Maceral alginite in Indian coals and lignites : Its significance and influence*

Basant K. Misra, Bhagwan D. Singh & Alpana Singh

Misra BK, Singh BD & Singh A 1998. Maceral alginite in Indian coals and lignites: Its significance and influence. *Palaeobotanist* **47** : 37-49.

The lamellar algae (lamalginite) has been recognised in the Indian Permian Gondwana coal seams of Son, Rajmahal, Mahanadi and Godavari basins. *Botryococcus* occurs in the coals of above Gondwana basins as well as in the Tertiary coals of north-east India and in the Tertiary lignites of Cauvery and Kutch basins. Another alga, *Pleurocapsa* is known from the lignites of Kutch Basin, whereas, *Tasmanites* is present in the Tertiary coals from Meghalaya. The presence of alginite in the coals and lignites is helpful in resolving certain discrepancies of their interpreted behaviour on the basis of petrological and chemical data, especially the carbonization behaviour and bye-product yield. The abundance, type, developmental stages, and association of alginite with other macerals provide much information about the depositional environment of vegetal matter accumulation for coal and lignite formation than was previously possible to deduce.

Key-words—Alginite (algae), Coals, Lignites, Fluorescence microscopy, Palaeoenvironment.

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

सारॉंश

भारतीय कोयलों और लगुडांगारों में मेसीरल एल्जीनाइट की उपस्थिति : इसका महत्व एवं प्रभाव

बसन्त कुमार मिश्र, भगवान दास सिंह एवं अल्पना सिंह

सोन, राजमहल, महानदी और गोदावरी द्रोणियों में विद्यमान भारतीय परमियनकालीन गोंडवाना कोयला सीमों से लेमेलायुक्त शैवाल प्राप्त हुआ है। इन द्रोणियों से प्राप्त कोयलों में *बॉट्रिओकोकस* नामक शैवाल मिलता है। इसी प्रकार उत्तर–पूर्व भारत के टर्शियरीकालीन कोयलों तथा कावेरी एवं कच्छ द्रोणियों के टर्शियरीकालीन लगुडांगारों से भी यह शैवाल मिलता है। कच्छ द्रोणी के लगुडांगारों से *प्ल्यूरोकेप्सा* तथा मेघालय के टर्शियरी कालीन कोयलों में *टस्मेनाइटिस* नामक शैवाल मिलते हैं। कोयलों तथा लगुडांगारों में एल्जीनाइट की उपस्थिति से होने वाली विसंगतियों, जो विशेषकर उपजातलब्धि तथा कार्बनीकृत व्याख्यात्मक व्यवहार से संबंधित हैं, को दूर करने में सहायता मिली है। इनकी प्रचुरता, प्रकार, वैकासिक अवस्थाओं तथा अन्य मैसीरलों से एल्जीनाइट के साहचर्य से कोयले तथा लगुडांगार निर्मित हेतु वानस्पतिक पदार्थ संचयन संबंधी निक्षेपणीय पर्यावरण के विषय में ऐसी महत्वपूर्ण जानकारियॉं मिली हैं, जिन्हें पहले प्राप्त करना संभव नहीं था।

THE interest in the petroleum source rocks in lacustrine sediments implied from the knowledge that algae generate hydrocarbon led to further investigations on the isolated hydrocarbons both from fossil and living algae. It is known that the oil shales and boghead coals comprise mostly the colonial algae *Botryococcus*, *Pila*, *Rheinschia* and *Tasmanites*. Certain oil shales are also there, for example lamosites which comprise predominantly (40-55%) the non-colonial lamellar algae (Hutton, 1980; Kantsler, 1980).

The *Botryococcus* is sporadic to common in coals and lignites. However, the algal contribution in a number of inertinite-rich Permian Gondwana coals of Australia and Brazil has been found to be much more than generally supposed (Correa da Silva *et al.*, 1985; Taylor *et al.*, 1988, 1989). The most common and, at times, frequent alginite recorded resembles the alginite-B (lamalginite) described by Hutton and Cook (1980) from Australian coals.

Ghose and Wolf (1974) were the first to record alginite of three types—a lamellar algae (lamalginite), *Pila* and *Rheinschia* in the Indian Permian coals from Kothagudem Coalfield, Godavari Basin. Ghosh *et al.* (1984) reported *Pila* in the coals from Chuperbhita Coalfield, however,

* This paper was presented at the Golden Jubilee Conference "*Vegetational dynamics of the Past and Present*", The Palaeobotanical Society, held at B.S.I.P., Lucknow from November 16-18, 1995.

with poor illustrations. After a lapse of two decades, the lamalginite has been recognised again in Gondwana coal seams of Singrauli (Son Basin) and Chuperbhita (Rajmahal Basin) coalfields (Misra & Singh, 1993-94). Its presence has also been observed in the coals of Talcher (Mahanadi Basin), Kothagudem, Mulug and Koyagudem (Godavari Basin) coalfields (Pers. Comm.— Dr O.S. Sarate, 1997).

Botryococcus has been recorded in Permian Gondwana coals from the preceding basins (Misra & Singh, 1990, 1994; Singh, 1995; Anand-Prakash *et al.*, 1996); in the Tertiary coals of Assam, Meghalaya and Nagaland (Misra, 1992a, 1992c; Misra & Ahmed, 1997); and in the Tertiary lignites from the Neyveli (Cauvery Basin), Tamil Nadu and Panandhro (Kutch Basin), Gujarat (Navale & Misra, 1980; Misra, 1992b; Misra & Navale, 1992; Singh & Misra, 1997). Other algae *Pleurocapsa* and *Tasmanites* have been reported, respectively, in the lignite seams and in associated sediments from Panandhro Lignitefield (Kutch Basin) and in the coals from the Bapung Coalfield, Jaintia Hills of Meghalaya (Misra, 1992b; Misra & Ahmed, 1997).

While investigating samples of carbonaceous and coaly sediments (Cretaceous) from a bore-hole in Palar Basin, Misra (1982 : unpublished data) recorded some elongated and digitate algal bodies with empty cups at the margins (Pl. 1, figs 1-3). However, this alga could not be assigned to any family or genus, because its affiliation with any known forms could not be ascertained.

The present paper aims to synthesize the available information, both published and unpublished, on the maceral alginite (algae) in relation to its mode of occurrence, fluorescence properties, contribution as vegetal source, and its influence on the optical and chemical properties of coals and lignites.

AVAILABLE INFORMATION

Before discussing the depositional environment and significance of the presence of alginite in coals and lignites, a brief description of different forms/types is imperative for a proper understanding of their contribution during coal formation. On the basis of gross morphology, the alginites are categorized into two groups, which for convenience are known as 'alginite-A' and 'alginite-B' (Hutton *et al.*, 1980):

Alginite-A—It incorporates discrete algal bodies, both colonial and unicellular, of elliptical, spherical and disc-shape. They occur with intact structural details only in certain specific coals, as for example boghead and sapropelic coals, besides in oil shales. The characteristic constituents of well-known oil shales, viz., *Torbanites* (after Torbane Hills, Scotland), *Tasmanites* (after Tasmania, New Zealand) and *Kukersites* (after Kukruse Stage, Ubja, Estonia), respectively are *Botryococcus*, *Tasmanites* and *Gloeocapsomorpha*. Whereas, the Coorongite formed by "algal mat" of the *Botryococcus* has been named after Coorong Lagoon in Australia (Hutton *et al.*, 1980; Guy-Ohlson, 1992).

Alginite-B—This category includes benthic and pelagic filamentous or thread-like algae of families Chlorophyceae (green) and/or Cyanophyceae (blue-green algae) occurring as fine laminated bands interbedded with mineral matter, both on macroscopic and microscopic scales in a deposit. The examples are shales of Green River Formation and Rundle (Hutton, 1980). They may occur as isolated films or as thick bands or strands, formed by the coalescence and anastomosis, with variable degree of compactness more or less parallel to the bedding plane. The thickness (< 5 microns) and length (0.5-1.5 mm) of an individual algal film are variable (Kantsler, 1980).

PLATE 1 ⟶

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

1-3. Algal bodies (unidentified) from Palar Basin. For descriptions refer to the text. [enlarged (1-2) ca. x800, (3) ca. x600]

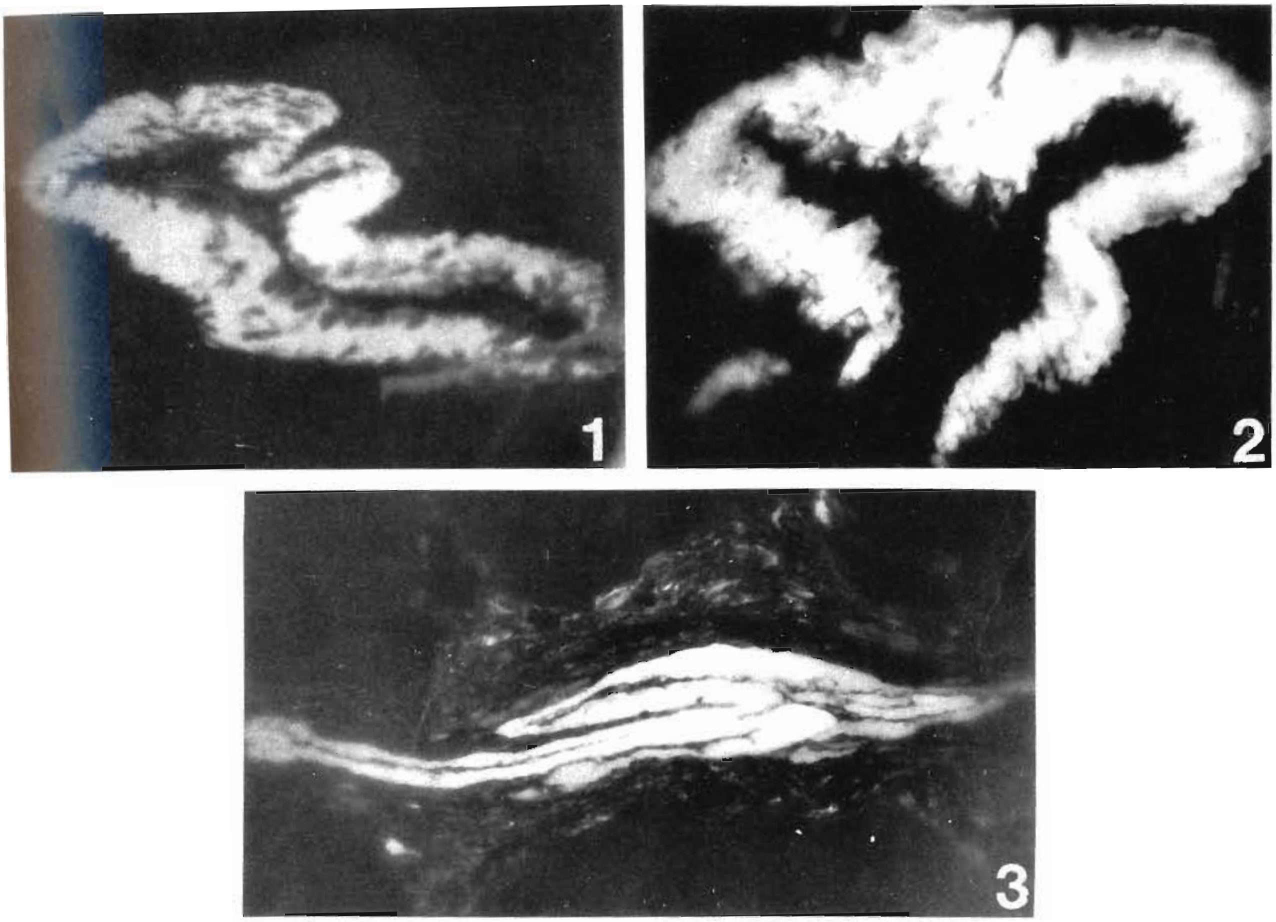

PLATE 1

Characteristic morphology, including lack of a definite structure and relatively low fluorescence intensity of the 'alginite-B' differentiate them from those of the 'alginite-A'. These alginites are known from Precambrian to Tertiary sediments (Kantsler, 1980).

Well-preserved alginites are found in oil shales and boghead and sapropelic coals, because their fine structural features remain intact only in a moderately high to high negative redox-potential (*Eh*) and alkaline (*pH*) milieu. Possibly, the size of algal colonies are influenced by the *pH* of the swamp water. In humic peats and humic carbonaceous shales not only structural details of the alginites are destroyed or obscured but also their growth is impeded (Stach *et al.*, 1982).

After biodegradation and decomposition, the algae in coals are no longer morphologically recognizable. Their decompositional products partly become amorphous bituminous matter (bituminite) and are partly incorporated into the aliphatic constituents of vitrinite, particularly in the desmocollinite fraction (Stach *et al.*, 1982). Therefore, it seems quite possible that many coals, other than boghead and sapropelic coals, and humic carbonaceous sediments may have relatively high amount of algal contribution than has been acknowledged so far. This fact has been ascertained by the work of Hutton and Cook (1980), Kalkreuth and Macauley (1984), Wolf and Wolff-Fischer (1984), Correa da Silva *et al.* (1985), Pierce and Barker (1985), Liu and Taylor (1987), Taylor and Liu (1987) and Taylor *et al.* (1989).

Following description of the alginite is restricted to those algae which are recorded or reported from the Indian coals and lignites, besides from the carbonaceous and coaly shales.

BOTRYOCOCCUS

The *Botryococcus*, a green planktonic colonial alga, is highly successful in the adoptation of different aquatic habitats and flourishes most in the shallow freshwater lakes, ponds, ditches, besides in the bogs and wet muds occurring in the areas with relatively low rainfall and wide seasonal fluctuations. When it blooms, several centimeter thick "mat" covering hundreds of square meters can be formed. When dead, the algal colonies float and may be transported by wind towards the margin of the basins to accumulate there (Guy-Ohlson, 1992). Geographically, it is widely distributed from tropical to sub-arctic regions and has been recorded throughout since Precambrian (Tappan, 1980).

Some species of *Botryococcus* can be differentiated, though not always, morphologically in fossil state. For example, the *Pila* is fan-shaped and *Rheinschia* has a hollow central space with cells radiating outwards, in vertical section (Kantsler, 1980). The *Gloeocapsomorpha*, believed to be a primitive blue-green alga, is now considered the synonym of *Botryococcus* (Tappan, 1980, p. 841; Dybkjaer, 1988).

From the intensive investigations on *Botryococcus*, significant inferences have been deduced which can be reliably applied to interpret about the fossil algae. Variations in the form exhibited by the extant *Botryococcus* has been related to the environmental changes (Stach *et al.*, 1982; Guy-Ohlson, 1992). The presence of algae indicates a freshwater, brackish or saline water influence, but never entirely the marine conditions. The colonies of *Botryococcus* are stunted when they grow in an environment rich in humic substances. The abundance of algal remains probably indicates an algal bloom in one season. Well-preserved state of the algae reflects a quiet and favourable conditions for growth, a stable climate and rapid burial in a shallow oxygenated waters. Thickened and much altered matrix of an older colony suggests several growth seasons and also less oxygen in the milieu, whereas almost structureless mass of the colony reflects reducing conditions of the habitat. All the forms in one sample indicate seasonal changes at the time of deposition.

The *Botryococcus* is sporadic to very common (2-4 specimens in a transect of a pellet) in Permian

Table 1—Percentage frequency (by volume) of *Botryococcus* recorded in Indian coals and lignites

Gondwana Coals	Tertiary Coals	Tertiary Lignites
SON BASIN **Singrauli Coalfield** up to 1.0% sporadic to very common (Early Permian Turra and Late Permian Jhingurdah seams)	ASSAM BASIN **Makum Coalfield** sporadic in two seams (Oligocene)	KUTCH BASIN (GUJARAT) **Panandhro Lignitefield** 0.2-4.6% common to very common (Early Eocene)
	Dilli-Jeypore Coalfield sporadic in two seams (Oligocene)	CAUVERY BASIN (TAMILNADU) **Neyveli Lignitefield** 0.2-2.3% common to very common in the Main Seam (Miocene)
MAHANADI BASIN **Talcher Coalfield** common in two seams (Early Permian)	NAGALAND **Nazira Coalfield** sporadic in two seams (Oligocene)	
RAJMAHAL BASIN **Chuperbhita Coalfield** 0.2-0.6% sporadic to very common in all the eight seams (Early-Middle Permian)	MEGHALAYA BASIN (Garo Hills) **West Daranggiri Coalfield** up to 1.0% sporadic to common in the Main Seam (Late Palaeocene)	
Hura Coalfield sporadic to common in all the five seams (Early Permian)	**(Jaintia Hills)** sporadic in three seams (Late Palaeocene)	
GODAVARI BASIN **All the coalfields** sporadic to common in four seams (Early-Middle Permian)		

(Peninsular India), Late Palaeocene (Garo and Jaintia Hills of Meghalaya) and Oligocene (Assam and Nagaland) coals; in Early Eocene (Panandhro, Gujarat) and Miocene (Neyveli, Tamil Nadu) lignites of India (Navale & Misra, 1980; Misra & Singh, 1990, 1994; Misra, 1992a-d; Misra & Navale, 1992; Singh, 1995; Anand-Prakash *et al.*, 1996; Misra & Ahmed, 1997; Singh & Misra, 1997). Generally, they are ill-preserved. However, well-preserved specimens are also common. Often broken and shreded specimens are also encountered.

Percentage frequency, besides the observed frequency of occurrence of the alga *Botryococcus*, has been given in Table 1.

The algae may be sparse and random as a colony of 4 to 8 empty cups, compound colonies, homogenized or structureless old matrix and skeletal remains and also as closely placed bodies in patches (Pl. 2, figs 4-6). Degraded or broken, but still recognizable, specimens are also commonly observed (Pl. 2, fig. 5). More than one form may be present in a single sample/pellet. Invariably, *Botryococcus* present in Tertiary and some Permian [Singrauli and Hura (Rajmahal) coalfields] coals is not as good (preservation) as those in Tertiary lignites (Panandhro and Neyveli lignite fields) and Permian coals [Chuperbhita (Rajmahal) Coalfield].

TASMANITES

Tasmanites is considered as a fossil representative of the living, oil secreting marine planktonic,

* The term 'lamalginite' used throughout the text is according to the concept of Taylor, Liu and Diessel (1989).

green unicellular and spherical alga *Pachysphaera pelagica* (Wall, 1962). It occurs as discrete elliptical bodies and also as flattened discs; and has a thick punctate wall, because of numerous radial canals passing partially or completely through it.

Under normal light, the *Tasmanites* appears translucent and homogeneous with dark reddish-brown to dark brown colours. At higher ranks, it is strongly reflecting (Kantsler, 1980). Under blue light excitation, the algae remain translucent and fluoresce strongly with greenish-yellow, lemon-yellow or yellow colours. In coals, its structural details are not discernible under both normal and fluorescence modes.

Tasmanites is very resistant to oxidation and weathering and, therefore, may also be found as reworked material in sediments. It has a stratigraphic range from Cambrian to Recent.

So far, in Indian coals, the *Tasmanites* has been observed sporadically only in Late Palaeocene coals from the Bapung Coalfield in Jaintia Hills, Meghalaya (Pl. 2, figs 7-8; Misra & Ahmed, 1997).

LAMALGINITE

In Permian Gondwana coals, the lamalginite is filamentous or film-like and has a variable thickness (2-5 microns) and length (few microns to more than one mm). It commonly occurs as complex anastomosing layered or laminated structures devoid of any symmetry. In coals, it may be sparse and random associated with sporinite or densely stacked. The alginite is frequently associated with inertinite macerals as encrustations or moulds directly onto the irregular surfaces of inertodetrinite and also on the earlier precipitated clay minerals (Pl. 2, figs 1-2).

TEM study of Australian coals by Taylor *et al.* (1989) revealed that the branches of lamalginite, at times, intrude into semifusinite. Variations recorded in the alginite suggest the presence of a number of types which were similar in morphology and habitat. However, in the absence of any distinctive character, they could not be affiliated with any known forms (Taylor *et al.*, 1989). A summary of the characteristics of the lamalginite is given in Table 2.

Table 2—The main distinguishing characteristics of lamalginite (after Taylor, Liu & Diessel, 1989)

Properties	Characteristics
External morphology and size	Thin tabular/elongated, without symmetry, thickness variable, anastomosing and densely or loosely packed. Size variable- few microns to mm.
Association with other macerals	Encrusted or moulded on inertodetrinite; branches may extend into semifusinite; occurs also in association with sporinite and previously gelified minerals.
Internal structure	Show zoning and flow structure when undeformed.
Hardness	Soft and deformable during pre- and post-deposition, polishing relief lower than sporinite.
Degradation stage	Show incipient to advance degradation.

The lamalginite appears dark grey, darker than the associated sporinite, under normal incident light. Under fluorescence mode, it displays orangish-yellow to yellowish-orange colours, depending upon coal rank, and alters positively in low rank coals (sub-bituminous B to high volatile bituminous C/B stages). The fluorescence intensity is identical to or relatively weak than the sporinite. The association of lamalginite with inertinite and the absence of relatively dark coloured streak-like lumen of pollen-spores (in pollen- or spore-mass) or sporinite, under fluorescence mode, are the distinguishing criteria between the two. In Australian coals, the

PLATE 2 ⟶

(All photomicrographs were taken on polished surface, under incident blue light excitation using oil immersion). For descriptions refer to the text.

1-2. *Lamalginite* from Permian Singrauli and Rajmahal coals respectively.(enlarged ca.x450)
3. *Pleurocapsa* from Eocene Panandhro lignite. (enlarged ca.x600)
4-6. *Botryococcus* from Miocene Neyveli lignite and Permian Rajmahal and Singrauli coals respectively. [enlarged 4)ca. x850, (5-6) ca. x800]
7-8. *Tasmanites* from Late Palaeocene coals of Meghalaya. (enlarged ca. x1100)

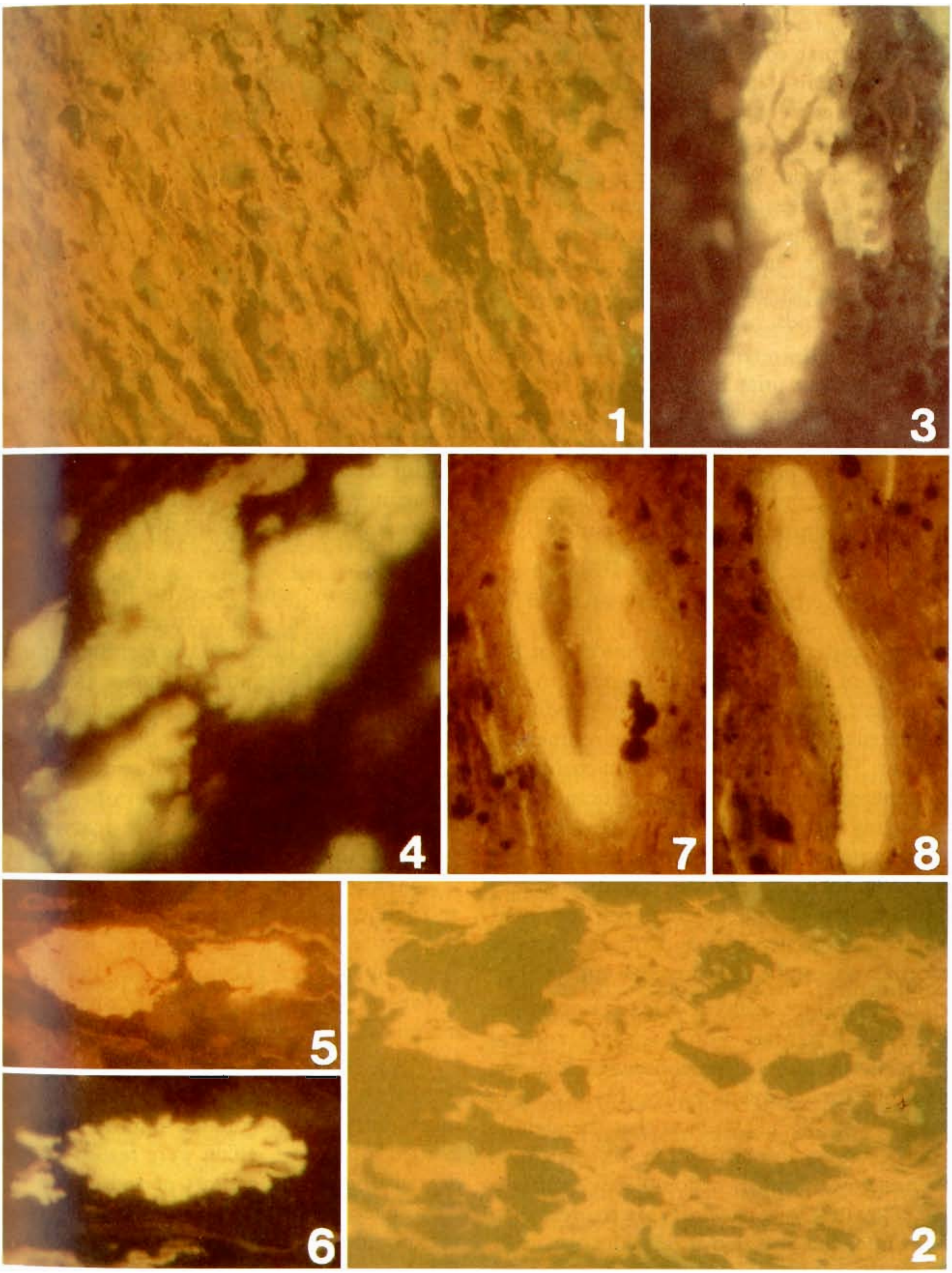

PLATE 2

lamalginite content has been found to be up to 7 per cent by volume (Taylor *et al.*, 1988). Whereas, in Indian Permian coals, especially in those from Rajmahal Basin (Hura and Chuperbhita coalfields), its content reaches up to 11 per cent.

The lamalginite is susceptible to dimunition and biodegradation. When severely degraded, it becomes structureless and unrecognizable (Taylor *et al.*, 1989). The structureless algal matter becomes mobile and flows along the irregular surfaces of inertodetrinite, clay minerals and other competent macerals.

Apart from the record of above alginite types (*Botryococcus*, *Tasmanites* and lamalginite) from Indian coals and lignites, another bright yellow fluorescing alga—*Pleurocapsa* with chain-like cells (Pl. 2, fig. 3) has been recorded from the Early Eocene lignite seams and associated sediments of Panandhro Lignitefield, Kutch Basin (Misra, 1992b).

DISCUSSION

Hagemann and Wolf (1989) found that the association of different liptinite macerals in coal is dependent on the varying tectonic conditions and differences among the palaeoenvironment of the basins. The presence of alginite in coal has an important palaeoenvironmental significance in reconstructing ancient peat-swamps. They observed that the presence of alginite and its degradational and decompositional products indicates wet conditions. The alginite-bearing coals, common in intermontane deposits and the deposits of platform type, can be interpreted as subaquatic.

The abundance and type of both lamalginite and inertodetrinite, besides their typical association are largely the consequence of the depositional environment, especially the climate (Taylor *et al.*, 1989). The facts that the alginite mostly occurs in close association with inertinite; it often encloses, partially or completely, inertodetrinite grains, occasionally intrudes into semifusinite; and also that it deforms plastically between the grains of inertodetrinite and other already hardened macerals and clay minerals, evidently indicate that the material on which alginite, in any form, is encrusted upon was in the process of transforming into inertinite. This kind of association precludes the possibility of the lamalginite deposition as a separate entity, for example sporinite and other particulate organic matter.

The lamalginite is more susceptible to biodegradation in comparison to other liptinite macerals (exinites) and this appears to be the cause for their depolymerization leading to mobilization or even intrusion into the available voids between different competent macerals. It is unlikely that alginite encrusted inertinite could latter have changed much in form and substance. Taylor *et al.* (1989) presumed that the freshwater lamalginite flourished at or near the surface of the swamps which periodically experienced dry seasons.

Palaeogeographic maps for Permian Period (Smith *et al.*, 1981; Dercourt *et al.*, 1993), show that Australian Plate and the eastern peninsular part, especially the regions comprising Gondwana basins, of Indian Plate lay at latitudes between 38° and 46° close to south pole, therefore, the prevailing climate, in both continents, must have been of moist and humid summers which favoured abundant growth of leafy plants. Whereas, the winters atleast during the peak seasons were rather cold. As a result, any hydrated and gelified plant material on aerial exposure at the peat surface was "freeze-dried" and became "proto-inertinite" (Taylor *et al.*, 1989). Since freeze-drying is an irreversible process, such materials subsequently can neither be rehydrated fully nor be oxidized easily (Taylor *et al.*, 1989).

Presumably, both semifusinite and inertodetrinite originated mainly from the gelified soft tissues which were readily prone to degradation within a short period of exposure. The intact gelified soft tissues, in consequence to exposure and dehydration formed semifusinite. Whereas, those dehydrated severely shrank and fragmented to produce the characteristic inertodetrinite. The proto-inertinite was already hard and the algal matter was still soft, because of high lipid content. As a result, the latter tended to deform readily, by passive flowing or squeezing into the available spaces between and along the competent macerals and/or minerals during the early stages of peat compaction.

In contrast to Australian Permian coals, Indian Gondwana coals in Damodar, Wardha, Satpura and Mahanadi basins do not have a similar abundance of gelified inertinites. However, their frequency, as observed by one of us (BKM), is definitely remarkable in the coals of Godavari Basin and, to certain extent, in those of the Son and Rajmahal basins. Furthermore, these coals are also characterized by the high incidence of lamalginite.

The lamalginite present in certain Indian Permian coals is almost identical in type, mode of occurrence and association with inertodetrinite to those found in Australian coals. Besides, considering the facts that the Indian and Australian Permian coal basins occupied more or less similar latitudinal positions during Permian Period, that the coals from both continents are inertinite-rich and also that they are grossly similar in their petrographic composition (mineral matter content is relatively high in Indian coals), imply that the proposed depositional model of Taylor *et al.* (1989) for the inertinite- and lamalginite-rich Australian coals can suitably apply, in most respects, to Indian Permian coals also. Particularly, to the coal seams of the following coalfields : Singrauli (Son Basin), Talcher (Mahanadi Basin), Chuperbhita and Hura (Rajmahal Basin) and Kothagudem, Yellandu, Ramkrishnapuram, Belampalli, Koyagudem and Mulug (Godavari Basin).

Forms, mode of occurrence and preservational stages of *Botryococcus* indicate that Late Palaeocene and Oligocene coals of India originated from peats which accumulated under brackish-water and highly reducing conditions. As a result, most of the algae present in them was degraded and their products were incorporated into the vitrinite. This reasoning is in conformity to the already established view about their depositional conditions (Misra, 1992a, 1992c, 1992d; Misra & Ahmed, 1997). On the other hand, most Permian coals were formed from peats which experienced relatively less severe anoxia than the peats for the Tertiary coals. Occasionally, the peat accumulated rapidly, experienced seasonal changes, under a shallow water cover in sub-oxic conditions and witnessed spells of stable climate, e.g., the coals from Chuperbhita and Hura coalfields (Rajmahal Basin).

The peats which formed Early Eocene lignites of Panandhro, Kutch Basin deposited mostly under brackish-water and anoxic conditions, because the lignite and associated sediments contain high amount of pyrite. However, there were spells of stable climate with marked seasonal changes accompanied by relatively high availability of oxygen, when the algae grew profusely. A similar view has already been expressed on the basis of petrological, geological and palaeobotanical evidences by Misra (1992d) and Misra and Navale (1992). It is also possible that such periods of algal growth coincided with a high rate of freshwater influx in the basin of peat accumulation. The Miocene lignite from Neyveli, Cauvery Basin, like that of Panandhro, originated from peat depositing under brackish-water and reducing conditions with spells of high oxygen levels caused by freshwater influx in the basin (Singh *et al.*, 1992).

It has been established that the inclusion of secondary lipid-rich material derived from the degradation of algae (algodetrinite) within the vitrinite, to a certain extent, is responsible for the lowering of its reflectance (Hutton & Cook, 1980; Kalkreuth & Macauley, 1984; Wolf & Wolff-Fischer, 1984; Pierce & Barker, 1985). TEM study has now confirmed that, besides algal derived inclusions, lipid-rich materials of bacterial and fungal origin are also present in some vitrinites (Liu & Taylor, 1987; Taylor & Liu, 1987). Püttmann *et* *al.* (1986) found that a decrease in the carbon preference index (CPI) value and pristane/phytane and euladene/phenanthrene ratios are related directly to the increase of algal content in coal extracts.

The vitrinite in non-caking and non-coking Permian coals of India chiefly comprises the desmocollinite which displays orangish-brown to dark brown colours with weak fluorescence intensity, a characteristic of primary fluorescence. The bituminite in these coals consists, almost entirely, of solid primary bitumen. Since they are acknowledged resinite-poor coals, the lipid-rich degradational products generated must have been derived largely from both sporinite and alginite. The bituminite in their vitrinite appears to be homogeneously impregnated, whereas, secondary lipid-rich inclusions are rare. Evidently, the entire lipid-rich substances formed were incorporated into the highly porous desmocollinite and also partly in telocollinite, particularly in low rank coals of Son, Mahanadi and Rajmahal basins.

This observation is also supported by the fact that the maceral exsudatinite could not be seen in the coal samples, analysed by us, from Damodar (coal seams of Raniganj Formation, Raniganj Coalfield), Son (Singrauli Coalfield), Mahanadi (Talcher Coalfield), Rajmahal (Chuperbhita and Hura coalfields) and Godavari (Kothagudem, Yellandu, Ramagundum, Ramkrishnapuram, Koyagudem and Mulug Coalfields) basins. However, oily exudations as droplets and/or smear films have been commonly observed. It, therefore, seems quite likely that the secondary mobilization of lipid-rich material generated in these coals either did not occur at all or it was restricted to occasional oily exudations only, because of certain reasons not yet understood.

Another noteworthy point, not realised so far, is that these low rank banded coals in spite of having a low vitrinite reflectance (R_0 max. 0.45-0.60%) are true hard coals in megascopic and other physical attributes. Chemically, they have been adjudged as the coals of high volatile bituminous C-B stages. Evidently, the reflectance properties of such Gondwana coals have been influenced by the incorporation of liptinite (sporinite and alginite) derived lipid-rich material into the vitrinite.

In Tertiary coals of Assam, Meghalaya and Nagaland also, the desmocollinite and a fraction of telocollinite are relatively low reflecting, because of the incorporation of degradational products of resinite, alginite and also bacterial and fungal material (Misra, 1992a, 1992c, 1992d; Misra, 1997; Misra & Ahmed, 1997).

It is now possible to ascertain the gross chemical nature of individual coal maceral and sedimentary organic matter on the basis of already established chemical affiliations. For example, the living algae and the algae (Type A) recovered from recent sediments contain oil which comprise esters of glycerols with high amount of saturated fatty acids, in which are also included the contributions from porphyrins, lipids and proteinaceous substances. The predominant fatty acids are of nC_{16} and nC_{18} carbon numbers. Besides, many olefinic acids (unsaturated), likewise concentrating at nC_{16} and nC_{18} are also encountered (Kantsler, 1980). Typical algal alkane is nC_{17}, whereas those with odd-carbon numbers are rare. The extracts of *Tasmanites* are dominated by saturated straight chain fatty acids. At higher maturity, the Alaskan *Tasmanites* contains more acids of lower carbon number, less functional groups and more highly aromatic tricyclic and tetracyclic acids (Kantsler, 1980). The alginite-B has a high content of algal lipids, proteins and pigments. Chemically, they are similar to those of the type A (Kantsler, 1980).

Table 3 provides a glimpse of the gross chemical composition of various coal macerals and kerogen in sedimentary rocks. This provision helps in the interpretation of the probable nature of bye-product yield from the solid fossil fuels.

The preceding conclusions lead to some significant inferences. For example, it explains as to why :

(i) a certain proportion of the inertinite in

Table 3—Major hydrocarbon source-macerals and their characteristic associations (modified after Mukhopadhya, Hagemann & Gormly, 1985).

Maceral	Source	Fluorescence colour (up to Ro max. 0.6%)	Kero Gen type	Gross Chemical nature	Hydrocarbon potential & nature	Characteristic association
Alginite (L_1)	Colonial and unicellular algae	Greenish-yellow to yellow	I.	Fatty-lipoid and proteinaceous	Very high	Oil shales, sapropelic coals
Mixed Liptinite (L_{3A})	Dinoflagellate, acritarch, chitinozoa, fishes and forams	Yellow-brown	I	Fatty-lipoid and proteinaceous	Very high	Oil shales, sapropelic coals
Fluorinite Exsudatinite	Mixed sources	Greenish-yellow to brownish-orange	I-II	Fatty-lipoid and proteinaceous	Very high	Humic coals, marine influenced coals
Sporinite (L_{3B})	Spores-pollen	Yellow to orangish-yellow	II	Fatty-lipoid and aromatic	Very high paraffinic	Humic coals, cannel and boghead coals
Cutinite (L_{3B})	Cuticles	Yellow to brown	II	Aromatic polyesters	High paraffinic	Humic coals, sapropelic coals
Suberinite (L_3)	Suberinized cell walls	Yellow to brown	II	Aromatic polyesters	High waxy	Humic coals, paper coals
Resinite (L_5)	Resins, waxes, lipids and oils	Green to brown	II	Terpenoid, lipoid and waxy	Very high naphthenic	Humic coals, marine influenced coals
Sapropelinite-I (L_2)	Algal detritus (Algodetrinite)	Golden yellow	I	Like alginite	Very high	Oil shales, boghead coals
Sapropelinite-II or bituminite	Phytoclasts, zooclasts, terrestrial liptinites, frequent ramboidal pyrite	Yellowish-brown	I	Like alginite or sapropelinite-I	Very high	Oil shales, oil source rocks, marine influenced coals, Sapropelic coals,
humic						coals
Liptodetrinite (L_4)	Terrestrial liptinites, ± phytoplanktons and algae	Variable yellow-brown	I-II	Variable : alginite to sapropelinite-II	Very high	Marine influenced coals, oil source rocks, humic coals
Humo-sapropelinite (V_3)	Humic matter, minor terrestrial, liptinites and occasional framboidal pyrite	Brown	II	Aromatic+fatty-lipoid and proteinaceous	Very high Aromatic-rich	Marine influenced coals, humic coals
Desmocollinite (V_2)	Humic matter and minor terrestrial liptinites	Brown	II	Aromatic + lipoid and proteinaceous	High aromatic -rich	Humic coals, marine influenced coals

inertinite-rich Permian coals is totally not infusible during carbonization and shows moderate to weak fluorescence, and

(ii) most of the non-caking/non-coking Gondwana coals of India which experienced relatively greater burial depth are unexpectedly low reflecting in spite of being older in comparison to certain Late Palaeocene sub-bituminous and high volatile bituminous coals from Garo and Jaintia Hills of Meghalaya. The latter coals, in fact, were formed at relatively shallow depth and did not suffer tectonic disturbances as much as did the Permian coals in question.

CONCLUSIONS

Both the types—'alginite-A' (*Botryococcus, Tasmanites*) and 'alginite-B' (lamalginite) have been recorded from Indian Permian Gondwana and Tertiary coals and Tertiary lignites. *Botryococcus* occurs commonly in coals and lignites. Its preservation is relatively better in lignites. While in coals, with few exceptions, *Botryococcus*, though still recognizable, occurs in deformed and degraded state. *Tasmanites* is recorded only in Tertiary coals of Meghalaya and another algae *Pleurocapsa* has been recovered from Panandhro lignites. Lamalginite, common to frequent in Indian Permian coals, is almost identical in type, mode of occurrence and association to those found in Australian Permian coals.

The presence of alginite in coals and lignites suggests marine influenced freshwater sites (near shore). The mode of occurrence, frequency and state of preservation indicate seasonal fluctuations (mainly the oxidizing/reducing) in palaeoenvironmental condition during the accumulation of vegetal matter for the formation of these deposits.

Evidences are apparent that the lipid-rich maceral alginite prone to easy deformation and decomposition (forming material— algodetrinite) gets diffused with other macerals; affecting to certain extent their optical and chemical properties. The incorporation of alginite into vitrinite gives rise to a new inter-maceral relationship ('perhydrous vitrinite'), causes the fluorescence and lowers the reflectivity of vitrinite.

REFERENCES

Anand-Prakash, Misra BK & Singh BD 1996. Fluorescence microscopy in the evaluation of Indian Gondwana coals. *9th Int. Gondw. Symp., Hyderabad (1994)* 2 : 1265-1272.

Correa da Silva ZC, Hagemann HW, Püttmann W & Wolf M 1985. Petrographische und geochemische Eingenschaften südbrasilia-nischer Kohlen. *Zentralbl. Geol. Paläontol.* 1 : 1565-1578.

Dercourt D, Ricou LE & Varielynck B (Editors) 1993. *Atlas: Tethys maps.* Gauthier-Villars, Paris, 307 pp.

Dybkjaer K 1988. Palynological zonation and stratigraphy of the Jurassic section in the Gassum No. 1-borehole, Denmark. *Dan. Geol. Unders.* 21, ser. A : 1-73.

Ghose S & Wolf M 1974. Algenführende Gondwana-Kohlen aus Indien. *Glückauf-Forschungsh.* 35: 114-119.

Ghosh A, Roy SP & Laskar T 1984. Biostratigraphy and some anomalous petrological properties of Chupervita coals, Rajmahal Coalfields, Bihar. *In*: Sharma AK, Misra GC & Banerjee M (Editors)—*Proc. Symp. Evolutionary Bot. Biostratigr.* (A. K. Ghosh Commem. Vol.), Department of Botany, University of Calcutta : 323-330.

Guy-Ohlson D 1992. *Botryococcus* as an aid in the interpretation of palaeoenvironment and depositional processes. *Rev. Palaeobot. Palynol.* 71 : 1-15.

Hagemann HW & Wolf M 1989. Palaeoenvironments of lacustrine coals : the occurrence of algae in humic coals. *Int. J. Coal Geol.* 12: 511-522.

Hutton AC 1980. Organic petrology of Australian and some overseas oil shales. *In*: Cook AC & Kantsler AJ (Editors)—*Oil Shale Petrology Workshop, Wollongong*, Keiraville Kopiers : 42-49.

Hutton AC & Cook AC 1980. Influence of alginite on the reflectance of vitrinite from Joadja, NSW, and some other coals and oil shales containing alginite. *Fuel* 59 : 711-719.

Hutton AC, Kantsler AJ, Cook AC & McKirdy DM 1980. Organic matter in oil shales. *APEA J.* 20 : 44-67.

Kalkreuth W & Macauley G 1984. Organic petrology of selected oil shale samples from the Lower Carboniferous Alberta Formation, New Brunswick, Canada. *Bull. Can. Petr. Geol.* 32 : 38-51.

Kantsler AJ 1980. Aspects of organic petrology with particular reference to the exinite group of macerals. *In*: Cook AC & Kantsler AJ (Editors)—*Oil Shale Petrology Workshop, Wollongong*, Keiraville Kopiers : 16-41.

Liu SY & Taylor, GH 1987. Liptodetrinite of algal origin in inertinite-rich coals. *Proc. Adv. Study Sydney Basin, 21st Newcastle Symp.* : 57-60.

Misra BK 1992a. Optical properties of some Tertiary coals from northeastern India: their depositional environment and hydrocarbon potential. *Int. J. Coal Geol.* 20 : 115-144.

Misra BK 1992b. Spectralfluorescence analysis of some liptinite macerals from Panandhro lignite (Kutch), Gujarat, India. *Int. J. Coal Geol.* 20 : 145-163.

Misra BK 1992c. Tertiary coals of the Makum Coalfield, Assam, India: Petrography, genesis and sedimentation. *Palaeobotanist* 39 : 309-326.

Misra BK 1992d. Genesis of Indian Tertiary coals and lignites: A biopetrological and palaeobotanical view-point. *Palaeobotanist* 40: 490-413.

Misra BK 1997. Fluorescence alteration behaviour of vitrinite in some Late Palaeocene bituminous coals from Garo and Jaintia Hills of Meghalaya, India. *Int. J. Coal Geol.* (in press).

Misra BK & Ahmed M 1997. Petrography, genesis and sedimentation of Late Palaeocene coals from Garo and Jaintia Hills of Meghalaya, India. *Int J. Coal Geol.* (in press).

Misra BK & Navale GKB 1992. Panandhro lignite from Kutch (Gujarat), India: Petrological nature, genesis, rank and sedimentation. *Palaeobotanist* 39 : 236-249.

Misra BK & Singh BD 1990. The Lower Permian coal seams from Singrauli Coalfield (M.P.), India: Petrochemical nature, rank, age and sedimentation. *Int. J. Coal Geol.* 14 : 309-342.

Misra BK & Singh BD 1993-94. *Annual Report 1993-1994*, Birbal Sahni Institute of Palaeobotany, Lucknow, pp. 11-12.

Misra BK & Singh BD 1994. Liptinite macerals in Singrauli coals, India: their characterization and assessment. *Palaeobotanist* 42: 1-13.

Mukhopadhyay PK, Hagemann HW & Gormly JR 1985. Characterization of kerogen as seen under the aspect of maturation and hydrocarbon generation. *Erdöl und Kohle-Erdgas-Petrochemie* 38: 7-18.

Navale GKB & Misra BK 1980. Systematic study of organic microconstituents of the Main Seam of Neyveli lignite, South India. *Geophytology* 10 : 245-264.

Pierce LC & Barker CE 1985. Suppression of vitrinite reflectance in amorphous rich kerogen a major unrecognised problem. *J. Petrol. Geol.* 8: 59-84.

Püttmann W, Wolf M & Wolff-Fischer E 1986. Chemical characteristics of liptinite macerals in humic and sapropelic coals. *Org. Geochem.* 10: 625-632.

Singh A & Misra BK 1997. Fluorescence microscopic investigations of the main lignite seam from Neyveli Lignitefield, Tamil Nadu, India. *Palaeobotanist* (in press).

Singh A, Misra BK, Singh BD & Navale GKB 1992. The Neyveli lignite deposits (Cauvery Basin), India: organic composition, age and depositional pattern. *Int. J. Coal Geol.* 21 : 45-97.

Singh BD 1995. Role of fluorescence microscopy in the assessment of Indian Gondwana coals. *Curr. Sci.* **69** : 998-1004.

Smith AG, Hurley AM & Briden JC 1981. *Phanaerozoic Palaeocontinental World Maps.* Cambridge University Press, Cambridge, 102 pp.

Stach E, Mackowsky M-Th, Teichmüller M, Taylor GH, Chandra D & Teichmüller R 1982. *Stach's textbook of coal petrology*, Gebrüder Borntraeger, 2nd edition, 535 pp.

Tappan H 1980. *The palaeobiology of plant protists.* Freeman, SanFrancisco, 1028 pp.

Taylor GH & Liu SY 1987. TEM and coal structure. *In*: Moulin JA, Nater KA & Chermin HAG (Editors)—*Proc. Int. Conf. Coal Science, Maastricht* pp. 29-32. Elsevier, Amsterdam.

Taylor GH, Liu SY & Diessel CFK 1989. The cold-climate origin of inertinite-rich Gondwana coals. *Int. J. Coal Geol.* **11** : 1-22.

Taylor GH, Liu SY & Smyth M 1988. New light on the origin of Cooper Basin oil. *APEA Conf., Brisbane, APEA J.* **28** : 303-309.

Wall D 1962. Evidence from recent plankton regarding the biological affinities of *Tasmanites* Newton 1875 and *Leiosphaera* Eisenack 1958. *Geol. Mag.* **99**: 353-363.

Wolf M & Wolff-Fischer E 1984. Alginit in Humuskohlen carbonischen Alters und sein Einfluss die optischen Eigenschaften des begleitenden Vitrinits. *Glückauf-Forschungsh.* **45**: 243-246.