



Identification of Prospective Areas for Future Exploration by demarcating High Pressure Area in Mahanadi and Bengal Basins

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Keywords

Disequilibrium compaction, overpressure, sedimentation rate, compaction, depocentre, prodelta.

Abstract

This study shows the relationship between overpressure and sedimentation rate. The Post Eocene time thickness map suggests very high sedimentation rate as the main cause of disequilibrium compaction within the N-S oriented depositional low. High pressure tops are marked and contoured in line with the contour pattern of this thickness map to demarcate the overpressure zone. Overpressures are not reported on the western side of Eocene shelf break but present towards east all along Bengal-NEC-Mahanadi basins. The narrow zone all along Eocene shelf break (both on the shelf and beyond till overpressure boundary) may be considered for future exploration in Mahanadi and Bengal Basins.

Introduction

The northern part of east coast of India, including offshore Mahanadi and offshore NEC-Bengal along with Bengal onland, have come to prominence as a new territory of petroleum exploration. In NEC and Mahanadi offshore a good number of wells tested biogenic and mixed biogenic-thermogenic gas from Mio-Pliocene reservoirs. In Mahanadi and NEC offshore, exploration of oil and gas has focussed primarily on the Mio-Pliocene reservoirs. Bengal exploration witnessed 46 onland and 12 offshore wells with history of surface flow of gas in five and oil in two onland wells.

Resource assessment of Bengal-Mahanadi focussed entire Miocene as the prolific reservoir for hydrocarbon. This is followed next by Paleogene-Pliocene and Cretaceous reserves respectively. All these undiscovered reserves may be targeted in future

exploration. Keeping in mind the high pressures as encountered in different wells in Bengal and Mahanadi within Mid-Miocene the present work tried to map and demarcate the area under high pressure. The work has brought out a narrow zone all along Eocene shelf break in Mahanadi-NEC-Bengal Basins devoid of high pressure for future exploration.

Seismic base-map with the study area is presented here (Fig-1). Time thickness maps are prepared to decipher sediment input directions, the trend of depositional lows and the rate of sedimentation. Data from high pressure wells suggest the disequilibrium compaction as the main reason for high pressure generation.

With the change in sedimentary environment, the properties of Formations also change. The shelf break indicates this change in the properties of Formations. High pressure distribution is observed only towards eastern side of Eocene shelf break. Combining depositional elements and high pressure contours, a narrow zone along the Eocene shelf-break has been demarcated as future exploration area, expected to be devoid of high pressure.

Tectonics- The Tectonic map shows Permo-Triassic NW-SE trending Son Mahanadi graben, Damodar graben and N-S trending Bengal-Purnea graben (Fig-2). Solid red line indicates traces of hotspots joined by the movement path of Indian plate towards north. Discontinuous red line suggests collision of Indian plate towards north and east. Distribution of Deccan trap, Proterozoic to Archean sediments and Alluvium are demarcated on the map. COB is marked by white dotted line. NE-SW trending Jagannath low and Kalinga low, separated by Vizag high are prominent tectonic features in the offshore. The tectonic map of

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Mahanadi and Bengal basin suggests Cuttack-Puri-Jajpur- Chandbali lows are distributed in Mahanadi

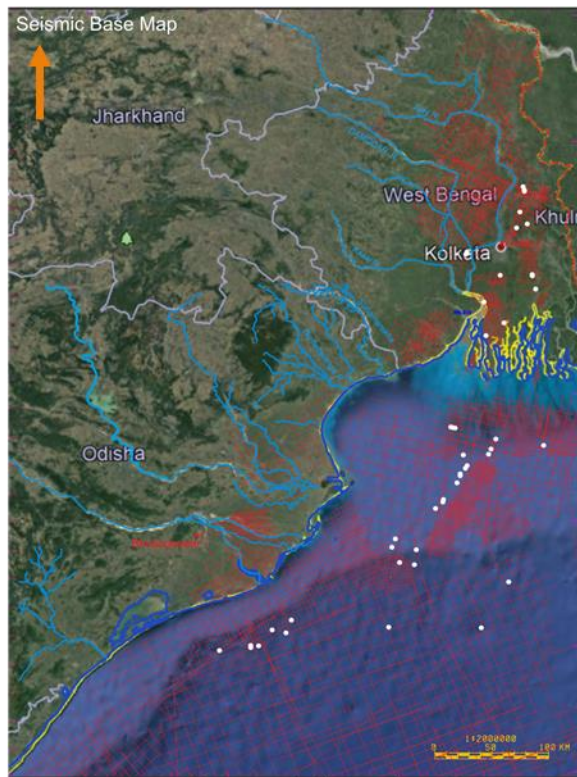


Fig-1 Base map of study area with wells and seismic lines.

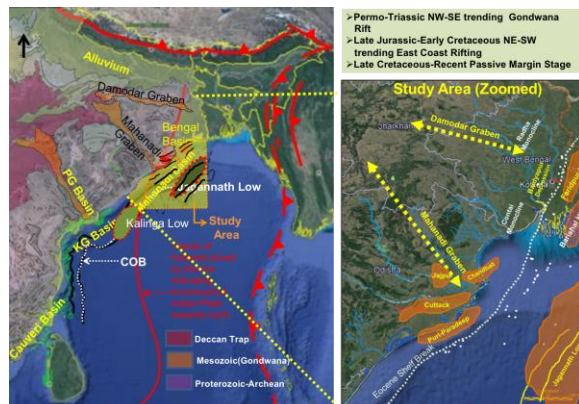


Fig-2 Tectonic map of East Coast of India showing the NW-SE and N-S Lower Gondwana and NE-SW Passive margin trends with the study area.

onland basin in NE-SW trend depicting the Early Cretaceous passive margin rift related development (Fig-2). Baidyapur depression in Bengal onland and its continuation towards south into NEC offshore indicates Gondwana trend. NW-SE Son-Mahanadi

and Damodar graben indicate Lower Gondwana trend. The Ganges-Brahmaputra from the north and all cratonic rivers like Subarnarekha, Ajay, Damodar, Mahanadi, Brahmani, Debi etc all from NW drain Bengal and Mahanadi onland and deposit the sediment load into the Bengal-NEC- Mahanadi offshore basins along the Eastern Continental Margin of India.

Tectonostratigraphy of Bengal- Mahanadi Basins

– The sedimentary packages of Bengal and Mahanadi Basins as a whole can be visualized from tectono-sedimentary point of view. The Gondwana sediments can be considered as graben-fill in the interior sags. The Raajmahal Volcanics, with the inter-trappeans, can be attributed to the rift-fill as no other sediment packages have been reported / confirmed so far from the Bengal and Mahanadi basins as the rift-fill within the study area. The Palaeogene and Neogene sequences had been deposited along the gently sloping shelf of Indian continental margin in a remnant ocean basin.

Both Bengal and Mahanadi stratigraphic events are correlated and tabled in Table-1.

Methodology- In the process of sedimentary compaction, the fluids in pores are excluded with increase in accompanied overburden pressure, and the pore pressure maintains constant hydrostatic pressure. Overpressure generation and development mechanisms are complex and can be classified into compaction disequilibrium and unloading (Ramdhan and Gouly, 2011). The unloading refers to fluid expansion, tectonic stress, and overpressure transfer caused by gas generation, hydrothermal pressurization, and clay mineral dehydration and compaction disequilibrium is caused by very high sedimentation rate (Bowers, 2002; Ramdhan and Gouly, 2011). So, higher the rate of sedimentation, higher is the chance of disequilibrium compaction which produces high pressure. Disequilibrium compaction is the major issue here for high pressure generation. Thickness maps are prepared to study this sedimentation rate and find out the area of higher thickness. For the preparation of thickness maps to study the overpressure history of the basin, three regional maps are considered i) Early cretaceous TWT map as Trap top, ii) Mid Eocene TWT map as carbonate top and iii) Recent map of onland and offshore. These maps were prepared after the

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correlation between Mahanadi and Bengal basin from Early Cretaceous to Recent. Two thickness maps, namely Pre-Eocene (Carbonate top to Trap top) and Post-Eocene (Carbonate top to Recent) are prepared and the details of these maps are taken into account for identification of high pressure area. Post Eocene thickness map helps us to identify the distribution of high pressure area with the help of high pressure well data. High pressure contours are prepared as guided

by the thickness contours and a composite map with depositional elements and high pressure area is presented in this paper.

Regional Maps – Two regional events like trap deposition in Early Cretaceous and Carbonate deposition in Eocene have been mapped from Mahanadi to Bengal.

Table-I
Tectonostratigraphy of Mahanadi and Bengal

	Age	Tectonic Phases	Stratigraphy	Tectonic Events	Structural Evolution	Stratigraphy	Formation	
Mahanadi	Recent	Post Collision Passive Margin		No significant tectonic events	Gravity driven system for CLCs. Presence of Polygonal faults (Mio-Plio)		Debagram Fm/ Ranaghat Fm	Bengal
	Pliocene			Major Himalayan Orogeny	Himalayan upliftment, Growthfault sequence		Pandua Fm/ Matla Fm	
	Up Miocene							
	Mid Miocene		Inter Continental Collision	Basin margin uplift & shelf edge failure		Burdwan/ D Harbour Fm		
	Oligocene	Pre Collision Passive Margin		Initiation of Himalayan Orogeny	Plate, Major detachment surface for Tertiary Growth fault system		Hoogly Shale Kalighat	
	Eocene			End of Drift Phase	Eastward drainage continued		Jalangi Fm Ghatal Fm	
	Paleocene			Deccan Volcanism	Reversal and adjustment of drainage due to Deccan upliftment		Bolpur Fm Dhananjapur	
	Late Cretaceous	Post Rift Sag		Northward drift initiated	Development of Thermal sag basins with major drowning		Rajmahal Trap	
	Early Cretaceous			Rajmahal Trap, 85degree E Ridge & opening of Indian ocean		Faulting activity reduced		
	Jurassic	Passive Margin Synrift		Initiation of Passive Margin Rifting	Initiation of faulting, uplift, erosion			
Basement						Permo-Carboniferous to Triassic (Panchet Raniganj Barakar Talchir)		
Basement								

Pay sand equivalent surface in Miocene in well-L in Bengal has also been mapped in the entire study area. Details of individual maps are illustrated here.

Early Cretaceous TWT map - Seismic coverage of Bengal-Mahanadi onland and offshore has been considered while preparing the Early Cretaceous time relief map. The TWT map suggests NE-SW trending contours running from Bengal in the north to Mahanadi basin in the south. The surface dips monoclonal to the SE from onland to offshore

without the development of shelf-slope break. NE-SW oriented low was observed at the deepest part towards SE (Fig-3).

Eocene TWT map - The map suggest NE-SW trending strike of the surface with south-easterly directed dip. The surface dips monoclonal towards SE with the well-developed platform and NE-SW trending shelf-slope break. The shelf break is marked by dashed black line. The shelf part is entirely covered by carbonate rocks as evident from the

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drilling results of wells distributed on the platform from Bengal to Mahanadi (Fig-4).

TWT Map of pay-sand equivalent in Miocene -

The NE-SW trending contour pattern from Mahanadi to Bengal changes in the central part i.e. towards south of Bengal. In this part some contours take a turn towards east and rest follow the earlier trend of NE-SW. The earlier NE-SW trending Shelf break changes to E-W trending towards south of Bengal (Fig-5). Huge influx of sediments from Ganges-Brahmaputra delta effected this change from NE-SW to E-W. This extended shelf south of Bengal continued its growth till recent as observed in the Google image (Fig-6). The gradual shift in shelf break from Eocene to Recent is presented in this map.

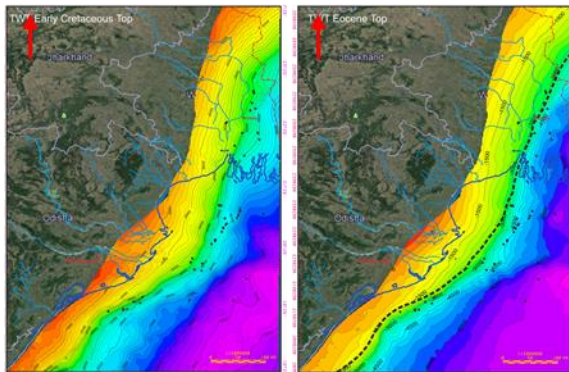


Fig-3 Time-relief maps of Early Cretaceous
Fig-4 Eocene with Eocene shelf break.

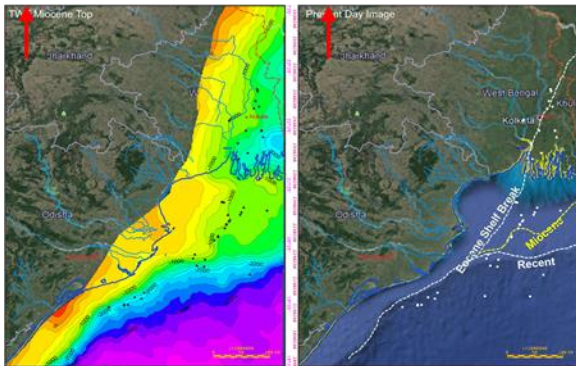


Fig5(left)-TWT map of pay-sand equivalent
Fig-6(right)-Google image of Recent

Pre Eocene (Between Trap top & Carbonate top) and Post Eocene (Between Carbonate top & Recent) Thickness maps - The thickness between Trap top and Carbonate top and between Recent and Carbonate Top suggest the following features as tabled below.

Table-II

Pre-Eocene Thickness Map (Early Cretaceous Top to Eocene)	Post Eocene Thickness Map (Recent to Eocene Top)
Two depocenters namely Jagannath low and Potuakhali low.	Both Patuakhali low and Jagannath low culminated into a single low.
Both depocenters oriented to NE-SW suggesting sediment influx from NW through cratonic rivers.	Orientation of the merged low becomes N-S indicating maximum influx from Ganges-Brahmaputra from the north.
Sediment input only from one direction.	Sediment input mainly from north through tertiary rivers along with easterly flowing cratonic rivers.
Maximum thickness of Jagannath low is more than 2000m and Faridpur low is 1200m within the time span of 65my.	Maximum thickness of merged Jagannath low is more than 6000m within the time span of 34my.
Rate of sedimentation is very slow compared to Post Eocene sedimentation rate.	Rate of sedimentation is very fast towards Bengal compared to Mahanadi side of the basin

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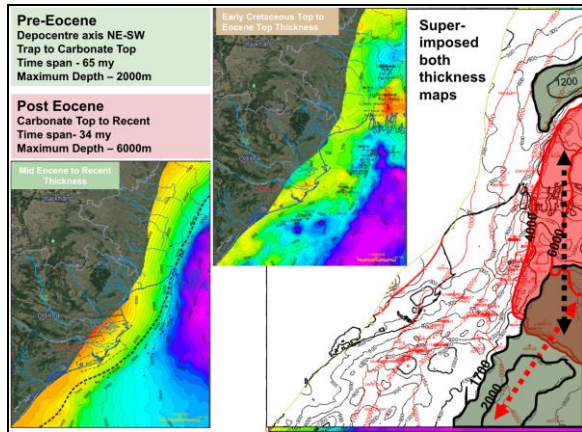


Fig.7 Superimposition of Pre and Post Eocene thickness maps

This comparison between the two thickness maps suggest the Post Eocene sedimentation rate as the only contributor for generation of high pressure. More than 6000m of sediments have been deposited within a time span of 34my from Eocene top to Recent. Both Pre and Post Eocene thickness maps are superimposed to observe the change in depocenter orientation. This rapid sedimentation through Ganges-Brahmaputra river system overpowered the sedimentation through Cratonic river system and changed the depocenter orientation from NE-SW to N-S. This huge amount of sediments effected disequilibrium compaction within the area as demarcated by the depocenter in N-S orientation (Fig-7).

High Pressure Demarcation and Regional Distribution - Higher the thickness of sediments higher is the rate of sedimentation which produces disequilibrium compaction. Change in sedimentation rate from north to south influencing the distribution of high pressure is shown in Fig-8. On four profiles from AA' to DD' positions of Eocene Shelf break are marked on the Post Eocene thickness map. From the measured thickness values on those sections, profiles of thickness gradients are constructed to observe the variation in thickness of sediments from Eocene shelf break to deep basin. Profile AA' represents abrupt

increase in sediment thickness within a very short distance from shelf-break suggesting very high sedimentation rate.

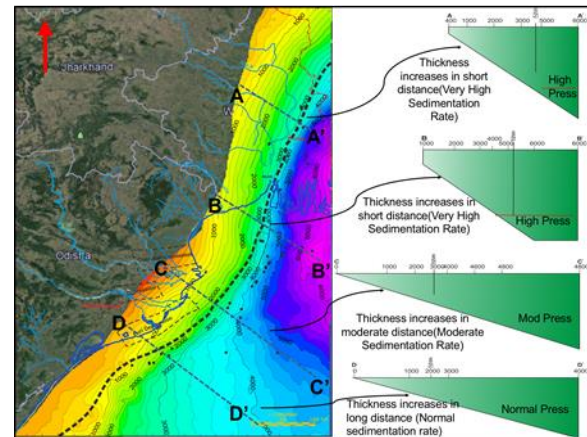


Fig.8. TWT time thickness map (left) between Eocene Top and Recent suggesting change in sedimentation rate from north-west to south-east influencing the distribution of high pressure area. Diagrams (right) showing variation in pressure with distance.

Profile BB' also suggest the abrupt increase in sediment thickness from the shelf break within a short distance suggesting very high sedimentation rate. Along profiles CC' and DD' thickness increases gradually in a long distance, suggesting normal sedimentation rate. High pressure wells are present near the profiles AA' and BB' and those high pressure tops are plotted along those profiles. For profiles CC' and DD', no nearby wells encountered any high pressure or transition pressure. Observations from these profiles helped to identify the variation in distribution of sediments from north to south of the basin influencing the distribution of high pressure. Drilling into highly over pressured formations has resulted in numerous kicks and blowouts through-out Bengal and Mahanadi basins. A large amount of over-pressure data has been collected in the Bengal-NEC-Mahanadi Delta provinces from wire line formation interval tests (e.g., repeat formation tests [RFTs], modular dynamic tests (MDTs), mud

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weights, kicks, and drillstem tests (DSTs). The pore-pressure database compiled herein Table-II indicates that overpressure in Bengal-Mahanadi is wide-spread and suggests that overpressures occur primarily in the prodelta shales within Mid Miocene due to very high rate of sedimentation or disequilibrium compaction. Contours of sediment thickness map are used as a guide to prepare a map of high pressure area. The depths to the top of overpressure in all over pressured wells have been mapped and contoured as guided by the thickness contours (Figure 9).

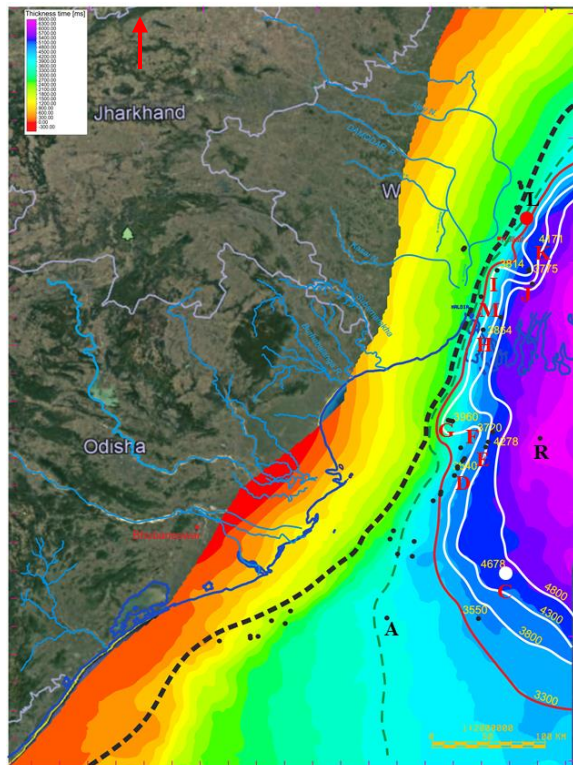


Fig.9 Contours of high pressure in thickness map between Mid-Eocene and Recent with demarcation of high pressure area by red colored contour.

The map can be broadly divided into two regions: High pressure area and Normal Pressure area. The red line demarcates the high pressure area from the transition or normal pressure area to the east of Eocene shelf break, demarcated by thick dashed line.

Towards Bengal side the high pressure contour runs almost parallel to Eocene shelf break. Southward this contour takes an eastward turn and restrict the area towards the deeper part of the basin suggesting area of rapid sedimentation helped by the Ganges-Brahmaputra delta sediments. The red contour marks the overpressure boundary and the area inside this boundary is considered as prodelta shale of Middle Miocene time or Matla Formation. All the wells within prodelta shale encountered high pressure within Matla Formation or within Middle Miocene. The geological model (Fig-10) with a few wells from NW to SE suggest presence of high pressure within Matla Formation in Bengal offshore. Distribution of cluster of discovered gas wells presented on the TWT surface equivalent to Gas sand in well-L is presented in Fig-11. The log correlation of a few high pressure wells suggest also the prodelta sequence for the said interval (Fig-12). The same high pressure is envisaged to be continued through Oligocene.

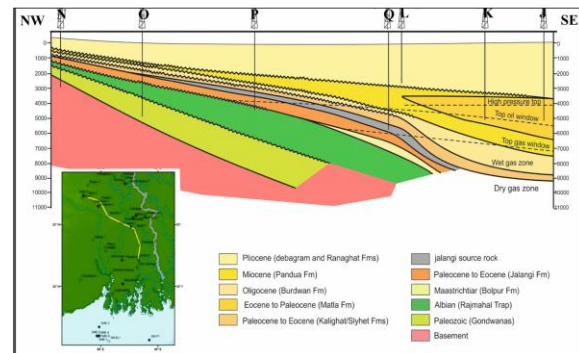


Fig-10. Geological model in Bengal onland through wells depicting different stratigraphic boundaries and high pressure horizon with depth.

Area for Future Exploration in Mahanadi-Bengal Basins - Once the high pressure area is identified and mapped in the basin the next task is to find out the area for further exploration. One surface equivalent to A1 pay sand is propagated throughout and a TWT relief map is prepared in Bengal and Mahanadi Basin area. Different clusters of gas bearing wells of Mahanadi-NEC and the recent discovery well in Bengal along with Eocene shelf break and Miocene shelf break are placed on the map. This reveals the

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cluster of gas wells are all present on the eastern side of the shelf-break i.e. on the slope and very close to the Eocene shelf break (Fig-11). No gas bearing wells are present on the Eocene shelf towards Mahanadi and NEC. Only in Bengal one well on Eocene shelf

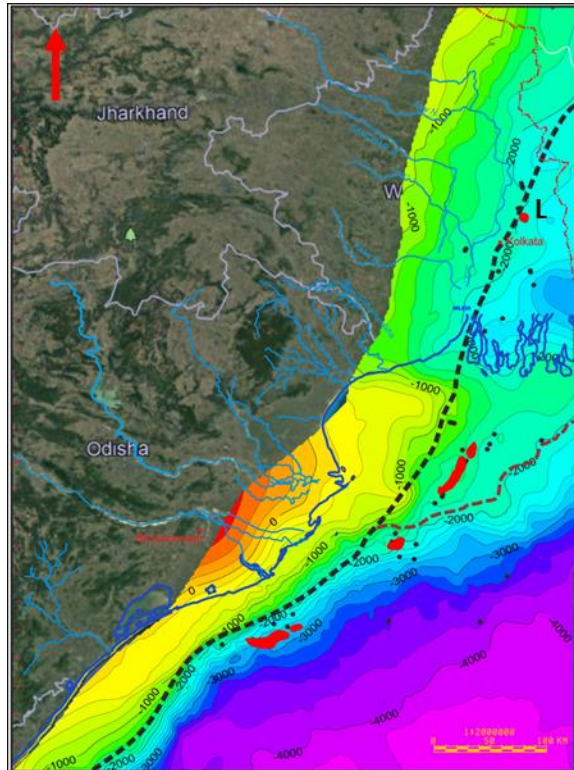


Fig-11 Distribution of cluster of discovered gas wells presented on the TWT surface equivalent to Gas sand in well-L.

produced minor oil in Oligocene. Among the clusters of gas wells in Mahanadi and NEC, the southernmost and the central clusters belong to biogenic gas and the northern cluster in NEC area belongs to both biogenic and mixed biogenic-thermogenic origin. Towards further north in the discovery well in Bengal, the oil and gas are totally of thermogenic origin. Therefore one corridor can be taken up for future exploration, parallel to the Eocene shelf break. This will cover mainly slope part along with a part of the shelf close to the slope. All the interpreted tertiary faults and the high pressure contours are placed on the High Pressure contour map. Faults are all

distributed parallel to the Eocene shelf break (Fig-13). One composite map (Fig-14) is prepared with all conceived delta mouth lobes, high pressure contours and probable area for future exploration. The area marked with red circle may be selected for future exploration. This area is just outside the high pressure area and located on the slope parallel to the Eocene shelf break.

Conclusions - Overpressures occur in onshore and offshore Bengal, NEC offshore and Mahanadi deep offshore basin as observed in well data. Eocene shelf break indicates the change in the properties of Formation pressure. Overpressures are not reported on the western side of Eocene shelf break all along Bengal-NEC-Mahanadi basins. Towards east of Eocene shelf break overpressures are encountered in a number of wells in Bengal, NEC offshore and Mahanadi deep offshore.

The regional distribution of overpressure is identified in the present study with the help of Post Eocene sedimentation map and high pressure well data. The high sedimentation rate as observed in Post Eocene thickness map is attributed to Ganges-Brahmaputra delta sedimentation. This high rate of sedimentation caused disequilibrium compaction in the prodelta sediments towards the depocenter area of the Bengal-Mahanadi basin which led to the generation of high pressure.

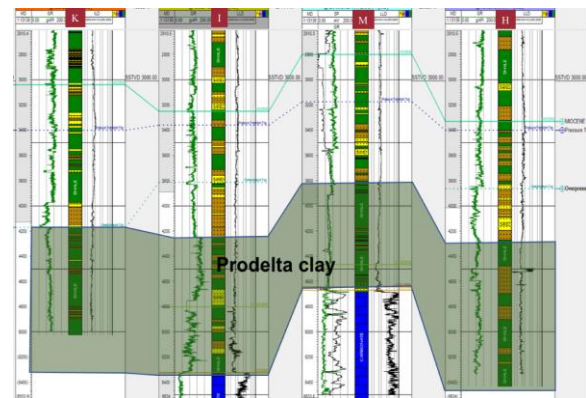


Fig-12 Log correlation and analysis showing presence of Prodelta clay in the High pressure wells in Bengal.

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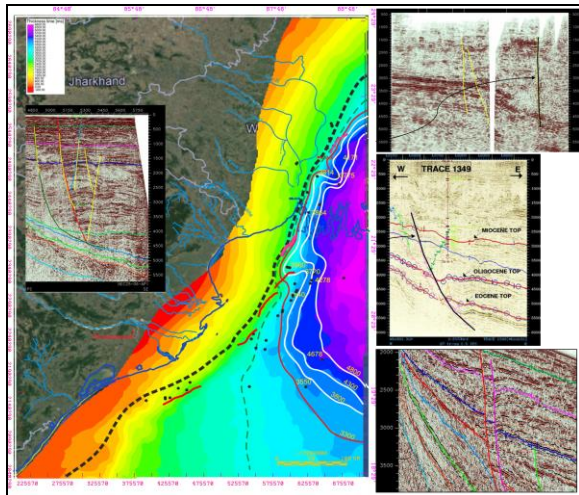


Fig.13 All the identified tertiary faults are distributed along the Eocene shelf. Seismic signatures of these faults are also presented with the map

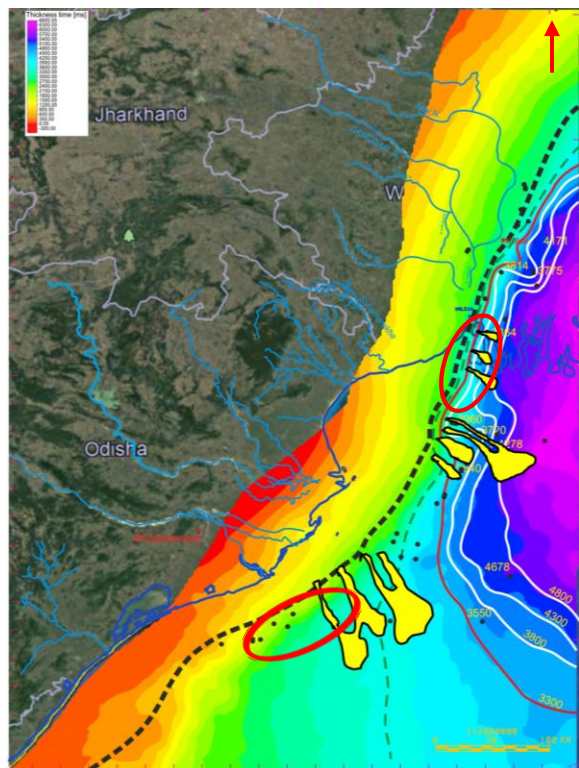


Fig.14 Composite map with all conceived delta mouth lobes, high pressure contours and identified area (red circle) for future exploration.

Hooghly shale on top of Eocene has been deposited as prodelta shale and is envisaged as source rock for Oligocene and Miocene reservoirs. Shale deposits in Oligocene may also be considered as prodelta shale and considered as source rock.

Area all along Eocene shelf break (both on the shelf and beyond till overpressure boundary) may be considered for future exploration.

Most of the Hydrocarbon finds from Mahanadi to Bengal including Asokenagar-1 are located in this area. Envisaged depositional elements suggest the identified area as prospective for future exploration. High Pressure seal thickness if at all present, is expected to be less here. Thereby, prospectivity of both below and above the high pressure can be explored.

Table-II

Well Name	Drilled Depth (m)	Transition Zone		Overpressure	
		Top (MD)	MWE (Sp.gr.)	Top (MD)	MWE (Sp.gr.)
D	4073	3048m	1.29	3640m	1.98
F	4951	3025m	1.21	3720 m	2.04
M	5555	3175	1.25	-	-
J	4950	3168 m	1.20	3775 m	1.89
G	5831.50	3100	1.19	-	
K	5007	3400m	1.31	4171 m	2.06
H	5339	3400m	1.31	3864m	2.01
E	4402	3560m	1.35	4278	2.12
I	5826	3360	1.32	3814	1.82
C	4904	4678 m	1.46	4878 m	1.78
B	5603	4519 m	1.26	5231	1.76
A	6339	-	-	6338	1.6

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