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Organic Matter Characterization of Carbonaceous Shales from Raniganj Coalfields and its Implications on Depositional Condition: A Palynofacies and Petrographic Overview

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Abstract: The present work deals with the palaeoenvironment and depositional setting of the subsurface sediments from bore hole RT-4 of Tamra block from Raniganj coalfield of Damodar Basin, India. Nineteen shale samples were subjected to palynological and coal petrographical analyses. On the basis of botanical affinity between the miospores and the parent plants as well as the different plant groups, each coal plant assemblage was determined. The dominance of bisaccates such as *Scheuringipollenites, Faunipollenites* (=*Protohaploxypinus*), *Striatopodocarpites* and presence of monosaccates such as *Densipollenites, Parasaccites* reflect a peat forming community composed mainly of gymnosperms. Subordinate trilete spores derived from filicopsids (*Cyclogranisporites, Horriditriletes, Brevitirletes, Callumispora, Microbaculsispora, Microfoveolatispora, Cyclobaculisporites*), lycopsids (*Indotriradites, Gondispoirtes and Didecitriletes*) and sphenopsids (*Laevigatosporites*) are less abundant occurring in variable proportions reflecting a hypautocthonous taphocenose. Presence of *Botryococccus* algae has been recorded. Palynofacies and petrographic analyses suggest deposition in open mires in a Limnic to limno-telmatic conditions with intermittent flooding of the site.

Keywords: Raniganj coalfield, Damodar basin, Palynofacies, Carbonaceous shales, Petrography

INTRODUCTION

The Gondwana basins of India account for 99% of the coal resources of the country and occur within the suture zones of Precambrian cratonic blocks of peninsular India along prominent linear belts (Acharyya, 2000) (Fig.1a). They were formed by rifting along Narmada-Son transform fault (mid continental rift zone), NW-SE intracontinental mobile belts (Pranhita-Godavari and Son-Mahanadi grabens), Eastern Ghat Orogenic belt between India and Antarctica (East coast rift zone) and N-S basin margin of Bengal (Purnea-Rajmahal-Galsi rift) (Biswas, 1999). In Eastern and Central India, rocks of the Gondwana Supergroup occur in a series of discontinuous graben basins along the Narmada-Son geo fracture which transects the Indian shield in the middle. These east west basins include Koel-Damodar, Rewa and Satpura basins.

The Damodar basin displays an excellent development of Lower Gondwana sediments in isolated depressions in an E-W trending narrow linear belt with southerly dips (Gee 1932, Jatindra 2006). There are two coal bearing formations which host numerous coal seams spreading from one end of the basin to the other with intricate pattern of splitting and merging (Datta et al., 2006). They are, the Barakar Formation consisting of low moisture, medium volatile and medium coking coal and Raniganj Formation which consists of high moisture and high volatile coal. The focus of the present investigation is to characterize the palynological and petrographic attributes of the subsurface sediments in bore hole RT 4, to understand the environment of deposition (Fig.1b). The borehole was drilled by Geological Survey of India in the Tamra block of the Raniganj coalfield. Murthy et al., (2010) have palynologically dated the RT-4 sediments and assigned a late Early Permian to Late Permian age to the sequence.

GEOLOGICAL SETTING

The Raniganj coalfield is the easternmost depository within the Damodar Basin. It covers an area of ca 3000 km^2 and lies between latitudes 23°03' and 23°51' N and longitudes 86°42' and 87°28' E. It is located at the border of the

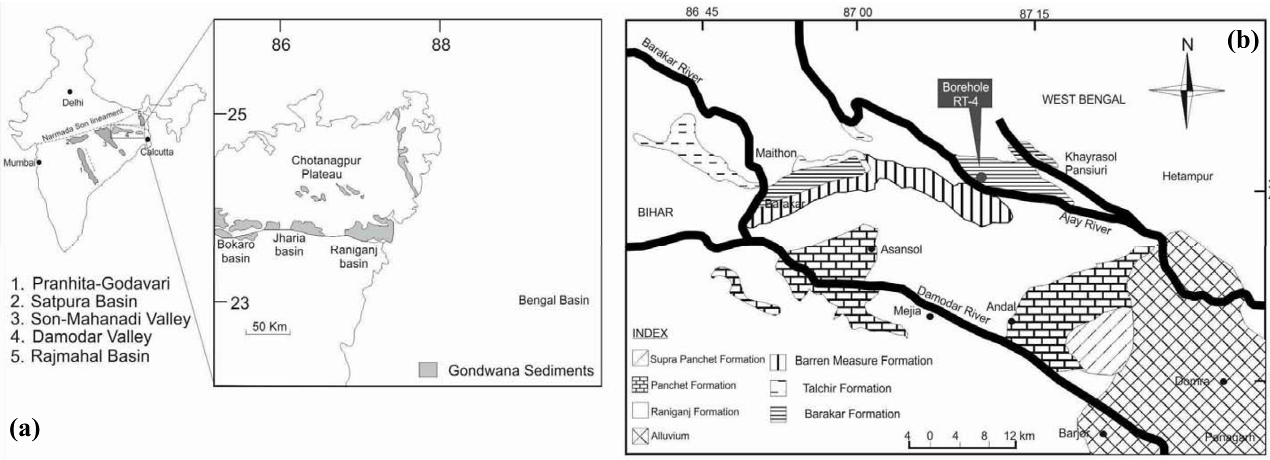

Fig.1. (a) Gondwana coal basins of India and coalfields of Damodar Valley (enlarged). **(b)** Geological map of Raniganj coalfield and location of borehole RT-4.

states of Bengal and Bihar, 200 km northwest of Kolkata (Calcutta). The Damodar river traverses the southern area of the coalfield. The coalfield was first mapped by D.H. Williams (1850). The coalfield is bound by Precambrian rocks in the north, south and west, whereas the eastern boundary is concealed beneath a thick succession of unconsolidated recent sediments. Morpho-tectonically the Raniganj coalfield shows a half-graben structure with a major E-W trending fault which brings the metamorphics in the south in juxtaposition with the Gondwanas. The Gondwana rocks are represented by Talchir, Barakar, Barren measures, Raniganj, Panchet and Supra Panchet formations, ranging in age from Early Permian to Early Cretaceous. Rajmahal traps have been encountered along the easternmost fringe of the Raniganj coalfield above the Panchet Formation. The generalised stratigraphic sequence in the Raniganj coalfield is given in Table 1.

The Tamra block is located in the northern part of the Raniganj coalfield in the Trans-Ajay area, Birbhum District West Bengal. It is bound between Barul-Bagdiha sector in the south and Kasta area to the west. The block covers an area of 8.5 km^2 and lies between latitudes 23°45' and 23°47'N and longitudes 87°06' and 87°09'E. During the course of the regional exploration by the Geological survey of India five boreholes viz. RT-1 in the southern part of the Tamra block, RT-2 in the north western part, RT-3 in the eastern part, RT-4 in the eastern central part and RT-5 in the western part of the Tamra block were drilled in order to appraise the coal resource potentiality of Barakar coal seams which revealed the presence of coal bearing Barakar Formation beneath a thick cover of Barren Measures Formation resting over a basement of Precambrian migmatitic gneisses. The Talchir rocks are unexposed but sporadic intersection in boreholes suggest patchy development within disconnected shallow depressions over the basement. The present studies are carried out in bore hole RT-4 which intersected the Barren Measures Formation and Barakar Formation but not the Talchir Formation. The Barakar Formation is characterized by alternate successions of dirty white, fine to coarse grained arkosic sandstone, minor siltstone, shale, carbonaceous shale and coal seams. Several fining upward sequences with gritty sandstone at the base and coal seam at the top have been recorded. The sandstone is composed of moderately sorted, sub-rounded quartz and altered feldspar grains in kaolinitic matrix. The intersected thickness of the Barakar Formation in bore hole RT-4 is 154.00 m. The Barren measures Formation consists of dark grey to black micaeous silty fissile shales, bands of ironstone shale and grey micaeous siltstone. The total thickness of Barren Measures Formation in bore hole RT-4 is 294.00 m.

METHODOLOGY

Palynofacies analysis was performed on 19 shale samples from bore hole RT-4 of Tamra block, Raniganj coalfield (Fig.2). The concentrated organic matter was prepared using the standard procedure described by Faegri and Iversen (1989). 50 gm of each sample was treated with HCL and HF. The preparation technique employed was the standard non-oxidative palynological procedure. The isolated organic matter was sieved using 500 mesh seive and mounted on strewn slides using Canada balsam as mounting medium. Palynofacies analysis was carried out to evaluate the content of particulate organic matter. The palynofacies technique involved the qualitative and quantitative assessment of the total organic matter comprising the identification of all particulate organic matter constituents. The relative percentages of these components are based on counting 200

Table 1. Stratigraphic sequence of Raniganj coalfield (Datta 2003)

Age	Formation	Lithology	Max. Thickness(m)
Recent and Quaternary	Surfacial deposits	Alluvial and residual soils, laterite capping.	90
		Unconformity	
Tertiary		Light grey mudstone and siltstone with bands of marlstone; white, soft, fine grained, clayey sandstone; mottled clay, loose sand with pebbles of vein quartz; occasional lignite in the basal part.	300
Cretaceous	Igneous intrusives	Basic (doleritic) dykes, ultra basic (mica-peridotite, mica-lamprophyre, lamproite) sills and dykes.	–
Cretaceous	Rajmahal Formation	Vesicular, porphyritic basalt and volcanic breccia, weathered aphanitic basalt at places and one to five inter-trappeans consisting of grey shale, fine grained sandstone and carbonaceous shale.	120
		Unconformity	
Late Triassic	Supra-Panchet/ Durgapur beds	Massive, very coarse to coarse quartzose sandstone, conglomeratic at places, bands of dark red silty shale.	300
		Unconformity	
Early Triassic	Panchet Formation	Coarse grained, greenish yellow and greenish grey, soft, micaceous, sandstone with slump structures; khaki green, fissile shales; coarse grained, immature sandstone with bright reddish brown claystone with calcareous concretions, conglomeratic at base.	600
		Unconformity	
Late Permian	Raniganj Formation	Grey to light grey, fine and medium grained, micaceous, felspathic sandstones with calcareous, clayey matrix in the upper part, siltstone and shale often interlaminated with fine grained sandstone, carbonaceous shale, and coal seams.	1150
	Barren Measures/ Ironstone shales	Dark grey to black, micaceous or carbonaceous, fissile shale with ferruginous laminae and thin bands of dense, hard, crypto-crystalline clay ironstone, rarely interbanded with fine grained sandstone.	600
Early Permian	Barakar Formation with Karharbari Formation (?)	Very coarse to medium grained, arkosic sandstones, often cross-bedded; grey and carbonaceous shales, at times interbanded with fine grained sandstone, fire clay lenses and coal seams, pebbly and carbonaceous in lower part.	750
Early Permian	Talchir Formation	Tillite/Diamictite with sandy or clayey matrix at the base, medium to fine grained khaki or yellowish green felspathic sandstones, siltstone, silty shale, needle shale and rhythmite with dropstones	500
		Unconformity	
Precambrian	Chotanagpur Gneissic Complex	Granite gneiss with migmatite gneiss, hornblende schist, hornblende gneiss, metabasic rocks, pegmatite and quartz veins etc.	–

particles per slide. The observation was carried out on Olympus BX61 microscope with DP-25 camera using Cell A software. The kerogen classification used in this study was that of Masron and Pocock (1981).

Palynodating of these samples were done by one of the authors (Murthy et al., 2010) and therefore have not been dealt in the present work but the same slides were used to determine the relative proportions of the groups of taxa. Assignments of dispersed spores and pollen grains to their respective parent plant groups were based on the compilations of Balme (1995).

For petrographic studies, the samples were crushed to -20 mesh size fraction and the pellets were prepared by embedding them in a mixture of epoxy resin and hardener in a ratio of 5:1 respectively. The hardened pellets were ground with different grades of silicon carbide paper and further polished with polishing alumina and used for the study as per specifications of ICCP (1971, 1975). The maceral analysis was carried out in fluorescent mode on the same microscope. Leica application suite (LAS) was used for image acquiring. Quantitative estimation of macerals was done on 450 counts per sample counted on automatic point counter using Petroglite 2.35 Software.

RESULTS AND DISCUSSION

Palynofacies

Three palynofacies have been recognised which are classified on the relative frequencies of the five categories of palynological matter as per Masron and Pocock (1981) - Structured terrestrial organic matter, Biodegraded organic matter, Amorphous organic matter (AOM), Black debris or charcoal (Opaque phytoclasts) and palynomorphs (Fig.3). The list of palynomorph taxa under their probable plant affinities is given in Table 2 and the palynofacies components are illustrated in Fig.4.

Palynofacies - type 1 (P-1)

It has been identified in samples RT-4/108, 104, 74, 69, 47, 44, 41, 38, 25, 21, 17 and is characterized by the

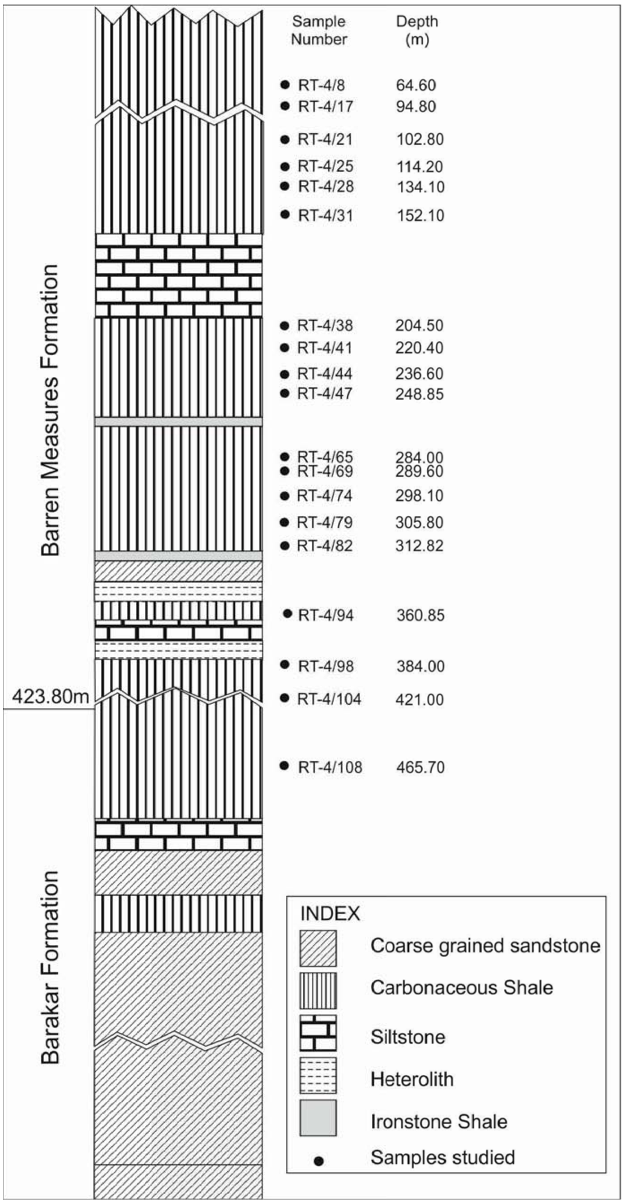

Fig.2. Litholog of borehole RT-4 with position of studied samples and their respective depth.

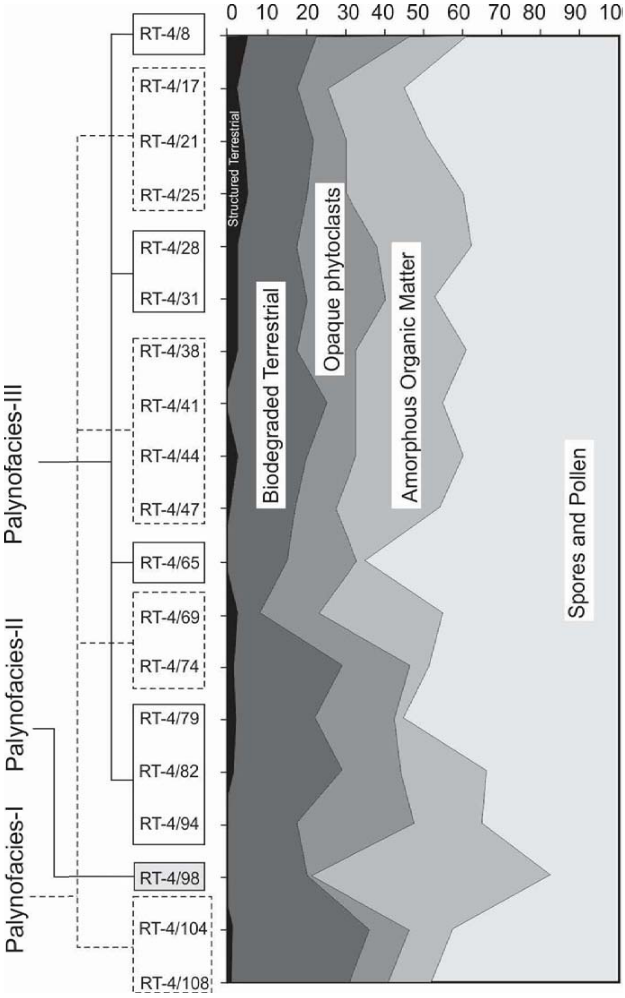

Fig.3. Frequency distribution of organic matter in carbonaceous shale and the palynofacies derived.

dominance of palynomorphs (42-48%). Among the palynomorphs, the gymnosperms are the dominant group accounting for 25%-45% of the palynomorph population and spores account for 15%. The coccal algae, *Botryococcus* constitutes 2-3%. The biodegraded organic matter constitutes 25-35 % of the total organic matter. AOM accounts for 5-22% of the organic matter, opaque phytoclasts make up 7-17% with the blade shape type dominating over the equidimensional ones, while structured organic matter constitutes 0-1.5%.

Palynofacies-type 2 (P-2)

It is represented in only one sample RT-4/98. The AOM is the predominant organic matter accounting for 62% of the total organic matter and is typical spongy type and finely divided fraction that dominates the association probably derived from vascular land plants (Batten 1983). Biodegraded organic matter accounts for 20%, palynomorphs constitute 17% represented by gymnosperms (10.5%) and spores account for 6.5% of the total palynomorph population. *Botryococcus* and Opaque phytoclasts constitute 1% each while structured organic matter is not recorded.

Palynofacies-type 3 (P-3)

It is found in samples RT-4/94, 82, 79, 65, 31, 28, 8. The total organic matter is constituted by the dominance of palynomorphs, followed by the abundance of opaque phytoclasts, biodegraded organic matter, amorphous organic matter and structured organic matter. Palynomorphs make up 35-65% of the total organic matter of which gymnosperms make up 50% with bisaccates reaching upto 47% and

Table 2. Botanical affinity of the recovered palynotaxa from borehole RT-4

Probable affinity	Palynotaxa
Sphenopsida	*Laevigatosporites* Ibrahim 1933
	Laevigatosporites vulgaris Balme & Hennelly 1956
Lycopsida	*Indotriradites* Tiwari 1964
	Indotriradites sparsus Tiwari 1965
	Indotriradites mammilatus Venkatachala & Kar 1965
	Didecitriletes Venkatachala & Kar 1965
	Didecitriletes horridus Venkatachala & Kar 1965
	Gondisporites Bharadwaj 1962
	Gondisporites reticulates Tiwari & Ram-Awtar 1989
	Gondisporites raniganjensis Bharadwaj 1962
Filicopsida	*Brevitriletes* Bharadwaj & Srivastava 1969
	Brevitriletes unicus Bharadwaj & Srivastava 1969
	Callumispora Bharadwaj & Srivastava emend. Tiwari et al. 1989
	Callumispora gretensis (Balme & Hennelly) Bharadwaj & Srivastava emend. Tiwari et al. 1989
	Callumispora. barakarensis Bharadwaj & Srivastava emend. Tiwari et al. 1989
	Cyclogranisporites Potonie & Kremp 1954
	Cyclogranisporites distinctus Kumaran & Maheshwari 1980
	Cyclogranisporites gondwanensis Bharadwaj & Salujha 1964
	Cyclogranisporites barakarensis Srivastva 1970
	Cyclobaculisporites Bharadwaj 1955
	Cyclobaculisporites bharadwajii Salujha 1965
	Cyclobaculisporites minutus Bharadwaj & Salujha 1964
	C.indicus Bharadwaj & Salujha 1964
	Didecitriletes Venkatachala & Kar 1965
	Didecitriletes horridus Venkatachala & Kar 1965
	Horriditriletes Bharadwaj 1962
	Horriditriletes curvibaculosus Bharadwaj & Salujha 1964
	Horriditriletes sp.
	Microbaculispora indicus Bharadwaj 1962
	Microbaculispora gondwanensis Bharadwaj 1962
	Microbaculispora barakarensis Tiwari 1965
	Microbaculispora indica (Tiwari) emend. Tiwari & Singh 1981
	Microbaculispora tentula Tiwari 1965
	Microfoveolatispora Bharadwaj 1962
	Microfoveolatispora bokaroensis Tiwari 1965
	Microfoveolatispora foveolata Tiwari 1965
Gymnosperms	
Cycado-ginkgopsida	*Marsupipollenites* Balme & Hennelly 1956
	Marsupipollenites triaradites Balme & Hennelly 1956
	M. triradiatus Balme & Hennelly 1956
	Praecolpatites Bharadwaj & Srivastava1969
	Praecolpatites sp.
	Tiwariasporis Maheshwari & Kar 1967
	Tiwariasporis flavatus Maheshwari & Kar 1967
	T.gondwanensis (Tiwari) Maheswari & Kar 1967
	Weylandites Bharadwaj & Srivastava 1969
	Weylandites circularis Bharadwaj & Srivastava 1969
	Weylandites indicus Bharadwaj & Srivastava 1969
Coniferopsida	
Monosaccate	*Barakarites* Bharadwaj & Tiwari 1964
	B. indicus Bharadwaj & Tiwari 1964
	B.indica Tiwari 1965
	Densipollenites Bharadwaj 1962
	Densipollenites densus Bharadwaj 1962
	Densipollenites indicus Bharadwaj 1962
	Densipollenites invisus Bharadwaj & Salujha 1964
	Densipollenites magnicorpus Tiwari & Rana 1981
	Distriamonosaccites Bharadwaj 1962
	Distriamonosaccites ovalis Bharadwaj & Salujha 1964

Table 2. Contd...

Probable affinity	Palynotaxa
	Parasaccites Bharadwaj & Tiwari 1964
	Parasaccites bilateralis Tiwari 1965
	Parasaccites korbaensis Bharadwaj & Tiwari 1964
	P. obscurus Tiwari 1965
	Plicatipollenites Lele 1964
	Plicatipollenites indicus Lele 1964
	Plicatipollenites gondwanensis (Balme & Hennely) Lele 1964
	Striomonosaccites Bharadwaj 1962
	Striomonosaccites circularis Bharadwaj & Salujha 1964
	Striomonosaccites ovatus Bharadwaj 1962
Nonstriate Bisaccate	*Krempipollenites* Tiwari & Vijaya 1995
	Krempipollenites indicus Tiwari & Vijaya 1995
	Platysaccus Naumova emend. Potonie & Klaus 1954
	Platysaccus densus Kar, 1968
	Scheuringipollenites Tiwari 1973
	Scheuringipollenites tentulus (Tiwari) Tiwari 1973
	S. maximus (Hart) Tiwari 1973
	S. barakarensis (Tiwa.) Tiwari 1973
Striate Bisaccate	*Crescentipollenites* Bhardwaj, Tiwari & Kar 1974
	Crescentipollenites amplus (Balme & Hennely)Tiwari & Rana1980
	Crescentipollenites fuscus (Baradwaj) Bhardwaj, Tiwari & Kar 1974
	Crescentipollenites. gondwanensis (Mahesh.) Bharadwaj et al. 1974
	Distriatites Bharadwaj 1962
	Distriatites bilateris Bharadwaj 1962
	Faunipollenites Bharadwaj 1962
	Faunipollenites varius Bharadwaj 1962
	Faunipollenites singrauliensis Sinhas 1972
	Faunipollenites magnus (Bose & Kar) Tiwari & Vijaya 1989
	Faunipollenites perexiguus Bharadwaj emend Tiwari et al. 1989
	Primuspollenites Tiwari 1964
	Rhizomaspora Wilson 1962
	Rhizomaspora indica Tiwari 1965
	R.triassica Tiwari &Vijaya 1981
	Schizopollis Venkatachala & Kar 1964
	Schizopollis disaccoides Venkatachala and Kar 1964
	Striasulcites Venkatachala & Kar 1968
	Striasulcites tectus Venkatachala & Kar 1968
	Striasulcites ovatus Venkatachala & Kar 1968
	Striatites Pant emend. Bharadwaj 1962
	Satriatites communis Bharadwaj & Salujha 1964
	Striatites reticuloides Tiwari 1964
	S. communis Bharadwaj & Salujha 1964
	Striatites tectus Venkatachala & Kar 1968
	*Striatopodocarpites S*oritsch & Sedova emend. Bharadwaj 1962
	Striatopodocarpites ovatus (Maheshwari) Bharadwaj & Dwivedi 1981
	Striatopodocarpites magnjficus Bharadwaj & Salujha 1964
	Verticipollenites Bharadwaj 1962
	Verticipollenites crassus Bharadwaj & Salujha 1964
	Verticipollenites debilis Venkatachala & Kar 1968
	Verticipollenites gibbosus Bharadwaj 1962
	V. secretus Bharadwaj 1962
	Verticipollenites oblongus Bharadwaj 1962
Taeniate Bisaccate	*Arcuatipollenites* Tiwari & Vijaya 1995
	Arcuatipollenites sp.
	Arcuatipollenites pellucidus (Goubin) Tiwari & Vijaya 1995
	Guttulapollenites Goubin 1965
	Guttulapollenites hannonicus Goubin 1965
	G.punctatus Venkatachala, Goubin and Kar

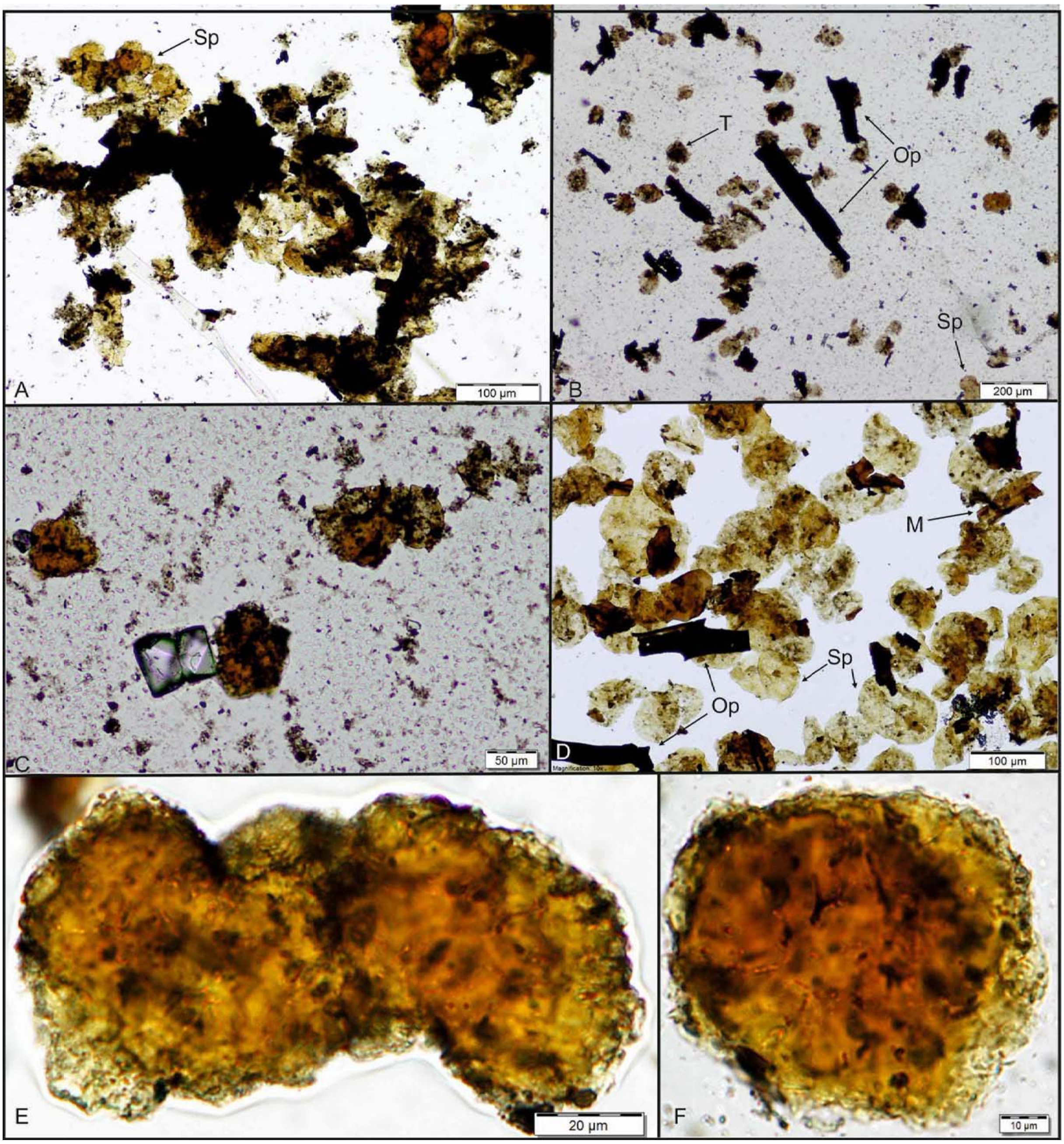

Fig.4. Dispersed organic matter from studied carbonaceous shale samples of RT-4. A. Mass of degraded organic matter with opaque phytoclasts and spores (Sp) BSIP Slide No.14604, B. Lath shaped opaque phytoclasts (Op) in a backdrop of terrestrial degraded matter (T) BSIP Slide No. 14606 , C. fragments of spores(Fs) and *Botryococcus* algae (B) BSIP Slide No. 14608, D. palynofacies components in a compact mass. Opaque phytoclasts (Op), Palynomorphs (Sp) and Membranes (M) BSIP Slide No. 14608, E-F. *Botryococcus* algae, BSIP Slide No. 14607.

monosaccates constitute only 5% and spores account for 15% of the total palynomorph population. *Botryococcus* algae accounts for 2%. Opaque phytoclasts vary from 17-30% with the blade shaped ones being dominant, biodegraded organic matter ranges from 15-20%, AOM accounts for 2-15% while structured organic matter is 0-5%.

PETROGRAPHIC STUDY

The petrographic studies of the shale samples reveal that the liptinite constitutes the most abundant maceral group in all the shales (Table.3, Fig.5). Detailed maceral analysis reveals that among the liptinite macerals sporinite is dominant (10.6-26.8 vol%) followed by alginite (4.8-34.2 vol%) and liptodetrinite (3-22 vol%). The structured

Table 3. Distribution of Macerals in the studied samples from borehole RT-4

Sample No.		RT-4/ 8	RT-4/ 17	RT-4/ 21	RT-4/ 25	RT-4/ 28	RT-4/ 31	RT-4/ 38	RT-4/ 41	RT-4/ 44	RT-4/ 47	RT-4/ 65	RT-4/ 69	RT-4/ 74	RT-4/ 79	RT-4/ 82	RT-4/ 94	RT-4/ 98	RT-4/ 104	RT-4/ 108
Vitrinite		8	15	13	10	10	12	12	12	12	11	18	16	7	11	13	13	16	18	15
Telovitrinite		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0
	collotelinite	0.0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0
Detrovitrinite		8.0	15	13	10	9.8	12.0	11.6	11.9	12.3	10.7	18	16.0	5.6	11.2	12.9	12.7	16.2	18.3	15.2
	Vitrodetrinite	8.0	15	13	10	9.8	12.0	11.6	11.9	12.3	10.7	18	16.0	5.6	11.2	12.9	12.7	16.2	18.3	15.2
Liptinite		49	42	56.4	58.4	56.2	46.5	43.8	48.3	46.5	47.6	36.9	37.5	45.8	35.0	41.6	29.2	31.8	32.0	24.2
	Sporinite	20.7	14.6	26.8	19.6	25.8	20.5	10.6	12.6	16.4	20.8	18.8	17.3	15.0	14.9	18.7	10.0	19.3	21.0	12.1
	alginite	19.0	16.1	24.2	34.0	24.7	19.2	30.2	28.4	18.3	4.8	5.8	11.9	26.1	8.3	6.8	6.9	6.1	5.8	4.5
	Liptodetrinite	9.2	11.6	5.4	4.8	5.7	6.8	3.0	7.3	11.8	22.0	12.3	8.3	4.7	11.8	16.1	12.3	6.4	5.2	7.6
Inertinite		2	2	1.3	2.9	3.1	1.3	0.5	0.4	1.1	2.4	3.2	3.4	2.5	2.4	0.0	2.3	4.4	5.8	12.1
	Fusinite	1.7	1.5	1.3	2.9	2.6	1.3	0.5	0.4	1.1	2.4	3.2	1.7	2.1	2.4	0.0	2.3	3.1	5.8	12.1
	Funginite	0.0	0.5	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.4	0.0	0.0	0.0	1.3	0.0	0.0
Mineral Matter		41.4	41.1	28.9	28.7	30.9	40.2	44.1	39.4	40.1	39.3	42.4	43.1	44.4	51.4	44.6	55.3	47.9	44.0	48.5
	Pyrite	2.3	11.2	0.7	0.0	0.0	1.7	0.0	1.1	1.4	1.2	0.6	2.7	1.7	2.3	1.4	1.5	1.9	2.1	1.5
	Carbargillite	25.1	18.0	20.0	23.5	20.3	19.8	30.0	31.0	29.1	33.3	33.1	30.0	28.0	38.9	38.4	39.2	32.6	36.8	47.0
	siderite	2.3	1.0	0.7	0.5	0.0	2.3	1.5	1.9	1.4	1.8	1.9	2.1	0.8	2.3	1.1	1.9	1.8	1.2	0.0
	calcite	5.4	3.2	3.5	3.3	8.0	10.0	11.6	0.0	3.6	0.0	3.9	4.1	11.3	0.0	0.0	0.0	0.0	0.0	0.0
	carbosilicate	6.3	7.7	4.0	1.4	2.6	6.4	1.0	5.4	4.6	3.0	2.9	4.2	2.6	7.9	3.7	12.7	11.6	3.9	0.0
GI		4.7	10	10	3	4	9	23	30	11	4	5.5	9	3	5	10	6	5	3	1
TPI		0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

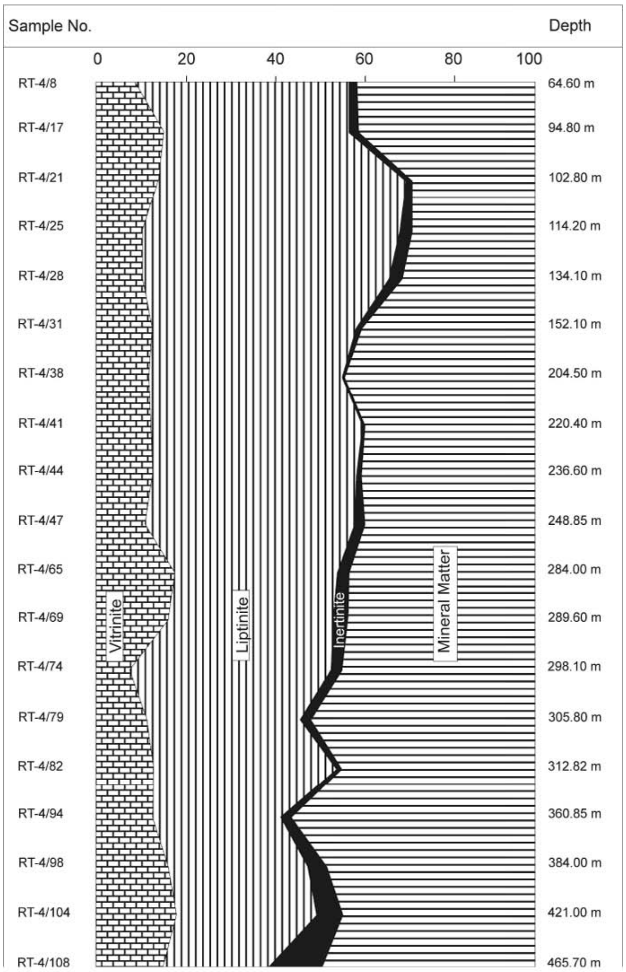

Fig.5. Maceral frequency distribution in the carbonaceous shales.

Liptinite macerals in the shales are represented by sporinite and alginite. Sporinite, constituting mainly microspores, occurs as elongated thread like or spindle shaped bodies with dark grey to blackish grey in reflected light. Under blue light excitation they appear yellow to orange brown in colour. The *Botryococcus* algae observed in the shales show typical hollow structure with brilliant fluorescence under blue light (Fig.6). The undistinguishable fragments and debris of liptinite macerals are grouped under liptodetrinite and is common in all the samples. Vitrinite ranges from 8-18 vol% and is represented mostly by vitrodetrinite. Inertinite content is low ranging from 0.4-6 vol% except in sample RT-4/108 where the inertinite content is 12 vol%. Inertinite is represented by fusinite with distinct absence of semifusinite. Fusinite is characterized by well preserved cell structures partially filled with mineral matter and shows white colour with very high reflectance. The funginite, usually a product of fungal bodies or spores, are noticed only in five samples. Mineral matter is generally high (28-55%) and occurs as primary ground mass mostly comprising

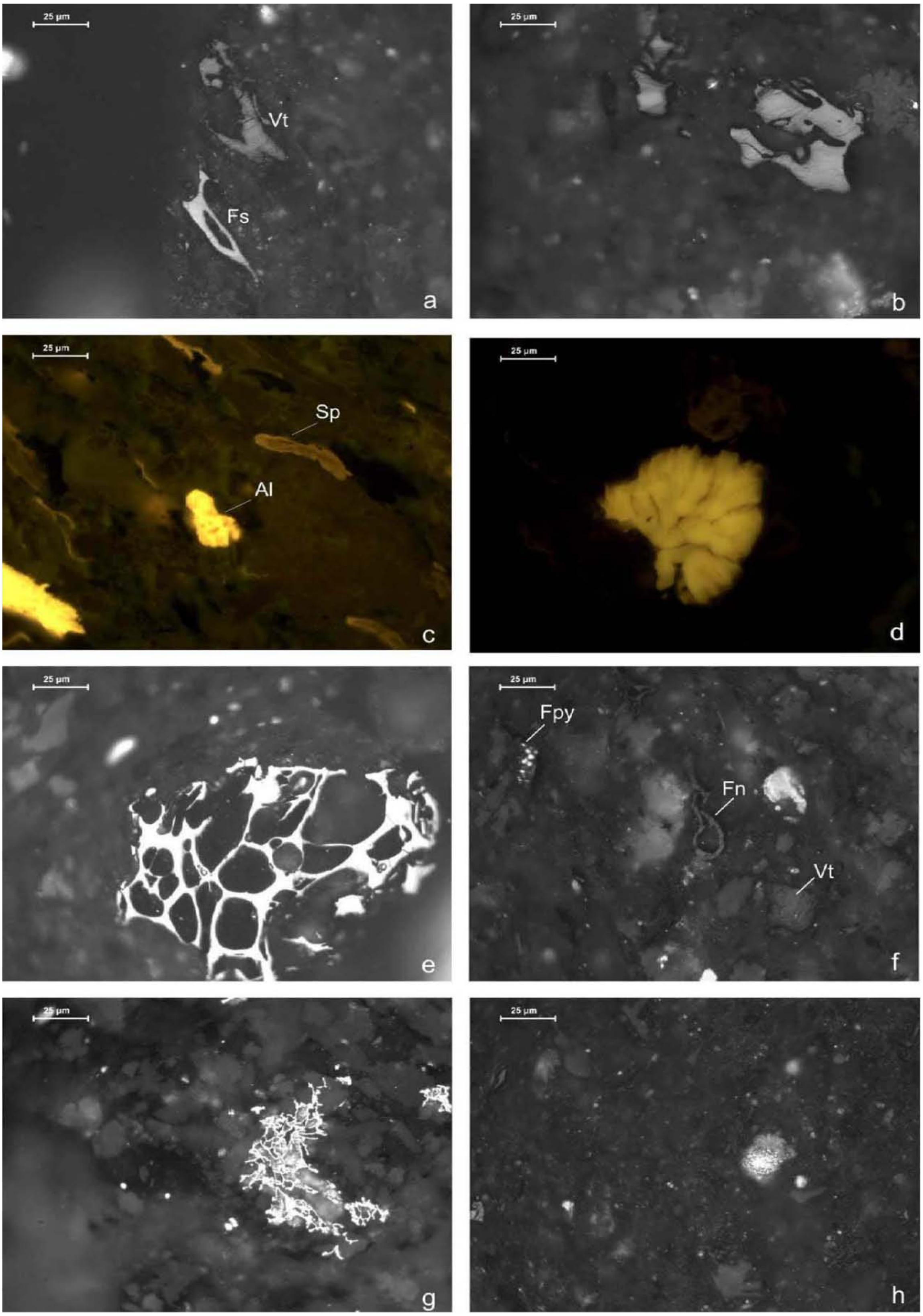

Fig.6. Representative photomicrographs of macerals from studied carbonaceous shale samples from RT-4. a) fusinite (Fs) and vitrinite(Vt) in mineral ground mass, b) Semi-fusinite, c) alginite (Al) and sporinite (Sp), d) Alginite, e) fusinite, f) funginite (Fn), framboidal pyrite (Fpy) and vitrinite (Vt); g) pyrite deposited in the intergranular spaces of minerals, h) framboidal pyrite.

of clay minerals and also as cell infillings in fusinite. Pyrite ranges from 0-11 vol.% in all the samples. It occurs in several forms such as disseminated particles, fissure fillings and isolated grains.

DEPOSITIONAL ENVIRONMENT

Palaeobotanical and Palynofacies inferences

On the basis of palaeobotanical affinity of the retrieved and identified palynomorphs (Fig.7) in RT-4 sediments, different plant communities have been recognised which suggest different palaeoecological conditions. The palynoflora is dominated by bisaccate pollen such as *Scheuringipollenites, Faunipollenites, Striatopodocarpites, Crescentipollenites, Verticipollenites, Rhizomaspora, Guttulapollenites, Striasulcites, Primuspollenites and Distriatites.* Monosaccates are few and represented by *Parasaccites, Barakarites, Densipollenites* and *Kamthisaccites.* The palynoflora suggests that the peat forming plant community mainly composed of gymnosperms such as glossopterids, conifers and cordaites which grow in mesophyllous and xerophyllous palaeoenvironments and flourished on low land peat forming environments (Knoll and Niklas 1987). Trilete spores are less abundant and reflect the presence of filicopsids (*Cyclogranisporites, Horriditriletes, Brevitirletes, Callumispora, Micro-*

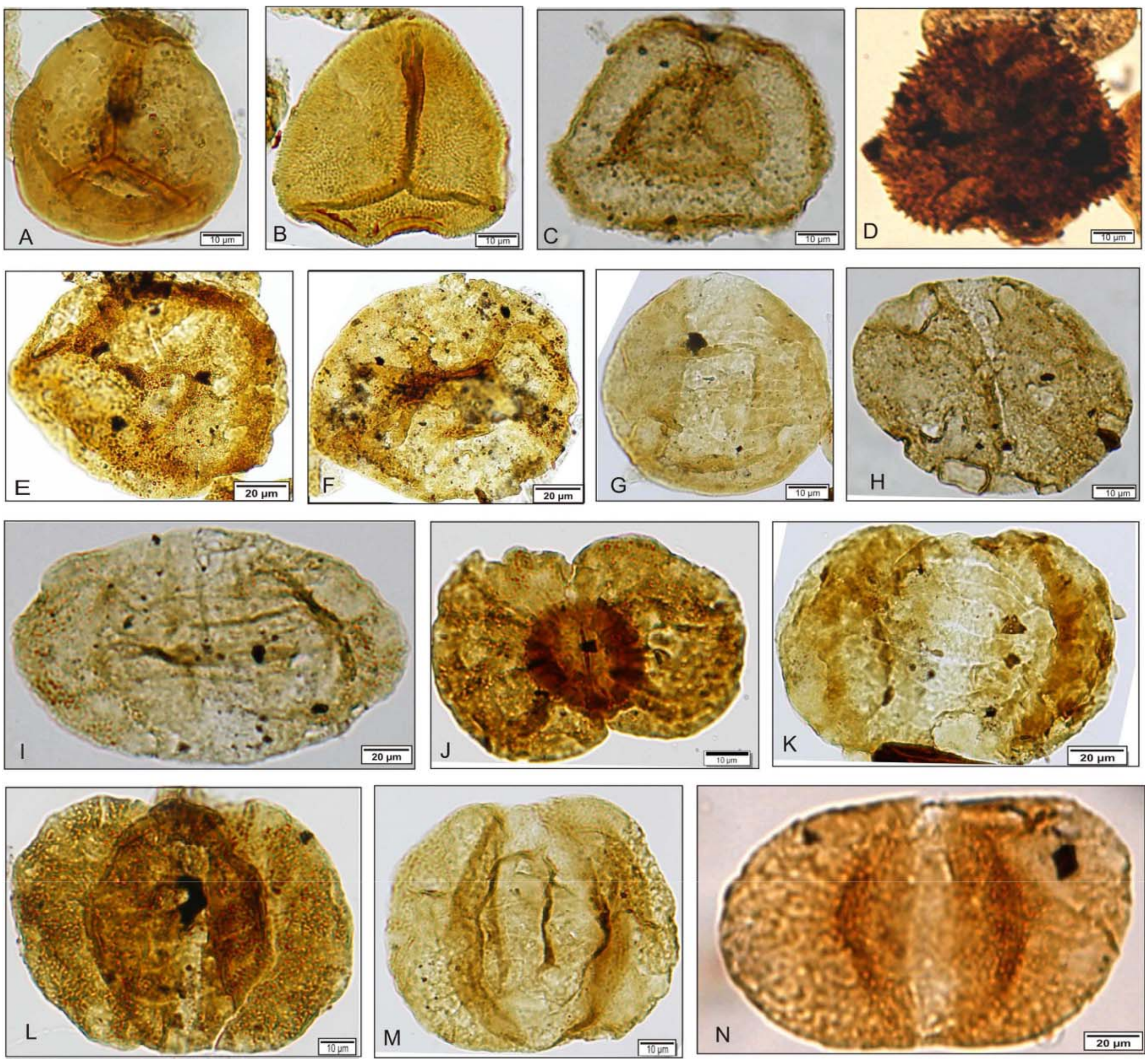

Fig.7. Representative photomicrographs of palynomorphs recovered from borehole RT-4. A.*Microfoveolatispora raniganjensis* B. *Microbaculispora villosa,* C. *Gondisporites raniganjensis*, D. *Brevitriletes unicus*, E. *Densipollenites magnicorpus*, F. *Densipollenites invisus*, J. *Striasulcites* sp., H. *Scheuringipollenites barakarensis*, I.*Faunipollenites varius*, J. *Rhizomaspora indica*, K. *Striatopodocarpites subcircularis*, L. *Striatites varius*, M. *Crescentipollenites crasus*, N. *Alisporites plicatus*.

baculsispora, Microfoveolatispora, Cyclobaculisporites) and lycopsids (*Indotriradites, Gondispoirtes and Didecitriletes*) which flourish in hygrophyllous to mesophyllous environments and might have tolerated flooded environments (Rothwell 1988, DiMichele & Phillips 1994). Scarce sphenopsids (*Laevigatosporites)* are also recorded, an ancient plant community which has been interpreted as swamp-margin colonist flourishing on flooded swamp or surrounding areas (Pryor, 1996). The high representation of glossopterids, conifers and cordaites co-occurring with filicopsids, lycopsids and sphenopsids are indicative of an hypautocthonous taphocenose (Birks and Birks, 1980). The presence of coccal algae *Botryococcus* a good palaeoecological marker indicates deposition in non-marine fresh or brackish environments with low salinity like lacustrine and lagoonal environments (Batten 1982; Guy-Ohlson 1992). Brackish waters have also been inferred by the presence of epigenetic pyrite.

Palynofacies analysis reveal that the opaque phytoclasts are common although not dominant with the predominance of the blade shaped type over the equidimensional ones reflecting deposition in proximal environments (Batten and Stead 2005). They also imply oxidizing conditions in exposed areas of flood plains and river beds. According to Batten and Stead (2002) in fresh water and brackish environments, oxidizing and high or low energy conditions may be associated with periodically exposed areas of floodplains and riverbeds, and lakes or lagoon margins. Low energy depositional setting such as a marsh or swamp has been attributed to the sediments in the studied series as palynofacies contain large palynomorph assemblages with varying amount of tissues and less altered (non-charcoalified) woody detritus i.e.vitrinite rather than inertinite (Batten and Stead (2002). The biodegraded organic matter and structured organic matter consists exclusively of higher plant debris at different stages of diagenetic alteration, as displayed by their partly preserved original structures implying the organic matter inputs were dominated by terrestrial materials. The AOM is mainly a spongy and membranous AOM that dominates the association probably derived from vascular land plants suggesting a non-marine provenance (Batten 1983). Fare amounts of AOM in each palynofacies, preferably in Palynofacies -2 implies deposition in deep seated dysoxic-anoxic conditions.

Petrographic Inferences

Palaeoecological reconstructions have been successively made with the aid of petrographical studies (Teichmüller 1989, Diessel 1986, Kalkreuth *et al*., 1991, Calder *et al*., 1991). The signatures of palaeodepositional environment can be seen by the presence/absence or abundancy/paucity of certain macerals. The mechanical breakdown of organic matter due to transportation prior to deposition and decomposition due to aerobic and anaerobic realms can be inferred (Kalkreuth *et al*., 1991). Therefore the facies critical macerals from the analysis provide a great deal of information to define the depositional environment (Kalkreuth and Leickie 1989). The same concept of petrographic indices derived from the macerals is used in the present study to assess the depositional mileu for the organic matter rich shales as the fraction of the macerals in the samples reflects the provenance of organic material contributing to the accumulation of sediment and conditions during accumulation.

Two petrographic indices, Gelification Index (GI) and Tissue Preservation Index (TPI) were introduced by Diessel (1986) on the basis of which the depositional setting of a basin or sedimentary sequence can be interpreted. The GI is considered to reflect the height of the water table during sediment accumulation and TPI represents the effects of the input of woody material and its preservation prior to final deposition (Kalkreuth *et al*., 2000). When plotted on the facies diagram (Fig.8), the sediments of the present study show high GI values indicating that the sediment accommodation site was submerged probably by flooding and hence low inertinite content and display low TPI values indicating deposition of these sediments in a limnic condition in limited influx-clastic marsh (Diessel 1992). These high GI and low TPI values are ascribed to microbial attack on the organic matter after the deposition of the sediments

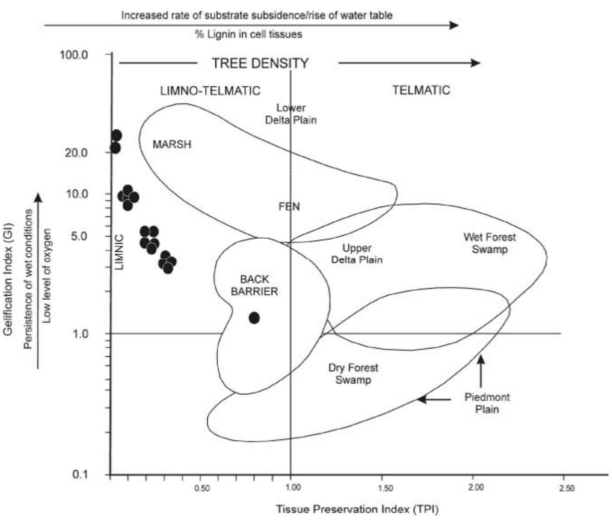

Fig.8. Facies deciphered from Gelification and Tissue Preservation indices in relation to depositional setting of the carbonaceous shales

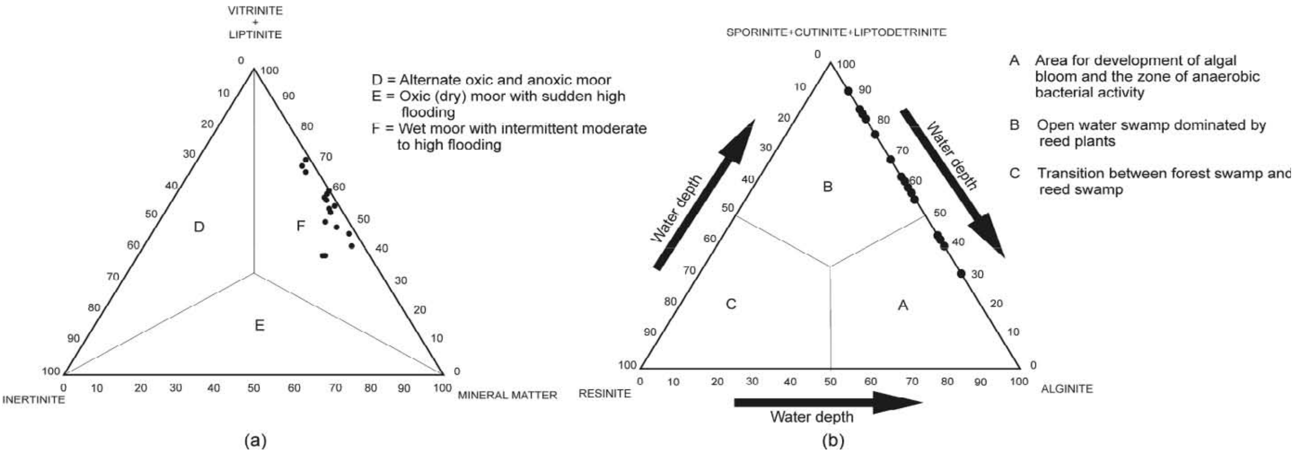

Fig.9. (a) Ternary diagram depicting the type of mire for studied carbonaceous shales (Singh and Singh, 1996). **(b)** Ternary diagram based on liptinite macerals showing water depth during the deposition of the studied carbonaceous shales.

(Suwarna 2006). The oxidation of the woody tissue is restricted in majority of the samples which is evident by low inertinite content (Lamberson *et al*., 1991) implying that the accommodation site was constantly fed with water either through precipitation or through fluvial sources. In sample RT-4/108 at a depth of 465.70 m inertinite content is 12.10 vol.% indicating a possible draining of water from the mire and thereby exposing the peat to atmospheric oxidation. The low TPI values clearly indicate that there was substantial transportation of sediments prior to deposition thereby mechanically breaking down the organic matter (Kalkreuth and Leckie 1989).

Singh and Singh (1996) emphasized the significance of mineral matter in the maceral content in the reconstruction of depositional environment for inferring the oxic and anoxic conditions which is related to ground water fluctuations in the depostional site (Fig.9a). The high mineral content with predominantly clay minerals indicates the sediments were of fluvial regime. The presence of epigenetic pyrite can be attributed to sulphate bearing waters in the form of brackish water incursion into the overlying strata as they are seen as percolation deposition in the form of cavity filling and vein lets (Sia and Abdullah 2012). Pyrite may have also formed by sulphate reduction in the upper few centimetres of a deposit, when one of its products H_2S may react with iron to form pyrite especially when deposition in anoxic conditions is slow (Batten 1996). Singh and Singh (2000) formulated a ternary diagram for interpreting the water depth conditions and the type of organic sediment facies which is based on the quantitative occurrence of liptinite macerals. In this diagram (Fig.9b) the plots of liptinite concentrations of the studied shales fall in the B and A zones indicating that the sediments were deposited in an open water swamp to moderately deep water setting. The alginite vol.% (Fig.10) also indicates that the sediments were deposited in an open water with high standing water table condition (Petersen and Ratanasthien, 2011). It can also be inferred that the low inertinite content in the studied samples might be due to the above inferred depositional environment where in the area was constantly underwater and there was no probability of the deposited organic matter being oxidized.

The petrographic data when extrapolated on the facies diagram of maceral vis-à-vis mineral matter clearly shows that the site of deposition was frequently flooded with a moderate to high rate of clastic sediment influx which resulted in substantial thickness of black shales rich in organic matter sourced by the hinterland vegetation. Hence, humid palaeoclimatic conditions favourable for forest development may have persisted in the hinterland during the deposition of the studied series which in turn favoured a fluvial system efficient for particulate organic matter transportation.

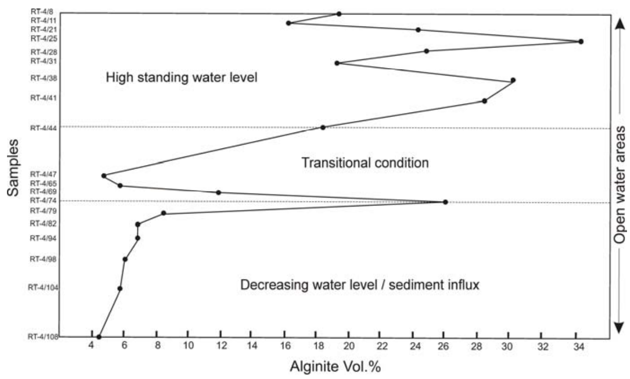

Fig.10. Alginite content (vol.%) in the carbonaceous shales and their inference for water table conditions during the time of their deposition (Petersen and Rathanasthien, 2012)

CONCLUSIONS

The palynological and palynofacies analysis of the shales from bore hole RT-4 of Tamra block from Raniganj coalfield reveal a hypautocthonous taphocenose as the area was populated by glossopterids, conifers and cordaites co-occurring with filicopsids, lycopsids and sphenopsids. Presence of *Botryococcus* reflects a brackish water incursion. These shales are mainly characterized by Type-III Kerogen based on the AOM-Phytoclast-Palynomorph diagram. The presence of pyrite also indicates an incursion of brackish or sulphur rich waters into the accommodation site. The dispersed organic matter analysis reveals that the majority of the amorphous organic matter is product of decay of the terrestrially derived plant debris with an almost equal frequency of algal amorphous matter. Petrographic study reveals that these shales are rich in liptinite content (mainly represented by sporinite, alginite and liptodetrinite) and mineral matter and were deposited in a limnic to limno-telmatic conditions with intermittent flooding of the site with moderate to high rate of sediment influx which brought in a great amount of organic debris from the hinterland vegetation and resulted in the organic matter rich shales.

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