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Petrographic signatures of marine inundation from the Barakar coal measures of Mahanadi–Ib Valley, Orissa, India

Onset of Gondwana sedimentation in peninsular India marks the end of a long phase of non-deposition since the late Proterozoic. The coal-bearing late Palaeozoic Gondwana successions are distributed in a number of isolated basins along the prominent lineaments demarcated by the present-day river valleys of the Indian peninsula, and are long believed to be a thick pile of continental sediments of fluvial origin[1,2]. Though marine Palaeozoic sequences are recorded from across the globe, e.g. South Africa (Karoo basin), South America (Paraná basin, Brazil), Australia (Hunter Valley Area, New South Wales), Madagascar, etc., little is known about the palaeo-sea conditions during the Permo-Carboneferous in peninsular India and is still an important issue in the Gondwana stratigraphy of India. Discovery of marine fossils from Umaria of Rewa basin by Sinor[3] and their description by Reed[4] added a new dimension to the idea about the depositional environment of these rock successions. Subsequently, marine influences in the Gondwana successions were reported from the Talchir Formation[5–8].

We report here some of the peculiar petrographic evidences from the Barakar coal measures which are uncommon in the Gondwana succession of India and are indicative of marine influence.

The samples were collected from the Lajkura seam of Samleswari Mines, Lakhanpur Coalfield (21°45′N, 83°40′E), Mahanadi–Ib Valley, Orissa. Geology of the area is shown in Figure 1 *a*. Stratigraphic succession is presented in Table 1. Petrographic studies were carried out following IS 9127/ISO 7404 standard, and proximate and ultimate analyses carried out following the procedure given in IS 1350 standard. The results are given in Table 2. Leica-make polarized light microscope was used to measure the per cent reflectance and for maceral analyses.

The coals studied are sub-bituminous type with reflectance values in the range 0.43–0.45%. The range of major group of macerals (on mineral matter basis) are vitrinite 31.4–43.8%, liptinite 12.2–17.8% and inertinite 21.4–25.5%. We report here from the studied coals two prominent features which are seldom found in Indian Gondwana coals, i.e. phlobaphinite and framboidal pyrites. Figure 2 *a* and *b* shows the development of plate-like phlobaphinite along with the vitrinite groundmass. Such plate-like phlobaphinites are reported especially in bark tissues, in particular cork. Characteristic cork tissues are well known from coals of marine origin. Phlobaphinites are chemically and structurally resistant and indicate a highly anoxic environment[10]. A few corpocollinites are observed in the studied samples (Figure 2 *c*). Corpocollinites share characters with the phlobaphinites and are indicative of a marine origin. Some typical funginites are also found (Figure 2 *e*). Sulphur content in the samples was >1% (Table 2); thus is rare in Indian Gondwana coals. Based on studies on the distribution of sulphur in modern peat-forming environments of southern Florida, Cohen *et al.*[11] established that marine to brackish peat contains more pyrite (and total sulphur) than the freshwater type.

Close association of framboidal pyrite and phlobaphinite in the samples further strengthens the idea of a marine influence. The earliest formed pyrites are usually preserved as framboids and are pre-compactional forms[12]. This precompactional pyrite is related to the influx of marine aqueous sulphate after deposition of the peat[13]. Figure 2 *d* shows the incipient developments of pyrite framboids on the organic substrate and illustrates the colonial mode of development of spherical pyrite framboids. Figure 2 *e* shows

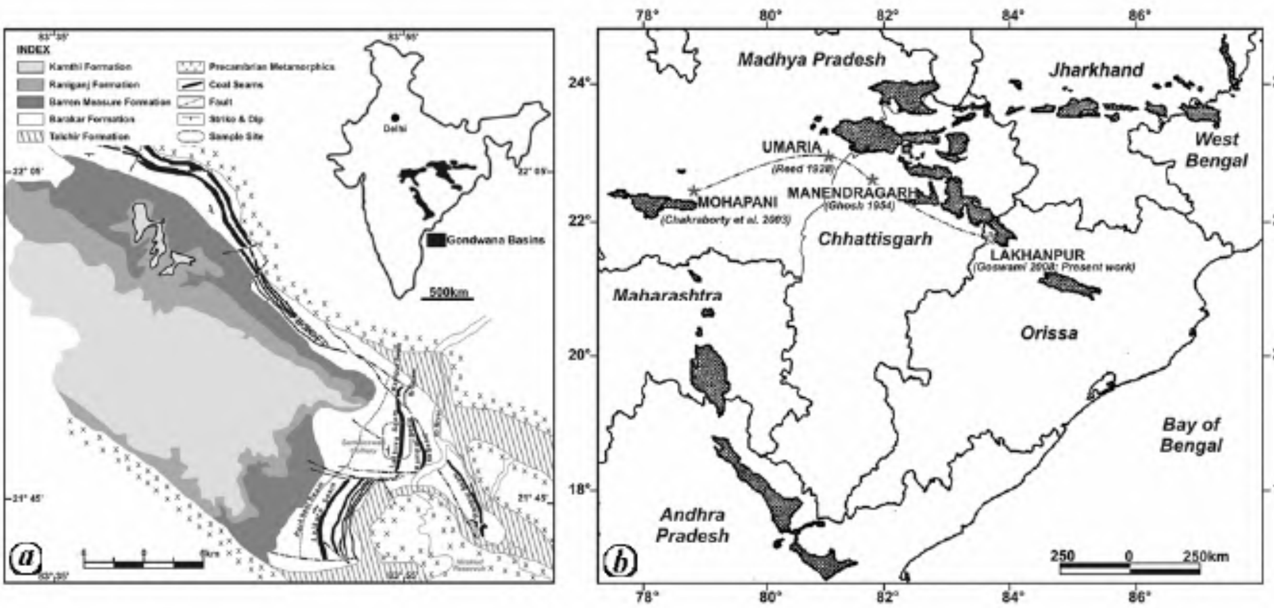

Figure 1. ***a***, Geological map of the study area with Gondwana coal measures of India (inset). ***b***, Location of reported occurrences of late Palaeozoic marine beds from peninsular India. Dotted line marks the probable path of marine incursion during the Permo-Carboniferous.

Table 1. Stratigraphic nomenclature for the Ib River basin (after Goswami[9])

Age	Group	Formation	Thickness (m)
Recent		Alluvium/laterite	
Early to middle Triassic	Upper Gondwana		150+
---Unconformity---			
Late Permian	Lower Gondwana	Lower Kamthi=Raniganj	180
Middle Permian		Barren measure	250+
		Upper Barakar	
			350–500
		Lower Barakar	
Early Permian		Karharbari	30–65
		Talchir	130+
---Unconformity---			
Precambrian			

the well-developed framboidal pyrite with aggregates of loosely packed, uniform-sized microcrystals (*inset*). The size of the well-developed framboids ranges from 25 to 50 μm. The uniformity in size and form of microcrystals, colonial mode of occurrence, organic association, loose to densely packed aggregate structures and spherical shape are all typical to the mode of formation of framboidal pyrite[14].

Framboidal pyrite results from indirect crystallization of pyrite via the conversion of iron monosulphide (amorphous FeS) to mackinawite to greigite to pyrite[14,15]. Indirect crystallization occurs when dissolved sulphide concentrations are also high, which kinetically favours the formation of iron monosulphides. Therefore, framboidal pyrite is typically formed during the early diagenesis of marine sediments[16].

On the basis of these petrographic evidences, we suggest a phase of marine incursion during the peat formation of the Barakar coal measures. Goswami[9] also suggested existence of marginal marine condition in the Mahanadi master basin throughout the Permian based on ichnological, palynological and sedimentological evidences. Recently, evidences of marine incursion have also been reported from the Barakar Formation of other Gondwana basins of India[17,18].

The present work along with those of Mukhopadhaya[17] and Chakraborty *et al.*[18] signifies a definite marine influence during the deposition of the Barakar Formation. Distribution of beds with evidence of deposition in a marine environment (Figure 1 *b*) suggests the probable path of marine incursion similar to the 'existence of a marine embayment' as suggested by Ghosh[8]. However, in the present study phlobaphinite in association with framboidal pyrite and corpocollinite is observed only in few of the samples, perhaps indicating a very short spatio-temporal phase of marine inundation. Therefore, the present authors in agreement with the view of Dasgupta[19], suggest that marine inundation may have been caused by a rise in the mean sea level of Tethys following a phase of deglaciation till the isostatic equilibrium was achieved. The sea receded soon after the continental block regained the

Table 2. Results of petrographic, proximate and ultimate analyses

Sample no.	A	B	C	D	E	F
Petrographic analysis (vol. %)						
Vitrinite	31.4	43.8	38.1	32.1	36.4	32.2
Phlobaphinite/corpocollinite	0.4	0.7	0.3	0.5	0.2	0.2
Liptinite	15.1	12.8	12.2	13.5	13.6	17.8
Inertinite	24.9	23.3	21.4	23.0	23.7	25.5
Mineral matter	28.2	19.4	28.0	30.9	26.1	24.3
Mean R_r%	0.45	0.43	0.44	0.43	0.44	0.44
Proximate analysis (wt%)						
Moisture	4.8	5.8	6.0	5.9	5.1	4.4
Ash	43.6	39.1	44.4	45.1	44.5	40.7
VM	25.3	26.8	25.1	25.3	25.3	26.8
FC	26.3	28.3	24.5	23.7	25.1	28.1
VM (daf basis)	49.0	48.6	50.6	51.6	50.2	48.8
FC (daf basis)	51.0	51.4	49.4	48.4	49.8	51.2
Ultimate analysis (wt%, daf basis)						
Carbon	73.62	71.71	73.99	73.67	72.80	71.28
Hydrogen	3.47	3.47	3.63	4.90	6.21	4.81
Sulphur	1.16	1.20	1.05	1.06	1.17	1.18
Nitrogen	2.10	1.28	1.20	1.22	1.51	1.33

Mean R_r%, Mean random reflectance in oil; daf, Dry ash free; VM, Volatile matter, and FC, Fixed carbon.

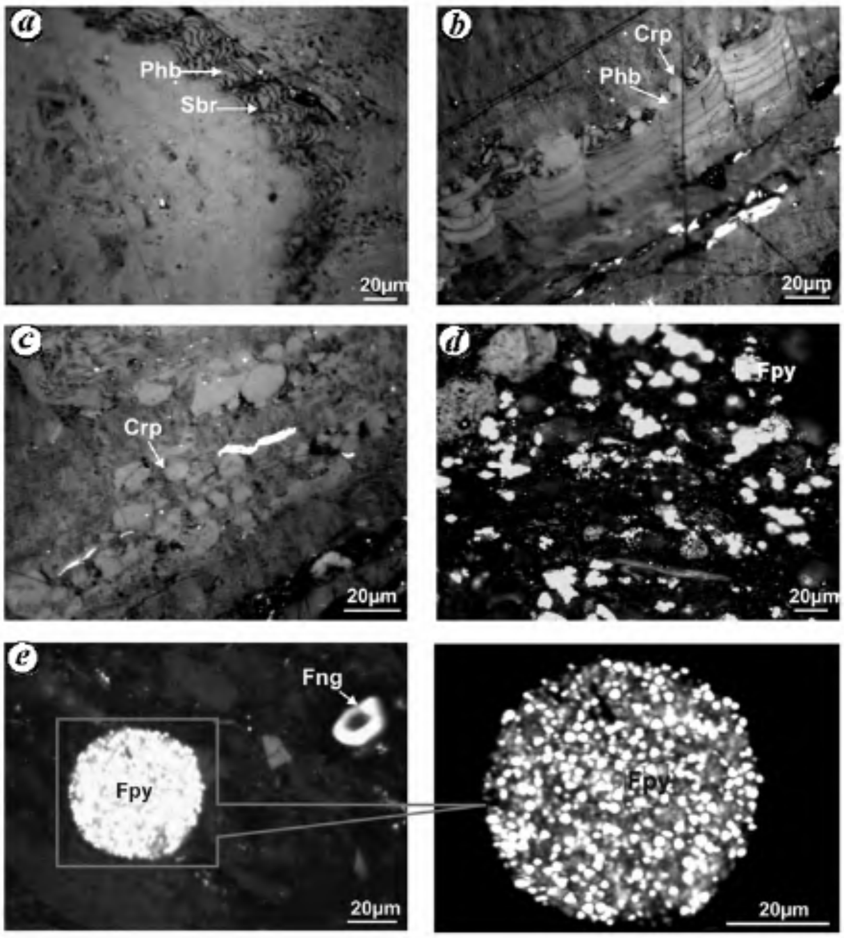

Figure 2. ***a***, Phlobaphinite with suberinite; ***b***, Rod-let or plate-like phlobaphinite with corpocollinite; ***c***, Corpocollinite; ***d***, Colonial mode of occurrence of framboidal pyrite on organic substrates; ***e***, Well-developed framboids with uniformly sized microcrystals of pyrite (inset). Phb, Phlobaphinite; Sbr, Suberinite; Crp, Corpocollinite; Fng, Funginite, and Fpy, Framboidal pyrite.

isostatic equilibrium. Further evidences of marine incursion will help in better delineation of the palaeo-sea conditions in peninsular India during the late Palaeozoic era.

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