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Speculated Petroleum Systems in Deep Offshore Mahanadi Basin in Bay of Bengal, India.

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Summary

Mahanadi Deep Water Basin is located in the Bay of Bengal, south of Bengal shelf, ranging in depth from 100 m to 2.5 Km, covering an area of 80000 Km^2. The Basin has accommodated more than 8 km of Upper Cretaceous to Recent sediments. The basin has been formed due to Cretaceous rifting of Gondwanaland and separation of Australia-Antarctica Plate from Indian Plate. The 85^{0}E ridge, which divides the basin, is a gravity low anomaly feature.

The study is mainly based on 2D seismic data, integrated with distant deep and shallow water wells of Krishna- Godavari and Mahanadi shelf. The Cretaceous rift led to the development of ponded low, which possibly had restrictive/ anaerobic marine environment, favourable for organic matter preservation. During Paleocene / Eocene time large areas in the southern part were aerially exposed and possibly favoured abundance of flora generation. These flora contents & benthonic fauna were deposited in adjoining lows, which may have acted as potential hydrocarbon generation areas.

The chaotic seismic reflections are envisaged as shallow marine clastic, slope fan and turbidity fan, which may act as possible clastic reservoirs. Chaotic reflection around the 85^{0}E ridge probably represents shallow marine clastics derived from aerially exposed highs. Chaotic reflections at base of slope are interpreted as slope fan, which may have acted as reservoir. Part of Bengal turbidity fan system which shows extension up to Mahanadi deep water comprising number of channel levee fan features, may contain clastic reservoir.

The maturity modeling for Generation–Migration– Entrapment has been conceptualized from the pseudo wells of deep water blocks. Time structure maps and paleo- structural studies reveal that the north west trending inversion structures in the southern part were formed at the close of Late Cretaceous. These structures may facilitate structural and strati-structural entrapment of hydrocarbon.

Three thermogenic petroleum systems are speculated in Mahanadi Deep Water of Bay of Bengal: I) Late Cretaceous -Paleogene system (?); II) Paleogene-Neogene system (?) & III) Neogene-Neogene system (?). The Biogenic petroleum system in the channel fill sediments of younger age is also expected for the area.

Introduction

The Mahanadi offshore basin covers an area of 80000 Km^2 and has accommodated more than 8 km of Upper Cretaceous to Recent sediments. The bulk of these sediments were supplied from Ganga- Brahmaputra deltaic system during Mio-Pliocene time. Mahanadi Deep Water area is located south of Bengal shelf, ranging in depth from 100 m to 2.5 Km (Fig.1,2).

Mahanadi Basin and other East Coast Indian Basins evolved through multigenetic rifts, initiating from intra cratonic rift of Gondwanaland containing Late Paleozoic and Mesozoic succession followed by break up of Gondwanaland during Late Cretaceous (Sastri, V.V., Venkatachala, B.S., Narayana V. 1981). During the Early Paleogene, the Basin experienced passive margin carbonate and finer clastics sedimentation, while during Neogene, it received major fan sediments from Ganga-Brahmputra system. A brief review of Mahanadi Delta and the deltaic sediment has been discussed by Bharali B., Rath S., and Sarma R.,1991.

Seismic facies of various sequences have been visualized as likely source and reservoir rocks. The maturity studies in the synthetic wells have indicated possible peak oil generation time. Three thermogenic petroleum systems are speculated in Mahanadi Deep Water of Bay of Bengal: I) Late Cretaceous -Paleogene system (?) in which critical moment has been envisaged during 23 to 9mybp in the southern part; II) Paleogene-Neogene system (?) In which critical moment has been envisaged to be during 2 mybp to present in the northern part & III) Neogene-Neogene system (?) in which critical moment was attained during 1mybp to present in northern part of the basin. The Biogenic petroleum system in the channel fill sediments of younger age is also expected for the area.

Objective:

The objective of this paper is to bring out views on speculated petroleum systems in Mahanadi Deep Water. Effort was to identify possible source pods, thus help in framing up of future exploration strategy.

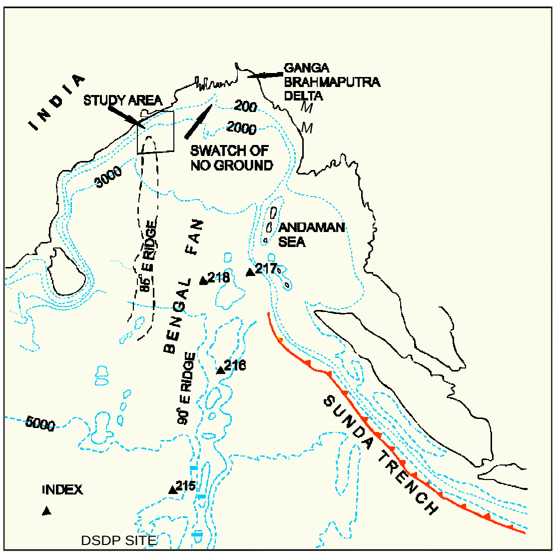


FIG.1 SHOWS POSITION OF STUDY AREA IN THE NW PART OF BENGAL FAN. 85° E RIDGE EXTEND UPTO STUDY AREA. OTHER PROMINENT PHYSIOGRAPHIC FEATUREAS REFLECTED BY BATHYMETRY CONTOUR ARE 90 E RIDGE, SUNDA-TRENCH IN SE & CANYON- 'SWATCH OF NO GROUND' IN NORTH.

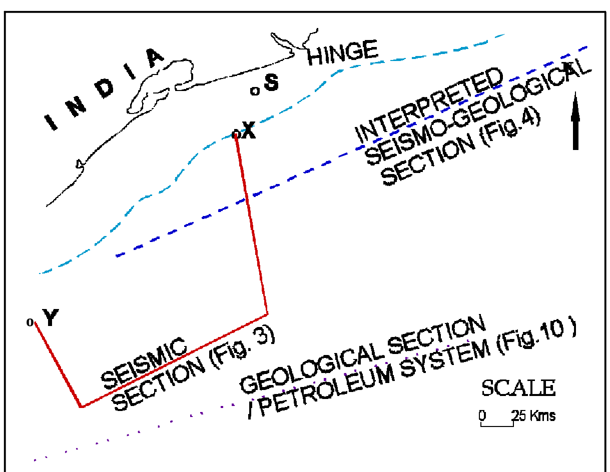
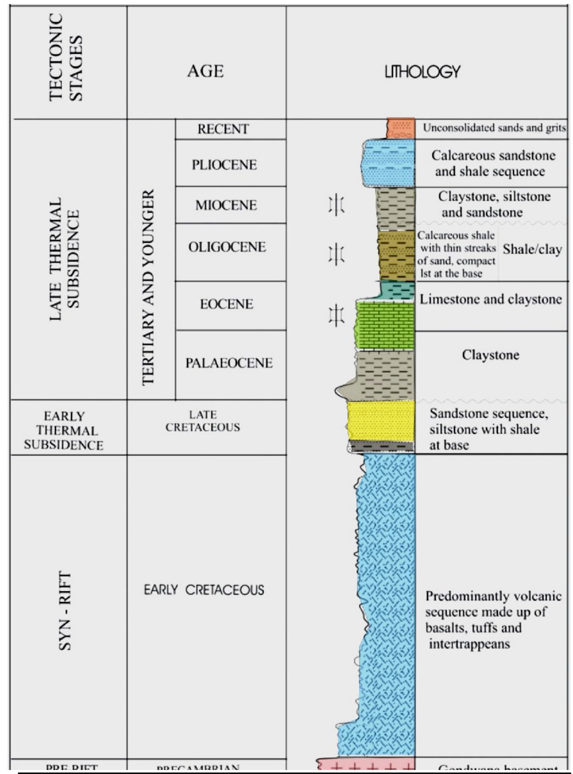


Fig. 2 SHOWS TRACE OF SEISMIC SECTION, INTERPRETED SEISMO-GEOLOGICAL SECTION AND DRILLED WELLS X & Y. SMALL DASH IS 200 M BATHYMETRY.

Generalized Stratigraphy of Mahanadi Basin



Seismic Studies

Fifteen seismic sequences were studied. Representative section of the area is shown in Fig.3. Top of the sequence boundaries have been correlated with Biostratigraphy of well Y of Krishna- Godavari deep water and well X of Mahanadi shallow water. The top of sequences 1, 2, 3, 4, 9 & 13 are correlatable with biostratigraphic top of Late Cretaceous, Paleocene, Eocene, Oligocene, Miocene, & Pliocene respectively.

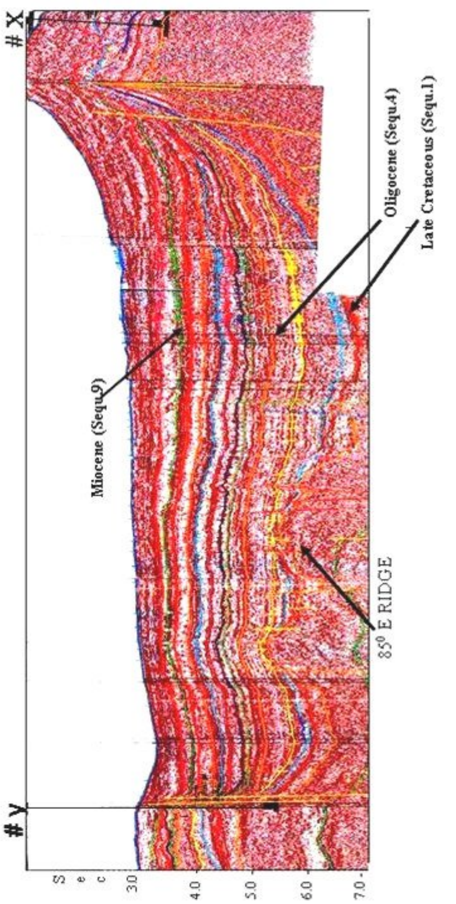


Fig Arbitrary seismic section passing through 85^{0}E ridge in Mahanadi deep water to shelf edge in the north west.(fig 2 shows profile)

Bottom of sediment is not well correlatable due to poor seismic response in western part and poor coverage in eastern part. The time structure map at top of Late Cretaceous (Fig.5) indicate general NE-SW trending basin with main depositional low toward eastern part (> 8000m sediments). 85^{0}E ridge separate eastern low from the western low. The highly conjectural thickness data of late Cretaceous indicate number of isolated lows in southern part, which may act as **possible source pods** (Fig.4 & 7). Fig.4 shows late Cretaceous rift grabbens, possibly filled with marine/marginal marine sediments which may act as source pods. Fig.7 shows north south trending isolated Cretaceous source pods in the southern part of the area. Some of these pods passed to structural inversion (85^{0}E trail) at the close of late cretaceous, resulting to aerial exposure and recycling of sediments. Approximately of 3000 sq. kms of aerial exposed area in the southern part supplied reworked sediments towards the steep western low and gentler eastern low. It may be envisaged that eastern and western low achieved more thermal maturity due to excess overburden.

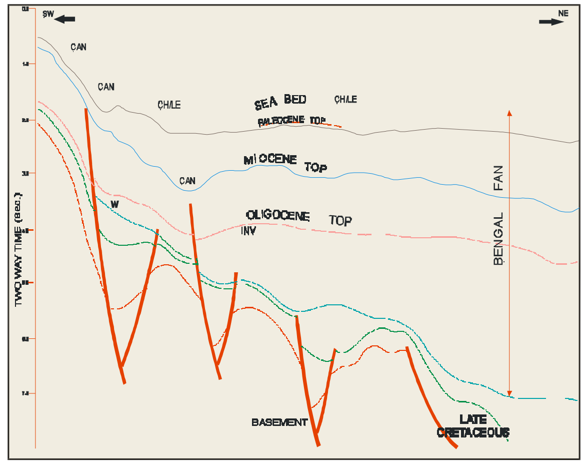


Fig.4 Seismo- Geological Section Along Ne-Sw Seismic Section (Fig.2 Show Profile) Showing Late Cretaceous Rift Sediments, Followed By Tertiary Bengal Fan . Can : Canyon, Ch/Le : Channel/Levee, W : Wedge, Inv : Inversion Structure

The Paleocene and Eocene sequences are well correlated and shows wedge out characters against 85^0 E ridge (Fig.3&10). Chaotic facies of Eocene sequences in the wedge outs indicate shallow water high energy sediments (Fig.6); however in the north east basinal low, parallel to sub parallel facies indicate pelagic to semi pelagic sediments.

Hence it is visualized that part of 85^0 ridge was aerially exposed during Early Paleogene period and acted as local provenance for sediment. The rise of ridge restricted circulation to the western low. Thickness contours suggest supply of sediments from north west and formation of slope apron (Fig.6). During Oligocene time Parallel/sub parallel Seismic reflections covers entire study area which indicates submergence of 85^0 ridge. Most of the chaotic facies of earlier sequences were sealed below this sequence.

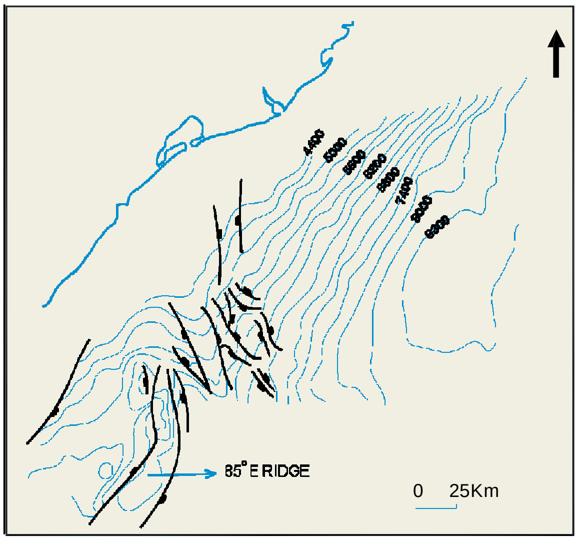


FIG. 5 TIME STRUCTURE MAP NEAR TOP OF SEQUENCE-1 (L. CRET.) SHOWING NE TRENDING BASIN & DOMINANT TERTIARY SEDIMENTS FILL IN NE PART. STRUCTURIZATION ALONG 85 E RIDGE SEPARATE SW FILL.

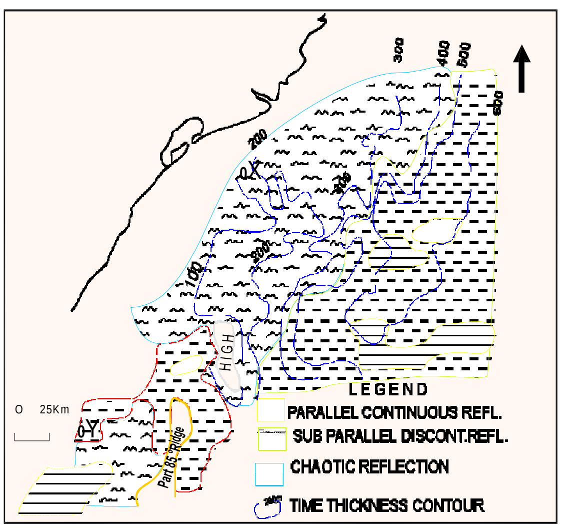


FIG. 6 SEISMIC FACIES MAP OF SEQUENCE-3 (EOCENE). CHAOTIC FACIES ALONG SLOPE & AROUND AERIALLY EXPOSED PART OF 85°E RIDGE TRAIL ARE LIKELY FAN & HIGH ENERGY SEDIMENTS. PARALLEL FACIES IN DEEPER PART INTERPRETED AS PELAGIC & SUB PARALLEL FACIES AS SEMI PELAGIC.

Thermogenic Petroleum System

Three petroleum systems are speculated in Mahanadi Deep Water.

1. Late Cretaceous -Paleogene system (?)

Late Cretaceous source rock is deposited in NE-SW & N-S trending paleo-lows towards the southern part of study area (Fig.7). The Paleogene reservoir facies appears to be deposited at the flanks of structural high, nosal feature and around wedge outs of Paleocene/Eocene. NS trending faults, which bound the southern structures act as conduits for vertical migration).

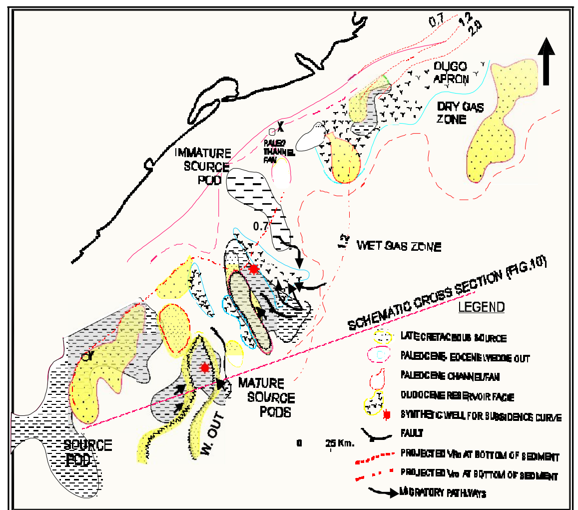


FIG. 7 LATE CRETACEOUS-PALEOGENE PETROLEUM SYSTEM (?)

2. Paleogene-Neogene system (?)

Geochemical maturation studies in north east part of deep water suggest possibilities of mature Paleogene sediments. The possibility of Oligocene shale facies down dip of shelf edge may be a potential source. Moreover, reworking and transportation of these Oligocene sediments may contribute to reservoir clastics in deep water basins. Neogene reservoir facies deposited as deep water channel fan, slope fan and slope apron in northern part may provide stratigraphic entrapment. Indications of hydrocarbon gas in RFT sample in wells up dip of Bengal off shore indicate presence of this petroleum system (Fig.8).

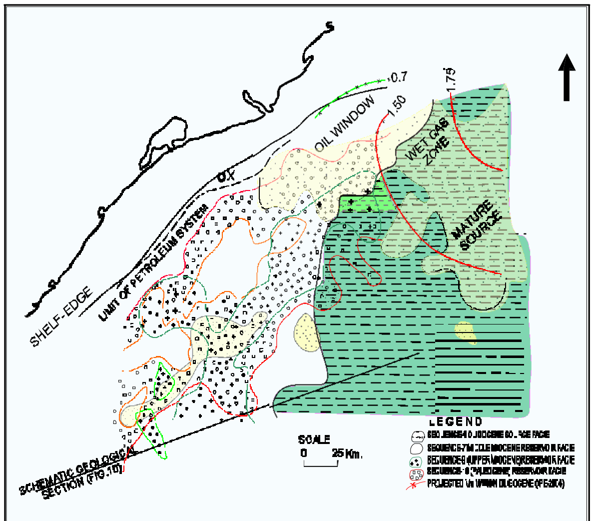


FIG. 8 PALEOGENE-NEOGENE PETROLEUM SYSTEM (?)

3. Neogene-Neogene system (?)

The subsidence curve studies bring out the possibilities of mature Early Miocene sediments in north east part, deposited in NE trending lows. Neogene reservoir facies are deposited as deep water channel/slope fan and slope apron in northern part. Overlying pelagic sediments act as vertical and lateral seal entailing stratigraphic entrapment. Turbidity channels act as conduits for lateral migration (Fig.9).

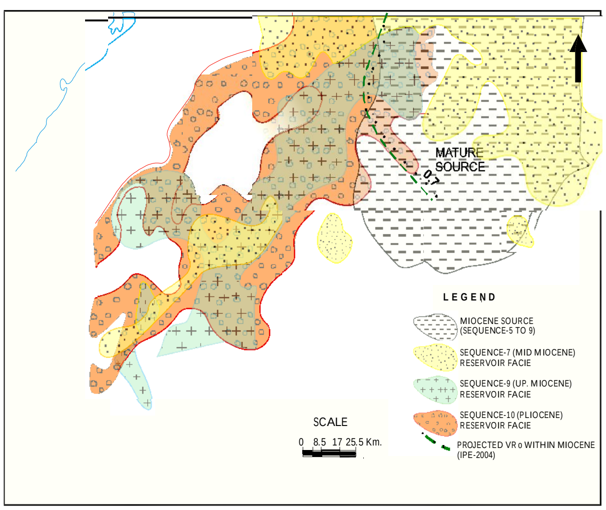


FIG. 9 NEOGENE-NEOGENE PETROLEUM SYSTEM (?)

Source Rock Potential:

The late Cretaceous rift led to the development of ponded low in Mahanadi shallow and deep water basins. The lows in deep water are filled with outer neretic to upper bathyal sediments (Raju et al) under restrictive/ anaerobic environment, entailing better preservation of organic contents. In KG deep water, the bathyal Late Cretaceous sediments exhibit fair to good organic matter richness (TOC 0.5 to 1.47%, Type III/IV).

During Paleocene/Eocene time more than 3000 sq.kms of the deep water in southern part were aerially exposed and subtropical paleoclimate was possibly conducive for abundant flora & benthonic fauna (generated in shallow marine). These, deposited in adjoining lows on either side of paleohighs exhibit organic matter richness (TOC 0.23 to 1.73 %, Type III/IV).

On the Mahanadi shelf, Paleocene sediments, deposited under fluvial to deltaic environment shows marginal to fair source rock richness. Eocene sediments, deposited under shallow shelf to fluctuating tidal environment shows carbonaceous content in well cuttings with fair source rock richness (TOC 0.5 – 5.1%). These shelf sediments were transported to deepwater and deposited as base of slope apron and fan with better organic preservation due to suboxic environment. The deposition of Eocene sediments down dip of shelf edge is expected to be argillaceous and good source rock (Purkait Malabika, Venkanna P).

Towards the eastern part, the NE trending main depositional low of sequence 4 (Oligocene) is mainly filled with deep water pelagic sediments (thickness of 1100ms). These hemi-pelagic and fan sediments possibly contain fair amount of allogenic organic content, which were supplied from Bengal shelf; where, fair to good TOC has been found in Oligocene formation.

Neogene deep water sediments have been deposited as bathyal oozes and turbidity fans. Oozes derived from -planktonic and nektonic organisms, may act as source of hydrocarbon. The DSDP wells (#218, 217, 216) ,which are at a greater distance from study area (FIG.1), show deep sea oozes (pelagic/ hemi pelagic sediment) alternating with turbidite layers; containing average organic content 0.37%, type III.

Maturity:

Pyrolysis study of Krishna -Godavari deep water well shows that the Late Cretaceous sediments have S2 ranging from 2 to 8.4 mg HC/g TOC which suggest good to fair hydrocarbon generating potential *(*Prasad IVSV, et. al,*)*.

Observed geothermal gradient is 3.17 ^{0}C/100 m in the southern part and 2.960c/100 in the northern parts. Heat flow 60 to 65mW/m^{2} have been considered for maturity modeling in synthetic well. The burial curve of synthetic wells in the southern part indicate that middle and bottom part of Late Cretaceous sediments are in possible Oil window. Projected VRo are 1.08 and 1.21% respectively, suggesting that the locales of Late Cretaceous sediments have attained oil generation. The study of subsidence curve indicates peak oil generation and migration in the adjoining lows of southern part ranging from 23 to 9 mybp (Early to Late Miocene). However accentuated shallower Late Cretaceous source have generated hydrocarbon during 4 to 1.3 mybp (Pliocene).

Thermal maturity modeling in the deepwater in eastern part, indicate that Paleogene sediments have attained possible oil window and wet gas window. Peak oil generation and migration ranges from 2 mybp to present (Late Pliocene to present). The study further shows that Early Miocene source rocks are within the oil window in the eastern part. Peak oil generation and migration started in Pleistocene time and continued till present.

Reservoir rock:

I Cretaceous reservoir: Interpreted geological section (Fig.4) shows number of Late Cretaceous synrift horst and grabens. These grabens are filled with synrift clastics derived from northern continental provenance. The well-X, drilled beyond present shelf edge, shows deposition of Cretaceous Clastics reservoir on gentle paleoslopes. Well-Y in KG deep water shows that Cretaceous Formation consists of clay, claystone, sand and silt. The late Cretaceous fans may possibly contain lenticular sand in proximal part and or tabular sand bodies in distal part, which may act as reservoirs.

II Wedge out: Inversion at the end of late Cretaceous was responsible for accentuation of structures in southern part, which led to aerial exposure of Late Cretaceous sediments. Seismic facies around wedge out are chaotic, indicating shallow water, high energy reservoir facies (Fig.6).

III Slope and base of slope deposition: The north western part of sequence 3 (Eocene) shows chaotic reflections (Fig.6) with few patch of high amplitude reflections suggesting transportation / dumping of sediments at the base of slope. (Lab studies in well X & Y also confirm transportation of shelf sediments into deep water).

IV Turbidite fan: Distribution of Miocene & Pliocene chaotic facie has been interpreted as possible reservoir rocks (fig 8,9). These facies possibly represent Bengal turbidity fan system extending to Mahanadi deep water. Number of channel levee fan features observed in the north eastern part, may consist clastic reservoir.

Migratory Pathways

Vertical migration: The N-S trending faults, which bound major structural highs in southern part connect deep Late Cretaceous source to Paleogene and Neogene reservoirs (Fig.10). Vertical migration through faults is a vital component in Late Cretaceous- Paleogene Petroleum system (?).

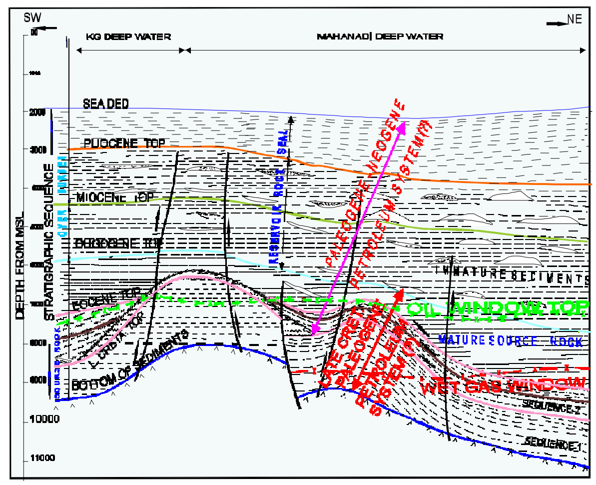


FIG. 10 SCHEMATIC NE-SW GEOLOGICAL SECTION, SHOWING SPECULATIVE PETROLEUM SYSTEM IN MAHANADI DEEP WATER

Lateral migration*:* The turbidity channel may receive hydrocarbon from vertical faults, connected to deeper source or directly receive hydrocarbon from adjacent pelagic source at basinal lows. Those turbidity channels which are connected to pelagic source down dip (at deep basin) and upper fan reservoir facies (at shallower proximal end) together with the fracture may act as conduits for lateral migration. Lateral migration through turbidity channels is a vital component in Paleogene-Neogene Petroleum system (?) and in Neogene-Neogene Petroleum system (?).

Major unconformities in the basin coincide with eustatic sea level falls and hence received low stand sediments (fan sediments for short span). These surfaces may also act as conduits for lateral migration from deeper source to shallower reservoirs (along channel-levee / fan complex).

Conclusion

1.Three petroleum systems have been speculated - Late Cretaceous -Paleogene system (?), Paleogene-Neogene system (?) & Neogene-Neogene system (?).

2.The late Cretaceous rift led to the development of ponded low, which possibly have restrictive/ anaerobic marine environment, favorable for organic matter preservation.

3.Paleocene / Eocene time evidenced aerial exposure of 3000 sq. kms of the southern deep water area. Wedge outs against this high having chaotic seismic facies are envisaged clastics reservoir rocks.

4.Neogene deep water sediments, deposited as bathyal oozes and turbidity fan, having type III organic content may act as good source facies.

5.Thermal maturity modeling on the synthetic wells indicate that middle and bottom part of Late Cretaceous sediments are in possible Oil window. Peak oil generation & migration ranges from 23 to 9 mybp (Early to Late Miocene). Paleogene sediments have attained possible oil window and wet gas window during 2 mybp to present day (Late Pliocene to present).

6.Major unconformity surfaces in deep water may have received low stand sediments (fan sediments), and may act as conduits for lateral migration from deeper pelagic source to shallower reservoirs .

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