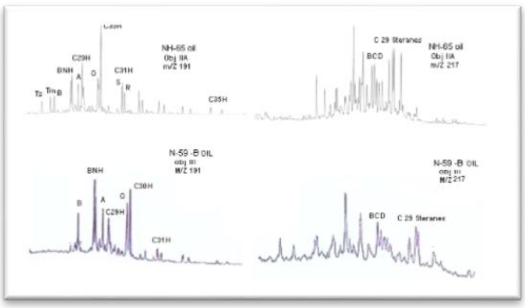

Fig.10 Mass chromatograms showing the triterpane (m/z 191) & sterane (m/z 217) distributions in NH-65 (Bombay Formation) & N-59B (Panna Formation) oils.

The variation in paleo environment of deposition of similar terrestrial organic matter in the sediments gives rise to the some distinct peaks which differentiates the oils/EOM. Based on the distinct biomarkers, Bisnorhopane (BNH) and unidentified peaks A, B & C in the triterpane fingerprints and of C-30 methyl sterane & varying amount of Bicadinanes, the oils of Mumbai High are classified into three groups.

Group I (Bisnorhopane (BNH) and unidentified peaks A, B & C in the triterpane fingerprints and dominant Bicadinanes in sterane fingerprints). The oils from wells on the SE & South of Mumbai High & EOM from C area fall in this group (Fig.8).

Group II (absence of Bisnorhopane and unidentified peaks A, B & C in the triterpane fingerprints. Presence of dominant Bicadinanes peak and C-30 methyl steranes in sterane fingerprints). The oils from wells on the SW & South of Mumbai High & EOM from B area belong to this group (Fig.9).

Group III (Bisnorhopane (BNH) and unidentified peaks A & B in the triterpane fingerprints and less dominant peak of Bicadinanes in sterane fingerprint). The oils are from wells on the North & North East of Mumbai High (Fig.10).

Maturity of oils

The homohopane isomerisation reactions as indicated by the parameter, 22S/(22S+22R), C32 hopanes has achieved the equilibrium maturation level and has crossed the diagenetic- catagenesis boundary for the oils. C29 sterane based maturity $\beta\beta/(\alpha\alpha(20S+\alpha\alpha 20R)+\beta\beta\ (20S+\alpha\alpha 20R)$ given in the plot, Fig.11 indicates that the oils of North MH has less maturity in comparison to other oils having moderate (SE MH) to high maturity(SW MH) indicating source kitchens at shallower depths & deeper depths.
The ratio of ßß/(xx20S+xx20R+ßß), C29 steranes maturity value corroborates the values obtained through 1D maturity modeling that the Panna sediments are at present % VRc 0.7 in N-154-2, 0.9% in BA/B-1 and 1.1% in C-4.

Isotopic analysis

The cross plot of δ C13 isotopic value of saturate fraction and aromatic fraction of the oils (Sofer plot, figure 12) show that the oils have terrestrial source organics as input. The Sofer plot also indicates the presence of three groups, one with oils of SW Mumbai High & nearby along with EOM from B/BA-1 is isotopically lighter than the oils of SE Mumbai high & nearby along with EOM from C-33. The oils of NE MH are the heaviest of all. The isotopic analysis also infers three source kitchens for Mumbai High oils.

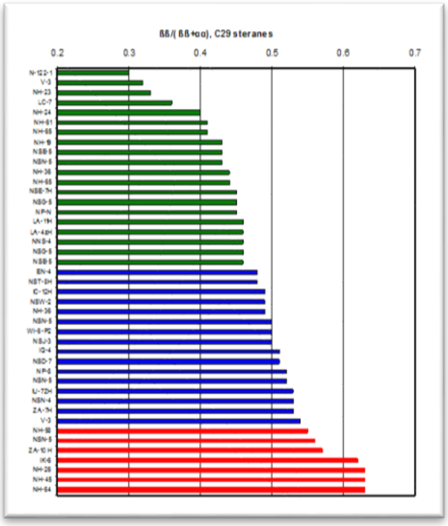

Fig.11 Plot of maturity based on ßß/(ßß+αα), C29 Steranes

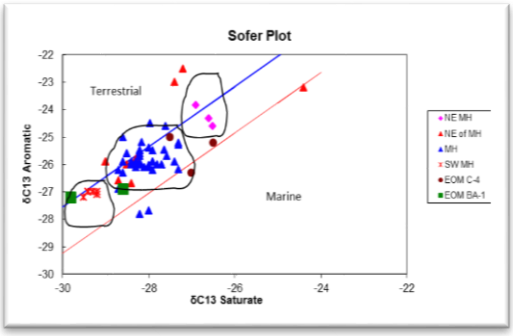

Fig.12 Sofer Plot of oils & EOM

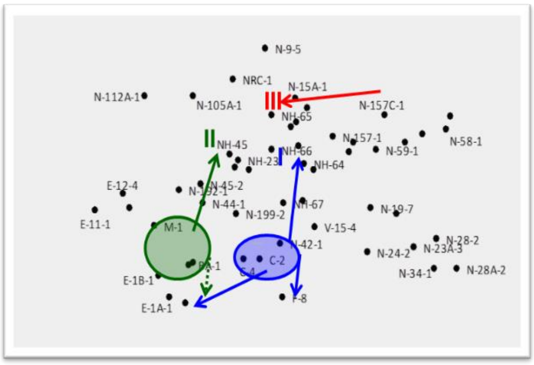

Fig.13 Source pods & reservoir (Mumbai High) – Petroleum systems

Conclusions

1. The oils are light, waxy, paraffinic in nature and the pour point of the oils are in general high (>18). The saturate /aromatic ratio of these oils ranges from 1-5. The oils are generated from terrestrial organic matter deposited in suboxic to oxic environment.
2. Three source pods C, B and NE of Mumbai in Mukta area are depicted in the opposite figure 13.
3. The Paleocene to Early sediments of N-154-2 (NE of Mumbai in Mukta area), B & C has generated oil about 8Mya, 15Mya & 22Mya respectively.
4. The variation in paleo environment of deposition of similar terrestrial organic matter in the sediments differentiates the Mumbai High oils. These oils with distinct biomarkers can be classified into three groups (I, II, III) and possible source kitchens are shown in the Fig.13. Thus three source pods have generated the oils of Mumbai High.

Abbreviations

m/z		**Mass/charge**
C-30		**Carbon number 30**
NE		**North East**
SE		**South East**
SW		**South West**
GC		**Gas chromatogram**
EOM		**Extracted organic matter**
NSO		**Nitrogen sulphur oxygen compound**
OM		**organic matter**
Ts		**18α(H) trisnorhopane**
Tm		**17α(H) trisnorhopane**
nC17		**Normal carbon number 17**
nC18		**Normal carbon number 18**
Pr		**Pristane**
Ph		**Phytane**

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