# Lower Mahuva/Mukta Limestone of the Eastern flank of Diu Arch of Saurashtra Offshore: Depositional environment and its role in hydrocarbon exploration.

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## Abstract:

Lower Mahuva formation in Tapti Daman sector is primarily over pressured shale/claystone deposited in low energy environment whereas Mukta formation a homotaxial of Upper Mahuva formation comprises dominantly Limestone and Shale deposited in changing energy conditions. Lower Mahuva formation and Mukta formation belong to the Early Oligocene period. Presence of hydrocarbon is well established in Mukta formation in the Mumbai offshore area particularly in the central Graben areas. The development of thick Limestone beyond Diu fault towards north of Mumbai High area in Tapti Daman sector in Saurashtra offshore juxtaposed with Lower Mahuva formation shale has been observed in some wells. Global sea level rise and clastic influx from the North East of the Tapti Daman sector played major role in the process of limestone deposition. Along the NE-SW trending shelf hinge these limestone are deposited as Autothonous deposits. The assemblage of Benthonic and planktonic fauna suggest bathymetry inner neritic environment. The clastic supply from the northeast was not enormous and the basin was starved. The limestones are hard, compact and fossiliferous in nature. Primary porosity has been reported from the cores cut in the wells of the area. Secondary porosity has also developed. The amplitude maps in 3D seismic data detremine the depositional trend of these limestone deposits anongwith inversion study suggest the broad locale for better reservoir development.

## Introduction

The Mumbai offshore basin, a passive margin basin on the continental shelf of western India continues into the on-land Cambay basin toward the northeast. On the north it is bounded by the Saurashtra Peninsula and on the east by the Indian craton. Its southern limit is marked by the east-west trending ridge south of Ratnagiri.

Hydrocarbon accumulations generaly occur in carbonate reservoirs ranging in age from Middle Eocene to Middle Miocene which are structurally controlled. However stratigraphic / combination plays in Paleocene - Lower Eocene and Oligocene clastic reservoirs are also significant. The area under study covers part of southern part saurashtra offshore in south of saurastra craton (Fig:1).

Present study is the result of interpretation of the 3D seismic data and Well log caliberations and integration of laboratory studies in the interpretation.

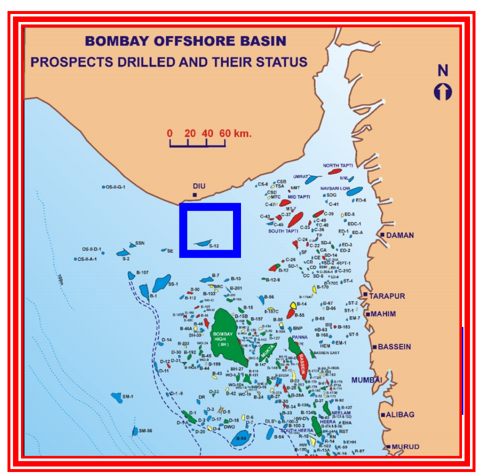



**Fig. 1: Location Map**

The area under study lies in the eastern part of Diu Arch of Saurashtra offshore area **(Fig:2)**. An attempt has been made to analyze the available geoscientific data and generate carbonate deposition model of the Lower Mahuva/ Mukta formation in the area. The deposition model will help in exploring further for the Lower Mahuva/ Mukta pays in the area.

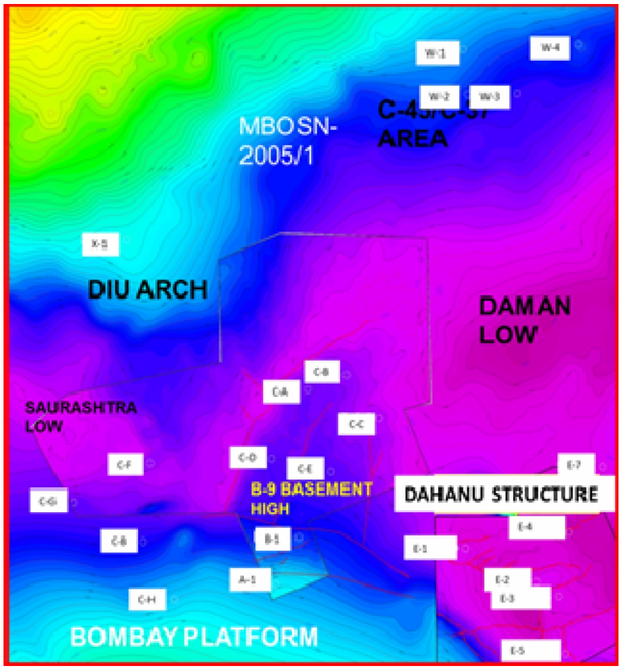



**Fig. 2: Time relief map on top of Mahuva / Heera formation**

## Tectonic setting and Structural framework

Basemnt controlled NW-SE (Dharwarian trend) to NS(Delhi trend) trending faults split the entire shelf area in longitudinal stripes. This has resulted in a horst-graben morphology which guided sedimentation in the basin throughout the Tertiary period up to Middle Miocene.

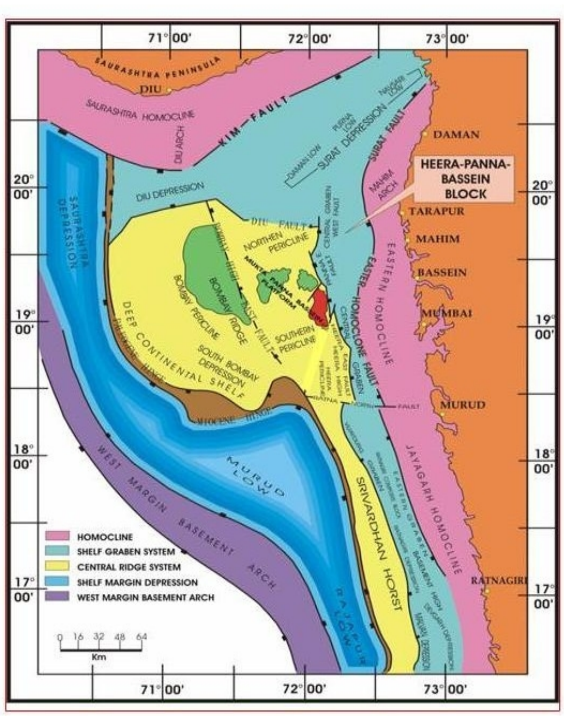



**Fig. 3: Structural elements of Mumbai Offshore Basin**

Five mega tectonic elements; viz. Eastern Homocline, Graben system, Central Ridge System, Shelf Margin Depression and West Margin Basement Arch **(Fig:3).** Each element is bounded by normal faults. Tectonics is primarily guided by major basement lineaments. The 'highs' are dissected by NE-SW cross trends. The most prominent among basement highs over Mumbai platform is the 'Mumbai High'.

In the North and North East of Mumbai high Diu arch, Dahanu structure, Saurashtra low, Surat depression, Daman low and Navasari lows have various Inversion structures formed due to transpressional and transtensional forces of strike slip movements.

## Stratigraphy and Depositional Setting

Mumbai Offshore basin is limited by the exposures of Deccan Trap in the east. A thin veneer of Neogene and Quaternary limestone, marl and clay form the outcrops along the coastal belt of Saurashtra Peninsula in the north. The subsurface sedimentary section ranges in age from Paleocene to Holocene and overlies non-conformably the Deccan Trap / Granitic / Metamorphic basement. Deccan Trap represents the basin floor geology with a few granitic/metamorphic inliers. Seismic sections and Cretaceous exposures in Wadhawan and Dhrangadhara areas of Saurashtra block reveal the presence of a sub Deccan Trap Mesozoic basin. The lithostratigraphy of the basin is shown **in Fig:4**

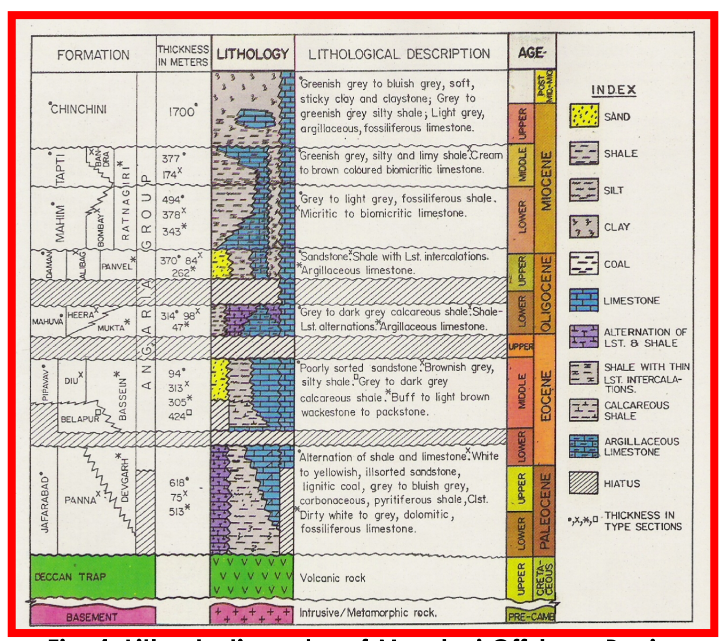



**Fig-4: Lithostratigraphy of Mumbai Offshore Basin**

## Significant Geologic and Tectonic Events

"Crustal scale" tectonic events affecting the passive margin in the study area include:

1. Long period of stable emergent craton from Pre-Cambrian to early Mesozoic. Initial rifting and separation of India from Africa in the mid-Jurassic
2. Continued rifting, separation of Madagascar from west India in the mid-Cretaceous
3. Northward drift of western India over a mantle plume at K/T boundary
4. Outpouring of Deccan Trap flood basalts over a large area between 66 and 65 Ma
5. Last major rift as Seychelles moves away from western India in the Early Tertiary. Deposition of Paleocene-Eocene source rocks in accommodation caused by rifting
6. Continued igneous activity along southward moving track of hotspot. Thermal cooling and subsidence after rifting event & movement away from plume
7. Localized wrench tectonics and intrusive & extrusive igneous activity in the Eocene
8. Initial contact of Indo-Australian and Eurasian plate in mid-Eocene
9. Significant subduction and first major Himalayan orogenic event in mid-Oligocene
10. Extension & block faulting in some areas of western Indian margin in Late Paleogene
11. Thermal-isostatic subsidence of margin appears to accelerate around mid-Miocene
12. A geo-chronological chart showing some of the above events and a global sea level curve is shown in **Figure 5**. A discussion of the various stratigraphic units follows.

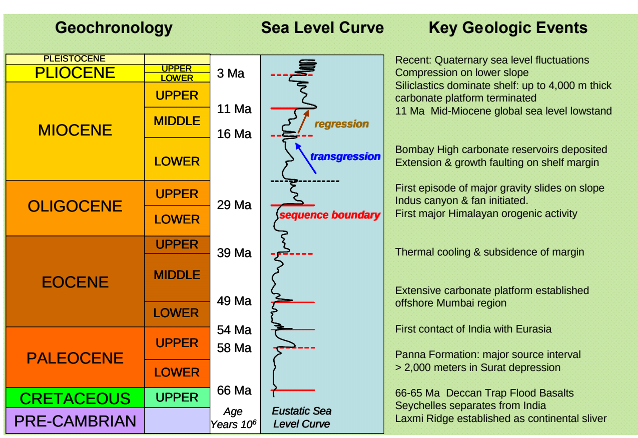



**Figure 5: Geo-chronological chart, Sea Level Curve and Key Geologic Events**

## G &G data observations and analysis

**1:** While interpreting the 2D seismic data of the area under study it was observed that High Amplitude anomalies (Fig: 6) below Daman and upper Mahuva formation belonging to Lower Mahuva equivalent of Early Oligocene age. Since the lithologies in drilled well in the area is Shale for this Lower Mahuva equivalent it was thought that Mukta equivalent limestone may be possible. 3D (Fig: 7) seismic data acquired and interpreted recently was interpreted carefully. The Amplitude anomalies of 2D seismic data is also present in 3D seismic data. One well A has been drilled on these high amplitde anamolies recently placed on/near the 2D seismic line and inline of seismic 3D. The high amplitude has been proved to be Limestone of Early Oligocene age.

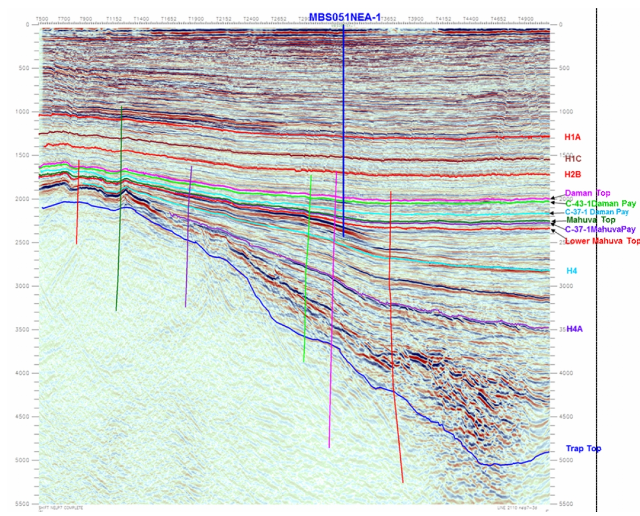



**Fig 6:** 2D seismic line showing High Amplitude Anamaly.

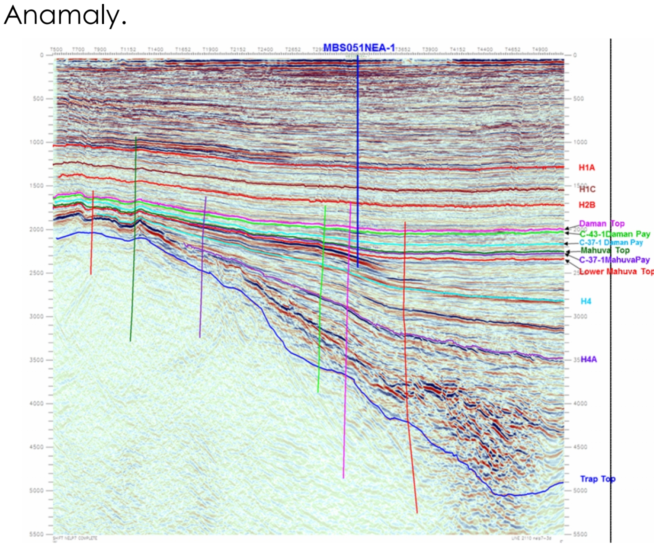



**Fig 7:** 3D seismic line showing High Amplitude Anamaly.

**2:** Different seismic attributes were attempted to analyse the high amplitude anolmaly in the 3D seismic volume. RMS amplitude and Max Pos amplitude horizon slice within the window belonging to ths highe amplitude anomaly were generated. **(Fig: 8-9)**. The linear trend of the amplitude anomaly along the paleoshoreline /shelf has been observed.

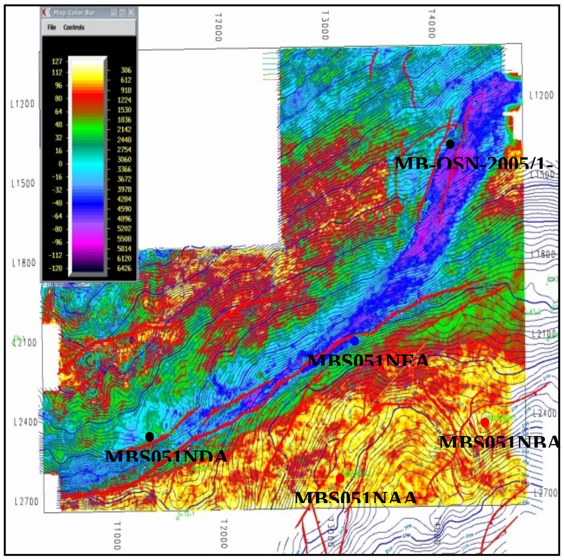



**Fig 8: RMS Amplitude map of Carbonate Build**

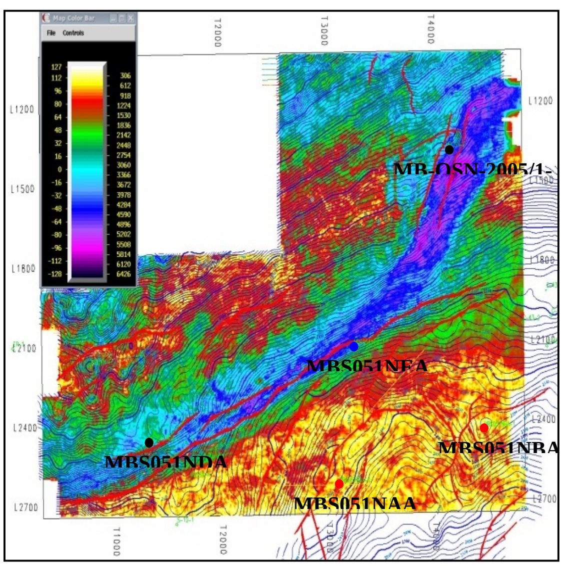



**Fig 9: MAX POS Amplitude map of Carbonate Build.**

**3:** In all the well logs within and in the proximity of the study area the Lower Mahua/ Mukta section were correlated. Profiles along the dip and strike were prepared and attempt were made to understand the size, shape, orientation, petrography, and detailed depostion model. The log correlation clearly indicates the development of these limestone situated on the Amplitude anomaly. The well located away from the anaomaly has clastics (Shale) in the lower Mahuva interval **(Fig: 10 and 11).**

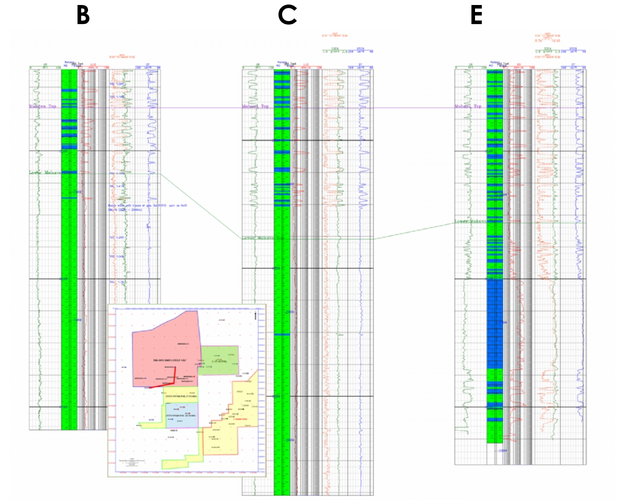



**Fig 10: Electrolog correlation of the Wells B,C and E**

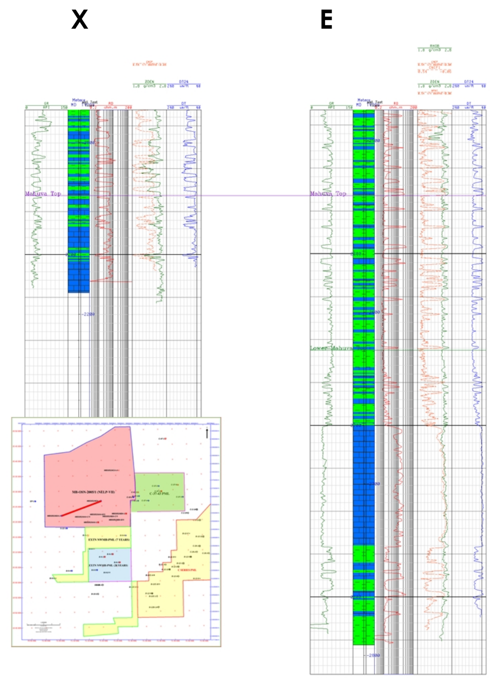



**Fig 11: Electrolog correlation of the Wells X and E**

**4:** Lower mahuva/Mukta Limestone In well A was cored. The detailed megascopic carried out by RGL Panvel. It has been observed that The limestone is Grey, whitish, hard, dense with abundant Nummulities and ooidic grains. These are sparitized at most of the places and occasionally pyritized. Disseminated pyrite is common throughout the segment. No distinct visual porosity observed. Vugs are occasionally filled with micrite along the clay matter. Disseminated calcite is also observed at places. Clay partings are occasionally seen. Towards top, significant clay parting with micritic composition distinct and at the centre of the same vugs of ooidic grain are filled with clay matter. The limestone appears to be Packstone type. At places vugs are filled with crystalline calcite. Core report is enclosed as (**Fig: 12**):

| DEPTH (m) | SEGMENT No. | CCONTAINER NO. | SEGMENT LENGTH (CM) | LITHOLOGICAL PROFILE | POROSITY: POOR | POROSITY: MODERATE | POROSITY: GOOD | POROSITY: V.GOOD | FLOURESCENCE | OIL CONTENT SOLVENT CUT: None | OIL CONTENT SOLVENT CUT: V.POOR | OIL CONTENT SOLVENT CUT: POOR | OIL CONTENT SOLVENT CUT: GOOD | OIL CONTENT SOLVENT CUT: V.GOOD | OIL & GAS BLEEDINGS | WATER BLEED | NACL% | CACO3% | MGCO3% | DIP & FRACTURES | TAKEN AWAY PARTS | DESCRIPTION Color- texture-hardness-lithology-fossils-porosity type, Mineralization etc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2701.00 | 227 | 02/11/11 | 11 | | | | | | PYF | | V.POOR | | | | | | | 76 | 18 | | TAKEN TO BASE | **(11 cm) LIMESTONE** Light grey, hard compact,fossiliferous, dark grey laminations present |
| 2701.11 | 226 | 02/11/11 | 10.5 | | | | | | | | | | | | | | | 65 | 32 | | | **(10.5cm):LIMESTONE** Light grey, hard compact,fossiliferous, dark grey laminations present,sharp contact with bottom segment.(segment no.225) |
| 2701.22 | 225 | 02/11/11 | 63.5 | | | | | | | | | | | | | | | 59 | 40 | | | **(63.5cm):LIMESTONE** Light grey, hard compact,fossiliferous. |
| 2701.85 | 224 | 02/10/11 | 49.5 | | | | | | | | | | | | | | | 83 | 17 | | | **(49.5cm):LIMESTONE** Dark grey to grey, hard compact,fossiliferous, fossils are aligned. |
| 2702.35 | 223 | 02/09/11 | 52 | | | | | | | | | | | | | | | | | | | **(52cm):LIMESTONE** Dark grey to grey, hard compact,fossiliferous, fossils are aligned. |
| 2702.87 | 222 | 02/09/11 | 43.5 | | | | | | | | | | | | | | | 86 | 14 | | | **(43.5cm):LIMESTONE** Dark grey to grey, hard compact,fossiliferous, fossils are disaligned. |
| 2703.30 | 221 | 02/08/11 | 50.5 | | | | | | NF | NC | | | | | | | | 87 | 13 | | | **(50.5cm):LIMESTONE** Dark grey to grey, hard compact,fossiliferous, fossils are disaligned. |
| 2703.81 | 220 | 02/08/11 | 36.5 | | | | | | | | | | | | | | | 76 | 24 | | | **(36.5cm):LIMESTONE** Dark grey to grey, hard compact,fossiliferous, fossils are disaligned. |
| 2704.17 | 219 | 02/07/11 | 21 | | | | | | | | | | | | | | | 77 | 22 | | | **(21cm):LIMESTONE** Dark grey to grey, hard compact,fossiliferous, fossils are disaligned. |
| 2704.38 | 218 | 02/07/11 | 53 | | | | | | | | | | | | | | | 95 | 5 | | | **(53cm):LIMESTONE** Dark grey to grey, hard compact,fossiliferous. |
| 2704.91 | 217 | 02/06/11 | 57.5 | | | | | | | | | | | | | | | 76 | 24 | | | **(57.5cm):LIMESTONE** Dark grey to grey, hard compact,fossiliferous. |
| 2705.49 | 216 | 02/05/11 | 41.5 | | | | | | | | | | | | | | | 81 | 19 | | | **(41.5cm):LIMESTONE** Dark grey to grey, hard compact,fossiliferous.Oolitic in nature towards bottom. |
| 2705.90 | 215 | 02/05/11 | 10.5 | | | | | | PYF | | V PC | | | | | | | 73 | 23 | | | **(10.5cm):LIMESTONE** Dark grey to grey, hard compact,fossiliferous.Oolitic in nature. |
| 2706.01 | 214 | 02/05/11 | 25 | | | | | | | | | | | | ABSENT | ABSENT | | | | | NONE | **(25cm):LIMESTONE** Grey to dark grey, hard compact fossiliferous, light grey spots(unfossiliferous, fractured) observed at middle |
| 2706.26 | 213 | 02/05/11 | 11 | | | | | | NF | NC | | | | | | | | 93 | 7 | | | **(11 cm):LIMESTONE** Grey, hard, compact fossiliferous, dark grey laminations present. |
| 2706.37 | 212 | 02/04/11 | 24 | | | | | | | | | | | | | | | 95 | 5 | | | **(24cm):LIMESTONE** Grey, hard, compact fossiliferous, dark grey laminations present at middle. |
| 2706.61 | 211 | 02/04/11 | 31.5 | | | | | | | | | | | | | | | 66 | 21 | | | **(31.5cm):LIMESTONE** Grey, hard, compact fossiliferous, dark grey laminations present at middle. |
| 2706.92 | 210 | 02/04/11 | 38 | | | | | | | | | | | | | | | 87 | 13 | | | **(38cm):LIMESTONE** Grey, hard, compact fossiliferous. |
| 2707.30 | 209 | 02/03/11 | 57 | | | | | | PYF | | V POOR | | | | | | | | | | | **(57cm):LIMESTONE** Grey, hard, compact fossiliferous, dark grey lamination present with fossils aligned along with it, towards top and bottom. |
| 2707.87 | 208 | 02/03/11 | 16 | | | | | | | | | | | | | | | 79 | 21 | | | **(16cm):LIMESTONE** Grey, hard, compact fossiliferous, dark grey laminations present. |
| 2708.03 | 207 | 02/02/11 | 35 | | | | | | NF | NC | | | | | | | | 82 | 18 | | | **(35cm):LIMESTONE** Grey, hard, compact fossiliferous, dark grey laminations present. |
| 2708.38 | 206 | 02/02/11 | 23 | | | | | | PYF | | V POOF | | | | | | | 66 | 30 | | | **(23cm):LIMESTONE** Grey, hard, compact fossiliferous, dark grey laminations present. |
| 2708.61 | 205 | 02/02/11 | 39 | | | | | | | | | | | | | | | 82 | 18 | | | **(39cm):LIMESTONE** Grey, hard, compact fossiliferous, belemnite fossils observed towards bottom. |
| 2709.00 | 204 | 02/01/11 | 51 | | | | | | NF | NC | | | | | | | | | | | | **(51cm):LIMESTONE** Grey towards bottom, dark grey towards top, hard, compact, fossiliferous, dark grey laminations present with fossils aligned along with it |
| 2709.51 | 203 | 02/01/11 | 39 | | | | | | | | | | | | | | | 83 | 17 | | | **(39cm):LIMESTONE** Grey, hard, compact, fossiliferous, dark grey laminations present with fossils aligned along with it, towards top. |
| 2709.90 | 202 | 02/01/11 | 5 | | | | | | PYF | | V POC | | | | | | | | | | | **(5cm):LIMESTONE** Grey to dark grey, hard compact, fossiliferous.Foram fossils observed (numulite) |
| 2709.95 | 201 | 02/01/11 | 4 | | | | | | PYF | | | POOR | | | | | | | | | TAKEN TO | **(4cm):LIMESTONE** Grey to dark grey, hard compact, fossiliferous.Foram fossils observed (numulite) |
| 2709.99 | | | | | | | | | | | | | | | | | | | | | | |
| 2710.00 | | | | | | | | | | | | | | | | | | | | | | |

**Fig 12: Core report CC-1 (………m to ……….m) of well XX**

**5:**Microscopic study was also carried out by RGL Panvel. The detailed microscopic study reveals that at places abundant disseminated silt sized calcite common. Moldic porosity towards bottom and top and isolated vuggy porosity are distinct. Tubular grains are also common. Larger foraminifera (Nummulities) are distinct. Moldic and isolated vuggy prosity are common. As a whole organic porosity is destroyed due to sparitization. Tubular grains and disseminated calcite are common. The **Foraminiferal packstone with** solution channel porosity is distinct. Adjacent to it, larger foramnifera is totally sparitized, thereby destroying the framework porosity. Disseminated silt sized calcite are distinct. Predominantly Foraminiferal packstone in which Moldic porosity is seen in the larger foraminifera (Nummulities) at the top and bottom (corner). Most of the Nummulities framework porosity is destroyed due to sparitization. Matrix is micrite. At the bottom, meleolid grain and at the top ooidic grain is distinct. Disseminated calcite is also common and embedded in the micritic matrix. (Fig: 13,14 and 15)

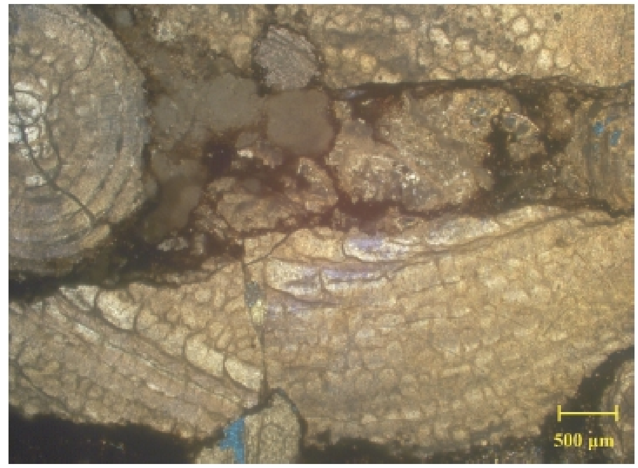



**Fig 13: Depth 2709.7m Foaminiferal Packstone. Abundant larger bioclasts like Numuliteswith other bioclasts. Stylolytes are broad with deposition of pyrite, very fine dolomite and pyrite.at places cutting across the bioclast. Isolated fair intergranular and moldic porosity.**

**Fig 14: Depth 2709.95 Foraaminiferal Packstone. Abundant numulites which are well preserved showing minor fracture. Algae present in minor amounts. Other smaller bioclasts seen around bigger bioclast. Sparatised partially. Porosity poor with isolated moldic porosity.**

**Fig. 15: Depth 2704.40m. Foraminiferal Algal Packstone. Tightly packed comprising many foram and few algae. The forams are better preserved and sparitised. Few stylolytes filled with black pyrite and few dolomitic grains. Good vuggy and moldic porosity.**

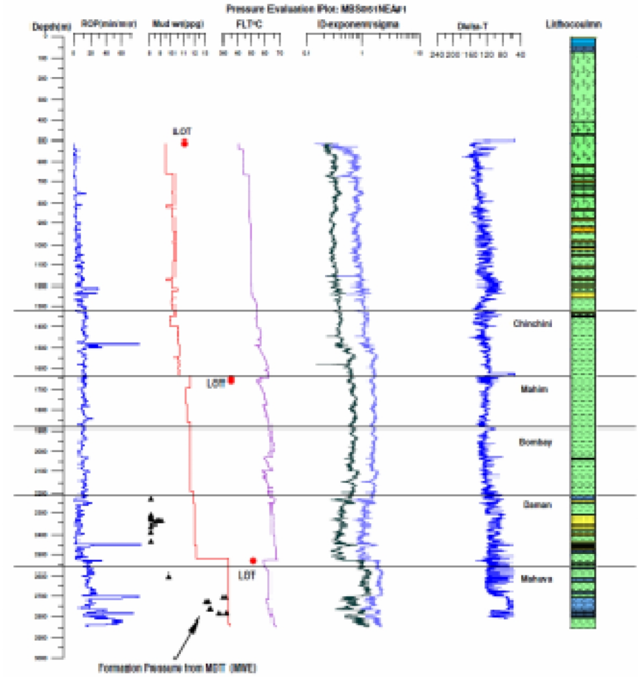
**Reservior Property:**

In the upper section (Foraminiferal packstone), the larger foraminifera like Lepidocyclina are sparitized and micritized with hairline fractures. No porosity is seen. The microfacies in the lower section are Foraminiferal packstone and Foraminiferal wackestone with minor mudstone. The Foraminiferal packstone comprises of larger foraminifera like Lepidocyclina, corals which are sparitised at places. Hairline fractures are seen. Some isolated vuggy and moldic porosity is present. At places framework porosity is seen in corals. Some place algal foraminiferal packstone comprises mostly of larger foraminifera in the lower portion and algae in the upper part. Stylolites with pyrite and fine grain dolomite are common feature. The foraminifera are fully or partially sparitised while the algae are partially sparitised. Bioclasts are fragmented at places. Fair vuggy and moldic, isolated channel porosity are noticed. In Foraminiferal algal packstone the foraminifera are better preserved and sparitised. Few stylolites filled with black pyrite and fine dolomitic grains.

Good vuggy and moldic porosity are observed.

Porosity logs from the interval also suggests poor porosity in general whereas at places good prosity pods are observed (Fig: 16 and 17).

Pore pressure data analysed by the MDT test suggests the limestone to be ……. Nature. The poor influx of water during testing of this limestone in one of the well suggest reservoir to have poor quality. MDT sample@ 2730m yielded water with salinity 80850gpl as NaCl.The interval 2710-2701m was perforated as Object-II. It did not yield anything; During reverse out observed 8.25 bbl influx of water of Salinity: 30360 to 37991 ppm as NaCl.



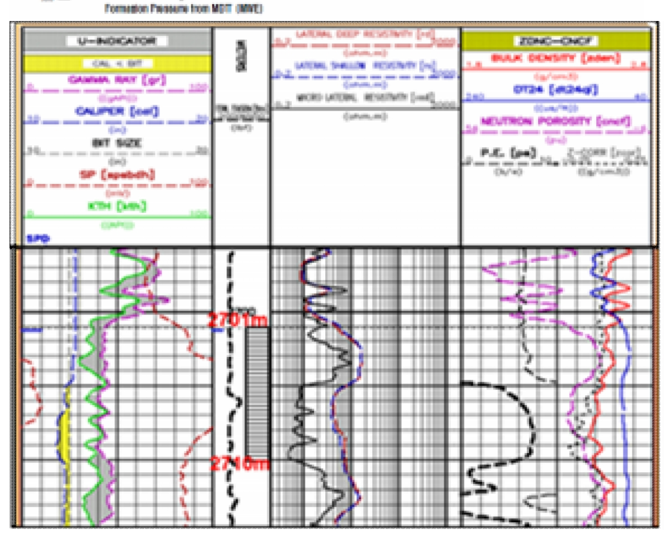




**Fig 16: Electrolog correlation of the Wells X,C and E**

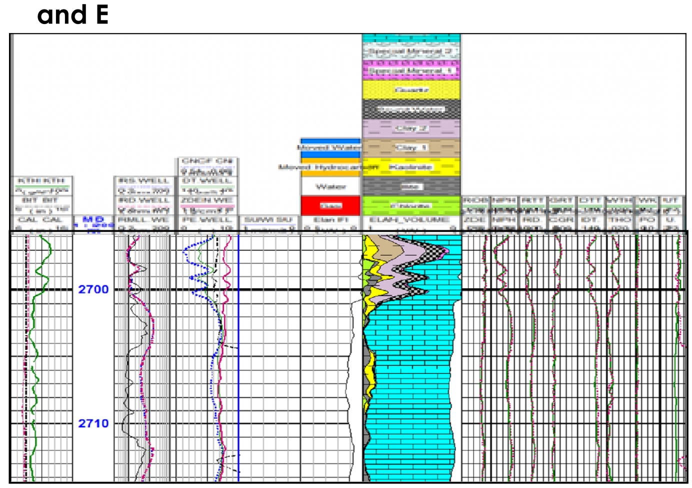



**Fig. 17: Log Motif and ELAN results of Object-II (2701-2710m) in Mahuva Limestone**

Calcimetry data suggests partial dolomitization of the limestone (Fig: 18).

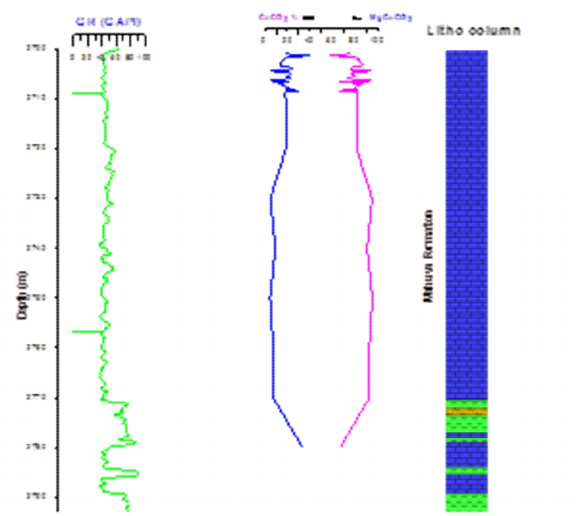



**Fig. 18: Calcimetry plot with GR curve and actual lithology of well XX**

Based on the observations from the wells bathymetry of the area and depositional environment was attempted. he foraminiferal assemblage and lithofacies suggest deposition in an inner shelf environment with bathymetry from 10m to 20m.

Based on the sequence startigraphic approch attempts were made to understand the type of depostion ie catch up or give up carbonate. Attempts has been made to invert the 3D volume and anlyse impedance in the limestone section. Through Geoprobe voume rendering has been attempted and 3 dimensional image of the Geobody was visualised.

## Conclusion:

A new play for the exploration of Hydrocarbon in Early Oligocene period belonging to Lower Mahuva/ Mukta formation is envisaged. Structural, Sratiostructural and Stratigraphic play are expected to play. Sinc the reserviors are in close vicinity to Panna source sediments and proximal to the Kitchen area make the Limestones capable of entraping hydrocarbon. Primary as well as secondary porosity has been developed in the limeston however the porosity destruction sptially and temporally is also observed. Thus a care is must for identifying the locale of exploration.

## Acknowledgement:

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