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Hydrocarbon Prospect Perception of Kerala-Konkan basin-An insight

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Abstract

Kerala-Konkan basin evolved through thermo-tectonic processes of continental rifting-drifting cum sea floor spreading (Kerry & Vine 1960) as volcanic passive margin (VPM) on the trailing edges of tectonic plates on the western continental margin of India (WCMI). It attracted exploratory focus owing to its geological contiguity to prolific Mumbai offshore basin as well as emerging Kutch-Saurashtra basin.

Twenty wells drilled so far over past four decades with the first well being drilled in 1978, turned elusive in Cenozoic provinces of K-K basin except for few gas shows and traces. The plate tectonic model supported a viable petroleum system with substantial prognosticated resources pending conversion into reserves. The insights from the adjoining basins and Global analogues provide several clues to look beyond Cenozoic window into Mesozoic that proved HC bearing all over the world. All basin variants are now suggestive of Mesozoic potential in K-K basin as petroleum system model could not be established in Cenozoic because of lack of one or more elements of PSM.

Recent PSM studies have brought into focus **Cochin low** as the envisaged kitchen with potential source rocks being identified at Early-Late Cretaceous to Early-Late Eocene. Heat flow maps also have manifested the flow patterns over Kerala shelf (south), Alleppey platform-Cochin low (middle) and Konkan area (north). A cluster of geochemical analyses have brought out convergence towards Early-Late Cretaceous and Early Eocene with potential source rocks from Cochin low charging the surrounding shelf zone of Kerala basin. This opens a new challenge to imaging south Kerala in Mesozoic transcending layers of basalts that pose difficulties to energy transmission.

This paper provides a glimpse of the hydrocarbon prospect of southern part of Kerala basin in Mesozoic sediments (Early -Late Cretaceous) and Late Eocene based on PSM studies.

Introduction

Kerala-Konkan basin (**FIG-1**) located on the western continental margin of India lying between Vengurla Arch and Comorin Ridge covers shelf, slope and parts of deep waters of Laccadive depression, Chagos Laccadive Ridge and Arabian Abyssal plain. It has evolved through thermo-tectonic rifting-drifting of Madagascar and Seychelles from India amid multiple volcanic eruptions. Exploration has been initiated in K-K basin since 1976 fueled by optimism fed from the prolific success in the adjoining Mumbai Offshore basin. Since the first well ‘G’ being drilled in 1978, a total of 20 wells have so far been drilled over shelf, slope and deep water settings. Some wells like M, K and F have shown faint fluorescence but no hydrocarbon accumulations could be established

FIG-1: Location Map

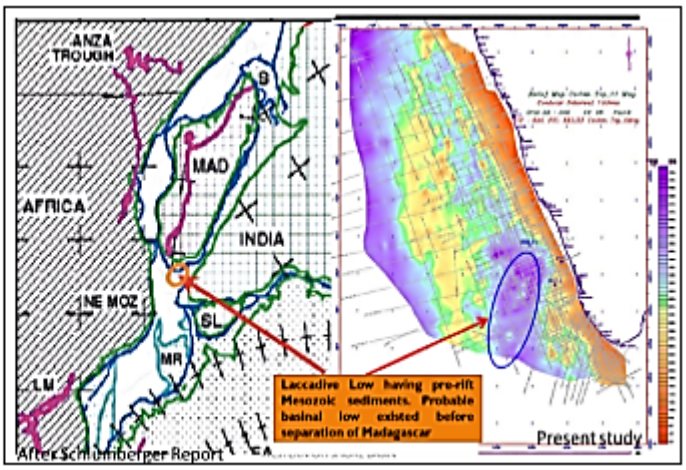

FIG.2. Depiction of restricted basin setting

The Cenozoic pursuits so far proved disastrous and stayed speculative with poor results. However, optimism still prevails as for such a vast basin the testing points has been too far and too few. Paleozoic and Mesozoic petroleum systems remain to be understood and unearthed. This is possible by modern long offset seismic for sub-basalt imaging, gravity-magnetic modelling and Plate tectonic reconstructions. The premise of Mesozoic potential appears to be set against the intense dextral and sinistral transtensional tectonics attracting sediment accumulations. The pulses of dextral and sinistral movements are associated with various degrees of transpression, transtension, uplift and erosion. Finally, the impact of separation of Seychelles inverted the Mesozoic stratigraphy along the eastern border impacting the depo-center shift in the Tertiary. Plate tectonic reconstructions of Late Jurassic to Early Cretaceous could be demonstrative of Kerala Basin being situated in the northeast part of Proto-Mozambique Ocean in contiguity with Morondava basin to the west and Gulf of Mannar basin in the east. This is suggestive of restricted basin set up (**FIG-2**) favorable for organic enrichment of sediments and their preservation.

Kerala Konkan basin underwent deposition through Mesozoic and Cenozoic eras. Two distinct volcanic eruptions occurred: one during Madagascar separation and the other during Seychelles separation. Two eruptions are attributed to two hotspots: **Marion** to former and **Re-union** to latter in the Indian Ocean. Late Cretaceous **Cochin Formation** is encountered in-between Mesozoic volcanic and Paleozoic volcanic. At places deposition of Cochin Formation continued till Early Paleocene. It is overlain by Kasaragod Formation of Paleocene- Early Eocene which in general is clastic dominated with occasional carbonate facies, Middle-Late Paleocene Karwar Formation (mostly carbonates), Early Oligocene Calicut Formation followed by Early Miocene Cannanore Formation and Quilon (carbonates) Formation. Late Miocene- Pliocene Mangalore Formation is encountered only in northern part of Konkan basin. Trichur Formation characterized by claystone is the youngest deposited during Pliocene to Recent.

Early Cretaceous and older sedimentary sequences are expected to be present in structural lows within the Kerala-Konkan Basin. The southern Cochin depocentre is most likely to hold such sedimentary succession. **In KK Basin Early Cretaceous sediments are yet to be drilled whereas Late Cretaceous sediments have been drilled in three wells**. The deposition appears to be bound to half-graben structures. Late Cretaceous stratigraphic interval hosting Cochin Formation comprises sand dominated strata. Generally Cochin Formation is interpreted as marginal shallow marine, dominated by clastic sequences close to the shelf (well G) to open marine (well D). Sediment sources are generally to the East. Applying the observations from the Gulf of Mannar, one can postulate some source potential within the Cochin Formation. It is envisaged to have better source rock facies available in Early and Late Cretaceous within the Cochin Low.

Tertiary sedimentation following the Paleocene volcanic is initially sourced from the East. During Late Paleocene - Early Eocene (Kasaragod Formation), clastic dominated sedimentation. Basin-ward grain sizes decreased and some shale showed fair to good source potential. With slow subsidence and change in drainage patterns towards the East resulted in development of widespread carbonates (Karwar Formation, Calicut Formation and Quilon Formation). Since the end of the Miocene, fine clastic dominated the sedimentary record (Mangalore & Trichur Formation).

This paper makes an effort, on the backdrop of the Cenozoic exploratory pursuits of K-K basin, to bring out the Mesozoic unexplored potential based on integrated G & G insights and exhaustive geo-chemical analyses.

Integrated Analytical studies

PSM has been built up based on integration of geological, geophysical and geochemical data connecting 16 wells and source rock characteristics are identified **(FIG-3**).

Early Cretaceous & Older Sediments

These sediments are not encountered in wells and so purely hypothetical. However, source facies of same age have been envisaged in restricted marine setup. These sediments with good quality organic matter & maturity due to deeper burial could be envisaged effective source rocks. Further, for analogy, since source rock data of Mannar is sparse and discrete, data of Majunga and Morondava basins of Madagascar have been considered for generating TOC and HI maps.

Late Cretaceous (Cochin Formation)

Three wells have so far penetrated this formation. In wells G and D, Cochin sediments comprise clastic with intermittent coals in well-G and limestone in well- J. TOCs of sediments range between 0.52-1.47%, S2 being poor (0.24-1.68 mg HC/g. rock). The organic matter is predominantly Type-III. In drilled wells, Cochin Formation, though thermally matured, does not exhibit significant source rock characteristics.

Paleocene -Early Eocene (Kasaragod Formation

Kasaragod Formation comprises shale, siltstone, and sandstone with discrete minor limestone. The organic carbon contents vary from 0.01-10.08% indicating poor to excellent TOCs, S2 ranging between 0.01-16.45 mg HC/g of rock. From HI and cross plots, it can be inferred that the organic matter is predominantly Type-III. From VRo plots, oil window threshold is inferred to be 3250m. Thus, sediments of basal Kasaragod Formation seem to be matured. Wells C & P are interesting from source rock point of view. In well P (north), 20m of sediments within depth interval 1660-1680m show presence of potential source rock. The organic carbon contents are good (Av TOC 3.83%) and residual generation potential is also good (Av S2 9.83 mg HC/g. rock) but sediments are immature

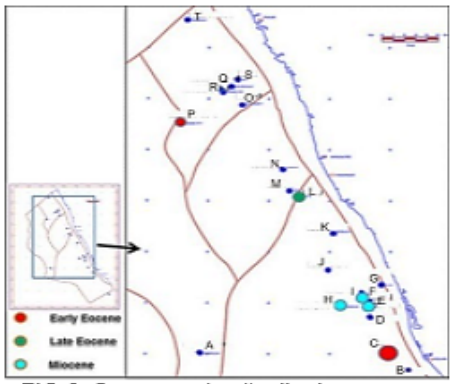

FIG-3: Source rocks distribution patterns

Similarly in well C around 200m of source rich sediments have been encountered. The interval 2470-2735m in shallower section indicates good carbon contents and generation potentials (Av TOC 2.64 - 6.6%, Av S2 4.02-7.91 mg HC/g rock) with predominantly Type-III organic matter but the sediments are immature. Some streaks of immature source rocks are also encountered in the intervals 3020-25m and 3120-35m. The 15m sequence within interval 4410-25m shows characteristics of an effective source interval where threshold maturity is reached.

Mid-Late Eocene (Karwar Formation)

Limestone is predominant lithology in Late Eocene Karwar Formation. Total organic carbon contents vary between 0.04 to 4.58% indicating poor to excellent organic matter. Residual generation potential values range from 0.03-13.48mg HC/g. rock. Organic matter is Type-III. The high source parameters are contributed by well L. The intermittent coal streaks have contributed to high TOC values in well L. The rest of the wells don't show any significant source characteristics as sediments are immature as seen from Tmax and VRo data.

Early Oligocene (Calicut Formation)

The Early Oligocene Calicut Formation comprises predominantly limestone except in wells F and E where shale/siltstone is encountered. The sequence shows TOC ranging between 0.04 -3.37%. S2 ranges between 0.01mg HC/g Rock and 16.03mg HC/g rock indicating poor to good source rock potential. Tmax and VRo indicate Calicut sediments being immature. A cumulative thickness of 100m of potential source rocks is envisaged in well F within interval 2125-2340m. The rest of the wells are devoid of source rocks in this formation.

Early Miocene (Cannanore Formation)

Cannanore Formation comprises predominantly carbonates with clastic in some wells. The Early Miocene sequence shows TOC in the range 0.13-16.83%, and S2 over this interval are poor to very good, (0.05-12.84 mg HC/g Rock), indicating poor to good source rock potential. Tmax and VRo indicate Cannanore sediments being immature. The organic matter is predominantly Type-III. Well J shows comparatively higher TOC and S2. This well was drilled using SOBM so there may be an overall increase in S2 due to residual mud contamination. Nevertheless, compared to rest of sediments drilled in the well, this interval within Cannanore Formation shows potential source characteristics.

Potential source rocks have also been identified in well H in this formation. The carbonaceous shales of well- G also show excellent TOCs but data on other parameters in these intervals are not available.

Middle Miocene (Quilon Formation)

The Quilon Formation comprises predominantly carbonates except in wells-F & E where clastic is also encountered. Total organic carbon content varies between 0.01 to 5.67% indicating poor to excellent organic matter. Residual generation potential ranges from 0.03-9.52mg HC/g rock where higher values are contributed by wells F and E.A thick suite of potential source rock (~500m) is encountered between intervals 1550-2085 in well F. The TOC values range from 1.6 to 5.67% and average S2 values around 5.98 mg HC/g rock. The organic matter is a mixture of Type-III and Type-II. Both Tmax & VRo data suggest immaturity of sediments as potential source rock. Similarly, Mid Miocene section of well-E being in proximity to well-F shows potential source characteristics.

Type of organic matter

Organically rich sediments with adequate generation potential were encountered within different stratigraphic levels from Late Paleocene to Miocene sections. The quality of organic matter varies vertically and spatially within the basin. To the north (Konkan), organic matter is predominantly Gas prone (Type-III).

Source Facies Maps

Play wise source rock layers are identified and mapped based on paleo structure maps, TOC, HI, VRo and depositional inputs. In absence of well data for Early Cretaceous, analogy for source rock is taken from Madagascar and Mannar basin. In Late Cretaceous one source rock layer (with average thickness ~65-70m) identified on log and included in source facies map. In Early Eocene three source rock layers (SR3, SR2 & SR1) are identified and mapped. The bottommost layer (SR3) shows good maturity (well-C). In all the facies maps for different stratigraphic levels the main facies is taken as organic rich shale. All the source rock facies distribution maps have been prepared and assigned to the respective source rock layers (Fig-4).

Maturation study (VRo & TR)

Deeper Early Cretaceous sediments are over matured to dry gas window whereas Late Cretaceous sediments are in late oil to wet gas window because of their deep burial. Early Eocene sediments are in late oil to gas window at the deeper basin in Cochin low. Late Eocene and Oligo-Miocene sediments are mostly immature and are in Early Oil Window in Cochin Low area. Thus the main contributor to Mesozoic and Tertiary petroleum system will be the envisaged Early and Late Cretaceous along with bottom part of the Early Eocene. Thus Cochin low emerges the main feeding source pod for all possible petroleum systems in Kerala-Konkan Basin.

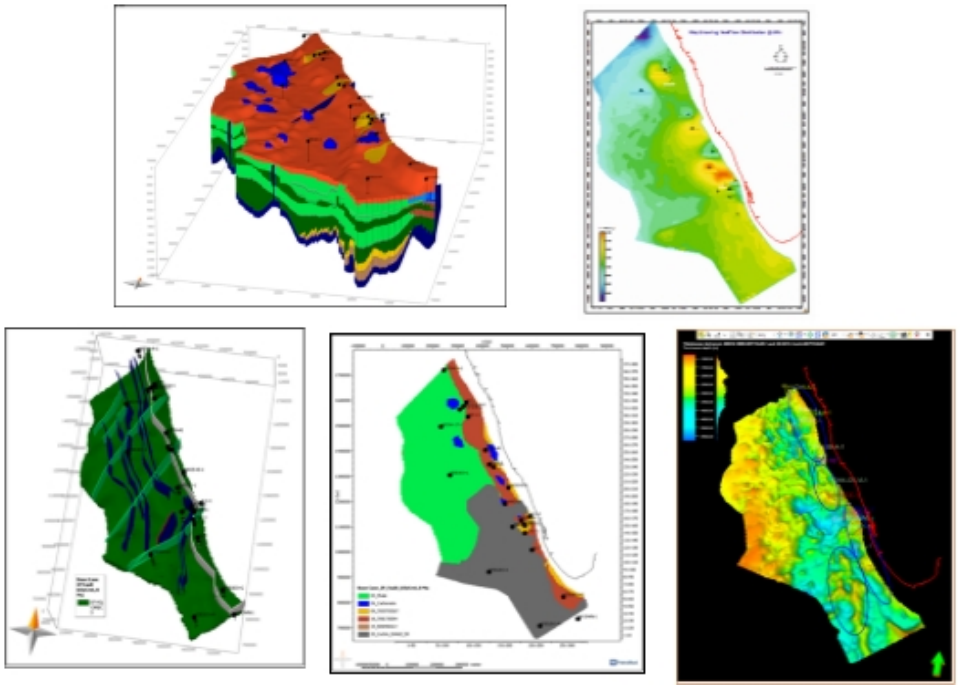

Fig-4: Final Model Geometry KK-Basin, Present Day Heat Flow Map, Fault Geometry overlain on Mesozoic Volcanics, Source Rock facies map of Early Cretaceous and Paleo structure map of Late Cretaceous top during Mid Miocene.

Transformation Ratio (TR) measures the quantum generated against the total Potential for any source rock or Kerogen (Espitalie et al, 1977). This ratio steadily increases with maturity (**FIG-5**). TR of 50% defines the critical moment when expulsion starts and effective migration takes place. This Critical moment is different for different source rocks with varied burial history. The present day TR overlay for Early and Late Cretaceous, and Early Eocene SR3 layer depicts that most of source rocks have attained higher TR% in southern Cochin Low in Kerala Basin. Maximum TR have been observed for envisaged source rock in Early Cretaceous (>90%) followed by Late Cretaceous.

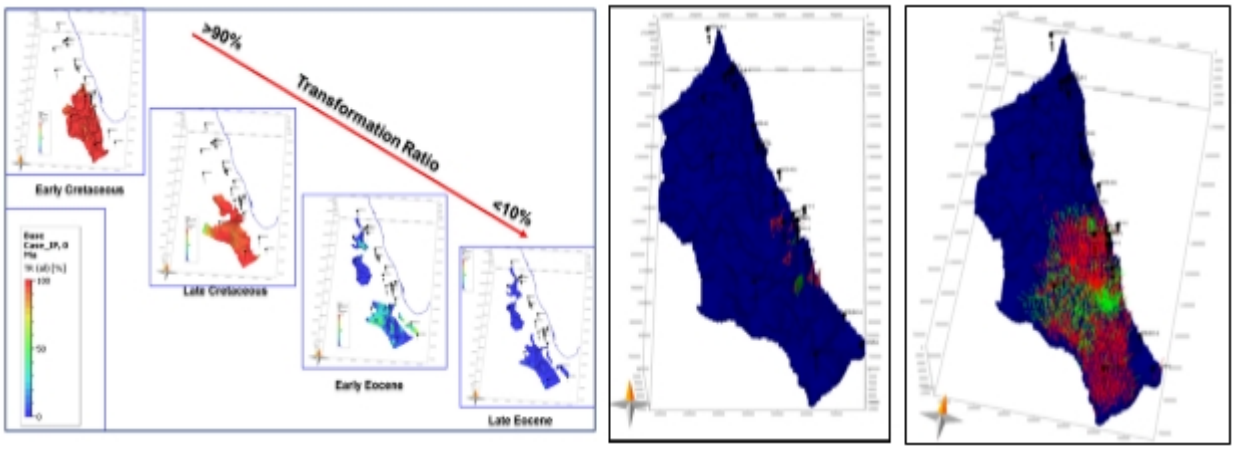

FIG-5.Transformation Ratio of different source rock, Migration vectors of SR & Flow paths of accumulations (Early –Late Cretaceous & Early Eocene) & Flow paths of accumulations for all source rock layers (Early –Late Cretaceous & Early Eocene) depicted over Basement.

The Tertiary Early Eocene section shows TR of around 44% in Cochin Low area whereas Late Eocene Source rock layer shows TR value <10% in the Cochin Low area . In other areas TR is very low (<10%) for all the Source rock layers.

Envisaged Play Analysis

Early Cretaceous Plays

Early Cretaceous plays are charged by envisaged Early Cretaceous source rock. And most of the accumulations are observed in upper part of Early Cretaceous where older Mesozoic layer act as good seal. Hydrocarbons are generated in Cochin Low from envisaged Early Cretaceous source rock, expelled and then accumulated.

Late Cretaceous Play

The main contributor to Late Cretaceous play is Late Cretaceous source rock within Cochin low along with some contribution from Early Cretaceous as observed from the source rock tracking. And accumulations are observed all along the Alleppey Platform and shelf areas where immediate structures are available for entrapment.

Play chance Analysis

The main charge area is limited to Kerala Basin. The migration pattern indicates that the charging for all the accumulations are mainly from Early and Late Cretaceous sources of main Cochin Low. Thus the shelf structures in and around Cochin Low are the main areas where charging can take place. The PSM study shows that the charging does not extend beyond Tellicherry Arch though there are some hydrocarbon shows in the wells drilled in Konkan Basin. Thus charging source pods may be different for those areas. And the charging is varied depending upon the proximity of source pod to the availability of structures. The paleo structural analysis shows that there were plenty of structures available for entrapment during the peak migration time in this basin. Overall the Late Cretaceous and Early Cretaceous plays show more accumulations (Fig 6)

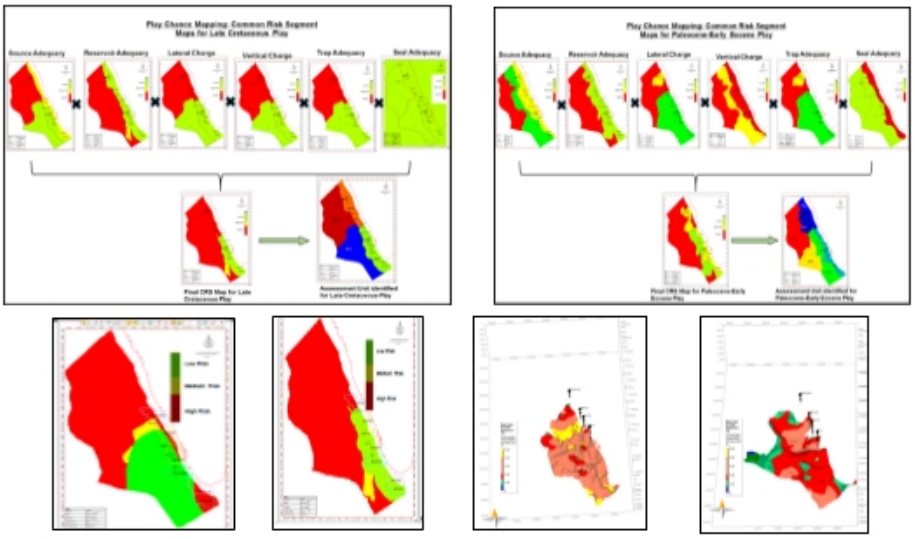

FIG-6. Play chance analysis and CRS mapping for Assessment Unit delineation for Late Cretaceous Play and Charge analysis of Late Cretaceous & Paleo-Early Eocene.Sweeny Burnham maturity for Late cretaceous & Early Cretaceous SR

L.Cretaceous -Mostly showing good maturity and gone in to gas window with some patches of early and late oil.SR-1 is shallower and SR-3 is deeper. Dark Green colour indicates Early oil and Light green is Late oil. In general source rock entered in to Early to Late oil window.

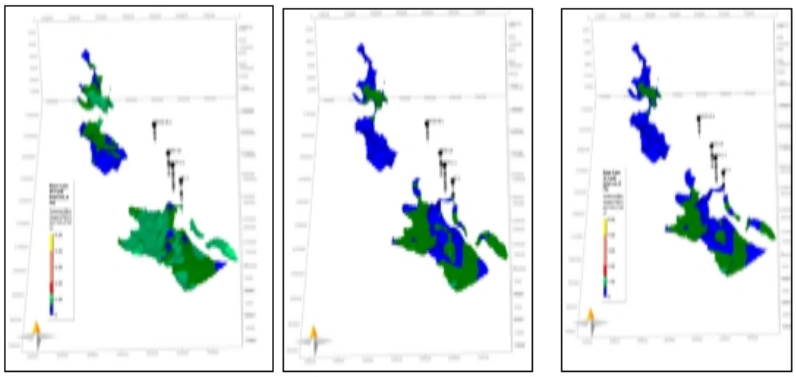

FIG-7.Sweeny-Burnham maturity for Early.Eocene SR-3, SR-2 & SR-1

Summary and Conclusions:

- Kerala-Konkan basin has so far eluded exploratory efforts in Tertiary ventures. However, it is envisaged to be endowed with HC generation potential in Cochin Low being the potential Kitchen.
- Cochin low being connected with Gulf of Mannar basin (Mesozoic) to the south further enhances the possibility.
- Petroleum systems being envisaged now are Mesozoic-Mesozoic, Mesozoic-Tertiary and Tertiary-Tertiary.
- PSM studies have brought out source rocks being identified at stratigraphic levels spreading across Early -Late Cretaceous to Early - Late Eocene. Early-Late Cretaceous and lower part of Paleocene-Early Eocene stratigraphic sequences are expected to be matured.
- As per present-day heat flow maps, southern part of Kerala Shelf show lower heat flow trend due to thicker sediment while Alleppey platform - Cochin low show heat flow in the range of 48-52 mW/m2 with the northern part showing heat flow in the range of 37-32 mW/m2.
- Maturity window comes out below ~3250m in Cochin low with Transformation ratio (TR) for all source rocks being good. Early - Late Cretaceous source Rocks show TR range up to 99% whereas Early Eocene show TR range up to 44%. Maximum hydrocarbon seems to be generated at Late Cretaceous source rock followed by Early Cretaceous source rock.

- PSM study demonstrates that accumulations at different stratigraphic levels are mainly fed by Early - Late Cretaceous, and Early Eocene source rocks. And these are concentrated in and around shelf of Cochin Low in Kerala Basin.

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