Genesis of Indian Tertiary coals and lignites : a biopetrological and palaeobotanical view point

Basant K. Misra

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Coal and lignite seams associated with the Tertiary sedimentary sequence of India are bright unbanded (coals) and sparingly banded (lignites) in appearance. They chiefly consist of vitrinite/huminite macerals with subordinate amounts of liptinites and inertinites. Desmocollinite/attrinite and densinite are the main vitrinite/huminite maceral groups. Sclerotinite (fungal remains) and inertodetrinite are the main inertinite macerals in the seams of northeastern States—Tamil Nadu, Rajasthan and Gujarat. Some of the coal and lignite seams of Meghalaya and Gujarat have predominance of structured inertinite macerals (semifusinite and fusinite). Main inorganics associated with the seams are syngenetic pyrite and calcite. Clay and quartz (argillaceous matter) are usually in low proportions except in certain seams of Gujarat and Meghalaya. The seams, under blue light excitation, are characterized by moderate to very high proportion of fluorescing macerals constituted chiefly by perhydrous vitrinite/huminite, liptodetrinite, bituminite and resinite. Other macerals of liptinite group, viz., cutinite, sporinite, suberinite, exsudatinite, alginite (*Botryococcus*) and fluorinite in order of decreasing abundance, are in subordinate amounts.

The coal and lignite-forming evergreen angiospermous forest vegetation flourishing under humid tropical climate comprised inland, coastal, beach, back mangrove to mangrove plant communities. Herbaceous and shrubby, including aquatic, angiosperms and pteridophytes formed prolific undergrowth. Some of the coal and lignite seams of Meghalaya, Rajasthan and Gujarat have definite marine and brackish water elements.

The Tertiary coal and lignite deposits of India originated from hypo-autochthonous to autochthonous rheotrophic peat accumulating in lagoons or near-shore back swamps in Assam, Nagaland, Tamil Nadu, Rajasthan and Gujarat and in small isolated estuarine or estuarine back swamps in Meghalaya. The vegetal matter experienced both aerobic and anaerobic microbial degradation under neutral to mildly alkaline subaqueous conditions. The coalification trends of the ancient peat were influenced more by putrefaction rather than purily by humification. Small and ephemeral fresh water ponds/lakes developed occasionally on peat surface were responsible for the presence of aquatic and water-edge taxa in the seams. Herbaceous and shrubby vegetation, especially pteridophytes, growing in the vicinity of ancient peat swamps were the main source of structured and detrital inertinites. Occasional natural cindering of the peat surface, e.g., in Gujarat and Meghalaya, was responsible for relatively high inertinite contents. Variations in the thickness and rank of coal and lignite seams were controlled by the existing tectonic conditions and geothermal gradients in different areas.

Key-words—Biopetrology, Coal and lignite genesis, Palaeoenvironment, India.

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

साराँश

भारतीय तृतीयक कोयलों एवं लगुझंगारों की उत्पत्ति : जैवशैलिकीय एवं पुरावनस्पतिक दृष्टिकोण

बसन्त कुमार मिश्र

भारत के तृतीयक युगीन अवसादी अनुक्रम से सहयुक्त कोयले एवं लगुडांगार की सीम देखने में चमकीली अपट्टित (कोयले) तथा यदा-कदा पट्टित (लगुडांगार) होती हैं। इनमें लिप्टीनाइट एवं इनर्टीनाइट की अल्प मात्रा के साथ-साथ मुख्यतया विट्रीनाइट/ह्यूमीनाइट विद्यमान हैं। डेस्मोकोलिनाइट/एट्रीनाइट एवं डेन्सीनाइट मुख्य विट्रीनाइट/ह्यूमीनाइट मेसीरल समूह हैं। उत्तर-पूर्वी प्रदेशों, तमिलनाडु, राजस्थान एवं गुजरात के सीमों में स्क्लेरोटिनाइट

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एवं इनर्टोडिट्रीनाइट मुख्य इनर्टीनाइट मेसीरल हैं। मेघालय एवं गुजरात की कुछ सीमों में इनर्टीनाइट मेसीरलों की प्रचुरता है। सीमों से सहयुक्त मुख्य अकार्बनिक पदार्थ सहजनित पाइराइट एवं केल्साइट हैं। नीले प्रकाश में सीम औसतन से बहुत अधिक दीप्यमान मेसीरलों से अभिलक्षणित हैं। लिप्टीनाइट समूह के अन्य मेसीरलों की भी अपेक्षाकृत कम मात्रा है।

नम जलवायु में विकसित होने वाली तथा कोयले एवं लगुडांगार का निर्माण करने वाली आवृतबीजी वनस्पति में स्थली, तटीय एवं मैंग्रोव पादप समुदाय सम्मिलित हैं। जलीय, आवृतबीजी एवं टेरीडोफ़ाइटीयों सहित शाकीय एवं झाड़ीदार पौधे अत्याधिक संख्या में विद्यमान थे। मेघालय, राजस्थान एवं गुजरात की कुछ कोयला और लगुडांगार सीमों में निश्चित रूप से समुद्री एवं खारे जल वाले अवयव विद्यमान हैं।

भारत के तृतीयक युगीन कोयले एवं लगुडांगार निक्षेपों की उत्पत्ति अधः-स्वस्थानिक से स्वस्थानिक धारानुवर्ती पीट से हुई है जो कि असम, नागालैंड, तमिलनाडु, राजस्थान एवं गुजरात में लैगून अथवा तटों के पास की दलदल तथा मेघालय में छोटे अलग ज्वारनदमुखी अथवा ज्वारनदमुखी दलदल में संग्रहित हुई थी। वनस्पतिक सामग्री का ह्रास वायवी एवं अवायवी दोनों ही परिस्थितियों में हुआ है। सीम में जलीय एवं पानी के पास की भूमि पर उगने वाले पौधों की उपस्थिति कभी-कभी पीट की सतह पर बनने वाले छोटे स्वच्छ जल वाले तालाबों का होना इंगित करती है। प्राचीन दलदली पीट क्षेत्र में उगने वाली शाकीय एवं झाड़ीदार वनस्पति, मुख्यतया टेरीडोफ़ाइटी पौधे, संरचित एवं अपरदी इनर्टीनाइटों का स्रोत रही हैं। पीट सतह की प्राकृतिक राख के कारण इनमें अपेक्षाकृत उच्च इनर्टीनाइटों की मात्रा विद्यमान है। कोयले एवं लगुडांगारों की मोटाई एवं कोटि में विभिन्नता विभिन्न क्षेत्रों में वर्तमान विवर्तनिक गतिविधियों एवं भूतापीय प्रवणता के फलस्वरूप हुई हैं।

"COAL is a rock derived mainly from plant remains that suffered peatification and coalification" (Teichmüller, 1989). Biopetrological combined with botanical methods of study have proved most effective in understanding the genesis of lignites (brown coal) and hard coals (bituminous coals). Microscopic studies (both petrological and botanical) of modern peats from different climatic conditions and depositional settings, study of associated minerals (siderite, pyrite, clay partings, etc.) in coal seams, chemical analysis of isolated coal constituents and comparison of coal-facies (micro-lithotypes and lithotypes) with sedimentology of the coal-bearing sequence have helped immensely in clarifying the problems of lignite or coal genesis (Teichmüller, 1989; Cameron *et al.*, 1989).

The genesis of coal/lignite, from biopetrological point of view, is basically the genesis of macerals, microlithotypes and lithotypes. Macerals are the microconstituents of lignites and coals including peat and are analogous to minerals in rocks. Microlithotypes are the typical maceral associations identifiable under the microscope and the lithotypes are megascopically distinguishable layers in coal seams. Macerals are the primary and most uniform physical constituents of peat, lignite and coal and are distinguished by their morphology and reflectance (ref. Table 1—after Teichmüller, 1989). In low-rank coals relatively hydrogen-rich macerals of liptinite group show least reflectance, relatively carbon rich macerals of inertinite group the highest reflectance whereas, relatively oxygen-rich macerals of vitrinite group show a medium reflectance between those of the former two groups. The liptinite and inertinite macerals in brown coals and hard coals have the same names. The precursors of vitrinite, i.e., huminite in peat and lignite stages are much more different than the hard coals (refer Table 2—after Stach *et al.*, 1982).

The present contribution deals with the genesis of some of the economically important Tertiary coal and lignite deposits of India mainly on the basis of biopetrological investigations alongwith available palaeobotanical, palynological and sedimentological information.

STATUS OF BIOPETROLOGICAL INFORMATION IN INDIA

Biopetrological study of Tertiary coals and lignites in India commenced during the later part of fiftees and early sixtees (Ganju, 1955, 1956; Pareek, 1960, 1962, 1964) and was primarily confined to morpho-petrography of thin sections of lignite and coal. Quantitative assessment of macerals and microlithotypes on polished coal and lignite surface under incident light was introduced soon thereafter (Ghosh, 1964, 1969; Sen & Sen, 1969). The reflectance measurements as a parameter for rank determination, though used sporadically in the early days (Ghosh, 1969), were routinely established when old Bereck photometer was replaced by more efficient device-photomultiplier (Navale & Misra, 1980a, b; Misra, 1981; Pareek, 1984). Fluorescence microscopic study of coal and lignite came into use only during later part of eightees (Misra, 1992a, b, c; Misra & Navale, 1992; Misra *et al.*, 1990).

It is because of the step-wise incorporation of various optical analytical procedures in the span of nearly 35 years in India that the earlier biopetrographic studies were primarily oriented towards the understanding of microconstituent composition of coal, in general, and Tertiary coals and lignites in particular. Nevertheless, biopetrographic information on most important and well known Tertiary coal deposits, viz., Makum and Dilli-Jeypore coalfields of Assam (Ghosh, 1969; Sen & Sen, 1969; Mukherjee, 1976; Navale & Misra, 1979a; Goswami, 1985, 1987), Daranggiri Coalfield, Garo Hills of Meghalaya (Ghosh, 1964, 1969; Ahmed & Bharali, 1985), Laitryngew Coalfield, Khasi Hills of

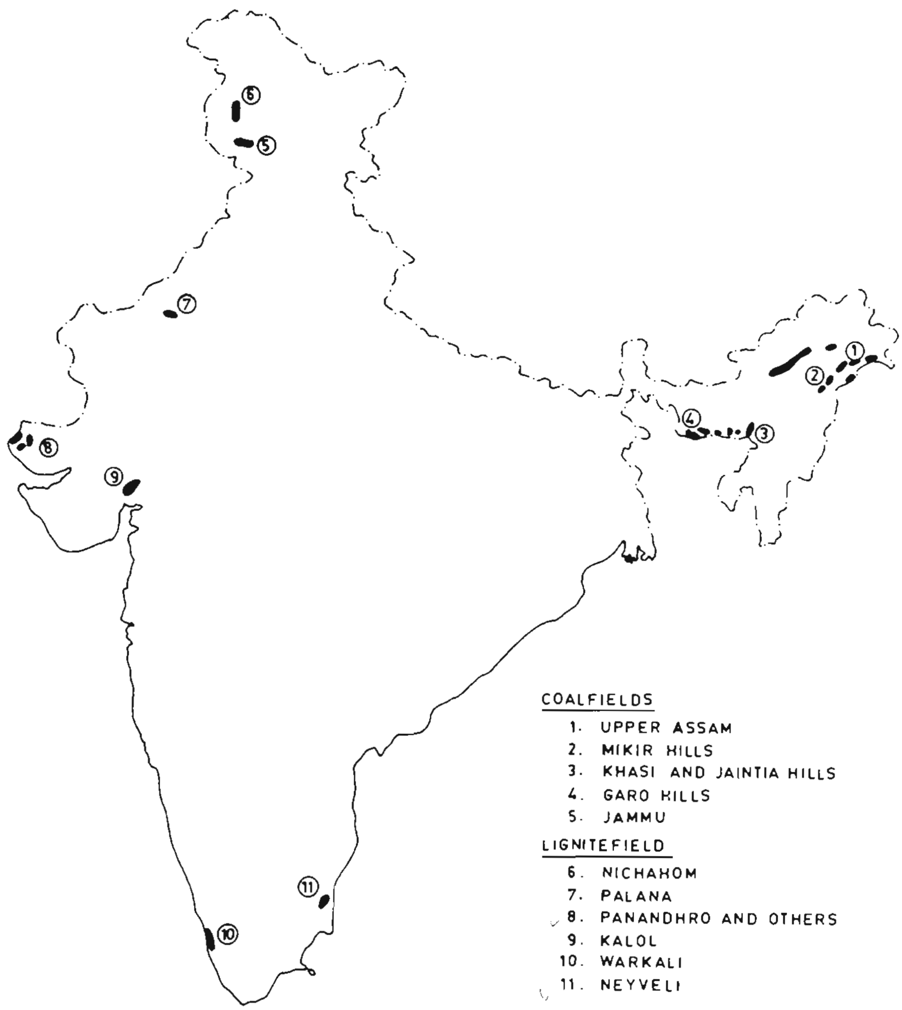
Table 1—Classification of maceral groups/macerals and their source material (modified after Teichmüller, 1989)

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
	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 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
	macrinite	amorphous gel (oxidized/microbial metabolic product)
Inertinite*	inertodetrinite	detritus of the above inertinite macerals
	micrinite	secondary relics of oil generation (mainly)
		*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")

Meghalaya (Ghosh, 1964, 1969; Sen & Sen 1969; Ahmed, 1971) and lignite deposits, viz., Neyveli Lignitefield, Tamil Nadu (Navale, 1971, 1974; Navale & Misra, 1980b), Palana Lignitefield of Rajasthan (Pareek, 1962, 1984), Nichahom Lignitefield, Jammu and Kashmir (Pareek, 1970), Kalol and Sobhasan

Table 2—Classification of vitrinite maceral group in hard coals and its precursors-huminite group in lignite stage (after Stach *et al.*, 1982)

BROWN COAL						HARD COAL		
Maceral Group	Maceral Subgroup	Maceral	Maceral Type		Maceral Variety	Maceral Type	Maceral	Maceral Group
		Textinite			A (dark)			
					B (bright)			
	Humotelinite		Texto-Ulminite		A	Telinite 1	Telinite	
					B			
		Ulminite						
			Eu-Ulminite		A	Telinite 2		
					B			
Huminite	Humodetrinite	Attrinite					Vitrodetrinite	Vitrinite
		Densinite				Desmocollinite		
				Detrogelinite				
			Levi-	Telogelinite		Telocollinite		
		Gelinite	gelinite	Eugelinite			Collinite	
	Humocollinite					Gelocollinite		
			Porigelinite					
		Carpo-	Phlobaphinite					
		huminite				Corpocollinte		
			Pseudo-phlobaphinite					



Text-figure 1—Map showing important Tertiary coal and lignite deposits of India.

areas of Gujarat (Pareek, 1983; Samanta, 1987) and Panandhro Lignitefield, Gujarat (Pareek, 1984) are available. Majority of the available information are based on the study of a few samples (Ghosh, 1969; Sen & Sen, 1969; Ahmed, 1971; Ahmed & Bharali, 1985; Navale & Misra, 1979a, Mukherjee, 1976), whereas some of these deal only with morphopetrography (Navale, 1971, 1974; Pareek, 1962, 1970, 1984). Some of the data appear unreliable as the authors (Sen & Sen, 1969) have recorded very low proportions of liptinite and inertinite macerals or extremely high amount of liptinite macerals (Goswami, 1987). There are others whose petrographic data are on mineral matter free basis (Sen & Sen, 1969; Navale & Misra, 1980b). There is, thus, an evident lack of information concerning the genesis of Indian Tertiary coals and lignites.

TERTIARY COAL AND LIGNITE DEPOSITS OF INDIA

Tertiary coal and lignite deposits in India are found associated with the sediments ranging in age from Palaeocene to Pliocene in as widely separated areas as Jammu and Kashmir in the north; coastal regions of Tamil Nadu, Kerala and Maharashtra in south and southwest; Arunachal Pradesh, Assam, Nagaland and Meghalaya in the northeast and Rajasthan and Gujarat in the west (Text-figure 1). However, the economic Tertiary coal deposits are restricted to Jammu, Arunachal Pradesh (south of Brahmaputra River), Assam, Nagaland and Meghalaya, whereas, the lignite occurrences are known from Kashmir, Tamil Nadu, Rajasthan and Gujarat. Table 3 shows important Tertiary coal and lignite deposits of India. The Tertiary coals of

Table 3—Important Tertiary coal and lignite deposits of India and their associated lithologies, formation, group and age (compiled from Raja Rao, 1981; Gowrisankaran *et al.*, 1987; Shukla, 1987)

AGE	GROUP/FORMATION	ASSOCIATED LITHOLOGY	LIGNITEFIELDS AND COALFIELDS (with district and state)
Upper Pliocene	Hirpur Formation	Carbonaceous shale, sandstone, conglomerate, lignite seams, silt & clay	Nichahom and other lignitefields of Kashmir
Miocene	Cuddalore Formation	Gritty, coarse argillaceous sandstone, lignite seams, clay & sand	Neyveli lignitefield and nearby areas in South Arcot District, Tamil Nadu
Oligocene	Barail Group Tikakparbat	Alternations of siltstone mudstone, shale, carbonaceous shale, clay & coal seams	Coalfields of Namchik-Namphuk, Tirap District, Arunachal Pradesh; Makum and Dilli-Jeypore, in Dibrugarh and Sibsagar districts, Assam; Nazira (Borjan), Safrai and Jhanzi-Disai, in Mon and Mokukchung districts, Nagaland
Oligocene	Tarkeshwar Formation	Sandstone with clay lenses, bentonite clay with carbonaceous clay, sandstone & lignite seams	Lignite in Baruch district, Gujrat
Upper Eocene	Subathu Group (Lower)	Carbonaceous shale, grey shale, ferruginous shale & coal seams	Coalfields of Kalakot, Metka, Chakkar, Salal, Jangalgali, Dhansawal and Salwalkot in Jammu and Kashmir.
Middle Eocene	Marh/Mudh and Kuchera-Khajwana/ Akli Fms. (in Bikaner, Nagaur & Barmer districts respectively)	Friable sandstone, occasional limestone, fuller's earth, variegated shale & clay, grey & black clay, occasional sandstone, lignite seams & under clay	Lignitefields of Palana, Gurha, Khari, Barsinghsar etc., in Bikaner District; Merta Road in Nagaur District; Kapurdi in Barmer District : All in the Rajasthan
Eocene	Kalol and Kadi formations	Shale, sand, sandstone claystone & lignite seams	Lignite in Kalol—Mehsana oilfield, Gujarat (700-1700 m below surface)
Lower Eocene	Panandhro Formation	Shale, clay & lignite seams	Lignitefields of Panandhro, Umarsar, Lefri, Matanomadh, Jhagadia and Akri-Mota, in Kutch District, Gujarat
Palaeocene	Jaintia Group Kopili Formation (Lakadong sst. member in Khasi & Jaintia Hills)/Turra Fm. (Middle member in Garo Hills)	Lithomargic clays, argillaceous sandstone & coal seams Ferruginous sandstone, clay & coal seams	Coalfields of Koilajan, Silvetta and Karbi etc., in Mikir Hills, Assam; Langrin, Laitryngew-Cherrapunjee, Mawlong-Shella, in Khasi Hills, Meghalaya; Bapung, Jarain, Lumshnong, and Lakadong, in Jaintia Hills, Meghalaya; East and West Daranggiri, Balphakram—Pendengru and Siju, in Garo Hills, Meghalaya

northeastern Himalaya (north of Brahmaputra) and Jammu area have been dealt in this volume by Anand-Prakash (1992), they are being excluded to avoid duplication.

MEGASCOPIC CHARACTERS OF COALS AND LIGNITES

Coals of northeastern India—The Tertiary coal seams of this region (Arunachal Pradesh, Assam, Nagaland & Meghalaya) are, in general, devoid of perceptible banding unlike typical banded coal seams of Permian Gondwana Sequence. They are bright black in appearance consisting entirely of vitrain lithotype (Raja Rao, 1981; Misra, 1981, 1992a). Certain coal seams of Laitryngew-Cherrapunjee area in Khasi Hills of Meghalaya are thinly banded. They contain < 1.0 to 3.0 cm thick bright bands alternating with equally thick semi-bright and occasional dull bands. Ahmed (1971) has also observed the presence of banding in coal seams of Laitryngew area. The main seam (Wakting Seam) in Nazira Coalfield, Nagaland contains a thick dull band in its basal part (Raja Rao, 1981). The coals, especially from Arunachal Pradesh, Assam and Nagaland show greasy to vitreous lustre and break with sub-conchoidal to conchoidal fracture. They are blocky in nature and crumble easily on separation from the seam because of rapid oxidation on aerial exposure. Tiny pyrite specks are commonly visible

Table 4—Petrographic composition and rank (R_o max. %) of Tertiary coals from northeastern India (as analysed under normal reflected white light)

AREA COALFIELD & COALSEAM	R_o max. (in oil) %	MACERAL COMPOSITION (Volume %)				
		Vitrinite	Liptinite	Inertinite	Mineral Matter	Average
Makum Coalfield, Assam (Ash content 2.0-8.0%, upto 20.0%)						
Seam no. 3	0.72-0.75	60.5-74.2	5.0-9.5	10.6-19.5	7.7-21.8	V. 68.2; L. 6.7
Seam no. 1	0.73-0.75	60.9-76.9	5.4-8.1	9.1-20.1	5.2-18.3	I. 14.2; M.M. 10.9
Dilli-Jeypore Coalfield, Assam (Ash content 6.0-13.0%, upto 20.0%)						
Seam no. 6	0.71	52.8-66.0	8.4-16.2	13.8-16.0	4.0-22.8	V. 56.7; L. 12.2
Seam no. 4	0.71	54.0	10.2-14.0	6.4-19.8	12.2-29.4	I. 14.0; M.M. 17.1
Nazira Coalfield, Nagaland (Ash content 3.0-5.0%, up to 23.0%)						
Main Seam	0.59-67	76.4-79.0	8.6-9.2	3.0-7.2	6.6-9.0	V. 77.7, L. 8.9, I. 5.7, M.M. 7.6
Bapung (including Rymbai area) Jaintia Hills, Meghalaya (Ash content 2.0-3.0% & variable)						
Top Seam	0.64-0.69	42.0-66.0	7.0-18.6	13.6-32.6	5.6-22.2	V. 54.0, L. 11.1,
Middle Seam	0.66-0.68	53.0-63.4	11.8-13.6	6.2-20.0	13.8-20.6	I. 19.8, M.M. 15.1
Bottom Seam	0.64-0.69	42.6-68.2	4.0-15.6	6.8-35.0	5.4-22.4	
Sutunga, Jaintia Hills, Meghalaya (Ash content 3.0-6.0% & variable)						
Top Seam	0.81-0.86	70.4-74.4	6.0-9.8	7.4-11.8	5.6-10.4	V. 68.9, L. 9.1,
Middle Seam	0.72	68.8	10.8	8.8	11.6	I. 11.4, M.M. 10.6
Bottom Seam	0.73	58.0	9.2	15.8	17.0	
Jarain, Jaintia Hills, Meghalaya (Ash content 4.4% & highly variable)						
Top Seam	0.68-0.69	46.6-59.6	10.8-14.0	7.4-19.6	16.6-35.2	V. 53.8, L. 11.3,
Bottom Seam	0.68-0.69	54.8-56.0	8.4-11.0	5.0-10.0	26.8-28.0	I. 10.4, M.M. 24.5
West Daranggiri Coalfield, Garo Hills, Meghalaya (Ash content 2.0-7.5%, upto 15.0%)						
Main Seam	0.54-0.62	36.8-64.8	7.6-13.2	15.4-34.4	10.6-26.2	V. 50.4, L. 10.2, I. 23.6, M.M. 15.8

in these coals. Pyrite concretions and encrustations are also common in some of the coal seams.

Neyveli Lignite, Tamil Nadu—The main seam of the Neyveli Lignitefield has been reported to be of uniform non-banded nature (Balasunder, 1968; Subramanyam, 1969), massive and compact devoid of any lateral and vertical variation in its physical character. However, Navale (1971, 1973) recognized three types of lignite bands merging with each other, viz., "woody" (xyloid), "peaty" (huminoid) and "coaly" types. According to him the "woody" lignite is hard and compact consisting of lignifield woods; "peaty" lignite is light brown to dark brown in colour, soft, friable, amorphous or fine textured and contains resins and the "coaly" type is of black brown ("deep dark brown") in colour more or less compact and granular in texture.

Infact, the seam is sparingly banded, as is clear from the colour variation of air dried samples. The banding is not clearly visible on exposed mine faces which are continuously kept drenched with water to suppress dust produced during mining and transportation. In the first mine, the lignite seam is predominantly formed of thick to very thick (up to few meters) brown to dark brown band of uniform amorphous texture punctuated by interbeds of (up to 0.5-1.0 m thick) light brown, soft and friable lignite band (? peaty type lignite of Navale, 1971). In the third mine area (unpublished information) lignite core sections show frequent and thinner bandings of the preceding types in comparison to those of that I mine area. At intervals, in the I mine area, brown to dark brown lignite band commonly contains prostrate as well as vertical and slanting vitrinized twigs and root-like structures (< 1.0-2.0 cm in diameter) embedded with hallow surroundings (representing shrinkage from original diameter) which possibly indicate "root-zones". These vitrinitized twigs and roots were referred by Balasunder (1968, p. 261) as "burnt logs of fire wood". Well-preserved fossil woods, shoots, twigs, etc. are also found at intervals in this lignite band. Thus, this brown to dark brown lignite band containing vitrinitized woods, and preserved roots, shoots and twigs respectively represent "woody" and "coaly" lignite type as reported by Navale (1971, 1973). The lignite seam is also characterized, especially in the middle and upper part, by the occurrence of spherical, oval (1.0-10.0 cm in size) or irregular marcasite (or pyrite) concretions (up to even 30.0 cm in size). The irregular concretions, studded densely with quartz clasts, appear to have formed later during late diagenetic or biochemical gelification stage. Polished section study of one such spherical concretion revealed that the yellow mineral is intimately associated mostly with fine organic matter and lacks typical radiating and anisotropic appearance characteristic of marcasite. It is therefore possible that all the regular concretions may not be made entirely of marcasite reported earlier in literature. Thus, pyrite is definitely present in regular concretions and also in lignite.

Palana Lignite (Bikaner), Rajasthan—The lignite seam is dark brown in colour with dull appearance (Pareek, 1984). It is soft, friable and fine textured (amorphous). Dark red resins (< 1.0 to few mm in size) occurs scattered or in dense patches in the lignite matrix. Pyrite specks and granules embedded in the lignite are commonly seen.

Panandhro Lignite (Kutch), Gujarat—The Panandhro lignite is brown to dark brown in colour with uniform amorphous texture and non-banded appearance (Pareek, 1984). It contains abundant specks, globules or lenses of yellow and red coloured resins at localized intervals. The seam sections show repetition and alternations of dull lignite layer with those containing resins. Evidently the lignite seam is sparingly banded, atleast containing few light brown and dark brown bands which is also corroborated by air dried samples. Pryite is a frequent mineral of the lignite seams and associated sediments. It occurs in the form of specks and coarse granules distributed sparsely or occasionally in aggregates.

Lignite of Cambay Basin, Gujarat—The lignites of Cambay Basin associated with Kalol and Kadi formations appear compact and dull banded. Dull and semibright black bands are interspersed with fragmentary, thin sheets, strips or moderately thick lenticles of lustrous compact bands (Pareek, 1983).

ORGANIC COMPOSITION AND NATURE OF COALS AND LIGNITES

The Tertiary coals and lignites of India, in comparison to Permian Gondwana coals, are rich in vitrinite/huminite macerals (coal : 41.0-79.0%; lignite : 41.0-81.0%) with low to moderate amounts of liptinite (coal : 5.0-19.0%; lignite : 4.0-16.0%) and inertinite (coal : 3.0-20.0%; lignite : 2.0-17.0%). Associated inorganics comprise mainly argillaceous matter (clay and quartz), pyrite and calcite. Their contents vary between 4.0 to 20.0 per cent (rarely up to 35.0%) in coals and between 2.0 to 30.0 per cent (up to 49..0%) in lignites (Tables 4-5). Certain coal and lignite seam sections occasionally have lower vitrinite/huminite (36.8% and 38.3%, respectively) and higher inertinite (29.4-35% and 32.0%, respectively) contents than the normal recorded range. The coals of northeastern India (Misra, 1981, 1992a, c) are well known for their pyrite content (1.0-20.0% max. 33.0%). In Panandhro lignite seams pyrite content up to 20.0 per cent has been recorded (Misra 1992b; Misra & Navale, 1992). Presence of pyrite in Neyveli and Palana lignite seams has also been reported (Navale & Misra, 1980b; Singh *et al.*, 1992; Pareek,1984). However, nothing is known about its occurrence in Kalol lignite. The earlier

Table 5—Petrographic composition and rank (R_o max. %) of Tertiary lignites from Tamil Nadu and Gujarat (as analysed under normal reflected white light)

AREA LIGNITEFIELD & LIGNITESEAM	R_o max. (in oil) %	MACERAL COMPOSITION (Volume %)				
		Vitrinite	Liptinite	Inertinite	Mineral Matter	Average
Neyveli Lignitefield, South Arcot, Tamil Nadu						
Main Seam	0.47 & 0.39	78.4-86.7	5.3-12.4	5.5-16.3	on m.m.f. basis	H. 82.6, L. 8.2, I. 9.2
Panandhro Lignitefield, Kutch, Gujarat						
Seam no. 4	0.43	38.3-45.4	4.0-13.6	7.6-11.2	34.8-44.2	H. 55.5,
Seam no. 3	0.43	53.8-75.4	6.0-11.2	1.6-8.4	15.4-30.0	L 9.4,
Seam no. 2	0.43	61.8-67.0	7.0-12.0	4.8-9.2	17.2-21.2	I. 7.4,
Seam no. 1	0.44	40.4-62.8	8.0-12.2	7.4-17.0	17.2-40.8	M.M. 27.7
Kalol Lignitefield, Gujarat						
Main Seam (Pareek, 1983)	0.30-0.40	50.0-81.0	1.0-16.0	11.0-32.0	2.0-49.0	H. 61.7, L. 6.0, I. 20.4, M.M. 11.9
Main Seam (Samanta, 1987)	0.28-0.35	75.0-94.0	3.6-22.6	0.8-6.4	on m.m.f. basis	H. 86.4, L. 10.7, I. 2.9

Table 6—Petrographic composition of Tertiary coals from northeastern India under normal reflected light (data from other sources)

AREA COALFIELD AUTHOR	MACERAL COMPOSITION (volume %)			
	Vitrinite	Liptinite	Inertinite	Mineral Matter
Makum Coalfield, Assam (Ash content 2.0-8.0% up to 20.0%)				
Ghosh (1969)	74.5-87.3	2.8-4.7	4.7-18.6	3.0-4.2
Sen & Sen (1969)*	87.8-96.4	0.9-1.5	2.7-10.7	
Mukherjee (1976)	86.5-94.2	0.9-5.0	2.2-6.2	2.2-3.7
Goswami (1985)*	86.3-94.0	1.1-6.3	5.0-7.3	
Goswami (1987)*	52.0-94.0	6.0-48.0	0-28.5	
Dilli-Jeypore (Jaipore) Coalfield, Assam (Ash content 6.0-13.0%-20.0%)				
Goswami (1985)*	95.0-98.0	0.3-2.4	1.5-2.4	
Nazira Coalfield, Nagaland (Ash content 3.0-5.0% up to 23.0%)				
Goswami (1985)*	72.5-78.8	3.0-9.7	17.8-18.3	
Khasi & Jaintia Hills, Meghalaya (Ash content 3.0-15.0% up to 28.6%)				
Ghosh (1969)	80.2-89.4	1.3-2.8	2.9-12.8	4.2-6.4
Sen & Sen (1969)*	94.0	1.2	4.2	
Ahmed (1971)	82.1-83.4	5.3	7.2-7.6	4.1-5.0
Goswami (1985)*	89.6-93.0	2.0-3.4	3.6-8.4	
Garo Hills, Meghalaya (Ash content 2.0-7.5% up to 15.0%)				
Ghosh (1969)	84.0-85.0	5.0-6.0	6.0-7.0	3.0-4.0
Goswami (1985)*	86.9-92.5	1.5-5.2	6.0-7.8	

*Data available on mineral matter free basis.

biopetrographic data (Table 6) appear to be unreliable because of the following reasons:

1. Very low amount of mineral matter has been recorded which is either equal to or mostly less than the ash content of the same sample, whereas, the mineral matter content should always be more than ash content of a coal.

2. Very high or very low amount of liptinite macerals are not supported by fluorescence microscopic assessment by the author. In fact, in the earlier works the resinite macerals, main liptinite maceral in these coals, have not been reported.

3. Low to very low proportions of inertinite macerals probably resulted from unrecorded fractions of fungal remains (sclerotinite: spores, sclerotia, hyphae and mycelium) and inertodetrinite which are common to frequent maceral in the Tertiary coals of northeastern India.

4. High vitrinite contents as seen in Table 6 are probably the cummulative effect of factors 1 to 3. The vitrinite content in these coals, occasionally may reach to the maximum of 80.0 per cent alongwith liptinite and inertinite macerals and associated inorganics under normal incident light assessment.

Microscopic assessment, under blue light excitation, of various macerals (Table 7 on mineral matter free basis) in the Tertiary coals (Misra, 1992a, c & unpublished data) and lignites (Misra, 1992b; Misra & Navale, 1992) revealed that the coals have high to very high proportion of fluorescing macerals (47.0-91.0%) constituted chiefly by perhydrous or fluorescing vitrinite (25.0-62.0%, max. 78.0%) and liptodetrinite (10.0-35.0%, max. 40.5%) with subordinate amount of other liptinite macerals (4.0-22.0%, max. 28.0%). The lignites, on the other hand (data available for only 4 lignite seams of Panandhro Lignitefield, Table 7), have relatively lower amount of fluorescing macerals (25.0-67.0%) formed mainly by liptodetrinite (10.0-43.0%) and other liptinites (9.0-25.0%). The liptinite fraction in these coals and lignites, excluding liptodetrinite, is constituted chiefly by resinite (coal : 4.0-13.0%, lignite : 6.0-23.0%) and cutinite + suberinite (coal : 0-7.0%; lignite; 0.5-5.2%). The sporinte is uniformly in low amount in both coals (0-3.6%) and lignites (0.4-2.1%). The coals of northeastern India (Misra, 1992a) and lignites from Panandhro (Kar, 1985; Misra & Navale, 1992; Misra, 1992b) and Neyveli (Navale & Misra, 1980b; Ramanujam, 1982) are characterized by the presence of algae (*Botryococcus*). Macerals like bituminite, exsudatinite and fluorinite are commonly present in these coals and also (excluding bituminite) in Panandhro lignite. Pareek (1983) reported the occurrence of exsudatinite and fluorinite in the Kalol lignite.

Table 7—Maceral composition (under incident blue light excitation/on mineral matter free basis) of Tertiary coals from Assam, Nagaland and Meghalaya and lignites from Panandhro, Kutch (Gujarat)

AREA COAL/LIGNITEFIELD COAL/LIGNITE SEAM	MACERAL COMPOSITION % (under blue light excitation)				
	Fluorescing Vitrinite (Huminite)	Liptinite (Sp.+Cu+Sub+ Re+Alg+Fl+Ex)	Liptodetrinite	Total Fluorescing Maceral	Non-fluorescing Vit. (Hum)+Inert.
Makum cf., Assam					
Seam no. 3	42.2-62.1	8.2-12.0	15.3-23.2	78.4-88.5	11.5-21.6
Seam no. 1	47.4-59.7	7.2-17.1	15.7-22.3	78.0-88.6	11.4-22.0
Dilli-Jeypore cf., Assam					
Seam no. 6	29.7-47.9	18.7-22.1	recorded	48.4-70.0	30.0-51.6
Seam no. 4	50.1-56.7	25.5-27.9	with Fluor. Vit.	78.0-82.2	17.8-22.0
Nazira (Borjan) cf., Nagaland					
Main Seam	35.3-40.9	16.7-20.5	recorded with Fluor. Vit.	52.0-61.4	38.6-48.0
Laitryngew cf. Khasi Hills, Meghalaya					
Main Seam	31.6-67.4	6.4-13.4	8.2-27.2	47.2-88.4	11.6-52.8
Bapung (& Rymbai), Jaintia Hills, Meghalaya					
Top Seam	23.0-42.0	11.5-17.6	22.0-34.1	72.3-89.2	10.8-27.7
Middle Seam	41.0-60.0	11.8-19.7	11.0-25.6	82.1-86.8	13.2-17.9
Bottom Seam	30.7-50.0	15.0-20.7	20.2-35.0	74.1-88.3	11.7-25.9
Sutunga, Jaintia Hills, Meghalaya					
Top Seam	57.5-78.1	2.0-7.0	8.0-9.1	59.5-91.2	8.8-40.5
Middle Seam	34.5	4.5	14.0	53.0	47.0
Bottom Seam	67.5	7.4	8.1	83.0	17.0
Jarain, Jaintia Hills, Meghalaya					
Top Seam	37.0-48.5	12.0-14.0	27.3-34.1	77.0-90.5	9.5-23.0
Bottom Seam	25.5-50.6	13.9-18.8	26.0-40.5	84.8-90.5	9.5-15.2
West Daranggiri cf., Garo Hills, Meghalaya					
Main Seam	35.0-56.0	12.1-18.8	9.3-22.0	70.0-81.4	18.6-30.0
Panandhro cf., Kutch, Gujarat					
Seam no. 4	—	10.0-25.4	16.2-43.6	41.2-54.4	45.6-58.2
Seam no. 3	1.9-17.0	11.0-18.3	12.4-27.7	30.5-54.1	45.9-69.5
Seam no. 2	0.7-2.6	10.9-20.3	10.0-24.6	24.9-45.6	54.4-75.1
Seam no. 1	0.9-6.5	9.0-20.1	11.9-43.9	27.5-67.3	32.7-72.5

COALS

The Tertiary coals of northeastern India (Misra, 1981, 1992a, c) are characterized by the dominance of vitrinite consisting chiefly of desmocollinite and telocollinite with subordinate and low proportions of corpocollinite and telinite macerals respectively. Desmocollinite, invariably, is the dominant maceral in all the coal seams. Desmocollinite and some amount of telocollinite show granular or spongy texture with relatively weak reflectance than the associated vitrinite. Frequent presence of fungal spores, fine clusters and knots of hyphae and sclerotinite in vitrinite is the evidence for the highly degraded nature of the vegetal matter which formed the coal seams. Ganju (1955) on the basis of thin section study already reported highly degraded woods due to fungal activity in the coals of Makum Coalfield, Assam. Specks, granules and framboids of pyrite are frequent in the coal seams associated with vitrinite, especially the desmocollinite, clarite and trimacerite (Misra, 1992a). Very fine granular pyrite has been found filled in cell lumens of telocollinite particularly in the coals of Nazira Coalfield, Nagaland. Crushing and shattering affects on vitrinite and inertinite macerals have been frequently observed in coals from Arunachal Pradesh, Assam, Nagaland and Garo Hills of Meghalaya.

Inertinite macerals are mainly semifusinite, fusinite (rank, degrado and pyro-inertinite types), inertodetrinite and sclerotinite with sporadic macrinite and micrinite. Usually inertodetrinite and sclerotinite together form most of the inertinite macerals (Misra, 1992a, c) especially in Assam and

Nagaland coals. In general, structured inertinites (semifusinite and fusinite) have empty cell lumens embedded in vitrinite or collinite. Occasionally, lumens are filled with calcite and pyrite framboids alongwith small amount of argillaceous matter. However, coal seams of Meghalaya have higher amount of inertinite contents constituted mainly by structured inertinites (Table 5) in comparison to Assam and Nagaland coal seams. The trend of variation in the contents of vitrinite, inertinite and mineral matter, in these coals, both vertically and laterally is not uniform.

Associated mineral matter in these coals are chiefly early diagenetic pyrite and calcite concretions. Argillaceous minerals (clay and quartz) are usually between 20.0-40.0 per cent of the total mineral matter content.

As observed by the author (no quantitative data is available) the coal seams of Assam and Nagaland have dominance of vitrite + clarite (sporinite-poor) microlithotypes. Subordinate amounts of duroclarite and vitrinertite microlithotypes are associated with them. Microlithotypes, clarodurite and inertite are uncommon and durite is absent. Some of the coal seams of Jaintia Hills (Meghalaya) have almost similar microlithotype composition as the preceding ones. However, coal seams of Meghalaya, in general, have higher proportions of duroclarite and clarodurite than those of Assam and Nagaland. Associated common microlithotypes are vitrinertite and inertite, whereas durite is also present sporadically especially in the coal seams of Garo Hills.

Under blue light excitation (quantitative data on mineral matter free basis), fluorescing or perhydrous vitrinite (Misra, 1992a, c) constitutes the major part of the total fluorescing macerals recorded (normally > 30.0-78.0%, Table 7).

Liptinite macerals have been assessed on the basis of observations made under normal white light and blue light excitation (for details see Misra, 1992a, c). Among the liptinite macerals liptodetrinite (8.0-40.5%) and resinite (1.0-18.0%) are dominant followed by cutinite + suberinite (0.4-7.6%) and sporinite (0.3-2.0% rarely up to 3.3%). Exsudatinite and fluorinite macerals are common in almost all the coal seams and are together recorded up to 2.9 per cent. Cutinites are usually tenuicutinites, however, crassi-cutinites do occur sporadically. Suberinite, as thin to thick bands and as fragments or shreds, occurs commonly in clarite, trimacerite and also in liptodetrinite. Maceral resinite is especially frequent in Jeypore (Assam), Nazira (Nagaland), Bapung and Jarain (Meghalaya) coalfields. Well-preserved and partially degraded alginite (*Botryococcus*), recorded up to 1.0 per cent, has been observed in Khasi and Jaintia Hills of Meghalaya. However, highly degraded and disorganized alginite, recognized on the basis of its fluorescence properties, has been observed in most of the coal seams. Liptodetrinite in these coals is either resinite-rich or resinite + cutinite + suberinite-rich. Granular bituminite is commonly associated in trimacerites, clarites and in desmocollinite. Pyrite has been commonly found associated with almost all the liptinite macerals.

It has been observed that most of the coal seams of Assam and Khasi and Jaintia Hills of Meghalaya have very high total fluorescing macerals contents (normally 72.0-91%). However, certain coal seams, especially from Nazira Coalfield (52.0-61.4%), some patchy seams of Jaintia Hills (47.0-53.0%) and the main seam(25.0-54.0%) of West Daranggiri Coalfield have relatively low proportions of total fluorescing macerals. Coal seams of Jaintia Hills, in general, have higher liptodetrinite content than those from other areas, whereas, coal seams of Garo and Jaintia Hills have higher amount of liptinite macerals (excluding liptodetrinite) than those from Makum Coalfield and Sutunga area.

LIGNITES

Neyveli Lignite, Tamil Nadu—Although the main seam of the Neyveli Lignitefield from the I mine area has been studied most (Navale, 1971, 1973, 1974; Navale & Misra, 1980b) but majority of the investigations dealt with only morphopetrographic nature of the lignite microconstituents. The only quantitative data available for the lignite microconstituents (Navale & Misra, 1980b: on m.m.f. basis) has been recently revised and given in Table 5. The main lignite seam, studied from 4 lateral sections of the I mine area has appreciably high contents of huminite macerals (78.4-86.7%) and low to moderate amount of liptinite (5.3-12.4%) and inertinite (5.5-16.3%) macerals. Associated mineral matter in the lignite is mainly constituted by quartz and clay beside early diagenetic pyrite specks, granules and framboids.

In general, macerals of humodetrinite (attrinite and densinite) predominate (45.0-70.7%) over the combined contents of macerals textinite, carpohuminite and gelinite (16.0-38.5%) in all the 4 sections. However, there is a distinct tendency of decrease in humodetrinite contents in the top (45.0-48.0%) and bottom (45.0-50.3%) sections of the seam with corresponding increase of humotelinite and humocollinite macerals (top 25.0-36.0%; bottom 30.0-38.5%). The middle section of the seam is characterized by distinctly high humodetrinite content (55.0-70.7%) and low proportions of other huminites (16.0-30.0%).

The macerals of the liptinite group are sporinite, cutinite, suberinite, resinite and alginite (*Botryococcus*). Quantitatively, resinite is the main maceral followed by suberinite + cutinite and sporinite. Assessment of alginite content was not possible under normal white light.

Macerals of inertinite group are constituted by semifusinite, fusinite, inertodetrinite and sclerotinite. The latter two macerals (3.5-8.4%) together are always higher than the former two (2.6-7.9%). Semifusinite is higher than fusinite and both appear to have formed mainly from degradation and oxidation of gelified humic material. Rank inertinites are also common but distinct pyro-inertinites have not been observed.

It appears that the ancient peat swamp suffered high to moderate degree of vegetal degradation as is evident from the high humodetrinite and fungal remains (sclerotinite). The degree of degradation in the middle section of the seam was distinctly higher than in the top and bottom sections. From the observations made by the author, on the lignite pellets from three bore-core sections of the III mine area, it is inferred that the lignite seam did not experience uniformly high rate of degradation as in the I mine. Instead, the degradational effects were pronounced only in certain sections of the seam in different core-sections (Singh *et al.*, 1992).

Palna Lignite, Rajasthan—Pareek (1984, p. 547) observed an "advanced stage" of "disintegration and degradation" of original plant material. From his short description it can be inferred that the Palana lignite seam consists chiefly of humodetrinite (attrinite and densinite) macerals. He described abundance of resinite bodies of light-red colour embedded in humodetrinite groundmass besides, suberinite, cutinite and sporinite in order of decreasing abundance as other liptinite macerals. Presence of liptodetrinite and fluorinite macerals can also be inferred by indirect evidences and by the nature of lignite seam. Inertinites consist of common fungal remains (sclerotinite) and inertodetrinite, rare semifusinite, fusinite and macrinite macerals.

Panandhro Lignite (Kutch), Gujarat—Pareek (1984, p. 540) observed that the Panandhro lignite seams have extensively decayed vegetal matter with complete obliteration of their microstructural details. Navale (1974, p. 583) attributed this as a cause for humus-rich "attrital nature" of the lignite seams. These observations, though not supplemented by quantitative petrographic data, appear to be partly true. Detailed biopetrographic investigation of the Panandhro lignite seams (Misra & Navale, 1992) shows that the vegetal source material underwent variable degree of both aerobic and anaerobic degradation, e.g. Seam nos. 1 and 4 experienced higher degree of degradation in comparison to Seam nos. 2 and 3. Seam no. 3 shows best vegetal matter preservation with 20.6-50.8 per cent of humotelinite macerals against 14.2-23.0 per cent in rest of them. The Panandhro lignite seams (Table 5) are characterized by moderate to high amounts of both huminite macerals (38.3-75.4%) and inorganic associates (15.4-44.2%). Seam nos. 1 and 4 have relatively low amounts of huminite (40.2-62.8% and 38.3-45.4%) and high amounts of inertinite (7.4-17.0% and 7.6-11.2%) and mineral matter (17.2-40.8 and 34.8-44.2%) in comparison to Seam nos. 2 and 3 (huminite 61.8-67.0% and 53.8-75.4%, inertinite 4.8-9.2% and 1.6-8.4%, mineral matter 17.2-21.2% and 15.4-30.0% respectively). Liptinite macerals (for details refer, Misra, 1992b) being better represented under blue light excitation (on m.m.f. basis, Table 7) are described accordingly. Dominant macerals are liptodetrinite (10.0-43.9%) and resinite (4.4-23.3%). Other associated macerals are suberinite + cutinite (up to 7.0%) and sporinite (0.3-2.1%). Semifusinite and fusinite are persistently present from basal parts of the seams and are the main inertinite macerals followed by inertodetrinite and sclerotinite.

Associated mineral matter are mainly constituted by argillaceous matter (clay and fine quartz) followed by granular, crystalline and framboidal pyrite and calcite concretions. Seam nos. 1 and 2 have lower proportions of pyrite (6.5-16.7% and 17.0-36.0%) than Seam nos. 3 and 4 (26.6-41.0% and 23.0-37.0%) of the total mineral matter content. Argillaceous matter content is quite high in Seam no. 1 (60.2-82.8%) and 2 (32.6-61.4%) in comparison to Seam nos. 3 and 4 (14.4-31.3% and 34.0-40.4%) of the total content.

Lignite of Cambay Basin, Gujarat—Very little information is available on lignite seams of Kalol and Kadi formations (Pareek, 1983; Samanta, 1987). The Kalol lignite is formed chiefly of highly decayed and disintegrated huminized mass of organic debris with predominance of attrinite and densinite macerals followed by textinite which "rarely exhibits well-preserved microstructures" (Pareek, 1983). Ulminite and gelinite macerals are occasional. Inertinite macerals (11.0-32.0%) are mainly sclerotinite (7.0-27.0%) and inertodetrinite and micrinite (1.0-12.0%). Fusinite and semifusinite are surprisingly absent. The liptinite macerals in Kalol lignite seam are resinite, liptodetrinite, cutinite, suberinite and sporinite. Resinite is the most common liptinite maceral of the seam whereas, suberinite is relatively uncommon. Exsudatinite is very common and alginite and fluorinite are also recorded in minor amounts. No description of microconstituents was provided by Samanta (1987).

RANK

Rank of the Indian Tertiary coals and lignite seams (Tables 4, 5) was determined by reflectance measurements on vitrinite/huminite macerals (mean maximum reflectance in oil-$R_o$max. %). The coal of Assam (R_o max. 0.71-0.75%) and those of Jaintia Hills of Meghalaya (R_o max. 0.64-0.69%, occasionally 0.72-0.86%) have attained a rank corresponding to high volatile bituminous B to occasionally A stages. The coal seams of Nazira Coalfield, Nagaland (R_o max. 0.59-0.67%) and West Daranggiri Coalfield of Garo Hills, Meghalaya (R_o max. 0.54-0.62%) have reached only a rank stage equivalent to high volatile bituminous C stage. Barring few exceptions, probably influenced by local faulting (Table 4 : Sutunga area R_o max. 0.72-0.86%), it has been observed that the younger coal seams (Oligocene) of Assam and Nagaland have attained higher maturity (rank) than those of Meghalaya (Palaeocene). With the result there is a westward decreasing trend in coal rank from Makum Coalfield, Assam to West Daranggiri Coalfield of Garo Hills in Meghalaya, coinciding with increasing age of the deposits. This inverse rank relationship with age is evidently related with the greater depth of burial of the coal seams (> 2,000-6,000 m thickness of overlying sediments), prevailing higher geothermal gradient and intense tectonic activity in Assam and Nagaland in comparison to Meghalaya where coal deposits are overlain by thinner sedimentary sequence (± 500 m thick overlying sediments) and almost uneffected with tectonic disturbance which could have caused any significant change in maturity of the coal seams (Misra, 1992a, c; Raja Rao, 1981).

The rank (R_o max. %) of the Tertiary lignites (Table 5) shows that the younger (Miocene) main lignite seams of Neyveli Lignitefield with R_o max. 0.47 per cent in the I mine and 0.42 per cent in III mine has higher rank than the older (Palaeocene-Eocene) lignite seams of Panandhro Lignitefield (R_o max. 0.43-0.44%) and Kalol and Kadi formations (R_o max. 0.28-0.44%) of Cambay Basin, Here again, the rank trend has inverse relation with the age of the deposits and appears to be influenced mainly by the existing geothermal gradient and tectonic set-up of the basins in different areas. Lower R_o max. values recorded for the Kalol lignite seams (Pareek, 1983; Samanta, 1987) do not conform with the greater depth of burial (700-1,700 m below surface). It seems probable that the graben formation in the Cambay Basin during Palaeocene (Raju & Srinivasan, 1983; Pareek, 1983) and consequent lignite bearing sedimentation was slow and the prevailing geothermal gradient in the area remained uniformly low since initiation of the vegetal accumulation. With the result lignite seams exhibit only low maturity-level (rank). However, higher burial depth of the Kalol lignite seams has contributed to severe dewatering and compaction resulting into exceptionally low moisture content (4.9% as against 21.0-53.0% for Palana, Panandhro and Neyveli lignites: refer table 10 of Pareek, 1983) and development of bright coaly streaks and lenses.

COAL AND LIGNITE FORMING PLANT COMMUNITIES AND THEIR ENVIRONMENTAL IMPLICATIONS

Record of mega-and microplant taxa recovered from coal and lignite bearing horizons of different areas are listed in Table 8. The world 'P' in the list denotes the record of pollen related with the taxa/family and the symbols habitat/community. Therefore, in the following text only significant taxa (at family level) belonging to pteridophytic representatives and those without established affinities have only been mentioned.

Northeastern India

Makum Coalfield, Assam—Palynological assemblage recovered from the coal seams and associated sediments in the basal part of the Tikak Parbat Formation, Barail Group is either dominated by angiospermous pollen or pteridophytic spores (Misra, 1981). Fungal remains including a variety of epiphyllous elements (excluding hyphae and mycelia) are abundant (25.0-69.0%, rarely below 25.0%) in both the seams (Nos. 1 and 3). The assemblage of the coal seams is mostly dominated by angiosperms (13.0-42.0%) in the top sections. Pteridophytic spores are occasionally in high frequency (26.0-57.0%), i.e., more than the angiosperms in the top sections of Seam no. 3 (Namdang and Tipang collieries) and bottom sections of Seam no. 1 (Baragolai and Tipang collieries) and Seam no. 3 of Namdang colliery.

Pteridophytic spores recovered from the coal seams are represented mainly by Parkeriaceae (*Striatriletes*), Polypodiaceae (*Polypodiisporites* and *Polypodiacaeasporites*), Cyathiaceae, Schizaeaceae (*Lygodiumsporites*) and Matoniaceae (*Dandotiaspora*). Spores of *Striatriletes* are present in very high frequency (40.0-60.0%) in the basal part of Seam no.

Table 8—List of angiospermous plant megafossils recorded from coal and lignite-bearing horizons of Assam, Meghalaya, Tamil Nadu and Gujarat with their living affinities. 'P' denotes record of pollen also and different symbols habitat/ communities

FAMILIES (Angiospermous)	ASSAM (Makum Coalfield)	MEGHALAYA (Jaintia, Khasi & Garo Hills)	RAJASTHAN (Palana Lignitefield)	GUJARAT (Panandhro Lignitefield, Kutch)	TAMILNADU (Neyveli Lignitefield)
Agavaceae	P0				*Dracaena*0
Alangiaceae	P†$		P†$	P†$	P†$
Anacardiaceae	*Mangifera*	*Drancotomelum*			*Bouea, Gluta*$
	P*†	P*†	P*†		P*†
Annonaceae		*Polyalthia*			
Apiaceae				P	
Apocynaceae					*Melodinus*
Araliaceae					P
Arecaceae	*Nypa** P*†$	*Nypa** P*†$	*Cocos*† P*†$	P*†$	*Phoenix**$0 P*†$0
Asteraceae				P	
Avicenniaceae	*Avicennia**				P*
Bombacaceae		*Bombacites*			
		P0	P0	P0	P0
Boraginaceae					*Cordia*
Brassicaceae					P
Burseraceae		*Bursera*			
		Canarium			
Celastraceae		*Lophopetalum*			
Clusiaceae	*Calophyllum*$0	*Calophyllum*$0	*Calophyllum*$0		*Calophyllum*$0
	Kayea, Mesua		*Garcinia, Mesua*		*Garcinia, Mesua*
	P	P	P0	P	P
Combretaceae	*Terminalia*$0			*Terminalia*$0	*Terminalia*$0
				P	P*
Ctenolophonaceae					P
Dipterocarpaceae					*Hopea, Shorea*
					P
Droseraceae	P	P			P
Ebenaceae					*Diospyros*$
Ericaceae	P0				
Euphorbiaceae		*Bischofia*			*Excoecaria**
		P			*Phyllanthus*
					P*
Flacourtiaceae		*Hydnocarpus*			
Gunneraceae		P0		P0	
Haloragaceae		P			P
Hamamelidaceae					*Altingia*0
Hippocrateaceae			P		P
Icacinaceae		*Gomphandra*			P
Labiatae		P			
Lauraceae		*Litsea*0, *Phoebe*0		*Cinnamomum*	*Machilus, Litsea*
		*Neolitsea*0			
Lecythidaceae		*Barringtonia*$†			*Barringtonia*$†
	P$†	P$†		P$†	P$†
Leguminosae	*Dalbergia*$	*Desmodium,*			*Casia-Acacia,*
	P	*Derris*$,	P	P	*Erthrina, Bauhinia,*
		Millettia,			*Eugenia, Dalbergia*$,
		Pongamia,			P$
		Albizia			
		P			
Lentibulariaceae		P			*Utricularia*
					P
Liliaceae	P	P	P	P	P
Lythraceae				*Lagerstroemia**$0	P*$
Meliaceae	P*$†	P*$†	P*$†	P*$†	*Azadirachta*
					P*$†
Moraceae		*Artocarpus*		*Ficus*	
Myricaceae		P			

Contd.

Table 8—Contd.

FAMILIES (Angiospermous)	ASSAM (Makum Coalfield)	MEGHALAYA (Jaintia, Khasi & Garo Hills)	RAJASTHAN (Palana Lignitefield)	GUJARAT (Panandhro Lignitefield, Kutch)	TAMILNADU (Neyveli Lignitefield)
Myrsinaceae	P°	P°			P°
Menispermaceae					P
Myristicaceae	*Myristica*§				
Myrtaceae		P		*Syzygium*°	
Nymphaeaceae		*Nelumbo*° P	P		P
Nyssaceae	P	P			P
Oleaceae	P	*Osmanthus*°, *Ligustrum*°	P		P
Onagraceae	P	P		P	
Pandanaceae				*Pandanus*§†°	
Plumbaginaceae					P*
Poaceae		*Poacites*		P	Cuticle P
Polygalaceae		P		P	P
Polygonaceae		P			
Potamogetonaceae		P	P		P
Proteaceae		P	P	P	P
Rhizophoraceae	P*	P*		P*	*Carallia** P*
Rosaceae					*Parinari* P
Rubiaceae	P§	P§	P§		*Randia* P§
Santalaceae					P
Sapindaceae		P			P
Sapotaceae	P				*Bassia*, *Mimusops* P
Sonneratiaceae		*Sonneratia**			*Sonneratia** P*
Sterculiaceae		*Sterculia*			P
Thymeliaceae				P	P
Tiliaceae		*Grewia*			P*§
Typhaceae					P
Ulmaceae		*Trema*†			P
Urticaceae					P

*Mangrove plants; †Mangrove associates; §Back mangrove plants; °Trees/herbs/shrubs of coastal or near shore (littoral/swampy) habitat. Data compiled from: Bande (1992); Awasthi (1974, 1984); Navale (1968); Singh *et al.* (1975); Singh (1977); Dutta and Sah (1970); Sah and Kar (1974); Tripathi and Singh (1984); Kar and Kumar (1986); Kar (1985); Misra (1981); Ramanujam (1966, 1982); Singh *et al.*, (1992) and Mandal (1986).

1 in Baragolai and Tipang collieries. The palynological assemblage, though rich in dicot pollen, has persistently high proportion of monocots belonging to families Arecaceae and Agavaceae alone. Most represented dicot families are: Rubiaceae, Anacardiaceae, Alangiaceae, Oleaceae, Lecythidaceae, Meliaceae, Rhizophoraceae, Onagraceae, Myrsinaceae, Sapotaceae, Nyssaceae, Ericaceae and Droseraceae. Significant pollen genera (of unknown affinity) are *Tricolpites (T. levis), Meyeripollis, Polycolpites* and *Engelhardtioipollenites. Octaplata* and *Palania* are the common microplanktons recorded besides, salt glands of mangrove leaves (*Oudhkusumites = Heliospermopsis*) by Banerjee (1985).

Plant megafossils referable to families—Anacardiaceae, Avicenniaceae, Clusiaceae, Combretaceae, Leguminosae and Myristicaceae and a gymnosperm Podocarpaceae are known to occur in the coal-bearing sediments of the area (pers. comm. Drs N. Awasthi & R. C. Mehrotra).

From the plant fossil records, a humid tropical climate with high annual precipitation is inferred, that facilitated the growth of luxuriant coastal to near-shore, including mangrove, forest vegetation with prolific undergrowths during the deposition of coal-bearing sediments of the Makum Coalfield. It has also been presumed that the climate and vegetation (unpublished palynological report by the author from coalfields of Dilli-Jeypore, Assam and Nazira, Nagaland) in the nearby areas of Assam and Nagaland were almost similar.

Khasi Hills, Meghalaya—The palynological assemblage of the coal-bearing sediments of Lakadong Sandstone Member, Sylhet Formation (Dutta & Sah, 1970; Kar & Kumar, 1986) is highly rich in pteridophytic spores (up to 70.0%). Significant pteridophytic taxa are—*Lycopodiumsporites* and *Dandotiaspora* alongwith subordinate amount of schizaeaceous and cyatheaceous spores, etc. Angiospermous pollen chiefly belong to monocot families, viz., Arecaceae (*Proxapertites, Spinomonosulcites* and *Spinozonocolpites*), Liliaceae (*Matanomadhiasulcites*) and Potamogetonaceae (*Retipilonapites*). Commonly represented dicot pollen taxa belong to families Euphorbiaceae, Onagraceae, Labiatae, Clusiaceae (*Kielmeyerapollenites*), Bombacaceae, Gunneraceae, Pellicieraceae, Leguminosae, Anacardiaceae, Meliaceae, Oleaceae, Myricaceae, Sapindaceae, Rhizophoraceae, Lecythidaceae, Polygalaceae, Proteaceae and Droseraceae.

All the five coal seams in Laitryngew and three coal seams in Cherrapunjee areas (Kar & Kumar, 1986) have yielded a trilete dominant assemblage with varying proportions of *Lygodiumsporites* (22.0-45.0%) and *Dandotiaspora* (18.0-40.0%). Associated angiospermous pollen are mainly those belonging to families Arecaceae, Liliaceae and Potamogetonaceae, Clusiaceae, Gunneraceae and Droseraceae.

On the basis of palynological assemblage Dutta and Sah (1970) and Kar and Kumar (1986) visualize a near-shore coastal environment. The coal seam according to them were probably deposited in shallow water close to shore-line. They presume a stretch of coastal swamp adjacent to the depositional area. However, Dutta and Sah (1970) assume that deposition of the coal seams was under fresh-water condition and also they find no evidence of arborescent vegetation.

Jaintia Hills, Meghalaya—Coal seams and associated sediments of Sylhet Formation (Palaeocene) in Jaintia Hills, unlike Garo and Khasi Hills, have yielded higher proportions of angiospermic pollen (29.0-66.0%) than the pteridophytic spores which vary between 30.0 to 58.0 per cent (Tripathi & Singh, 1984; Singh & Tripathi, 1986; Mandal, 1986).

Coal seams in Bapung area along Jowai-Sonapur Road have almost equal proportions of pteridophytic spores and angiospermic pollen besides fungal elements (Tripathi & Singh, 1984). The pteridophytic spores are mainly *Lycopodiumsporites* (Lycopodiaceae), *Lygodiumsporites* (Schizaeaceae), *Dandotiaspora* (Matoniaceae) alongwith the spores of Polypodiaceae and Parkeriaceae. Angiosperms are mostly represented by *Proxapertites, Palmaepollenites, Spinomonosulcites* and *Palmidites* of Arecaceae. Other pollen associates belong to families Liliaceae, Euphorbiaceae, Oleaceae, Myricaceae and Chenopodiaceae. Tripathi and Singh (1984) reported the dominance of *Lygodiumsporites* with subordinate amount of *Dandotiaspora* in the lower three seams (one local seam). The 4th and 5th seams (one local seam) have both these spore forms in almost equal amounts. The 3rd and the 5th seams are also characterized by fair amounts of dinoflagellate cysts, viz., *Cordosphaeridium, Adnatosphaeridium, Polysphaeridium* and *Homotriblium*.

Coal seams of Lat-Rymbai (Bapung area) and Jarain (pers. comm. Dr M. Kumar) have yielded angiospermous dominant assemblage from three (top, bottom and middle) and two (top and bottom) coal seams respectively. The main pollen genera of the assemblage are *Proxapertites, Spinomonosulcites, Spinozonocolpites,* etc. of Arecaceae besides subordinate amounts of pollen belonging to Liliaceae, Bombacaceae, Clusiaceae, etc. Lycopodiaceous, cyathiaceous and polypodiaceous spores are the main pteridophytic representatives. The coal seams in Lat-Rymbai have increasing frequencies of angiospermic pollen from 1st to 3rd seams (bottom to top : 53.0-64.0%). Correspondingly the seams have decreasing pteridophytic spores (47.0-36.0% : bottom to top). In Jarain area the bottom seam has relatively higher frequency of spores (58.0%) than pollen (42.0%) and the reverse is true for the top seam with 62.0 per cent of pollen and 38.0 per cent of spores.

The coal seam in the Sutunga area (Mandal, 1986) yielded a fairly high amount of angiospermic pollen, of which monocot pollen genera *Proxapertites, Spinomonosulcites, Spinozonocolpites* and *Acanthotricolpites* belonging to family Arecaceae constitute about 68.0 per cent of the bulk. Other pollen forms belong to families Bombacaceae, (*Lakiapollis*), Gunneraceae (*Tricolpites reticulatus*), Oleaceae, Anacardiaceae, Clusiaceae (*Kielmeyerapollenites*), Leguminosae and Onagraceae. Besides, certain unaffiliated forms like *Retitribrevicolporites* have also been recorded. Pteridophytic spores in the assemblage of the coal seams are mainly constituted by *Lycopodiumsporites* (Lycopodiaceae), *Lygodiumsporites* (Schizaeaceae), *Cyathidites*, etc. Here again, like in Lat-Rymbai and Jarain areas, the bottom coal seam has much more pteridophytic spores than the top seam which has more of angiospermous pollen.

Singh and Tripathi (1986) on the basis of pollen-spore records along Jowai-Sonapur Road (Tripathi & Singh, 1984) envisaged the existence of humid tropical flora during Palaeocene-Eocene epochs and on the basis of persistence presence of a variety of dinoflagellate cysts even in some coal seams they are of the view that the coal-bearing sediments "appear to have been deposited under brackish-water to shallow-marine conditions". On the other hand, from Sutunga (Mandal, 1986), Lat-Rymbai and Jarain area (pers. comm. Dr M. Kumar) no marine indications have been recorded. Nevertheless, coastal to near-shore conditions are evident from the palynological assemblages.

Garo Hills, Meghalaya—Palynological assemblage of coal seams and associated sediments (Singh *et al.*, 1975; Singh, 1977a, b) of Tura Formation, Jaintia Group in Nangwalbibra area of West Daranggiri Coalfield, is dominated by pteridophytic spores belonging chiefly to families Lycopodiaceae, Matoniaceae, Polypodiaceae, Schizaeaceae and Gleicheniaceae. The two important coal seams (No. 1 and 2 main seam) contain almost identical taxa. Pollen are represented most by genera *Spinomonosulcites, Proxapertites, Spinozonocolpites* (Arecaceae) and *Matanomadhiasulcites* (Liliaceae). Other significant angiospermous pollen associates belong to families Bombacaceae, Leguminosae, Gunneraceae, Meliaceae, Onagraceae, Nyssaceae, Labiatae, Polygonaceae, Myrtaceae, Myrsinaceae, Lentibulariaceae (*Utricularia*) and Droseraceae. Some coal seams, older than the main seam, in the southern part of the area are characterized by the persistent presence of microforaminifera (Singh *et al.*, 1975).

An analysis of palynofloral assemblages led Singh *et al.* (1975) and Singh (1977a, b) to believe that the coal seams and associated sediments in the northern and southern parts of the area were deposited under warm humid climate near coastal area in a shallow fresh water regime perhaps representing deltaic environment. However, sediments below main coal seam in the southern part of the area locally experienced marine incursions.

Plant megafossil records (Table 8) from Meghalaya includes several taxa belonging to tropical evergreen to semi-evergreen forests (tree of moderate to large size). They are *Drancotomelum, Polyalthia, Bombacites, Bursera, Canarium, Lophopetalum, Bischofia, Hydnocarpus, Gomphandra, Barringtonia, Calophyllum Artocarpus, Sonneratia, Sterculia, Grewia* and *Trema* besides coastal/beach/near-shore including back mangrove, mangrove associate and mangrove taxa, viz., *Nypa, Barringtonia, Sonneratia, Calophyllum, Litsea, Neolitsea, Phoebe, Ósmanthus, Ligustrum* and *Derris* (see Bande, 1992).

The megafossil records thus confirm the existence of tropical climate with high rainfall in the area as also reflected by palynofossils. The flora consists of desiduous forest vegetation with definite arborescent taxa (Singh & Sarkar, 1990). It is also confirmed that the coastal to mangrove vegetation were responsible for the formation of coal seams in Meghalaya during Palaeocene Epoch.

Neyveli Lignitefield, Tamil Nadu—Extensive palynological investigations carried out on the main lignite seam (Ramanujam, 1966; Ramanujam & Reddy, 1984; Ramanujam *et al.*, 1984, 1985; Navale & Misra, 1979b; Singh, 1987; Singh & Misra, 1991a, b, c) from three mines in the field reveal that the assemblage is very rich in angiospermous pollen (± 70.0-82.0%) with only subordinate amount of pteridophytic spores. Fungal remains are common to very common in the seam. Pteridophytes are represented mainly by a variety of schizaeaceous spores besides subordinate amounts of those belonging to Polypodiaceae and Osmundaceae. Occasionally, in one bore-core sections, spores of *Dandotiaspora* do occur commonly in the III mine just below the lignite seam (in lignitic clay bed : Singh *et al.*, 1992). Among the angiospermous remains, dicots are prevalent over monocots both qualitatively and quantitatively. Significant pollen taxa (Table 8) recovered from the main lignite seam belong to families Alangiaceae, Anacardiaceae, Araliaceae, Arecaceae, Avicenniaceae, Bombacaceae, Brassicaceae, Clusiaceae, Combretaceae, Ctenolophonaceae, Dipterocarpaceae, Droseraceae, Euphorbiaceae, Haloragaceae, Hippocrateaceae, Icacinaceae, Lecythidaceae, Leguminosae, Lentibulariaceae, Liliaceae, Lythraceae, Meliaceae, Menispermaceae, Nymphaeaceae, Nyssaceae, Oleaceae, Plumbaginaceae, Poaceae, Potamogetonaceae, Proteaceae, Rhizophoraceae, Rosaceae, Rubiaceae, Santalaceae, Sapindaceae, Sapotaceae, Sonneratiaceae, Sterculiaceae, Thymeliaceae, Tiliaceae, Typhaceae and Ulmaceae. In addition to this, other significant pollen genera with unknown affinity are—*Scrobiculatricolporites, Bacuspinulopollenites, Bacustephanocolpites, Vellaripollis, Dakshinipollenites, Tamilipollenites, Neyvelicolpites, Spinoporotetradites, Tricolporotetradites,* etc.

Plant megafossil records (Table 8) include taxa like *Bouea, Gluta, Phoenix, Calophyllum, Mesua, Garcinia, Terminalia, Hopea, Shorea, Diospyros,* *Litsea, Barringtonia, Dalbergia, Azadirachta, Carallia, Perinari, Altingia* and *Sonneratia*, etc. (Lakhanpal, 1974; Navale, 1973; Awasthi, 1974, 1984; Awasthi & Agarwal, 1986; Agarwal, 1988, 1990; pers. Comm. Drs N. Awasthi, M. B. Bande, J. S. Guleria & A. Agarwal). Besides, coniferous representatives (Podocarpaceae) clearly confirm deciduous (arborescent) forest vegetation of tropical climate with high rainfall (Awasthi, 1974, 1984). Taxa like *Phoenix, Barringtonia, Gluta, Terminalia, Diospyros, Dalbergia, Altingia, Calophyllum, Carallia, Sonneratia* including some others clearly establish the existence of luxuriant coastal beach, littoral, swampy including back mangrove and mangrove vegetation which were responsible for the formation of the main lignite seam in the Neyveli Lignitefield.

According to Ramanujam *et al.* (1984), in the I mine, the bulk of the seam including lignitic clay bed was laid down under back mangrove condition with more of fresh water influence than brackish. In the III mine area the lignite seam has the predominance of arecaceous pollen with mangrove elements and has similar floral composition as that of the I mine (Singh, 1987). All these evidences collectively indicate its deposition with brackish water influence, some what similar to that of the I mine (Singh *et al.*, 1992).

Palana Lignitefield (Bikaner), Rajasthan—In the Palana palynological assemblage (Sah & Kar, 1974) common pteridophytic spores are *Schizaeoisporites, Lygodiumsporites* and *Cheilanthoidspora* (Cheilanthaceae). Spores of Lycopodiaceae, Osmundaceae and Matoniaceae are minor constituents. Monocot pollen *Palmaepollenites* and *Spinomonosulcites* of Arecaceae, *Retipilonapites* of Potamogetonaceae and *Liliacidites* of Liliaceae are in dominance among angiosperms. The important dicot pollen genera are affiliated to Alangiaceae, Anacardiaceae, Clusiaceae (*Kielmeyerapollenites* and *Calophyllumpollenites*), Hippocrateaceae (*Hippocratiacidites*), Leguminosae (*Margocolporites*), Meliaceae (*Meliapollis*), Nympheaceae, Rubiaceae (*Cupuliferoidaepollenites*), Proteaceae, Onagraceae, etc. Algae are represented by *Botryococcus* only, whereas associated microplanktons, viz., *Palania, Octaplata, Psilasphaera,* etc. are common. Fungal remains include a variety of spores, hyphae and epiphyllous fruiting bodies. Plant megafossils (Table 8) include a representative of Arecaceae (*Cocos*) and *Mesua, Garcinia* and *Calophyllum* of Clusiaceae (Bande, 1992) which are inhabitants of tropical rainforest, especially of coastal to near-shore environment. Brackish water influence is indicated by *Cocos.* Even these scanty megafossil records support the view that during the lignite seam formation, a moist evergreen forest existed in the area, not far from the place of deposition which was presumably coastal to deltaic and the shore-line lay nearby (Sah & Kar, 1974). They also presume that near shore swamp was a natural habitat for fern and fern allies.

Panandhro Lignitefield (Kutch), Gujarat—The lignite seams and associated sediments of Panandhro Formation (Lower Eocene) have yielded a variety of pollen-spores, algae and phytoplanktons (Kar, 1985). Fungal elements are especially frequent (60.0-80.0%) in Seam no. 1 and 2. Phytoplanktons are occasionally dominant in the Seam no. 1 (up to 78.0%), whereas algae (*Botryococcus*) are persistently present (5.0-40.0%) with occasional high incidence above Seam no. 4 (40.0%).

The pteridophytic spores in the assemblage are referable to families Lycopodiaceae (*Lycopodiumsporites*), Schizaeaceae (*Lygodiumsporites*) and Matoniaceae (*Dandotiaspora*). Recovered significant angiospermous pollen (Table 8) belong to the families—Alangiaceae, Apiaceae, Arecaceae (*Proxapertites, Arengapollenites, Spinomonosulcites, Spinozonocolpites,* etc.), Bombacaceae (*Lakiapollis*), Asteraceae, Clusiaceae, Combretaceae, Lecythidaceae (*Marginipollis*), Liliaceae, Meliaceae, Poaceae, Polygalaceae, Proteaceae, Rhizophoraceae and Thymeliaceae. Since, the number of samples yielding pollen spores (10 samples out of 50) were limited, only a general conclusion can be deduced from the assemblage described by Kar (1985).

Very little megafossil information (Lakhanpal & Guleria, 1983) is available from the area (Table 8). The list includes *Terminalia* (Combretaceae), *Cinnamomum* (Lauraceae), *Lagerstroemia* (Lythraceae), *Ficus* (Moraceae), *Syzygium* (Myrtaceae) and *Pandanus* (Pandanaceae). Palynological and megafloral evidence (Lakhanpal & Guleria, 1983; Kar, 1985) reflect a coastal, beach and litroral swampy including mangrove plant communities of a evergreen forest dominated by angiospermous plants (mostly tree) fluorishing under humid tropical climate in the Panandhro Lignitefield and nearby areas during Early Eocene Epoch.

Lignite from Cambay Basin, Gujarat—The lignite seams and associated sediments of Kadi and overlying Kalol formations of Lower and Middle Eocene epochs respectively were palynologically investigated, in detail, by Rawat *et al.* (1977), Venkatachala and Chowdhary (1977) and Mathur and Chowdhary (1977). The microfloral assemblages recovered from the sediments of both the formations including lignite seams are dominated by angiospermous pollen referable to families—

Arecaceae (*Nypa, Arenga Calamus, Mauritia*), Liliaceae, Anacardiaceae, Apocynaceae (*Alyxia, Holorrhena, Tabermontana*), Araliaceae, Capparidaceae, Clusiaceae, Combretaceae, Cruciferae, Ctenolophonaceae (*Ctenolophon*), Fabaceae (*Caesalpinia*), Fagaceae (*Castanea*), Hippocrateaceae, Jugalandaceae (*Engelhardtia*), Lecythidaceae (*Barringtonia, Careya, Planchonia*), Lentibulariaceae, Meliceae (*Melia, Azadirachta*), Moraceae (*Ficus* type), Myriacaceae (*Myrica, Ganacomyrica*), Myrsinaceae (*Myrsine*), Myrtaceae, Oleaceae (*Anacolosa*), Pedaliaceae (*Sesamum*), Polygonaceae, Proteaceae (*Guevina, Pteriphila, Symphonema*), Rhizophoraceae (*Rhizophora, Brugiera* type), Rubiaceae (*Coprosma, Coffea*), Sapindaceae (*Cupenia, Cupaniopsis*), Sapotaceae, Sonneratiaceae (*Sonneratia*), Symplocaceae (*Symplocos*), Umbelliferae and Verbenaceae (*Avicennia*). Main pteridophytic spores are represented by Lycopodiaceae, Schizaeaceae and Osmundaceae. The pollen-spore assemblages of Kadi and Kalol formations have dominance of either pollen of palms or mangrove plants. Pteridophytic spores are normally poorly represented in Kadi Formation. Lignite seams and coaly shales contain higher proportions of pollen of mangrove and mangrove associate plants. Representation of arecaceous (Palm) pollen is next in abundance.

The preceding microfloral evidences led Rawat *et al.* (1977) and Venkatachala and Chowdhary (1977) to presume that the lignite seams of Kadi Formation were formed from *in situ* mangrove dominated-palm rich vegetation accumulating in near-shore brackish water swamps. Whereas, the lignite seams of the Kalol Formation were deposited in lagoons, brackish water marshes and swamps from the similar vegetation which contributed for the lignite seams of the underlying Kadi Formation (Mathur & Chowdhary, 1977). The vegetal matter was very rich in lipid material.

A synthesis of available geological (Raju & Srinivasan, 1983), biopetrological (Pareek, 1983; Samanta, 1987) and palynological (Rawat *et al.*, 1977; Venkatachala & Chowdhary, 1977; Mathur & Chowdhary, 1977) information on the Kadi and Kalol lignites and their apparent biopetrological similarities with those from Kutch and Rajasthan (Misra & Navale, 1992; Pareek, 1984) lead to the following generalization. The lignite seams of Kadi and Kalol formations formed from angiospermous coastal, intertidal to near-shore mangrove dominated vegetation in which arborescent plants played a major role as reflected by rich resinite content and predominance of huminite macerals. The lignite seams being quite thick (up to 60 m, average 15 m), extensive and very clean point to their autochthonous origin with supply from a wet deciduous forest in the area. Common presence of biogenic pyrite in the lignites and associated sediments confirms anoxic alkaline (brackish) nature of the swamp water. The accumulation of vegetal matter appears to have taken place in estuarine and lagoonal swamps. Existence of marsh as presumed by Mathur and Chowdhary (1977) is not corroborated either by biopetrological or palynological evidences.

DISCUSSION

As is evident, the available geological, sedimentological, mega- and micro-floral and biopetrological information are mostly of a general nature, non-sequential, of a very restricted nature and rather meagre in relation to the present context. In some areas there is complete lack of biopetrological and palaeobotanical information. Therefore, the present attempt to deduce the origin of the Indian Tertiary coals and lignites can only be of a general nature. Several questions still remain unanswered, which would be resolved only when sufficient information is accumulated.

The overall floral evidence (Table 8) reasonably establishes that the areas that provided source material for the Tertiary coal and lignite deposits were inhabited by tropical evergreen to semi-evergreen forests along with back mangroves, mangrove associates and mangrove plant communities. Herbs and shrubs including pteridophytes grew profusely as undergrowths in the forests and back mangroves, especially genera of Lycopodiaceae, Polypodiaceae and Schizaeaceae. Other moisture and shade loving ferns of cosmopolitan nature, viz., Cyatheaceae, Matoniaceae, Parkeriaceae, etc. were also commonly associated. Fresh-water lakes and ponds interspersed in the area were the sites for aquatic and water-edge angiospermous plants like *Nymphaea*, a waterlily, *Potamogeton, Utricularia, Drosera*, etc. In the tropics where temperatures are high, forest growth and swamp preservation are controlled by year round continuity of precipitation rather than the total annual volume (Thompson & Hamilton, 1983).

The Palaeocene-Eocene coals and lignites of Meghalaya, Rajasthan and Gujarat were primarily formed from a rich inland and mangrove vegetation dominated by arborescent and herbaceous angiosperms as well as herbaceous pteridophytic taxa. Among angiosperms, contribution of monocots, especially palms was much more significant than dicots. Pteridophytes were mostly represented by

Lycopodiaceae, Matoniaceae and Schizaeaceae associated with Cheilanthaceae, Cyatheaceae, Osmundaceae, etc. During Oligocene in Assam and Nagaland an apparent change, both in quality and quantity of pteridophytic contribution, is witnessed alongwith higher representation of dicots over monocots in the coal-forming vegetation. Important pteridophytes recorded belong to Parkeriaceae and Polypodiaceae alongwith Schizaeaceae. During Miocene, in Tamil Nadu, dicot taxa with new entrants were highly diversified and distinctly predominated over monocots. The pteridophytes registered further decrease represented mostly by spores of Schizaeaceae and Polypodiaceae.

Coastal to near-shore regions, normally being low-lying with their gradient gradually approaching sea-level are drained with river courses splitted into several minor distributory channels which cover a large areal extent. These channels, as a rule, are shallow, sluggish (low energy) and anastomosing. They are seasonally choked with stream-load material resulting into inundations of even larger areas alongwith suspended-load material. This periodic inundation helps to maintain persistently high (or raised or shallow) water-table (which may be even above ground level at places) and replenishes nutrients (inorganic or mineral solutes) for the plant growth. These regions when accompanied with high rainfall harbour extensive low-lying water-logged areas, potential sites for vegetal accumulations (rheotrophic-low lying, eutrophic-nutrition rich) and the resulting vegetation is prolific and dense.

The root-systems of the dense vegetation cover in and around water-logged areas serve as efficient filter mechanism to deposit normal clastic influx by the feeding channels at their margins. The coastal areas are also characterized by high seepage and heavy run-off which is conducive for the mangrove growth. This, presumably was the general environmental and depositional set up during the formation of Indian Tertiary coals and lignites. It is therefore, appropriate to call the vegetal accumulation during Palaeocene-Miocene epochs a swamp instead of marsh or bog as has been informally considered hitherto.

On the basis of geological and sedimentological studies only general and broad depositional models have been suggested for various Tertiary coal and lignite-bearing sedimentary formations of Palaeocene to Miocene epochs. Coastal, deltaic, lagoonal, estuarine, shallow marine and back-swamp conditions of deposition have been visualized in northeastern India (Mathur & Evans, 1964; Das Gupta, 1979; Raja Rao, 1981; Misra, 1981). However, Bhandari *et al.* (1973) consider that the coal seams in Assam and Nagaland formed under fluvial conditions on a delta plain. The lignite deposits of Tamil Nadu (Neyveli), Gujarat (Panandhro), Rajasthan (Palana) were laid down in lagoons (Ramanathan, 1979; Pareek, 1984; Biswas & Raju, 1973; Hardas & Biswas, 1973) whereas, those of Gulf of Cambay (Kalol) were formed under intertidal/tidal-swampy conditions (mangrove influenced : Raju & Srinivasan, 1983). Neyveli lignite is usually believed to be of autochthonous origin having more of fresh water influence than brackish (Navale, 1971, 1974; Ramanujam *et al.*, 1984, 1985). On the other hand, the Panandhro, Palana and Kalol lignites are believed to have had an allochthonous origin (Saraswati & Banerjee, 1984; Pareek, 1983, 1984). On the basis of high organic and inorganic sulphur contents in the coal seams, presence of seat-earth and intimate association with foraminiferal limestones, the coal seams in northeastern India are considered to be autochthonous in origin (Raja Rao, 1981; Misra, 1981, 1992a, c).

Low to very low proportions of clastic minerals (or ash content) in most of the Tertiary coal and lignite seams, formed *in situ* from the degradation of vegetal matter under alkaline mileau (Renton *et al.*, 1979); thick seams either devoid of (Kalol, Neyveli and Palana lignites) or with only minor parting bands (Panandhro lignites and coals of northeastern India); clean to very clean nature of vitrinite/huminite macerals and presence of clay, carbonaceous clay/shale or other fine grained sediments as seam floor and roof preclude the possibility of their formation primarily from drifted vegetal matter. Record of extensive well-preserved megafloral remains of resistant to delicate nature and presence of possible root-zones (refer megascopic characters) within the Neyveli lignite seam can only be explained as to have been incorporated from the *in situ* plants as well as from those growing just in the vicinity of the ancient peat swamp.

Cohen (1984) and MacCabe (1984) observed that the deltaic models for coal formation have been overplayed by the geologists and the peats of deltaic environments would produce only thin seams with too much ash or mineral matter to be of economic value. However, presence of typical mangrove, mangrove associate and back mangrove taxa, viz., *Rhizophora, Carallia, Sonneratia, Avicennia, Nypa, Phoenix, Barringtonia, Excoecaria, Calophyllum, Terminalia, Alangium*, etc. alongwith several varieties of other coastal/beach taxa (Table 8) can not be rejected for fear of over emphasizing similar conditions of deposition. The good quality coal and lignite seams with thickness varying between 0.5-18.0 m and 1.5-27.0 m, respectively testify for their economic significance.

Presence of microforaminifera (Singh *et al.*, 1975) and dinoflagellate cysts (Tripathi & Singh, 1984) in thin (1.0 m) coal seams of Garo and Jaintia Hills respectively and phytoplanktons in lignite seams (> 1.5- > 10.0 m) of Palana (Sah & Kar, 1974) and Panandhro (Kar, 1985) are the irrefutable proofs of marine and brackish water influences. Persistent and frequent to common association of early diagenetic pyrite together with calcite in coal and lignite seams are additional positive evidences establishing brackish-water influence during coal and lignite seam formation.

Bright unbanded coal seams and sparingly banded lignite seams with high to very high vitrinite/huminite and poor sporinite contents (Tables 4, 5, 7) are indicative of their formation from forest vegetation (Misra, 1992a, c; Misra & Navale, 1992; Stach *et al.*, 1982). Rich desmocollinite/humodetrinite fractions with common to frequent association of fungal remains in the seams relate with warm humid (tropical) climate and peat accumulation, in general, under subaqueous condition, i.e., under high water-table with high degree of aerobic fungal and bacterial degradation in acrotelm (aerobic upper zone) and anaerobic bacterial degradation in catatelm (Clymo, 1987). It is because of this reason that fungal remains in most of the seams, especially in the thick seams, constitute a significant proportion of the total inertinite content (Pareek, 1983; Misra, 1992c; Misra & Navale, 1992). Since, syngenetic pyrite and calcite occurring together are definite indicators of anaerobic and alkaline mileau, ombrogenous-oligotrophic (raised and nutrition poor) peat-bogs are acidic in nature (Teichmüller, 1989; Cameron *et al.*, 1989). Possibility of the Indian Tertiary coals and lignites to have been formed as raised-bogs (ombrogenous peat) is improbable. Instead they appear to have originated from rheotrophic-eutrophic peatswamp.

Palaeoshore-line parallel orientation of the Tertiary coal and lignite seams and deposits (Raja Rao, 1981; Ramanathan, 1979; Singh *et al.*, 1992; Pareek, 1984; Raju & Srinivasan, 1983) in Assam, Nagaland, Tamil Nadu, Rajasthan and Gujarat, in spite of intense tectonic disturbances in the former two areas, is itself indicative of the existence of lagoonal swamps. On the other hand, tectonically least disturbed, impersistent and thin (< 1.0-3.0 m thick) coal seams of Garo, Khasi and Jaintia Hills of Meghalaya with N-S, NE-SW or NW-SE orientation, in patches even in a single coalfield (Raja Rao, 1981) suggest peat formation in small and isolated low lying estuarine or estuarine back-swamps caused by encroachment of sea on an undulating Precambrian (Garo Hills) or Cretaceous (Khasi and Jaintia Hills) sediments. Thin and patchy nature of coal seams occurring at close vertical intervals (2 to 8 seams) also reflect frequent and relatively unstable conditions during coal forming episode of Palaoecene Epoch. Whereas, in Assam and Nagaland the basins enjoyed far more stable tectonic conditions during coal formation of Oligocene Epoch as is evident by the thick and areally extensive nature of coal seams. Similar tectonic conditions appear to have prevailed also in lignite-bearing areas of Tamil Nadu, Rajasthan and Gujarat.

Association of fine-grained sediments with the coal and lignite seams (Table 3) indicates deposition mostly from the suspended-load material by sluggish low-energy channels with sediment source from a quite probably an almost peneplained provenance. This condition is quite evident in Meghalaya where three limestone members occur alternating with arenaceous members including that which bears the coal seams (Raja Rao, 1981). From these evidences, it has been concluded that short-lived peat swamp formations in Meghalaya were controlled by minor sea-level fluctuations caused by episodic and a slightly increased rate of basin subsidence just imbalancing the prevailing rate of vegetal supply but not significant enough to cause any apparent change in the provenance. The fact that no drastic vegetational change has been recorded during the formation of coal seams in Meghalaya clearly indicates that minor sea-level fluctuations did not cause extermination of the existing flora in the area. More or less similar (continuance of existing flora) conditions appear to have existed in Assam and Neyveli as most of the common taxa are well recorded throughout the section. The apparent change in palynoflora from the top part of the Seam no. 3 upwards in the Panandhro Lignitefield may be due to poor/selective yield of the samples as well as barren nature of several samples below this horizon. Certain coal (Meghalaya) and lignite seams (Panandhro) have relatively high proportions of mineral matter. In this context a case study completed recently in Panandhro Lignitefield (Misra & Navale, 1992) is as follows:

In the initial stages of vegetal accumulation influence of feeding channels in the peat swamp is characterized by high detrital influx, low pyrite content suggesting dilution of anoxic-alkaline mileau by fresh water addition and replenishment of oxygen brought by the incoming waters in dissolved state. Seam nos. 3 and 4 reveal a much more anoxic-alkaline mileau with negligible clastic influx. On the basis of Gelification Index, Tissue Preservation Index and Huminite/Inertinite ratio, Seam nos. 1 and 4 and nos. 2 and 3 respectively are nearly identical petrographically. This indicates relapse of degradational affects in Seam no.4, under relatively higher anaerobic condition and alkaline water that existed in Seam no. 1 as is evident by the highest proportions of pyrite, calcite and liptodetrinite contents. From the preceding observations it seems probable that the ancient (Tertiary) peat swamps forming seams with relatively higher proportions of mineral matter were influenced by similar depositional conditions during their formative stages.

The dominance of taxa with fresh water habitat mixed with those of typical brackish water affinity (mangrove taxa) in the coal and lignite seams is not something unusual when considering an ancient virgin coastal and near-shore forest vegetation. Because, the intermixing of flora in fossil record (in swamp) is controlled by several factors, e.g., sea-ward distributory channels flowing through the mangrove belt, tidal influence, position of fresh water feeding channels and marine inlets in the swamp, etc. Major complications arise from the dispersal pattern of allochthonous spores and pollen. In this regard a gross analogy of the ancient peat swamps, disregarding specific details, can be made with the existing near-shore marine influenced lakes on the eastern coastal margins of India (pers. comm. Dr H. P. Gupta). It is also possible that certain land-ward swamps, especially in Meghalaya, remained unaffected by marine influence for a period of time with the result fresh water aquatic flora, e.g., *Potamogeton, Nymphaea, Utricularia*, etc. flourished there to be recorded, occasionally, in high frequencies in the coal and lignite seams (Dutta & Sah, 1970; Sah & Kar, 1974).

A general correlation between high pteridophytic content and high fungal activity with high inertinite contents in the coal/lignite seam sections (Misra, 1992c; Misra & Navale, 1992) evidently imply their primary role in the formation of inertinite. Since, the cell-lumens of structured inertinites in these coal and lignite seams are invariably empty, i.e., without clastic mineral fillings, it can be presumed that the pteridophytes and associated shrubby angiosperms also grew in nearby peat swamps. However, higher proportions of structured inertinites in Seam nos. 1 and 4 of the Panandhro Lignitefield has been considered as a result of cindering rather than burning of the exposed peat surface still saturated with water.

The genesis of perhydrous vitrinite, liptodetrinite and bituminite together with biogenic pyrite and calcite requires an almost identical and specific conditions. Therefore, high contents of these macerals and pyrite and calcite association in almost all the Tertiary coal and lignite seams of India have a direct bearing on their genesis (Misra, 1992a, c). This maceral and mineral association is characteristic of subaquatic and sapropelic including calcium-rich coals (Stach *et al.*, 1982; Teichmüller, 1989). Syngenetic (biogenic) pyrite formation requires anaerobic bacterial growth (negative Eh-potential), neutral to mildly alkaline mileau (pH 6.5-8) and stagnant water body (Stach *et al.*, 1982). Conditions favouring pyrite precipitation is readily available near marine influenced zones in certain lagoons and estuaries where wave and current action is negligible (Cecil *et al.*, 1979). Under such conditions, in the presence of abundant organic matter, though acrotelm may still have aerobic influence, coalification in catatelm proceeds by putrefaction (fermentation) with the help of anaerobic bacterial degradation instead of normal peatification. As a consequence of this process (bituminization) perhydrous vitrinite, bituminite and liptodetrinite are produced with enrichment of proteinaceous, fatty-lipoid and other hydrogen-rich microbial, algal and microfaunal degradational products (Stach *et al.*, 1982; Teichmüller, 1989). similar conditions, with varying degree of fermentation or putrefaction influence, have been visualized for the genesis of Indian Tertiary coal and lignite seams of northeastern India (Misra, 1992a, c), Rajasthan, Gujarat (Misra & Navale, 1992) and Tamil Nadu (Singh *et al.*, 1992).

CONCLUSIONS

The Indian Tertiary coal and lignite seams, in general, are bright unbanded (coals) and sparingly banded (lignites) in appearance, rich to very rich in vitrinite/huminite macerals with subordinate amounts of inertinite and liptinite macerals. The vitrinite/huminite macerals are mainly represented by vegetal degradational products—desmocollinite/humodetrinite fractions. Structured vitrinite macerals — telocollinite/humotelinite + humocollinite are occasionally predominant, e.g., in certain seams of Gujarat, Tamil Nadu and northeastern India. Main inertinite macerals are sclerotinite (fungal remains) and inertodetrinite with subordinate proportions of structured inertinites (semifusinite and fusinite). Structured inertinites are especially significant in some lignite seams of Panandhro and coal seams of Garo and Jaintia Hills. Associated inorganics are mainly syngenetic pyrite and calcite along with minor to moderate amounts of clay and quartz. The latter two minerals are only occasionally significant in certain seams (Gujarat & Meghalaya).

Under blue light excitation the Tertiary coal and lignite seams have been found to contain appreciably high amount of fluorescing macerals chiefly formed by perhydrous vitrinite/huminite (especially in coal), liptodetrinite and resinite macerals. Maceral bituminite is commonly associated intimately with the former two macerals. Maceral resinite, though commonly present in all the coal and lignite seams, is quite significant in certain seams of Gujarat, Meghalaya and Assam. Other liptinite macerals—cutinite, suberinite, sporinite, exsudatinite, fluorinite and alginite in order of decreasing abundance, are present in subordinate amounts. Alginite (*Botryococcus*), present in all the coal and lignite seams, is especially common in the lignites of Panandhro, Palana, Neyveli and coals of Garo Hills area.

The Tertiary coal and lignite deposits originated primarily from deciduous/evergreen angiospermous forest vegetation growing under humid tropical climate. The coal and lignite forming flora consisted of inland, coastal, beach, back mangrove, mangrove associate and mangrove plant communities besides, moisture and shade loving angiospermous herbs and shrubs as well as pteridophytes. The gymnosperms in most of the areas were represented by podocarpacean plants. In some areas, e.g., in Jaintia and Garo Hills of Meghalaya and Palana (Rajasthan) and Panandhro (Gujarat) occurrences of microforaminifera, dinoflagellates and phytoplanktons indicate definite marine or brackish water influence. A distinct changing pattern has been witnessed by coal and lignite forming fossil angiospermous and pteridophytic representations from Palaeocene to Miocene epochs.

These coals and lignite deposits originated from hypoautochthonous to autochthonous rheotrophic/eutrophic peat swamps. The vegetal matter experienced high aerobic fungal and bacterial degradation in the acrotelm and extensive anaerobic mainly bacterial degradation in the catatelm. The peats were hemic to sapric in nature. The vegetal accumulation took place under subaqueous condition (i.e., under high water table to even submerged conditions) in lagoons or near shore back-swamp with brackish water mileau in Assam, Nagaland, Rajasthan and Gujarat and in small isolated estuarine back swamps or estuarine swamps in Meghalaya. Occasionally, small fresh water ponds/lakes developed on the peat surface facilitating growth of aquatic and water-edge plants (e.g., in Rajasthan, Tamil Nadu and Meghalaya). Shrubby pteridophytes and angiosperms growing in the vicinity of peat swamps were responsible for the major part of the structured and detrital inertinites. However, occasional natural cindering of peat surface, e.g., in some seams of Gujarat and Meghalaya, produced relatively more structured inertinites. Extensive oxidation, desiccation or burning of peat surface due to aerial exposure or forest fire is non-existent. The genesis of coal/lignite or coalification trend of the ancient vegetal accumulation, e.g., in majority of seams from northeastern India, Rajasthan and Gujarat, was to a greater extent influenced by putrefaction rather than purely by humification. The variation in coal/lignite seam thickness and rank were controlled by the then existing tectonic conditions and geothermal gradients in different areas.

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