Liptinite macerals in Singrauli coals, India : their characterization and assessment*

Basant K. Misra & Bhagwan D. Singh

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The record of liptinite macerals in Indian Permian coals has been uniformly quite low under normal reflected light. In fact, high inherent clastic minerals intimately associated with liptinite macerals in these coals tend to mask them, at times, completely, obstructing identification and for this reason they are considered to be poor in liptinite content. Petrographic investigations carried out on Early Permian Turra coal seam and Late Permian Jhingurdah coal seam of Singrauli Coalfield, under blue light excitation, recorded appreciably high amounts of liptinite macerals (13-57% on mineral matter-free basis) as against maximum up to 19 per cent (m.m.f. basis) under normal reflected light. The liptinite macerals in these coals are formed chiefly by sporinite (7-40%) and liptodetrinite (1-16%). Cutinite, suberinite, resinite, alginite, exsudatinite and fluorinite are the other macerals of liptinite group together occurring in only subordinate amounts.

The coals of the Turra seam associated with Barakar Formation have relatively higher liptinite content than that of the Jhingurdah seam of Raniganj Formation. Such high concentration of sporinite has not been reported so far from the Indian Permian coals. The increase in liptinite/sporinite content coincides with increase in mineral matter content in many instances, i.e., dull coal bands normally have high liptinite content. The sporinite concentration in dull coal bands of the Permian coal seams marks the presence of semi-cannel or cannel coal bands.

Key-words—Biopetrology, Fluorescence microscopy, Permian coals, Singrauli Coalfield (India).

Basant K. Misra & Bhagwan D. Singh, Department of Biodiagenesis, Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.

सारॉंश

भारत में सिंगरौली से प्राप्त कोयलों में लिप्टीनाइट मेसीरल : इनके लक्षण एवं मूल्यॉंकन

बसन्त कुमार मिश्र एव भगवान दास सिह

भारतीय परमी कोयलो मे साधारण परावर्तित प्रकाश मे लिप्टीनाइट मेसीरलो की बराबर एव कम मात्रा प्रेक्षित की गई है। वास्तव मे इन कोयलो मे लिप्टीनाइट मेसीरलो से घनिष्ठ रूप से सहयुक्त अन्तरनिहित खडज खनिज़ इन्हे आवरित किये हुए है। कभी-कभी यह आवरण पूर्ण रूपेण होता है जिससे इनके अभिनिर्धारण मे कठिनाई होती है और इसी कारणवश इनमे लिप्टीनाइट पदार्थो की कम मात्रा मानी जाती है। सिगरौली कोयला-क्षेत्र के प्रारम्भिक परमी तुरा कोयला सीमों एव अनतिम परमी झिगुरदाह कोयला सीमो के नीले प्रकाश मे किये गये शैल-विन्यासीय अन्वेषणो से इनमे लिप्टीनाइट मेसीरलो की पर्याप्त अधिक मात्रा (13-57 प्रतिशत) अभिलिखित की गई हे जो कि साधारण परावर्तित प्रकाश मे अधिकतम् 19 प्रतिशत प्रेक्षित की गई थी। इन कोयलो मे लिप्टीनाइट मेसीरल मुख्यतया स्पोरीनाइट (7-40 प्रतिशत) एव लिप्टोडिट्रीनाइट (1-16 प्रतिशत) से बने हैं। क्यूटिनाइट, सुबेरिनाइट, रेर्जानाइट, एल्जिनाइट, एक्सूडेटिनाइट एव फ्लोरिनाइट लिप्टीनाइट समूह के कम मात्रा में मिलने वाले अन्य मेसीरल हैं।

बराकार शैल-समूह से सहयुक्त तुरा सीमा के कोयलो मे रानीगज शैल-समूह की झिगुरदाह सीमो की अपेक्षाकृत अधिक लिप्टीनाइट पदार्थ की मात्रा विद्यमान है। भारतीय परमी कोयलो से इस प्रकार की स्पोरीनाइट की अधिक मात्रा (साँद्रता) पहले प्रेक्षित नही की गई थी। लिप्टीनाइट/स्पोरीनाइट पदार्थ की मात्रा का खनिज पदार्थो की मात्रा से सीधा सम्बन्ध है उदाहरणार्थ मन्द कोयला पट्टीयो मे लिप्टीनाइट की अत्याधिक मात्रा विद्यमान है। परमी युगीन कोयला सीमो की मन्द कोयला पट्टीयो मे स्पोरीनाइट की सांद्रता अर्ध-कनल अथवा कनल कोयला पट्टीयो की उपस्थिति इंगित करती है।

THE liptinite or exinite maceral group which is chemically distinguishable from the other two maceral groups—inertinite (relatively carbon-rich) and vitrinite (relatively oxygen-rich) by its relatively higher hydrogen content, is heterogeneous in its biological origin. The liptinites are derived from various plant organs, viz., spores and pollen (sporinite), cuticles (cutinite), epidermal tissues,

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Table 1—Classification of maceral groups/macerals and their source material (modified after Teichmüller, 1989)

Group	Maceral	Origin
	Telinite	Cell walls (may be resin impregnated or lignified) rich in cellulose
	Telocollinite	Gelified plant tissues
Vitrinite	Desmocollinite	Gelified humic detritus (amorphous)
	Vitrodetrinite	Humic detritus
	Corpocollinite	Cell fillings (oxidation/condensation products of tannins or biochemically gelified humic matter)
	Sporinite	Spore and pollen exines of higher plants
	Cutinite	Outer layers of leaves, needles, shoots, thin stems of higher plants
	Suberinite	Suberinized cell walls (bark or cork cells)
	Resinite	Resin, balsam, copal, latex, wax, oils and fats from higher land plants
Liptinite	Fluorinite	Essential oils of higher land plants
or	Alginite	Colonial and unicellular algae
Exinite	Bituminite	Anaerobic biodegraded products (amorphous microbial, algal and/or faunal remains)
	Chlorophyllinite	Chlorophyll
	Liptodetrinite	Biodegraded or detrital liptinite macerals and/or phytoplanktons and algae
	Exsudatinite	Secondary exsudates
	Fusinite	Cell walls (charred, oxidized or fungus infested)
	Semifusinite	Cell walls (partly charred, oxidized or fungus infested)
	Sclerotinite	Fungal hyphae, mycelia, spores and sclerotia
Inertinite*	Macrinite	Amorphous gel (oxidized/microbial metabolic product)
	Inertodetrinite	Detritus of the above inertinite macerals
	Micrinite	Secondary relics of oil generation (mostly)

*A small part of inertinite originates from melanin-rich plant and animal material ("primary inertinite"). A greater part attains its inertinitic properties during early coalification process ("rank inertinite")

coatings on leaves and fruits, secretory materials—resins (resinite), essential oils, etc. and algae and bacterial biomass. Certain liptinite macerals originate only during coalification process (i.e., secondary maceral), for example fluorinite, liptodetrinite, exsudatinite and bituminite derived from degradation and decomposition of bacterial, algal and other existing liptinites (Table 1).

In the past few decades it has been realized that chemical properties of Permian coals, viz., carbonization, swelling index, liquefaction, etc. do not correspond well with the biopetrological results under normal reflected light (Chaudhuri & Ghose, 1990). The explanation was not possible till the fluorescence microscopy came into use. Observation under fluorescence mode, i.e., using light of short wavelength (blue light and ultra-violet light) to excite organic matter in producing auto-fluorescence was found to be the best optical microscopic method to properly identify, characterize and quantify liptinite macerals in lignites and coals. The fluorescence properties of various macerals, being reflection of their chemical nature, are distinct and show a definite range of variation with change in rank. Utilizing this technique, macerals like liptodetrinite, bituminite, exsudatinite and fluorinite were recognized for the first time and thus, not only added to the overall tally of liptinite macerals but also to their quantity.

Under normal reflected light macerals like sporinite, cutinite, suberinite and resinite are only poorly represented, whereas alginite, liptodetrinite, fluorinite, bituminite, etc. were normally mistaken for mineral matter. It is for this reason that mineral matter-rich (ash-rich) Permian coals of Gondwana countries are still considered to be poor in liptinites.

The present communication attempts to highlight the advantage of fluorescence microscopy in identification, characterization and quantitative estimation of coal macerals, especially the liptinite macerals, in Turra and Jhingurdah coal seams associated with Barakar and Raniganj formations respectively in the Singrauli Coalfield.

GENERAL GEOLOGY AND LITHOSTRATIGRAPHY

The Singrauli Coalfield, in the northern extremity of Son-Mahanadi Basin, is structurally divisible into Moher sub-basin (in the north-east) and Main sub-basin (in the south-west) along longitude 82°30′E. The Moher sub-basin, the area from where the coal seams were investigated, covers an area of about 350 sq km and exposes Lower Gondwana (Permian) sediments (Text-fig. 1). The Permian strata of Talchir, Barakar, Barren Measures and Raniganj formations, gradationally in ascending order, unconformably overlie the Precambrian rocks. A generalized lithological sequence of the coal-bearing strata in the field, after Raja Rao (1983), is as follows :

Raniganj Formation (390-417 m)

Sandstone, carbonaceous shale, fire clay .... 150 m

Coal, shaly coal, carbonaceous shale (Jhingurdah Top seam) .... 90-145 m
Medium grained sandstone, shale .... 39-58 m
Coal, coaly shale, carbonaceous shale (Jhingurdah Bottom seam) .... 10-15 m
Sandstone, carbonaceous shale with thin coaly stringers .... 60 m

Barren Measure Formation (125 m)

Barakar Formation (463-766 m)

Carbonaceous shale, sandstone, thin coal bands .... 45-70 m
Coal, shaly coal, carbonaceous shale (Pani Pahari seam) .... 1-2 m
Fine to coarse grained sandstone .... 110-125 m
Coal, carbonaceous shale (Khadia seam) .... 1-2 m
Sandstone, shale .... 30-40 m
Coal, carbonaceous shale, shaly coal (Purewa Top seam) .... 8-15 m
Fine to coarse grained sandstone .... 0-60 m
Coal, carbonaceous shale, shaly coal (Purewa Bottom seam) .... 10-14 m
Fine to coarse grained sandstone .... 45-75 m
Coal, carbonaceous shale, shaly coal (Turra seam) .... 14-23 m
Fine to coarse grained sandstone .... 45-90 m
Coal, coaly shale (Kota seam) .... 1-3 m
Fine to coarse grained sandstone .... 150-250 m

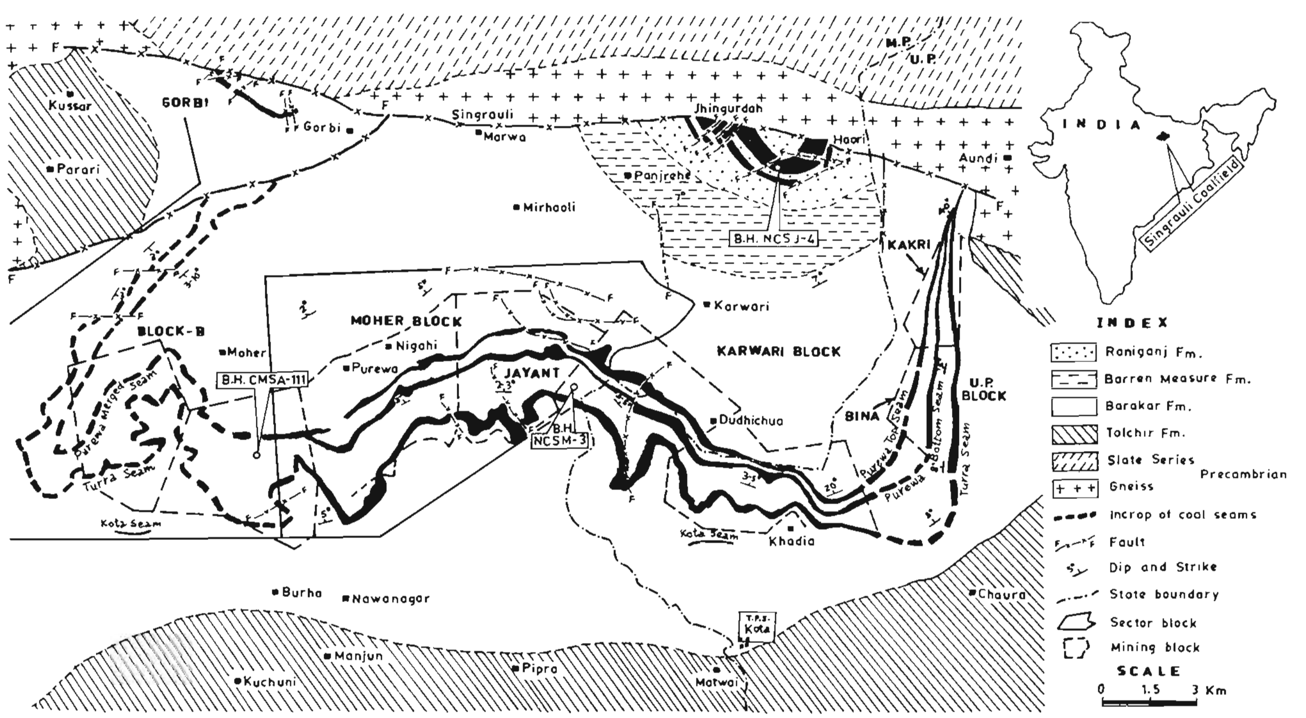
Talchir Formation (75-130 m)

The Lower Gondwana strata contain five exploitable and two to three additional uneconomic coal seams, disposed roughly in an arcuate pattern, abutting against east-west trending northern boundary fault (for details refer Raja Rao, 1983; Singh *et al.*, 1987; Singh & Misra, 1991). The Purewa Top and Bottom seams merge together forming Purewa Merge seam in the western part of the sub-basin (Text-fig.1). Exploitation of Turra seam has been carried out in Kakri (extreme NE), Bina, Jayant (central) and Gorbi (extreme NW) collieries.

MATERIAL AND METHOD

In all, 114 particulate pellets prepared by cold embedding in epoxy resin were analysed : 15 and 7 samples from bore-holes NCSM-3 and CMSA-111 respectively, 10 samples from Kakri Colliery, 11 from Bina Colliery, 8 from Jayant Colliery, 16 from Gorbi Colliery and 47 samples from bore-hole NCSJ-4. Bore-core coal samples from NCSM-3 and CMSA-111 and channel samples from four colliery sections represent Turra seam (Early Permian) of Barakar Formation and those of bore-hole NCSJ-4 are from Jhingurdah seam (Late Permian) of Raniganj Formation.

Biopetrographic results of the coal seams assessed under normal incident light have already been published alongwith preparation and analytical procedures (Singh *et al.*, 1987; Singh & Navale, 1989; Misra & Singh, 1990). Fluorescence microscopic investigation was carried out under blue light excitation (Filter block H3:420-490 nm violet-blue) on Leitz MPV-3 unit using 150 Watt ultra high pressure xenon lamp as source of illumination, 25x NPL Fluotar objective (oil) with 0.75 numerical aperture and fluorescence free immersion oil. 500 to 1000 points per sample were counted for quantitative



Text-figure 1—Geological map of Singrauli Coalfield (Madhya Pradesh) showing locations of different collieries and bore-holes (source—CMPDI Ltd., Singrauli Camp).

Table 2—Petrographic composition (macerals, mean and range vol. %) and Rank (Ro max. %) of the Singrauli field coals (as analysed under normal reflected while light)

	Jhingurdah Seam (Raniganj Formation)		Turra Seam (Barakar Formation)					
Macerals	Top	Bottom	Kakri Colliery	Bina Colliery	Bore-hole NCSM-3	Jayant Colliery	Bore-hole CMSA-111	Gorbi Colliery
Vitrinite	55 25-74	53 46-61	24 1-75	42 13-76	33 18-51	36 5-61	49 35-63	41 1-66
Liptinite	3 1-5	4 2-5	7 3-11	5 1-14	5 2-8	3 0-5	7 5-10	4 0-11
Inertinite	22 11-26	22 11-27	42 7-65	34 6-61	39 31-58	32 16-52	30 20-38	31 16-44
Mineral matter	20 10-25	21 15-31	27 9-54	19 4-36	23 14-28	29 13-61	14 11-18	24 6-55
Number of sample	41	6	10	11	15	8	7	16
Ro max. (in oil)	0.59 0.54-0.60	0.57 0.55-0.58	0.51 0.40-0.58	0.53 0.47-0.58	0.52 0.45-0.57	0.51 0.44-0.56	0.59 0.58-0.60	0.49 0.41-0.53

assessment of macerals and the results are expressed as volume per cent (vol. %) for various fluorescing and non-fluorescing macerals on mineral matter-free basis (m.m.f.).

PETROGRAPHIC COMPOSITION

Under normal reflected light

The Late Permian Jhingurdah coal seam is characterized by moderate to high vitrinite (normal range 40-74%), low liptinite (1-5%) and low to moderate inertinite (11-27%) contents (Table 2). Visible mineral matter content varies between 10 to 25 per cent. The Early Permian Turra seam, on the other hand, shows wide variations in vitrinite (normal range 18-76%, lower range (1-13%), inertinite (normal range 12-61%) and mineral matter (4-39%, max. up to 40%) contents as compared to the Jhingurdah seam (Table 2).

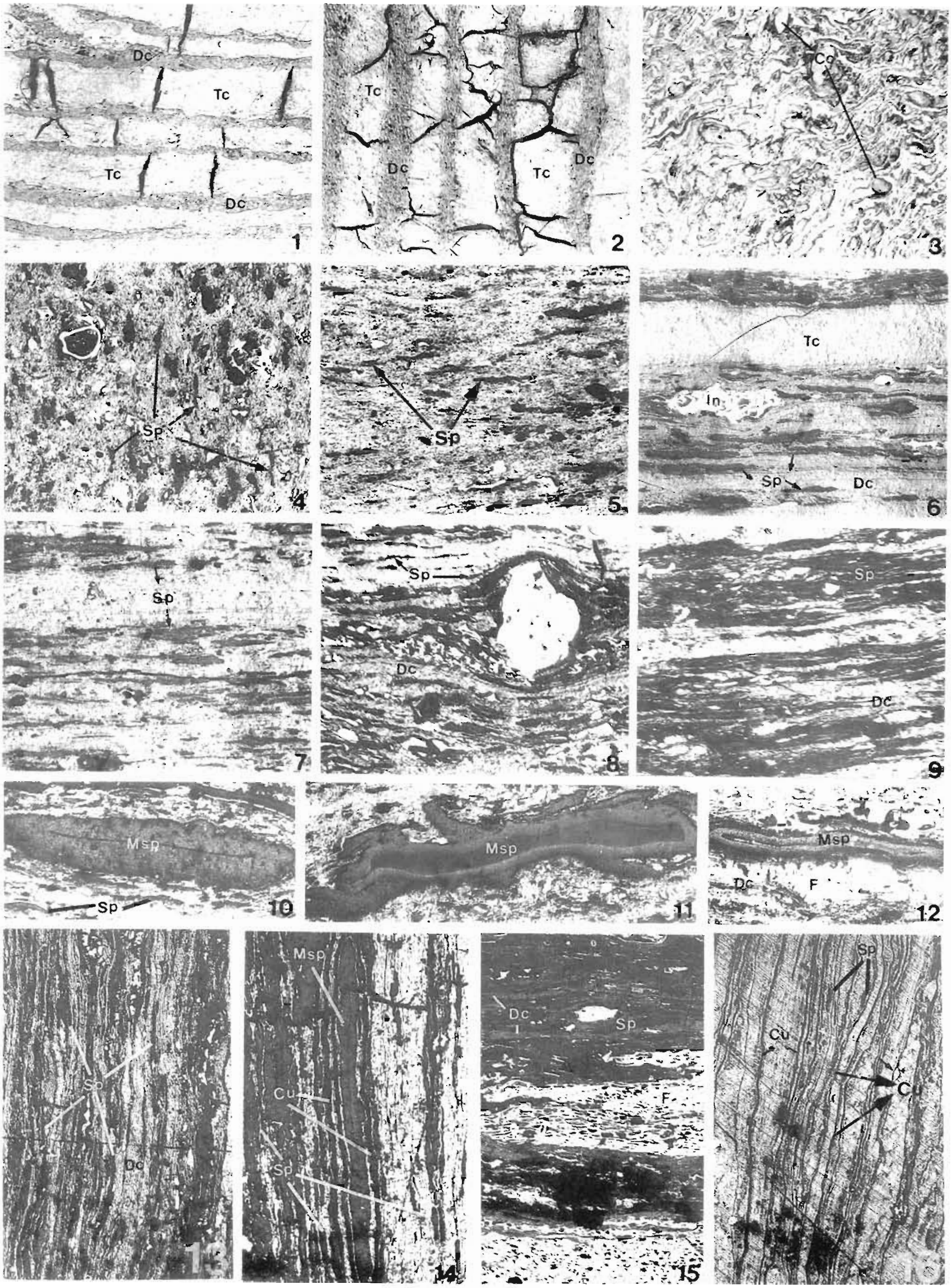
The vitrinite macerals are chiefly constituted by telocollinite and desmocollinite. Maceral telinite is less common to sporadic. Thin strips or microbands of dark grey desmocollinite alternating with thick microbands of light grey telocollinite were commonly recorded (Pl. 1, figs 1-2, 6-9). Stringers and streaks of dark grey desmocollinite, the visible portions of the groundmass are observed in inertinite-rich microlithotypes (Pl. 1, figs 12, 15; Pl. 2, fig. 7). Such dark grey streaks, strips and stringers can often be mistaken as resinite maceral (refer pl.1, figs 1, 2, 5, 7 of Saxena *et al.*, 1990).

Among liptinite macerals only sporinite and cutinite were commonly recorded. Maceral resinite and suberinite were sporadic to rare. The sporinite chiefly comprises tenui- and crassi-microspores and sporadic to common megaspores. It occurs as thin to thick and sparsely to

PLATE 1 →

(All photomicrographs were taken on polished surface under normal incident light using oil immersion).

1,2. Alternate bands of light coloured telocollinite (Tc) and thin dark coloured desmocollinite (Dc). Bright bands of vitrinite have random desiccation cracks.
3. Corpocollinite (Co): section of a wood showing parallely folded and compressed cork cells.
4-6. Sparsely distributed microsporinite (Sp) associated with inertodetrinite pieces, inertinite (In) and black granular mineral matter in desmocollinite groundmass.
7-9. Closely packed microsporinite in clarite (7) and duroclarite (8-9) microlithotypes.
10. A megaspore (Msp) and microspores in vitrinite groundmass.
11. An ornamented macrosporinite with wider lumen.
12. A relatively thin megaspore associated with fusinite (F) and strips of desmocollinite (Dc).
13. Densely packed microsporinite arranged in parallel rows in clarite band.
14. Macrosporinite, cutinite (Cu) and densely packed microsporinite in clarite band.
15. Alternate bands of fusinite and sporinite with streaks/strips of desmocollinite. Sporinite has been masked by fine and black mineral matter in trimacerite microlithotype.
16. Cutinite and sporinite in desmocollinite groundmass associated with streaks of argillaceous mineral matter.


Dc
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15
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Cu

PLATE 1

densely packed microbands (Pl. 1, figs 4-16; Pl. 2, figs 2-4). Pollen-mass or sporangium with densely clustered sporinite showing distinct or indistinct lumens and with or without covering layer was commonly observed in both the seams (Pl. 2, figs 1-4). Such dark grey mass or patch was earlier misidentified either as calcite mineral or resinite maceral (refer pl. 3, figs 2,4; pl. 5, fig. 3 of Saxena *et al.*, 1990). Mostly well-preserved discrete or rows of cutinite were found associated with clarite and trimacerite microlithotypes. It was also observed around certain tissue structures (Pl.1, figs 14,16).

Degrado-semifusinite and fusinite were the most common inertinite macerals followed by rank- and pyro-varieties. Inertodetrinite maceral was persistently common, micrinite was less common to sporadic while macrinite was sporadic. Maceral resino-inertinite was sporadic in Jhingurdah seam but common in Turra seam.

Mineral matter in Singrauli coals consists chiefly of black granular matter—a mixture of clay and subordinate amount of fine clastic quartz. It occurs as thin to thick regular or irregular microbands, infilling cell lumens of vitrinite, semifusinite, fusinite, etc., cracks and fissures associated with all microlithotypes. Clay minerals commonly occur as white to whitish-grey or pale yellow translucent blobs or blotches. Early diagenetic (concretionary) and post diagenetic (crack or fissure filling) siderite and calcite minerals are common in both the seams, especially in Turra seam (Singh *et al.*, 1987). Mineral siderite being anisotropic shows dark and light grey coloured patches. These dark patches on the siderite have been wrongly identified as resinite maceral (refer pl. 4, figs 1, 2, 6 of Saxena *et al.*, 1990). Pyrite is less common in Singrauli coals and occurs as randomly disseminated fine granules. However, coals of Turra seam in Kakri and Gorbi collieries contain crystals and framboids of pyrite.

Under incident blue light excitation

Perhydrous vitrinite and all the macerals of liptinite group were the fluorescing macerals in the Singrauli coals (Table 3). Macerals of inertinite group and corpocollinite and a fraction of telocollinite of vitrinite group were non-fluorescing.

The Jhingurdah seam contains relatively higher amount of total fluorescing macerals (54-76%, average 69%), perhydrous vitrinite (19-57%, average 40-48%) and lower amount of liptinite (13-53%, average 21-29%) macerals than the Turra seam (total fluorescing 41-77%, average 55-66%; perhydrous vitrinite 6-61%, average 16-44%; liptinite 15-57%, average 22-39%). Among the macerals of liptinite group sporinite is the dominant maceral (Jhingurdah 7-40%, average 13-18%; Turra 8-38%, average 15-26%) followed by liptodetrinite (Jhingurdah 4-16%; Turra 1-12%). Macerals cutinite + suberinite constitute 0 to 3 per cent in Jhingurdah and <1 to 7 per cent in Turra seams. The resinite has been recorded up to 3 and 2 per cent, respectively in Jhingurdah and Turra seams. Maceral fluorinite, though observed commonly, is only sporadically recorded. Exsudatinite is sporadic to rare. Maceral bituminite being associated with perhydrous vitrinite and liptodetrinite

Table 3—Maceral composition (on mineral matter-free basis %) of the Singrauli field coals (as analysed under incident blue light excitation)

	Jhingurdah Seam		Turra Seam					
Macerals	Top	Bottom	Kakri Colliery	Bina Colliery	Bore-hole NCSM-3	Jayant Colliery	Bore-hole CMSA-111	Gorbi Colliery
Fluorescing vitrinite	40 19-57	48 44-56	21 6-30	33 12-54	16 6-44	37 22-61	44 36-48	31 8-52
Non-fluorescing vitrinite + inertinite	31 24-46	31 27-34	40 30-59	35 24-49	45 33-57	35 22-49	34 30-40	40 31-54
Sporinite	18 7-40	13 7-17	25 16-38	21 13-34	26 13-35	16 8-26	15 13-16	20 10-35
Cutinite + Suberinite	1 0-3	<1 0-1	4 3-6	4 2-5	4 3-7	3 2-4	1 <1-3	3 1-5
Liptodetrinite	9 4-16	7 5-9	9 7-12	6 2-9	8 4-10	8 5-11	5 2-9	5 1-8
Other liptinites	1 <1-3	1 <1-1	1 <1-2	1 <1-2	1 <1-2	1 <1-2	1 <1-2	1 0-2
Total liptinite	29 14-53	21 13-25	39 27-57	32 22-45	39 20-50	28 16-42	22 20-25	29 15-47
Total fluorescing macerals	69 54-76	69 66-73	60 41-70	65 51-75	55 43-68	65 51-77	66 60-70	60 46-69

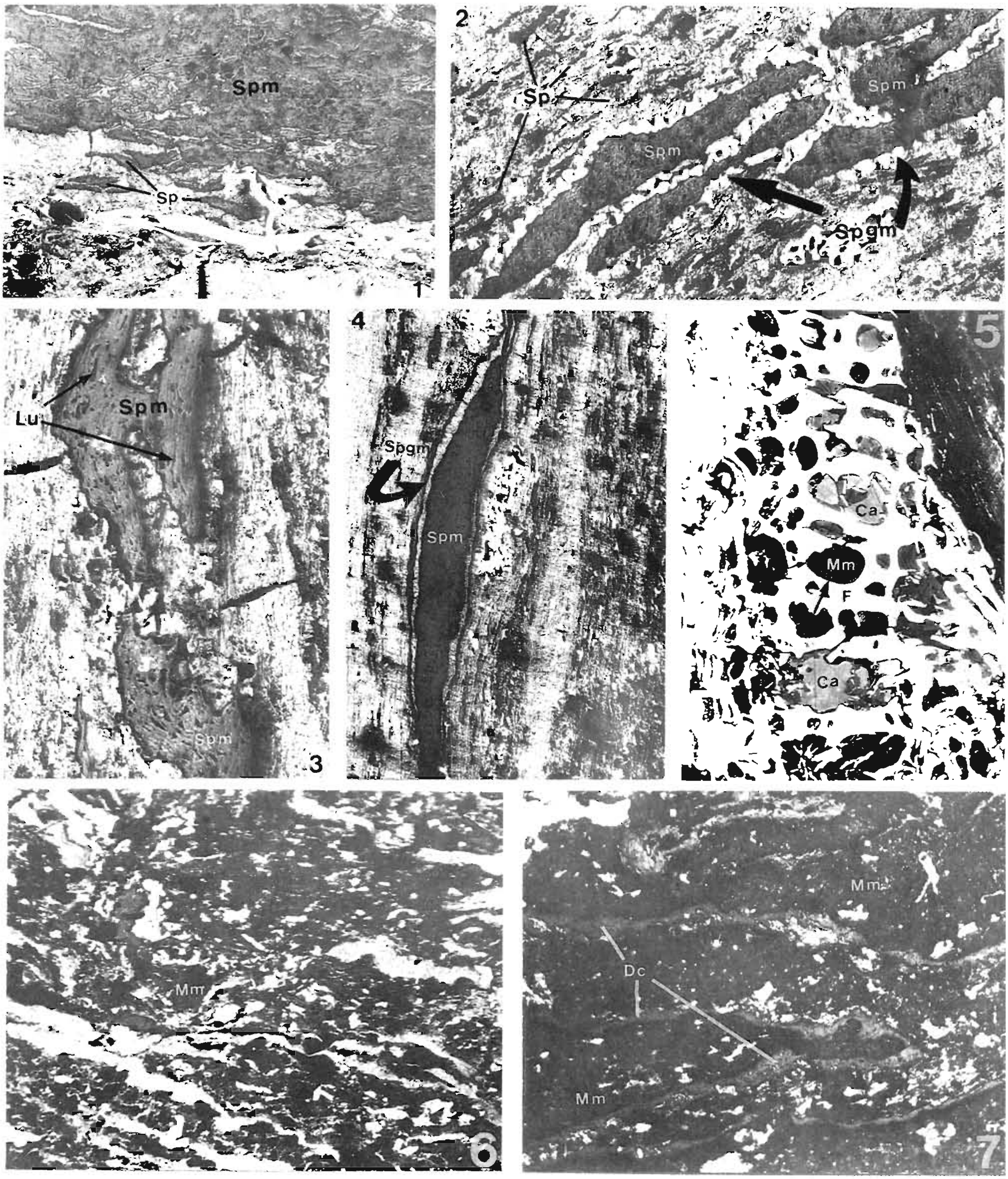

PLATE 2

(All photomicrographs were taken on polished surface under normal incident light using oil immersion).

1,3 Pollen-mass (Spm) with densely clustered sporinite showing distinct (3) or indistinct (1) lumens (Lu).

2,4. Sporangia (Spgm) showing pollen-mass with thick and wavy fusinized (2) and thin-walled (4) coverings.

5. Calcite (Ca) and argillaceous mineral matter (Mm) filled in cell lumens of fusinite (F)

6,7 Carbominerite (Mm) bands alongwith streaky desmocollinite (Dc) and inertinite macerals was not recorded separately. The presence of alginite (up to 1%) throughout the Turra seam sections is the first authentic record from Indian Permian coals.

Sporinite—In Singrauli coals, sporinite fluoresced with orangish-yellow, yellowish-orange, brownish-yellow to yellowish-brown colours (Pl. 3, figs 1-4). The sexinal part of spores and pollen fluoresced with relatively brighter colour than the nexinal part bordering streaky or slit-like lumen (Pl. 3, figs 3-8, 15). This is a characteristic feature of sporinite under fluorescence mode. Both tenui- and crassi-sporinites were present (Pl. 3, fig. 4). Megaspores were found alongwith microsporinite in clarite and trimacerite microlithotypes.

The sporinite was either sparsely distributed (Pl. 3, figs 1, 2) or was packed densely in thick microbands, especially in dull coals (Pl. 3, figs 3, 4, 10, 11). Densely packed sporinites were frequent in Turra seam sections of Kakri and Bina collieries and bore-hole NCSM-3 where a part of dull bands evidently developed into semi-cannel/cannel coal bands. The sporinite-rich bands were usually poor in inertinite macerals which occurred randomly as pieces and fragments. Such bands under normal light showed the presence of streaks and fragments of inertinite and vitrinite macerals alongwith mineral matter as groundmass. The coals commonly possessed gymnospermous pollen-mass or pollen in sporangium, with or without sporangial covering, in unreleased stage (Pl. 3, figs 5, 6). Two types of sporangia—(a) with thin and smooth sporangial wall, and (b) thick and wavy or corrugated wall were recorded. The individual pollen of the pollen-mass were tightly packed together so that their outline is generally obscured but their lumen could invariably be recognized. However, there are certain instances where pollen-mass and a couple of improperly focused sporinites pressed together were wrongly identified as resinite (refer pl. 6, figs 5, 7, 10; Saxena *et al.*, 1990).

Sporinite, particularly the gymnospermous pollen, showed wide range of preservational stages from well-preserved to highly degraded and fragmented. During biodegradation the pollen appears to have disintegrated into smaller pieces by granulation and ultimately got reduced to fine granular mass of liptodetrinite (Pl. 3, figs 11, 12). Mechanical breaking of pollen (Pl. 3, fig. 9) with or without biodegradation (Pl. 3, figs 7, 10, 11) also led to liptodetrinite formation. Another form of sporinite degradation noticed was by *in situ* pyrite growth. The pyrite crystals tended to grow preferentially inside the pollen saccus (Pl. 3, figs 14, 15, 20), ruptured it by blistering and facilitated further biodegradation and mechanical breaking (also refer Tiwari *et al.*, 1991).

Cutinite and suberinite—The cutinite showed brownish-orange to orangish-brown colours with relatively weaker intensity than the sporinite. In Singrauli coals, both tenui- and crassi-cutinites were observed generally in well-preserved state (Pl. 3, figs 4, 16-18). The maceral suberinite fluorescing with weak orangish-brown colour was only rarely observed.

Alginite—The maceral alginite represented by *Botryococcus* was commonly observed occurring discretely or in clusters in Turra coal seam sections in well-preserved to highly degraded conditions (Pl. 3, figs 1, 19, 20). Well-preserved alginite was sporadically observed in coals of the Jhingurdah seam. The *Botryococcus* fluoresced strongly (stronger than other liptinite macerals) with orange colour and showed rapid alteration. In degraded condition, it was recognized by its characteristic fluorescence colour, intensity and relict morphology. It seems that the Singrauli coals contain fair amount of alginite and most of which was later degraded and incorporated in perhydrous vitrinite (i.e., fluorescing vitrinite). Contribution of alginite to humic coals in fair amounts has already been recognized by Stach *et al.* (1982).

Resinite—The maceral is characterized by variable fluorescence intensity and wide range of colours than any other liptinite macerals in a given sample. Resinites fluorescing with green, yellow and orange colours (including their transitionary colours) have stronger intensities like those of sporinite and fluorinite, whereas those fluorescing with orangish-brown, reddish-brown and brown colours may have weaker intensities than even cutinite, suberinite and exsudatinite.

PLATE 3 →

(All photomicrographs were taken on polished surface under incident blue light excitation using oil immersion).

1. Sparsely distributed microsporinite (Sp) associated with alginite (Al) and clay (CL).
2,3. Well-preserved microsporinite with distinct lumen and nexine fluorescing with relatively dark colour.
4. Well-preserved densely packed microsporinite alongwith macrosporinite (Msp) and cutinite (Cu).
5,6. Pollen-mass (Spm) with distinct lumens.
7-9. Sporinite: degraded pollen (Spd).
10,11 Highly degraded and densely packed sporinite.
12,13. Degraded fragments of sporinite (Spd), liptodetrinite (Ld) and inertinite (In) alongwith perhydrous vitrinite (Pv).
14. Pyrite (PY) crystals inside pollen sacci (PS).
15. A bisaccate pollen showing growth of pyrite crystals inside sacci, whereas central body (CB) is free from pyrite.
16,17. Crassi- (16) and tenui-cutinites (17) enclosing small and isolated fluorinite (Fl) bodies.
18. A well-preserved thick-walled cutinite showing cuticular ledges.
19,20. Alginite (*Botryococcus*) and sporinite.

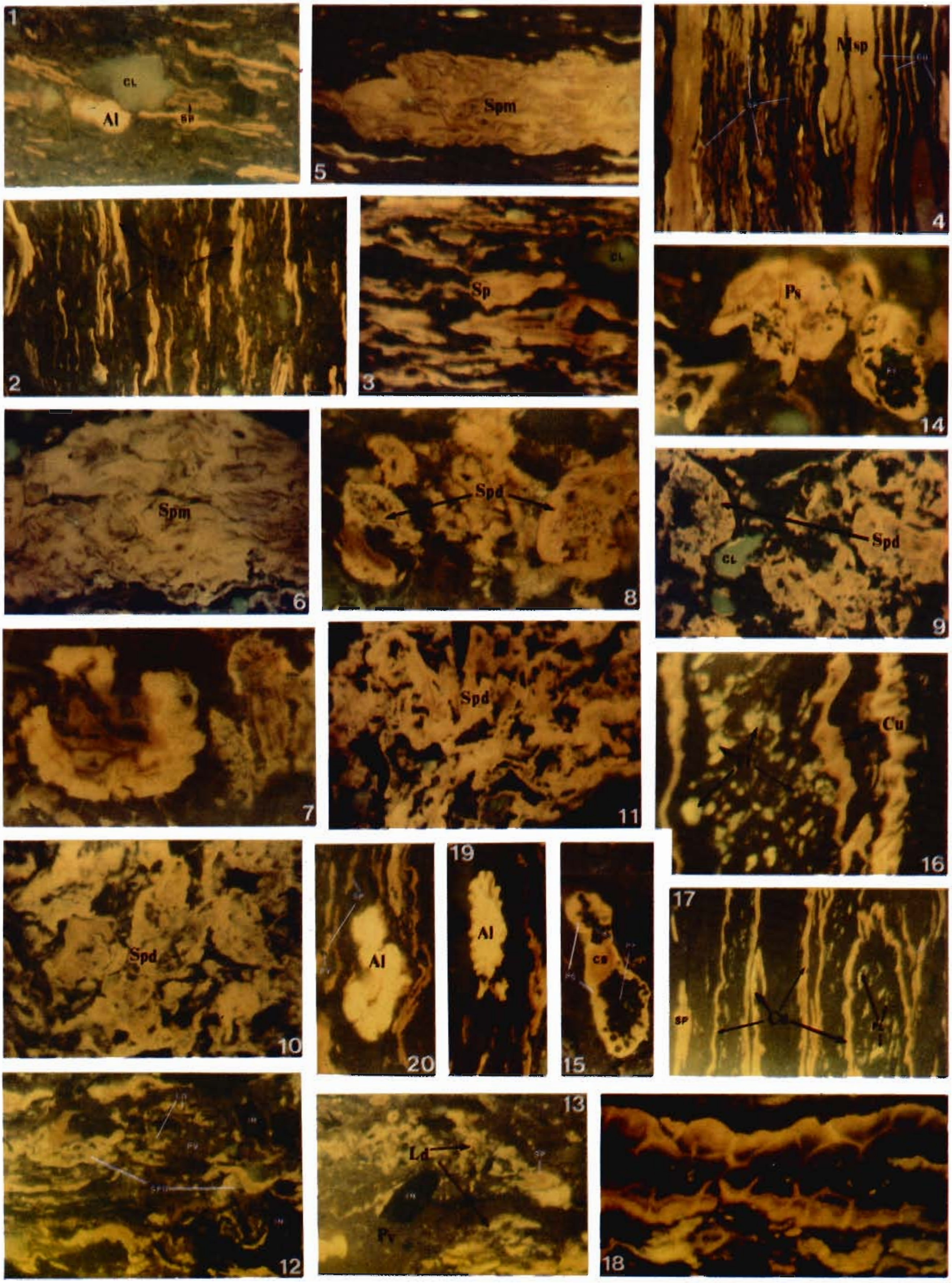
1
CL
Al
SP
5
Spm
Msp
Cu
4
2
3
CL
Sp
Ps
14
Spm
6
Spd
8
Spd
CL
9
7
Spd
11
Cu
16
Spd
10
Al
20
19
Al
CB
15
17
SP
12
13
Ld
Pv
18

PLATE 3

Macerals such as collinite in telocollinite and desmocollinite as thin micro-strips, streaks or stringers in durite and trimacerite microlithotypes have almost identical colours—light to dark grey, as that of resinite and cutinite under normal reflected light. It is for this reason that there is a possibility of misidentification of certain vitrinite macerals as resinite as has already been reported by Saxena *et al.* (1990; pl. 1, figs 1, 2, 5, 7). A critical observation of such cases under fluorescence mode confirm their identity as vitrinite.

In Singrauli coals, resinite occurred as discrete oval, elliptical or elongated bodies with regular or irregular margins of various dimensions (usually small) in clarite, durite and trimacerite microlithotypes. They fluoresced mostly with orangish-yellow, yellowish-orange, orange, yellowish-brown, orangish-brown colours (Pl. 4, figs 2-5). Green or yellowish-green resinites were not recorded. Greenish-yellow resinite was rare and that fluorescing with yellow colour was sporadic as expected according to the rank of these coals. Greenish-yellow to orange fluorescing resinites were generally translucent, whereas brown resinite appeared opaque.

Detailed observations made on resinite maceral in the Indian coals and lignites (Misra *et al.*, 1990; Misra, 1992a,b) revealed that with increase in rank (R_0 max. 0.40-0.75%) resinites fluorescing with green, yellowish-green or greenish-yellow and yellow colours gradually become less common being over taken by orange and brown colours (including transitionary colours). In addition to this, during the study it was observed that under normal incident light translucent white or pale-yellow clay blobs or blotches having fine internal striations and normally non-aligned with the surrounding macerals show greenish or yellowish colours under fluorescence mode (Pl. 3, figs 1, 3, 9). Such clay blobs/ blotches are likely to be mistaken as green or yellow resinites as reported by Saxena *et al.* (1990; pl. 6, figs 2, 3, 9).

Liptodetrinite—The maceral consists of degraded and detrital liptinite macerals including waxy granules and rods resembling waxy secretions on the surface of leaves and fruits and also alginite embedded in bituminite or desmocollinite groundmass. It is a common product of anaerobic microbial degradation and disintegration of liptinite macerals and is characteristically associated with sub-aquatic, calcium-rich and sapropelic coals. Because of its highly degraded nature and lack of morphology, the liptodetrinite is normally mistaken for mineral-rich patch under normal light.

In Singrauli coals, maceral liptodetrinite consisted chiefly of highly degraded and disintegrated sporinite, possibly alginite and certain amount of cutinite (Pl. 3, figs 9-13). The maceral being derived chiefly from sporinite fluoresced with brownish-orange to orangish-brown colours with medium intensity. Participation of resinite maceral in liptodetrinite formation was not recognized in these coals. Sporinites even if degraded and fragmented but still identifiable by their morphology were recorded as sporinite.

Fluorinite—The maceral originates from essential oils and lipid-rich cell-inclusions of various sources. The fluorinite has no morphology of its own and occurs as blobs or blotches, streaks and lensoid bodies or as thin bands. It is amorphous in texture, somewhat translucent and dark grey in colour under normal light. Because of indefinite morphology, amorphous nature and characteristic colour, the fluorinite is unidentifiable under normal light and is mistaken for voids or translucent minerals. Under fluorescence mode, fluorinite is characterized by strong intensity and rapid alteration.

In Singrauli coals, it has been commonly recorded as blobs or blotches in association with cutinite, especially in leaf tissues (Pl. 3, figs 16-18), with bright orangish-yellow to yellowish-orange fluorescence colours. Such fluorinite bodies can be easily mistaken for maceral resinite. Chaudhuri and Ghose (1990, p. 248) recorded crack-filling fluorinite (figs 8a,b). As is clear from their figure 8a, it is embedding medium between two coal particles and a crack in one of them. In fact, fluorinite is not a crack-filling maceral.

Exsudatinite—The exsudatinite is a secondary maceral which originates as fluid substance expelled from lipid-rich parent materials (in vitrinite, fluorinite, resinite, etc.) during the first coalification jump (Stach *et al.*, 1982). Representing as migrated bitumen, in coals it fills open cleats or fissures and pore spaces. The formation of exsudatinite is often associated with oil expulsions in the form of smear films and as droplets exsuding or oozing from cleats in vitrinite. These oily exsudates are not considered as maceral (Teichmüller, 1986). In low rank coals, under normal light, exsudatinite and oily droplets appear brown or dark grey, whereas

PLATE 4 →

(All photomicrographs were taken on polished surface under incident blue light excitation using oil immersion).

1. Granular bituminite (B) inside cell lumens of vitrinite separated by non-fluorescing cell walls.
2. Cell-filling yellow (YR) and brown (BR) resinites in vitrinite.
3. Closely packed sporinite (Sp) associated with random yellow resinite bodies.
4. A mass of yellow and brown resinite bodies with irregular cracks.
5. An orange resinite (OR) body associated with densely packed sporinite.
6. Partially degraded densely packed sporinite.

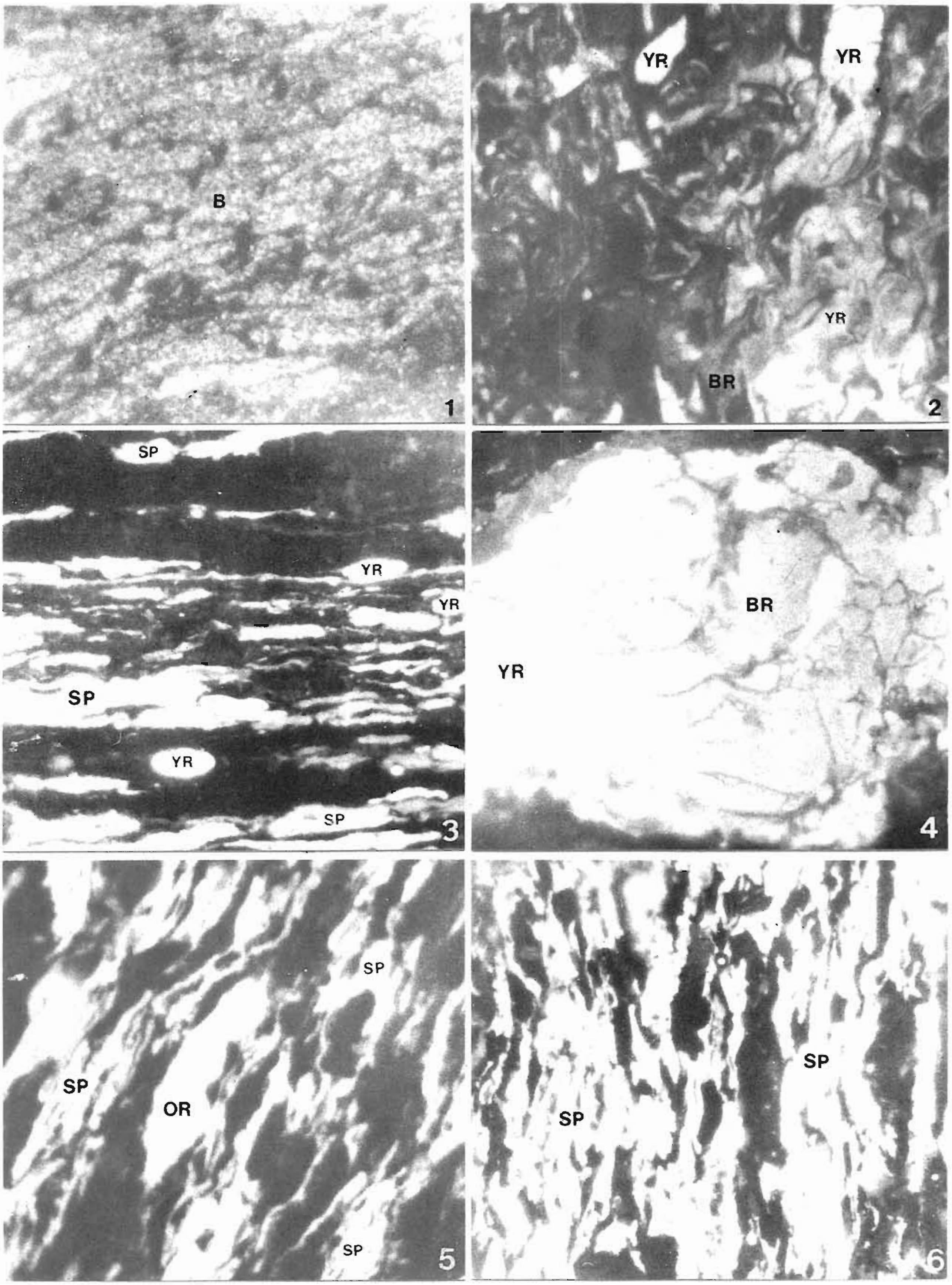

PLATE 4

the smear films often show rainbow colour bands. Under blue light excitation the maceral fluoresces with yellowish-orange, orange and orangish-brown colours with medium to weak intensity.

Exsudatinite and surface films in Singrauli coals were only sporadic in occurrence and fluoresced with weaker intensity than sporinite and some of the cutinites in orangish-brown or brownish-orange colours.

Bituminite—The maceral is the product of anaerobic biodegradation of algal, planktonic, bacterial and even fungal lipid-rich biomass formed in coals as a result of "bituminization" during biochemical gelification stage between vitrinite/huminite R_o max. more than 0.40 to 0.50 per cent (Teichmüller, 1974; Taylor *et al.*, 1991). It is an amorphous (unstructured) maceral of liptinite group with very low reflectance, weak fluorescence intensity and brownish fluorescence colour It occurs as fine granular patches, irregular streaks, stringers and lenses. Normally, the bituminite formed is pervasively impregnated in the pore-spaces of vitrinite rendering it perhydrous in nature. Therefore, most of the bituminite present in a coal is accounted for alongwith perhydrous vitrinite including desmocollinite groundmass of trimacerites and other microlithotypes.

Maceral bituminite was found associated with perhydrous vitrinite imparting weak to moderately weak reddish-brown fluorescence colour in Singrauli coals. Sometimes granules of bituminite were observed packed densely inside the original cell lumens of telocollinite separated by non-fluorescing cell walls (Pl. 4, fig. 1). Presence of alginite in these coals indicates that significant amount of bituminite was generated by alginite as well. The bituminite recorded by Chaudhuri and Ghose (1990; fig. 7, p. 247) does not conform with its characteristic morphology It is more like a resinite. Whereas, the fluorescence colour ("greenish-yellow") of the associated exsudatinite, in the same figure, is rather surprising for the coal of high volatile bituminous rank.

Though, the identification, characterization and quantification of liptinite macerals is easy and reliable under fluorescence mode, there is a likelihood of misidentification and thus erroneous estimation of certain macerals of the group, e.g., resinite, cutinite, fluorinite, exsudatinite, etc. in place of sporinite and fluorinite macerals and clay, calcite, siderite and chalcedony minerals (showing yellowish-green to orangish-brown colours) as well as embedding medium. The embedding medium, especially in a particulate pellet, reacts with vitrinite and liptinite macerals of low rank coals and shows greenish-yellow to bright yellow colours. When it is infilled in cracks and fissures of a coal particle or voids within the macerals, additional non-existent macerals may be recorded inadvertently. Therefore, a proper knowledge and understanding of morphology and characters of macerals in relation to rank and physical and optical properties of associated minerals in coals and lignites are prerequisites before any systematic study is undertaken under blue light excitation. In addition to this, quantitative evaluation of macerals under fluorescence mode may tend to give an over estimate of fluorescing matter. This is because of the fact that some of the light of short wavelength penetrates into the polished surface of the coal particle and thus generates subsurface three dimensional image of macerals. Therefore, in mineral matter-rich samples representation of fluorescing macerals, especially liptinite macerals, may be over estimated. However, in clean coals this factor may not be applicable at all.

CONCLUSION

The Indian Lower Gondwana (Permian) coals, barring few records of moderate amounts (up to 21%) of liptinite macerals under normal light (Navale *et al.*, 1983), are so far considered to be liptinite-poor. The present study, under fluorescence mode, clearly demonstrates that the earlier 'liptinite-poor' concept for the Indian Gondwana coals is no longer tenable as the coal seams in Singrauli Coalfield not only have moderate to high amounts of liptinite macerals, especially sporinite, but also perhydrous vitrinite. From the study being pursued at the Institute, it is expected that many more coal seams in other Gondwana coalfields would prove to be rich in macerals of the liptinite group.

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