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Depositional Model and Prospectivity of Paleogene Plays in Mahanadi Basin.

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Abstract

The Mahanadi Basin is under active exploration since early eighties. Post 1998, in the new exploration policy regime, national oil companies and other private players entered the fray which resulted in drilling of more than thirty deep water wells in the area in the past decade. These exploration endeavours resulted in finding of a number of biogenic gas discoveries in the Mio-Pliocene channel levee complexes. However, thermogenic petroleum system could not be established in the Basin till date.

The present study has brought out regional depositional model and sand dispersal pattern with the help of paleo-geographic reconstruction, paleo-drainage analysis, and regional sediment thickness maps at various stratigraphic levels and seismic attribute analysis.

The sedimentation model in the Mahanadi Offshore Basin can be broadly categorised into two; i) The Late Cretaceous–Paleogene sequences deposited by the peninsular rivers prior to Himalayan uplift, and ii) Post collision sequences transported by the Himalayan Rivers in Neogene. Late Cretaceous marks the beginning of shelf-slope system in the Mahanadi Basin. During Paleocene time, basin was clastic starved, and progradational carbonates were deposited on the shelf. At the time of Late Eocene, shelf was deeply eroded and a mix of carbonate and clastics deposited in the basin in the form of valley-fills and fans. Oligocene marks predominance of north-south flowing drainage and influx of sediment into the basin. Mio-Pliocene period represents phase of progradation and formation of channel-levee complexes and basin floor fans.

Thermal maturity modelling studies of the Basin indicate that the middle and bottom part of Late Cretaceous sediments fall in the late oil window whereas Paleogene sediments fall in early oil window. The huge thickness of Neogene section in and around the north eastern part of the Basin might have facilitated maturation of the Paleogene and older sediments. In the area, sediments below Middle Oligocene are matured to generate hydrocarbons. The study underlines the need to explore the Paleogene prospects to chase the elusive thermogenic hydrocarbon in the Mahanadi Offshore Basin.

Key words: Thermogenic petroleum system, Paleogene, Valley fills and fans,

Introduction

Mahanadi Basin is located in the Northeastern part of East coast of India, flanked by Bengal Basin in the north east and KG Basin in the southwest. In the onland area the Basin is restricted from north east of Chilka Lake in the south to Jagannathpur in the north east with Archean crystalline basement and Early Jurassic-Early Cretaceous sediments in the west. The Basin extends up to deep offshore of Bay of Bengal and covers an area of about 1, 65,000 km^2 (Fig.1). The present study area is restricted to the offshore part

Geological setting

The basement configuration of the Basin shows NE-SW to ENE-WSW trending horst and graben morphology similar to the southern Cauvery and K-G Basins. The Mahanadi Offshore Basin can be divided into major structural elements with a general NE-SW orientation i.e. from NW to SE as shelf, hinge zone or slope and basin fore deep.

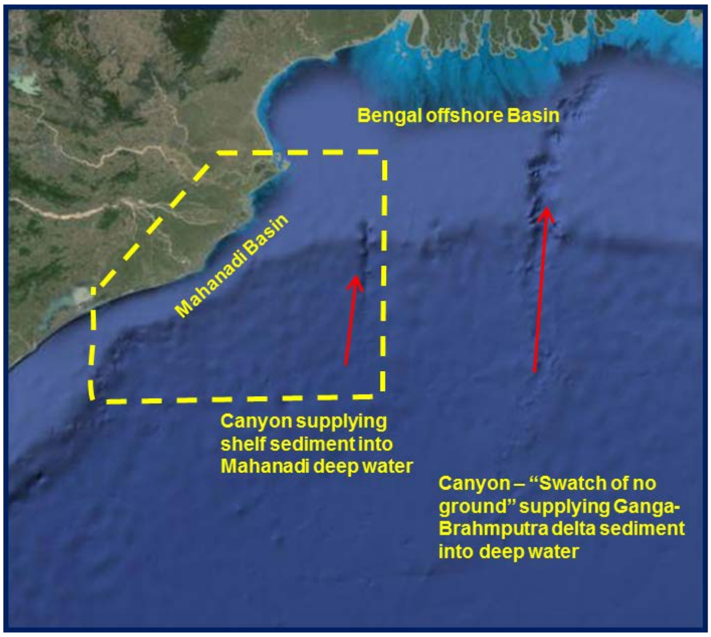

Fig.1: Map showing Mahanadi Basin area and major sedimentation conduit of modern day.

Following the rifting and the volcanism during Early Cretaceous period, the Mahanadi shelf received poorly differentiated sand/silt as Late Cretaceous continental deposits. During Paleocene period, the south western part of Mahanadi shelf experienced deltaic sedimentation sourced from Eastern Ghats and Central Indian craton due to the change in tilt of the Indian craton from a westerly to south easterly direction. In Eocene period, the Mahanadi shelf became clastic starved hence mainly limestone with interbedded clastics were deposited. This sequence is marked by pronounced shelf and slope break grading into basinal shales. Oligocene is conspicuous as a period of regression in the major part of Mahanadi shelf.

Miocene was a period of regional subsidence and marine transgression in Mahanadi Basin. Although subsidence started in Early Miocene, rate of subsidence became very high towards the beginning of the Middle Miocene period. This led to a renewed influx of clastics into the basin and progradation of deltaic sediments over the tectonically altered Miocene section which continued to present day.

Sedimentation model

Structural and stratigraphic analysis of various sequences was carried out in detail in the present study. Structural and depositional features were brought out through various relief and thickness maps.

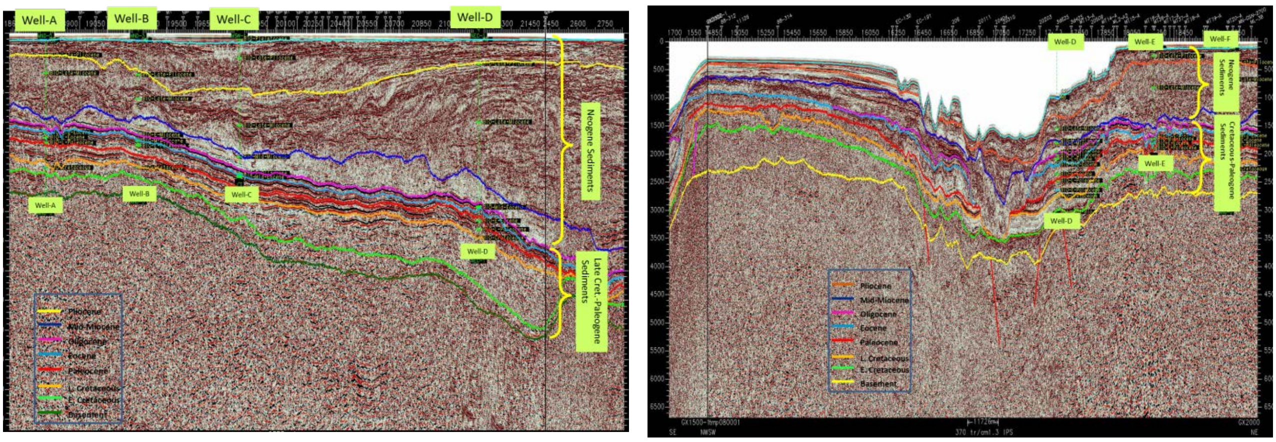

Fig.2: Seismic section showing two phases of sedimentation pattern in Mahanadi offshore

Two major tectonic events controlled the sediment dispersal pattern in the basin (i) The emplacement of 85° E Ridge, and (ii) Collision of Indian plate on to Eurasian plate and the uplift of the Himalayas. Based on the events, the sedimentation pattern in the area could be classified into two. ie. Pre-

Collision sedimentation pattern originated in the Eastern Ghats and Post-Collision sedimentation pattern, which is a synthesis of Mahanadi and Himalayan river systems. The seismic sections given depict this two different patterns of sedimentation (Fig.2) i) The Late Cretaceous-Paleogene sequence of sediments which are deposited as parallel events in a tectonically calmer period and ii) Neogene sedimentation concomitant with the "hard" collision of Indian plate with the Eurasian plate with high rate of sedimentation brought by the Himalayan river system. This could be seen as chaotic reflections in the seismic section due to the intermixing of sediments.

Pre collision sedimentation pattern

Prior to Indo-Asia collision in Upper Paleocene, (>59 Ma), major sediment supply into the basin was mostly from the NW by Mahanadi – Brahmani system of rivers. No active depositional system is envisaged from the north (Curray et al., 2003). Integrated analysis of seismic studies, paleogeographic reconstruction and paleo-drainage study indicates that prior to Eocene, Mahanadi offshore received sediments mainly from the North West direction by the rivers draining the central Indian craton. Rivers like Mahanadi and Brahmani which brought sediments into the Mahanadi offshore Basin were derived it from the northwest as relatively smaller river system in Late Cretaceous. This continued till early part of Paleocene and due to advent of peneplanation, sediment influx became reduced and later part of Paleocene and Eocene witnessed development of carbonate sedimentation in the shelfal part of Mahanadi Basin. In the post Eocene period, following the onset of "soft" collision, drainage in the north was also active which supplied sediments to the deeper part of the Basin even though Mahanadi River system continued to deliver sediment to the basin. The major tectonic event that affected the sediment distribution during the period was the emplacement of 85° E Ridge. The emplacement probably took place after Aptian / Albian (Bastia, R., et al. 2010). The ridge remained as positive topographic high till Early Oligocene and affected the sediment dispersal pattern from early part of Late Cretaceous to Paleogene time. Onlap / terminations of pre Late Oligocene sequence on both flanks of the ridge indicate that the sediments are younger to the volcanic emplacement. The Late Oligocene sediment draping over the ridge indicates its submergence for the first time after it is formed (Fig.3). The ridge also acted as a subsea physiographic divide between western Godavari Basin and north eastern Mahanadi Basin until Early Oligocene time. Sediment thicknesses on either flank of the ridge are different both in pre and post Oligocene time. The post Oligocene sequence also shows reduced thickness over the ridge and probably is due to differential compaction of sediments over the ridge and the neighboring basin.

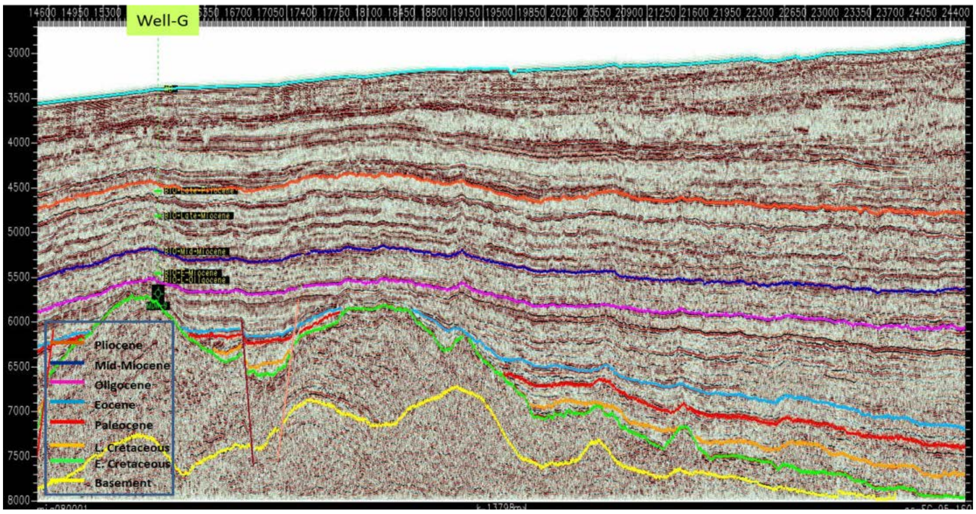

Fig.3: 2D Seismic line showing onlap/termination of pre Late Oligocene and draping of Oligocene sediments over 85 ° E Ridge

Post collision sedimentation pattern

Post "hard" collision, the Ganges-Brahmaputra system became dominant with rise of the Himalayas and the Bengal Fan sediments crossed the ridge which was by then buried and no longer acted as a divide. During Mid-Miocene the sedimentation from NW by Mahanadi river system continued in the western part of the Mahanadi Basin and became coalesced by the overwhelming Himalayan river inputs subsequent to the rapid uplift and erosion of Himalayas. This period marked the beginning of development of the largest submarine fan in the world called Bengal fan system (Curray, et al, 2003). Bengal fan is composed of numerous large, stacked and large overlapping, channel levee systems which are up to 50-60 km wide and 800-1000 m thick (Wynn, R.B et al ,2007). The Bengal fan system was active as early as Eocene but the channel activity was scarcer compared to post collision period and most of the channels were straighter in nature which could have carried coarser clastics.

Post Mid Miocene (<15 Ma) marks the rapid rise of the Himalayas resulting in manifold supply of sediments and progradation of the fan. The shelf and slope area of Mahanadi Basin witnessed wide spread erosion during this period. The depocentre also shifted and many channel-levee systems developed which transported the sediment further into the abyssal plain forming splay deposits / frontal lobes beyond the toe of the slope.

In addition to the sedimentation input from the north, increased progradation from the NW from the Mahanadi-Brahmani river system is also observed during the Mio-Pliocene time. As a consequence, the post collision depositional pattern in the Mahanadi Offshore Basin is interplay of different systems from N-S and NW-SE. While the N-S trending Bengal fan became more prominent after post Mid Miocene period, there were times when the deeper part received sediments from the Mahanadi.

Depositional Morphology

The Early Cretaceous effusive volcanic phase has been observed from the drilled well data in the shelf. The south western part of the basin contiguous with KG Basin has clastic sediments which could be correlated from the drilled wells in K-G Basin. The Early Cretaceous, in general, is a gently basin wards dipping surface and doesn't show any sediment trend. The Late Cretaceous is largely transparent reflections, the characteristic depositional morphologies are slope fan and wedge out against the volcanics mostly limited to the south and south-western part of the basin. Shelf- Slope system started appearing in Late Cretaceous.

Drilled well data suggests that, Early Paleocene sediments are clastics in the Basin, but in general, the period was sediment starved. The Late Paleocene to Mid Eocene period is represented by carbonate sequence showing progradational-aggradational geometries. The prominent morphology in the Late Paleocene is slope debris shed from the carbonate platform beyond the shelf as shown by bright amplitude reflectors which get contorted and deformed basin wards (Fig.4). Within Eocene, few valley fills and canyons could be mapped. Commonly these steep canyons and smaller valleys are perpendicular or are at high angle to the strike of the slope (Shepard, 1973). These high amplitude valley fills seem to be eroded carbonate debris from shelf along with coastal mix siliciclastic lithology which fans out down slope (Fig.5).

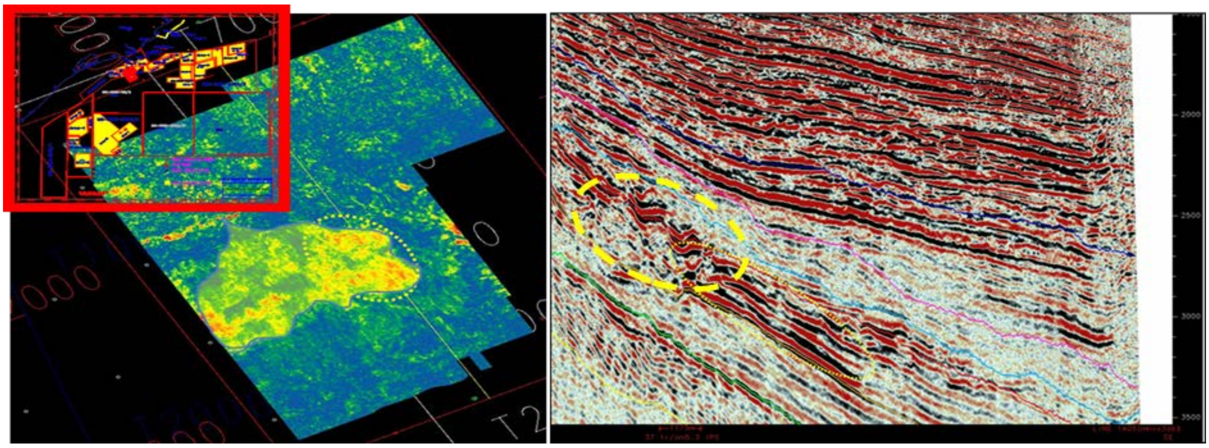

Fig.4: Morphology of Late Paleocene slope debris shed from the carbonate platform as shown by bright amplitude reflectors and their contorted seismic reflection

Within Oligocene NS and NE-SW trending channels have been mapped with the help of seismic attribute which appear to have originated from the Bengal fan. The Mio-Pliocene is characterized by thick sediments. The prominent depositional morphologies are channel levee complexes (CLCs), over bank deposits, crevasse splay and basin floor fan/ frontal splay (Fig.6). The high amplitude reflection packages representing basin floor fan generally could have good reservoir potential.

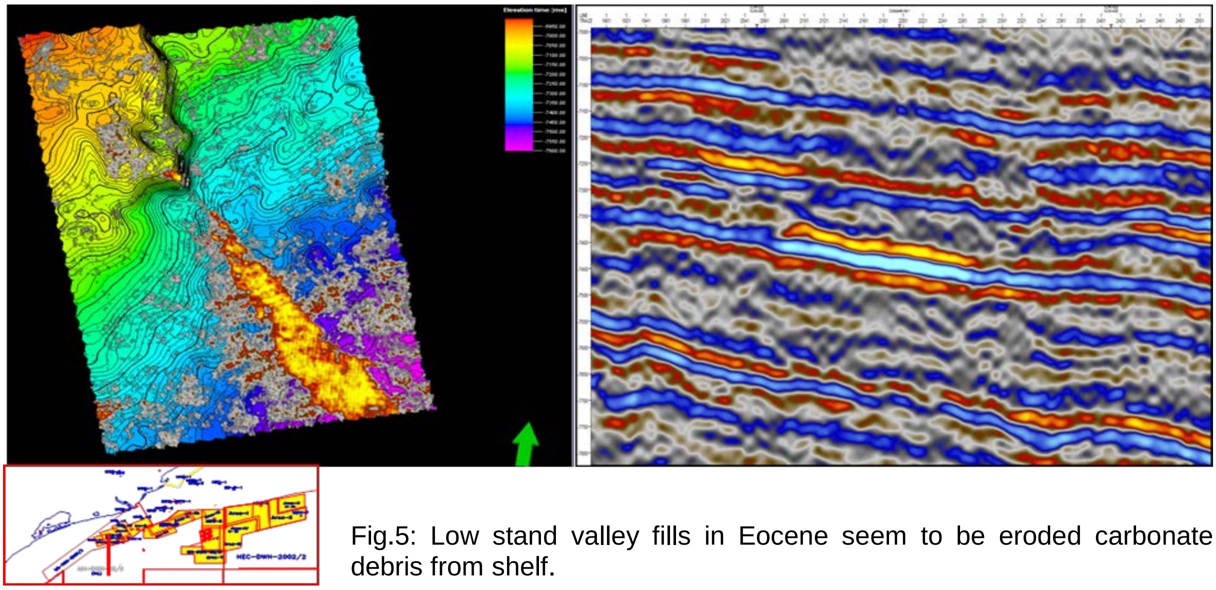

Fig.5: Low stand valley fills in Eocene seem to be eroded carbonate debris from shelf.

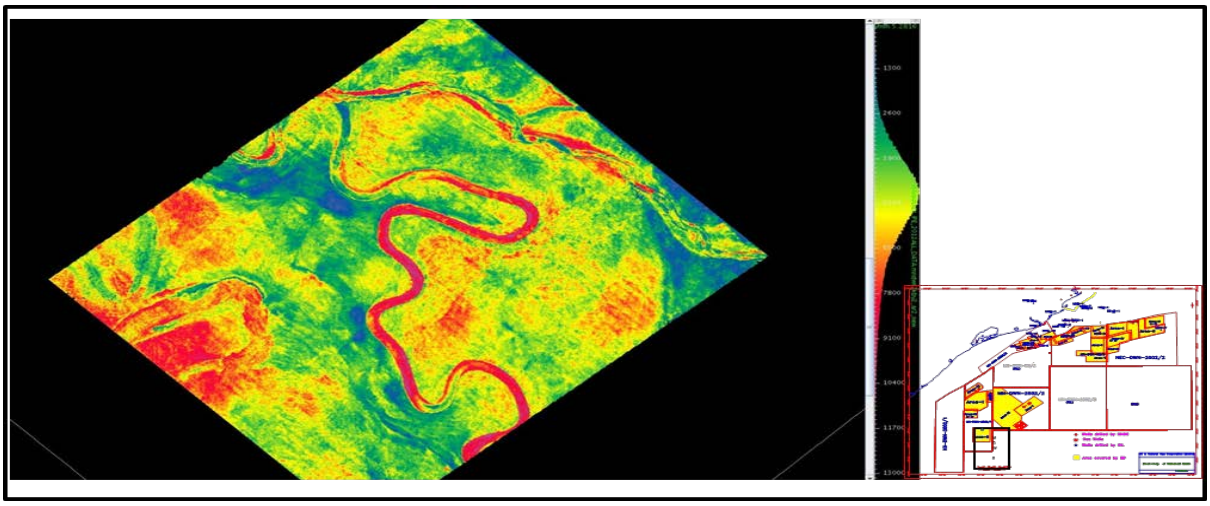

Fig.6: Channel levee complexes (CLCs), over bank deposits, crevasse splay and basin floor fans in Miocene

Prospectivity

Different speculative and hypothetical petroleum systems were postulated for Mahanadi by earlier workers. Dangwal et.al (2008) speculated three petroleum systems for Mahanadi. The most important petroleum system is the speculative Cretaceous/Paleogene – Neogene System. The only proven petroleum occurrence in the Basin is the Neogene – Neogene (biogenic) gas charging in the thin sands and silts. The rapidly deposited sand-shale couplets are acting as source and reservoirs for the system. The thick Mio-Pliocene sediments deposited at a fast rate of sedimentation might have helped in generation of biogenic gases in the section which charged the adjoining sand and siltstone lenses and pods.

From thermal maturity modeling in the area along with 2D petroleum system modelling, it is evident that only Paleogene and deeper sediments are thermally matured. Late Cretaceous sediments enter in late oil / wet gas stage and Paleocene in early oil window in MN-DWN-98/3 and NEC-DWN-2002/2 blocks. In the area, sediments below Middle Oligocene are matured to generate hydrocarbons. The huge overburden thickness of Neogene section in this area might have facilitated maturation in the area. The Modeling study shows that the Cretaceous source rocks entered into critical moment only in the Late Oligocene-Early Miocene period. The late transformation and maturation of the sources are attributed to the lesser overburden in the offshore basin till Miocene period. The geothermal gradient observed in deep water Mahanadi Basin is low in the range of 2.0-2.5 °C/100m and could be the cause for lower maturity of the sediments.

Conclusions:

1. The sedimentation pattern in the Mahanadi Offshore Basin can be broadly classified as Pre-collision (>59 Ma) and Post-collision (<15 Ma) sedimentation pattern.

2. During pre-collision period, the major sediment supply into the Basin came from the northwest by Mahanadi-Brahmani system of rivers. In the post-collision period, drainage from the north (Ganga-Brahmaputra) is forming major contributor in terms of volume.

3. Pre collision sediments are deposited as Paleocene slope fans, carbonate platforms, Eocene valley fills and Oligocene straight channels. In the post-collision period, it became interplay of sediment supply from Mahanadi-Brahmani system and N-S trending Bengal fan and is deposited as channel levee complexes (CLCs), over bank deposits, crevasse splay and basin floor fan/ frontal splay.

4. The 85° E Ridge, evolved during Late Cretaceous, remained as positive area till Early Oligocene and significantly controlled the depositional fairway for the Paleogene and older sediments.

5. Thermal maturity modelling studies of the Basin indicate that the middle and bottom part of Late Cretaceous sediments fall in the late oil window whereas Paleogene sediments fall in early oil window. The study underlines the need to explore the Paleogene prospects to chase the elusive thermogenic hydrocarbon in the Mahanadi Offshore Basin.

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