Sequence stratigraphy and Reservoir characterization of L-III Carbonates in Well X of WO field, Mumbai Offshore

Vikrant Patel[1], Pallav Baruah, Almas Ismail Shah, Tarulata Das
[1]Email: patel_vikrant@ongc.co.in, Oil and Natural Gas Corporation Limited

Abstract
Sedimentological and biostratigraphic studies for Sequence stratigraphic and Reservoir characterization of five nearly continuous conventional cores (CC-5 - CC-1) covering 81m thick L-III carbonates (Early Miocene, Burdigalina age) in well X in WO field located on SW of Mumbai High DCS sector, Mumbai Offshore Block, have been carried out. Lithofacies consist of mixed of carbonate and finer clastic (shale), carbonates consist of clean limestone, argillaceous to nodular limestone, claystone and the finer clatic consists of calcareous shale and carbonaceous shale. Based on distinct benthic foraminiferal suites and lithomicrofacies three depositional environments have been identified 1) Backshore; 2) Tidal flat (Intertidal zone); 3) Foreshore to shallow shoreface. Seven high-resolution sequences have been identified, representing response to short sea level oscillation of an unstable carbonate platform, with several short diastems at top of each sequence. The most widespread and common diagenetic phenomenon in these carbonates affecting the porosity development is sparitization and dolomitization, these have resulted in destruction of both primary and secondary porosity rendering poor reservoir quality. Dolomite development is often recorded in argillaceous limestone. Dissolution along with dolomitization has resulted in moderate to good porosity development at regressive cycle tops.

Introduction
After successful hydrocarbon strike in L-III limestones in a nearby well, well X was drilled with an objective to explore hydrocarbon potential of Basal clastic, Mukta (Early oligocene), L-VI, L-V, L-III, L-II carbonates. These carbonates show frequent temporal facies change. The sedimentological and biostratigraphic studies were carried out with an objective to establish age, litho-microfacies analyses, infer environment of deposition, evaluate T-R cycles within sequence stratigraphic framework and diagenetic study for reservoir characterization. Sequence stratigraphy is considered as one of the latest conceptual revolutions in the broad field of sedimentary geology and emphasizes facies relationships and stratal architecture within a chronological framework.

Methodology
Core gamma analysis was carried out for depth correction and identification of missing intervals of the cores. On correlating core gamma log with open hole wireline gamma electrolog, a uniform 6m downward shift of the cored intervals was inferred. Foraminiferal biostratigraphic studies were carried out to establish age, hiatuses, environment of deposition and paleobathymetry. Different *Miogypsina sp.*, have been used for determination of age. The faunal assemblage and lithomicrofacies are taken into consideration along with change in electro-log motifs in deciphering the environment of deposition and paleo-bathymetry. Sedimentological studies include megascopic, microfacies analyses, SEM studies and X-Ray diffractometry (XRD) studies to bring out lithological variations, mineralogical composition, environmental interpretation and reservoir characterization.

Observations
Litho-biostratigraphy studies of the sedimentary succession of the cored interval (1628m-1709m) reveal repeated deposition of lithofacies such as cleaner limestone, argillaceous- nodular limestone, nodular shale/claystone, calcareous shale and carbonaceous shale. A detailed litho biostratigraphic analysis of the five cores is discussed below:

CC-5 (Core interval- 1691-1709m; Recovery- 45.5% (8.2 m); Core loss- 9.8 m)
The core is represented predominantly by carbonates intercalated with claystone. Bioclastic foraminiferal wackestone and Foraminiferal Packstone/wackestone are dominant facies in the succession. Towards top, thin Foraminiferal Packstone/grainstone and mudstone are present. The matrix is sparitised and dolomitized. Porosity is poor represented by vugs and molds and occasionally channel. Stylolites filled with argillaceous matrix are also present. The foraminiferal assemblage includes *Sphaerogypsina sp., Elphidium sp., Pararotalia sp., Operculina sp., Ammonia sp., Archaias*

sp., milliolids and ostracodes. It suggests 10-15m bathymetry towards bottom and bathymetry decreases to 0-5m towards top.

CC-4 (Core interval: 1670-1688m; Recovery: 22.05% (4.05m); Core loss: 13.95m)
The core is represented by intercalation of carbonates and shale. Foraminiferal wackestone-mudstone is dominant facies in the bottom part. Towards top, Foraminiferal wackestone facies are dominant. Shale is calcareous in towards bottom and carbonaceous towards top. Matrix is sparitised and dolomitized. Porosity is poor, represented by interparticle and intraparticle porosities. The foraminiferal assemblage includes *Sphaerogypsina sp., Elphidium sp.,* and ostracodes. It suggests 0-5m bathymetry.

CC-3 (Core interval: 1655-1670m; Recovery: 54.33% (8.15m); Core loss: 6.85m)
The core is represented by intercalation of carbonates and shale. Coralline foraminiferal wackestone and foraminiferal wackestone represent microfacies, coralline claystone facies are present in the middle part of the core. Shale present in bottom part of core is calcareous and in top part it is carbonaceous. Matrix is sparitised and at places it is dolomitized. Porosity is poor, occasionally good represented by vugs and molds. The foraminiferal assemblage includes *Lepidocyclina sp., Miogypsina cushmani, Eplhidium sp., Heterostegina sp., Borelis sp., Archaias sp., Quinquiloculina sp.,* ostracodes and miliolids. It suggests 10-15m bathymetry which at places decreases to 0-5m towards bottom and middle part of succession.

CC-2 (Core interval: 1637-1655m; Recovery: 80.55% (14.5m); Core loss: 3.5m)
The core is represented predominantly by carbonates with shale intercalations. Mudstone/wackestone represents microfacies in the bottom and Foraminiferal wackestone/coralline foraminiferal wackestone/floatstone towards the top part of the core**.** Matrix is sparitised and dolomitized. Porosity is poor. The foraminiferal assemblage contains *Archaias* sp., *Sphaerogypsina* sp., *Borelis* sp., *Austrotrillina* sp., *Elphidium* sp., *Rotalia* sp., *Triloculina* sp., *Biloculina* sp., ostracodes and bivlaves. It suggests a very shallow 0-10m bathymetry which occasionally increases to 10-15m.

CC-1 (Core interval: 1628-1637m; Recovery: 41.66% (3.6m); Core loss: 5.4m)
The core is represented predominantly by carbonates. Coralline Foraminiferal wackestone, coralline foraminiferal packstone represent the microfacies. Matrix is sparitised. Porosity is poor. The faunal assemblage represents *Archaias sp., Borelis sp., Austrotrillina sp., Sphaerogypsina sp, Elphidium sp.,* miliolid, ostrocode, brachiopod and gastropod. It suggests a very shallow 0-5m bathymetry which occasionally increases to 10-20m.

Sequence Stratigraphy and Trangressive-Regressive (T/R) cycles

L-III carbonate is characterized by stacks of high frequency T/R cycles of variable thickness. Based on Biostratigraphic, Sedimentological studies and paleo-bathymetry curve, seven high-order sequences have been identified. The sequence stratigraphic genetic units identified in this study are transgressive system tract (TST), highstand systems tract (HST) and maximum flooding surface (MFS) which are bounded by sequence stratigraphic surfaces (SB). (Fig 1).

Sequence 1
Sequence 1 is 5.5 m thick and belongs to Burdigalian age. This sequence can be divided into a lower TST overlain by HST. TST is represented by Foraminiferal wackestone facies (Fig 2) and render poor porosity. HST is characterized by Dolomitic foraminiferal wackestone/packstone facies (Fig 3) and shows poor to good porosity.

Sequence 2
Sequence 2 is 11 m thick and belongs to Burdigalian age. This sequence can be divided into a lower TST overlain by HST. TST is represented by Dolomitic mudstone facies (Fig 4) and show poor porosity. Complete HST of sequence 2 falls in core loss zone.

Sequence 3
Sequence 3 is 13 m thick and belongs to Burdigalian age. This sequence can be divided into a lower TST overlain by HST. Complete TST of sequence 3 falls in core loss zone. HST is characterized by

Foraminiferal wackestone/mudstone facies (Fig 5) and render poor porosity, occasionally good porosity is also observed. Dolomitization is common.

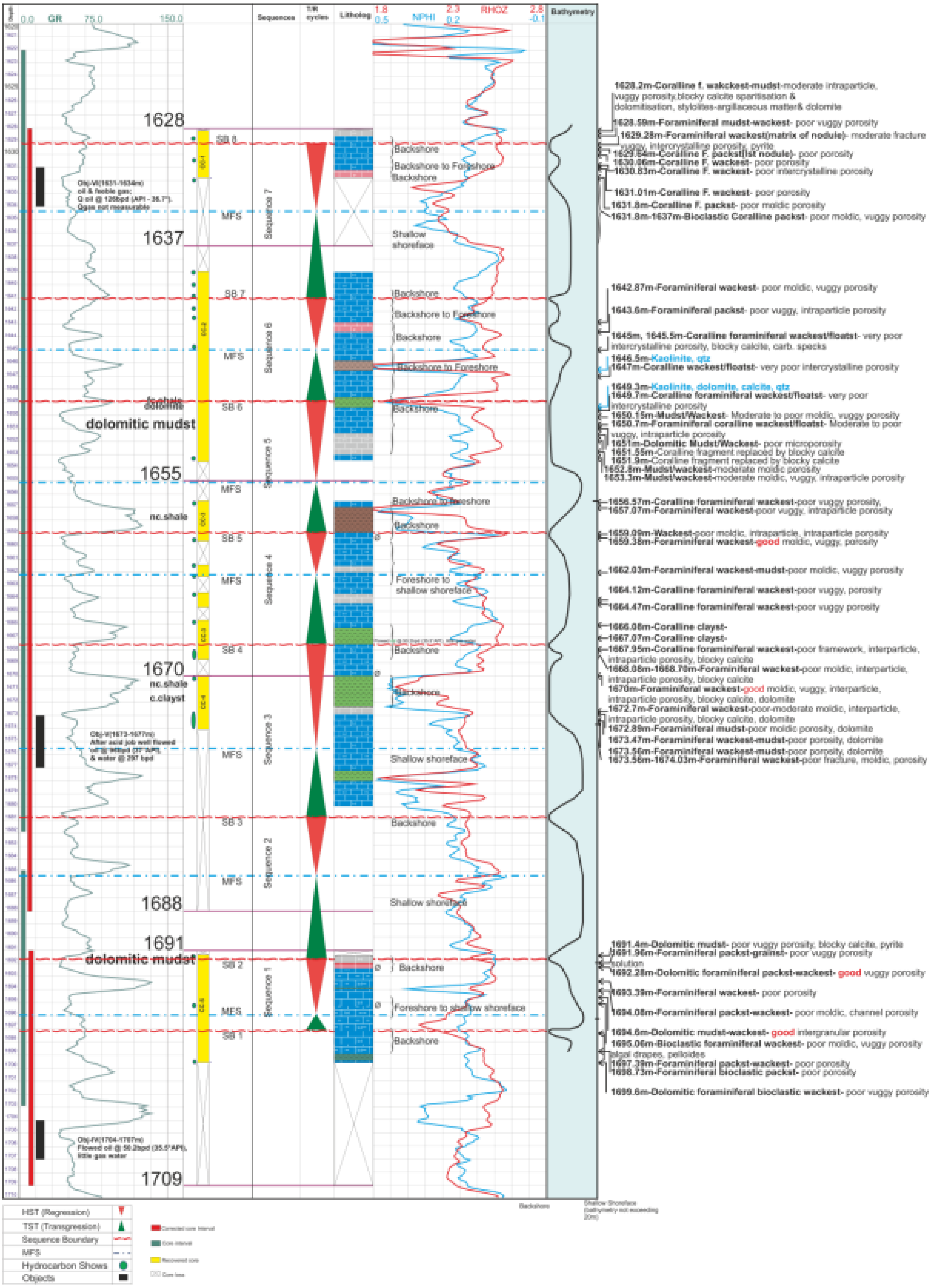


Fig 1: Intergrated summary chart of CC-1 to CC-5 of well X

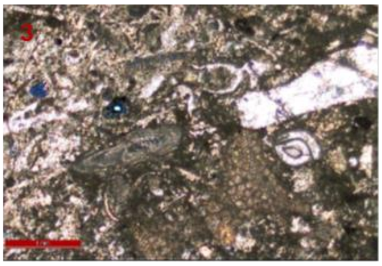




Fig 2: Microfacies developed during TST of Sequence 1; Depth 1697.39m, Foraminiferal wackestone; **Fig 3: Microfacies developed during HST of Sequence 1;** Depth 1694.08m, Foraminiferal packstone/wackestone; **Fig 4: Microfacies developed during TST of Sequence 2;** Depth 1691.40m, Dolomitic mudstone

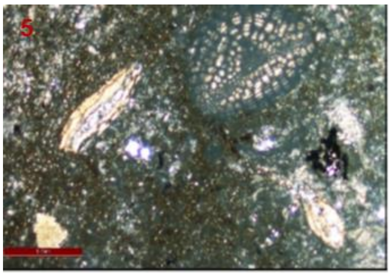
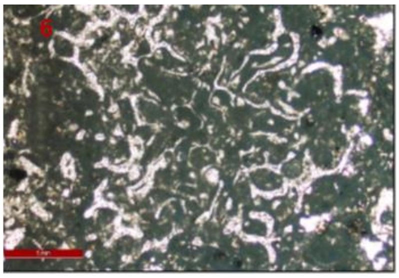
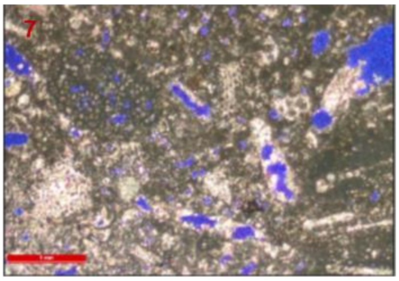




Fig 5: Microfacies developed during HST of Sequence 3; Depth 1673.56m, Foraminiferal wackestone/mudstone; **Fig 6: Microfacies developed during TST of Sequence 4;** Depth 1664.47m, Corraline foraminiferal wackestone; **Fig 7: Microfacies developed during HST of Sequence 4;** Depth 1659.38m, Dolomitic mudstone

Sequence 4

Sequence 4 is 8.5 m thick and belongs to Burdigalian age. This sequence can be divided into a lower TST overlain by HST. TST is represented by Coralline foraminiferal wackestone facies (Fig 6) and shows poor porosity. HST is characterized by Foraminiferal wackestone/mudstone facies (Fig 7) and render poor porosity, occasionally good porosity is also observed in the form of molds and vugs.

Sequence 5

Sequence 5 is 10 m thick and belongs to Burdigalian age. This sequence can be divided into a lower TST overlain by HST. TST is represented by carbonaceous shale and coralline foraminiferal wackestone facies (Fig 8), porosity is poor. HST is represented by Foraminiferal coralline wackestone/floatstone and Dolomitic Mudstone/Wackestone (Fig 9), and shows poor to moderate porosity.

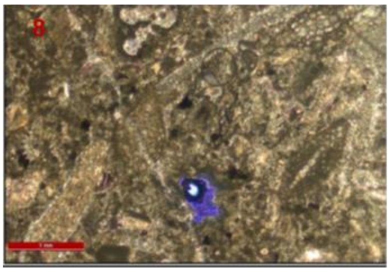
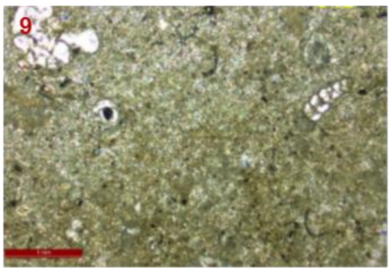
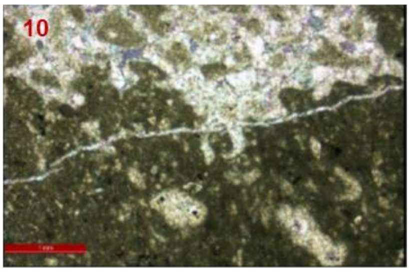
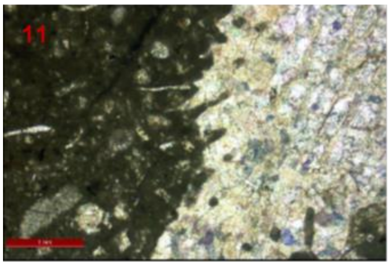
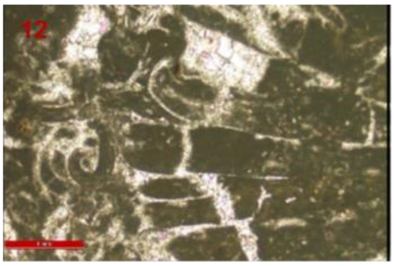




Fig 8: Microfacies developed during TST of Sequence 5; Depth 1657.07m, Foraminiferal wackestone; **Fig 9: Microfacies developed during HST of Sequence 5;** Depth 1651m, Dolomitic mudstone/wackestone; **Fig 10: Microfacies developed during TST of Sequence 6;** Depth 1647, Coralline wackestone/floatstone

Sequence 6
Sequence 6 is 8 m thick and belongs to Burdigalian age. This sequence can be divided into a lower TST overlain by HST. TST is represented by coralline foraminiferal wackestone/floatstone facies (Fig 10), showing very poor to poor intercrystalline porosity. HST is represented by foraminiferal wackestone/packstone facies (Fig 11), and shows poor vuggy, moldic porosity.

Sequence 7
Sequence 7 is 12 m thick and belongs to Burdigalian age. This sequence can be divided into a lower TST overlain by HST. TST is represented by Bioclastic Coralline packstone (Fig 12), showing poor moldic and vuggy porosity. HST is represented by Coralline foraminiferal wackestone/packstone facies (Fig 13), showing poor porosity.





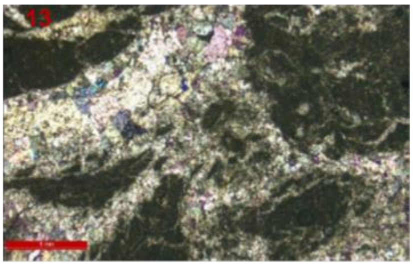


Fig 11: Microfacies developed during HST of Sequence 6; Depth 1645.5m, Coralline foraminiferal wackest/packstone; **Fig 12: Microfacies developed during TST of Sequence 7;** Depth 1637m-Bioclastic Coralline packstone; **Fig 13: Microfacies developed during HST of Sequence 7;** Depth 1630.06m-Coralline foraminiferal wackestone

Conclusions
L-III carbonates of Burdigalina age in well X are represented by lithofacies consisting of mixed of carbonate and finer clastic (shale), carbonates consist of clean limestone, argillaceous to nodular limestone, claystone and the finer clatic consists of calcareous shale and carbonaceous shale. Based on distinct benthic foraminiferal suites and lithofacies, three depositional environments can be identified. A) Backshore marshes B) Foreshore tidal flats (Intertidal zone) C) Shallow shoreface. Major diagenetic features include sparitisation, dolomitization, dissolution associated with subaerial exposure, pyrtisation and stylolaminations. Porosity is poor with occasional moderate to good porosity at places. Seven high-order sequences of variable thickness within sequence stratigraphic architecture, developed in response to short sea level oscillation of an unstable carbonate platform. Potential reservoir facies consisting of Dolomitized foraminiferal packstone facies are associated with HST (Regressive) cycles and these facies often exhibit good porosities (vuggy and moldic), developed during sub-aerial exposure.

Acknowledgement
The views expressed by authors are those of authors only. The authors are grateful to ONGC, for providing an opportunity to carry out the work. The authors also express their sincere gratitude to Shri Vikas J Pandey, ED-Basin Manager, WOB, Smt. Sapna Sethi, CGM(Chem)-Head RGL, Smt Bharati P Jagtap, GM (Geol) for encouragement and support to write the paper. Sincere thanks are also due to Ms.Fiona, JTA for Paleontological sample processing and sorting. The services of Shri G.B. Pawar, Sr. Worker, for Core Library support are praise worthy.

References
1. **Amirshahkarami, M., Karavan, M., 2015**. Microfacies models and sequence stratigraphic architecture of the Oligocene-Miocene Qom Formation, south of Qom City, Iran.
2. **Flügel Erik, 2003**. Microfacies of Carbonate Rocks Analysis, Interpretation and Application; Springer-Verlag Berlin Heidelberg.
3. **G. Wang et al., 2015.** Dolomitization process and its implications for porosity development in dolostones: A case study from the Lower Triassic Feixianguan Formation, Jiannan area, Eastern Sichuan Basin, China. Journal of Petroleum Science and Engineering; Volume 131, Pages 184-199.

4. **Raju D.S.N., 1991**. Miogypsina scale and IndianChronostratigraphy, Geoscience Journal 12(I), pp 53-65.
5. **Schaub Hans**, **1981**. Nummulites et, Assilines de La Thetys Paleogene, Texonomie, Phylogenese et biostratigraphie , Texte : Vol 104, Atlas 1 ; Vol 105, AtlasIIVol. 106, Birkhauser Bale, Swizarland.
6. **Scholle, Peter, 1978**. A colour illustrated guide to carbonate rock constituents, textures, cements and porosity. AAPG Memoir 27.