Tertiary coals of Makum Coalfield, Assam, India : Petrography, genesis and sedimentation

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The two most important coal seams, viz., Seam no. 1 (18 m thick) and Seam no. 3 (6 m thick), of the Tikak Parbat Formation, Barail Group (Oligocene) are overlain by > 2000 m thick sediments of younger age. The coals are bright and non-banded in appearance. They are rich in vitrinite with subordinate amounts of liptinite and inertinite macerals. Early diagenetic pyrite and calcite alongwith clay and quartz are the main associated minerals. Under blue light excitation high amount of fluorescing macerals recorded are formed chiefly by perhydrous vitrinite, liptodetrinite and resinite. Minor amount of sporinite, cutinite, suberinite and exsudatinite are also present with sporadic occurrence of fluorinite and alginite. A comparison of Makum coals with the other Tertiary coals of India has also been attempted. The coals have low moisture and ash contents with high volatile matter and calorific value in relation to their rank by reflectivity measurements. The rank of the coal seams (R_o max. 0.72-0.75%) corresponds to high volatile bituminous B stage.

From the biopetrological, palaeobotanical and geological evidences it has been concluded that the coal seams originated mostly from *in situ* mangrove-mixed angiospermous forest vegetation growing under humid to per-humid tropical climate. The vegetal accumulation took place in a rheotrophic swamp forming in a near-shore lagoon on a lower delta plain. The maceral and mineral associations in the coal seams indicate that the accumulated vegetal matter was mainly subjected to anaerobic microbial degradation under elevated swamp water pH (> 6). This facilitated the precipitation of early diagenetic pyrite, calcite and *in situ* release of plant-derived minerals in the peat. Under these conditions highly pyriteous and perhydrous coal seams were formed mainly by putrefaction. Whenever microbial degradation of organic matter was severe normal vegetal supply fell short to produce a peat layer, with the result minor and major authigenic partings within the coal seams were formed.

Key-words—Petrology, Petrography, Sedimentation, Makum Coalfield (India).

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साराँश

असम (भारत) में माकुम कोयला-क्षेत्र के तृतीयक कोयले : शैलविन्यास, उत्पत्ति एवं अवसादन

बसन्त कुमार मिश्र

बैरेल समूह के टिकाक पर्वत शैल-समूह की दो अत्यन्त महत्वपूर्ण कोयला-सीमों अर्थात् सीम-1 (18 मीटर मोटी) तथा सीम 3 (6 मीटर मोटी), के ऊपर अल्पायु के लगभग 2000 मीटर मोटे अवसाद विद्यमान हैं। ये कोयले देखने में चमकीले एवं अपट्टित हैं तथा लिप्टीनाइट एवं इनर्टीनाइट की कुछ मात्रा के साथ-साथ इनमें विट्रीनाइट की भरपूर मात्रा है। इसके अतिरिक्त मिट्टी एवं क्वार्ट्ज़ तथा प्रारम्भिक प्रसंघनीय पायराइट मुख्य सहयुक्त खनिज हैं। नीले प्रकाश में प्रेक्षित प्रतिदीप्त खनिज मुख्यतया परहाइड्रस विट्रीनाइट, लिप्टोडिट्रीनाइट एवं रेजिनाइट से बने हैं। इसके अतिरिक्त स्पोरीनाइट, क्यूटिनाइट, सुबेरीनाइट एवं एक्सूडेटिनाइट की अल्प मात्रा तथा यदा-कदा फ्लोरीनाइट एवं एल्जिनाइट भी प्रेक्षित किये जाते हैं। माकुम कोयला-क्षेत्र के कोयलों की भारत के अन्य तृतीयक कोयलों से तुलना का भी प्रयास किया गया है।

जैवशैलिकीय, पुरावनस्पतिक एवं भूवैज्ञानिक प्रमाणों से यह निष्कर्ष निकाला गया है कि इस क्षेत्र की कोयला-सीम मुख्यतया स्वस्थाने मैंग्रोव मिश्रित आवृतबीजी वनों से बनी हैं जहाँ पर कि उष्णकटिबन्धीय नम जलवायु विद्यमान थी। यह वनस्पति अधस्थ डेल्टा-मैदान में तटीय समुद्र तल में बनने वाली धारानुवर्ती दलदल में संग्रथित हुई थी। कोयला सीमों में मेसीरलों एवं खनिजों की उपस्थिति से इंगित होता है कि वनस्पतिक-सामग्री का अवायवी जैविक ह्रास पी-एच० 6 से अधिक वाली परिस्थितियों में हुआ था और इसी के फलस्वरूप पीट में पाये जाने वाले प्रारम्भिक प्रसंघनीय पाइराइट एवं केल्साइट का अवक्षेपण हुआ तथा स्वस्थाने पादप-उत्पादित खनिज पादप-अवयवों से मुक्त हो गये। इन्हीं परिस्थितियों में अत्याधिक पाइराइटमय एवं परडाइड्रस कोयला-सीमों का निर्माण हुआ। कार्बनिक पदार्थ के अत्याधिक जैविक ह्रास के कारण साधारण वनस्पतिक आपूर्ति कम हो गई तथा फलस्वरूप पीट सतहों के स्थान पर लघु एवं बृहत् तत्रजनित पट्टियाँ बन गईं।

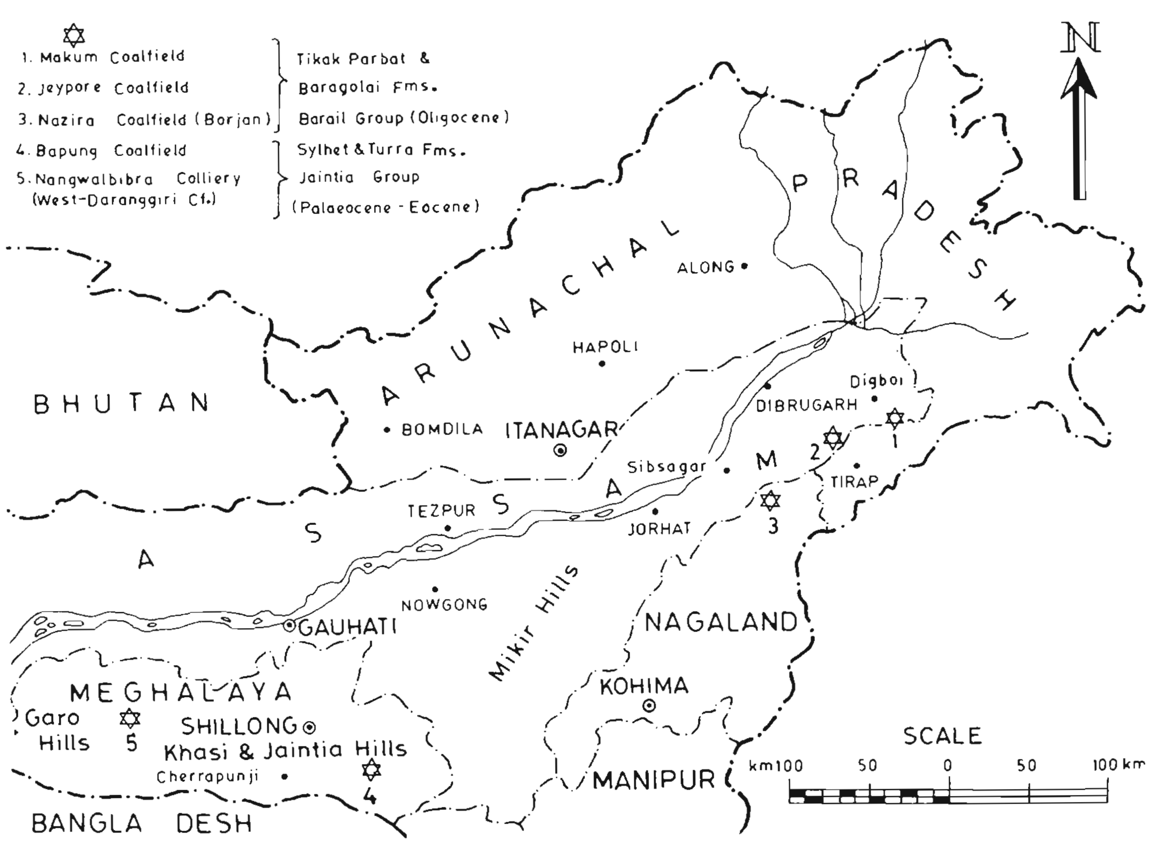
IN India, the northeastern states—Meghalaya, Assam, Nagaland and Arunachal Pradesh are well known for their Tertiary coal deposits (Text-fig. 1) associated with Palaeocene-Eocene and Oligocene sediments. Economically the most important Tertiary coal deposits of the region as well as of the country occur in Makum Coalfield, Assam. The field accounts for nearly 90 per cent of the coal produced in the region with an estimated reserve of 335.6 million tonnes (Raja Rao, 1981).

The Makum Coalfield lies between latitudes 27° 15′ to 27° 25′N and longitudes 95° 40′ to 95° 55′E towards the northeastern fringe of Dibrugarh District and adjacent to Margherita town. Coal mining operation in the field spreads within a linear belt of 25 km. Medlicott (1865) and Mallet (1876) did detailed geological work in the area. Later, Geological Survey of India (Raja Rao, 1981) and Coal India Limited (CIL, 1976, unpublished report) carried out a detailed geological and drilling operations for coal exploration in the area.

The Tertiary coals of northeastern India, in general, and that of Makum Coalfield, in particular, have not been studied in detail. Sporadic investigations carried out so far, based on only few samples (Mukherjee, 1976; Navale & Misra, 1979, 1980; Misra, 1991; Goswami, 1985, 1987), provide only a general information on these coals. The paper, therefore, deals in detail about nature and organic composition of economically most important coal seams of the Makum Coalfield alongwith their genesis and sedimentation pattern.

GEOLOGY, LITHOSTRATIGRAPHY AND STRUCTURE OF MAKUM COALFIELD

The Makum Coalfield is the largest of the four major coalfields (Namchik-Namphuk, Dilli-Jeypore and Nazira or Borjan) aligned along an active mobile belt with a series of imbricate overthrusts, known as 'belt of Schuppen'. The thrusting is accompanied by folding and interlocked slicing of the Tertiary strata. The sediments of this belt were presumably deposited in an external trough near the platform corresponding to miogeosyncline where rapid subsidence and detrital supply resulted into thick pile of Tertiary sequence. However, intermittent phases of slight emergence during Oligocene Epoch allowed the development of wide spread peat accumulation (Raja Rao, 1981). The lithostratigraphic sequence in the Makum Coalfield, after Raja Rao (1981) is as follows:



Text-figure 1—A map showing major Tertiary coalfields in northeastern India.

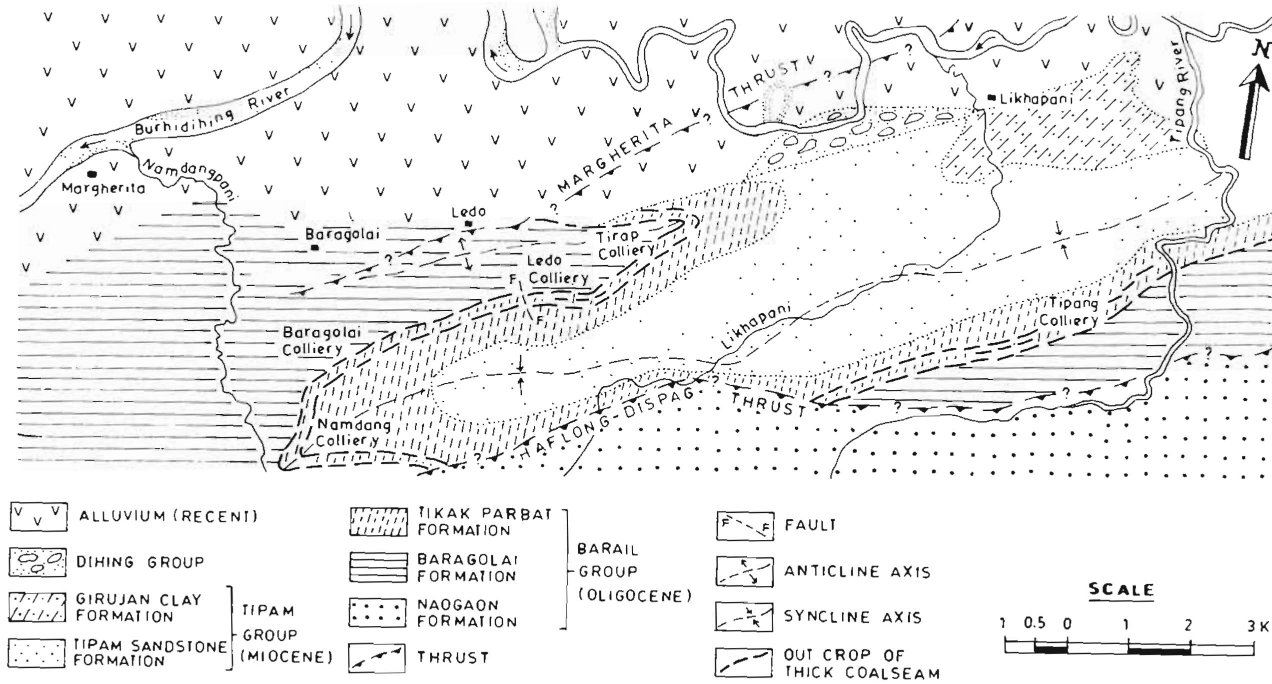
GROUP AGE	FORMATION	LITHOLOGY
Recent—Pleistocene	Alluvium	Alluvium and high level terraces
Dihing Pliocene		Alternating pebble beds, coarse bluish green, grey felspathic and ferruginous sandstone and grey to brown clay
	Girujan Clay Formation	Variegated clay, silty clay, bluish green and grey sandstone (± 470 m)
Tipam Miocene	Tipam Sandstone Formation	Coarse, gritty and massive bluish green to grey felspathic and micaceous sandstone. Variegated clay, sandy clay, shale, coaly streaks, silicified woods and conglomeratic sandstone (± 1000 m)
	Tikak Parbat Formation	Hard and light coloured quartose sandstone. Alternations of siltstone, sandy shale, shale, mudstone, carbonaceous shale and thin impersistent coal seams (± 409 m) Alternations of siltstone, mudstone, shale, carbonaceous shale, clay and workable coal seams. Occasional clayey sandstone, clay and sandy shale (± 200 m)
Barail Oligocene	Baragolai Formation	Alternations of buff, bluish green and grey coloured sandstone, sandy shale, carbonaceous shale, sandy clay, clay and thin impersistent seams of coal and shaly coal. Hard massive and flaggy, grey micaceous and ferruginous sandstone and oilsand (± 2743 m)
	Naogaon Formation	Hard compact and flaggy dark gray fine-grained sandstone and interbeds of grey splintary shale (± 1525 m)
Disang Eocene		Dark grey splintery shale with interbeds of dark grey and fine-grained sandstone (± 3000 m)

The upper two conformable formations i.e. the Tikak Parbat and Baragolai formations, of the Barail Group are coal-bearing and were designated as "Coal-Measure Sub-Series" by Mallet (1876). The Tikak Parbat Formation contains five coal seams in the basal 200 m section. The coal seams of the formation are listed in ascending order as under:

Seam no. 5	
(2.4 m/8 ft thick)	1.3-2.5 m abondoned
Parting	30.0-40.0 m
Seam no. 4	
(1.5 m/5 ft thick)	1.2-1.8 m/often merges with Seam no. 3. Abondoned.
Parting	3.0-18.0 m
Seam no. 3	
(6 m/20 ft thick) (composite seam)	2.0-7.5 m worked out in 2 sections
Parting	38.0-68.0 m
Seam no. 2 (New Seam)	
2.1 m/7 ft thick	1.5-2.6 m
Parting	5.0-20.0 m
Seam no. 1	
(18 m/60 ft thick) (composite seam)	10.0-20.8 m/worked out in 2 or 3 sections

The Tikak Parbat Formation comprises alternations of sandstone, siltstone, mudstone, shale, carbonaceous shale, clay and coal seams. Each such cycle commences from one sandstone band to the next in the sequence. The frequency of alternations of fine-grained sediments increases when a coal seam is approaching (Misra, 1981). No coal seam/seam section of a composite seam is in direct contact with a sandstone bed. Argillaceous sandstone and shale beds frequently contain nodules or nodular bands of clay iron-stone. Slumping and convolutions in fine-grained sediments are common. The coal seams and associated carbonaceous shale, shale, siltstone and mudstone beds contain specks of pyrite. Impure dolomitic limestone band is also encountered above seam no. 3 eastwards beyond Ledo colliery area (Misra, 1981; Raja Rao, 1981). Five additional younger and impersistent coal seams (0.10-1.7 m thick) have been recorded 127 meter above seam no. 3 in the eastern part of the area (Raja Rao, 1981). The Baragolai Formation conformably underlies Seam no. 1 of Tikak Parbat Formation which serves as the dividing stratum between the two formations. The Baragolai Formation is more arenaceous in nature and contains several impersistent coal seams (< 1 m thick) in the upper middle to upper sections of the sequence (Misra, 1981).

Coal seam no. 1 is separated into two, rarely three, sections with the development of one or two parting(s) of widely variable thicknesses. The major parting is usually 3 to 7 meter thick (range 1.5-10.0 m). There are additional, 2 to 5, minor partings within the seam sections with thickness mostly between 0.5 to 1.0 meter. In seam no. 3, 2 to 4 partings usually below 0.8 m are encountered at intervals (C.I.L, 1976). The partings mostly consist of clay, mudstone, carbonaceous shale or dark grey



Text-figure 2—A geological map of the Makum Coalfield, Assam (after Raja Rao, 1981 modified by Misra, 1981).

shale. Clay or carbonaceous shale occurs below (floor) the coal seams whereas, roof is usually represented by carbonaceous and dark grey shales occasionally with sandy shale.

Both the coal seams are nearly of uniform thickness between Namdang and Ledo-Tirap collieries. Towards the eastern part, in Tipang area, variation is more pronounced. This fact is also evident from coal/non-coal stratal ratio (1 : 3.9-5.5 in Namdang-Ledo area and 1 : 8.7-1 : 12.6 towards Tipang area) and the ratio between clay and sandstone (1 : 0 to 1 : 0.76 from west to east; Misra, 1981).

The Tertiary strata in the Makum Coalfield are sandwitched between Margherita and Haflong-Disang thrust in the north and south respectively (Text-fig. 2). With the result the beds have been folded into a major northeast plunging syncline and a complimentary anticline on its northern limb. The northern limb of the anticline has been abruptly cut off by Margherita thrust. Whereas, entire sediments of Baragolai Formation and a major part of the Tikak Parbat Formation on the southern limb of the syncline in the western part of the field are sliced off by Haflong-Disang thrust. The entire sequence reappears eastwards south of Likhapani and continues even beyond the coalfield (Misra, 1981; Text-fig. 2).

MATERIAL AND METHOD

Twenty seven representative samples were prepared after crushing all the 112 samples collected from freshly exposed mine and quarry faces in Namdang, Baragolai, Ledo-Tirap and Tipang collieries. Individual samples thus prepared represent a seam section. Additional samples were used wherever a thick clean coal section was encountered. Following is the details of sample/pellet used in the present study.

Collierv	Seam no. 1			Seam no. 3		
	Top	Middle	Bottom	Top	Middle	Bottom
Namdang	1	1	1	1	—	1
Baragolai	2	1	2	1	—	1
Ledo-Tirap*	1	3	2	1	—	1
Tipang	1	2	1	1	1	1

Twenty-seven particulate pellets were prepared and studied on Leitz MPV-1 and MPV-3 units under normal reflected light and reflected blue light excitation. Standard preparation methodology,

*In the following text, illustrations and Tables Ledo instead of Ledo-Tirap has been uniformly used if otherwise necessary.

maceral and rank ($R_o$max. %) assessment procedure were followed as described by Misra (1991). The Tables and illustrations (Tables 2,4,5,6; Text-figs 3-8) provide average maceral data where more than one pellet was studied for a seam section.

CHEMICAL CHARACTERISTICS

The coal seams of Makum Coalfield show a lower rank by their high volatile matter and fixed carbon contents whereas on the basis of their low moisture content and high calorific value a higher rank can be assigned. The chemical nature of coal seams in the area has been inferred presently on the data provided by Raja Rao (1981).

On the basis of overall proximate chemical data (Table 1) seam 1 and 3 appear to be identical, yet seam no. 1 differs from seam no. 3 in having lower ash and sulphur contents, higher fixed carbon and calorific value. Seam no. 3 has highest total sulphur content amongst five main coal seams in the coalfield. Total sulphur content and the different forms of sulphur, i.e., pyritic (2.8-21.9%), sulphate (2.8-19.6%) and organic (59.9-94.2%), in all the five coal seams vary widely without any trend both laterally and vertically. The abnormality in rank in relation to chemical properties of these coals has been attributed to their high sulphur content (Das Gupta, 1979; Raja Rao, 1981).

The Makum coals exhibit good coking property (caking index up to 39 B.S.S.) and high swelling index (5.0-5.5). On ultimate analysis they show 81.6 to 83.0 per cent carbon, relatively high hydrogen (5.3-5.9%) and low oxygen (8.5% by difference) contents for their rank. They yield 160 to 191 litres of tar per tonne and G type coke on L.T.C. at 600°C. This amount of tar yield is the highest amongst Indian coals. Their high conversion factor (80-85%) has been attributed to the catalytic influence of sulphur. Because of their easy amenability to liquefaction, they are loosely called as half-way between oil and coal (Das Gupta, 1979).

MEGASCOPIC CHARACTER

The Tertiary coal seams of Assam, in general and those of the Makum Coalfied in particular, are markedly dissimilar megascopically when compared

Table 1—Proximate analysis data of coal seam nos. 1 and 3 of Makum Coalfield, Assam (compiled from Raja Rao, 1981)

Colliery	Proximate Analysis (%) on ex-band air dried basis (*dry mineral free)					
	Moisture	Ash	Volatile Matter	Fixed Carbon	Calorific Value K Cals/kg	Total Sulphur
Seam no. 3						
Baragolai	2.4	5.9	42.4 (45.9)*	49.3	7310 (8030)*	5.31
Tikak	2.1-2.5	3.2-4.9	42.5-43.6 (45.2-46.0)*	50.4-50.8	7445-7500 (8030-8085)*	5.37-5.43
Tipang	2.5	4.1	44.0 (46.7)*	49.4	—	5.57
Seam no. 1 Top Section						
Baragolai	2.0	3.0	41.8 (43.6)*	53.2	7790 (8265)*	2.3
Tikak	2.3	2.7	42.5 (44.6)*	52.5	7730 (8110)*	2.76
Tipang	2.5	3.0-3.8	43.7-45.1 (45.9-47.7)*	48.9-50.8	7705 (8215)*	2.52-3.42
Seam no. 1 Bottom Section						
Namdang	2.2-2.3	3.2-3.3	42.1-44.6 (42.2-44.7)*	51.8-52.5	7740-7760 (8220-8305)*	2.7-2.8
Baragolai	1.9-2.4	1.9-4.8	41.9-44.5 (44.4-46.8)*	50.4-53.6	7595-7925 (8280-8370)*	2.35-2.95
Tipang	2.0-2.7	2.6-3.1	42.4-44.0 (44.3-46.1)*	50.6-52.8	7805-7830 (8240-8260)*	—

with the typical banded bituminous Gondwana (Permian) coals. These coals are jet black in colour with vitreous lustre, devoid of any perceptible lithotype banding and are entirely made up of vitrain (Misra, 1981). The coal is blocky in nature because of two sets of fracture planes and crumbles easily on separation from the seam. It breaks with subconchoidal to conchoidal fracture. Tiny pyrite specks are frequent in the coal. Pyrite concretions and encrustations are also common especially in seam no. 3 (Misra, 1981). The coal burns easily in flames when ignited. The coal surface breaking parallel to the bedding plane shows structureless and slightly raised circular or elongated glossy mass of various sizes. Similar structure has also been observed by the author in some of the tectonically affected vitrain-rich coal seams of India.

MICROSCOPIC CHARACTER

Under normal incident light

The coal seam nos. 1 and 3 (Table 2) are rich in desmocollinite (30.0-47.1%) and telocollinite plus minor amount of telinite (20.0-32.4%). Desmocollinite and telocollinite are highly gelified. Desmocollinite and a fraction of telocollinite show spongy or granular texture. Shattering and crushing effects are common in most of the samples. The liptinite macerals are in subordinate amount (5.0-9.5%) mainly consisting of resinite (2.5-6.3%) and sporinite (0.9-2.4%). Low to moderate proportion of inertinite macerals (9.1-17.0% in 23 samples; > 17.0-20.5% in 4 samples) are chiefly formed by sclerotinite (2.6-9.8%), inertodetrinite (1.5-9.6%)

Table 2—Composition of macerals and mineral matter in the coal seam section (Seam nos. 1 and 3) from four collieries of Makum Coalfield, Assam (under normal reflected light)

Seam section	Seam number	Ro max. %	Maceral composition (Volume %)																	
			Vitrinite				Liptinite						Inertinite				Mineral Matter			
			Telinite+ Telocollinite	Desmocollinite	Corpocollinite	Total	Sporinite	Cutinite	Suberinite	Resinite	Exsd. + Fluorinite	Total	Semifusin. + Fusinite	Intdt. + Macr. + Micr.	Sclerotinite	Total	Clastics	Pyrite	Calcite	Total
NAMDANG COLLIERY																				
Nd. Top	No. 3	0.73	22.5	42.0	2.5	67.0	2.4	0.7	0.6	3.5	0.5E.	7.7	3.3	4.7	7.9	15.9	4.1	2.2	3.1	9.4
Nd. Bottom			30.1	31.0	3.0	64.1	1.6	1.5	—	3.5	—	6.6	5.5	4.9	3.6	14.0	2.5	3.8	9.0	15.3
Nd. Top	No.		28.0	36.7	2.5	67.2	1.4	0.6	0.4	2.7	0.3E.	5.4	1.7	4.8	2.6	9.1	3.5	6.3	8.5	18.3
Nd. Middle	1	0.73	24.1	43.2	2.8	70.1	1.0	—	1.0	3.5	—	5.5	3.8	6.5	6.3	16.6	2.7	3.8	1.3	7.8
Nd. Bottom			28.7	46.1	2.1	76.9	0.9	—	0.7	4.1	0.3E.	6.1	4.4	3.4	4.0	11.8	1.4	2.6	1.2	5.2
BARAGOLAI COLLIERY																				
Bg. Top	No. 3	0.72	27.5	31.8	1.9	61.2	2.0	1.0	1.0	3.3	—	7.3	5.5	7.3	6.7	19.5	1.2	7.7	3.1	12.0
Bg. Bottom			27.7	32.9	3.2	63.8	1.5	0.8	2.0	3.8	0.7E.	8.8	5.0	4.0	8.0	17.0	3.2	4.9	2.3	10.4
Bg. Top	No.		32.3	41.1	1.4	74.8	1.0	0.4	0.9	3.8	—	6.1	2.9	5.2	5.0	13.1	—	5.0	1.0	6.0
Bg. Middle	1	0.74	30.1	40.1	1.3	71.5	1.0	0.9	0.3	4.0	0.6E.	6.8	1.3	5.5	7.9	14.7	5.8	0.8	0.4	7.0
Bg. Bottom			25.0	38.8	2.3	66.1	1.5	1.0	0.7	4.1	0.2E.	7.5	4.4	5.9	9.8	20.1	3.2	1.9	1.2	6.3
LEDO-TIRAP COLLIERY																				
Ld. Top	No. 3	0.74	23.2	42.4	1.8	67.4	1.5	1.0	0.8	4.7	—	8.0	2.3	7.5	4.4	14.2	3.9	4.0	2.5	10.4
Ld. Bottom			24.2	34.3	2.0	60.5	1.7	0.5	—	3.7	—	5.9	2.3	5.5	[illegible]	11.8	7.8	8.3	5.7	21.8
Ld. Top	No.		29.4	38.6	2.0	70.0	1.6	0.5	0.8	2.5	0.5E.	5.9	4.0	4.8	4.7	13.5	4.1	3.4	3.1	10.6
Ld. Middle	1	0.74	25.1	37.6	2.8	65.5	1.1	0.6	1.0	3.7	0.2E.	6.7	3.7	6.3	6.1	16.1	3.8	4.8	3.1	11.7
Ld. Bottom			26.9	46.1	1.8	74.8	1.2	0.7	0.6	3.8	0.6E.	6.9	2.3	4.4	3.9	10.6	2.5	3.6	1.6	7.7
TIPANG COLLIERY																				
Tp. Top	No.		31.5	39.0	1.7	72.2	1.3	0.9	0.7	6.3	0.3E.	9.5	3.0	1.5	6.1	10.6	1.1	5.1	1.5	7.7
Tp. Middle	3	0.75	26.5	40.1	1.9	68.5	1.8	1.9	0.9	3.5	0.3E.	8.4	2.7	4.0	5.9	12.6	5.0	3.8	1.7	10.5
Tp. Bottom			31.4	40.5	2.3	74.2	1.0	0.7	0.6	2.7	—	5.0	3.8	3.3	4.6	11.7	5.6	1.6	1.9	9.1
Tp. Top	No.		20.0	41.0	3.3	64.3	1.5	1.0	0.6	4.0	0.3E.	7.4	4.9	5.9	5.4	16.2	5.9	1.7	4.5	12.1
Tp. Middle	1	0.75	25.0	34.1	1.8	60.9	1.9	1.2	0.5	4.2	0.3E.	8.1	1.6	7.0	4.3	12.9	6.9	5.1	6.1	18.1
Tp. Bottom			22.6	44.0	2.0	68.6	1.3	0.8	0.4	3.8	—	6.3	1.7	8.3	5.4	15.4	4.3	3.6	1.8	9.7

and semifusinite plus fusinite (0.9-6.0%). The associated inorganics (4.4-12.4% in 22 samples; 14.5-21.8% in 5 samples) are early diagenetic framboidal and granular pyrite (0.8-8.3%), concretionary calcite (0.4-9.0%) and clastic minerals-clay and quartz (1.1-7.8%).

Under blue light excitation

Coal seam nos. 1 and 3 have high proportions of fluorescing macerals (78.4-88.5% and 78.0-88.6% m.m.f. respectively) of which 41.8 to 63.5 per cent is formed by perhydrous vitrinite (Table 3). Fluorescence properties of various macerals in the Tertiary coals of northeastern India including those from the Makum Coalfield have already been described by Misra (1991). Non-fluorescing vitrinite (a fraction of telocollinite and corpocollinite) and inertinite macerals together (10.9-22.0% m.m.f.) are low to moderate in amount in both the seams. Liptinite group (21.5-40.3% m.m.f.) consists chiefly of liptodetrinite (14.2-27.2% m.m.f.) and resinite (4.0-13.6% m.m.f.) macerals. Sporinite, cutinite, suberinite, exsudatinite and fluorinite together constitute 1.5 to 5.6 per cent (m.m.f.) in both the seams.

RANK OF COAL SEAMS

The calculated $R_o$max. percentage for Seam no. 1 in all the four collieries varies between 0.73 to 0.75 per cent. Seam no. 3 shows $R_o$max. ranging from 0.72 to 0.75 per cent (Table 2). On the basis of reflectance value the coal seams have attained the rank of high volatile bituminous B stage. The degree of shattering in the two coal seams does not show any positive influence on the rank ($R_o$max. %) variation. When compared with chemical properties, the $R_o$max. per cent values do not correspond with

Table 3—Composition of fluorescing and non-fluorescing macerals (m.m.f.) in the coal seam sections (Seam nos. 1 & 3) from four collieries of Makum Coalfield, Assam (as analyzed under incident blue light excitation)

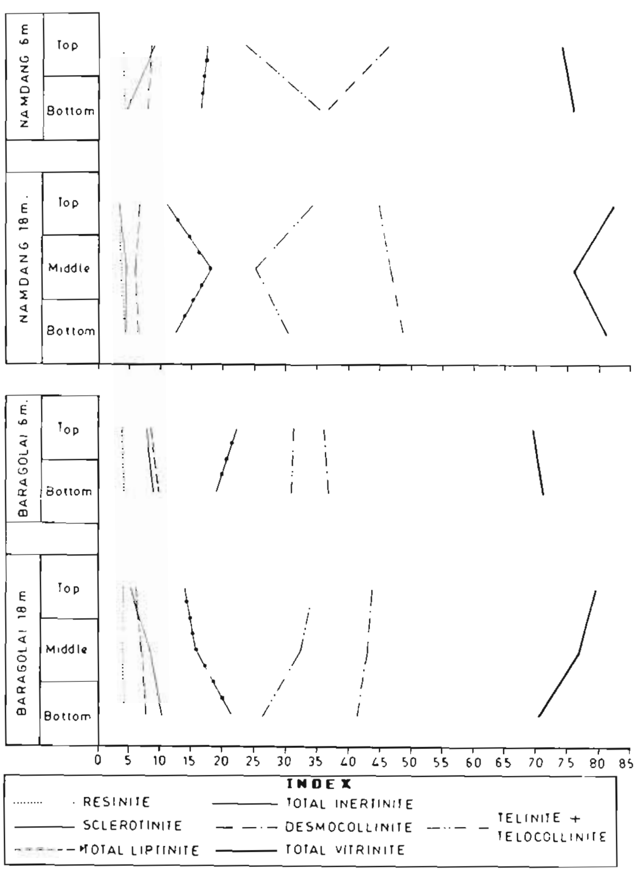
Seam section	Seam number	Maceral composition (under blue light excitation) % m.m.f.										
		Non fluorescing Vitrinite + Inertinite	fluorescing Macerals									
			Sporinite	Cutinite	Suberi-nite	Resinite	Exsudt. + Fluorin.	Sp.+Cu.+ Sub.+R.+ Exd.+Fl.	Liptodetrinite	Total Liptinite	Vitrinite	Total Fluoresc. Macerals
NAMDANG COLLIERY												
Nd. Top	No.	18.9	1.7	1.0	0.5	4.0	—	7.2	20.7	27.9	53.2	81.1
Nd. Bottom	3	16.1	1.5	—	—	8.9	—	10.4	21.5	31.9	52.0	83.9
Nd. Top	No.	11.5	0.8	0.9	1.5	7.2	0.3E.	10.7	21.6	32.3	56.2	88.5
Nd. Middle	1	19.3	0.3	0.2	1.0	7.5	0.3E.	9.3	19.6	28.9	51.8	80.7
Nd. Bottom		13.8	1.4	0.3	0.4	6.9	—	9.0	22.0	31.0	55.2	86.2
BARAGOLAI COLLIERY												
Bg. Top	No.	22.0	0.5	0.7	0.8	8.8	0.2F.	11.0	19.6	30.6	47.4	78.0
Bg. Bottom	3	19.7	1.5	0.8	2.5	6.4	0.8E.	12.0	19.5	31.5	48.8	80.3
Bg. Top	No.	14.8	0.7	1.0	0.6	5.5	0.4E.	8.2	15.3	23.5	61.7	85.2
Bg. Middle	1	16.5	0.5	1.0	0.3	8.1	1.4E.	11.3	17.5	28.8	54.7	83.5
Bg. Bottom		21.6	1.8	1.1	0.7	7.3	0.4E.	11.3	20.9	32.2	46.2	78.4
LEDO-TIRAP COLLIERY												
Ld. Top	No.	15.9	0.9	1.7	0.7	6.0	—	9.3	17.5	26.8	57.3	84.1
Ld. Bottom	3	13.0	0.8	2.3	0.7	7.4	0.4E.	11.6	15.7	27.3	59.7	87.0
Ld. Top	No.	14.9	1.5	1.2	0.5	8.5	0.3E.	12.0	17.7	29.7	55.4	85.1
Ld. Middle	1	17.3	1.1	0.6	0.6	6.0	0.2E.	8.5	17.7	26.2	62.1	87.7
Ld. Bottom		12.3	1.8	1.2	0.6	6.4	0.2E.	10.2	15.4	25.6	56.5	82.7
TIPANG COLLIERY												
Tp. Top	No.	11.4	0.7	0.7	0.7	13.6	1.4E.	17.1	20.1	37.2	51.4	88.6
Tp. Middle	3	12.2	1.1	2.8	1.1	7.7	0.4E.	13.1	27.2	40.3	47.5	87.8
Tp. Bottom		11.6	0.4	0.5	0.5	5.7	0.8E.	7.9	22.3	30.2	58.2	88.4
Tp. Top	No.	17.6	0.6	1.1	0.6	9.0	0.5E.	11.8	23.2	35.0	47.4	82.4
Tp. Middle	1	14.0	0.9	1.5	0.5	7.8	0.5E.	11.2	18.4	29.6	56.4	86.0
Tp. Bottom		17.3	1.5	0.7	0.3	8.0	—	10.5	18.0	28.5	54.2	82.7

each other. Instead their volatile matter contents show lower rank (between sub-bituminous B to high volatile bituminous C stages). Whereas, on the basis of calorific value the coal seams show a rank equivalent to high volatile bituminous A stage with expected $R_o$max. 0.8-1.2 per cent (Table 4). The abnormality in the rank in these coals, as ascertained by chemical properties and reflectance measurements, has been attributed to their high sulphur content (Das Gupta, 1979; Raja Rao, 1981). However, according to Cecil *et al.* (1979) variable pressure condition in the coal seams influences the partial pressures of volatile products of coalification and can cause anomalies in coal rank and organic maturation indices.

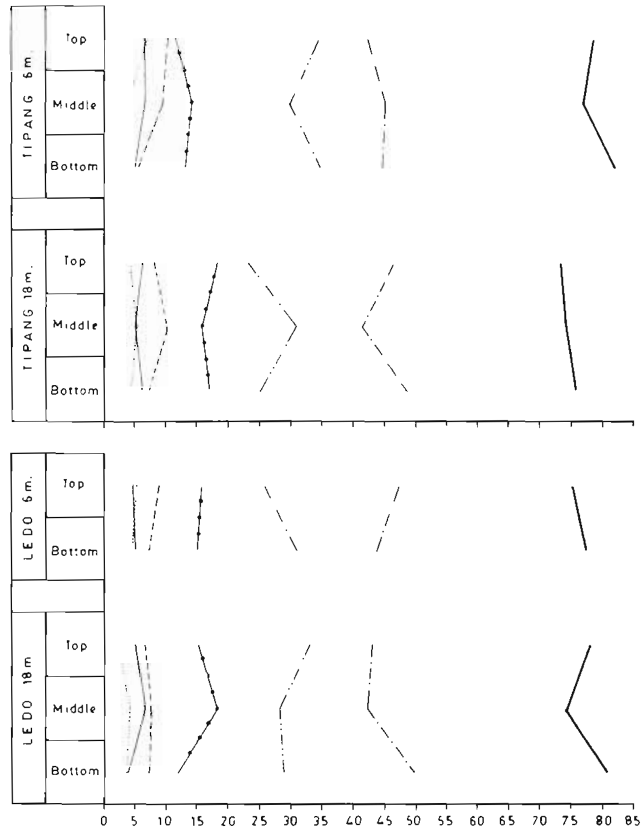
The rank ($R_o$max. 0.72-0.75%) attained by the Oligocene coal seams of the Makum Coalfield is higher than the Palaeocene coal seams of Meghalaya ($R_o$max. 0.56-0.69%). This abnormal rank behaviour has already been discussed by Misra (1991).

CHARACTERISTICS OF THE COAL SEAMS

(Table 2, 4; Text-figs 3a, b, 4a, b)



Text-figure 3a—Petrographic components (under normal) reflected light) in the top, middle and bottom sections of seam nos. 1 and 3 in Namdang and Baragolai collieries of Makum Coalfield.



Text-figure 3b—Petrographic components (under normal reflected light) in the top, middle and bottom sections of seam nos. 1 and 3 in Ledo-Tirap and Tipang collieries of Makum coalfield (index same as in Text-fig. 3a).

Seam nos. 1 and 3 are formed by vitric coal type (vitrinite-rich). Seam no. 1, except in Tipang colliery with fluctuations in the middle section, is characterized by higher vitrinite and perhydrous vitrinite contents as compared to those of seam no. 3. In Ledo-Tirap colliery both the seams have identical amount of perhydrous vitrinite. Seam no. 3 has slightly higher liptinite content than seam no. 1 which is mainly due to its higher resinite and liptodetrinite contents. On an average, the inertinite contents of both the seams appear almost identical. However, seam no. 3 in Namdang and Baragolai collieries and Seam no. 1 in Ledo-Tirap and Tipang collieries have higher amount of inertinite than those in the rest of the collieries. The low to moderate inertinite contents of both the seams are primarily because of higher proportions of sclerotinite and/or inertodetrinite rather than semifusinite + fusinite with which they do not show any apparent relation. The mineral matter content (average) of seam no. 3 is distinctly higher than that of seam no. 1 except in Tipang colliery. The pyrite content, though fluctuating, is higher in seam no. 3 than seam no. 1.

Table 4—Rank variations of the seam nos. 1 and 3 on the basis of volatile matter content (d.a.f.), calorific value (d.a.f.) and reflectance value (R_O max. %)

Colliery		Rank Stage based on Volatile Matter % (d.m.f.)	R_O max. % (Expected)	Rank Stage based on R_O max. % measured		Rank Stage based on calorific value (d.m.f.) K. Cals./kg	R_O max. % (Expécted)
Namdang	Seam 3	—	—	0.73	High volatile bituminous — B	—	—
Namdang	Seam 1	42.0-44.0 H. Vol. Bitum. — C	< 0.6	0.73	,,	8220-8305 H. Vol. Bitum. — A	> 0.9
Baragolai	Seam 3	45.9 H. Vol. Bitum. — C	< 0.6	0.72	,,	8030 H. Vol. Bitum. — A	> 0.8
Baragolai	Seam 1	43.0-46.0 H. Vol. Bitum. — C/ Sub-bitum. — B	> 0.5-< 0.6	0.74	,,	8265-8370 H. Vol. Bitum. — A/ Med. Vol. Bitum.	> 1.0-< 1.2
Tipang	Seam 3	46.7 Sub-bitum. — B	< 0.6	0.75	,,	—	—
Tipang	Seam 1	44.0-47.0 H. Vol. Bitum. — C/ Sub-bitum. — B	> 0.5-< 0.6	0.75	,,	8215-8260 H. Vol. Bitum. — A	> 0.9

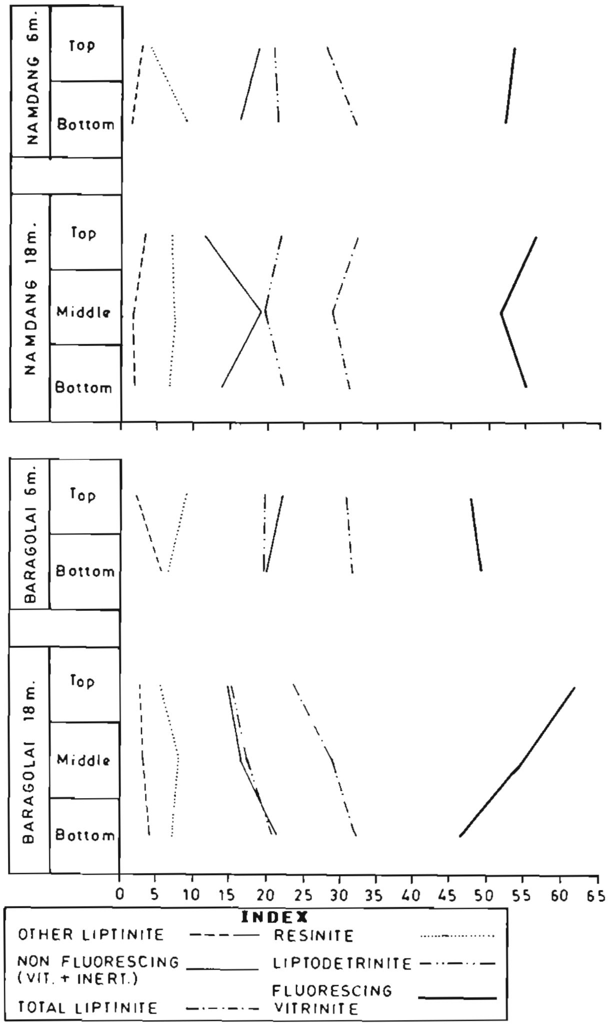
The trend of maceral variation in the two coal seams is exhibited best on mineral matter free basis. There is no apparent relationship between the contents of desmocollinite and total vitrinite, liptinites or with pyrite and calcite contents. However, telocollinite + telinite content shows positive relation with total vitrinite content. The vitrinite and perhydrous vitrinite contents, except in Namdang colliery, increase towards bottom part of seam no. 3. Whereas, in Namdang and Baragolai collieries a reverse trend is evident in seam no. 1. The liptodetrinite contents of both the coal seams, except in seam no. 1 of Namdang and seam no. 3 of Tipang collieries, show opposite trends with those of the perhydrous vitrinite and vitrinite. The liptinite contents of both the seams show mixed/fluctuating trends with those of vitrinite and perhydrous vitrinite. With one or two exceptions, the mineral matter content shows upwards and downwards increasing tendencies in seam no. 1 and 3 respectively.

COMPARISON WITH OTHER TERTIARY COALS OF INDIA

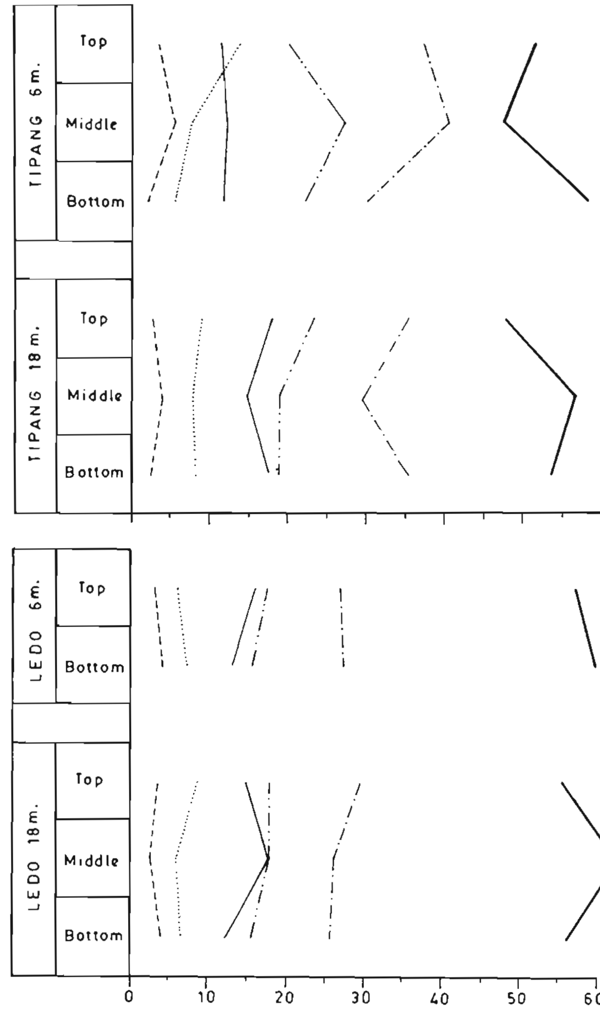
In India, Tertiary coal deposits occur in northern (Jammu & Kashmir) and northeastern (Arunachal Pradesh, Assam, Nagaland & Meghalaya) states. Published petrographic information on the Eocene semianthracites of Jammu and Kashmir are meagre (Ganju, 1956; Ghosh, 1969; Sen & Sen, 1969). The Palaeocene and Oligocene coals of northeastern India have been studied by several workers but only a general information is available based on the analysis of few samples from various localities (Ganju, 1955; Ghosh, 1964, 1969; Sen & Sen, 1969; Mukherjee, 1976; Navale & Misra, 1979; Misra, 1991; Ahmed & Bharali, 1985; Goswami, 1985, 1987). Of these, certain petrographic data are unreliable because some of them have recorded very low (Sen & Sen, 1969; 0.9-1.5% m.m.f.) or very high (Goswami, 1985; 17-48% m.m.f.) amount of liptinite macerals. Therefore, only pertinent published information and unpublished data of the author have been utilized here.

The Oligocene coals from Makum Coalfield (under normal reflected light) have a restricted range of distribution in field 4 (Text-fig. 5) partially overlapping with fields 2 and 3 of the Palaeocene coals of Jaintia Hills, Meghalaya. These coals, based on others data, lie in the field 5 with 85 >95 per cent vitrinite and decreasing liptinite and inertinite contents. Some of the other Oligocene coals of Baragolai Formation (minor coal and shaly coal seams in Makum Coalfield), Jeypore Coalfield of Assam and Nazira Coalfield, Nagaland are distributed in fields 2, 3, 5 and 6 respectively.

The Palaeocene coals of Garo and Jaintia Hills of Meghalaya show a wide range of distribution (Text-fig. 5 : fields 1-3). The coals of the Garo Hills, in the western part of Meghalaya, are characterized by the highest inertinite and lowest vitrinite contents (fields 1 and partly 2) than rest of the Palaeocene and Oligocene coals.



Text-figure 4a—Behaviour of fluorescing and non-fluorescing macerals (under blue light excitation) in the top, middle and bottom sections of seam nos. 1 and 3 in Namdang and Baragolai collieries of Makum Coalfield.



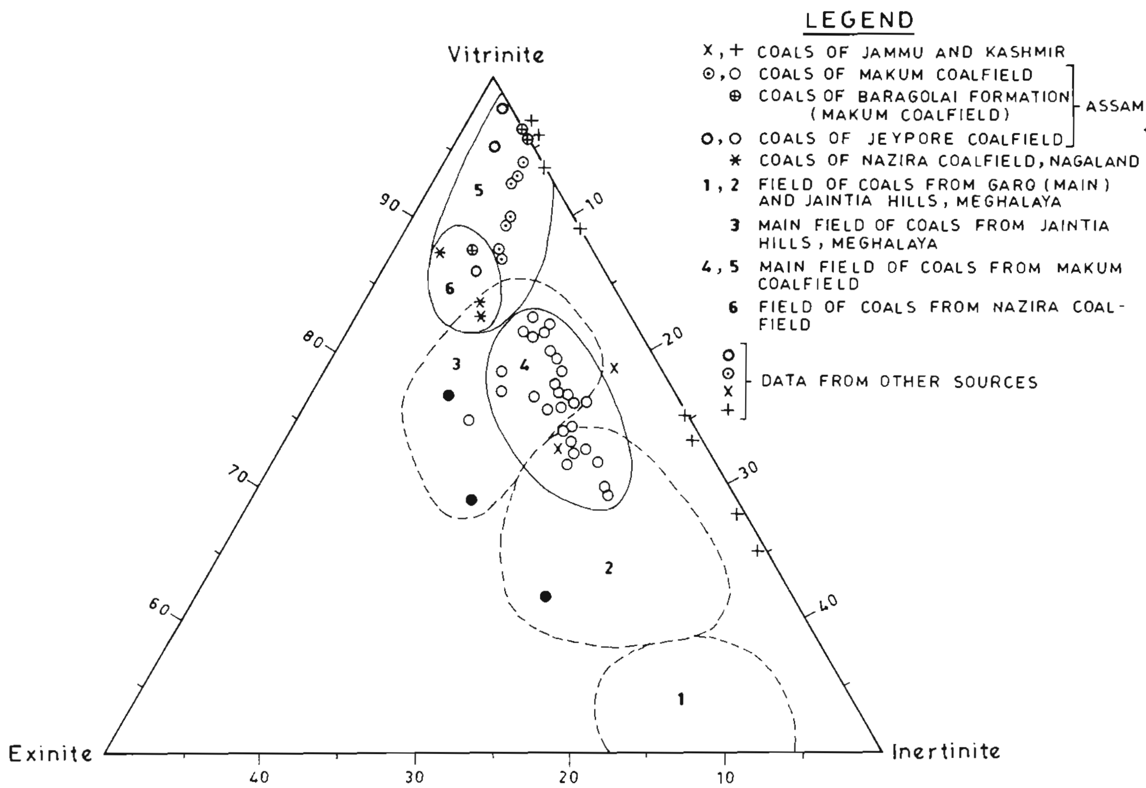
Text-figure 4b—Behaviour of fluorescing and non-fluorescing macerals (under blue light excitation) in the top, middle and bottom sections of seam nos. 1 and 3 in Ledo-Tirap and Tipang collieries of Makum Coalfield (index same as in Text-fig. 4a).

Text-figure 6, based on maceral data assessed under blue light excitation, shows identical distribution of Makum coals (field 4) as that in Text-figure 5. Majority of the coals from Garo (field 1) and Jaintia Hills (field 1, 2) have higher liptinite and non-fluorescing maceral contents than those of Makum Coalfield. Certain coal samples from Jaintia Hills have patchy distribution in field 3 overlapping with field 4 (Text-fig. 6). The coals from Jeypore (Assam) and Nazira (Nagaland) coalfields are characterised by higher non-fluorescing macerals than other Palaeocene and Oligocene coals and most of them do not figure in the diagram (Text-fig. 6).

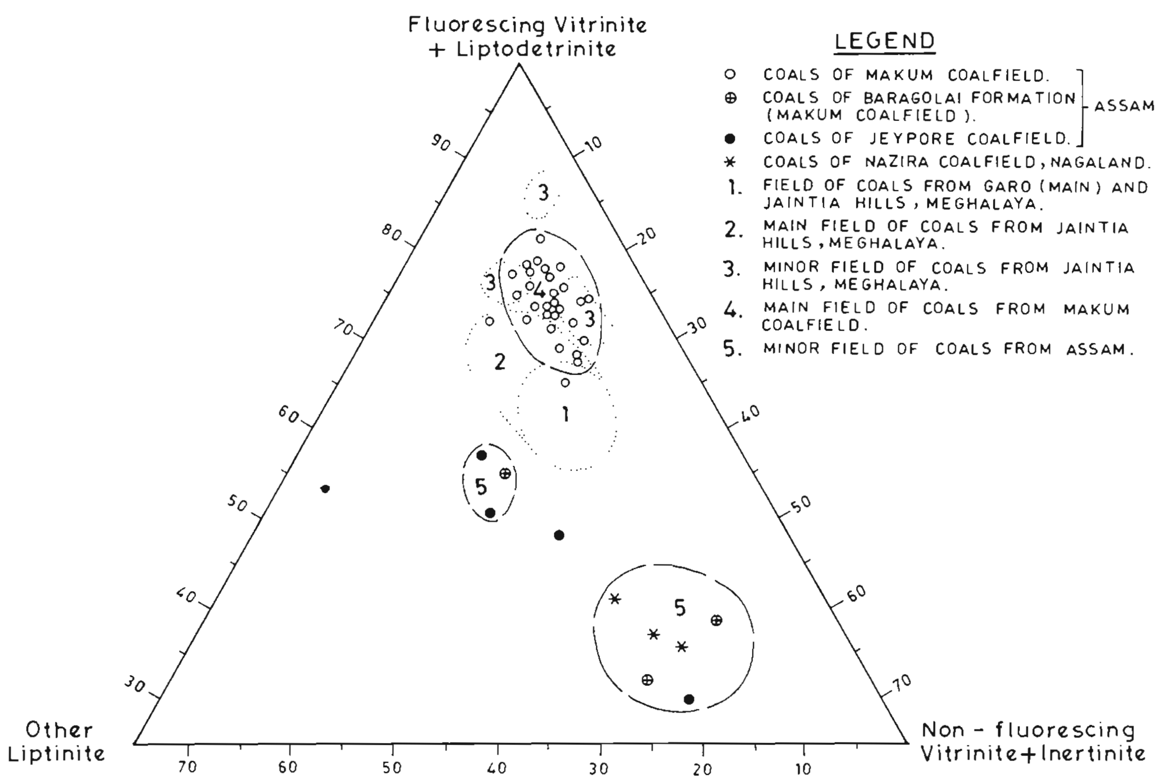
Comparison of Text-figures 5 and 6 reveals that the Makum coals and those from the coalfields of Meghalaya have nearly identical distribution pattern both under normal light and blue light excitation. This criterion may be utilized to distinguish and differentiate coal seams from different localities (spatial) and age (temporal). Text-figure 7 depicts the range of variation in Indian Tertiary coals *vis a vis* those of Gondwana, Cretaceous and Tertiary coals from western Pacific region as reported by Strauss *et al.* (1976) in Chao *et al.* (1982).

GENESIS OF MAKUM COALS

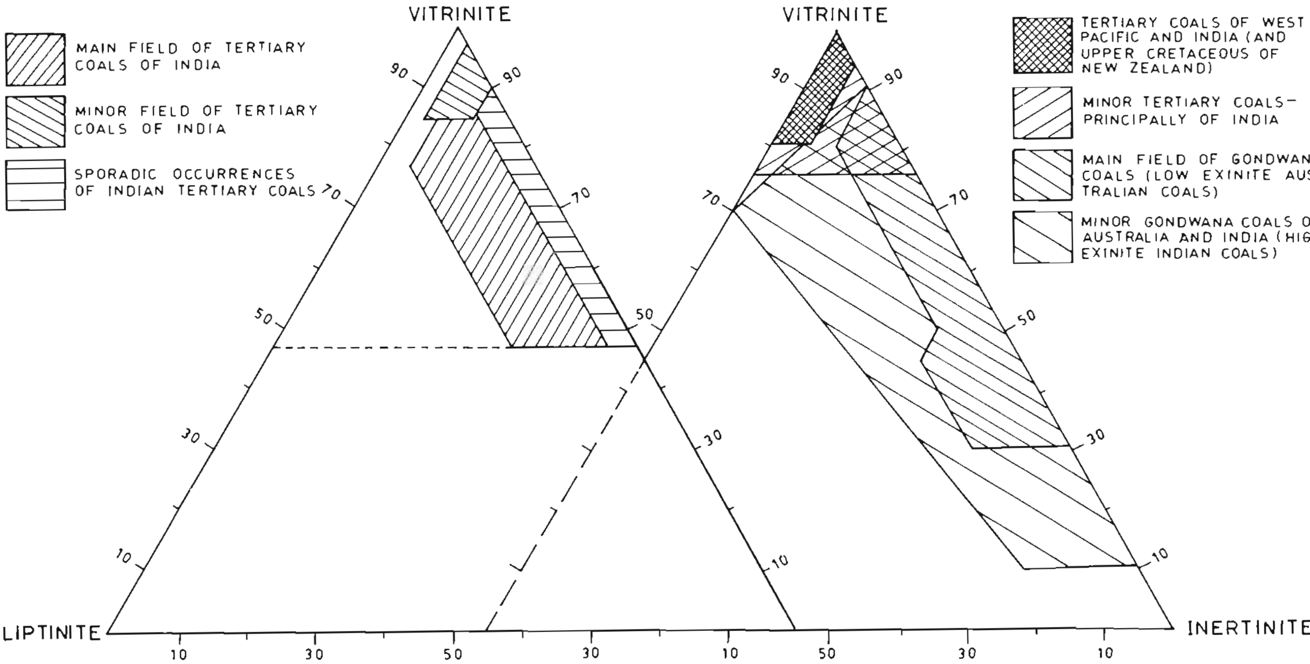
Geological information on the coal-bearing sediments of Tikak Parbat and Baragolai formations of Barail Group indicates that rising of Himalayas, coinciding with regression of sea during Oligocene Epoch, initiated deltaic sedimentation in Nagaland, eastern parts of Assam and southeastern Arunachal



Text-figure 5—Ternary diagram (VEI) showing the distribution of Tertiary coals (Palaeocene-Oligocene) of India (data from analysis under normal reflected light).



Text-figure 6— Ternary diagram showing the distribution of Palaeocene and Oligocene coals from Arunachal Pradesh, Assam, Nagaland and Meghalaya (data from analysis under blue light excitation).



Text-figure 7—Ternary diagram (VEI) showing distribution pattern of Indian Tertiary coals *vis-a-vis* Tertiary, Cretaceous and Gondwana coals of West Pacific (data source for West Pacific coals from Strauss *et al.*, 1976: in Chao *et al.*, 1982).

Pradesh (Mathur & Evans, 1964; Bhandari *et al.*, 1973; Shrivastava *et al.*, 1974; Khanna & Baghel, 1975; Raja Rao, 1981; Misra, 1981). The wide spectrum of lithofacies and their frequent lateral and vertical variations reflect a sequence of depositional environments varying from shallow marine, swampy, lagoonal and fluviatile. Isolated back water bodies or lagoons paralleling the shore-line on the prograding delta complex served as sites for peat accumulation. Presence of arenaceous foraminifera and formation-water salinity (3000-5000 ppm in terms of NaCl) indicate that the sediments of Barail Group were deposited under brackish water mileau (Das Gupta, 1979). Towards the terminal phase of Tikak Parbat Formation, fluvio-deltaic condition was established which allowed minor swamp formation, intermittently represented by 4 to 5 thin and impersistent coal seams ± 127 m above the major ones. The vegetation for the coal seam formation grew *in situ* (Raja Rao, 1981).

The present day climate of the area is tropical per-humid with a very heavy rainfall (254-320 cm) spreading between 150 to 180 days or even more annually. The water availability period (soil moisture after evapo-transpiration) is almost 350 days. The temperature and relative humidity during the year vary between 6°-36°C and 80-95 per cent respectively (Rao, 1981; Raja Rao, 1981). The vegetation in the area is luxuriant and the forest is dense with prolific undergrowths of lycopods, ferns and several varieties of herbs and shrubs. Palaeomagnetic data map (Owen, 1983; map no. 35, p. 89) indicates that during the Oligocene Epoch the area laid approximately 3°-4° south and 2°-3° east of the present day position (27°15′-25′N; 95°40′-55′E). The vegetation of the region (Champion & Seth, 1968) is more or less similar with that which grew during Oligocene as visualized on the basis of living affinities of the fossil micro-and mega-floral remains (Misra, 1992; pers. comm. Drs N. Awasthi & R. C. Mehrotra). The differences between the present and fossil flora of the region is due to the influence of Himalayan rise. Evidently, the area experienced almost similar climatic conditions as that of today.

Palynological assemblage recovered from seam nos. 1, 3 and 4 and associated sediments in the basal 200 m part of the Tikak Parbat Formation 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 (24-69%, rarely below 20%). Ganju (1955) on the basis of thin section study also noted that these coals "are entirely composed of wood which shows considerable sign of decay" caused by fungal growth. Angiospermous pollen are mostly dominant (13-42%) in the top sections of seam no. 3 (in Namdang & Tipang collieries), bottom sections of seam no. 1 (Baragolai & Tipang collieries) and seam no. 3 of Namdang colliery.

The main pteridophytic spores in the palynoassemblage (Misra, 1981) are represented by Parkeriaceae (*Striatriletes*), Polypodiaceae (*Polypodiisporites*), Cyathiaceae and Schizaeaceae (*Lygodiumsporites*). Spores of *Striatriletes* alone are present in very high frequency (40-60%) in the basal part of seam no. 1 in Baragolai and Tipang sections. The assemblage, though rich in total content of dicot pollen among angiosperms, has persistently high proportion of monocot 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 (*Heliospermopsis*; Banerjee, 1985).

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

The vitrinite-rich, sporinite-poor, bright non-banded nature of coal seams and frequent association of fungal remains indicate a tropical humid climate with high annual precipitation which facilitated the growth of luxuriant coastal to near-shore, mangrove mixed forest vegetation with prolific undergrowths during the deposition of coal-bearing sediments.

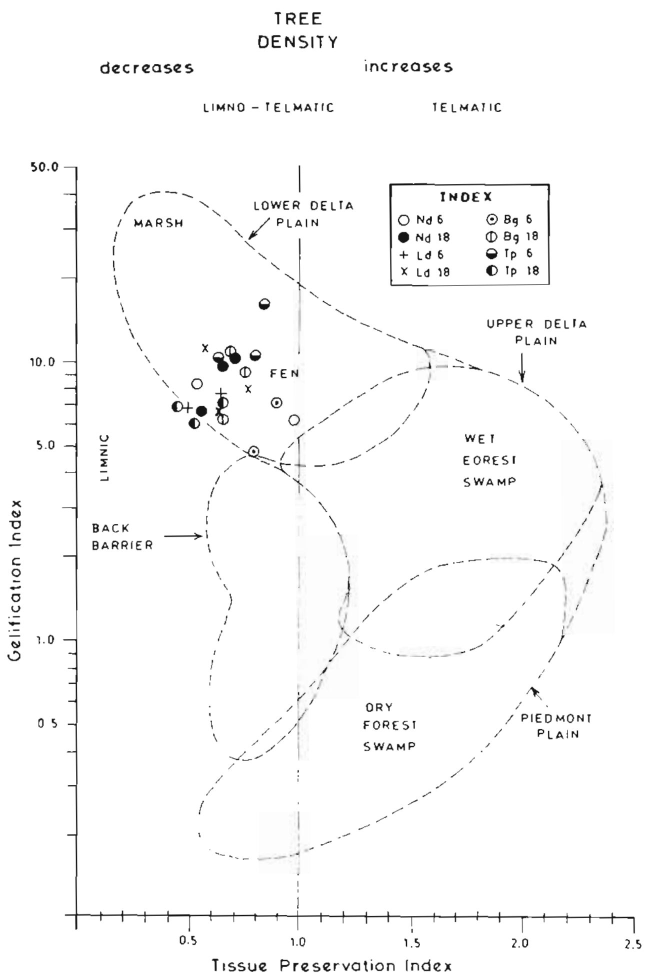
Tissue Preservation Index (TPI : 0.46-0.99) and Gelification Index (GI : 4.8-16) of the Makum coals (Table 5; Text-fig. 8) on the facies diagram of Diessel (1986) reveal that they were formed on a lower delta plain. The vegetal accumulation took place in a limno-telmatic swamp. Petrographic indices of the coal samples (Table 5), viz., VA/VB ratio (0.49-0.97), desmocollinite content (48.4-63.8%), I/R ratio (0.23-2.0) and V/I ratio (3.1-7.4), indicate decomposition of woody material with some amount of transportation prior to burial (Kalkreuth & Lackie, 1989; Diessel, 1986; Harvey & Dillion, 1985).

The preceding inferences based on petrographic indices and facies diagram (Table 5; Text-fig. 8) do not conform with the present study and geological and palaeobotanical evidences. It is, therefore, necessary to discuss the genesis of clastic minerals and inertinite macerals besides the mode of vegetal degradation in the ancient peat swamp which formed the coal seams in the Makum Coalfield.

Low amount of clastic minerals in coal seam nos. 1 and 3 (Table 2) can be explained to have been formed mainly as a result of *in situ* release of minerals bound in the tissues of existing plants (mostly woody) degrading under anaerobic alkaline mileau and partly by fixation of inorganic ionic

Table 5—Petrographic indices of the sections of coal seam nos. 1 and 3 from four collieries of Makum Coalfield, Assam

Colliery/seam	Tissue Preservation Index	Gelification Index	Vitrinite A/ Vitrinite B Ratio	Desmocollinite % on 100% Vitrinite basis	Vitrinite/ Inertinite Ratio	I/R (Sf+F/ Inertodetr.) Ratio
Nd. 6 m Top	0.55	8.4	0.53	62.6	4.2	0.70
Nd. 6 m Bottom	0.99	6.2	0.97	48.4	4.6	1.12
Nd. 18 m Top	0.71	10.3	0.76	54.6	7.4	0.35
Nd. 18 m Middle	0.56	6.8	0.56	61.6	4.2	0.58
Nd. 18 m Bottom	0.67	9.9	0.62	60.0	6.5	1.30
Bg. 6 m Top	0.80	4.8	0.86	52.0	3.1	0.75
Bg. 6 m Bottom	0.90	7.1	0.84	51.5	3.7	1.25
Bg. 18 m Top	0.76	9.2	0.78	55.0	5.7	0.56
Bg. 18 m Middle	0.69	10.5	0.75	56.0	4.9	0.23
Bg. 18 m Bottom	0.66	6.4	0.64	58.7	3.3	0.74
Ld. 6 m Top	0.51	6.9	0.55	62.9	4.7	0.31
Ld. 6 m Bottom	0.66	7.8	0.70	56.6	5.1	0.42
Ld. 18 m Top	0.77	8.0	0.76	55.2	5.2	0.83
Ld. 18 m Middle	0.65	6.5	0.66	57.4	4.0	0.58
Ld. 18 m Bottom	0.58	11.2	0.58	61.6	7.0	0.52
Tp. 6 m Top	0.85	16.0	0.80	54.0	6.8	2.00
Tp. 6 m Middle	0.66	10.2	0.66	58.6	5.4	0.67
Tp. 6 m Bottom	0.81	10.5	0.77	54.7	6.3	1.15
Tp. 18 m Top	0.53	6.0	0.49	63.7	4.0	0.83
Tp. 18 m Middle	0.65	7.1	0.73	56.0	4.7	0.23
Tp. 18 m Bottom	0.46	6.9	0.51	64.0	4.5	0.20



Text-figure 8—Facies diagram of the coal seam nos. 1 and 3 from the Makum Coalfield in terms of Gelification Index (GI) and Tissue Preservation Index (TPI) in relation to palaeodepositional environments (after Diessel, 1986).

fractions of organic matter and that of the swamp water (Cecil *et al.*, 1979; Renton *et al.*, 1979). Under such conditions formation of syngenetic pyrite in the peat and associated sediments is also frequent (Cecil *et al.*, 1981; Renton & Bird, 1991). Clastic influx by channels feeding the swamp, therefore, appears improbable.

Low proportions of semifusinite + fusinite (Table 2) invariably with empty cell-lumens indicate their *in situ* formation partly from oxidative vegetal degradation and partly from the influence of alkaline mileau by 'base exchange' reactions as suggested by McKenzie Taylor (1926, 1927). Presence of inertodetrinite mostly in the vicinity of semifusinite and fusinite indicates that its major fraction was produced *in situ* by mechanical break down of the structured inertinites during early stages of coalification by the cumulative action of rapid compaction of the peat and associated fine-grained sediments and upward bubbling of gases from inside the peat (detail work under finalization). Both these processes can cause slumping and/or minor synsedimentary disturbances in the peat during its formative stages.

In order to ascertain the preceding view points, relations among desmocollinite, total inertinite, sclerotinite, other inertinites (semifusinite, fusinite, inertodetrinites, etc.), pyrite and clastic mineral contents have been shown in Table 6 (Text-fig. 9) and following observations were made: (i) Increase or decrease of any set of maceral-maceral or maceral-mineral contents is of relative value and restricted to each coal seam section individually irrespective of the contents of the same set in other sections, (ii) There is a good relation (i.e. increase with increase and vice-versa) between pyrite and desmocollinite (in 66.6% cases), desmocollinite and clastic minerals (66.6%), sclerotinite and other inertinites (57.1%), sclerotinite and clastics (52.4%), pyrite and sclerotinite (52.4%), pyrite and other inertinites (52.4%) and sclerotinite and desmocollinite (47.6%). Correlation between pyrite and clastic minerals (33.4%), however, is slightly of lower order.

These inter-relationships among macerals and minerals appear to be the reflections of certain interdependent factors active during coalification but not yet fully understood. Nevertheless, in general they support the chemical model of Cecil *et al.* (1979) and Renton *et al.* (1979) for the role of alkaline mileau in microbial degradation of organic matter, *in situ* formation of pyrite and *in situ* incorporation of plant-derived clastic minerals in the accumulating peat. The above relationships also strengthen the inferences made earlier that the semifusinite and fusinite including inertodetrinite macerals in the coal seams of Makum Coalfield were formed mostly under anoxic conditions and a certain fraction of fungi that participated in vegetal degradation were facultative and/or obligate anaerobes. Thus, certain discrepancies in relationships between maceral-maceral and maceral-mineral sets (Table 6) have partly been explained.

Thin (0.6 to max. 1.2 m) pyriteous clay, mudstone or carbonaceous shale bands (minor partings) within the coal seam sections of the Makum Coalfield have been presumed to be formed authigenically by severe microbial degradation of organic matter under subaqueous condition (Renton & Hamilton, 1988; Renton & Bird, 1991). Similar conditions appear to have existed during the formation of carbonaceous shale, grey shale and clay floor and roof of the coal seam nos. 1 and 3. Exceptionally high rate of biodegradation of organic

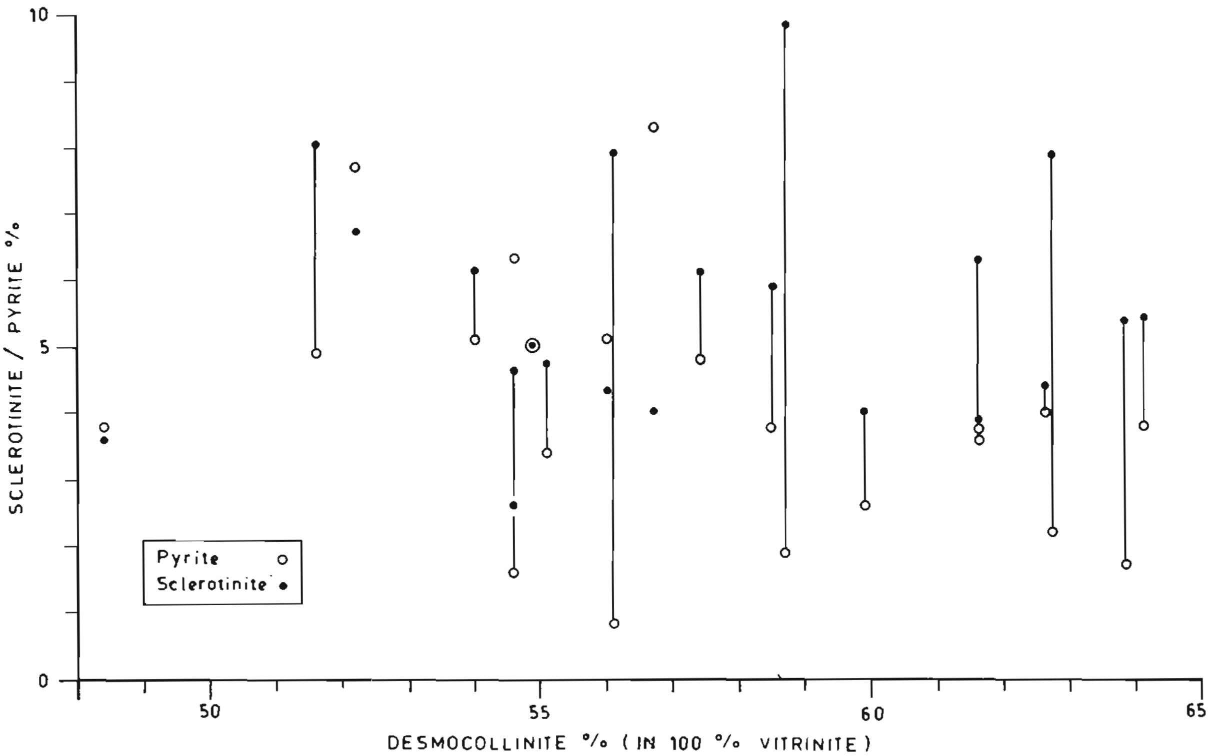
Table 6—Some selected maceral and mineral contents of coal seam sections (Seam nos. 1 and 3) from four collieries of the Makum Coalfield compiled to ascertain their relationships with vegetal degradation

Colliery/Seam/ Section			Desmoco-llinite (on 100% vitri-nite basis)	Inertinite (m.m.f.)			On 100% m. m. basis	
				Total Inertinite %	Sclerotinite %	Other Inertinite macerals %	Pyrite %	Clastic minerals %
NAMDANG	Seam 3	Top	62.6	17.5	8.7	8.8	23.4	43.6
		Bottom	48.4	16.5	4.3	12.2	24.8	16.4
	Seam 1	Top	54.6	11.1	3.2	7.9	34.4	19.2
		Middle	61.6	18.0	6.8	11.2	48.7	34.6
		Bottom	60.0	12.5	4.2	8.3	50.0	27.0
BARAGOLAI	Seam 3	Top	52.0	22.2	7.6	14.6	64.2	10.0
		Bottom	51.5	19.0	8.8	10.2	47.1	30.8
	Seam 1	Top	55.0	14.0	5.3	8.7	83.3	—
		Middle	56.0	15.8	8.5	7.3	11.5	82.5
		Bottom	58.7	21.5	10.5	11.0	30.1	50.8
LEDO-TIRAP	Seam 3	Top	62.9	15.9	4.9	11.0	38.5	37.5
		Bottom	56.6	15.0	5.1	9.9	38.1	35.8
	Seam 1	Top	55.2	15.1	5.2	9.9	32.1	38.7
		Middle	57.4	18.2	6.9	11.3	41.0	32.5
		Bottom	61.6	11.5	4.2	7.3	46.8	32.5
TIPANG	Seam 3	Top	54.0	11.5	6.6	4.9	66.2	14.3
		Middle	58.6	14.1	6.6	7.5	36.2	47.6
		Bottom	54.7	12.9	5.0	7.9	17.6	61.5
	Seam 1	Top	63.7	18.4	6.1	12.3	14.0	48.8
		Middle	56.0	15.8	5.3	10.5	28.2	38.1
		Bottom	64.0	17.0	6.0	11.0	37.1	44.3

matter in the ancient peat swamp created an apparent vegetal short supply resulting into partings instead of peat (Misra, 1991). Whenever, conditions with biodegradation rate surpassing vegetal supply were prolonged, especially in the case of Seam no. 1, thick partings rendering composite nature to the seam were developed.

The termination of coal seams in the Makum Coalfield was probably a gradual process initiated mostly by the conditions mentioned above which gave way to relatively faster rate of subsidence partly induced by compaction of peat and associated fine-grained sediments. As a result water-table was raised inundating the swamp and causing temporary extermination of vegetation in the area. In consequence channels feeding the swamp encroached upon the basin of peat accumulation and gradually a relatively high energy regime was established depositing sandstone units in the sequence. This sequence of events was repeated with the formation of every coal seam in the field producing a cyclic pattern in the coal-bearing sediments of the Tikak Parbat Formation. The absence of detrital influx, excluding inorganic colloidal and ionic fractions from the streams feeding the swamp, has been visualized as a result of efficient filtering by dense vegetation cover (and root-net of the plants) which impeded their normal flow causing deposition of transported material, thus choking the channels and probably diverting them periodically as well.

High desmocollinite, perhydrous vitrinite, liptodetrinite and bituminite contents; high GI and low TPI and high contents of early diagenetic pyrite even in associated fine-grained sediments, organic sulphur and calcite (Table 2, 3, 5) are the characteristics of coals that formed on a lower delta plain in brackish water bodies or lagoons (Neavel, 1981; Teichmüller, 1989, p. 32). The preceding maceral, mineral and sedimentary association together with physical (bright, unbanded nature and subconchoidal to conchoidal fracture) and chemical (high swelling index and fluidity and high L.T.C. tar yield, etc.) properties of coal seam nos. 1 and 3



Text-figure 9—Behaviour of pyrite and sclerotinite (m.m.f. basis) contents in relation to that of desmocollinite (on 100% vitrinite basis) in the coal samples of seam nos. 1 and 3 of Makum Coalfield, Assam.

suggest that their genesis was influenced much by putrefaction rather than by normal peatification (Misra, 1991). This is possibly the reason for their perhydrous nature, high volatile matter content and high syncrude yield (Radke *et al.*, 1980; Teichmüller, 1989).

Synthesizing all the available geological, chemical, palynological and megafloral information with the biopetrological inferences, it has been concluded that the coal seam nos. 1 and 3 in the Makum Coalfield originated mostly from autochthonous vegetal accumulations on a lower delta plain in a near-shore lagoon. The source material was supplied from dense mangrove-mixed forest vegetation in a rheotrophic peat swamp. For most of the time vegetal accumulation was subaqueous, however, occasional lowering of water-table facilitating aerobic fungal degradation led to the formation of inertinite macerals.

CONCLUSIONS

The Oligocene coal seam nos. 1 and 3 of the Makum Coalfield are bright, non-banded and vitric in nature with predominance of desmocollinite and perhydrous vitrinite. Liptodetrinite and resinite are the main liptinite macerals followed by others including fluorinite and exsudatinite. Inertinite maceral group consists chiefly of sclerotinite and inertodetrinite followed by semifusinite + fusinite. Inorganic constituents are quantitatively low to moderate, of which early diagenetic pyrite and calcite share the major proportion. Clastic mineral content is usually low. Both the coal seams with a rank (R_0max.%) equivalent to high volatile bituminous B stage have distinctly higher maturity than the Palaeocene coal seams of Meghalaya. The higher rank of the coal seams of Makum Coalfield has been attributed to the greater depth of burial, higher geothermal gradient and intense tectonic disturbance in the areas.

Petrographic, tissue preservation and gelification indices of the coal samples from seam nos. 1 and 3 indicate that they were formed from hypoautochthonous to allochthonous source on a lower delta plain with relatively low density of arborescent trees in limno-telmatic conditions. These inferences are only partly supported by geological, palaeobotanical and other biopetrological parameters. It has been concluded that the coal seams in the Makum Coalfield were mainly formed from tree dominated autochthonous mangrove-mixed angiospermous forest vegetation with dense undergrowths growing in humid to perhumid tropical climate. The dense vegetation cover acted as efficient filter warding off detrital influx in the peat swamp during floods in the feeding streams. The vegetal accumulation took place in a rheotrophic peat swamp on a lower delta plain in a near-shore lagoon under relatively tranquil conditions.

The wood dominated vegetation in the peat swamp was moderately (hemic) to highly (sapric) degraded by both aerobic and anaerobic microbial agencies under tropical humid conditions. However, the effect of anaerobic degradation under alkaline mileau was more pronounced and produced pyriteous and perhydrous coals by the influence of putrefaction. Probably, a fraction of semifusinite and fusinite macerals was also formed under similar conditions. Most of the inertodetrinite maceral was presumably formed *in situ* by the mechanical breakdown of the existing inertinites Anaerobic and alkaline conditions in the ancient swamp facilitated severe microbial degradation of organic matter resulting into authigenic formation of not only minor partings within the seam sections but also produced thicker organic matter-rich partings and roof and floor of the coal seams. The termination of coal seams in the Makum Coalfield was induced by increased rate of microbial degradation resulting in an apparent vegetal short supply and rapid compaction of peat and associated fine-grained sediments (inundating the peat formed and exterminating the existing vegetation) followed by faster rate of basin subsidence.

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