DISTRIBUTION OF BENTHIC FORAMINIFERAL ASSEMBLAGES IN THE HOLOCENE SEDIMENTS OF THE CONTINENTAL SHELF REGION OFF WEST BENGAL AND ORISSA, BAY OF BENGAL

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ABSTRACT

Seabed sediments off Hoogly and Dhamra rivers indicate a distinct change of biogenic and terrigenous components in the eastern and western sides of the Ganga prodeltaic region in the continental shelf, Bay of Bengal. A total of 96 samples were collected between 5 m and 112 m isobaths covering an area of 2136 sq km off Hoogly river (eastern domain) and 160 samples between 9 m and 45 m water depths covering an area of 2200 sq km off Dhamra river (western domain) respectively for the study of foraminiferal biofacies, faunal assemblages and sediment characteristics. Three foraminiferal biofacies have been delineated separately in both the domains and their relation to the bathymetry and bottom sediments was analyzed. The biofacies contact is nearly parallel to the bathymetric contours and shore line in the eastern domain but shows incongruous relation in the western domain. The overall biogenic component in the seabed sediments are less (10 to 20%) in the former and more (20 to 30%) in the latter domain. The biogenic material comprises foraminifera and molluscs with some amount of ostracods, bryozoa/coral fragments and echinoid spines as well as a few worm tubes, fish otoliths and burrows.

The seabed samples, within the depth range from 20 m to 45 m isobath, show the presence of anomalous sediment containing relict foraminiferal and mollusc taxa along with Recent biota. The anomalous sediments are made of illsorted concretions, grits, very coarse to coarse sand with considerable biogenic material and some oolite/pellets at places. The relict faunal assemblage and sediment character reveals their deposition at low sea stand in the past. Benthic foraminifera are of smaller size, thin test, and show lower diversity and low TFN (Total Foraminiferal Number) in the eastern domain than the western sector within the inner shelf zone. A good number of bivalves and gastropods with some scaphopods, coral/bryozoaan fragments and echinoid spines is observed in the western domain but their number is considerably less and the assemblage is different in the east.

A total of 54 benthic and 12 planktic foraminiferal taxa has been identified along with 14 gastropod, 13 bivalve, 4 scaphopod and 8 pteropod species. The sediments of the western part are relatively older and show offlap character, while the eastern domain is younger and shows onlap behavior. The younger deltaic sediments are continuously overlapping the older sediments in the western domain during the Holocene time. Two domains are distinctly different in grain size, texture, mineral composition and fossil content from each other which are responsible for the huge sediment flux in the macrotidal Hoogly River on the east and low sediment influx in the meso-tidal Dhamra River on the west.

Keywords: Benthic Forminifera, Holocne, continental shelf, Bay of Bangal

INTRODUCTION

Benthic foraminiferal population has a great role in interpretation of depositional environment because its occurrence is related to different occenographic parameters such as depth, temperature, salinity, dissolved oxygen, sediment distribution pattern and physiographic set-up of the basin. They are sensitive even to subtle changes in the ambient environmental conditions and, have emerged as potential tool for assessing any environmental changes (Bhalla *et al.*, 2007). During last several decades, it was established that the foraminifera are important ecological indicators and one of the primary means in deciphering the present and past climate/ environment. The foraminifers were one of the first taxonomic groups to be widely employed as indicators of ancient water depth and they are particularly sensitive to water pressure (Raup and Stainley, 1977).

Ganga-Brahmaputra river system is draining a large volume (971 km³ /year, Milliman *et al.*, 1989) of sediments from the rising Himalayan province and accommodating them in the subsiding Bengal basin to form the vast Sunderban delta. This process is responsible for the development of rapidly prograding delta and the Bengal deep-sea fan during the late Pliocene-Quaternary time (Biswas and Agarwal, 1992). The physiographic set-up of this region is mainly guided by the huge sediment discharged and shelf progradation in the Bengal

Basin. The extensive deposition of sediments at a high rate and the changing characteristics of the sediment is an important geological event during Quaternary Period (Curray *et al.*, 1982 and Emmel and Curray, 1985).

The territorial water (12 Nautical miles from the coast) covers an area of 14,460 sq km in the West Bengal and Orissa coast in the Bay of Bengal. The present work covers an area of 2135 sq km and 2200 sq km within the continental shelf region off Hoogly and Dhamra Rivers, respectively (Fig.1). These sediments represent an archive of Quaternary foraminifera which can be applied in quantitative analysis of important benthic taxa for environmental studies. In this paper, the author has endeavored to present the difference in depositional environment to the eastern and western domains of the Ganga prodeltaic region. An attempt has been made to delineate different foraminiferal biofacies, study the mollusc population and sedimentological parameters for understanding their environmental implication during the Quaternary time.

PREVIOUS WORK

Many micropalaeontologists have taken up foraminiferal investigation in the prodeltaic region off Hoogly River for the study of the Quaternary sea-level changes, nature of sedimentation and faunal diversity. Sporadic micropalaeontological studies have been carried out in some parts of continental shelf of this vast coastal area which are
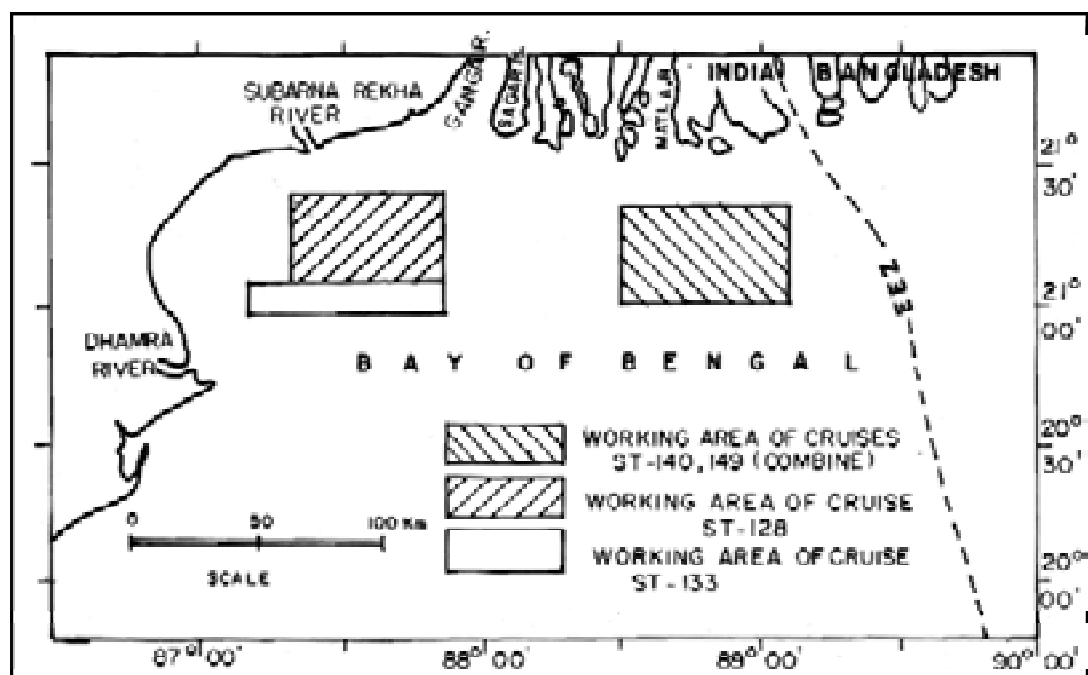
Fig.1. Location map of the working area.

mostly of qualititative nature. The foraminiferal studies got most importance among the micro-organisms due to their maximum occurrence in the sediments and their reliability to incorporate the environmental changes compared to other group of marine biota. Distribution of foraminifera in and around the northern Bay of Bengal had been studied by various workers in the last few decades. However, no comprehensive foraminiferal biofacies map is published till date. Bhalla (1968) studied the recent foraminifera from beach sand of Puri. Ghosh and Chaudhary (1976) and Pal (1988, 89) examined the distribution pattern of foraminifera in the northern parts of Bengal fan. Cullen (1981) studied the effects of changing salinity on microorganisms in the Bay of Bengal. Banerjee and Sen (1987 and 1990) studied the palaeobiological aspects to understand the sea-level and coastline change during the Holocene Period on the basis of *Ammonia*. Palaeoenvironmental signifance of foraminifera in the territorial water (TW) of West Bengal and Orissa was studied by Panda *et al.* (2005) and Bhattacharjee *et al.* (2002, 2003) for their ecological interpretation on the basis of the foramgeographic affinity of various species.

PRESENT WORK

The seabed survey during the two and half decades by Geological Survey of India with the help of research vessel "*Samudra Kaustabh*" had covered a major part of the prodeltaic region within the TW of West Bengal and Orissa thereby acquiring huge scientific data. The present work was carried out in parts of Ganga prodeltaic region off Hoogly and Dhamra rivers during the GSI cruises ST: 128, ST: 133, ST: 140 and ST: 149 (Fig.1). During the Cruises ST:128 and ST:133, one hundred sixty seabed samples were collected between the latitudes 20^0 55' N and $21^0$15' N and longitudes 87^0 10'E and 87^0 55' E, covering an area of 2200sq km within 9 m to 45 m isobaths at 2.5 X 2.5 km grid interval. In cruises ST:140 and ST:149, ninety six seabed samples were collected within an area of 2135 sq km, lying between the latitudes 21^0 00' N and 21^0 15' N

and longitudes from 88^0 24'E to 89^0 08'E from 5 m to 112 m water depths at a grid interval of 5km X 5km (NHO Chart no.351). Sampling work was carried out, in connection with geological mapping, during December, 1998; January, 2000; January, 2001 and January, 2002 respectively.

In the present work, foraminiferal biofacies map has been prepared based on the relative abundance of different foraminiferal taxa in the seabed sediments. The biofacies units are discussed in relation to sediment texture and bathymetric contours. The work throws light on possible correlation among seabed sediment distribution pattern, physiographic set-up and faunal-water mass relationship on the strength of 160 samples of seafloor sediments.

MATERIAL AND METHODS

Twenty four and seventy six seabed samples were selected for quantitative and qualitative palaeontological studies respectively from the survey area. About 10 gm dry sample is processed for foraminiferal studies following the standard micropalaeontological procedures (Boltovoskoy and Wright, 1976). The weight percentage of the coarser fraction (>63 μm) and the ratio of Terrigenous (T): Biogenic (B) of the sediments has been calculated (Tables 1 and 2). The representative coarser fractions of each and every sample were evenly distributed over the graduated metallic tray and individual grain of terrigenous and biogenic material was scanned under binocular microscope. Percentage of these two fractions was calculated by grain counting and finally their ratio was determined. The biogenic material of the coarser fraction (>63 μm) mainly comprises benthic foraminifera with some amount of planktic foraminifera, gastropods, bivalves, ostracodes, pteropods, scaphopods, bryozoa/coral fragments, echinoid spines as well as a few crinoids stems, worm tubes, fish otolith and burrows.

Foraminifera and other micro-organisms are handpicked from the coarser fraction under the binocular microscope and mounted on the micropalaeontological trays for taxanomic identification. The classification by Loeblich and Tappan (1988)

Table 1: Distribution pattern of benthic foraminiferal taxa in seabed sediments off Hoogly river, Bay of Bengal.

Spl.No.	Depth(m)	Sediment	Sand—Silt—Clay	B:P	T:B	Dominant benthic Taxa	Important Benthic taxa
140:3/5	8.83	Sand	91.12—5.56—3.32	22:1	10:1	*A. trispinosa*	*A.beccarii, E.crispum, Q .seminulum, T.saggitula,C.lobatulus.*
149:9/2	9.12	-do-	86.32—10.36—3.42	23:1	10:1	*-do-*	*-do-*
140:7/3	10.62	Sand	90.23—4.26—2.51	24:1	9:1	*-do-*	*-do-*
149:10/4	12.58	Silty sand	49.26—32.14—18.60	14:1	9:1	*-do-*	*A.beccarii, E.crispum, T.inflata,Q .seminulum, T.saggitula,C.lobatulus.-*
140:6/4	11.65	sand	78.36—16.14—5.50	20:1	10:1	*-do-*	*-do-*
149:14/2	14.34	Silty sand	50.49—34.11—5.40	14:1	8:1	*-do-*	*-do-*
149:9/4	15.39	Fine Sand	78.32—15.28—6.40	15:1	8:1	*A.trispinosa*	*-do-*
149:13/2	16.80	Sand-Silt-clay	35.81—30.56—33.63	14:1	8:1	*A.beccarii, A .trispinosa*	*A.beccarii, E.crispum, Q .seminulum,B.robsta, T.saggitula,C.lobatulus.*
140:7/5	17.80	Silty Sand	44.26—42.2—13.56	15:1	8:1	*-do-*	*-do-*
149:16/2	18.84	Silty Sand	46.70—39.21—14.91	13:1	7:1	*-do-*	*-do-*
140:2/6	19.07	Silty sand	48.68—35.65—15.67	21:1	7:1	*do*	*A.beccarii, M. subrotunda, E.crispum, B. robsta, Q.vensta, T.agglulutinans, E. rependus, C. calcar*
140:5/6	19.58	Sand	80.46—10.36—9.18	15:1	8:1	*do*	*do*
149:12/4	21.87	Sandy silt	32.40—46.02—21.58	9:1	7:1	*-do-*	*-do-*
140:8/6	27.28	Sandy silt	30.98—49.65—19.37	13:1	6:1	*-do-*	*-do-*
149:9/6	32.73	Clay silt	10.56—51.44—38.00	10:1	6:1	*do*	*-do-*
149:13/5	41.90	-do-	9.78—50.96—39.26	7:1	6:1	*N.scapham, N.asterizans*	*N .depressula, C. teretris, L.calcar, C.oblonga C. laevigata, S. communis.*
149:11/6	42.81	-do-	12.86—48.11—39.03	7:1	5:1	*-do-*	*-do-*
149:12/6	54.22	-do-	4.66—49.00—46.34	6:1	5:1	*-do-*	*-do-*
149:14/6	84.17	-do-	3.43—48.97—47.60	5:1	4:1	*-do-*	*N. depressula, N. turgida, B. alata C. oblonga, S. depressa, S. communis*
149:16/5	111.2	Sand	89.08—6.48—4.44	3:1	3:1	*-do-*	*-do-*

and Eliss and Messina (1940) for foraminifera has been followed for most of the generic level identification. Specific level identification has been done as per Bolli *et al.* (1987), Kennett and Srinivasan (1976), Barker (1960), Ingle *et al.* (1980), Gupta (1994) and Wells *et al.* (1994). Foraminiferal biofacies map was prepared on the basis of dominant taxa as per the method adopted by Walton (1964) and Patterson (1993). Identification of the molluscs and pteropods were made following the work of Ludbrook (1984), Bé and Gilmer (1977) and Ujihara (1996). A total of 54 benthic and 12 planktonic foraminifera, 8 pteropods, 14 gastropod, 13 bivalve and 4 scaphopod taxa were identified. 19 SEM photographs are

shown in Plates I and II for the taxonomic identification of 17 benthic taxa from the western and eastern domains of the prodeltaic region.

Frequency distribution of 46 benthic taxa was tabulated (Table.3 and 4) from 24 seabed samples. The well-preserved shells are considered to be *in situ* forms and the broken, damaged, corroded or rubbed, partly or completely petrified and brownish/yellowish brown specimens are considered as relict. The number of benthic specimens, their diversity index and percentage in three major suborders (Rotalina-Miliolina-Textularina) was calculated (Table 5). Diversity index of benthic foraminifera in different seabed samples was determined as

Table 2: Distribution pattern of benthic foraminiferal taxa in seabed sediments off Dhamra river, Bay of Bengal.

Spl. No.	Depth (m)	Sediment	Sand—Silt—Clay	B:P	T:B	Dominant ben. Taxa	Important benthic taxa
128:11/5	10.60	Silty sand	70.49—24.05—5.46	30:1	7:1	*A.trispinosa*	*A.beccarii, Q. lamarckana, C. lobatulus E.crispum, T. tricarinata, T. saggitula* .
133:16/4	11.71	-do-	71.54—24.19—4.27	30:1	7:1	*-do-*	*-do-*
128:1/7	12.96	Sandy silt	22.24—66.88—10.88	28:1	6:1	*A.beccarii*	*A. trispinosa, E. crispum, P. bradyi T.inflata, Q. seminulum, Textulariasp,.*
128:11/7	13.55	-do-	18.52—68.47—3.01	26:1	6:1	*A.trispinosa*	*A. beccarii, E. crispum, T. inflata Q. seminulum, T. saggitula, C. lobatulus.*
128:3/7	16.23	-do-	34.16—59.31—6.53	26:1	6:1	*A.beccarii*	*A.trispinosa,E.crispum, T.inflata Q .seminulum, Textularia sp, P.bradyi,.*
128:6/5	15.80	-do-	36.40—58.86—4.74	26:1	6:1	*-do-*	*-do-*
133:14/4	18.00	Silty sand	61.97—30.10—8.30	25:1	5:1	*A.trispinosa*	*A.beccarii, E. crispum, T. inflata Q. seminulum, T. saggitula, C. lobatulus*
128:2/5	19.10	-do-	67.53—27.41—5.06	25:1	5:1	*A.beccarii,*	*A. trispinosa E. crispum, C. lobatulus Q. seminulum, B. robsta, T. tricarinata,.*
128:5/5	20.68	Sandy silt	34.22—58.54—7.24	23:1	5:1	*-do-*	*-do-*
128:1/3	22.45	Sand	80.69—15.06—4.25	23:1	4:1	*-do-*	*-do-*
133:2/2	22.60	Sand	76.88—18.31—5.21	22:1	4:1	*A.beccarii,- A.trispinosa*	*M. subrotunda, E. crispum, B. robsta, Q. vensta, T. agglulutinans, E. rependus*
133:4/4	23.40	Sand	78.74—16.47—5.39	22:1	4:1	*-do-*	*-do-*
128:7/3	24.10	Silt	14.87—77.10—8.03	20:1	4:1	*A .trispinosa*	*A.beccarii, E. crispum, T. inflata Q. seminulum, T. saggitula, C. lobatulus*
133:12/4	27.10	Sandy silt	23.12—69.71—7.27	20:1	3:1	*A.beccarii,- A..trispinosa*	*M. ostaralis, E.advenum, C, calcara, Q. vensta, Loxostomum sp, E. rependus*
133:8/4	28.60	Silty sand	72.88—20.57—6.55	20:1	3:1	*do*	*-do-*
133:11/1	30.2	Sand	89.82—7.21—2.97	17:1	3:1	*do*	*-do-*
128:9/1	33.40	Silt	10.84—82.71—6.44	17:1	3:1	*A .trispinosa*	*A.beccarii, E. crispum, T. inflata Q. seminulum, T. saggitula, C. lobatulus*
133:10/4	34.32	Silty sand	62.65—29.42—7.93	15:1	2:1	*-do-*	*-do-*
128:7/1	38.81	do	60.81—30.23—8.96	15:1	2:1	*A.beccarii,- A.trispinosa.*	*T. tricarinata, E. advenum, C. calcara, Q. vensta, A. convexa, E. rependus*
133:15/1	44.5	do	54.41—32.14—13.45	15:1	2:1	*do*	*-do-*

per the number of the various species divided by the logarithm of the number of total specimen (Margalef, 1967). The seabed sediments are air dried and treated with 30% H_2O_2 to remove the organic materials for size analysis. The coarser (sand) fraction (>230 ASTM size) are separated with the help of running water over a 230 mesh. Pippeting is then carried out to obtain the percentage of silt and clay in the sediments. Different sediment types are classified (Shepard, 1954) on the basis of sand, silt and clay percentage and shown in Table 1 and 2.

PHYSIOGRAPHIC SET-UP

Bathymetric survey, with the help of "Bathy-1500" at five minute time interval, reveals a comparatively gentle relief of the continental shelf region off Hoogly river (Fig. 2). The shelf, in general, slope at an angle less than 1^0 towards south. The northern part of the shelf shows very gentle gradient (1:3000 to 1:1000) but the gradient increases gradually and becomes moderate (1:300) to the outer shelf zone (Fig. 2). The bottom topography of the near shelf region is slightly complex due to strong wave action, tidal effect and very high rate of sedimentation. Shoaling is the common feature in this region as indicated by tongue-shaped contours with characteristic flexure (Fig. 2). Two elongated subparallel ridges and broad channels showing N-S to NNW-SSE trend in the western side of the area which are restricted within 8 m to 15 m isobaths. Various morphological features of the eastern domain show high influence of river influx. Bathymetric map in the continental shelf region off Dhamra river is nearly smooth and gently sloping towards the south (Fig. 3). Isobaths indicate very low gradient (1:3300) in the west and low to moderate gradient (1:667) in the east (Fig. 3). Two subdued channels are observed in this region. Presence of some elongated ridges are observed
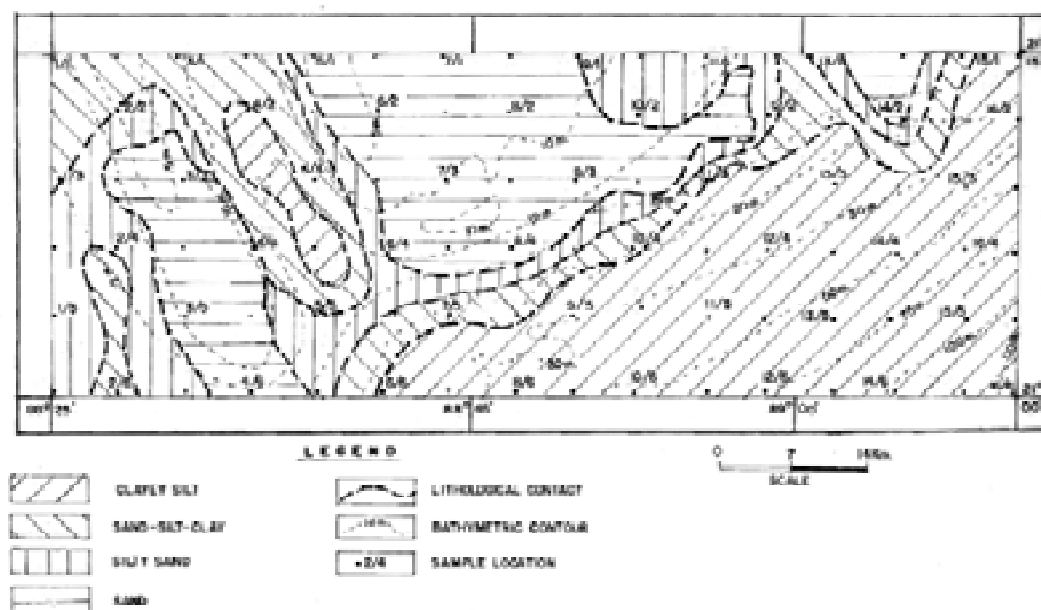
Fig. 2. Sample location and sediment distribution map off Hoogly river, Bay of Bengal

in the adjoining areas off the Hoogly river within the continental shelf domain with the help of IRSP-5 imagery but they are absent off Dhamra river. The topography of the continental shelf plays an important role in controlling the growth rate of prodeltaic formation in this region.

SEDIMENT DISTRIBUTION PATTERN

Six types of sediments viz. sand, silty sand, clayey silt , sand-silt-clay, silt and silty sand are delineated on the basis of size analysis of the seabed sediments (Tables 1 and II and Figs. 2 and 3). Weight percentage of the coarser fraction of the surficial sediments has been calculated in different physiographic domains for 40 samples and this value is very high to high (96.11 to 44.26%) in the near shelf of the area but is considerably reduced (24.34 to 3.45%) in the outer-shelf region. Off Hoogly River, sand and silty sand sediments dominate in the western and northern sides of the area. Shoals are mostly covered by well-sorted coarse sands. Two tidal ridges in the western side of the area are made of coarse to medium sand. Silty sand mainly occupies in the down slopes on either sides of the shoals and ridges between 8 m and 18 m water depths. The southeastern side of the area is mainly covered by clayey silt. A narrow strip of sand-silt-clay sediment occurs between silty sand and clayey silt and extends from the central part to the northeastern part of the region.

Off the Dhamra River, concretionary sand covers about fifty percent area. It is made of ferruginous/calcareous concretions, grits, and very course to course sand with lot of shell materials. Size of the concretions varies from 0.5 to 6.0 cm. Oolites and pellets are observed at places but heavy minerals (ilmenite, sillimanite, rutile, garnet, zircon and monazite) are often present in minor proportion. Characteristics of this concretionary sand indicate the presence of anomalous (relict) sediments in this domain. The sediments show remarkably different behavior with respect their faunal assemblage and sedimentlogical properties from the present inner-shelf sediments. This aspect has been discussed under the heading discussion-interpretation. Silty sand and silt occur as elongated

patch extending in the NW-SE direction (Fig. 4). Patches of carbonaceous material with black clay are occasionally associated with these two sediments. Sandy silt mainly covers the northern part of the area. An inverse relationship between coarser and finer sediments along depth can be ascertained by the sediment distribution map in this area.

FORAMINIFERA AND MOLLUSCS

The overall biogenic components in the seabed sediments are more (20 to 30%) in the western domain and less (10 to 20%) in the eastern domain respectively. Benthic foraminifera and molluscs are the most dominant components and is constitute about 75 to 80% of the biogenic components in the seabed sediments. Hence, they are studied in detail and described separately for environmental interpretation.

FORAMINIFERAL BIOFACIES

Distribution of dominant (> 10%) and important (3 to 10 %) benthic taxa in different bathymetric set-up and their relation to the bottom sediments is shown in Tables 1 and 2 for the preparation of the biofacies map. A check list of 35 benthic taxa was prepared in each domain on the basis of qualitative analysis of the individual taxon present in the five gram (approximately) of dry samples.(Tables 3 and 4). A total of about 9200 specimens were examined from 40 seabed samples (24 quantitative and 16 qualitative, shown in Tables 1 and 2) for the preparation of the biofacies map. The benthic assemblage is dominated by five families (Rotaliidae, Bolivinidae, Elphidiiae, Hauerinidae and Nonionidae) in the eastern domain, while it is dominated by four former families in the western domain. Another five important families (Buliminidae, Bagginidae, Spiroloculinidae, Textulariniidae and Cassidulinidae) are present in both the domains. Besides these, seven families (Calcarinidae, Cibicididae, Eponidae, Harmosonidae, Trochomnidae, Buliminellidae and Vaginulinidae) are commonly observed in the prodeltaic region.

Utilising this distribution pattern of total benthic taxa, three foraminiferal biofacies (*Astroroalia, Astroroalia-Ammonia and*

Table 3: Check list of benthic taxa in the surficial seabed sediments off Hoogly river, Bay of Bengal

Name of Taxa	Sp.no.	149:9\2	140:7\3	149:10\4	149:9\4	140:7\5	149:16\2	149:12\4	149:9\6	149:11\6	149:12\6	149:14\6	149:16\5
	W.D (m)	9.1	10.6	12.6	15.4	17.8	18.8	21.9	32.7	42.8	54.2	84.2	111
Ammonia beccarii (Linnaeus)			4	5	6	21	25	30	30	12	10	12	8
A .inflata (Sequenza)						4	4	5			16	18	16
Astrorotalia trispinosa(Thalman)		19	21	23	27	22	30	28	32	9		10	8
Bolivina alata Sequenza										6	10	12	16
B.robasta Brady						5	4	6		10	20	24	10
B.spatulata (Williamson)							6				12	20	14
B.striatula Cushman							4		7	8	8	10	16
Bulimina elongate d'Orbigny									3	10		12	18
Calcarina calcar d'Orbigny					4	5			6		4		3
Cancris oblonga(Williamson)									3	14	11	22	24
Cassidulina laevigata d'Orbigny										6	8	10	17
C. teretis Tappan								4	4	12	12	18	20
Cibicides lobatulas (Walker & Jacob)					4		6						
Elphidium advenum (Cushman)							4					8	10
E.crispum(Linnaeus)		4	5	6	6	6	7	6	8				20
E.macellum (Ficktel & Moll)						2		4	6	8		6	8
Eponoides rependus(Ficktel & Moll)				5			3	3					
Lenticulina calcar(Linnaeus)									4	8	10	14	16
Miliolinella subrotunda (Brady)					4	5	6	7			8		4
Nonion asterizans(Ficktel & Moll)									8	28	30	34	36
N.depressula(Walker & Jacob)									4	8	10	12	14
N.scapham(Ficktel & Moll)									6	12	18	8	10
Nonionella turgida(Williamson)												14	19
Psedorotalia schroeteriana Carpenter,Parker & Jones					4	6	8	4					
Quinqueloqulina lamarcana								4	5			4	3
Q.seminulum(Williamson)		4	4	4	4	4	6	6	8		12		8
Q.venusta Karrer						4	6	6		6	8	8	6
Reussella simplex(Cushman)								5	4		6	10	16
Spiroloculina communis Cushman & Todd							3	4	4			6	8
S. depressa d'Orbigny									3	6	7	4	8
Textularia agglutinans d'Orbigny			3	3	7	6	4						4
T.saggitula Brady		3	2	2		3		5			6		2
Trochomina inflata(Montagu)		3		3		2							
Triloculina trigonula (Lamarck)					2				4		5		4
Ti. striatotrigonula Parker & Jones							4	5		6			6

Nonion) are delineated off Hoogly river (Fig. 4) and another three (*Ammonia, Astroroalia* and *Astroroalia-Ammonia*) off Dhamra river (Fig. 5) in the Bay of Bengal respectively. Variation of the faunal behaviour of benthic taxa in above biofacies is shown in Tables 3 and 4. A brief description of the biofacies is given below.
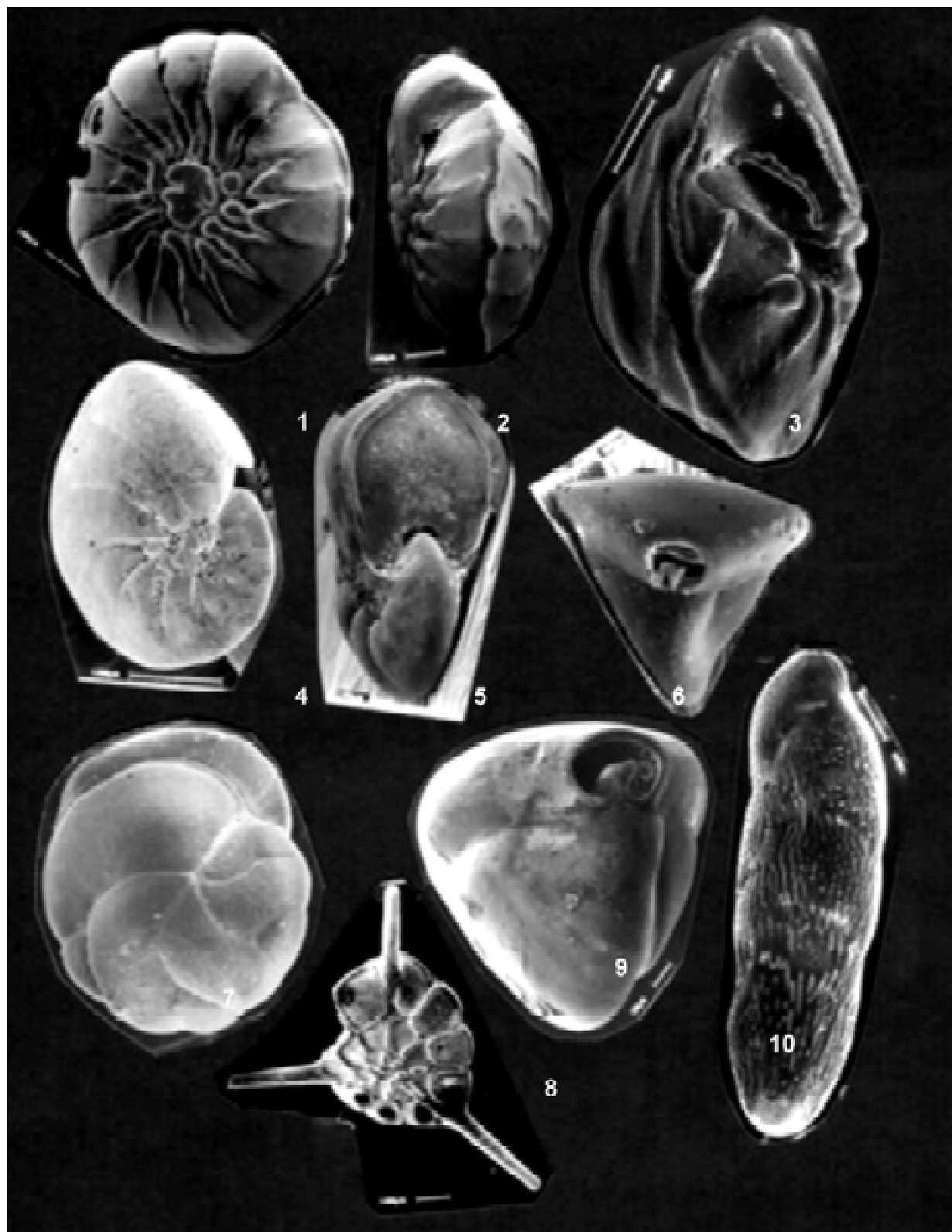
***Astrorotalia* biofacies**

This biofacies occurs over a large area in both the domains in sand, silty sand, silt and sandy silt sediments (Sp. no.128:11/ 5, 11/7, 7/3, 9/1; 133:16/4, 14/4, 10/4; 140:3/5, 7/3 and 149:9/2, 10/2,14/2, 9/4). In the eastern domain, it occurs from 5 to 18 m

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EXPLANATION OF PLATE I

SEM photographs of some benthic taxa from near and inner shelf domains off Hoohly river, Bay of Bengal

1. ***Ammonia beccarii*** (Linnaeus) X 200. Umbilical view with deeply incised suture and umbilical plug.

2. ***Ammonia beccarii*** (Linnaeus) X 200. Peripheral view showing thick carinated margin and apertureal face.

3. ***Eponoides rependus*** (Fichtel & Moll) X250. Peripheral view showing unequal biconvex test, perforated surface with rounded peripheral carina.

4. ***Triloculina tricarinata*** (d' orbigny) X250. Apertural view showing nearly triangular out line, sharply angled periphery and aperture with tooth.

5. ***Nonion asterizan*** (Fitchel and Moll), X300. Lateral view showing planispiral test with sub elliptical outline.

6. ***Nonion asterizan*** (Fitchel and Moll), X300. Profile view showing arch shaped aperture and rounded periphery.

7. ***Cassidulina laevigata*** d'orbigny, X220. Dorsal view showing perforate surface and narrow arched slit aperture at the base of the apertural face.

8. ***Triloculina trigonula*** (Lamark), X250. End view showing broad aperture at distal end of chamber with distinct bifid tooth and slightly convex test.

9. ***Bolivina straitula*** (Cushman) X250. Lateral view showing elongated test perforated surface and striations, test shows tapering in early stage and nearly parallel sides in the adult stage.

10. ***Astrorotalia trispinosa*** (Thalmann) X200. Spiral view showing raised and straight dorsal sutures with three long spines.
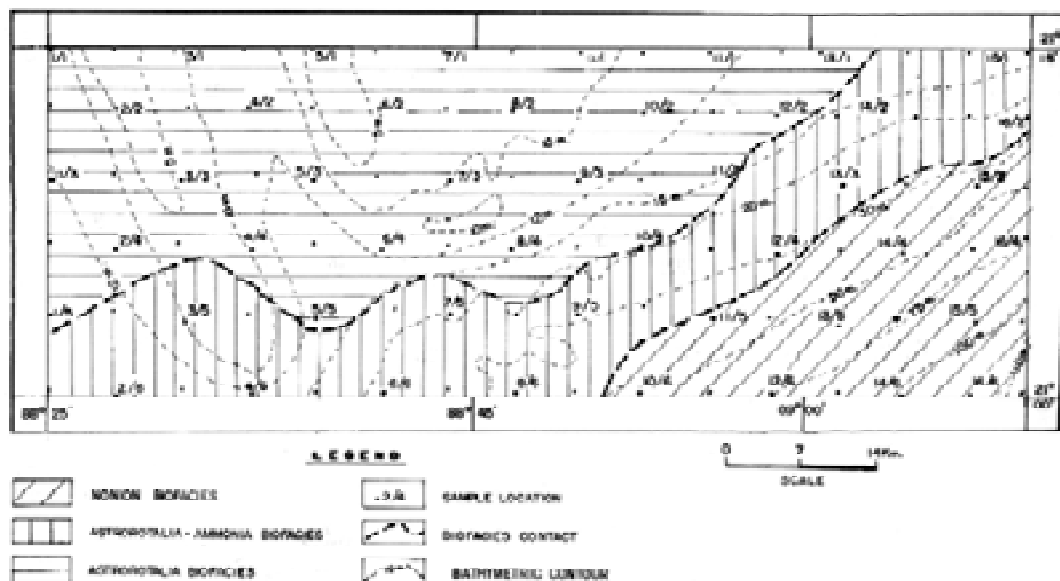
Fig. 3. Bathymetric and Foraminiferal biofacies map off Hoogly river, Bay of Bengal.

isobaths while in the western domain it occurs between 11 m and 35 m water depths. *Astrorotalia trispinosa* is the most important constituent (50 to 60%) of this facies. The other benthic taxa present along this are *A. pulchella, A. beccarii, C. lobatalus, E. crispum, Q. seminulum, E. rependus, T. agglutinans, M. subrotunda* and *Pseudorotalia schroeteriana*. Planktic foraminifera are very rare and B: P ratio of this facies varies from 14:1 to 30:1. Diversity index of benthic foraminifera is low (3.3 to 10.5) and total foraminiferal number (TFN) per gram of sample varies from 8 to 37.

Some shells and shell fragments of gastropods, bivalves, burrowing gastropods, echinoid spines, worm tubes, bryozoa/coral fragments and burrows are commonly present in this biofacies. Fragmented nature of these shells indicates high energy condition which is operating at the site of deposition. Probably waves and littoral currents churn the sediment and segregate the shelf organisms into the coarser sediments in this biofacies.

Ammonia biofacies

Ammonia biofacies occurs in the sandy silt and silty sand bottom sediments between 10 m and 22 m water depth towards the northern side of western domain (Sp. no. 128: 1/7, 3/7, 2/5, 1/3 and 5/5). *Ammonia beccarii* is the most important constituent (30 to 40%) of this facies and it generally favors fine to medium sandy horizon. The other important benthic taxa of this faceis are *A. gaimardi, A. convexa, C. lobatulas, E.*

crispum, T. inflata, E. rependus, P. schroetriana and *B. robusta.* Benthic: planktic ratio varies from 28:1 to 23:1 and diversity index changes from 5.46 to 9.62 in this facies. Some amount of molluscs, echinoid spines, worm tubes and burrows are also observed in this biofacies which show partial fragmentation of shells.

Astrorotalia-Ammonia biofacies

This biofacies is observed as an elongated NE-SW trending strip covering about 25 to 30 per cent portion in the eastern domain. The sediments that host this biofacies are mainly silty sand and it is restricted within the water depths ranging from 12 m to 25 m. In the western domain, this biofacies extends from 22 m to 45 m isobaths within the sand and silty sand and cover a large part of the area (Figs. 4, 5). *Astrorotalia trispinosa* and *Ammonia beccarii* is the major constituent (50 to 55%) of this facies. The former taxon dominates the latter in abundance and shows better mode of preservation. The other important taxa of this biofacies are *A. gaimardi, A. convexa, A. pulchela, Pseudorotalia schroeteriana, E. crispum, C. lobatulus, Q. seminulum, Q. agglutinans, S. communis, E. advenum,* and *Bolivinia robusta.* Some tests of planktic foraminifera are present but the B: P ratio remains high (22:1 to 10:1). Diversity index of benthic taxa increases (5.4 to 13.0) and TFN value changes from 20 to 42 in per gram of sample.

Relict foraminiferal taxa (*Astroroalia* sp, *Amphistegina radiata, Ammonia* sp*., C. calcar, Q. agglutinans, Q.*

EXPLANATION OF PLATE II

SEM photographs of some benthic taxa from near and inner shelf domains off Hoohly river, Bay of Bengal

1. **Ammonia beccarii** (Linnaeus) X 200,Umbilical view showing partly eroded surface and calcification, surface ornamentation is obliterated due to calcification.
2. **Ammonia beccarii** (Linnaeus) X 200, side view showing circular outline, raised and straight dorsal sutures.
3. **Elphidium crispum** (Linnaeus) X200. Lateral view showing coarsely perforated umbo with canaliculated umbilical plug, test shows erosional effect.
4. **Quinqueloculina agglutinans** (d' orbigny) X200. Axial view showing broadly oval periphery, nearly rounded test and agglutinated surface.
5. **Quinqueloculina seminulum** (Linnaeus) X 200. Axial view showing

partly erosion of a few chambers and pitted surface, periphery nearly rounded with rounded aperture and simple tooth.
6. **Astrorotalia trispinosa** (Thalmann) X250.Dorsal view showing raised and straight dorsal sutures with broken spines.
7. **Pseudorotalia schroeteriana** Carpenter, Parker & Jones, X180. Peripheral view with apertural face and umbilical pillars.
8. **Borelis schlumbergeri** (Reichel) X150. Axial view showing elongated-ovoid test, surface ornamented by low and wavy ridges located over the chamberlet sutures.
9. **Amphistegina radiata** (Fitchel & Moll) X180. Dorsal view showing the partial removal of peripheral outlines at places and raised umbo.
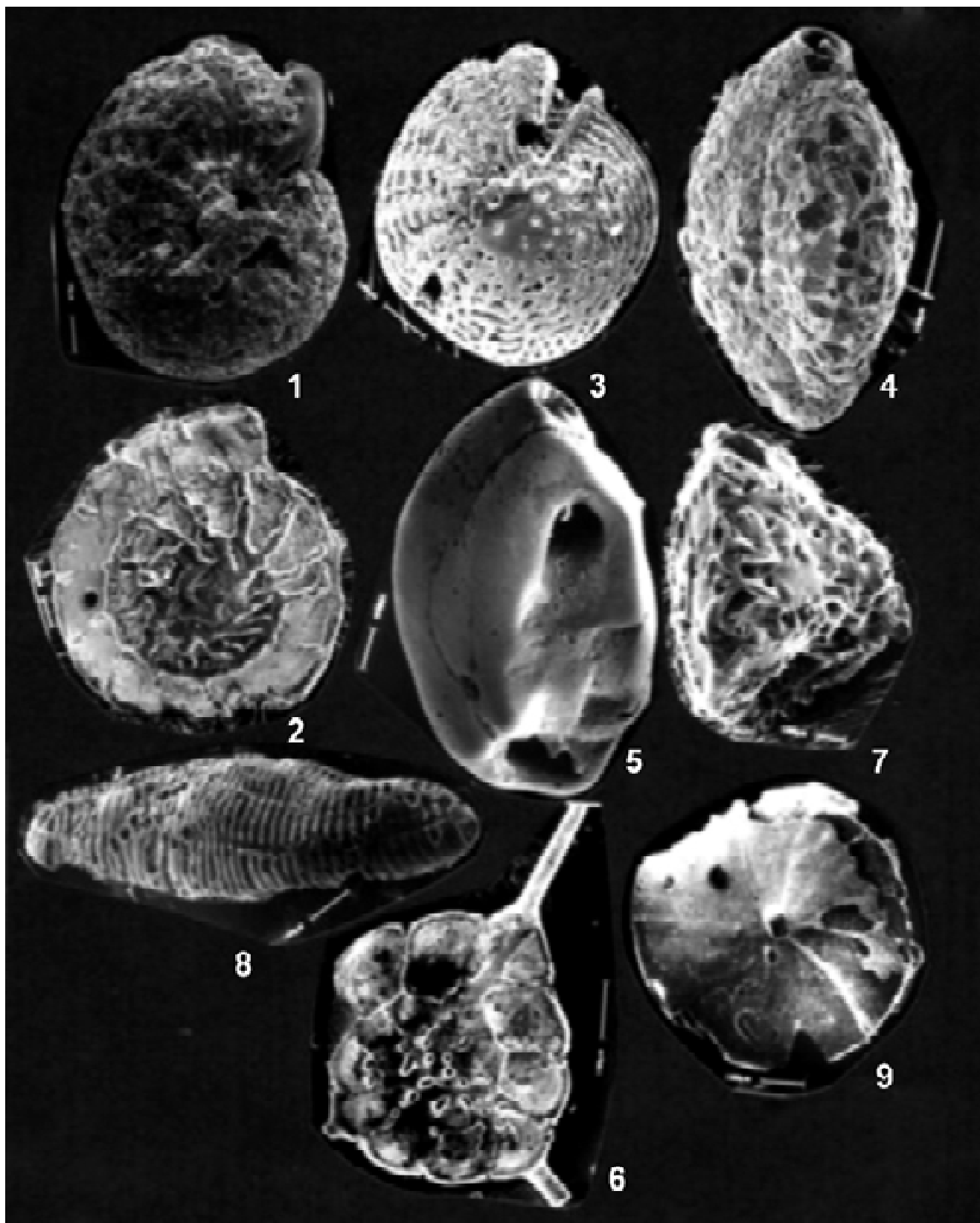
Plate II

BHATTACHARJEE

Table 4: Check list of benthic taxa in the surficial seabed sediments off Dhamra river, Bay of Bengal.

Name of Taxa	Sp. no	128:11\2	128:1/7	128:3\7	133:14\4	128:5\5	128:1\3	133:8\4	133:11\1	128:9\1	133:10\4	128:7\1	133:15\1
	W.D (m)	10.6	12.9	16.2	18	20.7	22.5	28.6	30.2	33.4	34.3	38.8	44.5
Ammonia beccarii (Linnaeus)		8	26	28	10	30	32	30	28	10	12	32	34
A gaimardi (Sequenza)		3	9	10	7	9	10	8	11	6	8	9	8
A.convexa Collins		2	5	7		6	5	4	4			4	6
Astrorotalia trispinosa (Thalman)		29	8	7	30	12	7	34	30	33	36	34	33
A.pulchella d' Orbigny		6	3	2	7	10	3	9	10	11	8	11	10
Bolivina .robasta Brady						9	4	6	4	3	3	12	6
B.spatulata (Williamson)								3			6	4	5
B.striatula Cushman						6		4		5		4	7
Bulimina marginata d' Orbigny								4	4		6	7	3
Calcarina calcar d' Orbigny						3	4	6	4		7	5	4
Cassidulina laevigata d' Orbigny								3		4	6	5	4
Cibicides lobatulas (Walker & Jacob)		4		6		7	5			4	5	6	5
C.pseudolobatulus Perelis & Reiss					3	2			4	9		7	6
Elphidium.crispum (Linnaeus)		3	4	3		2	8	3	7		9	6	3
E. advenum (Cushman)						2		4		4	7		3
Eponoides rependus (Ficktel & Moll)			3			4	2		2				
Lenticulina calcar (Linnaeus)				3		3			4	3	6	4	3
Loxostomina limbata (Brady)				2	7	3		7	6	4	5	7	2
Miliolinella subrotunda (Brady)					2		3		3		3	4	2
Planulina bradi Tolmachoffi					3		2	5		3	4	3	2
Psedorotalia schroeteriana Carpenter,Parker & Jones			2		2	3	4		6	4		4	3
Quinqueloqulina laevigata d'Orbigny							4	4			7	4	3
Q. lamarcana d'Orbigny					2		3	6	4	7		6	7
Q.parkari (Brady)					3		4		3		9		
Q.seminulum(Williamson)				2	3			3		9			4
Q.venusta Karrer		2						4	3	9	6	3	6
Reussella simplex (Cushman)								4	6	3		4	5
Spiroloculina communis Cushman & Todd				3	1	4	5	5	4			5	4
S. depressa d'Orbigny								3	4	5	6	5	3
Textularia agglutinans d'Orbigny				2			2	3	4			3	2
T.saggitula Brady						2	3			3	5		
Trochomina inflata(Montagu)		2	5		4		5		3				
Triloculina trigonula (Lamarck)		3			2		5		4	3	4	3	7
Ti.trcarinata Parker & Jones			2			2	4	3		9		4	5

parkari, Q. vensta, Q. seminulam, Operqulina sp., *Alveolinella* sp, *Borelis schlumbergeri)* and various mollusc specimens are observed, which are partly or completely coated by calcareous or ferruginous material in the western domain. Nine SEM photographs of relict benthic foraminiferal taxa are shown in Plate II. Surface coating sometimes obscures the morphological characters of the specimens as shown in the SEM photographs.

Nonion biofacies

This biofacies occurs in the southeastern side of the area within 25 m to 112 m water depth in clayey silt sediments in the eastern domain only. It covers about 20 to 25% area where shelf gradient is moderate (1:300). Abundance of *Nonion* varies from 40 to 45 % and it is represented by *N. scaphum, N. asterizan* and *N. depressulum.* The other important taxa of this facies constitute nearly 35-40% of the assemblage. They are represented by *Bolivina alata, B robusta, B. spatulata, B. striatula, A. beccarii, N. turgida, R. simplex, L. calcar, Q. seminulum* and *S. depressa.* These taxa generally possess less resistant thin test and show more pore-surface density. Diversity index of benthic foraminifera changes from 8.0 to 12.5 and TFN value varies from 50 to 90.

A good number of planktic foraminifera (15 to 25 %) is observed. They are represented by *Globigerina* sp., *Globigerinoides ruber, Globogerinita glutinata, Gs. immaturus, Globigerinella calida, B. adamsi, P. obliquiloculata, S. dehiscens, H. digitata, O. universa* and *Ng. dutertrei.* The B: P ratio of this unit considerably decreases
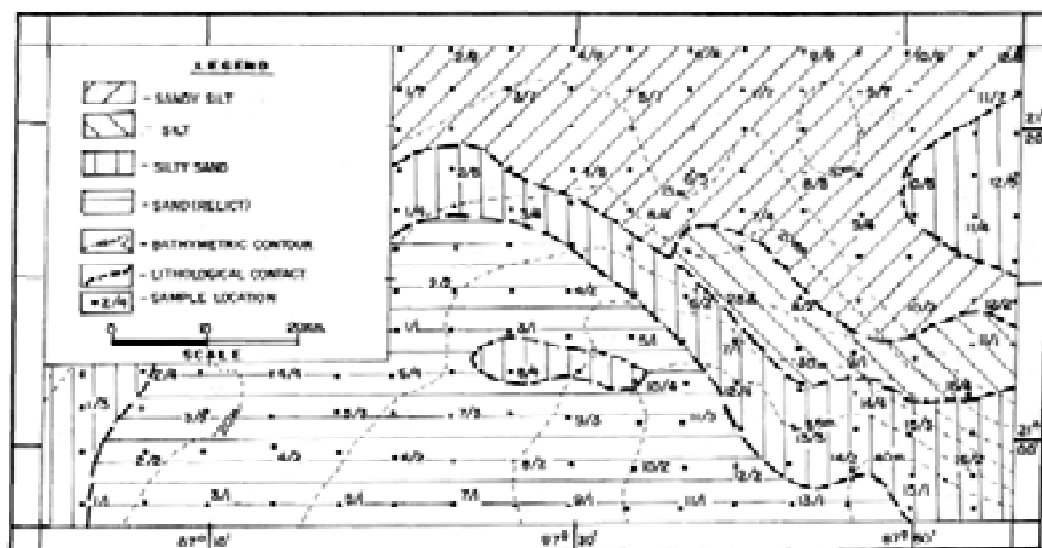
Fig. 4. Bathymetric and sediment distribution map off Dhamra river, Bay of Bengal.

(11:1 to 3:1) due to the relative increase of Planktic members. The faunal assemblage of planktic foraminifera in seabed sediment indicates that they belong to Holocene time (N_{23} Zone of Blow, 1979). A few pteropods (*L. inflata, L. trochiformis, C. virgula, C. acicula acicula, Clio* sp. and *Cavolina* sp.) are observed in this facies. Pteropod tests show more fragmentation than the planktic and benthic foraminifera because of their more fragile nature. Gastropod and bivalves are very rare in this facies.

DISTRIBUTION OF MOLLUSCS

Various mollusc shells commonly occur in the northern side of the eastern domain and are a very significant biogenic component of the sediment in the western domain. Five important families of bivalve (Arcadae, Glycimerididae, Carditdae, Veneridae and Mactridae) and five gastropod families (Muricidae, Clubellidae, Nassaridae, Olividae and Conidae) are commonly observed in the relict sand. The characteristic bivalve taxa observed are *Glycimeris convexa, G. mayi, Andra trapezia, Circumhalus disjecta, Mactra australis, M. refescens, Megacardita* sp., *Cardiocardita* sp, *Arca* sp., *Meretix* sp. and *Cardita crassicostata*. Important gastropod species are *Niotha pyrrhus, N. pauperata, Seila crocea, Bulla botanica, Diala lautu, Littorina unifascita, Conus compressus, C. anemone, Oliva australis, Marginella* sp., *Nerita* sp., *Drillia* sp., *Terebra* sp., and *Selia* sp. These autochthonous mollusc assemblages represent a littoral to sub littoral facies of deposition in arenaceous sediments. Mollusc shells are partly calcified and deep brown to yellowish brown in colour in the western domain. They are fresh without surface coating, white to dirty white in colour, show less frequency and are more fragmented in the eastern domain. Fragmented nature of these shells indicates high-energy condition which is operating at the site of deposition. Occasional presence of *Tellina detoidalis* and *Nuculla pusilla* as well as some taxa of Potamididae and Cerithiopsidae families are observed in the eastern domain which are the characteristic assemblage of deltaic environment.

The elongated conical burrowing molluscs (scaphopod) commonly occur in the concretionary sand (Sp. no. 133:1/1,1/3, 2/2, 3/1, 3/3, 4/2, 5/1 & 6/2) in the western domain. They are

absent in the sand and silty sand of eastern domain. Four taxa had been recorded which are identified as *Dentalina flindersi, D. bednalli, Antalis hemileuron* and *A. hyperhemileuron*. This assemblage points to a littoral arenaceous facies of deposition. A few specimens of pelagic gastropods (Pteropods) occurs in sand and silty sand sediments (Sp. no.133:4/1, 8/2, 10/2 and 14/2). They are partly calcified and pale brown in colour and show poor mode of preservation. Only three species of pteropods are identified which are *Creseis acicula, Limacina inflata* and *L. trochiformis*.

DISCUSSION AND INTERPRETATION

The bioclastic materials, concretions, kankars and coarser sands at 20 to 45 m isobaths suggest the presence of anomalous sediments in the western domain. The anomalous sediments are different from the present inner-shelf sediments from its colour, grain size, composition and faunal assemblage. The benthic foraminiferal assemblage that shows different characteristics from the normal Recent specimens could be identified by their partly abraded tests, yellowish brown colour, dull lustre with slightly larger in size than the present-day population. These features are the characteristics of the relict fauna (Murry, 1973). An inverse relationship between coarser and finer sediments along depth can be ascertained by the sediment distribution map in this area. Emery (1968) termed this type of sediment as relict sediment which has been deposited within the littoral and sub-littoral zone during the lowstand sea-level of late Pleistocene time. The brownish to yellowish brown concretions represent a palaeo-undulatory surface which indicates the sub-aerial exposure of sediments to warm and humid conditions. The oxidized coating on the surfaces of bioclasts, skeletal and non skeletal grains were developed due to deposition of ferruginous and calcareous materials during the lowstand sea-level of late Pleistocene time.

Occurrence of these relict sediments reveals the presence of lag deposit in this region. Siddiquie *et al.* (1970) reported the presence of relict sediments off Dhamra river mouth within the continental shelf region of Orissa coast. Similar types of relict sediments have been reported from several locations along the erosion tract of east coast from Gopalpur to Dhamra river mouth between 20 m and 41m water depth (Banerjee and

Table 5: Percentage of major suborders in different seabed sediments with depth and diversity index of benthic taxa off Hoogly and Dhamra rivers, Bay of Bengal.

Cruise ST:140 &149	Sp. no.	9\2	7\3	10\4	9\4	7\5	16\2	12\4	9\6	11\6	12\6	14\6	16\5
	W.D (m)	9.1	10.6	12.6	15.4	17.8	18.8	21.9	32.7	42.8	54.2	84.2	111
Name of Suborders													
Rotalina													
Number		23	30	34	51	66	71	90	124	142	186	258	301
Percentage		70	77	73	74	74	73	68	81	85	78	89	81
Miliolina													
Number		4	4	5	10	13	22	32	24	24	40	22	47
Percentage		12	10	10	16	14	23	24	16	15	17	8	13
Textularina													
Number		6	5	8	7	11	4	10	4	-	12	10	22
Percentage		18	13	17	10	12	4	8	3	-	5	3	6
Total no of species		5	5	6	7	8	9	17	20	17	22	23	32
Total no of specimens		33	39	47	69	90	97	132	152	160	238	290	370
Diversity index		3.29	3.77	4.78	5.44	6.65	8.05	8.02	9.17	7.73	9.28	9.35	12.5
Cruise ST:128 &133	**Sp. no.**	**11\2**	**1\7**	**3\7**	**14\4**	**5\5**	**1\3**	**8\4**	**11\1**	**9\1**	**10\4**	**7\1**	**15\1**
	W.D (m)	10.6	12.9	16.2	18	20.7	22.5	28.6	30.2	33.4	34.3	38.8	44.5
Name of Suborders													
Rotalina													
Number		55	60	70	69	111	87	133	136	106	131	161	156
Percentage		88.7	89.5	94.6	76.6	94.9	72.5	82.6	80.5	68.4	76.6	81.3	78.4
Miliolina													
Number		5	2	2	15	3	26	28	26	46	35	34	41
Percentage		8.1	3	2.7	16.7	2.6	21.7	17.4	15.4	29.7	20.5	17.2	20.6
Textularina													
Number		2	5	2	6	3	7	0	7	3	5	3	2
Percentage		3.2	7.5	2.7	6.7	2.5	5.8	0	4.1	1.9	2.9	1.5	1
Total no of species		10	10	12	16	18	20	23	23	23	23	28	30
Total no of specimens		62	67	74	90	117	120	161	169	155	171	198	199
Diversity index		5.59	5.46	6.42	8.21	8.7	9.62	10.41	10.31	10.5	10.31	12.18	13.04

Sengupta, 1992). The overall faunal assemblages of benthic foraminifera, gastropods, bivalves and scaphopods of the relict sediment also suggests very shallow neritic zone in more agitated environment during the above period. Presence of oolite and pellets in this sediment also corroborates the existence of lowstand sea-level in the past, since oolites are developed essentially within 2m depth near the shore (Newell *et al.*, 1960). These sediments were inundated subsequently by marine transgression in the Holocene time.

The eastern part of the area is mostly made of deltaic sediments containing lot of quartz, feldspar and mica which are deposited due to discharge of voluminous sediments (Milliman *et al.*, 1989) by Ganga-Brhmaputra river system. Waves and littoral currents churn the sediment and segregate the shelf organisms into the coarser sediments in this biofacies. Sediments of this part show low value of $CaCO_3$, Ba and Sr due to less biogenic components. This character of sediments corroborates

high input rate of riverine sediments (Colmen and Wright, 1975). The coarser sandy sediments settle in the near shelf zone forming sand shoal and tidal ridges, whereas silty clay is deposited in the outer-shelf zone. *Astrorotala* and *Astrorotala-Ammonia* biofacies lie in the coarser sand and silty sand deposited in the near and inner-shelf region in both sectors of the area, while *Nonion* biofacies lies in the outer-shelf in the silty clay sediment. The former group represents endopelic taxa while the latter one indicates epipelic taxa (Bonnet *et.al.*, 1999). The above-mentioned two biofacies gradually decrease as one moves from coarser to finer sediments with the increase of water depth. The faunal assemblage of *Nonion* biofacies in the outer shelf region is less resistant, fragile and prefers a relatively tranquil environment of deposition. The foraminiferal assemblage of the study area matches well with the neighboring region of continental shelf described by earlier worker (Bhattacharjee, 2006, 2007).

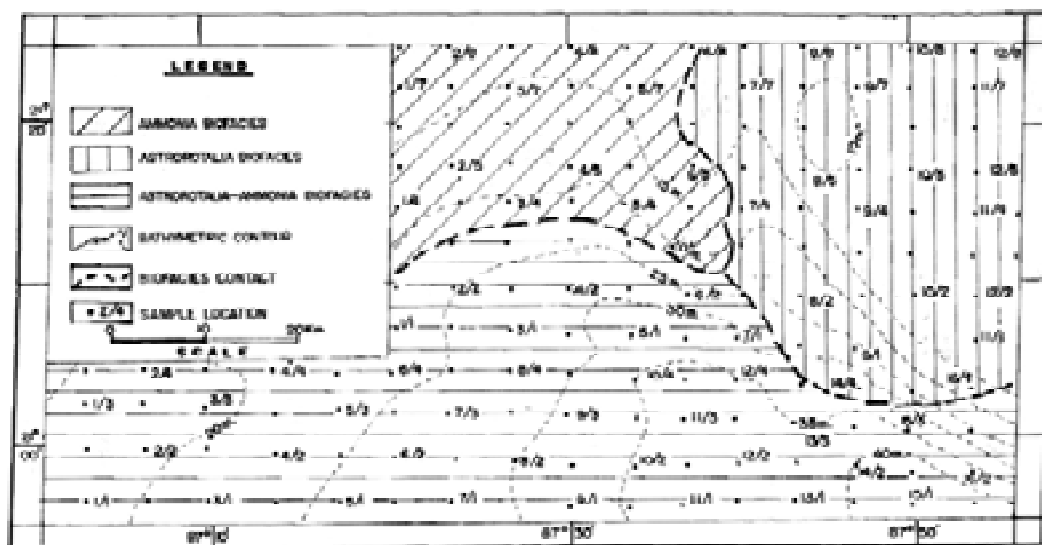High discharge of sediments and huge fresh water influx

Fig. 5. Foraminiferal biofacies map off Dhamra river, Bay of Bengal.

by numerous rivers in the eastern sector may create unfavorable condition for any rich benthic productivity in the near and inner-shelf zone. Relatively low sediment supply towards the western sector by Dhamra-Mahanadi river system ($20x\ 10^{10}$ ton/year: Subramanian, 1978) may be responsible for higher TFN and high diversity of foraminifera. An agitated deltaic environment prevails in the eastern part as indicated by the higher content of dissolved oxygen (DO) in the surface water (10.48 ml/l at 24.7^0 C) as compered to the western domain where DO is much less (6.00 ml/ l at 26.8^0 C). The maximum value of pH is 7.59 at 25.5^0 C and 7.08 at 25.5^0 C in the western and eastern sectors respectively revealing the dilution of sea-water alkalinity in the east. More diversity of biota in the western domain is due to the higher salinity of sea-water. This mismatching between the eastern and western sectors may be due to the difference in the deposition in the macro-tidal environment in the east and meso-tidal set-up in the west respectively. In the eastern domain sediment deposition shows an onlap (Swain, 1949) nature but in the western domain deposition is offlapping (Mitchum, 1977) environment.

CONCLUSIONS

Four benthic foraminiferal biofacies, namely *Astrorotalia, Ammonia, Astrorotalia-Ammonia* and *Nonion* are delineated in the total survey area. Former three biofacies generally lie in the sand and silty sand sediments in the near shelf to inner shelf environment. The wide extent of these facies may be due to the very gentle gradient (1:3300 to 1:1000) of the ocean floor. *Nonion* biofacies occurs in the clay silt sediment within the outer-shelf region in moderate gradient (1:300). Distribution pattern of benthic foraminiferal biofacies shows a positive relation with bathymetry and reveals the normal prodeltaic environmental sequence of sediment deposition in the eastern domain but shows some irregular relation in the western domain.

Occurrence of subrounded concretion, iron-stained coarse quartz grains and thick-shelled bioclasts at 20 m to 45 m isobaths suggests the presence of anomalous (relict) sediments in the western sector. This concretionary sand shows inverse relation with depth. The relict sands probably deposited in littoral environment during the low seastand of late Pleistocene time.

The presence of ooides and pellets of the relict sand also corroborates the very shallow marine facies in the past. Similar type of relict sediments had been reported from several locations along the erosional tract of east coast from Gopalpur to Dhamra river mouth between 20 to 42 m water depths but the same is not observed in the eastern domain of the area. On the other hand, huge sediments are depositing in the eastern part due to voluminous terrigenous materials brought by the Ganga-Brahamhaputra river system. The present work reveals that the older sediments of the western part and the younger sediments of the eastern side are distinctly different in grain size, texture, mineral composition and fossil content. The younger sediments are continuously overlapping the older sediments of western domain during the Holocene time.

ACKNOWLEDGEMENTS

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MORPHO-TAXONOMIC REASSESSMENT OF CERTAIN PLICATE PALYNOMORPHS FROM THE PERMIAN SUCCESSIONS IN INDIA

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ABSTRACT

Dispersed fossil spores and pollen taxa assigned to Turma Monoletes Ibrahim, 1933, and Turma Plicates Erdtman (1952) respectively, bearing the ribbed body surface are reviewed from the Permian successions in India. The exinal structure/ornament in these taxa includes ridges or plicae and reduced lateral sacci. These taxa are rare in palynoassemblages, but a few of them are stratigraphically significant. Although originating in the Carboniferous elsewhere, representatives of these groups appeared episodically through the Permian in India, and some persisted into the basalmost Triassic. The diagnostic morphological characters listed for each species permits to delimit the distinct species among the six taxa dealt herein, and to enhance their stratigraphic significance.

Keywords: Plicate, Ridges, Ribs, Striations, Spore– Pollen, Permian, India

INTRODUCTION

Many spores–pollen taxa have been identified in the Permian succession of India. These have been found to bear contrasting morphologies with respect to distribution of longitudinal/horizontal ridges, ribs, plicae, and striae and also the variable stratigraphic distributions. The dominant ornamental features are normally directed longitudinally with inconsistent transverse or oblique partitions. In a few cases, the longitudinal ribbing may represent a pseudo–ornament. Clear morphological demarcation is lacking for many taxa in this group. This paper aims to clarify the nature of the ornamental features across this broad group and provide better demarcation of species (Tables 1, 2) recorded from the Indian Permian succession (Fig. 1) to enhance their biostratigraphic utility.

SYSTEMATIC DESCRIPTION

Terminology: Potonie's (1956, 1966, 1970) classification scheme for dispersed spores and pollen is used herein. The terminology for exinal features is outlined below:

Ridges/ribs — formed by exoexine and separated by more or less deep furrows / grooves. Ribs may be straight or wavy, and smooth or verrucate.

Clefts – strips of intexine.

Striae – linear furrows < 0.5 wide, nexinal in nature.

Plicae – surficial body folds (folded fan like)

The characteristic features of the exinal sculpture (ridges, ribs, plicae, folds or striations) and modifications of the exine as reduced sacci among the spores and pollen (genus and species) on record from India (Table 2) are discussed herein. This would provide detailed information about each taxon to get assessed their apparent form similarity, and the taxa finally retained. In the foregoing chapter each taxon is dealt in the category of spore or pollen, and then followed in alphabetical order, not in the status of their priority of being instituted.

SPORES

Anteturma **Sporites** Potonie' 1893
Turma **Monoletes** Ibrahim 1932
Subturma **Azonoletes** Luber 1935

Genus **Columinisporites** Peppers, 1964
(Fig. 2,A)

Type species: *Columinisporites ovalis* Peppers, 1964; pl. 1, fig. 11; size 48.9 x 32.4 μm.

Lithounit and age: MeLeansboro Group, Late Pennsylvanian.

Locality: Illinois Basin, USA.

Diagnostic features: Spore; bilateral, reniform; monolete, laesura generally clear; exine thick, ridges distributed all over body surface, broad, more or less parallel, inter–connected with numerous, small, transverse partitions.

Remarks: Playford and Dino (2000, p. 22-23) have placed genus *Columinisporites* under the synonymy of *Striatosporites* on the basis of all pertinent literature. And the type species *Columinisporites ovalis* has been proposed a new combination as *Striatosporites ovalis* (Peppers). Although , this species is found similar to the *Striatosporites brazilensis* Bharadwaj *et al.*, 1976 (see Table 4).

Genus **Kendosporites** Surange & Chandra, 1974
(Fig.2, B)

Type species: *Kendosporites striatus* (Salujha) Surange & Chandra, 1974 ; pl.3, fig. 64; size 120 μm.

Lithounit and age: Raniganj Formation, Late Permian.

Locality: VIII Seam, Raniganj Coalfield, Damodar Basin, West Bengal, India.

Diagnostic features: Spore; oval to subcircular; monolete, laesura more or less distinct; exine thick, laevigate, surface folded into thick, irregular ridges, parallel to longitudinal axis.

Remarks: Surange and Chandra (1974, p. 257) and Foster (1979, p. 63) have commented on the nature of surficial ridges and noted that these are inconsistent features that may get removed during maceration. Nevertheless, these structures appear to be common features since they are recognized in specimens that have undergone standard chemical processing. The holotype of *Kendosporites* (*Latosporites*) *striatus* described by Bharadwaj and Salujha (1964, p. 230) is considered here to be conspecific with *Striatosporites major* Bhardwaj (1954) based on their dimensional ranges and ornaments.
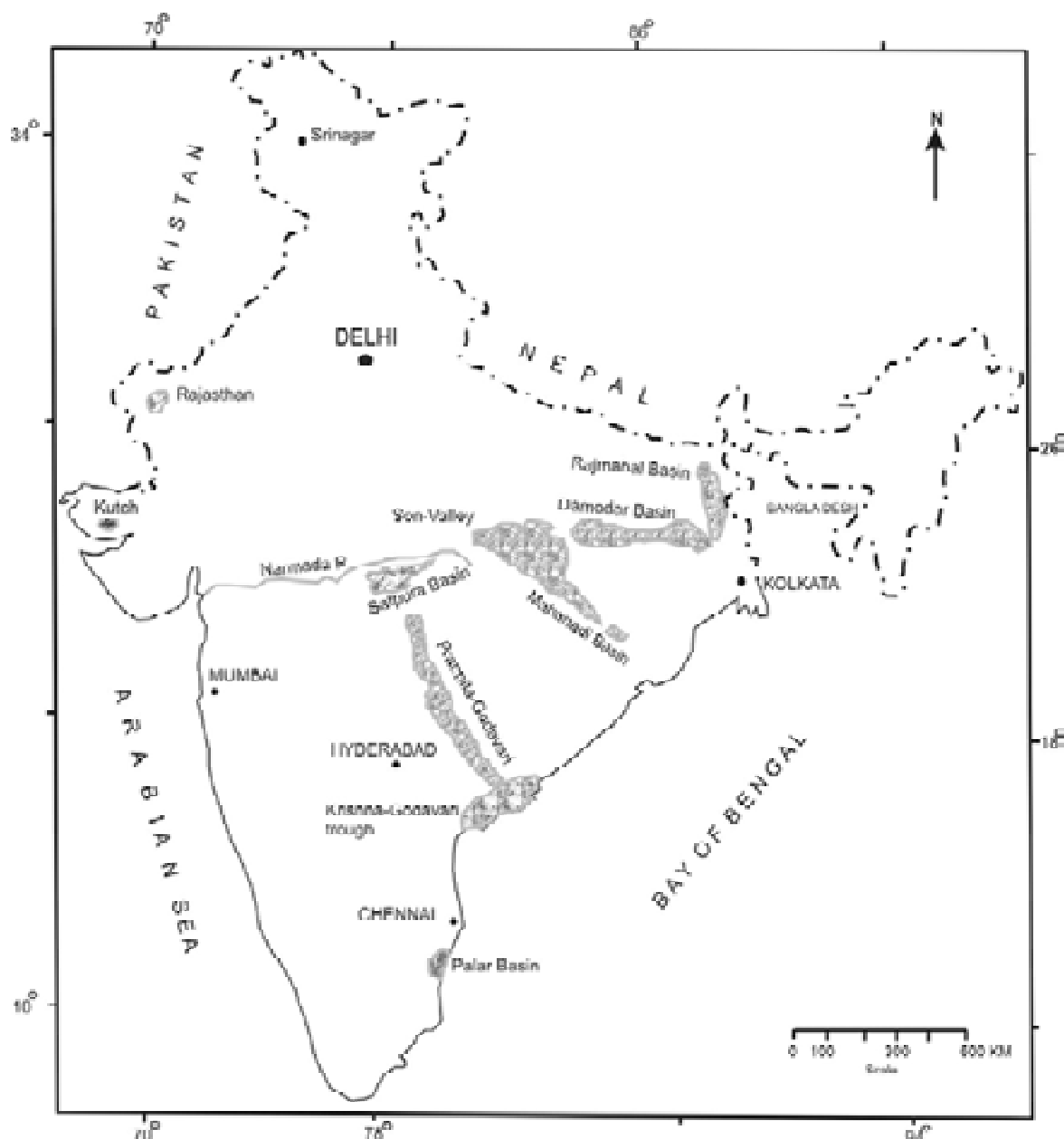
Fig. 1 Map of India showing the distribution of the Permian basins (after GSI).

Although, Surange and Chandra (1974, p. 257– 258) did not compare these two taxa. According to Balme (1995, p. 211) and Playford and Dino (2000, p. 23) taxonomic status of *Kendosporites* is still uncertain.

Genus *Striatosporites* Bhardwaj emend. Playford & Dino, 2000

Type species: *Striatosporites major* Bhardwaj, 1954.
Lithounit and age: ? Saar Coals, Late Carboniferous.
Locality. Labachgrube: Breitenbach, Germany.

Diagnostic features: Spore; bilateral, oval to elliptical; monolete, laesura not usually sharply defined, might extend full length horizontally; exine canaliculate with two kinds of ridges/ muri; the larger one, more elevated and parallel to longitudinal axis, intre- connected by transverse, finer and closer spaced muri.

Remarks : This genus has been emended by Playford and

Dino (2000) to accommodate the additional exinal features observed.

Striatosporites major Bhardwaj, 1954
(Fig.2, C)

1964 *Kendosporites striatus* Bharadwaj & Salujha; pl.3, fig. 64; size 120 μm.

Holotype : Bhardwaj,1954; fig. 6; size 140 x 94 μm.
Lithounit and age : ?, Saar Coals, Late Carboniferous.
Locality: Labachgrube, Breitenbach, Germany.

Diagnostic features : Dimensions 120–160 x 90–120 μm; laesura extend ? of horizontal length, flanked by *ca* 2 μm thick, elevated labrae; exine *ca* 2 μm thick with canaliculate sculpture consisting of 5–6 broad (2–3 μm wide) longitudinal ridges,connected by thin, oblique to transverse partitions/ muri.

Striatosporites brazilensis Bharadwaj, Kar & Navale, 1976

Table 1: List of spores and pollen taxa in the plicate group on record from the Permian successions in India, and their taxonomic placement in Potonié's classification.

Holotype: Bharadwaj, Kar & Navale, 1976; pl. 2, fig. 32; size 110 x 65 µm.

Lithounit and age: Middle Rio Bonito Formation, Early Permian.

Locality: Sample No.12, Borecore C, Maranhão Basin, Brazil.

Diagnostic features: Length 60–83 µm; laesura perceptible; exine 1.5– 3 µm thick bearing 4–8 longitudinal ridges on proximal and distal surfaces, ridges 2–7 µm broad, 12–30 µm apart, inter–connected with dense transverse partitions, giving the appearance of fish bones.

Remarks: This species is distinct in the features of longitudinal ridges.

Striatosporites ovalis (Peppers) Playford & Dino, 2000
Holotype: Peppers ,1964; pl. 1, fig. 11; size 48.9 x 32.4 µm.
Lithounit and age: McLeansboro Group, Late Pennsylvanian.
Locality: Illinois Basin, USA.
Diagnostic features: Length 37–81 µm; incipient laesura evident; exine 1–2 µm thick, three to many major parallel ridges that are elevated, 2–3 µm wide, branched, transversely inter–connected by thin partitions.
Remarks: In the present assessment of species characters, *Striatosporites ovalis* is placed under *S. brazilensis* Bharadwaj *et al.*, 1976 (see in Table 4).

Table 2: Species of spores and pollen taxa of the plicate group on record from the Permian successions in India.

SPORES

Genus   *Columinisporites* Peppers, 1964
        Columinisporites ovalis Peppers, 1964

Genus   *Kendosporites* Surange & Chandra, 1974
        Kendosporites striatus (Salujha) Surange & Chandra, 1974

Genus   *Striatosporites* Bhardwaj, 1954
        Striatosporites major Bhardwaj, 1954
        Striatosporites brazilensis Bharadwaj, Kar & Navale, 1976

Genus   *Tiwariasporis* Maheshwari & Kar, 1967
        Tiwariasporis flavatus Maheshwari & Kar, 1967
        Tiwariasporis gondwanensis (Tiwari) Maheshwari & Kar, 1967
        Tiwariasporis indicus Srivastava, 1970
        Tiwariasporis novus (Srivastava) Bharadwaj & Dwivedi, 1981
        Tiwariasporis simplex (Tiwari) Maheshwari & Kar, 1967

POLLEN

Genus   *Ephedripites* Bolkhovitina emend. Potonié, 1958
        Epedripites mediolobatus Bolkhovitina, 1953
        Epedripites dentatus Kar, 1968
        Epedripites ellipticus Kar, 1968

Genus   *Gnetaceaepollenites* Thiergart emend. Jansonius, 1962
        Gnetaceaepollenites ellipticus Thiergart, 1938
        Gnetaceaepollenites acutus Kar, 1968
        Gnetaceaepollenites biplicatus Kar, 1968
        Gnetaceaepollenites diffusus Lele & Makada, 1974
        Gnetaceaepollenites grandis Maheshwari, 1967
        Gnetaceaepollenites pachydermatus Kar, 1968
        Gnetaceaepollenites punctatus Venkatachala & Kar, 1968

Genus   *Gondiastriatites* Kar, 1981
        Gondiastriatites tenuis (Bharadwaj & Salujha) Kar, 1981
        Gondiastriatites magnus (Maithy) Kar, 1981
        Gondiastriatites minutus (Maithy) Kar, 1981

Genus   *Marsupipollenites* Balme & Hennelly emend. Balme, 1970
        Marsupipollenites triradius Balme & Hennelly, 1956
        Marsupipollenites striatus (Balme & Hennel.) Foster, 1975

Genus   *Praecolpatites* Bharadwaj & Srivastava, 1969
        Praecolpatites nidpurensis Bharadwaj & Srivastava, 1969
        Praecolpatites acutus (Kar) Bharadwaj & Dwivedi, 1981
        Praecolpatites biplicatus (Kar) Bharadwaj & Dwivedi, 1981
        Praecolpatites diffusus (Lele & Makada) Bharadwaj & Dwivedi, 1981
        Praecolpatites pachydermatus (Kar) Bharadwaj & Dwivedi, 1981
        Praecolpatites punctatus (kar) Bharadwaj & Dwivedi, 1981
        Praecolpatites sinuosus (Balme & Hennel.) Bharadwaj & Srivastava, 1969

Genus   *Vittatina* Luber emend. Jansonius, 1962
        Vittatina subsaccata Samoilowitch, 1953
        Vittatina fasciolata (Balme & Henn.) Bharadwaj, 1962
        Vittatina globosa Maheshwari, 1967
        Vittatina lata Wilson, 1962
        Vittatina permegna Tiwari, 1965
        Vittatina scutata (Balme & Henn.) Bharadwaj, 1962
        Vittatina striata (Luber & Valtz) Samoilovich, 1953
        Vittatina verrucosa Tiwari, 1968

Genus   *Welwitschiapites* Bolkhovitina, 1953
        Welwitschiapites magniolobatus Bolkhovitina, 1953
        Welwitschiapites extansus Bharadwaj & Salujha, 1964
        Welwitschiapites gondwanensis Tiwari, 1965
        Welwitschiapites magnus Maithy, 1965
        Welwitschiapites minutus Maithy, 1965

Genus *Tiwariasporis* Maheshwari & Kar, 1967
Type species: *Tiwariasporis flavatus* Maheshwari & Kar, 1967.
Lithounit and age: Barakar Formation, Early Permian.
Locality: North Karanpura Coalfield, Damodar Basin, Jharkhand, Bihar, India.
Diagnostic features: Spore; oval – elliptical; monolete with incipient, barely traceable laesura; exine thick, sculptured with closely spaced verrucae–bacula on proximal and distal surfaces, arranged in linear rows forming pseudo–striations; narrow flap-like folds (rudimentary sacci) at lateral ends may be present.
Remarks: The exinal infrastructure on the distal face (Balme 1970, p.410) and the weakly developed lateral extension of exine along the longer axis (Foster 1975, pp. 152–153; 1979, pp.101–102) place *Tiwariasporis* within the *Vittatina*–type complex. However, this taxon is dealt out-side the ribbed group in the basic difference of having very narrow flap-like folds at the extreme ends and distinctly sculptured exine.

Tiwariasporis flavatus Maheshwari & Kar, 1967
(Fig. 2, D)
Holotype: Maheshwari & Kar,1967; figs 1, 2; length 62 µm.
Lithounit and age: Barakar Formation, Early Permian.
Locality: North Karanpura Coalfield, Damodar Basin, Jharkhand, Bihar, India.
Diagnostic features: Length 62–68 µm; laesura indistinct; exine up to 3 µm thick, beset with verrucose sculpture, verrucae *ca* 2 µm wide, densely spaced, evenly arranged in more than 20 rows, to produce pseudo–striations that may give the appearance of infrastructural features; at extreme lateral ends very narrow flap–like folds up to 2 µm wide are developed.

Tiwariasporis gondwanensis (Tiwari) Maheshwari & Kar, 1967
Holotype: Tiwari ,1965; pl. 8, fig 195; dimensions 95 x 53 µm.
Lithounit and age: Barakar Formation, Early Permian.
Locality: 202 (IV Seam), borehole R–34, Korba Coalfield, Son Valley, Chattisgarh, India.
Diagnostic features: Dimensions 72–100 x 40–66 µm; exine *ca* 2 µm thick, verrucae closely set, 2–3 µm in diameter, arranged irregularly forming 16 – 18 longitudinal striations on proximal face, inter-connected, striae forming a reticuloid pattern on distal face; at the lateral termini, 3–8 µm wide protuberances form rudimentary sacci.

Tiwariasporis indicus Srivastava, 1970
Holotype: Srivastava ,1970; pl.2., fig. 20; dimensions 100 x 78 µm.
Lithounit and age: Barakar Formation, Early Permian.
Locality: Dera Colliery, Talcher Coalfield, Orissa, India.
Diagnostic features: Dimensions 60–110 x 45–82 µm; exine *ca* 2 µm thick, infrapunctate; puncta 0.5 µm in diameter; 12– 24 pseudo–striations developed proximally consisting of bifurcated furrows 2–3 µm wide; distal ornament reticuloid to verrucoid; verrucae 2–4 µm in diameter; equatorial rim present; flap–like folds, 2–5 µm wide, developed at lateral termini.
Remarks: This species compares with *T. novus* (Srivastava) Bharadwaj and Dwivedi, 1981 in the exinal features (see Table 4).

Tiwariasporis novus (Srivastava) Bharadwaj & Dwivedi, 1981

Holotype: Srivastava ,1970 ; pl. 2, fig 22 ; dimensions 92 x 70 µm.
Lithounit and age: Barakar Formation, Early Permian.
Locality: Deulbera Colliery, Talcher Coalfield, Orissa, India.
Diagnostic features: Dimensions 65–120 x 45–90 µm; laesura perceptible; exine *ca* 1 µm thick, micropunctate, bearing horizontal 11–26 dichotomous pseudo–striations, interconnected by transverse partitions, furrows 3–5 µm wide, distally formed of irregularly arranged verrucae 3–5 µm in diameter; flap– like folds, 5–8 µm wide, are developed at lateral termini.
Remarks: This species is similar to *T. gondwanensis* having irregularly arranged verrucae and terminal folds (see Table 4).

Tiwariasporis simplex (Tiwari) Maheshwari & Kar, 1967
Holotype: Tiwari ,1965; pl. 9, fig. 200; dimensions 85 x 62 µm.
Lithounit and age: Barakar Formation, Early Permian.
Locality: 214, borehole R–69, Korba Coalfield, Chattisgarh, India.
Diagnostic features: Dimensions 57–100 x 42–72 µm; exine *ca* 1 µm thick, verrucae 1–3 µm broad at base tapering to 0.5– 1 µm in diameter at crests; verrucae arranged in linear arrays to form 15–24 horizontal striations, spaced at 0.5 µm, interconnected by thin transverse partitions; no exinal protuberances seen.
Remarks: Weak folds at the lateral termini appear as rudimentary sacci .

POLLEN

Anteturma **Pollenites** Potonie,1931
Turma **Plicates** (Naumova) Potonie, 1960
Subturma **Polyplicates** Erdtman, 1952
Genus ***Ephedripites*** Bolkhovitina ex Potonie, 1958
(Fig.2, E)
Type species: *Ephedripites mediolobatus* Bolkhovitina ex Potonie, 1958.
Lithounit and age: ?, Early Cretaceous.
Locality: Western Kazakhstan.
Diagnostic features: Broadly elliptical to oval pollen; exine beset with numerous rounded ridges, separated by narrow furrows.
Remarks: Janosonius (1962, p.77) remarked while discussing *Gnetaceaepollenites* (Thiergart) that the genotype *E. mediolobatus* Bolkhovitina (1953; pl. 9, fig.15) was transferred to *Schizaea* by Bolkhovitina (1961). Hence, the genotype does not hold valid status and the genus name *Ephidripites* itself becomes invalid. Potonié (1966, p. 152) noted that a new generic name should be selected for the remaining species of *Ephedripites*. Nichols (2002) also expressed the opinion that *Ephedripites* may not be a correct name (see also Singh, C 1964, 1971). However, Ramirez-Arriage *et al.* (2005) have suggested the name as a general category for (Poly) plicate pollen (see also Balme, 1970).
Here, the below given species described under this genus are placed in the synonymy with other taxa of plicate group accordingly (see Table 4).
Ephedripites dentatus   Kar, 1968
Ephedripites ellipticus   Kar, 1968

Ephedripites dentatus Kar, 1968
Holotype: Kar,1968; pl. 4, fig. 97; size 45 x 35 µm.

Lithounit and age: Barren Measures, Late Permian.

Locality: Borehole No. J.K.5, Jharia Coalfield, Damodar Basin, Jharkhand, India.

Diagnostic features: Dimensions 35–38 x 45–52 µm; exine 1.5–2.5 µm thick, finely intra–microreticulate, 5–7 longitudinal ridges on both the faces.

Remarks: Although, the specimens are smaller, but similar in the exinal characters to the *Praecolpatites sinuosus* (Balme and Hennelly) Bharadwaj and Srivastava (1969), hence placed under the synonymy (see Table 4).

Ephedripites ellipticus Kar, 1968

Holotype: Kar ,1968; pl. 4, fig. 95; size 65 x 35 µm.

Lithounit and age: Barren Measures, Late Permian.

Locality: Borehole No. J.K.5, Jharia Coalfield, Damodar Basin, Jharkhand, India.

Diagnostic features: Dimensions 65–75 x 27–35 µm; exine ± 1 µm thick, intra–microbaculate, 6–10 longitudinal ridges on both the faces.

Remarks: This species is similar to *Gnetaceaepollenites grandis* Maheshwari (1967), in nature of exine and body- folds (see Table 4).

Genus ***Gnetaceaepollenites*** Thiergart emend.
Jansonius, 1962
(Fig. 2, F)

Type species: *Gnetaceaepollenites ellipticus* Thiergart, 1938.

Lithounit and age: ?, Miocene

Locality: Grube Marga, Senftenberg, Germany.

Diagnostic features: Elliptical to fusiform pollen; exine infra- structured, beset with several to numerous longitudinal ridges, more or less fused at the ends, in some cases extending full length of grain, rarely branching; some having one extra wide or high and elevated ridge separated by deep furrows.

Remarks: Jansonius (1962, p. 77) considered both *Ephedripites* and *Welwitschiapites* Bolkhovitina, 1953 to be junior synonyms of *Gnetaceaepollenites* (Thiergart) Jansonius 1962, because the type species of these taxa are being equivalent in their morphological characters . However, Balme (1970, p. 406, 408) questioned the generic status of *Gnetaceaepollenites* and had retained only *G. sinuosus*. This assignment was tentative since insufficient specimens were available for systematic revision. Pollen of *Welwitschia mirabilis* is monoaperturate and *Ephedra altsissima* inaperturate, but dimorphison has been reported in pollen of *Ephedra*. *Ephedripites*- type pollen are very similar to pollen of araceous *Spathiphyllum* (Rydin and Friis, 2005*)*.

Among the species, so far on record in India under genus *Gnetaceaepollenites* (Table 2), the following five species had previously been transferred to *Praecolpatites* Bharadwaj and Srivastava, 1969 by Bharadwaj and Dwivedi (1981, p.39). Later on, Foster (1975, p.155; 1979, p.103) placed these species under the synonymy *Praecolpatites sinuosus* (Balme & hennelly) Bharadwaj and Srivastava (1969).

Gnenaceapollenites acutus Kar, 1968
Gnenaceapollenites biplicatus Kar, 1968
Gnenaceapollenites diffusus Lele & Makada, 1974
Gnenaceapollenites pachydermatus Kar, 1968
Gnenaceapollenites punctatus Venkatachala & Kar, 1968

The following one is described below:

Gnetaceaepollenites grandis Maheshwari, 1967

Holotype: Maheshwari (1967, pl. 9, fig. 72: size 184 x 92 µm).

Lithounit and age: Barakar Formation, Early Permian.

Locality: Near Bargo, Bansloi Valley, Santhal Parganas, Jharkhand, India.

Diagnostic features: Dimensions 100 –120 x 78–101 µm; exine ca 1.5 µm thick, intra– microbaculate; 2–4 prominent longitudinal ridges.

Genus ***Gondiastriatites*** Kar, 1981
(Fig.2, G)

Type species: *Gondiastriatites* (*Welwitschiapites*) *tenuis* (Bharadwaj & Salujha) Kar 1981.

Lithounit and Age: Raniganj Formation, Late Permian.

Locality: Raniganj Coals, Raniganj Coalfield, Damodar Basin, West Bengal, India.

Diagnostic features: Oval to spindle–shaped pollen; exine generally laevigate, may be variously intrastructured (granulate, baculate, or punctuate), beset with longitudinal ridges / striae.

Remarks: A new genus *Gondiastriatites* was instituted by Kar (1981) to accommodate specimens bearing simple longitudinal ridges / striae on body surface, described under *Welwitschiapites* from the Permian deposits of India. However, on comparison with other similar looking taxa, that is *Welwitschiapites* Bolkhovitina (1953), *Vittatina* Luber emend. Jansonius (1962), and *Tiwariasporis* Maheshwari and Kar (1967), it is noted that *Gondiastriatites* does not exhibit any distinguishable features of its own. Neither its proper taxonomic placement is given by Kar (1981, p.298). Hencefoth, the valid status of *Gondiastriatites* Kar (1981) is redundant. The three species referred as new combinations by Kar (1981), are found to posses the exinal features similar to that *Tiwariasporis* Maheshwari and Kar (1967), and are placed accordingly in the synonymy under this genus (see Table 4).

Genus ***Vittatina*** Luber emend. Jansonius, 1962
Type species: *Vittatina subsaccata* Samoilovich, 1953.
Lithounit and Age : ?, Early Permian.
Locality: Solikamsk City, Western Cis– Urals, Russia.

Diagnostic features: (Potonié, 1970; p. 96). Bilateral pollen; monolete mark distinct; exine being granulose, verrucose or pitted in its sculpture, on proximal face beset with horizontal ridges / costae alternating with furrows which are sometimes bifurcated, on distal surface more thickened ribs at the right angle to ridges; thin area acts as sulcus, equator appears rim like; at extreme lateral ends transverse folds simulating incipient small sacci.

Remarks: This taxon is variedly commented upon the exinal features and also its taxonomic placement by Bharadwaj (1962, p. 92); Pocock (1962,p. 69–70); Wilson (1962, p.24–25); Jansonius (1962, p.73); Potonié (1966, p.152–155); Chaloner and Clarke (1962, p.648); Venkatachala and Kar (1968, p.74–75); and Foster (1979, p. 102). However, genus *Vittatina* is placed under Turma Polyplicates along with other genera – *Ephedripites, Gnetaceaepollenites* and *Welwitschaipites* (Potonié 1958, p.90; 1966, p.152,155).

Vittatina subsaccata Samoilovisch, 1953
(Fig.2, H)

Holotype: Samoilovisch, 1953; pl. 9, fig. 4a; size 60 µm (ca).

Lithounit and Age : ?, Early Permian.

Locality: Solikamsk City, Western Cis- Urals, Russia.

Diagnostic features: Dimensions 50–66 x 36–40 µm; monolete mark curved , extend 2/3 of horizontal axis; exine ca 2 µm thick, beset with 7–20 ridges / costae proximally, ridges rounded to flat, converging at ends; on distal face, thickened ribs at the right angle of ridges, 3 to 10 or more ; ridges being smooth to sculptured with micro- puncta, grana,verrucae or reticulate; greminal slit   seen inbetween central ribs on distal face.

*Vittatina striata (*Luber) Samoilovisch, 1953

Holotype: Samoilovisch, 1953; pl.9, fig.3; size 78 µm.

Lithounit and Age : ?, Early Permian.

Locality: Cherdyn area, Western Cis–Urals, Russia.

Diagnostic features: Dimensions 60–80 x 40–50 µm; exine ca 1 µm thick, granulose, beset with oblique ridges in two directions, crossing at longer axis, ridges 2–3 µm wide, leaving broad furrows inbetween, ridges on distal face at two terminal ends leaving 25–35 µm wide thin area.

Besides, while assessing the exinal features among the species, so far described under the genus *Vittatina* form the Permian succession in India, it has been noticed that non of the below given species posses neither perpendicular ribs on distal face crossing the proximal ones — a marking feature of genus *Vittatina*; nor the pseudo-striations as in *Tiwariasporis*. Henceforth, these are suggested to be referred as *Tiwariasporis* – complex Group.That includes horizontal striations or ridges with many connecting vertical partitions on proximal face , resulting in an irregular verrcose pattern distally, and the 2 -3 folds at the right angle on lateral ends, which simulate as flaps / sacci like. The sulcus / thinning on distal face seems to act as germinal exit.

Vittatina fasciolata (Balme & Hennelly) Bharadwaj, 1962

Holotype: Balme & Hennelly 1956; pl. 3, fig. 42; size 36 x 36 µm (ca).

Lithounit and Age: ?, Permian.

Locality: Main Seam, Co–operative Colliery, Collie, Western Australia.

Diagnostic features: Dimensions 25–38 x 30–46 µm; exine less than 1 µm thick, beset with about 15 tranverse ribs, 2–4 µm wide, less than 1 µm apart; distal furrow 8–15 µm wide, marginal folds narrow.

Remarks: No perpendicular ribs, and presence of marginal folds place this species in *Tiwarisporis* – complex (see Table 4).

Vittatina globosa Maheshwari, 1967

Holotype: Maheshwari, 1967; pl. 6, fig. 53; size 90 x 90 µm.

Lithounit and Age: Barakar Formation, Early Permian.

Locality: Near Bargo, Bansloi Valley, Santhal Parganas, Jharkhand, India

Diagnostic features: Length 81–121 µm; exine 1µm thick, intra–micropunctate, bearing 8–15 horizontal ridges; at extreme lateral ends one or two transverse folds; sulcus 10–20 µm wide.

Remarks: The transverse terminal folds, but no perpendicular ribs place this species in *Tiwariasporis*- complex (see table 4).

Vittatina permegna Tiwari, 1965

Holotype: Tiwari 1965; pl. 9, fig.206; size 144 x 94 µm.

Lithounit and Age: Barakar Formation, Early Permian.

Locality: Borehole R–69, Korba Coalfield, Chattisgarh, India.

Diagnostic features: Dimentions 100–182 x 75–120 µm;exine thin, less than 1 µm,beset with 10–20 horizontal ridges, inter–connected by transverse partitions, at terminal ends two small flap–like foldings, upto 10 µm broad; equatorial rim ca 2 µm thick; thinning of exine may be seen on distal face.

Remarks: This species is similar with *Tiwariasporis gondwanensis* (Tiwari) Maheshwari and kar (1967) in having flap–like terminal folds, rather than perpendicular ribs (see Table 4).

Vittatina scutata (Balme & Hennelly) Bharadwaj, 1962

Holotype : Balme and Hennelly 1956; pl.2, fig. 39; size 56 x 46 µm.

LithoUnit and Age : ?, Permian.

Locality : Homeville Seam, Hebburm No. 1 Colliery, N.S.W., Australia.

Diagnostic features : Dimentions 43–52 x 34–58 µm; exine ca 4 µm thick, horizontal ribs (transverse striae), 1–3 µm wide,0.5 µm apart, on distal face flattened verrucae,1–3 µm across,less than 1 µm high; at terminal ends flapy folds, 2–3 µm wide.

Remarks : Absence of perpendicular striations / ribs and flattened verrucae compares this species with *Tiwariasporis flavatus* Maheshwari and Kar (1967).

Vittatina verrucosa Tiwari, 1968

Holotype: Tiwari, 1965; pl. 8, fig. 88; size 85 x 75 µm.

Lithounit and Age: Barakar Formation, Early Permian.

Locality: Hingir – Rampur Coalseam, Ib – River Coalfield, Mahanadi Basin, Orissa, India.

Diagnostic features: Dimensions 75–108 x 60–75 µm; exine ca 1 –2 µm thick, infrapunctate, 20–26 longitudinal ribs, forked, inter–connected with transverse partitions on proximal surface, more irregular pattern, reticulatoid to verrucose on distal surface; 4 to 7 perpendicular ribs at terminal end.

Remarks: This species compares with *Tiwariasporis flavatus* Maheshwari and Kar (1967) in the nature of ribs / striations, which are pseudo in nature.

Genus **Welwitschiapites** Bolkhovitina ex Potonie, 1958
(Fig. 2, I)

Type species: *Welwitchiapites magniolobatus* Bolkhovitina 1953.

Lithounit and Age: ?, Early Cretaceous.

Locality: Kainar, Embi Basin, Western Kazakhstan, USSR.

Diagnostic features: Oval pollen; exine thin, beset with numerous parallel longitudinal ridges, occasionally connected with transverse partitions or bifurcated, converge at narrow ends.

Remarks: The exinal characters in *Welwitschiapites* had already been commented vigorously (Bharadwaj, 1962, p.99; Jansonius, 1962, p.77; Kar, 1981, p.297–298). The folded and damaged state of the genotype specimen *Welwitschiapites magniolobatus* (Bolachovitina, 1953; pl. 9, fig. 18; size 56 µm ca) had created doubts towards the valid morpho- taxonomic status of genus *Welwitschiapites* (Jansonius ,1962; p. 77).

The below given species, already described under *Welwitschiapites*, are presently transferred in the synonymy of other taxa (see in Table 4).

Welwitchiapites extansus Bharadwaj & Salujha, 1964

Holotype: Bharadwaj & Salujha 1964; pl.12, fig. 166; size

54 x 44 µm.

Lithounit and Age: Raniganj Formation, Late Permian.

Locality: Seam VIII, Raniganj Coalfield, Damodar Basin, West Bengal, India.

Diagnostic features: Length 36–60 µm; exine ca 1 µm thick, coarsely intra–microbaculate, body surface irregurlarly folded, proximally 6–8 longitudinal striations, rarely bifurcated.

Remarks: *Welwitchiapites extansus* compares with *Gnetaceaepollenites grandis* Maheswari (1967), hence placed in the synonymy (see Table 4).

Welwitschiapites magnus Maithy, 1965
Holotype: Maithy, 1965, pl. 7, fig. 48; size 150 x 96 µm.
Lithounit and Age: Karharbari Formation, Early Permian.
Locality: Giridih Coalfield, Damodar Basin, Jharkhand, India.

Diagnostic features: Dimentions 150–180 x 94–120 µm; laesura indisdinct; exine 2 µm thick, microverrucose, several longitudinal striations, inter–connected by transeverse partitions.

Remarks: Except being bigger in size, the specimens illustrated by Maithy (1965) are similar with *Tiwariasporis simplex* (Tiwari) Maheshwari and Kar (1967).

Welwitschiapites minutus Maithy, 1965
Holotype : Maithy, 1965, pl. 7, fig. 50; size 66 x 46 µm.
Lithounit and Age : Karharbari Formation, Early Permian.
Locality: Karharbari Beds, Giridih Coalfield, Damodar Basin, Jharkhand. India.

Diagnostic features: Length 60–80 µm; exine beset with verrucae, verrucae linearly arranged, inter–connected forming reticuloid pattern; small protuberances seen at two polar ends as reduced sacci.

Remarks: The specimen illustrated by Maithy (1965) is similar with the *Tiwariasporis flavatus* Maheswari and Kar (1967).

Welwitschiapites tenuis Bharadwaj & Salujha, 1964
Holotype: Bharadwaj, 1962, pl. 5, fig. 90; size 56 x 98 µm.
Lithounit and Age: Raniganj Formation, Late Permian.
Locality: Raniganj Coalfield, Damodar Basin, West Bengal, India.

Diagnostic features : Length 72–122 µm; exine ca 2–3 µm thick, intra–microbaculate, bearing 6-10 longitudinal striations, rarely bifurcated, inter–connected with transverse partitions, exine variably structured,and irregularly folded in between these striations.

Remarks:This species compares with *Gnetaceaepollenites grandis* Maheshwari (1967) in having many surficial folds (see Table 4). Ramirez- Arriage *et al.* (2006) included this species in *Praecolpatites sinuosus.*

Subturma **Praecolpates** Potonie' and Kremp, 1954
Genus **Marsupipollenites** Balme & Hennelly emend. Balme, 1970
Type species: *Marsupipollenites triradiatus* Balme & Hennelly 1956.
Lithounit and Age: Newcastle coal, Late Permian.
Locality: Seam at 688ft., South Wallarah No. 5 bore, New South Wales, Australia.

Diagnostic features: Oval to subcircular pollen; invariable trilete scar on proximal face with a oval to circular sulcus distally;

exine sculptured with grana,verrucae,elements arranged longitudinally or in tranverse rows, simulating striations.

Remarks: Genus *Marsupipollenites* is considered to have its valid taxonomic status, inspite of variedly commented upon by Bharadwaj (1962, p. 99) who had transferred *M. sinuosus* to genus *Gnetaceaepollenites*. Later on, Bharadwaj and Srivastava (1969, p. 141) placed *M. sinuosus* under *Praecolpatites sinuosus*

Marsupipollenites triradiatus Balme & Hennelly, 1956
(Fig.2, J)
Holotype: Balme & Hennelly 1956; pl. 2, fig. 29; size 70x 40 µm.

Lithounit and Age: Newcastle coal, Late Permian.
Locality: Seam at 688ft, South Wallarah No. 5 bore, New South Wales, Australia.

Diagnostic Features: Dimensions 42–73 x 25–65 µm; laesurae extend upto 6 µm along horizontal axis ; exine ca 2 µm thick, sculptured with flattened verrucae or grana, form a irregular pattern; distal sulcus extend to full length.

Marsupipollenites striatus (Balme & Hennelly) Foster, 1975
Holotype: Balme & Hennelly 1956; pl.2, fig. 36; size 70 x 50 µm.

Lithounit and Age: Newcastle coal, Late Permian.
Locality: Lithgow Seam, Kandos Colliery, New South Wales, Australia.

Diagnostic features: Dimensions 45–75 x 40–65 µm; laesurae extend upto 2–10 µm along horizontal axis; exine ca 2 µm thick, sculptured with parallel or curved thickenings (folds), arranged in longitudinal rows, 1–2 µm wide and 0.5 µm apart, simulating striations.

Remarks: The striae–like arrangement of sculptured elements in the specimens described as *M. triadiatus* forma *striatus* Balme and Hennelly (1956, p.61), has been up-graded to the species status (Foster ,1975; p. 154).

Genus **Praecolpatites** Bharadwaj & Srivastava, 1969
Type species: *Precolpatites nidpurensis* Bharadwaj & Srivastava 1969.
Lithounit and Age: Nidpur Plant Bed, Early Triassic.
Locality: Nidhpuri, Sidhi District, Son Valley, Chhattisgarh, India.

Diagnostic features : Ellipsoidal or elongated pollen; exine infra- structured, micro-reticulate or punctate; single longitudinal furrow on one face extend almost full length, three longitudinal folds on other face.

Remarks: Many new combinations had alraedy been proposed to this taxon of those species described under *Gnetaceaepollenites* by Bharadwaj and Dwivedi (1981). Palynotaxon *Mulicopollenites* Gowankor (1996) superficially resembles *Praecolpatites* (see Zavialova *et al.*, 2001).

Praecolpatites nidpurensis Bharadwaj & Srivastava, 1969
(Fig. 2, K)
Holotype: Bharadwaj & Srivastava 1969; pl. 29, fig. 117; size 115 x 60 µm.

Lithounit and Age: Nidpur Plant Bed, Early Triassic.
Locality: Nidhpuri, Sidhi District, Son Valley, Chhattisgarh, India.

Diagnostic features: Dimensions 115–162.5 x 57.5 – 80 µm; exine 1–2 µm thick, laevigate to intra– microreticulate;

single longitudinal furrow on proximal face, extend full length, three irregularly over–lapping surficial folds on distal face.

Praecolpatites acutus (Kar) Bharadwaj & Dwivedi, 1981
   Holotype: Kar 1968; pl. 4, fig.90; size 92 x 32 µm.
   Lithounit and Age: Barren Measures, Late Permian.
   Locality: Borehole No. J.K. 5, Jharia Coalfield, Jharkhand, India.
   Diagnostic features: Dimensions 60–92 x 25–32 µm; exine 1.5 –2µm thick, finely intra- structured; one deep furrow accompanied with two major folds.
   Remarks: This species is similar to *P. nidpurensis,* except having smaller size (see Table 4).

Praecolpatites biplicatus (Kar) Bharadwaj & Dwivedi, 1981
   Holotype: Kar 1968; pl.4, fig.87; size 92 x 32 µm.
   Lithounit and Age: Barren Measures, Late Permian.
   Locality: Borehole No. J.K. 5, Jharia Coalfield, Jharkhand, India.
   Diagnostic features: Dimensions 59–92 x 23–32 µm; exine ± 1.5 µm thick, finely intra– micropunctate; single narrow furrow, extend full length, accompanied with 3– 4 major longitudinal folds.
   Remarks: It compares with *P. sinuosus* in having many surficial (wave –like) body folds (see Table 4).

Praecolpatites diffusus (Lele & Makada) Bharadwaj & Dwivedi, 1981
   Holotype: Lale & Makada 1974; pl.3, figs.42–43; size 98x31 µm.
   Lithounit and Age: Karharbari Formation, Early Permian.
   Locality: Misra village, Jayanti Coalfield, Damodar basin, Jharkhand, India.
   Diagnostic features: Dimensions 96–116 x 23–48 µm; exine ca 1–2 µm thick, micro-granulose to punctate; usually with 2 or 4–5 longitudinal folds, rarely ruptured exine inbetween the folds simulate sulcus.
   Remarks: This species compares with *P. nidpurensis* (see in Table 4).

Praecolpatites pachydermatus (Kar) Bharadwaj & Dwivedi, 1981
   Holotype: Kar 1968; pl. 4, fig. 89; size 46 x 27 µm.
   Lithounit and Age: Barren Measures, Late Permian.
   Locality: Borehole No. J.K. 5, Jharia Coalfield, Jharkhand, India.
   Diagnostic features: Dimensions 46–70 x 25–27 µm; exine 2.5– 3.5 µm thick, intra– microbaculate, one deep furrow on surface, ill developed ,accompanied with 3– 4 longitudinal folds, margin dentate.
   Remarks: Apparently, this species compares with *P. sinuosus* (see in Table 4).

Praecolpatites punctatus (Venkatachala & Kar) Bharadwaj & Dwivedi, 1981
   Holotype: Venkatachala & Kar, 1968; pl.10, fig.178; size 73 x 36 µm.
   Lithounit and Age: Barakar Formation, Early Permian.
   Locality: Badam area, North Karanpura Coalfield, Damodar Basin, Jharkhand, India.
   Diagnostic features: Dimensions 73– 78 x 36– 41 µm; exine ca 2 µm thick,infra–punctate,puncta evenly spaced all over;

two longitudinal folds seen on body surface.
   Remarks : This species is similar to the *P. nidpurensis* (see in Table 4).

Praecolpatites sinuosus (Balme & Hennelly) Bharadwaj & Srivastava, 1969
   Holotype: Balme & Hennelly 1956; pl. 2, fig.; 25 size 90 x 40µm.
   Lithounit and Age: Newcastle coal, Late Permian.
   Locality: Seam at 688 ft, South Wallarah No. 5 bore, N.S.W. Australia.
   Diagnostic features: Dimensions 70–101 x 32–48 µm, exine ca 2µm thick, smooth or faintly granulate, heavily plicate with 4 to 6 longitudinal folds, running full length, associated with linear, narrow clefts, presumably one or more clefts functions as germinal exist.
   Remarks: Balme (1970, p. 408) has mentioned the separate generic status for *Gnetaceaepollenites* (*Marsupipollenites*) *sinuosus*, but insufficient specimens does not allow the systematic revision of this species.

DISCUSSION

From an overview of the exinal features among the taxa, listed in Table 2 from the Permian deposits of India (dealt in the preceding pages), the four major patterns in the exine characters are identified, which display singnificant role in delimiting a genus or species within the plicate group (Tables 3, 4).

i) Ridges / ribs / plicae might be true structural exinal feature on body surface as seen in *Striatosporites/Vittatina* or the pseudo–impressions made by the arrangement of sculptural elements (verrucae in *Tiwariasporis* or simple linear markings in *Marsupipollenites*)

a) in general are two distinct kinds of ridges / plicae – one broad, elevated, parallel to the longitudinal axis; and other much finer, inter–connecting by thin transverse partitions, which might be straight, oblique (*Striatosporites, Tiwariasporis*) or irregularly intervening (*Marsupipollenites*)

b) longitudinal body folds (*Gnetaceaepollenites, Praecolpatites*) extend along longer axis independent of any kind of inter- connectivity

c) prominent rounded to flat ribs, parallel to longitudinal axis proximally, terminate / orient at right angles on proximo - distal face; variously micro-sculptured (*Vittatina*)

ii) Space inbetween the longitudinal folds (*Gnetaceaepollenites*) or distal thinning (*Vittatina*) to distal sulcus (*Marsupipollenites*) may act as germinal passage in these pollen taxa.

iii) whereas, a separate monolete mark (usually not sharply defined) exists in between these ridges / plicae in the spore (*Striatosporites, Tiwariasporis*).

iv) at the terminal ends, two flap–like folds in spore (*Tiwariasporis*) or rudimentary sacci in pollen (*Vittatina*) might be present.

The morpho–taxonomy of these taxa had already been discussed in detail (see in Balme, 1970; Jansonius, 1962; Wilson, 1962; Foster, 1979). Presently, the characteristic features of - two spores and four pollen taxa are briefly given in Table 3. In general, the occurrences of these species representing the plicate group are reported in the Permian successions, are displayed in Fig.3, but no comments are made about their

Table 3 Brief summary of distinguishing exinal features among the spores and pollen taxa bearing ridges / ribs , and the horizon from where originally described.

	Spore/pollen taxa	Horizon (Instituted)	Distinct exinal characters	Occurrence in India	Essential Notes
	SPORES				
1.	*Striatosporites*, Bhardwaj 1954	Late Carboniferous, Europe	Monolete present, exine beset with broad longitudinal ridges on both faces, inter-connected by transverse partitions, appear like fish bones	Late Permian Deposits	Definite longitudinal ridges forming zig-zag pattern, germinal aperture as lete or slit
2.	*Tiwariasporis* Maheshwari & Kar 1967	Late Permian, India	Occasional presence of monolete mark, exine beset with well pronounced verrucae, arranged in linear rows imparting pseudo-striations, flap like folds at terminal ends	Early to Late Permian Deposits	Pseudo-striations, no definite germinal exit, flapy folds at lateral ends
	POLLEN				
3.	*Gnetaceaepollenites* Thiergart emend. Jansonius 1962	Late Tertiary, East Germany	Exine faintly structured, bearing several longitudinal surficial folds, more / less fused at ends.	Early to Late Permian Deposits	No definite germinal exit seen, body surface folded
4.	*Marsupipollenites* Balme & Hennelly emend. Balme 1970	Late Permian, Australia	Single furrow on distal face, exine sculptured with varied kind of elements or indeterminate markings on proximal face	Middle to Late Permian Deposits	Sulcus as germinal exit, linear markings on body surface impart pseudo-impression of linear markings
5.	*Praecolpatites* Bharadwaj & Srivastava 1969	Early Triassic, India	Exine intra-microbaculate to micropunctuate, single longitudinal furrow on one face, on other face three over-lapping longitudinal folds/furrows.	Late Permian Deposits	Sulcus as germinal exit, longitudinal body folds uniq feature
6.	*Vittatina* Luber emend. Jansonius 1962	Early Permian, Russia	Distal thinning, exine beset with differential pattern of, regular ridges on proximal face and perpendicular distally, with or without incipient sacci	Middle to Late Permian Deposits	Distal thin area as germinal exist, definite pattern of ridges on both faces

Note: The two congeneric spore taxa *Columinisporites* and *Kendosporites;* and the two pollen taxa *Ephedripites* and *Welwitchiapites* do not hold separate generic status as discussed in preceding pages, hence, not included in this Table.

morpho–taxonomy. Here, it is noted that apparent from similarity is clearly visible among certain taxa, henceforth, the similar looking taxa are placed in the following four groups:

Group I: It includes genus *Striatosporites,* to which the two taxa *Columinisporites* and *Kendosporites* are placed in synonymy.

Group II: Genus *Tiwariasporis* holds its separate status.

Group III: It is represented by the *Gnetaceaepollenites* and *Vittatina*. To the former one, certain species so far described under *Ephedripites* and *Welwitschiapites* have now been transferred.

Group IV: Here, *Marsupipollenites,* and *Praecolpatites* broadly belong to a common pool of exinal features that is distal sulcus, but are different from each other in the indeterminate markings/ longitudinal folds on body surface respectively.

SPORES

Among the spore taxa listed in Table 2, it is clear from the preceding account that genus *Striatosporites* Bhardwaj 1954, holds the status of valid taxon (Table 3). And the other two genera *Columinisporites* Peppers (1964) and *Kendosporites* Surange and Chandra (1974) are congeneric with that *Striatosporites* (Playford and Dino, 2000; p. 23). Even then without giving much attention towards this apparent form similarity, specimens assignable to *Columinisporites* Peppers (1964) have been identified in the Upper Permian deposits, which counts less than 0.5 percent (Godavari Basin, Jha and

Srivastava, 1996).

Genus *Tiwariasporis* Maheshwari and Kar (1967)is the only taxon among the monolete spores which bears the pseudo–striations formed by longitudinal arrangement of the sculptural elements (verrucae). Taxonomically *Tiwariasporis* had been dealt variedly (Potonié, 1966, 1970).The oldest record of this taxon is from the Talchir deposits earliest Permian in India (Chandra and Lele, 1979).

The exinal features in *Striatosporites* (*Columinisporites, Kendosporites*) and *Tiwariasporis* suggest a specialized adaptation in the parent plants towards a particularly set climate within a peat–swamp environment.

POLLEN

Among the many plicate pollen taxa, the very commonly reported one from the Permian deposits in India are –– *Ephedripites*, *Gnetaceaepollenites*, *Praecolpatites, Marsupipollenites, Vittatina* and *Welwitschiapites* (Table 2). Morpho–taxonomy of these taxa had already been discussed at length by Bharadwaj, 1962; Jansonius, 1962; Wilson, 1962; Hart, 1964; Tiwari, 1965; Potonié, 1970; Balme, 1970; Foster, 1975, 1979, etc. From the preceding account, it is derived that in Group III, *Gnetaceaepollenites* is the only taxon to have distinct morphology and valid taxonomic status among the three taxa (*Gnetaceaepollenites, Ephedripites* and *Welwitchiapites*) and the *Vittatina*. In Group IV, *Marsupipollenites,* and *Praecolpatites* hold their separate morpho- taxonomic status. After an assessment of exinal features among the species on record (Table 2), the distinct
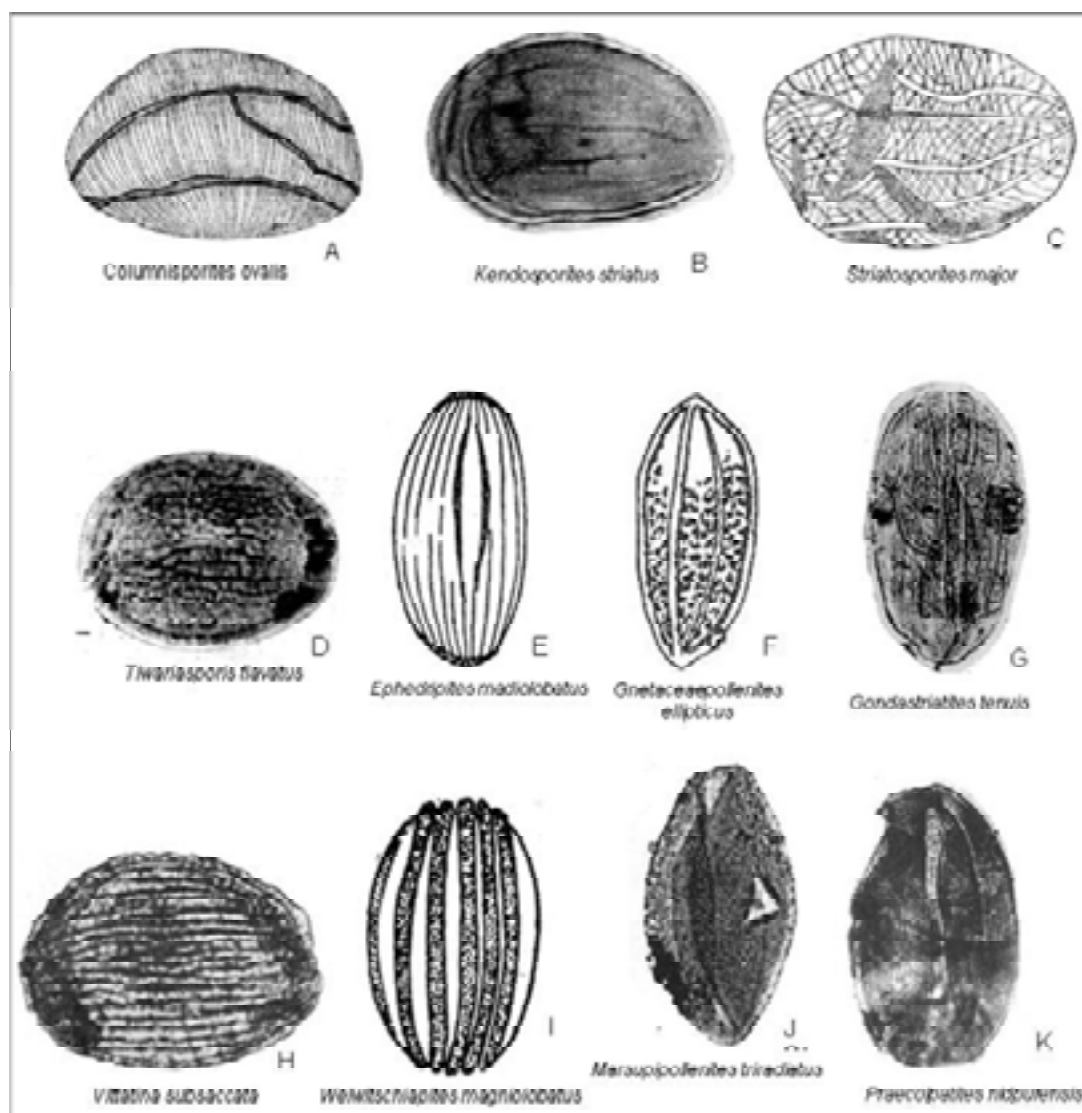
Table 4: After analysing the exinal features of those species on record in the Permian successions in India, the following species are retained under the plicate spores and pollen taxa.

SPORES	TAXA	CONSPECIFIC SPECIES
[illegible]	[illegible] [illegible]	[illegible] [illegible]
	[illegible]	
[illegible]	[illegible] [illegible]	[illegible] [illegible] [illegible] [illegible]
	[illegible] [illegible]	[illegible] [illegible]
	[illegible] [illegible]	[illegible] [illegible] [illegible] [illegible]
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POLLEN		
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ones in Groups III and IV, are listed in Table 4.

Genus *Praecolpatites*, significant marker taxon in the Upper Permian, and so also marks its presence into the basalmost Triassic strata in India (Tiwari and Vijaya, 1991, 1994; Bharadwaj and Srivastava, 1969). In the present review, it is observed that many of other species so far described under other plicate pollen taxa (see Table 2), now find their placement in the synonomy under *Praecolpatites* (Table 4)

Fig.2. The genotype specimen of each taxon listed in Table 2. AD Spores and EL Pollen, A *Columinisporites ovalis*, B *Kendosporites striatus*, C *Striatosporites major*, D *Tiwariasporis flavatus*, E *Ephedripites mediolobatus*, F *Gnetaceaepollenites ellipticus*, G *Gondiastriatites tenuis*, H *Vittatina subsaccata*, I *Welwitchiapites magniolobatus*, J *Marsupipollenites triradiatus*, K. *Praecolpatites nidpurensis*.

These pollen taxa *Marsupipollenites, Vittatina* and allied pollen taxa (*Gnetaceaepollenites, Ephedripites*) have been grouped variedly on the basis of their exinal features – Jansonius (1962, p.73), Wilson (1962, p.24–25), Bharadwaj (1962, p.99–100), Tiwari (1965, p. 206–207), Hart (1964, p.1195), Venkatachala and Kar (1 968, p.74–75), Potonié (1970, p. 96) and Balme (1970, p. 410). And the validity of genus *Vittatina* is questioned? Moreover, here the morpho–taxonomy by Samoicovisch (1953) is considered . Few species described under *Vittatina* are now grouped under *Tiwariasporis-* complex on the basis of exinal features (Table 4).

Bharadwaj (1962, p.100) commented upon the validity of genus *Marsupipollenites* Balme and Hennelly 1956, and grouped the two taxa – *Marsupipollenites* and *Vittatina* - in Monocolpates. The reason explained for this placement is that folds in these two taxa run perpendicular to the striations, whereas in polyplicates, the folds lie parallel to the striations. Keeping aside all these remarks, the two taxa *Marsupipollenites* (indeterminate markings on body surface) and *Vittatina*, (differtial pattern of ribs) are different in their morphography

from each other, and hold separate generic status in the plicate taxa (Table 3).

The separate generic status for *Gondiastrites* Kar (1981) is redundant, because this taxon does not hold the basic criterion to be differentiated from *Ephedripites, Welwistchiapites* and *Tiwariasporis* (given under its synoymy Kar, 1981; p.299).

Not enough data is available at present to allow phylogenetic relationships of these spores *Striatosporites, Tiwariasporis,*and *Gnetaceaepollenites, Marsupipollenites Praecolpatites* and *Vittatina* pollen taxa. Only of certain taxa botanical affinities are documented in time. It is interesting to note that both *Striatosporites* and *Kendosporites* have been found in-situ, while *Striatosporites* is definitely a sphenophyllalean spore, *Kendostrobus* too seems to be a sphenophyllalean cone (McLean *et al.,* 2006).

Ephedripites–type forms have also been included in the genus *Equisetosporites*, and a possible relationship with Chlamydospermae is suggested. Polyplicate pollen in fossil state is usually assigned to genus *Ephedripites*, although some

place them in *Gnetaceaepollenites* or even in the living genus *Ephrdra* (see Volkheimer and Quattrocchio, 1975; van Konijenenburg, 1992). A considerable disparity in exinal characters including the inaperturate / monosulcate germinal types, the psilate and polyplicate stand in sharp contrast in the pollen morphology in fossil gnetophytes. These pollen are mostly asaccate or rarely with rudimentary sacci. The ultrastructure of extant gnetophytes lends support to phylogenetic relatedness of extinct forms (Tekleva and Krassilov, 2009). The incoming information from the recent palynological studies might further re–instate the evolutionary patterns in the exinal features of these spores and pollen.

The earliest record of this specific morphology (Plicate, Table 1) dates back in Late Carboniferous (Hart 1964, p.1198; Souza, 2006), but in India not before the earliest Permian (Talchir Formation; Lele, 1975). As such, there is no record of Carboniferous on Indian peninsula (Vijaya, 1996).A wider geographical record of these apparently similar looking form taxa during the Permian time might be that the two regional floras existing may have ancestry to a common gene pool of parent plant in Carboniferous (Vijaya and Tiwari, 1991). From the functional aspect of exinal features in these spores and pollen, it might be possible that plants producing these taxa occupied similar ecological niches.

Regarding the stratigraphic occurrences of these species (Table 4), an assessment of the better known palynofloras from the different horizons in the Permian successions in India (Damodar Basin – Bharadwaj, 1962; Tiwari, 1965; Maheshwari, 1967; Vijaya, 1996; Rajmahal Basin – Tripathi, 1996; Vijaya, 2006; Son Valley – Tiwari and Ram Awatar, 1988; Tripathi *et al.*, 2005; Godavari Basin – Jha and Srivastava, 1996) delivers that these species had meager occurrences and restricted vertical ranges, as depicted in Fig. 3.

Palynoflora from the basalmost fluvio–glacial sediments of the Talchir Formation earliest Permian is well recorded on the Indian peninsula (Vijaya, 1996). In general, the palyno–composition from this horizon is more or less impoverished flora (not much diversified). Very rare representation of these spores and pollen is observed. Only one–two specimens referable to *Tiwariasporis* sp. is on record that too in the basalmost Permian (the younger part of the Talchir Formation) comprising siltstone bed (Lele, 1975; Bharadwaj and Srivastava, 1973). Subsequently, in the earliest Permian (Talchir–Karharbari formational transition), rich and diversified palynoflora is on record. But here too, it is only *Tiwariasporis flavatus*, which occurs sporadically (that is 1 to 2 percent) at the onset of the coal deposits (Barakar Formation ; Lele and Makada, 1972; Bharadwaj and Srivastava, 1973; Tiwari and Ram Avatar, 1988).

In sharp contrast to the Karharbari Formation, the palynoflora of the Coal horizon (Barakar Formation) is not only quantitatively rich but also substantially diversified in genera and species. Here, in the total population of spores and pollen, representation of plicate taxa is recognized by the first occurrences of *Tiwariasporis simplex, T. gondwanensis, Marsupipollenites triradiatus, Gnetaceaepollenites grandis.* In this horizon, clearly a definite presence is observed with substantial increased number of species which gradually become stable constituents in the younger palynoflora (Maheshwari, 1967; Shukla, 1983; Srivastava, 1984; Tiwari and Ram Avatar, 1988).

These species continue to maintain their stronghold with the additional number of species in the Barren Measures Formation (Lower–Upper Permian transition; Kar, 1968; Tiwari *et al.*, 1981; Tiwari and Rana, 1984). In the younger horizon of Upper Permian Succession, (Raniganj Formation) species representation of this group had increased relatively, almost in most of the coalfields (Tripathi, 1996; Jha and Srivastava, 1996; Tiwari and Ram Avatar, 1990), as illustrated in Fig. 3.

From the above given data , it is evident that there existed recognizable qualitative changes in the exinal characters, and quantitative variations in the occurrences of these plicate taxa. These differences both in morphography and relative counts seem obviously related with the climatic changes. The earliest Permian (Talchir Formation), commencing with cold climate but subsequently ameliorating to a cool and temperate condition towards the Early Permian (Karharbari Formation), seem to be the responsible factor for the meager occurrences of these ribbed / plicate taxa. According to Utting *et al.* (2005) dominance of taeniate bisaccate and polyplicate pollen indicates a probable arid climate

Precise stratigraphical occurrences of the species, as illustrated in Fig. 3, might be dependent of the depositional set–up that is changing humidity (dry/arid, wet) and temperature (warm/hot, cold), and also other related geo-physical factors . These taxa being very low in counts and also with inconsistent vertical ranges throughout the Permian successions, signify themselves as an impoverished elements of the then vegetation. (Bharadwaj 1975; Tiwari and Tripathi, 1988; Vijaya 1996, Venkatachala *et al.* 1995).

CONCLUSIONS

From the preceding data, here it is derived that:
- Among the taxa dealt herein (Tables 1, 2), only six taxa (Table 3) and twelve species (Table 4) are retained based on their exinal features.
- Each taxon is distinct in having particular type of exinal features that vary from linear arrangement of sculptural elements to regularly running ribs or ridges / plicae
- Species diversity in the plicate group is attained gradually through the Lower Permian, (Barakar Formation) into the Upper Permian (Raniganj Formation).
- These species (Table 4) exhibit restricted vertical ranges through Permian time (Fig. 3), but render their role in stratigraphy , might be limited
- Very low occurrences of these species in the Permian successions (Fig. 3) might be the resultant of fluctuating impact of palaeoclimate on the then parent vegetation.

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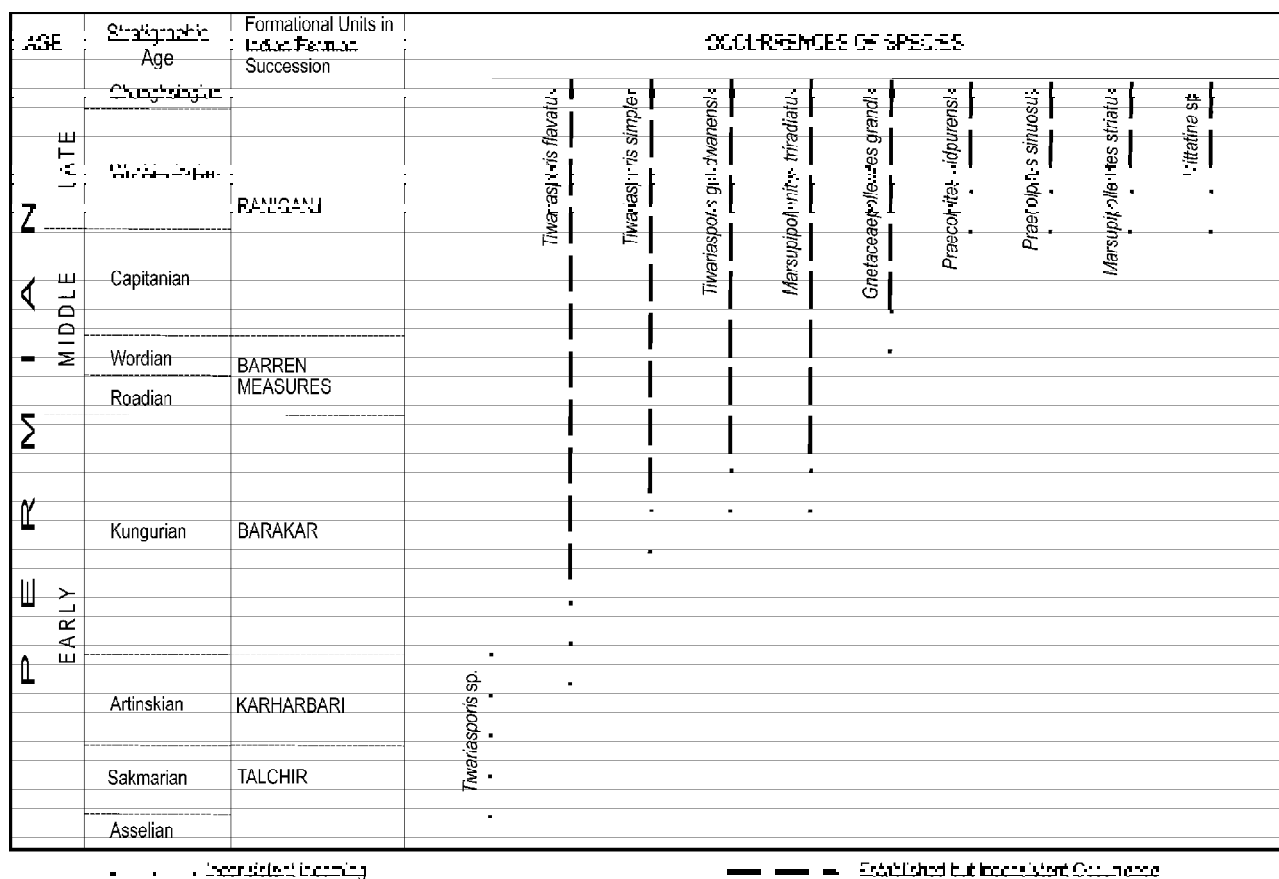**Bharadwaj, D.C**. 1954. Einige neue Sporengattungen des Saarkarbons.

Fig. 3. Pattern of occurrences of species of species of Plicate taxa in the Permian successions on Indian peninsula (from published data)

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EARLY PLIOCENE - HOLOCENE *FAVIA* FROM THE NORTHERN AND NORTHWESTERN COASTAL AREAS OF SAURASHTRA PENINSULA, WESTERN INDIA

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ABSTRACT

The scleractinian coral genus *Favia* from the early Pliocene–Holocene sediments and the patch reefs in intertidal lagoon along the northern and northwestern coastal areas of Saurashtra peninsula, western India is represented by three morphospecies, viz. *Favia favus*, *Favia speciosa* and *Favia matthaii*. These species have been found intricately related and cannot be easily seperated; however, based on combination of characters like anastamosing nature of septa, size and shape of paliform lobes, size and density of septal ornamentation these have been differentiated. The nomenclatural problem has also been discussed. The significance of the genus for palaeoecological reconstruction and their detail morphological variation through time has been given.

Keywords: Saurashtra coast, Neogene-Quaternary, *Favia*, taxonomy, palaeoecolgy

INTRODUCTION

The coastal areas at the northern and western margins of Saurashtra peninsula, western India have been known for Neogene-Quaternary carbonate sediments (Rao *et al.*, 1994; 1996; Flügel, 2004), coral reefs (Rosen, 1971; Patel, 1978; Pillai and Patel; 1988; Rashid, 1988; Bakus, 1994; Pandey *et al.*, 2003) and their importance in sea-level and palaeoclimatic studies (Gupta, 1972; Gupta and Amin, 1974; Somayajulu et al., 1985; Mathur *et al.*, 1988; Pant and Juyal, 1993a, b; Juyal *et al.*,1995; Bhatt and Patel, 1998; Mathur 1993a, b; 1999; Merh, 1995; Bhatt, 2000; Mathur and Pandey, 2002; Rao *et al.*, 2003; Pandey *et al.*, 2003; Mathur *et al.*, 2004) (Fig. 1). Lithostratigraphically, the sediments belong to the lower Gaj and Dwarka formations, the middle Miliolite and the Chaya formations and the upper Katpur and Mahuva formations (Mathur *et al.*, 1988; De, 1989; Bhatt, 2000; Pandey *et al.*, 2005). They range from middle Miocene to late Holocene (Table 1).

The diversity of scleractinian corals along the northern and northwestern coastal areas of Saurashtra peninsula is moderately high. Earlier workers recorded 54 species from this area (Chhaya and Patel, 1982; Pillai and Patel, 1988). Recently, in all, 110 coral specimens, collected from the early Pliocene and terminal late Pleistocene-Holocene sediments and living patch reefs in intertidal lagoon (ratio of Fossil : Dead : living is 3 : 5 : 4) along the northern and northwestern coastal area of Saurashtra peninsula, have been assigned to 26 species, belonging to 13 genera and five families (Table 2) following recent advances in coral systematics. Most of the species have been recorded for the first time from the area (Singh, 2003).

Of the five families, the family Faviidae has been found most abundant. It contributes alone 65% of the total individuals. These have been frequently used for study of coral growth bands, and both stable and unstable isotopes, which have been used to interpret changes in climatic and environmental conditions (Chakraborty and Ramesh, 1998; Mathur and Pandey, 2002; Pandey *et al.*, 2003).

The large number of specimens (numbering 42; including both fossil and extant) of the genus *Favia* gives ample material to study microstructural, microarchitectural details and variability of morphological features of the genus from early Pliocene–Holocene sediments and living patch reefs in intertidal lagoon (see Table 2). The few taxonomic publications on the various species of genus *Favia* from the Gulf of Kachchh (Patel, 1978; Chhaya and Patel, 1982; Pillai and Patel, 1988) give very little information. Previous authors have not used the conventional terms for describing the corals. In the present paper, the nomenclatural problem and the significance of the genus for palaeoecological reconstruction are discussed.

MATERIAL AND METHODS

The samples of living, dead and fossil corals were collected from several localities along the northern and northwestern margins of Saurashtra peninsula, western India (Fig. 1, Table 2). The abbreviations used in table 2 are mentioned below against each horizon and locality. In the horizon and locality where the species is represented by a single specimen the abbreviations are not followed by any numerical number.

1. Living (L) and dead (D) corals from patch reefs in the Narara intertidal lagoon (NL), Vadinar (low tide depth: 0.5m – 0.75m).

2. Fossil (F) corals from the Kalyanpur Limestone Member (Early Pliocene), Dwarka Formation, Aramda (Ar).

3. Fossil corals from the conglomerate bed of the Okha Shell Limestone Member (terminal Late Pleistocene), Chaya Formation exposed along the coastal area near Mojap (Mj).

4. Fossil corals from Coral-algal reef facies of the Aramda Reef Member (terminal Late Pleistocene), Chaya Formation exposed along the coastal area near Beacon (Be), Mithapur.

5. Fossil corals from Coral-algal reef facies of the Armada Reef Member (terminal Late Pleistocene), Chaya Formation exposed in a large diameter dug-wells (Dw), located
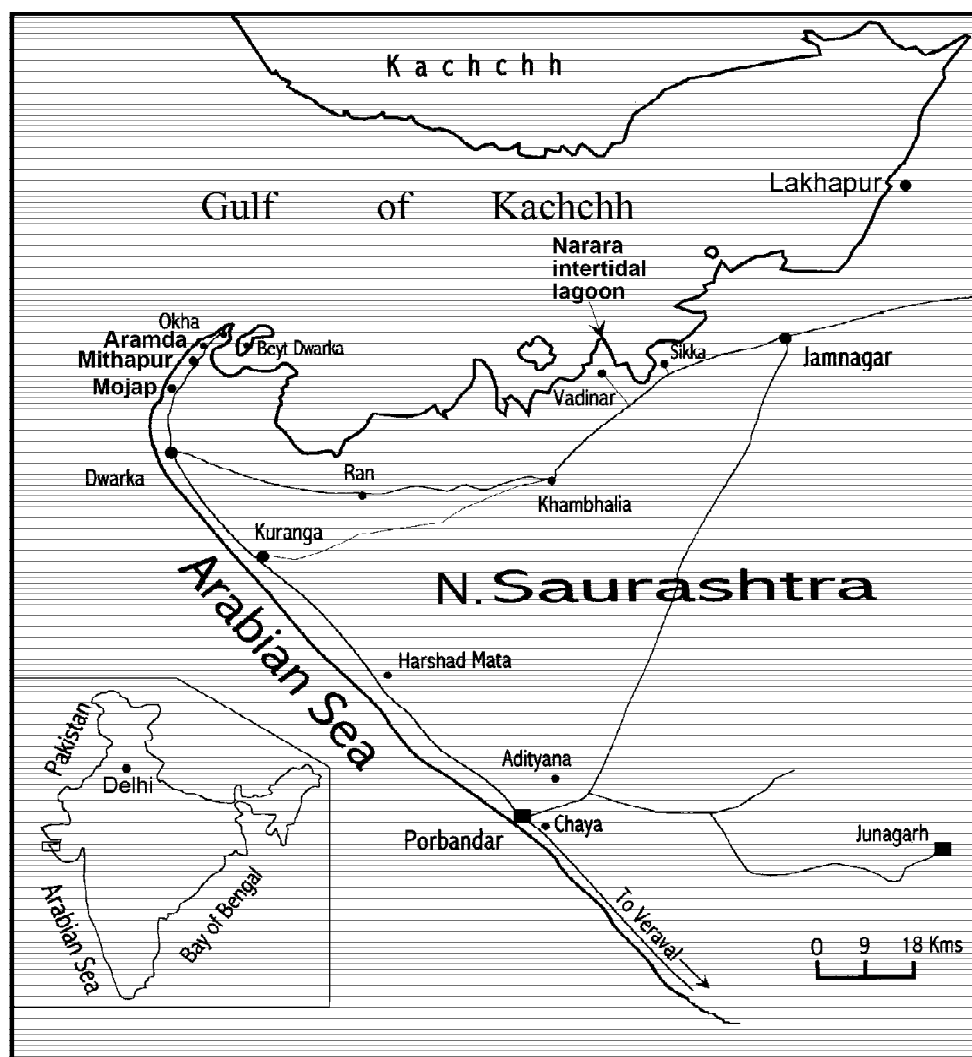
Fig. 1. Locality map showing locations of specimens collected.

near Shaktipeeth temple, 1.75 km NW of Mithapur Railway Station (69⁰ 00' 30": 22⁰ 25' 00").

6. Semi-fossilized (Sf) corals from Coral-algal beds of the Aramda Reef Member (Holocene), Chaya Formation exposed in a trench near Bala Hanuman (BH) Temple, Mithapur.

All the specimens were washed and studied under high-resolution stereozoom binocular microscope for detailed microarchitectures, and some were cut with a Logitech section cutting machine for the preparation of thin sections for the examination of microstructures. Geometrical characters were measured as per convention of the coral taxonomy. The abbreviations used in the present paper are given below:

Diameter of corallum – large: D, small: d; Height of corallum (H); Diameter of the calice (Dc); Corallite outline (CO) - circular: c, oval: o, elongated: e, polygonal: p, irregular: i; Corallite shape (CS) - crater-like: cr; Septa (S) - number of cycles of septa (Ncs); density of septa in mm: Sd; number of septa in the corallites along the periphery: Ns, distal margin denticulate: dmd, distal margin finely denticulate: dmfd, distal margin, regu-

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EXPLANATION OF PLATE I

1 - 7 *Favia favus* Forskal from northern and northwestern coastal areas of Saurashtra

1. Upper surface of a plocoid living colony. Note intratentacular distomodaeal budding. Narara lagoon, RUC1999II 47

2. Detail of a septum in thin transverse section showing distribution of trabeculae. Trabeculae are at right angle to the section near the wall and oblique towards the inner part of the septa. Recent, Narara lagoon RUC1999II 1

3. Longitudinal broken surface showing endothecal and exothecal dissepiments, carinae (ca) on the lateral surface of septa (s) and paliform lobe (pl). Living Narara lagoon RUC1999II 31

4. Longitudinal broken surface showing steeply deeping endothecal dissepiments (arrow) and paliform teeth. Living Narara lagoon RUC1999II 40

5. General view of a calyx showing the organisation of the septal apparatus and the papillose columella. Recent, Narara lagoon RUC1999II 1

6. Transverse thin section showing a corallite surrounded by peritheca. Note the relation between costae (c) of adjacent corallites. Recent, Narara lagoon RUC1999II 1

7. Detail of four septa in thin transverse section showing parathecal wall (pw). The section is tangential to the dissepiment (compare with fig. 6). Recent, Narara lagoon, RUC1999II 138

PANDEY AND SINGH
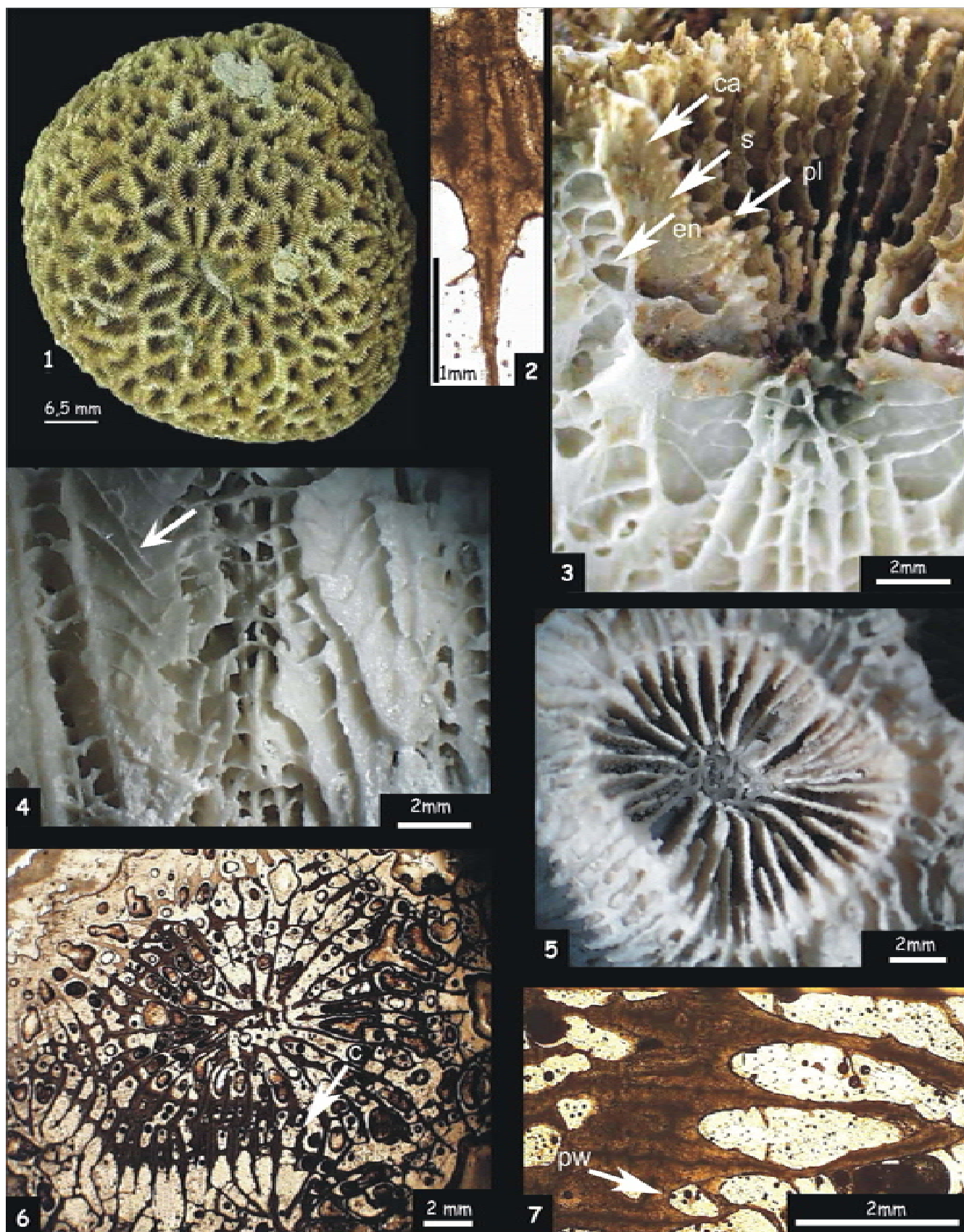
Table 1: Lithostratigraphy of Tertiary - Quaternary of Saurashtra (modified after Mathur *et al.*, 1988; De, 1989; Bhatt, 2000 & Pandey *et al.* 2007).

Stratigraphic unit			Lithology	Age
Group	Formation	Member		
	Mahuva Formation		Unconsolidated freshwater alluvium (sands and clays), coastal deposits; lime mud, Rann clays, calcareous sands with marine calcareous skeleton and shells	**Late Holocene**
	Katpur Formation		Oxidised and podogenised tidal flats clays/silt	Middle Holocene
	Unconformity			
Porbandar Group	Chaya Formation	*Porbandar Calcarenite Member*	Semi consolidated to consolidated calcarenite with megafossils	Late Pleistocene to Early Holocene
		Aramda Reef Member	Coral-algal reef and coral-algal beds with mega-fossils	
		Okha Shell *Limestone Member*	Semi-consolidated to consolidated shell limestones	
	Miliolite Formation	Adatiana Member	Pelletoid limestones	Middle Pleistocene
		Dhobaliya Talav Member	Alternating sequence of pelletoid Limestones and fine grained limestone	
	Unconformity			
	Dwarka Formation	Kalyanpur Limestone Member	Recrystallised fossiliferous limestone and arenaceous limestone	Middle Miocene (?) to Early Pliocene
		Shankhodar Sand-Clay Member	Sandy clays and sandstones	
		Positra Limestone Member	Bioclastic and coralline limestones with few dolomite bands	
	Disconformity			
	Gaj Formation	Ranjitpur Limestone Member	Hard, compact, fine grained limestone with abundant foraminifers, gastropods, bivalves, echinoids etc.	Middle Miocene
		Ashapura Clay Member	Variegated clay with gypsiferous bands	
	Nonconformity			
	Deccan trap Formation		Basalt and other derivatives covered at places by laterite and bauxite	Upper cretaceous to Eocene

larly denticulate: dmrd, septa exsert: Se; Paliform lobe (PL) - distinct with crown: dc, present: p, poorly developed: prd, absent: a; Width of peritheca (Wp); Wall exsert (We); Columella (col); Intercalicular distance from columella center (c-c); Density of dissepiments in mm (Dd).

Photographs were taken with a digital camera and bubbles were removed from the photographs of thin sections using Canvas 5.0.3 before making the final plates. The specimens have been numbered with a prefix RUC1999II (Rajasthan University collection of 1999) and deposited in the Department of Geology, University of Rajasthan, Jaipur, India.

SYSTEMATIC PALAEONTOLOGY
Order **Scleractinia** Bourne, 1900
Suborder **Faviina** Vaughan and Wells, 1943
Family **Faviidae** Gregory, 1900
Genus **Favia** Milne-Edwards, 1857
(after Cuif and Perrin, 1999: 139)

Type species: *Madrepora fragum* Esper, 1795 after Wells 1956: F402 and Cuif and Perrin (1999: 139), *Madrepora ananas* Pallas, 1766 after Zlatarski and Martnez Estalella (1982: 26, 61), *Madrepora ananas* Oken, 1815 *after* Gregory (1900: 68).

Diagnostic characters: Colony massive, globular, commonly hemispherical, or thickly encrusting, plocoid, being separated by dissepimental coenosteum, or ploco-cerioid. Intracolonial variability is high. Budding intracalicular, usually distomodaeal. Division biseptal; axial margin of two opposite major septa gradually fused until they form a distinct and compact separation. Simultaneously or subsequently on each side of this new wall, new septa are developed resulting from twisting and growth of distal teeth of the initial septa. Calices shallow to deep, rounded, irregular, angular to subangular, subpolygonal, elongated to meandroid in outline.

Costosepta are cuneiform, confluent to nonconfluent, usually straight or slightly curved, subcompact with rarely developed pores at their axial margin or sometime also in the

Table 2: Checklist of living (L), dead (D) and fossil (F) corals found in the north and northwestern Saurashtra.

Families (5)	Genera (13)	Species (26) (total 110 specimens)	Age	Horizon & Locality (Specimens)	Status
Acroporidae	*Montipora*	**M. turgescens**	Late Pleistocene	NL	D
		M. capricornis	Late Pleistocene	Dw	F
		M. angulata	Late Pleistocene	Dw	F
	Acropora	*Acropora sp. 1*	Late Pleistocene	NL (10)	F
			Late Pleistocene	Be	F
			Late Pleistocene	Dw	F
		Acropora sp. 2	Late Pleistocene	NL	D
			Late Pleistocene	Be	D
		Acropora sp. 3	Late Pleistocene	Dw	F
	Astreopora	*Astreopora sp.*	Late Pleistocene	Be	D
			Late Pleistocene	Mj	D
Poritidae	**Porites**	*P. stephensoni*	Holocene	NL (2)	L
		P. mayeri	Holocene	NL	L
		P. murrayensis	Holocene	NL	L
		P. lutea	Holocene	NL	L
		P. myrmidonensis	Holocene	NL	L
	Goniopora	**G. norfolkensis**	Holocene	NL	L
Siderastreidae	**Pseudosiderastrea**	*P. tayami*	Holocene	NL	L
			Late Pleistocene	Dw	F
	Siderastrea	*S. savignyana*	Holocene	NL (4)	L
Mussidae	**Symphyllia**	**S. radians**	Holocene	NL (3)	L
Faviidae	**Favia**	**F. speciosa**	Holocene	NL (12)	L
			Late Pleistocene	NL (2)	D
			Late Pleistocene	Be (7)	D
			Late Pleistocene	Mj (2)	D
			Late Pleistocene	Dw	F
			Late Pleistocene	Dw (3)	F
		F. favus	Holocene	NL (4)	L
			Late Pleistocene	NL	D
			Late Pleistocene	Be	D
			Late Pleistocene	Mj	D
			Late Pleistocene	Dw	F
			Dwarka Fm.	Ar	F
		F. matthai	Late Pleistocene	Be (2)	D
			Late Pleistocene	Dw (2)	F
			Late Pleistocene	Dw (3)	F
	Favites	*F. abdita*	Holocene	NL (2)	L
		F. acuticolis	Late Pleistocene	Mj	D
			Late Pleistocene	Dw	F
		F. complanata	Late Pleistocene	Mj	D
		F. halicora	Late Pleistocene	Dw	F
	Goniastrea	*G. retiformis*	Late Pleistocene	Dw (7)	F
	Platygyra	*P. daedalea*	Holocene	NL (4)	L
			Late Pleistocene	NL (2)	D
		P. sinensis	Late Pleistocene	NL	D
			Late Pleistocene	Be	D
			Late Pleistocene	BH	F
		P. lamellina	Late Pleistocene	NL	D
			Late Pleistocene	Be	D
	Montastrea	*M. curta*	Late Pleistocene	NL (3)	D
			Late Pleistocene	Be (5)	D
		M. annuligera	Late Pleistocene	Dw	F

middle part of the septa of younger cycles, arranged in more than four cycles; first two cycles and all or few of third are almost equal and reach the columella, rest of third cycle reach half or three quarters of the calcinal radius and may anastomose with neighboring septa at their internal margin. Those of the fourth cycle incomplete and weakly developed. Laterally, the septa are ornamented with spinules along the trabeculae arranged in one uniform fan system. Distal teeth correspond to trabeculae, consist of groups of small points with a conical straight or curved axis. Paliform crown around trabecular, papillose to spongy columella occasionally developed. Endotheca consist of vesicular dissepiments, gently inclined towards the periphery, become horizontal towards the center. Wall parathecal or septoparathecal. Holotheca thin (Gregory 1900: 68, Veron *et al.* 1977: 20, Veron 1986: 450, Pillai and Patel 1988: 66, Wijsman-Best 1972: 12, Vaughan & Wells 1943: 166, Chevalier 1971: 104, Cuif and Perrin 1999: 140).

Microstructure: The first description of the microstructure of *Favia* was given by Alloiteau (1957: 138, figs. 96-101). Zlatarski and Martinez Estalella (1982) made a very

comprehensive study but could not add any more detail of microstructure of *Favia* than given by Alloiteau. The most recent work of microstructures of *Favia* is by Cuif and Perrin (1999). Accordingly, septa consist of trabeculae and the transverse section through septum shows several centers of calcification, aligned parallel to the septal plane. Stolarski (2003: 526) redefined the term centers of calcification as centers of rapid accretion. Traditionally, these centers have been referred to as dark spots from which acicular ornfibrous crystals radiate toward those of neighbouring centers (Vaughan and Wells 1943: 32). They are circular in section or elliptical in shape (Ogilvie, 1897: 113) and mark the central point from which calcification has taken place (Stolarski 2003: 526). In the present specimens, these centers are smooth and rounded or rhomb-shaped in outline (pl. 1, figs. 2 & 7), about 25µm in diameter, consisting of very small equant crystals surrounded by concentric layers of fibers arranged approximately at right angles to the boundary. The distribution of calcification centers is refleted in the external septal micromorphology, especially the teeth. The formation of the teeth occurs through the development of aragonitic layers around these centers. Differential growth of aragonite fibers from each center gradually fills up the space between two neighboring teeth and the junction of fibers showing opposite growth from successive teeth is usually well marked by suture lines.

Remarks: The diagnostic characters of the genus has been mentioned here by combining those modified after Gregory (1900: 68), Veron *et al.* (1977: 20), Veron (1986: 450), Pillai and Patel (1988: 66), Wijsman-Best (1972: 12), Vaughan and Wells (1943: 166), Chevalier (1971: 104) and Cuif and Perrin (1999: 140); Gregory (1900) considered *Madrepora ananas* Oken, 1815 as the type species of the genus *Favia* Oken, 1815, whereas Verrill (1902) considered *Madrepora fragum* Esper, 1795 as the type species of the genus, which was a view adopted by Wells (1956: F402), Alloiteau (1957: 138), and Cuif and Perrin, (1999: 139). *Madrepora ananas* sensu Pallas 1766 was considered a synonym of *Madrepora fragum* Esper 1788 not 1795 (Zlatarski & Martinez Estalella 1982: 26, 61). *Madrepora ananas* was preoccupied by Linnaeus (1758) for a Palaeozoic coral from Gotland (now belonging to the genus *Acervularia* Schwegger (1819) and also applied to extant species (Cuif and Perrin 1999: 139). However, according to International Council of Zoological Nomenclature (ICZN) (decision 417) all taxa proposed by Oken (1815) have been rejected.

The holotype of the type species no longer exists in the Muséum National d'Histoire naturelle, Paris (Zlatarski and Martinez Estalella, 1982). Therefore, the material of Milne-Edwards has been designated as type material of *Favia* and, from the formal point of view, the genus has to be referred to as *Favia* Milne-Edwards, 1857 and not *Favia* Oken, 1815 (Cuif and Perrin 1999: 139). *Favia* and *Favites* are quite close to each other and as mentioned above, sometimes they are difficult to differentiate. Matthai (1914) considered *Favia* and *Favites* synonymous, as there are some species of *Favia* showing ploco-cerioid growth form and vice-versa species of *Favites* showing cerio-plocoid growth form. Vaughan and Wells (1943) differentiated *Favites* with cerioid growth form and septotheca, while later on Wells (1956) differentiated only by cerioid growth form. Another related genus *Goniastrea* has been differentiated on the bases of tendency of formation of short series of calices (meandroid) resulting tristomodaeal or polystomodaeal buddings and multitrabecular polyform lobes (= multiaxial paliform lobes) organized in divided fan system (Chevalier, 1971) in contrast to distinct corallites, paliform lobes and one uniform septal fan system in *Favia*. In fossil colonies where the septal microstructure is obliterated during diagenesis, the separation of two groups of faviids under question would be difficult.

Regarding variability in the morphological features within single species of *Favia*, different species cannot be differentiated on the basis of any single character. Similarly, too much empasis on functional morphology and epigenetic characters lead to conclusion that *Favia* was represented by a lower number of species than is known from record. However, in absence of complete knowledge of living representative of all the morphospecies of *Favia* and personal examination of holotypes, in extreme cases morphological dimensions can be used as criteria of species differentiation.

<div align="center">

Favia favus (Forskal, 1775)
(Pl. I, figs. 1-7)

</div>

Madrepora favus Forskål:, 1775, p. 132 (Type locality – Red sea)
Favia favus (Forskal) – Matthai:, 1914, p. 79, pl. 9, fig. 2, pl. 20, figs. 1-6, pl. 21, figs. 1-8, pl. 21, figs. 1-5, pl. 32, fig. 1, pl. 36, figs. 1-2 [see for extensive synonymy].
*Favia favus* (Forskal) – Scheer and Pillai:, 1983, p. 110, pl. 27, figs. 8-9 [see for extensive synonymy].

Description: Corallum colonial, plocoid, massive,

<div align="center">

EXPLANATION OF PLATE II

</div>

1-9. ***Favia speciosa*** Dana from northern and northwestern coastal areas of Saurashtra

1.   Upper surface of a plocoid living colony. Note intratentacular distomodaeal budding. Narara lagoon, RUC1999II 25

2.   Detail of a septum in thin transversal section showing important development of laminar layers. Recent, Narara lagoon RUC1999II 138

3.   Longitudinal oblique section showing dissepiments and a paliform lobe. Recent, Narara lagoon RUC1999II 138.

4.   Close up view of septa along distal margin showing prominent sharp teeth (t) diverging along the septal plan. Note the tiny denticles near the top of teeth which diverge perpendicularly to the septal plan. Living, Narara lagoon RUC1999II 25

5.   Detail of two septa in thin transversal section showing

relationships of laminar layers between septa and endotheca. Recent, Narara lagoon, RUC1999II 138

6.   Longitudinal broken surface showing endothecal and exothecal dissepiments and the papillose columella and paliform lobes (arrow). Aramda reef member Late Pleistocene, Mithapur, RUC1999II 80

7.   Lateral view of a septum showing vesicular dissepiments (vd) and organisation of carinae (ca), teeth (t) along the inner edge and paliform lobe (pl). Living, Narara lagoon RUC1999II 25

8.   General view of a calyx showing the organisation of the septal apparatus. Living, Narara lagoon RUC1999II 25

9.   Transverse thin section showing few corallites and narrow peritheca. Note abundant dissepiments and papillose columella. Recent, Narara lagoon, RUC1999II 136

PANDEY AND SINGH
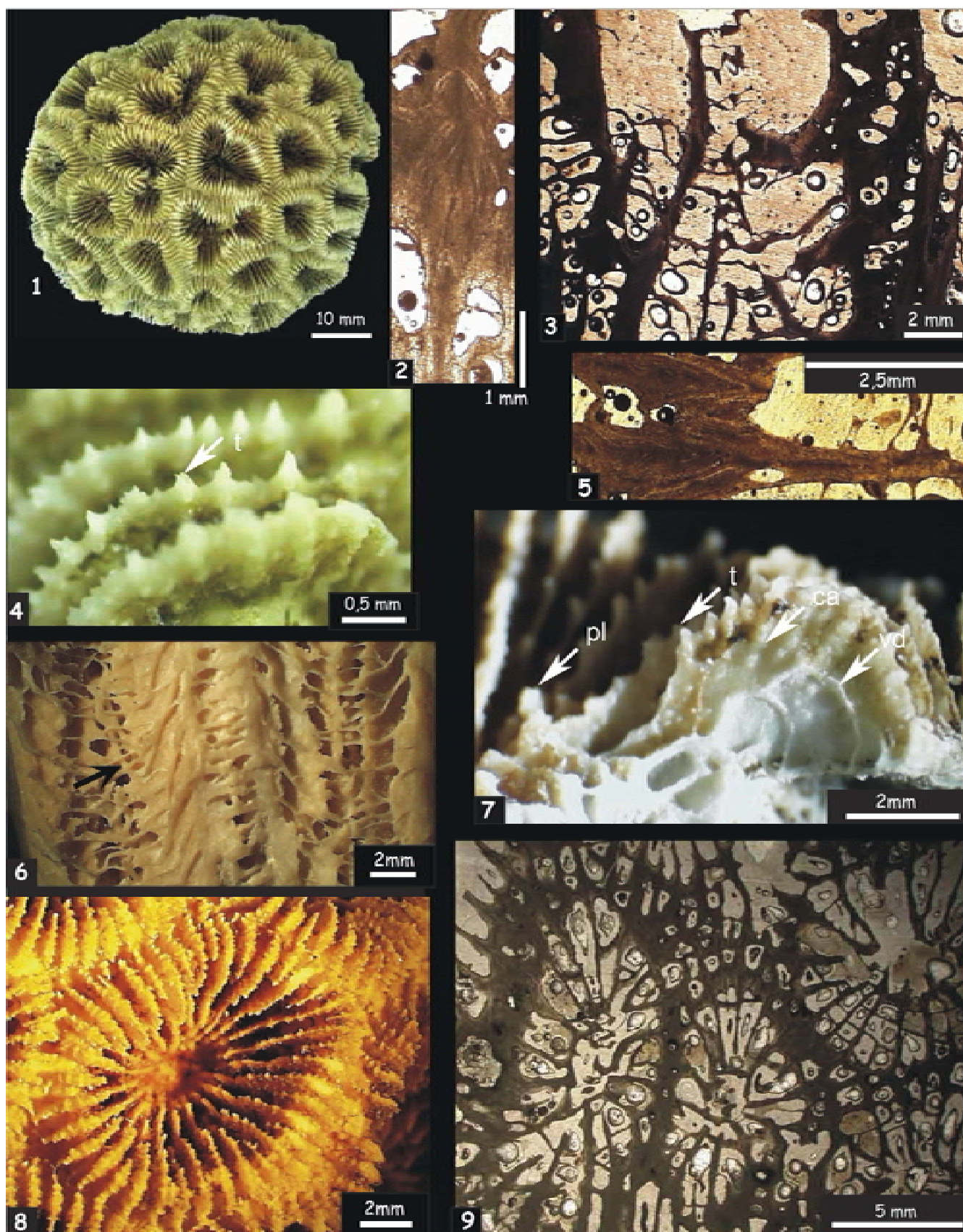
Material: 8 specimens.

Horizon and Locality:	Specimen Nos.
Mahuva Fm., Narara lagoon, Vadinar	RUC1999II 1, 31/40, 47, 53
Aramda Reef mb., Chaya Fm., coastal area near Mithapur	RUC1999II 69
Aramda Reef mb., Chaya Fm., Mithapur	RUC2001III 15-B
Okha Shell mb., coastal area near Mojap	RUC2001III 40
Kalyanpur Limestone Mb., Dwarka Fm., near Aramda	RUC2001III 50

Dimensions (in mm):

	H	D	d	Dc	c-c	Ns	Ncs	Sd (in 2 mm)	Dd (in 2 mm)
RUC1999II 1	65	83	69.3	7-13.1	7-12	35-60	4-5	3-4	3-4
RUC1999II 31/40*	329	365	318	4.1-11.3	5.3-10	20-28	4	4	3-4
RUC1999II 47	58	124	106	7-13.6	4.3-13.3	24-44	4	3-4	3-4
RUC1999II 53	150	155	147	8.2-16.2	8.2-14.3	30-42	4	3-4	3-4
RUC1999II 69	44	62	36	8.1-15	9-13.1	37-39	4	3-4	3-4
RUC2001III15-B	61	80.5	71	6-14.6	5.1-13.2	23-39	4	3	3
RUC2001III 40	89	124	70	5.5-13	7.1-11	16-40	4	3	3-4
RUC2001III 50	106	114	90	7.5-15	6-18	21-37	4	3	3

*: RUC1999II 31 & RUC1999II 40, both are same specimens in two pieces.

hemispherical, dome-shaped circular to subcircular in outline with moderately small attachment area. Budding intracalicular-mono to distomodaeal, sometimes extracalicular. Calices shallow to deep (depth 5-7 mm), conical in shape, circular to subcircular in outline with distinct calicular margin, strong relief and septal linkage.

Wall parathecal: Peritheca thin to thick (1-3.7mm) composed of costae and small vesicular or more or less tabular dissepiments.

Costosepta bicuneiform, straight or sinuous. Costae confluent, often break in the middle, rest continue across peritheca, with fine denticles along distal margin. Septa, thin, compact, exsert, numerous, evenly distributed, rarely anastomosing, composed of trabeculae. Trabeculae arranged in one fan system. Major septa reach the center. Lateral surface ornamented with fine granules and spinules, arranged along the trabeculae in addition to those distributed irregularly. Carinae present. Distal margin with fine to coarse denticles, near the wall teeth are separated, those towards the center are fine and at the deeper part it develops into oblique to vertical cylindrical paliform lobes with spinules. Endotheca consists of abundant, elongated, steeply inclined vesicular dissepiments along the periphery, which become more or less tabular towards the center. Columella papillose.

Microstructurally, the septa show bilateral symmetry. The axis, consisting of center of calcification and forming a dark line, runs parallel to the septal plane. The lines periodically interrupted by the lateral axis of the trabeculae. Septa thickened by laminar layers. Occasionally, the laminar layers are formed by extension of dissepiments along the septal plane. Near the wall six centers representing trabeculae are widely separated. The fibers radiate from the centers.

Remarks: *Favia favus* is one of the most common species present in considerable amount in the Gulf of Kachchh. *Favia favus* is a comparatively slow growing massive species, which can resist much wave action and high degree of sedimentation.

The species recorded by earlier worker shows a variable outline, depth of the calices, and thickness of peritheca ranging up to fusion of the walls. The variability is a consequence of environmental variation (Wijsman-Best, 1972: 14; Wijsman-Best 1974: 252), while the later situation persists mostly at the time of final separation of daughter from mother corallites during intracalicular budding. The granules and ornamentation at the lateral surface of the septa, are finer than in *Favia speciosa*. Septa are either not exsert or little exsert. Pali or paliform lobes are either not developed in the present species (Chevalier, 1971: 139-140, fig. 82-83; Wijsman-Best, 1972: 12) or poorly developed (Scheer and Pillai, 1983: 110, Veron, 1986, 2000). The colony has a spiny appearance when the very closely spaced teeth (called serration by Scheer and Pillai, 1983) along the distal margin are well developed, features that are characteristics of

EXPLANATION OF PLATE III

1-7 *Favia matthai* Vaughan from northern and northwestern coastal areas of Saurashtra

1. Upper surface of a plocoid fossil colony. Aramda reef member, Late Pleistocene, Mithapur, RUC1999II 81
2. Detail of a calyx and its surrounding peritheca. Note organisation of septal apparatus and dentition along distal edges of septa, Aramda reef member, Late Pleistocene, Mithapur, RUC1999II 81
3. External upper surface showing a subcerioid arrangement of corallites. Note bicuneiform costosepta. Aramda reef member, Late Pleistocene, Mithapur, RUC1999II 79
4. External upper surface showing a plocoid arrangement of corallites with a thick peritheca. Note intracalicular distomodaeal budding. Aramda reef member Late Pleistocene, coastal area near Mithapur, RUC1999II 76
5. Longitudinal broken surface showing endothecal dissepiments and the papillose columella. Aramda reef member Late Pleistocene, coastal area near Mithapur, RUC1999II 76
6. Longitudinal broken surface showing exothecal dissepiments in the peritheca. Aramda reef member Late Pleistocene, coastal area near Mithapur, RUC1999II 76
7. Lateral view of a septum showing granules. Aramda reef member, Late Pleistocene, Mithapur, RUC1999II 79

shallow water forms (Wijsman-Best, 1972: 14), and well preserved. This aspect is very similar to *Favia savignyi* Milne Edwards and Haime described by Marenzeller (1906), a junior synonym of the present species (Scheer and Pillai, 1983: 110). Crossland (1952) creation of new varieties of *favus* is only useful when such morphotypes are associated with their environment as the species shows variable outline, depth of the calices and thickness of the peritheca and septa.

Favia stelligera (Dana) and *Favia laxa* (Klunzinger) differ clearly on the basis of a less than average diameter of the corallites (2-6 mm), fewer number of septa and fewer septal orders (up to 2-3) (Wijsman-Best, 1972: 25; Veron *et al.*, 1977, Veron, 1986: 454). The shape of *Favia stelligera* (Dana) exhibits hillocky appearance (Veron, 1986: 452; Veron, 2000: 102; Chevalier, 1971: 162; Wijsman-Best, 1972: 24). *Favia danae* Verrill (Veron, 2000: 123), although similar to *F. favus* in overall morphology of the septa, exhibits more beaded costae and less uniform septo-costae. *Favia maritima* Nemenzo (Veron, 2000: 130) has large corallites and more numerous but regular septa. *Favia rosaria* (Veron, 2000: 119) has similar morphological characters but exhibits spongy columella.

Favia speciosa Dana, 1846
(Pl. II, figs. 1-9)

Astraea (*Fissicella*) *speciosa* Dana:, 1846, p. 200, pl. 11, fig. 1 (type locality – reef Indonesia, Holotype USNM No. 37).

Description: Corallum colonial, plocoid to ploco-cerioid, massive, hemispherical, dome-shaped, encrusting or flat with moderately small to large attachment area. Budding intra- and extracalicular, mono- to distomodaeal. Calices small to large in diameter (5-12.8 mm, c-c 7.6-11.4 mm), deep (depth up to 6 mm), margin distinct, subrounded to polygonal in outline.

Wall thin, parathecal. Peritheca thin (thickness 0-2 mm), composed of costae and dominantly tabular dissepiments. Dissepiments convex upward.

Costosepta confluent, often zig-zag, sometimes non-confluent. Costae often join and make undulate profile with those of adjacent corallite with acute trough at the midline of peritheca. Lateral surface of costae spinulose and granulose with acute, deep denticles along distal margin. Septa thin, compact, anastamosing, arranged at least in 4 cycles. Septa composed of trabeculae, arranged in two fan systems, corresponding to septum and paliform lobe. Lateral surface of the septa covered with coarse granules, spines and carinae whereas those of paliform lobes with finer granules. Carinae arranged at regular intervals. Distal and inner margins are regularly dentate. Denticles acutely sharp. Size of denticles increases with depth and ultimately, in few cases, takes the form of paliform lobes. Paliform lobes inclined, platy, crowned. The cyclic arrangement of the septa is not regular (pl. 2, figs. 8-9) because of uneven distribution of the septa of different hierarchical cycles in different calicular sectors. The arrangements of the septa can be interpreted either as exhibiting hexameral or octameral symmetry. In the case of former, the septa are arranged in four to five cycles (6+6+12+5 or 6+6+10+4+5), whereas in the second option it is 8+8+15. Endotheca composed of tabular and vesicular dissepiments. Tabulars are confined to the central part where as vesiculars near to the periphery. The vesicular dissepiments become elongated and steeply inclined near the wall. Columella rudimentary, papillose to spongy, rarely absent. Microstructurally, the trabeculae consist of center of calcifications running parallel to septal plane. Fibres radiate from these centers. Holotheca moderately thick, covered with concentric folds, rugae, in parts regular, occasionally not parallel.

Remarks: We observed in one of the living specimens (RUC1999II 136) that the soft part rests above the distalmost dissepiments and no trace of the soft part is seen below the distalmost dissepiments. As already discussed, there is a great variability in the morphological dimensions due to variation in the microenvironment (Wijsman-Best, 1972: 17, Veron, 2000: 101); it is difficult to separate present species from *F. favus* only on the basis of skeletal features. However, based on conventional distinguishing features this species differs from *Favia favus* on the basis of more dense denticles along distal margin of costae and more and prominent granules on the lateral surfaces of costosepta. The low density of septa (Wijsman-Best, 1972: 17), small diameter of corallites and well-developed paliform lobes (Chevalier, 1971: 119, fig. 75) in *speciosa* described by earlier workers are not effectively recorded in the present specimens. Veron (1986: 457, Veron, 2000: 108) was also of the opinion that the paliform lobes are poorly developed in both species. It is also difficult to differentiate the two species on the basis of density of dissepiments. The colony (specimen no. RUC1999II 136) has a spiny look because of its coarse and deep distal dentitions and coarser lateral ornamentation of the septa. The possibility of these characters being ecophenotypic cannot be ruled out, because, as discussed by Wijsman-Best (1972), the magnitude and intensity of denticles and size of corallites vary with water energy. However, for lack of intermediate forms these two species have been described separately in the present work.

Favia speciosa and Favia favus are the most common species found around the world in most of the coral reefs (? not in Caribbean sea) suggesting that this species can survive in all the reef favorable environments. *Favia speciosa* is abundant in the Gulf of Kachchh and is found in the largest number as compared to other species. Many specimens do not have prominent ornamentations such as dentitions and granular surface. These are cases of the dead corals. This may be due to a long period of exposure to fresh water, which diagenetically altered or changed and consequently destroyed the microarchitecture.

Material: 27 specimens:

Horizon and Locality:	Specimen Nos.
Mahuva Fm., Narara lagoon, Vadinar	RUC1999II 7, 8, 25, 28, 32*, 33, 39*, 43, 51, 54, 56, 57, 136, 138
Aramda Reef Mb., Chaya Fm. coastal area near Mithapur	RUC1999II 62, 64, 65, 68, 72, RUC2001III 46, 49
Aramda Reef Mb., Chaya Fm., Mithapur	RUC1999II 80, 86, RUC2001III 9, 21
Okha Shell Mb., Chaya Fm. coastal area near Mojap	RUC2001III 36, 37

Dimensions (in mm):

	H	D	d	Dc	c-c	N s	Ncs	Sd (in 2 mm)	Dd (in 2 mm)
RUC1999II 7	-	47	40	5.7-14.9	5-9.9	25-48	4	3-4	4
RUC1999II 8	80	111	61	5-13	5-9.3	25-48	4	3-4	4
RUC1999II 25	33	61	53	7.5-14.1	5.5-10.1	45-58	4-5	3-4	4
RUC1999II 28	43	72	61	6.7-16.5	7.2-11.4	31-46	4	3	4
RUC1999II 32	205	300	189	5.4-10.6	4.1-9.5	22-30	4	3-4	4
RUC1999II 33	127	130	120	5.2-17.8	5-10	25-40	4	3-4	4
RUC1999II 43	26	35	23	5.5-12.3	5.7-9	21-39	4	3	3-4
RUC1999II 51	40	89	85	6-15.4	6-10	34-53	4	4	3
RUC1999II 54	50	138	110	5.0-12.5	5.0-10.5	31-35	4	4	3
RUC1999II 56	152	167	155	5.3-13.5	4.4-8.6	30-42	4	4	3
RUC1999II 57	29.5	255	184	7-18	5-15.5	16-36	4	3	3
RUC1999II 62	113	24.3	24	5.5-9	5-8.3	26-30	4	4	3
RUC1999II 64	59	116	106	4.1-10.1	7-10.3	32-33	4	4-5	3-4
RUC1999II 65	108	28	28	4.1-10	4.9-5.5	16-31	4	4	4
RUC1999II 68	79	87	-	5.3-10.1	5.1-9	21-42	4	3-4	3
RUC1999II 72	71	115	83	4.1-9.5	5.1-10	25-31	4	4	4
RUC1999II 80	67.3	157	117	4.6-11.8	6.4-11.3	24-35	4	3-4	3-4
RUC1999II 86	130	161	83	6.5-17.2	6.3-17.5	25-42	4	3-4	3-4
RUC1999II 136	34	51	-	7-14	6-10	30-44	4	3-4	3
RUC1999II 138	-	163	113	6-14	5-12	24-38	4	3	3-4
RUC2001III 9	130	124	-	4.5-9.4	5.3-9.3	24-27	4	3	4
RUC2001III 21	88	123	93	7.3-12.7	5.5-13.2	24-38	4	3	3
RUC2001III 36	38	76.2	46	3.3-9.3	3.1-5.2	12-20	3	3-4	3
RUC2001III 37	69	91	66	7.3-14	8.5-14.5	20-35	4	3	3
RUC2001III 46	-	48	37	6.1-11.6	6.7-12	21-30	4	3-4	3
RUC2001III 49	87	129	111	7.2-13.1	7-12.2	22-41	4	3	3

* RUC1999II 32 & RUC1999II 39, both are same specimens in two pieces.

Nemenzo (1959) differentiated *Favia speciosa* from *Favia pallida* on the basis of alternating thick and thin costae, the latter being absent in *Favia pallida*. According to Chevalier (1971: 118, fig. 3.7), the character differentiating the two species is the ornamentation of the costal edge. In *Favia speciosa*, the denticles are stronger and more widely spaced in comparison to *Favia pallida*. However, he considered these characters as transitional and representing an early stage of the differentiation process. Wijsman-Best (1972: 12, 18) distinguished skeletons of *Favia pallida* from those of *Favia speciosa*, on the basis of the circular or elliptical outline of the calices, whereas in *speciosa* the calices are more conical, crowded and unequal. In *speciosa,* the septa are thinner and more numerous, whereas in *pallida* the septa are widely spaced. She further mentioned that in *Favia pallida* costae do not continue through the coenosteum while in *Favia speciosa* the costae are well developed within the coenosteum. The wall is septothecal in *pallida* (Veron *et al.*, 1977: 36; Veron 1986: 456-457; Veron 2000: 114). Veron (1986) further mentioned poorly developed paliform lobes in both the species. *Favia helianthoides* Wells (Veron 1986: 455; Veron, 2000. 110) exhibits more conical corallites. *Favia lizardensis* Veron, Pichon and Wijsman-Best (Veron 1986: 459, Veron 2000: 120) is characterized by uniformly thin and widely spaced septa without paliform lobes. *Favia maxima* Veron, Pichon and Wijsman-Best (Veron, 1986: 463, Veron 2000: 126) is similar with respect to the development of a crown of paliform lobes around columella but differs in its thicker septa. Similarly, *Favia rotundata* Veron, Pichon and Wijsman-Best (Veron, 1986, 462, 2000: 124) has a crown of paliform lobes and a higher density of septa.

Favia truncatus (Veron, 2000: 113) is again similar but has been differentiated on the basis of more exsert septo-costa, smaller corallites and the hooded appearance of corallites. *Favia veroni* Moll and Borel-Best (Veron, 1986: 465, Veron, 2000: 128) is also a similar form but paliform lobes are absent.

Septa in one of the colonies (RUC2001III 9) exhibit secondary laminar layers. This thickening appears as groove or line on the distal part of the septa and wall.

Favia matthaii Vaughan, 1918
(Pl. III, figs. 1-7)

Favia matthai Vaughan:, 1918, p. 109, pl. 39, fig. 2. Holotype, USNM No. 38381.

Description: Corallum colonial, massive, plocoid to subcerioid, hemispherical, with moderately small to large attachment area. Budding intracalicular, mono- to distomodaeal, occasionally extracalicular. Calices surficial to deep (depth up to 5 mm), margin distinct, subrounded, elongated to polygonal in outline (D - 8.8 – 11.8 mm; c-c – 9.4 - 11.3). Wall parathecal and septo-parathecal, peritheca thin to thick (0-2 mm), composed of costae and dominantly tabular dissepiments.

Costosepta compact, confluent to nonconfluent, bicuneiform. Costae short, thick, raised above coenosteum, arranged radially, continuing across coenosteum or sometimes terminating at the middle of coenosteum, and often sharply bent to join costae of the adjacent corallite, granular on lateral surface, denticles present, Costae absent in subcerioid growth structures (Pl. III, fig. 3). Septa (numbering 27, 29, 40) and arranged in three perfect cycles (6+6+12) or with fourth incomplete ones (6+6+12+14 or 17). The septa of first and/ or

Material: 7 specimens.

Horizon and Locality	Specimen Nos.
Aramda Reef mb., Chaya Fm., coastal area near Mithapur	RUC1999II 76, RUC2001III 30
Aramda Reef mb., Chaya Fm. Mithapur	RUC1999II 79, 81, 84 RUC2001III 26, 27

Dimensions (in mm):

	H	D	d	Dc	c-c	Ns	Ncs	Sd (in 2 mm)	Dd (in 2 mm)
RUC1999II 76	82.3	216	100	5.9-13	6.5-12	22-25	3-4	3	3-4
RUC1999II 79	61	110	88	5.2-13.1	5.5-10	34-36	4	3-4	3
RUC1999II 81	61.8	168	150	6-17	5.5-9.5	29-34	4	4	3-5
RUC1999II 84	43	65	38	7.7-12.2	8.2-10.6	21-33	3-4	3	3
RUC2001III 26	76	85	53.5	5-8.3	4.2-7	21-29	3-4	4	2-3
RUC2001III 27	46	91.6	23.1	6-16.3	5.4-8.4	23-45	4	3	3-4
RUC2001III 30	51.2	168	111	4.6-9.5	5-8.3	21-25	3-4	3	3-4

*: RUC1999II 31 & RUC1999II 40, both are same specimens in two pieces.

second cycle are large and reach the center, often anastomosing, whereas those of third and fourth cycles are correspondingly smaller. Lateral surface ornamented with coarse granules (ragged) along carinae and very small spinules. Spinules show no particular arrangement. Distal margin with broad to sharp denticles. Inner margin of septa spinose. Paliform teeth present. Dissepiments thin, abundant, mostly vesicular, gently inclined, rarely reach the axial region. In the axial region, the paliform lobe dominates the dissepiments. Columella parietal, papillose to spongy. Holotheca thick with concentric folds.

Remarks: The septa are often anastamosing in contrast to *F. favus* and *F. speciosa* described above. The paliform lobes and septal ornamentation are poorly preserved. The vertical papillae dominate the horizontal dissepiments in the axial region. The dissepiments along the periphery are less steep than in the species described above. The costae are poorly developed but uniformly thick. One of the specimens (number RUC2001III 30) shows secondary thickening of septa by laminar layers.

Favia matthaii is often confused with other species of *Favia*, but it is distinguished from the other species by its exsert or ragged septa and paliform crowns (Veron, 1986: 460). According to Wijsman-Best (1972: 20), the last teeth may form paliform lobes around the small columella consisting of small columellar teeth. The costae can be thin or absent and the width of coenosteum varies between corallites. *Favia albidus* (Veron, 2000: 112) is a comparable form, which differs from *matthaii* in its thicker septa, more developed paliform crown and large teeth along the distal margin of septa near the wall. *Favia marshae* (Veron, 2000: 122) differs in its thin septa and concentric arrangement of the corallites at the periphery of the corallum. *Favia rotumana* Gardiner (Chevalier, 1971: 129; Wijsman-Best, 1972: 20; Veron, 2000: 121) is similar with respect to the growth form, septa and poorly developed paliform lobes. However, the wall structure is irregular in *rotumana*

PALAEOECOLOGY

Favia thrives in the Gulf of Kachchh in shallow water, tropical, high energy, lagoonal environments. The fossilized colonies of *Favia* were found in the Kalyanpur Limestone Mb., Dwarka Fm (early Pliocene), Okha Shell Limestone Mb., Chaya Formation (late Pleistocene) and coral-algal lithofacies of Aramda Reef Member, Chaya Formation (late Pleistocene), Mithapur. The latter has been interpreted as representative of platform-margin lagoonal reef environment (Pandey *et al.*, 2003). The degree of variation seen in the three species of *Favia* mentioned above and those mentioned by earlier workers (Vaughan, 1918; Wells, 1954: 457; Wijsman-Best, 1972; Veron, 2000: 101; Amaral and Ramos, 2007) is ecophenotypic and occurs in response to environmental parameters. The morphotypes are called "ecotypes" (Wijsman-Best, 1972: 60). In other words, *Favia* species have been found to exhibit plasticity (non genetic) (Vaughan, 1918, Wijsman-Best, 1972).

The specimens (numbering 42) of *Favia* examined here show similar growth forms, colony shapes and measurements of the skeletal elements. However, the following differences have been observed:

Of the three species, *favus* and *speciosa* are present in the living community, whereas *matthaii* occurs with *favus* and *speciosa* only in the coral algal reef facies of the terminal late Pleistocene as semi-fossilized from. In the present work, it has been shown how the microarchitecture, particularly the denticles along the distal and inner margins of the septa, change or decrease in magnitude during fossilization. The shallow depth of calices, in the case of *matthaii*, can be partially related to the erosion of the upper surface. The latter is corroborated by partial absence of denticles along the distal edge of the septa in those colonies, which exhibit shallow calices.

Favia is a comparatively slow growing, massive, stoutly built species, which can resist heavy wave action and high degrees of sedimentation (Wijsman-Best, 1972: 15). The distribution of *Favia* in shallow water both in the open sea and sheltered environments has been studied in detail by (Wijsman-Best, 1972, 1974; Amaral and Ramos, 2007). The colony exhibits large deep calices and thick septa with stronger teeth at the distal margin, when growing in shallow water near the shore (Wijsman-Best, 1972: 14). *Favia* found near the surface generally exhibits narrowly spaced corallites, especially on the upper side of the corallum (Wijsman-Best, 1972:14). The condition is similar in the intertidal lagoon, Gulf of Kachchh (w. India). *Favia favus* and *E. speciosa* exhibit deep (5-7 mm)

Characters	F. favus (living)	F. speciosa (living)	F. matthaii (semifossilised)
Depth of calices	Deep (5-7mm)	Deep (5-6mm)	Shallow to deep (up to 5mm)
Anastamosing septa	Very rare	Very rare	Often
Density and magnitude of septal ornamentation	Low	High	Not well preserved
Size & shape of paliform teeth	High, cylindrical with spinules	Low, platy, crown forming	Poorly developed
Inclination of dissepiments near the wall	Steep	Steep	Gentle to steep
Dissepiments near distal part	Absent	Absent	Present*
Theca	Paratheca	Paratheca	Paratheca or septoparatheca

and large diameter (6.7-14mm) calices, together with conspicuous dentition, along distal margins of the septa. The depth and size of calices, number and thickness of septa and size of teeth along the distal margin decrease in *Favia favus* occurring in waters below 15-20 meters as light decreases and energy intensifies (Wijsman-Best, 1972). The paliform lobes are better developed, calices are shallower, theca is thinner and coenosteum is wider, consequently the density of corallites decreases in comparison to those in the shallow water (Wijsman-Best, 1972: 14, 59). These changes may also be seen in a larger spherical colony when the top and lower parts of the colony are compared. *Favia* colonies found on bays have extremely large polyps (up to 10-15 mm) (Wijsman-Best, 1972: 15). *Favia pallida* could be divided into six morphotypes corresponding to different sets of environmental parameters (Vaughan, 1918). In other words, the growth rate of the colony very much depends upon the microenvironment. Even the same colony shows different linear growth increment along different directions. In addition to light, the rate of sedimentation is a major controlling factor for the skeletal growth. The degree of colony integration plays an important role in the internal exchange of energy to combat the localized stress. In the colonies with lower degrees of colony integration, such as in *Favia,* there is a less dissemination of resources from sites of acquisition to sites of demand (Oren *et al.*, 1997; 2001), and consequently the patchy skeletal response to the microenvironment leads to increase in size of microarchitectures in different parts of the same colony.

Cuif and Perrin (1999: 144) gave an excellent illustration and description of the teeth at the distal margin of the septa in *Favia fragum* about their formation and relationship with septal ornamentation. These teeth at the distal edge provide grip to the living tissue. The corals from Red Sea have a smoother habit because they generally live under more exposed conditions (Gardiner, 1904; Wijsman-Best, 1972: 59). The growth form, which is commonly plocoid in *Favia*, changes to phaceloid. in extreme conditions particularly with increasing rate of sedimentation, (Wijsman-Best, 1972: 59).

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OCCURRENCE OF GYMNOSPERMS FROM LOWER GONDWANA FORMATIONS OF THE IB-RIVER COALFIELD, ORISSA, INDIA WITH A CLUE ON THE PALAEOECOLOGY AND THE PALAEOENVIRONMENT OF THE AREA

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ABSTRACT

Extensive investigations were carried out recently in the Ib-River Coalfield, a part of Mahanadi Master Basin to locate fossiliferous beds in the Lower Gondwana deposits. As a result, a large cache of plant fossils was recovered from six different localities belonging to the Barakar and Lower Kamthi Formations. The diverse and abundant plant remains collected in this operation includes 23 genera representing nine orders viz., Lycopodiales, Equisetales, Sphenophyllales, Filicales, Cordaitales, Coniferales, Ginkgoales, Cycadales and Glossopteridales.

The gymnosperm genera namely *Macrotaeniopteris*, *Ginkgoites*, *Buriadia*, *Surangephyllum*, *Palaeovittaria*, *Ottokaria*, *Scutum* and *Vertebraria* along with some scale leaves and stem casts have been dealt with in this paper. The remaining plant groups of this collection are already published in different journals. The exposures of the Barakar Formation in Lajkura and Jurabaga collieries contain two distinct floristic assemblages and based on this, the sediments here have been divided into lower and upper stages. The genera *Buriadia* and *Ottokaria* reported in the present study and *Gangamopteris, Noeggerathiopsis, Cordaites, Euryphyllum* and *Kawizophyllum* described earlier are found preserved only in the lowermost horizon, i.e. the 4th horizon of the Barakar Formation and they are completely absent in all the three younger fossil horizons of these two localities. Thus, the oldest carbonaceous shale beds (4th fossil horizon) of Lajkura and Jurabaga collieries belong to Lower floral zone (Lower Barakar). The younger three fossiliferous shale beds of Lajkura and Jurabaga collieries, pinkish brown shale of locality near Belpahar Railway Station and fireclay bed of Ratanpur Fireclay Quarry belong to upper floral zone (Upper Barakar). These beds contain a good number of gymnosperms herein described, namely *Ginkgoites, Surangephyllum, Palaeovittaria, Scutum, Vertebraria,* scale leaves and stem casts as well as the taxa reported earlier viz., *Cyclodendron, Schizoneura, Raniganjia, Bengalia, Trizygia, Benlightfootia, Neomariopteris, Dichotomopteris, Glossopteris, Senotheca* and equisetaceous stems.

The flora, collected from the Kamthi beds exposed at Dungri and Sitaram Hillocks, has yielded only Late Permian elements, namely *Macrotaeniopteris, Vertebraria, Glossopteris, Schizoneura, Neomariopteris,* and equisetaceous stems (first two reported in this study and the rest described earlier). No typical Triassic element like *Dicroidium, Lepidopteris,* etc. could be reported in these beds, hence it is suggested that these rocks might belong to the Lower member of the Kamthi Formation, and not the Upper member that is now considered to be Triassic in both Ib-River Coalfield (Pal *et al.*, 1992) and Talcher Coalfield (Pal and Ghosh, 1997). The composition of overall flora of Ib-River Coalfield suggests a palaeoclimatic shift from temperate warm moist to warm dry conditions during Early Permian (Barakar Formation) time to warm and humid during Late Permian (Lower Kamthi) time.

Keywords: Barakar, Kamthi, Gymnosperm, Ib-River, Mahanadi Basin, Orissa

INTRODUCTION

The Permian sediments belonging to the Talcher Coalfield, Mand-Raigarh Coalfield and Korba Coalfield, all parts of Mahanadi Basin, have been extensively investigated by a number of workers during the past few years. However, the largest coal-bearing coalfield of Orissa state, i.e. Ib-River Coalfield, also in Mahanadi Basin was not investigated in a big way for plant fossil studies. Keeping the mentioned goal in mind the Lower Gondwana sediments of the Ib-River Coalfield were thoroughly searched for the fossils to know the early developmental history and evolution of the flora in this coalfield.

The Ib-River Coalfield is located in the South-eastern part of NW-SE trending Mahanadi Master Basin Belt between 21°30' to 22°06' N and 83°37' to 84°10' E. It embraces the Himgir sub-basin in the north and the Rampur sub-basin in the south. The Ib-River Gondwana belt is named after the river Ib, a tributary of the Mahanadi River which lies entirely within the state of Orissa and covers parts of Sundargarh, Jharsuguda and Sambalpur districts. Plant megafossils have been collected intensively from the Barakar sediments (Early Permian) exposed in the Jurabaga and Lajkura Collieries, Ratanpur Fireclay Quarry, a locality near Belpahar Railway Station and from the Lower Kamthi Formation (Late Permian) exposed in the Dungri and Sitaram Hillocks of this Coalfield. The complete flora includes 23 genera representing nine orders. They are Lycopodiales (*Cyclodendron*), Equisetales (*Schizoneura, Raniganjia* and *Bengalia*), Sphenophyllales (*Trizygia* and *Benlightfootia*), Filicales (*Neomariopteris* and *Dichotomopteris*), Cordaitales (*Noeggerathiopsis, Cordaites, Euryphyllum* and *Kawizophyllum*), Cycadales (*Macrotaeniopteris*), Ginkgoales (*Ginkgoites*), Coniferales (*Buriadia*) and Glossopteridales (*Glossopteris, Surangephyllum, Gangamopteris, Palaeovittaria, Ottokaria, Senotheca, Scutum* and *Vertebraria*). Qualitatively and quantitatively, the palaeoflora recorded from this Coalfield is one of the richest floras recorded so far from the Indian Permian beds.

The present paper deals with the systematic study of eight gymnosperm genera, namely *Macrotaeniopteris, Ginkgoites, Buriadia, Surangephyllum, Palaeovittaria, Ottokaria, Scutum, Vertebraria* and some specimens of scale leaves and stem casts collected from the Barakar and Lower Kamthi formations of the Ib-River Coalfield. The remaining 15 genera found in the same collection are published elsewhere (Goswami *et al.*, 2006a, 2006b; Singh *et al.*, 2006a, 2006b, 2007). The study also incorporates the distribution of gymnosperm taxa in different localities within the Ib-River Coalfield (Fig. 3).

PREVIOUS PALAEOBOTANICAL STUDIES

The first palaeobotanical record from the Ib-River Coalfield was by Feistmantel in the year 1880 who reported *Schizoneura*
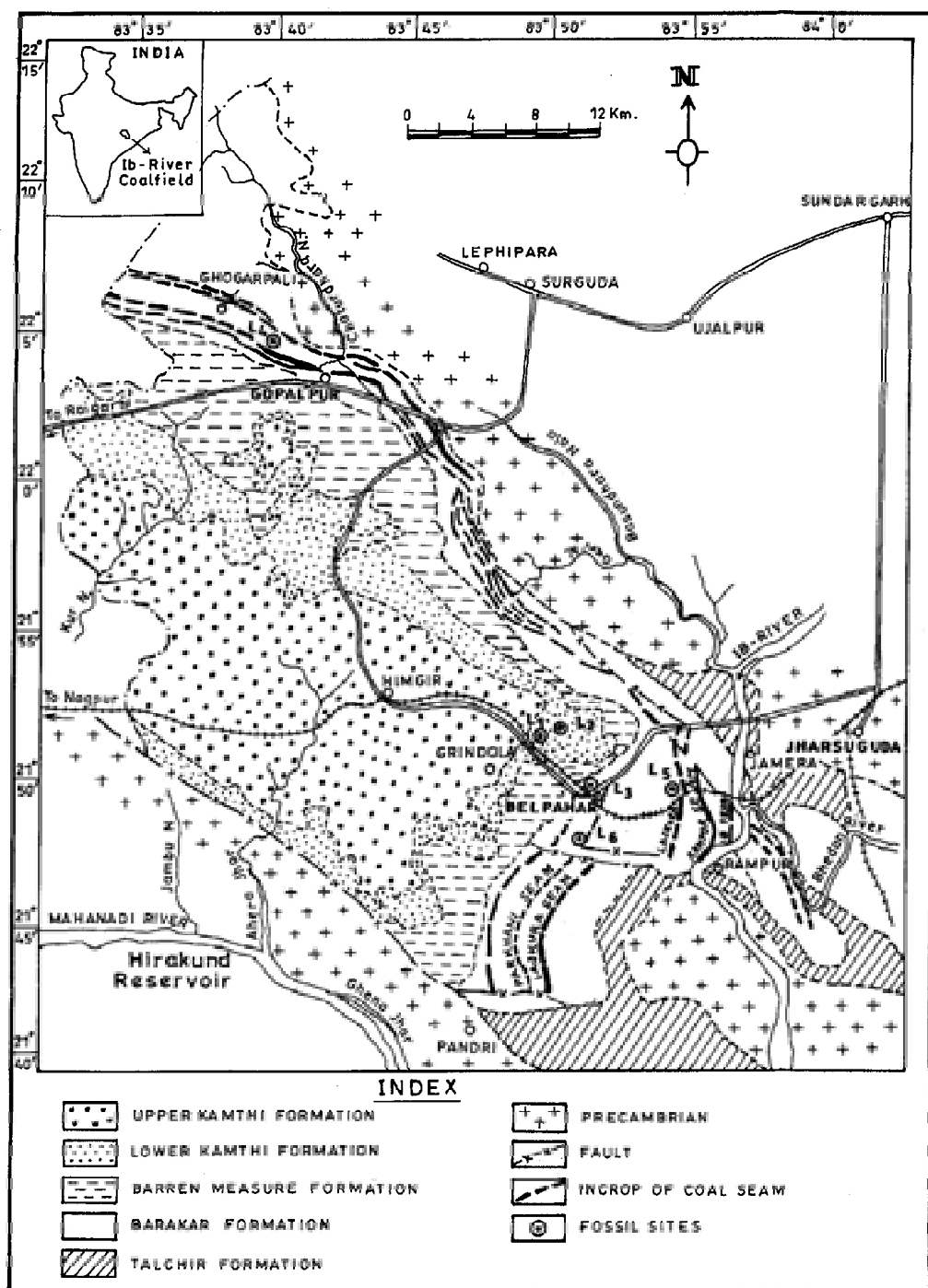
Fig. 1. A part of the geological map of Ib-River Coalfield, Orissa showing various localities.

gondwanensis, Vertebraria indica, Sphenopteris sp. cf. *S. polymorpha* and four species of *Glossopteris,* viz., *G. communis, G. indica, G. damudica* and *G. browniana* from the Lower Kamthi rocks exposed at the Garjan Hill, Girundla, Kodaloi and Belpahar areas. Mehta and Anandalwar (1960) recorded *Sphenopteris polymorpha* from Barakar shales near Patrapali Village. Pande and Chakraborty's (1964a, b) fossil assemblage reported from the Lower Kamthi Formation includes *Glossopteris indica, G. browniana, Schizoneura gondwanensis, Vertebraria indica* and *Pecopteris* sp.

Singh and Chandra (1990) recorded an African sphenophyllalean taxon, *Benlightfootia indica* from a Barakar exposure near Belpahar Railway Station. *Dicroidium* was recorded from the red shale beds of Upper Kamthi Formation by Pal *et al.* (1992). Singh and Chandra (1995) described in-situ preserved *Vertebraria* axes from the Barakar outcrops exposed near the Brajrajnagar Railway Station. *Senotheca murulidihensis,* a rare glossopteridean fructification was described from the carbonaceous shale bands of the Lajkura Colliery by Singh and Chandra (1996). Singh and Chandra (1999) also reconstructed a fern plant, *Neomariopteris hughesii,* based on 55 hand specimens collected from the Barakar Formation exposed near Brajrajnagar Railway Station.

Recently pteridophytic plants comprising nine taxa viz., *Cyclodendron leslii, Schizoneura gondwanensis,*

Age	Group	Formation	Lithology and Fossil contents (Thickness)
Recent		Alluvium/ Laterite	Gravel and conglomerate.
Early to Middle Triassic	Upper Gondwana	upper Kamthi	Conglomerate, red shale with *Dicroidium* flora (Pal *et al*., 1992), coarse ferruginous-sandstone with clasts (150 meters +).
--- Unconformity-------------------------------------
Late Permian	Lower Gondwana	lower Kamthi =Raniganj	Fine-medium grained well sorted sandstone, siltstone, clay bed, coal, shale with broad mesh *Glossopteris* species, some articulates and sphenophytes. Palyno-assemblage dominated by *Striatopodocarpites, Crescentipollenites, Faunipollenites*, along with *Arcuatipollenites* and *Densipollenites* (Meena, 1998) (180 meters).
Middle Permian		Barren Measures	Grey shale, carbonaceous shale, fine to coarse-grained sandstone, clay and ironstone nodules/shale. (250 meters+).
Early Permian		Upper Barakar	Feldspathic sandstone, grey and carbonaceous shales with many *Glossopteris*, some ferns and articulates, fireclay and thick coal seams. Palyno-assemblage dominated by *Scheuringipollenites, Faunipollenites, Striatopodocarpites, Punctatisporites* and *Horrilitriletes* etc. (Tiwari, 1968, Meena, 1999, 2000) (200-250 meters).
		Lower Barakar	Feldspathic sandstone, grey and carbonaceous shales with *Gangamopteris-Noeggerathiopsis-Euryphyllum* fossil assemblage, fireclay and thick coal seams. Palynoassemblage dominated by *Brijrajisporites, Rhizomaspora, Primuspollenites, Lahirites, Sulcatisporites, Cuneatisporites, Platysaccus* and *Apiculatisporis* (Tiwari, 1968) (350-500 meters).
Early Permian		Karharbari	Conglomerate, carbonaceous sandstone with fresh feldspar grains containing thin coal bands, only along the NW margin of the basin (30–65 meters).
Early Permian		Talchir	Diamictite, greenish sandstone, olive green colored needle shales and rhythmites (130 meters+).
--Unconformity--
Precambrian			Granites, gneisses, amphibolites and migmatites

Fig. 2. Geological succession of Ib River Coalfield, Jharsuguda District, Orissa (after RajaRao 1982, GSI, 1997 and Goswami *et al*. 2006b)

Raniganjia bengalensis, Bengalia raniganjensis, Trizygia speciosa, Benlightfootia indica, *Neomariopteris hughesii, N. talchirensis* and *Dichotomopteris* sp. have been reported from Ib-River Coalfield by Goswami *et al*., (2006a). Singh *et al*., (2006a, 2006b) recorded seven species of *Gangamopteris* and 53 species of *Glossopteris* respectively from the same coalfield. Six cordaitalean taxa viz., *Noeggerathiopsis hislopii, N. minor, Euryphyllum whittianum, E. maithyi*,

Kawizophyllum dunpathriensis and *Cordaites* sp. are also described from the Ib-River Coalfield by Singh *et al*., 2007.

GEOLOGICAL SETTING

The geological setting of the Ib-River Coalfield is fairly simple. Transverse sections examined in the field demonstrate that the Precambrian rocks underlying the Gondwana sediments are exposed surrounding this basin.

Plant types	Barakar Formation				Lower Kamthi Formation	
	Locality near Belpahar Railway Station	Jurabaga Colliery	Lajkura Colliery	Ratanpur Fireclay Quarry	Dungri hillock	Sitaram hillock
Cycadales (1)						
Maeratoeniopteris feddeni						+
Ginkgoales (1)						
Ginkgoites eximia			+			
Coniferales (1)						
Buriadia heterophylla			+			
Glossopteridales (Leaf forms-2)						
Surangephyllum elongatum	+	+				
Palaeovittaria kurzii			+			
Glossopteridales (Fertile forms-2)						
Ottokaria bengalensis		+				
Scutum sahnii		+	+			
Glossopteridales (Root form-1)						
Vertebraria indica		+	+	+	+	+
Scale leaves		+	+			
Stem casts	+	+	+			
No. of taxa studied at each locality	2	6	7	1	1	2

Fig. 3. Distribution of gymnosperms in different localities of the Ib-River Coalfield.

The trend of the Gondwana basin bears close parallelism with the structural grain of the Precambrian rocks. The southern boundary of this master basin is defined by a major NW-SE lineament. This lineament forms the southern limit of the Mahanadi Basin. The Ib-River Coalfield shows a westerly plunging synclinal flexure, which is like a half elliptical basin closed towards the northwest having an axial trend in NW-SE direction. In the northwest it forms a continuous basin with the Mand-Raigarh Coalfield. The southwestern boundary of the basin is marked by a boundary fault juxtaposing the Kulti Formation and the Raniganj Formation against the Precambrian. The Ib-River Coalfield represents a synformal basin with an arcuate, long northern limb (GSI, 1997).

Geological mapping in this coalfield was first carried out by Ball (1871). Subsequently this basin was resurveyed by Mehta and Anandalwar (1960); Raja Rao (1982); Chaudhury (1988); Mukhopadhyay (1987, 1989); Pal *et al.* (1992); GSI (1997); Goswami (1997, 2002); Goswami *et al.*, (2006b). Based on the work carried out by these workers and the observations

made by us, the following geological succession for Ib-River Basin is proposed (Fig. 2).

OCCURRENCE, MATERIAL AND METHODS

The gymnosperms plants described here were collected from the six different exposures (Fig. 1) within the Ib-River Coalfield (21°30' to 22°06' N Latitude and 83°37' to 84°10' E Longitude), Jharsuguda and Sundargarh districts, Orissa during four excursions. They are:

A. Lower Kamthi Formation Exposures   **Latitude**   **Longitude**
1. Dungri hillock near Belpahar   21°51' N   83°50' E
2. Sitaram hillock near Belpahar   21°51' N   83°51' E
B. Barakar Formation Exposures
3. Locality near Belpahar Railway Station   21°50' N   83°51' E
4. Ratanpur Fireclay Quarry   22°04' N   83°39' E
5. Lajkura Colliery   21°50' N   83°54' E
6. Jurabaga Colliery   21°47' N   83°51' E

These six localities are delineated as L_1 to L_6 in Fig. 1. The

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EXPLANATION OF PLATE I

1. *Ginkgoites eximia* Feruglio 1942, emend. Cuneo, 1987, Specimen No. 39051, x 3, Barakar Formation, Lajkura Colliery.
2. *Palaeovittaria kurzii* Feistmantel 1876, Specimen No.39052, x 1, Barakar Formation, Lajkura Colliery.
3. *Vertebraria indica* Royle 1839, Specimen No. 39053, x 1, Barakar Formation, Jurabaga Colliery.
4. *Buriadia heterophylla* Seward and Sahni 1920, Specimen No. 39054, x 3, Barakar Formation, Lajkura Colliery.
5. **Scale leaf**, Specimen No. 39055, x 1, Barakar Formation, Jurabaga Colliery.
6. *Scutum sahnii* Surange and Chandra 1974, Specimen No. 39056, x 1, Barakar Formation, Lajkura Colliery.
7. *Ottokaria bengalensis* Zeiller 1902, Specimen No. 39057, x 1, Barakar Formation, Jurabaga Colliery.
8. **Scale leaf**, Specimen No. 39058, x 1.5, Barakar Formation, Jurabaga Colliery.
9. *Surangephyllum elongatum* (Lacey, Van Dijk and Gordon Gray, 1975) Chandra and Singh, 1986, Specimen No. 39059, x 1, Barakar Formation, locality near Belpahar Railway Station.

Plate I

Lithology :

⬚ Alluvium
⬚ Laterite
⬚ Sandstone
⬚ Pebbly sandstone
⬚ Pebbly ferruginous sandstone
⬚ Siltstone
⬚ Pebbly siltstone
⬚ Sandstone with silty layers
⬚ Silty shale
⬚ Shale
⬚ Compact shale
⬚ Iron stone shale
⬚ Carbonaceous shale
⬚ Sandy clay
⬚ Fireclay
⬚ Coal

Structures :

Small scale trough cross-bedding
Cross-bedded

Colour symbols :

Gray
Dark grey (colour of carbonaceous shale)
Earthy
Black (colour of coal)
Buff

▲ Brown
▽ Maroon
⬚ Greyish white (colour of fireclay)
⊠ Variegated

Plant megafossils :

Cyclodendron
Equisetaceous stems
Schizoneura
Trizygia
Benlightfootia
Raniganjia
Bengalia
Neomariopteris
Dichotomopteris
Macrotaeniopteris
Noeggerathiopsis
Euryphyllum
Cordaites
Kawizophyllum
Ginkgoites
Buriadia
Glossopteris
Surangephyllum
Gangamopteris
Palaeovittaria
Ottokaria
Scutum
Senotheca
Vertebraria
Stem casts
Scale leaves

Fig. 4. Legend for all geological sections.

EXPLANATION OF PLATE II

1. A whorl of five leaves of *Surangephyllum elongatum* (Lacey, Van Dijk and Gordon Gray, 1975) Chandra and Singh, 1986, Specimen No. 39060, x 0.5, Barakar Formation, Jurabaga Colliery.

2. *Ginkgoites eximia* Feruglio 1942, emend. Cuneo, 1987, Specimen No. 39051, x 1, Barakar Formation, Lajkura Colliery.

3. *Buriadia heterophylla* Seward and Sahni 1920, Specimen No. 39054, x 1, Barakar Formation, Lajkura Colliery.

4. *Surangephyllum elongatum* (Lacey, Van Dijk and Gordon Gray, 1975) Chandra and Singh, 1986, Specimen No. 39060, x 1, Barakar Formation, Jurabaga Colliery.

5. *Vertebraria indica* Royle, 1839, Specimen No. 39061, x 1, Barakar Formation, Lajkura Colliery.

6. Stem cast, Specimen No. 39062, x 1, Barakar Formation, Lajkura Colliery.

7. Photograph showing basal lobes in *Surangephyllum elongatum* (Lacey, Van Dijk and Gordon Gray, 1975) Chandra and Singh, 1986, Specimen No. 39063, x 1, Barakar Formation, Locality near Belpahar Railway Station.

8. *Macrotaeniopteris feddenii* Feistmantel, 1890, Specimen No. 39064, x 1, Lower Kamthi Formation, Sitaram Pahar.

9. *Scutum sahnii* Surange and Chandra, 1974, Specimen No. 39065, x 1, Barakar Formation, Jurabaga Colliery.
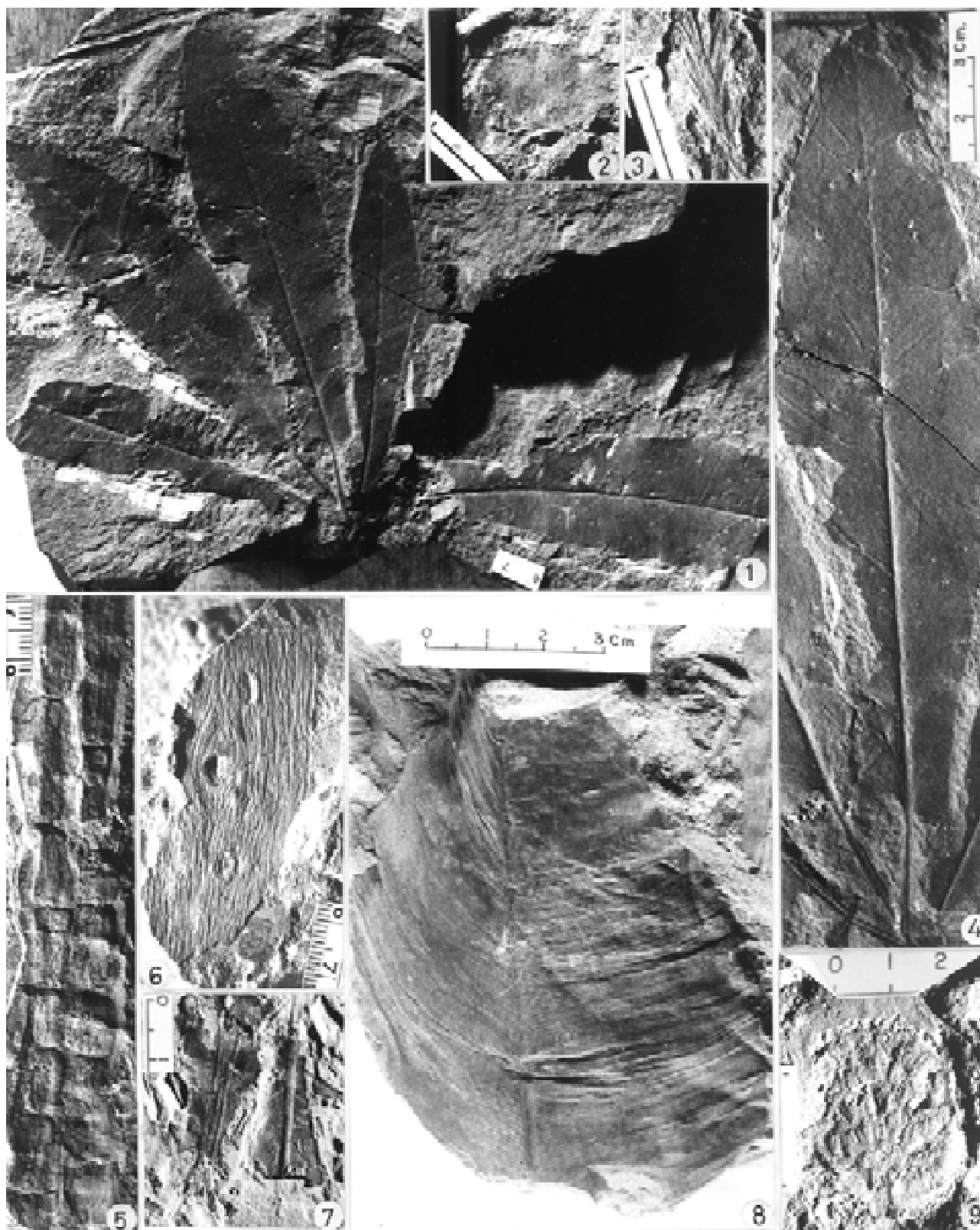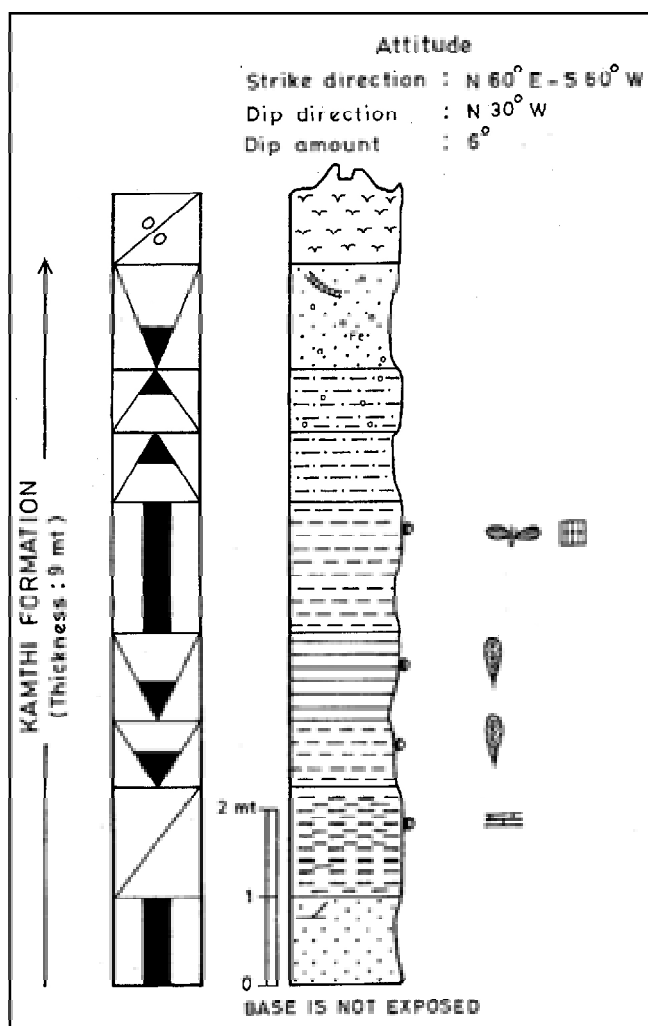
Fig. 5. Geological section, Dungri Hillock.

Fig. 6. Geological section, Sitaram Hillock.

legend for all the geological sections of these localities is given in fig. 4. The plant fossils collected from various fossiliferous horizons in these localities are mentioned along with the lithology and those included in the present study are shown in italics and bold letters.

1 & 2. Dungri and Sitaram hillocks (L₁, L₂): Dungri hillock, situated near the Village Gidhaghara on Jharsuguda-Belpahar main road, is about 110 m higher than the surrounding countryside. About 2 km. east of Dungri hillock, there is a bigger hillock about 230 meters in height named Sitaram situated near Garrakhai Village, about 3 km. northwest of Belpahar Railway Station. A major portion of these two localities has the Lower Kamthi sediments. Lithological successions of these two locations are similar except for a thickness variation of individual units. There are four fossil-bearing horizons on the northern and eastern flanks of these hillocks, each having a different lithology, namely grey shale, pinkish red shale, red compact shale and yellowish shale. The following lithological successions have been encountered at these Lower Kamthi localities (Figures 5 & 6).

1. Dungri Hillock (Fig. 5)

Rock types	Thickness in meters
Alluvium	0.8
Pebbly ferruginous sandstone	1.2
(Small scale tabular and trough-cross bedding)	
Pebbly siltstone	0.7
Silty shale	0.8
Yellowish shale(♠)	1.5
(*Schizoneura*, equisetaceous stems)	
Red compact shale (♠) (*Glossopteris*)	1.0
Pinkish red shale (♠) (*Glossopteris*)	0.8
Grey shale (♠) (**Vertebraria**)	1.2
Cross bedded sandstone	1.0
Base is not exposed	
[Legend (♠): Fossiliferous bed]	

2. Sitaram Hillock (Fig. 6)

Rock types	Thickness in meters
Alluvium	0.8
Pebbly ferrugenous sandstone	1.0
(Small scale tabular and trough cross bedding)	
Sandstone with silty layers	0.8
Pebbly siltstone	0.6
Silty shale	0.8
Yellowish shale (♠) (*Schizoneura*, *Neomariopteris*, equisetaceous stems)	1.5
Red compact shale (♠) (*Glossopteris*, *Macrotaeniopteris*)	1.0

(small scale trough cross bedding)
Silty shale
Grey shale
Fine to medium grained feldspathic sandstone
Pinkish brown shale (♠) (*Glossopteris*, **Surangephyllum**, *Trizygia*, *Schizoneura*, *Benlightfootia*, *Neomariopteris* and *Dichotomopteris*)
Carbonaceous shale
Cross-bedded sandstone
Base is not exposed
[Legend (♠): Fossiliferous bed]

4. *Ratanpur Fireclay Quarry* ($L_{4\ \&}$ *Fig. 7*): This locality is a small fireclay quarry in a hillock about 300 feet high, located on the right side of the motorable road between Ratanpur and Ghogarpali Towns about 2 km. from Ratanpur and 5-6 kms from Gopalpur, in the Sundargarh District. Soil and laterite form the surface capping. The Fireclay seam is up to 4-5 meters in thickness and confined to the Barakar Formation. The seam is discontinuous and lenses along the strike. The fossils collected from two fossiliferous beds in this quarry are shown in the lithological succession (Fig. 7.). The following lithological succession occurred is exposed at this locality.

Rock types	Thickness in meters
Alluvium	0.3
Laterite	0.7
Pebbly feldspathic sandstone	1.0
Feldspathic sandstone	1.2
Sandy clay	0.4
Greyish shale	0.8
Carbonaceous shale (♠) (*Glossopteris*)	0.4
Iron stone shale	0.6
Fire clay (♠) (*Glossopteris*, *Schizoneura*, *Vertebraria*, eqisetaceous stems)	4.1
Base is not exposed	

[Legend (♠): Fossiliferous bed]

5. & 6. *Lajkura and Jurabaga Collieries (L_5, L_6)*: Lajkura Colliery is located very close to the Ganganagar rivulet near Lajkura Village. Jurabaga Colliery is located in the vicinity of Jurabaga and Nullah Villages near the Lilari rivulet. Both collieries are situated between Belpahar and Brajrajnagar Towns in the Jharsuguda District. The fossiliferous Barakar Formation strata are exposed at four different horizons in each colliery as shown in the lithological sections (Figures 8 & 9).

5. Lajkura Colliery (Fig. 8)

Rock types	Thickness in meters
Alluvium	4
Laterite	3
Feldspathic sandstone (Small scale trough cross bedding)	3.7
Greyish micaceous shale (♠) (*Glossopteris*)	3.4
Fine to medium grained sandstone	3.1
Carbonaceous shale (♠) (*Raniganjia*, *Bengalia*, equisetaceous stems, *Ginkgoites*, *Scutum*, *Glossopteris*)	0.8
Coal seam (Top)	5.2
Carbonaceous shale (♠) (*Glossopteris*, *Palaeovittaria*, *Senotheca*, *Vertebraria*, stem casts, scale leaves)	1

Fig. 7. Geological section, fireclay quarry, near Ratanpur.

Pinkish red shale (♠) (*Glossopteris*)	0.8
Grey shale (♠) (*Vertebraria*)	1.1
Cross bedded sandstone	1.1
Base is not exposed	

[Legend (♠): Fossiliferous bed]

3. *Locality near Belpahar Railway Station (L_3)*: This locality is a newly dug well, located just outside the Belpahar Railway Station on the main road from Raigarh to Jharsuguda. Plant megafossils are collected from the Barakar sediments excavated from this well. The fossil horizon, having a thickness of approximately 1.5 meters, contains 27 species of *Glossopteris* along with *Surangephyllum*, *Trizygia*, *Schizoneura*, *Benlightfootia*, *Neomariopteris*, *Dichotomopteris* and scale leaves. Since the well was very narrow, therefore the total thickness of the geological section inside it could not be measured accurately, however it seemed to be approximately 6-7 meters. The following lithological succession was seen at this fossil locality.

Rock types
Alluvium
Pebbly feldspathic sandstone

Fig. 8. Geological section, Lajkura colliery near Lajkura Village.

Coal seam (Middle)	4
Carbonaceous shale (♠)	1.8
(*Glossopteris, Gangamopteris,*	
Noeggerathiopsis, Cordaites, *Euryphyllum,*	
Kawizophyllum, Buriadia and *Vertebraria*)	
Coal seam (Bottom)	5
Base is not exposed	
[Legend (♠): Fossiliferous bed]	

6. Jurabaga Colliery (Fig. 9)

Rock types	Thickness in meters
Alluvium	7
Pebbly feldspathic sandstone	0.8
Coarse-grained feldspathic sandstone	3
(Small scale trough cross bedding)	
Greyish micaceous shale (♠)	1.2
(*Glossopteris*)	
Fine to medium grained sandstone	0.8
Carbonaceous shale (♠)	1
(*Glossopteris, Surangephyllum, Scutum,*	
Cyclodendron, Trizygia, Raniganjia,	
Neomariopteris, equisetaceous stems)	
Coal seam (Top)	6.2
Carbonaceous shale (♠)	0.6
(*Glossopteris*, scale leaves, stem casts)	
Coal seam (Middle)	5.6
Carbonaceous shale (♠)	0.5
(*Glossopteris, Gangamopteris,*	
Noeggerathiopsis, *Euryphyllum,*	
Ottokaria, Vertebraria)	

Coal seam (Bottom)	3.7
Base is not exposed	
[Legend (♠): Fossiliferous bed]	

The plant fossils were collected from the grey shale, pinkish red shale, red compact shale and yellowish shale of the Lower Kamthi Formation exposed around Dungri hillock and the Sitaram hillock. The fireclay bed at the Ratanpur Fireclay Quarry, pinkish brown shale at the locality near Belpahar Railway Station, carbonaceous shale and grey shale at the Lajkura and Jurabaga collieries belong to the Barakar Formation. The specimens occur both as impressions and compressions in these shales. The morphological characters of the specimens were examined using a Leica low power binocular microscope and photographed using a Nikon 35 mm camera. All the megafossil specimens have been deposited in the repository of Birbal Sahni Institute of Palaeobotany, Lucknow vide statement no. 1099 and museum specimen nos. from 39051 to 39065.

SYSTEMATIC PALAEOBOTANY
Class **Cycadopsida**
Order **Cycadales**
Genus ***Macrotaeniopteris*** Schimper, 1869
Type species: *Macrotaeniopteris ovata* (Oldham) Schimper, 1869
Macrotaeniopteris feddenii Feistmantel 1876
(Pl. II, fig. 8)

Description: There are only two specimens in the present collection, one is almost complete. They are medium in size and comparatively broad. The apex, preserved in one leaf looks to be acute and the base rounded. The most complete leaf is 11 cm long and 8 cm wide, the length/width ratio is 1-1.5: 1. The midrib is about 2 mm at the base and 0.75 mm at the apex. The secondary veins are dense and are very closely spaced and emerge from the midrib at an angle of 70-80° and run almost parallel to each other and meet the margin at the same angle. Hence the veins are almost horizontal in the lower portion of the leaves and becoming more oblique towards the apex. In both the leaves the veins are slightly turned upwards near the margin and also dichotomize there. The cross-connections in between the veins and also the meshes are absent in the leaves.

Comparison and remarks: The present specimens of *Macrotaeniopteris feddenii* resemble closely the specimens described and figured by Feistmantel (1881: Pl. 21, fig 3; Pl. 22, figs. 1-4; 1882: Pl. 21, fig. 5; 1886: Pl. 1, fig.1) in their shape, size and venation pattern. This is the first report of this taxon from the Ib-River Coalfield and the Son-Mahanadi Basin.

Locality: Sitaram hillock.

Horizon: Lower Kamthi Formation.

Distribution: *Macrotaeniopteris feddenii* occurs only in the Barakar, Raniganj and Kamthi formations of Indian Gondwana.

Class **Pinopsida**
Order **Ginkgoales**
Genus ***Ginkgoites*** Seward, 1919
Type species: *Ginkgoites obovata* (Nathorst) Seward, 1919
Ginkgoites eximia Feruglio 1942-*emend.* Cuneo (1987)
(Pl. I, fig. 1; Pl. II, fig. 2)

Description: This species is represented by two reniform leaves. The leaves seem to be petiolate, though the petiole is not preserved. They look somewhat kidney shaped. The lamina
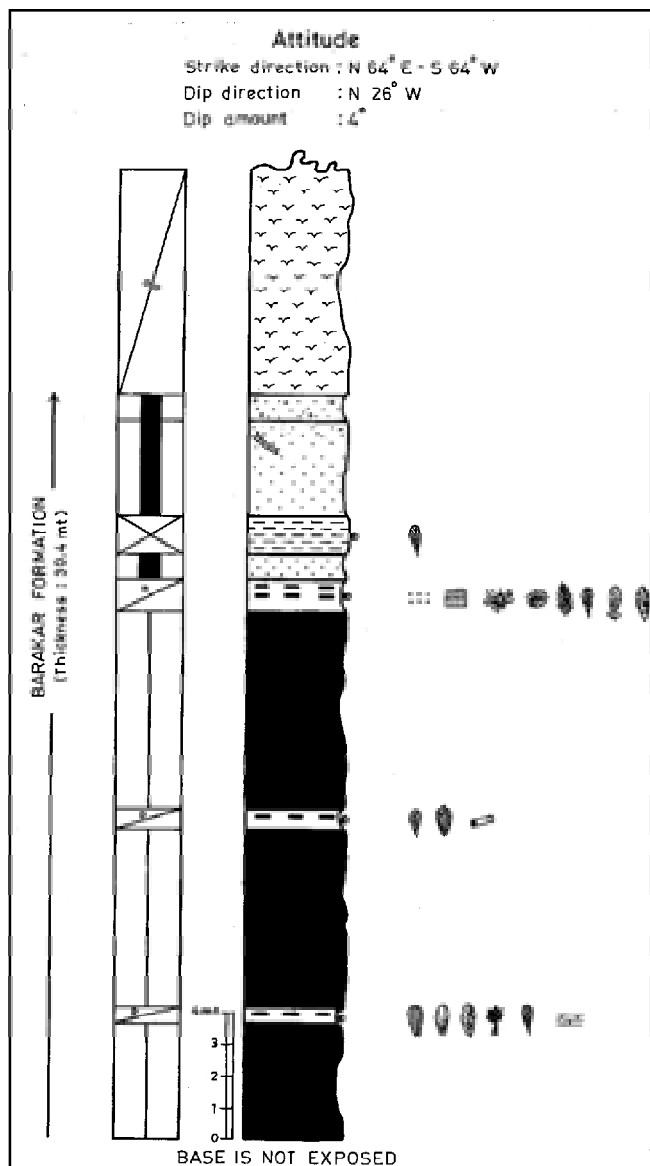
Fig. 9. Geological section, Jurabaga colliery near Nullah Village.

is 2.2 cm in width and 1.5-1.9 cm in length. The leaf margin is entire, although the lobing is also seen at places. The veins dichotomize 2-4 times and run almost parallel to each other towards the distal margin of the lamina with a mild outward curvature at the upper portion. There are 28-33 veins per cm^2 near the apical margin.

Comparison and remarks: The present specimens resemble closely the photographs and figures described by Cuneo (1987) and Bajpai (1991). It is the first record from the Ib-River Coalfield and Son-Mahanadi Basin.

Locality: Lajkura Colliery.

Horizon: Barakar Formation.

Distribution: *G. eximia* occurs only in the Barakar Formation of Indian Gondwana.

Class **Pinopsida**
Order **Pinales**
Family **Buriadiaceae** Pant, 1977
Genus *Buriadia* Seward and Sahni, 1920

Type species: *Buriadia heterophylla* (Feistmantel) Seward and Sahni, 1920

Buriadia heterophylla (Feistmantel) Seward and Sahni, 1920
(Pl. I, fig. 4; Pl. II, fig. 3)

Description: There are three specimens of *Buriadia heterophylla* in the present collection. The stems are between 1-2 mm wide. The simple and undivided leaves arise alternately on the shoots and they are linear and acicular in shape. The leaves in three different specimens arise from the shoot at varied angles. The leaves have broad attachment and their bases are invariably decurrent. The apices of the leaves show all transitions of shapes, ranging from an obtusely pointed tip to a narrowly acute apex. The length of the leaf ranges from 2 to 5 mm and the width 0.4 to 1 mm.

Comparison and remarks: The present specimens of *Buriadia heterophylla* resemble closely the figures and descriptions given by Seward and Sahni (1920) and Singh *et al.*, (2000, 2003, 2005 and 2006). It is the first report from the Ib-River Coalfield and Barakar Formation of Indian Gondwana.

Locality: Lajkura Colliery.

Horizon: Barakar Formation.

Distribution: *Buriadia heterophylla* is restricted to the Karharbari and Barakar formations of Indian Gondwana.

Class **Gymnospermopsida**
Order **Glossopteridales**
Genus *Surangephyllum* Chandra and Singh, 1986

Type species: *Surangephyllum elongatum* (Lacey *et al.*, 1975) Chandra and Singh, 1986

Surangephyllum elongatum (Lacey *et al.*, 1975) Chandra and Singh 1986
(Pl. I, fig. 9; Pl. II, figs. 1, 4, 7)

Description: There are 13 leaves of this taxon in the present collection, nine are almost complete. Two of the specimens (part and counterpart) have five leaves each, arranged in a whorl. Leaves are small to medium in size, generally broadest near the apical portion. They are narrow oblanceolate to lanceolate to narrow elliptic in shape and their length/width ratio is 2-6: 1. The apex is obtuse or acute and the base sagittate. The length of the leaves ranges from 4-16 cm and the width from 1.8 to 4 cm. At the basal end, laminae show bluntly pointed lobes on either side of the midrib at an angle of 20°-45° with the petiole. The lamina is constricted above the basal lobes and the leaves thus are unicostate. The midrib is prominent and ranges from 4-7 mm in width at the base of the lamina. The secondary veins emerge from the midrib at an angle of 50°-60°and run straight to the margin to meet it at 70°-80° in the upper part of the leaf. At the junction of the basal lobes and the midrib, secondary veins emerge at right angles and run horizontally up to the margin. In the basal lobes, the veins form an angle of 115°-140° with the midrib. The veins fork continuously and anastomose to form quite broad and short rhomboidal to pentagonal shaped meshes near the midrib and long and comparatively narrow hexagonal meshes near the margin. There are 4-7 meshes between the midrib and the margin. The secondary veins in the basal lobes join a fine marginal vein that leaves the midrib and follows around the inner edge of each lobe.

Comparison and remarks: The present specimens of *Surangephyllum elongatum* resemble closely the figures and description of the specimen no. NM. 1743, collected by Lacey *et al.*, 1975 (page 374, fig. 1). from Mooi river, District of Natal, South Africa, and described as *Belemnopteris elongata*. Chandra and Singh (1986) designated this specimen as the

Holotype specimen of a new genus *Surangephyllum* with species *elongatum* which they instituted after including the leaves *Belemnopteris elongata* (Lacey *et. al.*, 1975; Rigby, 1978), *Belemnopteris* sp. (Schopf 1970) and *Glossopteris duocaudata* (Homes, 1981). Our specimens also compare with the specimens of *Surangephyllum elongatum* described from the Kamthi Formation of Handapa area, Angul District, Orissa (Chandra and Singh,1986) and from the Karharbari Formation of South Balanda Colliery, Talchir Coalfield, Angul District, Orissa (Singh *et al.*, 2006c).

This is the first report from the Ib-River Coalfield, and Barakar Formation of Indian Gondwana.

Locality: Near Belpahar Railway Station and Jurabaga Colliery.

Horizon: Barakar Formation.

Distribution: *Surangephyllum elongatum* occurs in Karharbari, Barakar and Kamthi formations of Indian Gondwana.

<div align="center">

Class **Gymnospermopsida**

Order **Glossopteridales**

Genus ***Palaeovittaria*** Feistmantel, 1876

</div>

Type species: *Palaeovittaria kurzii* Feistmantel, 1876

<div align="center">

Palaeovittaria kurzii Feistmantel 1876

(Pl. I, fig. 2)

</div>

Description: There are only two specimens in the present collection, one is almost complete. The leaf is simple, elongate spathulate in shape having obtuse apex and a tapering base. The length of the more complete leaf is 9.3 cm, width 3.1 cm with a length/width ratio of 3:1. The midrib is present only in the lower half of the leaf lamina or slightly more. The midrib is thick near the base and made up of 3-4 parallel running strands and is evanescent in the upper portion of the leaf. The lateral veins emerge from the midrib at a very acute angle 15°-25° in the middle part of the leaf. They run parallel in the basal part and start forking above the base but never anastomose. After forking, the veins diverge from each other and become subparallel. The concentration of veins is 10-12 near the midrib and 18-20 near the margin at the middle part of the leaf.

Comparison and remarks: The present leaves resemble the specimens described by Feistmantel (1876, Pl. 19, figs 3, 3a, 4, 4a). This is the first report from the Ib-River Coalfield and the Son-Mahanadi Basin.

Locality: Lajkura Colliery.

Horizon: Barakar Formation.

Distribution: *Palaeovittaria kurzii* occurs only in the Barakar and Raniganj formations of Indian Gondwana.

<div align="center">

Class **Gymnospermopsida**

Order **Glossopteridales**

Genus ***Ottokaria*** Zeiller, 1902

</div>

Type species: *Ottokaria bengalensis* Zeiller, 1902

<div align="center">

Ottokaria bengalensis Zeiller 1902

(Pl. I, fig. 7)

</div>

Description: This taxon is represented by a single specimen in our present collection. It consists of a long, slender stalk, attached marginally to the base of the terminal head which is orbicular or somewhat oval in shape. The margin of the head shows acute to sub-acute lobes and its face shows numerous radiating veins with occasional anastomoses. The head, with dentate margins, is about 1.5 cm wide that possesses dichotomizing veins on its entire surface. The long slender stalk (petiole) measuring 2.8 cm is attached to the margin of a poorly preserved *Glossopteris* leaf.

Comparison and remarks: The present specimen of *Ottokaria bengalensis* compares closely with the figures given by Zeiller (1902) and with the Lectotype specimen (No. 7287, kept in the Geological Survey of India Museum, Kolkata) of *Ottokaria bengalensis* (in Banerjee 1979, Pl. 49, fig. 6; Pl. 53, fig. 6, 7). *Ottokaria bengalensis* is reported for the first time from the Ib-River Coalfield and Barakar Formation of Indian Gondwana.

Locality: Jurabaga Colliery.

Horizon: Barakar Formation.

Distribution: *Ottokaria bengalensis* occurs in Talchir, Karharbari and Barakar formations of Indian Gondwana.

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Class **Gymnospermopsida**

Order **Glossopteridales**

Genus ***Scutum*** Plumstead, 1952

</div>

Type species: *Scutum leslium* Plumstead, 1952

<div align="center">

Scutum sahnii Surange and Chandra 1974

(Pl. I, fig.6; Pl. II; fig. 9)

</div>

Description: There are three specimens of this species in our collection, one is almost complete. The fructification appears to be round to oval in shape with a bilateral symmetry. The complete specimen measures 3.4 cm in length and 2.5 cm in width. The short-stalked specimens look concave or saucer-shaped in the middle part surrounded by a 2 mm wide wing-like rim except at the base. Some oval structures are seen on the central head of the specimens which could possibly be attached seeds. Few irregular cavities can also be seen on the head that might be the places from where the seeds have been shed. The present specimens seem to be the seed-bearing part of the fructification known as the receptacle; however, the other part, i.e. the protective bract having veins, is not preserved.

Comparison and remarks: The present specimens resemble very well the Holotype specimen (No. 35093) of Surange and Chandra (1974) in all aspects. It is reported for the first time from the Ib-River Coalfield and Son-Mahanadi Basin.

Locality: Jurabaga and Lajkura collieries.

Horizon: Barakar Formation.

Distribution: *Scutum sahnii* occurs only in the Barakar and Raniganj formations of Indian Gondwana.

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Class **Gymnospermopsida**

Order **Glossopteridales**

Genus ***Vertebraria*** Royle, 1839

</div>

Type species: *Vertebraria indica* Royle, 1839

<div align="center">

Vertebraria indica Royle 1839 emend. Schopf 1965

(Pl. I, fig. 3; Pl. II, fig. 5)

</div>

Description: There are fifty three specimens of *Vertebraria indica* in the present collection. The length of the specimens ranges from 3.6 cm to 14 cm and the width from 0.9 cm to 4 cm. The axis consists of square areas in two linear rows, separated by a median longitudinal furrow. The areas are transversely separated by grooves.

Comparison and remarks: Morphologically, the present specimens resemble very well the photographs and descriptions of the Holotype specimen (Natural History Museum, London, No. V. 4189) of *Vertebraria indica* given by Royle, 1839 (p. xxix; pl. 2, figs 1,2).

Locality: Dungri and Sitaram hillocks, Ratanpur Fireclay Quarry, Jurabaga and Lajkura collieries.

Horizon: Barakar and Lower Kamthi formations.

Distribution: In India, *Vertebraria indica* occurs in the Talchir, Karharbari, Barakar, Barren Measures, Raniganj and Kamthi formations.

Class **Gymnospermopsida**
Order **Glossopteridales**
Scale leaves
(Pl. I, figs. 5, 8)

Description: They are represented by eight specimens in our collection. All are of different morphology and found in detached condition. They are small to medium in size ranging from 2 cm to 6.5 cm in length and 1 to 2 cm in width. There is no seed nor sporangia found associated with the scales. The apices of most of the scales are obtuse and their bases are truncated and contracted. The scale leaves have dentate margins and they also possess parallel running interconnecting veins. The veins arise from the base, dichotomize and reach up to the apex. The meshes formed by the anastomosing of the veins are narrow and elongate.

Locality: Locality near Belpahar Railway Station, Jurabaga and Lajkura collieries.

Horizon: Barakar Formation.

Distribution: Scale leaves occur only in the Karharbari, Barakar, Raniganj and Kamthi formations of Indian Gondwana.

Class **Gymnospermopsida**
Order **Glossopteridales**
Stem casts
(Pl. II, fig. 6)

Descriptions: There are 12 specimens of stem casts in the present collection. The length of the specimens ranges from 4 cm to 14 cm and the width from 1.5 cm to 4 cm.

Locality: Jurabaga and Lajkura collieries.

Horizon: Barakar Formation.

Distribution: Stem casts occur in the Talchir, Karharbari, Barakar, Raniganj and Kamthi formations of Indian Gondwana.

DISCUSSION AND CONCLUSIONS

The gymnosperm fossils such as *Macrotaeniopteris, Ginkgoites, Buriadia, Surangephyllum, Palaeovittaria, Ottokaria, Scutum, Vertebraria,* scale leaves and stem casts are reported in six different exposures of the Barakar and Lower Kamthi formations, Ib-River Coalfield. Their distribution is given in Fig. 3. Besides *Vertebraria indica,* all the above gymnosperm taxa are recorded for the first time from this coalfield. The taxa *Buriadia heterophylla* and *Ottokaria bengalensis* reported in this study are the first records of these from the Barakar Formation of Indian Gondwana.

While analyzing sediment sequences from older to younger strata, it is observed that the exposures of the Barakar Formation in two of the localities (Lajkura and Jurabaga collieries) contain four fossil horizons with two distinct floristic assemblages or floral zones and based on this, the sediments here have been divided into lower and upper stages. The genera *Buriadia* and *Ottokaria* reported in the present study and *Gangamopteris, Noeggerathiopsis, Cordaites, Euryphyllum* and *Kawizophyllum* described earlier (Singh *et al.*, 2006a, 2007) are found preserved only in the lowermost horizon, i.e. the 4th horizon of the Barakar Formation and they are completely absent in all the three younger fossil horizons of these two localities (figs. 8, 9). The oldest carbonaceous shale beds (4th fossil horizon) of the Lajkura and Jurabaga collieries belong to the Lower floral zone (Lower Barakar). The floral assemblage of these beds is more or less similar to that of the Karharbari Formation and comprises *Buriadia, Ottokaria, Glossopteris, Gangamopteris, Noeggerathiopsis, Cordaites, Euryphyllum,*

Kawizophyllum and *Vertebraria.* This assemblage compares closely with Lower Barakar floras described by Maheshwari and Prakash (1965, Bansloi Valley, Rajmahal Hills); Kulkarni (1971, South Karanpura Coalfield); Bajpai (1990, Deogarh Coalfield); Srivastava (1992, Raniganj Coalfield) and Srivastava and Tewari (1996, Auranga Coalfield). These beds are assigned an age equivalent to the Lower Barakar (Early Permian). The occurrence of a typical Karharbari floral assemblage in the lowermost carbonaceous shale of the Lajkura and Jurabaga Collieries (otherwise a part of Barakar Formation) suggests that the Karharbari elements might have flourished even in the Lower Barakar rocks in this region.

The younger three fossiliferous shale beds of the Lajkura and Jurabaga collieries (figs. 8, 9) occur in a pinkish brown shale at the locality near Belpahar Railway Station, and the fireclay bed of Ratanpur Fireclay Quarry (fig. 7) belongs to the upper floral zone (Upper Barakar). These beds contain many herein described gymnosperms, namely *Ginkgoites, Surangephyllum, Palaeovittaria, Scutum, Vertebraria,* scale leaves and stem casts as well as the taxa reported earlier (Goswami *et al.*, 2006a, Singh *et al.*, 2006b) viz., *Cyclodendron, Schizoneura, Raniganjia, Bengalia, Trizygia, Benlightfootia, Neomariopteris, Dichotomopteris, Glossopteris, Senotheca* and equisetaceous stems. The assemblage of the upper floral zone can be correlated with the Upper Barakar floras described by Maithy (1971, Auranga Coalfield); Srivastava (1977, Auranga Coalfield); Srivastava (1992, Raniganj Coalfield); Srivastava and Tewari (1996, Auranga Coalfield) and Singh and Chandra (1996b, Talcher Coalfield). These shale beds are assigned an age equivalent to the Upper Barakar (Early Permian).

The flora collected from the Kamthi Formation beds of this coalfield, i.e., from Dungri and Sitaram hillocks (figs. 5, 6) has only Late Permian elements, namely *Macrotaeniopteris, Vertebraria, Glossopteris, Schizoneura, Neomariopteris,* and equisetaceous stems (first two reported in this study and the rest described earlier). No typical Triassic elements like *Dicroidium, Lepidopteris,* etc. were found in these beds, hence it is suggested that these rocks might belong to the Lower member of the Kamthi Formation, not the Upper member that is now considered to be Triassic both in the Ib-River Coalfield (Pal *et al.*, 1992) and the Talcher Coalfield (Pal and Ghosh, 1997) because of the presence of typical Triassic species belonging to the *Dicroidium* flora. This Lower Kamthi flora is quite comparable with the flora from the Handapa and Madhupur localities in the adjoining Talcher Coalfield (Chandra and Singh, 1992; Singh and Chandra, 2000). It is also comparable with that of Ball's (1877) record from the Kamthi Formation of the Mahanadi Basin as both the assemblages include *Schizoneura gondwanensis, Vertebraria indica, Neomariopteris* sp.*, Glossopteris indica* and *G. communis* in common.

Vertebraria indica axes were also reported by Singh and Chandra (1995) from the Barakar Formation in the Ganganagar rivulet section near Brajarajnagar town of the Ib-River Coalfield. These were preserved vertically and diagonally (*insitu*) in the sediments. Incidentally, we have also found similar *in situ* *Vertebraria* roots in the Jurabaga and Lajkura collieries during the present study. These two records of *insitu* preservation of *Vertebraria* axes demonstrate the possibilities of autochthonous preservation of the vegetation and might indicate the presence of palaeosols at least in some areas in this coalfield.

Therefore, it warrants a thorough and systematic study of the sediments around these localities for the authenticity of the palaeosolic nature of the sediments.

The genus *Glossopteris* comprises about 65% (593 specimens) of the total plant fossil assemblage collected from the Barakar and Lower Kamthi Formations from the Ib-River Coalfield. Altogether, 53 species of *Glossopteris* have been identified from the Ib-River Coalfield. This is the greatest diversity of species within the genus *Glossopteris* recorded from the Barakar Formation in the various Lower Gondwana coalfields of India. The conifer genus *Buriadia* represented by only two specimens depicts its localized occurrence in this coalfield. These were small and bushy plants. *Macrotaeniopteris* was probably arborescent in habit. The *Ginkgoites* species was also of localized occurrence, and constituted only a small fraction of the overall vegetation. *Palaeovittaria kurzii* and *Surangephyllum elongatum* were also of localized occurrences.

The floral affinity of the Lower Barakar Formation with that of the Karharbari Formation suggests the existence of Karharbari climatic conditions in the early phase of Barakar time in this region. Successive climates in the Upper Barakar might comparatively be warmer and more humid and this climatic shift did not favour the continuation of plants of Karharbari Formation further, and in time they almost disappeared from the scene in Upper Barakars. Hence, a definite change in ecological conditions is predicted during the Upper Barakar time. This floral composition suggests the existence of temperate climate with a change from warm moist to warm dry condition during Barakar time in the Ib-River area. The Lower Kamthi forests in the Ib-River Coalfield (Dungri and Sitaram Hillocks) were perhaps growing on uplands, unlike the lowland *Glossopteris* forests of the Raniganj Formation. The climate during Kamthis was warm and humid and thus very suitable for the luxuriant plant growth. The red bed facies of the ferruginous sandstones in these two localities indicate seasonal variability of dry spells and semi-arid conditions. This association of red bed facies can be ascribed to locally, oxidizing conditions.

The fine-grained, compact carbonaceous, grey, yellow, pinkish red and pinkish brown shale and fireclay of the Ib-River Coalfield having well-preserved fossil plant remains were probably deposited in a low-energy environment of an ox-bow lake as is shown by its unaltered nature of the specimens. A large number of undamaged leaves of *Glossopteris, Gangamopteris, Macrotaeniopteris, Surangephyllum, Palaeovittaria, Euryphyllum, Noeggerathiopsis* and *Cordaites* having well-preserved phytolemma on them clearly indicates that the burial and preservational environment of the lake was reducing and also there was little long distance transportation of the plant material. These genera probably grew very luxuriantly around the vicinity of the lake in this coalfield.

The overall floral assemblage recovered from all the six localities of the Ib-river Coalfield depicts that this area had a dense forest type vegetation dominated by gymnosperm plants such as *Glossopteris, Gangamopteris, Macrotaeniopteris, Surangephyllum, Palaeovittaria, Euryphyllum, Noeggerathiopsis, Cordaites, Kawizophyllum* and *Buriadia* with a few pteridophyte plants belonging to lycopodiales, articulates, sphenophyllales and filicales. These plants grew in some small open patches near the water bodies such as lakes, ponds or rivers. Hence, there were two inter-connected ecosystems in the Ib-River area during Early Permian (Barakar) and Late Permian (Lower Kamthi) viz., the terrestrial system and the marshy system. Most of the gymnosperms grew within the terrestrial system which provides organic detritus for the formation of coal, whereas the majority of the pteridophytes inhabited the marshy system (Goswami, 1997, 2002; Goswami *et al.*, 2006).

ACKNOWLEDGEMENTS

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ANNOUNCEMENTS

The Department of Geology, University of Rajasthan, Jaipur will organize a National Conference on "Statigraphy, Palaeontology and Palaeoenvironment" from February 3 to 5, 2011 to address issues relating to above geological aspects of the Indian sedimentary basins. Professor D. K. Pandey, who is the Convener and Organising Secretary, may please be contacted for further details through following e-mail addresses and phone:

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The Centre of Advanced Study in Geology, University of Lucknow, is organising a National Seminar on "Late Quaternary Geology of the Himalayan Orogen and the Foreland Basin" from February 16-17, 2011. Dr. Rameshwar Bali, the Organising Secretary, may please be contacted through following e-mail addresses and phones:

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Applications are invited for the award of **Mani Shanker Shukla Gold Medal** in Micropalaeontology for the year 2010. The award will be given to a young scientist preferable below 40 years in age for his contribution in the field of micropalaeontology. The nominations should reach the secretary, Palaeontological Society of India by 31th December, 2011.

FLUVIAL TRACE FOSSILS FROM THE UPPER GONDWANA (EARLY CRETACEOUS) SUCCESSION OF CENTRAL INDIA

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ABSTRACT

A rich assemblage of trace fossils is recorded from the Early Cretaceous fluvial arenaceous and argillaceous Gondwana sediments of Central India. The succession is 90-100m thick, and consists of cross bedded to parallel bedded sandstone, siltstone, mudstone and conglomerate, of which the siltstone horizons show maximum preservation of trace fossils. The assemblage is characterized by *Baroccoichnites, Cochlichnus, Lockeia, Palaeophycus, Planolites beverleyensis, P. montanus, P. reticulates, Rutichnus, Scolicia, Scoyenia, Skolithos, Steinichnus,* feeding structures, insect burrows, grazing traces and spindle-shaped burrows. This study attempts to ascertain the palaeoecological and palaeoenvironmental significance of the trace fossils and discusses its placement in the *Scoyenia* ichnofacies.

Keywords: Upper Gondwana, Early Cretaceous, Trace fossils, Fluvial sediments, Bairam-Belkher area, Maharashtra

INTRODUCTION

The trace fossil record from the fluvial successions of India is still very limited. However, a few descriptions of trace fossils from the Gondwana successions have proved to be very significant in the interpretation of animal communities and palaeoecology, particularly in the successions devoid of animal fossils (Maulik and Chaudhuri, 1983; Sarkar and Chaudhuri, 1992; De, 1993; Guha *et al.,* 1994; Mukhopadhyay, 1994; Maulik *et al.,* 2000). In the study reported here, the trace fossils are also the only tools available for the interpretation of the animal community, their behaviour, habitat, etc. as the succession is otherwise devoid of faunal remains.

The uppermost Gondwana succession is well exposed in two adjacent localities viz., Bairam (21° 22': 77°37') and Belkher (21° 22': 77° 32') of Central India (Fig.1), consisting respectively of 90m and 100m. of arenaceous and argillaceous sediments. Both the exposures are similar in lithostratigraphy. The age of the succession has been a matter of debate; however, Early Cretaceous is confirmed on the basis of the diverse assemblage of pteridophytic and gymnospermous leaf impressions (Srivastava *et al.,* 1995, 1996, 1999, 2001, 2004a; Gawande, 2003). The megafloral assemblage is comparable to the established co-eval floras of the uppermost Gondwana successions of Central and Peninsular India. Bandhopadhyay and Chaudhary (2000) considered it equivalent to the upper part of the Jabalpur Formation and proposed 'Belkher Beds' for the exposures at the Belkher area.

A preliminary report of trace fossils from the Gondwana succession, based on a limited collection was earlier made by Srivastava *et al.* (1996). However, the present study incorporates a systematic analysis of entire assemblage including new collections. The taxa are described in detail and their stratigraphic positions indicated. Emphasis is given to the interpretation of the palaeoecology and animal-sediment relationships; and also to the placing of the assemblage in established trace fossil models, particularly the *Scoyenia* ichnofacies characterstic of non-marine environment.

GEOLOGY OF THE AREA

The Gondwana successions are represented mainly by the arenaceous and argillaceous sediments, exposed as inliers within the widespread Deccan Trap Volcanics. The Lameta Formation with chertified limestone, nodular limestone, sandstone and yellowish, brownish to greenish clays and calc-siliceous units rests disconformably on the Gondwana, and is overlain by alluvium and soil. The basement is formed of quartzo-feldspathic gneiss of Archaean age and is exposed at a distant locality viz., Salbardi (lat 21° 25' 15"N - long 78° 00' 00"E), lying at a distance of about sixty kilometers in the east. The stratigraphy of the area is shown on Table 1 and fig. 1.

Table 1: The stratigraphy of the area.

Age	Stratigraphic Unit	Rock type
Quaternary		Soil and alluvium
---------------------------	--------Unconformity------------	------------------------------
L. Cretaceous-Eocene	Deccan Traps	Non-porphyritic and porphyritic basalt.
---------------------------	--------Unconformity------------	------------------------------
L. Cretaceous	Lameta Formation	Sandstone, shale and limestone
---------------------------	--------Disconformity-----------	------------------------------
E. Cretaceous	Upper Gondwana (Jabalpur Formation)	Sandstone, siltstone, conglomerate and mudstone
---------------------------	--------Unconformity------------	------------------------------
Archaean		Quartzo-feldspathic gneisses - at places sheared/fractured.

DEPOSITIONAL ENVIRONMENT

The two sections belonging to the same succession, i.e. Bairam (100 m) and Belkher (90 m) show four distinct lithologies. The dominant lithounit is white to grayish-brown sandstone showing parallel beddings and cross beddings. The sandstone is coarse to fine grained, poorly to moderately sorted with subangular to subrounded grains and ferruginous cement. A few horizons are bioturbated. The lithological unit covers a 40-50 m thick lower part of the succession. This unit is overlain by 15-20 m sandstone similar to previous unit with interbedded lenticular bodies of mudstone ranging in length from 2-5 m and width up to 3 m. The mudstone is grayish-
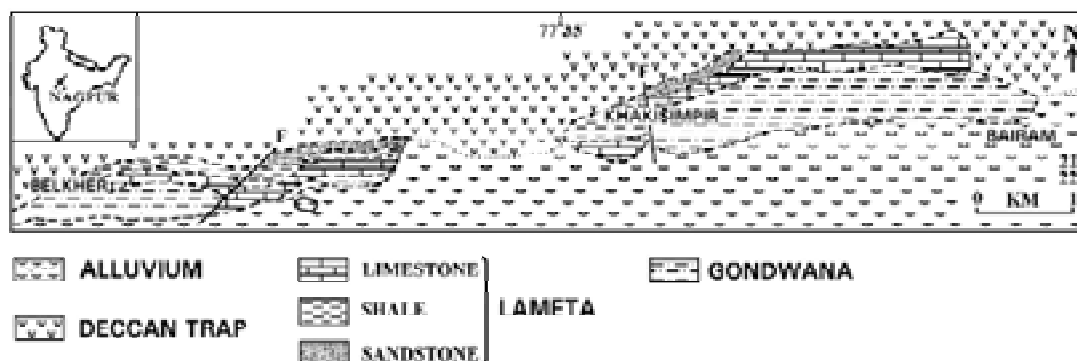
Fig. 1. Geological map of the area (Gadewar and Sukhtankar, 1990).

white, light to medium gray, medium bluish-gray in colour. It shows good preservation of pteridophyte and gymnosperm leaf impressions. The overlying 20-25 m thick succession consists of alternations of siltstone and mudstone. The siltstone is dirty white to light gray, cross laminated and parallel laminated bedded horizons of 0.5 cm to 1m thickness. The overlying 5-10 m top part is represented by conglomerate/grit.

On the basis of detailed sedimentological and lithological observations (Figs. 2a, b), the succession is categorized into four lithofacies which are more or less the major units of the succession viz., i) cross bedded and parallel bedded sandstone lithofacies, ii) sandstone-clay lithofacies, iii) siltstone-clay lithofacies and iv) conglomerate-grit lithofacies. On the basis of detailed lithofacies analysis, Srivastava *et al.* (2004b) interpreted it as a deposit of various subenvironments of a braided river system ranging from point-bar (lithofacies - i), point-bar and flood-plane (lithofacies - ii and iii) and channel-floor (lithofacies - iv).

SYSTEMATIC DESCRIPTION
Baroccoichnites Vyalov, 1971
(Pl. I, fig. 1)
Material: Two specimens; referred sample AU/G/R/11.

Description: Epichnial, densely-populated, horizontal to inclined burrows represented by U-shaped, curved or semicircular structures. Normally, they are represented by curved structures of uniform diameter ranging from 3 to 5 mm, both the ends of which, show tapering. The surface of the burrow is smooth; the infilling is fine grained, silty material as of the 5 to 10 mm thick layers on the top of a fine to medium grained ferruginous sandstone horizon of sandstone-clay lithounit.

Discussion: This ichnogenus is reported from the Upper Triassic of the Central Asia (Pamir) and interpreted as feeding structure of worm (Häntzschel, 1975). A preliminary report of the burrow has been made by Srivastava *et al.* (1996).

Cochlichnus Hitchcock, 1858
(Pl. I, fig. 2)
Material: One specimen; AU/G/R/12.

Description: Epichnial, meandering or wavy structure, entrenched, following the bedding plane. The burrow surface is smooth while the fill is similar to the host rock, i.e. yellowish-brown, fine to medium grained sandstone. The diameter of the burrow is 4 to 5 mm while the length is 70 cm. It is preserved in fine grained sandy horizon of sandstone-clay lithofacies.

Discussion: Hakes (1976) reported it from the Upper Pennsylvania of Kansas marginal marine and considered it repichnia and probably fodichnia of small worm like animals and, interpreted that *Cochlichnus*-producing animal represents an intermediate environment between fresh water and well developed brackish environment, which is mainly based on the record of traces from different environments. Miller (1984) reported it from the Channel Fill Sandstone of the Rock Castle Conglomerate of Lower Pennsylvanian and considered it a structure of transition zone where the fresh water body was freely connected by the seawater.

Lockeia James, 1879
(Pl. I, fig. 3)
Material: One sample having numerous structures; AU/G/R/13.

Description: Small almond shaped structures, preserved as convex hyporelief. Surface is smooth; length varies from 5 to 10 mm while the maximum width is 3mm. The host rock is a fine-grained, grayish-white horizon of cross-bedded and parallel- bedded sandstone.

Discussion: Chamberlain (1971) reported it from the shallow water Mississippian-Pennsylvanian rocks of Ouachita Mountain, southeastern Oklahoma. Häntzschel (1975) considered it a resting trace of bivalves, perhaps a semi-sessile form.

Palaeophycus Hall, 1847
(Pl. I, fig. 4)
Material: Two poorly preserved specimens; referred sample AU/G/R/14.

Description: Predominantly horizontal, straight or slightly curved, cylindrical burrows. Individual burrow may cross each other which sometimes gives an appearance of branching;

EXPLANATION OF PLATE I
(Scale: one centimeter)

1. Horizontal to inclined, curved surficial burrows of ***Baroccoichnites***.
2. Meandering, unbranched burrow of ***Cochlichnus***.
3. Almond-shaped burrows of ***Lockeia***.
4. Straight to slightly curved burrow of ***Palaeophycus***.
5. Cylindrical, infilled, straight burrows of ***Planolites beverleyensis***

associated with densely-packed, minute, elongated, curved, surficial burrows of insects.

6. ***Planolites montanus*** showing straight to slightly sinuous, unbranched burrows crossing each other.

Plate I

SRIVASTAVA
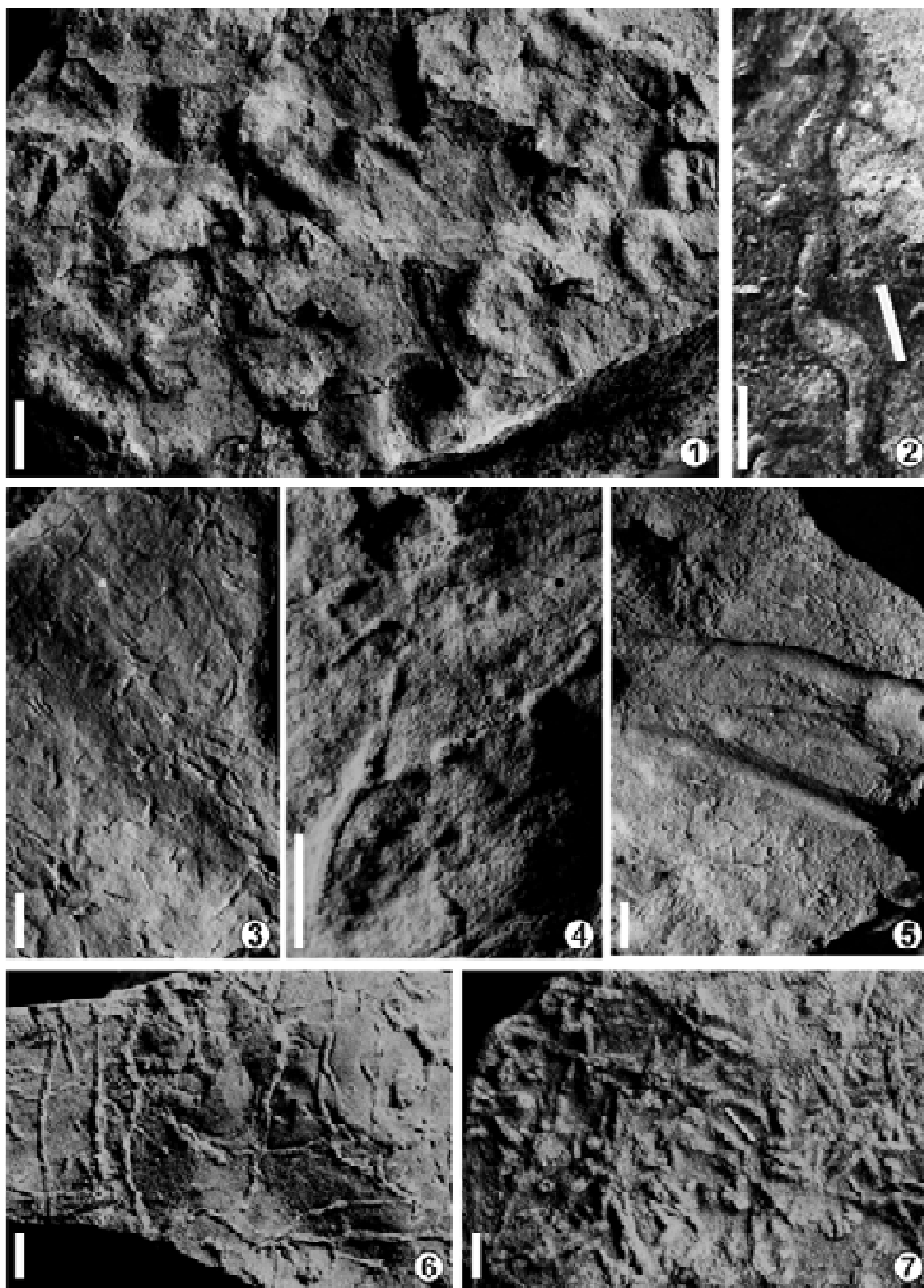
however, rare branching is also noticeable. The burrow surface is smooth but sometimes, minute longitudinal striations can be noticed. The burrow fill is structureless and is made up of the same sediments as of the host rock. A poorly preserved faint burrow lining can be noticed at one or two places. The length of the burrow is 13 cm while the diameter ranges from 2-3 mm. The burrow is preserved in siltstone of siltstone-clay lithofacies.

Discussion: *Palaeophycus* is a highly debatable ichnogenus regarding its possible trace maker and its behavioural pattern, i.e. repichnia of infaunal origin; pathways of various groups of errant animals, etc. (Häntzschel, 1975). Pollard (1981) reported *P. striatus* from the Triassic of Cheshire and south Germany and interpreted it as a surface burrow made by a bristled limbed invertebrate during locomotion. Miller (1984) in her actualistic model considered it a burrow occurring in non-marine to marine environments. This environmental interpretation is based on the association of *Palaeophycus* with *Scoyenia* ichnofacies reported from the Rock Castle Conglomerate, which shows fluvial origin or fluctuating salinity conditions within a coastal low sinuosity stream system. D' Alessandro *et al.* (1987b) reported *Palaeophycus* from the Duchense River Formation (Eocene), Utah and considered it a structure of moderately shallow burrowing infaunal arthropod, possibly a predatory crustacean or insect. Sarkar and Chaudhuri (1992) reported *Palaeophycus* from the Middle to Late Triassic fluvial Red Beds and considered it to occur in floodplain drainage system.

Planolites Nicholson, 1873

Material: One rock sample having numerous cylindrical burrows and a solitary spindle-shaped burrow; AU/G/R/15.

Description: Horizontal, straight to slightly sinuous, unbranched, cylindrical burrows preserved in epirelief or hyporelief.

The structure is associated with the spindle shaped burrows.

P. beverleyensis Billings, 1862
(Pl. I, fig. 5)

Material: One rock sample having two burrows of referred ichnotaxa associated with numerous insect burrows; AU/G/R/16.

Description: Distinguishable due to its relatively large size, straight to slightly curved, horizontal to slightly inclined, cylindrical, unbranched burrows, occasionally showing undulose to tuberous tendency, preserved parallel to the bedding plane. The burrow surface is smooth, while the fill is fine grained sandstone. Locally, the tapering of burrow ends can be noticed. The diameter is 4 to 6 mm. while length is up to 120 mm. The structure is preserved in siltstone of siltstone-clay lithounit.

The burrow is associated with densely packed, minute, cylindrical burrows of the insects.

P. montanus Richter, 1937
(Pl. I, fig. 6)

Material: Field observations and sample no. AU/G/R/17.

Description: Relatively small, epichnial, straight to slightly sinuous, smooth, horizontal, rarely branched burrows, which may show local undulose structures. It may cross each other. Burrow surface is smooth. The infilling material is fine-grained arenaceous material. The diameter ranges from 2 to 5 mm while length is up to 8 cm.

P. reticulatus Alpert, 1975
(Pl. I, fig. 7)

Material: Field observations and sample no. AU/G/R/18.

Description: Densely packed, horizontal, rarely curved, epichnial burrows; crossing-over present, which sometimes gives an appearance of branching. Locally, undulations can be noticed. The tapering of the burrow ends is also recorded. The surface is smooth while the fill is fine grained reddish-white sandstones. Burrow length varies from 0.5 to 2 cm while width is 1 to 2 mm.

Discussion: *Planolites* is a facies crossing trace fossil, widely reported from shallow to deep marine environments (Häntzschel, 1975). However, it is frequently reported from fluvial and lacustrine environments also (Chamberlain and Frey, 1976; Frey and Pemberton, 1984; Miller, 2007). *Planolites, P. beverleyensis* and *P. montanus* are reported from the Carboniferous to Permian flood plain deposits of Boskovice Basin, Czech Republic (Mikuláš, 1999; Mikuláš and Martínek, 2006). Smith *et al.* (2008) also reported *Planolites* sp. from the flood plains of Palaeocene-Eocene Willwood Formation, Wyoming. Raina *et al.* (1983) reported *P. reticulates* and *P. beverleyensis* from the Precambrian-Lower Cambrian shallow water marine deposits of Lolab valley of Kashmir Himalaya. Sanganwar and Kundal (1997) described it from the Nimar Sandstone Formation of Madhya Pradesh.

Rutichnus D' Alessandro *et al.*, 1987
(Pl. II, fig. 1)

Material: Two specimens; referred sample AU/G/R/19.

Description: Epichnial, cylindrical to subcylindrical branched burrows commonly following the bedding plane. Branching is frequently giving rise to two to three offshoots mostly of twig shape. The surface is irregular showing a faint tendency of rugose or undulose nature. The burrow fill is medium to fine grained, grayish-brown, silty material as of the host rock. The length of the burrow is 6 cm. while diameter ranges from 3 to 5 mm.

Discussion: The burrow shows similarity with *R. rutis* of D'Alessandro *et al.* (1987a), though the latter is reported from the Upper Permian, shallow marine sandstone, interbedded with siltstone, Central East Greenland. They interpreted that the possible mode of construction of the structure is by outward and return journey of a worm-like

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EXPLANATION OF PLATE II
(Scale: one centimeter)

1. Cylindrical, branching burrows of **Rutichnus**.
2. Long, bilaterally symmetrical trails of **Scolicia**.
3. Slender, unbranched burrow of **Scoyenia**, occasionally showing rope like structure.
4. Polished surface showing infilled burrows of **Skolithos**.
5. Deeply striated, cylindrical burrow of **Steinichnus.**
6. Feeding structures, top and bottom surfaces respectively marked by isolated hollow circular depressions on the top whereas, the bottom surface shows compressed circular openings.
7. Grazing traces showing unbranched, densely packed grooves.
8. Spindle-shaped burrow preserved on the top of the surface (Coin diameter = 2 cm).

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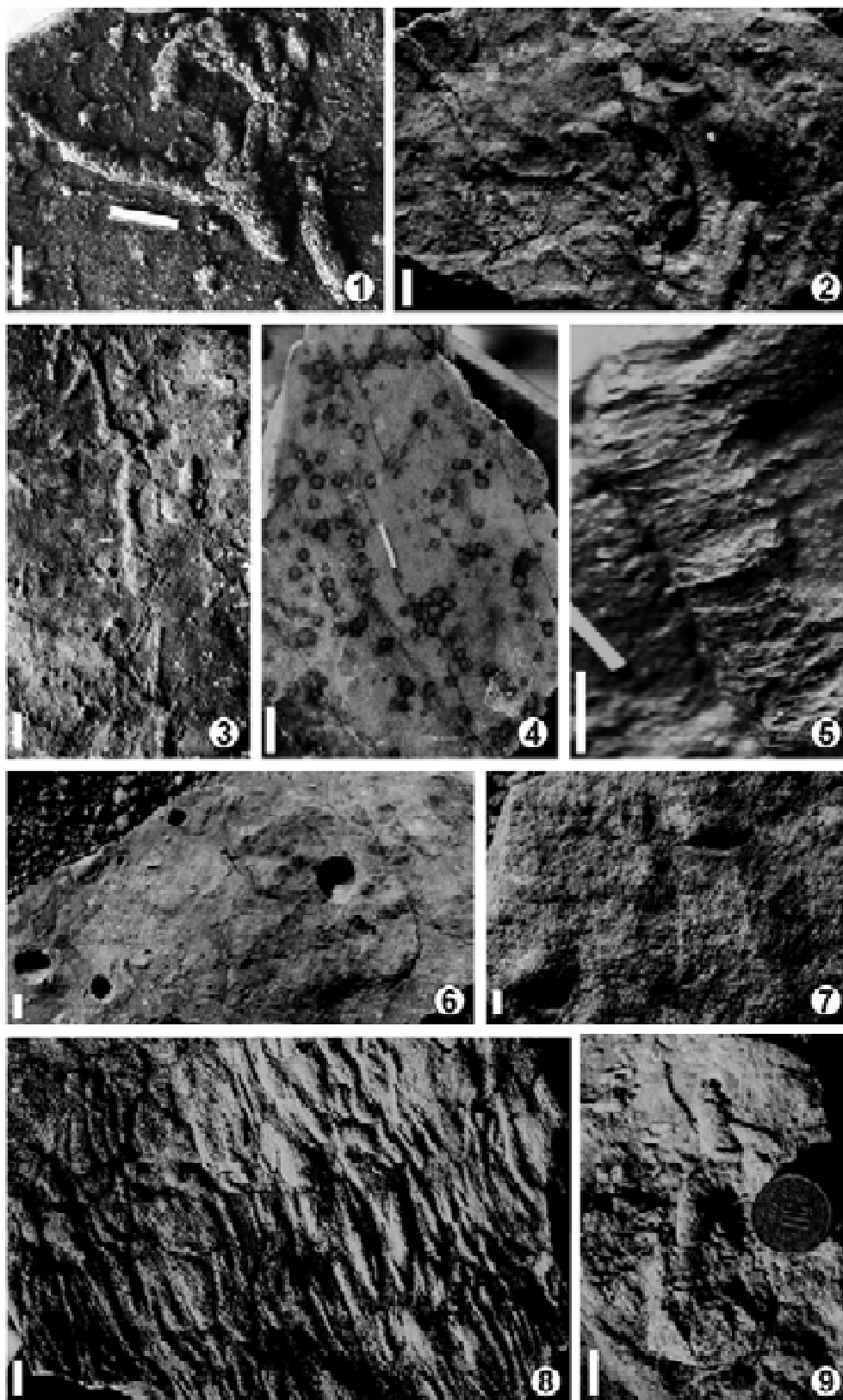
animal, i.e. a fodichnia of mobile deposit feeder.

Scolicia de Quatrefages, 1849
(Pl. II, fig. 2)

Material: One specimen; AU/G/R/20.

Description: Long, bilaterally symmetrical trail preserved on the top of the surface as positive epirelief. Locally, the structure shows a faint, median groove furrow of 2 mm width. Both the sides of the furrow are marked by 3-4 mm wide longitudinal ridges showing faint transverse striations. Length of the structure is 5 cm while the width is about 1 cm. The structure is poorly preserved in the silty horizon of siltstone-clay lithofacies.

Discussion: The *Scolicia* is considered as a trail produced by gastropods or other animal of similar habit (Häntzschel, 1975).

Scoyenia White, 1929
(Pl. II, fig. 3)

Material: Four specimens; referred sample AU/G/R/21.

Description: Endichnial and hypichnial slender burrows with rope like structure, straight to gently curved, unbranched, showing variable diameter ranging from 2 to 5 mm and length from 3 to 11 cms. Burrows are horizontal or inclined to the bedding plane. The burrow surface locally shows faint longitudinal striations with poor preservation while the fill is similar to the host material. The structure is preserved in 3 to 6 cms thick, fine-grained silty horizon of the siltstone-clay lithounit.

Discussion: *Scoyenia* is one of the important and common burrows of non-marine *Scoyenia* ichnofacies, probably produced by polychaetes (Häntzschel, 1975). Frey *et al.,* (1984) consider it as a feeding structure of arthropods (other than insects or decapods) which preferred moist or wet, non-marine substrate of shallow aquatic environment, periodically exposed to air or low-lying subaerial sediments and periodically inundated by water. Its non-marine fresh water occurrence has also been reported from the Duchense River Formation (Eocene), Utah (D'Alessandro *et al.,* 1987b).

Skolithos Haldemann, 1840
(Pl. II, fig. 4)

Material: Field observations, polished rock sample having numerous structures AU/G/R/22

Description: Pipe-like   structures,   unbranched, unornamented, closely spaced, vertical to inclined, sediment filled tubes, which are circular in cross-section. The burrow is infilled with the similar material as of the host rock but darker in colour. The host rock is medium-grained to fine-grained, yellowish-brown sandstone of the cross-bedded and parallel-bedded sandstone lithofacies. The diameter of the burrow ranges from 2 to 3 mm and length 10 to 30 mm.

Discussion: *Skolithos* is reported from the Gondwana exposures of India, i.e. the Barakar Formation, Hazaribagh, (De, 1993); the Talchir Formation in Raniganj (Guha *et al.,* 1994); coal-bearing successions of the Barakar and Raniganj formations of Son and Damodar valleys (Mukhopadhyay, 1994); Middle to Late Triassic fluvial red beds of Pranhita-Godavari valley (Sarkar and Chaudhuri, 1992) and Early Cretaceous Gondwana of Central India (Srivastava *et al.,* 1996). *Skolithos* is normally considered as a feeding-dwelling structure of suspension feeder and is widely reported from marine Palaeozoic

strata (Häntzschel, 1975). Its non-marine fresh water occurrences have been reported from the Duchense River Formation (Eocene), Utah, (D'Alessandro *et al.,* 1987b); Triassic fresh water deposit in Carlsberg Fjord, East Greenland (Bromley and Asgaard, 1979).

Steinichnus Bromley and Asgaard, 1979
(Pl. II, fig. 5)

Material: One poorly preserved specimen; AU/G/R/23

Description: Endichnial, vertical to subvertical, cylindrical burrow of 8 to 12 mm diameter. The burrow wall is deeply striated, transverse to the axis of the burrow, having a relief of up to 1mm. The burrow surface is darker in colour than the host material, which is light gray. The burrow fill is the same as of host material. Solitary specimen preserved in a lenticular body of clay in sandstone-clay lithounit.

Discussion: The trace fossil is comparable with the *S. carlsbergi* of Bromley and Asgaard (1979), reported from the Triassic fresh water deposit of Carlsberg Fjord, East Greenland. They considered it as a burrow of a terrestrial insect because the striae may be interpreted as deep excavation scratches produced by an arthropod, probably an insect.

Feeding structures
(Pl. II, figs. 6, 7)

Material: Field observations and two samples; AU/G/R/ 24, 25.

Description: These are represented by circular tube-like structures, vertical or inclined to the bedding plane. On the surface, it is represented by isolated hollow, circular or cylindrical structures of 1-2 cm diameter which may go up to 3 cm. depth; burrow fill is normally eroded, or, of the same material as of the host rock but differs in colour or sometimes in grain size. Locally, the burrow, initially vertical or inclined, may run parallel to the bedding plane after a depth of 1 to 2 cm. The structures are preserved in cross bedded and parallel bedded sandstone lithounit.

Discussion: Stanley and Fagerstorm (1974) reported horizontal feeding burrows and vertical passageways from the Miocene braided-river environment of western Neuraska, USA and interpreted that the trace maker may be a different type of beetles. However, the present taxa is comparable with *Solecurtus strigilatus* of Bromley (1990). Bromley (1990) made a detailed study of *S. strigilatus*, which is a cylindrical bivalve and prefers medium sand substrate in the shallow subtidal environment. The burrower makes the digging activity by the foot and have a very effective escaping tendency or excavating deeper or horizontally into the substrate. These behaviors produce different types of traces within or above the sediments.

Grazing traces
(Pl. II, fig. 8)

Material: One sample; AU/G/R/26.

Description: These are unbranched, non-overlapping densely packed grooves, furrows, showing dominantly parallel orientation with each other or sometimes, inclined or curved. The structure is preserved on the top surface of the bed. The length of the structure ranges from 1 to 5 cm while the width is 2 to 5 mm. The structure is preserved in medium grained, ferruginous sandstone of cross- and parallel-bedded sandstone lithofacies.

Discussion: Structure may be considered as a grazing trace

of lower group invertebrates.

Insect burrows
(Pl. I, fig. 5)

Material: AU/G/R/16.

Description: Densely packed, minute, surficial burrows preserved in epirelief following the bedding plane. The burrows are elongated, curved, and circular to elliptical with variable diameters ranging from 1 to 2 mm. Locally, the tapering of burrow ends is also noticed. Branching is very rare. Sometimes, a networking of different shapes is noticed because of dense population of the burrows. The burrow length ranges from 5 to 10 mm. Burrow fill is same as of the host rock. Burrow is preserved in 5 to 10 mm thick fine-grained sandy a layer in the medium grained ferruginous sandstone of cross bedded and parallel bedded sandstone lithofacies.

The structure is associated with *Planolites beverleyensis.*

Discussion: The structure is similar to the insect burrows reported by Singh (1978) from the Ganga river sediments.

Spindle-shaped structure
(Pl. II, fig. 9)

Material: AU/G/R/15

Description: Epichnial, elongated structures with tapering ends. The surface is smooth but sometimes fine annulations are present. The burrow fill is structureless consisting of yellowish-grey siltstone similar to the host rock. The length of the burrows range from 2 to 4 cm, while the maximum diameter at middle portion is 5 mm. The structure is preserved in siltstone horizon of siltstone-clay lithofacies.

The structure is associated with the feeding burrows of *Planolites*.

Discussion: The spindle shaped structures are normally considered as *Lockeia* as a resting trail of small burrowing pelecypods but the present specimen differs considerably because of its larger dimensions, hence, not comparable. It may be considered it as fodichnia of deposit feeding animal probably worm.

DISCUSSION AND CONCLUSIONS

Trace Fossil Horizons, Lithofacies Association and Depositional Environment

A total of seventeen trace fossils are recorded from three different lithostratigraphic horizons of the Early Cretaceous Gondwana succession. The distribution of trace fossils in vertical column, lithological details, lithofacies architecture and probable environment of deposition are as follows (Fig. 2);

i) Stratigraphically, the lowermost trace fossil horizon constitutes the uppermost 1-3 m of the cross bedded and parallel bedded sandstone lithofacies (Fig. 2, H-1). It is marked by the presence of *Skolithos,* feeding structures and grazing traces. The lithofacies is 40-50 m thick, consisting of cross-bedded and parallel-bedded, medium to coarse, yellowish to brownish sandstone. Srivastava *et al.* (2004b) interpreted it as a point-bar deposit based on bedding geometry as proposed by Reineck and Singh (1980) and Krzyszkowski (1992). The uppermost 1-3 m unit with rich preservation of trace fossils definitely shows a change of environment, which has promoted the growth of biotic community and preservation of their behavioural patterns.

ii) The second horizon is the interbedded, lenticular bodies of the clay in medium-grained sandstone (Fig. 2, H-2). The

ichnotaxa are fewer in number and are marked by *Steinichnus* and a few ill-preserved locomotary trails and resting marks. This sandstone-clay lithofacies is 15-20 m thick, overlying the cross-bedded and parallel-bedded sandstone lithofacies with abundant leaf impressions of pteridophytic flora. It is interpreted as a flood deposit in which small depressions acted as a site of deposition for fine sediments including the vegetational remains.

iii) The third horizon is the siltstone beds of the siltstone-clay lithofacies, which shows preservation of *Scoyenia*, *Cochlichnus*, *Rutichnus*, *Baroccoichnites*, *Lockeia*, *Planolites* sp., *P. beverleyensis*, *P. montanus*, *P. reticulates*, insect burrows, and spindle-shaped burrows (Fig. 2, H-3). This lithofacies covers 20-25 m thick succession, which is represented by alternations of horizontally bedded siltstone and clay of varying thickness ranging from 10-50 cm. The alternations of siltstone and clay show the prevalence of floodplain conditions when the flow velocity decreased (Krzyszkowski, 1992); and also the interchannel areas (Reading, 1986). The traces of diverse animal community indicate presence of rich organic matter during the time of deposition.

Trace Fossil Community and Palaeoecology

The lowermost trace fossil horizon (H-1) is marked by *Skolithos* and other feeding structures of invertebrates. The feeding structures are quite significant and show variety of morphological features, e.g. sand-filled tubes, circular to cylindrical hollow depressions, etc. Frey and Pemberton (1984) stated that the same animal produces different type of structures during different behaviour. Likewise, the feeding structures are comparable with the *Solecurtus* of Bromley (1990), which produces different traces in different behaviour.

Overall, the trace fossil producing community show both surface and burrowing activity; however, in the present case, mostly vertical or inclined burrows are preserved within the sediments. It is quite obvious that the same animal community might have also produced the surface feeding and locomotary structures, but because of high energy condition, these could not get preserved. The petrological study of the host rock also indicates the same as the sediments are medium to coarse grained, sub-angular to sub-rounded, indicating a medium to high energy conditions, where subsurface biogenic structures were more sustainable for preservation than surface structures.

The second horizon (H-2) is the pocketed occurrence of clay, which shows the presence *Steinichnus*. The taxa show similarity with the *S. carlsbergi* of Bromley and Asgaard (1979), for which the probable trace maker is the arthropod. Therefore, it can be interpreted that arthropods were one among the animal community inhabited during the deposition of fine-grained sediments of this horizon.

The maximum diversity of the trace fossils has been recorded from the uppermost horizon (H-3), which is a lithofacies of interbedded siltstone and mudstone. The siltstone horizon is marked by the presence of feeding structures of invertebrates, i.e. simple burrows of *Baroccoichnites, Cochlichnus, Planolites, Rutichnus, Scoyenia, Skolithos* and spindle-shaped structure, etc. However, the horizon is marked by abundant traces of *Planolites*. *Planolites* is a facies-crossing taxon reported from non-marine to marine environment ranging from shallow shelf to deep abyssal zone (Häntzschel, 1975; Frey and Pemberton, 1984; Kumar and
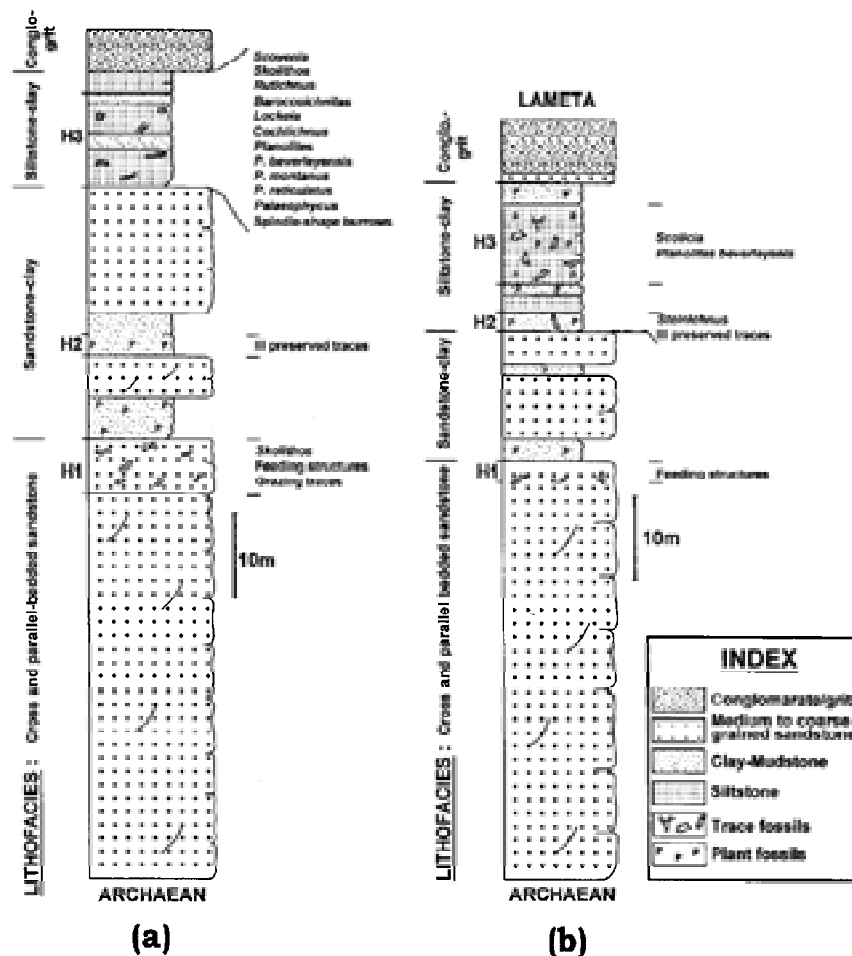
Fig. 2. Lithologs showing trace fossil horizons in the Bairam area (2a) and Belkher area (2b).

Srivastava, 1989). The solitary record of *Palaeophycus* and *Rutichnus* is significant as it is rarely reported from the fluvial environment (D'Alessandro *et al.,* 1987a, b). Considering the ethology of the trace-makers of the assemblage, it is evident that the community is dominantly composed of soft-bodied invertebrates.

Considering the assemblage in lithological context, it is noticed that the argillaceous sediments show the presence of arthropod community, whereas the siltstone and sandstone horizons are marked by simple, branched, meandering burrows and trails of lower invertebrates, probably the worms.

Scoyenia Ichnofacies

The placing of present trace-fossil assemblage in a particular ichnofacies needs a little discussion because of the diverse nature of the assemblage including certain uncommon taxa, which are normally considered specific to either fluvial or marine environments. The categorization of ichnofacies as proposed by Seilacher (1967) is mainly based on the behavioral pattern of trace-fossil assemblage, which is characteristic of specific environment. The only category, he specified for non-marine trace fossil is *Scoyenia* ichnofacies. The sedimentological and lithological details of the succession clearly reveal that it is a product of a braided river system including channel-floor, point-bar and flood-plain environments (Srivastava *et al.,* 2004a). The clay-mud unit of the succession with occasional preservations of traces contains rich and diversified pteridophytic flora indicating a fluvial environment.

Similarly, the siltstone horizons with a diverse ichnofauna are interbedded with the fossiliferous clay having leaf impressions. Therefore, it can be concluded that although the trace-fossil assemblage shows various uncommon taxa of the fluvial environment viz., *Lockeia, Palaeophycus, Planolites, Scolicia, Skolithos*, etc., even then, it can be placed into the *Scoyenia* ichnofacies of Seilacher (1967) because of their occurrences in fluvial deposit. However, the *Scoyenia* ichnofacies has been refined because of the wide range of environments covered initially in a single 'non-marine' category (Frey *et al.,* 1984, Frey and Pemberton, 1985, 1987; Smith *et al.,* 1993; Buatois and Mángano, 1995, 1998).

In view of the expanding boundaries both in number of ichnotaxa and depositional environments of the *Scoyenia* ichnofacies of Seilacher (1967), based on continental 'Red Beds', Frey *et al.* (1984) suggested to restrict the ichnofacies to the assemblage in which *S. graclis* and *Ancorichnus coronus* or their ethological equivalents dominate. Frey and Pemberton (1984). Frey and Pemberton (1984) considered the *Scoyenia* ichnofacies as an assemblage characteristic of non-marine clastic, moist to wet, argillaceous to sandy sediments at low energy sites, flood plains or an area intermediate between aquatic or non-aquatic terrestrial environments. Its characteristic trace fossils are small, horizontally lined, feeding burrows, trails and tracks, abundant insect and other arthropod traces However, further redefinement of the same ichnofacies by Frey and Pemberton (1987) includes those genera which are normally thought to be more typical of marine facies, e.g. *Cochlichnus, Scolicia, Skolithos*, etc.

Recent developments in the understanding of continental non-marine association, has led to the recognition of various trace fossil associations, i.e. fully terrestrial *Termitichnus* ichnofacies (Smith *et al.,* 1993); more or less predominantly exposed, continental *Coprinisphaera* ichnofacies (Genise *et al.,* 2000) and fluvial to lacustrine *Scoyenia* and *Mermia* ichnofacies (Buatois and Mángano, 1995, 1998). Buatois and Mángano (1995, 1998, 2007) tried to specify the ichnotaxa, ethology and depositional environment of *Scoyenia* and *Mermia* ichnofacies. Accordingly, the present assemblage is placed in the *Scoyenia* ichnofacies as it includes *Cochlichnus, Palaeophycus, Scoyenia, Skolithos,* etc. The arthropod track ways are also included in *Scoyenia,* though a major component of *Mermia* ichnofacies.

REPOSITORY

All the specimens are deposited in the museum of Geology Department, SGB Amravati University, Amravati – 444602.

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PALYNOSTRATIGRAPHY AND CORRELATION OF THE LOWER GONDWANA COAL-BEARING AND ASSOCIATED SEDIMENTS IN THE SATRAJPALLI AREA, GODAVARI GRABEN, ANDHRA PRADESH

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ABSTRACT

Palynological investigations in the sub-surface sediments of bore core GSP-1 and GSP-9 from the Satrajpalli area, Mulug coal belt, Godavari sub-basin have revealed presence of two palynoassemblages, one belonging to the Early Permian (Barakar) palynoflora and other belonging to the Late Permian (Raniganj) palynoflora. Assemblage-I is characterized by dominance of non-striate disaccate *Scheuringipollenites* and sub-dominance of striate disaccates, *viz. Striatopodocarpites* and *Faunipollenites*. The other taxa recorded in the assemblage include *Platysaccus, Ibisporites, Primuspollenites, Divarisaccus, Parasaccites, Indotriradites, Brevitriletes* and *Horriditriletes*. Assemblage-II is characterised by dominance of striate disaccates, chiefly, *Striatopodocarpites* and *Faunipollenites* along with presence of rare but stratigraphically significant taxa *viz., Strotersporites, Verticipollenites, Corisaccites, Hamiapollenites, Falcisporites, Crescentipollenites, Lunatisporites, Guttulapollenites, Kamthisaccites, Weylandites* and *Lundbladispora.*
The presence of the Lower Raniganj palynoflora has been demarcated in the lithologically designated Barren Measures Formation.

Keywords: Palynology, Lower Gondwana, Permian, Barakar, Raniganj, Godavari Graben.

INTRODUCTION

Godavari Graben - one of the biggest Gondwana basins in India- is the only coal-producing area in south India. Structurally, it has been subdivided into four sub-basins – Godavari, Kothagudam, Chintalapudi and Coastal Gondwana tract of the Krishna-Godavari sub-basin (Raja Rao, 1982).

About 15 coal belts have been identified in this Graben. Mulug coal belt is 140 km long linear track occupying southwest periphery of the central part of Godavari Graben. It is situated between the two active mining centres of Ramagundam in

northwest and Kothagudam in southeast. In order to prove that the coal-bearing sequence of Ramagundam should continue south-eastward, a regional exploration in the Bhopalpalli and the Chelpur areas was undertaken by Geological Survey of India and existence of workable coal seam was established. Exploration in the Satrajpalli area was taken up as north-westward continuation of the Bhopalpalli area of Mulug coal belt, where existence of workable coal seams was established.

Satrajpalli is situated in northwestern part of Mulug coal belt of Godavari Graben (Fig. 1). It is bordered to the southeast

Fig. 1. Geological map of Godavari Graben and the Satrajpalli area showing location of bore cores.
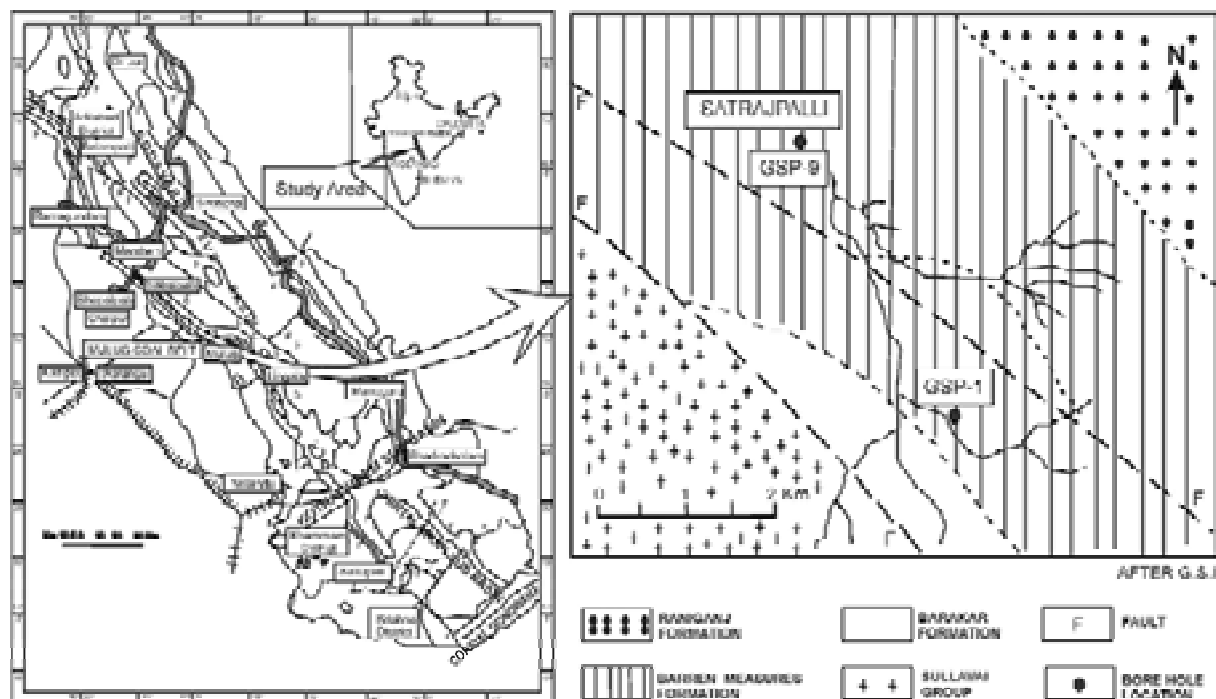
by the Bhopalpalli-Chelpur area, to the southwest by Gondwana Sullavai interface and to the northwest by Tadcherla block. The entire area is covered by Tadcherla reserved forest. It falls within the Tadcherla Mondal of Karimnagar district, Andhra Pradesh. A number of bore cores were drilled by Geological Survey of India in this region.

GEOLOGY

The area is geologically surveyed by Datta *et al.* (1989). Based on subsurface lithological data, occurrence of the Talchir Formation, Barakar Formation and Barren Measures Formation have been established. The area is segmented by two strike faults. The southern one is the northerly hading boundary fault that has juxtaposed the Barakar sediments against the Sullavai Formation omitting the Talchir strata. The northern one hades southwards with a throw of about 200m and has brought the Barakar coal seams of the northern segments at shallow depth (Datta *et al.*, 1989). Stratigraphic succession in the Satrajpalli area is as follows (after GSI).

> Barren Measures Formation
> Barakar Formation (Coal-bearing)
> Talchir Formation
>
> ————Unconformity————-
>
> Sullavai Formation
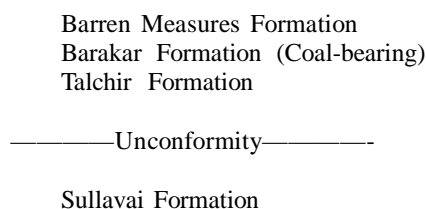
Two bore cores GSP-9 and GSP-1 were studied from the Satrajpalli area. On the basis of lithological attributes, the sediments from 365.70 to 147m in bore core GSP-9 have been designated as the Barakar Formation and the sequences above 147m have been designated as the Barren Measures Formation (Fig.2). The Raniganj or Kamthi Formation has not been defined in the area. The borehole was closed at 385.20m.

Bore hole GSP-1 was scout bore hole. Four samples of carbonaceous shale were received for palynological studies.

MATERIAL AND METHODS

27 samples were collected from different lithologies mainly consisting of clay, grey shale, coal, carbonaceous shale and sandstone. Bore holes GSP-1 and GSP-9 were drilled by Geological Survey of India (GSI) form Satrajpalli area. The lithological details of samples along with the depth in both the borecores i.e. GSP-9 and GSP-1 have been shown in Fig. 2. Out of 27 samples, 23 yielded palynomorphs. The vertical distribution of various palynotaxa in the samples yielding palynomorphs in countable numbers have been represented in histograms (Figs. 4&5).

Recovery of palynomorphs from the rock samples was accomplished by usual maceration technique. About 10-20 gm of the material from each sample was taken and mashed into peanut-sized pellets in an iron mortar and pestle. The material was initially treated with conc. hydrofluoric acid (HF) for two days to remove silica content, followed by treatment with commercial nitric acid (HNO_3) for 3-4 days for digestion of humic matter. Finally, after thorough washing with water, samples were treated with 10% potassium hydroxide (KOH) to get clear palynomorphs. All samples were checked under microscope at each step of maceration before further treatment. The material was then mounted in Canada balsam with the help of Polyvinyl Chloride (PVC). The slides were scanned and studied under Olympus BX62 microscope. The palynological succession of these bore cores, as represented by the palynofloral assemblages through the sediments in the Satrajpalli area of Godavari Graben, has been investigated for their qualitative composition and quantitative abundance after the count of 200 specimen in each sample.

PALYNOLOGY

Palynoflora recovered from the subsurface sediments of the Satrajpalli area consists of 35 genera and 39 species comprising alete, triletes, monosaccates, striate disaccates and non-striate disaccates. Two distinct palynoassemblages have been recognized on the basis of quantitative and qualitative distribution of various palynotaxa (Figs. 3 and 4). Spore pollen species recorded in the Early and Late Permian palynoflora of the Satrajpalli area have been listed in table 1. Nicely preserved, stratigraphically significant taxa have been shown in plate-1.

ASSEMBLAGE-I

The Assemblage-I, identified in bore core GSP-9 at 240.20-114m and GSP-1 at 96.75-158.25m, consists of dominance of non-striate disaccate *Scheuringipollenites* (38-76%) and sub-dominance of striate disaccates *Faunipollenites* (4-23%) and *Striatopodocarpites* (1-15%). Triletes are represented by *Lophotriletes* (12%), *Brevitriletes* (1-8%)*, Callumispora* (1%), *Horriditriletes* (1-8%)*, Indotriradites* (8%), *Didecitriletes* (8%), *Lacinitriletes* (1%), *Pseudoreticulatispora* (1%). Monosaccates include *Parasaccites* (1-15%), *Divarisaccus* (1%), *Caheniasaccites* (1%), *Densipollenites* (1%), *Striomonosaccites* (1%). Other palynotaxa present in the assemblage are *Ibisporites* (4-14%), *Platysaccus* (2-8%), *Verrucosisporites* (3%), *Verticipollenites* (5%), *Schizosporis* (2%), *Laevigatosporites* (1%), *Schizopollis* (1%) *Leiotriletes* (1%), *Primuspollenites* (1%) and *Lophotriletes* (1%). Besides these, *Ginkgocycadophytus, Tiwariasporis, Callumispora* and *Maculatasporites* are also present.

ASSEMBLAGE-II

Present Assemblage-II, demarcated at 85.04-104.80m in bore core GSP-9, consists of dominance of striate disaccates chiefly *Faunipollenites* (36%) and *Striatopodocarpites* (33%) rare but stratigraphically significant palynotaxa present in this assemblage in low percentage are *Falcisporites* (2-4%), *Crescentipollenites* (2%), *Hamiapollenites* (1-6%), *Klausipollenites* (2-3%), *Distriatites* (1%), *Marsupipollenites* (2%), *Lundbladispora* (2%), *Densipollenites* (4%), *Lunatisporites* (1-6%), *Weylandites* (1-3%)*, Striatites* (2-3%), *Polypodiidites* (1%), *Corisaccites* (1%), *Strotersporites* (1%)*, Chordasporites* (1%). Other palynotaxa present in the assemblage are *Alisporites* (2-9%), *Scheuringipollenites* (5-15%), *Platysaccus* (5%), *Verrucosisporites* (3%), *Parasaccites* (1-2%), *Brevitriletes* (2%), *Lophotriletes* (1%), *Horriditriletes* (1%), and *Verticipollenites* (1-2%). Besides these genera, *Guttulapollenites, Kamthisaccites* and *Striomonosaccites* have also been recorded.

DISCUSSION AND CORRELATION

In the present study, two stratigraphically different palynoassemblages have been identified in the bore core GSP-9 and GSP-1. Assemblage-I, identified at 240.20-114m in bore core GSP-9 and at 96.75-158.25m in bore core GSP-1, shows dominance   of   non-striate   disaccates   chiefly,
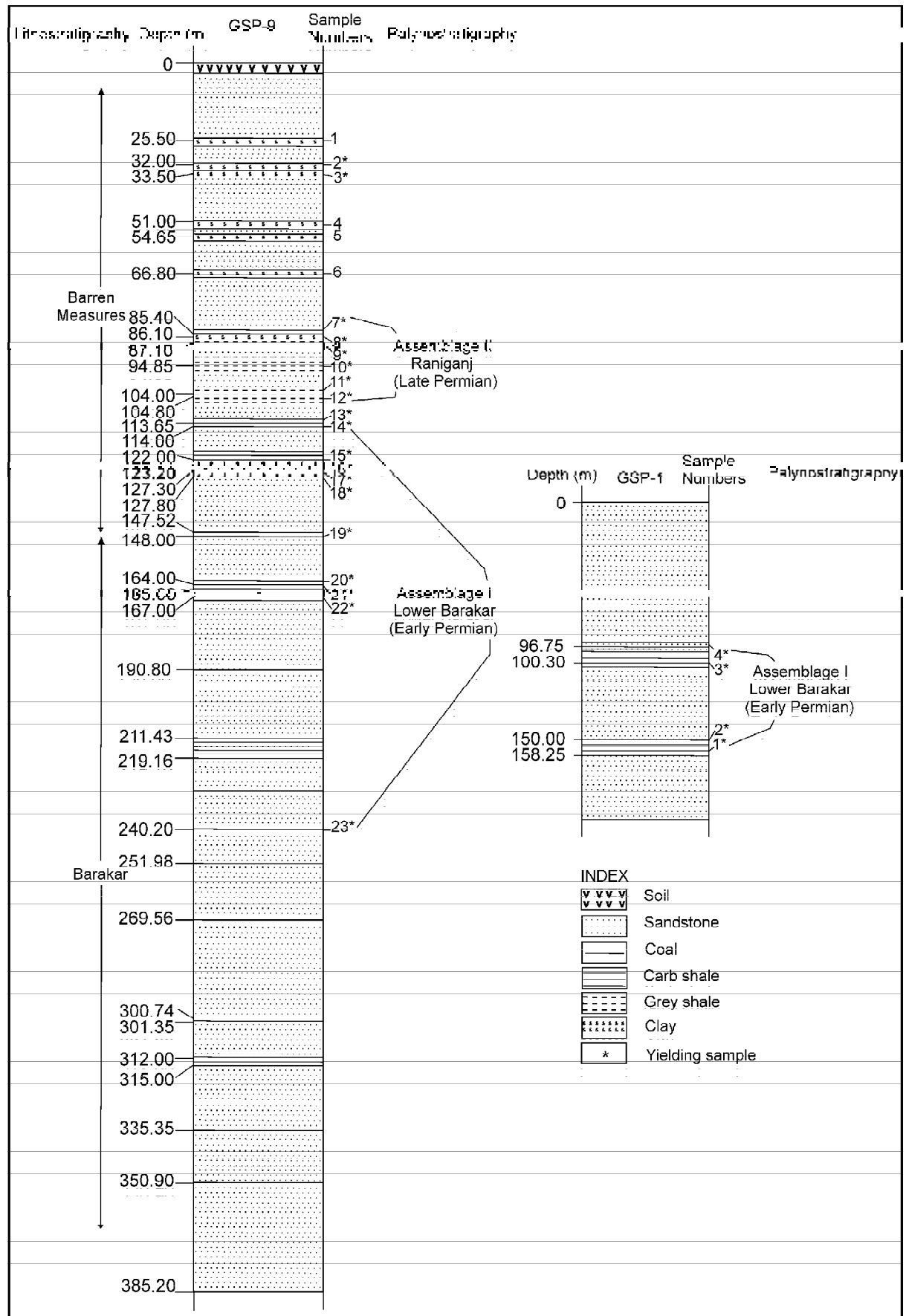
Fig. 2 Lithology of bore core GSP-9 and GSP-1 showing positions of samples and palynoassemblages.

Table 1: showing spore-pollen species in the Early Permian (Barakar) and Late Permian (Raniganj) sediments of the Satrajpalli area, Godavari Graben.

EARLY PERMIAN
Triletes
Indotriradites sparsus Tiwari, 1965
Leiotriletes sp.
Lophotriletes rectus Bharadwaj and Salujha, 1964
Horriditriletes rampurensis Tiwari, 1968
Brevitriletes communis Bharadwaj and Srivastava emend Tiwari and Singh, 1981
B. unicus (Tiwari) Bharadwaj and Srivastava emend Tiwari and Singh, 1981
Pseudoreticulatispora sp.
Verrucosisporites sp.
Callumispora sp.
Didecitriletes sp.
Lacinitriletes sp.
Monosaccates
Densipollenites invisus Bharadwaj and Salujha, 1964
Divarisaccus lelei Venkatachala and Kar, 1966
Caheniasaccites distinctus Lele and Makada, 1972
Parasaccites korbaensis Bharadwaj and Tiwari, 1964
P. obscurus Tiwari, 1965
P. distinctus Tiwari, 1965
Striomonosaccites sp.
Non striate disaccates
Scheuringipollenites maximus (Hart) Tiwari, 1973
S. barakarensis (Tiwari) Tiwari, 1973
S. tentulus (Tiwari) Tiwari, 1973
Ibisporites jhingurdahiensis Sinha, 1972
I. diplosaccus Tiwari, 1968
Platysaccus sp.
Striate disaccates
Striatites communis Bharadwaj and Salujha, 1964
Verticipollenites sp.
Striatopodocarpites tiwarii Bharadwaj and Dwivedi, 1981
S. solitus Bharadwaj and Salujha, 1964
S. diffusus Bharadwaj and Salujha, 1964
S. decorus Bharadwaj and Salujha, 1964
Faunipollenites varius Bharadwaj, 1962
F. bharadwajii Maheswari, 1967
Schizopollis sp.
Primuspollenites levis Tiwari, 1964
Others
Laevigatosporites colliensis (Balme and Hennelly) Venkatachala and Kar, 1968
Tiwariasporis gondwanensis (Tiwari) Maheshwari and Kar, 1967
Ginkgocycadophytus sp.
Schizosporis sp.

LATE PERMIAN
Triletes
Lophotriletes rectus Bharadwaj and Salujha, 1964
Horriditriletes rampurensis Tiwari, 1968
H. ramosus (Balme and Hennelly) Bharadwaj and Salujha, 1964
Brevitriletes communis Bharadwaj and Srivastava emend Tiwari and Singh, 1981
B. unicus (Tiwari) Bharadwaj and Srivastava emend Tiwari and Singh, 1981
Verrucosisporites gondwanensis Srivastava, 1970
Lecinitriletes sp.
Lundbladispora raniganjensis (Tiwari and Rana, 1981)

L. microconata (Bharadwaj and Tiwari, 1977)
Monosaccates
Densipollenites indicus Bharadwaj, 1962
D. invisus Bharadwaj and Salujha, 1964
Parasaccites korbaensis Bharadwaj and Tiwari, 1964
P. obscurus Tiwari, 1965
P. distinctus Tiwari, 1965
Kamthisaccites kamthiensis Srivastava & Jha, 1986
Striomonosaccites sp.
Non striate disaccates
Scheuringipollenites maximus (Hart) Tiwari, 1973
S. barakarensis (Tiwari) Tiwari, 1973
S. tentulus (Tiwari) Tiwari, 1973
Ibisporites jhingurdahiensis (Sinha, 1972)
I. diplosaccus Tiwari, 1968
Platysaccus plicatus (Bharadwaj and Dwivedi, 1981)
P. papilionis (Potonié and Klaus, 1954)
P. densicorpus (Anand Prakash, 1972)
Alisporites indarraensis (Segroves, 1969)
Chordasporites sp.
Klausipollenites sp.
Falcisporites nuthallensis (Clarke, Balme, 1970)
Falcisporites stabilis Balme, 1970
Falcisporites sp.
Taeniate disaccates
Lunatisporites diffusus (Bharadwaj and Tiwari, 1977)
L. ovatus (Goubin) Maheshwari and Banerji, 1966
L. pellucidus (Goubin, 1965) Maheshwari and Banerji, 1975
Corisaccites alutas Venkatachala and Kar, 1966
Corisaccites distinctus Venkatachala and Kar, 1968
Guttulapollenites hannonicus Goubin, 1965
Hamiapollenites minimus (Jha, 1996)
Striate disaccates
Striatites communis Bharadwaj and Salujha, 1964
S. solitus Bharadwaj and Salujha, 1964
Verticipollenites secretus Bharadwaj, 1962
V. finitimus Bharadwaj and Salujha, 1964
Striatopodocarpites tiwarii Bharadwaj and Dwivedi, 1981
S. diffusus Bharadwaj and Salujha, 1964
S. multistriatus Jha, 1996
S. labrus Tiwari, 1965
S. globosus (Maheshwari) Bharadwaj and Dwivedi, 1981
Faunipollenites varius Bharadwaj, 1965
F. bharadwajii Maheshwari, 1967
F. parvus Tiwari, 1965
F. goraensis (Potonié and Lele) Maithy, 1965
Strotersporites crassiletus Jha, 1996
Distriatites insolitus Bharadwaj and Salujha, 1964
Cresentipollenites globosus Maithy and Jha, 1996
C. fuscus (Bhardwaj) Bharadwaj, Tiwari and Kar 1974
C. brevis (Bose and Kar) Bhardwaj, Tiwari and Kar 1974
C. gondwanensis (Maheshwari) Bharadwaj, Tiwari and Kar 1974
Others
Laevigatosporites colliensis (Balme and Hennelly, 1956) Venkatachala and Kar, 1968
Polypodiidites sp.
Inaperturopollenites sp.
Schizosporis sp.
Weylandites circularis Bharadwaj and Srivastava, 1969
Marsupipollenites sp.
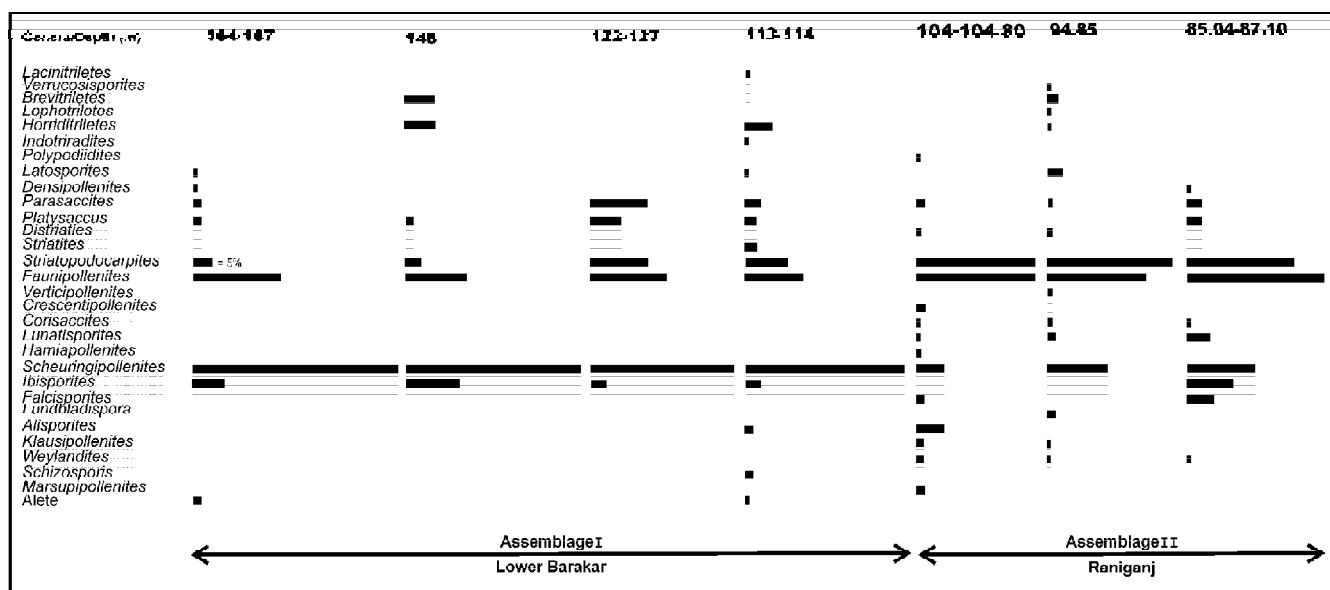
Fig. ? dendrogram showing vertical distribution of different genera recorded in the bore core GSP-9.

Scheuringipollenites, while Assemblage-II, identified in the bore core GSP-9 at the depth of 85.04-104.80m, shows dominance of striate disaccates chiefly *Faunipollenites* and *Scheuringipollenites*.

In the Lower Gondwana palynological succession, dominance of *Scheuringipollenites* has been observed in the Early Permian Lower Barakar palynoflora. Hence, Assemblage-I showing dominance of *Scheuringipollenites* and subdominance of striate disaccates belongs to Early Permian (Barakar Formation). The striate disaccates *viz.*, *Faunipollenites* and *Striatopodocarpites* which remain subdominant in the Lower Barakar attain dominance in the Upper Barakar sequence and remain the dominant component of palynoflora up to the Raniganj Formation. Hence, they loose the stratigraphic significance and the associated taxa become more important while identifying the palynoassemblages in the younger formations of Late Permian time. The dominance of striate disaccates in Assemblage-II along with stratigraphically significant taxa *viz.*, *Falcisporites*, *Guttulapollenites*, *Kamthisaccites*, *Crescentipollenites*, *Hamiapollenites*, *Klausipollenites*, *Distriatites*,

Fig. ? Histogram showing vertical distribution of different genera recorded in the bore core GSP-9.

Marsupipollenites, *Densipollenites*, *Lunatisporites*, *Weylandites*, *Polypodiidites*, *Corisaccites* indicates the Late Permian (Raniganj) age. Besides, some stratigraphically significant species *Strotersporites crassiletus*, *Kamthisaccites kamthiensis* and *Striatopodocarpites multistriatus* which are restricted to Late Permian (Jha, 1996) have also been recorded in the present Assemblage-II. Hence, Assemblage-II belongs to Late Permian (Raniganj) palynoflora.

Palynoassemblage-I of the Satrajpalli area compares well with the Lower Barakar palynoassemblage of the Budharam area (Srivastava and Jha, 1995), Ramkrishanpuram (Srivastava and Jha, 1992) and Manuguru area (Srivastava and Jha, 1992) and is equivalent to *Scheuringipollenites barakarensis* Assemblage Zone of Tiwari and Tripathi, 1992.

Assemblage-II of Satrajpalli area compares with the Palynoassemblage-7 of Budharam area (Srivastava and Jha, 1995), Playnoassemblage-4 of Manuguru area (Srivastava and Jha, 1992). Assemblage-I of Gattugudem (Jha, 2002) and Bottapagudem area (Jha, 2004) of the Chintalapudi Basin. Present Assemblages II is correlatable with the Assemblage I of Chelpur area (GJ-3) in having dominance of striate disaccates along with occurrence of some significant forms *viz. Falcisporites*, *Klausipollenites*, *Lunatisporites* and *Marsupipollenites* in rare percentage. Assemblage-II of the Satrajpalli area also resembles Assemblage I of Bhopalpalli (Fig. 5) in having dominance of striate disaccates and presence of significant forms such as *Falcisporites, Lunatisporites, Crescentipollenites, Corisaccites* and *Hamiapollenites*. Existence of Lower Raniganj palynoflora has already been established in the Chelpur (borecore GJ-3, Srivastava and Jha, 1987) and Bhopalpalli areas (borecore GJ-6, Srivastava and Jha, 1998) of Mulug coal belt, Godavari Graben. Palynological correlation of various assemblages identified in different areas (Chelpur, Bhopalpalli, Satrajpalli) of Mulug coalbelt has been shown in fig.5. This assemblage can be accommodated in *Striatopodocarpites + Faunipollenites*, zone A of Tiwari and Tripathi, 1992.

Outside Godavari Graben, the Assemblage-II also compares well with the palynoflora of Jhingurdah seam in
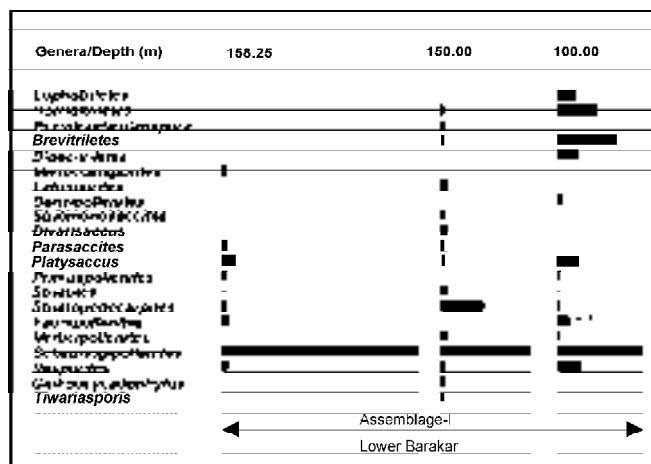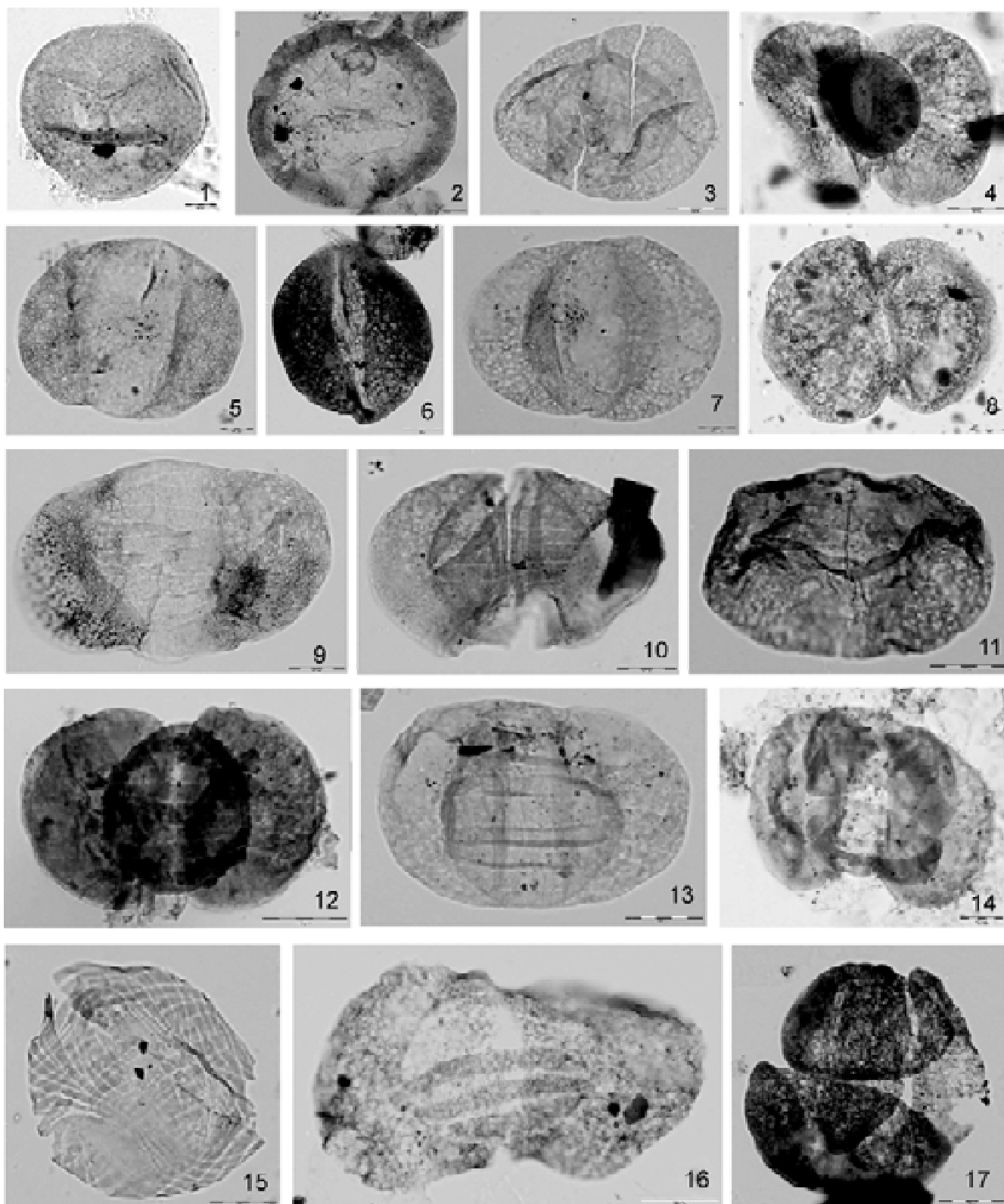
Table 2: showing palynocomposition of samples from bore core GSP-9.

Sample nos.	Depth (m)	Formation	Palynocomposition	Palynozones	Age
2-3	32.00-33.50	**B A R R E N M E A S U R E S**	Rare presence of *Striatopodocarpites* and *Faunipollenites*		
7-9	85.04-87.10		Dominance of *Striatopodocarpites* and *Faunipollenites* along with subdominance of some nonstriate disaccates *viz., Scheuringipollenites, Ibisporites* and *Falcisporites*.	=(*Striatopodocarpites + Faunipollenites*, zone A) Tiwari and Tripathi, 1992	**R A N I G A N J**
10	94.85		Dominance of *Striatopodocarpites* and *Faunipollenites* along with some striates, and some significant forms *viz., Klausipollentes* and *Lundbladispora*.		
11-12	104-104.80		Dominance of *Striatopodocarpites* and *Faunipollenites* alongwith some associated taxa *viz., Verticipollenites, Crescentipollenites, Corisaccites, Lunatisporites, Hamiapollenites, Scheuringipollenites, Falcisporites, Klausipollentes, Weylandites* and *Marsupipollenites, Distriatites, Polypodiidites* and *Parasaccites*.		**L A T E P E R M I A N**
13-14	113-114	**B A R A K A R**	Dominance of non striate disaccate *Scheuringipollenites* alongwith sub dominance of striate disaccates *Faunipollenites, Striatopodocarpites*. While associated taxas are *Ibisporites, Alisporites, Schizosporis, Striatites, Platysaccus, Parasaccites, Latosporites, Horriditrileres* and *Lacinitrileres*.	=(*Scheuringipollenites barakaren-sis* zone) Tiwari and Tripathi, 1992	**B A R A K A R**
15-18	122-127		Dominance of non striate disaccate *Scheuringipollenites, Ibisporites* and sub dominance of striate disaccates *Faunipollenites, Striatopodocarpites*. Other taxa present in these samples are *Platysaccus* and *Parasaccites*.		**E A R L Y P E R M I A N**
19	148		Dominance of non striate disaccate *Scheuringipollenites, Ibisporites* and sub dominance of striate disaccates *Faunipollenites, Striatopodocarpites*. Other associated taxas are *Platysaccus, Horriditrileres* and *Brevitrileres*.		
20-22	164-167		Dominance of non striate disaccate *Scheuringipollenites, Ibisporites* and sub dominance of striate disaccates *Faunipollenites, Striatopodocarpites*. Other associated taxas are *Latosporites, Densipollenites, Platysaccus* and *Parasaccites*.		
23	240.20		Abundance of trachides but poor in spore and pollen in having *Scheuringipollenites, Paltysaccus, Striatopodocarpites* and *Faunipollenites*.		

Singrauli coalfield (Tiwari and Srivastava, 1984) in occurrence of younger elements *viz., Falcisporites, Gondisporites, Lunatisporites, Corisaccites* besides dominance of striate disaccates. *Densipollenites* is sporadic in both the Assemblages. Assemblage-II can also be compared with Raniganj palynoflora of Auranga coalfield (Lele and Srivastava, 1979). The Assemblage-II, of borehole RNM-2 (Tiwari and Rana, 1984) from east Raniganj shows in having dominance of striate disaccates. However, some of the forms which appear in Raniganj palynoflora of Godavari Graben, *viz- Falcisporites, Klausipollenites,* are absent in the assemblages from Raniganj and Auranga coalfield.

CONCLUSIONS

1. Occurrence of two Assemblages has been recorded in the Satrajpalli area, one belonging to the Early Permian (Barakar Formation) and other belonging to the Late Permian (Raniganj Formation).
2. Presence of this Raniganj palynoflora has been demarcated in the lithologically designated Barren Measures Formation. Thus, presence of Raniganj equivalent sediments has been recorded in the Satrajpalli area on the basis of present palynological studies.

EXPLANATION OF PLATE I

1. *Lunbladispora microconata*, BSIP Slide no., 13983, Q51-1,
2. *Kamthisaccites kamthiensis*, BSIP Slide no., 13984, R46,
3. *Striomonosaccites* sp., BSIP Slide no., 13985, Q58,
4. *Platysaccus densicorpous*, BSIP Slide no., 13986, F66-3,
5. *Klausipollenites* sp., BSIP Slide no., 13984, P33-4,
6. *Scheuringipollenites maximus*, BSIP Slide no., 13987, P41-1,
7. *Falcisporites stabilis*, BSIP Slide no., 13988, F56-4,
8. *Ibisporites* sp., BSIP Slide no., 13986, O67-3,
9. *Striatopodocarpites* sp., BSIP Slide no., 13984, T66-2,
10. *Crescentipollenites fusus*, BSIP Slide no., 13985, Q55-1,
11. *Strotersporites crassiletus*, BSIP Slide no., 13989, G43-2,
12. *Striatites communis*, BSIP Slide no., 13990, O39-4,
13. *Crescentipollenites fusus*, BSIP Slide no., 13988, G36-1,
14. *Corisaccites distinctus*, BSIP Slide no., 13991, H50-4,
15. *Weylandites circularis*, BSIP Slide no., 13985, N45-2,
16. *Lunatisporites pellucidus*, BSIP Slide no., 13991, P52-4,
17. *Guttulapollenites hannonicus*, BSIP Slide no., 13991, K60.

Plate I

Fig. 4. Diagrammatic representation of palynological correlation of bore cores GSP-9, GSP-1 (Satrajpalli), GJ-3 (Chelpur) and GJ-6 from Bhopalpalli area of Mulug coal belt

Table 3: showing palynocomposition of samples from bore core GSP-1.

Sample nos.	Depth (m)	Formation	Palynocomposition	Palynozones	Age
4	96.75	B A R A K A R	Poorly yielded with presence of *Scheuringipollenites*, *Faunipollenites* and *Striatopodocarpites*	=(*Scheuringipollenites barakaren-sis* zone) Tiwari and Tripathi, 1992	E A R L Y P E R M I A N
3	100.30		Dominance of non striate disaccate *Scheuringipollenites* along with subdominance of *Ibisporites* with good percentage of triletes.	Lr. B A R A K A R	
2	150.00		Dominance of nonstriate disaccate *Scheuringipollenites* along with subdominance of striates *viz.*, *Striatopodocarpites, Striatites, Verticipollenites*. Beside it some monosaccates and triletes are also present		
1	158.25		Dominance of non striate disaccate *Scheuringipollenitessis* along with *Ibisporites, Platysaccus, Parasaccites, Primuspollenites* and very few striates *viz.*, *Striatopodocarpites* and *Faunipollenites*.		

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PALYNOFOSSILS FROM THE MIDDLE SIWALIK SEDIMENTS OF NEPAL WITH REMARKS ON AGE AND PALAEOENVIRONMENT

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ABSTRACT

A rich palynofloral assemblage has been recovered from the Middle Siwalik sediments exposed at west of Tapt Kund near Rehar on Lamahi – Nepalganj road, Nepal. The palynofloral assemblage mainly consists of algal zygospores, fungal spores and conidia, pteridophytic spores, gymnospermous and angiospermous pollen; in all, 52 species belonging to 45 genera have been recorded. Quantitatively, the assemblage is dominated by pteridophytic spores followed by gymnospermous pollen. Occurrences of fungal spores and conidia along with microthyraceous ascostromata in large quantity throughout the succession suggest the prevalence of a warm, humid, subtropical climate during the deposition of the Middle Siwalik sediments in the area of investigation. The sediments seem to have been deposited under fresh water conditions. Comparative study of this assemblage with the known Middle Siwalik palynofloral assemblages from Nepal and India points out that it may perhaps belong to late Late Miocene age.

Keywords: Palynofossils, Middle Siwalik, late Miocene, Nepal, Palaeoenvironment

INTRODUCTION

The Siwalik Group of rocks form the foothills along the entire Himalayan margin of Nepal of a length of ca 800km from Mahakali in the west to the east of Arun river in the East. They consist of molasses sediments of sandstones, mudstones, shales and claystones.

They are deposited during the last ca. 15 million years as erosional debris from the rising Himalayas into the foredeep basin along the foot of the mountains. The Siwalik Group of rocks in Nepal is well known for its abundant mammalian fossils and several papers have been published on geological and palaeontological aspects (Hagen, 1969; Itihara et al.,1972; Yoshida and Arita, 1982; Mascle and Herail, 1982; Herail et al., 1986; Delcailau et al., 1987; Takuoka et al., 1986, 1988; Corvinus,1994; Corvinus and Nanda, 1994; Corvinus and Rimal, 2001) However, very little palynological information is known from the Siwalik sediments of Nepal. Mathur (1973) for the first time reported a Lower Siwalik palynofloral assemblage from the Tharukhola-Chepang area of Nepal. In recent years, some information regarding the Siwalik palynoflora from Nepal have been gathered (Mathur, 1984 ; Sarkar, 1990; Awasthi et al, 1994 and Hoorn et al., 2000). During palynological investigation of the Siwalik Group of rocks in the Surai Khola and its adjoining areas of Nepal, we have recovered a rich palynofloral assemblage from the Siwalik sediments exposed at Tapt Kund (Hot water spring) near Rehar. The objective of the present communication is to record palynofossils from the Middle Siwalik sediments exposed at a new locality and also to evaluate their bearing on palaeofloristics, palaeoclimate and palaeoenvironment in the area of investigation.

GEOLOGICAL SETTING

The Siwalik Group of rocks was deposited under fluviatile/lacustrine conditions in the fore deep of the southern side of the rising Himalaya. In Nepal, they are generally known as the Churia Group after the Churia Hills. About 8000m thick molasse sediments of the Siwalik Group of rocks in Nepal can be conveniently divided into three major stratigraphic divisions based on lithology viz., Lower, Middle and Upper Siwalik. Detailed work on lithostratigraphy, palaeontology, magnetostratigraphy of the Siwalik Group of rocks at Surai Khola and its adjoining areas have been carried out by several workers (Adhikary,1993 ; Appel et al., 1989; Appel et al.,1991; Corvinus, 1988; Corvinus and Nanda,1994; and Corvinus and Rimal, 2001). All subgroups of the Siwalik Group of rocks are represented in this area. viz., upper part of the Lower Siwalik and Middle and Upper Siwalik. These have been divided into five lithological units which in ascending order of stratigraphy are the Bankas, Chor Khola, Surai Khola, Dobatta and Dhan Khola formations (Corvinus and Nanda, 1994). The lowermost Bankas Formation consists of variegated claystones, mottled sandstones and shales and of smaller intercalated beds of hard, fine-grained sandstones. The middle part of the succession is composed of multistoried micaceous sandstones while the sediments of the Chor Khola Formation show a gradual increase of calcareous sandstones. The sandstone increases in the overlying Surai Khola Formation. They form massive thick banks of coarse, soft micaceous sandstones. Lithology of the Dobatta Formation is more clayey with grey to black and ochre-coloured clays intercalated with soft micaceous sandstones. The last unit of the Surai Khola sequence is the Dhan Khola Formation (upper part of the Upper Siwalik) which is characterized by compact hard boulder conglomerates intercalated with yellow coarse sandstones and yellow silts.

MATERIALS AND METHODS

The material for the present study was collected from the Siwalik sequence exposed at the west of Tapt Kund (Hot Spring) near Rehar on Lamahi –Nepalganj in Kapilwastu district (Fig.1). The samples consist of claystones, siltstones and carbonaceous shales. Seven samples have yielded rich well-preserved palynofossils (Fig.2). Samples were processed using standard chemical processing techniques. HCL HF, HNO_3 and KOH were used to complete the process. In case of poorly yielding samples heavy liquid flotation technique using
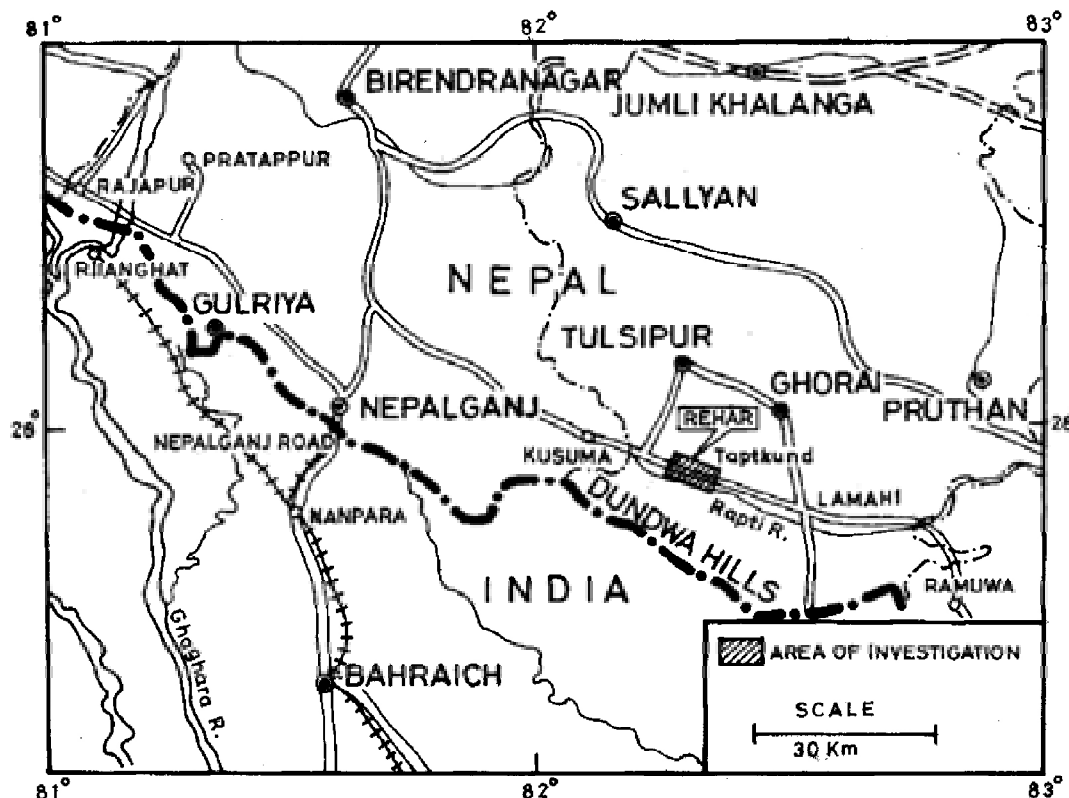
Fig.1. Showing the location of the Tapt Kund section in Kapilwastu district of Nepal.

Potassium-Cadmium Iodide solution was employed for better recovery of palynofossils. The slides were prepared in polyvinyl alcohol and mounted in Canada balsum.The productive samples are mostly black carbonaceous shales. Two hundred palynofossils per sample were counted for quantitative estimation of the palynoflora. All the figured slides are housed in the repository of the Birbal Sahni Institute of Palaeobotany, Lucknow.

RESULTS

The Tapt Kund palynofloral assemblage consists of algal zygospores, fungal spores and conidia, pteridophytic spores, gymnospermous and angiospermous pollen; in all 52 species belonging to 45 genera have been recorded. Among these, the genus *Triangulorites* has been considered as reworked. Some

of the important palynofossils have been illustrated (Pl. I & II). A checklist of the recorded palynotaxa is given below:

Algal remains
Pediastrum compactum Singh & Khanna,1978
Psiloschizosporis psilata Kar & Saxena,1981
Zygospores of *Spirogyra* Link,1820
Fungal remains
Callimothalus assamicus Kar &Singh,1970
Dicellaesporites aculeolatus Sheffy&Dilcher,1971
Dicellaesporites sp.
Diporicellaesporites acuminatus Sheffy & Dilcher,1968
Dyadosporonites grandiporous Singh etal,1986
Frasnacritetrus josettae Tougourdu,1968
Fusiformisporites elongatus Ramanujam &Rao,1978
Inapertisporites vulgaris Sheffy&Dilcher,1971

EXPLANATION OF PLATE I
(All photomicrographs are magnified ca x 750, unless otherwise mentioned)

1. *Dicellaesporites aculeolatus* Sheffy & Dilcher, BSIP Slide No 13901; coordinates : 32x67.
2. *Dyadosporonites grandiporous* Singh *et al.* BSIP Slide No 13903; coordinates:45x78.
3. *Diporicellaesporites* sp. BSIP Slide No 13903 ; coordinates:31x81.
4. *Malvacearumpollis* bakoonyensis, Nagi BSIP Slide No 13902; coordinates; 27x53.
6. *Dictyophillidites* sp. BSIP Slide No 13902 ; coordinates;29x54.
7. *Todisporites kutchensis* Sah & Kar. BSIP Slide No 13907; coordinates:49x89.
8. *Polypodiaceaesporites chaterjii*,Kar BSIP Slide No13905; coordinates:37x102.
9. *Bacustephanocolpites globatus* (Venkatachala & Kar) Saxena BSIP Slide No13902; coordinates30x61.
10 *Polypodiisporites ornatus* Sah BSIP Slide No13904; coordinates:47x55.

11. *Polypodiisporites repundus* Takahashi BSIP Slide No 13906; coordinates:29x105.
12. *Lycopodiumsporites* sp. BSIP Slide No 13908 ; coordinates:39x83.
13. *Leptolepidites verrcatus* Couper BSIP Slide No13905; coordinates:28x101.
14. *Stratriletes sussannae* Van der Hammen emend Kar BSIP Slide No13907; coordinates; 40x106.
15. *Notothyrites amorphous* Kar &Saxena BSIP Slide No 13908; coordinates:23x109.
16. *Psiloschizosporis psilata* Kar & Saxena BSIP Slide No 13906; coordinates:27x95.
17. *Pinuspollenites tenuicorpus* Singh&Sarkar BSIP Slide No13908; coordinates:30x96.
18. *Abiespollenites* sp. BSIP Slide No13911 ; coordinates :59x112. x 500.
19. *Multicellaesporites* sp. BSIP Slide No 13903; coordinates 47x103.

Plate I

SARKAR AND CORVINUS
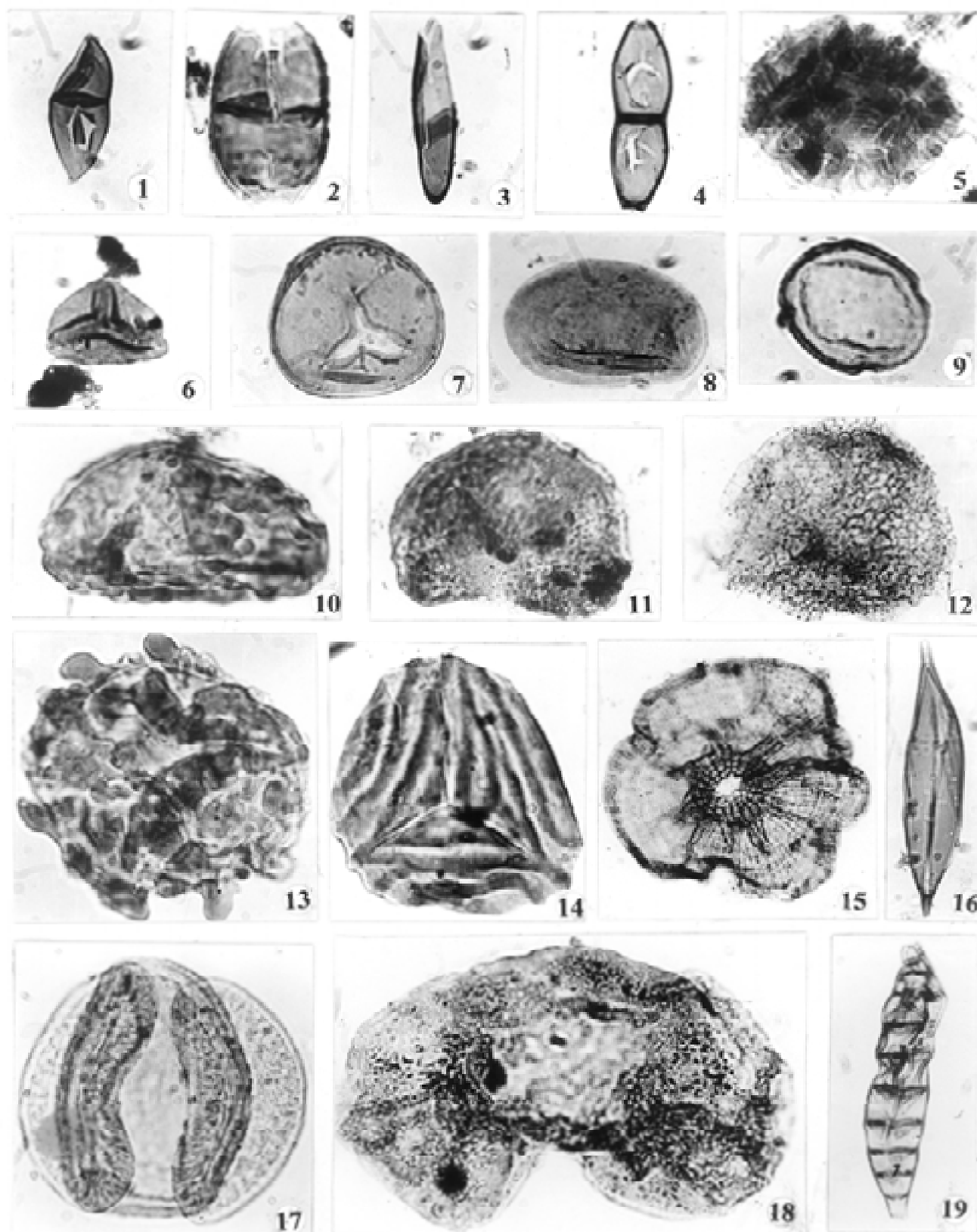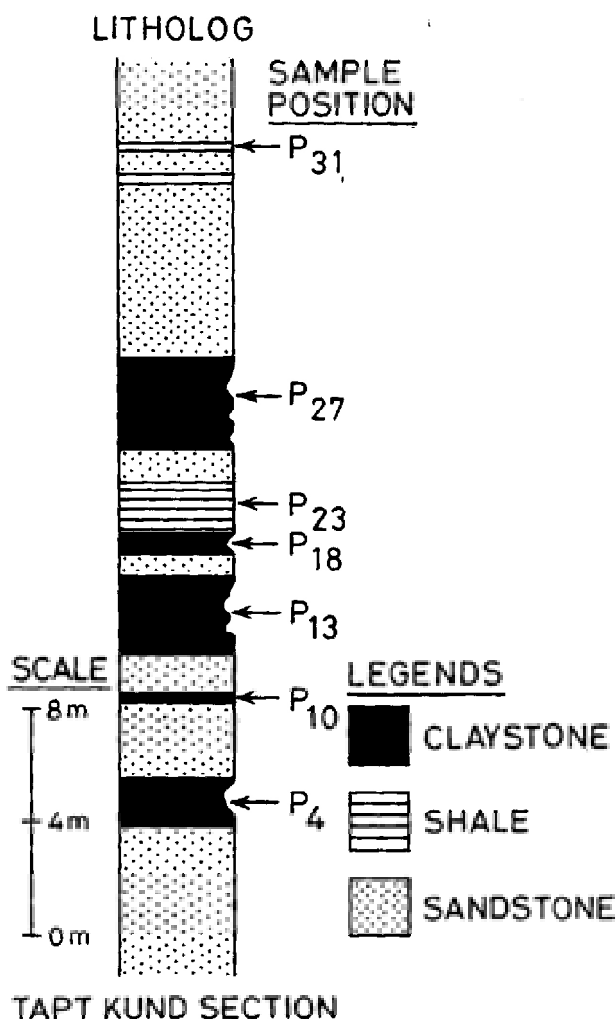
LITHOLOG

Fig. 2. Litholog of the Tapt Kund section showing sample position.

Inapertisporites disciformis Sheffy&Dilcher,1971
Inapertisporites ovalis Sheffy&Dilcher,1971
Multicellaesporites acuminatus Shefy&Dilcher,1971

Notothyrites amorphous Kar &Saxena,1976
Pluricellaesporites psilatus Clarke,1965
Pteridophytic spores
Cheilanthoidspora monoleta Sah & Kar,1974
Cyathidites australis Couper, 1953
Cyathidites minor Couper, 1953
Dictyophilidites granulatus Saxena, 1978
Leptolepidites verrucatus Couper, 1953
Lycopodiumsporites sp.
Lygodiumsporites lakiensis Sah & Kar, 1969
Osmundacidites sp.
*Polypodiaceaesporites chatterjee,*Kar, 1979
Polypodiisporites ornatus Sah, 1967
Polypodiisporites oligocenicus Sah & Dutta, 1968
Polypodiisporites repandus Takahashi, 1964
Striatriletes susannae (Van der Hammen) Kar, 1979
Todisporites kutchensis Sah & Kar, 1969
Todisporites major Couper, 1958
Verrucatosporites speciosus Sah, 1967
Gymnospermous pollen
Abiespollenites sp.
Cedripites sp.
Pinuspollenites tenuicarpus Singh &Sarkar, 1984
Podocarpidites ellipticus Cookson, 1947
Tsugaepollenites vellatus Kar, 1985
Angiospermous pollen
Accaciapollenites myriosporites Cookson, 1954
Bacustephanocolpites globatus (Venkatachala & Kar) Saxena, 1982
Droseridites spinosa (Cookson) Potonie, 1960
Malvacearumpollis bakonyensis Nagy, 1962
Monoporopollenites graminioides Meyer, 1956
Palmidites maximus Couper, 1953
Palmidites naviculus Kar & Saxena, 1981
Palmaepollenites kutchensis Venkatachala & Kar, 1969
Pellicieroipollis langenheimii (Sah & Kar) Kar, 1978
Perfotricolpites neyvelli (Navale & Mishra) Mandal & Kumar, 2000
Polybrevicolporites nadhamunii (Venkatachala & Kar) Kar, 1985
Retistephanocolpites ornatus (Dutta & Sah) Saxena, 1982
Rhoipites anacardioides Ramanujam, 1987
Sapotaceaedites sp.

EXPLANATION OF PLATE II
(All photomicrographs are magnified ca x 750, unless otherwise mentioned)

1. *Sapotacaedites* sp.   BSIP Slide No 13907; coordinates: 38x107.
2. *Palmidites naviculus* Kar & Saxena BSIP Slide No 13912; coordinates:41x88.
3. *Rhoipites anacardioides* BSIP Slide No 13915; coordinates 31x106.
4. *Tricolpites reticulatus* Cookson BSIP Slide No 13915; coordinates 49x105.
5. *Polypodiisporites oligocenicus* Sah & Dutta, BSIP Slide No13914; coordinates:25x109.
6. *Cheilanthoidspora monoleta* Sah & Kar, BSIP Slide No 13904; coordinates:37x93.
7. *Perfotricolpites neyvelii* (Navale &Mishra) Mandal & Kumar, BSIP Slide No13911; coordinates : 51x80.
8. *Polycolpites ornatus* Dutta &Sah, BSIP Slide No13912; coordinates:31x106.
9. *Triangulorites bellus* Kar, BSIP Slide No 13910; coordinates: 40x93.
10. *Verrucatosporites speciosus* Sah, BSIP Slide No 13913;
    coordinates:27x110.
11. *Palmaepollenites kutchensis* Venkatachala & Kar, BSIP Slide No13911; coordinates:55x104.
12. *Polybrevicolporites nadhamunii* Venkatachala & Kar, BSIP Slide No13910 coordinates:19x87.
13. *Monoporopollenites graminioides* Meyer, BSIP Slide No13914; coordinates:50x114.
14. *Lygodiumsporites* sp. BSIP Slide No13906; coordinates :35x109.
15&16. *Pellicieroipollis langenheimii* (Sah & Kar) Kar, BSIP Slide No 13907; coordinates 29x101 ;34x78.
17. *Lygodiumsporites lakiensis* Sah & Kar, BSIP Slide No 13908; coordinates:37x99.
18. *Tsugaepollenites velatus* Kar, BSIP Slide No 139115; coordinates:47x103.
19. *Droseridites spinosa* (Cookson) Potonie, BSIP Slide No 13910; coordinates:28x111.
20. *Dicellaesporites* sp. BSIP Slide No13906; coordinates: 29x89.x1000
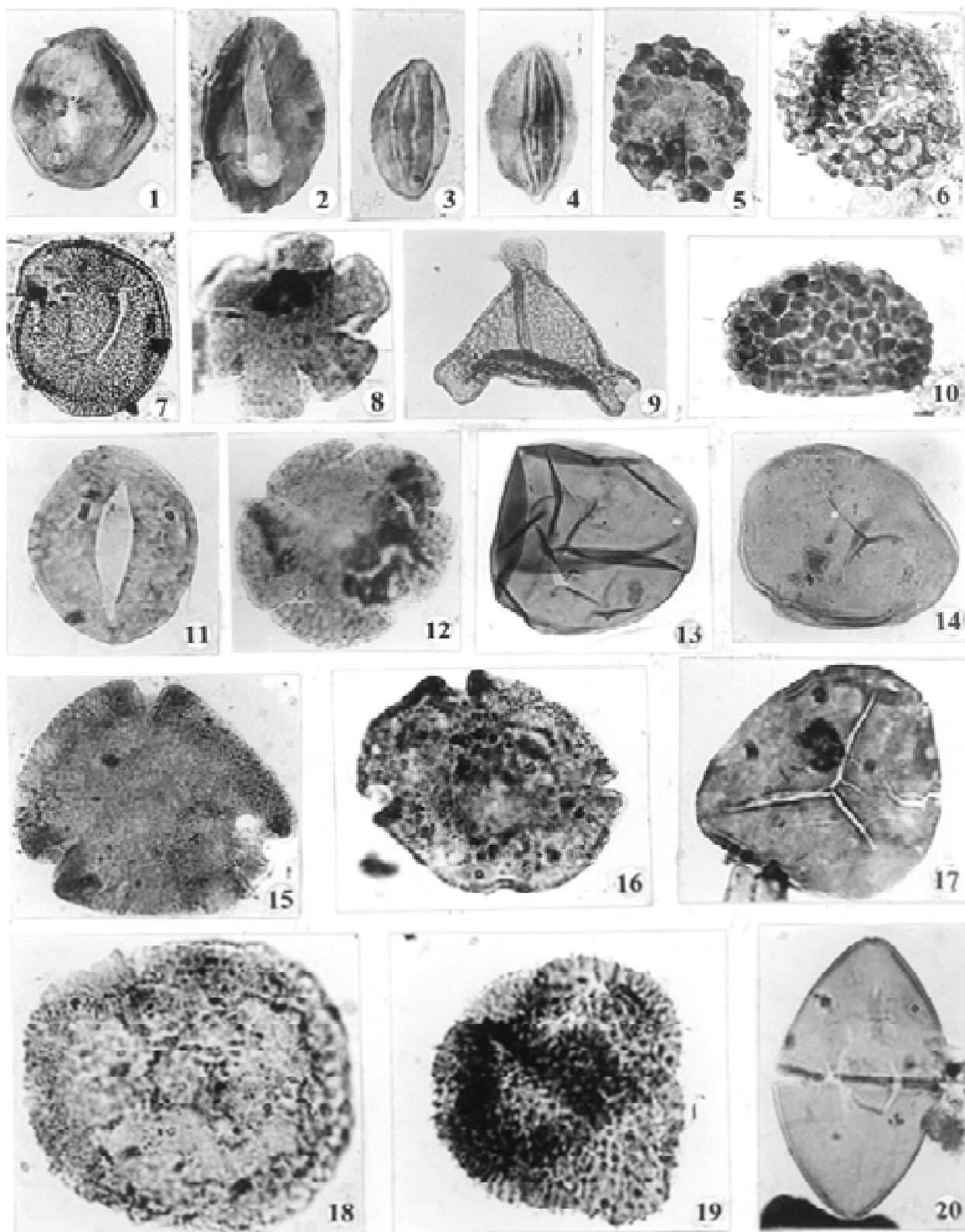
Table 1: Showing botanical affinities of the palynotaxa

Palynofossils	Botanical affinities	Present day distribution
Algal remains		
Pediastrum compactum	*Pediastrum* (Hydrodyctyaceae)	Abundant in freshwater plankton, common in ponds and ditches, Cosmopolitan
Psiloschizosporis psilata	Zygnemataceae	Cosmopolitan
Zygospores of *Spirogyra*	*Spirogyra* (Zygnemaceae)	Common in freshwater of small ponds or temporary pools in wet areas ,cosmopolitan
Fungal remains		
Callimothalus assamicus	Ascostromata of Microthyriaceae	Warm and humid tropical climate
Notothyrites amorphous	Ascostromata of Microthyriaceae	Warm and humid tropical climate
Frasnacritetrus josettae	*Tetraploa* (Fungi Imperfecti)	Warm and humid tropical climate
Multicellaesporites acuminatus	Fungi Imperfecti	Warm and humid tropical climate
Pluricellaesporites psilatus	Fungi Imperfecti	Warm and humid tropical climate
Pteridophytic spores		
Cheilanthoidspora monoleta	*Lycopodium* (Lycopodiaceae)	Terrestrial or epiphytic, cosmopolitan
Lycopodiumsporites sp.	Lycopodiaceae	Cosmopolitan
Cyathidites australis	Cyatheaceae	Common in the undergrowth of moist forest , mostly in Tropics
Cyathidites minor	Cyatheaceae	
Dictyophilidites granulatus	Dicksoniaceae	Tropical to subtropical
Leptolepidites verrucatus	Polypodiaceae	Tropical to subtropical
Lygodiumsporites lakiensis	*Lygodium* (Schizaeceae)	Tropical to subtropical
Osmundacidites sp.	*Osmunda* (Osmundaceae)	Terrestrial, Cosmopolitan
Polypodiaceaesporites chatterjee	Polypodiaceae	Terrestrial or epiphytic, prefer wet forest, Tropical-subtropical
Polypodiisporites ornatus,	Polypodiaceae	Tropical-subtropical
Polypodiisporites oligocenicus	Polypodiaceae	Tropical-subtropical
Polypodiisporites repundus	Polypodiaceae	Tropical-subtropical
Striatriletes susannae	*Ceratopteris* (Parkeriaceae)	Aquatic or wet habitat, Tropical-subtropical
Todisporites kutchensis	Osmundaceae	Cosmopolitan
Todisporites major	Osmundaceae	Cosmopolitan
Verrucatosporites speciosus	Polypodiaceae	Tropical-subtropical
Gymnospermous pollen		
Abiespollenites sp.	*Abies* (Pinaceae)	Terrestrial-Temperate
Cedripites sp.	*Cedrus* (Pinaceae)	Terrestrial-Temperate
Pinuspollenites tenuicarpus,	*Pinus* (Pinaceae)	Terrestrial-Temperate
Podocarpidites ellipticus	*Podocarpus* (Podocarpaceae)	Mostly in tropical to warm temperate
Tsugaepollenites vellatus	*Tsuga*(Pinaceae)	Terrestrial-Temperate
Angiospermous pollen		
Accaciapollenites myriosporites	*Accacia* (Mimosaceae)	Tropical-Subtropical
Droseridites spinosa	*Drosera*(Droseraceae)	Cosmopolitan
Malvacearumpollis bakonyensis	Malvaceae	Tropical-Subtropical
Monoporopollenites graminioides	Poaceae	Cosmopolitan
Palmidites maximus,	Arecaceae	Tropical-subtropical
Palmidites naviculus	Arecaceae	Tropical-subtropical
Palmaepollenites kutchensis	Arecaceae	Tropical-subtropical
Pellicieroipollis langenheimii	Alangiaceae	Tropical-subtropical
Perfotricolpites neyvelli	Plumbaginaceae	Tropical
Polycolpites ornatus	Pedaliaceae	Terrestrial ,mostly in tropics
Rhoipites anacardioides	*Melanorrhea* (Anacardiaceae)	Tropical-subtropical
Tricolpites reticulates	Clusiaceae	Tropical-Temperate
Sapotaceaedites sp.	Sapotaceae	Tropical

Triangulorites bellus Kar, 1985
Tricolpites reticulatus Cookson ex Couper, 1953

Qualitative and quantitative analyses of the palynoflora reveal the dominance of pteridophytic spores over the gymnospermous and angiospermous pollen. The possible botanical affinities of various palynotaxa and their present day distribution are given in Table 1. The algal forms represented by three genera viz., *Pediastrum*, *Psiloschizosporis* and *Spirogyra* are found throughout the whole sucession. Among these, zygospores of Zygnemataceae are most dominant, whereas the colonial alga *Pediastrum* of the family Hydrodyctiaceae is relatively less represented. Fungal remains form the most important constituent of the assemblage. It consists of 12 species belonging to 10 genera. The present fungal assemblage consists mainly of species of *Inapertisporites* and *Multicellaesporites*. The occurrence of microthyraceous ascostromata is comparatively less than the spores and
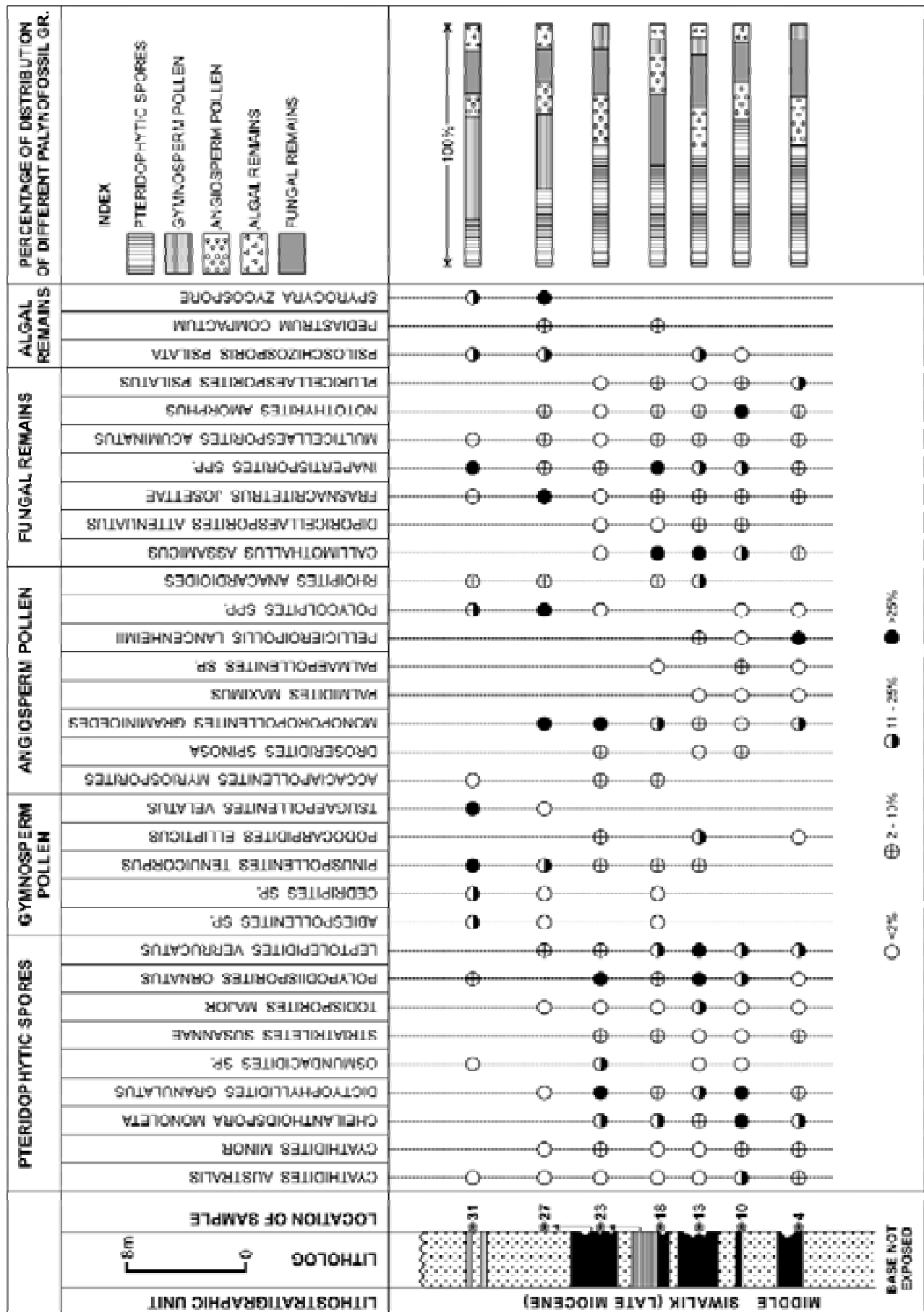
Fig. 3. Showing the distribution of significant palynofossils in the Tinau Khola Middle Siwalik succession.

conidia. The natural affinities of the form genera are difficult to find out because of morphological variations of the spores and conidia in the same genera. *Inapertisporites*, *Multicellaesporites* and *Pluricellaesporites* are spore types which are generally produced by the Hyphomycetes fungi. Pteridophytic spores represented by 12 genera and 16 species constitute one of the most important botanical groups in this palynofloral assemblage. Palynofossils assignable to the following families: Lycopodiaceae, Cyatheaceae, Dicksoniaceae, Polypodiaceae, Schizaeaceae, Osmundaceae and Parkeriaceae have been identified. Smooth walled, monolete, bilateral spores of the family Polypodiaceae are most dominant. The gymnosperms are represented by two families Pinaceae and Podocarpaceae. *Pinuspollenites* and *Tsugaepollenites* are the major constituents of Pinaceae followed by *Abies and Cedrus*. The *Podocarpidites* pollen grains are comparatively less represented in the assemblage.

The Tapt Kund palynofloral assemblage contains 14 genera and 15 species of angiosperm pollengrains. Out of these, 3 genera and 3 species belong to monocotyledons and 11 genera and 12 species to dicotyledons. The dicotyledonous pollen grains are represented by the following families viz., Mimosaceae, Droseraceae, Malvaceae, Alangiaceae, Plumbaginaceae, Anacardiaceae and Cluciaceae.

Monocotyledonous palynofossils are comparatively less represented in the present assemblage. Only Poaceae and Arecaceae have been identified. The gymnospermous pollen constitute about 30% of the recovered palynofossils.

PALYNOFLORAL COMPARISONS AND REMARKS ON AGE

The palynofloral assemblages recorded from the Middle Siwalik sedments of the Chepang-Chinji section, east of Nepalganj (Mathur,1984), and Surai Khola Siwalik succession (Sarkar,1990; Awasthi *et al.,* 1994; Hoorn *et al.,* 2000) of Nepal show close similarity with the Tapt Kund palynoflora in the dominance of bisaccate pollen grains viz., *Pinuspollenites, Abiespollenits* and *Cedripites* along with pollengrains of Poaceae. Qualitatively, the palynoflora from Tapt Kund shows close resemblance to those described from the upper part of the Surai Khola Formation (Sarkar, 1990, Awasthi *et al.,* 1994); except for few minor differences in the occurrences of some spore and pollen genera or species otherwise the-above mentioned palynofloras are definitely homotaxial in their palynofloral spectrum. The Tapt Kund palynofloral assemblage correlates very well with the upper part of the Surai Khola Formation of the Surai Khola Siwalik succession which was dated late Late Miocene on the basis of palaeomagnetic study (Appel *et al.,* 1991). Hoorn *et al.,* (2000) recognized three ecological zones in the Surai Khola Siwalik succession. The Tapt Kund palynofloral assemblage resembles that described from the upper Middle Siwalik sediments which is Late Miocene in age. Abundance of pteridophytic spores belonging to the families Parkeriaceae and Lycopodiaceae along with the algal form *Spirogyra* and dominance of grass pollen are noteworthy features of this assemblage. A similar feature has also been observed in the present palynofloral assemblage.

Palynological information published from the Siwalik group of rocks of Nepal is rather poor. Because of this, a comparison of the Tapt Kund palynofloral assemblage with other known Middle Siwalik palynofloras recorded from India has been carried out in order to assess the dating potential of the assemblage. The Middle Siwalik palynoflora from India has been described by several workers (Banerjee, 1968; Lukose, 1969; Nandi and Bandyopadhay, 1970; Nandi 1972, 1975; Ghosh 1977; Saxena *et al.*, 1984; Sarkar *et al.*, 1994). The Middle Siwalik palynofloral assemblage recorded from the Bhakra Nangal area is dominated by gymnospermous pollen grains. (Banerjee, 1968; Saxena *et al.*, 1984). This feature is also very much pronounced in the present assemblage. Lukose (1969) reported a rich palynofloral assemblage from Raxual in Bihar. The Tapt Kund and Raxual palynoflora are comparable in having common occurrences of several palynotaxa, viz., *Polypodium*, *Schizea*, *Lygodium*, *Pteris, Podocarpus*, *Abies*, *Pinus* and *Tsuga*. Nandi and Bandyopadhy (1970) recorded some monoporate, periporate, inaperturate, polycolpate, monosaccate, bisaccate and fungal spores from the Middle Siwalik sediments of Himachal Pradesh. The composition of the palynofloral assemblage resembles Tapt Kund palynoflora very closely.

Nandi (1972) described the Middle/Siwalik palynofloral assemblage from Mohand (east) Field in Saharanpur district of Uttar Pradesh. A comparison between the two assemblages reveals that several forms viz., *Cyathidites*, *Polypodiisporites, Polypodiaceasporites. Pinuspollenites, Leptolepidites*, *Todisporites*, *Tsugaepollenites*, *Abiespollenites*, etc are shared by both the assemblages. A qualitatively rich palynofloral assemblage has been reported by Nandi (1975) from various formations of Siwalik rocks in Himachal Pradesh recognizing four palynological assemblages. The Taptkund assemblage resembles the one described from the zone III which is of Middle Siwalik age. Several forms *viz., Cyathidites, Polypodiisporites, Polypodiaceasporites, Pinuspollenites, Podocarpidites, Leptolepidites* , *Todisporites* are common between the two assemblages.

The Tapt Kund palynofloral assemblage is comparable to the palynological zones A and B of the Bagh Rao Section, Uttar Pradesh (Sarkar *et al.*, 1994) which is considered to be of late Miocene age. The palynofloral assemblage of this zone is characterized by the abundant occurrence of bisaccate pollen grains and spores related to Parkeriaceae.

The overall palynofloral associations throw some light on the age of the Middle Siwalik sediments from Tapt Kund when considered in conjunction with earlier data. Earlier studies in the Himalayan foothills (Banerjee,1968; Nandi, 1972, 1975; Saxena and Singh, 1980, 1982a, 1982b; Singh and Saxena, 1980 and Mathur,1984) show that bisaccate pollen grains belonging to Abietineae (Pinaceae) viz., *Pinus*, *Abies*, and *Cedrus* attained dominance only after the mid Miocene orogeny of the Himalaya. Therefore the high incidence of *Pinupollenites* and *Abiespollenites* belonging to the family Pinaceae in the present material strongly suggests that those of the Middle Siwalik sediments may pertain to late late Miocene. Apart from this high incidence of pollen genera viz., *Malvacearumpollis, Acaciapollenites, Monoporopollenites* along with gymnosperm taxa also provide logical support for a late Late Miocene age.

PALAEOENVIRONMENT AND PALAEOCLIMATE

The palynoflora recorded from the Middle Siwalik sediments of Tapt Kund is dominated by pteridophytic spores and angiosperm pollen. Gymnosperm pollen and algal remains are also present in large numbers in the younger horizons. The presence of *Stritriletes*, *Polypodiisporites*, *Pediastrum, Psiloschizosporis* and zygospores of *Spirogyra* is indicative of fresh water swamp or pond conditions near the site of deposition. The distributional pattern of palynofossils in the Tapt Kund sequence clearly points towards a change in the environment of deposition from the older to younger horizons (Fig.3). The lower part of the sequence is characterized by the dominance of pteridophytic spores along with high percentage of fungal spores and conidia and microthyraceous ascostromata. In the younger horizons, the frequency of occurrences of pteridophytes and fungal remains gradually reduced and it is replaced by taxa belonging to upland forest communities mainly represente by gymnosperms. Frequency of grass pollen increased quite significantly in the younger horizons. It is envisage that a warm and humid climate prevailed during the sedimentation of the older horizons and subsequently it was more or less dry in the younger horizons. The fluctuations in the abundance of the aquatic and montane elements may be due to humidity and rainfall.

The Tapt Kund palynoflora have affinities with 41 extant families. Of these, 23 families are restricted to tropical-subtropical climate and 10 families are cosmopolitan in distribution. Two families are restricted to the tropics and Six families have temperate associations. The presence of spores of Schizaeceae, Parkeriaceae, Polypodiaceae and ascostromata of Microthyriaceae in the assemblage indicates that a subtropical climate prevailed at the time of deposition of the Middle Siwalik sediments in Tapt Kund area. Abundunce of fern spores and the occurrence of tropical rainforest type of elements provide supporting evidence of a climate with a high rainfall. Majority of the of the recorded taxa have a tropical to subtropical distribution and are present in moist deciduous forests. The pteridophytic families Schizaeceae, Polypodiaceae and Pteridaceae have an extensive distribution predominantly in the tropics and contribute to the undergrowth of the dense moist forest (Kubitzki,1990). The occurrence of *Pinuspollenites*, *Abiespollenites*, *Cedripites* in the palynofloral assemblage indicates that most probably they were the blown in elements from highlands around the sedimentary basins. The Tapt Kund palynofloral assemblage comprises palynotaxa having affinity with those families which are found mainly in the tropical and subtropical region except some gymnospermous taxa. Based on the available palynological evidences from Tapt kund, prevalence of a low land rainforest type of vegetation is envisaged in the area of investigation during late Miocene.

CONCLUSIONS

1. The Middle Siwalik palynofloral assemblage from the Tapt Kund area of Nepal consists of algal zygospores, fungal spores and conidia, pteridophytic spores, gymnospermous and angiospermous pollen. The assemblage is dominated by pteridophytic spores, followed by gymnospermous pollen.

2. On the basis of affinity with the modern families, it is suggested that a warm humid tropical climate may have prevailed during sedimentation of the Middle Siwalik sediments in the older horizons. The climate became more or less dry during deposition of younger horizons.

3. The composition of the palynofloral assemblage suggests that the sediments were deposited under fresh water environment and the area was mainly inhabited by lowland rainforest type of vegetation during late Miocene.

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SHORT COMMUNICATION

DIFFERENTIAL DISSOLUTION OF BIOGENIC CARBONATES: IMPLICATION OF SECRETION AT HIGHER pH

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ABSTRACT

A selective preferential dissolution of a few initial chambers of several specimens of calcareous planktic foraminifera *Globigerinoides ruber* has been noted in the surface sediments collected from the eastern Arabian Sea and northern Bay of Bengal. Based on a recent finding stating the capability of foraminifera to modulate the vacuolar seawater pH for easy secretion of calcite, it is postulated that these initial two-three chambers were formed at relatively higher pH conditions, inside the cyst during asexual reproduction. The secretion of chambers at relatively higher pH results in increased incorporation of magnesium into the calcareous test. This increased Mg carbonate probably renders the initial chambers more prone to dissolution. The findings have an implication for the application of *G. ruber* for palaeoclimatic/palaeoceanographic studies.

Keywords: *Globigerinoides ruber*, breakage, dissolution, pH, foraminifera, Indian Ocean

INTRODUCTION

Foraminifera are preferentially marine micro-organisms, whose fossil counterparts have often been used for palaeoclimatic studies (Gupta *et al*., 2005; Naidu and Malmgren, 2005; Nigam, 2005; Murray, 2006; Khare *et al*., 2007). The major population of foraminifera has a hard calcium carbonate exoskeleton or test, while other forms have the test of sediment particles collected from nearby environment. Breakage and dissolution of calcareous foraminiferal tests is very common and has often been used to infer changes in terrigenous input and seawater chemistry during the past (Johnson *et al*., 1977; Coulbourn *et al*., 1980; Cullen and Prell, 1984; Caron *et al*., 1990; Pfuhl and Shackleton, 2004; Saraswat *et al*., 2007a). The dissolution susceptibility of the foraminiferal species, however, vary spatially and temporally. The water column dwelling species of foraminifera have been ranked into dissolution susceptible and resistant, based on differential dissolution of these species in experiments and in natural settings (Berger, 1971; Honzo and Erez, 1978). The pattern of dissolution of the tests also varies from species to species and has been attributed to the robustness and morphology of the tests (Malmgren, 1983). The dissolution of the tests is not uniform; a few portions of the tests get selectively dissolved. The reason for selective dissolution of parts of the tests is still not clear. Here, we have studied the dissolution of the tests of surface-dwelling planktic foraminifera *Globigerinoides ruber* in surface, sediments collected from the Arabian Sea and the Bay of Bengal. *G. ruber* is a surface-dwelling species and its isotopic and elemental analysis has been widely used to infer past climatic changes from the northern Indian Ocean (Saraswat *et al*., 2005; 2007b; Anand *et al*., 2008). *G. ruber* is a dissolution susceptible species (Cullen and Prell, 1984). The dissolution of *G. ruber* is discussed in view of the recent advances in the understanding of secretion of foraminiferal tests.

MATERIALS AND METHODOLOGY

The surface sediments collected during two *Sagar Kanya* cruises, namely SK-187 and SK-237 were used (Fig. 1). A small aliquot of sediment sample was collected in watch glasses and dried overnight. The dried sediment sample was weighed and then soaked in water for twenty four hours. The following day, the overlying water was decanted carefully, without disturbing the sediments. The water was added again if the decanted overlying water was not clear. The process was repeated till the overlying water became clear. Once the overlying water was clear, the sediments were sieved over a 63 μm sieve. The sand fraction (> 63 μm) was collected in 25 ml beakers and dried. The dried sand fraction was weighed and transferred to plastic vials. A small aliquot of sand fraction was taken after coning and quartering. This sand fraction was weighed and spread into a picking tray. A minimum of fifty specimens of *G. ruber* were picked from each sample and mounted into micropalaeontological slides.

RESULTS AND DISCUSSION

The spines were missing in the majority of the specimens. In general, the tests of the specimens collected from the Arabian Sea were relatively more dissolved as compared to the specimens retrieved from Bay of Bengal sediments. While the tests collected from the Bay of Bengal had a pale yellow hue, those from the Arabian Sea were mostly opaque and white. Beside this, a peculiar pattern of breakage in *Globigerinoides ruber* was noted. The initial whorl of chambers was missing in a number of specimens of *G. ruber*. The last (later formed) few (three to five in number) chambers however, were fully intact.

It is a known fact that a few of the initial chambers of the foraminiferal offspring are formed within the mother test, whereas the rest of the chambers are secreted by the juveniles, once they come out of the mother test. Temporal changes in the number of broken tests and the state of dissolution of foraminiferal tests are often attributed to the shift in foraminiferal lysocline which refers to a change in carbonate ion concentration of the seawater (Berger, 1970; Igarashi, 2001). If foraminiferal test had a uniform composition throughout, all the chambers should have been equally dissolved. Therefore, this preferential dissolution of initial chambers probably reflects secretion under different seawater chemistry inside and outside the foraminiferal test. Such a difference in the chemistry of microenvironment of the foraminifera and the bulk seawater has been reported by Zeebe *et al* (1991).

The change in carbonate ion inventory of seawater is closely associated with the change in its temperature (Goyet *et al*., 1993). The change in seawater temperature is one of the
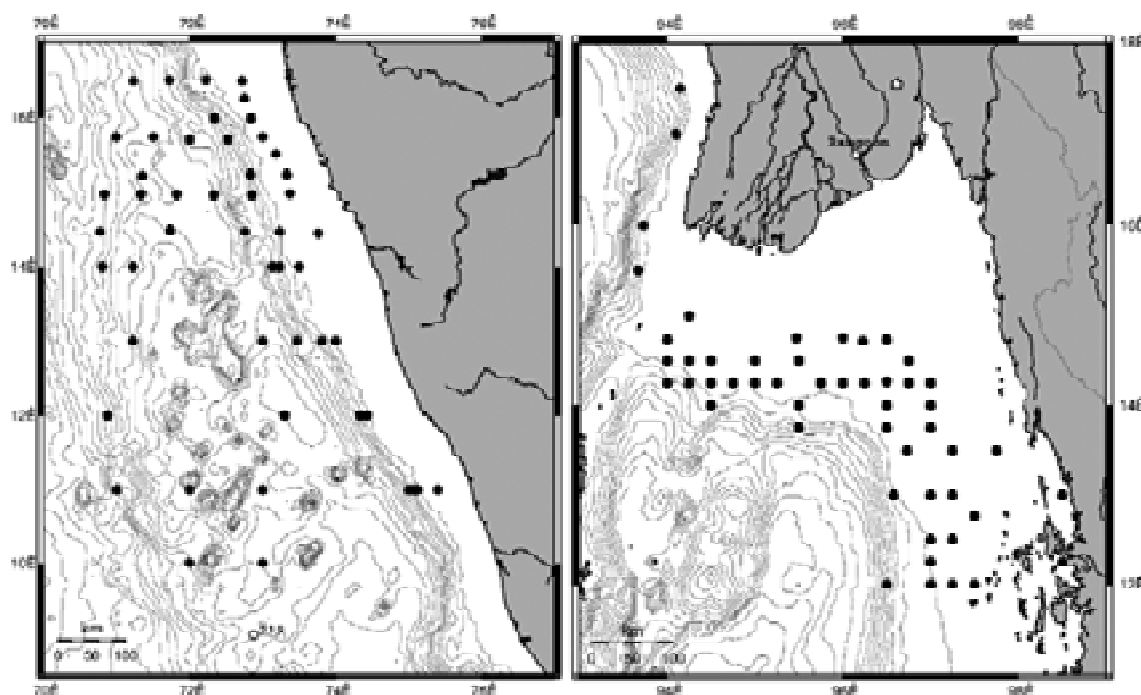
Fig. 1. The location of surface sediment samples used to study the selective dissolution of planktic foraminifera *Globigerinoides ruber*.

causes for variation in seawater pH (Hunter, 1998). But a larger change in the seawater pH occurs due to a change in atmospheric carbon-di-oxide concentration (Haugan and Drange, 1996), which has been cited as one of the main reasons for the change in seawater pH during recent times and is often attributed to anthropogenic activities (Caldeira and Wickett, 2003). This increased CO_2 lead seawater pH change has affected a large number of marine fauna (Zondervan *et al.*, 2001; Orr *et al.*, 2005). Based on the projected CO_2 levels, it is further postulated that it will be increasingly difficult for the calcareous and aragonitic organisms to survive in a sea of low pH (Feely *et al.*, 2004). Though, the normal seawater conditions are not conducive for secretion of $CaCO_3$ due to excess magnesium (Stanley, 2006), a few of the groups has mastered this process. Recently, it was found that foraminifera have the capability of increasing the pH by upto 1 unit, at the time of precipitation of calcite (Nooijer *et al.*, 2009). However experiments have shown that the calcites precipitated at higher pH tend to have relatively more amount of magnesium (Zeebe & Sanyal, 2002). Increased amount of Mg renders the calcite unstable as the calcite containing more amount of Mg tends to dissolve first than the one having lesser magnesium (Chave, 1964).

A possible reason for increased magnesium content of the initial chambers can be secretion at higher temperature. The replacement of calcium by magnesium during precipitation of calcite is an endothermic process and is thus exponentially proportional to seawater temperature (Burton and Walter, 1991; Lopez *et al.*, 2009). But, it seems highly unlikely that the foraminifera can modulate and increase the vacuolar temperature to an extent to affect the magnesium content significantly. However, completely ruling out the possibility of secretion of initial chambers at higher seawater temperature is beyond the scope of this paper. It requires point measurement of both Mg/Ca ratio and oxygen isotopic composition of the initial and final chambers, which can help determine contribution

from increased seawater pH and temperature.

The other possible mechanism leading to high Mg content in initial few chambers can be the formation of these chambers of the offsprings at a relatively higher pH than rest of the chambers secreted by babies outside the mother test. The chambers formed at higher seawater pH will have more magnesium and thus increased tendency to break/dissolve than the chambers formed at lower pH which will be relatively more resistant to dissolution due to less magnesium content (Chave, 1964). The secretion of initial chambers at relatively higher pH, seems feasible due to the peculiar way in which foraminifers reproduce. It appears relatively easy for the foraminiferal specimens undergoing reproduction to modulate the vacuolar seawater pH as they tend to form a cyst at the time of reproduction, enwrapping the complete tests (Heinz *et al.*, 2005). The cyst isolates the foraminifera from the ambient seawater. The physico-chemical conditions inside the cysts are different from that of the seawater outside (Heinz *et al.*, 2005). The difference in physico-chemical conditions inside the cyst mainly arises due to the various vital processes of the living cell, especially respiration. The development of offsprings takes place inside this cyst. These initial several chambers of the juveniles are secreted inside the cyst before the juveniles are released out of this cyst (Kimoto and Tsuchiya, 2006). Recently, Nooijer *et al.* (2009) have demonstrated the capability of foraminifera to modulate the vacuolar seawater pH. Increasing the pH at the site of calcification has the added advantage of increasing the availability of carbonate ions which results in a many-fold increase in calcite saturation state and thus in a more enhanced calcite precipitation than the bicarbonate ions (Lopez *et al.*, 2009). It also helps in dissipation of respired CO_2 into high pH vacuolar seawater thus further increasing the availability of carbonate ions (Nooijer *et al.*, 2009). A few of the planktic foraminiferal species also tend to secrete additional calcite termed as gametogenic calcite, before

undergoing reproduction, which results in thickening of the test wall (Caron *et al.*, 1990). The process of formation of initial chambers inside the test is different from the secretion of the chambers by the offsprings outside the tests wherein the new chambers are formed without the cyst formation. Probably, it is difficult for the foraminifera to modulate the vacuolar pH in open conditions than inside the cyst. A further argument for addition of low magnesium, dissolution resistant calcite towards the later phase of foraminifera is the increase in the weight of the individuals of several species during its ontogeny, which indicates calcification in relatively cooler waters at deeper depths (Erez and Honzo, 1981; Schiebel *et al.*, 2005).

CONCLUSIONS

In the surface sediment collected from the Arabian Sea and the Bay of Bengal, a few of the chambers of the initial whorl of the planktic foraminiferal species *Globigerinoides ruber* were found to be dissolved. The preferential dissolution of the chambers of the initial whorl is attributed to its secretion at higher pH, while the juveniles were inside the mother test at the time of reproduction. The secretion at higher pH might have led to increased incorporation of Mg carbonate in the tests rendering this portion of the tests more susceptible to dissolution. These findings have an implication on the application of isotopic and elemental composition of foraminifera for palaeoclimatic studies, wherein whole test is dissolved to find out stable carbon and oxygen isotopic composition and elemental ratio.

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THE TRACE FOSSIL *DACTYLOIDITES* HALL, 1886 FROM THE MIDDLE JURASSIC KHADIR FORMATION OF BELA ISLAND, KACHCHH, INDIA AND ITS PALAEOENVIRONMENTAL SIGNIFICANCE

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ABSTRACT

The trace fossil *Dactyloidites* Hall, 1886 is being recorded from the Indian subcontinent, described in the present paper as *Dactyloidites ottoi* (Geinitz, 1849) and its palaeoenvironmental significance has been discussed. The specimens have been collected from the medium-grained, calcareous sandstone beds of the Khadir Formation (Upper Bathonian-Lower Callovian), exposed at a ridge north of Bela village, Kachchh, India.

Keywords: Trace fossil, *Dactyloidites*, Khadir Formation, Middle Jurassic, Palaeoenvironment, Kachchh, India.

INTRODUCTION

Rosette-shaped problematica occur throughout the geological records. They have been accorded a variety of names in shallow to deep marine environments and have been interpreted either as biogenic structural trace fossils, medusoids or as other body fossils (Häntzschel, 1970, 1975). Fürsich and Bromley (1985) demonstrated the biogenic origin of *Dactyloidites* Hall, 1886 and also dealt with the morphology of *Dactyloidites* in detail besides its synonyms. In the present paper, the ichnogenus *Dactyloidites* Hall, 1886 is being recorded from the Indian subcontinent, and the material has been described as *Dactyloidites ottoi* (Geinitz, 1849). The palaeoenvironmental significance of the taxon is also discussed. Fürsich and Bromley (1985) interpreted the behaviour of *Dactyloidites ottoi* (Geinitz, 1849) and demonstrated its three-dimensional structure.

The Kachchh Basin, situated on the western margin of the Indian plate, is known for its rich and well preserved Jurassic invertebrate fauna since early eighteenth century. Grant (1840) gave general descriptions of the geology and of some fossils. It is an E-W oriented palaeorift basin with a Jurassic and early Cretaceous (pre-Bajocian to Tithonian) sedimentary fill.

On Bela Island (Fig.1), the lithological succession of the Khadir Formation starts with the sediments of the upper part of the Hadibhadang Shale Member (Bajocian-Bathonian/Bathonian) and these are exposed all along the northern slopes of the escarpment of the hill on the northern margin of Bela Island (Khosla *et al.*, 2003). Still older sediments of the Cheriya Bet Conglomerate Member are missing here. The Hadibhadang Shale Member is conformably followed by sediments of the Hadibhadang Sandstone Member (basal part) [Upper Bathonian-Lower Callovian] which forms the upper part of the escarpment. The hard limestone of the Raimalro Limestone Member [Patcham Formation (Bathonian)], locally contains lenses of golden oolite, being at the top. The Gadhada Sandstone Member [Gadhada Formation (Callovian)] forms the back slope of the escarpment of the hill. The fossiliferous bands (Biswas, 1977) in the Hadibhadang Shales are full of *Indocorbula* and *Vergellia* besides other bivalves, gastropods, corals, and brachiopods (*Rhynchonella*). The limestone bands in the Gadhada Sandstone Member are full of crinoid debris, rhynchonellids, gastropods, bivalves and contain some ammonites.

The ichnofauna of the Jurassic rocks of Kachchh were reported earlier by many workers and the important contributions were made by Howard and Singh (1985), Fürsich (1998), Desai *et al.* (2008) and Patel *et al.* (2008, 2009).

The Jurassic invertebrate fauna, recorded from the Kachchh Basin, consists of bivalves (Kitchin, 1903; Cox, 1940, 1952; Jaitly *et al.*, 1995; Fürsich *et al.*, 2000; Pandey *et al.*, 1996), ammonites (Waagen, 1873-1875; Spath, 1924, 1927-1933; Jaitly and Singh 1983; Krishna 1984; Krishna and Ojha, 1996; Krishna and Westermann, 1987; Pandey and Callomon, 1995; Jain *et al.*, 1996), corals (Gregory, 1900; Beauvais, 1978; Pandey and Fürsich, 1993), gastropods (Jaitly *et al.*, 2000; Jaitly and Szabo, 2002, 2007), sponges (Mehl and Fürsich, 1997), brachiopods (Kitchin, 1900), belemnites (Desai and Patel, 2009), echinoids (Gregory, 1893), asteroids (Srivastava *et al.*, 2010) and crinoids, etc. in order of decreasing abundance. Recently, Khosla *et al.* (2003) described a variety of ostracodes from the Jurassic sediments of Bela Island, Kachchh, India.

The specimens have been collected by the second author (MPS) jointly with the late Prof. S. K. Singh, Centre of Advanced Study in Geology, University of Lucknow, in the year 1997 from yellow to dark-brown, medium-grained, calcareous sandstone (Hadibhadang Sandstone Member) of the Khadir Formation (Plate I, fig. 4) [Middle Jurassic (Upper Bathonian-Lower Callovian)] (Khosla *et al.*, 2003) exposed at a ridge about a km north of Bela village (23° 52'35": 70° 48'13"), Kachchh, India.

SYSTEMATIC PALAEONTOLOGY

Ichnogenus Dactyloidites Hall, 1886
Type ichnospecies: *Dactyloidites asteroids* (Fitch, 1850).

Diagnosis: Elongate radial elements having a central shaft that fans out and preserved in a full relief (Fürsich and Bromley, 1985).

Remarks: Recently, Uchman and Pervesler (2007) advocated that the ichnogenus *Dactyloidites* Hall, 1886 needs re-evaluation because the type material of the type ichnospecies *Dactyloidites asteroids* (Fitch, 1850), from the Lower Cambrian of the New York State, displays only a few rays of uneven width (Häntzschel, 1975: Fig. 88.7).

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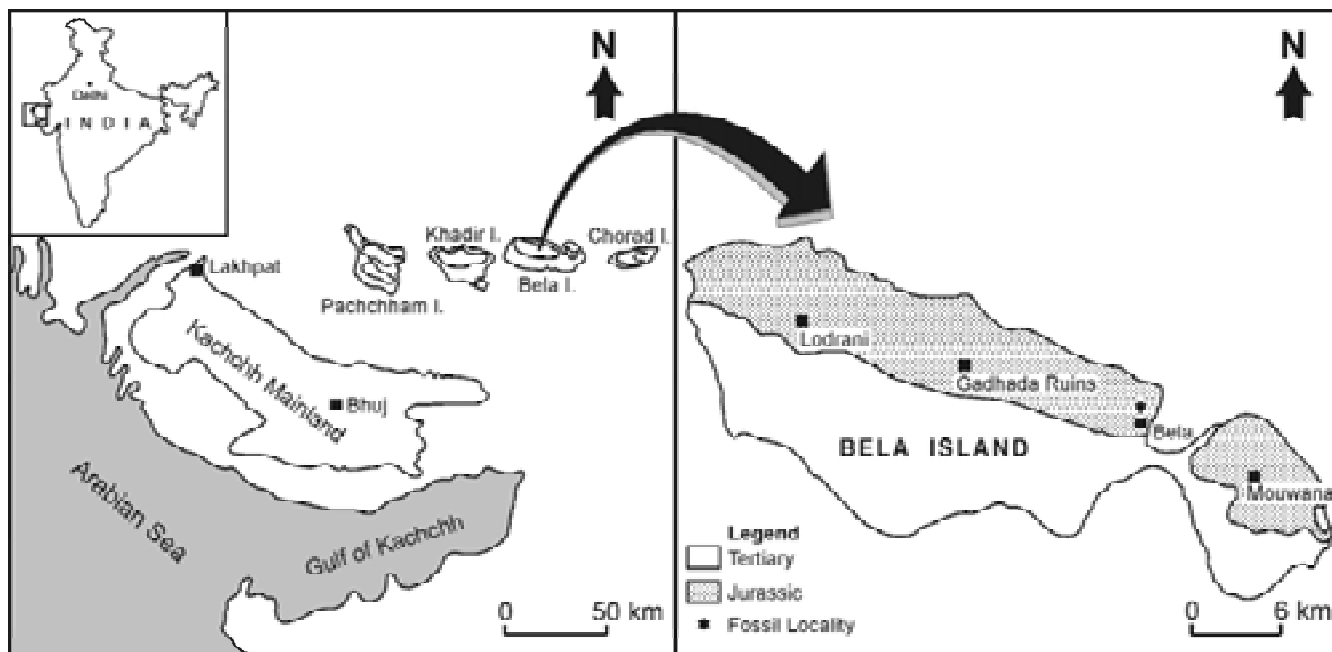
Fig. 1. Geological map of the area showing fossil locality (after Khosla *et al.*, 2003 and Srivastava *et al.*, 2010).

Dactyloidites ottoi (Geinitz, 1849)
(Plate I, figs. 1-3)

Material: Three specimens (*KTF 01, KTF 02 and KTF 03), preservation excellent. [*Kachchh Trace Fossil].

Description: The Kachchh specimens consist of about six to eight elongate, slightly bulbous radial spreite originating from the central shaft that fan out, radiate about half a circle and weathered out as convex relief. These spreites are preserved as hypichnial traces and occur in three arcs arranged around the central shaft. The diameter of the central shaft is about 4.0 mm, the radial elements branched off at about 50° and the width of the radial elements ranges from 3.0 mm to 6.0 mm. A few minor radial spreite also branched off from the main elements at an angle of about 40°.

The radial elements are the protrusive spreiten made by an organism that mined the sediments by probing radially from a central shaft and shifting the causative burrow in a downward direction. After completion of one radial spreite, the organism withdrew its body partly from the final burrow, and re-extends it to produce a second or even third side branches. These side branches do not cross and rarely cut each other. Later, the animal starts a new set of spreiten after completion of a fan shaped set from the same central shaft.

Remarks: The Kachchh specimens are similar to *Dactyloidites ottoi* (Geinitz, 1849) recorded from the Upper Cretaceous (Santonian or early Campanian) sediments of Greenland (Fürsich and Bromley, 1985), Neogene sediments of Jamaica (Pickerill *et al.*, 1993) and Lower Cretaceous sediments of Western Pyrenees (Agirrezabala and Gibert, 2004). The Kachchh specimens have less branched radial spreites than those present in the specimen described from the younger horizons by Fürsich and Bromley (1985), Pickerill *et al.*, (1993) and Agirrezabala and Gibert (2004). It may be either an evolutionary trend in *Dactyloidites* from simple radial spreite (having un-branched/less branched radial spreite in the specimens of older horizon) to complex radial spreite (having more branched radial spreite in the specimens of younger horizon), warranting a new ichnospecies or a variation within *Dactyloidites ottoi* (Geinitz, 1849). However, a new ichnospecies for the described Kachchh specimens has not been erected for want of more specimens. The comparison of *Dactyloidites ottoi* with the other known ichnospecies of *Dactyloidites* has nicely been dealt by Fürsich and Bromley (1985).

Locality: The ridge about a km north of Bela village, Kachchh, India.

Horizon: Khadir Formation [Middle Jurassic (Late Bathonian-Early Callovian)]

DISCUSSION AND CONCLUSIONS

The Khadir Formation represents the oldest unit in the region and the sediments of the formation are exposed in Khadir, Bela and Chorar islands. Biswas (1977) subdivided it into five members. Recently, Khosla *et al.* (2003) proposed four assemblage zones in Bela Island, based on the stratigraphical distribution of the ostracode fauna. Out of the four assemblage zones of Khosla *et al.* (2003), the *Progonocythere laeviscula* Assemblage Zone of the Hadibhadang Sandstone Member is distinct and the sediments of this assemblage zone were deposited in the sublittoral environment. The *Progonocythere*

EXPLANATION OF PLATE I

(Bar represents 10.0 mm)

Dactyloidites ottoi (Geinitz, 1849) [Specimen No. KTF 01]
1. Bedding surface showing rosette.
2. Closer view of the specimen showing the spreite weathering as a

ridges surrounded by less resistant layer of wall material.
3. Details of ridges.
4. Litholog of the sample locality.

Plate I

SRIVASTAVA, SINGH AND KULSHRESTHA
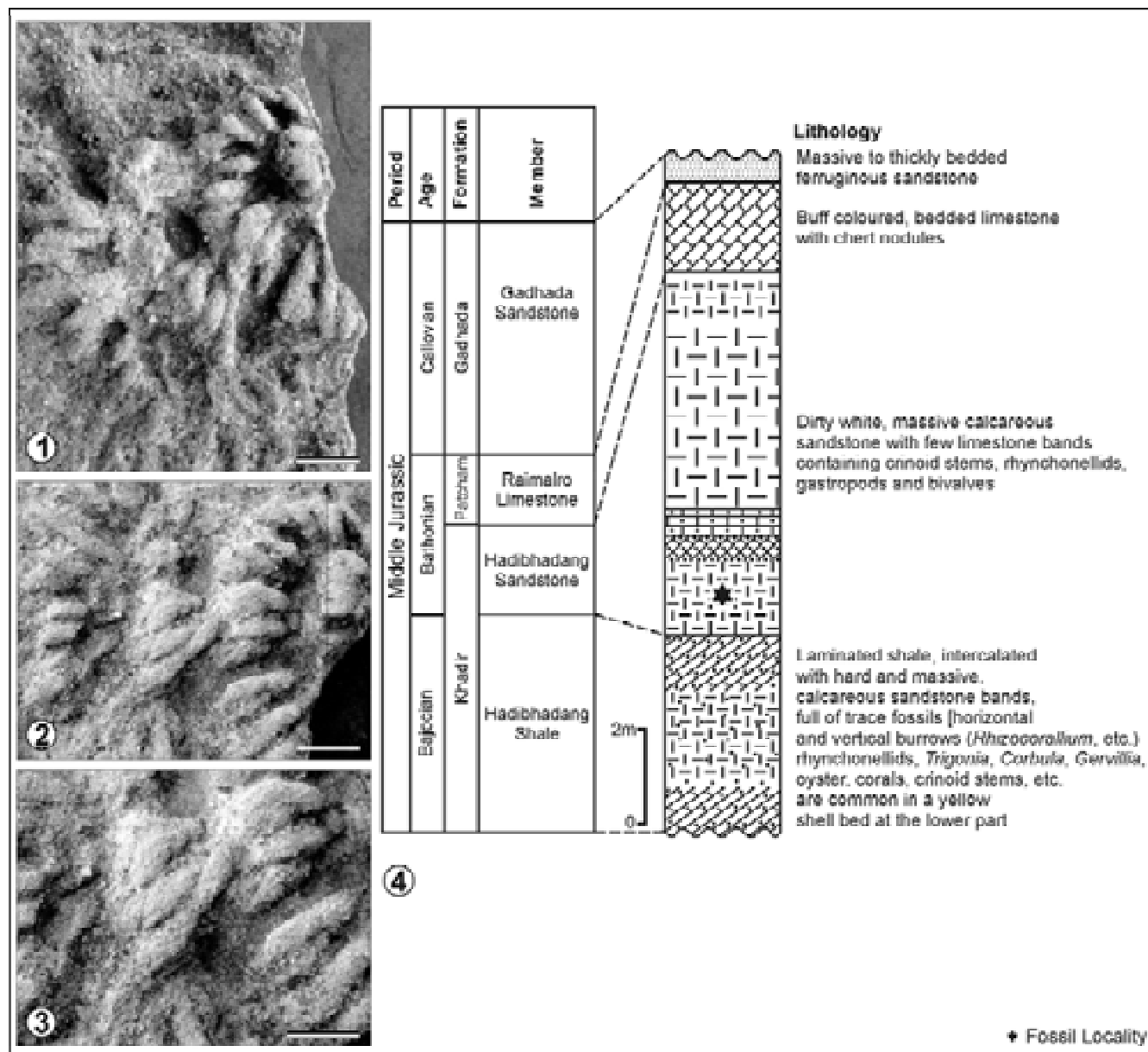
laeviscula Assemblage Zone is traceable in Habo, Jhura and Jumara domes of the Kachchh Mainland. However, the Jurassic beds of Bela Island show (Khosla *et al.*, 2003) a strong affinity with those of the Majunga Basin, Madagascar and to a lesser extent with those of Tanzania, Saudi Arabia and Israel.

The occurrence and distribution of trace fossils are mainly controlled by various environmental parameters namely, substrate, energy and oxygen levels, light, bathymetry, etc. Most of the Middle Jurassic environments of the Kachchh Basin appear to have been shallow and well within the photic zone (Fürsich, 1998). The abundance and diversity of benthic invertebrates present in the Khadir Formation also point to the existence of the similar conditions. The biogenic structures indicate that the probable trace markers were polychaetes and crustaceans of shallow marine environments. The sedimentological, palaeontological, palaeoecological and ichnological evidence suggests normal salinity in marine offshore and shallow-water, sublittoral environmental conditions of the area.

REPOSITORY

The described specimen has been deposited in the Museum, Centre of Advanced Study in Geology, University of Lucknow, Lucknow.

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ORIGIN AND GROWTH OF THE EDIACARAN FAUNA AT MISTAKEN POINT, NEWFOUNDLAND, CANADA: A HYPOTHESIS

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ABSTRACT

Origin and growth pattern of some of the elements of the oldest Ediacaran assemblage of Mistaken Point, most crucial to deciding their biological affinity, have been discussed. The fauna of Newfoundland marks the beginning from small globular bodies like strings of beads. The bead-like globular bodies had a tendency to align themselves as chains, double chains and radiating forms producing spindle-shaped organisms. The globular bodies thus represent a link between pre-Ediacaran and Ediacaran life forms. Some of the globular bodies formed concentric aggregates or developed tendency to split in to several parts to initiate the development of lobate structures (Ivesia or Ivesheadia). Isolated beads or globules germinated to stalk that evolved to frond-like forms.

Keywords: Ediacaran, evolution, growth, Mistaken Point, string of beads

INTRODUCTION

Ediacaran fossils can be broadly grouped into elongated forms, round bodies and combination of the two types. The round bodies have been variously named by scientists as *Beltanella, Conomedusites, Cyclomedusa, Ediacaria, Kimberia, Mawsonites, Medusinites, Rugoconites, Eoporpita, Brachnia, Tribrachidium* and *Ivesia* or *Ivesheadia* (Round Lobate forms) among others. Many of them are now thought to be junior synonyms of the fossil *Aspidella* (see Gehling *et al.*, 2000). The elongated forms include *Arborea, Pteridinium, Rangea, Charnia* and *Fractofusus* (Spindle-shaped organisms). Most of them are fronds having frondlets on either side of a narrow axis. The combination types represented by *Charniodiscus* are a frond or leaf attached to the round hold-fast or float through a stalk. Whether the three types have evolved independently of each other or one of them has given rise to the other two types, has not received adequate attention.

A related issue is myriad of biological assignations and classifications of the Ediacaran forms as algal fronds, Hydrozoans, Anthozoans, Petalonamae (organisms intermediate between animals and plants), Vendobionta (a new kingdom of life), unicellular protists, stem group of fungi, lichens and bacterial colonies. Had the biological assignations been based on the origin and growth patterns, it would not be free for all. The Mistaken Point assemblage constituting the oldest Ediacarans appears to offer an answer to some of the problems.

Ediacaran forms like *Charnia, Charniodiscus* and various types of discoidal bodies are found in good measure in the Mistaken Point assemblage (Anderson and Misra, 1968; Misra, 1969, 1971; Anderson and Conway Morris, 1982; Waggoner, 2003; Brasier and Antcliffe, 2004; Narbonne and Gehling, 2003) of the Avalon Peninsula of Newfoundland (Fig. 1). Origin of the life forms has been explained in the past through reproduction by spores or gametes (Seilacher, 1989, p. 237) or by vegetative reproduction through centimeter scale modules designated as Rangeomorph frondlets (Narbonne, 2004; Brasier and Antcliffe, 2004). However, the spores and gametes are not known to occur in the Mistaken Point assemblage and the frondlet modules were not precursor to the Ediacaran life forms. Moreover, the question how the modules are shaped and combined to produce the myriad of rangiomorph constructions remains unanswered. Brasier and Antcliffe (2004) explained the life cycle of *Charnia* passing through the stages of spindles and *Bradgatia* (radiating spindles?). But the proposition confines itself to the growth of fronds from fronds only. The holdfast, an integral part of the frondose structures, is overlooked.

Although, the Ediacaran life forms are supposed to have evolved from a single globally homogeneous biota (Waggoner, 2003), the nature of such a biota is uncertain. The present note tries to explain the origin of frondose structures with disc, stalk and leaf in totality as a single unit. The other forms are related in origin and might have evolved from a single biota—the string of beads.

ORIGIN AND GROWTH

Ancestors of the Ediacaran fauna are said to be unknown (Fedonkin, 1992, p. 94). In this backdrop the sudden appearance of Ediacaran soft bodied organisms in the Mistaken Point assemblage of Newfoundland is termed, at times, as 'Ediacaran Explosion' (Shen *et al.*, 2008). It may not be similar to 'Cambrian Explosion' yet its link with the pre-Ediacarans appears to be missing. Nevertheless, it goes without saying that the forms must have evolved from something. There are indications in the Mistaken Point assemblage that the life forms evolved from round, hollow, small globular bodies like beads in a string (Plate I). Such round bodies were continuing from pre-Ediacaran time as strings of beads (Grey *et al.*, 2001; Fedonkin, 2003) that continued through Ediacaran Period.

The forms that were pre-cursor to Ediacaran life include Acritarchs, strings of beads, small spheroids, *Horodyskia, Chuaria, Beltanelliformis* and simple discoidal forms of the intertillite beds (Hofmann *et al.*, 1990). Of these, the small discoidal bodies occurring in direct association of the oldest Ediacarans and continuing from pre-Ediacaran time played a significant role in the evolution of Spindle-shaped (*Fractofusus*), Leaf-shaped (*Charniodiscus*), radiating (*Bradgatia*) and round lobate (*Ivesia* or *Ivesheadia)* organisms in the Mistaken Point assemblage.
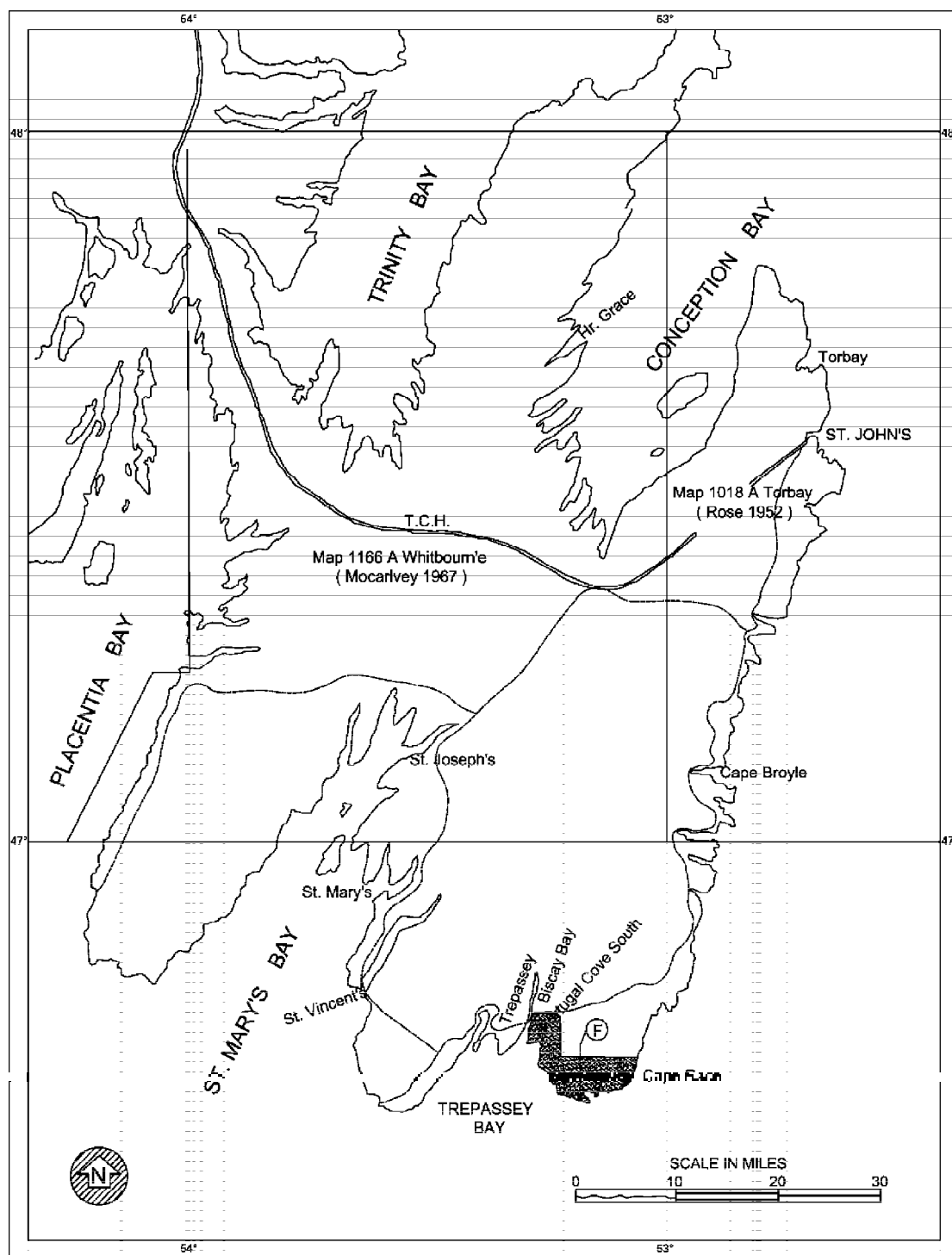
Fig. 1 Map of the Avalou Peninsula of Newfoundland, Canada showing the portion mapped (shaded part) and location of the Ediacaran Mistaken Point Fossils marked (F).

Simple globular bodies in the Mistaken Point assemblage, like the intertillite discoidal forms and the strings of beads (Hofmann *et al.*, 1990; Grey *et al.*, 2001; Fedonkin, 2003), had a tendency to align in a linear fashion (Plate I, centre; Fig. 2.2). Such bodies also had a tendency of splitting (Plate I, below arrow 1) and clustering. The splitting of beads might suggest growth from within not without. Somehow, the small globular bodies of Mistaken Point assemblage escaped attention of scientists possibly because the small globules are not pre-served in large numbers in the assemblage. It is possible they

were pelagic forms and were destroyed by subaerial volcanic fumes on the surface of water. Round bodies as *Aspidella* are found aplenty (Gehling *et al.*, 2000) in the younger sequence when volcanism had ended.

Spindles, it is suggested sometimes, acted as 'crèche' in the life cycle of *Charnia* (Brasier and Antcliffe, 2004). But, the origin of 'crèche' needs to be explained. The juvenile forms that became adult *Fractofusus* were possibly the chains (Fig. 2.2) and folded double chain of strings of beads, with the double chains producing a central canal between the limbs. In further
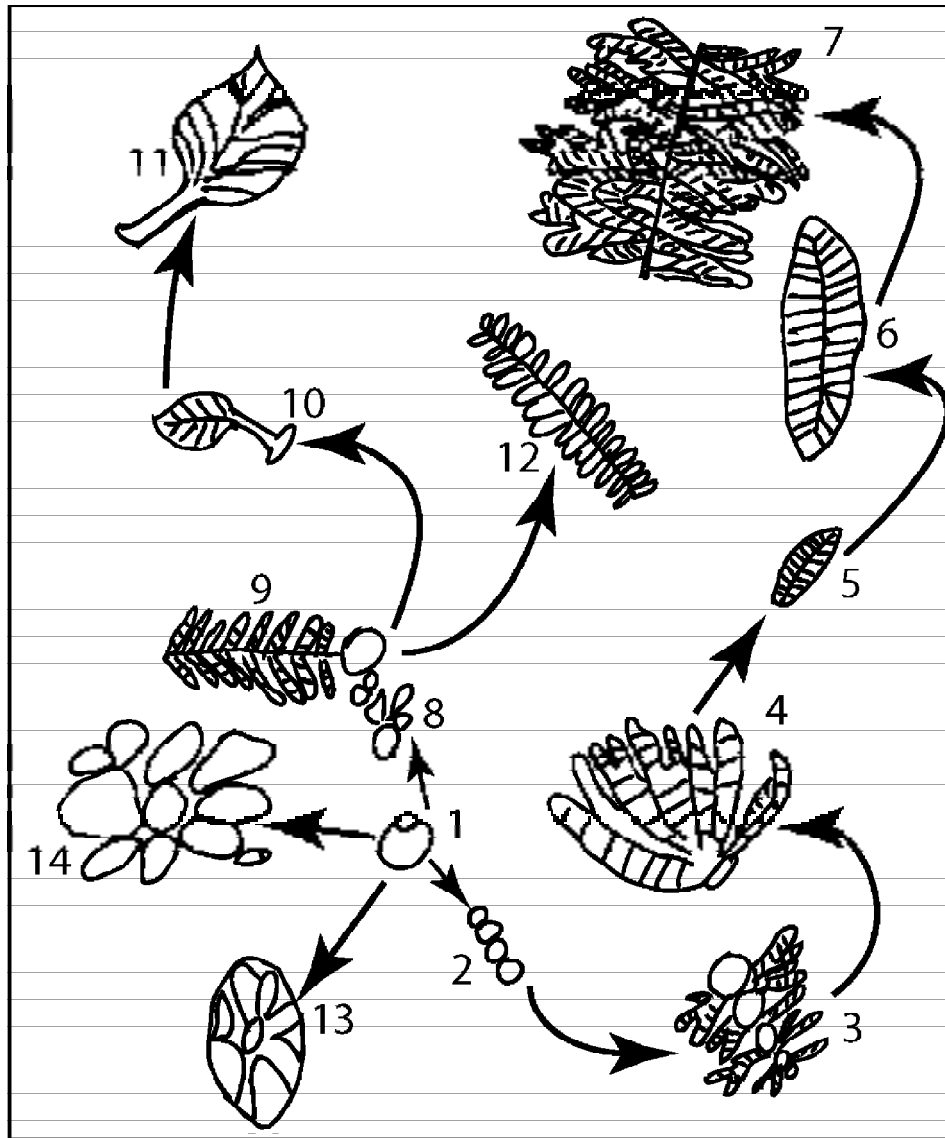
Fig. 2. Thematic diagram based on field photographs suggesting evolutionary stages passing through isolated globule (1), string of beads (2), globules to spindles (3), *Bradgatia* having radiating mini-spindles (4), juvenile spindle (5), adult spindle (6) overspecialization in spindles (7), scattered globules (8), frond grown out of globule (9), juvenile *Charniodiscus* (10), Full grown *Charniodiscus* with disc detached (11), *Charnia* (12), round lobate organism with outline (13) and round lobate organism without outline (14).

development the round bodies in the chains became discoidal and finally lost their identity as beads. They changed to internal support structure as ducts across the central canal. Subsequently, the central canal became more prominent and became feeder canal similar to the ducts in Petalonamae *Ventogyrus*. In a few cases, the strings remained unfolded and frondlets germinated laterally on both sides (Fig. 2.3) imparting a knotted appearance to the medians of some of the spindles (Misra, 1969, plate 7B). Such forms represent an intermediate stage between the string of beads and spindles (*Fractofusus*). Space constraint does not permit reproduction of numerous intermediate stages between the chains of globules and full grown spindles. The growth pattern from globules to organisms with canal like structure having single opening and the system of branching ducts might indicate their affinity to Cnidarians.

Ducts emerging from the median (Figs. 1.5 and 1.6) evolved into more and more complex forms (Fig. 2.7) of primary, secondary and tertiary branches. They appear to represent an intricate canal system and consequent overspecialization that possibly was the cause of extinction of spindle-shaped organisms. The spindles appeared much deeper in time and disappeared before all others like *Charnia, Charniodiscus* and *Aspidella*. There can be no explanation other than overspecialization for spindles to begin their life in the Mistaken Point assemblage and end there only. The other organisms did not overspecialize and continued beyond Mistaken Point assemblage. For the sake of analogy we can think of Ammonoids that faced extinction in Late Mesozoic due to overspecialization of suture lines.

The radiating or dendrite like forms (Misra 1969) have been designated as *Bradgatia* (see Clapham *et al.*, 2003 and references therein) and recently compared to different shapes of alphabets I, V, U and O depending on the stage of growth (Flude and Narbonne, 2008). However, the arrangement of spindle-like arms in a radiating fashion indicates that the or-

ganism was made up of radiating spindles (Fig. 2.4) rather than fronds and petals (contra Jenkins, 1992; Ford, 1999).

The strings of beads had multiple folds (Plate I-5) such that the folded parts converged at a point to produce a radiating pattern. The globules of radiating chains possibly germinated into radiating mini-spindles to form Dendrite like or Radiating organisms. The small sized, closed spindles constituting radiating forms were juveniles that could even be disjointed (Fig. 2.5) and grew separately to become full grown spindles. The strings of beads in some cases formed a loop like bend (Plate I-2) on the outer side of which might have grown frondlets to produce comb-like structure (Misra, 1969). The spindles, *Bradgatia* and comb-like structures had a common origin and ancestry.

The origin of round bodies has been discussed by a few scientists. Fedonkin (1992) designated round bodies having concentric organization as Cyclozoa and explained their genesis through 'primitive, periodic, additive growth'. Thereafter, the evolution is believed to have proceeded from concentric to radial body plan. However, the round lobate organisms of Mistaken Point (Call them *Ivesia* or *Evesheadia*) are different. The origin of lobes in the round lobate organisms has not been explained in the past.

The lobate forms are of two types from the genetic stand point. One of them had distinct outline and common walls between the lobes (Fig. 2.13) while the other type appears to have had separate lobes without a common wall (Fig. 2.14). The first type having a common wall between the adjacent lobes possibly formed as a result of splitting (Plate I, below arrow 1) of globular bodies. Subsequently there was inflammatory growth and budding off of mini-lobes, to produce more and more lobes (see Misra, 1971, Fig. 2A).The second type developed as result of clustering of globular bodies (Fig. 2.14) around a globule.

Leaf-shaped organisms (Misra, 1969) classified as *Charnia* and *Charniodiscus* are perhaps the most crucial as they occur in most of the Ediacaran areas. The fossils are made up of frond, stalk and bulbous holdfast. The origin of the frond part of the organisms has been discussed (Waggoner, 2003; Brasier and Antcliffe, 2004; Narbonne, 2004) but the growth relation between the disc, stalk and the main body remains uncertain. Disc and frond being organs of the same organism (Figs. 1.9 and 1.10) could not possibly have origins independent of each other. Jenkins (1985) had noticed the presence of *Charnia masoni* in Misra's (1969, plate, 6) where the *Charnia* is seen to germinate from globular bodies (Plate I-4; Fig. 2.9). It has been observed (Gehling *et al.*, 2000, p. 444) that the stems are preserved emerging from the upper sides of discs in Ediacaran fossils worldwide. Since the growth is believed to have been unipolar (Seilacher, 1989) in frondose forms, their growth possibly started from the holdfast or floats and continued through stalk to main body (Fig. 2.9). Stalk was the main duct (see Jenkins, 1992, p. 161) connected on one side to the hollow base and on the other end branched off into the canal system in the main body (Fig.

2.10). It continued to grow into a system of canals in the main body (Fig. 2.11) that became more and more complex with the canals bifurcating and trifurcating towards the periphery of the main body. Many fronds without a bulbous base (Fig. 2.11) and many discs without a frond indicate a week joint between them. The type of growth (Plate I-4) might be suggestive of medusa-polyp relation in Cnidarians. The pattern of growth in *Charnia* may be different from 'sea pens' but the evolutionary trend in *Charniodiscus* starting from globular bodies (Fig. 2. 8) through stalk to main body (Fig. 2. 9) is discernible.

Biological affinity of organisms has remained highly debatable (Clapham and Narbonne, 2002) and the organisms were possibly Cnidarians possibly not (Ford, 1999). In the recent years after the discovery of eggs, larvae and embryos from the Weng'an Fauna in the Doushantauo phosphorites and dolostones in Southwest China (Chen *et al.* 2002; Fedonkin 2003), the idea of organisms being Cnidarians (Glaessner and Wade, 1966; Misra, 1969, 1971) appears to have gained support after many twists and turns (see Narbonne, 2005).

CONCLUSIONS

The four main categories of animals (*Fractofusus, Charniodiscus-Charnia, Bradgatia* and *Ivesia/Ivesheadia*) had common parentage possibly in the globular bodies similar to the strings of beads. Such globular bodies existed before the Ediacaran Period. They joined to form chains that grew into frondlets on either side or got folded as double chains to form spindle-shaped animals with a median canal in between and opening at one end of it.

No single mechanism could produce different types of organs like bulbous holdfast, elongated stalk, a frond and antenna like tip in a single organism except the organic growth from one part to the other. The relation between the bulbous holdfast (float?) and frond was akin to Medusa -Polyp relationship in the Cnidarians.

Radiating (*Bradgatia*) forms were produced by converging arrangement of chains of globules. The forms thus represent spindles in a different preservation. Round lobate organisms having common wall between lobes were formed by splitting of globular bodies while those having individual lobes without common wall could form by concentric aggregation of globules. Spindle-shaped animals suffered extinction due to over specialization of their canal system while the other forms did not overspecialize and continued beyond Mistaken Point assemblage.

ACKNOWLEDGEMENTS

EXPLANATION OF PLATE I

Field photograph showing growth of different Ediacaran organisms of Mistaken Point Fauna in the Avalon Peninsula of Newfoundland including through splitting of globule (below arrow 1), **globular bodies** forming a chain (1to 3), **loop-like string** of globules (2), *Charnia* germinating from the chain of globules (4) **converging strings of beads** or **chain of globules** (5) and chains arranged as *Charnia grandis* (6).

Plate I

S. B. MISRA
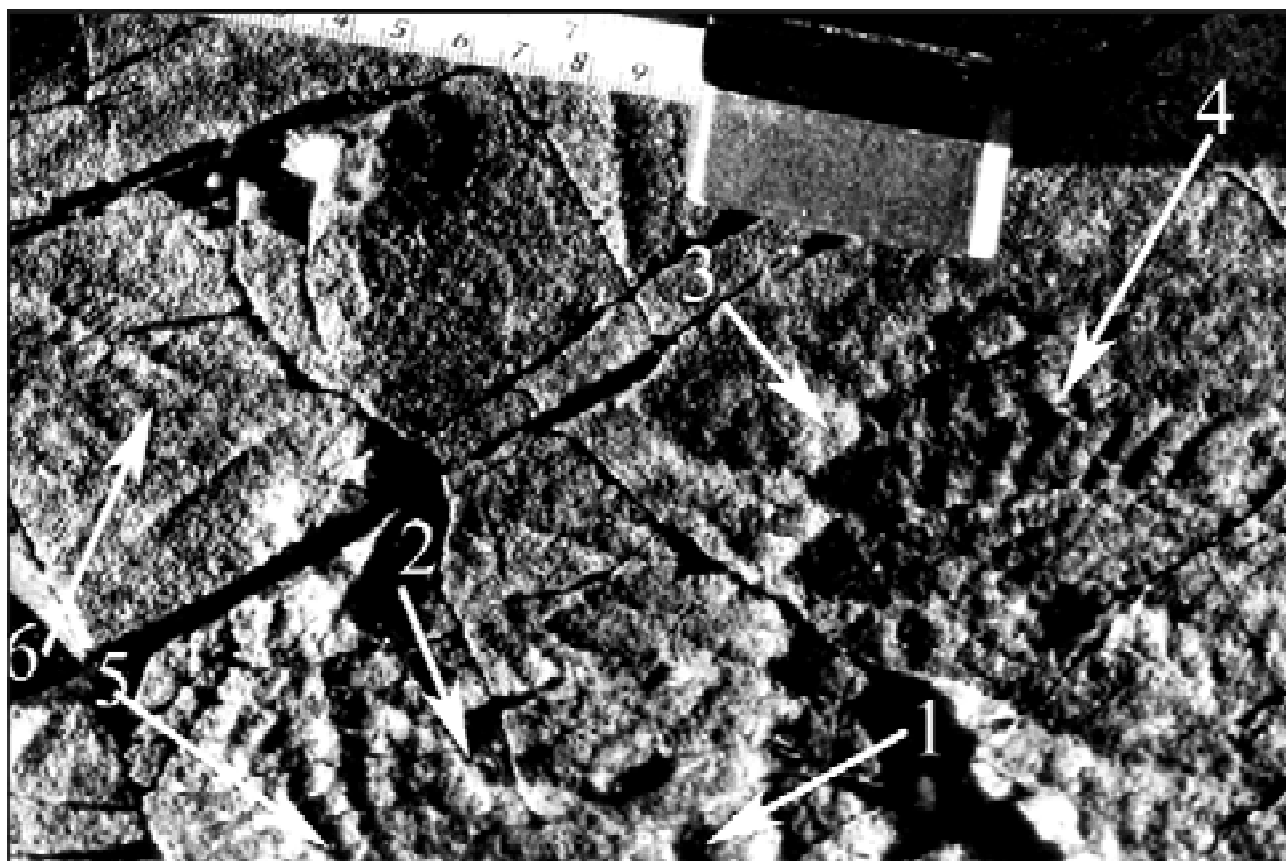
University, India in February, 2010. I am thankful to the unknown reviewers for helpful comments.

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A REPORT ON THE "PRE-COLLOQUIUM WORKSHOP ON APPLICATIONS OF MICROPALEONTOLOGY IN ENVIRONMENTAL AND ENERGY RESOURCE MANAGEMENT"

A pre-Colloquium (XXII – ICMS) National Workshop on "Applications of Micropaleontology in Environmental and Energy Resource Management" was organized by the Department of Geology, National College, Tiruchirapalli on 14th and 15th December 2009 at Tiruchirapalli, Tamil Nadu. In the Inaugural function (14th December, 2009), Dr.V. Kumar, Head of the Department and Convener of the workshop delivered the Welcome Address. Later, Dr. K. Anbarasu, Principal of the college delivered the Presidential address. Dr.Rajiv Nigam, Scientist, NIO, Goa delivered the inaugural address. A special address was given by Dr. A. Govindan, Rtd. DGM, ONGC, Chennai. Dr.P.Kundal, Nagpur University, Nagpur offered felicitations followed by vote of thanks proposed by Dr. S. M. Hussain, Co-Convener, Department of Geology, University of Madras, Chennai.

Several special lectures were given by the eminent researchers/scientists who shared their knowledge with young scholars/participants to help them pursue higher research in the field of micropalaeontology. The first key-note lecture was delivered by Dr. Rajiv Nigam, NIO, Goa on "Some New Applications of Foraminifera: Examples from Indian Waters". Dr. A. Govindan, Asia Bio-Industries, Chennai and formerly DGM, ONGC, talked on "Foraminifera in Paleoenvironmental Studies and in Hydrocarbon Exploration Pursuits". He also showed a few index foraminiferal taxa to the participants in the afternoon during the practical session. Dr. Anjum Farooqui, a Scientist from BSIP, Lucknow, spoke on "Potentials of the Thecamoebians as a proxy for monitoring Palaeoecology and Palaeoclimate".

The second day (15th December 2009) was marked by five special lectures. Prof. P. Kundal from Nagpur University, Nagpur gave a talk on "Significance of Calcareous Algae in Petroleum Exploration". Dr. R.Venkatachalapathy, Department of Geology, Periyar University, Salem spoke on "Role of Microfossils in identifying source rock for petroleum". Dr. S. M. Hussain, Department of Geology, University of Madras highlighted in his talk the "Importance of Ostracoda in Environmental and Ecological studies". Dr. A. N. Reddy, ONGC, Chennai delivered an interesting lecture on "Biostratigraphic Applications in Oil Exploration". Dr. Anand S. Kale, Reliance Industries, Navi Mumbai talked on "Application of Microfossils in Oil Exploration".

During the two-day deliberations in the workshop, the significance of important microfossils such as Foraminifera, Ostracoda, Calcareous algae and Thecamoebians was highlighted in ecological/climatic studies, hydrocarbon and oil exploration and pollution studies. About 90 participants from Colleges/Universities of different parts of the country have benefited from experts through interaction and discussion on matters relating to micropaleontology. A few constructive suggestions were also given to the young scholars by the senior scientists as to how to utilize these microfossils in the context of the current energy scenario of the country, climatic conditions as well as in the pollution studies.

At the end, in the valedictory session of the Workshop on 15th December, 2009 Dr. S. M. Hussain, Co-Convener welcomed the participants. Dr. K. Anbarasu, Principal of the college, delivered the Presidential Address. Prof. S .N. Bhalla, Professor and Head (Rtd.) and a well known micropaleontologist from Aligarh Muslim University, Aligarh gave the valedictory address and distributed the Certificates to the participants. Prof. Anand S. Kale delivered the special address. Dr. M. R. Rao, Scientist, BSIP, Lucknow and Dr. A. N. Reddy, Chief Geologist, ONGC, Chennai offered felicitations, and a vote of thanks was proposed by Dr. V. Kumar, Convener. This National Workshop brought to attention the significance of micropaleontological research work in environmental and energy resources and opened a new chapter for the young geologists and geological community.

S. M. HUSSAIN

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Subclass **Ostracoda** Latreille, 1806
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Subfamily **Cypridinae** Baird, 1845
Genus ***Sclerocypris*** Sars, 1924
Sclerocypris dharwadensis n. sp.
(PI. I, figs. 2a-e; PI. III, figs. 4a-b,5)
or
Paijenborchella (*Eopaijenborchella*) *angulosa* Siddiqui, 2006

(PI. I, figs. 7-8)

Synonymies - **to be presented in the following abbreviated order:** *Globulina gibba* d' Orbigny, 1846, p. 227, pl. 13, figs. 13-14. - Bhatia and Mohan, 1959, p. 635, text-fig. 3, fig. 10. - Mohan and Bhatt, 1968, p. 171, pl. 13, fig. 36.

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