

Source Rocks in Deep Water Depositional Systems of East and West Coasts of India*

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Abstract

The deep water areas of India (beyond 400m isobaths) cover about 43% (1.3 million sq.km) of the total sedimentary area of the country. ONGC has undertaken the biggest-ever deep water exploration campaign on East and West coasts of India globally by a single operator and has made the first ultra-deepwater discovery at the water depth of 2841m in the country.

The Western offshore deep water area (220,000 sq. km) stretches from northernmost Kutch-Saurashtra to southernmost Kerala-Konkan sub-basins. Ten wells have been drilled in deep water (bathymetry 1074 to 3008m) penetrating Tertiary sedimentary thicknesses ranging from 872 to 4331m. The source rock development seems to be poor in Tertiary for the drilled deep water locations of western offshore area, as revealed by source rock analyses.

Mahanadi Basin in Eastern offshore extends over an area of 141,589 sq. km. Six wells have been drilled in the bathymetry ranging from 795m to 1088m and have encountered sedimentary thicknesses between 1035m and 2298m. Thin source-rock sequence having fair source potential of Plio-Miocene age has been identified in one well. One of the wells has flowed gas at the rate of 210,000 m³ per day which is of biogenic origin, as revealed by carbon isotopic studies. This discovery opens the seventh basin successfully proved by ONGC. Fourteen wells have been drilled in five deep water NELP blocks in NE part of KG basin covering shelf, slope, and deep water regime (bathymetry 50m-3000m). The total sedimentary thickness is around 10,000m in basinal lows. Good to excellent potential source rocks are observed in Paleocene and Cretaceous sediments in two wells. Significant gas discoveries of biogenic origin were made in Pliocene formation in a few wells. The deep water areas, specially eastern offshore of India, hold promise for significant hydrocarbon discoveries in the near future.

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Presentation Outline

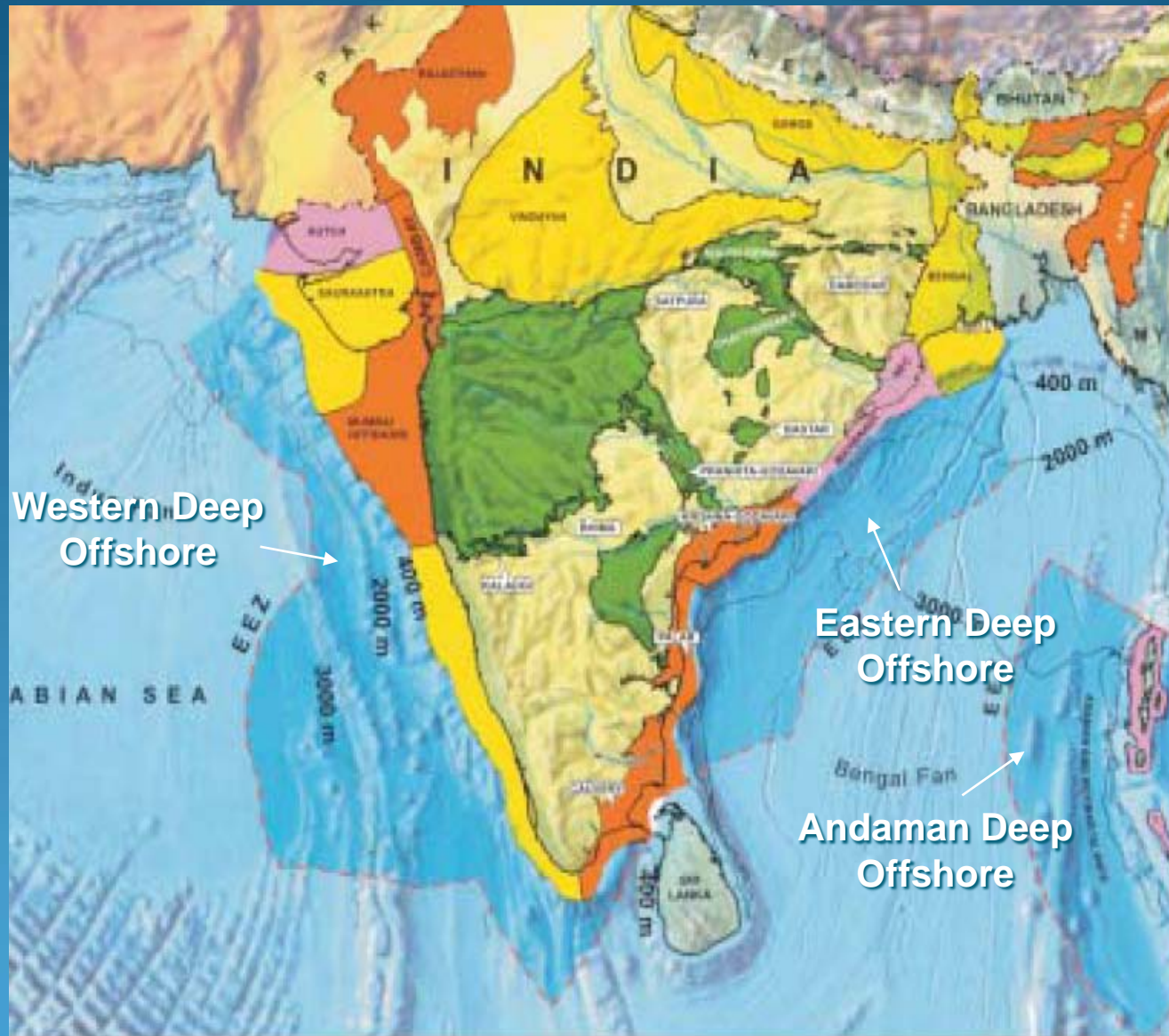
- Objectives
- Regional Geology
 - Western Deep Offshore*
 - Eastern and Andaman Deep Offshore*
- Exploration History and Hydrocarbon
- Source Rock Characterization
- Thermal Maturity
- Conclusion

Objectives

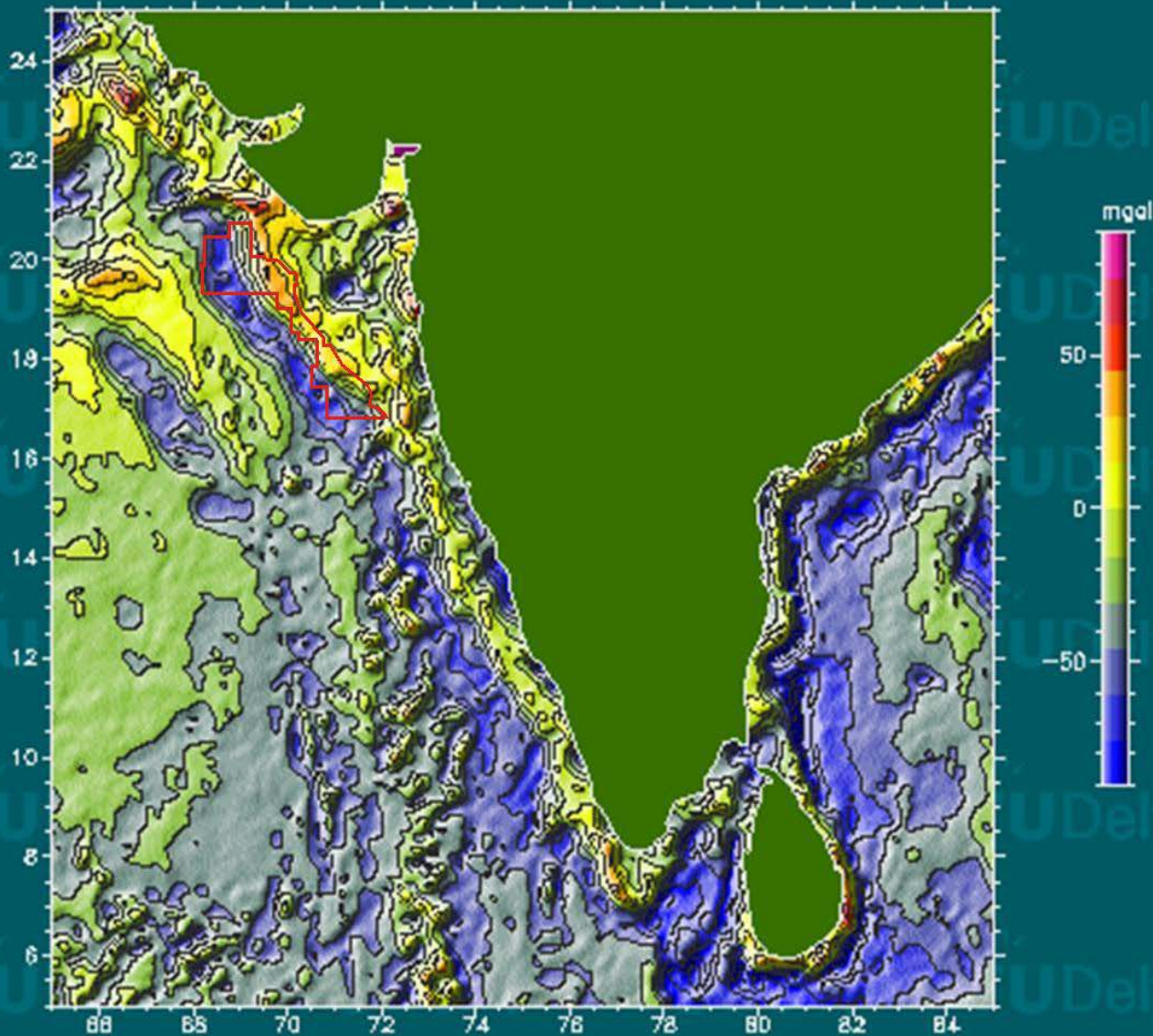
- Evaluation of hydrocarbon source rock potential of Indian Deep Offshore Basins
- Evaluate thermal maturity of sedimentary organic matter in space and time
- To derive focused exploration leads for future

Regional Geology and Tectonics

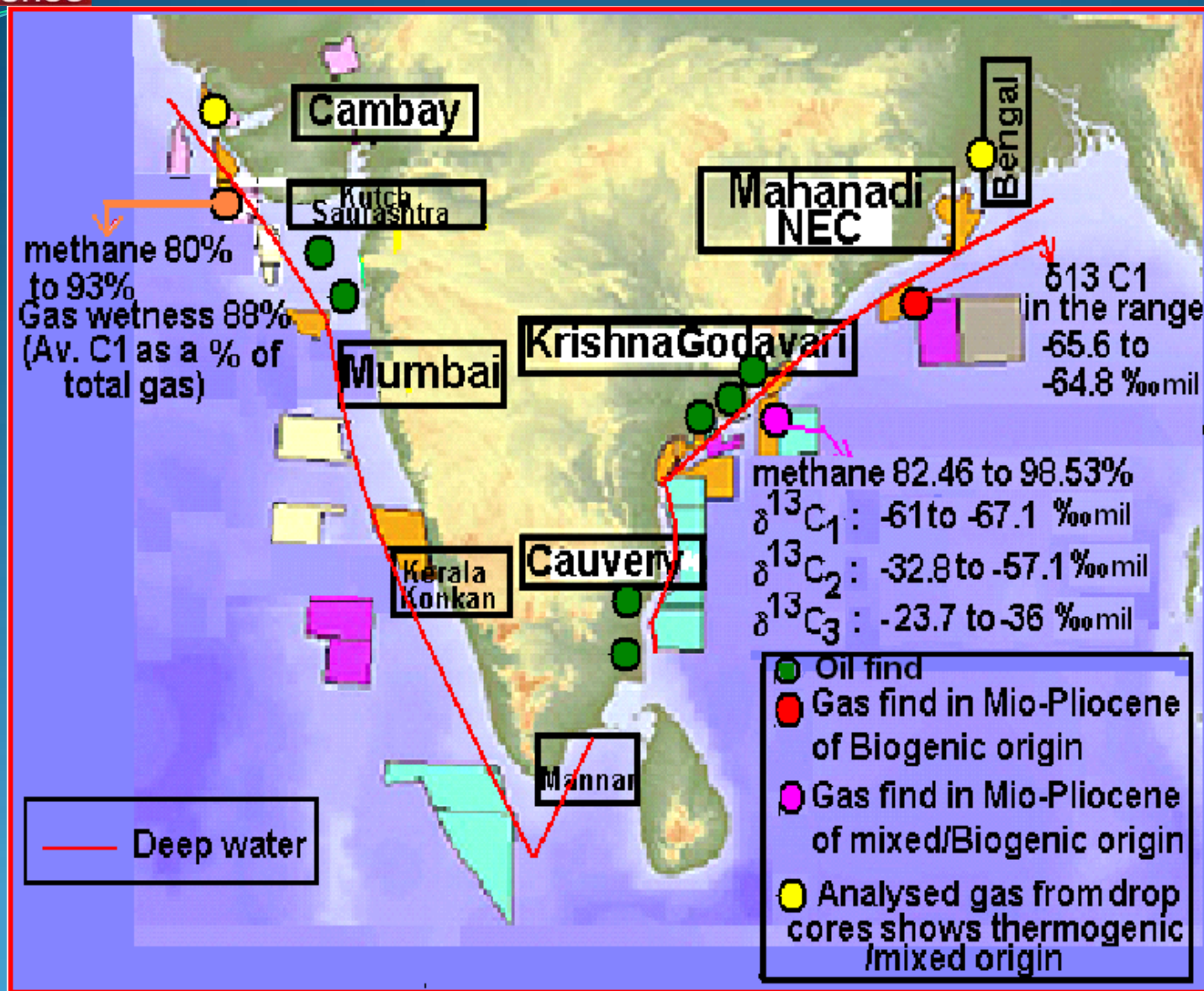
Indian Deep waters



Satellite derived free air gravity map depicting the regional trends



Hydrocarbon occurrences in Indian Deep Offshore



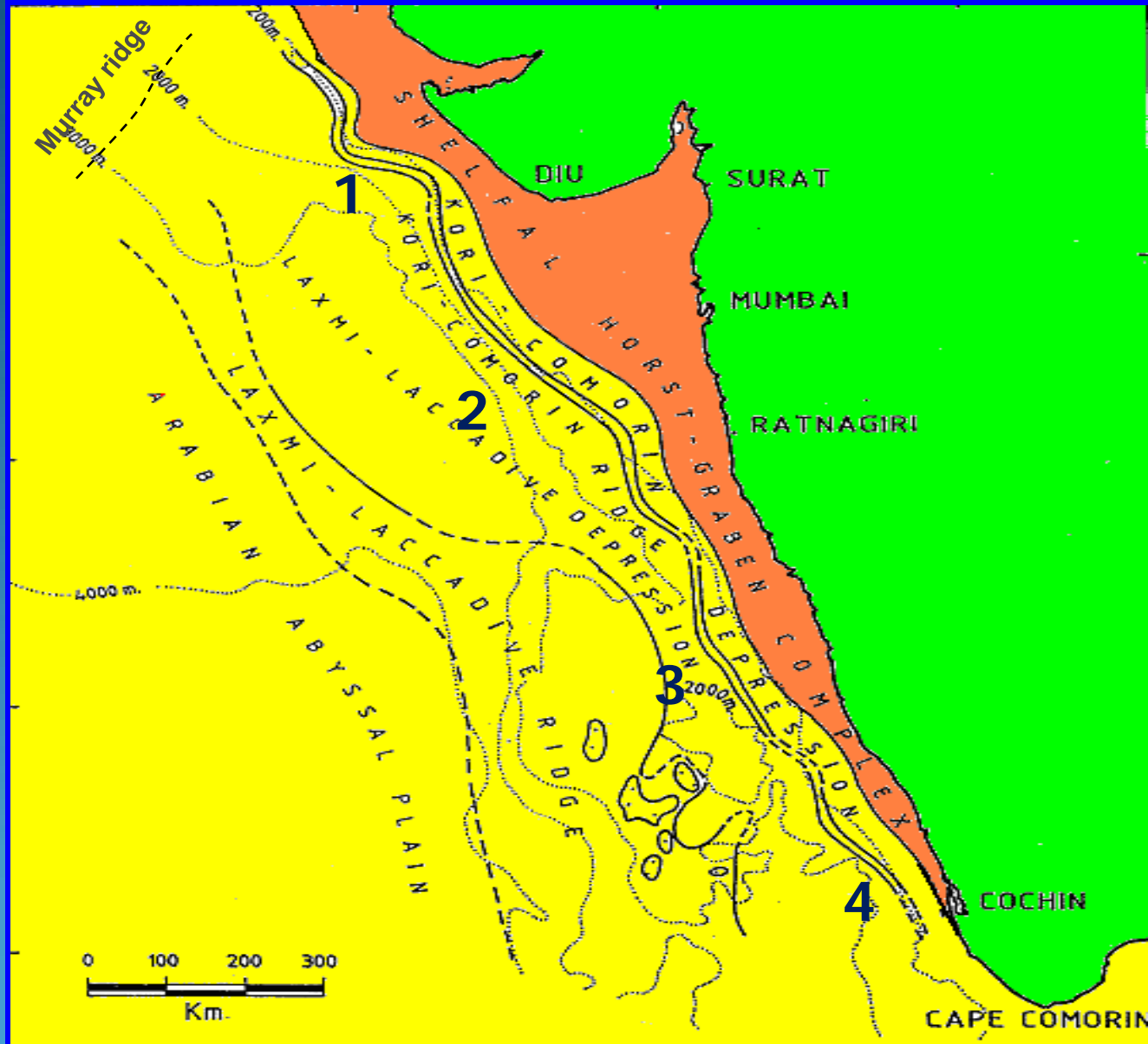
Gas analysis on drop core samples from Kutch-saurashtra area reveals thermogenic/mixed origin of gas.

Gas find on east coast show biogenic/mixed origin

Western Deep Offshore

- *Tectonic Elements*

Major tectonic elements-Western Deep Offshore



Western Offshore - *Deep Water Events*

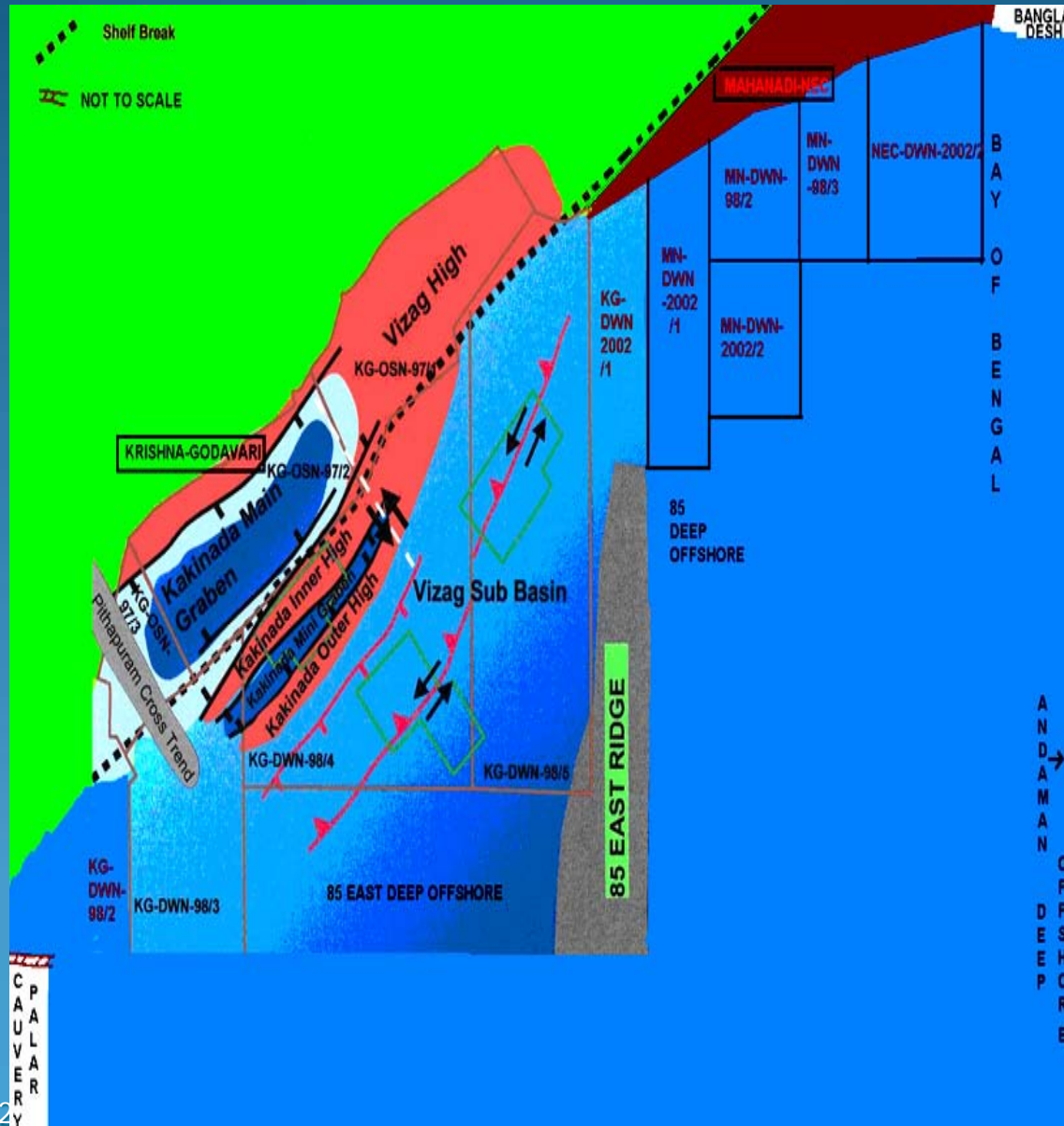
- Indus Fan deposition continues to fill lower slope of Western Margin
- Compression & thrusting on mid lower slope from Lt Miocene to recent
- First Indus Fan reached base of Western continent slope by Mid Miocene
- Accelerated subsidence of margin led to creation of deepwater basin
- Bypassing of clastics from shelf and deposition across slope, growth faulting and imbrication on slope, progradation of shelf margin
- **Differentiation of shelf into shelf-slope-rise, further subsidence along hinge**
- **Basin faced starved conditions leading to deposition of thin Oligocene pack**
- Establishment of Paleogene hinge west of Bombay DCS, Accelerated subsidence of area west of hinge, Cessation of carbonate activity
- Mid Eocene regression partially exposed carbonate highs which generated limited Karstification and secondary porosity
- Widespread carbonate deposition in Lt Paleocene- Mid Eocene, Aggradation of carbonate on highs, deposition of shale-limestone alterations
- **Weathering of Basalt and exposed granite form trap wash and basal clastics**
- **Thermal cooling and subsidence of basin**
- Outpouring of Deccan Trap in flows
- Formation of ridges, deepwater basement highs along Precambrian weak zones

	PLEISTOCENE
UP	PLIOCENE
LR	
UP	MIOCENE
MID	
LR	
UP	OLIGOCENE
LR	
	EOCENE
UP	
MID	
LR	
UP	PALEOCENE
LR	
	CRETACEOUS
UP	
LR	

Eastern Deep Offshore

- *Tectonic Elements*

Eastern Deep Offshore



Eastern Offshore-Deep water events

- Heavy Influx of Bengal fan clastic sediments
- Major tilting of basin and regional regression
- Himalayan orogeny
- Accelerated subsidence leads to creation of deepwater
- Collision of Indian Plate with Burmese plate
- Eastward tilting of basin, development of typical shelf slope
- Basin experienced starved conditions
- Initial collision of Indian plate with Eurasian plate
- Carbonate deposition on paleo-highs and deposition of shale in lows
- Basin experienced starved conditions
- Thermal cooling and subsidence of basin
- Northward flight of India and Sri Lanka, Kerguelen hotspot activity, uplift, Reunion hotspot activity
- Cretaceous volcanism
- Major plate reorganization with spreading, Separation of India from Antarctica, Rifting of India and Sri Lanka. Rift fill and transgression
- Passive Margin rift initiation and continental break up with sea floor spreading, formation of ridges

	PLEISTOCENE
UP	PLIOCENE
LR	
UP	
MID	
LR	MIOCENE
UP	
LR	OLIGOCENE
UP	
MID	EOCENE
LR	
UP	PALEOCENE
LR	
UP	CRETACEOUS
LR	
UP	JURASSIC
BASIN FLOOR	

Exploration Initiative & hydrocarbon finds in deep waters

- ONGC drilled 41 deep/ultra-deepwater wells
 - 13 wells in Western deep offshore (Bathy upto 3008m)*
 - 28 wells in Eastern Deep Offshore (Bathy upto 2850 m)*
- In Western Deep Offshore hydrocarbon yet to be proved.
- Gas analysis on drop core samples from Kutch-Saurashtra area reveals thermogenic origin of gas.
- In Eastern Deep Offshore significant gas discoveries from Neogene Formation established.
- Isotopic study on produced gas from DST samples in Mio-Pliocene in Mahanadi deep water indicate biogenic origin

Source Rock Characterization

Source Rock Characterization–Western deep offshore

Well	Bathy m	Drilled depth m	Potential Source rock interval m	Age	TOC %	S2 mgHC/g	OM type	VRo %
A	1862	6050	3750-3755 Cret-Ely Pal	Paleocene/Cret.	<=1	2-5	III	.69-.72
B	2200	4620	Absent	Late Eocene	<0.5	<2	III-IV	-
C	2850	3800	Absent	Paleocene	0.5	0.01-0.45	III	-
D	3008	3917	3644, 3790 Paleocene	Paleocene	0.5-2	2.5-10	II	-
E	2543	3838	3644, 3790 Paleocene	Late Paleocene	0.5	0.08-0.91	III	-
F	1074	5404	Absent	Paleocene	<0.5	<2	III-IV	-
G	2378	3250	Absent	Paleocene	<0.5	<2	III-IV	-
H	880	4123	Absent	Paleocene/Cret.	<0.5	<2	III-IV	-
I	1054	3772	Absent	Paleocene	<0.5	<2	III-IV	-
j	37	2999	Absent	Cretaceous	<0.5	<2	III-IV	-

Indicate the absence of Tertiary source rock facies capable of generating hydrocarbons based on the data generated so far.

Source Rock Characterization–Eastern deep offshore

We ll	Bathy m	Drilled Depth m	Potential Source rock interval m	Age	TOC %	S2 mgHC/g	VRo %
K	776	3545	1990-2025	Ely.Oligocene	1.01-1.39	2.42-3.86	0.4-0.47
L	778	3779	2780-2850 3330-3510 3720-3730	Cretaceous	1.85-2.96 1.42-2.47 1.33	2.5-2.6 2.8-6.4 4.9	-
M	2552	4767	Absent	Cretaceous	<0.5	<2	-
N	608	2416	Absent	Cretaceous	<0.5	<2	-
O	2678	7084	3500-3520 4860-4880 5050-5060 6010-6040	Paleocene Cretaceous Cetaceous Cretaceous	3.99 1.07 2.06 2.0-2.2	3.7-4.17 2.6 3.61 2.5-3	- 0.46-0.5 0.46-0.5 0.6-0.66
P	1500	2425	Absent	Pliocene	<0.5	<2	-

Good to excellent source rocks are observed in Paleocene and Cretaceous sediments in two wells of Krishna Godavari deep water in Eastern deep Offshore.

Source Rock Characterization–Eastern deep offshore ---

We ll	Bathy m	Drilled Depth m	Potential Source rock interval m	Age	TOC %	S2 mgHC/g	VRo %
Q	1500	2670	Absent	Pliocene	<0.5	<2	-
R	795	3093	Absent	Mio-Pliocene	<0.5	<2	-
S	987	2064	1650-1655 1660-1665	Mio-Pliocene	1.1-1.5	2-2.69	-
T	1065	2100	Absent	Mio-Pliocene			-
U	1085	2450	1612-1640	Mio-Pliocene	1.27-1.33	1.65-2.69	-
V	1088	2600	2095-2100 2110-2115 2160-2165 2360-2365	Mio-Pliocene	1.19-1.44	2.24-2.75	-

Source sequence of Mio-Pliocene age, having fair source potential has also been identified in Mahanadi-Bengal deepwater in Eastern deep Offshore.

Burial and Thermal History

Burial & maturity window at Location A(Kutch) and I (Keral-Konkan) Western deep offshore

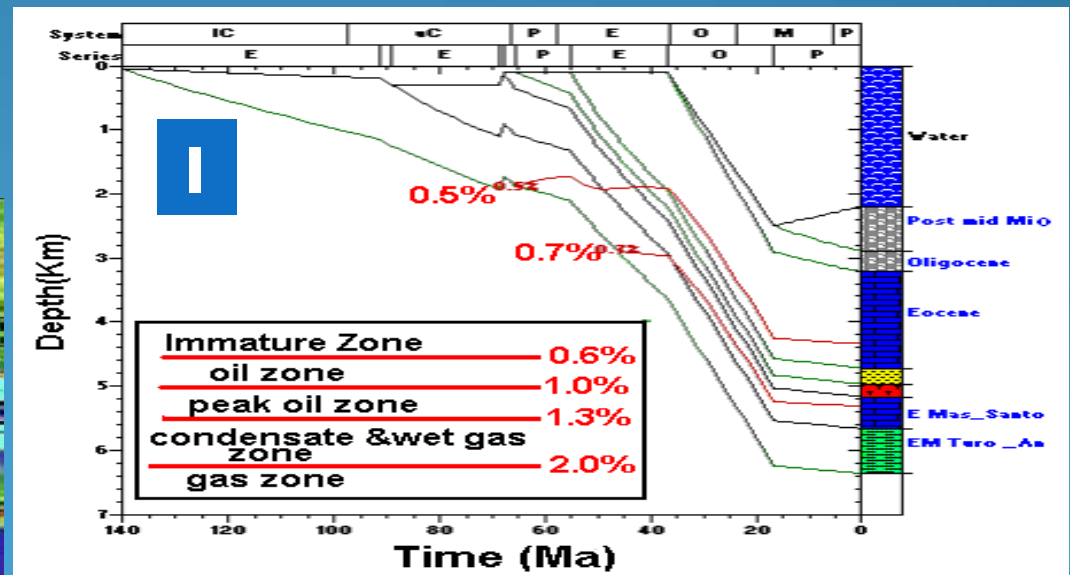
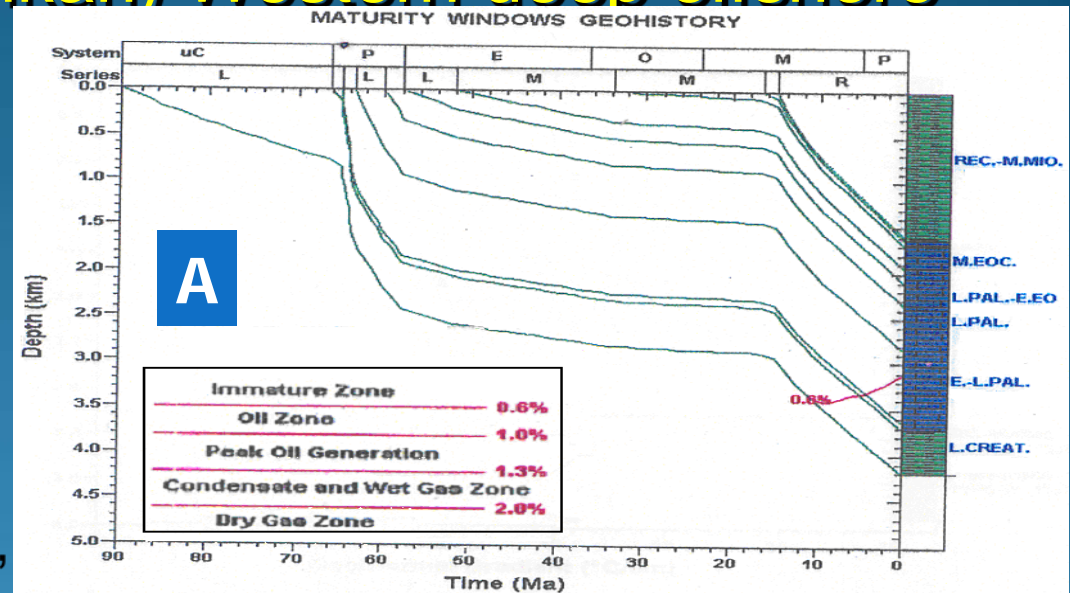
Cretaceous and Early Paleocene in oil window (0.6%VRo).

No sediments in oil expulsion window (1.0%VRo)

Late Cretaceous attained oil window maturity at 8 Ma, and Paleocene at 2-3 Ma.

Early Cretaceous in oil zone whereas Late Cretaceous immature

Peak oil zone under intrusive activity



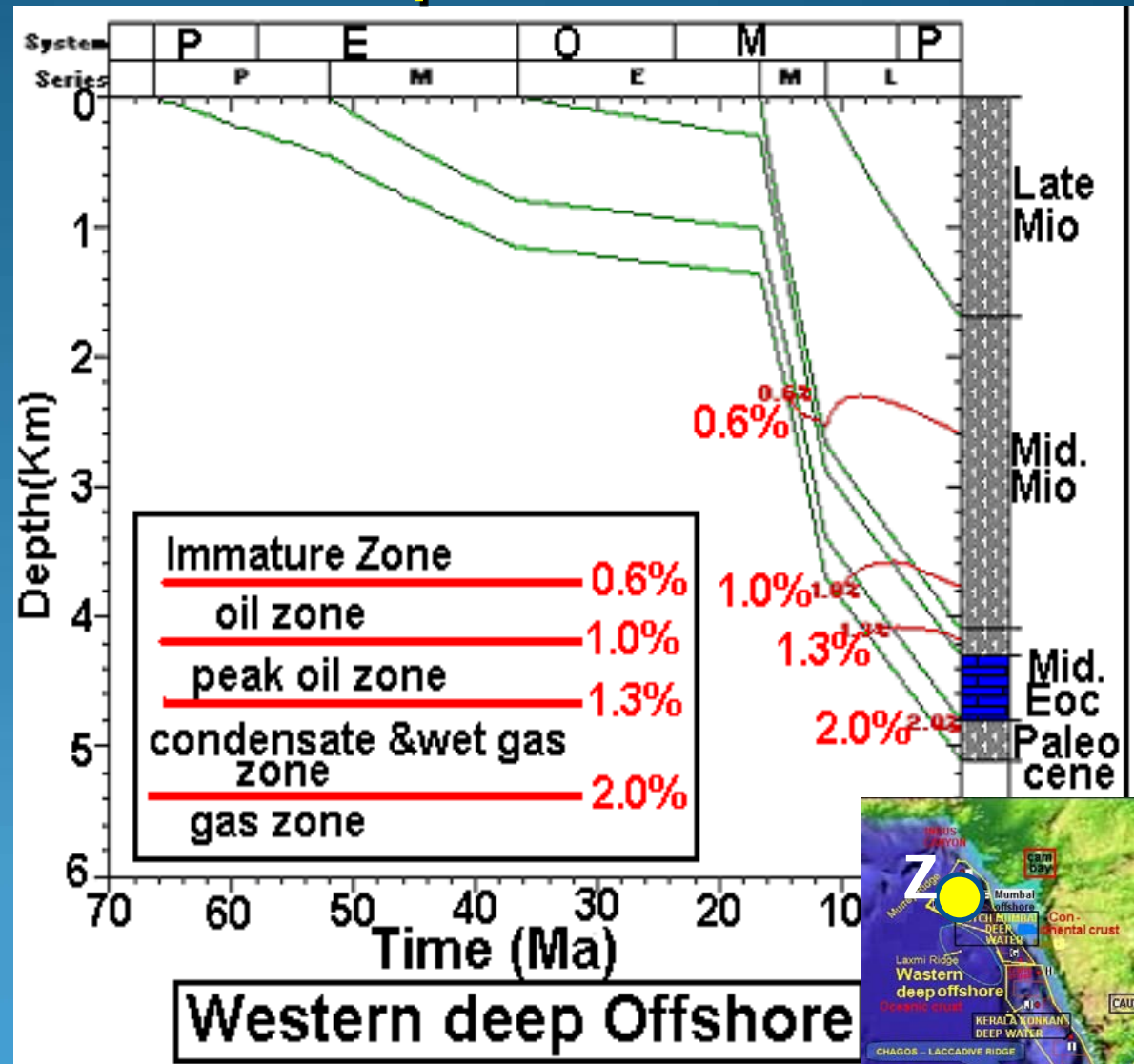
Burial & maturity window at Pseudo Location Z of Western deep offshore

Mid. Miocene in oil window at the depth of 2590m below the sea bed

Oil expulsion window is at 3760m below the sea bed.

The condensate and gas window (1.3 %VRo) in Early Oligocene.

The bottom-most Paleocene sediments are in dry gas zone (2.0% VRo).



Burial & maturity window at Pseudo location Y, (Kerala-Konkan) Western deep offshore

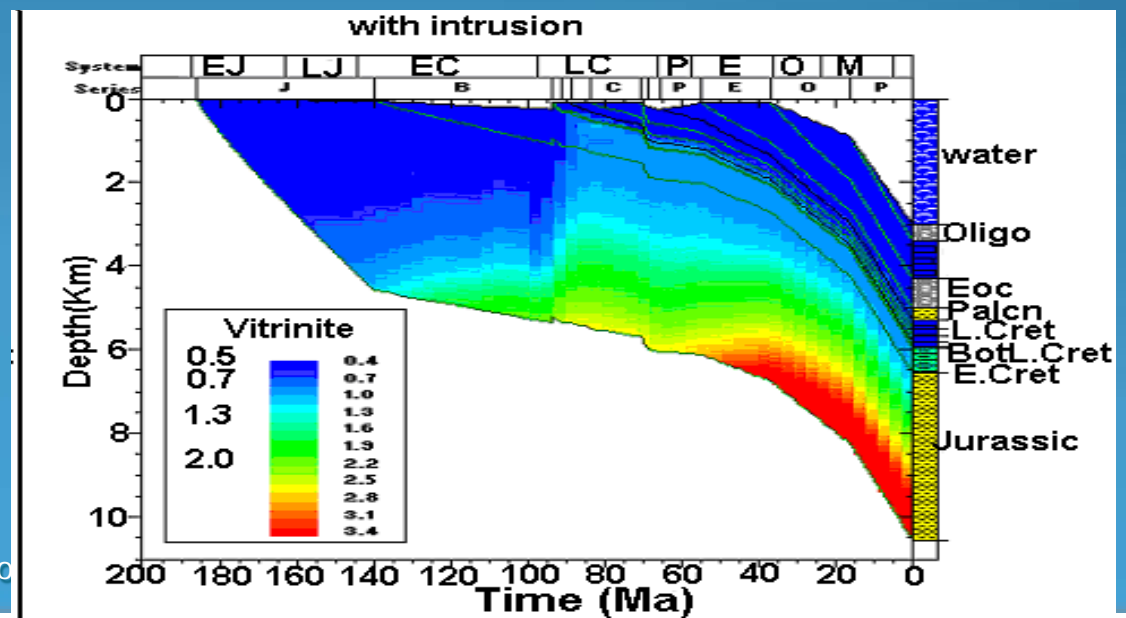
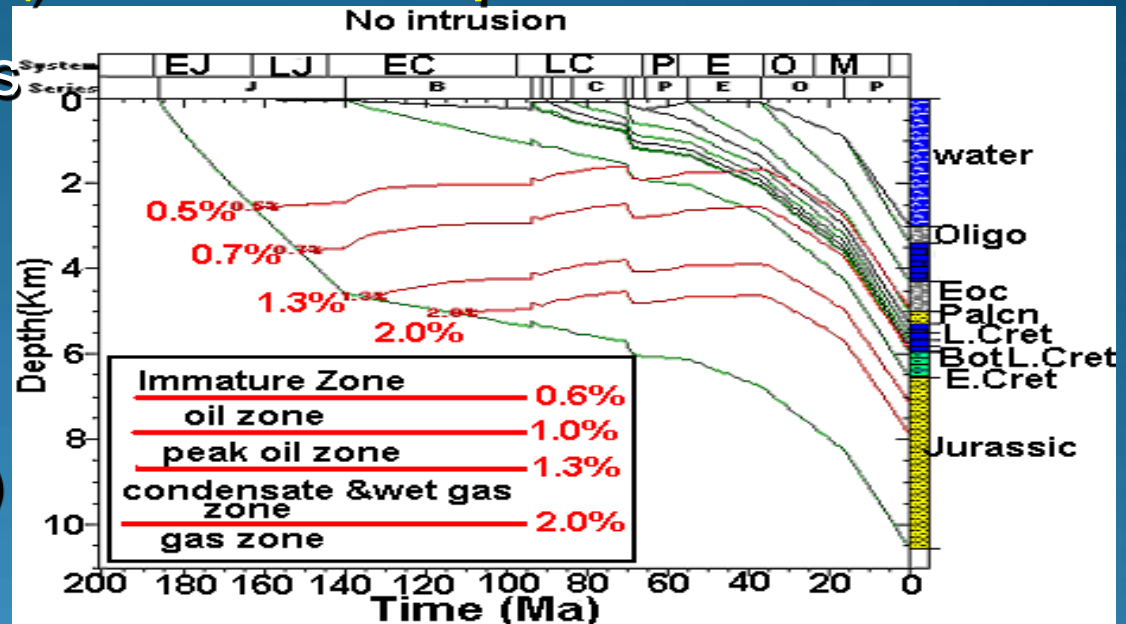
Early Jurassic in dry gas zone whereas Late Jurassic in peak oil zone to dry gas zone.

Early Cretaceous in peak oil zone gas zone (under intrusive activity)

Late Cretaceous and Paleocene peak oil zone (under intrusive activity)



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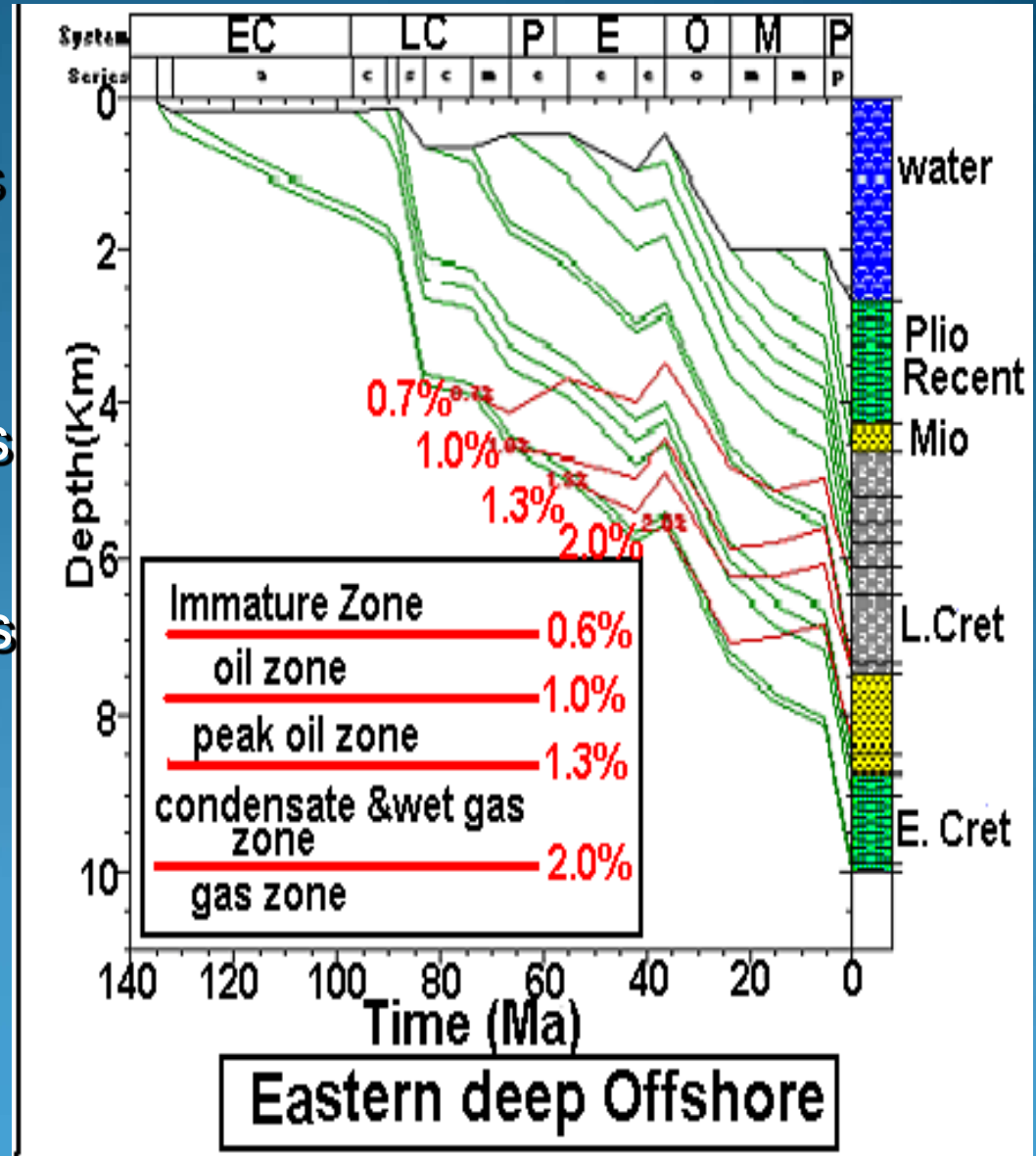


Burial & maturity window at Pseudo location X of Eastern deep offshore

Early Cretaceous and bottom of Late Cretaceous in dry gas zone

Middle of Late Cretaceous in condensate and wet gas zone

Top of Late Cretaceous as well as Paleocene in peak oil zone



Burial & maturity window at Pseudo location Z1 & location O of Eastern deep offshore

In Pseudo location Z1

Early part of Late Cretaceous in condensate and wet gas zone

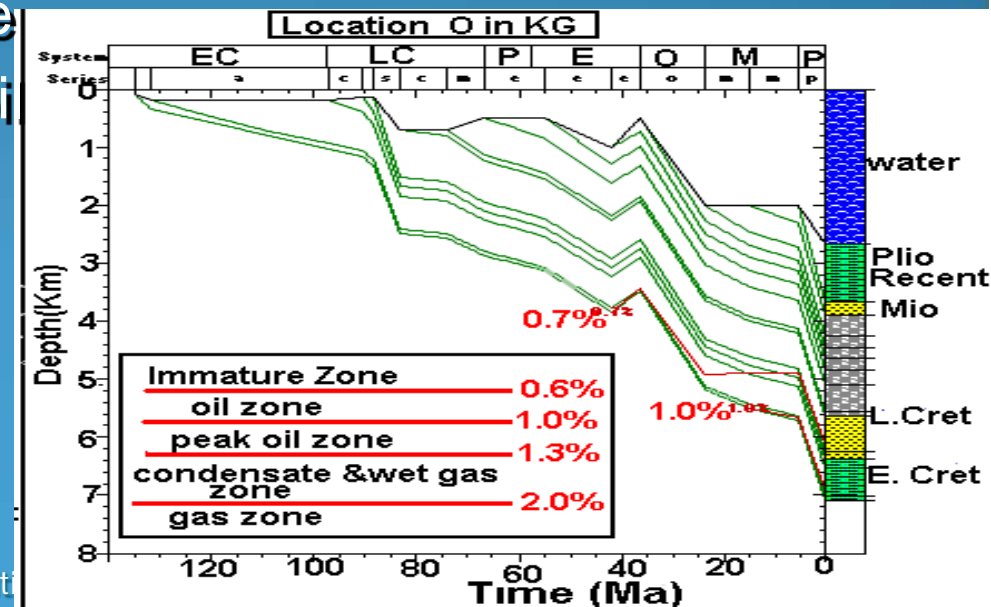
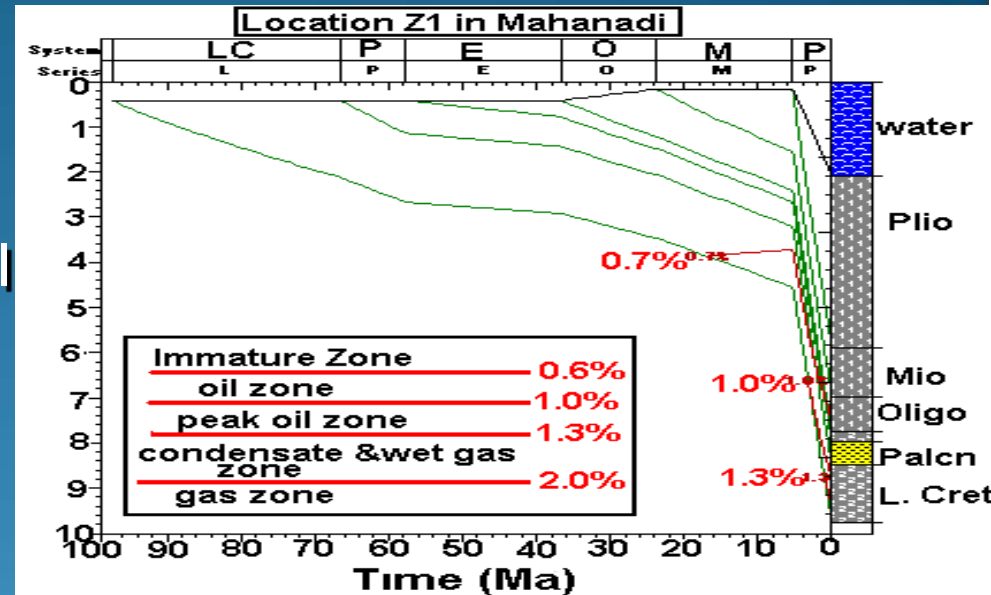
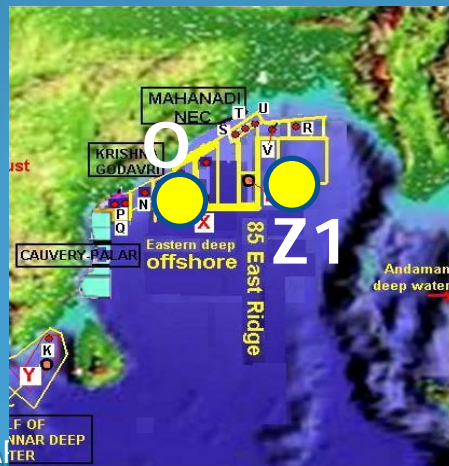
Top of Late Cretaceous in peak oil zone whereas

Early Oligocene to Paleocene in oil zone.

In location O

Early Cretaceous in peak oil zone

Early part of Late Cretaceous in oil zone



Conclusions

Western Deep Offshore Basins

- Limited source rock development in Tertiary fill based on the available data.
- Source rock potential of Cretaceous is visualised in Kutch and Kerala Konkan areas.

Eastern Deep Offshore

- Fairly good source potential has been identified in Mio-Pliocene Sequence in Mahanadi-Bengal deepwater.
- Paleocene/Cretaceous synrift sediments with good source rock potential is preferred as an exploration target in the Eastern offshore deep waters.