Biopetrological study of Mulug coal belt, Godavari Basin, Andhra Pradesh, India

Omprakash S. Sarate

Sarate OS 1996. Biopetrological study of Mulug coal belt, Godavari Basin, Andhra Pradesh, India. *Palaeobotanist* **43**(3) : 51-66.

Biopetrological investigation of 12 coal seams from Mulug coal belt of Godavari Basin has been carried out to evaluate their economic potentials. The coal seams are associated with the Karharbari and Barakar formations of the Lower Gondwana sequence. The maceral study has revealed that seams IV A, IV, III B, II, I below index, I, and I A contain vitric coal. However, IV below index, III and I B seams are characterised by a mixture of both vitric and fusic coals. Besides, III A and II below index seams contain fusic coal. The microlithotype analysis indicates that the vitric coal has the dominance of vitrite, clarite and duroclarite constituents. The mixed type of coal contains variable frequencies of vitrite and inertite with intimate association of clarite, durite, trimacerite and carbominerite microlithotypes. However, fusic coal has overall dominance of inertite with carbominerite. The reflectance study revealed that I B, I, I below index, IV below index and the lowermost IV A seams have attained high volatile bituminous C rank. Whereas, coal of II below index seam is represented by transitional stage of rank between high volatile bituminous C and sub-bituminous A. The coal seams III B and III A contain coal of high volatile bituminous B rank. However, the seams III and II are characterised by coal having rank ranging between high volatile bituminous C to B. Seam I A contains coal of high volatile bituminous C to A rank. However, seam IV comprises coal having reached high volatile bituminous A stage.

Key-words—Biopetrology, Coal, Godavari Basin, Permian (India).

Omprakash S. Sarate, Department of Biodiagenesis, Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India.

सारांश

आँध्र प्रदेश (भारत) में गोदावरी द्रोणी की मुलुग कोयला पट्टी का जैवशैलिकीय अध्ययन

ओमप्रकाश शिवदास सराटे

गोदावरी द्रोणी की मुलुग कोयला पट्टी की 12 कोयला-सीमों की आर्थिक उपयोगिता का मूल्याँकन करने के लिए इनका जैवशैलिकीय अन्वेषण किया गया है। ये कोयला सीमों अधरि गोंडवाना अनुक्रम के करहरबारी एवं बराकार शैल-समूहों से सहयुक्त हैं। मेसीरल अध्ययन से व्यक्त होता है कि चतुर्थ ए, चतुर्थ ,तृतीय बी, द्वितीय, प्रथम (सूचक के नीचे), प्रथम एवं प्रथम ए नामक सीमों में विट्रिक कोयले हैं। तथापि, चतुर्थ (सूचक के नीचे), तृतीय एवं प्रथम बी सीम विट्रिक एवं फ्यूजिक कोयलों से अभिलक्षणित हैं। इसके अतिरिक्त तृतीय ए एवं द्वितीय (सूचक के नीचे) सीमों में फ्यूजिक कोयला विद्यमान है। सूक्ष्मशैलप्ररूप विश्लेषण से व्यक्त होता है कि विट्रिक कोयलों में विट्राइट, क्लेराइट एवं ड्यूरोक्लेराइट अवयवों की आधिक्यता है। मिश्रित प्रकार के कोयलों में क्लेराइट, ड्यूराइट, ट्राइमेसीराइट एवं कार्बोमिनराइट सूक्ष्मप्रारूपों के साथ-साथ विट्राइट एवं इनरटाइट की घटती-बढ़ती मात्रा विद्यमान है। तथापि, फ्यूजिक कोयले में कार्बोमिनराइट के साथ-साथ इनरटाइट की बाहुल्यता है। परावर्तकता अध्ययन से प्रेक्षित किया गया है कि चतुर्थ सीम के कोयले उच्च वाष्पशील बिटुमेनी ए. कोटि के हैं। अन्य सीमों के कोयले अलग-अलग उच्च वाष्पशील कोटि प्रदर्शित करते हैं।

THE drilling operations in Mulug coal belt has revealed the existence of 12 coal seams, of which, only six coal seams have attained workable thickness. Since no detailed biopetrological study on these coal seams has been done so far, the present study has been taken up which may serve as a parameter to evaluate the economic potentials of each coal seam of Mulug coal belt.

Godavari Basin is rich with enormous coal deposits localized in different sections on the western margin. The number of coal seams and their thickness vary from one section to another. Each section for convenience is described as sub-basin. Mulug coal belt, named after the village Mulug, is located south of Ramagundam sub-basin and has recently been worked out geologically as one of the most promising coal-bearing sectors with good quality coal reserves. As observed in Ramagundam area here also the coal deposits having economic potential are mostly confined to western edge of the basin. The coal seams present on the northern side of Maneri River are described under Ramagundam sub-basin, whereas, those on its southern side are described as Mulug coal belt. General stratigraphic sequence of the Lower Gondwana sediments of Pranhita-Godavari Basin, Andhra Pradesh is as under:

Age	Formation	Maximum thickness (meters)	Lithology
Upper Permian to Lower Triassic		500	Upper Member : Coarse grained ferruginous sandstones with clay clast and pebbles and subordinate violet cherty siltstone and pebble beds.
	Kamthi	600	Middle Member : Alternating sequence of medium grained white to greenish grey white sandstones and buff to greenish grey clays.
		200	Lower Member : Medium to coarse-grained, greyish white calcareous sandstones with a few coal seams.
Upper Permian	Barren Measures	500	Medium to coarse-grained, greenish grey to greyish white felspathic sandstones with subordinate variegated clay and micaceous siltstones
	Barakar	300	Upper Member : Coarse, white sandstones with subordinate shales and coal seams.
			Lower Member : Coarse-grained sandstones with lenses of conglomerates, subordinate shales/ clays and few thin bands of coal.
Lower Permian	Talchir	350	Fine-grained sandstones, splintery green clays/shales, chocolate coloured clays, pebble beds and tillite.
------Unconformity------			

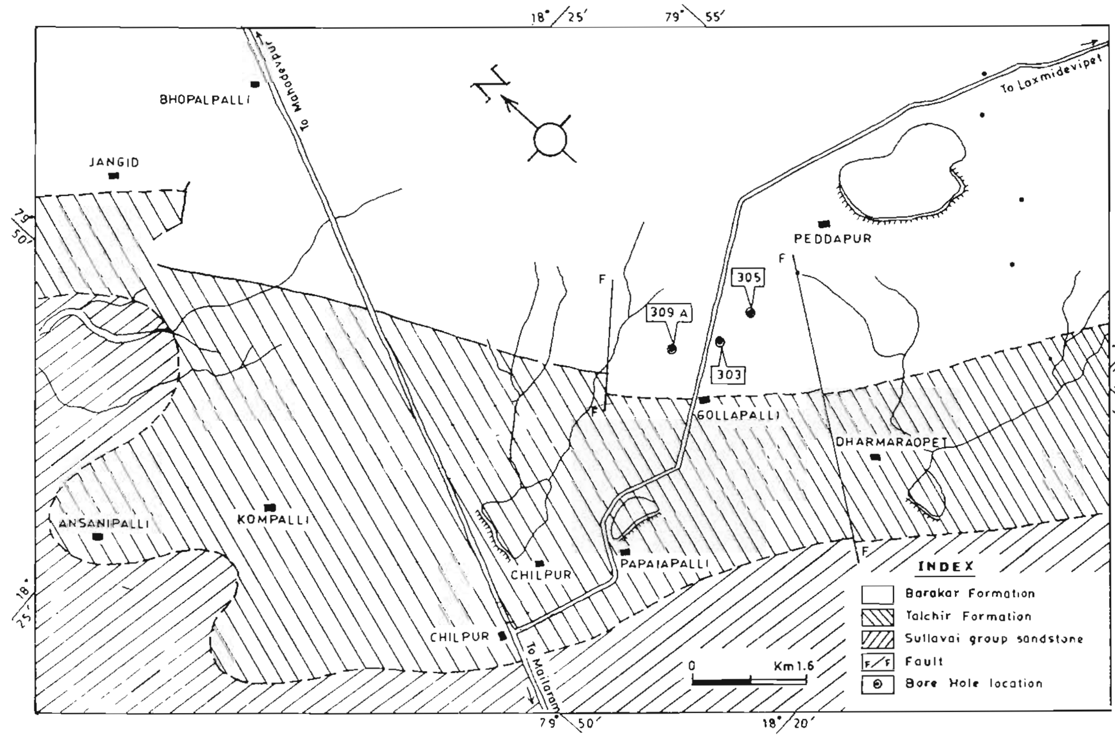
(after Raja Rao, 1982).

GENERAL GEOLOGY

The present knowledge regarding geological details of the Lower Gondwana sequence of Godavari Basin is based upon the significant works carried out by Wall (1857), Hughes (1877, 1878), King (1872, 1873, 1877, 1881), Krishnan (1949), Kutty and Roy Chowdhury (1970), Fox (1931, 1934) and Raja Rao (1982). The Godavari Basin displays a succession of rocks assigned from Permian to Lower Cretaceous periods, marked between the latitudes 16°38' and 19°32' and longitudes 79°12' and 81°39' covering an area of about 17,000 sq km extending from the north of Boregaon Village in Maharashtra up to Eluru in East Coast of Andhra Pradesh. The occurrence of workable coal is mostly confined to the Barakar Formation.

The basement metamorphic rocks of Sullavai Group are overlain by the Lower Gondwana sediments of Talchir Formation, which contains tillites at the base, succeeded by a thick sequence of alternate bands of clay, dispersed clasts, siltstone and sandstone with conglomerates (Map 1). The Talchir Formation is overlain by the coal-bearing Barakar Formation which is characterised by coarse grained sandstone with lenses of conglomerates at the basal portion. However, the upper portion lithologically includes sandstones, shales and coal seams. The strata overlying the Barakar Formation was previously described under Kamthi Formation. However, Ramanamurthy (1976) established the existence of Barren Measures Formation and described the strata characterised by medium to coarse grained felspathic or ferruginous sandstones of greenish to greyish white in colour having quartz pebbles and subordinate variegated clay.

The lithostratigraphic unit lying between Barren Measure and Maleri formations is designated as Kamthi Formation. However, its extension in the coastal areas is referred as Chintalapudi Formation (Raja Rao, 1982). Kamthi Formation is generally divided into upper, middle and lower members, covering an area of about 1300 m. The lower and the upper members have a striking lithological and palynological similarity with the Raniganj and Panchet formations of Damodar Valley respectively. The lower member is characterised by greyish white calcareous sandstone and contains a workable coal seam near the village Sondilla and Manuguru (Ramanamurthy,



Map 1—Geological map showing location of bore-hole nos. 305, 303 and 309 in Mulug coal belt, Godavari Basin (after Raja Rao, 1982).

1976). The middle member contains alternate sequence of medium grained white to grey-white sandstones and buff to greenish grey clays. However, the upper member has coarse grained ferruginous brick red sandstone with bands of pebbles and conglomerates containing dispersed clasts and fragmentary fossils.

Table 1—Lithological details of bore-hole nos. 305, 303 and 309, Mulug coal belt, Godavari Basin, Andhra Pradesh

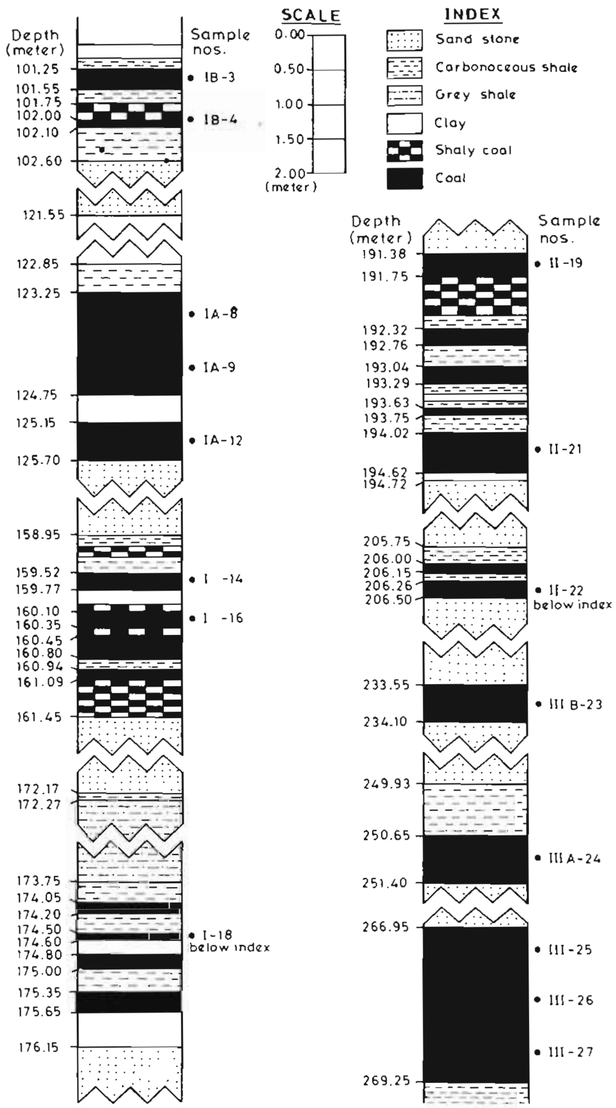
Depth in méter	Lithology	Coal seam	Pellet no.
Bore-hole no. 305			
100.40-101.10	Clay		
101.10-101.25	Carbonaceous shale	IB	IB-3
101.25-101.55	Hard and compact coal with vitrain bands	101.10-102.60 (1.50m)	
101.55-101.75	Carbonaceous shale		
101.75-102.00	Shaly coal		
102.00-102.10	Bright coal		I B - 4
102.10-102.60	Shale		
102.60-121.55	Sandstone		
121.55-122.85	Clay		
122.85-123.25	Carbonaceous shale	IA	
123.25-124.00	Bright coal	122.85-125.70	I A - 8
124.00-124.75	Hard and compact coal	(2.85m)	I A - 9
124.75-125.15	Clay		
125.15-125.70	Hard and compact coal		I A - 12
125.70-158.95	Sandstone with pyrite		
158.95-159.12	Carbonaceous shale	I	
159.12-159.27	Shaly coal	158.95-161.65	
159.27-159.52	Carbonaceous shale	(2.70m)	
159.52-159.77	Hard and compact coal		I - 14
159.77-159.99	Clay		
159.99-160.10	Shaly coal		
160.10-160.35	Dull coal		I - 16
160.35-160.45	Shaly coal		
160.45-160.80	Bright coal		
160.80-160.94	Carbonaceous shale		
160.94-161.09	Dull coal		
161.09-161.65	Shaly coal		
161.65-172.17	Sandstone (pyritic)		
172.17-172.27	Carbonaceous shale		
172.27-173.75	Grey carbonaceous shale	I below index,	
173.75-174.05	Carbonaceous shale	173.75-175.75,	
174.05-174.20	Dull coal	(1.90m)	
174.20-174.50	Carbonaceous shale		
174.50-174.60	Dull coal		
174.60-174.80	Clay		

174.80-175.00	Coal		I below -
175.00-175.35	Carbonaceous shale		index - 18
175.35-175.75	Coal		
175.75-176.15	Clay		
176.15-191.38	Sandstone	II	
191.38-191.75	Bright coal	191.38-194.6 2	II - 19
191.75-192.32	Shaly coal	(3.24m)	
192.32-192.52	Carbonaceous shale		
192.52-192.76	Coal		
192.76-193.04	Carbonaceous shale		
193.04-193.29	Coal		
193.29-193.43	Carbonaceous shale		
193.43-193.55	Clay		
193.55-193.63	Carbonaceous shale		
193.63-193.75	Coal		
193.75-194.02	Carbonaceous shale		
194.02-194.62	Coal		II - 21
194.62-194.72	Clay		
194.72-205.75	Sandstone (greenish)	II	22nd
205.75-206.00	Carbonaceous shale	below index	below
206.00-206.15	Coal	205.75-206.50	-index
206.15-206.26	Carbonaceous shale	(0.75m)	
206.26-206.50	Coal		
206.50-233.55	Sandstone	III B	
233.55-234.10	Coal	233.55-234.10	IIIB-23
234.10-249.93	Sandstone	(0.55m)	
249.93-250.65	Carbonaceous shale	III A	
250.65-251.40	Coal	249.93-251.40	III A-24
251.40-266.18	Sandstone	(1.47m)	
266.18-269.25	Coal	III	III - 25
269.25-269.55	Shale	(3.07m)	26 & 27
Bore-hole no. 303			
167.50-168.20	Sandstone	IV	
168.20-168.70	Bright coal	168.20-168.70	303/1
168.00-168.80	Grey shale	(0.50m)	
168.80-180.25	Sandstone		
180.25-180.75	Siltstone		
180.75-180.90	Micaceous shale		
180.90-181.00	Coal		303/2
181.00-195.50	Sandstone	IV	
195.50-195.95	Bright, hard and compact coal	below index 195.50-196.35	303/3
196.95-196.35	Bright, hard and compact coal	(0.85m)	303/4
196.35-200.00	Sandstone		
	Talchir Formation intersected at 275.30 m		
Bore-hole no. 309			
117.75-123.5	Sandstone	IV A	
123.75-124.35	Bright coal	123.75-125.00	IV A/1
124.35-125.00	Bright coal	(1.25m)	IV A/2
125.00-125.65	Siltstone		

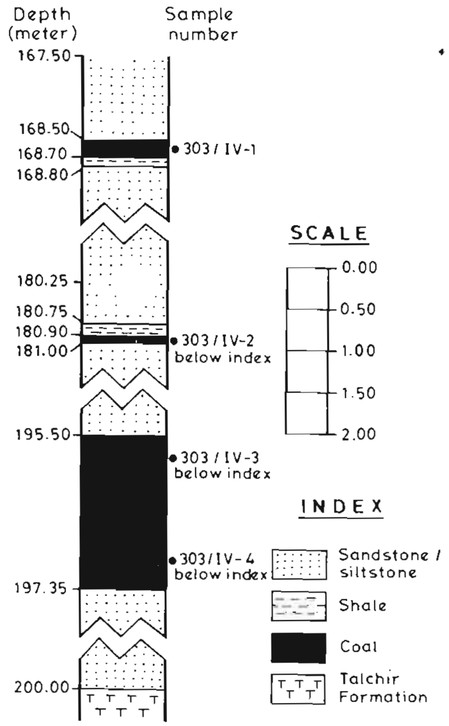
MATERIAL AND METHOD

The samples were collected from near Golapalli Village (Map 1) and represent a sequence of 12 coal seams from the Permian sediments. Since it was not possible to get a complete sequence of all the coal seams from a single bore hole, the samples have been collected from three bore-holes (viz., 305, 303 & 309; Text- figures 1, 2, 3; Table 1). The coal samples were crushed and sieved to get ± 18 mesh sized particles. Particulate pellets were prepared and polished following International specifications. All 22 particulate coal pellets as mentioned below were prepared and analyzed. The quantitative analysis of macerals, microlithotypes and the reflectance measurements have been carried out on Leitz MPV-1 microscope following the specifications of the I.C.C.P. (1971).

Coal seam	Depth (in meter)	Pellets prepared
Bore-hole no. 305		
IB	101.10-101.85 (0.75)	I B (Top)
	101.85-102.60 (0.75)	I B (Bottom)
IA	122.85-123.80 (0.95)	I A (Top)
	123.80-124.75 (0.95)	I A (Middle)
	124.75-125.70 (0.95)	I A (Bottom)
I	158.95-160.30 (1.35)	I (Top)
	160.30-161.65 (1.35)	I (Bottom)
I (below index)	173.75-175.65 (1.90)	I (below index)
II	191.38-193.00 (1.62)	II (Top)
	193.00-194.62 (1.62)	II (Bottom)
II (below index)	205.75-206.50 (0.75)	II (below index)
III B	233.55-234.10 (0.55)	III B
III A	249.93-251.40 (1.47)	III A
III	266.18-267.20 (1.02)	III (Top)
	267.20-268.22 (1.02)	III (Middle)
	268.22-269.25 (1.03)	III (Bottom)
Bore-hole no. 303		
IV	168.20-168.45 (0.25)	IV (Top)
	168.45-168.70 (0.25)	IV (Bottom)
IV below index	195.50-195.92 (0.42)	IV (below index) (Top)
	195.92-196.35 (0.43)	IV (below index) (Bottom)
Bore-hole no. 309		
IV A	123.75-124.37 (0.62)	IV A (Top)
	124.37-125.00 (0.63)	IV A (Bottom)



Text-figure 1—Showing position of coal samples studied from bore-hole no. 305.



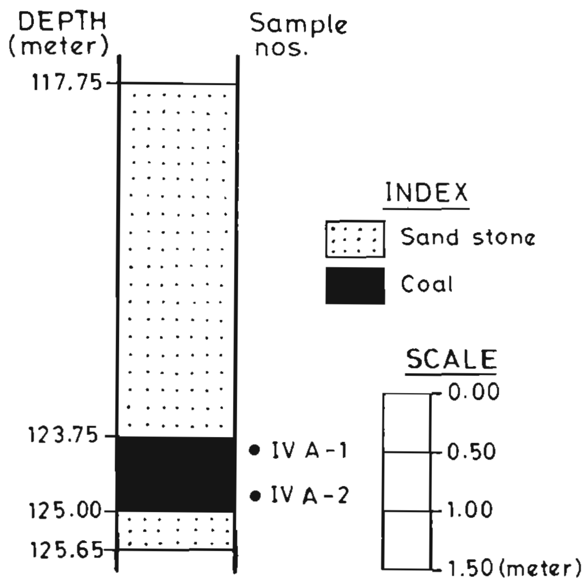
Text-figure 2—Showing position of coal samples studied from bore-hole no. 303.

MACROSCOPIC CHARACTERISTICS

The Mulug coals are hard and compact in nature and generally characterised by alternate bands of dull, bright and shaly coal containing occasional shale and bands. The bright coal is invariably associated with thin vitrain and fusain bands with pyrite and calcite veins.

MICROSCOPIC CHARACTERISTICS

The Mulug coals have predominance of vitrinite, exinite and inertinite contents. Vitrinite group is mainly represented by telocollinite, desmocollinite, corpocollinite and telinite. Transition from telinite to collinite is a common feature of these coals. Corpocollinite is generally recognizable in the trimacerite microlithotype. Exinite group is mostly represented by rows of compactly arranged microspores, sporangia (individual and in groups), spore masses (Pl. 1, fig. 8), megaspores of different size and shapes and tenui and crassi- cutinites (Pl. 2, figs 7, 8). Inertinite group shows variation in cellular structures; sometimes there is a marked degree of cellular disintegration. Bogen structure of the cells (Pl. 2, fig. 2) and transitional stages from vitrinite to semifusinite and semifusinite to fusinite are frequently observed (Pl. 2, figs 3, 5). Carbonate (siderite commonly and calcite rarely) and clay (Pl.1, fig. 7) are the common associated minerals found embedded within the cracks and fissures of vitrinite and inertinite. However, silica minerals (quartz) are scantily distributed, while pyrite occurs mostly as framboids (Pl. 1, figs 5, 6) in Mulug coals.



Text-figure 3—Showing position of coal samples studied from bore-hole no. 309.

MACERAL COMPOSITION

Bore-hole no. 305

Text-figure 4

I B seam—This represents the topmost seam in the area. The coal of upper part of the seam is dominated by vitrinite (35%) intimately associated with mineral matter (27%), inertinite (28%) and exinite (10%). However, the coal at the bottom contains very high frequency of mineral matter (47%) in association with inertinite (24%), vitrinite (15%) and exinite (14%).

I A seam—The coal of this seam is vitrinite-rich with an increasing trend towards the middle part (48-64%) which declines towards the bottom. Exinite, however, shows decreasing trend towards the middle part (28-18%). Inertinite (8-11%) and mineral matter (6-12%) both show increasing trend towards the bottom.

I seam—The coal of this seam is also vitrinite-rich (58-46%) but differs from the overlying I A seam in having decreasing trend of vitrinite distribution towards the bottom. However, inertinite (6- 25%) increases while mineral matter (16-9%) decreases towards the bottom. Exinite has a constant frequency (20%) throughout the coal seam.

I seam (below index)—This coal seam is characterised by the dominance of exinite (33%) in association with vitrinite (31%), inertinite (21%) and mineral matter (15%).

II seam—The coal of this seam is characterised by the dominance of vitrinite (35-50%) with increasing trend towardsthe bottom. Exinite (33-26%), inertinite (18- 13%) and mineral matter (14-11%) decrease in their percentage distribution towards the bottom.

II seam (below index)—The coal seam is represented by very high association of mineral matter (62%) intermixed with inertinite (26%), exinite (7%) and vitrinite (5%).

III B seam—This seam is characterised by the dominance of vitrinite (45%) associated with inertinite (24%), exinite (19%) and mineral matter (12%).

III A seam—The coal of III A seam also contains high frequency of mineral matter (3%) in association with inertinite (27%), vitrinite (23%) and exinite (18%).

III seam—The coal of this seam contains vitrinite (23-43%) dominance with an increasing trend towards bottom. Exinite (26-28%) has an increasing trend towards the middle part and a sharp decline at the bottom (8%). Inertinite (32-23%) has decreasing trend towards bottom. However, mineral matter (19-26%) has slightly decreasing trend towards the middle part (15%) and increases at the bottom (26%).

PLATE 1

(All magnifications x 250)

1-4. Vitrinite.
2-4. Vitrinite showing cracks with oil ooze.
5, 6. Aggregation of framboidal pyrite.
7. Calcite spread over vitrinite band.
8. Spore mass embedded in vitrinitic ground mass.

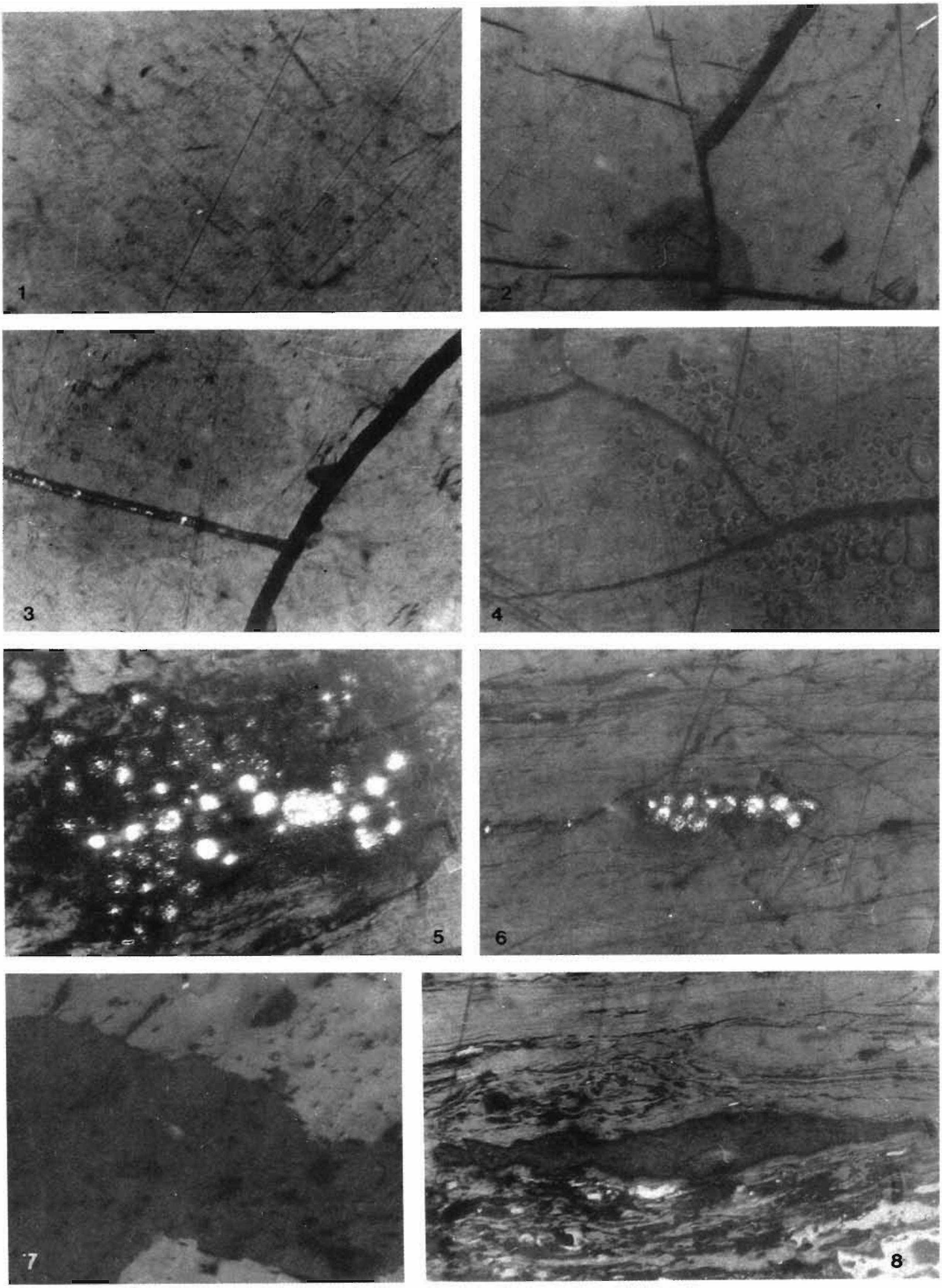


PLATE 1

Table 2—Microlithotype composition of bore-hole nos. 305, 303 and 309, Mulug coal-belt, Godavari Basin, Andhra Pradesh

Coal seam	Sample no.	Vitrite %	Clarite %	Inertite %	Vitrinertite %	Durite %	Duroclarite %	Clarodurite %	Carbominerite %
Bore hole no. 305									
IB	3	11	16	22	12	-	28	5	6
--do--	4	3	11	32	4	1	21	13	15
IA	8	22	37	3	1	-	28	6	3
--do--	9	27	21	15	2	-	24	4	7
--do--	12	17	34	6	2	-	27	5	9
I	14	12	41	4	4	4	28	2	9
--do--	16	10	29	9	6	-	36	9	1
I below index	18	4	30	20	6	2	23	12	3
II	19	11	7	7	2	-	43	27	3
--do--	21	11	21	7	5	-	38	12	6
II below index 22	1	1	43	4	-	20	4	27	
III B	23	8	8	10	4	-	57	9	4
III A	24	6	6	18	4	4	30	12	20
III	25	4	5	32	9	-	24	25	1
--do--	26	9	10	21	3	1	29	21	6
--do--	27	17	5	10	9	1	32	16	10
Bore-hole no. 303									
IV	1	3	2	7	1	-	46	36	5
IV below index	2	4	4	4	2	-	56	30	-
--do--	3	1	3	22	4	1	40	25	4
--do--	4	4	6	23	5	2	39	18	3
Bore-hole no. 309									
IV A	1	8	2	18	6	5	37	25	1
--do--	2	25	12	2	3	1	51	5	1

PLATE 2

(All magnifications x 250)

1, 2, 4. Inertinite with cellular compression.
3, 5. Transition from vitrinite to semifusinite.
6. Fusinised resin bodies.
7, 8. Cutinite in vitrinitic ground mass.

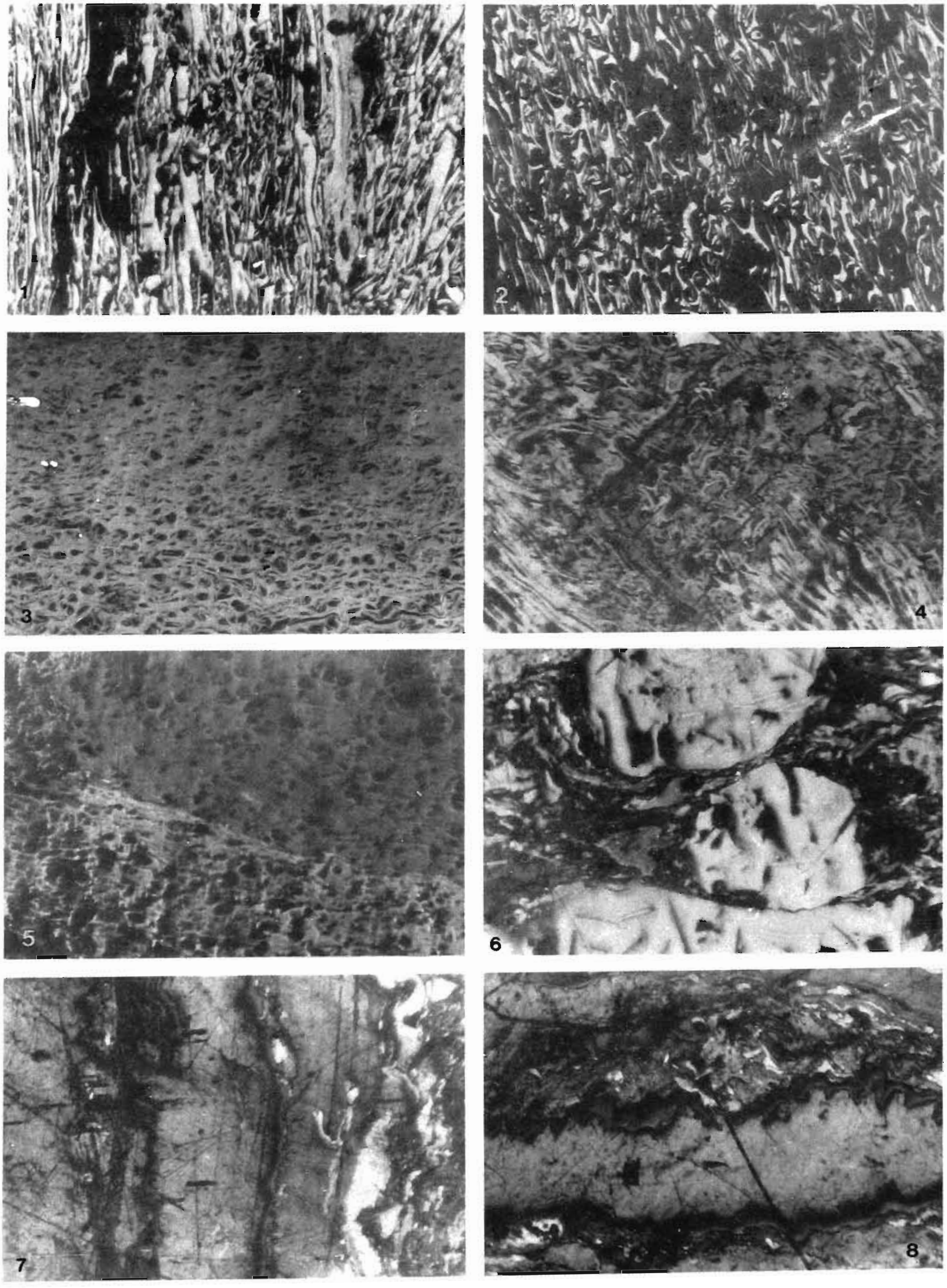
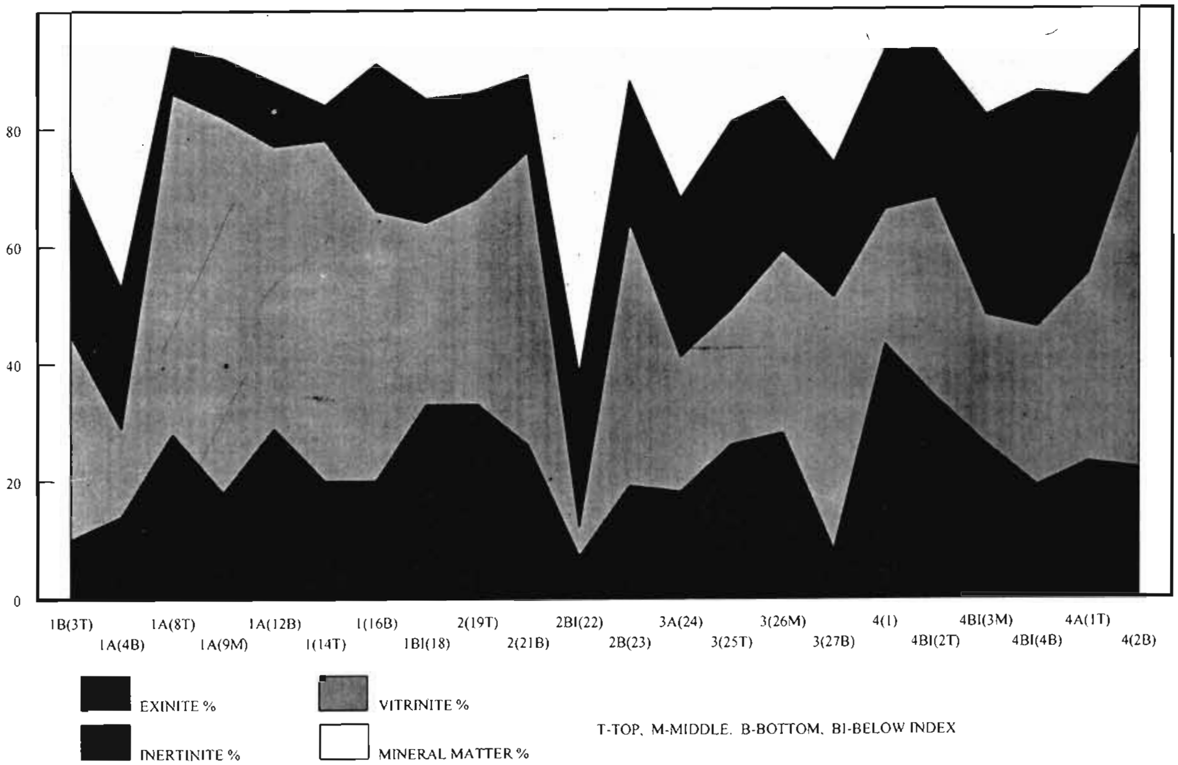


PLATE 2



Text-figure 4—Maceral composition of coal seams in bore-hole nos. 305, 303 and 309.

Bore-hole no. 303

Text-figure 4

IV seam—Exinite rich coal (43%) characterizes the VI seam in intimate association with inertinite (27%) and vitrinite (23%). Mineral matter has low frequency distribution (7%). Such a high frequency of exinite contents has not been found in the coal seams I B, I A, I, I (below index), II, II (below index) and III B of Bore-hole no. 305

IV (below index)—The coal at the top of this seam is constituted by vitrinite and exinite (34%) each invariably associated with inertinite (25%) and mineral matter (7%). However, in the middle and lower portions inertinite (34-40%) gained dominance with an increasing trend towards the bottom. Exinite (26-19%) and mineral matter (18-14%) both decrease and vitrinite (22-27%) increases at the bottom.

Bore-hole no. 309

Text-figure 4

IV A seam—The coal of this seam though contains the dominance of vitrinite (32-58%) with increase in percentage distribution towards bottom. Inertinite (30-13%) indicates a sharp decline towards the bottom and is associated with exinite (23-22%). Mineral matter (15-6%) also shows the same decreasing trend towards bottom.

MICROLITHOTYPE COMPOSITION

Bore-hole no. 305

Table 2

I B seam—The coal in the upper part is characterised by duroclarite (28%) dominance in association with inertite (22%), clarite (16%), vitrinertite and vitrite (11-12%). Carbominerite (6%) and clarodurite (5%) have scanty distribution. The lower part of this seam contains the dominance of inertite (32%) associated with duroclarite (21%), carbominerite (15%), clarodurite (13%) and clarite (11%). Vitrinertite (4%), vitrite (3%) and durite (1%) have low frequency distribution.

I A seam—The coal of I A seam is clarite rich (37%) at the top and is invariably intermixed with duroclarite (28%) and vitrite (22%) besides, clarodurite (6%), carbominerite and inertite (3%) each and vitrinertite (1%). The middle portion has the dominance of vitrite (27%) intimately associated with duroclarite (24%), clarite (21%) and inertite (15%). However, carbominerite (7%), clarodurite (4%) and vitrinertite (2%) have low frequency distribution. The bottom portion of this seam is marked by the dominance of clarite (34%) in association with duroclarite (27%), vitrite (17%) and carbominerite (9%). However, inertite (6%) and vitrinertite (2%) have scanty distribution.

I seam—As observed in IA seam (bottom part) the coal representing the top of I seam is also characterised by the dominance of clarite (41%) in association with duroclarite (28%), vitrite (12%) and carbominerite (9%). However, inertite, vitrinertite and durite show 4 per cent each and clarodurite (2%) has low frequency distribution. The bottom portion has the dominance of duroclarite (36%) in association with clarite (29%). Vitrite, clarodurite and inertite have frequency range of 9-10 per cent besides, vitrinertite (6%) and carbominerite (1%).

I seam (below index)—The coal of this seam contains dominance of clarite (30%) followed by duroclarite (23%) as observed in the upper portion of the overlying I seam, intimately associated with inertite (20%) and clarodurite (12%). Vitrinertite (6%), vitrite (4%), carbominerite (3%) and durite (2%) show low frequency distribution.

II seam—The coal is characterised by the dominance of duroclarite (43-38%) in association with clarodurite (27-12%) having decreasing trend towards the bottom. On the other hand, clarite (7-21%), carbominerite (3-6%) and vitrinertite (2-5%) have increasing trend towards the bottom. Vitrite (11%) and inertite (7%) have constant frequency distribution throughout the coal seam.

II seam (below index)—The coal of II (below index) seam is characterized by the dominance of inertite (43%) intimately associated with carbominerite (27%) and duroclarite (20%). However, clarodurite and vitrinertite are 4 per cent each and vitrite and clarite (1%) have scanty distribution.

III B seam—The coal seam is characterised by the dominance of duroclarite (57%), invariably associated with inertite (10%), clarodurite (9%), vitrite and clarite (8%) each alongwith vitrinertite and carbominerite (4%) each.

III A seam—The coal of III A seam closely resembles the overlying III B seam with respect to duroclarite (30%) dominance; however, it differs in having high frequency of carbominerite (20%), inertite (18%) and clarodurite (12%). Vitrite and clarite (6%) and vitrinertite and durite (4%) each follow the order of dominance.

III seam—Thetop of III seam has dominance of inertite (32%) invariably associated with clarodurite and duroclarite (24-25%) and vitrinertite (9%). Vitrite and clarite range 4-5 per cent besides, carbominerite (1%). The middle part of this seam contains duroclarite (29%) alongwith clarodurite and inertite (21%), Clarite (10%), vitrite (9%), carbominerite (6%), vitrinertite (3%) and durite (1%). The coal at the bottom, however, is dominated by duroclarite (32%) associated with clarodurite (16%), vitrite (17%), inertite (10%) and vitrinertite (9%) besides, clarite (5%) and durite (1%).

Bore-hole no. 303

Table 2

IV seam—The coal seam is characterised by the dominance of duroclarite (46%) in association with clarodurite (36%), inertite (7%), carbominerite (5%), vitrite (3%), clarite (2%) and vitrinertite (1%).

IV seam (below index)—The top of IV seam (below index) is marked by the dominance of duroclarite (56%) invariably associated with clarodurite (30%). However, vitrite, clarite and inertite(4%) each and vitrinertite (2%) have low frequency distribution. The middle section of the seam contains duroclarite (40%) intimately associated with clarodurite (25%) and inertite (22%). Carbominerite, vitrinertite and clarite (3-4%) alongwith vitrite and durite (1%). The bottom part of this seam is duroclarite rich (39%), a feature similar with the middle part but differs in having sub-dominance of inertite (23%) followed by clarodurite (18%). Clarite (6%), vitrinertite (5%), vitrite (4%), carbominerite (3%) and durite (2%) show decreasing trend in their percentage distribution.

Bore-hole no. 309

Table 2

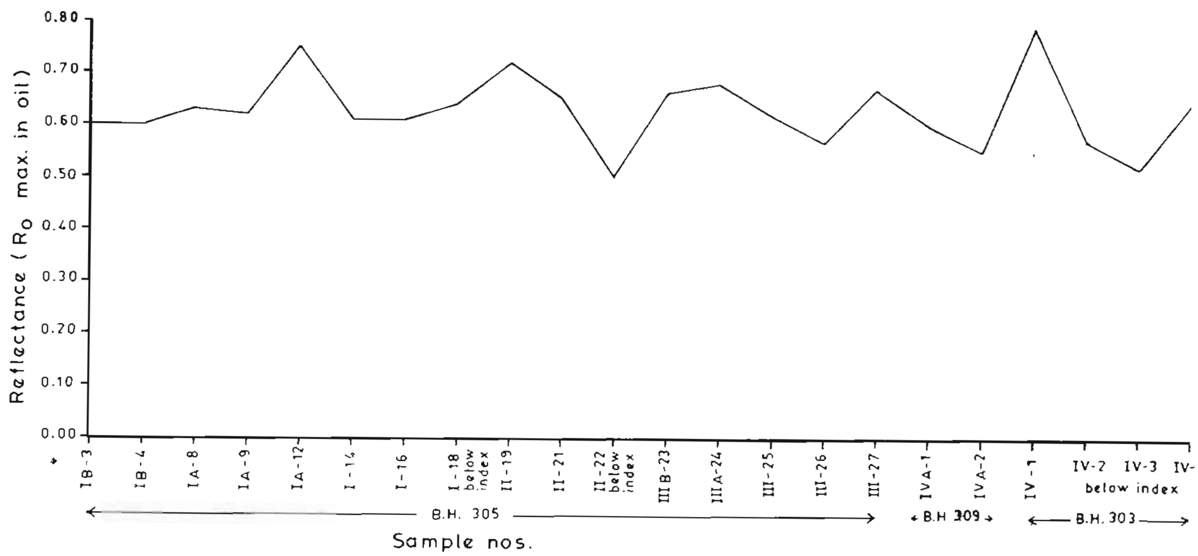
IV A seam—This represents the lowermost coal seam in Bore-hole no. 309 of Mulug coal belt. The coal from the upper part is characterised by the dominance of duroclarite (37%) in association with clarodurite (23%) and inertite (18%). Vitrite (8%), vitrinertite (6%), durite (5%), clarite (2%) and carbominerite (1%) follow the order of dominance. The coal at the bottom also contains the dominance of duroclarite (51%) but with the sub-dominance of vitrite (25%), intimately associated with clarite (12%). However, clarodurite (5%), vitrinertite (3%), inertite (2%), durite and carbominerite (1%) have scanty distribution.

REFLECTANCE ANALYSIS

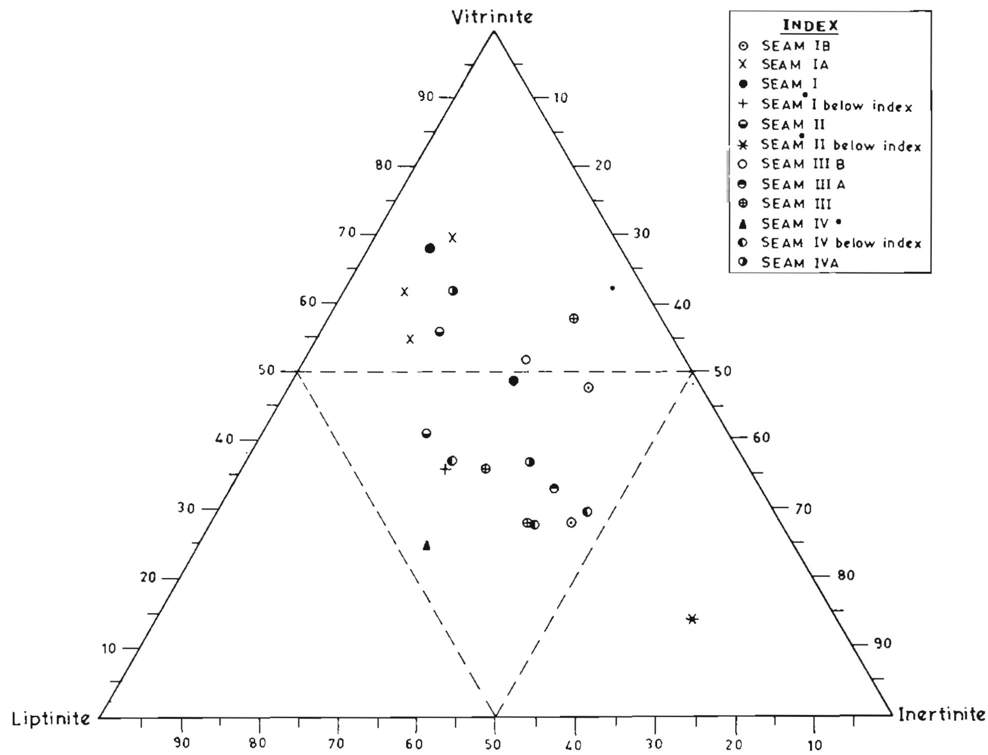
The different seams of Mulug coal belt in general have indicated the calculated reflectance value (R_o max.) ranging from 0.50 to 0.75 per cent as documented in the chart of reflectance analysis. The coals of IV A in Bore-hole no. 309 and IV (below index) seam of Bore-hole no. 303 have attained the rank of high volatile bituminous C stage. The reflectance values (R_o max.) in the seams IV A and IV have shown decreasing trend towards the top. Seams I (below index), I and the topmost I B have also reached high volatile bituminous C stage (Text-figure 5).

Coal seam	R_o max. %	Rank of coal
Bore-hole no. 305		
I B (Top)	0.60	•HVB C
I B (Bottom)	0.60	•HVB C
I A (Top)	0.63	•HVB C
I A (Middle)	0.62	•HVB C
I A (Bottom)	0.75	•HVB A
I (Top)	0.61	•HVB C
I (Bottom)	0.61	•HVB C
I (below index)	0.64	•HVB C
II (Top)	0.72	•HVB B
II (Bottom)	0.65	•HVB C
II (below index)	0.50	•HVB C (Sub-bituminous A)
III B	0.66	•HVB B
III A	0.68	•HVB B
III (Top)	0.63	•HVB C
III (Middle)	0.57	•HVB C
III (Bottom)	0.67	•HVB B
Bore-hole no. 303		
IV	0.79	•HVB A
IV below index (Top)	0.57	•HVB C
IV below index (Middle)	0.52	•HVB C
IV below index (Bottom)	0.65	•HVB C
Bore-hole no. 309		
IV A (Top)	0.55	•HVB C
IV A (Bottom)	0.60	•HVB C

•HVB-High volatile bituminous

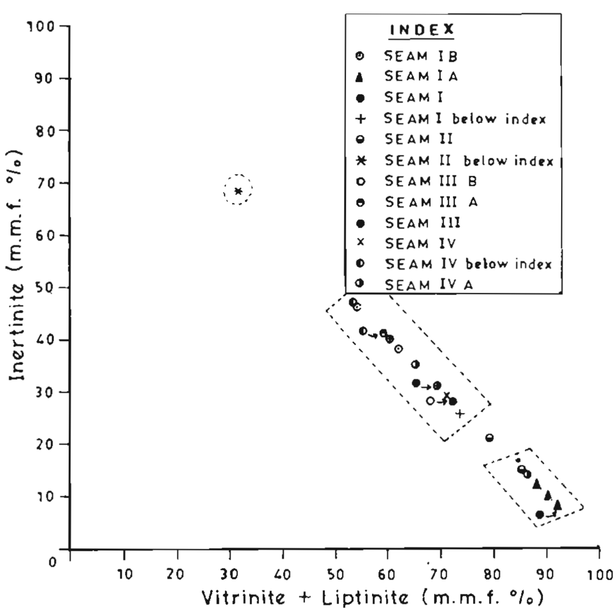


Text-figure 5—Showing reflectance analysis of coals from bore- hole nos. 305, 303 and 309.



Text-figure 6—Showing triangular (m.m.f.) data plotting of coal macerals of bore-hole nos. 305, 303 and 309.

The coal from I A seam in Bore-hole no. 305 is classified under high volatile bituminous C rank at the top and up to the middle portion. However, the coal at the bottom portion has reached the rank of high volatile bituminous A stage. The calculated reflectance values (R_o max.) in this seam have increasing trend towards the bottom. The coal of II (below index) seam in the above bore-hole is of transitionary rank, i.e., high volatile bituminous C to sub-bituminous A stage. The coals of seams III A and III B in bore-hole no. 305 have reached high volatile bituminous B stage. The top of II and the bottom portion of III seam in the same bore-hole also contains coal of high volatile bituminous B rank. However, the top and middle portions of III and the bottom part of II seam contain coal of high volatile bituminous C rank. The reflectance values (R_o max.) have shown decreasing trend towards the top in III and increasing trend towards the top in II coal seam. The coal of IV seam has attained the rank of high volatile bituminous A stage.



Text-figure 7—Showing biaxial (m.m.f.) data plotting of coal macerals of bore-hole nos. 305, 303 and 309.

SEAM CORRELATION

The coal seams IV A in Bore-hole no. 309, IV (below index) in bore-hole no. 303 and I (below index), I and I B in Bore-hole no. 305 have attained high volatile bituminous C rank throughout the seam. The top and middle parts of I A, III and bottom portion of II seams also contain coal of high volatile bituminous C rank. Thus these seams or the part of seams are similar in rank. The coal seams III B, III A, top portion of II and the bottom part of III in Bore-hole no. 303 have indicated high volatile bituminous B rank. Thus they can be grouped together on the basis of similar rank.

The triangular data plotting (Text-figure 6) of vitrinite, exinite and inertinite macerals has indicated that the Mulug coals are divisible under three categories— (i) vitric or vitrinite-rich, as observed in the coals of I A and III B seams; (ii) mixed (vitro-fusic and fuso-vitric) as evidenced by the coals of I, II, III and IV A, I B, I below index, III A, IV and IV below index seams; and (iii) fusic or inertinite-rich coal is recorded in the coals of II below index seam.

The biaxial plotting (Text-figure 7) of vitrinite + exinite on one axis and inertinite on the other has also confirmed the existence of vitric mixed (fuso-vitric and vitro-fusic) and fusic coal types in Mulug area. The coal of I A seam, upper part of I seam, bottom part of IV A seam and II seam contains (80-95%) exinite and vitrinite association. The coal of II (below index) seam, however, is represented by fusic coal, whereas the rest of the coal seams contain (50-75%) vitrinite and exinite association indicating the existence of vitric and mixed nature of the coal.

COMPARISON AND DISCUSSION

The coal from the lowermost IV A seam of Bore-hole no. 309 Mulug coal belt is comparable with the lowermost Bagdona coal seam of Pathakhera Coalfield in having vitrinite dominance and low mineral matter association (Anand-Prakash & Sarate, 1993). Palynologically the Bagdona seam has been dated as Karharbari (Srivastava & Sarate, 1988; Srivastava & Jha, 1989, 1992a, b, 1995). Srivastava (1987) has also given palynological evidence for the occurrence of coal seams of Karharbari age from various localities of Godavari Basin. Navale *et al.* (1983) studied the microconstituents from various coalfields of Godavari Basin. Mulug coals of I A, I, I (below index), II and III from Bore-hole no. 305, IV seam of Bore-hole no. 303 and IV A seam of Bore-hole no. 309 are comparable with Top I seam (9 and 10 Incline) of Kothagudem Coalfield, Queen seam of Pelampalli, "D"seam (Pit no. 2), Queen seam, Pit no. 22 of Yellendu Coalfield, Seam I (Incline no. 3), Seam II (Incline no.3) and seam III (Incline no.7) of Ramagundam Coalfield, Shantikhani Top seam and "85 Dip" Salarjung seam of Belampalli Coalfield with respect to the vitrinite dominance and low mineral matter association. However, King seam (Incline no. 2), King seam (Incline 6, 7), Green seam (Incline 9, 10) and Top 2 seam of Pit no. 20 of Kothagudem Coalfield, King seam of Pit no. 20, Queen seam of Pit no. 22 and "D" seam of Pit no. 22 of Yellendu Coalfield, PK 1 seam no. 3 and PK 1 seam no. 4 of Ramakrishnapuram Coalfield and bottom seam of Belampalli Coalfield are comparable with II (below index) and III A seams of Bore-hole no. 305 of Mulug coal belt with respect to the inertinite dominance. The mineral matter association in all the coal seams studied by Navale *et al.* (1983) in general varies from 6-17 per cent except for Top 2 seam (Pit no. 20) from Kothagudem and seam no. 1 (Incline no.3%) of Ramagundam coalfields having mineral matter association up to 28 per cent and 32 per cent respectively. Mulug coals are also characterised by low frequency of mineral matter association. Ghosh (1962), Pareek *et al.* (1964) recorded megaspores and resin bodies from Ross and Salarjung seams in Tandur area of Godavari Basin which are also observed in IV A seam of Bore-hole no. 309. Vitrinite rich coal seams (Mulug coal belt) mentioned above are also comparable with Ramanwara Khas colliery, seam no. 4 of Pench Kanhan Valley Bharadwaj *et al.* (1974) and Sasti, Ballarpur and Lalpeth collieries of Wardha Valley coalfields (Anand-Prakash & Khare, 1976).

ECONOMIC POTENTIALS

Present investigation incorporates an assessment of 12 coal seams of Mulug coal belt. However, only eight I B, I A, I, I (below index), II, III A and III seams of Bore-hole no. 305 and IV A seam from Bore- hole no. 309 have attained workable thickness and have economic significance. Economic potential of any coal seam depends upon the low mineral matter and inertinite association and high frequency of vitrinite and exinite in the coal constituents. Different coal seams of Mulug coal belt have been classified in three groups, (i) coal seams containing mineral matter up to 12 per cent, (ii) 13-16 per cent and (iii) 17-27 per cent.

Group 1—The coal seam I A, bottom portions I and II seams of Bore-hole no. 305, bottom portion of IV A seam Bore-hole no. 309 contain mineral matter up to 12 per cent. These coal seams have also attained workable thickness. In view of low mineral matter and high frequency of vitrinite and exinite these coals can be utilized for blending or some other allied purposes. Seam III B (Bore-hole no. 305), IV and top portion of IV (below index) seam of Bore-hole no. 303 are not of more economic utility because of their non-workable thickness.

Group 2—The top portion of II seam, I (below index) and middle portion of III seams of Bore-hole no.305 and top portion of I A seam of Bore-hole no. 309 contains mineral matter from 13-17 per cent. Thus these coal seams or their portions have economic potentials for blending and/or allied purposes. The coal from bottom portion of IV (below index) in Bore-hole no. 303 contains fusic coal and the seam is of non workable thickness. Therefore, they may not be of economic importance.

Group 3—The coals representing top portion of I B and bottom part of III seam (Bore-hole no. 305) contain mineral matter from 17 to 27 per cent. These coals/portions of coal seams may be of economic significance. The top portion of III seam of Bore-hole no. 305 contain fusic coal with non-workable thickness and therefore is not suitable for any economic utility.

Thus Mulug coals are, in general, distinctly different than the Lower Gondwana coals of Damodar, Son-Mahanadi, Satpura, Wardha Valley coalfields in their hard and compact nature and also having dominance of vitrinite with high concentration of exinite and comparatively low mineral matter association.

ACKNOWLEDGEMENTS

I am thankful to Shri Venkatapayya the then, Chief Geologist of the Singareni Collieries Company Limited, Kothagudem, Andhra Pradesh for permission to collect samples. I also express my thanks to Drs Anand-Prakash and Suresh C. Srivastava for their valuable suggestions and Mr V.P.Singh for preparing the illustrations.

REFERENCES

Anand-Prakash & Khare RC 1976. Petrology and palynostratigraphy of some Wardha Valley coals, Maharashtra, India. *Palaeobotanist* **28** (2):124-138.

Anand-Prakash & Sarate OS 1993. Nature, composition and rank of Lower Gondwana coals from Pathakhera Coalfield, Satpura Graben. *Geophytology* **23** (1) :115-130.

Bharadwaj DC, Navale GKB & Anand Prakash 1974. Palynostratigraphy and petrology of Lower Gondwana coals in Pench Kanhan Coalfield, Satpura Gondwana Basin, M.P., India. *Geophytology* **4**(1):7-24.

Fox CS 1931. Coal in India - II. The Gondwana system and related formations. *Mem. geol. Surv. India* **58** : 1-128.

Fox CS 1934. Lower Gondwana coalfields of India. *Mem. geol. Surv. India* **59** : 1-386.

Ghosh TK 1962. Microscopic study of Tandur coal, Godavari Valley, Andhra Pradesh. *Q. J. geol. Min. metall. Soc. India* **34** (2):169-174.

Hughes TWH 1877. The Wardha Valley Coalfield. *Mem. geol. Surv. India* **13** (1) : 1-154.

Hughes TWH 1878. Notes on the geology of Upper Godavari Basin between the rivers Wardha and Godavari, near the civil station of Sironcha. *Rec. geol. Surv. India* **11**(1): 30.

International Committee on Coal Petrography 1971. *International hand book of coal biopetrography*. Supl. 2nd., ed., C.N.R.S., Paris.

King W 1872. Notes on a new coalfield in South-eastern part of the Hyderabad territory. *Rec. geol. Surv. India* **5** (2):41-74.

King W 1873. Notes on the Barakar (coal measures) in the Beddadanole Field, Godavari District. *Rec. geol. Surv. India* **6**(3): 49-76.

King W 1877. Notes on the rocks of Lower Godavari. *Rec. geol. Surv. India* **10**(2) : 55-106.

King W 1881. The geology of Pranhita-Godavari Valley. *Mem. geol. Surv. India* **18** (3) : 150-311.

Krishnan MS 1949. Coal in Godavari Valley, Madras Presidency. *Trans, M.G. M.I.* **45** : 81-112.

Kutty TS & Roy Chowdhury 1970. The Gondwana sequence of Pranhita Godavari Valley, India and its vertebrate faunas. *Proc. II int. Gondw. Symp. 1970, South Africa* **13** : 303-308.

Navale GKB, Mishra B K & Anand-Prakash 1983. The microconstituents of Godavari coals, south India. *Int. J. Coal Geol.* **3** : 31-61.

Pareek HS, Deekshitulu MN & Ramanamurthy BV 1964. Petrology of Salarjung and Ross seam coal, Tandur area, Godavari Valley Coalfield, Andhra Pradesh. *Research pap. in petrology by the officers of geol. Surv. India* : 141-158.

Raja Rao CS 1982. Coal resources of Tamil Nadu, Andhra Pradesh, Orissa and Maharashtra. *Bull. geol. Surv. India.* ser. A, *no. 45, Coalfields of India* **2** : 9-40.

Ramanamurthy BV 1976. Report on occurrence of a coal seam in Kamthi Formation from the Ramagundam area of Godavari Valley Coalfield and its stratigraphic significance. *Geol. Surv. India. Misc. Publ.* **45**.

Srivastava Suresh C 1987. Palynological correlation of coal seams in Godavari Graben, Andhra Pradesh, India. *Palaeobotanist* **35**(3): 281-296.

Srivastava Suresh C & Jha N 1989. Palynostratigraphy of Lower Gondwan sediments in Godavari Graben, Andhra Pradesh, India. *Palaeobotanist* **37**(2): 199-209.

Srivastava Suresh C & Jha N 1992a. Palynostratigraphy of Permian sediments in Manuguru area, Godavari graben, Andhra Pradesh. *In* : Venkatachala BS, Jain, KP & Awasthi N (Editors)—Proc. Birbal Sahni Birth Centenary Palaeobotanical Conference. *Geophytology* **22** : 102-110.

Srivastava Suresh C & Jha N 1992b. Permian palynostratigraphy in Ramakrishnapuram area, Godavari Graben, Andhra Pradesh, India. *Geophytology* **20**(2): 83-95.

Srivastava Suresh C & Jha N 1995. Palynostratigraphy and correlation of Permian-Triassic sediments in Budharam area, Godavari Graben, India. *J. geol. Soc. India* **460** : 647-653.

Srivastava Suresh C & Sarate OS 1988. Palynostratigraphy of the Lower Gondwana sediments from Shobhapur Block, Pathakhera Coalfield, Madhya Pradesh. *Palaeobotanist* **37**(1) : 125-133.

Wall PW 1857. Report on a reputed coal formation at Kota on the Upper Godavari River. *Madras J. Lit. Sci.* **18** : 256-269.