PaperID **AU333**

Author **Sayani Mondal , ONGC , India**

Co-Authors **Mrs. Sayani Mondal, Shri S Bhattacharya & Mrs. Manomita Kundu**

Hydrocarbon Prospectivity of Bengal Onland based on 3D PSM & Hydrocarbon Resource Assessment

Authors: Shri D. K. Roy, Mrs Sayani Mondal, Shri S. Bhattacharya & Mrs Manomita Kundu, MBA Basin, ONGC, Kolkata

Abstract

Based on the available G&G, drilled wells & carbon isotopic data in Bengal Onland, presence of three Petroleum Systems viz. Paleogene-Neogene Hypothetical Petroleum System (.), Paleogene-Paleogene Hypothetical Petroleum System (.) and Gondwana-Paleogene Speculative Petroleum System (?) postulated. Subsequently, comprehensive studies on Bengal Onland were carried out based on 3D Petroleum System Modelling (PSM). Based on 3D PSM studies, the existence of Neogene-Neogene Speculative Petroleum System (Biogenic) (?), Cretaceous-Paleogene Speculative Petroleum System (?), Cretaceous-Cretaceous Speculative Petroleum System (?) & Gondwana-Gondwana Speculative Petroleum System (?) is envisaged, in addition to the already existing petroleum systems mentioned earlier. Subsequently, various Play maps were generated through the method of Play Chance Mapping. Based on the Chance of Success (COS) for each input (Source Rock quality and effectiveness, Reservoir presence and quality, Seal adequacy & Entrapment) in each play, Common Risk Segment (CRS) map for each play was generated. Based on the drilled wells data, play wise exploration audit, result of 3D PSM vis-à-vis analyses of CRS, it is envisaged that area close to Hinge zone corridor, is interesting for both Thermogenic & Biogenic/Mixed hydrocarbon in Paleogene & Neogene sequences. In Oligocene sequence, all the Thermogenic accumulations are expected very close to hinge zone & accordingly, down dip portion of Oligocene Basal play (where oil flowed to surface in well ON-8), needs to be explored in near future. In Eocene sequence, based on gas shows from ON-21, the area along hinge zone (southern part of Bengal onland) may only be relooked for porous refold anomalies & exploration of Thermogenic hydrocarbon. In Paleocene-Cretaceous sequence, three prospective areas for exploration of Thermogenic hydrocarbon are identified viz. a) around ISPP-1 & ON-12 area in the northern part b) eastern part of the basin (ISPP-8 & ON-8 area), close to hinge zone corridor and c) around ON-24 & ON-26 in the southern part.

Introduction:

Hydrocarbon exploration in Bengal Onland Basin has become a long history for about six decades. A total of forty six exploratory wells were drilled so far in Bengal Onland with the status - **"Presence of hydrocarbon proved, without commercial success".** There are several evidences of hydrocarbon shows in drilling muds/cuttings/cores and also in few cases hydrocarbon surfaced during production testing (Oil in ON-8 & 19 and Gas at ON-24, 26 & 29). The carbon isotope data of surfaced gas indicated Thermogenic nature of hydrocarbon. However, there were few gas shows during drilling from the shallower Neogene sequences which do not have any isotopic analysis. Based on the distinctive characteristics of well logs, presence of gas has been interpreted in few more wells. Based on the current exploration scenario, detailed play wise exploration strategies are essential for delineation of future exploration activities in the Bengal onland. Till date, in Bengal Onland area, presence of three Petroleum Systems has been postulated as per analysis of gas geochemical data viz. Paleogene-Neogene Hypothetical Petroleum System (.), Paleogene-Paleogene Hypothetical Petroleum System (.) and Gondwana-Paleogene Speculative Petroleum System (?).

Regional geological setting, major tectonic events & stratigraphy:

Bengal basin, a polycyclic basin, has evolved through two distinct tectonic episodes. It initiated as an intracratonic rifted basin within Gondwana land during the Paleozoic-Mid Mesozoic time. This phase of basin development ended with wide spread volcanism (Rajmahal Trap). Second phase of basin formation took place when Indian Craton separated out completely from the Gondwana land and kept on moving northwards. During this journey of the Indian plate, the pericratonic part having loaded with Gondwana sediments, were sagging eastward and received colossal volume of sediments from Late Mesozoic through Tertiary to Recent times. At the end phase of its northern journey, the Indian plate collided with the Eurasean plate and caused up folding and thrusting of Tethian sediments to build the Himalayan Orogenic belt. Bengal basin is sub-divided into four NE-SW trending tectonic zones which are Narrow basin margin zone, wide stable shelf zone that becomes narrower from onshore to offshore, Hinge zone & Deep basin with huge thickness of Neogene sediments.

Talchir, Barakar, Barren measure, Raniganj, Panchet and Supra-Panchet formations of Lower and Upper Gondwanas were deposited during the rift phase in the grabens followed by widespread basaltic and andesitic lava flow during Late Jurassic-Early Cretaceous period resulted deposition of Rajmahal trap. After a major hiatus, Upper Cretaceous-Paleocene siliciclastic sediments were deposited throughout the Basin. During Eocene period, the Indian Plate was in paleo-equatorial position favouring the deposition of carbonates, giving rise to distinct basin architecture of wide carbonate platform, narrow slope and deeper basin. During Early Oligocene period the relative sea-level fall gave rise to the deposition of low stand sediments on the slope as well as in deeper basin. With the initiation of the collision of the Indian Plate with the Eurasian Plate during Late Oligocene, the basin had witnessed regression and prograding delta systems during Middle and Late Oligocene high stand period. The sedimentation rate had increased drastically during Late Oligocene/Early Miocene period and the detritus derived from this high relief provenance of the Himalayas was brought by Proto-Ganga-Brahmaputra river system into this basin. The fluctuation of the sea level and the differential sedimentation rate during Mio-Pliocene period gave rise to the complex pattern of delta building activities in different parts of Bengal Basin.

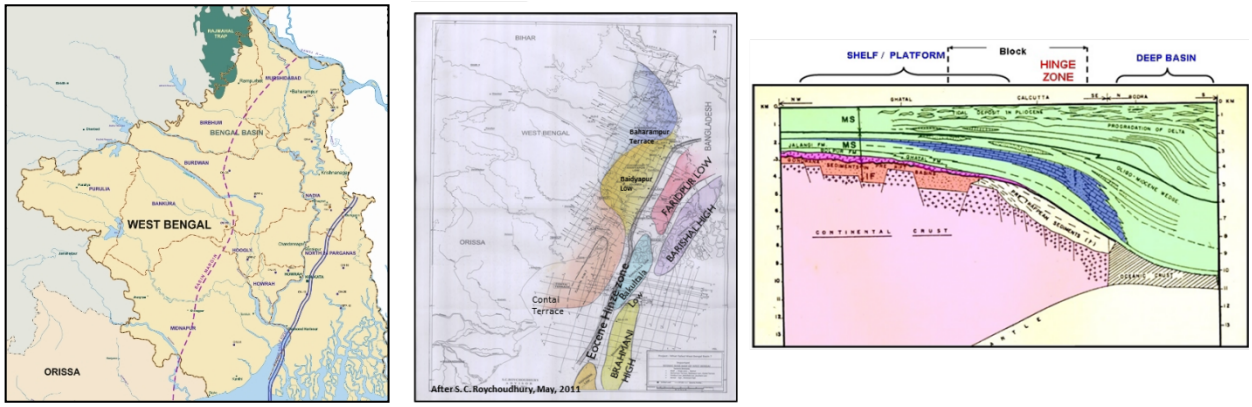


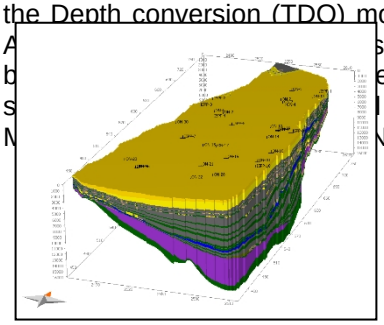
Figure. 1. Location Map & Geological map of Bengal Basin with major Tectonic Elements

Data set & Methodology:

In order to decipher detailed play wise Thermogenic & Biogenic prospectivity of Bengal Onland basin, all geological, seismic, geochemical data were used. Static model was build up which includes depth maps of corresponding stratigraphic horizons followed by preparation of Facies model. Data of 46 wells (10 ISPP & 36 ONGC) were used in the present study. All biostratigraphic, sedimentological & geochemical data were scouted from available reports & used for interpretation & subsequent Petroleum System Modelling. All available VRo, BHT, pressure & porosity data of the wells are used for model calibration.

Static Model:

Based on electro log correlation of all Bengal Onland wells & subsequent tie with seismic, Time structure maps were prepared for thirteen horizons corresponding to Basement, Karharbari, Barakar, Lower Gondwana, Gondwana, Rajmahal Trap, Late Cretaceous, Paleocene, Eocene, Hooghly Shale, Oligocene, Miocene and Pliocene. The majority of the faults in Bengal Onland are basement controlled and restricted to the Shelfal part, which got reactivated in different geological time. The velocity model generated was used in the Depth conversion (TDQ) module & these depth grids/maps along with fault polygons were exported in A stem Modelling. In Bengal Onland, different facies are identified & marked b eneity of all stratigraphic units. The RMS amplitude maps of different s l decomposition and RGB blending of the seismic data, Petrel Property M Neural Network, etc were used for generation of final Facies maps (**Fig. 2b**).



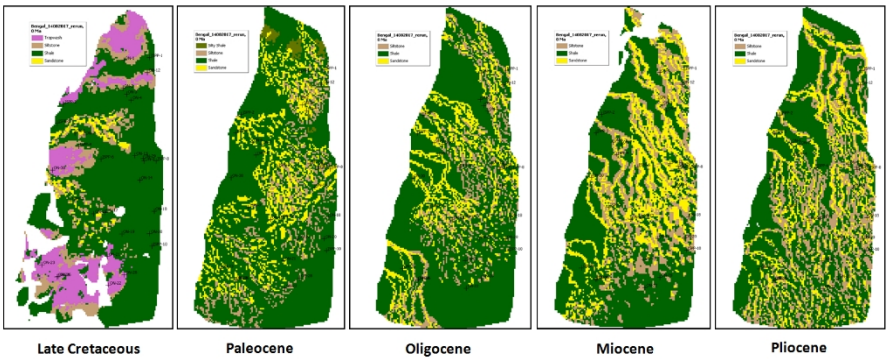


Figure. 2a. 3D Models of Bengal Onland

Figure. 2b. Facies Maps for Bengal Onland

The carbon isotopic studies indicates that heavier isotopic values for gases in ON-15 (-35 to -38) are in general, found below the Eocene Limestone and their origin can be attributed from matured Paleocene sequence. The gases found in Gobindapur structures indicate higher maturity ($\delta^{13}C_1$ -30 to -35) which inferred generation from deeper coal sources. The medium to light isotopic composition (-42 to -45) in Eocene gas in ON-19 and Miocene gas in ON-20 in the deeper part of the basin indicates both have generated from an Eocene shale sequence or older source rock having mid-catagenetic stage of maturation. The lighter isotopic composition of Miocene gas of ON-18 and ON-22 and that of Oligocene in ON-8 (-46 to -50) indicated the same is arising out of mixing of the gas sourced from Paleogene shale with less matured Oligocene gas during its migration. Presence of Thermogenic petroleum system is proved by surfacing of oil from Basal Oligocene sand (4346-4349m) in well ON-8. In well ON-29, the gas flow form Oligocene Burdwan Formation further supports the presence of Thermogenic petroleum system. Based on geochemical data, it is suggested that the oil in this area is mostly migrated from the deeper part of the basin i.e. to the east of the Eocene hinge. Mixed Thermogenic & Biogenic System is also anticipated in Bengal Basin, especially in the Deeper Miocene Section, based on geochemical data & associated play dynamics.

For 3D PSM studies, all the maps prepared under Static Model have been imported to PetroMod platform. 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. All the depth maps, as discussed earlier, have been used to make a layer cake model and the basic structural framework of the basin have been restored. Chronostratigraphic data have been provided to each layer. The source and non-source layers of different sequences of Bengal Basin have been identified based on log correlation coupled with the available source rock log wells.

Source Rock & Thermal modelling:

Source rock studies have been carried out using all available geochemical data in the study area. Based on the all available geochemical data, coupled with geological concept of the basin, TOC and HI maps have been prepared. The Van Krevelan diagram of Pliocene, Miocene, Oligocene, Eocene, Paleocene & Gondwana sequences were prepared to find out the nature of kerogen. Based on the available geochemical data and prior geological knowledge of the basin, Mio-Pliocene sequence has been modelled for Biogenic Hydrocarbon system. All other older source rock sequences are modelled for Thermogenic Hydrocarbon. For Mio-Pliocene sequence, a low temperature Biogenic kinetics (Gaussian) is applied to model, effecting low temperature methane generation in the temperature range of 45-55 degree centigrade with maxima at 50 degree centigrade. For Cretaceous, Palaeocene, Eocene, Hooghly Shale and Oligocene sequence, and also for Gondwana conventional petroleum sequence, Burnham (1989) _T III kinetics has been used with Modified Gas to Oil ratio. Igneous intrusions, in form of dykes, are present within Lower Gondwana Sequence, as observed in drilled well ON-7 and ON-6. Accordingly, the intrusive modelling has been carried out, to check the effect of intrusion on HC generation. The model has been further supplemented with all other data types viz. boundary conditions (Paleo Water Depth, Sediment Water Interface Temperature) to build a viable dynamic model. Crustal Heat flow modelling was carried out using crustal thickness, type and details of rifting phases & the output Heat Flow maps of different stratigraphic ages were incorporated as input in the 3D PSM model.

Maturation Results from 3D output for different plays:

The maturation results in Gondwana sequence indicates that overall the Lower Gondwana sequence is within the Late oil to Gas window and the source rock sequences has experienced high transformation in most of the places. However, the area surrounding the igneous intrusions attained early maturation, almost at the time of intrusion and at present those parts are over mature. The cretaceous sequence has attained high maturity which is increasing towards the deep basinal side. While most part of the shallow shelfal sequences is within Late Oil to Gas window, the sequences beyond hinge zone are showing mostly over mature zone. The major part of the Paleocene source rock sequence, close to the hinge zone, is within the wet gas to dry gas zone and the deep basinal part is showing over maturity (**Fig. 3**). Eocene source rock

sequence has entered gas window near hinge zone and towards the deep basinal part it also has attained very high maturity. The Hooghly shale (major contributor for Oligocene and Miocene reservoirs), is in the late oil to gas window near hinge zone and slope and towards the deep basinal part it has entered dry gas window. In the shelf area Oligocene sequence is mostly immature or has just entered oil window (**Fig. 3**). However, beyond hinge zone the sequence is within gas window. The Miocene Section is overall immature in the shelfal part and beyond the hinge zone it has entered in the oil to gas window due to increased depth of burial. In general Miocene source rock is not contributing in thermogenic hydrocarbon system of Bengal Basin. The Pliocene Section is immature in respect of Thermogenic hydrocarbon generation window in Bengal Onland Basin.

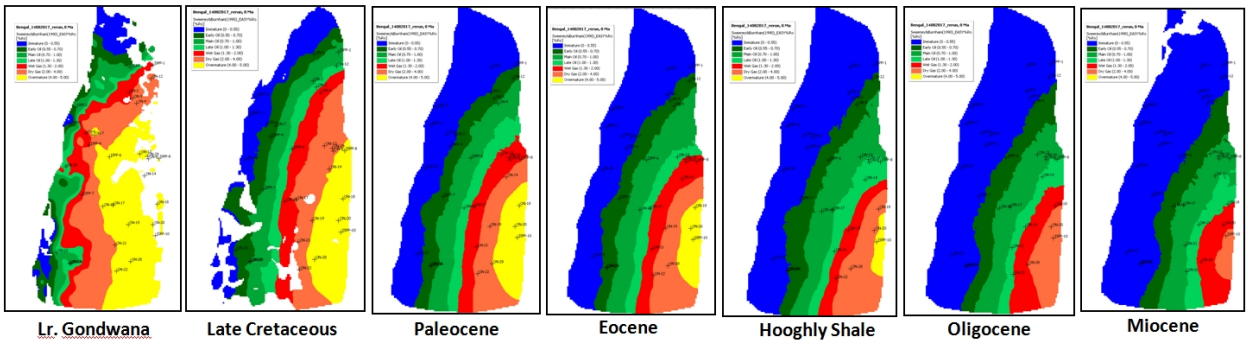


Figure. 3. Maturity (%Ro) of Source Rocks

Accumulation:

In Gondwana sequence**,** Raniganj & Karharbari source rocks are acting as the main contributors for conventional Thermogenic system. In addition, Gondwana coal sequences are also capable of generating considerable amount of Thermogenic Gas which is mostly adsorbed within the source itself as non-conventional PS. In Cretaceous sequence**,** expulsion of HC from Cretaceous source rock has started from Paleocene onwards.The reservoirs within Cretaceous are charged by Cretaceous source rocks only.The source rock sequences within Paleocene have started expelling from Mid Eocene onwards. The origin of the charges within Paleocene is mostly from Paleocene source rock itself, though secondary contribution from Cretaceous is also evidenced. The accumulation information in Eocene showed major contribution from Paleocene with minor charging from Eocene, Hooghly shale, Cretaceous as well as Gondwana. The Hooghly shale is acting as the major contributor for Oligocene and Miocene reservoirs. This source rock has started expelling from Early Miocene onwards. Expulsion of the generated HC from Oligocene sequence has started in Late Miocene (**Fig. 4a**).

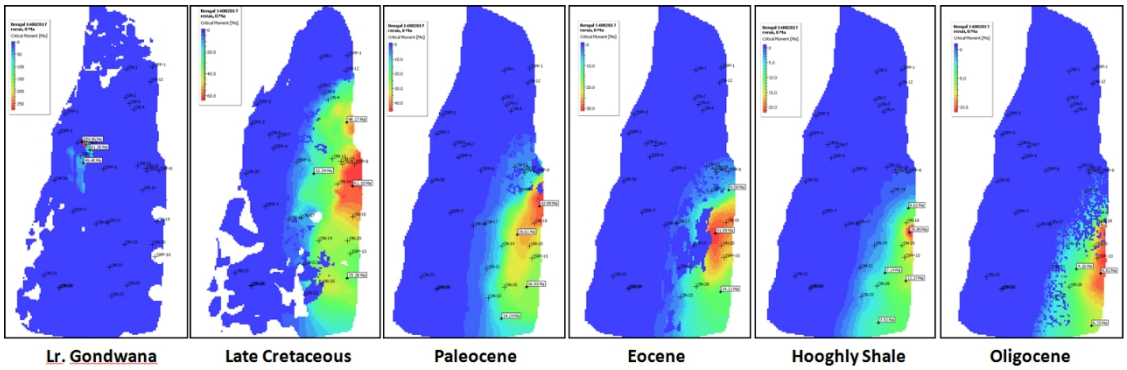


Figure. 4a. Critical Moment for expulsion from Source Rocks

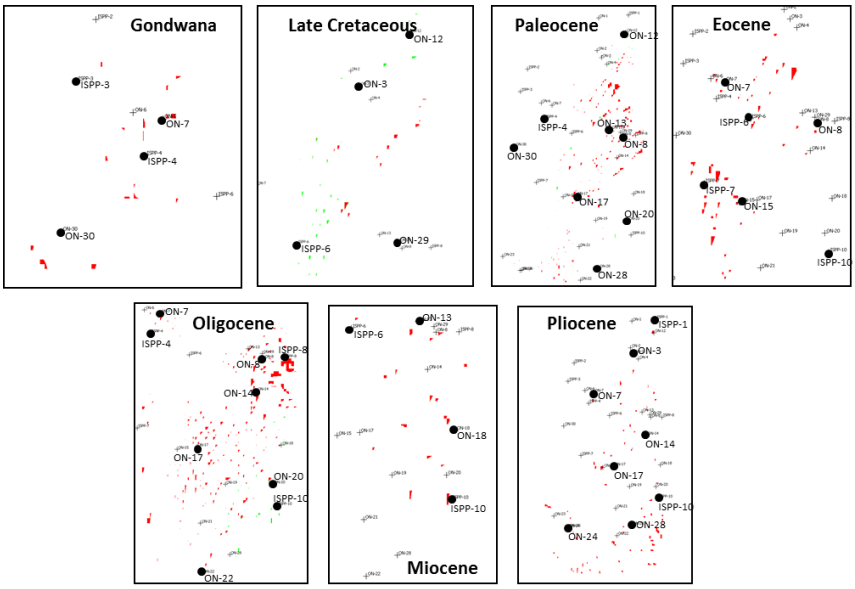


Figure. 4b. Accumulation for various sequences

In Bengal Basin, Miocene can contribute as a potential sequence mostly Thermogenic with minor mixed/Biogenic hydrocarbon in favourable areas where the combined effect of sedimentation rate and temperature can aid methanogenesis. The accumulation in Miocene sequence is showing considerable amount of Thermogenic hydrocarbon migrated from Hooghly Shale, Oligocene source rock as well as other deeper source rock layers**.** The accumulation in Pliocene sequence is most0ly biogenic, though minor Thermogenic hydrocarbon has migrated from the deeper source rock layers of Paleogene**.**

PSM Results and Analysis:

Till date, in Bengal Onland area, presence of three Petroleum systems postulates as per the gas geochemical data of the drilled wells:

- Paleogene-Neogene Hypothetical Petroleum System (.), viz. ON-20, ON-22
- Paleogene-Paleogene Hypothetical Petroleum System (.), viz. ON-8, ON-29, ON-19
- Gondwana-Paleogene Speculative Petroleum System (?), viz. ON-24

In addition to these, the present PSM study envisaged the following Petroleum Systems which are till now not established through drilling -

- Neogene-Neogene Speculative Petroleum System (Biogenic) (?)
- Cretaceous-Paleogene Speculative Petroleum System (?)
- Cretaceous-Cretaceous Speculative Petroleum System (?)
- Gondwana-Gondwana Speculative Petroleum System (?)

Common Risk segment maps:

For Bengal Onland, the Common Risk Segment (CRS) Maps for eight plays (Pliocene, Miocene, Oligocene, Eocene, Palaeocene, Cretaceous, Upper Gondwana & Lower Gondwana sequence) have been generated. Inputs maps for common risk segment for each plays are Chance of Success (COS) Maps, like, vertical charge (including source rock presence in terms of TOC and effectiveness in terms of transformation ratio), lateral charge (migration pathway), reservoir presence (facies distribution) & quality (effective porosity) and seal adequacy (capillary entry pressure). Using these COS maps, the play chance mapping process was carried out, which generated CRS map for each play.

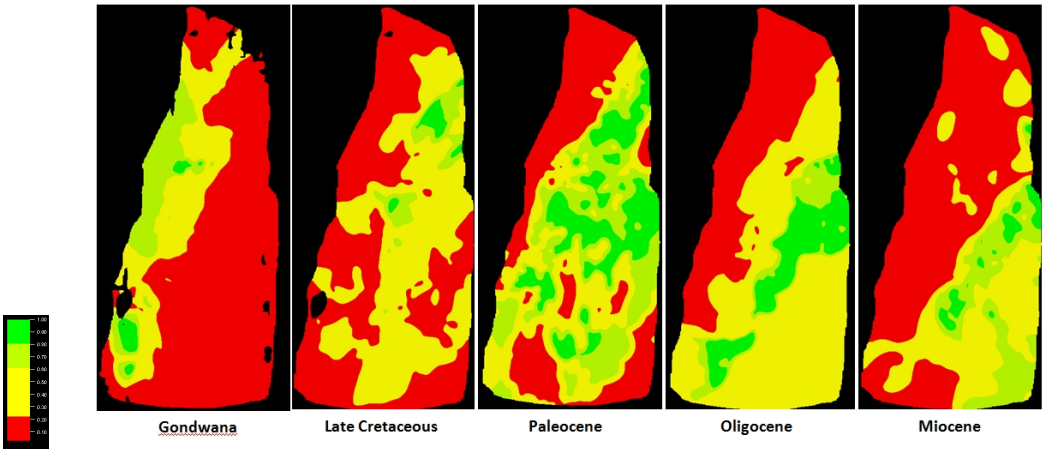


Figure. 4b. CRS Maps for Thermogenic Plays

Play wise exploration strategies:

a) Gondwana Thermogenic Play: In Gondwana sequence, drilled well data indicate the presence of mainly Type-III kerogen. Raniganj & Karharbari source rocks are acting as the contributors for minor conventional Thermogenic system for Gondwana-Gondwana PS. However, Gondwana coal sequences are also capable of generating considerable amount of Thermogenic Gas which are mostly adsorbed within the source itself as non-conventional PS as evidenced from surfaced gas in well ON-30 (Lower Gondwana Coal Shale sequence, TG-53.77%). Based on above evidence, the gas shows within coal-carb shale of Lower Gondwana sequence may be relooked as a non-conventional PS, depending upon play economics vis-à-vis production technology.

b) Cretaceous Thermogenic Play: The Cretaceous source sequences have attained high maturity which is increasing towards the deep basinal side. Expulsion of hydrocarbon from Cretaceous source rock has started from Paleocene onwards. The reservoirs within Cretaceous are charged by mostly Cretaceous source rocks. The accumulations are very minor & sporadic in nature.

c) Paleocene Thermogenic Play: Based on PSM model accumulation, CRS map vis-à-vis well data, three prospective areas were identified. Prospective area-1, lies in the NE part of Bengal Onland (around ISPP-1 & ON-12 area in the northern part) which is supported by Oil core of ON-12, possible missed hydrocarbon zone in ISPP-1 (based on Log & shows) & numerous hydrocarbon shows & gas from RFT in ON-3. Prospective area-2 lies in the eastern part of the basin (ISPP-8 & ON-8 area), close to hinge zone corridor. In the said area, three prospects were identified for exploration of envisaged Barrier bar within Paleocene which are close to generation centre, falls in the migratory trend along the hinge zone & likely to be charged. Prospective area-3 lies in the southern part of Bengal onland where two wells ON-24 & ON-26 produced non-commercial gas from Paleocene sequence on conventional testing.

d) Eocene Thermogenic Play: In Eocene sequence, based on gas shows from ON-21, the area along hinge zone (Amtala–Diamond Harbour area may only be relooked for porous refolds anomalies & exploration of Thermogenic hydrocarbon.

e) Oligocene Thermogenic Play: In Oligocene sequence, all the Thermogenic accumulation is located very close to hinge zone & accordingly, down dip portion of Ichapur pay equivalent to be targeted based on facies distribution. In addition, two distributory channels have been identified based on different attributes (around southern portion of present NELP block), the equivalent of which was not probed earlier in Bengal Onland. This type of distributary channel complex in Oligocene near Eocene shelf break area (close to kitchen), seems highly prospective in terms of play dynamics.

f) Miocene Mixed Thermogenic/ Biogenic Play: The Miocene Section is overall immature in the shelfal part and beyond the hinge zone, it is in the oil to gas window. The accumulation in Miocene sequence is showing considerable amount of Thermogenic hydrocarbon migrated from Hooghly Shale, Oligocene source rock as well as other deeper source rock layers, with depth of accumulation greater than 3000m. Miocene can contribute as a potential sequence for biogenic hydrocarbon too in favourable areas where the combined effect of sedimentation rate and temperature as well as depositional environment can aid methanogenesis.

g) Pliocene Mixed Thermogenic/ Biogenic Play: As indicated by 3D PSM output, Pliocene sequence can only contribute Biogenic hydrocarbon in favourable areas. Biogenic Gas accumulations are very much

dependent on its location within the basin, in relation to sediment thickness & its proximity to the delta mouth that provides the volume of sediments and organic matter necessary for initiation of methanogenesis. Based on the PSM study, the generation centres for biomethane are identified beyond hinge zone, further south-eastern part of basin. There is also a chance of getting Thermogenic hydrocarbon within Pliocene, migrated from deeper source in favourable areas.

Conclusions:

Based on the available G&G, drilled wells, carbon isotopic data, Play maps, play wise exploration audit, 3D PSM vis-à-vis analyses of Common Risk Segment map of each play, out of the prospective areas mentioned above, two areas have been identified for future exploration in immediate short term. Area-1 lies south & SE part (close to Hinge zone corridor) of Bengal onland which is interesting for both Biogenic/Mixed & Thermogenic hydrocarbon from Neogene & Oligocene sequence. In Oligocene sequence, all the Thermogenic accumulation is located very close to hinge zone & accordingly, down dip portion of Oligocene play (equivalent to ON-8) to be targeted based on detailed facies analysis. The Area-2 lies in the north & NE part near (around ISPP-1 & ON-12 area) in the northern part for exploration of Thermogenic hydrocarbon.

Acknowledgement:

The authors are grateful to Shri A. K. Dwivedi, Director (Exploration)-ONGC for giving opportunity to MBA Basin, ONGC, Kolkata for carrying out the job Hydrocarbon Resource Assessment of Mahanadi Basin, part of which is used in the present studies. The authors are grateful to Shri S. K. Das, GGM-Basin Manager, MBA Basin, ONGC, Kolkata for his keen interest, encouragement & valuable suggestions during the course of the studies. The authors convey their sincere thanks to all Hydrocarbon Resource Assessment Team members of MBA Basin for providing necessary support.

References:

Roy D. K. etal 2018. Biogenic & Thermogenic Prospectivity of Bengal Onland Basin covering existing NELP Blocks & surrounding areas, unpublished report.

Kingston John, 1996, Bengal Basin evolution & exploration recommendations

Roychoudhury S C, 2011, What failed Bengal? Are there any rays of hope?

Other than these, many unpublished ONGC reports & WCR of drilled wells have been used in this paper.