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Note:

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RESEARCH ARTICLE

Role of fluorescence microscopy in the assessment of Indian Gondwana coals

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When a light of short wavelength excites organic matter, light of relatively longer wavelength is emitted from it and this phenomenon is known as autofluorescence. The coal maceral analysis under fluorescence mode (blue light/UV light excitation), therefore, has been found to be best suited to properly identify, characterize and quantify hydrogen-rich macerals. Utilizing this technique, macerals like bituminite, fluorinite and exsudatinite were recognized for the first time. Certain other macerals – alginite and liptodetrinite, normally mistaken for mineral matter under routine petrographic analysis, were also identified. Fluorescence microscopy, thus, not only added to the overall tally of liptinite group of macerals in Indian Gondwana coals, but also to their quantity. In addition to this, recognition of fluorescing vitrinite (perhydrous vitrinite) significantly contributed to the abundance of hydrogen-rich microconstituents for these coals.

FLUORESCENCE microscopic study of solid fossil fuels (coals/lignites) and kerogen (in sedimentary rocks) has been found quite successful particularly in identification, characterization and quantitative assessment of hydrogen-rich macerals, especially the liptinite (or exinite) group of macerals. It is a useful technique for determination of rank or maturity and even better suited in cases where vitrinite/huminite macerals are not in sufficient quantities or not suited for reflectivity measure-

ments, e.g. sapropelic coals, bog-head coals, oil shales, kerogen, etc. It affords a quantitative estimation of spectral fluorescence emission which is characteristic of both the individual maceral as well as rank/maturity and enables easy and reliable distinction of liptinites.

The liptinite maceral group, which is chemically distinguished from its two precedents – inertinites (relatively carbon-rich) and vitrinite (relatively oxygen-rich) by its relatively higher hydrogen content, is particularly heterogeneous in its biological origin. Because it mixes organs (or fragments of organs) and plant organisms: these are, on the one hand, spores–pollen grains (sporinite), cuticles (cutinite) and certain epidermal tissues, plant secretions – resins (resinite), essential oils, etc. and, on the other hand, the immense class of algae (alginite). Certain other liptinite macerals originate during coalification process, e.g. liptodetrinite, fluorinite, bituminite; derived from bacterial substances and decomposition products (Table 1), besides a secondary maceral – exsudatinite. Plants lipids, proteins, cellulose and other carbohydrates are characteristic source materials of liptinites[1].

Evidently, various liptinite macerals having different modes of occurrences and chemical properties behave differently under fluorescence mode and their fluorescence characteristics are correlatable with rank stages. They are all characterized by a fluorescence which takes on various colouration according to their nature and their rank; the intensity of this fluorescence decreases with the increasing rank and disappears towards 1.0 to 1.3% R_0 max[3,4]. Since the fluorescence property of organic matter or maceral is the reflection of its overall chemical characteristics, the technique helps in understanding the changing pattern of macerals through various coalification stages.

Gondwana coals are normally rich in mineral matter/ash contents. Also their liptinite contents recorded under normal reflected light is quite low (usually 1–15%). In fact, high inherent clastic minerals intimately associated with these macerals in the coals tend to mask them, at times completely, rendering their identification difficult or even impossible under normal incident light. Earlier, only macerals like sporinite, cutinite, suberinite and resinite were subnormally recorded, whereas liptodetrinite, alginite, fluorinite, bituminite, etc. were normally mistaken for mineral matter. It is primarily because of this reason that mineral matter-rich Lower Gondwana (Permian) coals of India were and are still considered to be poor in liptinite contents.

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. The explanation was not possible till the use of fluorescence microscopy came into routine service, by which hydrogen-rich macerals quantities show a manifold increase in the same coals. It is the intention of

Table 1. Classification of coal maceral groups/macerals and their source material (ref. 2, modified after ref. 1)

Group	Maceral	Origin
Vitrinite	Telinite	Cell walls (may be resin impregnated or lignified) rich in cellulose.
	Telocollinite	Gelified plant tissues.
	Desmocollinite	Gelified humic detritus (amorphous).
	Vitrodetrinite	Humic detritus.
	Corpocollinite	Cell filling (oxidation/condensation products of tannins or biochemically gelified humic matter).
Liptinite or Exinite	Sporinite	Spores 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.
	Fluorinite	Essential oils of higher land plants.
	Alginite	Colonial and unicellular algae.
	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 exudates.
Inertinite*	Fusinite	Cell walls (charred, oxidized or fungus-infested).
	Semifusinite	Cell walls (partly charred, oxidized, or fungus-infested).
	Sclerotinite	Fungal hyphae, mycelia, spores and sclerotia.
	Macrinite	Amorphous gel (oxidized/microbial metabolic products).
	Inertodetrinite	Detritus of 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'.

this communication to highlight the advantage of fluorescence microscopic method in evaluation of certain Lower Gondwana coal seams from Raniganj, Singrauli and Rajmahal fields of India.

Materials and method

In principle, irradiation or excitation with a light of short wavelength, routinely blue or ultra-violet light, on organic matter or maceral causes emission of fluorescence colours and this phenomenon continues till stoppage of excitation – 'auto-fluorescence'. During auto-fluorescence, emitted colour and intensity changes with time and this dual change is known as 'alteration effect'. Alteration of fluorescence colour and intensity are typical of a particular organic matter or maceral at a given

rank or maturity stage. Based on these criteria, various types of organic matter/macerals are identified and characterized

Maceral content was determined under blue light excitation (filter block H3.420-490 nm, violet-blue excitation) on Leitz MPV-3 unit using 150 W ultra high pressure xenon lamp (to initiate fluorescence) as source of illumination, 25× NPL Fluotar objective (oil) with a 0.75 numerical aperture and fluorescence-free immersion oil. The reported results, based on 500–1000 point counts per sample, are expressed as volume per cent of the various fluorescing and non-fluorescing macerals on a mineral matter-free basis.

A total of 192 particulate coal pellets prepared by cold embedding in epoxy resin were analysed by coal petrographic procedures. Some pertinent details about number and nature of samples, name of coal seams and their respective coalfields are given in Table 2. The coals range in rank between sub-bituminous A to high volatile bituminous C–A stages (R_0 max. 0.40–0.88% in oil).

Caution

It must be mentioned here that in identifying organic matter/coal macerals in fluorescence mode, one should have proper morphological knowledge. There are some minerals, viz. calcite, siderite, fluorite, a variety of quartz, etc. which fluoresce and can be mistaken for resinite and cutinite macerals. Certain translucent minerals, such as clay, because of internal reflection/refraction appear green, yellowish-green to yellow colours giving a false impression of being resinite. Beside this, embedding medium being a chemical substance, does react with embedded coal particles producing yellowish-green – yellow to yellowish-orange colours and, thus may add to the tally of resinite.

The 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 short wavelength light penetrates into underlying coal and, thus generates three-dimensional image of macerals below the polish surface of the grain mount. Therefore, quantitative estimation of macerals, especially the liptinite macerals, in mineral matter-rich coal samples may represent over estimated results. However, in clean coals this factor may not apply at all.

Characteristic features of fluorescing macerals

Perhydrous vitrinite and all the macerals of liptinite group were the fluorescing macerals in the Lower Gondwana coals of the Raniganj, Singrauli and Rajmahal coalfields. Corpocollinite and a fraction of telocollinite macerals of vitrinite group and macerals of inertinite group were non-fluorescing in these coals.

Table 2. Details of coal samples studied from some Lower Gondwana coalfields of India

Late Permian – Raniganj Formation
Raniganj Coalfield (Damodar Basin), West Bengal
Three bore-hole sections from:
Girmint block (bore-hole TAD GRT/0160/CM-009)
    Seam nos. (bottom to top): I, II, III bot, III top, IV, Bankshimulia, V, VI, Century, VII, VIII bot, VIII top, Kusudanga, IX, XA and X   (16 samples)
Dhemo Main block (bore-hole DMM/0030/CM-006)
    Seam nos. (bottom to top): VA, V, VI bot, VI mid. VI top, VIIA, VII, VIII bot, VIII top, IX and X
           (11 samples)
Shyamsunderpur block (bore-hole SS-5)
    Seam nos. (Bottom to top) IV, V, VI, VIIA, VII, VIII bot., VIII mid., VIII top and IX   (9 samples)
Singrauli Coalfield (Son Basin), Madhya Pradesh
One bore-hole section of Jhingurdah seam from
    Jhingurdah colliery (bore-hole NCSJ-4)
    Top seam (41 samples)
    Bottom seam (6 samples)   (47 samples)
Early Permian – Barakar Formation
Singrauli Coalfield (Son Basin), Madhya Pradesh
Five sections of Turra seam from:
    Kakri (10 samples), Bina (11 samples), Jayant (8 samples),
    Gorbi (16 samples) collieries and bore-holes NCSM-3 (Moher block-15 samples) and CMSA-111 (block-B-7 samples)   (67 samples)
Chuperbhita Coalfield (Rajmahal Basin), Bihar
One bore-hole section from:
Chuperbhita basin (bore-hole RCH-3)
    Seam nos. (bottom to top): I (samples), II (9 samples), III (6 samples) IV (4 samples), V (3 samples), VI (3 samples), VII (3 samples) and VIII (9 samples)
           (42 samples)

Sporinite is derived from the outer cell walls of spores and pollen. It fluoresced with orangish-yellow, yellowish-orange, brownish-yellow to yellowish-brown colours in studied Gondwana coals. The sexinal part of the spores and pollen fluoresced with relatively brighter colour than the nexinal part bordering streaky slit- or thread-like lumen. Both tenui- and crassi-sporinites were present along with sporadic to common macrosporinite (Figures 12, 15). The microsporinite in coals was either sparsely distributed (Figures 3, 4) or was packed densely in thin to thick microbands (Figures 5, 8, 15, 22), especially in dull coals. Densely packed sporinite as thick microbands were frequent in Singrauli[2] and Rajmahal coals, where a part of dull bands evidently developed into semi-cannel or cannel coals. This is the first record of the presence of semi-cannel/ cannel coal bands in India. The sporinite-rich bands were usually poor in the inertinite macerals which occurred randomly as pieces and fragments (Figure 17).

The Lower Gondwana coals commonly contained gymnospermous pollen-mass or pollen in sporangium with or without sporangial covering/wall in unreleased stage (Figures 6, 7). In normal light, such dark grey

FLUORESCING MACERALS(VITRINITE & LIPTINITE) IN INDIAN GONDWANA COALS
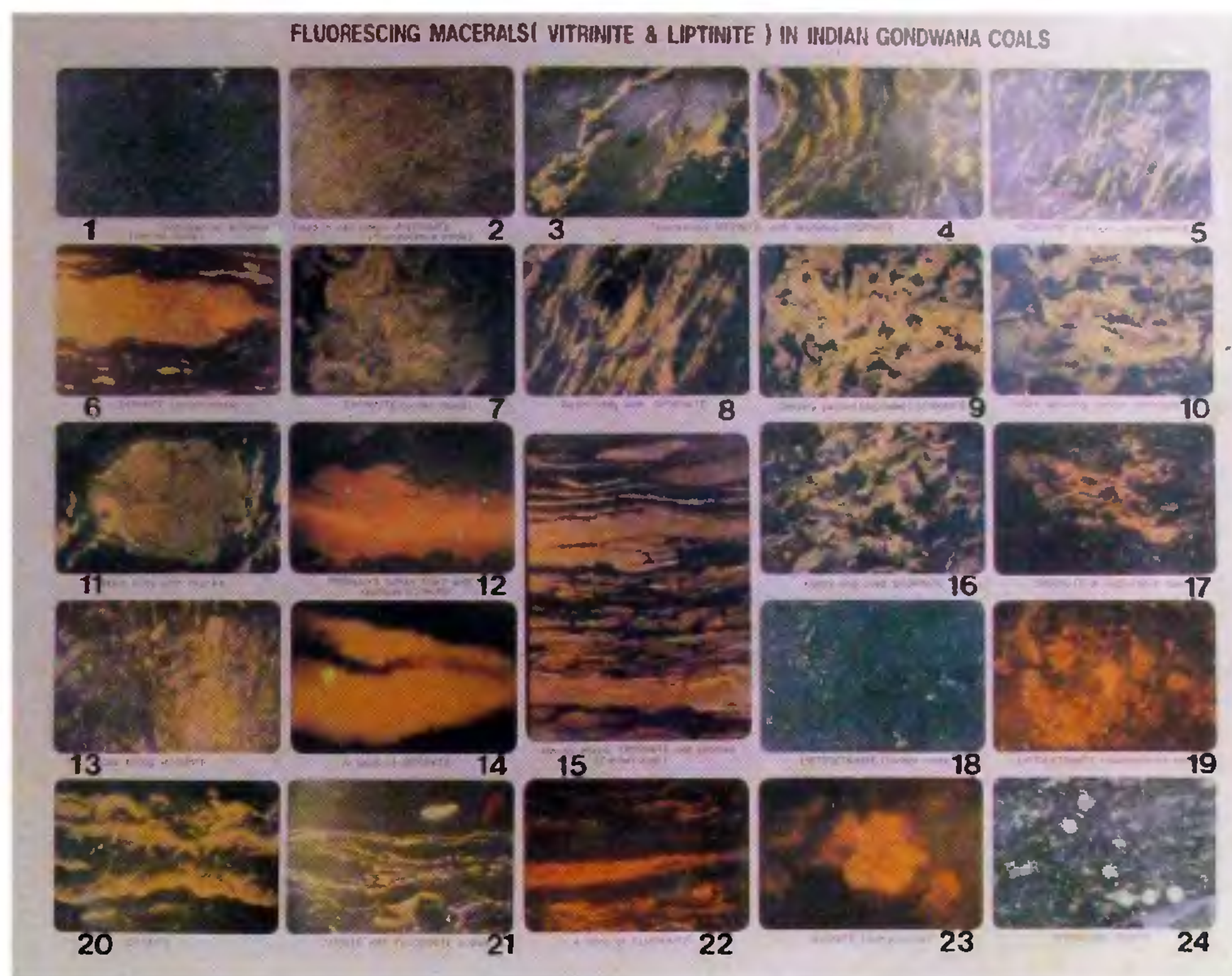
Figures 1, 2. Granules of bituminite filled in cell lumens of vitrinite, Singrauli Coalfield (Figure 1 under normal mode), Figures 3, 4. Fluorescing (perhydrous) vitrinite with degraded sporinite in Raniganj (3) and Singrauli (4) coals; Figure 5. Sporinite in fluorescing vitrinite, Rajmahal Coalfield; Figures 6, 7. Sporinite (pollen mass) in Singrauli coals, Figure 8. Resin body with sporinite in Singrauli coals; Figure 9. Densely packed (degraded) sporinite in Singrauli coals, Figure 10. Pollen showing saccus structure (sporinite) in Singrauli coals, Figure 11. Resin body with cracks in Singrauli coals, Figure 12. Megaspore lumen filled with resinous (?) matter in Rajmahal coals, Figure 13. Cell filling resinite in Singrauli coals; Figure 14. A band of resinite in Rajmahal coals; Figure 15. Cannel coal, macro-, microsporinite and cutinite in Singrauli coals, Figure 16. Highly degraded sporinite in Singrauli coals, Figure 17. Sporinite in inertinite band of Rajmahal coals; Figures 18, 19. Liptodetrinite in Rajmahal coals. (Figure 18 under normal mode); Figure 20. Cutinite showing cuticular ledges, Singrauli coals, Figure 21. Cutinite with fluorinite bodies in Singrauli coals, Figure 22. A band of fluorinite in Rajmahal coals; Figure 23. Alginite (*Botryococcus*) in Rajmahal coals; Figure 24. Framboidal pyrite in Singrauli coals under normal mode. [All photomicrographs were taken on polished surface under incident blue light excitation (except nos. 1, 18 and 24) using oil immersion]

densely clustered sporinite was earlier misidentified either as calcite mineral or resinite maceral by others. The individual pollen of the pollen-mass are tightly packed together so that their outline is generally obscured but their lumen can invariably be recognized.

During the investigation, it was observed that sporinite showed wide variety of preservational stages from well-preserved to highly degraded and fragmented (Figures 9, 10, 16). During biodegradation the pollen appears to have disintegrated into smaller pieces by granulation and ultimately got reduced to fine granular mass of liptodetrinite. Mechanical breaking of pollen with or without biodegradation also led to liptodetrinite formation. Another form of sporinite degradation noticed was by *in situ* pyrite growth where pyrite crystals tended to grow inside the pollen saccus, rupture it by

blistering the saccus wall, thus facilitated further biodegradation and mechanical breaking.

Cutinite is derived from cuticles and cuticular layers which occur at the surface of leaves, twigs, and other areal parts of plants as a protection from dessication. It showed brownish-orange to orangish-brown colours with relatively weaker fluorescence intensity than the sporinite in these coals. Both tenui- and crassi-cutinites were observed generally in well-preserved state (Figures 15, 20). Cutinite enclosing certain tissue structure, such as leaf sections, was normally associated with fluorinite which appear as irregular amorphous bodies of various dimensions (Figure 21).

Fluorinite originates from essential oils and lipid-rich cell inclusions of various sources. It occurs as blobs or blotches, streak and lensoid bodies or as thin bands and

Table 3. Maceral composition (mean and range) and reflectance value of the coal seams from the studied fields of India

	Raniganj Coalfield Seams I-X	Singrauli Coalfield Jhingurdah seam	Turra seam	Rajmahal Coalfield Seams I-VIII (Chuperbhita)
Under normal incident light (volume %)				
Vitrinite	59.90	54.23	37.58	36.57
	41.4–77.0	25.0–74.0	3.6–76 0	5.0–80.8
Liptinite	5.24	3.32	5 66	4 83
	1 0–11.0	1.0–5.4	1.0–13 6	1 0–12.2
Inertinite	14.51	21 98	25.20	36.22
	4.2–23.2	11.2–26 6	6.0–60.6	8 0–72.0
Mineral matter	20.35	20.47	21.56	22.38
	8 0–40 6	10 4–25.2	4.0–36.4	3.6–49.4
R_o max. (% in oil)	0.56–0.88	0.54–0.60	0 43–0.60	0.43–0.57
Under blue light excitation (mineral matter-free %)				
Vitrinite	49 08	44.16	29.03	30.33
(fluorescing)	20.8–64.0	19 0–57.0	6.0–54.0	2.0–80.2
Liptinite	20.98	25.10	32 13	33.80
	14.3–27.4	13.5–53.1	14 5–57.4	5.4–66.2
Sporinite	10.29	15.12	21.49	24.28
	4.9–15.5	7 2–39.7	9.6–38.3	2.0–58.0
Resinite	1.60	0.83	1.08	0.32
	0.4–3.5	0.0–2.9	0.0–2.1	0.0–3.2
Other liptinites	1.24	1.07	3.17	0.18
	0.0–3 8	0.2–3.1	0.5–6.5	0.0–2 6
Liptodetrinite	7.85	8.08	6.39	9.02
	4.5–13.2	3.8–15.7	1.2–12.0	1.6–20.0
Vitrinite + inertinite	29 94	30.74	38 84	35.87
(non-fluorescing)	19.2–64.9	23.8–46.3	24.0–59 2	12.0–72 0

having strong fluorescence intensity (of bright orangish-yellow to yellowish-orange fluorescence colours; Figures 21, 22). Such fluorinite bodies can be easily mistaken for resinite even in fluorescence mode, unless their rapid alteration is ascertained. Because of indefinite morphology, amorphous nature and characteristic colour (dark grey), the maceral fluorinite is unidentifiable under normal light and is mistaken for voids or translucent minerals.

Suberinite is derived from suberin layers of corkified cell walls, mainly in tree barks. Suberin is formed also at the surface of roots and fruits, acting as a protection against dessication. The maceral suberinite fluoresced with weak orangish-brown colour and was only sporadically observed in these Gondwana coals.

Alginite represented by Botryococcus was commonly observed occurring discretely or in clusters in well-preserved to highly degraded conditions. Well-preserved alginite was not observed in the Late Permian coal seams. It fluoresced more strongly (with orange colour) than other liptinites and showed rapid alteration. In degraded condition it was recognized by its characteristic fluorescence colour, intensity and relict morphology. Alginite appearing as dark grey and black coloured discrete globular or small lumpy bodies with granular texture under normal reflected light has been misidentified as mineral lumps. Presence of Botryococcus in Singrauli (persistent[2]) and Rajmahal (common) fields is the

first authentic record from the Palaeozoic coals (Figure 23). It seems that these coals contain a fair amount of alginite, most of which was later degraded and incorporated in perhydrous vitrinite. Contribution of alginite to humic coals in fair amounts has already been recognized by Stach et al.[5]

Resinite is derived not only from resins but also from balsams, latexes, fats and waxes. It is characterized by variable fluorescence intensity and colour than any other liptinite macerals in a given coal. It occurred as discrete oval, elliptical or elongated bodies with regular or irregular margins of various dimensions (usually small) in Gondwana coals (Figures 8, 11, 13, 14). Macerals such as collinite in telocollinite/desmocollinite as thin micro strips, streaks or stringers in bi- and trimaceral associations have almost identical light to dark grey colours as that of resinite and cutinite under normal light. It is for this reason that there is a possibility of misidentification of certain vitrinite maceral as resinite. In addition to this, transluscent white or pale yellow clay blobs or blotches normally non-aligned with the surrounding macerals, as has already been mentioned, are likely to be mistaken as green or yellow resinites in fluorescence mode.

In fact, green or yellowish-green resinites were not recorded in these coals. Greenish-yellow resinite was rare and that fluoresced with yellow colour was sporadic as expected according to rank of these Gondwana coals.

Greenish-yellow to orange fluorescing resinites were generally translucent, whereas brown resinite appeared opaque. With increase in rank, it has been proved in Indian coals and lignites[6] that resinite fluorescing with green, yellowish-green or greenish-yellow and yellow colours gradually become less common, being overtaken by orange and brown colours (including transitionary colours).

Liptodetrinite is a common product of anaerobic microbial degradation and disintegration of liptinite macerals, chiefly sporinite, possibly alginite and certain amount of cutinite in these coals. Participation of resinite maceral in liptodetrinite formation was not recognized in studied coals. Because of its highly degraded nature and lack of morphology, the maceral is normally mistaken for mineral matter-rich patch under normal incident light (Figures 18, 19). Its recognition is routinely possible under fluorescence mode only.

Bituminite is the product of anaerobic biodegradation formed in coals as a result of 'bituminization' during biochemical gelification stage between vitrinite R_0 max. >0.40 to 0.50% (ref. 7). It is an amorphous (unstructured) maceral of liptinite group with brownish fluorescence colour of weak intensity. This maceral is properly recognized only under fluorescence mode. Normally, the bituminite formed is pervasively impregnated in the pore spaces of vitrinite rendering it perhydrous in nature (Figures 1, 2). Therefore, most of the bituminite present in a coal is accounted for alongwith perhydrous vitrinite (imparting weak to moderately weak reddish-brown fluorescence colour) including desmocollinite groundmass. Sometimes granules of bituminite were observed packed densely inside the original cell lumens of vitrinite separated by non-fluorescing cell walls. Presence of alginite in studied coals indicate that significant amount of bituminite was generated by alginite as well.

Exsudatinite originates as fluid substances expelled from lipid-rich parent material (in vitrinite, fluorinite, resinite, etc.) during 1st coalification jump. Appearing as migrated bitumen, in coals it fills open cleats, fissures and pores. The formation of exsudatinite is often associated with oil expulsions in the form of smear films and as droplets exuding/oozing from cleats in vitrinite. These oily exudates are not considered as maceral by Teichmüller[8]. In studied coals, exsudatinite and surface films were only sporadic in occurrence and fluoresced with weaker intensity than sporinite and some of the cutinites in orangish-brown or brownish-orange colours. In low rank coals, exsudatinite and oily droplets appear brown or dark grey in colour under normal light, whereas the smear films often show rainbow colour bands. This secondary maceral is properly recognized only under fluorescence mode.

Biopetrographic composition of coals

The coal seams of Barakar Formation from Rajmahal and Singrauli fields are normally rich in inertinite (6.0–72.0%) and the vitrinite ranges between 3.6 to 80.8%.

The Raniganj coal seams (from Singrauli and Raniganj fields), on the contrary, contain high vitrinite (25.0–77.0%) and relatively low inertinite (4.2–26.6%). These Gondwana coals are characterized by persistently low (1.0–13.6%) and randomly distributed liptinite contents (Table 3). Associated minerals are usually fine black granular argillaceous matter, besides siderite, calcite and pyrite minerals, commonly found dispersed and intimately associated with organic constituents.

Under blue light excitation, the coals of both Barakar and Raniganj Formations were found to contain appreciably high amounts of liptinite macerals (7.0–66.2%) and perhydrous vitrinite (6.0–80.2%). However, the coal seams of the Barakar Formation are characterized by higher proportions of liptinite macerals, especially the sporinite (4.9–58.0%) than the coal seams of the Raniganj Formation (4.8–39.7%), whereas the coal seams of the latter formation have higher proportion of perhydrous vitrinite (19.0–64.0%) than those of the former (2.0–80.2%). The liptinite macerals in these coals are formed chiefly by sporinite (4.8–58.0%) and liptodetrinite (1.2–20.0%). Cutinite, suberinite, resinite, exsudatinite and fluorinite are other liptinite macerals together occurring in only subordinate amounts. Maceral bituminite being associated with perhydrous vitrinite and liptodetrinite was not recorded separately. Presence of maceral alginite was commonly recorded (up to 0.8%) in the Barakar coal seams.

It must be mentioned here that Chakrabarti[9], Chaudhuri and Ghose[10], and Saxena et al.[11] carried out fluorescence microscopy of certain Indian Gondwana coals. However, their petrographic data in certain specific aspects do not correspond well with those obtained presently. Therefore, it has been deemed necessary to explain the reasons of the discrepancies between the two data sets.

Chakrabarti[9] has evaluated representative coal samples (seams) from various Gondwana fields and remarked that 'higher-volatile bituminous coals (VM >40%) with reflectance values varying from 0.45–0.65% do not show any fluorescence property in primary structured constituents like vitrinite and fusinite'. Absence of fluorescing (perhydrous) vitrinite in this rank range is surprising, even coals having abundant liptinites. However, desmocollinite and a fraction of telocollinite (of vitrinite group) were presently found to be fluorescing with dull reddish-brown to dark brown colours, although with weak intensity.

The bituminite recorded by Chaudhuri and Ghose[10] (Figure 7) does not conform to its characteristic morphology. It is more like a resinite, whereas 'greenish-yellow' colour of the associated exsudatinite (in same figure) is rather surprising for high volatile bituminous coal rank. They also recorded crack-filling fluorinite. Actually it is not a crack-filling maceral. As is clear from their figure (8a, p. 248) it is an embedding medium between two coal particles and a crack in one of them.

Saxena *et al.*[11] carried out analysis of Raniganj coal seams (R-I – R-X) from the Raniganj field. They have not, however, provided information about the location and sequence of samples, lateral representation of coal seams and fate of split seams, besides coal quality and rank. Therefore, generalization made on the coal seams (for the coalfield) by them is unacceptable. Absence of cutinite under blue light excitation (Table 2, p. 61), but their presence in certain seams under normal light (Table 4, pp. 66, 67) is surprising. More than 5–10% (m.m.f) of resinite and 65 to above 69% (m.m.f.) of perhydrous vitrinite contents reported by Saxena *et al.*[11] (Table 2) is also abnormally high. Such high quantities of perhydrous vitrinite is not recorded even in Tertiary coals of Assam which are best suited for liquefaction[12]. High resinite content (5–10%) in coal seams R-II, R-III, R-VII to X recorded by Saxena *et al.*[11] is because of wrong identification of macerals collinite, desmocollinite, corpocollinite and sporinite and calcite, siderite and a certain fraction of clay minerals as resinite. The following are some examples from the illustrations of Saxena *et al.*[11] to support my contention:

(1) Plate 1, Figures 1, 2, 4, 5: the resinite (R) shown are collinite-filled lumens of telocollinite.

(2) Plate 3, Figure 2: resin (R) fillings and bitumen (B) shown are sporinite and calcite respectively. Figure 4: is not resin fillings in irregular spaces but sporinite in desmocollinite.

(3) Plate 4, Figures 1, 2, 6: are not resinite (R) but anisotropic siderite whose dark grey portions were identified as resinite. Refer siderite concretion in Plate 5, Figure 1. Figures 3, 4: are not resinite but corpocollinite and desmocollinite (in trimacerite) respectively. Figure 5: is calcite not resin (R) content filled in elliptical shape.

(4) Plate 5, Figure 3: is a pollen-mass (sporinite) not resin (R) fillings along the cracks. Note sporinite lumens are clearly discernible.

(5) Plate 6, Figures 2,3: illustrate green resinite (GR) which, in fact, are voids of fusinite lumen filled with embedding medium. Green to orange resinites do not fluoresce with such weak intensity. Figure 4: is not yellow resinite (YR) but oily droplets (exsudatinite) oozing out from a crack in vitrinite. Figure 5: illustrates two identical patches one (arrow pointing orange colour thread-like structures which is, in fact, lumen) recognized as sporinite (S) and the other (arrow pointing coalesced sporinite walls) as yellow reactive resin (YR)/hydrocarbon. In fact, both of them are pollen-mass (sporinite). Sporinite wall can never become resinite. Figure 6: is not green reactive resinite (GR) filled in fusinite lumen. Instead it is either embedding medium (epoxy) or fine clastic mineral with internal reflection. Such examples are frequently observed in Permian coals. Figure 8: is more like exsudatinite

(mark the morphology and nature of encroachment on the associated macerals) rather than yellow to orange colour reactive resin (YR) filled along vitrite cracks. Figure 9: is not a lath-shaped resinite (R) body but a blob of clay mineral showing its characteristic internal striations. The body is not in alignment with the surrounding sporinites, which clearly indicates it to be a secondary matter. Figure 10: shows yellow resinite (YR) filled in sporinite. In fact, if properly focussed it will reveal 3–4 sporinites compressed together.

No resinite (resin) as that shown in black and white photographs (Plates 1, 3–5) have been illustrated under fluorescence mode. Calcite is a weakly fluorescing mineral and can be mistaken as resinite. Absence of corpocollinite, cutinite and calcite and low amount of siderite recorded clearly explain the reasons for high amount of resinite erroneously recorded by Saxena *et al.*[11] in the Raniganj coal seams of the Raniganj field.

Conclusions

Utilizing the fluorescence technique, macerals like liptodetrinite, bituminite, exsudatinite, alginite and fluorinite, in addition to fluorescing or perhydrous vitrinite, have been recognized for the first time in Indian Lower Gondwana (Permian) coals of the Raniganj, Singrauli and Rajmahal fields. Thus, these not only add to the number of liptinite macerals but also to their quantity (2–4 times or even more than recorded in normal incident light). This positively indicates that the earlier 'liptinite-poor' concept for Indian Gondwana coals is no longer tenable. High concentration of especially sporinite in some coal bands of Singrauli and Rajmahal fields make them of cannel/semi-cannel coals types.

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