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Prospectivity Perception and Exploration Challenges in Deep-Water Exploration in Mahanadi – NEC Area

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Abstract

Mahanadi-NEC area has been explored from onland to shallow shelf-slope region up to deep-water basinal part in recent past. 23 deep water wells have been drilled in Mahanadi offshore resulting in six discoveries. Discoveries made so far are in Mio-Pliocene reservoirs; as a result focus of all exploratory efforts has been on Mio-Pliocene stratigraphic plays. Although, basin modeling study suggests that there is a working thermogenic source system and the recent Paleogene discovery of mixed hydrocarbon raises the hope of major discoveries in deeper stratigraphic level, but till date almost all the discoveries are biogenic in nature and therefore to find the thermogenic plays in the basin remains the biggest challenge. So far the exploration strategy was mainly amplitude driven delineation of reservoirs. The channel – fan complexes have been explored through bright amplitude anomalies. However, the results indicate that amplitude brightening need not necessarily be indicative of gas charged sands. Though some success is met in identifying gas charged sands through AVO analysis, but it has been observed that all Class–III AVO anomalies are not gas sands.

Paleogeography of Mahanadi, suggest that in Pre-collision (>59 Ma) period, major input came from North West direction by Mahanadi-Brahmani drainage system. Post-collision (<15 Ma) period shows sediment input from dual sources i.e. Mahanadi input from the NW and Bengal (Ganga-Brahmaputra) input from the North. Moreover, in Pre-collision (>59 Ma) period the Proto-Mahanadi has been draining the Archean basement terrain rather than basaltic terrain. The drainage system was well established and the rivers started forming deltas in the shelf as evident from drilled well data .The deltaic sediments were reworked by the long shore currents and got distributed into the mouths of canyons to be carried into the slope and deeper basinal areas. Hence, the Low stand deep-water canyon fill deposits and the associated relict structures of Eocene age and the slope fans of Paleocene and Eocene age demand attention as prospective candidates for future exploration targets in this area. In this paper, an attempt has been made to bring out all the G & G challenges faced during the course of journey of exploration made so far. A re-look into potential exploration targets in deeper stratigraphy to establish the thermogenic system are warranted.These however would require dovetail of geological concepts and innovative geological techniques.

Geology and tectonic setting

All the basins developed along the eastern passive continental margin of India (Mahanadi, Krishna-Godavari and Cauvery) resulted from rifting and breakup of Gondwanaland during the Jurassic period. The Cretaceous rift led to the development of ponded low, which possibly had restrictive / anaerobic marine environment, favorable for organic matter preservation. During the Oligocene, a major hinge developed all along the coast, resulting in thick Neogene sediments along the basin ward side of the hinge. This hinge marks a facies change from platform carbonates to basinalsiliciclastic rocks, thus delineating a possible Eocene continental shelf break. During this time, large sedimentary basins formed at the deltas of the major rivers.

Mahanadi basin is one of the passive margin basins located along the east coast of India, occupies an area of more than 50,000 Sq. Km. which is bounded by the Bengal Basin in the NE and Krishna-Godavari in the SW (Fig.1).

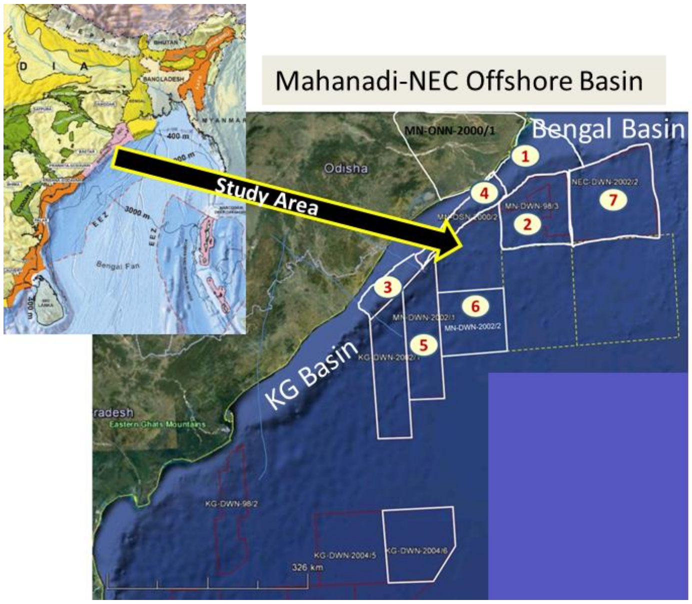

Fig-1. Map showing the study area of Mahanadi-NEC offshore area

It is located between hydrocarbon producing KG basin to the southwest and Bengal basin to the northeast. Mahanadi graben was an intra-cratonic basin, with NW-SE trending graben in the then Gondwana land, which was initiated during Permo-Carboniferous time. During Middle to Late Cretaceous, Indian plate first drifted towards north and after collision with Eurasian plate it drifted towards east. Due to this movement a new ocean floor was created. During this period paleo-coast was tilted towards east, which resulted in the development of rejuvenated drainage systems into the newly formed ocean floor. Drilled data to the north of the area indicate that sedimentary fill consists of Early Cretaceous to Recent sediments. A basaltic lava flow (Rajmahal trap) is present in between Early and Late Cretaceous sediments. Middle Eocene carbonate is also a well-known litho-marker (Bastia.R). Overlying Neogene sequence comprises of clastics in the form of channel-levee complex, fans and mass transport systems in a deep-sea setup. Expected total sedimentary thickness is of the order of 5 km. Deep water blocks of Mahanadi basin witnessed the confluence of dual sedimentation by the Ganga and the Mahanadi rivers (C.D Johnstoneetal).

Petroleum System

So far in Mahanadi basin all the gas discoveries are biogenic. Although, studies by consultants and by company's experts suggest the presence of thermogenic petroleum system and the recent Paleogene discovery in the basin opens up the possibility of presence of thermally rich source rock in the Cretaceous rift related sediments, but it is yet to be established.2D modeling of the Mahanadi Basins has shown that the potential source rock would be mature for HC generation along the East Coast of India (IES-ONGC collaborative report). In the Mahanadi Basin the Bengal fan deposition is the key driver for source rock transformation. They are all passing the critical moment during the latest Paleogene to early Neogene. Therefore, these source rocks are likely to have contributed charge to both, stratigraphic and structural traps. The required preservation times are also favorable. As limited structural traps are available in deepwater regime in Mahanadi, stratigraphic traps may play an important role as exploration targets. Pinchouts against structural highs, low-stand fans and Tertiary channel sands could be charged by thermogenic hydrocarbon. Model showed that in Mahanadi basin maturation started from Coniacian-Santonian/ Maastrichtian time and the critical moment was from Oligocene to Miocene (Fig 2).The proven petroleum system that is acting in the basin is the Neogene (biogenic). Biogenic gas will most likely be trapped within intra-source rock channel sands within Mio-Pliocene window.

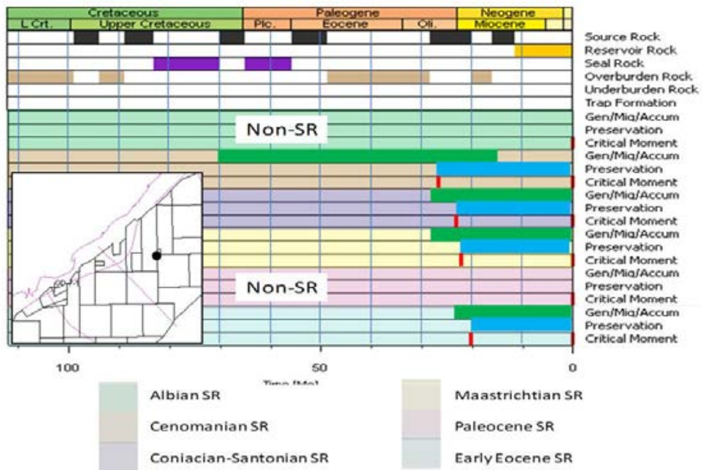

Fig-2 . Petroleum System Element Chart of Mahandi Basin

Exploration Challenges

Although east coast has emerged as the hotspot of hydrocarbon exploration in the country; commercial success remained elusive in Mahanadi-NEC sector. Majority of the drilled wells have evidence of gaseous hydrocarbon accumulation of biogenic origin in shallow stratigraphic level.Establishing the thermogenic play in the basin remains the biggest challenge.

The Channel – fan complexes in Mahanadi have been explored through bright amplitude anomalies and some success is also met in identifying gas charged sands through amplitude standouts and AVO analysis. But deep-water channels are high risk areas because of their varied genesis and complex lithology variation. This indicates the difference in provenance, transportation and genesis though they were deposited in nearby areas with same slope system, like the adjacent areas of Mahanadi and NEC.In NEC drilling results indicate that amplitude brightening need not necessarily be indicative of gas charged sands; nor even necessarily sand-shale interfaces (Fig.3). Seismic amplitude distribution and related attributes may be misleading as the same amplitude distribution may be generated by several lithology-fluid combinations with positive AVO anomaly (Fig.4).

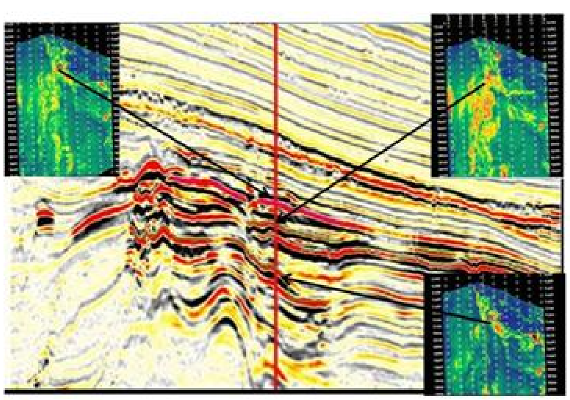

Fig-3. High amplitude channels proved to be clay filled in NEC area.

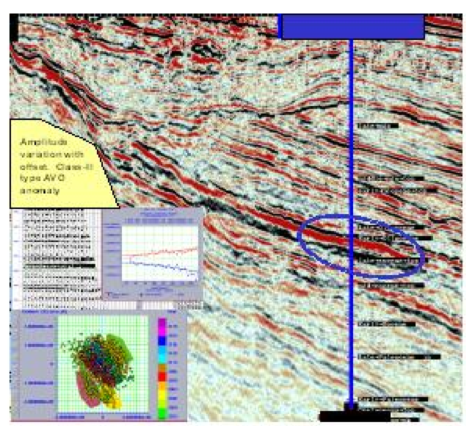

Fig- 4. Bright amplitude proved to be presence of limestone streaks in one of the Mahanadi well, although AVO analysis suggested Class-III type of anomaly

Large deposition of finer clastics from Bengal Fan over the NEC area might have added the abundance of argillaceous clastics. So, all the channels of CLC are not sand rich, and that all Class-III AVO anomalies are not gas sands (Fig. 5). In fact the Mio-Pliocene section of NEC area appears to be clay rich without any significant sand reservoirs. The bright amplitudes seem to be due to thick section of claystones with differential compactions. Petrophysically, it's all consolidate and unconsolidated clay alterations. These anomalies are false DHI's without any gas sands. Moreover similar amplitude response gave different fluids. So, amplitude standouts and reservoir relationship is not properly understood yet which is another big challenge for future exploration in this sector.

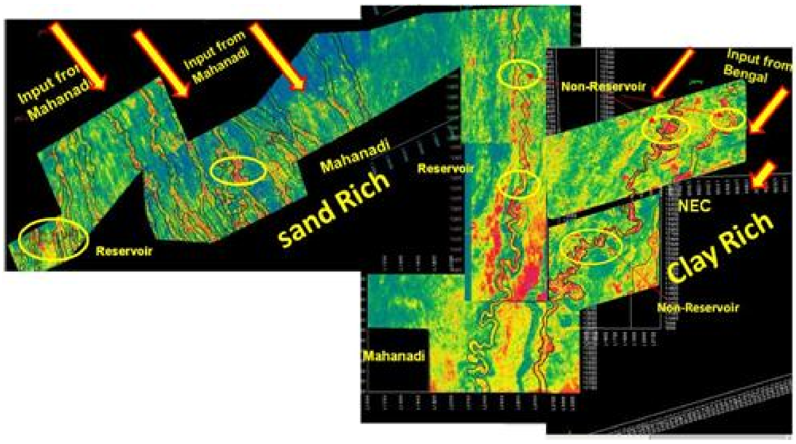

Fig- 5. Discrimination between sand rich and clay channels in Channel - Levee system is a big challenge. In NEC sector channels are mostly clay rich.

In Mahanadi Offshore area, gas sands are thin and are sub-seismic in resolution in the normal seismic band in most of the drilled wells. Moreover, Post-stack and Pre-stack simultaneous inversion results have indicated that the gas reservoir sands are limited in thickness as well as in areal extent and are preferentially charged. Thus, the mapping of continuity of the identified gas bearing sand across channel-levee complex continues to be a challenge for the development. On the contrary, relatively cleaner sands are thick in general, but are filled with brine (Fig.6). Hence, identification of these thin gas sands from seismic signature prior to drilling is difficult and to map the continuity of thesesands isa big challenge.

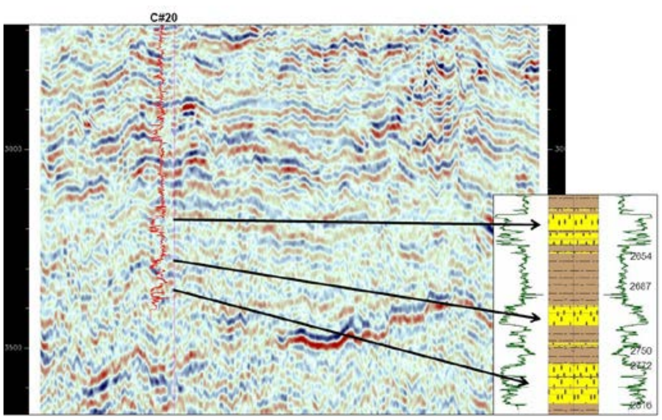

Fig.6. Deciphering Thick sand from seismic signature prior to drilling is difficult. Mapping the continuity of the sand isequally difficult.

Ambiguous seismic signature often poses big challenge in exploration. In two contiguous blocks of Mahanadi and KG basin Pinnacle reefs have been mapped purely on the basis of the perfect seismic morphology in the basal part of Late Cretaceous sequence, close to Early Cretaceous shelf edge (Fig.7). Shallow bathymetry prevalent close to Early Cretaceous shelf edge must have been conducive for reefal growth. These features are consistent with a carbonate build-up and form a cluster. Interval velocity section along lines in Mahanadi block shows that the reefal unit has higher velocities than the overlying Late Cretaceous shale (ONGC unpublished report). Velocity pull-up below the reefal body also indicates an internal velocity higher than their surroundings. But the prospect turned out to be mud volcano after drilling. So this ambiguous seismic signature for reservoir geometry is a big challenge in frontier areas.

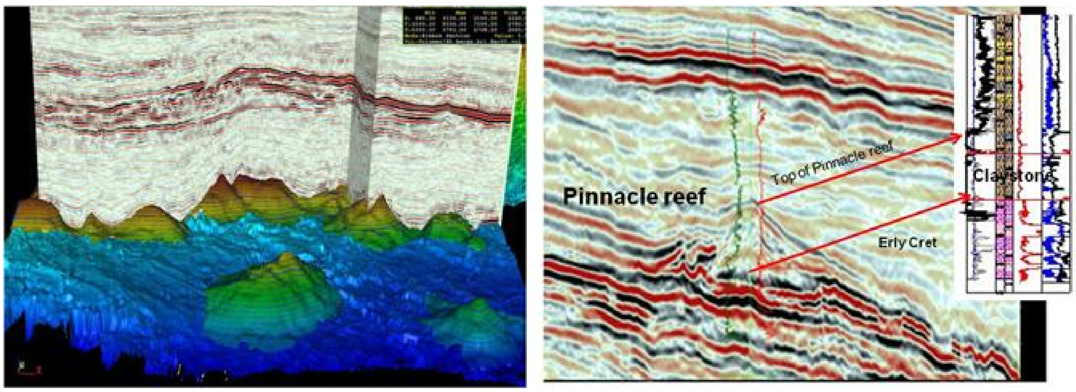

Fig.7. Interpreted Pinnacle reef from seismic morphology turned out to be mainly Clay stone (mud volcano).

In another block of Mahanadi a Paleocene clastic fan was identified on the basis of perfect fan geometry, distinct feeder channel and high amplitude seismic anomaly as seen in the seismic lines and attributes. The reservoir quality was expected to be mainly good porous clastic sediments. Both Impedance section along seismic line and impedance attribute map indicated presence of reservoir sand within the fan (Fig.8). But the envisaged clastic fan turned out to be tight limestone somewhat dolomitic in nature devoid of any hydrocarbon (ONGC unpublished PDA report). This is another example of challenges associated with seismic signature for reservoir geometry.

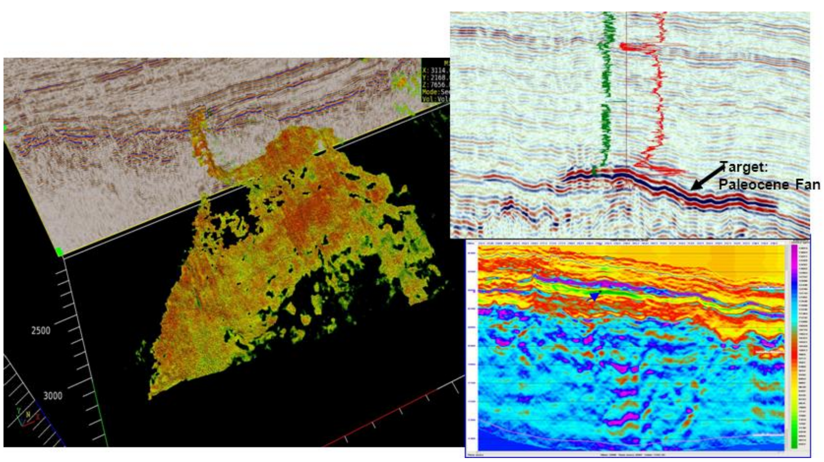

Fig.8. Clastic Fan (Paleocene) turned out to be tight carbonate devoid of hydrocarbon

In the discovery block of Mahanadi, reservoir characterization study has been carried out taking all the geo scientific data of the discovery well to develop a methodology for differentiating gas bearing pay sand from water bearing sand over a sub area of the block. The study has produced a successful work-flow which uses a combination of stochastic inversion, neural network analysis and a gas-signature screening process together with a rock-physics-defined EI(30) cut-off which identifies gas bearing sands. It has been shown that gas-bearing sands in this basin are characterized by Seismic reflection character, Peak-over-trough, Amplitude increase with offset and Elastic Impedance EI (30) $<$ 720 (m/s g/cc). With this methodology two potential gas sand-bodies identified from the seismic data (Fig.9) and potential gas volumes have been estimated. The techniques include a high-frequency stochastic inversion method, a neural network analysis and a seismic attribute analysis (icon science report). Porosity model prediction corresponding to these two bodies indicated high porosity (Fig.9). But predicted Gas sand bodies turned out to be clay/brine sand after drilling. Stochastic/Neural network based Elastic inversion failed in prediction of gas charged sand bodies in this case. So, the challenge remains for identification of reservoir sand, as there is no direct tool/ technique to discriminate gas sand and brine sand bodies.

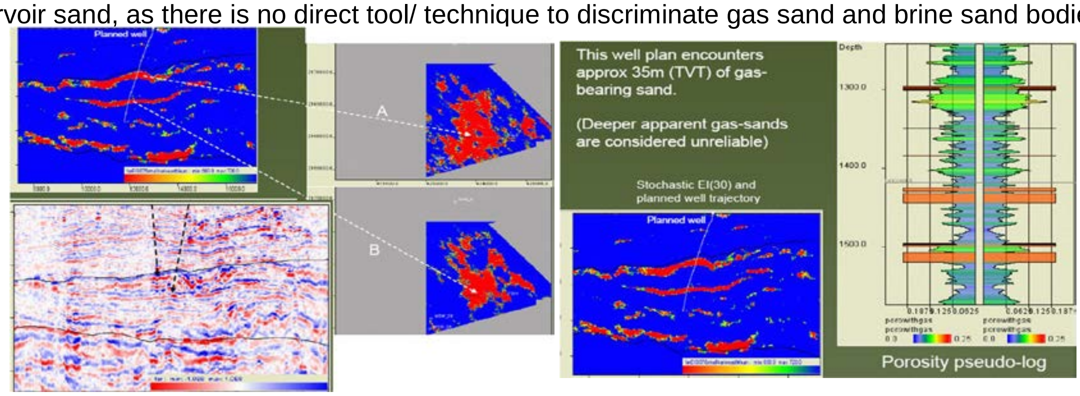

Fig.9. Gas charged bodies identified based on Seismic attributes, Stochastic Elastic Impedance and Neural network.Porosity model prediction corresponding to sand bodies showed high porosity, but the Predicted Gas sand bodies turned out to be Claystone with very little sand.

Prospectivity Perception

Exploration for hydrocarbons in a basin is driven by understanding of its evolution through geological times and linked with its sedimentation history and tectonics. In reference to Mahanadi basin the geological evolution in terms of identified rift architecture and its extension in deep water area are well documented. The pre- collision and post collision tectonic imprints can also be mapped and analyzed on seismic.

Intra-cratonic breakup of Gondwanaland during late Permian to Early Jurassic leading to deposition of continental sediments in rifted grabens along with continued activity along fault blocks, subsidence of grabens deposition of rift fill sediments during Late Cretaceous are clear precursor to a logical process response model in extension setting. Thickness & Spatial geometry of Mapped sequence are related to basin evolution & basins fill processes. Late Cretaceous depo-center occurs in Kalinga low along 85 east ridge in Mahanadi basin (Fig.10). The broader geographical extent and thickness of Late Cretaceous compared with Early Cretaceous and Paleocene thicks indicate maximum subsidence and spatial basin expansion during Late Cretaceous period.

The syn-rift sediments represented by sandstone siltstone sequence topped by a major unconformity have been reported in wells drilled on shelf. Thus rift fills of late Cretaceous are envisaged to be a worthy high reward exploration targets, however in Mahandai deep water these are envisaged to be located at depths greater than 7 Km.(Fig.11)

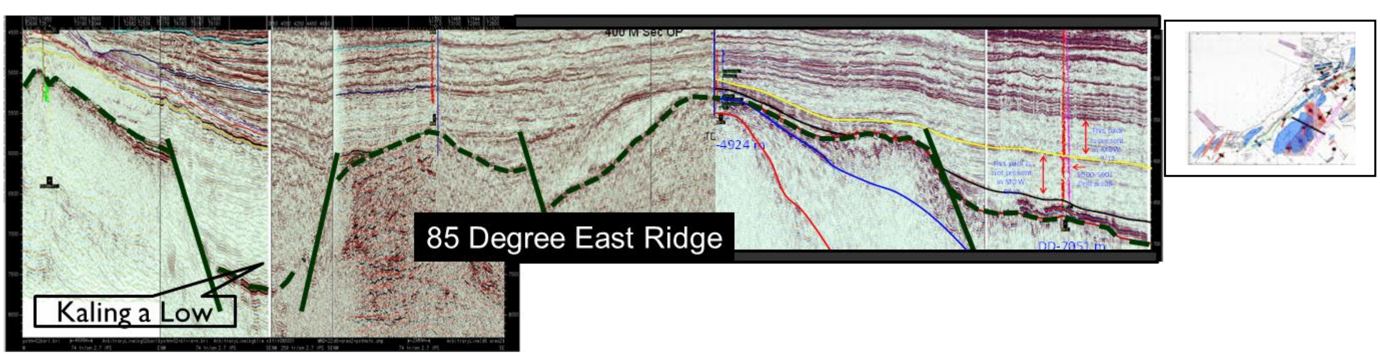

Fig.10. Emplaced 85 Degree east ridge complex in relation to Kalinga low- Late Cretaceous sediment depo-center.

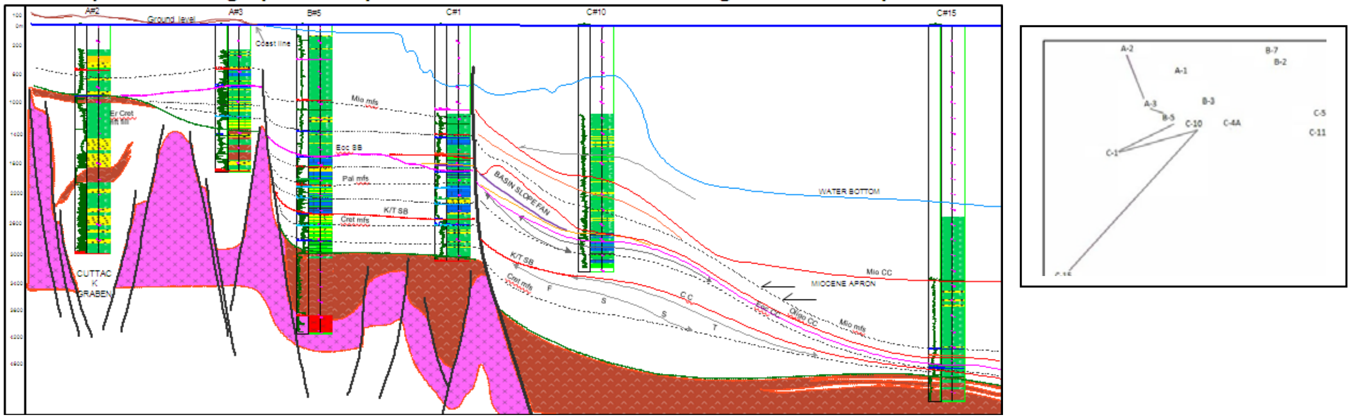

Fig.11.Cretaceous rift sequence with thick sedimentary fill in the Shelf area of Mahanadi.

The development of Tertiary play system is well represented through drilled well data wherein Palaeogene channel fan complexes, Neogene slope fans, slope channels, basin floor fans and channel levee complexes have been mapped and drilled with mixed results.

In reference to deep water exploration especially for deeper play solution is envisaged to be provided by technology whereas understanding of CLC characteristics through lithology discrimination and fluid prediction would lead to realization of true potential of tertiary play systems.

Conclusion

Deep-water resources are simply conventional reserves in an unconventional setting, but they constitute a class of their own largely because they face a common set of G & G challenges in the course of their identification. Mahanadi-NEC offshore area of east coast also offers unique challenge for deep water exploration. Although intensive exploration activities in the recent years by ONGC has resulted a good number of discoveries with fairly good success rate, but till date exploration is restricted in shallow stratigraphic level only. Although deeper plays (Eocene and Paleocene) have already been identified and attempted to drill, but due to drilling complications deeper prospects could not be drilled. So, now the big challenge in this sector is to establish thermogenic petroleum system by drilling the deeper prospects without complications with a robust GME model.And needless to say that, a lot is still to be done at the end of the seismic industry. Promises of deeper level bonanza are only possible with high quality imaging. With the advancement of technology, we would soon be able to conquer these hurdles and perhaps start seeing beyond them.

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