

Biostratigraphy and palaeoenvironment of Oligo-Miocene sediments in the area south of Mori- Kommarada fault, Krishna-Godavari Basin, South India

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Foraminiferal and calcareous nannofossil studies have been carried out on the Oligo-Miocene sediments in the area south of Mori- Kommarada fault, Krishna- Godavari Basin. The study was undertaken to establish finer biozonation of reservoir rocks (Matsyapuri Sandstone/Ravva Formation) in the area to build a robust, local biostratigraphic framework as seismic markers are poor in the area. Seven foraminiferal and six calcareous nannofossil bio-events (Last Appearance Datums) and the corresponding zones are recorded in the Oligo-Miocene sediments of three offshore wells viz., A, B, C and one onshore well D. One foraminiferal Zone P22 and two calcareous nannofossil zones viz., Zone NP21 and Zone NP25 are recorded in the Oligocene sediments of the area. In the Miocene sediments, six foraminiferal zones viz., Zone N5 (Lower), Zone N6 (Lower), Zone N7 (Lower), Zone N8, Zone N12, and Zone N14 and four calcareous nannofossil zones viz., Zone NN1, Zone NN2, Zone NN4, and Zone NN6 are recorded. Besides, one foraminiferal Zone N20 and one calcareous nannofossil Zone NN15 are also recorded in the Early Pliocene sediments of the area. The Oligocene sediments are found to be deposited under inner to middle shelf conditions in three wells namely A, C, and D. In well B, a deeper bathymetry is indicated for Oligocene sediments which were deposited under middle-outer shelf palaeoenvironmental conditions. The deposition of basal Early Miocene sediments is also noted in well B which continued under middle-outer shelf palaeoenvironmental conditions. Subsequently, the palaeoenvironmental conditions became shallower during the Early Miocene and sediments in all the four wells were deposited under inner shelf palaeoenvironmental conditions. Middle Miocene and younger sediments were deposited under inner to middle shelf conditions in all the wells except for well A, where the sediments are inferred to have been laid down under varied palaeoenvironmental conditions ranging from inner shelf to upper bathyal.

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INTRODUCTION

The Krishna-Godavari basin is a proven petroliferous basin in the eastern continental margin of the Indian plate. Commercial accumulations of hydrocarbon have been observed in all ages from Gondwana sediments of Permo-Triassic to as young as Godavari clay of Pliocene-Pleistocene (Rao, 1991). In the present study, biostratigraphic studies are carried out in four selective wells of KG Basin in the area south of the Mori-Kommarada fault which comprises both on land and offshore parts of the basin. Lithostratigraphically, on land part of the area comprises the Palakollu Shale of Paleocene age overlain by the Pasarlapudi Formation of Early Eocene age. Middle Eocene facies comprises the Bhimanapalli

Limestone. The offshore part comprises the Vadaparru Shale of the Late Paleocene to Oligocene age. Coastal and shallow water areas comprise arenaceous sequence of Late Eocene to Oligocene age, known as the Matsyapuri Sandstone. Further south of the Mori-Kommarada fault in the offshore area, coarser clastics are presently known as the Ravva Formation representing the Oligo-Miocene age. The Matsyapuri Sandstone and the Ravva Formation are significant reservoir rocks in KG Basin and are known to house significant hydrocarbon accumulations (Pandey and Rao, 2001).

The area has poor seismic signatures owing to the complex structural and stratigraphical framework of the area. The present study is undertaken to establish finer bio-chronological datum planes in the reservoir rocks and thereby to help resolve the correlation problem in the area by providing a robust biostratigraphic framework.

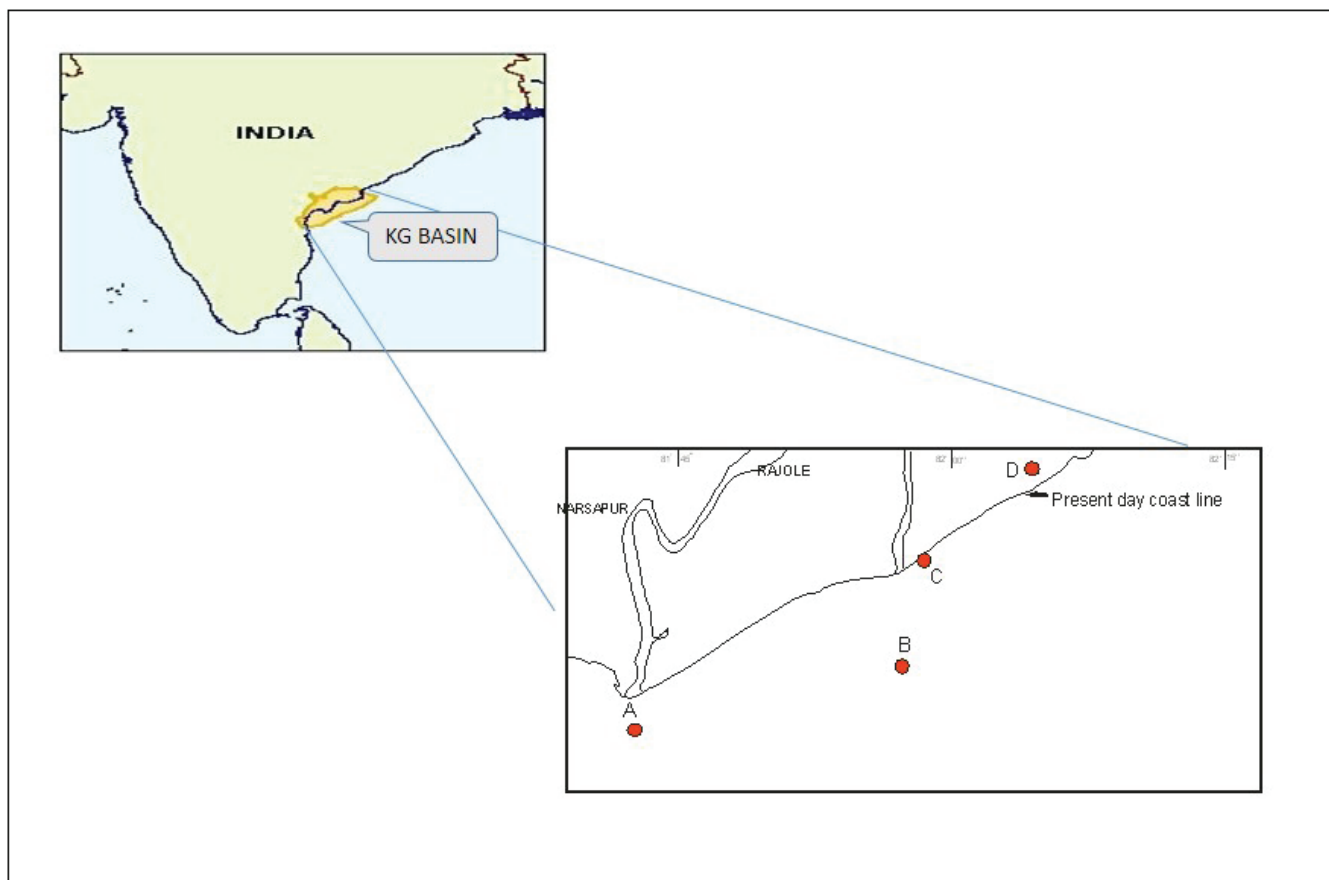


Fig. 1. Location map of the studies wells

MATERIALS AND METHODS

The studied four wells A, B, C and D are located in Krishna- Godavari Basin in the area south of the Mori-Kommarada fault (Fig. 1). The biostratigraphy and palaeoenvironmental interpretations are carried out in the Oligo-Miocene successions of wells A (1170-2100 m), B (1891.15-2835 m), C (1000-2450 m), and D (940-1500 m).

The processing of cutting samples for the yield of foraminifera and calcareous nannofossils were carried out according to the standard processing techniques as outlined by Pandey and Rao (1991). The samples were studied at 10-15m intervals and also at closer intervals at the age boundaries. Index taxa are identified using standard treatises and catalogues on planktonic foraminifera as Bolli *et al.* (1985); Loeblich and Tappan (1988), Kennet and Srinivasan (1983), and other published data and subsequently biostratigraphic and palaeoenvironment interpretations are made. Sediments have been dated based on the Last Appearance Datum (LADs) of age significant taxa and paleodepositional environment have been interpreted based on benthic foraminifera. The distribution of foraminifera and calcareous nannofossils in the studied wells is shown in Figs. 2-5.

RESULTS

Biostratigraphy and Palaeoenvironment of Well A (1170-2100 m)

Cutting samples in the interval 1170-2100 m are analyzed for foraminifera and nannofossils studies at 10 m intervals to demarcate the age boundaries and to interpret the palaeoenvironment of deposition. Age boundaries with the corresponding fossil assemblages and palaeoenvironments are illustrated in Figs. 2a and 2b. The results of the study are as follows:

Early Pliocene (interval 1170-1360 m)-The interval is highly fossiliferous and yielded both planktonic foraminifera and calcareous benthic foraminifera. LAD's of foraminifera *Pulleniatina primalis* and *Neogloboquadrina humerosa* suggest that the interval is not younger than the Early Pliocene. The base of Pliocene couldn't be ascertained due to the absence of index fauna and the interval is assigned ?Middle Miocene to Early Pliocene age. Characteristic planktonic foraminifera includes *Globigerina bulloides*, *G. woodi*, *G. decoraperta*, *G. falconensis*, *Globigerinella*

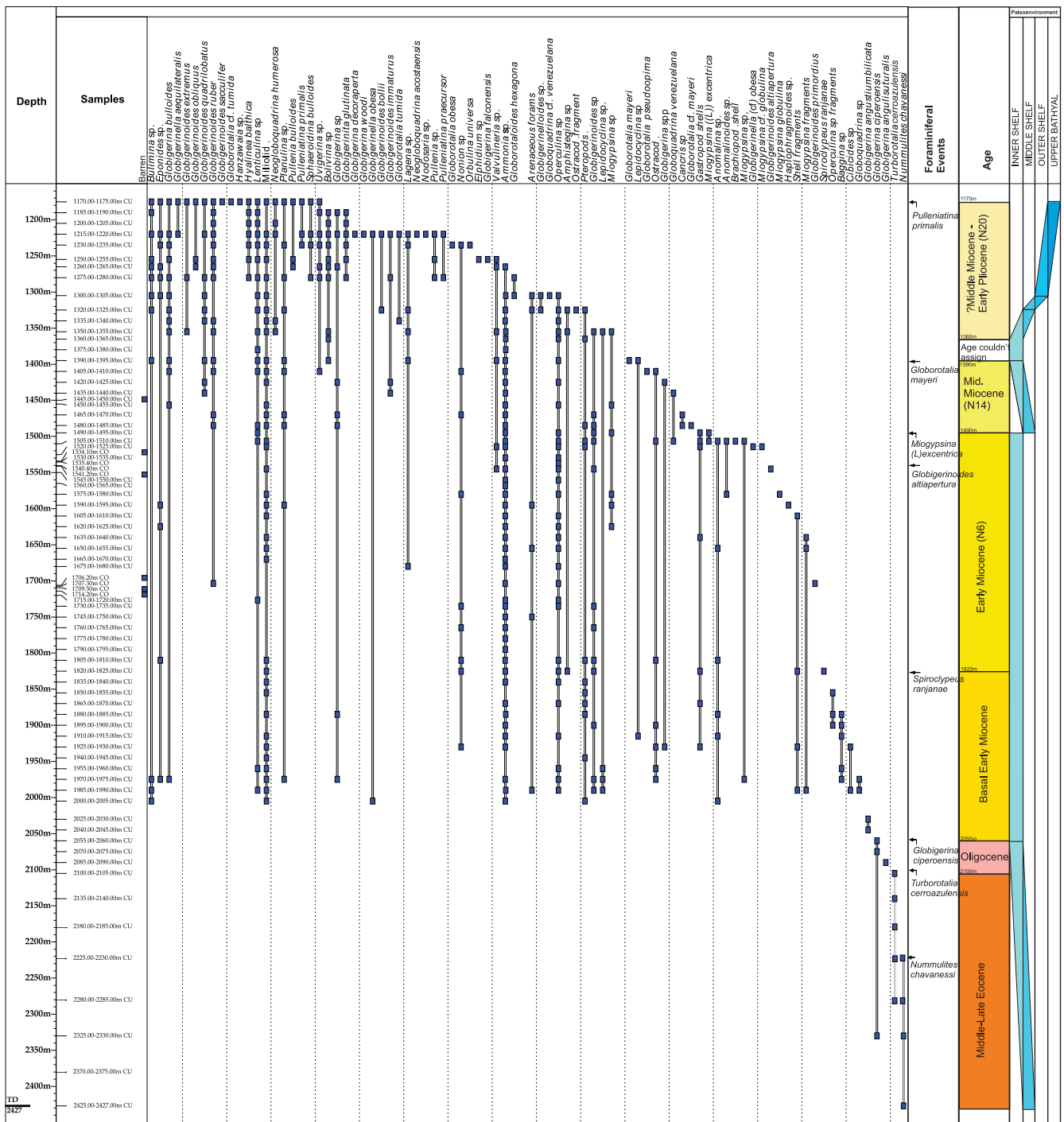


Fig. 2a Distribution of foraminifera, age and paleoenvironment in well A, Krishna-Godavari Basin

aequilateralis, *G. obesa*, *Globigerinita glutinata*, *Globigerinoides obliquus*, *G. extremus*, *G. sacculifer*, *Globoquadrina venezuelana*. *Globorotalia tumida*, *Globorotaloides hexagona* *Neogloboquadrina humerosa*, *N. acostaensis*, *Orbulina universa*, *Pulleniatina primalis*, *P. praecursor*, and associated benthic foraminifera include *Ammonia* sp., *Amphistegina* sp., *Bolivina* sp., *Bulimina* sp., *Eponides* sp., *Hanzawaia* sp., *Hyalinea balthica*, *Lagena* sp., *Lenticulina* sp., *Lepidocyclina* sp., Miliolids, *Nodosaria* sp., *Nonion* sp., *Operculina* sp., *Planulina* sp., *Pullenia*

sp., *Pullenia bulloides*, *Sphaeroidina bulloides*, *Uvigerina* sp. and *Valvulineria* sp. Calcareous nannofossils include *Calcidiscus leptoporus*, *Helicosphaera carteri*, *Coccolithus pelagicus*, and *Reticulofenestra producta*. Sediments in the interval 1170-1300 m were deposited under outer shelf to upper bathyal conditions as interpreted by the presence of deep water benthic foraminifera viz., *Sphaeroidina bulloides*, *Pullenia bulloides*, *Hyalinea balthica* etc., Interval 1300-1320 m shows shallower bathymetry i.e., middle to outer shelf. The presence of *Amphistegina* sp., Miliolids, *Ammonia* sp.,

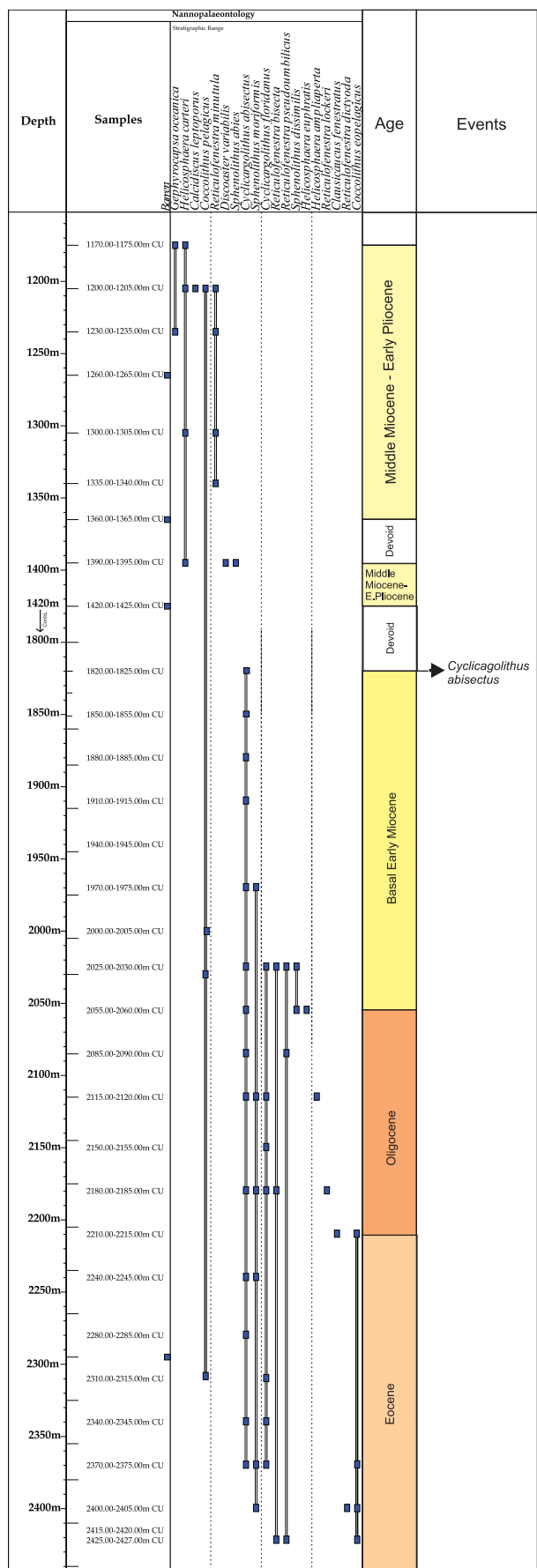


Fig. 2b Distribution of nannofossil taxa in well A, Krishna-Godavari Basin

and other larger benthic foraminifera indicates that sediments in the interval 1320-1360 m were deposited under inner to middle shelf palaeoenvironmental conditions.

Poorly fossiliferous (interval 1360-1390 m)-The studied interval is poorly fossiliferous and devoid of any age diagnostic planktonic foraminifera and calcareous nannofossils. Hence, definite age could not be assigned. A rare occurrence of benthic foraminifera such as *Ammonia* sp., *Bolivina* sp., *Lenticulina* sp., and *Operculina* sp. are recorded in this interval. The presence of benthic foraminifera such as *Ammonia* sp., *Bolivina* sp., *Operculina* sp., etc. indicates shallow bathymetry, hence, palaeodepositional environment is interpreted as Inner shelf.

Middle Miocene (interval 1390-1490 m): Middle Miocene (N14) age is assigned to this interval based on LAD of foraminifera *Globorotalia mayeri*. Other characteristic planktonic foraminifera recorded are *Globigerina bulloides*, *Globigerinoides ruber*, *G. quadrilobatus*, *G. immaturus*, *Globorotalia pseudopima*, *Globorotaloides hexagona*, *Globoquadrina venezuelana*. Benthic foraminifera include *Ammonia* sp., *A. umbonata*, *Bolivina* sp., *Bulimina* sp., *Cancris* sp. *Lagena* sp., *Lenticulina* sp., *Lepidocyclus* sp., *Miliolids*, *Nonion* sp., *Operculina* sp., *Planulina* sp., *Uvigerina* sp. and *Valvulineria* sp. along with ostracoda, pteropods and gastropoda shells. Calcareous nannofossils include *Discoaster variabilis*, *Helicosphaera carteri*, and *Sphenolithus abies*. Interval 1420-1490 m is devoid of nannofossils. The presence of foraminifera *Ammonia* sp., *Lenticulina* sp., *Lepidocyclus* sp., etc. indicate that sediments in the interval 1390-1490 m were deposited in the inner to middle shelf palaeoenvironmental conditions.

Early Miocene (N6) (interval 1490-1820m)-Presence of larger benthic foraminifera *Miogyssina (Lepidosemicyclina) excentrica* and planktonic foraminifera *Globigerinoides altiapertura* suggests Early Miocene (N6) age. Other benthic foraminifera includes *Ammonia* sp., *A. umbonata*, *Anomalina* sp., *Eponides* sp., *Lenticulina* sp., *Miogyssina* cf. *globulina*, *Miogyssina globulina*, *Miliolids*, *Nonion* sp., *Operculina* sp., *Planulina* sp. and *Valvulineria* sp. along with arenaceous foraminifera *Haplophragmoides* sp., ostaracoda, brachiopod shells, gastropod shells and pteropods. Solitary occurrence of calcareous nannofossil *Coccolithus pelagicus* is also recorded in this interval. The presence of larger benthic foraminifera such as *Miogyssina* sp., *Operculina* sp., etc. indicates shallow bathymetry. Hence, palaeodepositional environment is interpreted as the Inner shelf.

Basal Early Miocene (interval 1820-2055 m): The studied interval is mainly comprised of benthic foraminifera such as *Ammonia* sp., *A. umbonata*, *Amphistegina* sp., *Anomalina* sp., *Baggina* sp., *Bulimina* sp., *Cibicides* sp., *Lenticulina* sp., *Lepidocyclus* sp., *Miliolids*, *Miogyssina* sp., *Nonion* sp., *Operculina* sp., and *Spiroclipeus ranjanae*. Planktonic foraminifera viz., *Globigerina angustiumbilitica*, and very few and juvenile globigeriniids are also recorded at some intervals. Gastropoda shells, pteropods, ostracodes, and other shell fragments are also recorded. Characteristic nannofossils include *Cyclocargolithus abisectus*, *C. floridanus*, *H. euphratis*, *Reticulofenestra bisecta* and *S. dissimilis*. Basal Early Miocene (lower part of Aquitanian) age is assigned to this interval based on foraminifera *Spiroclipeus ranjanae* and calcareous nannofossil *Reticulofenestra bisecta* and *Cyclocargolithus abisectus*. The presence of larger benthic

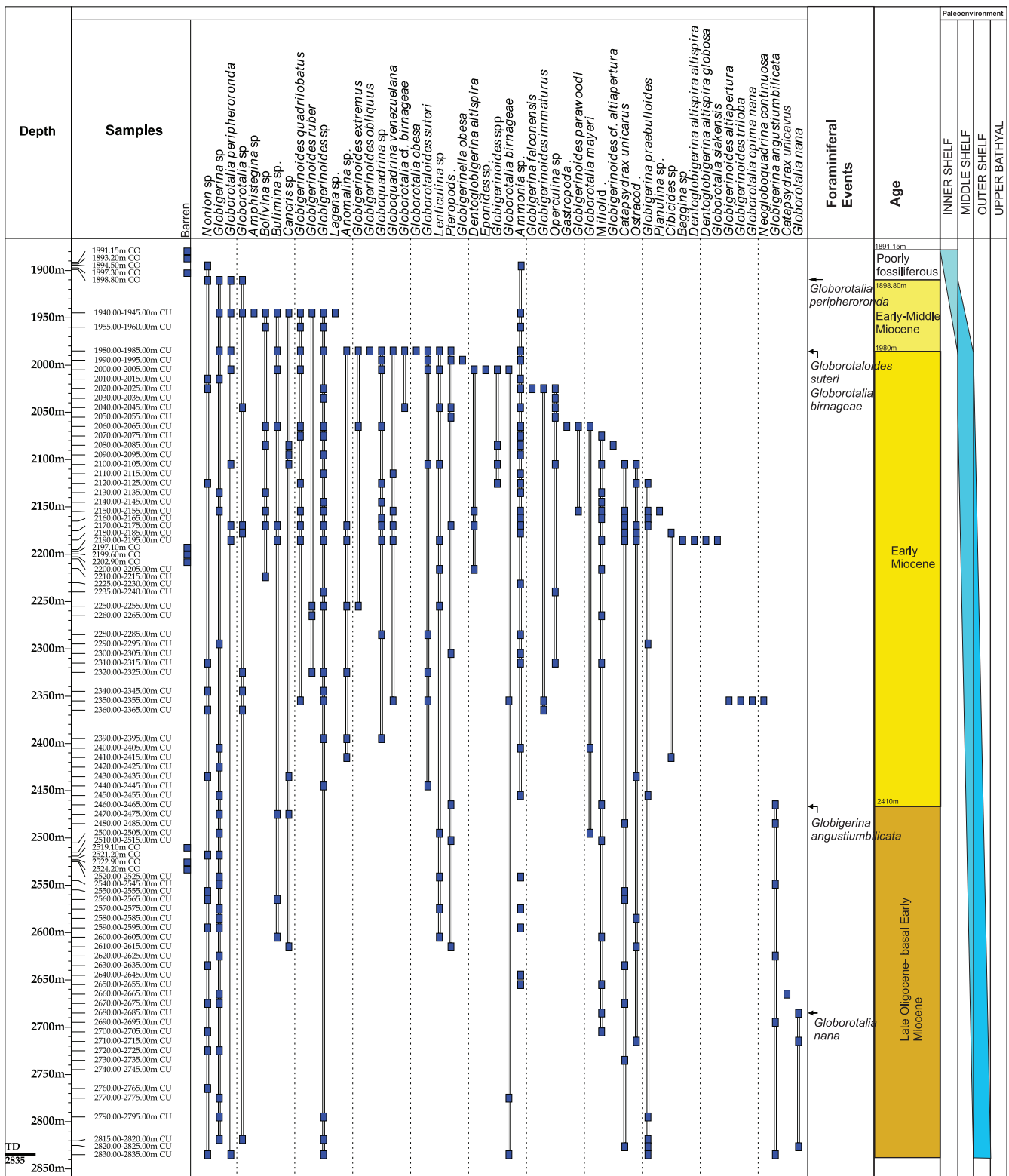


Fig. 3a Distribution of foraminifera, age and paleoenvironment in well B, Krishna-Godavari Basin

foraminifera indicates the inner shelf palaeodepositional environment.

Oligocene (interval 2055-2100 m)-The interval is characterized by planktonic foraminifera of Oligocene age such as *Globigerina ciperoensis* and *Globigerina*

angulituralis. Other associated foraminifera is *Ammonia* sp., *Catapsydrax unicus*, *Discorbis* sp., *Globigerina angustumblicata*, *Globigerina praebulloides*, *Lepidocyclina* sp., *Lenticulina* sp., Miliolids, *Planulina* sp. along with gastropod shells, brachiopoda shells, and Ostracoda.

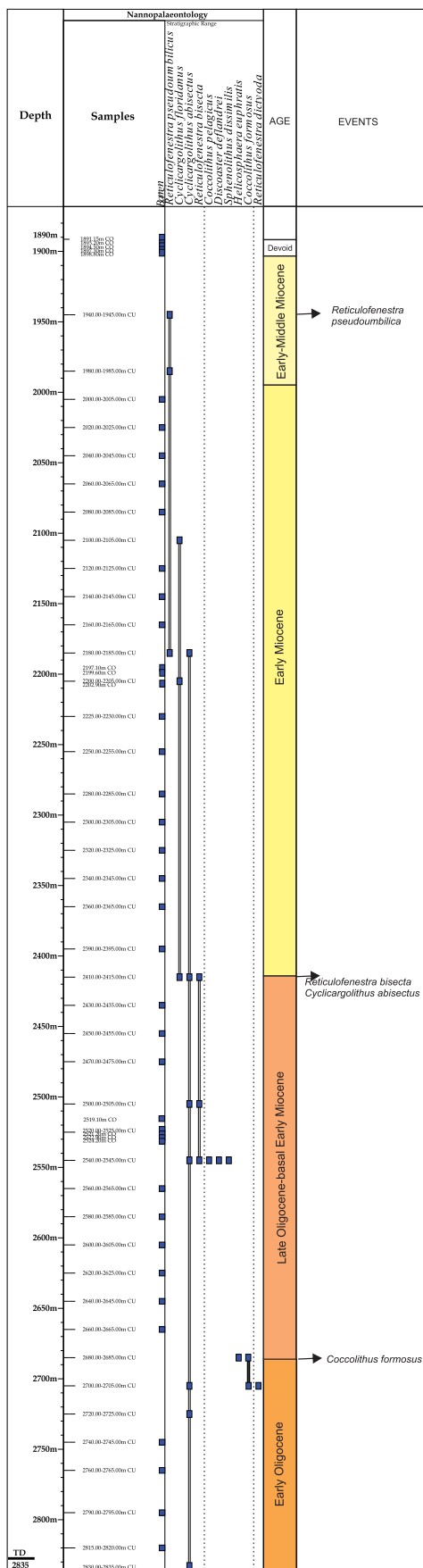


Fig. 3b. Distribution of nannofossil taxa and events in well B, Krishna-Godavari Basin

Calcareous nannofossils include *Cyclicargolithus abisectus*, *C. floridanus*, *Helicosphaera euphratis*, *Reticulofenestra bisecta*, *R. pseudoumbilica*, and *Sphenolithus dissimilis*. The sediments in this interval seem to be deposited in inner to outer shelf palaeoenvironmental conditions.

Biostratigraphy and Palaeoenvironment of Well B (1891.15-2835 m)

Cutting and core samples in the interval 1891.15-2830 m were studied for foraminiferal and calcareous nannofossil biostratigraphy to establish age and palaeoenvironment. Age boundaries with the corresponding fossil assemblages and palaeoenvironments are illustrated in Figs. 3a and 3b. Results of the study are given below:

Poorly fossiliferous (interval 1891.15-1898.80 m; cc#1)- This studied core interval is mainly devoid of foraminifera and calcareous nannofossils except for the solitary occurrence of *Ammonia* sp. and *Nonion* sp. at depth interval 1894.50 m. Due to the absence of fauna age could not be assigned to this interval. The presence of *Ammonia* sp. and *Nonion* sp. indicates inner shelf palaeoenvironmental conditions of deposition.

Early to Middle Miocene (interval 1898.80-1980 m)- The interval is characterized by the occurrence of *Ammonia* sp., *Amphistegina* sp., *Bolivina* sp., *Bulimina* sp., *Cancris* sp., *Globigerina* sp., *Globigerinoides* sp., *G. quadrilobatus*, *G. ruber*, *Globorotalia* cf. *peripheroronda*, *Globorotalia* sp., *Lenticulina* sp., *Lagena* sp., *Nonion* sp. along with ostracods and fish tooth. Associated calcareous nannofossil is *Reticulofenestra pseudoumbilica*. Early to Middle Miocene age may be suggested based on the presence of foraminifera *Globorotalia* cf. *peripheroronda*. The sediments are inferred to be deposited in inner - middle shelf.

Early Miocene (interval 1980-2410 m)-The interval is represented by planktonic foraminifera *Catapsydrax unicavus*, *Dentoglobigerina altispira*, *D. globosa*, *Globigerina falconensis*, *Globigerinella obesa*, *Globigerinoides quadrilobatus*, *G. obliquus*, *G. extremus*, *G. immaturus*, *Gs. triloba*, *Globorotalia birnageae*, *G. mayeri*, *G. peripheroronda*, *Globorotaloides suteri*, and *Globoquadrina venezuelana*. Benthic foraminifera includes *Ammonia umbonata*, *Anomalina* sp., *Baggina* sp., *Bolivina* sp., *Bulimina* sp., *Cancris* sp., *Eponides* sp., *Lenticulina* sp., *Miliolids*, *Nonion* sp., *Operculina* sp., *Planulina* sp., along with pteropods, gastropoda shells and ostracoda. Associated nannofossils include *Cyclicargolithus abisectus*, *C. floridanus* and *R. pseudoumbilica*. Based on the fauna such as *Catapsydrax unicavus*, *Globorotalia birnageae* and *Globorotaloides suteri*. Early Miocene could be assigned to this interval. Benthic foraminifera viz., *Bulimina* sp., *Cancris* sp., *Planulina* sp., etc., along with a good number of planktonic foraminifera shows that the sediments were deposited under the middle to outer shelf palaeoenvironmental conditions.

Late Oligocene to basal Early Miocene (interval 2410-2680 m)-Interval 2410-2560 m yielded calcareous nannofossils *Cyclicargolithus abisectus* and *Reticulofenestra bisecta* on whose basis the interval is dated as Late Oligocene to basal Early Miocene. Associated foraminifera include *Ammonia umbonata*, *Bulimina* sp., *Cancris* sp., *Catapsydrax*

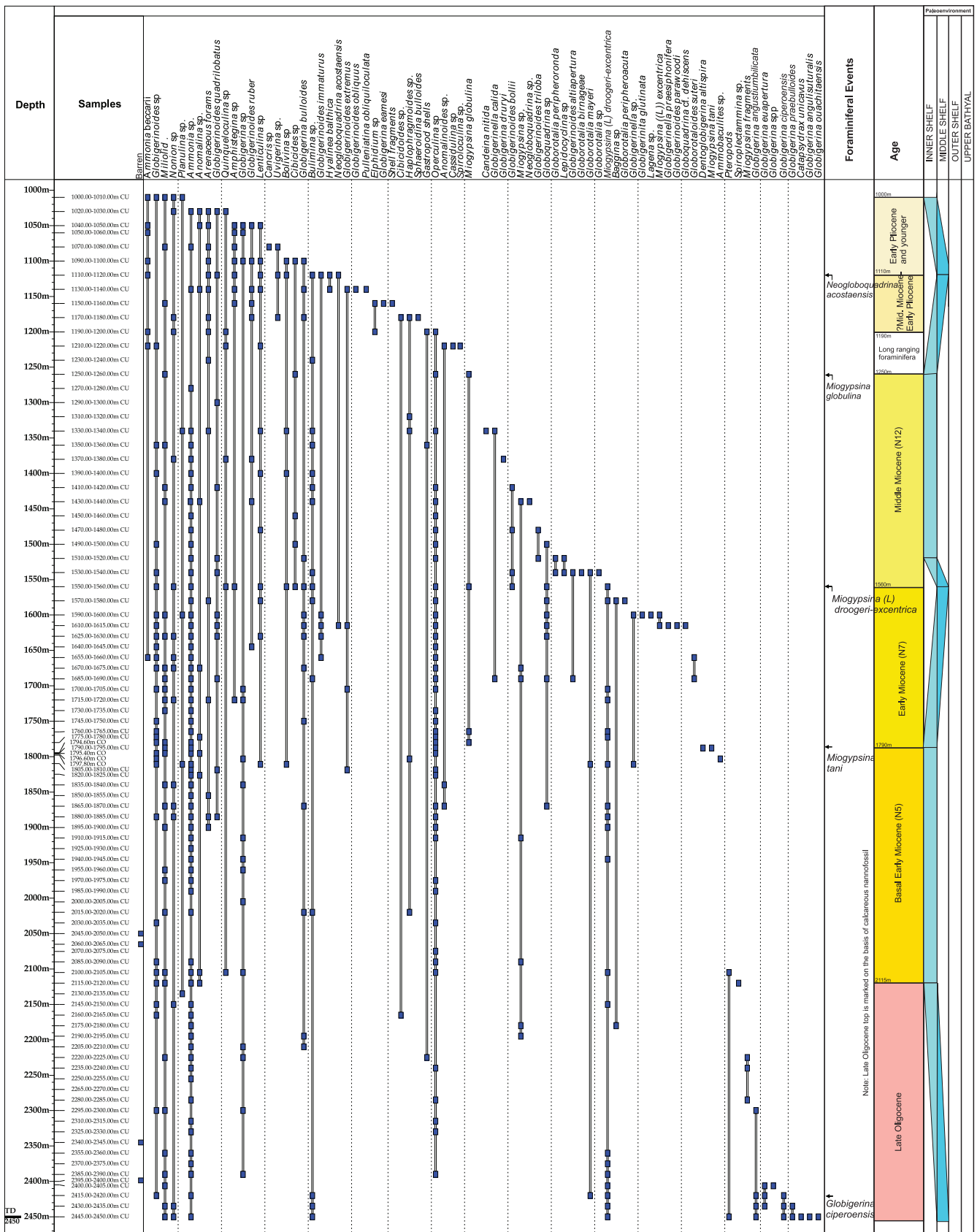


Fig.4a Distribution of foraminifera, age and paleoenvironment in well C, Krishna-Godavari Basin

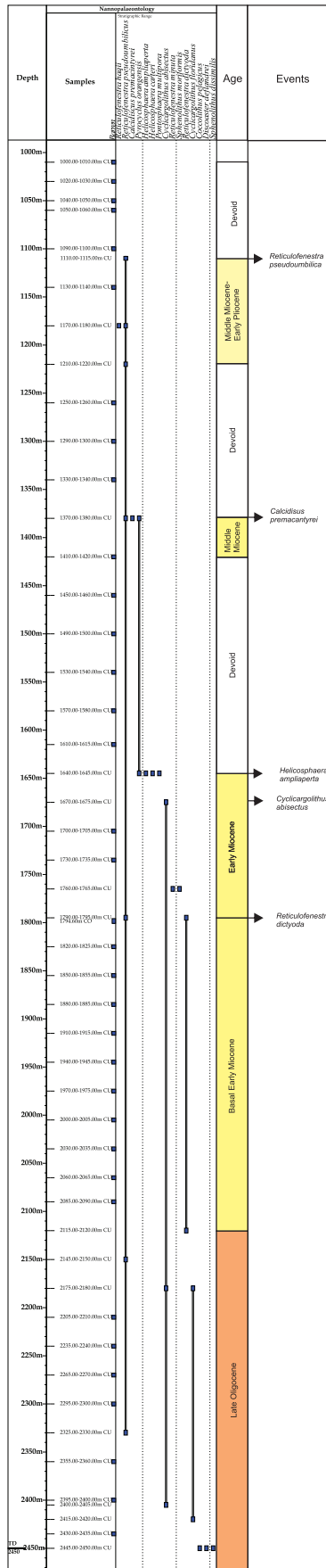


Fig. 4b Distribution of nannofossil taxa in well C, Krishna-Godavari Basin

unicavus, *Globigerina angustiumbilitata*, *Lenticulina* sp., *Miliolids*, and *Nonion* sp., along with pteropods and Ostracoda. Interval 2560-2680 m is devoid of calcareous nannofossils. The recorded fauna indicates middle to outer shelf palaeoenvironmental conditions of deposition.

Early Oligocene (interval 2680-2830 m)-Early Oligocene age is assigned to this interval based on LAD of calcareous nannofossil *Coccolithus formosus*. Associated foraminifera include *Globigerina angustiumbilitata*, *Globorotalia nana*, *Miliolids*, and *Nonion* sp. along with Ostracoda. Interval 2740-2830 m is devoid of calcareous nannofossils. Based on the recorded fauna, it is interpreted that middle - outer shelf palaeoenvironment conditions prevailed during the deposition of Early Oligocene sediments.

Biostratigraphy and Palaeoenvironment of Well C (1000-2450 m)

Foraminiferal and nannofossil biostratigraphic studies are carried out in intervals 1000-2450 m at 10 m intervals to demarcate age boundaries and infer the palaeoenvironment. Age boundaries with the corresponding fossil assemblages and palaeoenvironments are illustrated in Figs. 4a and 4b. The results of the study are as follows:

Early Pliocene and younger (interval 1000-1110 m)-The interval yielded long-ranging foraminifera and is devoid of calcareous nannofossils. Recorded foraminifera include *Ammonia* sp., *Amphistegina* sp., *Anomalina* sp., *Bolivina* sp., *Cancriis* sp., *Cibicides* sp., *Nonion* sp., *Lenticulina* sp., *Miliolids*, *Planulina* sp., *Uvigerina* sp., and arenaceous foraminifera with rare occurrence of planktonic foraminifera such as *Globigerina* sp., *Globigerinoides* sp., *G. quadrilobatus* and *G. ruber*. On the basis of stratigraphical order Early Pliocene and younger age is assigned to this interval. Inner - middle shelf palaeoenvironmental conditions are inferred for the depositions of studied sediments on the basis of presence of benthic foraminifera viz., *Ammonia* sp., *Amphistegina* sp., *Bolivina* sp. etc.

Early Pliocene (interval 1110-1190 m)- Upper limit of Early Pliocene is recorded at 1110 m and is represented by planktonic foraminifera *Neogloboquadrina acostaensis*. Other associated foraminifera include *Ammonia* sp., *Amphistegina* sp., *Anomalina* sp., *Bolivina* sp., *Bulimina* sp., *Cibicides* sp., *Elphidium* sp., *Globigerina bulloides*, *Globigerinoides quadrilobatus*, *G. immaturus*, *G. obliquus*, *G. extremus*, *G. ruber*, *Haplophragmoides* sp., *Hylinea balthica*, *Lenticulina* sp., *Miliolids*, *Nonion* sp., *Operculina* sp., *Pulleniatina obliquiloculata*, and *Uvigerina* sp. Calcareous nannofossils include *Reticulofenestra pseudumbilicata* and *R. haqii*. The presence of benthic foraminifera such as *Ammonia* sp., *Elphidium* sp., *Amphistegina* sp., etc indicates inner - middle shelf palaeoenvironmental conditions.

Poorly fossiliferous (interval 1190-1250 m)-This interval is mainly dominated by benthic foraminifera with no occurrence of age diagnostic planktonic foraminifera and calcareous nannofossils. Benthic foraminifera includes *Ammonia* sp., *Anomalinoidea* sp., *Bulimina* sp., *Cassidulina* sp., *Elphidium* sp., *Miliolids*, *Nonion* sp., *Operculina* sp., arenaceous foraminifera, and microgastropod. Definite age could not be assigned to the studied interval due to the

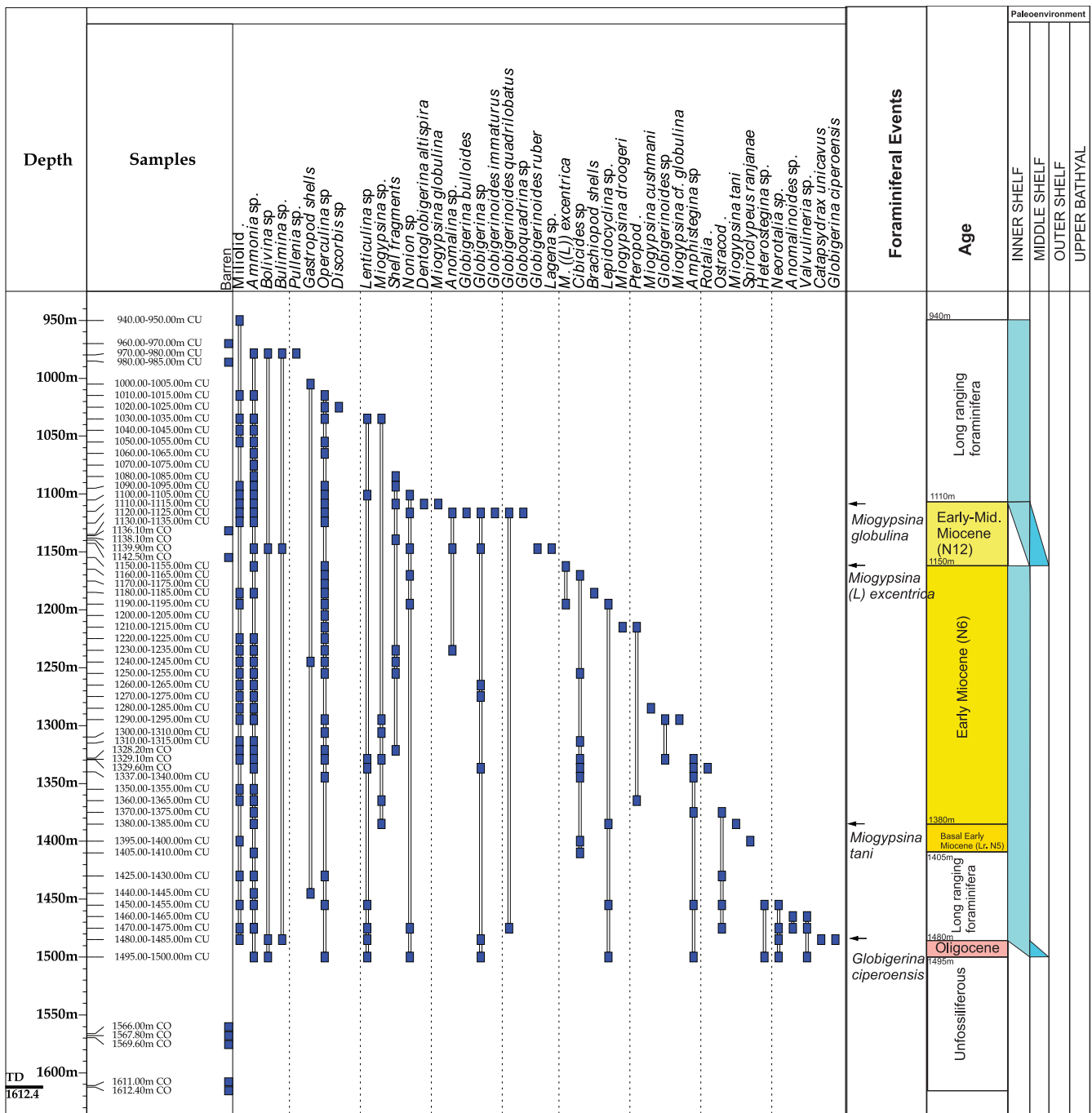


Fig. 5a Distribution of foraminifera, age and paleoenvironment in well D, Krishna-Godavari Basin

absence of age diagnostic fauna. Recorded fauna suggests inner - middle shelf palaeoenvironmental conditions for deposition.

Middle Miocene (N12) (interval 1250-1560 m)-Interval 1250-1510 m is mainly dominated by larger benthic foraminifera such as *Lepidocyclina* sp., *Miogypsina* sp., *M. globulina*, *Operculina* sp., along with very few planktonic foraminifera viz., *Globigerina* sp., *Globigerinoides quadrilobatus*, and *G. Ruber*. Moderate to a good yield of planktonic foraminifera recorded in the interval 1510-1560 m namely *Globigerina bulloides*, *Globigerinita glutinata*,

Globigerinoides sp., *G. quadrilobatus*, *G. triloba*, *G. bolli*, *Globoquadrina* sp., *Globorotalia* sp., *Globorotalia mayeri* and *G. peripheroronda*. Other smaller benthic foraminifera includes *Ammonia* sp., *Bolivina* sp., *Bulimina* sp., *Cibicides* sp., *Lenticulina* sp., *Planulina* sp., *Haplophragmoides* sp., and other arenaceous foraminifera. The interval from 1250-1370m is devoid of calcareous nannofossils. Interval 1370-80m recorded *Calcidiscus premacantyreii*, *Pyrocyclus* sp., and *Reticulofenestra pseudoumbilica*. Middle part of Middle Miocene (N 12) age is assigned to this interval based on foraminifera *Miogypsina globulina* and calcareous

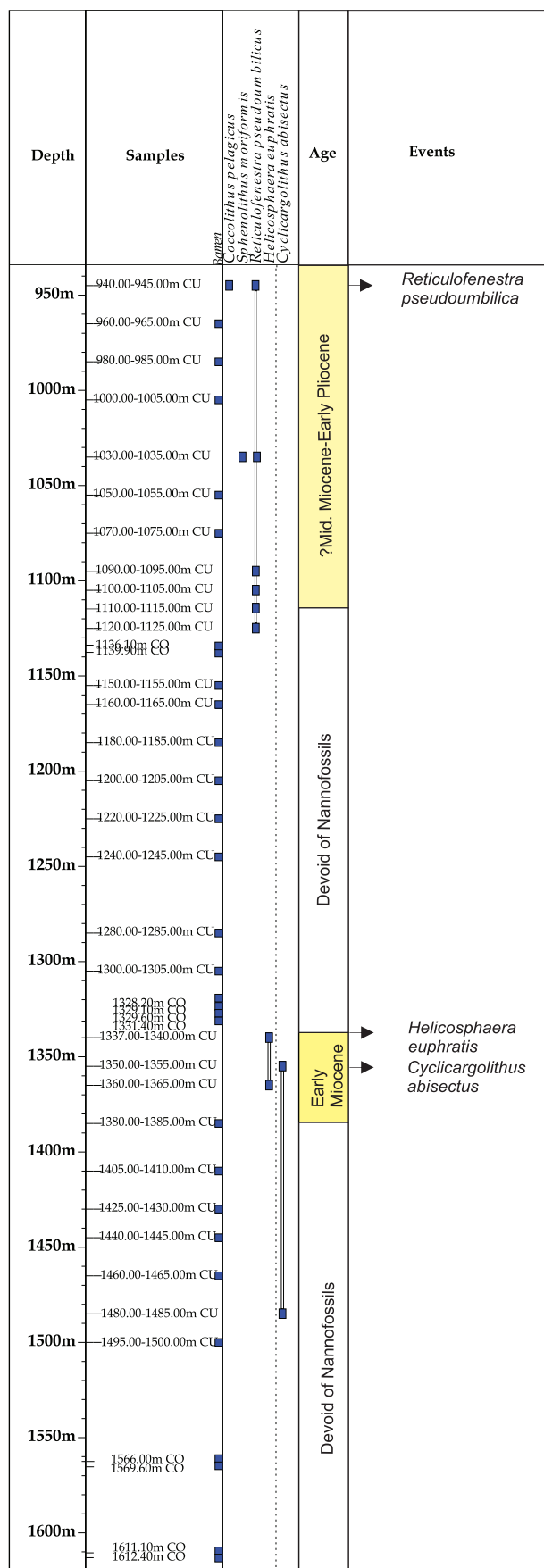


Fig. 5b. Distribution of nannofossil taxa and events in well D, Krishna-Godavari Basin

nannofossil *Calcidiscus premacantyreii*. Interval 1250-1510 m yielded larger benthic foraminifera such as *Miogypsina* sp., *Operculina* sp., etc. Hence, sediments were deposited in inner shelf paleoenvironmental conditions. Sediments in the interval 1510-1560 m were deposited under inner-middle shelf conditions as interpreted based on foraminifera *Bulimina* sp., *Cibicides* sp., *Lenticulina* sp., *Planulina* sp. etc.

Early Miocene (N7) (interval 1560-1790 m)-Characteristic foraminifera recorded in this interval includes *Ammonia* sp., *A. umbonata*, *Amphistegina* sp., *Anomalina* sp., *Bulimina* sp., *Globigerina bulloides*, *Globigerinella* sp., *G. praesiphonifera*, *Globigerinita glutinata*, *Globigerinoides immaturus*, *G. extremus*, *G. ruber*, *Globoquadrina* sp., *Lagena* sp., *Miogypsina (L) droogeri-excentrica*, *Miogypsina (L) excentrica*, *Miogypsina* cf. *M. globulina*, Miliolids, *Nonion* sp., *Operculina* sp., *Planulina* sp., arenaceous foraminifera, and Ostracoda. The interval from 1560-1640 m is devoid of calcareous nannofossils. Interval 1640-1794.4 m recorded *Helicosphaera ampliaperta*, *Helicosphaera carteri*, *Pontosphaera multipora*, *Pyrocyclus orangensis*, *Reticulofenestra minuta*, *R. pseudoumbilica* and *Sphenolithus moriformis*. Early Miocene (N7) age is assigned based on LAD of foraminifera *Miogypsina (L) droogeri-excentrica* and calcareous nannofossil *Helicosphaera ampliaperta*. The presence of larger benthic foraminifera such as *Miogypsina* sp., *Operculina* sp., along with smaller benthic foraminifera such as *Lagena* sp., *Bulimina* sp., etc. suggests inner-middle shelf paleoenvironmental conditions.

Basal Early Miocene (N5) (interval 1790-2115 m): Moderate to poor foraminifera recorded in this interval such as *Ammonia* sp., *A. umbonata*, *Ammobaculites* sp., *Anomalina* sp., *Bolivina* sp., *Bulimina* sp., *Globigerina* sp., *G. bulloides*, *Globigerinoides* sp., *G. quadrilobatus*, *G. extremus*, *Globorotalia mayeri*, *Haplophragmoides* sp., *Lenticulina* sp., Miliolids, *Miogypsina tani*, *Nonion* sp., *Operculina* sp., *Planulina* sp., arenaceous foraminifera, ostracoda, microgastropoda, shell fragments, and pteropods. Calcareous nannofossils recorded are *Cyclocargolithus abisectus* and *Reticulofenestra pseudoumbilica*. The interval from 1800-2090 m is devoid of calcareous nannofossils. Basal Early Miocene (N5) age is assigned based on LAD of foraminifera *Miogypsina tani* and calcareous nannofossil *Cyclocargolithus abisectus*. Inner shelf paleodepositional environment is inferred based on the presence of benthic foraminifera such as *Miogypsina tani*, Miliolids, *Ammonia* sp. etc.

Late Oligocene (interval 2115-2450 m)-Interval 2115-2415 m recorded very few planktic foraminiferas such as *Globigerina* sp., *G. bulloides*, *Globigerinoides* sp., *G. quadrilobatus* along with benthic foraminifera such as *Ammonia* sp., *A. umbonata*, *Anomalina* sp., *Miogypsina* sp., Miliolids, *Nonion* sp., *Operculina* sp., *Planulina* sp., microgastropoda, Ostracoda, brachiopod shells, etc. Yield is poor to moderate in this interval. Interval 2415-2450m recorded Oligocene planktonic foraminifera such as *Globigerina ciperoensis*, *G. angustiumbilitata*, *G. euapertura*, *G. praebulloides* and *Catapsydrax unicavus*. Associated calcareous nannofossil are *Reticulofenestra dictyoda*, *R. pseudoumbilica*, *Cyclocargolithus abisectus*, *Discoaster deflandre*, *Sphenolithus dissimilis* and *Coccolithus pelagicus*. Late Oligocene age is assigned based on LAD of calcareous nannofossil *Reticulofenestra dictyoda* at 2115-20

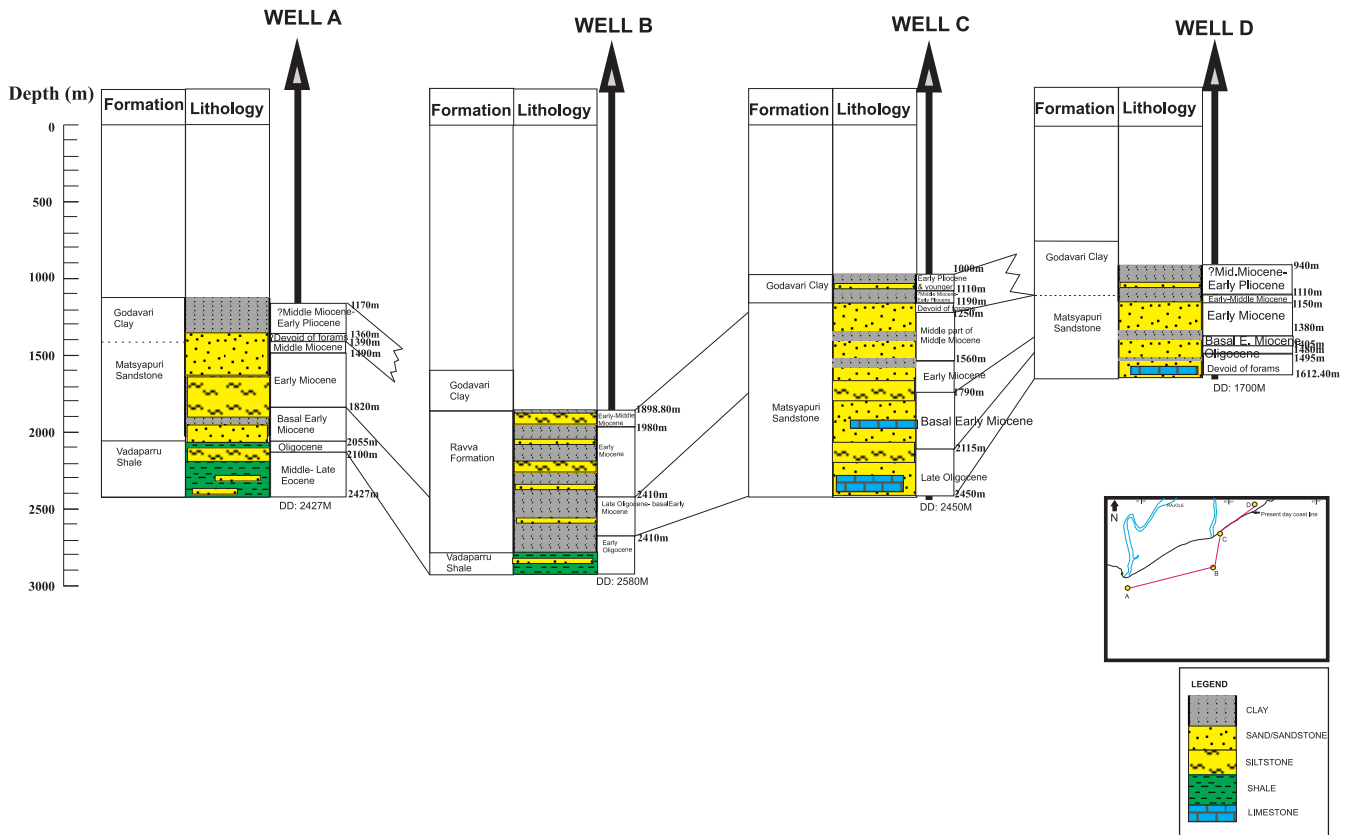


Fig. 6. Biostratigraphic correlation along wells A, B, C and D in Krishna-Godavari Basin

m. Record of foraminifera *Globigerina ciproensis* at 2415-20 m also indicates Late Oligocene age to the studied interval. Inner-middle shelf paleoenvironmental conditions are inferred based on the presence of foraminifera *Miogypsina* sp., *Ammonia* sp., *Nonion* sp., etc.

Biostratigraphy and Palaeoenvironment of Well D (940-1500 m)

Foraminifera and nannofossils biostratigraphic studies were carried out in the interval 940-1612.40 m to demarcate age and palaeoenvironment. Age boundaries with the corresponding fossil assemblages and palaeoenvironments are illustrated in Figs. 5a and 5b. Results of the study are given below:

?Middle Miocene - Early Pliocene (interval 940-1110 m): The studied interval is mainly comprised of benthic foraminifera such as *Ammonia* sp., *A. umbonata*, *Bolivina* sp., *Bulimina* sp., *Discorbis* sp., *Lenticulina* sp., Miliolids, *Miogypsina* sp., *Nonion* sp., *Operculina* sp., *Pullenia* sp., gastropods shells and other shell fragments. Calcareous Nannofossil includes *Coccolithus pelagicus*, *Reticulofenestra pseudumbilica*, and *Sphenolithus moriformis*. ?Middle Miocene - Early Pliocene age is assigned based on calcareous nannofossil *R. pseudumbilica*. The interval yielded mainly shallow-water benthic foraminifera such as *Miogypsina* sp., *Ammonia* sp., etc. Therefore, palaeodepositional environment is inferred as the inner shelf.

Early to Middle Miocene (N5-N12) (interval

1110-1150m)-Characteristic foraminifera includes *Ammonia* sp., *Anomalina* sp., *Dentoglobigerina altispira*, *Globigerina* sp., *G. bulloides*, *Globigerinoides* sp., *G. immaturus*, *G. quadrilobatus*, *G. ruber*; *Globoquadrina* sp., *Globorotalia* cf. *peripheroronda*, *Lagena* sp., Miliolids, *Miogypsina globulina*, *Nonion* sp., *Operculina* sp., and shell fragments. The interval is devoid of calcareous nannofossils. Early to Middle Miocene (N5-N12) age may be suggested based on the presence of foraminifera *Miogypsina globulina*. Foraminifera such as *Ammonia* sp., *Miogypsina globulina*, *Nonion* sp., etc., suggests inner-middle shelf palaeoenvironment conditions of deposition.

Early Miocene (lower N6) (interval 1150-1380 m)-The interval is mainly comprised of benthic foraminifera such as *Ammonia umbonata*, *Amphistegina* sp., *Anomalina* sp., *Cibicides* sp., *Lepidocyclus* sp., Miliolids, *Miogypsina (Lepidosemicyclina) excentrica*, *Miogypsina cushmani*, *Miogypsina* cf. *globulina*, *Nonion* sp., *Operculina* sp., shell fragments, gastropod shell, brachiopod shell, pteropods, and Ostracoda. Solitary occurrence of calcareous nannofossil *Helicosphaera euphratis* is also recorded. Early Miocene (Lower N6) age is assigned to this interval based on foraminifera *Miogypsina (Lepidosemicyclina) excentrica*. The interval mainly yielded larger benthic foraminifera such as, *Miogypsina* sp., *Operculina* sp., *Lepidocyclus* sp., etc., therefore, inner shelf palaeoenvironment of deposition is inferred for the studied interval.

Basal Early Miocene (lower N5) (interval 1380-1480 m)-Characteristic foraminifera of the interval includes *Ammonia* sp., *Anomalinoides* sp., *Cibicides* sp., *Heterostegina* sp.,

Lenticulina sp., *Lepidocyclina* sp., *Miogypsina tani*, Miliolids, *Neorotalia* sp., *Nonion* sp., *Operculina* sp., *Spirochlopeus ranjanae*, *Valvulineria* sp., along with rare occurrence of juvenile globigeriins and Ostracoda and gastropoda shell. Interval is devoid of calcareous nannofossils. Basal Early Miocene (Lower N5) age is assigned to this interval based on foraminifera *Miogypsina tani* and *Spirochlopeus ranjanae*. The interval mainly yielded larger benthic foraminifera such as *Miogypsina* sp., *Operculina* sp., *Lepidocyclina* sp., etc, therefore, the inner shelf paleoenvironment of deposition is inferred for the studied interval.

Oligocene (interval 1480- 1495 m)-Characteristic planktonic foraminifera of this interval include *Globigerina* sp., *G. ciperoensis*, *Catapsydrax unicavus*, and benthic foraminifera include *Ammonia* sp., *Amphistegina* sp., *Anomalinoidea* sp., *Bolivina* sp., *Heterostegina* sp., *Lenticulina* sp., *Lepidocyclina* sp., *Neorotalia* sp., *Nonion* sp., *Operculina* sp., and *Valvulineria* sp. Calcareous nannofossil recorded is *Cyclicargolithus abisectus*. Oligocene age is assigned to this interval based on the occurrence of foraminifera *Globigerina ciperoensis*. Recorded fauna in the interval suggests inner - middle shelf palaeoenvironmental conditions.

Interval 1566.0-1569.60 m (cc#4): Studied core samples are devoid of foraminifera and calcareous nannofossils.

Interval 1611.00-1612.40m (cc#5): Studied core samples are devoid of foraminifera and calcareous nannofossils.

BIOSTRATIGRAPHIC CORRELATION

The biohorizons of foraminifera and calcareous nannofossils in four studied wells are correlated along with the strike profile in the SW-NE direction (Fig. 6).

Oligocene sediments are well developed in the offshore part being as thick as 420 m in well B and decreasing in thickness towards the on-land part of the basin. Palaeodepositional conditions vary from inner shelf to outer shelf in the offshore part of the basin during the deposition of Oligocene sediments. The deepest palaeo depth was observed in well B where palaeobathymetry reaches up to 200 m. On onland part, inner shelf to middle shelf palaeoenvironmental conditions prevailed during the deposition of sediments.

Early Miocene sediments are well developed in both the offshore and onshore area of the basin and deposited under the palaeoenvironmental conditions ranging from inner to middle shelf except for well B where middle- outer shelf conditions prevailed during the deposition of sediments. The Late Miocene sediments are not recorded in the studied wells. Topmost studied depths are not younger than the Early Pliocene in all the studied wells.

DISCUSSION

Foraminiferal and nannofossil studies have helped in bringing out important events taxa which would help in demarcating finer zones in the reservoir rocks of Oligo-

Miocene age in wells A, B, C, and D of Krishna- Godavari Basin.

Rupelian stage of Oligocene (33.8-28.5 Ma) is assigned to foraminiferal Zones P18- P21a of Berggren *et al.* (1995) and calcareous nannofossils Zones NP21-NP23 of Martini (1971). Zone NP21 is defined by LAD of calcareous nannofossil *Coccolithus formosus* in well B at the depth of 2680-85m. It is taken as a marker of the Early Oligocene. Foraminiferal events/zones are not recorded in this stage.

Chattian stage (28.5-23.03 Ma) is assigned to foraminiferal Zones P21b – P22 (Berggren *et al.*, 1995) and calcareous nannofossils Zones NP24-NP25 (Martini, 1971). Record of foraminifera *Globigerina ciperoensis* in wells A (at 2055-60 m), C (2415-20 m), and D (1480-85 m) mark Late Oligocene in these wells. LAD of this age marker is equivalent to Zone P22. Zone P21b is not recorded in the studied wells. LAD of calcareous nannofossil *Reticulofenestra dictyoda* defined the Zone NP25.

Aquitanian stage (23.03- 20.44 Ma) of Early Miocene is defined by foraminiferal Zone N4- lower part of Zone N5 (Blow, 1969). The Zone is recorded in wells C (1820-25 m) and D (1395-1400 m) as defined by the LADs of larger benthic foraminifera *Spirochlopeus ranjanae* and *Miogypsina tani*. Equivalent calcareous nannofossils Zone NN1 (Martini, 1971) as defined by the LADs of calcareous nannofossil *Cyclicargolithus abisectus* and *Reticulofenestra bisecta* is also recorded in all the studied wells.

Burdigalian stage (20.44-15.97 Ma) belongs to Zones N5-N6 of Blow (1969) and Zone NN2 of Martini (1971). Lower part of Zone N6 as defined by LAD of larger benthic foraminifera *Miogypsina (Lepidosemicyclina) excentrica* is recorded in wells A (1490-95m) and D (1150-55m). Equivalent calcareous nannofossil Zone NN2 is recorded in well D (1337-40m) as defined by the presence of calcareous nannofossil *Helicosphaera euphratis*.

Langhian stage (15.97-13.82 Ma) falls within Zone NN4 and NN5 of Martini (1971). Base of Langhian marks at the first evolutionary appearance of *Praeorbulina glomerosa* (Zone N8) and is widely accepted as Early - Middle Miocene boundary. In well B, this Zone (N8) is marked at 1980-85m on the basis of LADs of foraminifera *Globorotaloides suteri* and *Globorotalia birnageae*. Equivalent calcareous nannofossil Zone NN4 is recorded in well C (1640-45 m) and is marked by the occurrence of calcareous nannofossil *Helicosphaera ampliaperta*.

Serravallian stage (13.82-11.63 Ma) corresponds to Zones NN5-NN7 (Lr.) of Martini (1971) and Zones N12-N14 (partly) of Blow (1969). In studied wells, foraminiferal event LAD of *Globorotalia mayeri* is recorded in well A at 1390-95 m that marking the upper limit. Calcareous nannofossils are poorly recorded in this stage.

Tortonian stage (11.63-7.246 Ma) represented by calcareous nannofossil Zones NN7-NN11 (Martini, 1971) and foraminiferal Zones N14-N17 (Blow, 1969) and Messinian stage (7.246-5.333 Ma) corresponds to calcareous nannofossil Zones NN11-NN12 and foraminiferal Zones N17-N18 are not recorded in the studied wells.

Besides, Foraminiferal Zone N20 (Blow, 1969) as defined by LADs of *Pulleniatina primalis* and *Neoglobobadrina acostaensis* is also recorded in wells A (1170-75 m) and C (1110-20m). The Zone lies within Zanclean stage (5.333-3.600 Ma) of the Early Pliocene. Equivalent calcareous

nannofossil Zone NN15 (Martini, 1971) is represented by LAD of calcareous nannofossil *Reticulofenestra pseudoumbilica* and is recorded in wells B (1940-45m), C (1110-15m) and D (940-45 m).

CONCLUSIONS

Biostratigraphic studies (including foraminifera and nannofossils) of four wells of Krishna- Godavari basin brings out seven foraminiferal and six nannofossils events in the Oligo- Miocene sediments which are known to house significant hydrocarbon accumulations. These bio-events helped in the finer refinement of these potential reservoir rocks and their correlation in the study area.

Also, the study brings out the palaeoenvironmental

conditions during which the sediments get deposited, thereby, helps in understanding the palaeodepositional history of the area. Biostratigraphy and inferred palaeoenvironment of deposition will further help in enhancing the geological model of the area.

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