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Center for Petroleum Exploration

Division of Energy and Innovation
UNIVERSITY OF HOUSTON

A review of the oil and gas exploration potential of the offshore Andaman, Mahanadi and Bengal Basins of Eastern India. A New Frontier Exploration Play.

By

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Hume Energy Enterprises LLC
and the
The Division of Energy and Innovation at
The University of Houston

What is the Center for Petroleum Exploration?

A partnership between the U of H and the Directorate General of Hydrocarbons, India.

Our mandate is to:

1. Provide third-party, independent evaluation of the work conducted on the Anadaman and Mahanadi/Bengal Basins using all available data provided by the DGH.
   i. This phase is now complete, and a structured and cleaned database has been created.
   ii. A data room is available to companies interested in accessing this data and pursuing oil and gas exploration in these areas.
2. Allow the faculty and students at the University of Houston to conduct research on the basins.
   i. The aim is to add additional value to the work conducted to date and make the prospects for future exploration more attractive to a broader oil and gas community.
   ii. It will also allow students access to real data and will challenge them to solve real issues associated with exploration while they pursue their graduate degrees.
   iii. The results of this work will be published and made available through the UH/DGH data room.

Why Invest in Upstream Oil and Gas in India?

- India wants to increase domestic oil and gas production and reduce reliance on foreign energy imports
- India is committed to reduce the use of high carbon forms of energy by switching to a gas-based economy
- As the Indian economy grows, the market for hydrocarbons In India will continue to expand
- India recognizes the need for western investment and technology to help achieve these goals
- India has made major reforms to how exploration is conducted and has become a very favorable jurisdiction for petroleum exploration and development
- Many restrictions previously in place have been lifted and data is now easily accessible

Prospects in ~99% of EEZ Opened up for E&P

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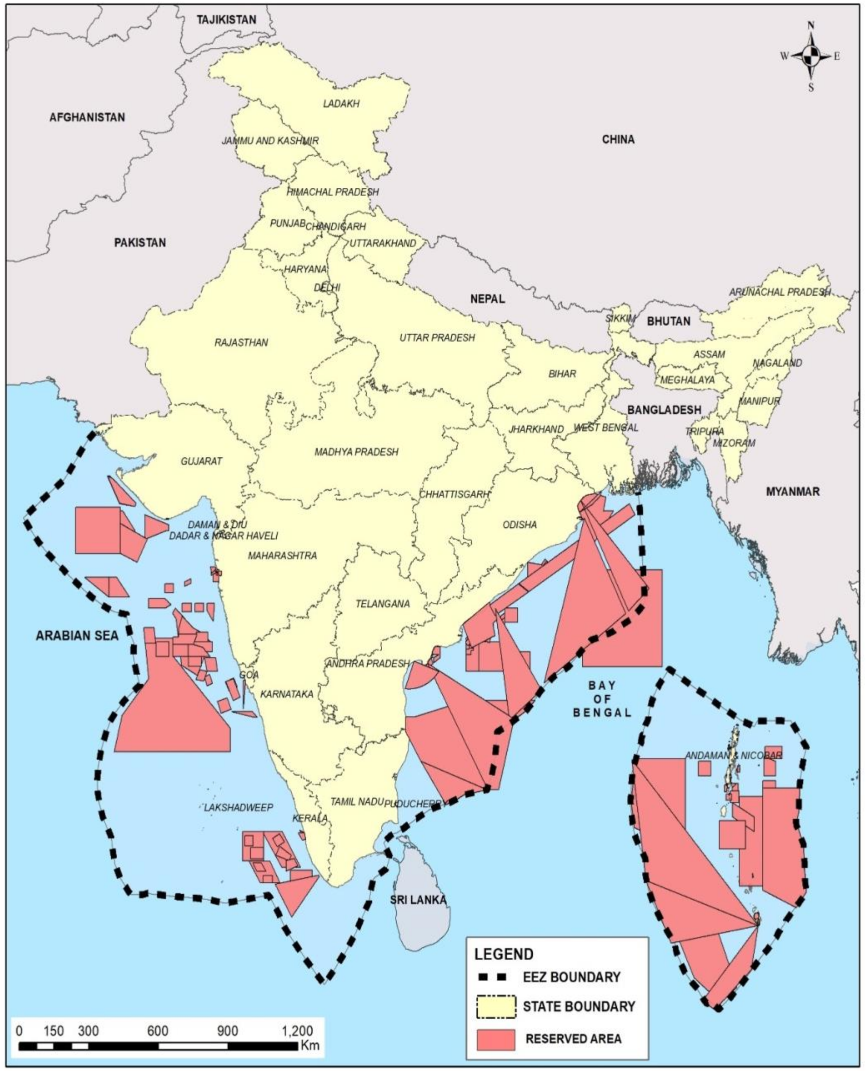
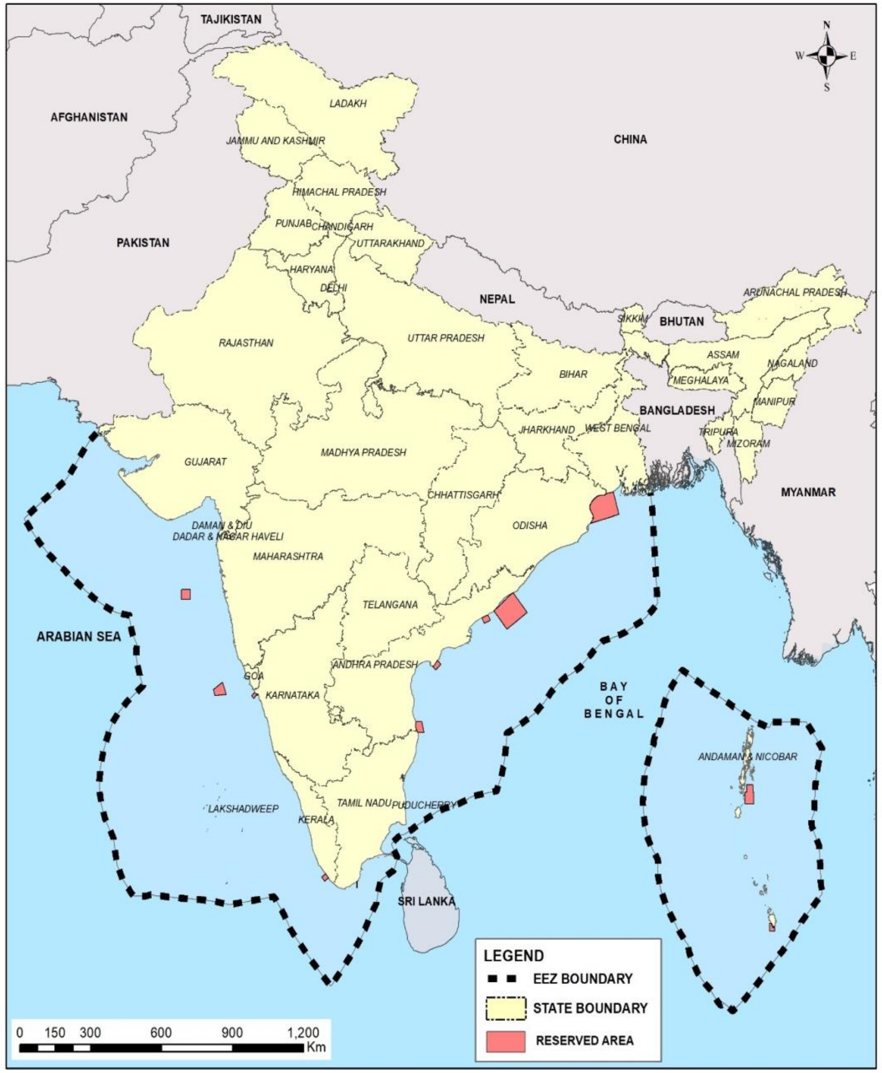
Earlier



Present



Note: Exclusive Economic Zone (EEZ) extends to a maximum of 200 Nautical miles from the baseline

Reforms to boost exploration in Cat II & III basins

- Extended & Phased Exploration Period of 7 years
- Bidding only on 2D & 3D Seismic with no well commitment in Phase 1
- Originator Incentive increased from 5 to 10 marks
- Easy Exit option
- Swapping of work programme with other Surveys and Wells

Streamlined processes to further drive sector attractiveness

Freedom to carve out blocks
Operators have freedom to submit EoIs throughout the year

Play based exploration
Longer exploration duration and larger block areas to incentivize play-based exploration

Shared responsibility
Statutory clearances are taken as shared responsibilities

Opportunity to partner with existing players
Global players have entered partnerships with Indian companies

Royalty Structure under HELP (Hydrocarbon Exploration and Licensing Policy)

ROYALTY RATES

GRADED ROYALTY STRUCTURE

ONLAND
Oil: 12.5% - Gas: 10%

Shallow Water
7.5%

Deep-Water
5%

Ultra-Deep
2%

INCENTIVISED ROYALTY STRUCTURE

Incentive for Offshore Exploration
Reduced Royalty Rates in Offshore

Long Royalty Holiday period
7 Years for Deep & Ultra Deep Waters

Incentive for Gas & CBM –
2% Reduced Royalty rates for on-shore blocks

CONCESSIONAL ROYALTY

(Incentive for Early Production)

Category I Basins
10% Concession

Category II Basins
20% Concession

Category III Basins
30% Concession

Applicable on Commercial Production within **4 years in Onland & Shallow water;**
Applicable on Commercial Production within **5 years in Deep & Ultradeep water;**

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1.1 Basin Locations

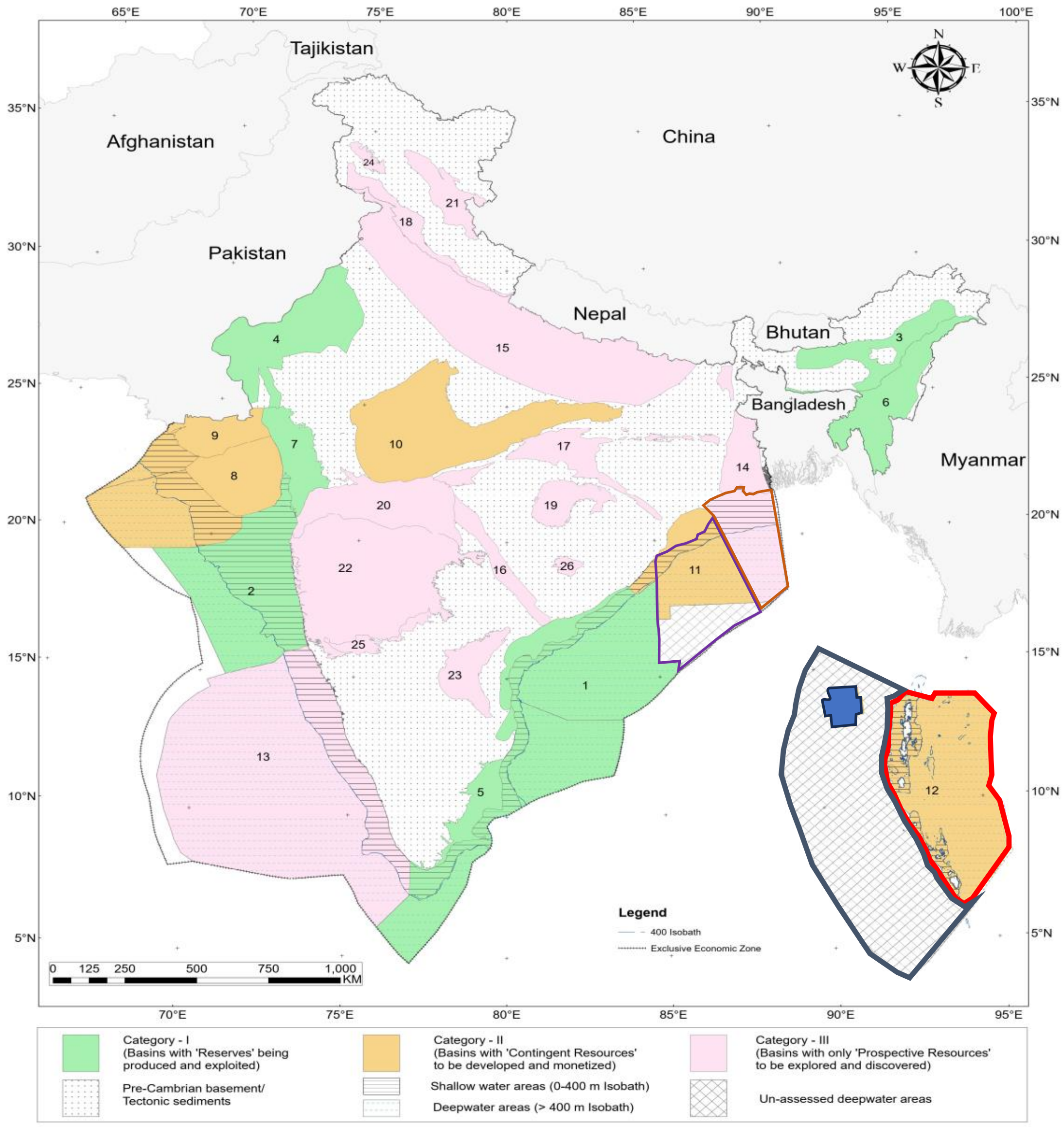
East Andaman Basin

West Andaman Basin

Mahanadi Basin

Bengal Basin

Indian Sedimentary Basins



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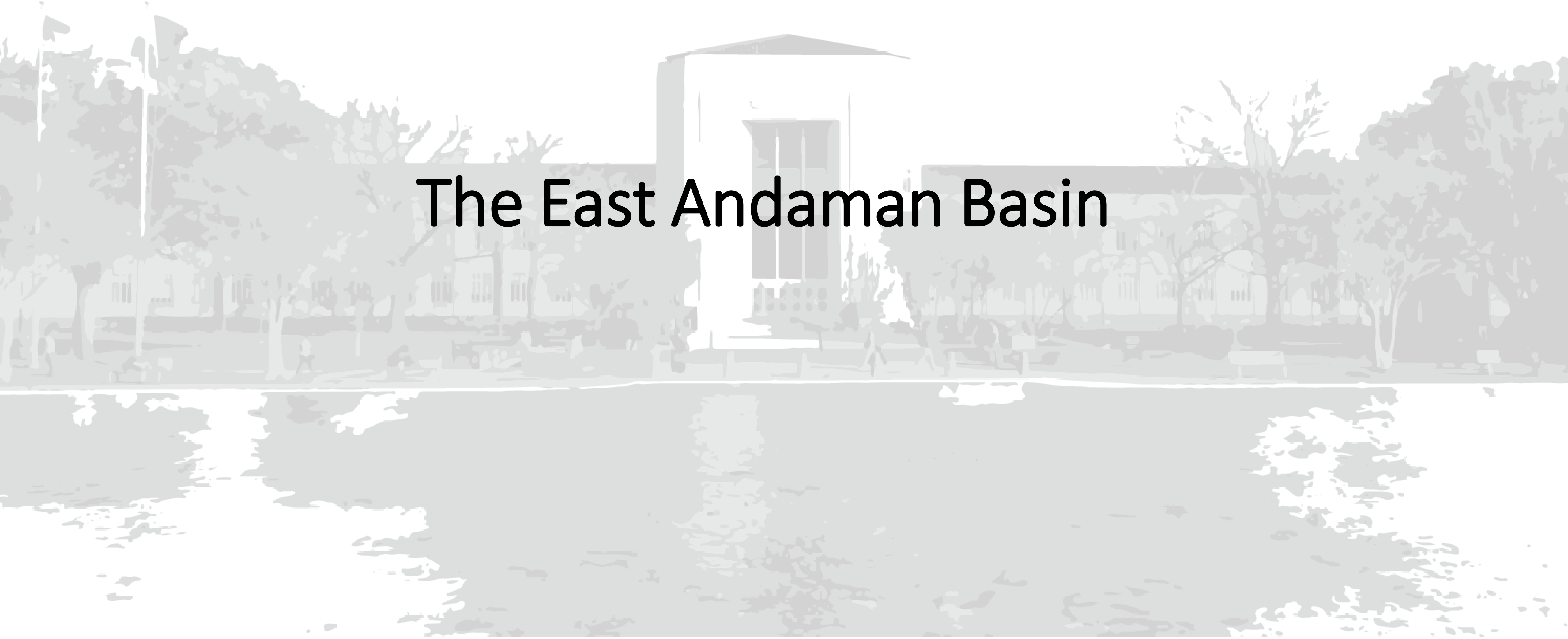

The East Andaman Basin

1.2 Physiography and Bathymetry East Andaman

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Physiography and Bathymetry of the Andaman Basin

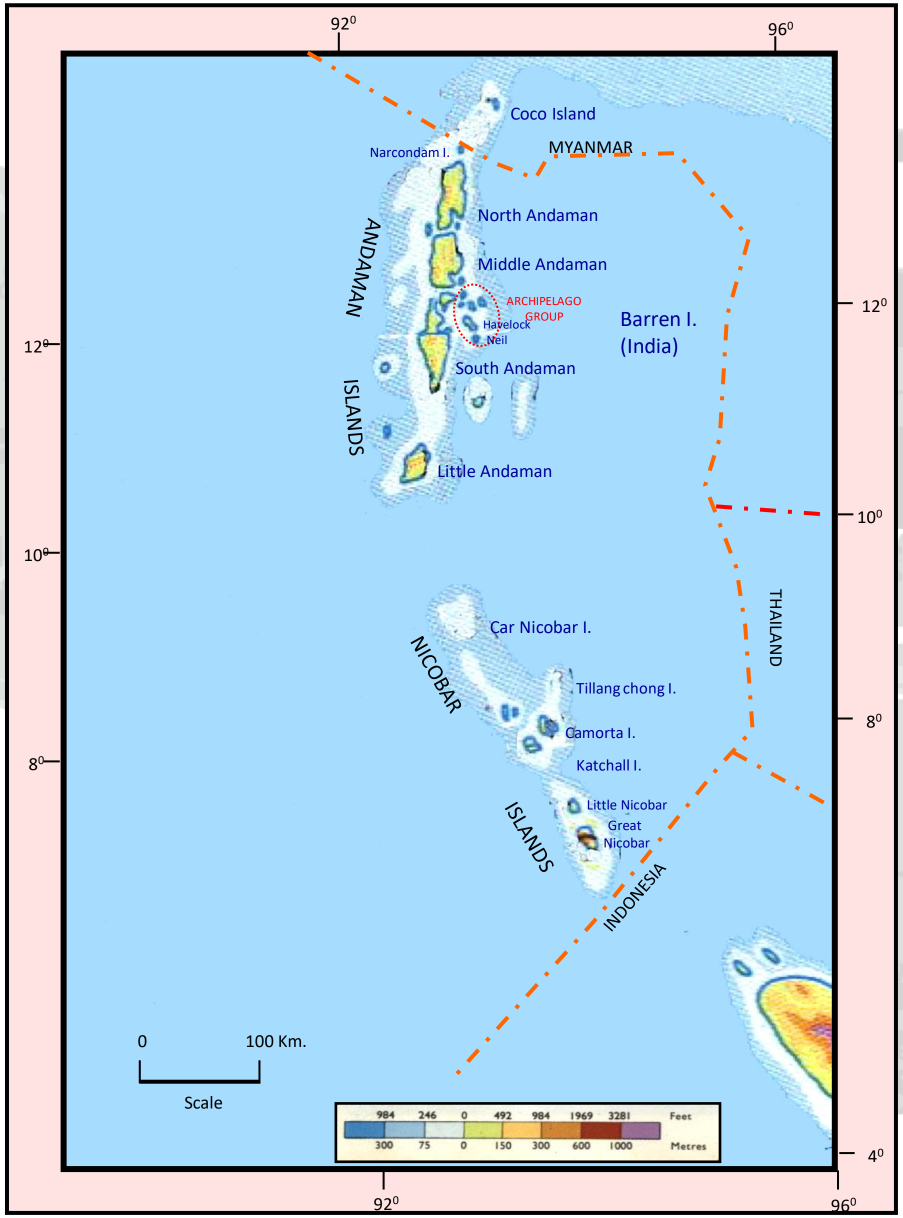


FIG.4 PHYSIOGRAPHIC MAP OF ANDAMAN-NICOBAR

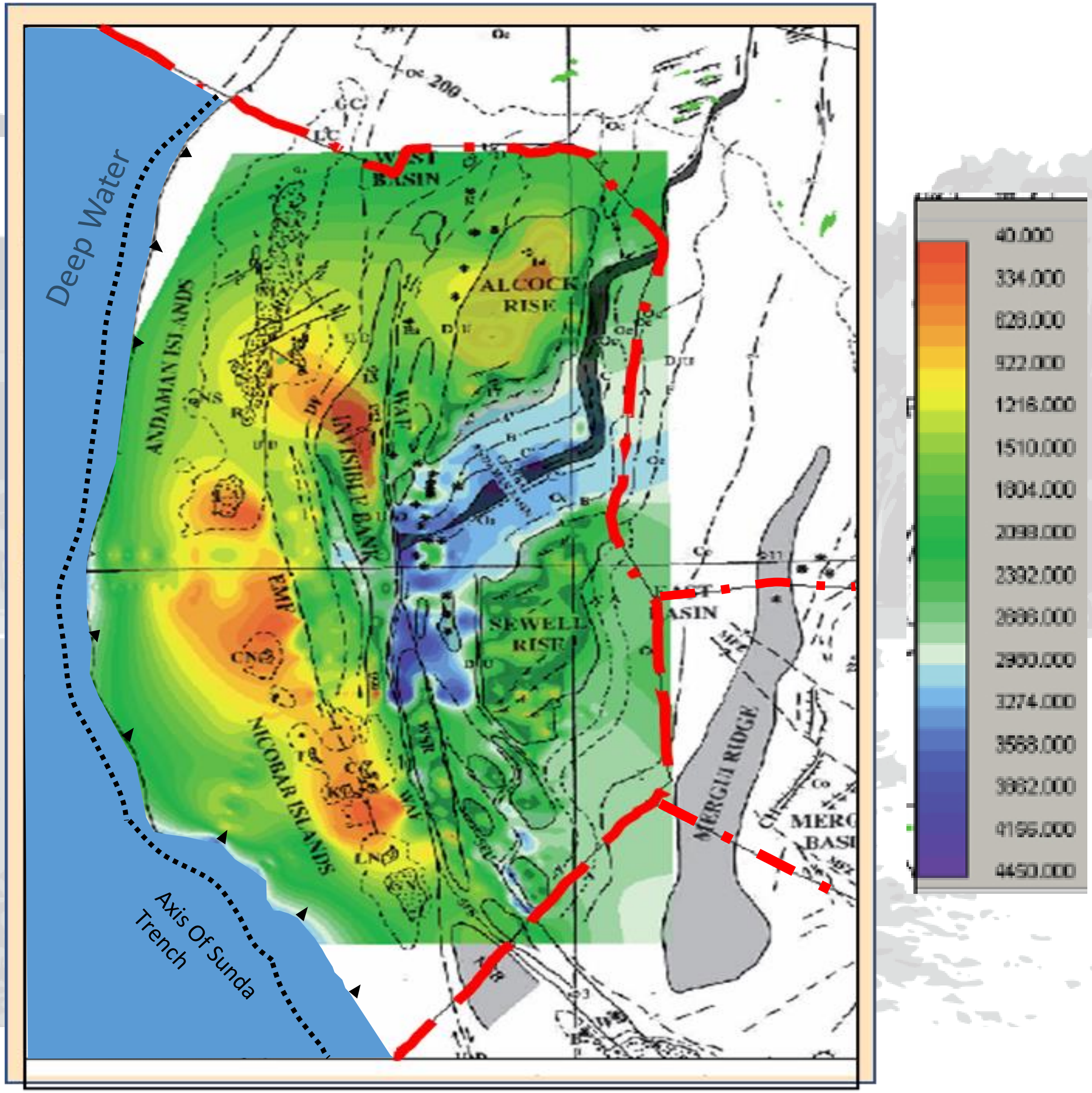
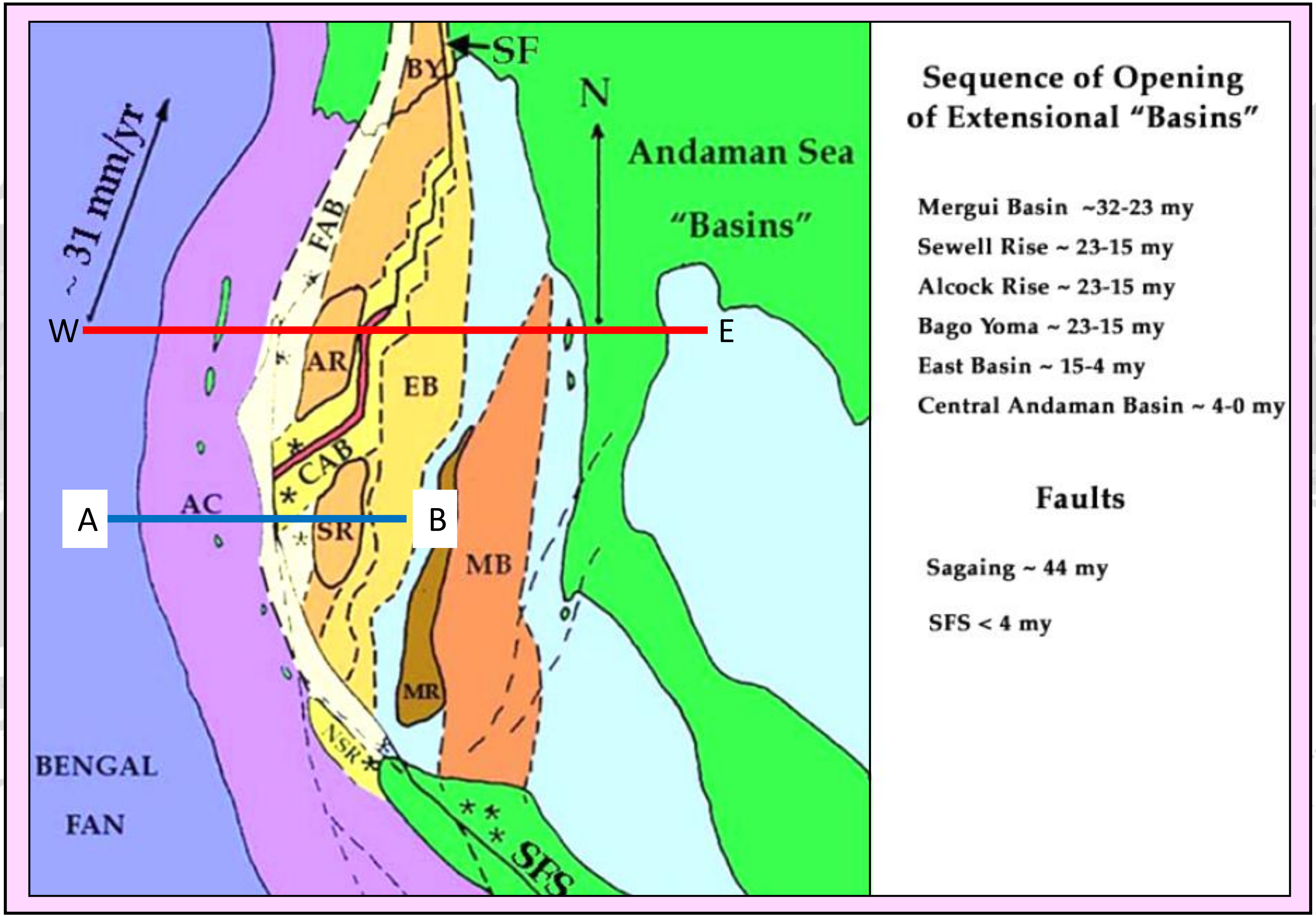


FIG. 5 BATHYMETRY OF ANDAMAN BASIN

Tectonic Setting

- The East Andaman Basin is composed of a complex series of sub-basin related to the tectonic setting



Tectonic Setting

- Tectonic Setting of The East and West Andaman Basins

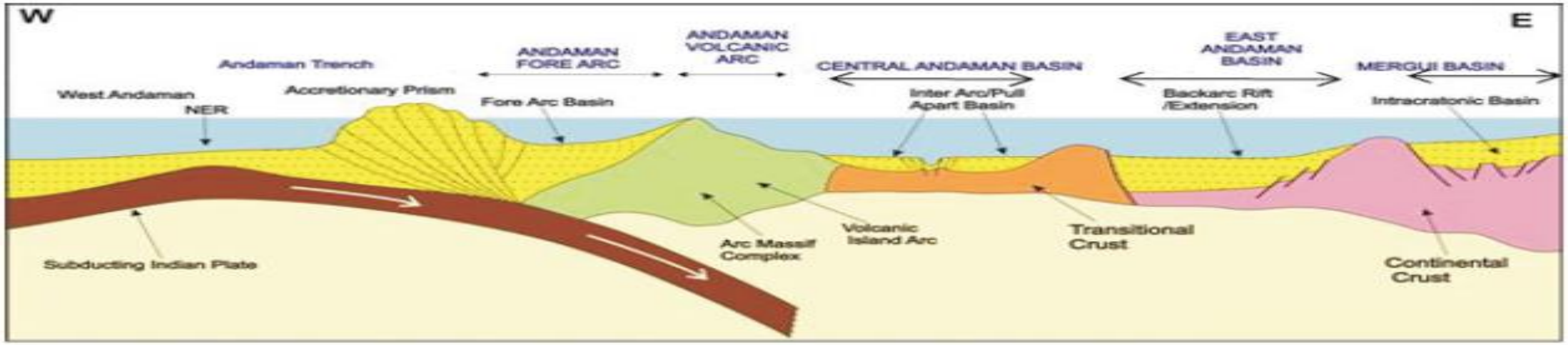


Fig. 2.2 Schematic Geological cross section across Andaman Subduction Zone

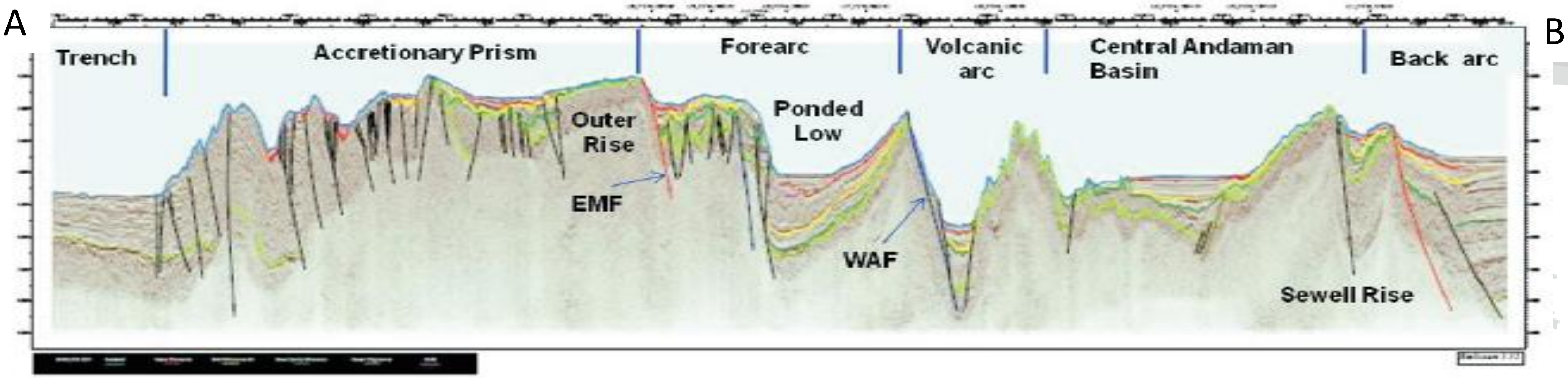


Fig. 2.3 Regional 2Dsection (E-W) PGS 12 showing Tectonic elements

General Stratigraphy

- Generalized Stratigraphy of the East Andaman Basin

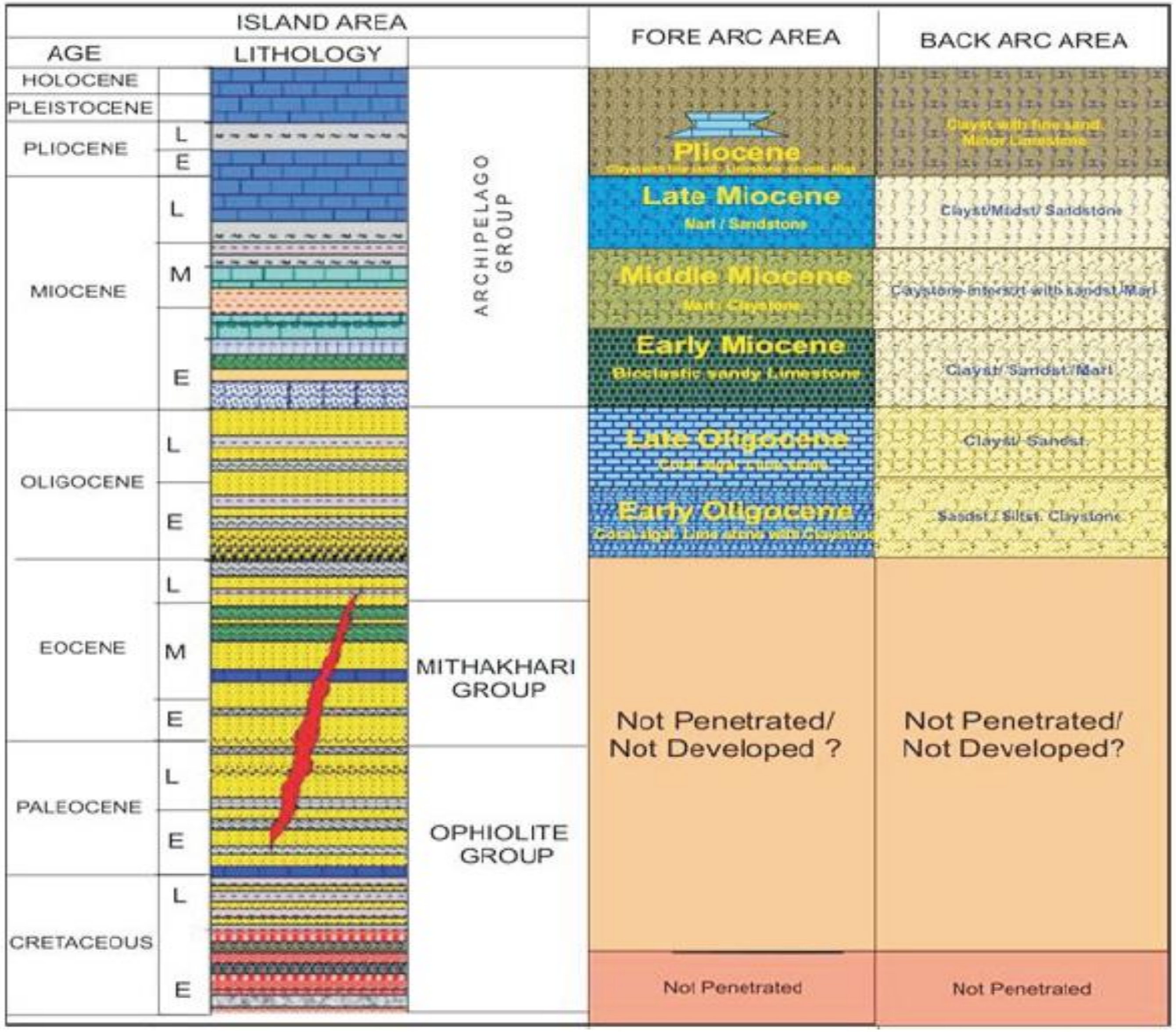
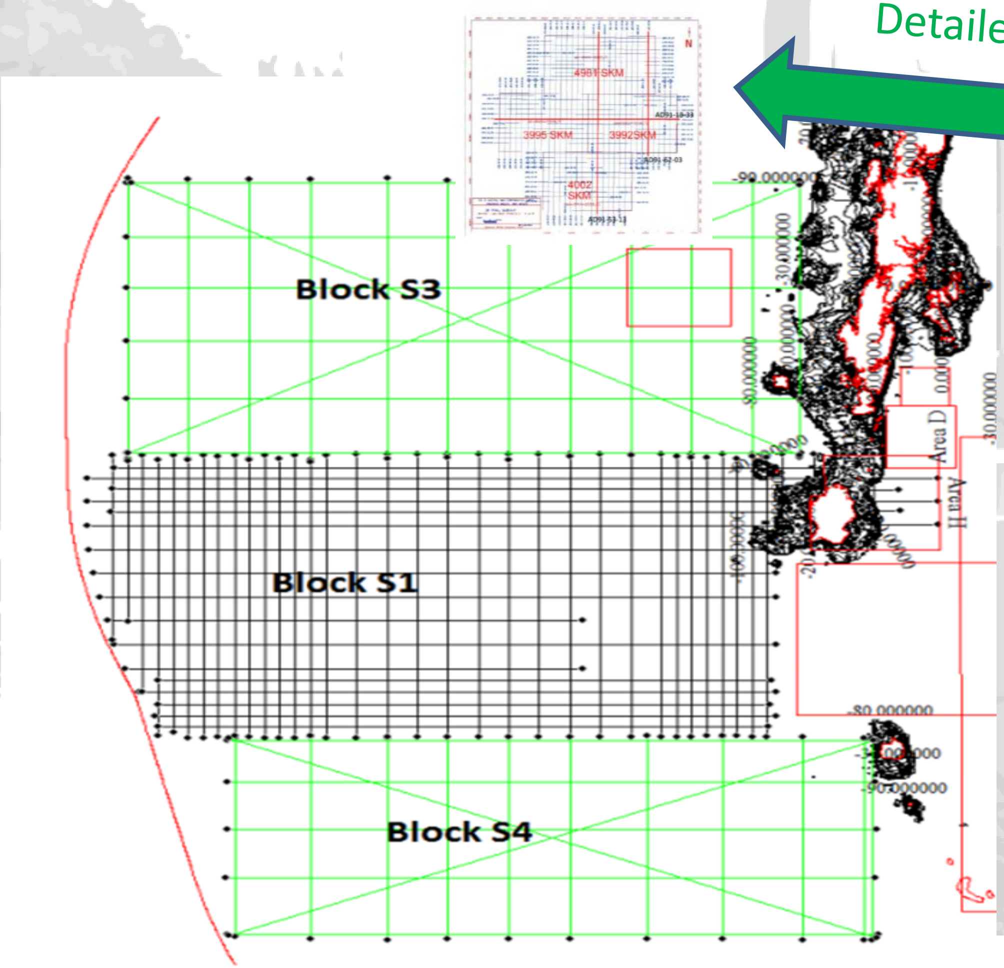


Table. 2.4.2. Generalised stratigraphy of Andaman Basin (Modified after Allen et al., 2007)

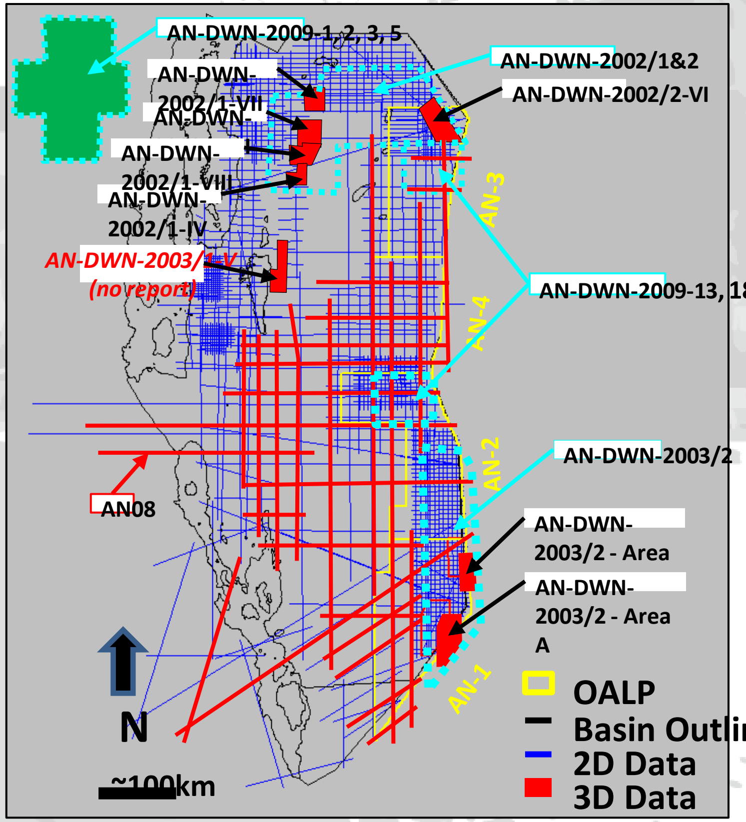
Geological, Geochemical and Seismic Surveys

West Andaman

Detailed Study Area



East Andaman



Wells Drilled, Status and Hydrocarbon Shows

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Wells Drilled in Andaman Basin.

Sl. No.	Name of well	Date of Spudding / Completion	Water Depth (m)	Target Depth / Drilled Depth (m)	Well bottomed in	Status
1	AN-1-1	18.03.80/24.06.80	94.8	4000/3737	Late Cretaceous	Gas discovery
2	AN-2-1	31.12.80/13.04.81	33	4000/4088	Late Cretaceous	Dry
3	AN-1-2	22.03.81/11.05.81	93.5	4500/2882	Middle Miocene	Dry
4	AN-1-3	26.05.81/26.09.81	101.38	3500/3412	Pre-Miocene	Dry
5	AN-32-1	01.04.85/09.07.85	56	2500/2510	Early-Miocene	Gas shows
6	AN-14-1	29.06.85/04.12.85	77	3000/2538	Oligocene	Dry
7	AN-1-4	14.08.85/26.10.85	99	2700/2720	Middle Miocene	Dry
8	AN-63C-1	23.12.85/27.02.86	74	3000/1853	Early Miocene	Dry
9	AN-42-1	08.03.86/27.06.86	52	4400/3972	Late Cretaceous	Dry
10	AN-27-1	23.07.86/22.10.86	175	2500/2556	Early Miocene	Dry
11	AN-70-1	16.11.86/14.03.87	90	3500/3500	Late Cretaceous	Dry
12	H L O	23.03.87/17.08.87	30	3000/3078	Oligocene	Dry
13	AOE-1	01.05.86/19.09/86	387	4500/4422	Late Eocene	Dry
14	AOE-2	22.09.86/01.05.87	390	5000/4984	Late Paleocene	Dry
15	ANDW-1	07.02.2011	2021	5525/5121	Oligocene	Gas bearing in Pliocene & Abandoned
16	ANDW-2	18.05.2011	1502	4225/3766	Basalt	Dry& Abandoned
17	ANDW-3	23.06.2011	1980	4725/4725	Miocene	Dry &Abandoned
18	ANDW-4	07.08.2011	1412	5625/4744	Oligocene	Dry & Abandoned
19	ANDW-5	07.11.2011	1984	5575/5500	Late Oligocene (?)	Dry & Abandoned
20	ANDW-6	17.06.2012	1984	5225/4171	-	Prematurely terminated
21	ANDW-6A	24.07.2012	1980	5225/4922	Lower Miocene	Dry& Abandoned

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Wells Locations and Hydrocarbon Shows

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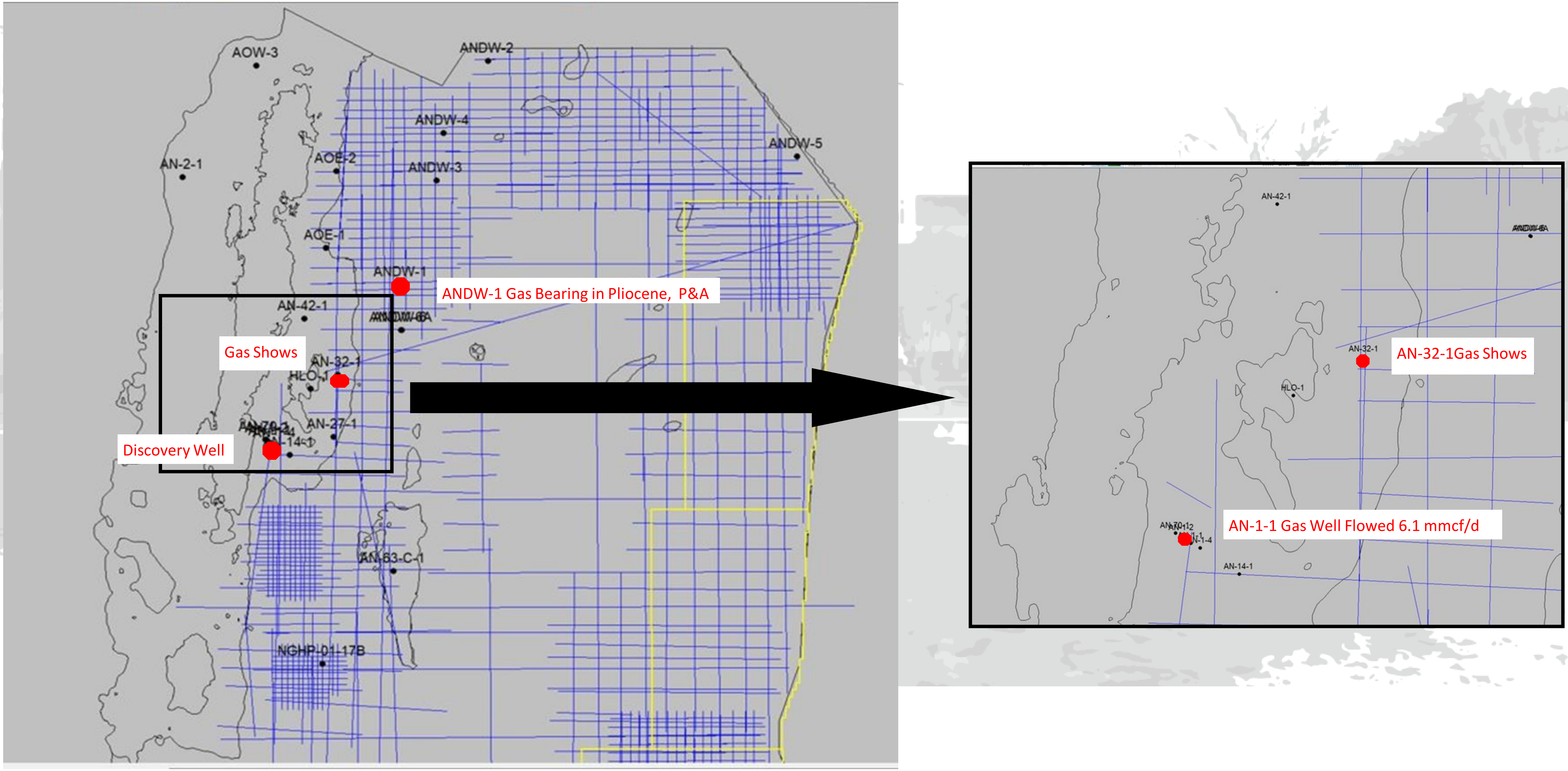

Hydrocarbon Sources/Maturity – East Andaman Basin

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- The Paleocene, Cretaceous, Eocene, Oligocene and lower Miocene fall within thermal maturity windows (Ro% > 0.5)

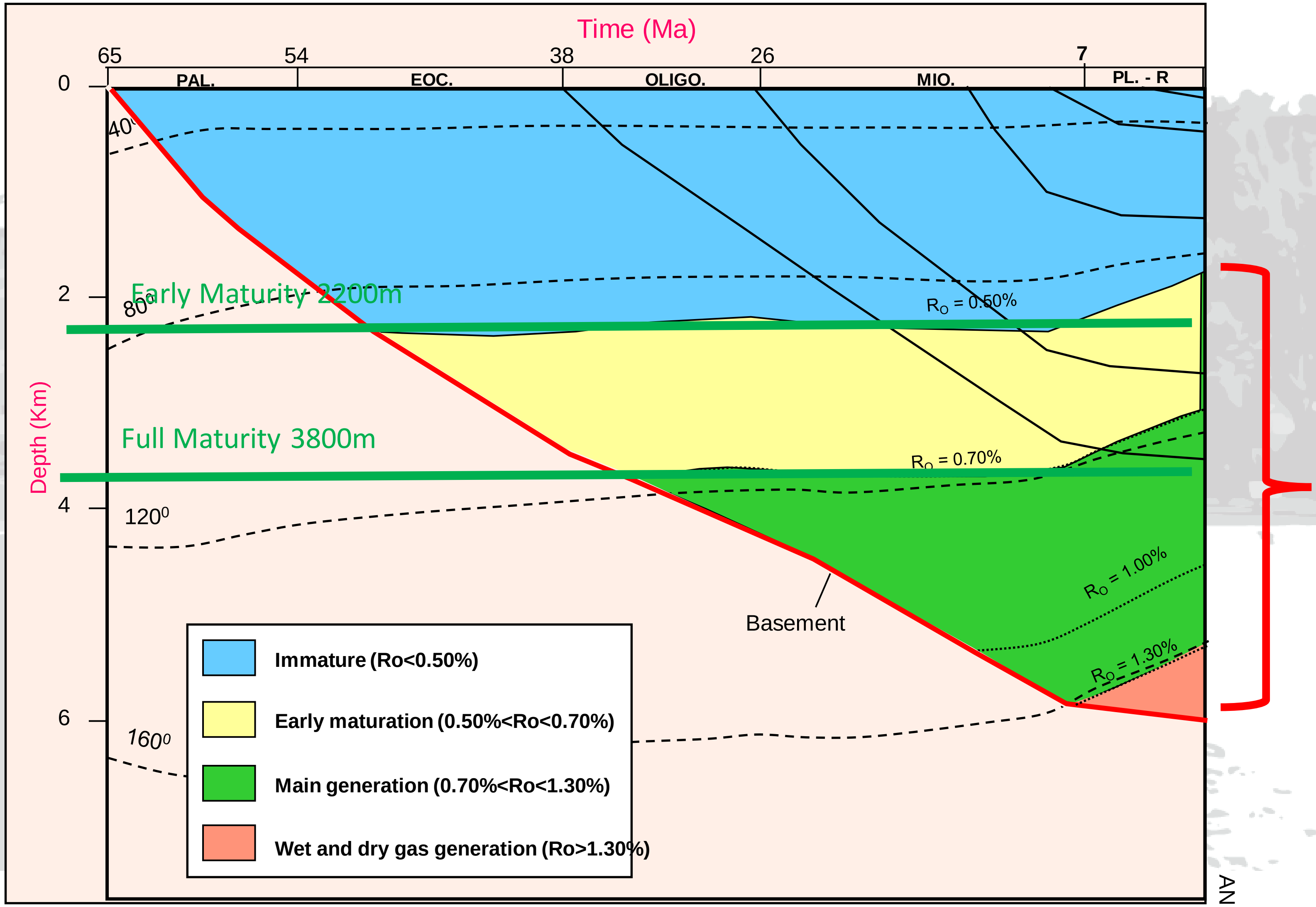

FIG. 55 REPRESENTATIVE THERMAL & MATURATION HISTORY IN DEEP WATERS OF ANDAMAN BASIN

Hydrocarbon Sources/Maturity – E. Andaman Basin

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- Modelled Sweeny & Burnham Easy Ro% Foor the Paleocene and Eocene, East Andaman Basin

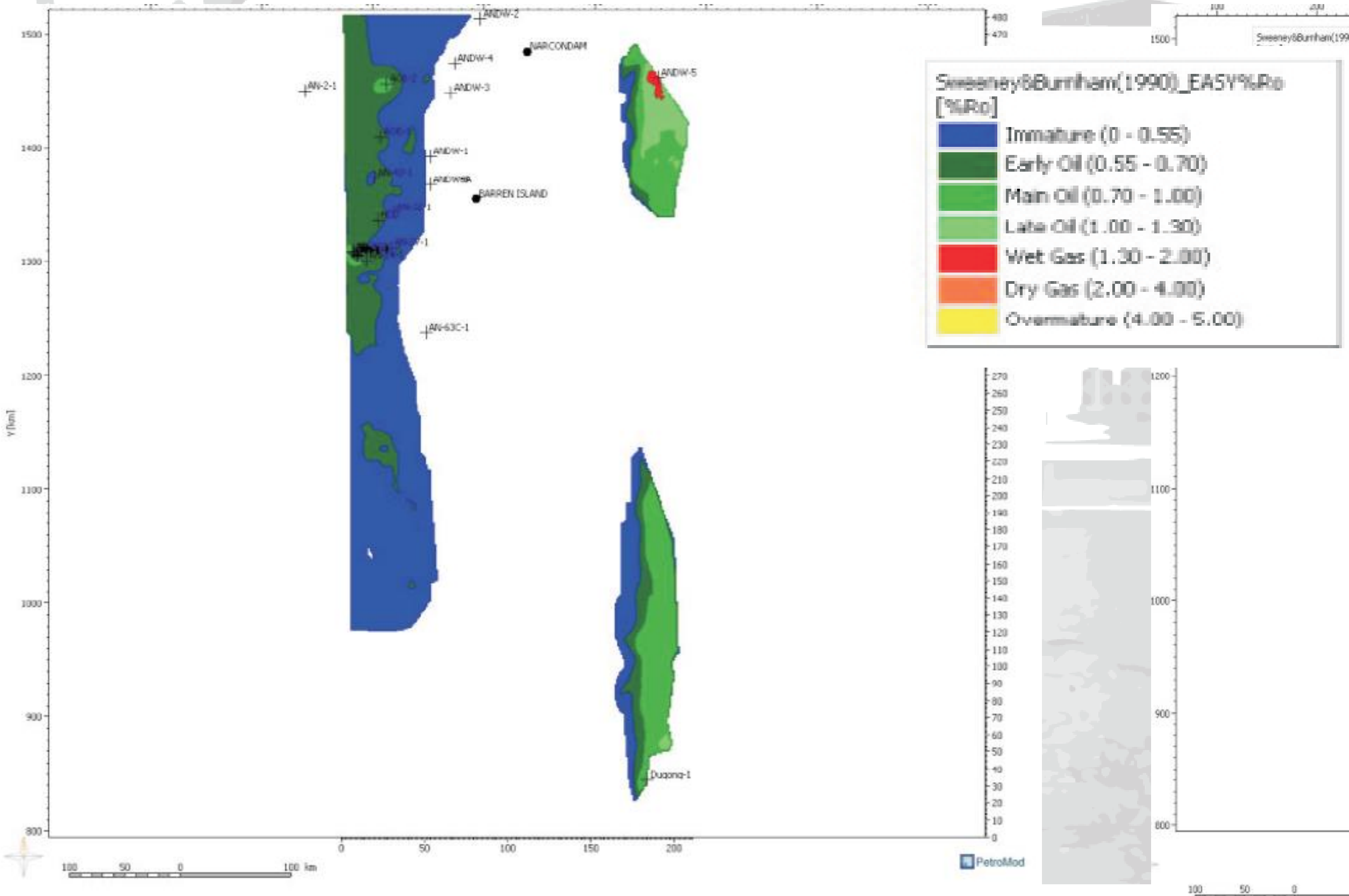

Fig. 4.3.7.1. Sweeney & Burnham Easy Ro% - Paleocene SR1

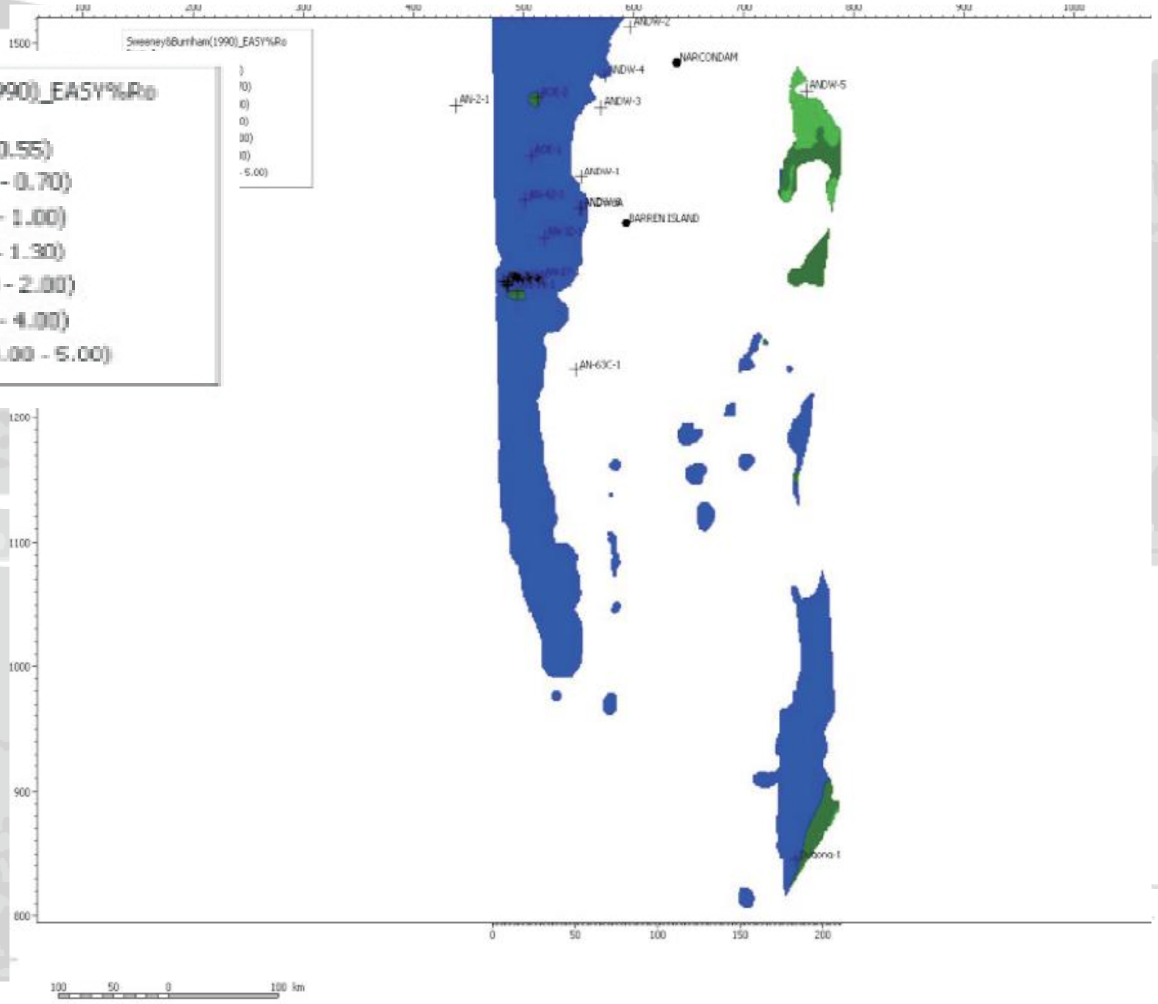

Fig. 4.3.7.4. Sweeney & Burnham Easy Ro% - Eocene SR1

Biogenic Gas Sources

- Various gas shows have been attributed to biogenic sources.
- By their nature these occur in shallower reservoirs where formation temperature and water chemistry is favorable for bacterial activity.
- The Pliocene and Upper Miocene reservoirs may be sufficiently charged to warrant further investigation.

Reservoir – E. Andaman Basin

- Formation Stratigraphy of the Andaman Islands showing potential reservoir zones.

Age	Group / Formation / Member			Thickness (m)	Lithological Description
Pleistocene	Neill Fm			45	Mod hd. buff col. fine to med. grained foram / algal calcarenite
Mid Mio-Pliocene	Long Fm			1450	Grey massive mudstone, silty shale, hard limestone with sandstone at lower part
Early-Mid Miocene	InglisFm			280	Nanno / foram chalk, silty shale, shale
Early Miocene	Strait Fm			90	Sandy limestone, soft marl, tuff, siliceous chalk, calc. siltstone
Oligocene	KalapaniFm	Port Blair Fm		1000+	Gray, brown, buff to light grey sandstone with grey / buff silt and shale interbeds; grits & conglomerates at base
Eocene to Cretaceous	KalapaniFm	BaratangFm	Burma-Dera	410	Mainly shale with sand, marl, siltstone, and occ
Eocene to Cretaceous	KalapaniFm	BaratangFm	Neali Alternation	318	Sand-shale alternation with minor limestone, conglomerates, Coal
Eocene to Cretaceous	KalapaniFm	BaratangFm	Lipa Sst	452	Sand, grit & conglomerate beds
Eocene to Cretaceous	KalapaniFm	BaratangFm	Kalsi Shale	260	Grey to dark grey carbonaceous shale / claystone with siltstone and sandstone
Eocene to Cretaceous	KalapaniFm	BaratangFm	Karma-tang Sst	846	Sandstone, carb. and phyllitic shale & limestone
Pre-Cretaceous	Port Meadow Fm				Quartzites, phyllites, chert, jasper, slate, cherty limestone and marble

Fig. 2.4.1: Generalized Stratigraphy of Andaman Islands by ONGC (Partly Modified)

Reservoir-East Andaman

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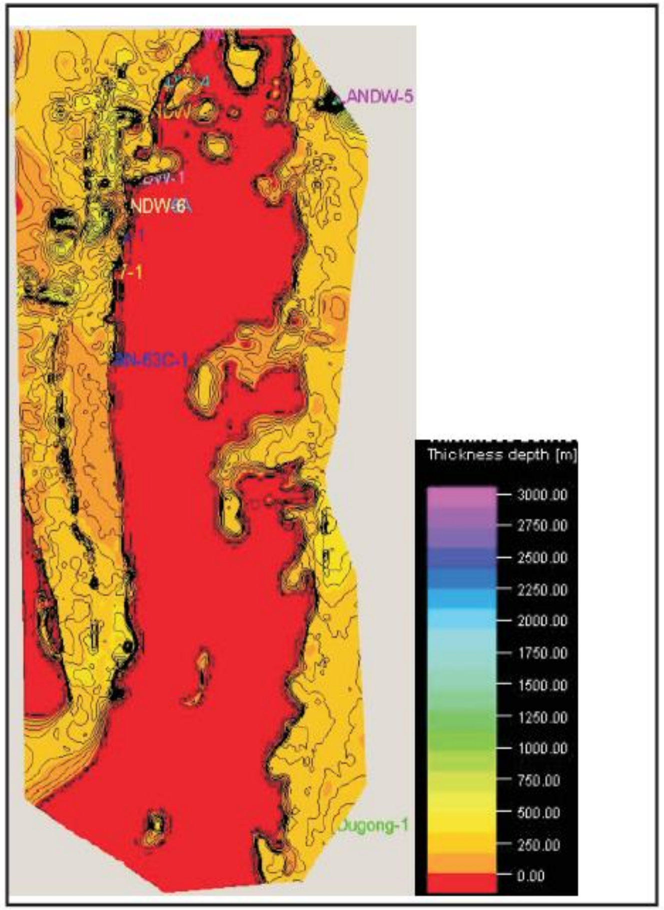
Mid Miocene Thickness and Reservoir Facies



Thickness Map of Mid Miocene

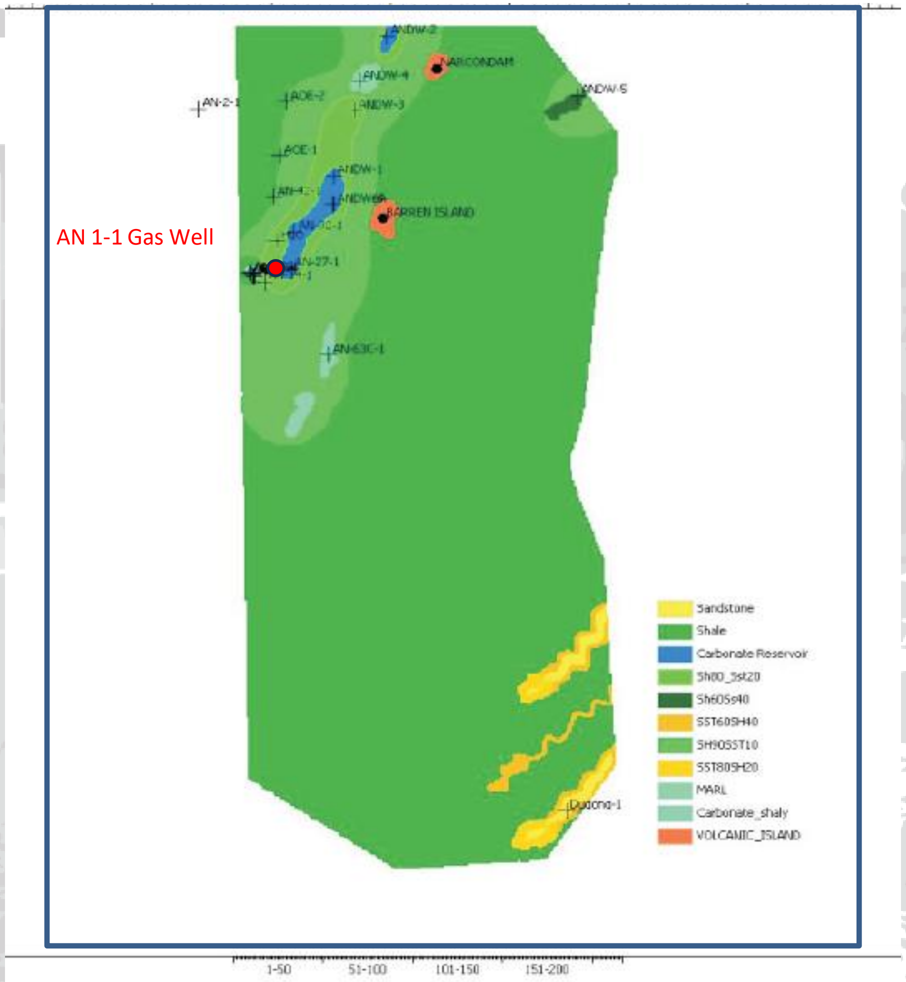


Fig. 3.6.1.4. Reservoir Facies - Mid Miocene

Reservoir – East Andaman Basin

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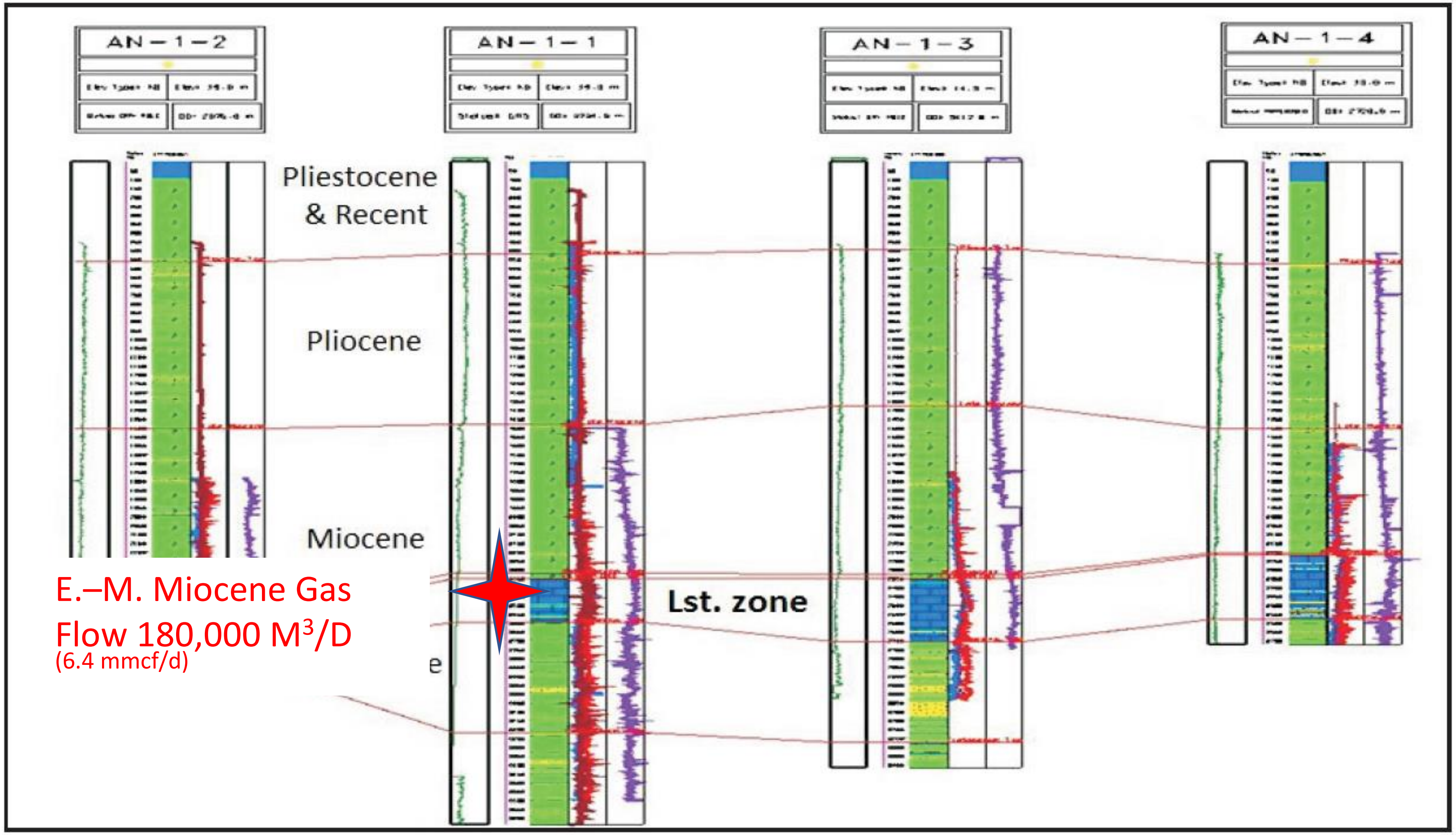

Fig 3.2.1 Electrolog Correlation of Wells AN-1-2, AN-1-1, AN-1-3 & AN-1-4

Trapping and Prospects – East Andaman

- The best traps are structural closed fault blocks or anticlinal traps related to the complex tectonic history of the basin.
- The Time Structure Map of the Deepest Mappable Reflector shows the vast structural relief across the basin
- There is potential for stratigraphic traps in the form of carbonate buildups and truncated sandstones associated with the Mid-Miocene Unconformity

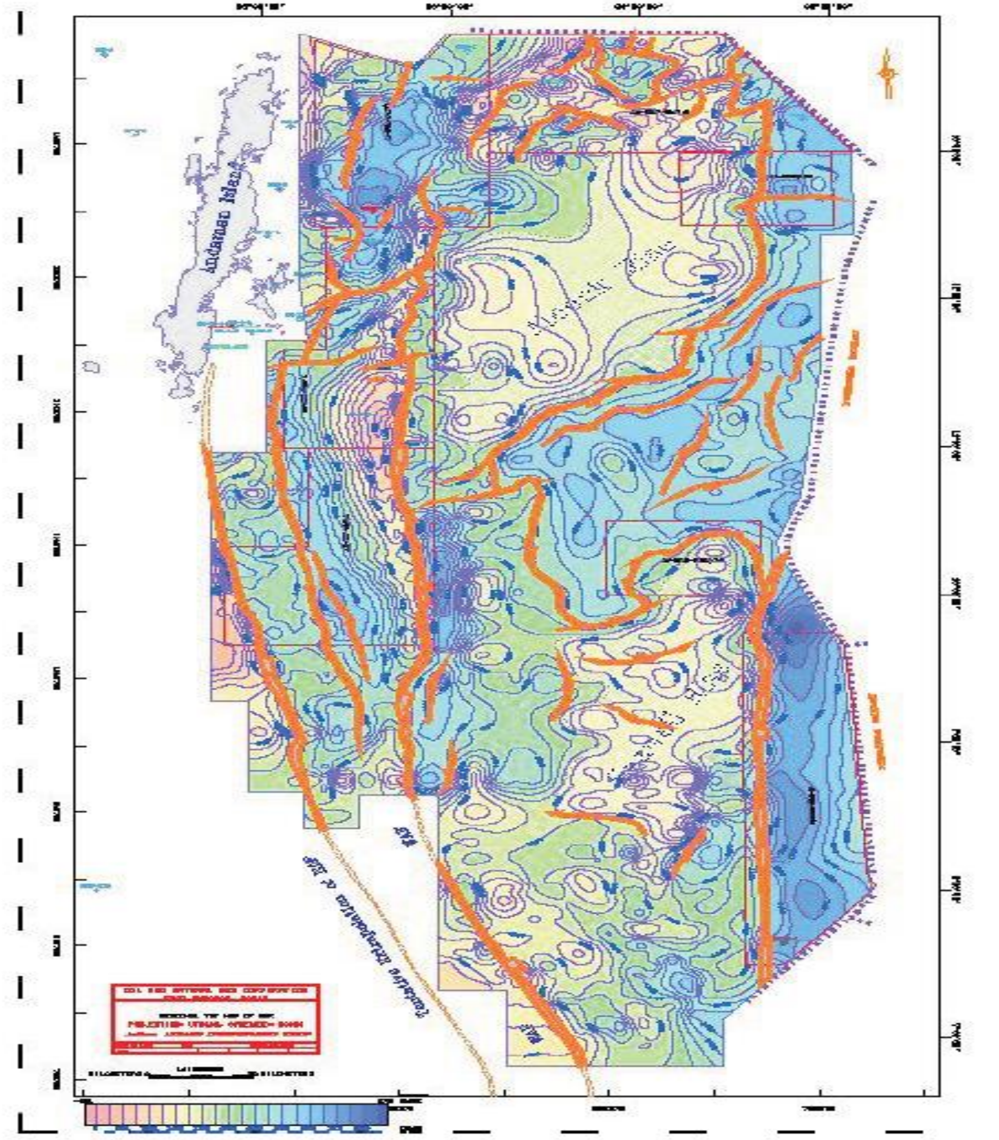

Fig. 3.3.1.1 Time structure map – DMR

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Trapping and Prospects East Andaman

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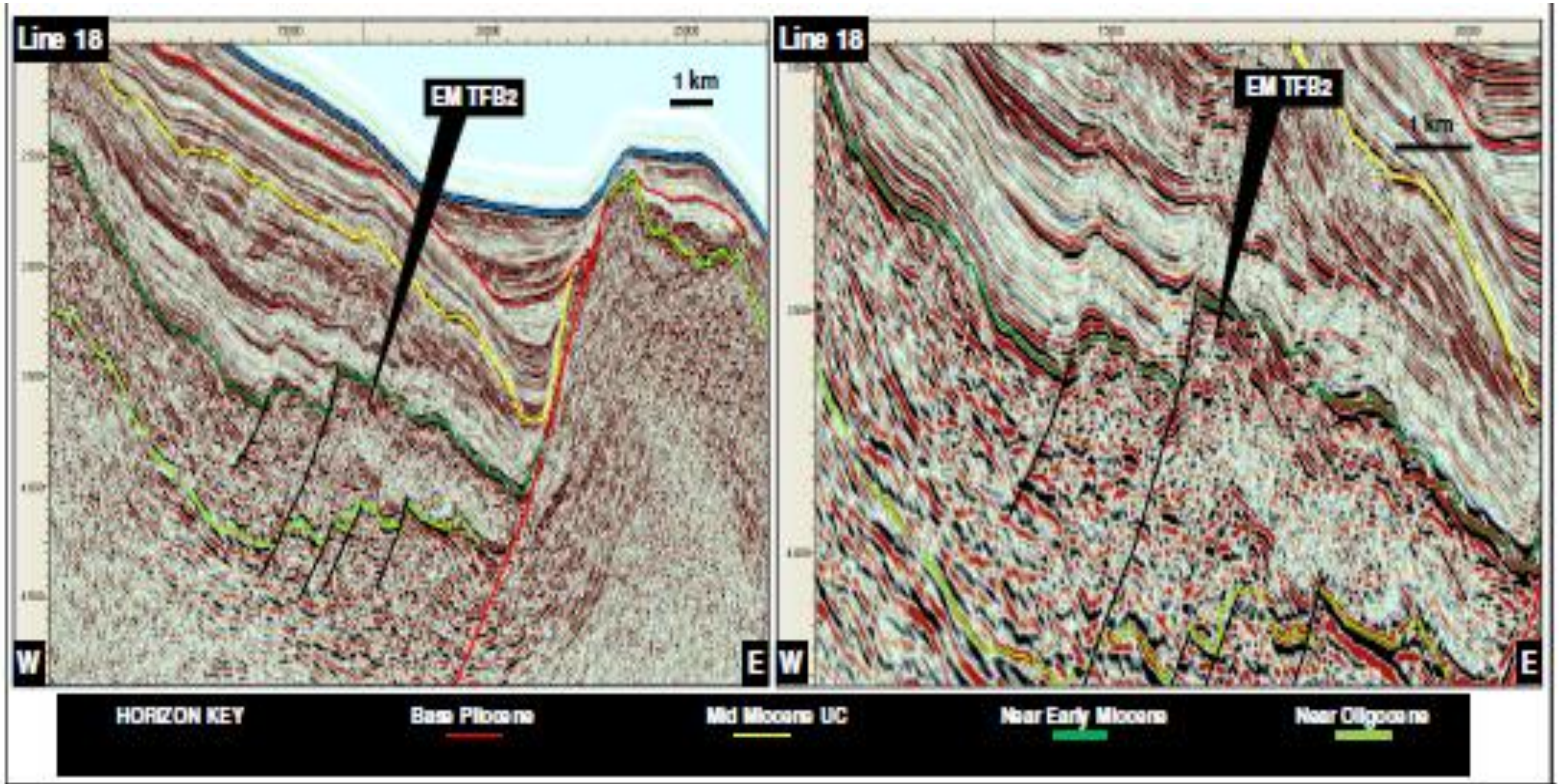
- Example of a Structural Trap



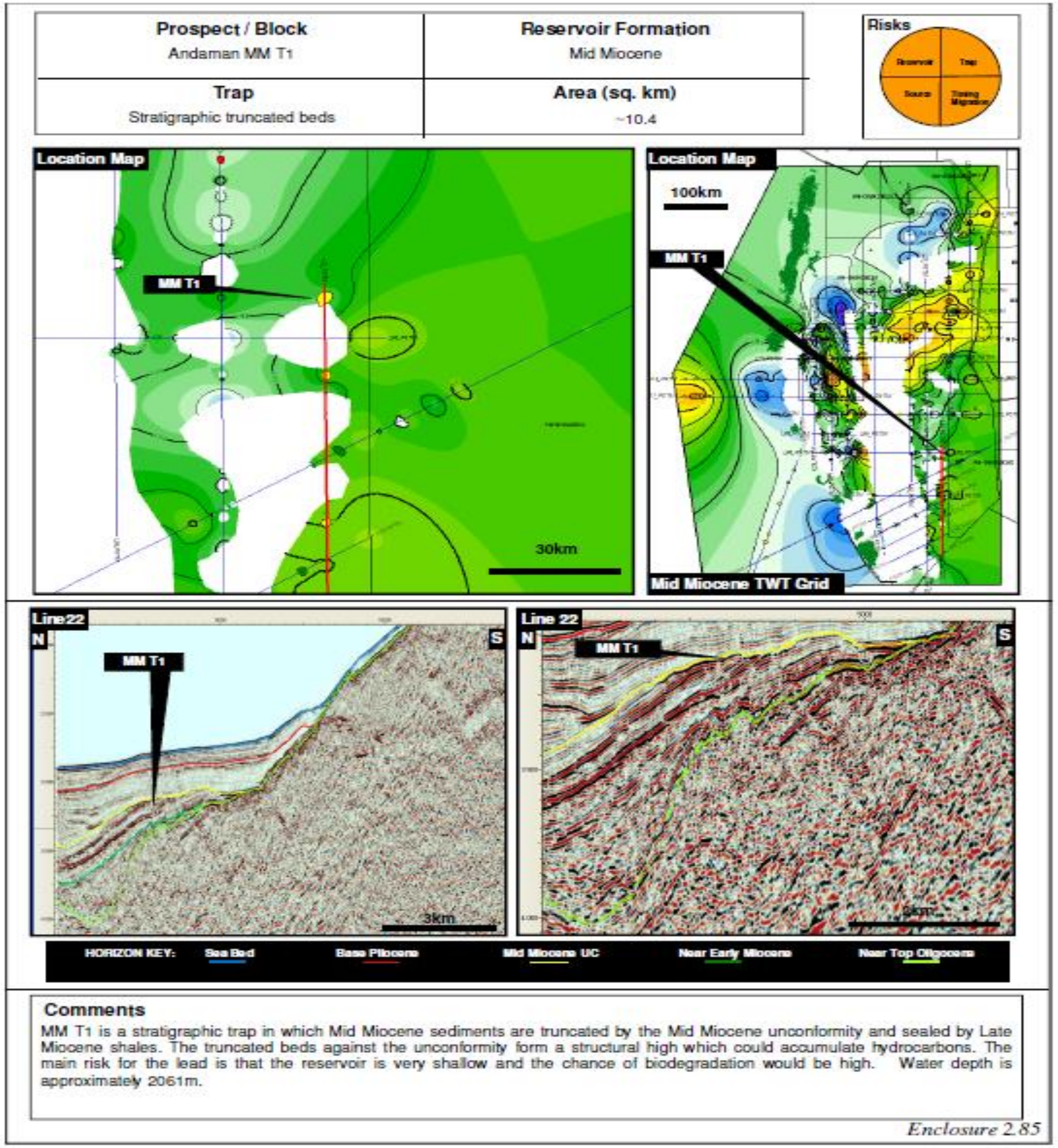
Comments

Trap is a tilted fault block of Early Miocene carbonates. The structure is sealed by Mid Miocene shales, although there is an updip amplitude anomaly that could possibly be an indication of hydrocarbon leakage. This makes migration/timing a risk. Water depth is approximately 1275m.

Enclosure 2.18

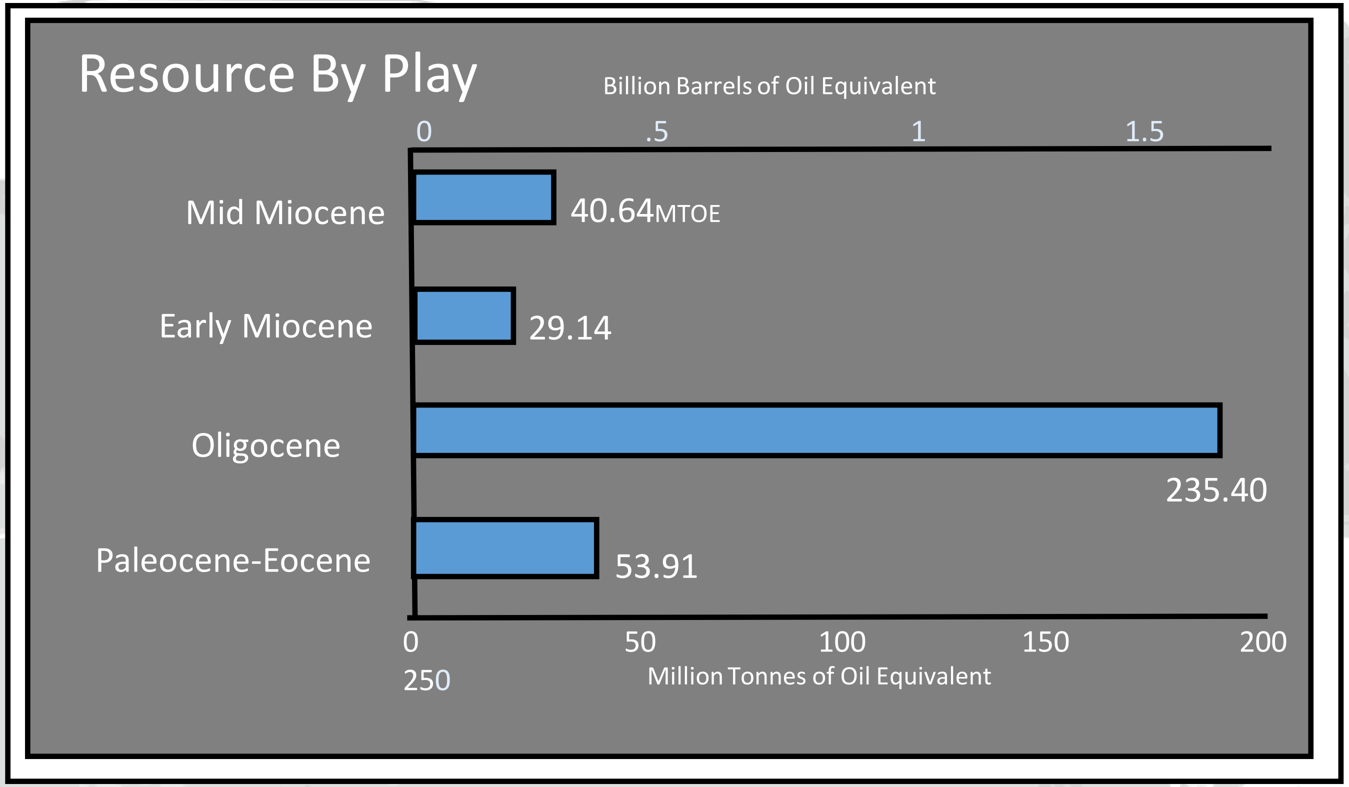
Traps and Prospects East Andaman

- Summary sheets are provided for each prospect
  - ➢ Example of Mid-Miocene truncation play.



East Andaman Resource Potential

- The East Andaman Model results show 359.1 MMTOE (2.5B BBLS) of Accumulated Hydrocarbons.
- The Oligocene shows the most promise with 235.4 MMTOE (1.68B BBBLS)



East Andaman Resource Potential

- Potential Pool Sizes Top 20 Prospects

Line Number	Lead ID	Area Km Sq	Area Ac.	Est h Ft	Est Porosity	Est Sw	Estimated Depth Ft.	Estimated P Psi	Reservoir Formation	Trap	OOIP MBLS	OGIP BCF	Risking Average	Water Depth (m)
28	MM B1	15.0	3706.5	25	0.08	0.25	15,500	7207.5	Mid Miocene	Carbonate build up	36.6	107.6	1.5	2160
28	LM A1	20.0	4942.0	20	0.15	0.35	15,000	6975	Late Miocene	Anticline 4 way dip closure?	63.4	108.5	1.75	1125
27, 10	MM TFB2	101.0	24957.1	25	0.15	0.35	15,500	7207.5	Mid Miocene	Fault bound 3 way closure	401.1	1177.0	1.75	1935
20	EM A1	98.0	24215.8	30	0.15	0.35	16,000	7440	Early Miocene Sands	Faulted Anticline	467.1	1415.0	1.75	2285
16	MM A1	58.0	14331.8	25	0.15	0.35	15,500	7207.5	Mid Miocene Sands	Faulted Anticline	230.4	676.1	1.75	3075
27	MM A3	27.0	6671.7	30	0.15	0.35	15,500	7207.5	Mid Miocene	Anticlinal 4 way closure	128.7	377.7	2	1875
23	MM A13	18.0	4447.8	30	0.15	0.35	15,500	7207.5	Mid Miocene	Anticlinal fold	85.8	251.8	2	3007.5
16	LM A2	33.0	8154.3	20	0.15	0.35	15,000	6975	Late Miocene Sands	Anticline	104.8	297.8	2	3070
31	MM A27	40.5	10007.6	25	0.15	0.35	15,500	7207.5	Mid Miocene Sands	Anticline	160.8	472.1	2	3750
31	UNK A28	20.0	4942.0	25	0.15	0.35	15,500	7207.5	Mid Miocene Sands	Anticline	79.4	233.2	2	3050
31	UNK A29	29.3	7240.0	30	0.15	0.35	15,000	6975	Unknown aged Sands	Anticline	139.6	396.7	2	1240
27, 13	LO B3	19.5	4818.5	25	0.15	0.35	16,500	7672.5	Oligocene	Carbonate build up	77.4	242.0	2	1537.5
13	LO B4	15.3	3780.6	25	0.08	0.25	16,500	7672.5	Oligocene	Carbonate build up	37.4	116.8	2	1146
19	LO B7	27.0	6671.7	25	0.08	0.25	16,500	7672.5	Late Oligo Carbonates	Carbonate Buildup	66.0	206.2	2	1530
27	LO B1	42.0	10378.2	30	0.15	0.35	16,500	7672.5	Oligocene	Structural High	200.2	625.5	2	1745.25
27	LO B2	33.0	8154.3	30	0.15	0.35	16,500	7672.5	Oligocene	Structural High	157.2	491.4	2	2151
17	MM A10	16.0	3953.6	25	0.15	0.35	15,500	7207.5	Mid Miocene Sands	Anticline	63.5	186.5	2.25	1890
27	LM LST1	18.7	4620.8	20	0.15	0.35	15,000	6975	Late Miocene	Basin floor fan	59.4	168.8	2.25	2650.5
19	LM P1	56.0	13837.6	20	0.15	0.35	15,000	6975	Late Miocene Sands	Stratigraphic Pinchout	177.9	505.4	2.5	1530
23, 17	MM TFB20	39.3	9711.0	25	0.15	0.35	15,500	7207.5	Mid Miocene	Tilted fault block	156.1	458.1	2.5	2640

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West Andaman Basin

Traps and Prospects West Andaman

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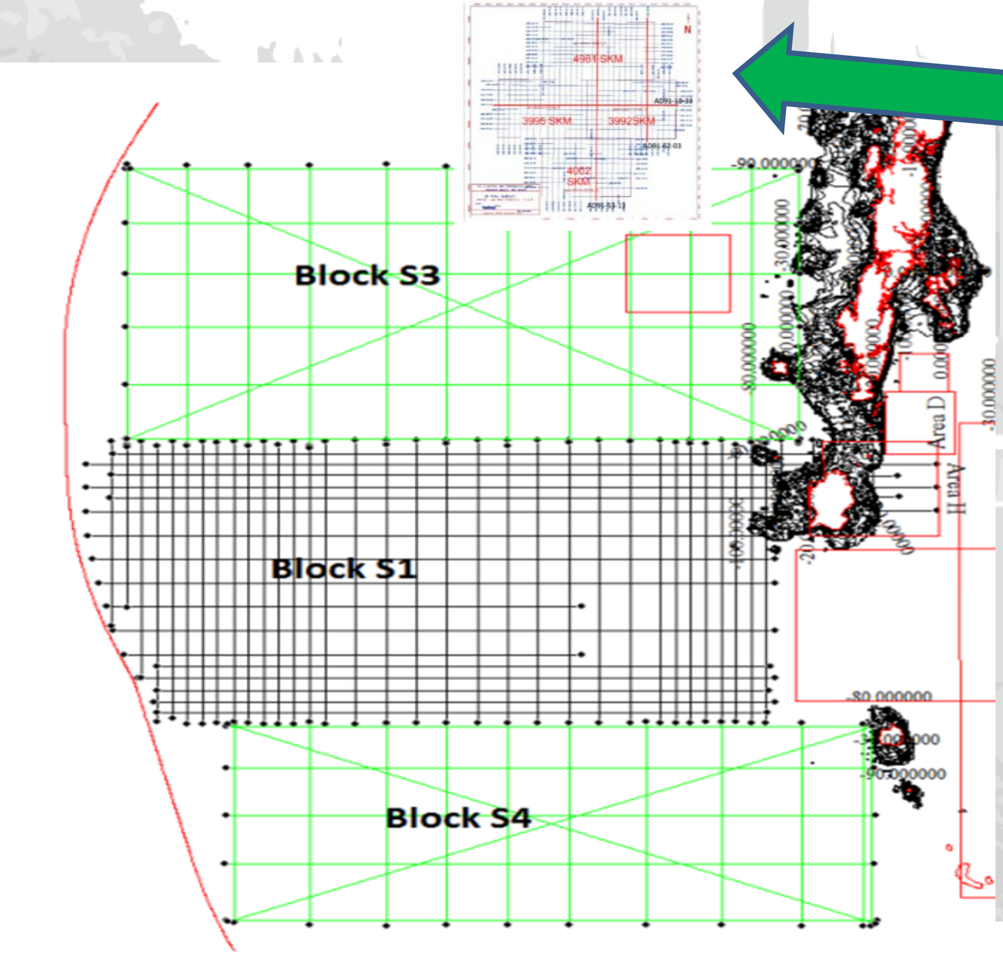
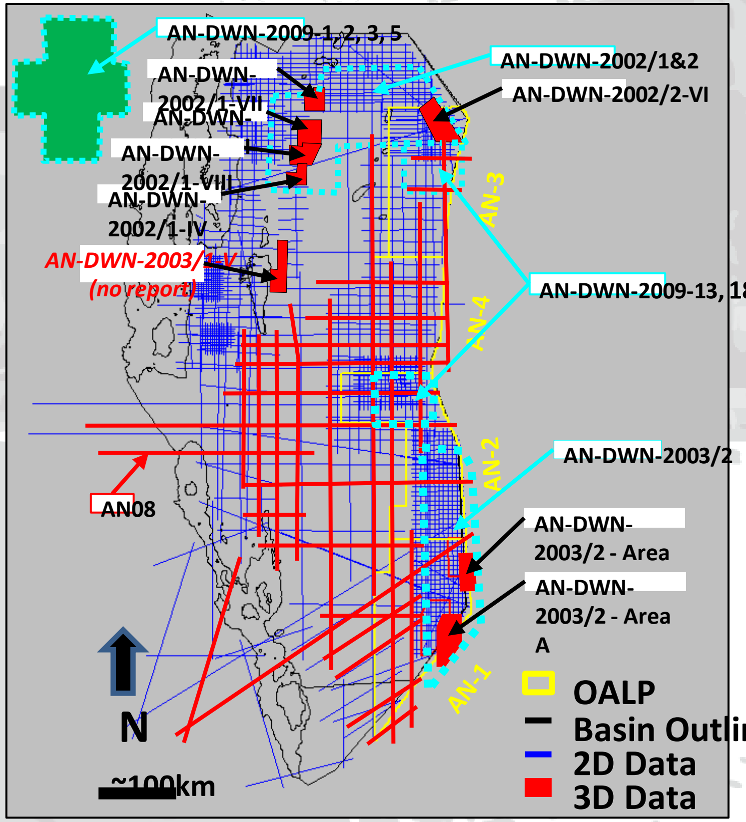
- The potential of the West Andaman Detailed Study Block has been evaluated using seismic





Hydrocarbon Sources and Maturity – W. Andaman Basin

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- Maturity Model for the West Andaman Basin

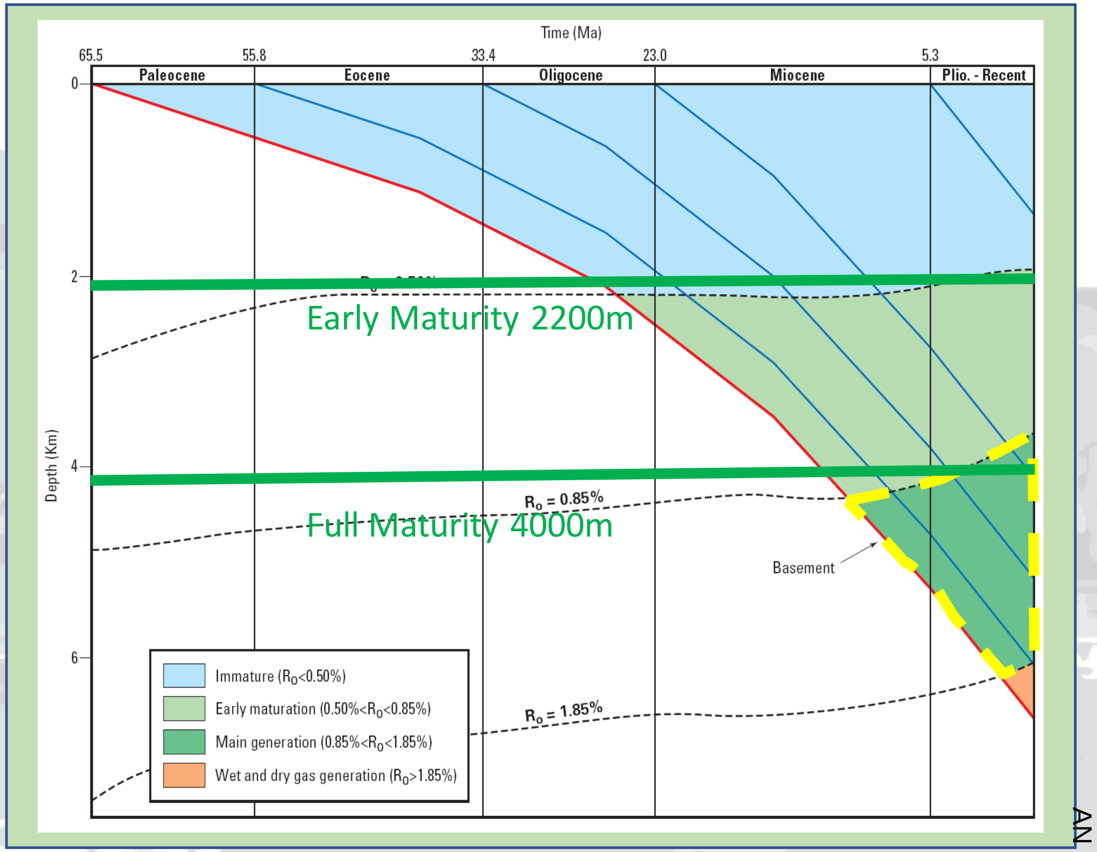
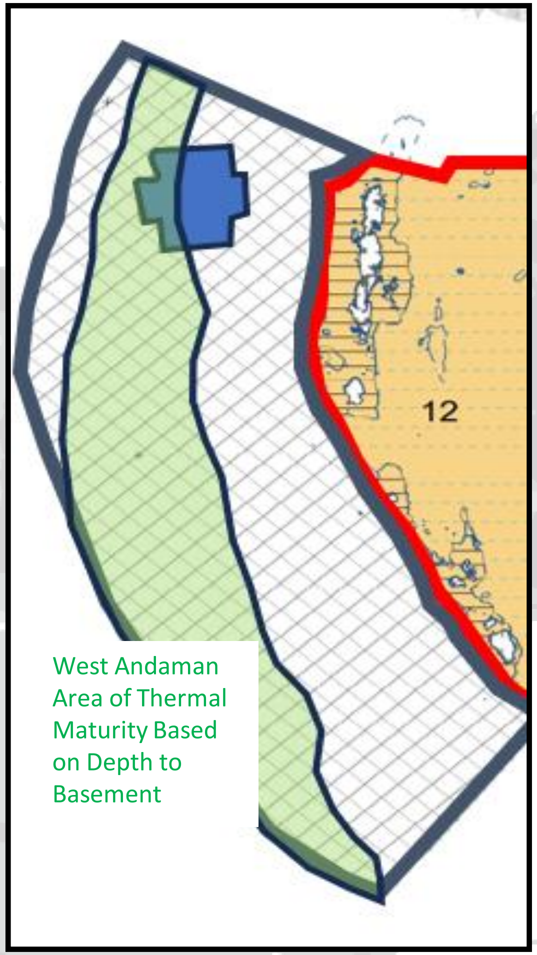
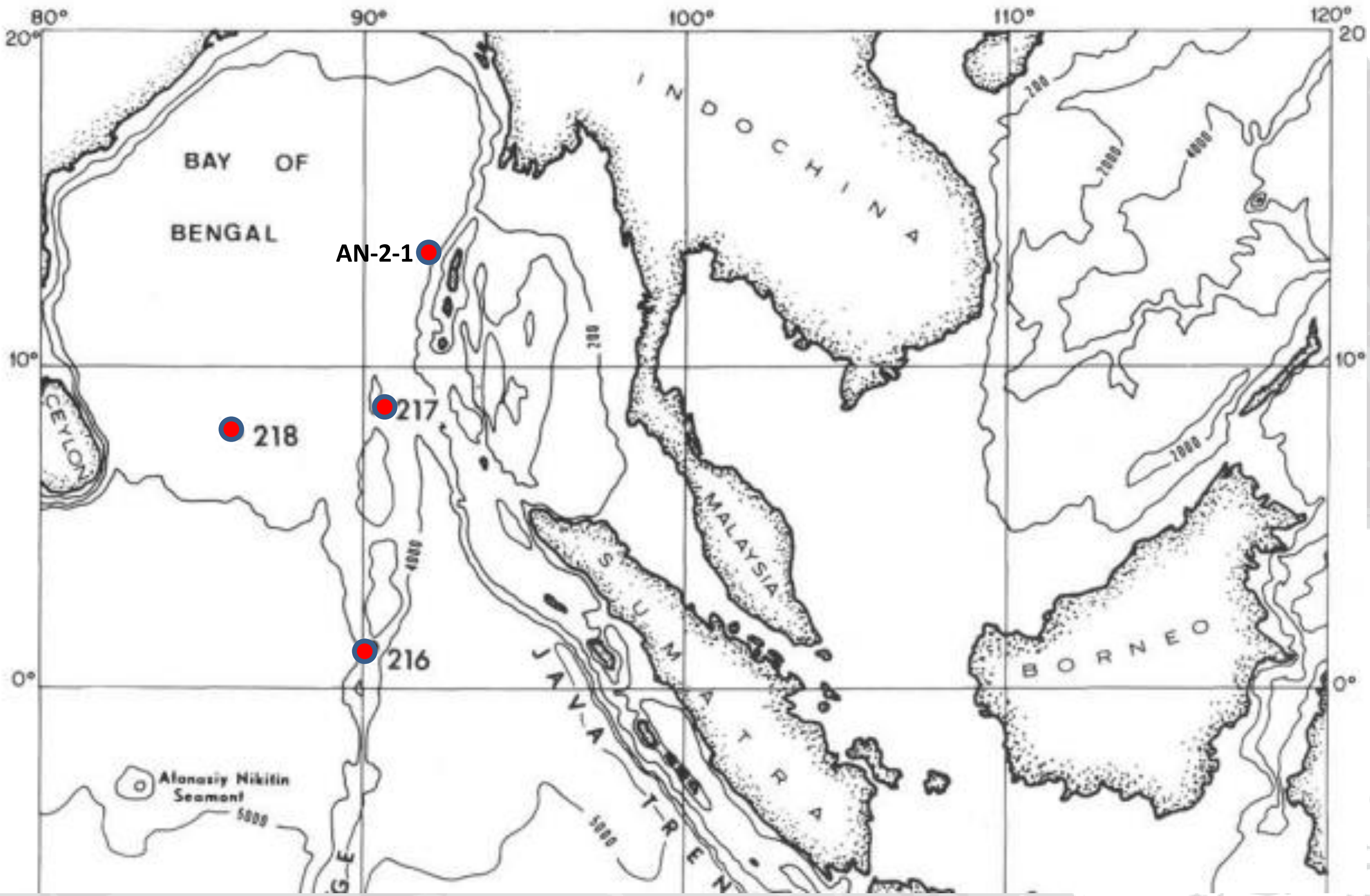


FIG. 58 USING CURIALE'S MODEL FOR BACK-ARC EXTENSION AND AN ESTIMATION OF GEOTHERMAL GRADIENT



Reservoir West Andaman

- There are no wells drilled in the West Andaman Basin
- There are three DSDP wells drilled in the Bay of Bengal
- DSDP 217 is the closest to the Andaman Basin
- The Well AN-2-1 is located west of Andaman Island, but East of the Sunda Subduction Zone and hence is on the Asian Tectonic Plate.



Reservoir West Andaman

- AN-2-1 was drilled to 4088m in the Cretaceous.
- Cretaceous Sandstones, Cretaceous to Eocene carbonates and Miocene to Pliocene sandstones (Turbidites) are potentail reservoir targets.

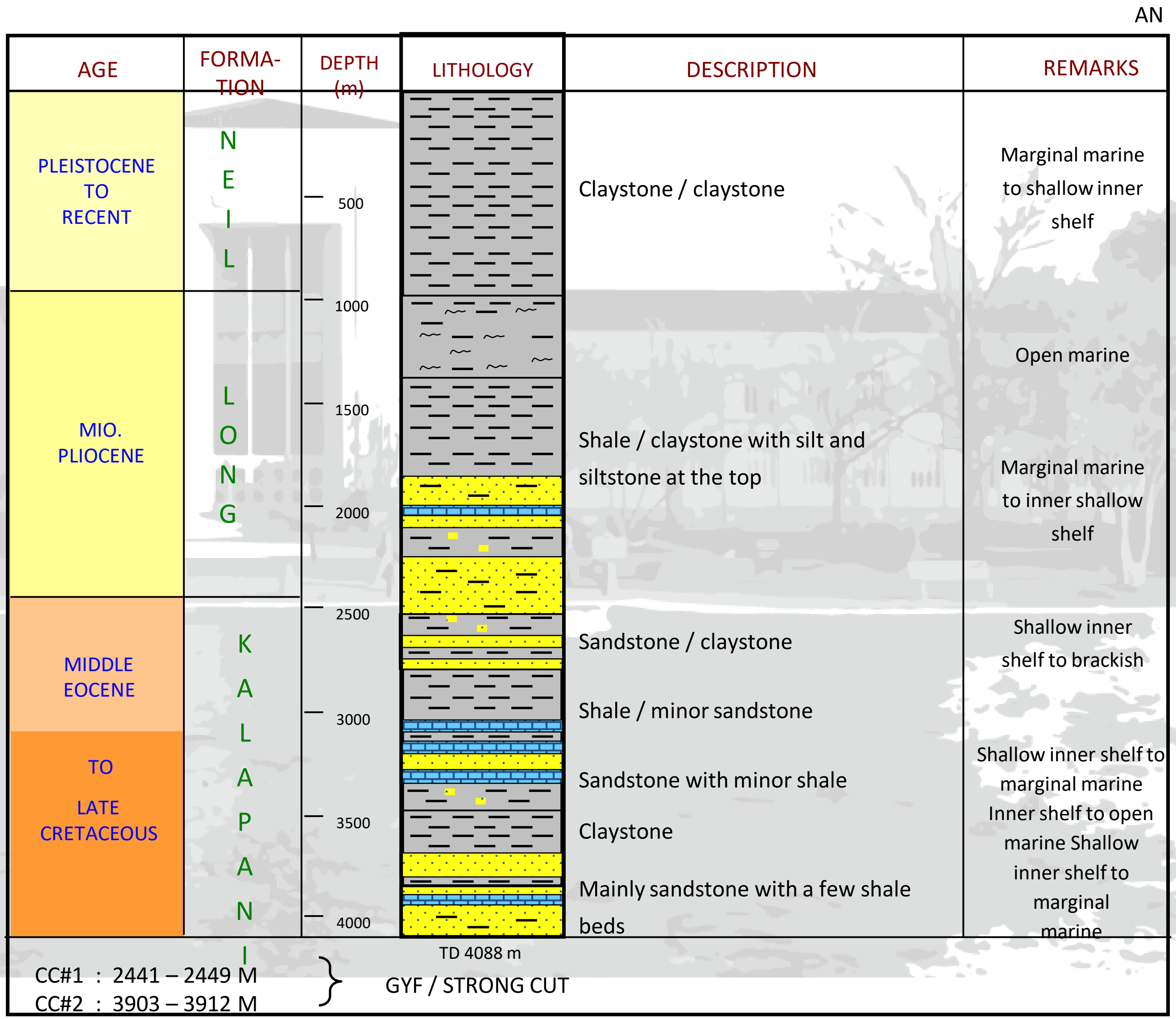
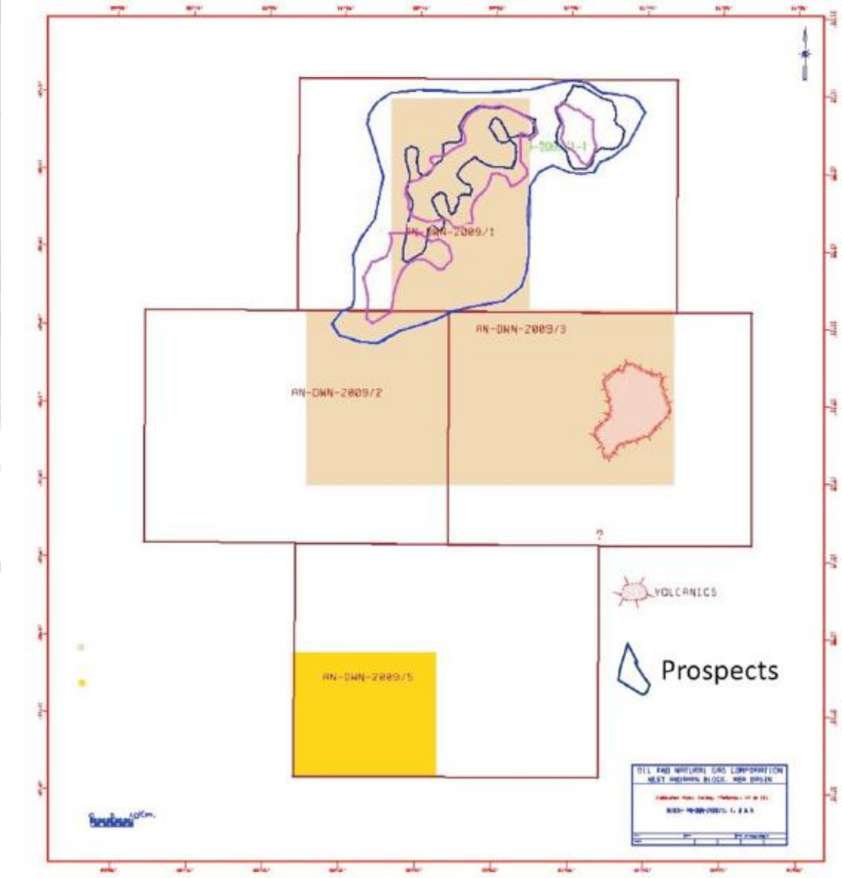


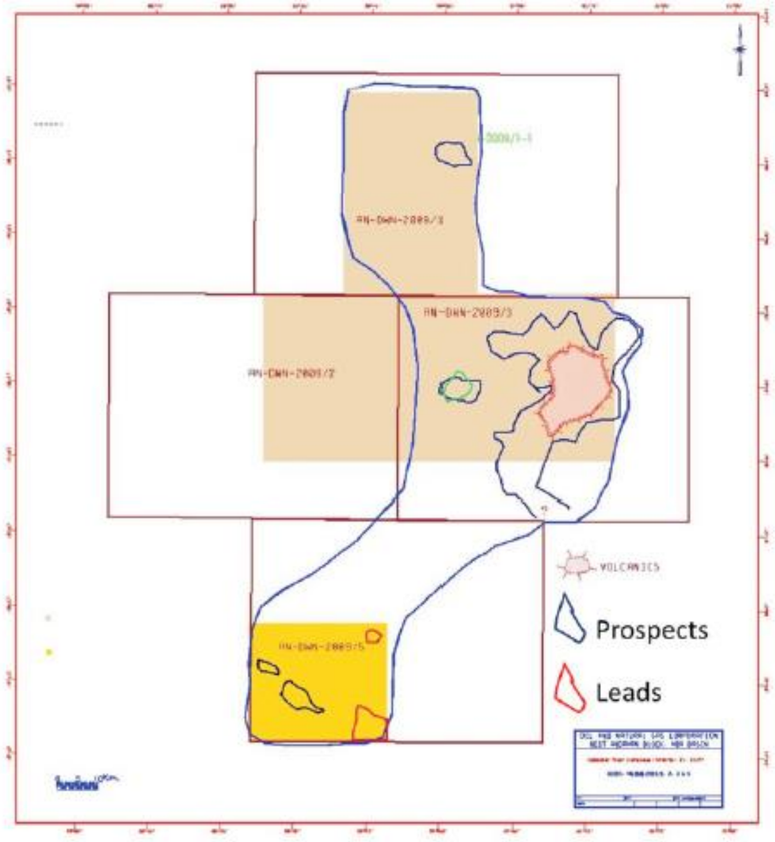
FIG. 25 LITHOSTRATIGRAPHIC COLUMN OF WELL AN-2-1

Traps and Prospects – West Andaman

- Based on seismic modelling Play fairways have been defined for the Cretaceous and Tertiary



ig. 4.1.1.18: Map showing the available prospects for Tertiary Play



g. 4.1.1.17: Map showing the available prospects and leads for Cretaceous Play

West Andaman Resource Potential

- Using the aerial yield method undiscovered resources were determined for the West Andaman Basin
- A resource of 12.26 MMTOE (90M BL OIL) has been calculated for the West Andaman

Plays	H=G1+G2+G3+G4 Total known traps in assesment	I=G2+G3 Total known leads and prospects	J=F-H Postulated prospects in assesment unit.	K=I+J Total undrilled future prospects	L Future success rate	M=LxK Future fields	N Future field size	O=MxN Undiscovered resource (Play Chance 1)	P AU COS	Q=OxP Undiscovered resource (MMOMOE)	Undiscovered resource Play (MMTOE)
Teriary	2	2	1.44	3.44	0.1	0.34	21.32	7.34	0.256	1.88	1.69
Cretaceous	5	5	3.61	8.61	0.1	0.86	50.71	43.67	0.2688	11.74	10.56
									TOTAL	13.62	12.25654452

Table 4.1.1.1b. Calculation of Undiscovered Resources

Mahanadi Basin

MAHANADI / BENGAL BASINS – Well Penetrations

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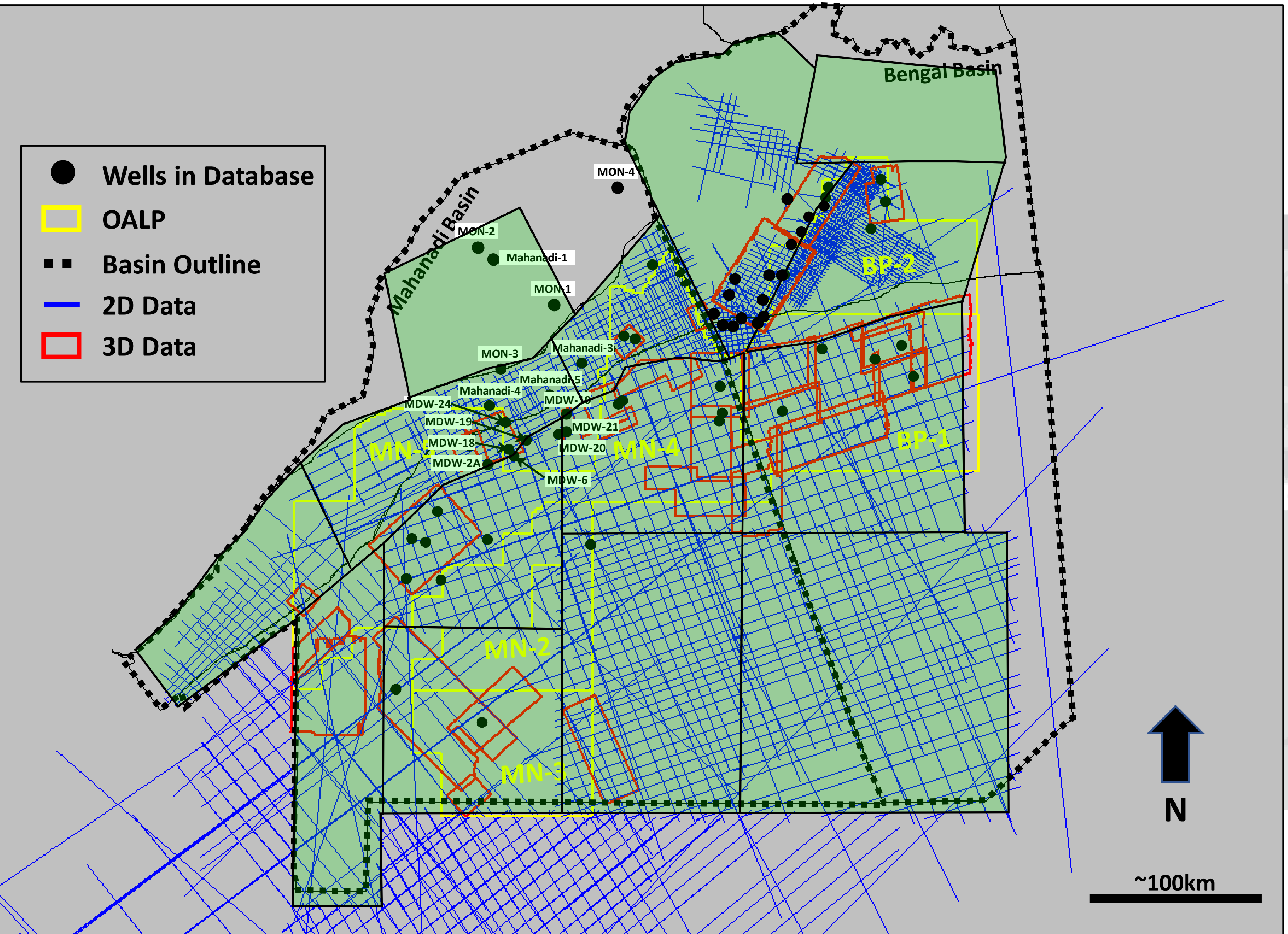

Mahanadi: Geological Setting / Litho-stratigraphic Column

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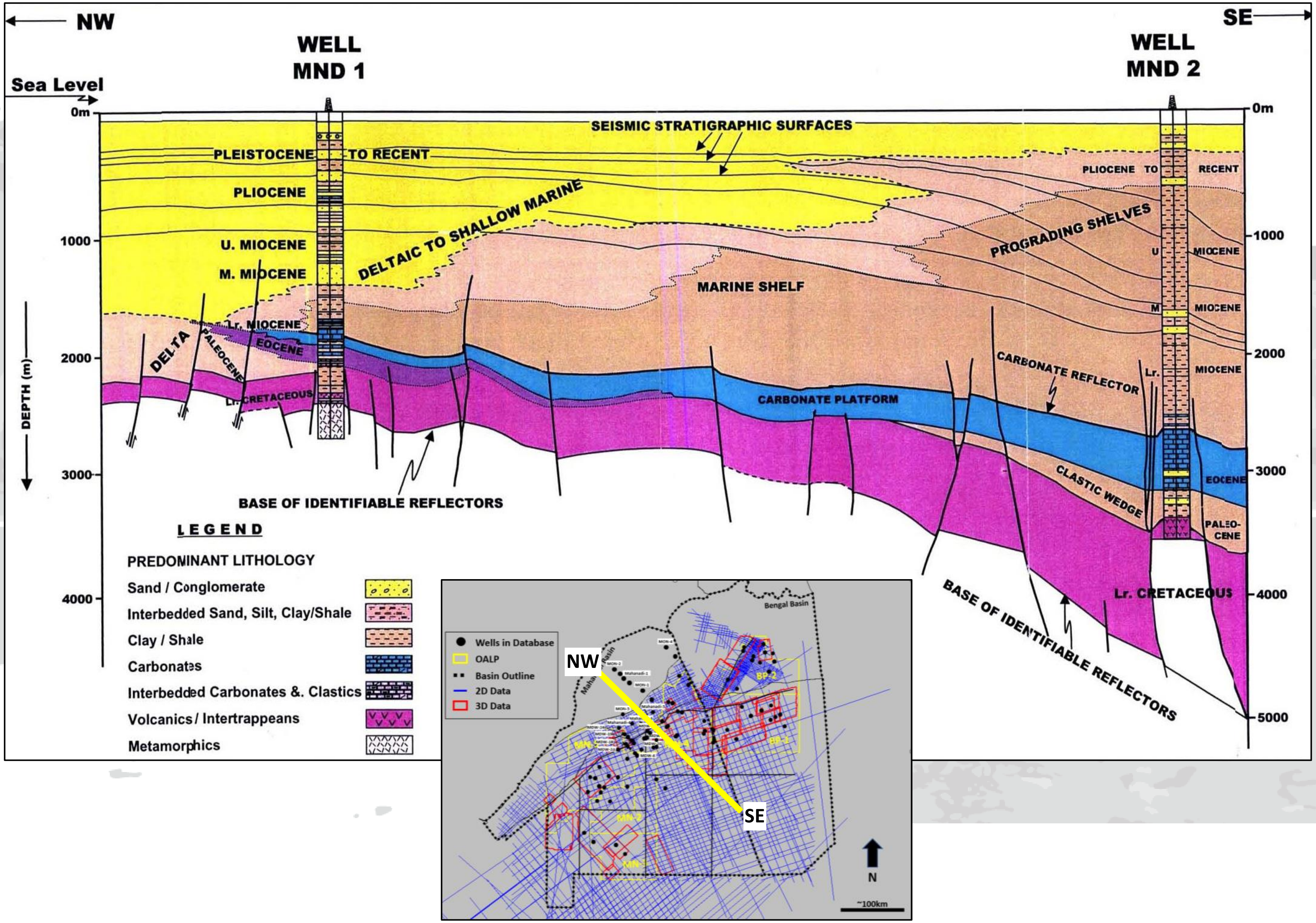
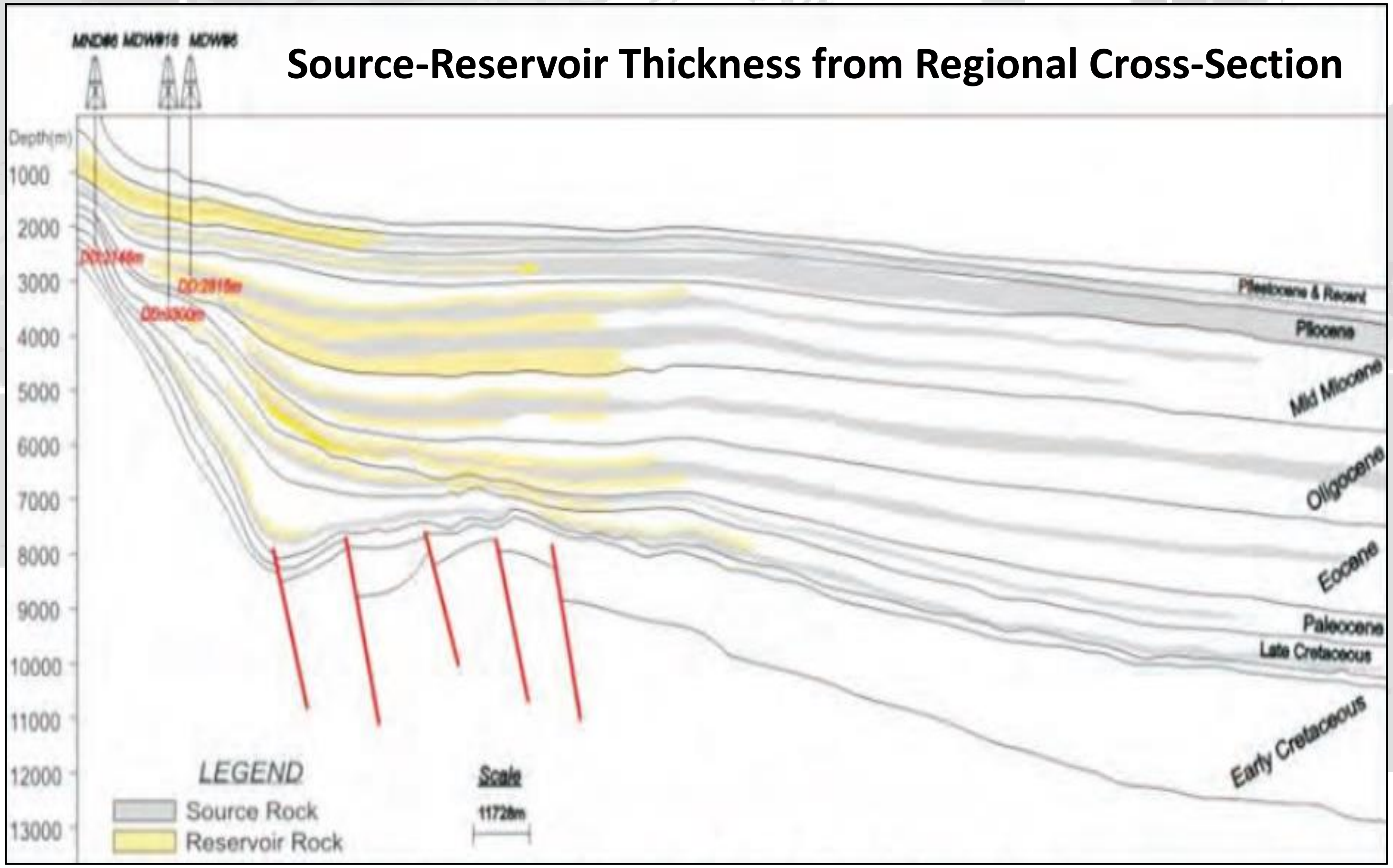
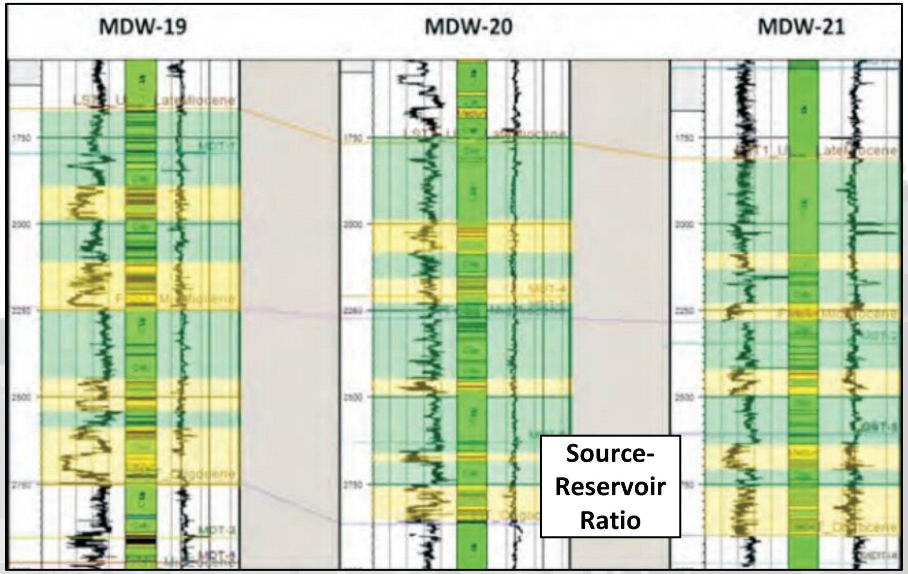


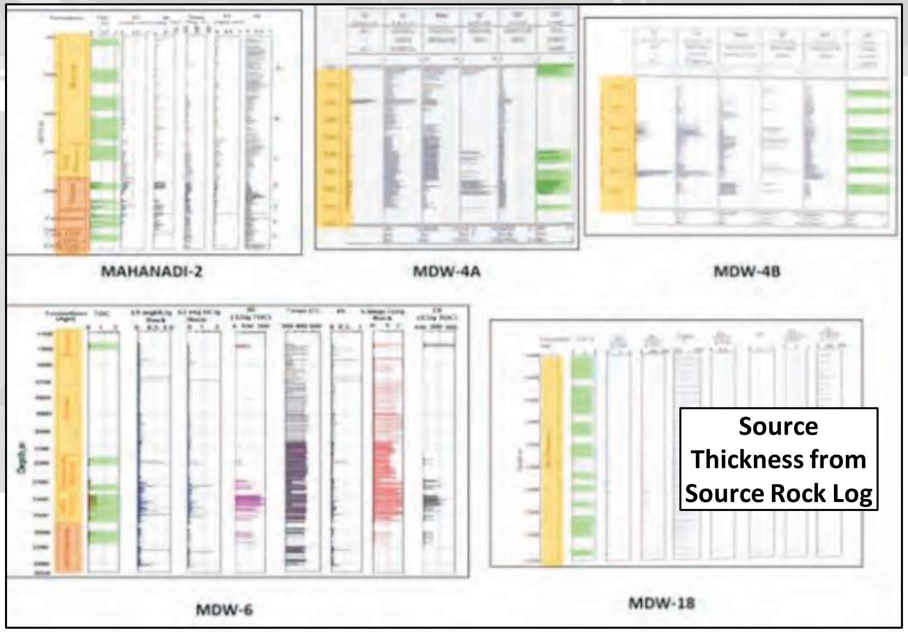
Age	LITHOLOGY	EOD	THICKNESS (m)
Pleist-Recent	Sands, clays and silts	Deltaic to shallow marine	200-600
Pliocene	Sands and clays	Prodelta to marine	200-700
Miocene	Claystones, siltstones, sandstones, fossiliferous patchy limestones in lower part	Deltaic to open marine	600-1900
E-M Eocene	Fossiliferous limestones, carbonaceous shales, siltstones and sandstones	Shallow marine (inner shelf)	200-400
Paleoc.	Argillaceous limestones, shales, siltstones and sandstones	Deltaic to shallow marine	50-600
L. Cret.	Mainly sandstones with minor shales and limestones	Shallow marine (shelf)	0-500
E.Cretaceous	Basalts, tuffs and interbedded shales/claystone	Sub-aerial and sub-aqueous	25-850
Pre-Camb.	Granite and gneisses (Basement Complex)		

Mahanadi: Hydrocarbon Source

- In the Mahanadi Basin numerous source rock facies have been identified
- Source Thickness from Source Rock Log
  - Mahanadi -2, MDW-4A, MDW-4B, MDW-6, MDW-18
- Example Source-Reservoir Ratio in Mio-Pliocene
  - MDW-19, MDW-20, MDW-21







Mahanadi: Total Organic Carbon (TOC)

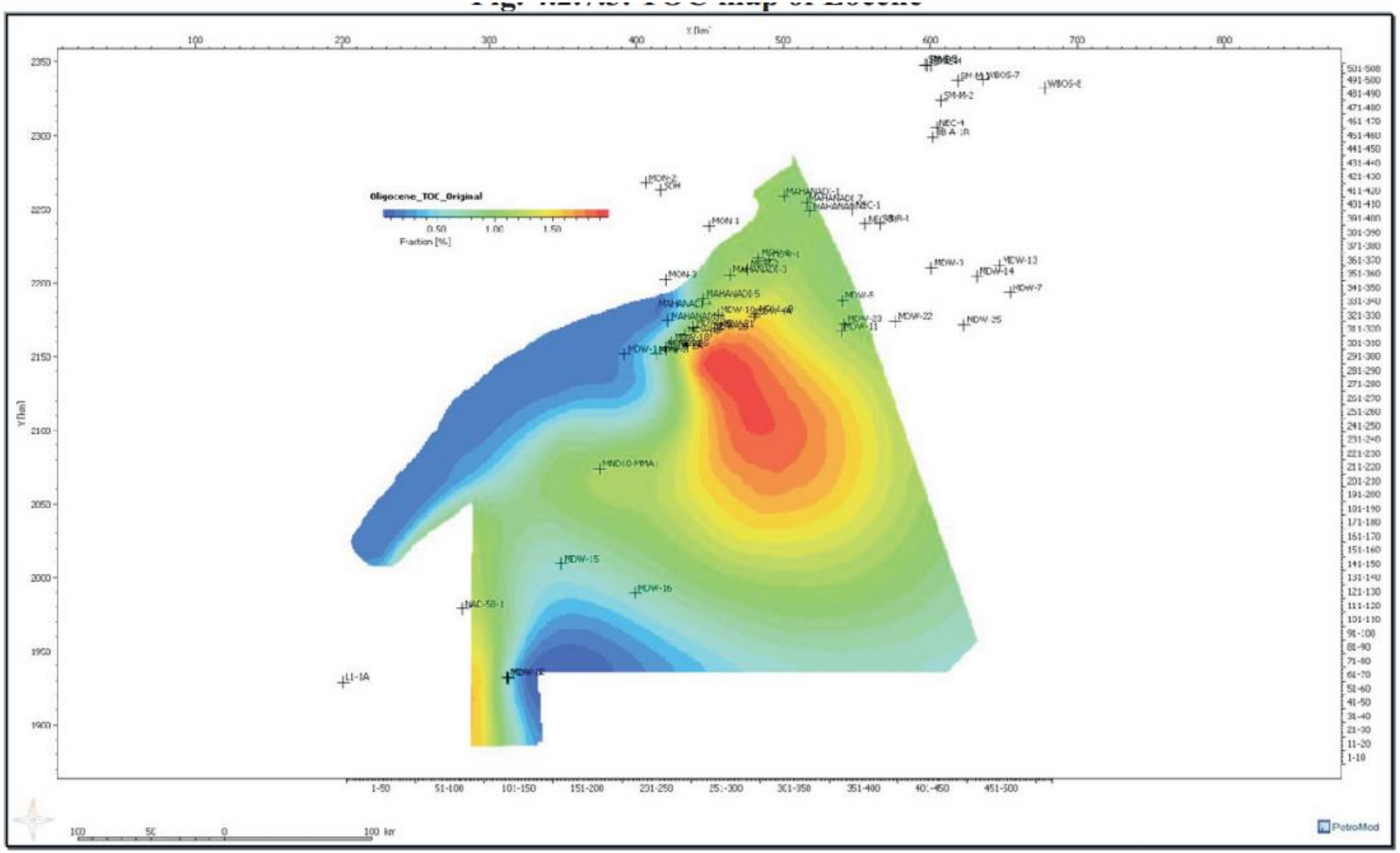


Fig. 4.2.7.4. TOC map of Oligocene

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Mahanadi: Maturation

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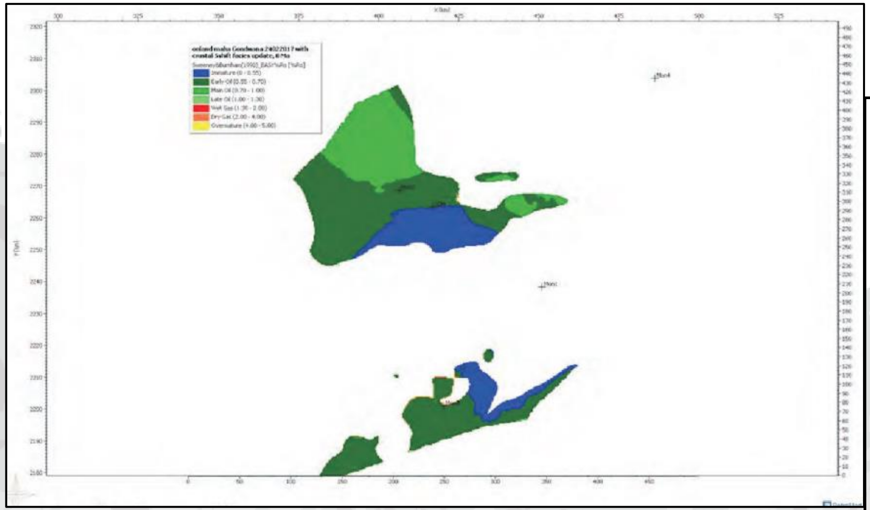


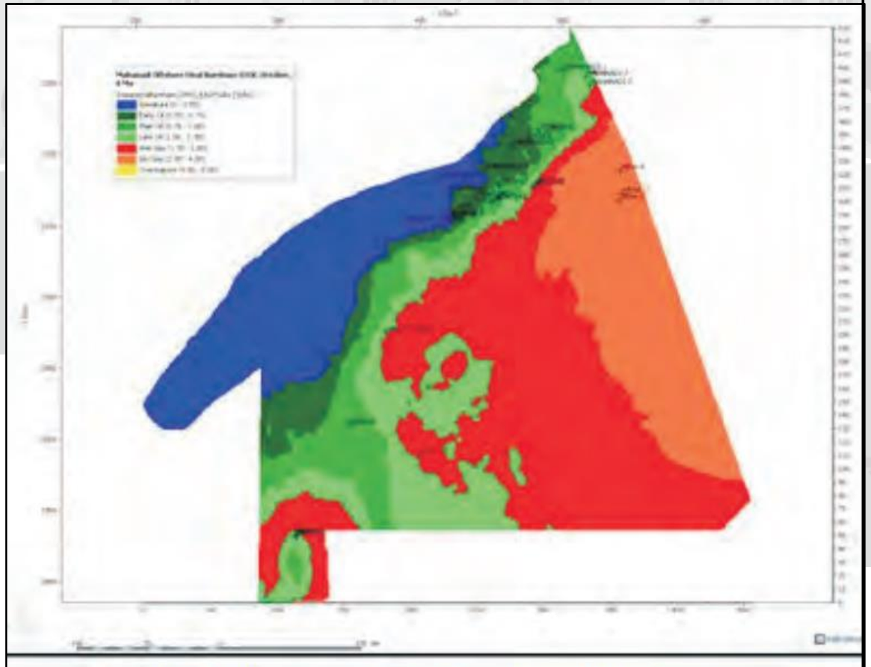
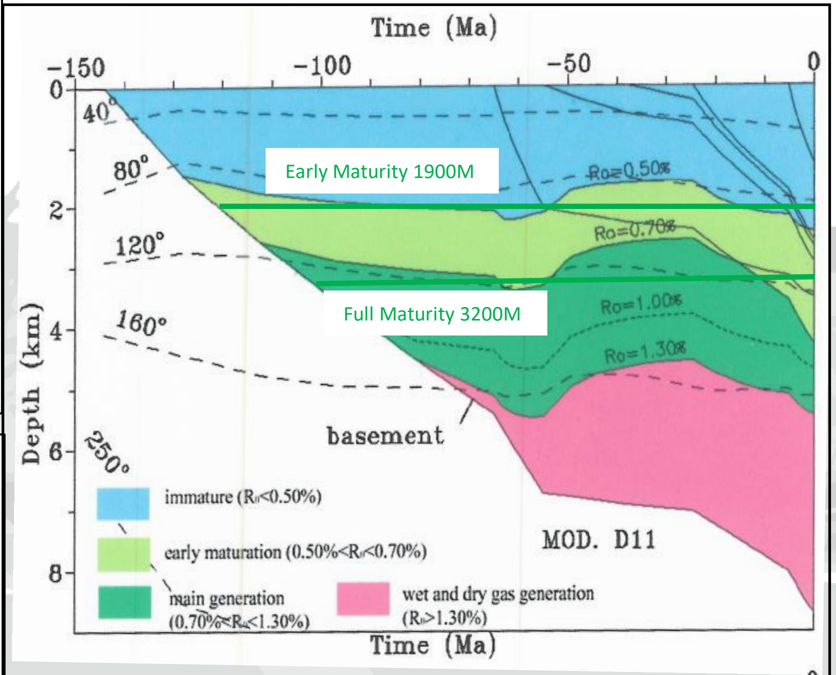
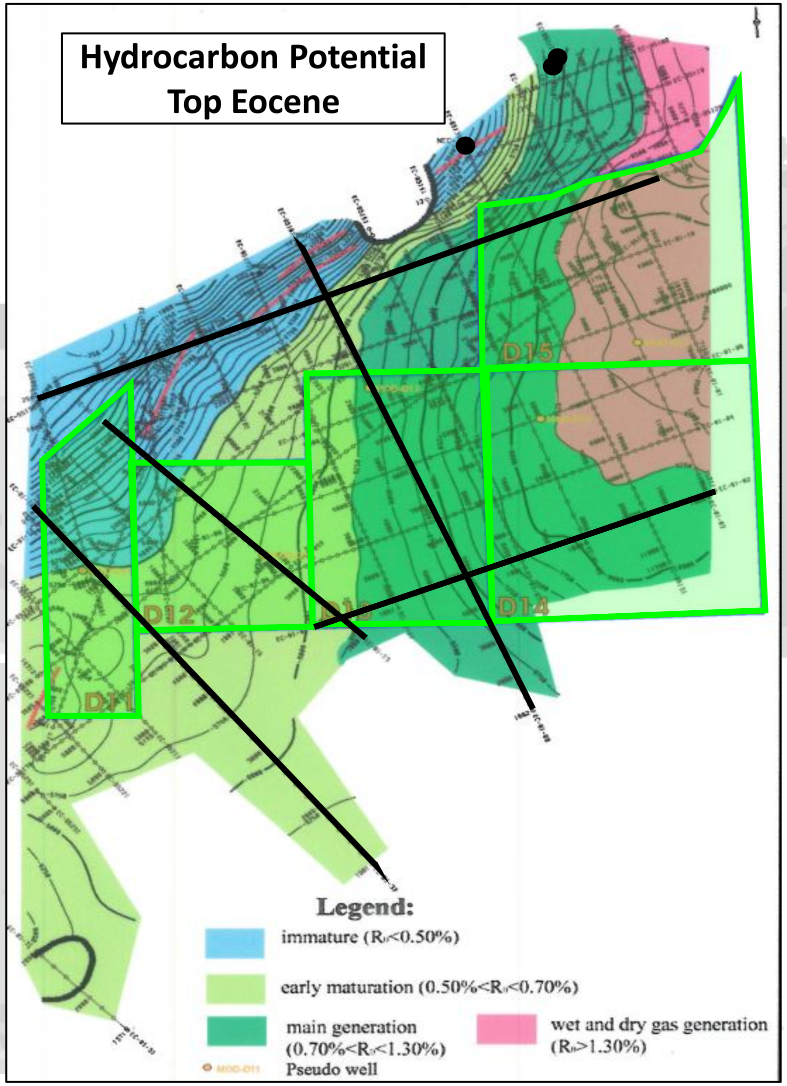


Fig. 4.3.7.5. Sweeney & Burnham Easy Ro% - Eocene





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Mahanadi: Reservoir

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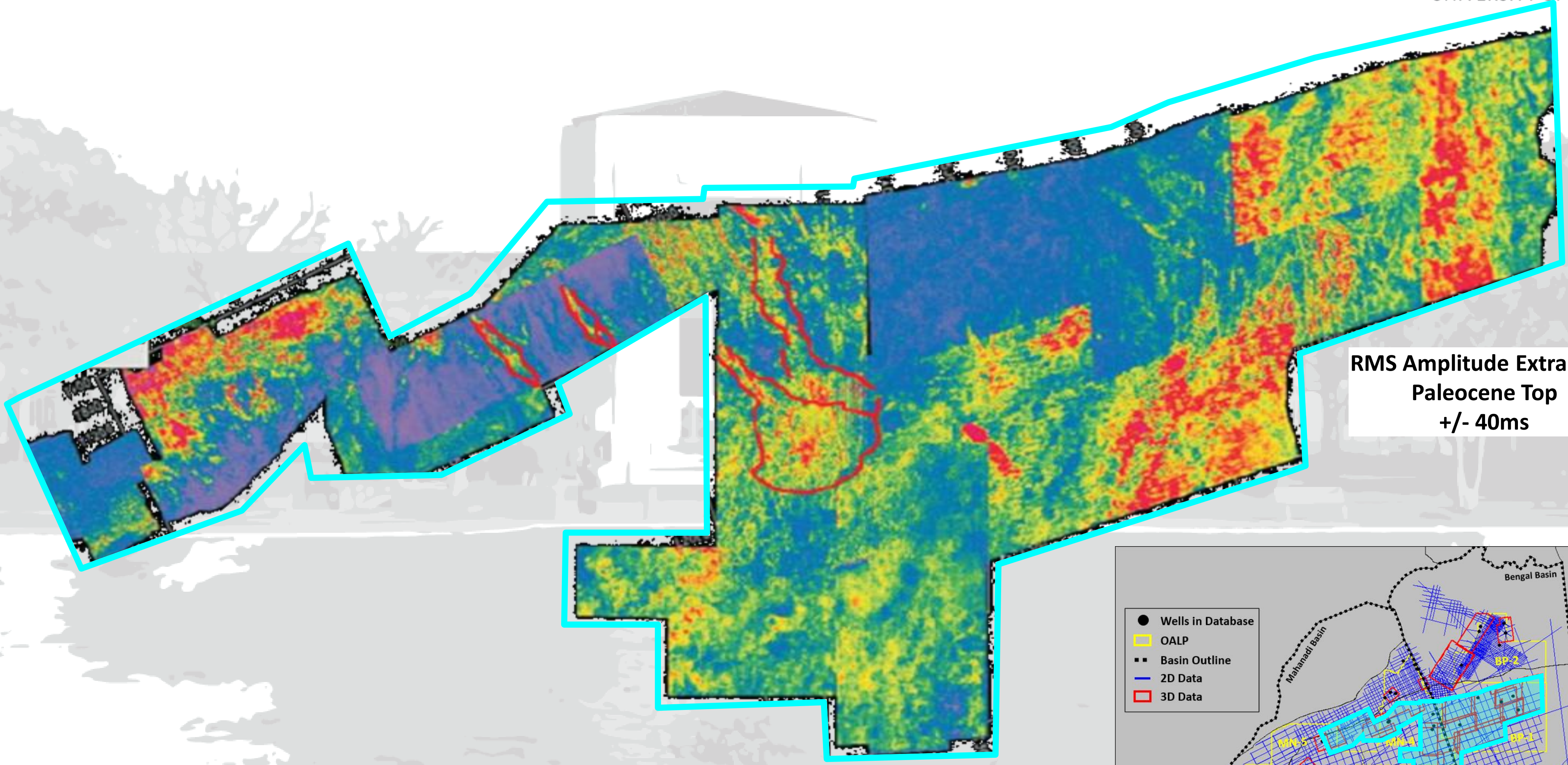
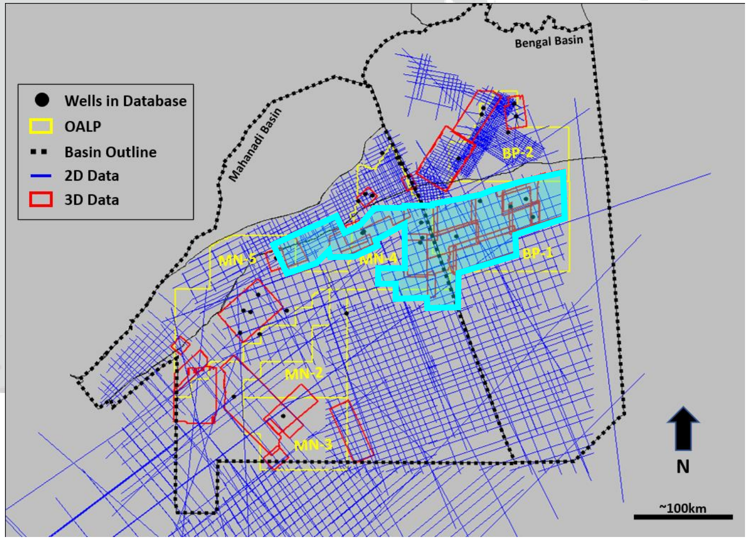
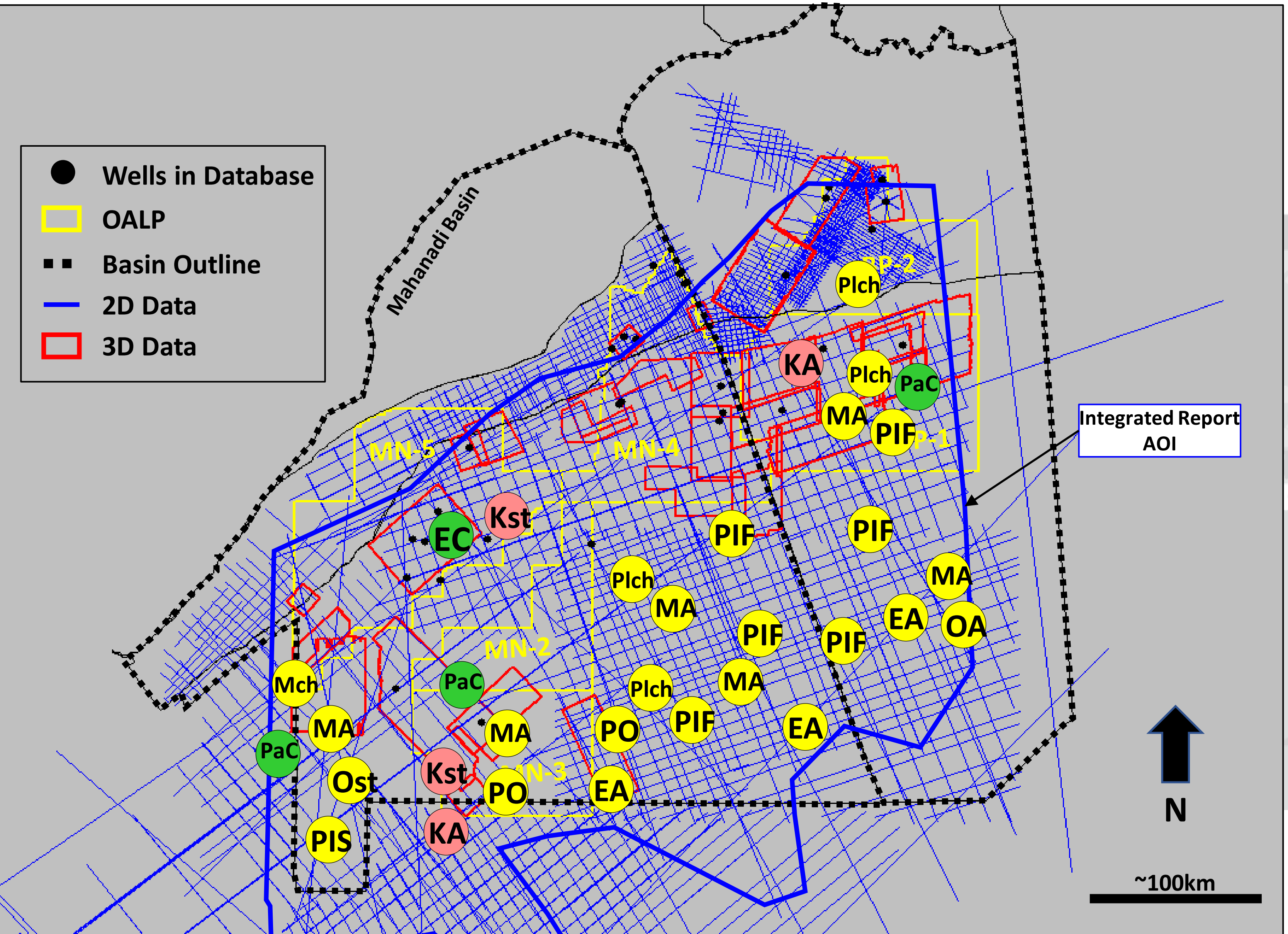
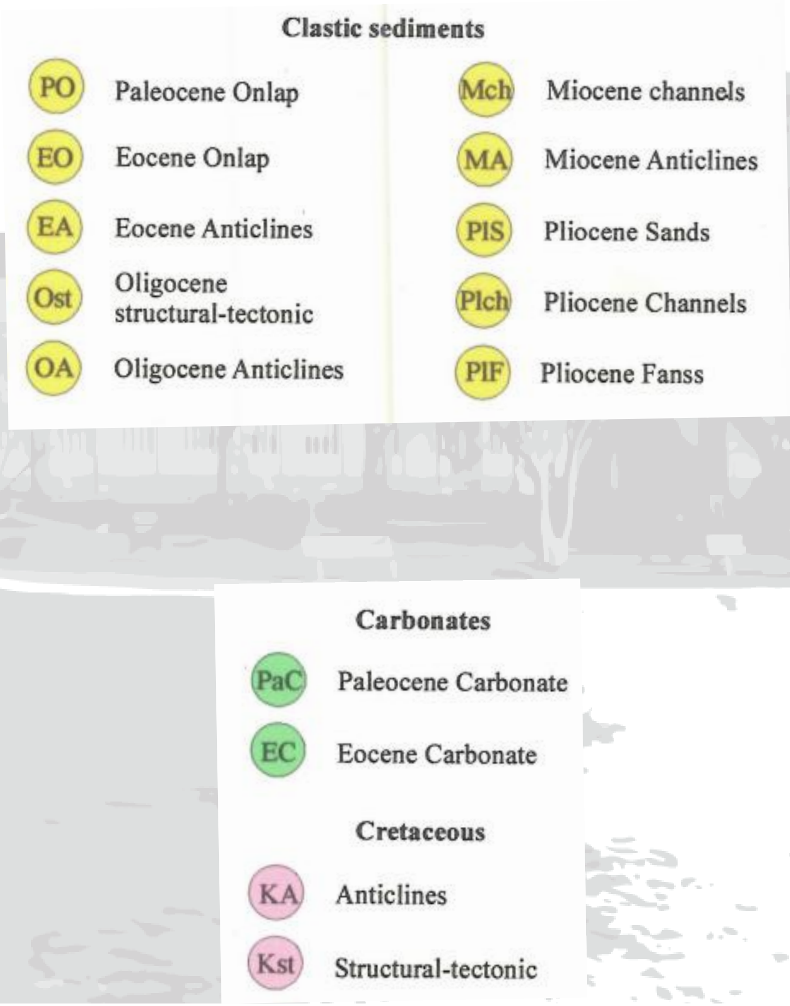


RMS Amplitude Extraction
Paleocene Top
+/- 40ms



Mahanadi: Trap Type





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Seismic Examples: Trap Types

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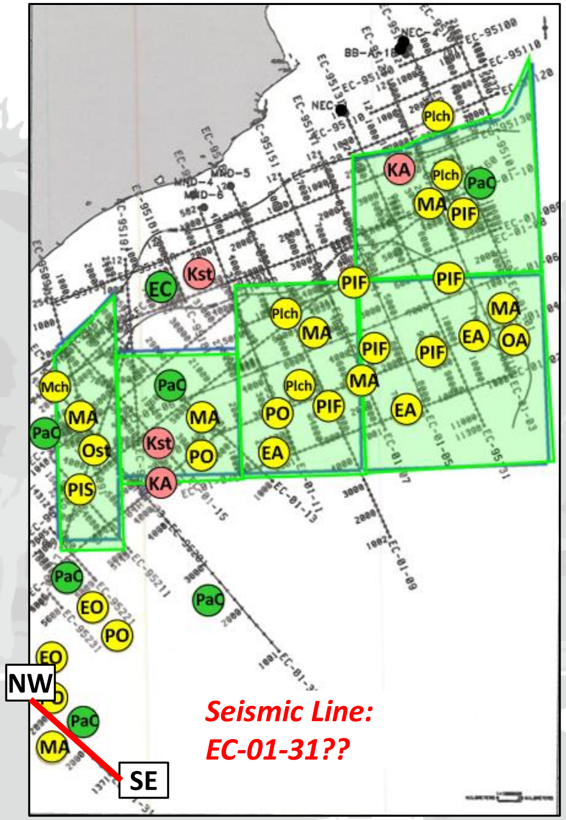
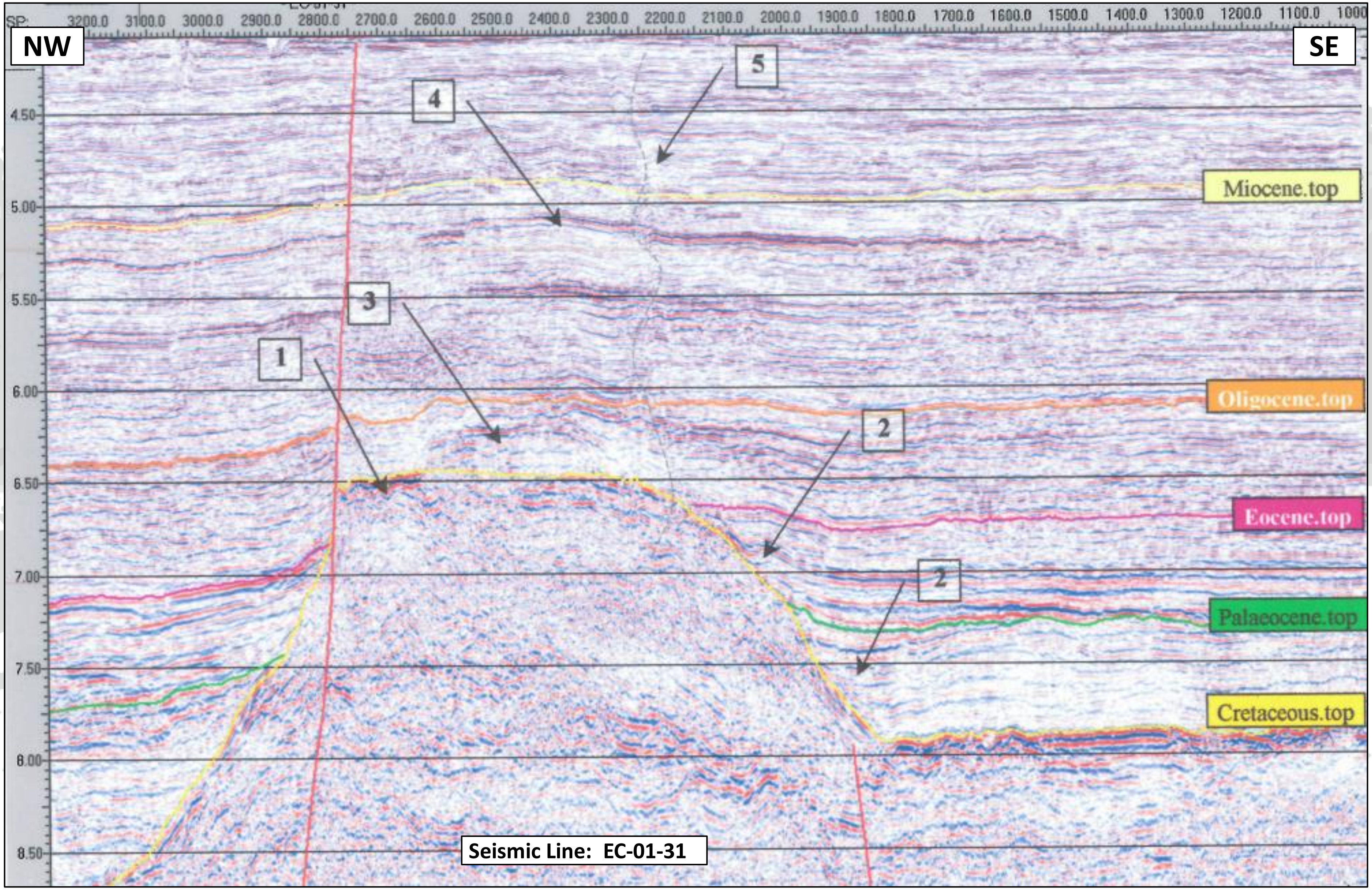


1 Erosional Surface
2 Pinchouts
3 Carbonate Build-up?
4 Bright Spots
5 Gas Chimney



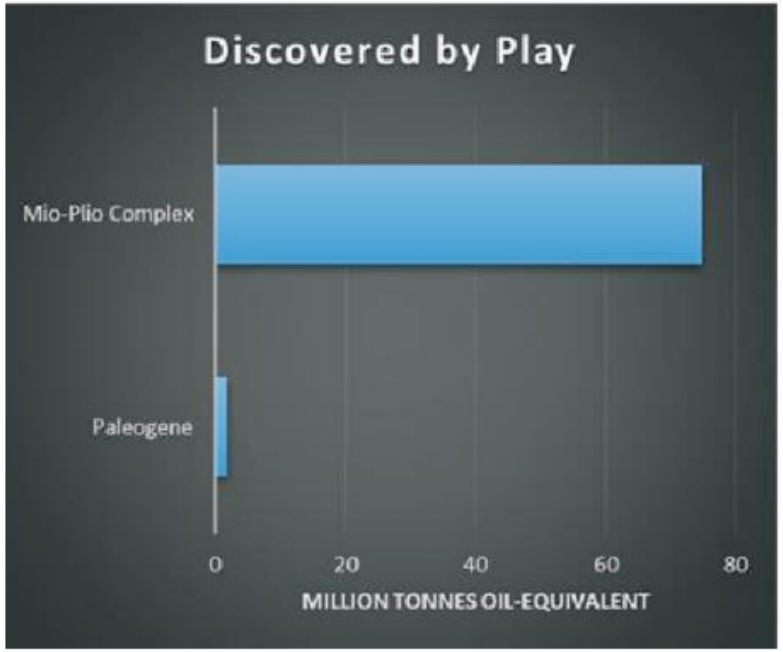
Mahanadi Volumetrics

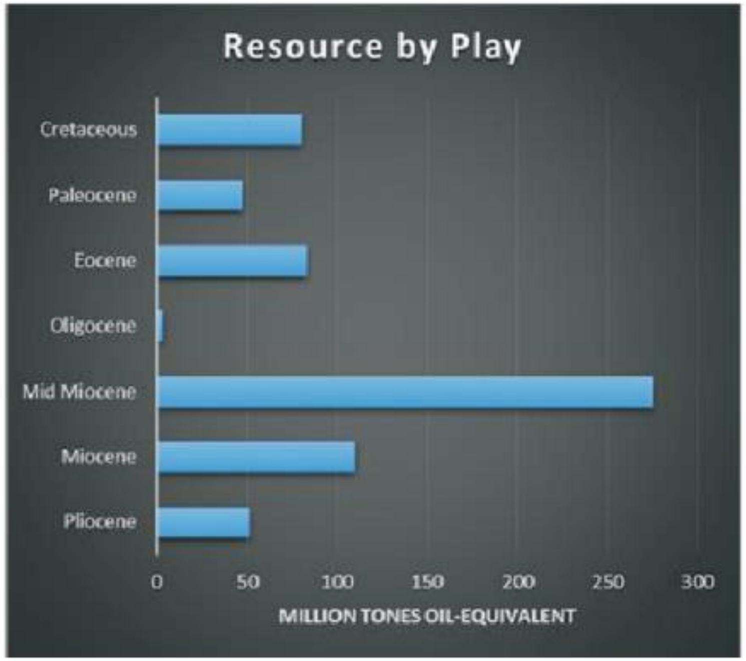
- 574 MMTOE (3.9 BBOE) remain undiscovered
- The Upper Miocene has the potential for 270 MMTOE (1.8 BBOE)

Prognosticated Volumes (In-place MMTOE)

Discovered	Undiscovered	Total
76.6	574	650.6

Proven basin with significant discovered volumes. Significant potential in proven plays. Primarily Biogenic Gas.





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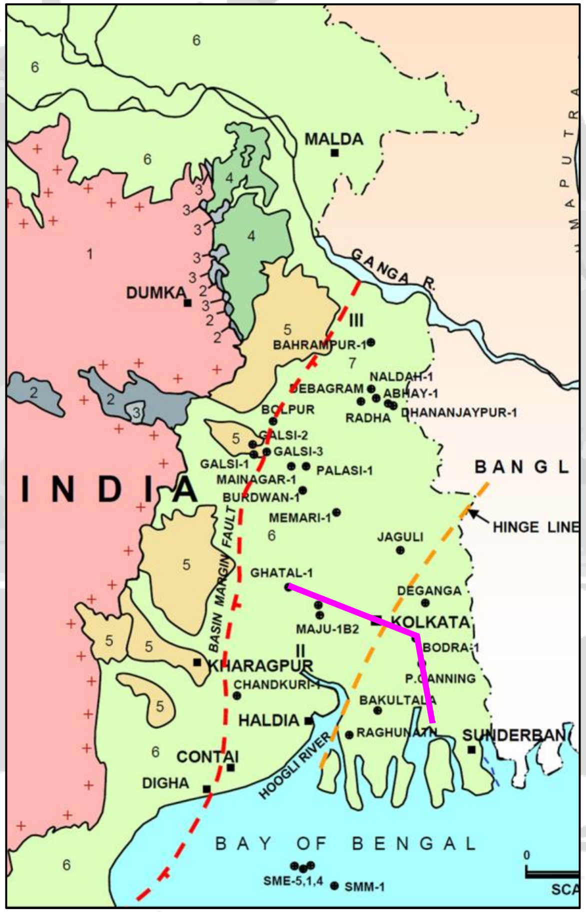
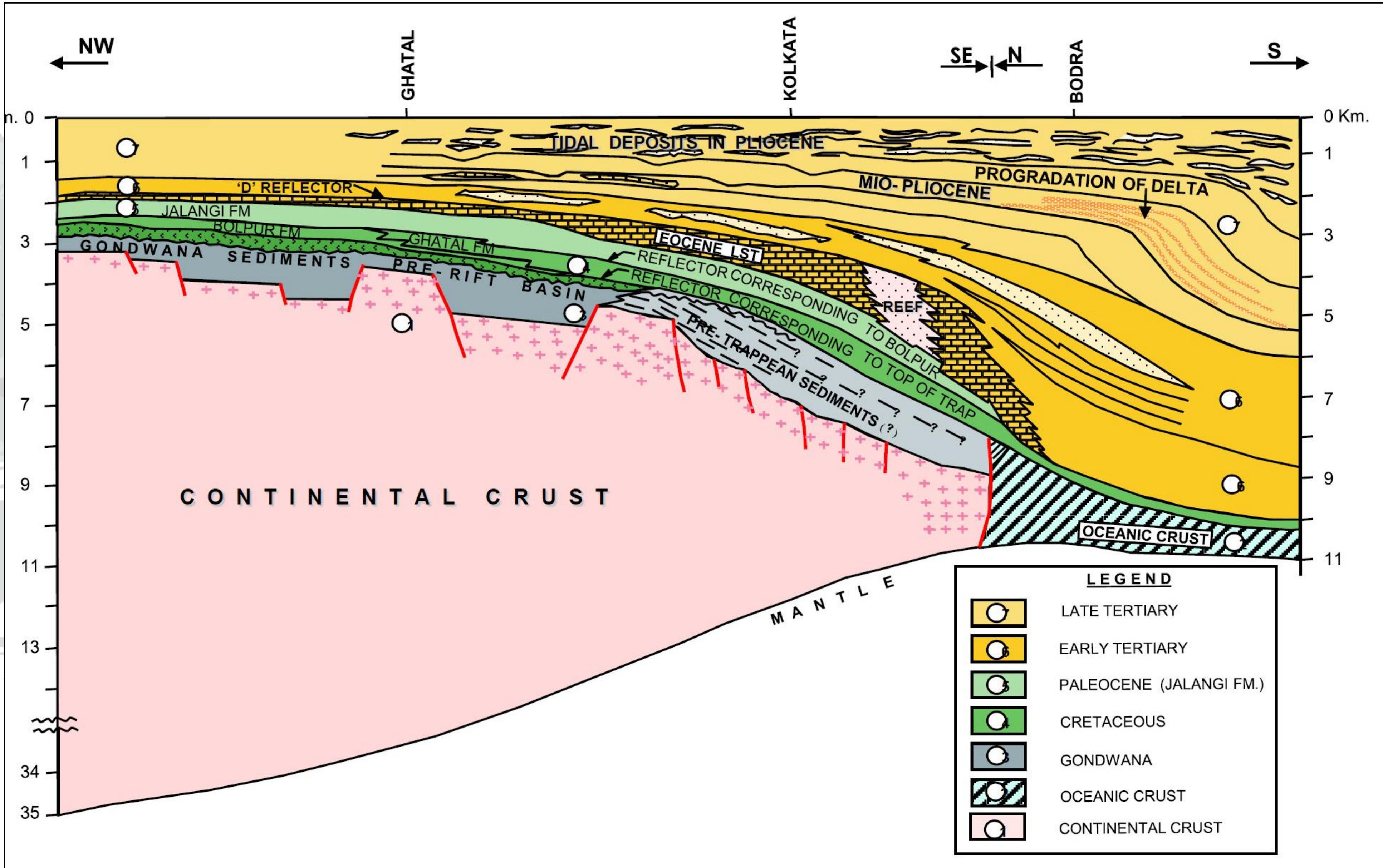
Bengal Basin

Bengal Basin: Schematic Section – Crustal Elements





Bengal: Generalized Stratigraphy

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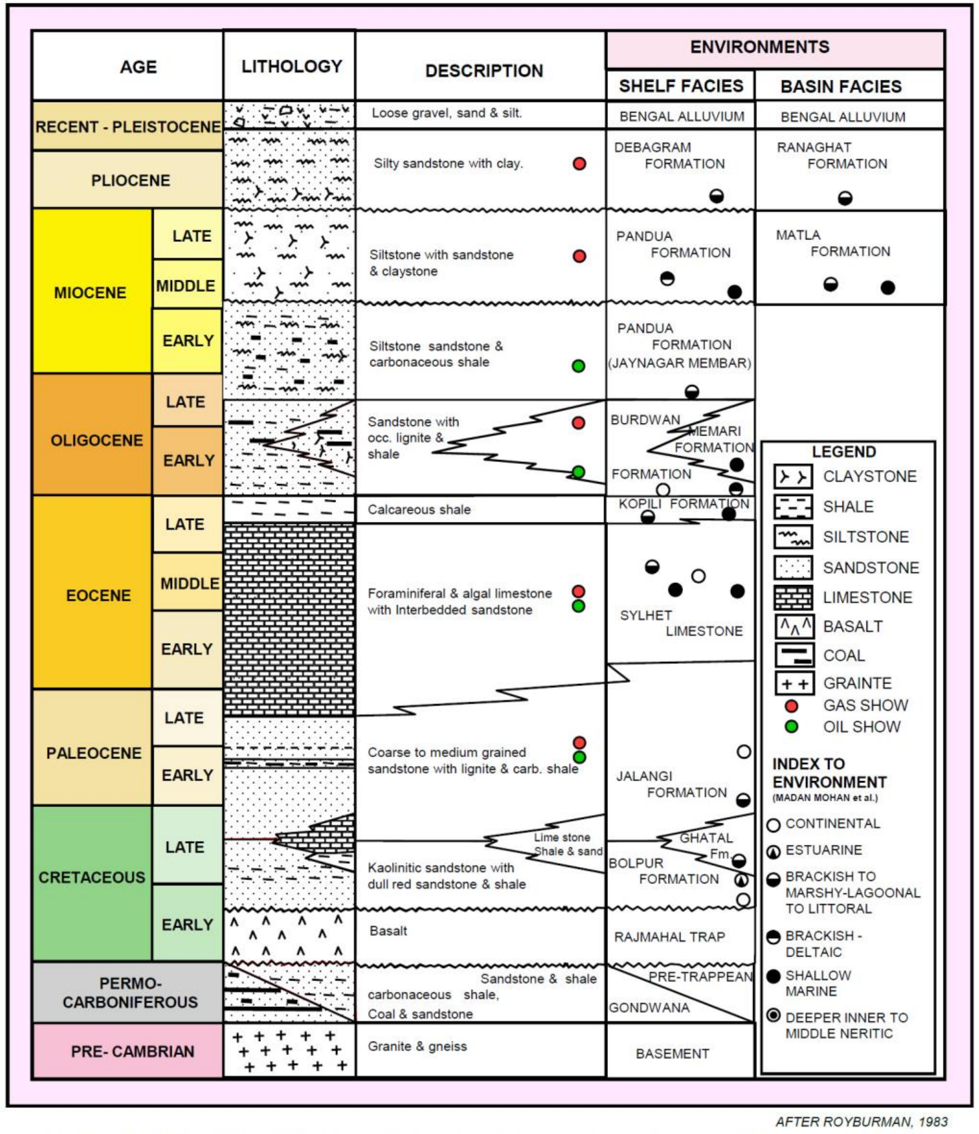


FIG.25 GENERALISED STRATIGRAPHY OF BENGAL BASIN

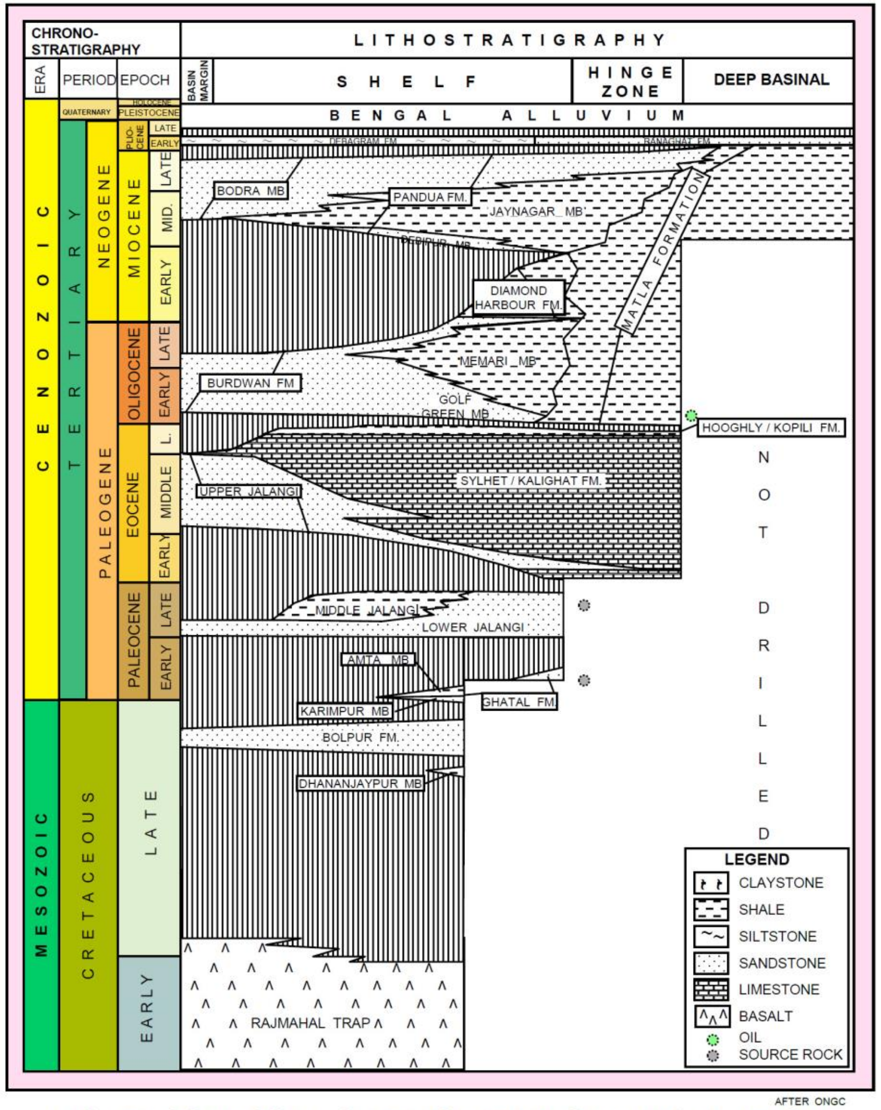
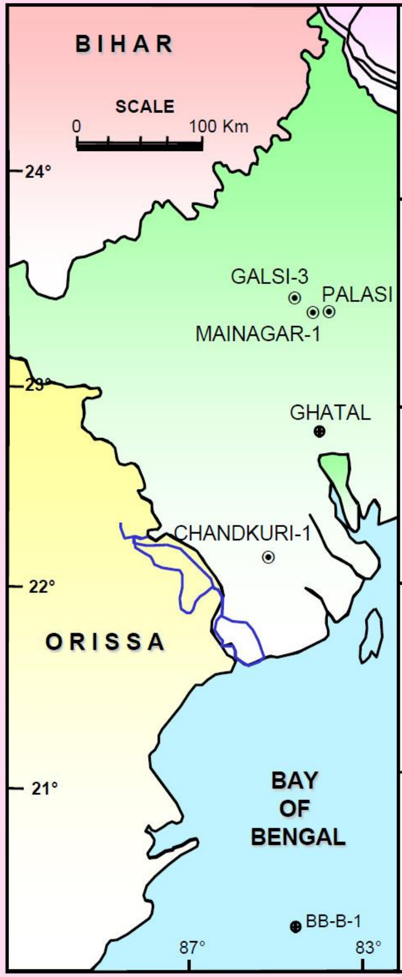


FIG. 24 COMPOSITE STRATIGRAPHY OF BENGAL BASIN

Bengal: Source Rocks



Well Nos.	TOC%	S_2 Mgm/gm Of rock	HI Mgm/gm Corg	VRo % Maturity
Galsi-3 III *	0.04 – 11.36 Average: 2.17	–	–	0.47 – 0.51 (early phase) 2.98-3.27 (Section intruded by dolerite)
Mainagar-1 III *	0.55 – 39.51 Average: 14.76	1.56-37.88	9-160	1.02 – 3.29 (Section intruded by dolerite)
Palasi – 1 III *	6.01 – 42.96 Average: 17.96	0.6 – 90.59	11 - 153	1.35 – 3.29 (Section intruded by dolerite)
Chandkuri – 1 III+II *	0.3 – 30.19 Average: 10.31	0.08 – 95.12	103 - 561	0.65 – 0.81

* KEROGENE TYPE

FIG. 35 SOURCE ROCK DATA OF LOWER GONDWANA, BENGAL BASIN

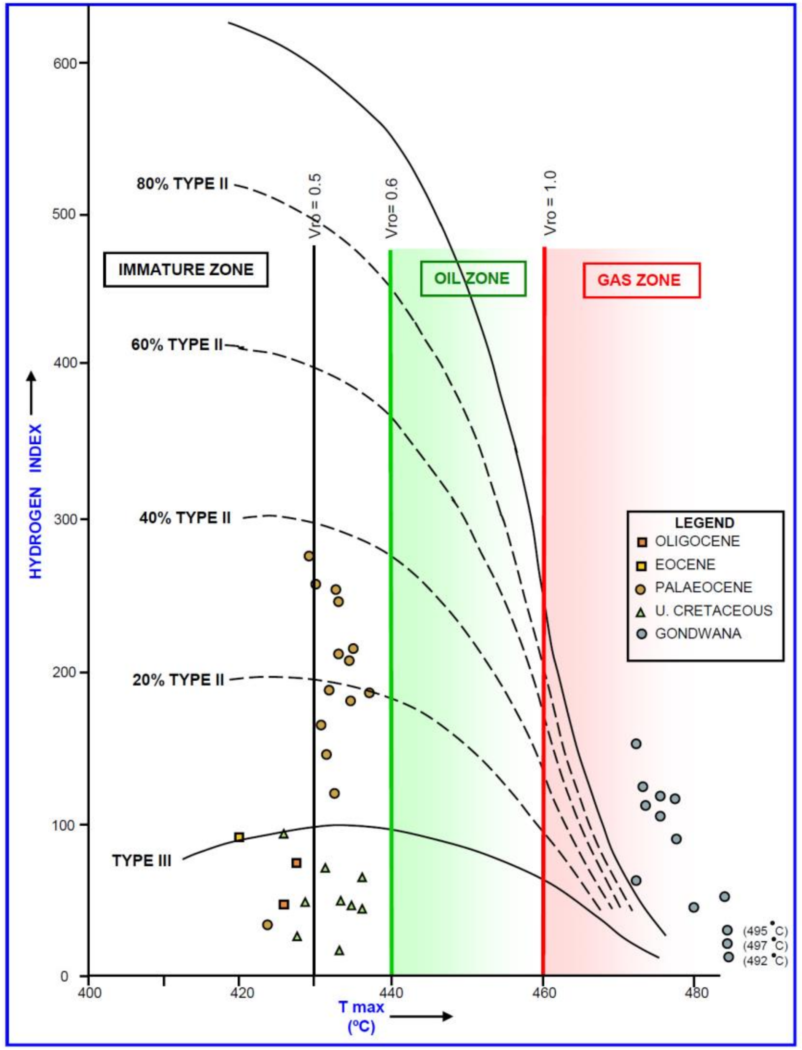


FIG. 36 CROSS PLOT OF HI Vs. Tmax OF PALASI – 1, BENGAL BASIN

Bengal: Total Organic Carbon (TOC)

4.2.7 Source Facies Maps

TOC of Source rock:

The generated TOC which are used in map/3D model input maps are given below as figs. 4.2.7.1 -4.2.7.4

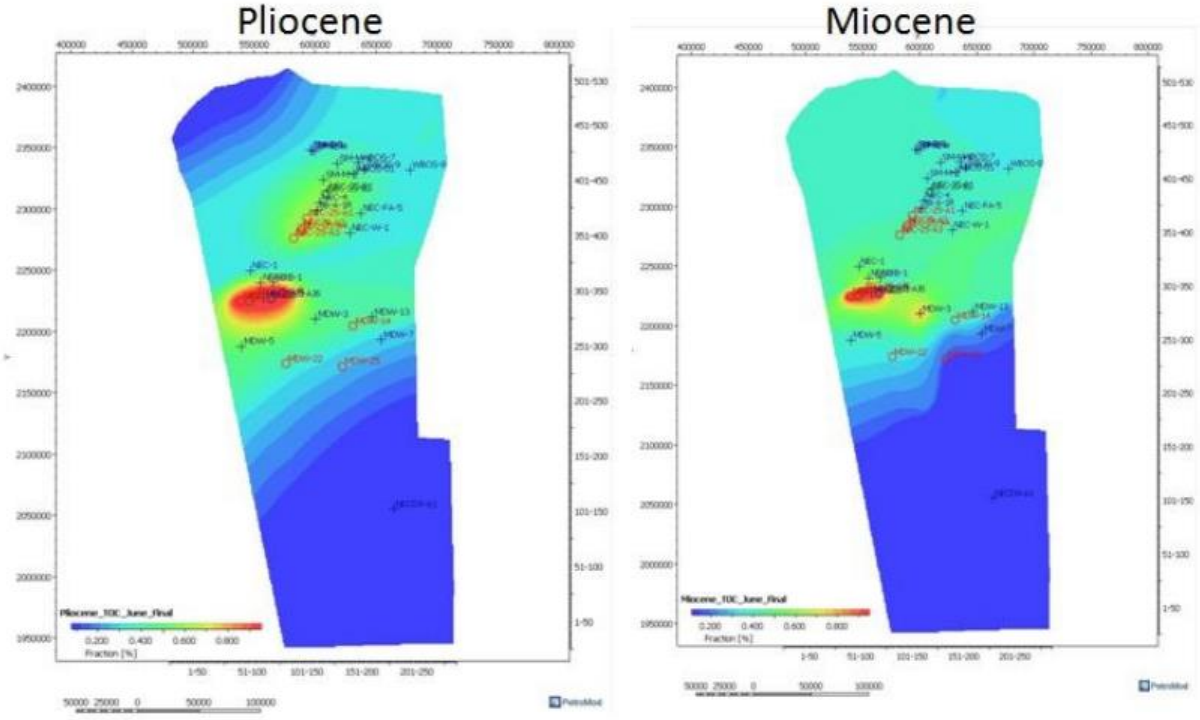


Fig 4.2.7.1: TOC map of Pliocene & Miocene sequence

Bengal: Maturation

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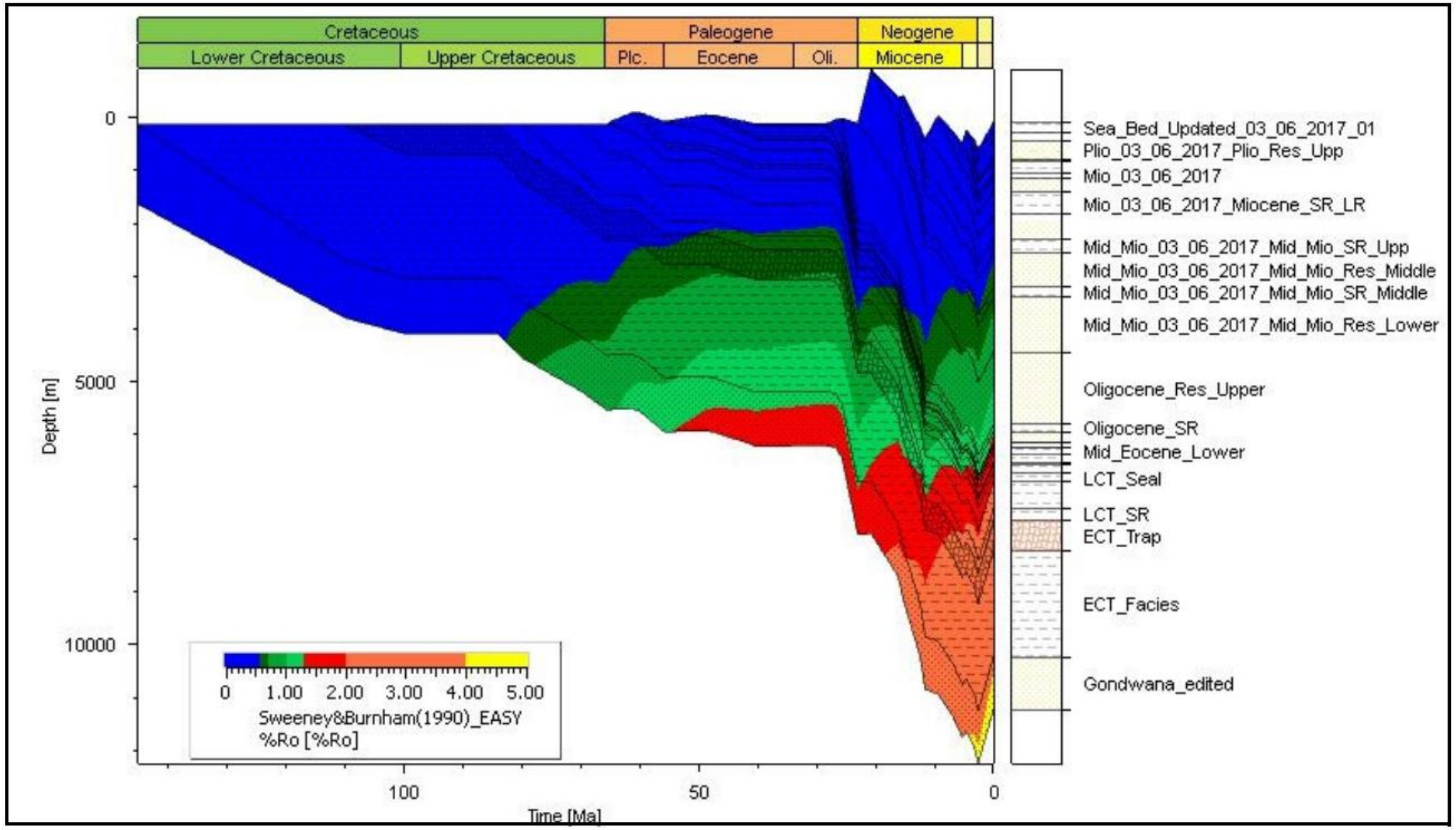
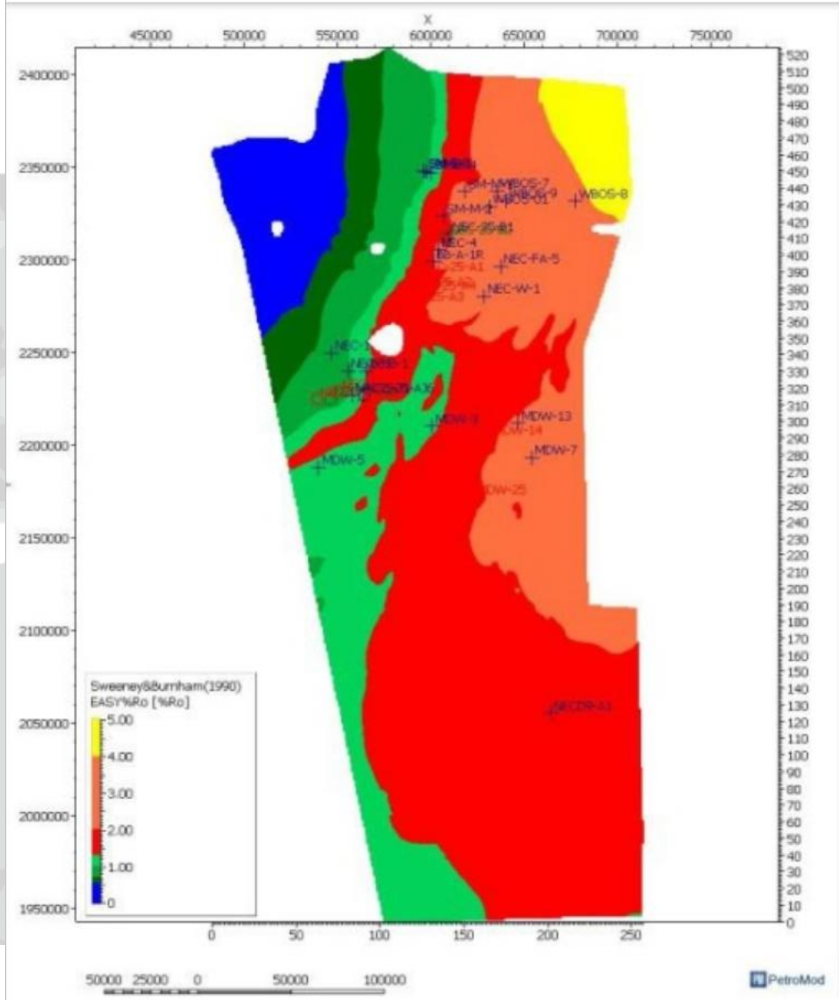


Fig. 4.3.7.8 : Maturity overlay on burial plot of well BB-A1-R

Fig 4.3.7.16 : Maturity (Sweeny & Burnham (1990)_Easy %Ro of Eocene Source



Bengal: Reservoir

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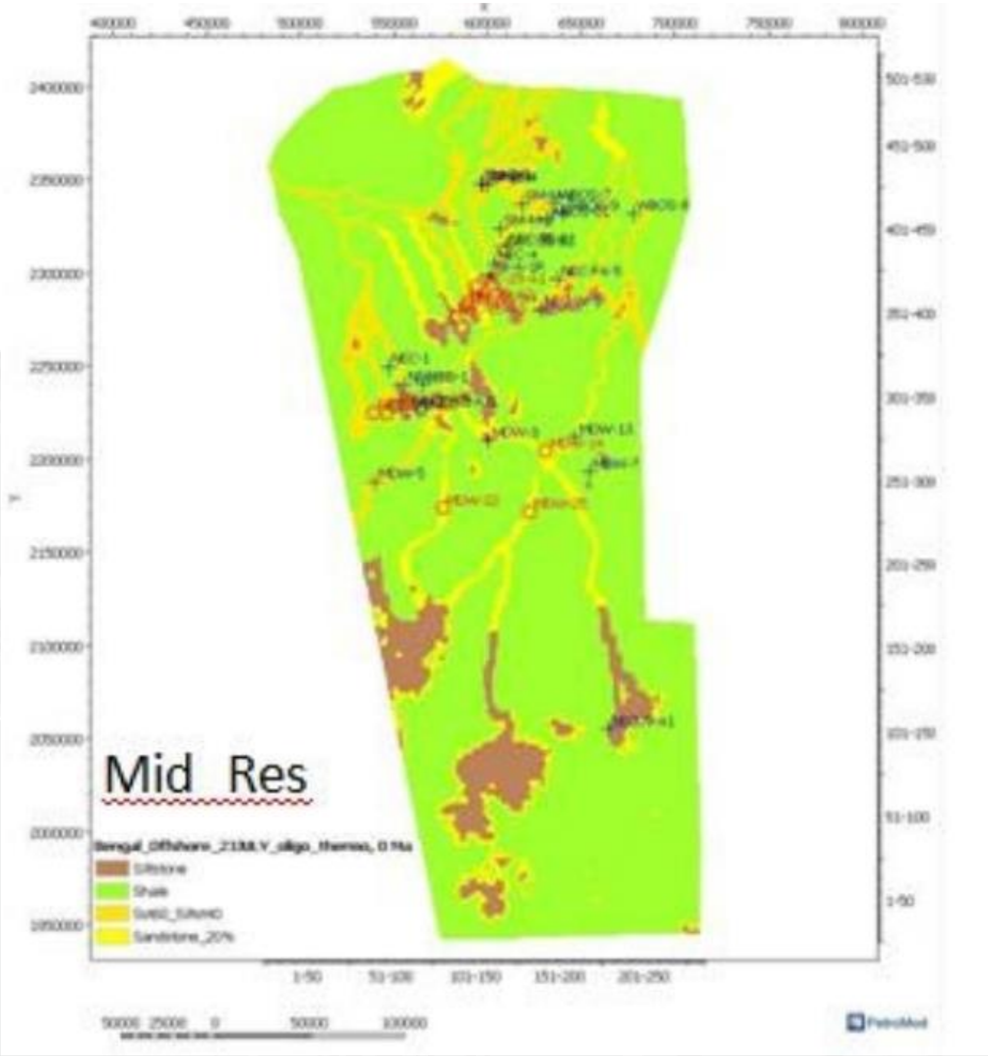
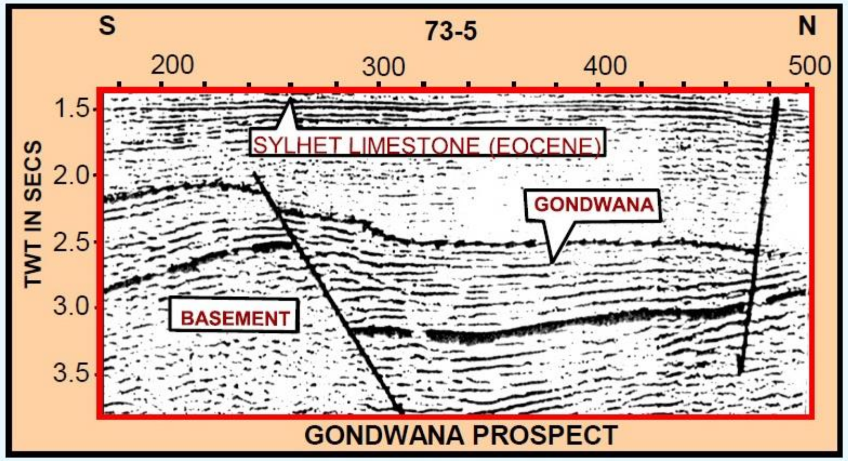
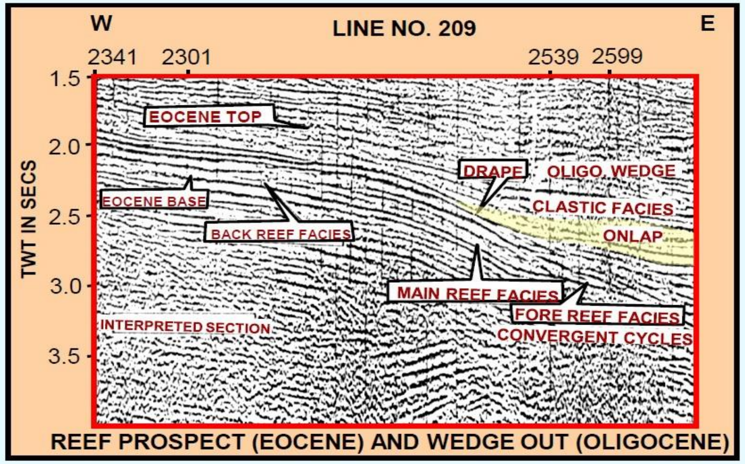
Pliocene Facies Map (Bengal)



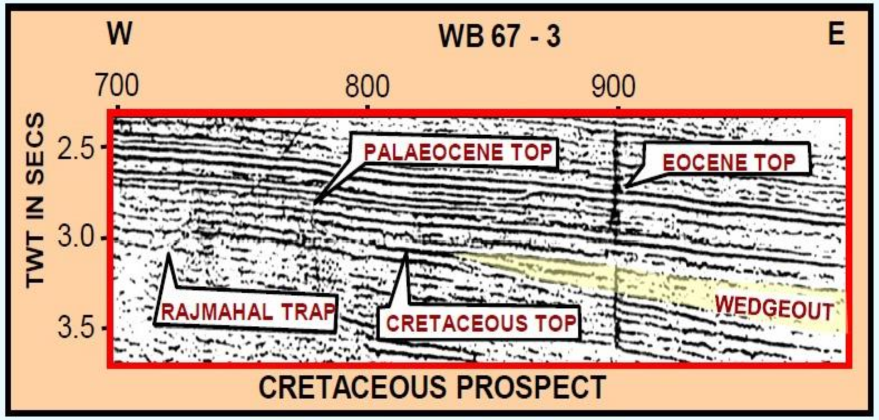
Bengal: Hydrocarbon Plays



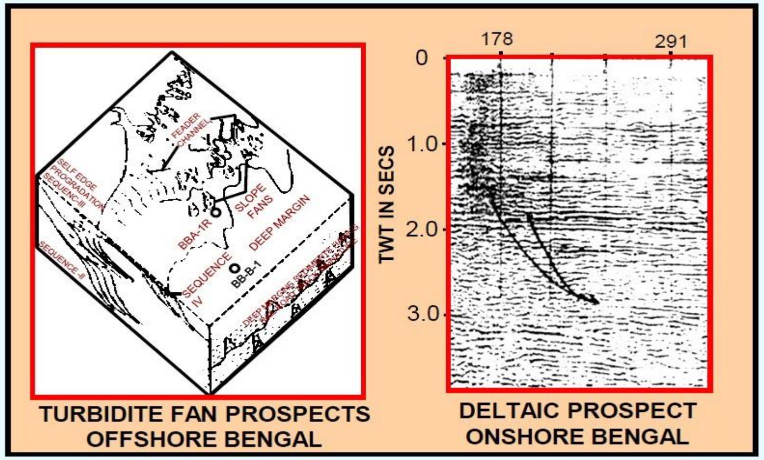
GONDWANA STRUCTURAL PROSPECT



EOCENE REEF AND OLIGOCENE WEDGEOUT PROSPECTS



CRETACEOUS WEDGEOUT PROSPECT



DELTA AND TURBIDITE PROSPECT

Bengal Volumetrics

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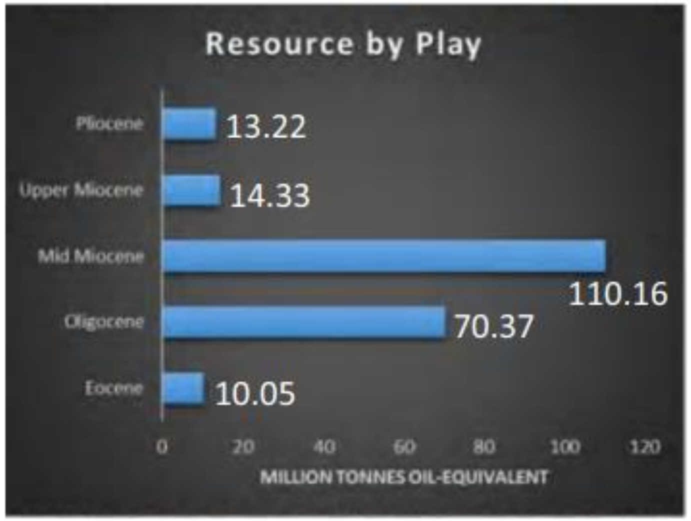
Prognosticated Volumes (In-place MMTOE)

Discovered	Undiscovered	Total
0	219	219

Significant potential in Pliocene plays. Primarily Biogenic Gas expected in strati-structural traps.

- There is 219 MMTOE (1.5 BBOE) Undiscovered in the Offshore Bengal Basin of which 110 MMTOE (752 MMBOE) is in the Middle Miocene



Bengal Offshore

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Thank You

धन्यवाद

For More Information Please Contact:

UH -DGH Center

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Ministry of Petroleum & Natural Gas, Government of India

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Contact us: https://mopng.gov.in/en/about-us/phone-directory

DGH Directorate General of Hydrocarbons

Website- https://dghindia.gov.in/
Contact us: http://dghindia.gov.in/contact_english.php

Get in touch at "investOnG@gov.in"

Hydrocarbon Exploration and Licensing Policy OALP Bid Rounds

Website- http://online.dghindia.org/oalp/
Facilitation Desk Email: Facilitationoal@dghindia.gov.in

National Data Repository

Website: https://www.ndrdgh.gov.in/NDR/
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