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NANNO-BIOCHRONOLOGY FOR REFINED SEQUENCE STRATIGRAPHIC BOUNDARIES IN MUMBAI OFFSHORE BASIN, INDIA

Abstract

Nanno-biochronology is used to subdivide sedimentary sequences comprising Panna, Devgarh, Bassein/Belapur, Heera/Mukta, Alibagh/Panvel, Mumbai/Ratnagiri, Mahim formations of Western Offshore of India into various bio-chronostratigraphic units vertically and to correlate laterally with the adjoining area. The standard best worldwide applicable nannofossil bioevents/zones are utilized in the study.The wells from Tapti-Daman, Heera-Panna-Bassein, DCS and Ratnagiri Blocks (C-37-D, B-28A-E, WO-16-F, D-33-B and DLS-A and Ratnagiri-A) from Mumbai Offshore Basin were selected for the nannofossil biochronostratigraphic framework and to record the sequence stratigraphic boundaries in the Cenozoic succession. The Nannofossil biochronostratigraphic data, mostly applied in the oil industry provides regional sequence stratigraphic boundaries of the Cenozoic sediments of Mumbai Offshore. The first order rift/passive margin sequences are punctuated by regional hiatuses/unconformities of varying magnitudes, have been identified during Paleocene to Miocene times.

Introduction

In Mumbai Offshore, basaltic basement forms the floor of the sedimentary succession with excellent development of Paleocene to Pliocene sediments. Mumbai Offshore is the most explored basin lies on the western continental margin of India which covers an area of over 1, 48,000 sq. kms upto 200m isobath. Zutshi et al., 1993 provided integrated stratigraphic framework of the formations encountered in the Mumbai Offshore Basin and is divided into six tectono-sedimentary blocks namely Tapti-Daman, Diu, Panna-Bassein, Mumbai High-DCS, Ratnagiri and shelf margin blocks. Based on major tectonic events, the complete sequence of Mumbai Offshore Basin has been grouped into Rift and Passive margin sequences. In order to understand finer time slicing of its sedimentary record, marked by unconformities, it is essential to understand the development of various age sequences and their environment of deposition. In view of this, calcareous nanno-biochronology facilitated a biochronostratigraphic scheme in Cenozoic carbonates/clastic postrift megasequence and synrift/rift sediments in Ratnagiri, Tapti -Daman, Bombay High-DCS and Heera-Panna-Bassein areas of the Mumbai Offshore. Biostratigraphic studies of Datta and Singh, 1976; Guptha, 1976; Saxena, 1986, 1996; 2000 & 2007; Singh, 1980 and Ravindran et al., 2005 were consulted for the study. The sequence stratigraphic nomenclature is based on the study of Petroleum system sequence stratigraphy, 2008.

Methodology

Time framework of the sedimentary succession of the studied area is evolved on the basis of nannofossil biostratigraphic data. Selected cuttings and cores are used for the recovery of the nannofossils. Conventional permanent smear slides are prepared for each sample using standard processing technique. The calcareous nannofossils were observed under the Polarizing Research Microscope under X1000 magnification in cross polarized light and normal light. The NP(Nannofossil Paleogene) and NN(Nannofossil Neogene) zonation scheme proposed by Martini, 1971 and additional studies of Perch-Nielsen, 1985; Okada & Bukry, 1980; Young, 1998 and Gradstein et al., 2004 are utilized to date the sediments of Panna/ Devgarh/ Jafarabad, Belapur/ Bassein/Diu, Mahuva/ Mukta/ Heera, Alibag/ Panvel/ Daman, Mumbai/ Mahim/ Ratnagiri formations as presented in Zutshi et al., 1993. A detailed nannofossil biostratigraphic study of well Ratnagiri-A of Ratnagiri area, well C-37-D of Tapti -Daman , wells WO-16-F, D-33-B and DLS-A of Bombay High-DCS and well B-28-B of Heera-Panna-Bassein of Mumbai Offshore have been carried out for deciphering the sequence stratigraphic boundaries. The well samples are examined for nannofossil markers for detailed nannofossil biochronostratigraphy.

Rift sediments in the well Ratnagiri-A

The well Ratnagiri-A lies in the Ratnagiri depression (Figure1) and penetrated upto 3720m depth in trap.The 3015 to 3720m rift clastic sediments of Panna Formation, have been studied for nannofossil biochronostratigraphy (Figure 2).The interval 2800-3015m recorded diversified assemblage of nannofossils. Highest occurrence of nannofossil *Lanternithus duocavus* at 2850m marks the top of NP4 zone(=60.4Ma) of Selandian age, suggesting the oldest sediments of Middle Paleocene were deposited during rift/synrift sedimentation in the Ratnagiri area and is equated with the 1st order sequence CI20.

Passive Margin Sediments

Well DLS-A was successfully drilled down to the depth of 4065m, penetrating Panna Formation (Figure 1).The nannofossil biostratigraphic study between depth interval 2760 to 4065m is taken up (Figure 3). FAD (First Appearance Datum) of *Toweius* spp. at 3945m in the section suggests Ypresian age equivalent to nannofossil zone NP12.The section above 3945m indicate Lower NP12 zone (52.2 Ma) and suggests hiatus of 3.6Ma,corresponding to CI20 sequence stratigraphic boundary. LAD (Last Appearance Datum) *Cribrocentrum reticulatum* (33.9Ma) and *Discoaster barbadiensis* at 3120m in well section indicate the top of NP20 (34.4Ma) nannofossil zone and suggests minor hiatus of 0.5 Ma corresponding to CII 40 at Late Eocene.

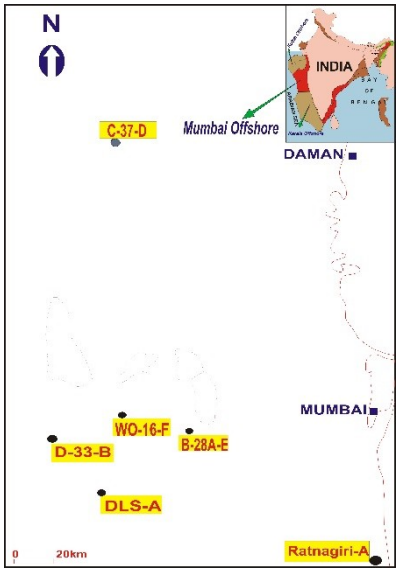


Figure 1. Location Map of the studied wells in the Mumbai Offshore Basin

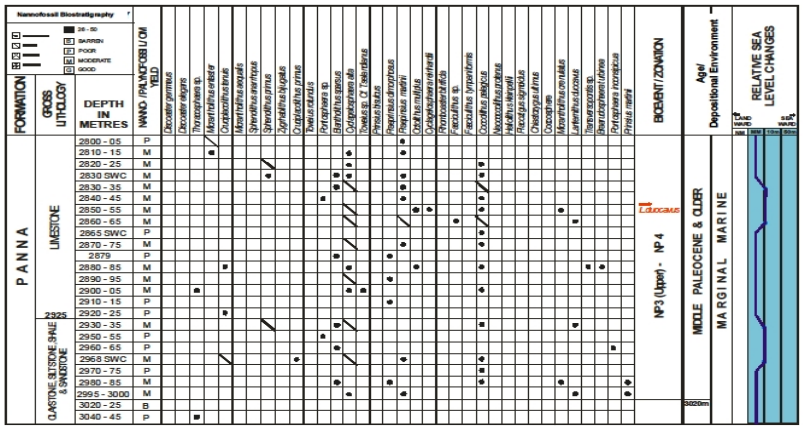


Figure 2:Distribution of nannofossils, events/zones, age and environment in the well Ratnagiri- A

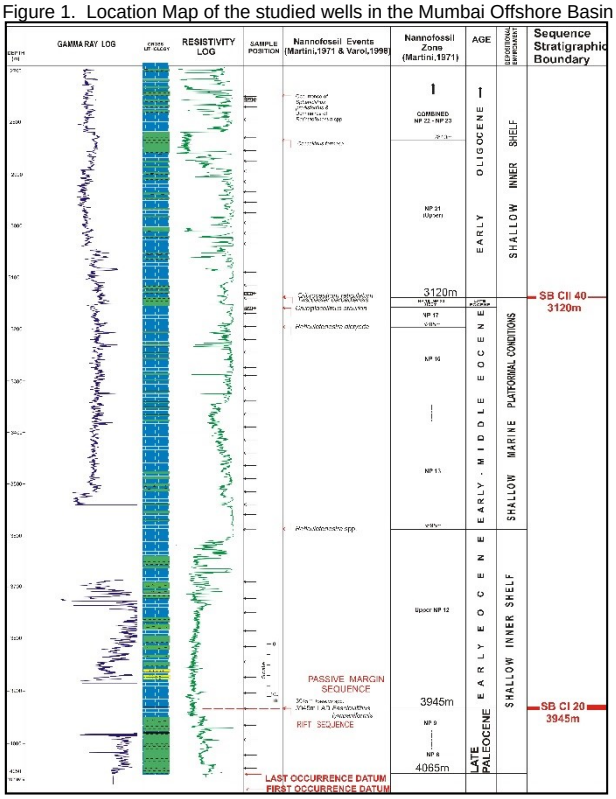


Figure 3: Sequence stratigraphic boundaries in well DLS-A

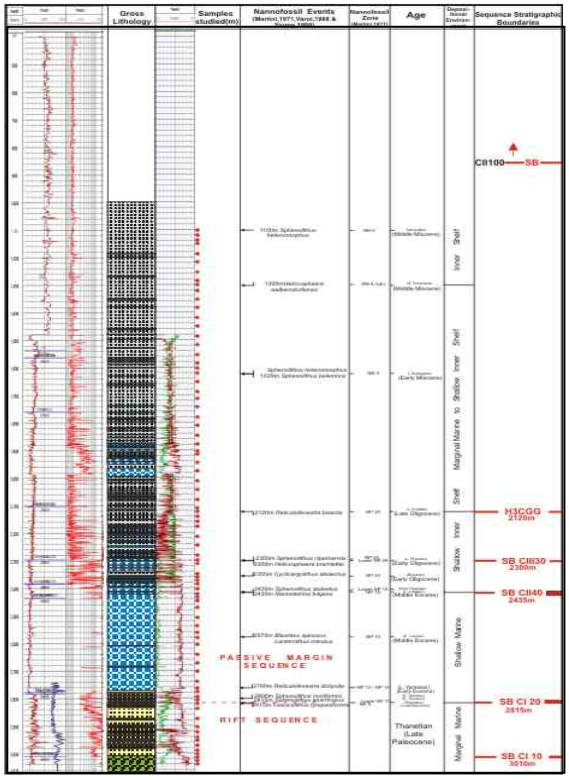


Figure 4: Sequence stratigraphic boundaries in well WO-16-F

Well WO-16-F (Figures 1 and 4) is penetrated in the Basalt upto 3070m depth. The rift sequence (2815-3000m) is lying on the trap at 3010m is of Thanetian age. The nannofossils depicted third order unconformity of 2.0Ma at CI20 level.The span of unconformity 5.1- 11.1Ma (Late Eocene) is equated with sequence stratigraphic boundary CII40 or H3B in wells WO-16-F and D-33-B. In well B-28A-E, hiatus is low i.e. 2.1Ma. A minor hiatus of 0.2Ma is depicted at 2300m, equating with sequence stratigraphic boundary CIII30 in Early Oligocene. The limit of latest Oligocene sequence is characterised at 2120m, which suggests top of NP25 zone (Late Oligocene) and approximates with the local seismic marker H3CGG.

Well D-33-B (Figure 1) penetrated in Panna Formation upto a depth of 3844m. At 3120m, presence of *Nannotetrina fulgens* is reported at lower NP15 zone (=44.0Ma) of Lutetian (Middle Eocene) age (Figure 5). Also present *Sphenolithus distentus* at 3120m indicating nannofossil zone NP23 (=31.8Ma) of Late Rupelian age. A hiatus of 12.2 Ma covering Bartonian to Early Rupelian age, corresponding to CII40 sequence stratigraphic boundary is interpreted at 3120m. The upper limit approximates with the local seismic marker H3CGG.
Well B-28A-E (Figures 1 & 6), penetrated in the Basalt upto the depth of 2520m. Interval 2435m-2466m recorded LAD

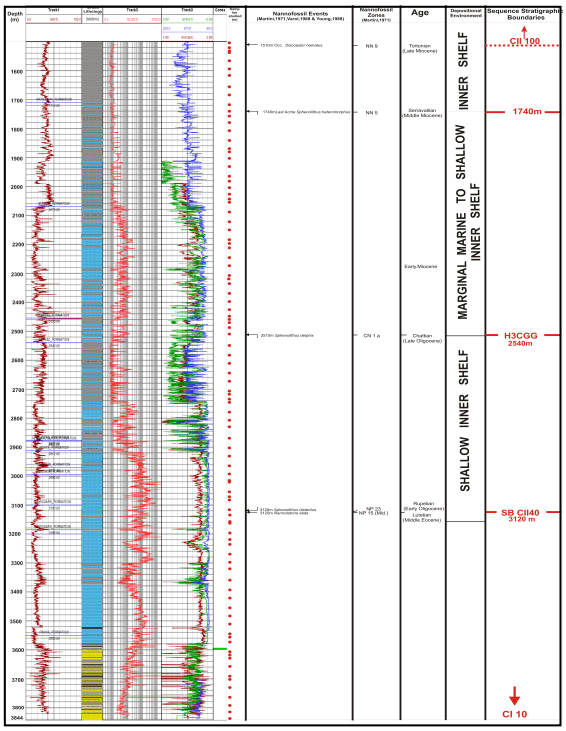


Figure 5: Sequence stratigraphic boundaries in well D-33-B

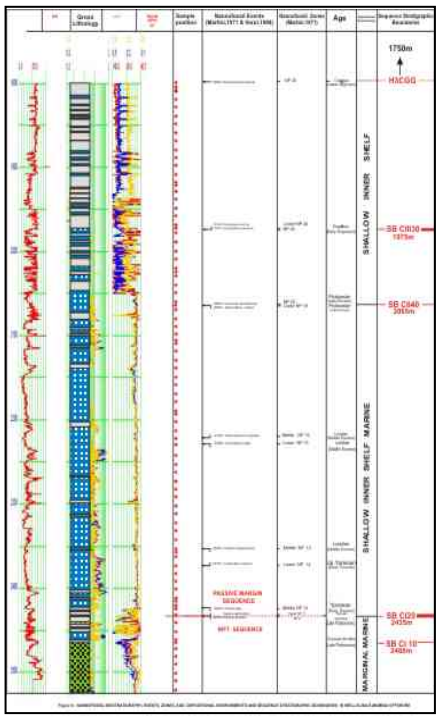


Figure 6: Sequence stratigraphic boundaries in well B-28A-E

Prinsius bisulcus (55.8Ma), which suggests NP9 zone of Late Paleocene and FAD *Toweius gammation* (53.0Ma) suggests upper NP11 zone of Early Eocene age at 2435m, indicating an unconformity of 2.8Ma,corresponding to sequence stratigraphic boundary CI20. LAD *Sphenolithus radians* (36.8Ma) at 2065m of Lower NP18 zone and also LAD *Discoaster barbadiensis* at 2065m suggesting nannofossil zone NP20 (=34.4Ma) of Early Priabonian age. A hiatus of 2.4Ma of Late Priabonian (Late Eocene) is inferred at CII40 sequence boundary. Interval 1975-2050m represents E-L Oligocene at 1975m, which corresponds to H3G and represents unconformable contact (1.6Ma hiatus) of sequence stratigraphic boundary CIII30.The overlying section (1800-1910m, Chattian age) corresponds to H3CGG.

Well C-37-D is (Figure 1) drilled upto 4185m in Panna Formation. (Figure 7a and 7b). Middle-Late Eocene (Interval 3195-3343m) section recorded FAD *Cribrocentrum reticulatum* at 3343m (Upper NP15=44.0Ma) and FAD of *Lanternithus minutus* at 3343m (Lower NP14=48.0Ma), which suggests hiatus of 4.0Ma, marking CII30 sequence stratigraphic boundary. LAD *Cribrocentrum reticulatum* and *Discoaster barbadiensis* (NP20) at 3195m of Priabonian (Late Eocene) age. The Rupelian (Early Oligocene) section is represented by LADs of *Lanternithus minutus* at 3115m (Lower NP 21=34.2 Ma) and *Pemma papillatum* (NP 21= 33.0Ma), which indicates a hiatus of 1.2Ma corresponding to CII40 sequence stratigraphic boundary.

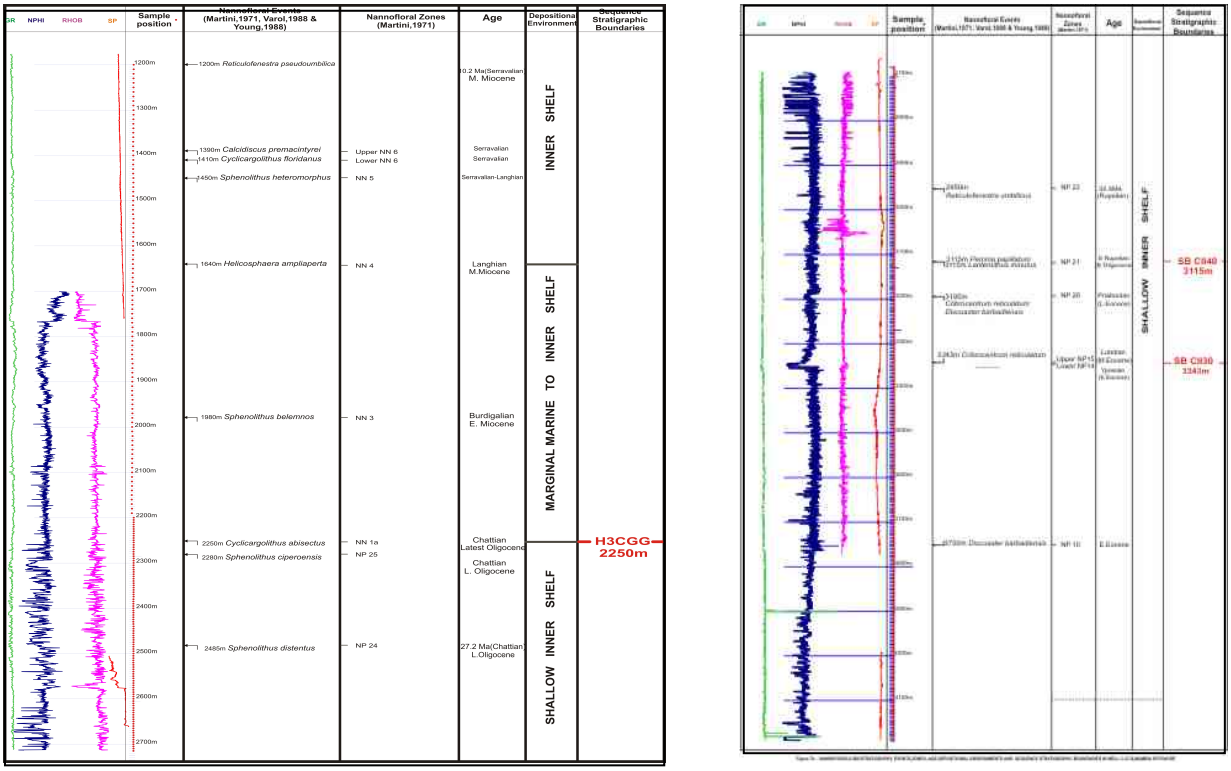
Stratigraphic sequence boundaries of Mumbai Offshore

The nannofossil biochronostratigraphic studies of Cenozoic sequences encountered in seven wells viz., Ratnagiri-A, C-37-D, B-28-B, WO-16-F, D-33-B and DLS-A have been carried out and the basement Precambrian granite gneiss or Deccan Trap is encountered in some wells. Interpretations of the biochronostratigraphic boundaries are linked with the sequence stratigraphic boundaries (Figures 2,3,4,5, 6,7a and 7b).Sequence biochronostratigraphic analysis of the Mumbai Offshore leads to assigning sequence stratigraphic boundary/unconformities in between Selandian (Middle Paleocene) to Messinian (Late Miocene) stages (Figure 8).

The CI10 sequence boundary is a contact between the trap and overlying sediments. The oldest datable rift/synrift sediments overlying the traps are of Selandian (Middle Paleocene) age in the Ratnagiri area (Saxena, 2007), which corresponds to oldest 1st order rift sequence recorded in the basin.The lower boundary is marked by trap unconformity

(CI10). It is penetrated in the wells WO-16-F and B-28A-E at depth Intervals 3010m and 2466m respectively. The studied rift sequence has yielded rare to rich assemblage of nannofossils of Selandian (Middle Paleocene)-Thanetian (Late Paleocene) age. In general the paleoenvironmental regime in this sequence ranges from fluvial to marginal marine/shallow inner shelf.

The CI20 sequence boundary is an unconformity at rift/passive margin. Unconformity of 2.0Ma magnitude at rift/passive margin is recorded in the well WO-16-E and relatively higher magnitude (2.8-3.6Ma) in wells B-28A-E and DLS-A in the basinal side of Mumbai Offshore. In well WO-16-F at depth 2815m, an unconformable contact (span2.0Ma), ranging from LAD *Sphenolithus anarrhopus* (53.80 Ma) to LAD of *Fasciculithus tympaniformis* (55.8 Ma)



Figures 7a and 7b: Sequence stratigraphic boundaries in well C-37-D

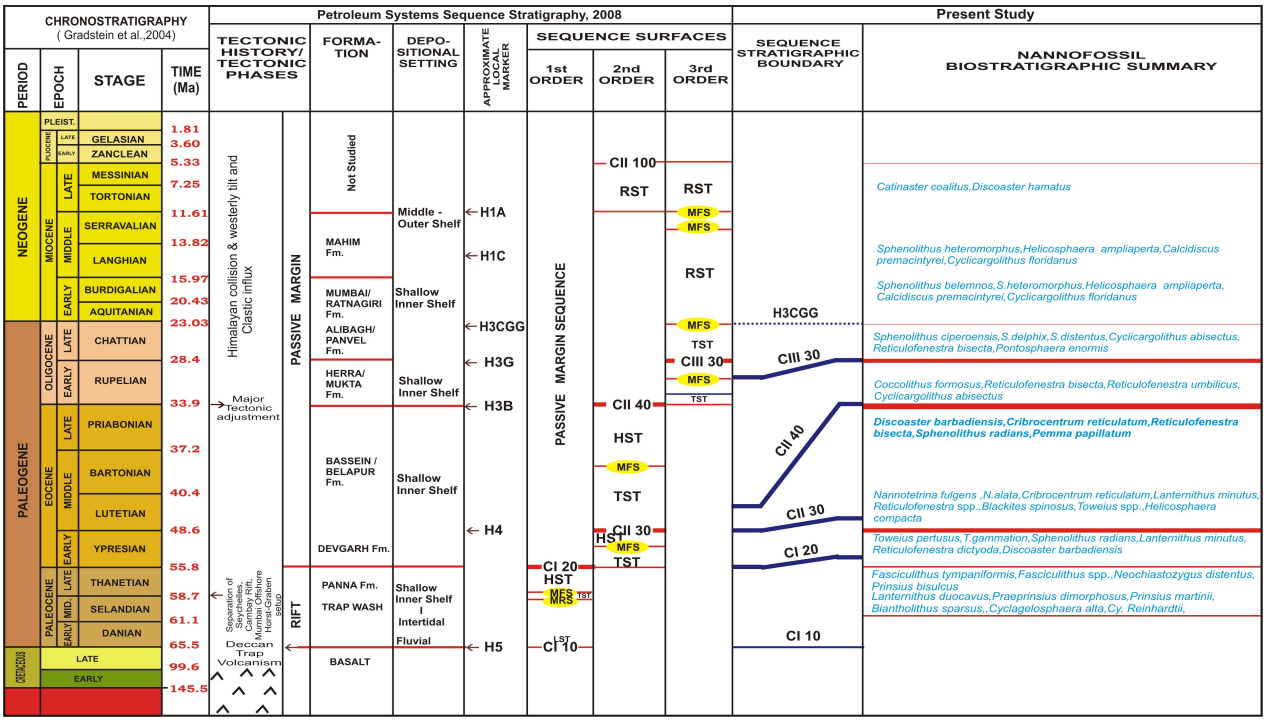


Figure 8. Sequence stratigraphic summary based on nannofossil biochronostratigraphy of Mumbai Offshore Basin

encompassing the rift sequence. In well B-28A-E at depth 2435m, the unconformable contact show 2.8 Ma span. (Figure 6). The entire sequence resting over the CI20 sequence boundary is termed as Passive Margin Sequence. The CI20 sequence stratigraphic boundary differentiate between the rift and passive margin sequences and is identified in the other wells BSE-F at 2395m, DLS-A at 3945m and Ratnagiri-A at 2800m.

The CII30 sequence boundary is represented by Early Eocene and is identified in the well B-28A-E at depth 2425m and in well C-37-D at depth 3343m. In well B-28A-E,a second order sequence is identified at 2435m with the LAD of *Toweius* spp. (48.6Ma). In well C-37-D, FADs of *Lanternithus minutus* and *Cribrocentrum reticulatum* indicate unconformity of 6.2Ma. The sequence stratigraphic boundary CII30 with the span of unconformity 4.4Ma of second order is identified at 2435m in the well B-28A-E, which is easily correlatable with other wells in the HPB, Tapti-Daman and Bombay High-DCS area in the Mumbai Offshore.

The CII40 sequence boundary is recorded as an unconformity of Bartonian to Priabonian. In well WO-16-F at 2430m, unconformity spanning 11.1Ma from Bartonian to Priabonian, in well C-37-D, the sequence boundary is represented at 3115m encompassing Late Eocene age. In the well B-28A-E, the sequence is represented at 2065m in Latest Bartonian age. The hiatus of CII40 sequence boundary span in the well WO-16-F is 11.1Ma, 2.1Ma in the well B-28A-E and 5.1 Ma in the well D-33-B covering Latest Bartonian to Priabonian age. The span of unconformity is major one ranging from 2.1 -11.1Ma at this level in Bombay High-DCS area.

The CIII30 sequence boundary is Early/ Late Oligocene unconformity and is a widely recognized by the seismic marker H3G and estimated time span of this hiatus to be around 2.5-3 Ma. In well WO-16-F, CIII30 is at 2300m, in well B-28A-5, CIII30 at 1930m in the HPB block of Mumbai offshore Basin. It is extended up to Bombay High-DCS and Tapti-Daman area. The span of unconformity is 1.6Ma at this level.

H3CGG is a seismic marker, which corroborates with Oligocene / Miocene unconformity and sequence boundary. In the well C-37-D, at 2250m marks the upper limit equivalent to the top of Late Oligocene and in well WO-16-F, H3CGG surface is represented at 2120m. The H3CGG level lies in the latest Chattian (Late Oligocene).The upper sequence i.e younger to H3CGG seismic marker in Miocene times reflects relatively deeper inner shelf marine conditions than Oligocene, thus pointing to an overall deepening trend with time. The CII100 sequence boundary is represented by the correlative conformity between Miocene-Pliocene sequences. It is not recorded in the studied wells.

Discussion

The oldest Middle Paleocene (60.4Ma) rift sediments are encountered after cessation of Deccan Trap volcanism in

Mumbai Offshore Basin. Raju (2009) discussed the stratigraphy and environment of deposition of various formations in Mumbai Offshore and has been considered here. The sediments of Panna Formation are represented by sandstone intercalated with carbonaceous shale, coal and siltstone in the eastern and southern wells of Mumbai Offshore. The deposition is equated with oldest Middle Paleocene rift fill sediments overlying the CI10 boundary. The rift was aborted during late Paleocene and the overlying clastics associated with limestone are represented by the rich late Paleocene nannofossils, suggesting first oldest marine transgression in the area. The lower limit of the 1st order rift sequence is diachronous ranging from Middle Paleocene to Late Paleocene. The unconformity bounding CI20 boundary is identified at 55.8Ma during Thanetian (Late Paleocene) times in the HPB area, at 54.0Ma in the Tapti-Daman area and at 53.6 Ma in the Bombay High-DCS area. Subsequently, basin witnessed the development of Passive margin Late Paleocene to Pliocene sedimentation. The second transgression was most extensive during Middle Eocene sediments inundating the Mumbai High-DCS area completely with the deposition of widespread monotonous carbonates in platformal regime. The sequence stratigraphic boundary CII30 with the span of unconformity 4.4-6.2Ma of second order is identified in the HPB, Tapti-Daman and Bombay High-DCS areas during early/middle Eocene. A major regression is witnessed between Late Eocene and Earliest Oligocene sedimentation. It transformed into basin wide major unconformity spanning 2.1-12.1Ma from Bartonian to Priabonian and equated with sequence stratigraphic boundary CII40.The marine transgression deposited Early Oligocene sediments in shallow shelf and later Early/ Late Oligocene unconformity is widely recognized equating with CIII30 and seismic marker H3G. The estimated time span of this hiatus is to be around 2.5-3.0Ma and suggests also an increase in duration of hiatus from west to east in the basin. During extensive marine transgression Late Oligocene sediments were deposited in shallow inner shelf setup. The seismic marker H3CGG corroborates with Oligocene / Miocene unconformity, though of low magnitude. Subsequently, relatively deeper inner shelf conditions prevailed during Early Miocene sedimentation. The late Miocene sediments were deposited in a transgressive phase with very high sedimentation rates.

The study embodies the nannofossil biostratigraphic data, the chronology of the nanno-events which are closely linked with sequence stratigraphic boundaries regionally and helped to identify seven unconformities of varying magnitudes in the Cenozoic succession of the Mumbai Offshore for sequence stratigraphy.

Conclusions

1.The 1st order rift sequence range from Selandian (Middle Paleocene) –Thanetian (Late Paleocene) age. The oldest known Panna sediments overlying the traps are of Selandian (60.4Ma; Middle Paleocene) age in the Tapti-Daman and Ratnagiri area.
2. First regional marine transgressive phase with in rift-fill Panna sediments of basin is witnessed during Thanetian (Late Paleocene) times between CI10 and CI20 sequence boundaries.
3.A third order unconformity spanning 2.0-2.8Ma at CI20, demarcating the Passive margin sequence with rift sequence of Selandian – Thanetian age. The span of unconformity is identified for the first time at 55.8Ma during Thanetian (Late Paleocene) times in the HPB and Bombay High-DCS areas.
4.The sequence stratigraphic boundary CII30 with the span of unconformity 4.4-6.2Ma during Ypresian (Early Eocene) times of second order demarcating Devgarh-Belapur/Bassein sedimentation, easily correlatable in the HPB, Tapti-Daman and Bombay High-DCS area.
5.The CII40 sequence stratigraphic boundary conspicuously spanning 2.1 -11.1Ma during Late Bartonian to Priabonian times is identified between Bassein-Heera/Mukta Formations and correlatable in the HPB and Bombay High-DCS area. It is a prominent hiatus and regarded as Eocene/Oligocene unconformity in the Mumbai Offshore.
6.The CIII30 sequence boundary is widely recognized as Early/ Late Oligocene unconformity with the estimated time span of 2.5-3.0 Ma between Heera/Mukta - Alibag/Panvel Formations and suggests an increase in duration of hiatus from west to east.
7.The seismic marker H3CGG corroborates with the 3rd order Late Oligocene / Miocene unconformity between Alibag/Panvel - Mumbai/Ratnagiri formations in the Tapti-Daman and Bombay High-DCS areas.
8. Miocene times reflect relatively deeper marine conditions than Oligocene, thus pointing to an overall deepening trend with time which is evidenced by a rich and diverse marine phytoplankton calcareous nannofossil species during Burdigalian (Early Miocene) and (Serravalian) Middle Miocene times. Tortonian (Late Miocene) section contains age diagnostic nannofossils FAD of *Catinaster coalitus* of zone NN8 and LAD of *Discoaster hamatus* of zone NN9 and inferred to be deposited in inner shelf depositional conditions.
9. The sequence stratigraphic boundaries are identified with the span of hiatus in the Cenozoic sections of Mumbai Offshore using nannofossil biochronostratigraphy, which added geological information in refining the subsurface sequence stratigraphic boundaries as applicable to sequence stratigraphy for interbasinal correlation in Western Offshore of India.

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References

Datta,A.K. and Singh,P.(1976). Nannoplankton from the Late Early Pliocene subsurface formation of the Bombay Offshore region,p 408,In :Srinivasan,M.S. (Editor) Proc. 6th Ind. Colloq. Micropal. Strat., Varanasi, 40-52.

Gradstein, F.M., Ogg, J.G., Smith, A.g., Bleeker, W. and Lourens, L.J (2004). A new geological Time Scale, with special reference to Precambrian and Neogene. Episode, 27 (2): 83-100.

Guptha,M.V.S.(1976). Calcareous nannofossils from sediments of the continental slope off Bombay (India), Rtv. Ital. Paleont., 82(2), 417-430.

Martini, E. (1971). Standard Tertiary and Quaternary calcareous nannoplankton zonation, In: A. Farinacci (Ed.) Proceed. Second Planktonic Conference Roma 1970, Edizioni Tecnoscienza, Roma, 2, 739-785.

Okada, H and Bukry,D. (1980).Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry,1973;1975), Marine Micropaleontology,5(3),321-325.

Petroleum System Sequence Stratigraphy, Mumbai Offshore Basin. (2008). Folder of Petroleum systems sequence stratigraphic summary of Mumbai Offshore Basin, KDMIPE, ONGC,Dehradun.

Perch-Nielsen, K. (1985). Cenozoic calcareous Nannofossils, In: H.M.Bolli et al. (Eds.), Plankton Stratigraphy, Cambridge University Press, Cambridge, 427-554.

Raju,D.S.N. (2009). Stratigraphy of Mumbai Offshore Basin,In. Proterozoic and Phanerozoic integrated stratigraphy, Raju,D.S.N and Misra,R.(Eds.),44(2),344-346.

Ravindran,C.N., Porwal,D.K., Kundu,R.N., Saxena,R.K., Banerjee,T. and Tiwari,J.P. (2005). Establishing the 3rd order and 4th order eustatic sea level changes from Paleocene to Oligocene sequence in HPB area, Western Offshore, RGL, WOB, ONGC, Mumbai (Unpublished Report).

Saxena, R.K. (1986). Calcareous nannoplankton from the Bassein area, Bombay Offshore, In: XII Indian Colloquium of Micropaleontology and Stratigraphy, Delhi (Abstract)

Saxena,R.K.(1996). Calcareous nannoplankton biochronostratigraphy of Bombay Offshore Basin, Contrs. XV Indian Colloq.Micropal. Strat., Dehradun,1996,723-732.

Saxena, R.K. (2000). Calcareous nannofoassils datum levels in the Paleogene shale sections of Krishna–Godavari, Basin, India. In: XVI Indian Coloq. Micropal.Strat. 22–24 Jan., 1998, Goa, Bull ONGC, Vol. 37 (2), p. 161–172.

Saxena, R.K. (2007). Age and environment of depositional setup of synrift sedimentation in the Ratnagiri area, Western Offshore basin, India.In**:**Procced. PETROTECH-2007, 15-19 Jan., 2007, New Delhi.

Singh,P. (1980). Calcareous nannoplankton from the Early Miocene-Early Pliocene subsurface sequence of Bombay Offshore region, Geoscience Jour., 1(1), p.31-45.

Young,J.R. (1998). Neogene In: Bown, P.R. (ed.) Calcareous Nannofossil Biostratigraphy, Kluwer Academic Publishers, London, 225–265.

Zutshi, P.L., Sood, A., Mahapatra, P., Ramani, K.K.V., Dwivedi A.K and Srivastava H.C, (1993). Lithostratigraphy of IndianPetroliferousBasins, Document-V, Bombay Offshore Basin, KDMIPE; ONGC Publication, pp. 1-383.