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Palyno-petrographical Facet and Depositional Account of Gondwana Sediments from East Bokaro Coalfield, Jharkhand

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Abstract: Palynological and petrological studies have been undertaken on the Gondwana coal and associated lithologies encountered in borehole EBM-2 of East Bokaro coalfield of Damodar Basin, India. The palynological investigation resulted in the recognition of Assemblage –III (*Densipollenites*, 27.9 m – 214.30 m), Assemblage – II (*Striatopodocarpites* + *Faunipollenites*, 225.00 m – 297.60 m) and Assemblage – I (*Faunipollenites* + *Scheuringipollenites*, 307.00m – 433.00 m). Lithofacies study was also done for better understanding of the preservation and abundance/paucity of the spores and pollen in different lithologies as the current borehole has significant thickness of mudstones, shales and siltstone. Palynofacies study and Petrographical studies of coal samples encountered in the borehole were used to determine the depositional environment of the coal precursor peat swamp. Palynological data has revealed the presence of younger Raniganj palynoflora between 27.00-214.30 m depth that is lithologically defined as Barren Measures Formation. This spore pollen study has proved that these sediments were deposited during late early Permian to late Permian period. Further the maceral analysis of organic sediments as well as the Thermal Alteration Index (TAI) has revealed that the coaly shale at 336.5 m depth has hydrocarbon generation potential.

Keywords: Permian Palynology, Gondwana sediments, Damodar Basin, Maceral analysis, Thermal Alteration Index, East Bokaro Coalfield, Jharkhand.

INTRODUCTION

Damodar basin is the most important coal basins in India and it spreads in the states of West Bengal and Jharkhand. Important coalfields in this basin are Raniganj, Jharia, East Bokaro, West Bokaro, Ramgarh, South and North Karanpura. The Bokaro coalfield is an elongated strip and a part of the coalfield, east of longitude 85°42' is commonly known as East Bokaro coalfield. East Bokaro coalfield is third among the Indian coalfields, because of its coal potentiality and has number of thick coal seams.

GEOLOGY OF THE EAST BOKARO COALFIELD

The East Bokaro coalfield lies between latitudes 23° 44' and 23° 49' and longitudes 85° 42' and 86° 04'. This is a east-west trending elongated basin within Damodar-Koel river valley basins. The coalfield contains a continuous succession from Talchir to supra-Panchet formations (Table 1) (after Raja Rao, 1987). The major part of this basin to the east is occupied by Barakar Formation whereas the crescent-shaped outcrops of the Barren Measures are exposed in the central and western part of the coalfield (Fig.1). Successively overlying Raniganj and Panchet formations have same pattern further towards west, where Lugu Pahar has the latter at its lower elevation. Supra-Panchet Formation, occupying the higher elevation in Lugu Pahar at the western most part of this coalfield shows angular unconformity with the underlying Panchet Formation at the south-eastern part of the Lugu Pahar. Few scattered exposures of Talchir Formation overlie unconformably basement rocks to the north-eastern part of the coalfield around Chapri area and to the west of Gomia, in the northwestern portion.

Muditoli block is situated in the western part of the east Bokaro coalfield where only the rocks of the Barren Measures are exposed on the surface (Fig.1). Barakar coal seams are intersected by thick cover of the Barren measures beneath. These seams vary in thickness from 0.34 m to 19.10 m. The general strike of the beds is NNW-SSE with 12° to 17° dip towards southwest. The borehole EBM-2 was drilled to a depth of 433 m on the northern bank of Bokaro river on the south-eastern part of the Muditoli block. The bore

Table 1. General stratigraphic Succession of sediments in East Bokaro Coalfield. Jharkhand (after Raja Rao, 1987)

Supergroup	Group	Formation	Lithology	Age
		Intrusive	Lamprophyre and Dolerite dykes and sills.	Early Cretaceous
Gondwana	Upper Gondwana	Supra-Panchet (Mahadeva?)	Grey, mostly coarse-grained ferruginous sandstone with profuse mega cross-beddings; pebbly sandstone and red clay.	Late to Middle Triassic
		Angular Unconformity		
		Panchet	Khaki micaceous siltstone; greenish to buff coloured, fine to coarse grained, cross-bedded, micaceous sandstone; red and green shale	Early Triassic
	Lower Gondwana	Raniganj	Off-white to greenish, micaceous fine-grained sandstone; grey, medium to coarse grained, calcareous sandstone; grey shale (=mudstone); carb.shale; a few thin coal seams / bands.	Late Permian
		Barren Measures	Dirty-white, micaceous, ferruginous, flaggy, fine-grained sandstone; siltstone; finer heterolithic sequence; thick mudstone (=grey shale); ironstone bands in sandstone and mudstone.	Late Permian
		Barakar	Off-white, fine to medium to coarse grained, micaceous, cross-bedded, arkosic and feldspathic sandstone with occasional gritty / pebbly horizons; grey shale (=mudstone); siltstone; carbonaceous shale; about 25 to 27 economic coal seams.	Early Permian
		Talchir	Greenish needle shale; greenish, fine-grained sandstone; greenish siltstone; rhythmites; varves; tillites and diamictites.	Early Permian to Late Carboniferous
	Unconformity			
		Basement	Granite, gneisses, mica-schist, amphibolite etc.	Neo-Proterozoic to Palaeo-Proterozoic

hole has a lithology of bioturbated sandstones, siltstone, mudstone, shaly coal, shale and coal (Fig.2). The coarse grained sandstone seen in the outcrops are uncommon in the core section of the present borehole excluding the medium grained micaceous sandstone at a depth of 27.90 m. Graded bedding (both normal and reverse) were recorded in cores samples intersected at different depths. Wavy laminations were also noticed in fine grained sandstones of Barakar Formation. Lenticular sand inclusions were noticed in certain grey shale beds in the bore hole. The coal seam with a thickness of 0.60 m is encountered at a depth of 432.00-433.00 m belonging to Barakar Formation (Fig.2).

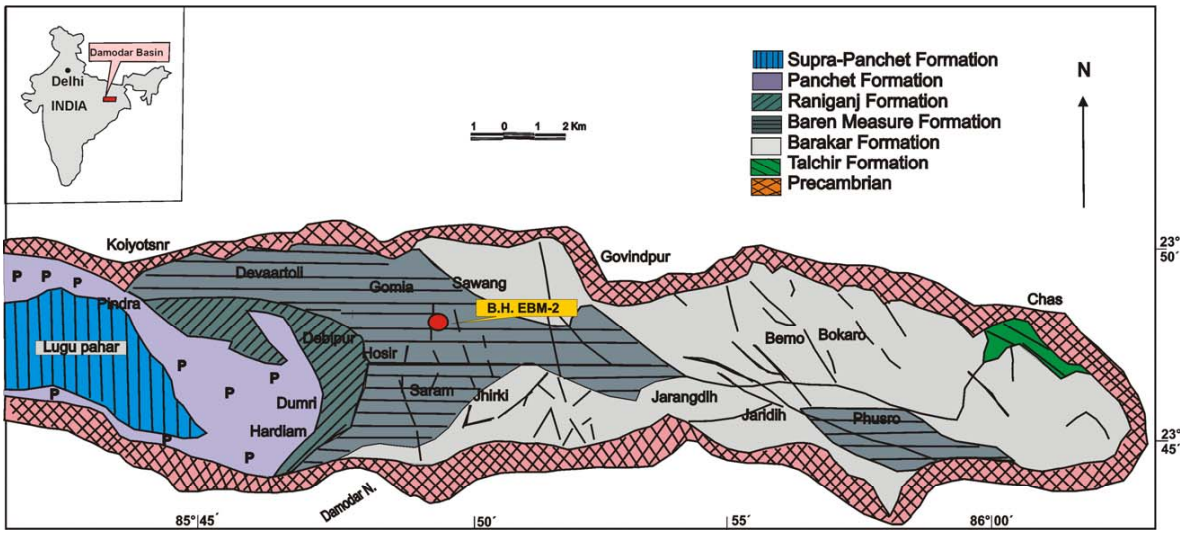

Fig. 1. Geological map of East Bokaro Coalfield showing location of borehole EBM-2 (after Raja Rao, 1987).

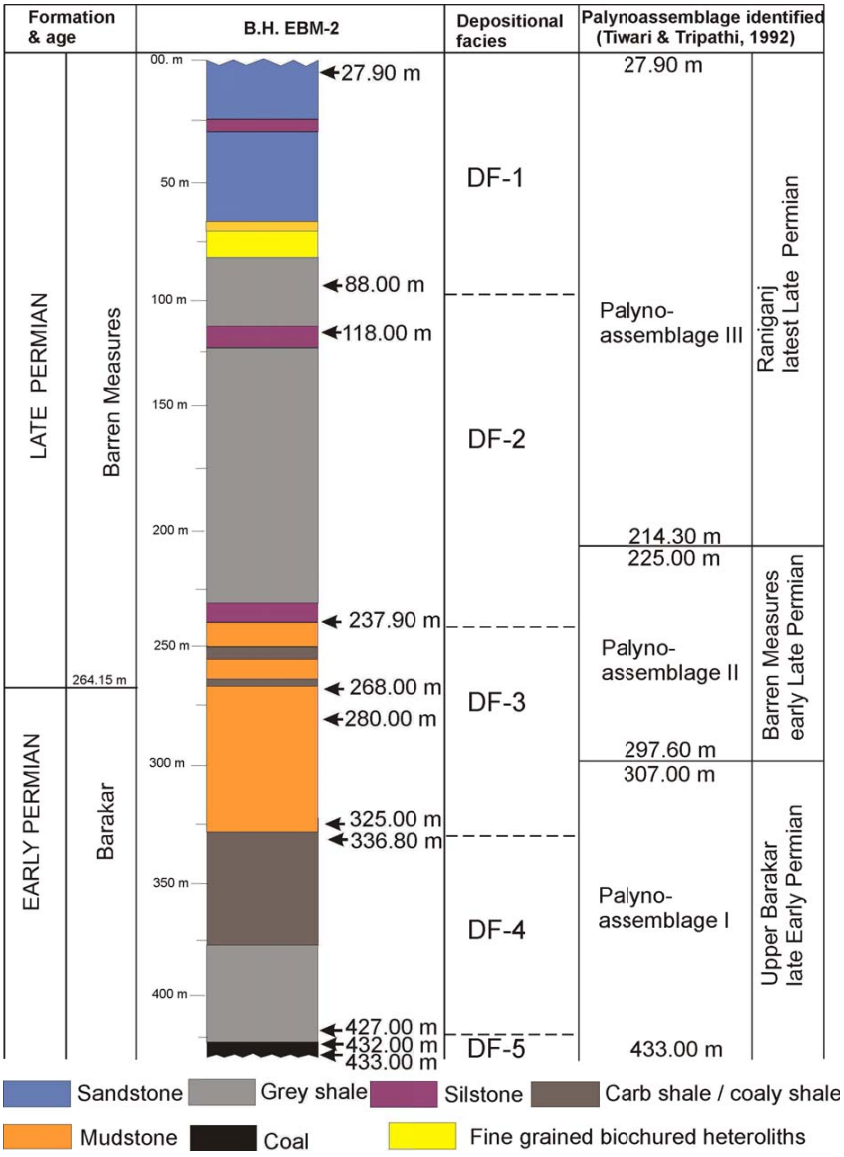

Fig.2. Litholog of Bore hole EBM-2

MATERIAL AND METHODS

The rock samples for palynological study was from borecore—EBM-2, measuring 405.10 m depth (27.90-433.00m) of Gondwana sediments from Muditoli block. Sediments are processed by standard maceration technique. Five slides from each sample were prepared for palynological observations under tmicroscope.

For petrographic studies the samples were prepared as per specifications of ICCP (1971, 1975). The maceral analysis was carried out on Leica DM4500P microscope in flurescent mode. Leica application suite (LAS) was used for acquiring image. Quantitative estimation of macerals was done on 450 counts per sample counted on automatic point counter using Petroglite 2.35 software.

PALYNOLOGY

The preservation of the palynomorphs is variable within the samples, but recovery is frequently low to moderate, and the specimens are light yellowish-dark brown, distorted, broken to fairly well-preserved. The studied litho-succession has revealed the existence of pollen grains with dominant association of *Striatopodocarpites*, *Faunipollenites, Scheuringipollenites and Densipollenites.* On the basis of qualitative and quantitative analysis of various palynotaxa, three distinct palynoassemblage have been recognised and representative palynomorphs is shown in Plate 1. The relative occurrences of the taxa vary from rare (<1%), common (1-5%), fair (6-10%), sub-dominant (11-19%) and dominant (>20%) in an assemblage.

Assemblage – III; Depth: 27.90- 214.30 m

Recovered assemblage in siltstone, mudstone, dark grey shales, fine-grained bio churned heteroliths and intercalated sandstone with shale bands in 186.40m thick strata (27.90- 214.30 m) is represented by the dominance of *Densipollenites* (>20%) followed by sub-dominance of *Striatopodocarpites* (11-19%) and *Faunipollenites* (11-17%). The other significant species such as trilete spore are (1-5%) *Cyclograni-sporites, Cyclobaculisporites, Microbaculispora, Didecitriletes, Indotriradites, Gondisporites*; pollen grains includes *Striomonosaccites* (<1%), *Platysaccus* (<1%), *Crescentipollenites* (6-7%), *Verticipollenites* (1-5%), *Striasulcites* (6-8%), *Distriatites* (6-7%), *Weylandites* (1-5%) *and Distriamonocolpites* (1-5%).

The recovered palynoassemblage compares with the *Densipollenites magnicorpus* palynozone of Tiwari and Tripathi (1992) in having relatively fair occurrence of *Densipollenites magnicorpus* and also compares well with palynoassemblage of Raniganj Formation in the Raniganj coalfield, Damodar basin, which is dated as late Permian in age (Tiwari and Rana, 1984; Bharadwaj et al., 1979; Bharadwaj and Salujha, 1965, 1965a).

Palynodating: Raniganj (latest late Permian)

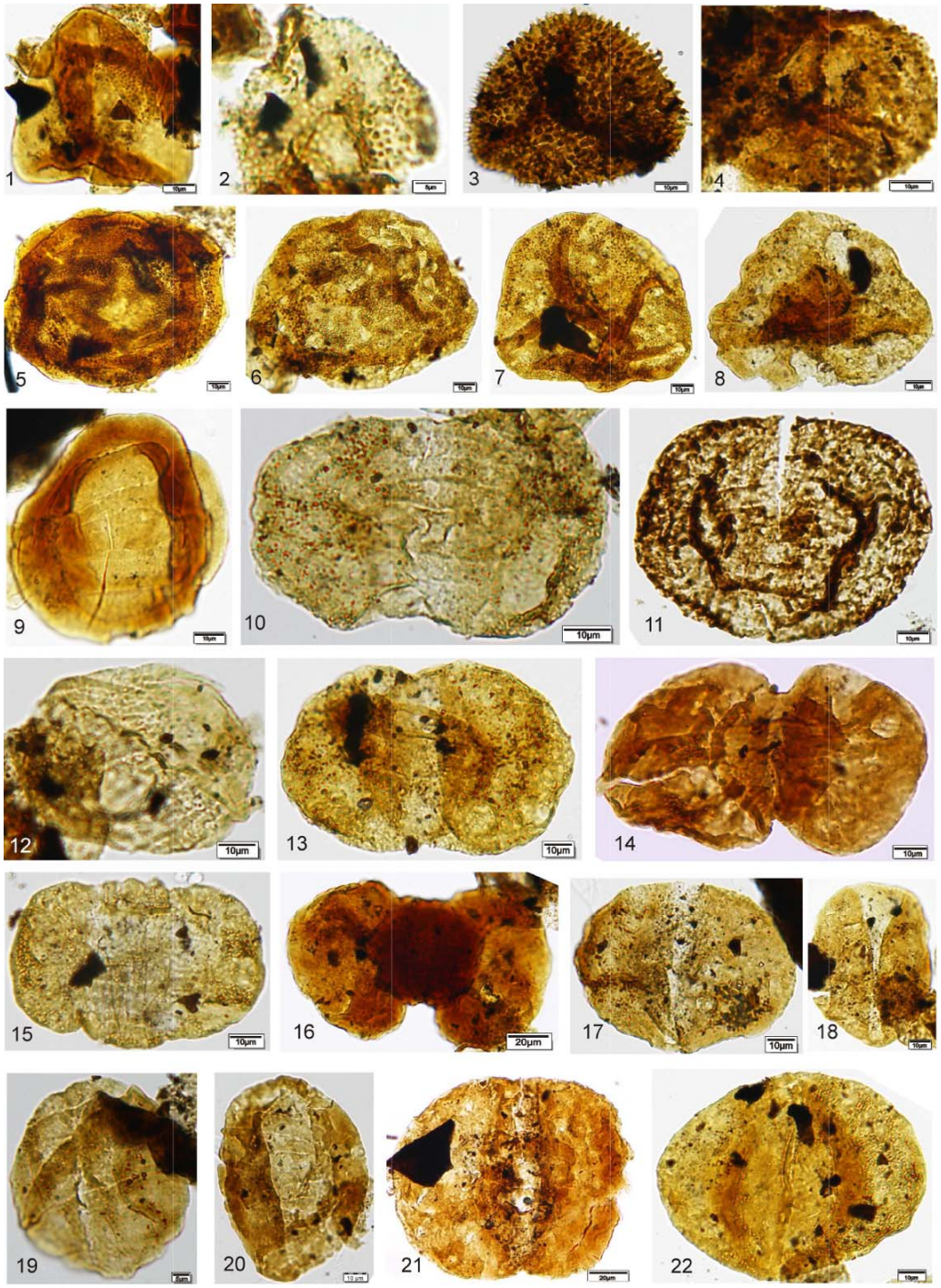

Plate 1. Representative palynomorphs from the 3 assemblages derived from borehole EBM-2. **(1)** *Microfoveolatispora bokaroensis* Tiwari 1965, **(2)** *Microbaculispora indica* Tiwari 1965, **(3)** *Didecitriletes ericianus* (Balme & Hennely) Venkatachala & Kar 1965, **(4)** *Gondisporites raniganjensis* Bharadwaj 1962, **(5)** *Densipollenites magnicorpus* Tiwari and Rana 1981, **(6)** *Densipollenites magnicorpus* Tiwari and Rana 1981, **(7)** *Densipollenites invisus* Bharadwaj & Salujha 1964, **(8)** *Densipollenites densus* Bharadwaj & Srivastava 1969, **(9)** *Trabaculosporites gopadensis* (Tiwari & Mishra) Tiwari & Ram-Awatar 1992, **(10)** *Faunipollenites varius* Bharadwaj emend. Tiwari *et al.* 1989, **(11)** *Faunipollenites gopadensis* Bharadwaj & Srivastava 1969, **(12)** *Weylandites circularis* Bharadwaj & Srivastava 1969, **(13)** *Crescentipollenites fuscus* Bharadwaj, Srivastava & Kar 1974, **(14)** *Verticipollenites gibbosus* Bharadwaj 1962, **(15)** *Distriatites bilateris* Bharadwaj 1962, **(16)** *Striatites varius* Kar 1968, **(17)** *Scheuringipollenites barakarensis* (Tiwari) Tiwari 1973, **(18)** *Scheuringipollenites tentula* (Tiwari) Tiwari 1973, **(19)** *Guttulapollenites hannonicus* Goubin 1965, **(20)** *Striasulcites ovatus* Venkatachala & Kar 1968b, **(21)** *Arcuatipollenites* sp., **(22)** *Satsangisaccites nidpurensis* Bharadwaj & Srivastava 1969.

Assemblage-II; Depth 225.00m - 297.60 m

The assemblage zone recognised between 225.00-297.60m (72.60m) depth comprising grey shales, siltstones, mudstones, carbonaceous shales, shaley coal is characterised by the dominance of striate bisaccate *Striatopodocarpites* (20-24%), and *Faunipollenites*(20-22%) and sub dominance of pollen *Densipollenites* (11-18%) (*D.densus, D. indicus and D. invisus)*. The other striate bisaccate pollen are *Platysaccus* (<1%), *Rhizomaspora* (6-9%), *Striatites* (6-7%), *Distriatites* (1-5%), *Schizopollis* (<1%), *Verticipollenites* (1-5%), *Crescentipollenites* (6-8%). Trilete spores (1-5%) and represented by *Microfoveolatispora, Microbaculispora, Horrriditriletes and Brevitriletes*. The monosaccate pollen includes *Plicatipollenites* (<1%) and *Striomonosaccites* (<1%).

The palynoassemblage recorded between 225.00-297.60m depth is correlated with the *Densipollenites indicus* palynozone from the Barren Measures Formation of Raniganj coalfield, Damodar basin (Tiwari and Tripathi 1992; Tiwari and Vijaya Rana 1984) and correlates with Raniganj Formation of Jharia coalfield (Bharadwaj et al. 1965).

Palynodating: Barren Measures (early late Permian)

Assemblage-I; Depth: 307.00 – 433.00 m

This assemblage is obtained in the mudstones, carbonaceous shales and coal is in approximately 135.40m thick strata, has dominance of *Faunipollenites* (20-23%), and sub-dominance of *Scheuringipollenites* (11-17%). The other palynomorphs of this assemblage are *Horriditriletes* (1-5%), *Barakarites* (6-7%), *Striatites* (1-5%), *Striomonosaccites* (6-7%), *Densipollenites* (<1%), *Rhizomaspora* (1-5%), *Verticipollenites* (1-5%) and *Striasulcites* (<1%). Trilete spores (<1%) represented by *Microbaculispora, Microfoveolatispora,* and *Cyclogranisporites.*

This palyno-composition (307.00 - 433.00m depth) correlates the studied strata with *Faunipollenites varius* assemblage zone of the upper Barakar Formation in the Raniganj coalfield, Damodar basin (Tiwari, 1973; Tiwari and Tripathi, 1992, Bharadwaj and Srivastava 1969), which is late early Permian age.

Palynodating: Upper Barakar (late early Permian age)

LITHOFACIES

In bore core EBM-2 of East Bokaro Coalfield, approximately 405.10 m thick strata has been intersected which includes the sediments of Barren Measures and Barakar formations. From this litho-succession three palynozones are identified and discussed here to assess the biostratigraphic status of the studied strata. The three palynoassemblages identified (I-III) having vertical distribution in the lithosuccession is based on the stratigraphical importance of the key taxa, and their relative occurrence along with other significant species recovered in the present study.

On the whole the bore core displays a dominant low energy depositional regime represented by massive mudstone with a thickness of 56.50 m at a depth of 280.00m and grey shale with a thickness of 86.90m and 29.80m encountered at a depth of 151.00 m and 400.00m respectively. Towards the upper part of the bore hole there prevailed a medium to high energy regime depositional condition in the form of medium to coarse grained sandstone. As mentioned earlier these sandstones are commonly found in the outcrops in Muditoli block but are not encountered in the present bore hole. Based on the core studies and interpretation, five facies have been derived.

DF- 1: Sandstone- shale

In this facies (27.90- 88.00 m depth) sandstone was deposited in a medium-high energy environment as bed load particles before the cessation of flood water inflow into the adjacent plains from the river. The shale intercalation indicates the deacceleration of sediment inflow and suspended load particle due to low energy. This clearly indicates the fluctuating velocity of water flow during the time of deposition. Apart from the top part of the core, this facies is not encountered in the rest of the core. This also suggests that the sedimentation, as perceived from core interpretation, was largely medium to low energy to very low energy regime (Fig.2).

DF-2: Shale - siltstone

Grey shale occurs between 118.00m to 237.90 m (Fig.2) which grade into underlying siltstone and also with an intercalation of siltstone band at a depth of 127.2 m. Shales are devoid of any structure with infrequent occurrence of thin isolated lenses of silt. The high organic content in the sediments gives dark colour to these shales. The siltstone were formed by suspension settling of silt by density currents which at times moved into the flood basin as an interflow suspended above the basin floor.

DF-3: Massive Mudstone

Mudstone that does not show any recognizable layering or bedding has been grouped in this facies. Usually these mudstones are formed by either biotrubation or flocculation of silt and clay sediments. A massive mudstone bed is

encountered at a depth of 268.90 to 325.00 m (Fig.2) in the present borecore. This is interpreted as the product of waning out of turbidity current and a depositional regime of calm water stage where the flow velocity is practically zero. This represents the suspension fall out of the finest terrigenous deposit as mud layers.

DF-4: Coaly shale

This facies is a product of a peat swamp where organic material accumulation is interrupted by frequent influx of clay particles. Coaly shale beds range from 336.80-427.00 m) (Fig.2) in the studied core. The lithology clearly shows the association of coaly shale facies with mudstone facies but the former differs in higher carbonaceous content.

DF-5: Coal

Coal forms from the accretion of organic vegetation in a mire environment that is not influenced by great amount of clastic influx. The anaerobic condition of the mire helps in preservation of the organic material thus accumulated. The coal thickness ranges from 1m- 2m at the depth of 432.00-433.00 m (Fig.2) in the present section and is closely associated with coal, coaly shale, shale and mudstone. The waxy appearance of coal indicates that it contains the lithotype clarain composed of sporinite maceral formed from algae, leaf particles, resins and spore and pollens. This is suggestive of exuberant vegetation and a low energy hydrodynamics which controlled the drainage.

DISCUSSION

Palynofacies Analysis

On the whole the core displays a rhythmic succession of organic matter rich sediments and the palynofacies shows a well balanced ratio between all types of organic matter (Fig.3). These were grouped as amorphous organic matter (AOM), phytoclasts (all tissue remains, trachied, epidermal cells etc. of plants) and palynomorphs (spores and pollen).

Organic matter categories in the samples with their constituents are given below following Tyson (1995) classification and description (Fig. 3).

The productive samples studied from the bore hole clearly show the abundance of phytoclasts with subdominant palynomorphs in almost all samples. These phytoclasts are composed of dark brown to brown oxidized opaques and epidermal tissues, trachied and cuticles.

The AOM found in certain samples are over matured indicating a shallow depositional environment in a semi arid condition (Batten, 1996). Majority of the AOM till the depth of 297 m not fluorescent or show a faint fluorescence indicating that these AOM are the product of terrestrial organic matter decay. Whereas the AOM found at a depth of 336.50 m are algal bodies which exhibit bright fluorescence. This is further supported by a fair amount of alginate macerals found in the samples.

The dark colour obtained by phytoclast particles is due to partial oxidation of the accumulated organic matter in the peat swamp. Mudstones are rich in tracheids with bordered pits and black woody particles with brown edges which reflect pre-oxidation state of the sediments. The organic fragments that are regularly perforated with bordered pits and partly split into woody splinters are commonly identified as charcoal fragments (Batten 1973; 1981). A prevailing vegetation of vascular plants can be inferred as these trachieds are water conducting tissues. They are abundant in the palynological preparations and these charcoal fragments encountered in the present study area infers a possible wildfire in the vegetal matter accumulated swamps (Cope 1981, Chaloner 1989) or a terrestrial wildfire after which the sediments were flushed by the floods into the swamps.

Palaeo-environmental Analysis of Coal Facies

Palaeo-environmental studies were carried out based on the coal petrographic and dispersed organic matter studies to understand the precursors of coal and its associated

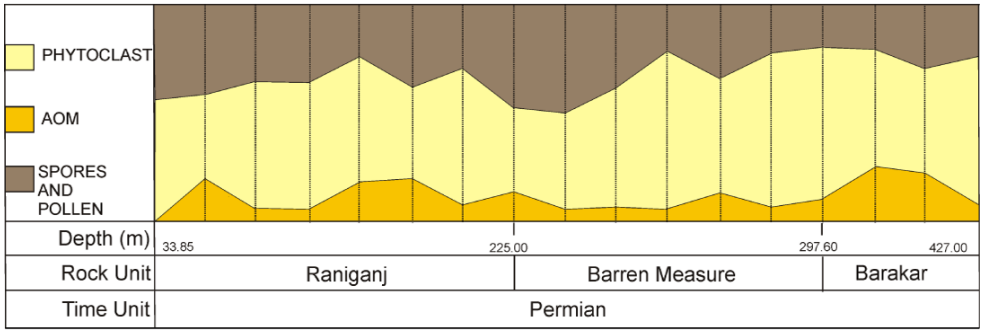

Fig.3. Percentage frequency of Organic Matter from Borehole EBM-2

sediments. The organic matter found in the sediments hold a great amount of information on the various controls that influenced the environment in which it was generated, its proximity, the deposition site, burial, extent of decay and degradation etc. This data interlinked with the palyno-logical as well as petrographic investigations gives a comprehensive idea of the prevailing conditions of deposition and post burial diagenesis.

Coal petrographic studies have shed light on the palaeoenvironment of peat swamps. The determination of the prevalent conditions of the coal precursors relies on various indices like gelification index (GI) and tissue preservation index (TPI), groundwater index (GWI) and vegetation index (VI) besides maceral composition and sedimentary environments.

The GI is the relative amount of gelation components to non-gelation which reflects the degree of wetness and duration of peat mire. Increasing values of GI indicates wet mire where as lower values indicate dry mire (Diessel, 1986). TPI indicates the tissue dilapidation and the relative amount of wood in coal forming plants (Diessel, 1986).

Coal seam encountered in the bore hole has a low GI value (<1) (Fig. 4) and was deposited in a transitional phase between dry forest swamp and wet forest swamp which is evident by high to moderate proportion of semi-fusinite. GWI values are considered to be medium if the value falls between 0.1 to 1.0. Again the VI against GWI plot gives us a clear indication that the vegetation was undergoing a transitional time from ombrotrophic to Mesotrophic condition (Fig.5). This condition results in short supply of

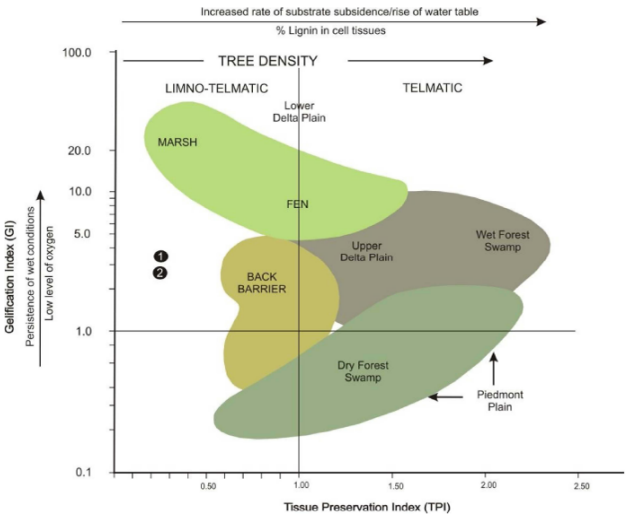

Fig.4. Gelification Index (GI) versus Tissue Preservation Index (TPI) plot to determine the depositional setting of Coal (sample no.1= 433.00 m) and Coaly shale (sample no. 2 = 336.80 m) of the studied borehole

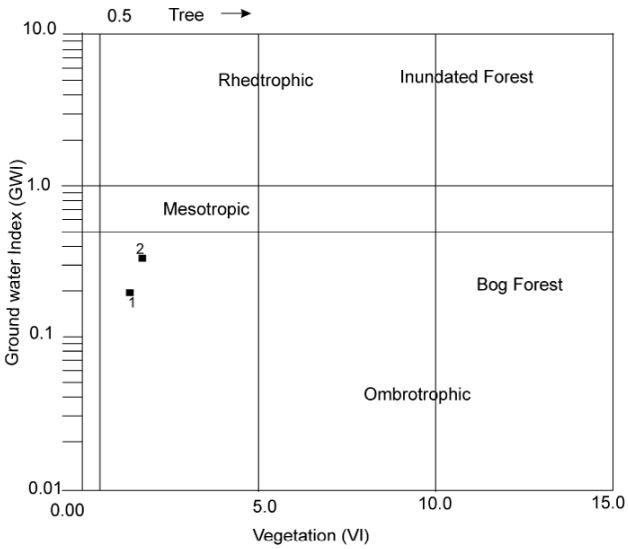

Fig.5. Ground water index (GWI) and Vegetation Index (VI) plotting for the two coal samples (sample no.1= 432.00 m & sample no.2 = 433.00 m) from the borehole EBM-2 (After Zhang et al., 2010)

nutrients for plant growth indicating controlled vegetation during the formation of peat. The plot clearly indicates that the site of deposition witnessed alternate oxic and anoxic condition with the recurrence of dry and wet spells. The exposure of the peat mire to the atmospheric oxygen results in the formation of humic acid and the oxidation of the maceral results in the formation of a rim around the edge of the maceral (Plate 2, Fig.3).

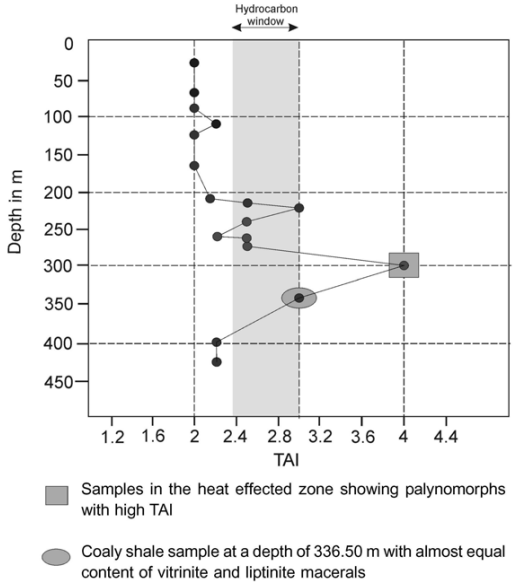

Fig.6. Thermal Alteration index (TAI) of recovered spores and pollen at various depths from borehole EBM-2. Heat affected sample with palynomorphs showing high TAI (boxed) and sample rich in liptinite and vitrinite content with a TAI of 3.0 (circled)

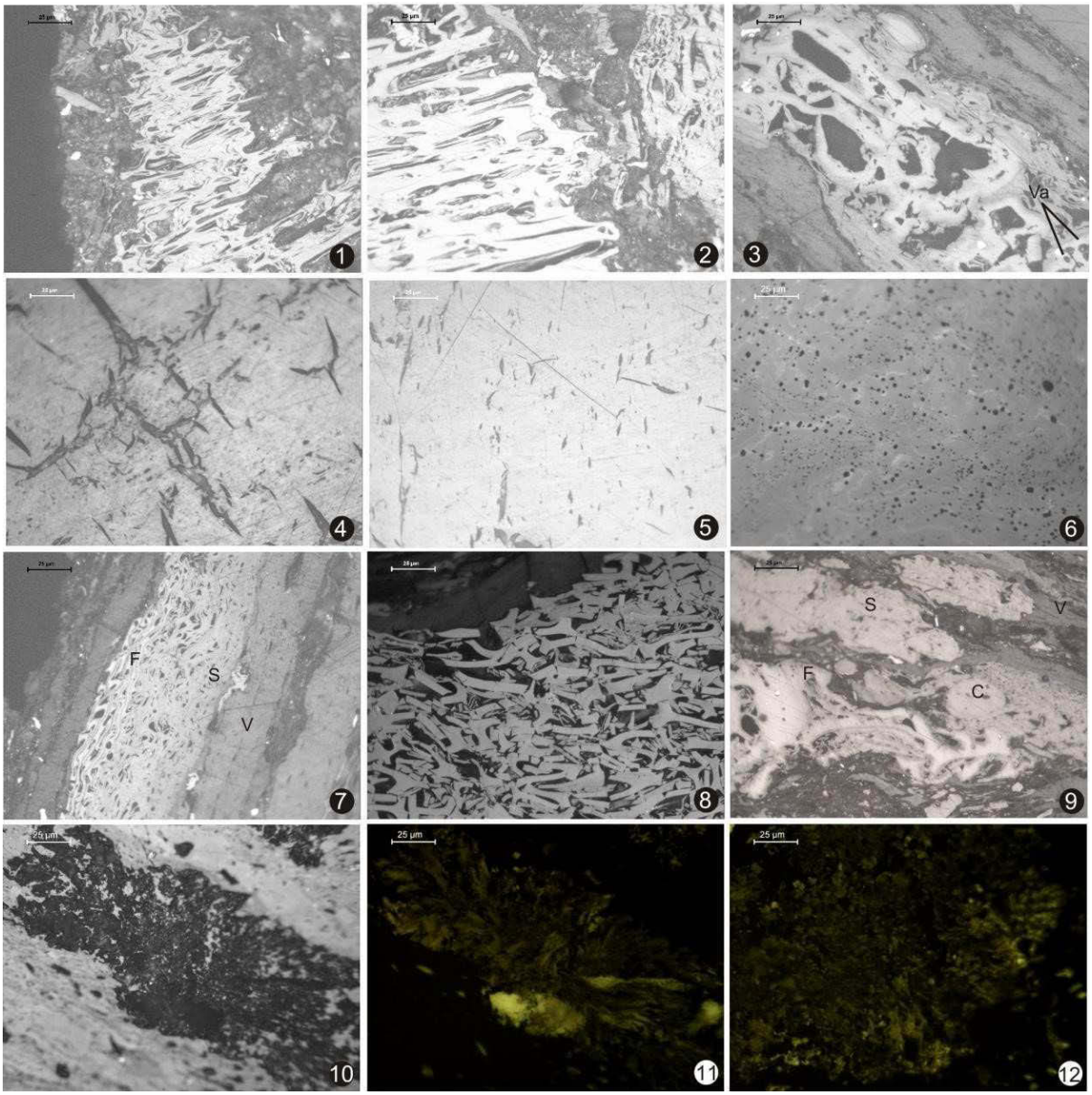

Plate 2. (1) & **(2)**. Stretched cell lumens in semi-fusinite, **(3).** Fusinite showing oxidation rims and devolatilization vacuoles(Va). **(4).** Characteristic heat affected shrinkage cracks in vitrinite grain, **(5).** Comma pits and cracks in vitrinite, **(6).** Gas escape vacuoles in a heat affected vitrinite grain, **(7).** Fusinite(F), Semi-fusinite (S) and Vitrinite (V). Observe the gradational oxidation from semi-fusinite to fusinite, **(8).** Typical bougen structure of semifusinite, **(9).** Semifusinite (S), Fusinite (F) and Corpogellinite (C). Heat affected fusinite showing welded edges, **(10 & 11).** Algnite in normal white light and the same in Flourescent mode, (12) Flourescing Alginite.

Further, the analysis of the miospores, thermal alteration indices (TAI) of sediments was undertaken to determine the diagenesis of organic matter in the accreted sediments. The observations showed a varying range of TAI values in individual samples. The consistent trend of increase in TAI with increase in depth is not seen in the present study (Fig. 6). Miospores recovered at a depth of 297 m shows a high value of TAI, whereas, the careful observation of slides revealed the presence of light coloured palynomorphs in the same sample with a TAI range of 2.25 – 3.0. The bi-modal value of the samples clearly indicates that the dark coloured palynomorphs are affected by heat due to local faults which are also recorded in the field. This is further supported petrographically by the presence of shrinkage cracks in vitrinite grains, devolatilization vacuoles and welded edges in fusinized organic particles, characteristic of thermal encroachment (Plate 2, Figs.4, 5, 6 and 9). The maceral analysis of coaly shale samples at a depth of

336.5 m shows an increase in alginite content (22.2%) of liptinite group with a TAI of 3.0 which indicates that the sample falls in the oil window (Fig. 6).

CONCLUSION

- The LAD (last available datum) of the Barakar palynoflora is witnessed at a depth of 307.00 m.
- The palynoassamblages III, II and I shows a clear relationship with late Permian (Raniganj Formation), early late Permian (Barren Measures Formation) and late early Permian (upper Barakar Formation), miofloral assemblages respectively. The occurrence of abundant plant debris in this assemblage zones is suggestive of wet and dry conditions during the sedimentation.
- The dominance of bisaccate pollen along with abundance of *Densipollenites* in the Raniganj Formation (palynoassemblage- III) indicates warm climate with very high humidity throughout the span of Raniganj Formation (Tiwari & Tripathi 1987).
- The palynocomposition (palynoassemblage- II) having dominant *Densipollenites* in Barren Measures Formation reveals relatively warm and dry conditions (Lele 1976; Chandra and Chandra 1988).
- The dominance of *Scheuringipollenites* and bisaccate pollen morphological characters (palynoassemblage- I) indicates cool climate in the beginning, which gradually warms up and becomes moderately warm with the dominance of *Faunipollenites* in the Barakar Formation. (Tiwari &Tripathi 1987).
- Comprehensively the sediments from the area were deposited in an alternating oxic and anoxic moor as suggested by the petrographic as well as palynological studies. The GI vs TPI diagram clearly indicates a limno-telmatic condition of deposition of the shaly coal and coal beds.
- Presence of amorphous organic matter along with high frequency of terrestrial derived phytoclasts and spores and pollen indicate that the sediments were deposited in deep water due to suspension settling with a close proximity for terrestrial source of organic debris.
- Coaly shale at a depth of 336.50 m has the hydrocarbon potential which is palynologically inferred by TAI value of 3.0 and amorphous organic content of 25% which falls into Kerogen-I category. This is also supported by the maceral analysis which shows alginite associated with vitrinite grains.

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