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Author **Sayani Mondal , ONGC , India**

Co-Authors **Shri D K Roy, Shri A K Sarkar & Mrs. Nagma Parwin**

Biogenic & Thermogenic prospectivity of Mahanadi Offshore

Abstract

Based on the available G&G, drilled wells & carbon isotopic data in Mahanadi Offshore Basin till date, presence of three Petroleum systems established viz. 1) Neogene-Neogene Known Biogenic System (!), 2) Paleogene-Neogene known Mixed Biogenic & Thermogenic System (!) & 3) Paleogene-Paleogene knownThermogenic System (!). In order to have a better understanding on Hydrocarbon habitat of the basin, comprehensive studies have been carried out followed by 3D Petroleum System Modelling (PSM). Based on the output of these studies, baring presences of three Petroleum systems mentioned above, the existence of one more petroleum system viz. Cretaceous-Paleogene Speculative Petroleum System (?) is envisaged. The play maps were subsequently generated through the Play Chance Mapping process, based on the Chance of Success for each GME inputs (Source Rock quality and effectiveness, Reservoir presence and quality, Seal adequacy & Entrapment). On the basis of drilled wells data, Play wise exploration audit, 3D PSM vis-à-vis analysis of Common Risk Segment, potential Biogenic & Thermogenic plays for future exploration in Mahanadi Offshore Basin, is envisaged. For exploration of Thermogenic hydrocarbon, Paleocene play is more interesting in the eastern part of the basin near Jagannath low. Eocene play can also be considered as exploration interest, depending on availability of good reservoir rock near slope. For exploration of Biomethane, a large area within Mid Miocene, Miocene & Pliocene sequence can be explored near the self-slope break and slope area further down, especially near the conjuncture of Mahanadi and Ganges-Brahmaputra sediment input. In addition, the Mid Miocene Mixed Thermogenic/Biogenic plays in Mahanadi Offshore areaappears most promising from these studies and to be targeted for future exploration.

Introduction:

Exploratory drilling activities in offshore Mahanadi Basin were initiated in the year 1980 and more than 40 wells were drilled till date (Pre-NELP & NELP region). However, the exploration activity during the pre-NELP regime was only restricted to onland or shallow offshore part. The Deep water exploration in Mahanadi started in the year 2005 and in the subsequent drilling phase, 16 wells penetrated Neogene and 8 wells were drilled up to Paleogene section. Hydrocarbon shows were observed in many wells during testing and 14 wells declared as gas bearing/wells with gas indications after MDT results, except for one well in which conventional testing was carried out (MO-16). Liquid hydrocarbon has not been encountered in Mahanadi Basin till date. All the hydrocarbon discoveries in Mahanadi offshore basin are mainly restricted to Neogene. Gas isotope studies indicate that most of the gas finds are of Biogenic in nature except for MO-21, MO-26 and MO-35 where the gas samples showed some Thermogenic component in the analyses.

Based on the drilled well data and discovery from deep water wells three types of Petroleum systems have been established in Mahanadi Basin viz. 1) Neogene-Neogene Known Biogenic System (!), 2) Paleogene-Neogene known Mixed Biogenic & Thermogenic System (!) & 3) Paleogene-Paleogene known Mixed Biogenic &Thermogenic System (!)

In the present studies, the southern limit of Mahanadi Offshore is taken at the western boundary of 85 Deg E ridge.The boundaries between Mahanadi offshore Basin in the west & Bengal Basin in the east are marked by NNW-SSE trending Dhamara lineament (**Fig.1**).

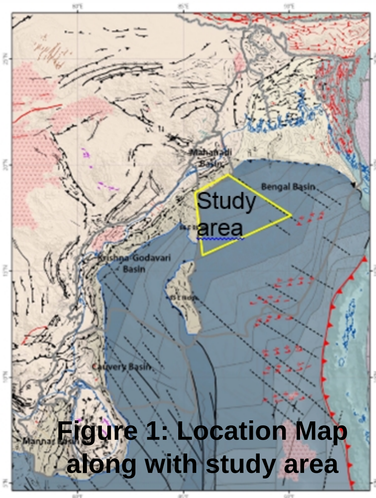
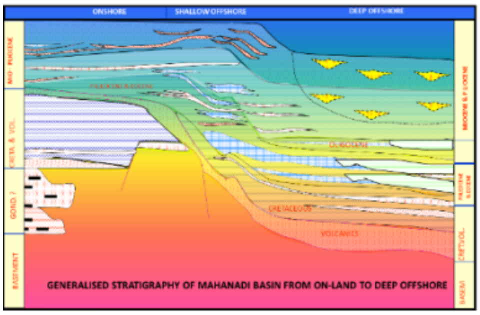


Figure 1: Location Map along with study area

Regional geological setting, major tectonic events & stratigraphy:

Mahanadi Basin, along with other passive margin basins of the east coast of India, came into existence during Late Jurassic-Early Cretaceous separation of Indian plate from Antarctica &

Australia. The pre-rift Gondwana sediments are represented in the onland part in outcrop, though no wells drilled in the sequence. The syn-rift phase of the Basin is characterised predominantly by volcanic sediments & intertrappeans of Early Cretaceous age. In Late Cretaceous, basin received early drift transgressive phase sedimentation, with a regional unconformity marking the end of Cretaceous deposition, followed by carbonates & clastic in Palaeogene period. An Unconformity above



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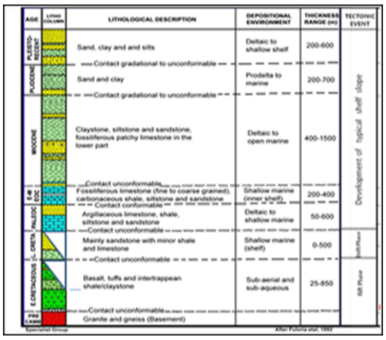

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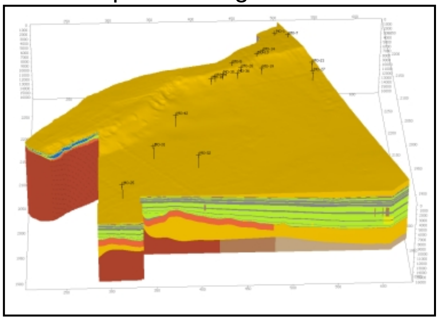
the Ganga-ments weBrahmaputra Delta system. The Eocene hinge zone lies almost parallel to the coast line in this area. The Basin Fore deep is essentially marked by an increased subsidence rate compared to Shelf area & the sediments have attained a greater burial depth in this part of the Basin (**Figs. 2a & b**).

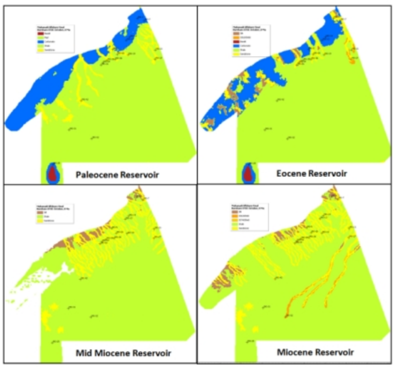
Figure 2a & b: Generalised Stratigraphy

Data set & Methodology:

The various inputs for generation of Static model include s on t



Depth top of stratigraphic surfaces, maps of faults in basin with definitions how these behaved



maps differen hic Fault major the fault (i.e. faults in

geological time), Erosion map, Facies model (displaying lithological variations, both vertically & laterally with respect to geological time), Geochemical inputs in the model (TOC & HI maps), thickness & kinetics of source rock and different boundary conditions (PWD, SWIT & HF maps). A 3D geological model (**Fig. 3a**) was constructed using twelve depth relief surfaces at top of key stratigraphic levels viz. Sea bed, Pliocene, Miocene, Mid Miocene, Oligocene, Eocene, Paleocene, Late Cretaceous, Early Cretaceous, Trap bottom, Syn-rift Sediments (Gondwana?) & Basement. Different Facies were identified & marked based on lithological heterogeneity. Facies maps (**Fig. 3b**) were prepared integrating well & seismic data, RMS amplitude maps of different stratigraphic horizons as well as Sand probability maps and Paleogeographic maps. The model has been further supplemented with all other data types viz. source rock data, boundary conditions, paleo geometries etc. to build a viable dynamic model.

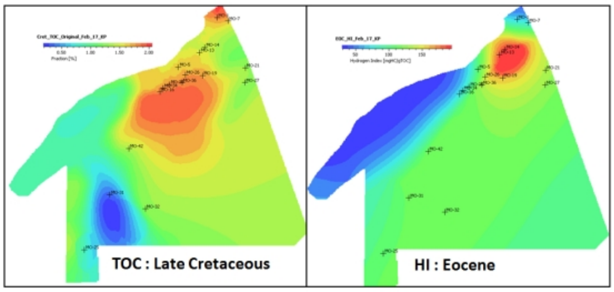


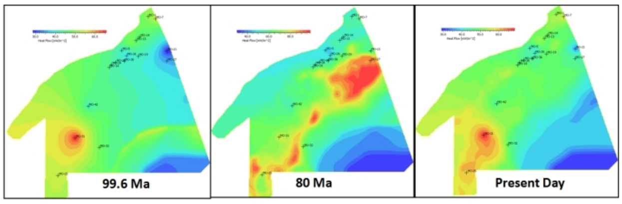
Figure 3a: Static Model

Figure 3

Source Rock & Thermal modelling:

The main geochemical input in the model is the source rock inputs comprising of identification of source rock, thickness of source rock, organic matter richness (TOCo i.e. Total organic Carbon original, wt. %), source potential (S2, mg HC/g rock), type of organic matter (HIo i.e. Hydrogen Index original), maturation data in terms of vitrinite reflectance and source rock kinetics.

Discovered hydrocarbons in Mahanadi Basin are (i) Biogenic and (ii) Mixed Biogenic/Thermogenic in nature. Presence of Biogenic gas is proved in the samples of wells MO-16 (Pliocene), MO-17 (Pleistocene), MO-19 (Pliocene) and MO-22 (Pliocene). Mixed gases are proved in the samples of wells MO-19 (Pliocene), MO-20 (Miocene), MO-22 (Pliocene), MO-21 (Mid Miocene), MO-22 (Pliocene), MO-26 (Early Pliocene & Eocene?), MO-27 (Pliocene & Late Miocene), MO-28 (Late Miocene), MO-29 (Mid-Miocene), MO-30 (Early Miocene), MO-34 (Pliocene), MO-35 (Late Miocene, Mid-Miocene/Paleogene?), MO-36 (Pleistocene, Late Miocene) & MO-41 (Miocene).



Identification of potential source rock sequences within different stratigraphic units has been done through source rock studies. It is observed that wells situated in the shelf area (MO-1 to MO-8) have shown fair to good TOC in different stratigraphic levels. TOC & HI values based on available geochemical (Rock-Eval) were used to calculate the original TOC & HI values using Jarvie and Hantschel Method & subsequent generation of original TOC& HI maps **(Fig. 4a).**

In Mio-Pliocene sequence, a low temperature Biogenic kinetics (Gaussian) is applied to model, effecting low temperature Methane generation in the temperature range of 40-60 DegC with maximum generating rate at 50 DegC. In Cretaceous, Palaeocene, Eocene and Oligocene source rocks, the source rock parameters were assigned based on limited available well data. A generic type III kinetic model based upon Burnham (1989) _T III, has been assigned to model kerogen conversion.

For input of lower boundary conditions, Crustal Heat Flow modelling method is adopted for Mahanadi Basin. Crustal thickness map **(Fig. 4b)** has been prepared from the available deep seismic lines and published papers on crustal thickness of Bay of Bengal. The Mantle thickness is taken as 95km based on the global average data. Crustal facies has been assigned as Continental Granite for the continental part, Granodiorite for transition zone, Oceanic Basalt for oceanic crust and that of Mantle has been taken as Upper Mantle (Peridotite). From the Tectonic evolution history of the basin, from 115Ma to 99Ma period i.e. end of Trap Basalt eruption, has been assigned under syn-rift phase and the period upto 23Ma i.e. end of Oligocene, is considered as post-rift phase.

Sediment Water Interface Temperature (SWIT) and Paleo Water Depth (PWD) are the two upper boundary conditions in the modelling processes, defining the surface temperature through geological time. In case of Mahanadi Basin, system generated auto SWIT method has been used defining the geographical position of the Basin as 18 Deg North. PWD maps through ages have been prepared based on the biostratigraphy and lithological data.

Figure 4b: Crustal HF Maps

Maturation Results from 3D output for different plays:

In Mahanadi Offshore, all the source rock sequences from Late Cretaceous to Oligocene are mature in the deep basin area, towards the Jagannath Low and small part of Kalinga Low present within the study area and can contribute as potential Thermogenic hydrocarbon source (**Fig. 5a**). The area under the huge sediment load of Ganges-Brahmaputra System is the main kitchen area for Mahanadi Basin. However, the source sequences in the shelfal part are, in general, immature.

Figure 5a: Maturity Profile

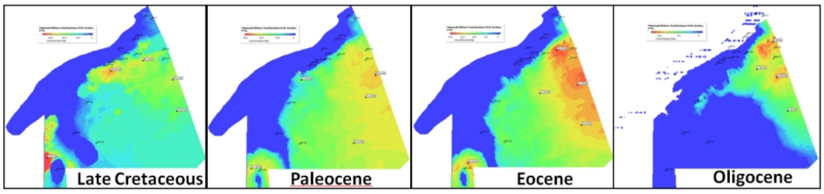
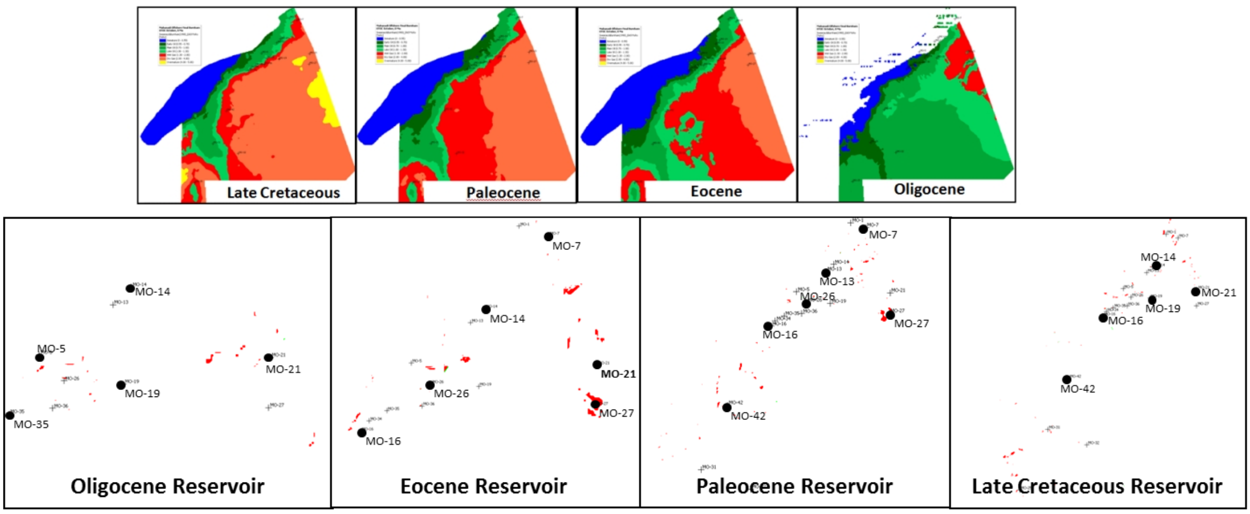


Figure 5b: Critical Moment for expulsion

The Mio-Pliocene source sequences are still in the digenetic stage and hence could not produce any Thermogenic hydrocarbon. However, as the conditions for production of Biomethane are optimum, in terms of temperature and sedimentation rate, this sequence can generate considerable amount of Biogenic gas which is well demonstrated in the generation mass overlay in output model. This has further been calibrated with the actual well results.However, generation of the Biomethane is restricted to a limited area, situated in the shelf and part of slope.In addition, there is high chance of getting Mixed Thermogenic and Biogenic gases in the lower part of Mid Miocene in slope area.

Accumulation:

The accumulations within Cretaceous and Paleogene are Thermogenic in nature and more likely to be found in slope areas upto the shelf-slope break. In most of the areas, Thermogenic accumulations are entrapped under the Late Oligocene-Early Miocene high pressure zone, which is acting as the natural seal for the entrapped hydrocarbon.The Biomethane accumulations within Neogene are likely to be near shelf-slope break and further down slope, entrapped in strati-structural reservoir. Mid Miocene is likely to have most of the major accumulations from generated from mixing of Biogenic and Thermogenic hydrocarbon.



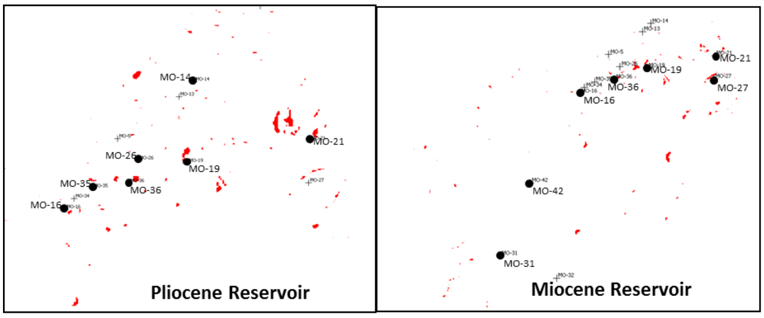


Figure 6: Accumulations

PSM Results and Analysis:

Based on G&G inputs, well data & subsequent 3D PSM studies, four Petroleum systems (three known & one speculative) exists in Mahanadi Offshore.

1. Neogene-Neogene Known Biogenic Petroleum system (!): Already confirmed by the discovery from MO-16 and MO-19.

2. Paleogene-Neogene known Thermogenic/mixed Petroleum system (!): Established by the presence of mixed (Thermogenic + Biogenic) gas in well MO-21 from Mid Miocene level.

3. Paleogene-Paleogene known Thermogenic Petroleum system (!): Envisaged based on the Palaeogene source rock potential observed in some of the wells and presence of Thermogenic gas in well MO-26.

4. Cretaceous-Paleogene Speculative Thermogenic Petroleum system (?): Speculated based on the observation of Cretaceous source rock potential n some of the wells and 3D PSM output also confirms the presence of this system. Though, not confirmed by source rock tracking, Thermogenic gas within the Paleogene section of well MO-35 is most likely the manifestation of the same.

Common Risk segment (CRS) maps:

For Mahanadi Offshore basin, the CRS for eight plays (Three maps for Biogenic viz. Pliocene, Miocene& Mid Miocene and five maps for Thermogenic viz. Mid Miocene, Oligocene, Eocene, Palaeocene & Late Cretaceous) have been generated. Inputs maps for common risk segment for each plays are vertical charge (include source rock input), lateral charge, reservoir adequacy and seal adequacy. The chance of success for each input (TOC, Transformation ratio, reservoir porosity, Reservoir facies, Migration, Capillary entry pressure) has been assigned. Subsequently, CRS map for each Play were generated through Play chance mapping process.

Play wise exploration strategies:

1. Thermogenic Play:

a) Late Cretaceous Thermogenic Play: Source sequences have attained very high maturity and towards the Jagannath Low the source is mostly over mature. Expulsion of hydrocarbon from Cretaceous source rock has started **(Fig. 5b)** from Late Paleocene/Eocene onwards except for the part of Kalinga Low where the source rock has attained early maturation and expulsion started from Early Paleocene. The reservoirs within Cretaceous are charged by mostly Cretaceous source rocks. Reservoir rocks are restricted to the shelf and slope part of the basin. Therefore, CRS map indicates a narrow part near shelf and partly slope area as the low risk zone for future exploration in this play.

b) Paleocene Thermogenic Play: Paleocene source rocks are within Gas zone in the Jagannath Low and Kalinga Low where expulsion has started **(Fig. 5b)** from Oligocene onwards. Paleocene source rocks are getting contribution from both Cretaceous source and Paleocene source. The accumulations are restricted to the slope due to the limitation of reservoir facies and most of the accumulations are under high pressure zone. The CRS map also indicates the high probability area for future exploration in this play, along a stretch of the slope.

c) Eocene Thermogenic Play: Eocene source sequence in the kitchen area is mostly within the gas zone and critical moment analysis **(Fig. 5b)** is showing that the expulsion has started from Mid Miocene onwards. However, presence of good quality reservoir rock is very restricted, mainly in the slope part, especially towards the north-eastern part of the basin which is further supported by accumulation overlay as well as CRS map.

d) Oligocene Thermogenic Play: Oligocene sequence is mostly in the late oil to wet gas window where expulsion has started from Late Miocene **(Fig. 5b)**. However, due to presence of huge unconformity over Oligocene, deposition of good quality reservoir rock within Oligocene is uncertain. This is further supported by accumulation and CRS analysis which depicts that Oligocene play is less promising in Mahanadi Offshore.

e) Mid Miocene Thermogenic Play: Most part of the Mid Miocene is still in the digenetic stage and is not contributing in Thermogenic system of Mahanadi Offshore. However, the basal part of Mid Miocene reservoir is getting considerable contribution from Paleogene source rocks, especially in the eastern part of the basin and the same has already been validated from the carbon isotopic data of drilled wells. Accordingly, this area is very promising for future exploration of Mid Miocene Thermogenic Play.

2. Biogenic Play:

f) Mid Miocene Biogenic Play: The temperature and sedimentation in Mid Miocene sequence is optimum for generation of Biomethane. Outputs from 3D PSM as well as CRS Map showed a considerable area under the Ganges-Brahmaputra sediment cover is falling within the potential zone for generation of Biogenic hydrocarbon. As Mid Miocene is also getting a considerable amount of Thermogenic hydrocarbon from deeper strata, Mid Miocene is likely to act as mixed hydrocarbon play which is also validated from well data.

g) Miocene Biogenic Play: The Miocene sequence is also having high potential of generation of Biomethane like Mid Miocene sequence wherein also, a significant area is showing high chance of success as per CRS map. The accumulation, which is calibrated with the drilled well data, is showing considerable potential areas for future exploration.

h) Pliocene Biogenic Play: As indicated by 3D PSM output and CRS map, only a small area within Pliocene sequence is fulfilling the criteria for generation of Biomethane and accordingly the potential area for future exploration of Pliocene Biogenic Play is only restricted to the north-eastern part of the basin, near the shelf-slope break.

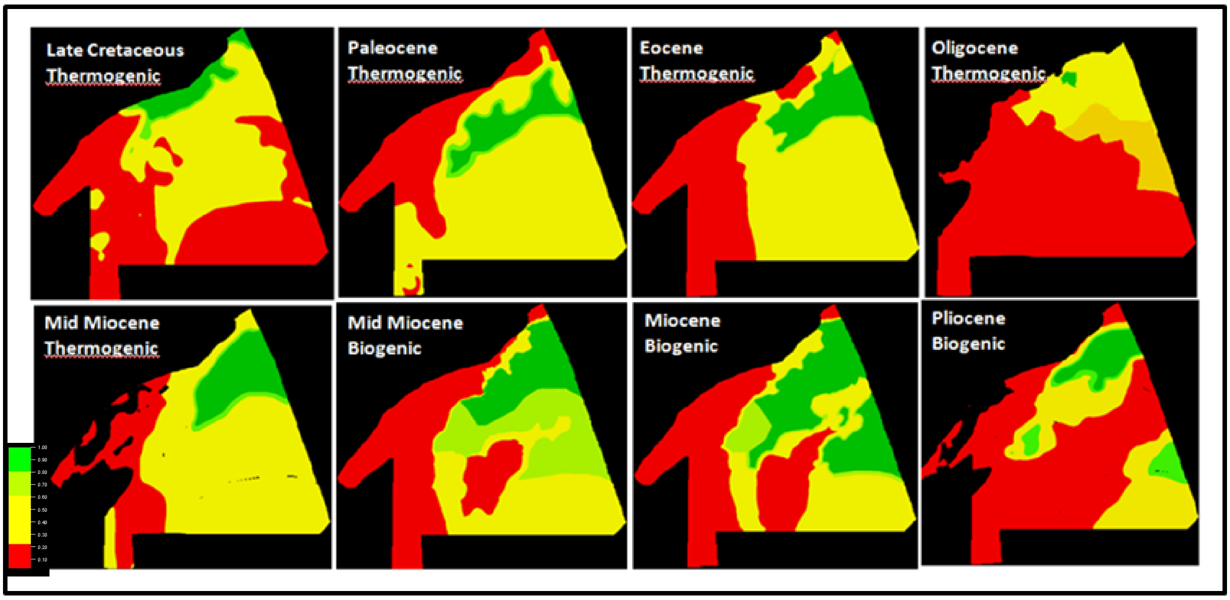


Figure 6: Play wise CRS Maps

Conclusions:

Based on the available G&G, drilled wells, carbon isotopic data, Play maps, Play wise exploration audit, 3D PSM vis-à-vis analysis of Common Risk Segment maps of each play, it can be concluded that Mahanadi Offshore is having a considerable potential for future exploration for both Biogenic & Thermogenic hydrocarbon. For exploration of Thermogenic hydrocarbon, Paleocene play is more interesting in the eastern part of the basin near Jagannath low. Eocene play can also be considered as exploration interest, depending on availability of good reservoir rock near slope. For exploration of Biomethane, a large area within Mid Miocene, Miocene & Pliocene sequences need to be explored near the self-slope break and slope area further down, especially near the conjuncture of Mahanadi and Ganges-Brahmaputra sediment input. In addition, the Mid Miocene Mixed Thermogenic/Biogenic play in Mahanadi Offshore appears most promising from these studies and to be targeted for future exploration.

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