Neogene biosiliceous microfossils and their efficacy in deep sea water oil exploration and expansion of petroleum prospects from cavernous sediments in the Mahanadi Basin, East Coast of India

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ABSTRACT

The biosiliceous microfossils viz. Diatoms and Radiolarians are emerging contemporary potential tools for dating of sediments, deciphering depositional environment, biochronological correlations, inferring paleotemperature and recognition of paleo-oceanographic events in deep sea water sediments, where other conservative microfossil groups are deficient. The studies of these rare siliceous fossil groups are enabling to provide the valuable information, where the seismic signatures or other related deep sea water structures are not properly identified or recognised by the conventional methods.

A well-preserved and diverse assemblage of biosiliceous microfossils (diatom and radiolarians) is recorded first time from the Neogene subterranean sediments, in the Mahanadi Basin, East Coast of India. An attempt has been made to provide laboratory backup for age determination, deciphering of depositional environments, paleoclimatic conditions, biochronological correlations and paleo-oceanographic events to explore expansions of petroleum prospects in deeper sediments of the basin.

The studies of Middle to Upper Miocene (13.82 Ma to 07.25Ma) sediments at well-C and Upper Miocene to Lower Pliocene? (07.25 Ma to 5.33 Ma) sediments of wells - A and B (Hydrocarbon producers) proposed three diatoms and four radiolarians biozonation schemes and tied directly to paleomagnetic reversal records.

The recovered Middle to Late Miocene biosiliceous microfossils suggest deeper water condition of deposition (>400-1000 m) under warm to temperate climate; whereas Upper Miocene to Lower Pliocene? sediments are observed to be deposited in shallow water (0-400m) under warm water realm.

The studied section of these wells, which comprises two distinct age, paleoenvironmental regimes , paleobathymetric realms and paleo-oceanographic events, may be useful in biochronological correlations, refinement of paleo-oceanographic and paleogeographic analysis of deep water sedimentary processes to delineate the extension of petroleum prospects in the study area and in close proximity of the basin.

INTRODUCTION

The Mahanadi Basin is situated in the Bay of Bengal, along the east coast of India (Fig.-1). The thickest accumulation sediments occur in the Bengal fan, where the sediment is more than 10 km thick. It covers the deltaic plains of Mahanadi River and its distributaries, and lies geographically between Jagannathpur in the northeast and Chilka Lake in the southwest. In Mahanadi Basin, the oldest sediments belong to the Gondwana succession of Permo-Triassic age that deposited in Mahanadi Gondwanic graben. The east coast of India represents a passive continental margin originated during break up of Gondwanaland. The breaking of Gondwana land was started during Late Jurassic -Early Cretaceous. During Middle to Late Cretaceous, the Indian plate first drifted towards north and collided with Tibetan plate and then tilted towards northeast. This event was responsible for building up a new ocean floor in the basin. This episode has changed the course of drainage pattern of surrounding areas and started charging the sediments into the newly formed ocean floor. This major event resulted in the alteration of intra-cratonic basin to divergent margin basin.

In the Early and Late Cretaceous period, the basin was charged with sand/silt deposition. The Paleocene sediments of shelf part are derived from the Eastern Ghat and Central Indian cratons. The Eocene period had witnessed the deposition of limestone with interbeded clastics. The Oligocene was a period of deposition / erosion in the shallow water and on land part, and wedged out in the offshore part. The Miocene period was affected by regional subsidence and it started in Early Miocene. The maximum subsidence was noticed in Middle Miocene period (part of present study). The upliftment in the west and subsidence in the east are responsible for the deposition of prograding deltaic sedimentation on the tectonically altered Miocene section of the basin. The deposition of progradational deltaic sediments is still continued.

GEOLOGY

The sedimentary succession as encountered in the MNO-A, B & C wells, is ranging in age from Cretaceous to Miocene and post Miocene. The generalized stratigraphy of Mahanadi Offshore proposed by Fuloria (1993) has considered for the present interpretation (Fig.-2). The basement is of continental type and made up of granulites and gneisses of Precambrian age. The Lower Cretaceous flow (= Rajmahal Traps) is underlying the Precambrian basement complex, with a mark unconformity and overlain by Upper Cretaceous-Paleocene clastic sediments, which are

unconformably overlain by the Eocene sediments. The Eocene sediments are made up of fossiliferous limestone with subordinate shales and fine grained sandstones. The Oligocene sedimentary sequence is generally absent in the shelf part and represented by a regional unconformity. The Oligocene has represented by silica - clastics sediments and overlain by the Miocene and Post-Miocene sections. This stratigraphic unit comprises essentially of claystones and siltstones with subordinate sandstones. The Pliocene rocks have an unconformable to gradational contact with the underlying Miocene sequence. The Pliocene sequence is made up of coarse to very fine grained unconsolidated sand and grayish silty clays. The youngest stratigraphic unit of Pleistocene – Recent is made up of fluviatile alluvium and the boundary between the unit is generally unconformable.

MATERIAL AND METHODS

Three wells MNO-A, B & C of Mahanadi Offshore Basin has selected for biosiliceous microfossil studies. The wells MNO-A and B are closely located and well MNO-B is stratigraphically lowered by 39m with respect to well MNO-A. The well MNO-C is positioned deeper in SW of well MNO-B and approximately 25-30 kms, away from these two wells.

The cutting and core samples from wells MNO-A, B & C belonging to Middle Miocene to Upper Pliocene sediments are undertaken for siliceous microfossil studies. In all 80 samples between the average depths intervals from 1400-2200m, are studied. The samples have observed under simple biological microscope at 400-x magnification. The standard maceration techniques have followed for the recovery of biosiliceous fossils.

BIOSILICEOUS MICEROFOSSIL BIOSTRATIGRAPHY

In India, biosiliceous microfossils viz. Diatoms and Radiolarians, have been reported mainly from Andman Islands and rarely from Himalayan foothills only (Desikachary, T.V. et al. and 1956, Mathur et al., 1978, 1990, 1992). The standard biozonation schemes for Indian Diatoms and Radiolarians biosiliceous microfossils have yet to be recognized. A general biostratigraphic framework for diatoms and radiolarians developed by Bukry,1981b, 1983, 1985, 1995; Perch-Nelsen,1985, Kobayashi,1988, , Barron,1976,1985, Hajòs ,1971, Dumitrica, 1970, Morley, 1978 have followed.

On the basis of recognition of last and first occurrence datum of age potential biosiliceous species, three diatoms and four radiolarians biozones have been recognized in the studied sections of

wells MNO-A, B & C. A detailed account of the recognized diatoms and radiolarians biozones zones has outlined below in ascending order:

Table-1. Diatom Zones and Age

Diatom Zone (after Barron 1985)	**Wells**			**Age**
	MNO-A	**MNO-B**	**MNO-C**	
Denticula kamtschatica-Denticula saeminae	**1885-1600m**	**1635-1510m**	-	Early to Late Pliocene
Denticula hustedtii-Denticula kamtschatica	-	-	**1475-1450m**	Late Miocene to Early Pliocene
Denticulopsis praedimorpha-Denticula hustedtii	-	-	**1525-1475m**	Middle to Late Miocene

BIOSILICEOUS ZONES: (A=Diatoms, B=Radiolarians)

A. *Denticulopsis praedimorpha-Denticula hustedtii*:
B. Diartus petterssoni-Didymocyrtis antepenultima

Reference Section: Mahanadi Offshore Well C (1525+-1475m); This section is mainly dominated with mudstone to wackestone with sponge spicules fragments and glauconitic pellets.

Definition: In this section of interval both diatom and radiolarians biozones recognised (Table-1). The base of this zone has not recognized due to nonappearance of biosiliceous fossils. The top of this zone has defined at 1475m, as the first occurrence of diatom *Denticula hustedti* and **radiolarian** *Diartus petterssoni* have been recorded.

Common species: This zone includes frequent occurrence of Middle to Late Miocene marker **diatoms** such as *Denticula praedimorpha, Denticulopsis lauta, Denticula hustedtii, Denticulopsis hyaline, Denticulopsis dimorpha, Coscinodiscus cuneiformis* and **radiolarians** viz., *Stichocorys peregrine, Pterocanium prismatium, Lamprocyrtis neoheteroporos, Theocorythium trachelium, Sphaeropyle robusta* and *Actinomma medianum* .

Remarks: This zone has recorded only in well MNO-C and absent in other remaining wells. The overall diversity of diatom and radiolarians species is moderate in this zone.

Biochronological correlation and Age: The dominant occurrence of **diatom** *Denticula hustedti* with *Denticula praedimorpha, Denticulopsis lauta, Denticula hustedtii, Denticulopsis hyaline, Denticulopsis dimorpha* and **radiolarian** *Diartus petterssoni, Didymocyrtis antepenultima, Stichocorys peregrine, Pterocanium prismatium, Lamprocyrtis neoheteroporos* are generally range from Middle to Late Miocene age. The diatoms and radiolarians of this zone resemble with the silicoflagellate zones such as

Dictyocha varia interval Zone of Leg 138, Eastern Equatorial Pacific Ocean (McCartney, 1995) and in east coast of Indian Ocean of well MNO-A (Gupta and Shanmukhappa, 2009) of Middle to Late Miocene age. The foraminiferal zone N9 (*Globorotalia fohsi peripheroronda* Zone) to N10 (*Globorotalia fohsi fohsi* Zone) and nannoplankton zone NN5 (*Sphenolithus heteromorphus* Zone) to NN9 (*Discoster hamatus* Zone) zones of Middle to Late Miocene age have recorded (Sharma and Ali, 2006) in the area. Therefore, Middle to Late Miocene age has inferred for this informal zone.

Paleomagnetic correlation: This zone is correlatable with upper part of C5 to Middle part of C3 polarity chron.

Paleobathymetry : 400-1000m (Gupta and Shanmukhappa,2009)

Paleotemperature: Warm to temperate water (Gupta and Shanmukhappa, 2009)

A. *Denticula hustedtii-Denticula kamtschatica* Zone
B. *Didymocyrtis antepenultima-Didymocyrtis penultima* Zone

Reference section: Mahanadi Offshore well C (1475-1450m); Mostly clays-tone with thin bands of moderately sorted loose sands.

Definition: It is the top most zone of this well. Abundance of **diatoms** viz, *Denticula hustedtii, Denticula kamtschatica, Actinocyclus ingens, Mediaria splendid, Actinocyclus ingenusvar. nodus, Coscinodiscus plicatuss* and *Coscinodiscus temperi* and **radiolarians** such as *Didymocyrtis penultima, Sphaeropyle langii, Botryostrobus aquilonaris* and *Theocorythium trachelium dianae* have recorded.

Base: Last appearance datum (LAD) of **diatom** *Denticula hustedtii* and **radiolarian** *Didymocyrtis antepenultima penultima*

Top: Top of this zone has recognized on the basis of last appearance datum (LAD) of **diatom** *Denticula kamtschatica* and **radiolarian**. *Didymocyrtis penultima*

Common species: Rich assemblages of diatom Denticula hustedtii, *Denticula kamtschatica* are generally the dominant species. *Hemidiscus cuneiformis, Denticulopsis dimorpha,* are the common species of this zone. Poor to moderate **radiolarians** *Didymocyrtis penultima, Sphaeropyle langii, Botryostrobus aquilonaris* and *Theocorythium trachelium dianae* also observed.

Biochronological correlation and Age: The dominant occurrence of **diatom** *Denticula hustedtii* and *Denticula kamtschatica,* significant presence of *Actinocyclus ingens, Mediaria splendid, Actinocyclus ingenusvar. nodus, Coscinodiscus plicatuss ,Coscinodiscus temperi* and **radiolarian** *Didymocyrtis penultima, Sphaeropyle langii, Botryostrobus aquilonaris , Theocorythium trachelium dianae* of Late Miocene to Early Pliocene age have observed in this zone. This zone is also comparable with

the *Distephanus speculum speculum* Zone of Nontropical Regions (Bukry, 1974c)**,** *Dictyocha extensa* Zone of Leg 138, Eastern Equatorial Pacific Ocean (McCartney, 1995), upper part of the *Distephanus quinquangellus* Zone of Ling (1973, 1974) and *Distepanus speculum speculum* zone of MNO-A ,east coast of Indian Ocean (Gupta and Shanmukhappa, 2009). This zone has range from Late Miocene to Early Pliocene age. Foraminiferal Zone N16 (*Globorotalia acostaensis* zone) and N 17 (*Globorotalia humerosa* zone) of Late Miocene and nannoplanktone zone NN9 (*Discoaster hamatus* zone) of Middle to Late Miocene age has also recorded in this interval (Sharma and Ali, 2006). The dominant occurrence of *Distephanus speculum speculum* and *Dictyocha extensa* of Early Pliocene taxa at the top of this zone and characteristic silicoflagellate assemblage of Late Miocene age indicates the Late Miocene to Early Pliocene age for this Zone.

Paleomagnetic correlation: This zone is falling between C3 to C2 polarity chron.

Paleobathymetry : 400-1000m (Gupta and Shanmukhappa,2009)

Paleotemperature: temperate water (Gupta and Shanmukhappa, 2009)

A. *Denticula kamtschatica-Denticula saeminae* Zone

Reference Section: Mahanadi Offshore well-B (1635-1510m) and A (1885-1600) ;Grey to dark grey, silty and highly calcareous Clay/Claystone with thin bands of colorless, dark red, medium to coarse grained, sub rounded to sub-angular moderately sorted loose sands.

Definition: The extension of *Denticula kamtschatica* from the lower zone and appearance of *Denticula saeminae* recorded with significant species *Thalassiosira convexa, Nitzschia fossilis* etc.

Base: Last appearance datum (LAD) of **diatom** *Denticula kamtschatica* and **radiolarian** *Didymocyrtis antepenultima* .

Top : Upper limits of this zone has not demarcated due to non-availability of diatom.

Common species: *Thalassionema schraderi, Thalassionema burckliana, Thalassionema praeconvexa, Nitzschia porteri,* and *Asterolampra acutiloba* are rare to common species.

Biochronological correlation and Age: The present zone corresponds to the lower part of *Dictyocha extensa* zone of McCartney, 1995 (Leg 138, eastern equatorial Pacific Ocean), zone of Gupta and Shanmukhappa, 2009 (well MNO-A) ,east coast of Indian Ocean and *Distephanus speculum speculum* Zone of Bukry (1974c) of Early Pliocene age. The LADs of characteristic Pliocene silicoflagellates viz. *Bachmannocena elliptica, Bachmannocena* sp. A, (Gupta and Shanmukhappa, 2009 and their regular occurrence throughout in this zone along with the rare

occurrence of dinoflagellate cyst *Multispinula quanta*, (Gupta and Singh, 2006), suggests an Early to Late Pliocene age for this zone.

Paleomagnetic correlation: This zone is covered in C2 polarity chron.

Paleobathymetry : < 0-400m (Gupta and Shanmukhappa,2009)

Paleotemperature: Warm water (Gupta and Shanmukhappa, 2009)

On the basis of diatoms zonztion the Early and Late Pliocene can not be demarcated in the well MNOA- and B but two distinct radiolarians biozones have been recognised (Table-2) and useful in demarcating the boundary between Early and Late Pliocene. The details of the siliceous zones are given below:

Table-2. Radiolarians Zones, Age

Radiolarian Zones (after Morley, 1978)	**Wells**			**Age**
	MNO-A	**MNO-B**	**MNO-C**	
Stichocorys peregrine-Lamprocyrtis heteroporos	**1885-1600m**	-	-	Late Pliocene
Didymocyrtis penultima-Stichocorys peregrina	-	**1635-1510m**	-	Early Pliocene
Didymocyrtis antepenultima-Didymocyrtis penultima	-	-	**1475-1450m**	Late Miocene to Early Pliocene
Diartus petterssoni-Didymocyrtis antepenultima	-	-	**1525-1475m**	Middle to Late Miocene

B. *Didymocyrtis penultima - Stichocorys peregrine*

Reference Section: Mahanadi Offshore well-B (1635-1510m); Grey to dark grey, silty and highly calcareous Clay/Claystone with thin bands of colorless, dark red, medium to coarse grained, sub rounded to sub-angular moderately sorted loose sands.

Definition: The extension of *Didymocyrtis penultima* from the lower zone and appearance of *Stichocorys peregrine* in this zone.

Base: Last appearance datum (LAD) of *Didymocyrtis antepenultima* .

Top: Upper limits of this zone has not been demarcated due to non-availability of significant radiolarians.

Common species: *Didymocyrtis penultima, Stichocorys peregrine, Sphaeropyle langii,, lamptocyrtis heteroporosSaturnaliscirculu..*

Biochronological correlation and Age: The present zone corresponds to the lower part of *Dictyocha extensa* zone of McCartney, 1995 (Leg 138, eastern equatorial Pacific Ocean), Gupta and Shanmukhappa, 2009 (well MNO-A) ,east coast of Indian Ocean and *Distephanus speculum speculum* Zone of Bukry (1974c) of Early Pliocene age. The LADs of characteristic Pliocene radiolarians and silicoflagellates and their regular occurrence throughout in this zone, suggests an Early Pliocene age for this zone.

Paleomagnetic correlation: This zone is covered in C2 polarity chron.

Paleobathymetry : < 0-400m (Gupta and Shanmukhappa,2009)

Paleotemperature: Warm water (Gupta and Shanmukhappa, 2009)

B. *Stichocorys peregrine - Lamprocyrtis heteroporos*

Reference Section: Mahanadi Offshore well-A (1885-1600m); Grey to dark grey, silty and highly calcareous Clay/Claystone with thin bands of colorless, dark red, medium to coarse grained, sub rounded to sub-angular moderately sorted loose sands.

Definition: The extension of *Stichocorys peregrine* from the lower zone and appearance of *Lamprocyrtis heteroporos* in this zone.

Base: Last appearance datum (LAD) of *Stichocorys peregrine.*

Top: Upper limits of this zone has not been demarcated due to non-availability of significant radiolarians diatoms.

Common species: *Didymocyrtis penultima, Stichocorys peregrine, Sphaeropyle langii,, lamptocyrtis, Heteroporos Saturnaliscirculu..*

Biochronological correlation and Age: The present zone corresponds to the lower part of *Bachmannocena quadrangula* zone of McCartney, 1995 (Leg 138, eastern equatorial Pacific Ocean), Gupta and Shanmukhappa, 2009 (well MNO-Aeast coast of Indian Ocean) and *Distephanus speculum speculum* Zone of Bukry (1974c) of Late Pliocene age. The LADs of characteristic Late Pliocene radiolarians and their regular occurrence throughout in this zone along with the rare occurrence of dinoflagellate cyst *Multispinula quanta,* (Gupta and Singh, 2006), suggests an Late Pliocene age for this zone.

Paleomagnetic correlation: This zone is covered in C2 polarity chron.

Paleobathymetry : < 0-400m (Gupta and Shanmukhappa,2009)

Paleotemperature: Warm water (Gupta and Shanmukhappa, 2009)

PALEO-OCEANOGRAPHIC AND PALEOGEOGRAPHIC ANALYSIS

The Indian Ocean floor is characterized by a system of three active spreading ridges that now separate four major remains of the earlier main continent Gondwana into Africa, India, Australia, and Antarctica. The central Indian ridge joins the south west and south east Indian ridge. In the South East Indian ridge, there are numerous small ridges and plateaus. The spreading ridges, continental margins, interpolate ridges and plateaus are separated by a series of major basins. The ridges and plateaus provide a remarkable prospect of sedimentation accumulating in-between water depths and over the full extent of the oceanic basin. (Thomas, 1995).

During the Late Miocene time the paleogeography is resemble that of the present day. India placed north of the Equator and Australia sat firmly astride latitude 30^0S. Following rapid growth of the East Antarctica ice sheet in Mid-Miocene, carbonate sedimentation has been progressively restricted to the shallow ridges and plateaus. In the Middle to Late Miocene in the Mahanadi basin, the deposition of carbonate sediments were restricted due to the segregation of Antarctica Bottom water circulation and steepening of thermal gradients in the ocean. Therefore in late Middle to Late Miocene period the development of biosiliceous fossils of warm to temperate water habitat took place. So generally

Looking in Pliocene period, major uplift of the Himalayas is reflected in sharp increased rates of terrigenous sedimentation on both the Indus and Bengal fans and the temperature was rising due to tectonic activity. Due to rise in temperature warm water siliceous biofossils appears.

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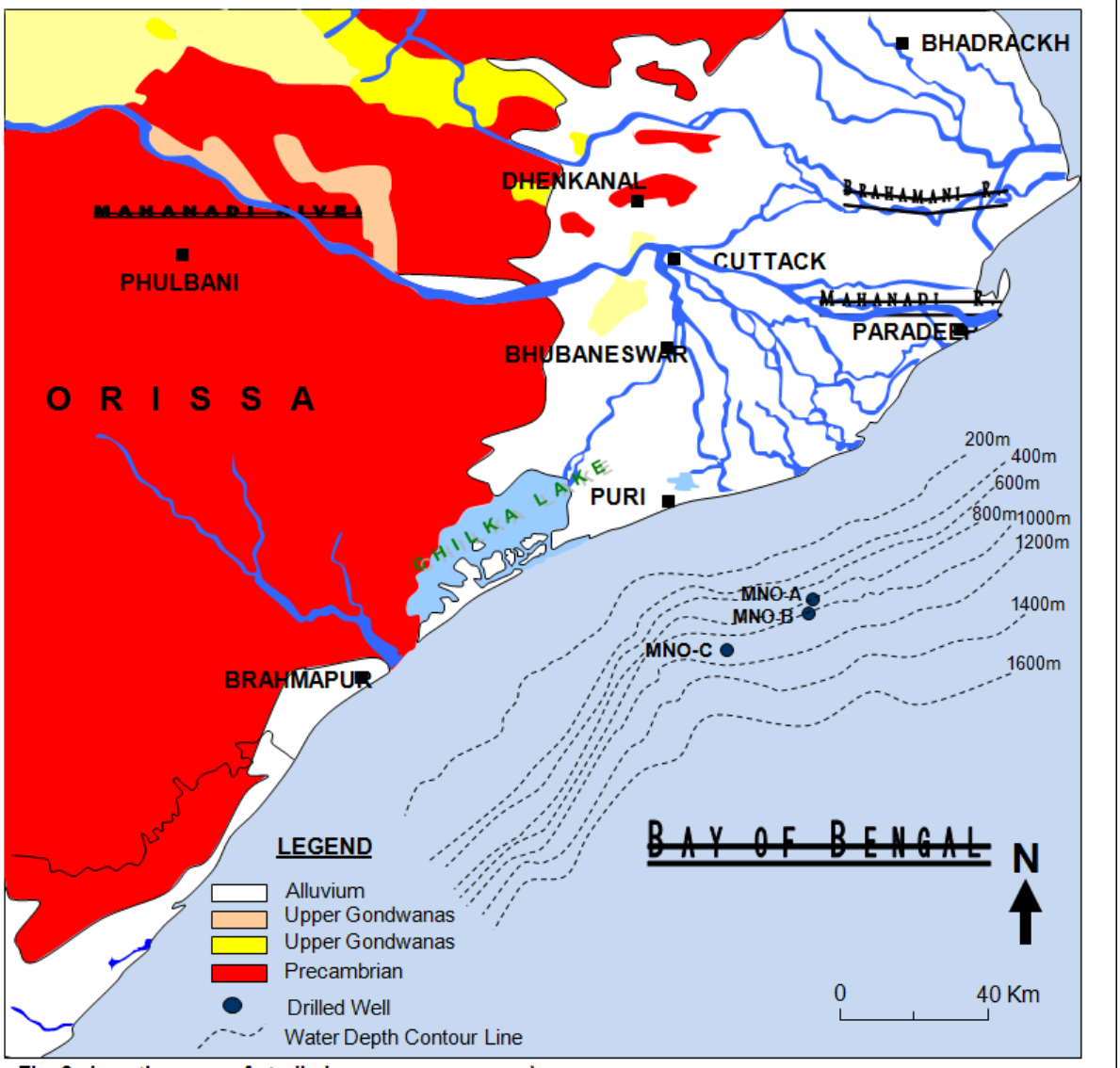
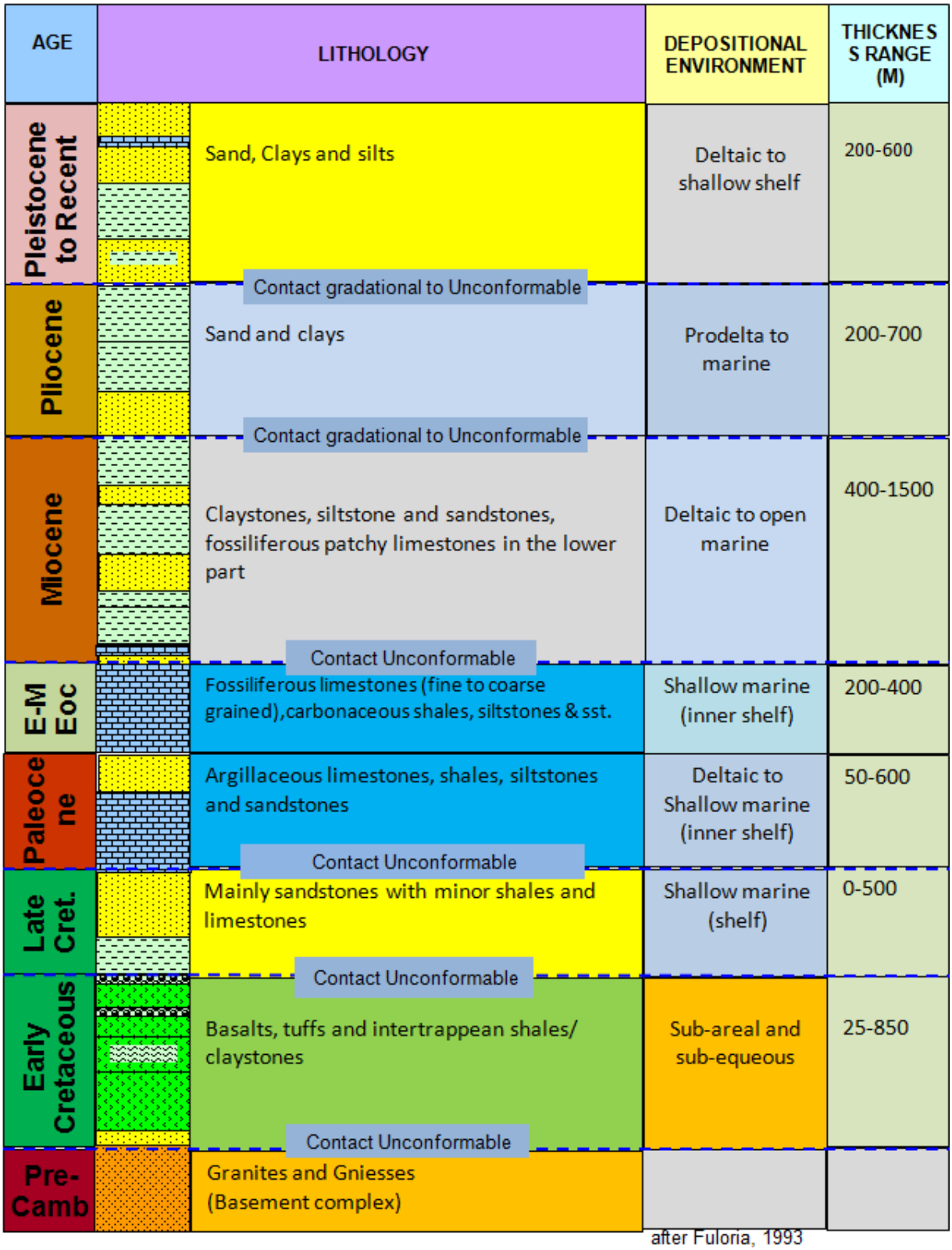


Fig. 2: Location map of studied area (After Chatterji,2006)



after Fuloria, 1993

Fig. 3 Genralised Litho-stratigraphy of Mahanadi Offshore