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*

Anand Gupta[1], M. Shanmukhapp[1], and M.D. Sutariya[1]

Search and Discovery Article #50578 (2012)**
Posted March 26, 2012

*Adapted from extended abstract presented at GEO-India, Greater Noida, New Delhi, India, January 12-14, 2011

[1]Palynology Division, Geology Group, KDMIPE, ONGC, Dehradun, India (anandpaly@gmail.com)

Abstract

The biosiliceous microfossils, 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 providing valuable information where the seismic signatures or other related deep sea water structures are not properly identified or recognized by conventional methods.

A well-preserved and diverse assemblage of biosiliceous microfossils (diatoms and radiolarians) is recorded for the 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 diatom and four radiolarian biozonation schemes and tied directly to paleomagnetic reversal records.

The recovered Middle to Late Miocene biosiliceous microfossils suggest deeper water conditions 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 (0-400 m) under a warm water realm.

The studied section of these wells, which comprises two distinct ages, 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 (Figure 1). The thickest accumulation of sediments occurs in the Bengal Fan, where the sediment is more than 10 km thick. It covers the deltaic plains of the 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 the break up of Gondwanaland. The breaking up of Gondwanaland started during Late Jurassic-Early Cretaceous. During Middle to Late Cretaceous, the Indian Plate first drifted towards the north and collided with the Tibetan Plate and then tilted towards the northeast. This event was responsible for building up a new ocean floor in the basin. This episode has changed the course of drainage patterns of surrounding areas and started charging the sediments into the newly formed ocean floor. This major event resulted in the transition of an intra-cratonic basin to a divergent margin basin.

In the Early and Late Cretaceous period, the basin was charged with sand/silt deposition. The Paleocene shelf sediments are derived from the Eastern Ghat and Central Indian cratons. The Eocene period had witnessed the deposition of limestone with interbedded clastics. The Oligocene was a period of deposition/erosion in the shallow water and on land, and wedged out into the offshore. The Miocene period was affected by regional subsidence, starting in Early Miocene. The maximum subsidence was noticed in Middle Miocene period (part of present study). The uplift 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 continues.

Geology

The sedimentary succession as encountered in the MNO-A, MNO-B, and MNO-C wells, ranges in age from Cretaceous to Miocene and Post-Miocene. The generalized stratigraphy of Mahanadi Offshore proposed by Fuloria (1993) is considered for the present interpretation (Figure 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 marked 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 is represented by siliciclastic sediments and overlain by the Miocene and Post-Miocene sections. This stratigraphic unit is comprised 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.

Materials and Methods

Three wells MNO-A, -B, and -C of the Mahanadi Offshore Basin were selected for biosiliceous microfossil studies. The wells MNO-A and -B are close together and well MNO-B is stratigraphically lowered by 39 m 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, and -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 1400-2200 m were studied. The samples were observed under a simple biological microscope at 400X magnification. The standard maceration techniques have followed for the recovery of biosiliceous fossils.

Biosiliceous Microfossil Biostratigraphy

In India, the biosiliceous microfossils diatoms and radiolarians have been reported mainly from Andman Islands and rarely from the Himalayan foothills only (Desikachary, T.V. et al., 1956; and Mathur et al., 1978, 1990, 1992). The standard biozonation schemes for Indian diatom and radiolarian biosiliceous microfossils have yet to be recognized. A general biostratigraphic framework for diatoms

and radiolarians were later developed by Bukry (1981b, 1983, 1985, 1995), Perch-Nelsen (1985), Kobayashi (1988), Barron (1976,1985), HajÒs (1971), Dumitrica (1970), and Morley (1978).

On the basis of recognition of last and first occurrence datum of age potential biosiliceous species, three diatom (Table 1) and four radiolarian (Table 2) biozones have been recognized in the studied sections of wells MNO-A, -B, and -C. A detailed account of the recognized diatoms and radiolarians biozones zones is outlined below, in ascending order.

Biosiliceous Zones: (A=Diatoms, B=Radiolarians)

A. *Denticulopsis praedimorpha-Denticula hustedtii*:
B. *Diartus petterssoni-Didymocyrtis antepenultima*
Reference Section: Mahanadi Offshore Well C (1525-1475 m); This section is mainly dominated by mudstone to wackestone with sponge spicules fragments and glauconitic pellets.
Definition: In this section both diatom and radiolarian biozones are recognized (Table 1). The base of this zone has not been recognized due to nonappearance of biosiliceous fossils. The top of this zone is defined at 1475 m, 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 have been recorded only in well MNO-C and is absent in the other 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* generally range from Middle to Late Miocene age. The diatoms and radiolarians of this zone resemble the silicoflagellate zones such as *Dictyocha varia* interval Zone of Leg 138, Eastern Equatorial Pacific Ocean (McCartney, 1995) and in the 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 is inferred for this informal zone.
Paleomagnetic correlation: This zone is correlatable with the upper part of C5 to Middle part of C3 polarity chron.

Paleobathymetry : 400-1000 m (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 (1475-1450 m); Mostly clays-tone with thin bands of moderately sorted loose sands.
Definition: It is the top most zone of this well. Abundance of diatoms *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 been recorded.
Base: Last appearance datum (LAD) of diatom *Denticula hustedtii* and radiolarian *Didymocyrtis antepenultima penultima.*
Top: Top of this zone is 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* are 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 a range from Late Miocene to Early Pliocene age. Foraminiferal Zone N16 (*Globorotalia acostaensis* zone) and N 17 (*Globorotalia humerosa* zone) of Late Miocene and nannoplankton zone NN 9 (*Discoaster hamatus* Zone) of Middle to Late Miocene age has also been 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 between the C3 to C2 polarity chron.
Paleobathymetry : 400-1000 m (Gupta and Shanmukhappa, 2009).
Paleotemperature: Temperate water (Gupta and Shanmukhappa, 2009).

A. *Denticula kamtschatica-Denticula saeminae* Zone

Reference Section: Mahanadi Offshore well-B (1635-1510 m) and A (1885-1600 m); 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 have not been demarcated due to non-availability of diatoms.
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 in the C2 polarity chron.
Paleobathymetry : < 0-400 m (Gupta and Shanmukhappa, 2009).
Paleotemperature: Warm water (Gupta and Shanmukhappa, 2009).

On the basis of diatom zonation, the Early and Late Pliocene cannot be demarcated in the well MNO-A and MNO-B, but two distinct radiolarians biozones have been recognized (Table 2) and are useful in demarcating the boundary between Early and Late Pliocene. The details of the siliceous zones are given below:

B. *Didymocyrtis penultima - Stichocorys peregrine*
Reference Section: Mahanadi Offshore well-B (1635-1510 m); 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 have 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 : < 0-400 m (Gupta and Shanmukhappa, 2009).
Paleotemperature: Warm water (Gupta and Shanmukhappa, 2009).

B. *Stichocorys peregrine - Lamprocyrtis heteroporos*
Reference Section: Mahanadi Offshore well-A (1885-1600 m); 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 and 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 a Late Pliocene age for this zone.
Paleomagnetic correlation: This zone is covered in C2 polarity chron.
Paleobathymetry : < 0-400 m (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 southwest and southeast Indian ridge. In the Southeast 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 between water depths and over the full extent of the oceanic basin (Thomas, 1995).

During the Late Miocene the paleogeography resembled that of the present day, with India placed north of the equator and Australia firmly astride latitude 30 degrees south. 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 the development of biosiliceous fossils of warm to temperate water habitat took place.

In the Pliocene, 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 the rise in temperature, warm water siliceous biofossils appear.

Acknowledgments

Authors are grateful to Shri D.K. Pande, Director Exploration, Oil and Natural Gas Corporation Ltd., New Delhi, and Shri P.K. Bhowmick, ED-HOI, KDMIPE, ONGC, Dehradun for kind permission to publish this paper. The views expressed in this paper are those of the authors only and not necessarily of the organization for which they are working or those with whom they had discussions.

References

Barron, A.J., 2005, Diatom biochronology for the early Miocene of the Equatorial Pacific: Straigraphy, v. 2/4, p. 281-309.

Bukry, D., 1995, Silicoflagellates and their geological application, U.S. Geological Survey, Open-file Rept. 95-260, p. 1-27.

Bukry, D., 1987, Eocene siliceous and Calcareous phytoplankton, Deep Sea Drilling Project, Leg 95, *in* C.W. Poag, A.B. Watt et al., Initial Reports DSDP, 95: Washington (U.S. Government Printing office), p. 395-415.

Bukry, D., 1985, Tropical Pacific Silicoflagellate zonation and paleotemperature trends of the late Cenozoic, *in* L. Mayer, F. Theyer, and E. Thomas, et al., Initial Reports DSDP, 85: Washington (U.S. Government Printing office), p. 477-497.

Bukry, D., 1983, Upper Cenozoic Silicoflagellate from offshore Ecuador, Deep Sea Drilling Project site 50, *in* J.R. Cann, M.G. Langseth, J. Honnorez, R.P. von Herzen, and S.M. White, et.al., Initial Reports DSDP, 69: Washington (U.S. Government Printing office), p. 321-342.

Bukry, D., 1981b, Silicoflagellate stratigraphy of offshore California and Baja California, Deep Sea Drilling Project, Leg 63, *in* R.S. Yeats and B.U. Haq, et al., Initial Reports DSDP, 63: Washington (U.S. Government Printing office), p. 551-581.

Bukry, D., 1979, Coccolith and silicoflagellate stratigraphy, northern Mid-Atlantic Ridge and Reykjanes Ridge, Deep Sea Drilling Project, Leg 49, *in* B.P. Luyendyk and J.R. Cann, et al., Initial Reports DSDP, 49: Washington (U.S. Government Printing office), p. 321-342.

Bukry, D., 1974c, Stratigraphic value of silicoflagellate in nontropical regions: Geological Society of America Bulletin, v. 85, p. 1905-1906.

Bukry, D., and J.H. Foster, 1973, Silicoflagellate and Diatom stratigraphy, Leg 16, Deep Sea Drilling Project, *in* van T.H. Andel and G.R. Heath, et al., Initial Reports DSDP, 16: Washington (U.S. Government Printing office), p. 815-871.

Bukry, D., and S. Monechi, 1985, Late Cenozoic silicoflagellates from the Northwest Pacific, Deep Sea Drilling Project Leg 86, paleotemperature trends and texture classification, *in* G.R. Heath, and L.H. Burckle, et al., Initial Reports DSDP, 86: Washington (U.S. Government Printing office), p. 367-397.

Burckle, L.H., 1981, Paleomagnetic data on the *Dictyocha aspera/fibula* cross-over at the equatorial Pacific: Micropaleontology, v. 27, p. 332-334.

Burckle, L.H., 1977, Pliocene and Pleistocene diatom datum levels from the equatorial Pacific: Quat. Res., v. 7, p. 330-340.

Chatterjee, V., S. Haldar, S.K. Roy, D.K. Roy, T.K. Sarkar, and H.S. Rana, 2007, Well completion report on MN-OS-B1 & MN-OS-B2: an unpublished ONGC Report.

Chatterjee, V., et al., 2006, Well completion report on MN-OS-2000/A-1: an unpublished ONGC Report.

Ciesielski, P.F., 1975, Biostratigraphy and paleoecology of Neogene and Oligocene silicoflagellates from cores recovered during Antarctic, Leg 28, Deep Sea Drilling Project, *in* D.E. Hayes, L.A. Frakes, et al., Intital Reports DSDP, 28: Washington (U.S. Govt. Printing Office), p. 625-691.

Ciesielski, P.F., and F.M. Weaver, 1974, Early Pliocene temperature changes in the Antarctic Seas: Geology, v. 2, p. 511-515.

Davies, A., K. Thomas, B. Robertt, and T.S. Ramsay, 1995, A time-slice approach to the history of Cenozoic sedimentation in the Indian Ocean: Sedimentary Geology, v. 96, p. 157-179.

Deflandre, G., 1950, Contribution a I'□tude des silicoflagellid□s actuels et fossils: Microscopie, v. 2, p. 72-108.

Dumitricá, P., 1973, Paleocene, late Oligocene and post-Oligocene silicoflagellates in southwestern Pacific sediments cored on DSDP, Leg 21, *in* R.E. Burns and J.E. Andrews et al., Inital Reports DSDP, 21: Washington (U.S. Govt. Printing Office), p. 837-883.

Frenguelli, J., 1940, Consideraciones sobre los silicoflagelados f˙osiles: Mus. La plata Rev. Paleontol., v. 2/7, p. 37-112.

Fuloria, R.C., 1993, Geology and hydrocarbon prospects of Mahanadi Basin, India, *in* S.K. Biswas et al., (eds), Proceedings 2nd Seminar on Petroliferous Basins of India: v 1, Indian Petroleum Publishers, Dehradun, 248001, India.

Gemeinhardt, K., 1930, Silicoflagellate, *in* L. Rabenhorst (ed.), Kryptogamen-Flora von Deutschland: Osterreich und der Schweiz, Leipzig (Akad. Verlagsgesell.), p. 1-87.

Gupta, A., and M. Shanmukhappa, 2009, Silicoflagellate Biostratigraphy, Paleoclimatic Events And Their Utility In Biochronological Correlations From Deep Water Sediments Of Mahanadi Basin, India: North American Micropaleontological Section, SEPM, Houston, Texas, USA (abstract).

Gupta, A., and K. Singh, 2007, Palynological studies of wells MDW-2A and MDW-2B, *in* S. Prabhakaran, et al., Sedimentolological modeling including palynological, paleontological and geochemical studies of subsurface samples from drilled wells (ONGC) and wells to be drilled in 2006-07 in Blocks MN-OSN-97/3, MN-OSN-2000/1, MN-OSN-2000/2, MN-DWN-98/3, NEC-DWN-2: an unpublished ONGC report.

Kobayashi, H., 1988, Neogene silicoflagellate biostratigraphy of the Japan sea coastal region, with reference to DSDP hole 438A, Tohoku Univ., Sci. rep., 2nd ser. (Geo. l), v. 59/1, p.1-98, California Academy of Science, v. 99, p. 1-35.

Lemmermann, E., 1977, Late Cenozoic silicoflagellates and ebridians from the eastern North Pacific region, *in* T. Saito and H. Ujiie, (eds.), Pacific Neogene Stratigraphy, Tokyo: Proceedings First International Congress, p. 205-233.

Locker, S., 1975, *Dictyocha varia* sp. n., eine miozäne silicoflagellaten-Art mitkompliziertem Variationsmodus: Akod. Geol. Helv., v. 67, p. 631-646.

Locker, S., 1974, Revision der Silicoflagellaten aus der Mikrogeologischen Sammlung von C.G. Ehrenberg: Ecologae geol. Helv., v. 67, p. 631-649.

Locker, S., and E. Martini, 1986a, Ebridians and actiniscidians from the southwest Pacific, *in* J.P. Kennett and C.C. von der Borch et al., Initial Reports DSDP, 90: Washington (U.S. Govt. Printing Office), p. 939-951.

Ling, H.Y., 1973, Silicoflagellates and ebridians from Leg 19, *in* J.S. Creager and D.W. Scholl, et al., Initial Reports DSDP, 19: Washington (U.S. Govt. Printing Office), p. 751-775.

Ling, H.Y., and L.M. Mcpherson, 1974, Study on the ebridian genus *Parathranium* Hovasse: Rev. Espan. Micropaleontology, v. 6, p. 191-200.

Lozar, F., and M. Mussa, 2003, Silicoflagellate Biostratigraphy, hole 1149A (ODP Leg 185, Nadezhda Basin, Northwestern Pacific), *in* J.N. Ludden, T. Plank, and C. Escutia, (eds.), Proceedings of the Ocean Drilling Program, Scientific Results: 185, p.1-18.

Mandra, Y.T., and H. Mandra, 1972, Paleoecology and taxonomy of silicoflagellates from an upper Miocene diatomite near San Felipe, Baja California, Mexico, Occas. Pap.

Mandra, Y.T., and H. Mandra, 1971, Upper Eocene silicoflagellates from NewZealand: U.S. Antarctic J., v. 6, p. 172-174.

Mandra, Y.T., 1969, Silicoflagellate: A new tool for the study of Antarctic Tertiary climates: U.S. Antarctic. J., v. 4, p. 172-174.

Mathur, K., and K. Singh, 1992, Establishing Biostratigraphic criteria based on silicoflagellates for delineating age and zonal boundaries in the Andaman Basin: Project No. GRI.04.028, (An unpublished ONGC Report).

Mathur, K., 1975, Studies in the microfossils of Andaman Islands 3. Fossil silicoflagellates from Havelock Island, Andaman: Bulletin of ONGC, v.12/2., p. 11-16.

Mathur,Y.K., and K. Mathur, 1991, Cenozoic transgressive-regressive events in the Himalayan foothills and the global cycles of sea-level change: Geoscience Journal, v. 12/2, p. 149-154.

Mathur,Y.K., and K. Mathur, 1990, Miocene marine microfossils from the Dharamsala and lower Siwalik sediments of the Subhimalayan Region, India: Geoscience Journal, v. 11/1, p. 31-46.

Mathur, Y.K., and K. Mathur, 1978, Presence of nannoplankton in the lower Siwalik subsurface sediments of Puranpur well No.2, Ganga basin, U.P. and their significance: ONGC Report 51, (Unpublished).

Martini, E., 1971, Neogene silicoflagellates from the equatorial Pacific, *in* E.L. Winterer and W.R. Riedel, et al., Initial Reports DSDP, Washington (U.S. Govt. Printing Office), v. 7/2, p. 1695-1708.

McCartney, K., and W.S. Wise, 1990, Cenozoic silicoflagellates and Ebridians from ODP Leg 113: Biostratigraphy and notes on Morphologic variability, *in* P.F., Barker, et al., Proceedings of the Ocean Drilling Program, Scientific Results, v. 113, p. 729-760.

McCartney, S. Churchill, and L. Woestendiek, 1995, Silicoflagellates and Ebridians from Leg 138, Eastern Equatorial Pacific, *in* N.G. Pisias, L.A. Mayer, T.R. Janecck, A. Palmer-Julson, and van T.H. Andel, (eds.), Proceedings of the Ocean Drilling Program, Scientific Results:v. 138, p. 129-162.

Morley, J.J., 1978, Radiolarias from the Northwest Pacific: Deep Sea Drilling Project, Leg 86, p. 399-422.

Perch-Nelsen, K., 1985, Silicoflagellates, *in* H.M. Boli, J.B. Saunders, and K. Perch-Nelsen (eds.), Plankton Stratigraphy: Cambridge University Press, Cambridge, UK, p. 811-846.

Sharma, D.C., and Q.A. Ali, 2006, Foraminiferal and Nanoplankton Study Of Well MNO-1 (MN-OS-2000/A-1), *in* S. Prabhakaran et al., Micropaleontological and sedimentological study of sediments encountered in the well MNO-1 in Mahanadi offshore Basin: an unpublished ONGC report.

Tsuchi, R., 1997, Marine climatic response to Neogene tectonics of the Pacific Ocean seaways: Tectonophysics, v. 281, p. 113-124.

Van Valkenburg, S.D., 1980, Silicoflagellates, *in* E.R. Cox, (ed.), Phytoflagellates: Elsevier, New York, USA, p. 355-350.

Van Valkenburg, S.D., and R.E. Norris, 1970, The growth and morphology of the Silicoflagellate Dictyocha fibula Ehrenberg in culture: J. Phycology, v. 6, p. 48-54.

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

Table 1. Diatom zones and ages.

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

Table 2. Radiolarian zones and ages.

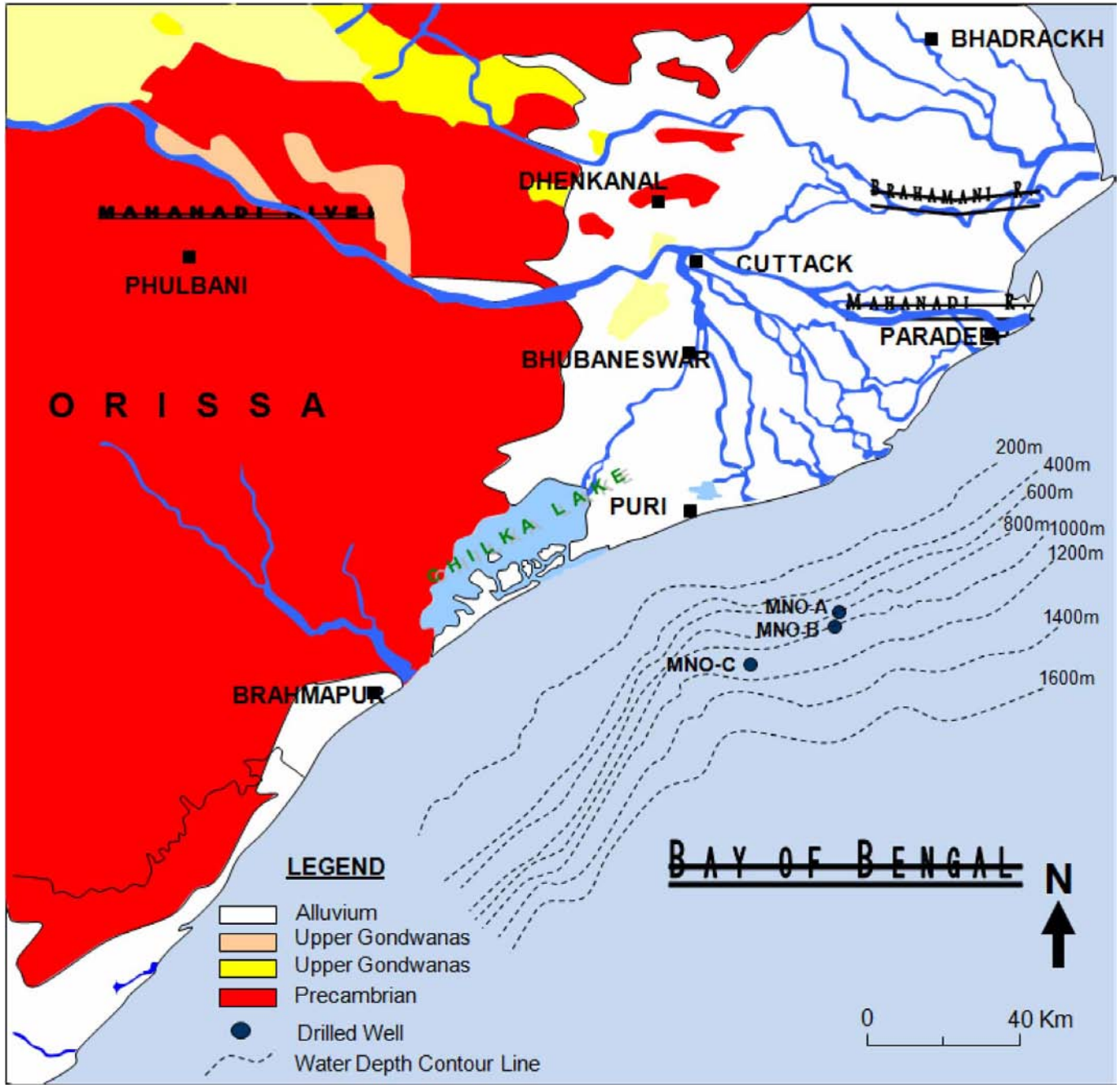

Figure 1. Location map of studied area (after Chatterji, 2006).

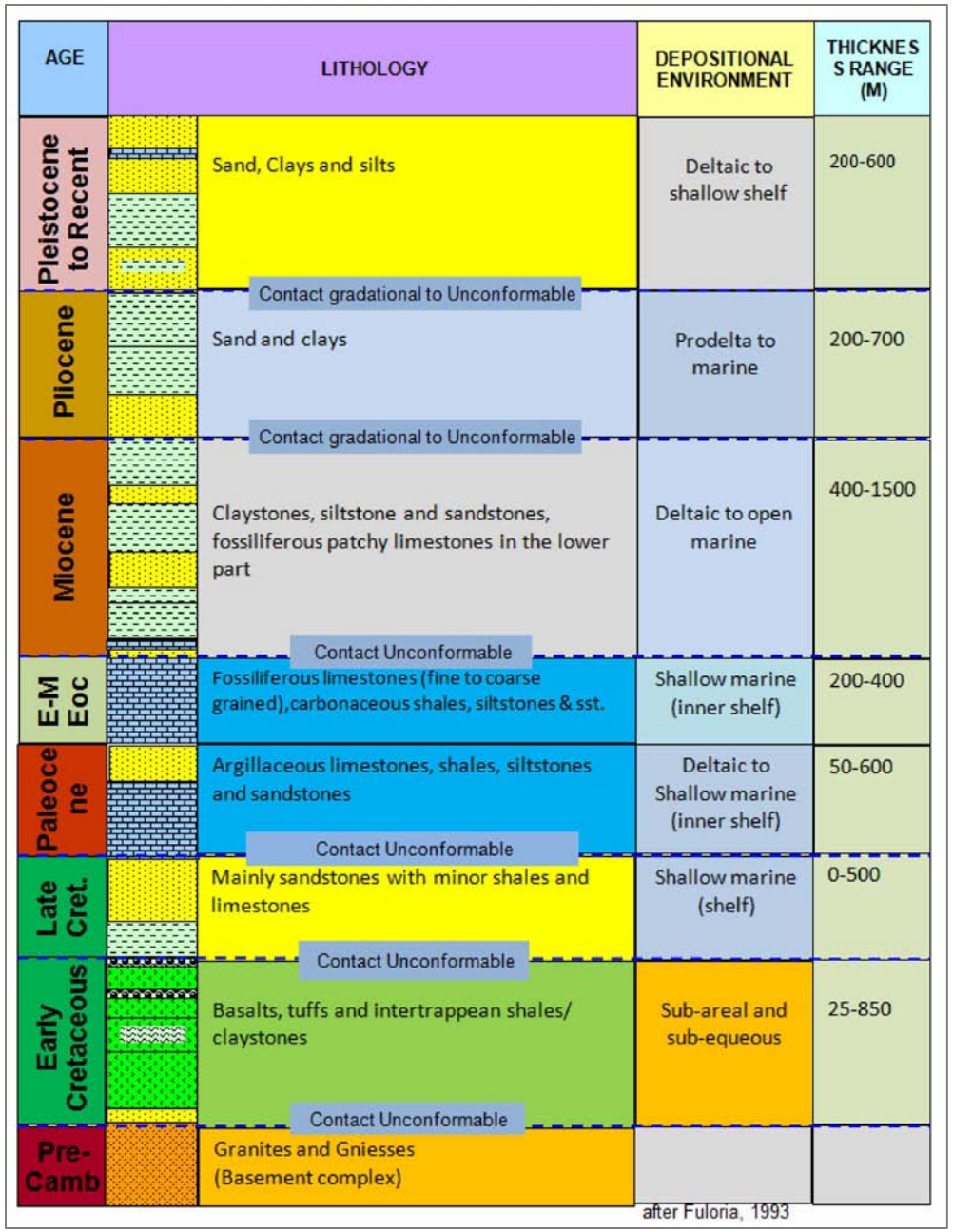

Figure 2. Generalized lithostratigraphy of Mahanadi Offshore area.