Biopetrological study of coals from Ramagundam Coalfield, Godavari Basin, Andhra Pradesh, India

Omprakash S. Sarate

Sarate OS 1996. Biopetrological study of coals from Ramagundam Coalfield, Godavari Basin, Andhra Pradesh, India. *Palaeobotanist* **43**(3) : 122-138.

A detailed petrographic study of eight coal seams from Ramagundam Coalfield, Andhra Pradesh is presented here. The top section of coal seam I A, I, II, III A, III and IV contains workable thickness. Reflectance study has revealed that the seams IA (middle), III B, III A, III (top) and IV contain coal of high volatile bituminous C rank. Coal seams I A (top and bottom parts), I, II and III (middle) seams/part their of are constituted by alternate coal bands of high volatile bituminous C and high volatile bituminous B rank. Besides, coal seam III and coal bands present below I seam have attained intermediate stage (high volatile bituminous C to sub-bituminous A) and high volatile bituminous C rank. Index seam is represented by coal of high volatile bituminous C and intermediate stage of the rank. The maceral study has revealed that the different seams are characterized mostly by the dominance of collinite maceral. Occasionally cracks in the vitrinite bands are filled either by clay or pyrite (grains/framboids) minerals. Exinite is represented by the microspores and megaspores of variable shape and size, sporangia, seeds, resin bodies, tenui and crassi-cutinites and algal elements. Inertinite Group is characterized by fusinite, semifusinite, inertodetrinite, sclerotinite and pyro-and degrado-fusinite macerals. Transition from vitrinite to semifusinite and semifusinite to fusinite is frequently observed. The microlithotype analysis has shown that the shaly coal, bright coal and dull coal have characteristic composition. These coals have been grouped under three categories as vitric, fusic and mixed (vitro-fusic and fuso-vitric) type. It is inferred that the sight of deposition has been a tectonically controlled slowly sinking basin.

Key-words—Biopetrology, Lower Gondwana coals, Ramagundam Coalfield, Godavari Basin, India.

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

सारांश

आँध्र प्रदेश में गोदावरी द्रोणी में रामागुंडम कोयला-क्षेत्र के कोयलों का जैवशैलिकीय अध्ययन

ओमप्रकाश शिवदास सराटे

इस शोध-पत्र में आंध्र प्रदेश में रामागुंडम कोयला-क्षेत्र की आठ कोयला-सीमों का विस्तृत शैलिकीय अध्ययन किया गया है। इनमें से ऊपरी छः सीमें अच्छी मोटी हैं। कोयला सीम प्रथम ए. (मध्य), तृतीय बी., तृतीय ए., तृतीय एवं चतुर्थ में उच्च वाष्पशील बिटुमेनी सी. कोटि के कोयले हैं। इसके अतिरिक्त कोयला-सीम प्रथम ए., प्रथम ,द्वितीय एवं तृतीय में उच्च वाष्पशील बिटुमेनी सी. एवं उच्च वाष्पशील बिटुमेनी बी. कोटि की ऊपर नीचे कोयला पट्टीयाँ हैं। कोयला सीम तृतीय तथा प्रथम सीम के नीचे कोयला पट्टीयाँ मध्यम अवस्था एवं उच्च वाष्पशील बिटुमेनी सी. कोटि के हैं। सूचक सीम उच्च वाष्पशील बिटुमेनी सी. तथा मध्यम कोटि की है। मेसीरल अध्ययन से व्यक्त होता है कि विभिन्न सीमें कोलीनाइट मेसीरल से प्रभावी हैं। प्रायः विट्रीनाइट पट्टीयों में विद्यमान दरार या तो पाइराइट से अथवा मिट्टी से भरी हुई हैं। एक्जीनाइट सूक्ष्मबीजाणुओं, गुरुबीजाणुओं, बीजाणुधानियों, बीजों, रेजिन तथा शैवालीय अवयवों से निरूपित हैं। इनर्टीनाइट समूह फ्यूजीनाइट, सेमीफ्यूजीनाइट, इनर्टोडिट्रिनाइट, स्क्लेरोटिनाइट तथा पाइरो एवं डिग्रेडोफ्यूजीनाइट मेसीरलों से अभिलक्षणित है। इन कोयलों में विट्रीनाइट से सेमीफ्यूजीनाइट तथा सेमीफ्यूजीनाइट से फ्यूजीनाइट परिवर्तन सरलता से देखने को मिलते हैं। ये कोयले विट्रिक, फ्यूजिक एवं मिश्रित प्रकार के कोयलों में समूहबद्ध किये गये हैं। इस अध्ययन से व्यक्त होता है कि इन कोयलों के निक्षेपण के समय यह द्रोणी धीरे-धीरे नीचे धंस रही थी।

RAMAGUNDAM Coalfield represents a tract having eight coal seams, out of which five are commercially exploited. However, meagre information is so far available regarding their biopetrological characteristics. Therefore, maceral, microlithotype and reflectance analyses of all the eight coal seams intersected in a Bore-hole no. 732 from Ramagundam Coalfield have been carried out.

GENERAL GEOLOGY

The existence of coal deposits within Lower Gondwana sequence of Godavari Basin was recorded by Walker (1841) near Kota (18°54' : 79°58'), followed by extensive geological work by Wall (1857), Blanford (1871), King (1872, 1881), Hughes (1877, 1878) and Raja Rao (1982). Ramanamurthy (1985) proposed the following classification for the lithological sequence of Ramagundam-Mantheni area.

Age	Group		Formation	General Lithology	Maximum thickness (m)
Late Lower to Middle Triassic	UPPER GONDWANA	MAHADEVARI	Upper	Mainly vermilion clays with subordinate sandstones and lime pellet rocks	200
			Middle	Dominantly argillaceous sandstones with variegated clasts (forms low hillocks)	200
			Lower	Dominantly brown sandy clays	
?Upper Permian to Early Triassic	LOWER GONDWANA	KAMTHI	Upper	Ferruginous sandstone with subordinate clays (forms prominent hill ranges)	400
				------Unconformity------	
			Middle	Sandstone and shales	1000
			Lower	Sandstones with subordinate shale and coal seams	200
			Barren Measures	Coarse to pebbly felspathic sandstone with subordinate clays	450 ± 50
Permian	GONDWANA		Barakar	Dominantly sandstones with seven regionally persistent coal seams and subordinate shales	300
			Talchir	Greenish sandstones, clays/shales conglomerates and boulders	200
			Sullavi & Pakhal	---------Disconformity--------- White to brown sandstones, shales, phyllites, dolomites	
				-------Non-conformity--------	
			Archaean	Granite with dolerite, quartz and pegmatite intrusives	

Godavari Basin contains almost a continuous sequence of sediments from Permian to Lower Cretaceous periods, which include terrestrial, marine and paralic deposits. Characteristic floral and faunal records, marine signatures and tectonic events are also described (Kutti *et al.*, 1970). Godavari Valley has a general NNW-SSE trend. About 55 km wide Lower Gondwana sequence is spread in an area of approximately 17,000 sq km between the latitudes 16° 38' and 19° 32' and longitudes 79° 12' and 81° 39'. The Lower Gondwana exposure at the confluence of Wardha and Wainganga rivers near Anantnag Village in Adilabad District of Maharashtra represents the northernmost extension of the basin. Whereas, the Lower Gondwana sequence at Eluru in the East Coast of Andhra Pradesh demarcates its eastern limit. The area is drained by two major rivers Pranhita and Godavari, henceforth, within Andhra Pradesh it is described as Pranhita-Godavari Valley Coalfield and in Maharashtra the Wardha-Godavari Coalfield.

The Singareni collieries Company Limited has developed Godavari Khani township to execute coal exploitation which is about 10 km east of Ramagundam Railway station on Nagpur Kazipet line of the south-central railway, in Karimnagar District, Andhra Pradesh. Ramagundam-Godavari belt is spread in an area of nearly 500 sq km, between the north latitudes 18° 33' to 18° 51' and east longitudes 79° 24' to 79° 50' with Godavari River demarcating its northern and north eastern limit while, Maneru River near the Ladnapuram Village marks its southern and south eastern extension.

Barakar Formation— All the coal seams intersected in Bore-hole no. 732 are assigned to Barakar Formation on the basis of lithological characters. The contact between the Talchir and overlying Barakar Formation is gradational. The Barakar succession has been divided into upper and lower members on the basis of distinct lithological characteristics. The Barakar sediments from the base up to the floor of IV seam with a thickness of 105-140 m are mostly characterized by white, medium to coarse grained felspathic sandstones which are calcareous at places. It also includes thin coal and shale bands. However, the sediments at the floor of IV seam up to Barakar-Barren Measure contact constitute the upper member with a maximum thickness of 160-200 m. It is characterized by the predominance of medium to very

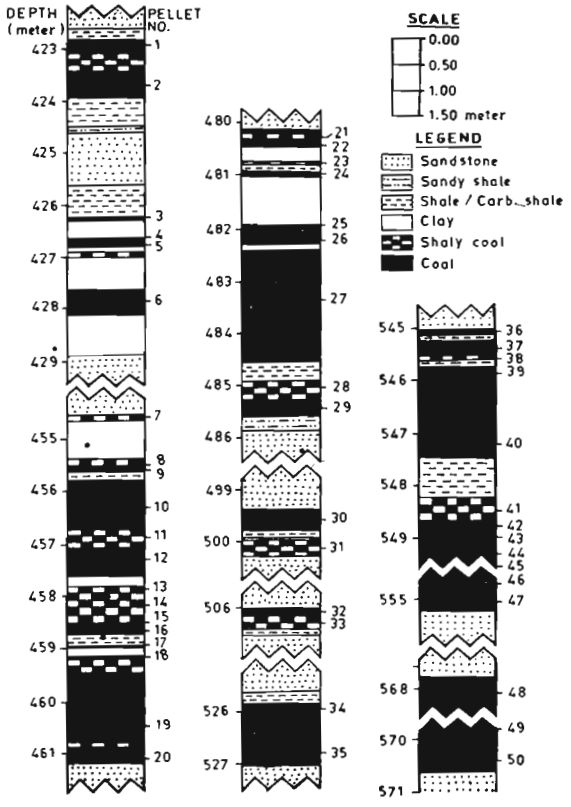
coarse grained white profusely cross bedded sandstones with micaceous shale, siltstone and six workable coal seams.

MATERIAL AND METHODS

The coal samples have been collected from bore-hole no. 732, located at about 2.5-3 km NNW of Kannal Village (Map 1, Table 1, Text-figure 1). This bore-hole displays the existence of eight coal seams as detailed below.

	Coal seam	Depth (in meters)
1.	I A (Top section)	422.83 - 423.95 (1.12)
	I A (Middle section)	426.65 - 426.98 (0.33)
	I A (Bottom section)	427.60 - 428.18 (0.58)
2.	I	455.34 - 461.25 (5.91)
3.	II	481.84 - 485.60 (3.76)
4.	III B	499.34 - 500.25 (0.91)
5.	Index	505.98 - 506.40 (0.42)
6.	III A	525.82 - 527.05 (1.23)
7.	III	545.02 - 555.30 (10.28)
8.	IV	567.73 - 570.65 (2.92)

Below I seam four thin (7-16 cm) coal bands are present between 480.10-481.02 m.



Text-figure 1—Litholog of bore-hole no. 732, Ramagundam Coalfield, Godavari Basin, Andhra Pradesh.

Table 1—Lithological details of Bore-hole no. 732, Shaft Block II, Ramagundam Coalfield, Godavari Basin, Andhra Pradesh

Depth (in meter)	Lithology	Seam	Pellet no.
419.60-422.60	Sandstone with quartz pebbles		
422.60-422.83	Dark grey shale		
422.83-423.14	Bright coal with vitrain and fusain bands at places	IA (Top section) 422.83-423.95	732/1
423.14-423.42	Shaly coal	(1.12 m)	
423.42-423.95	Bright coal with vitrain and fusain bands		732/2
423.95-424.47	Dark grey shale		
424.47-424.64	Sandy shale		
424.64-425.60	Grey-white sandstone		
425.60-426.17	Dark grey shale		
426.17-426.26	Bright coal with vitrain and fusain bands		732/3
426.26-426.65	Clay (grey)	IA (Middle sectin)	
426.65-426.78	Bright coal with vitrain and fusain bands	426.65-426.98 (0.33 m)	732/4
426.78-426.91	Clay		
426.91-426.98	Shaly coal		732/5
426.98-427.60	Grey shale		
427.60-428.18	Bright coal with fusain and vitrain bands	IA (Bottom section) 427.60-428.18	732/6
428.18-428.85	Clay (grey)	(0.58 m)	
428.85-454.50	Sandstone		
454.50-454.59	Shaly coal		732/7
454.59-455.34	Grey clay		
455.34-455.60	Bright coal	I Seam	732/8
455.60-456.74	Bright coal with vitrain bands	455.34-461.25 (5.91 m)	732/9
456.74-456.71	Coal (vitrain bands at places)		732/10
456.71-457.06	Shaly coal with vitrain bands		732/11
457.06-457.59	Coal with thin vitrain bands		732/12
457.59-457.88	Grey clay		
457.88-457.98	Shaly coal		732/13
475.98-458.07	Carbonaceous shale		
458.07-458.47	Shaly coal		732/14
448.47-458.60	Bright coal		732/15
458.60-458.70	Dull coal		732/16
458.70-458.88	Carbonaceous shale		
458.88-459.22	Dull coal (Calcite-rich)		732/17
459.22-459.40	Shaly coal		732/18
459.40-460.80	Bright coal with vitrain bands		732/19
460.80-460.90	Carbonaceous shale		
460.90-461.25	Coal with thin vitrain bands		732/20
461.25-480.10	Sandstone		
480.10-480.26	Bright coal		732/21

Contd.

480.26-480.33	Shaly coal		732/22
480.33-480.46	Bright coal		732/23
480.46-480.71	Dark grey clay		
480.71-480.77	Shaly coal		
480.77-480.91	Carbonaceous shale		
480.91-481.02	Bright coal		732/24
481.02-481.84	Grey clay		
481.84-482.28	Bright coal with vitrain bands and calcite veins	II Seam 481.84-485.60	732/25
482.28-482.43	Shaly coal	(3.76 m)	732/26
482.43-484.54	Coal with vitrain bands		732/27
484.54-485.00	Dark grey carbonaceous shale		
485.00-485.24	Shaly coal		732/28
485.24-485.60	Bright coal with vitrain bands		732/29
485.60-485.80	Sandy shale		
485.80-499.34	Sandstone		
499.34-499.79	Bright coal with vitrain and fusain bands	III B Seam 499.34-500.25	732/30
499.79-499.92	Carbonaceous shale	(0.91 m)	
499.92-499.96	Clay		
499.96-500.25	Shaly coal		732/31
500.25-500.60	Sandstone, pyritic at places		
500.60-505.98	Sandstone		
505.98-506.17	Bright coal, pyritic at places	Index seam	732/32
506.17-506.40	Shaly coal	505.98-506.40	732/33
506.40-506.50	Siltstone (dark)	(0.42 m)	
506.50-525.61	Sandstone		
525.61-525.82	Carbonaceous shale		
525.82-527.05	Bright coal with vitrain bands calcitic and pyritic at places	III A seam 525.82-527.05	732/34 and
527.05-545.02	Grey white sandstone	(1.23 m)	732/35
545.02-545.13	Dull coal	III Seam	732/36
545.13-545.18	Carbonaceous shale	545.02-555.30	
545.18-545.46	Dull coal pyritic at bottom	(10.28 m)	732/37
545.46-545.60	Shaly coal		732/38
545.60-545.69	Carbonaceous shale		
545.69-547.43	Coal (bright) with vitrain and fusain bands, calcitic at places		732/39 and 732/40
547.43-547.72	Grey shale		
547.72-548.18	Carbonaceous shale		
548.18-548.60	Shaly coal		732/41
548.60-555.30	Bright coal with thin vitrain bands at places		732/42 to 732/47
555.30-567.73	Grey white felspathic sandstone with quartz pebbles		
567.73-569.60	Coal (bright) with vitrain and fusain bands	IV Seam 567.73-570.65	732/48 732/49
569.60-570.65	Coal pyritic at places	(2.92 m)	732/50
570.65-570.82	Sandstone with soft coal streaks		

The coal samples have been crushed to get ± 18 mesh sized particles. Particulate pellets (fifty) have been prepared and studied as per the guidelines of I.C.C.P. (1971).

Seam I and III are composite in nature for description of maceral, microlithotype and reflectance I seam is divided into the top (Pellet nos. 8-12) and middle (Pellet nos. 13-20) parts and III seam into top (Pellet nos. 36-38), middle (Pellet no. 39 and 40), and bottom (Pellet nos. 41-47) parts. The coal samples collected from four thin bands lying below I seam are described as "coal below I seam".

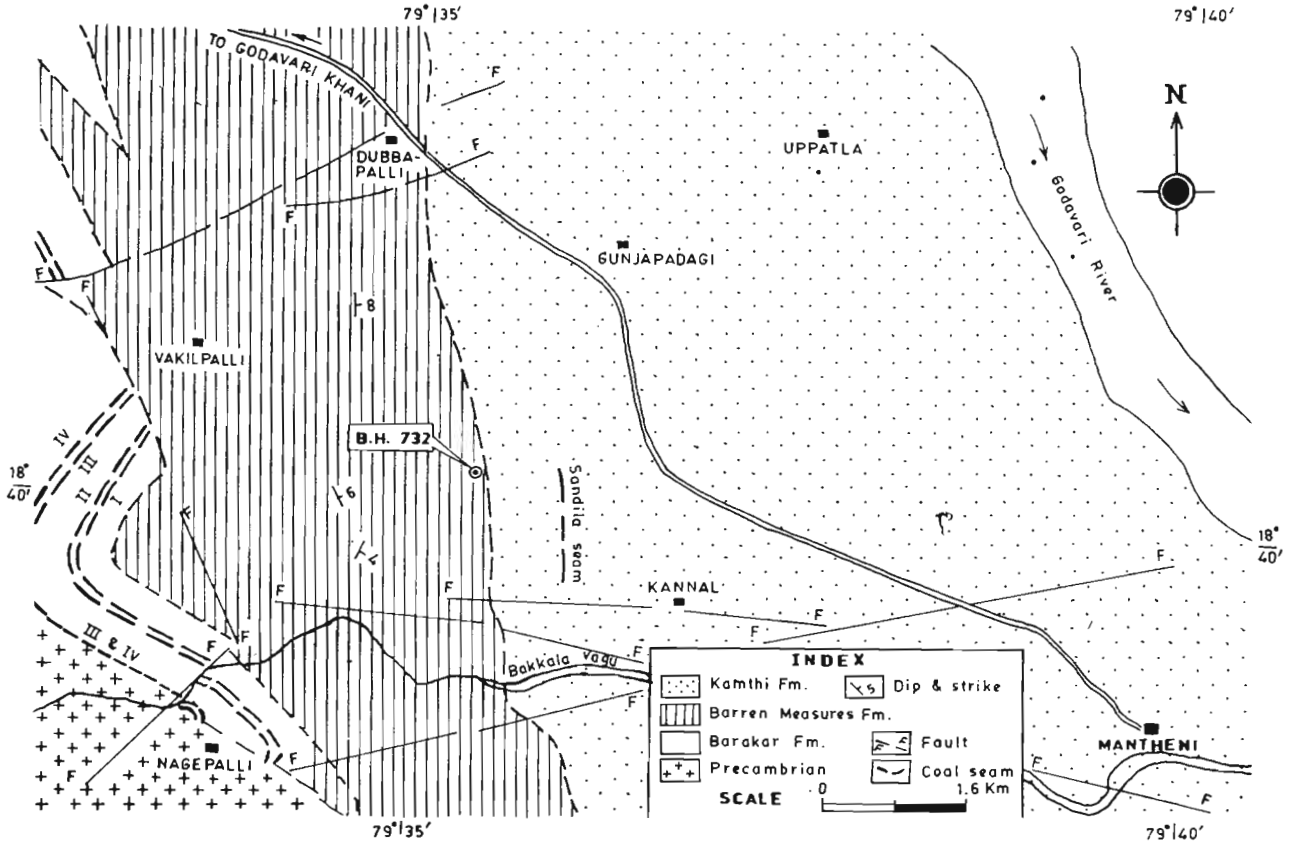
MACROSCOPIC CHARACTERISTICS

Ramagundam coals are hard and compact in nature as in case of Godavari coals. The coal seams mostly contain alternate bands of dull and bright coal with occasional shale or clay bands and thin veins of pyrite and calcite. Thick and thin bands of dull coal are generally of lenticular shape. The coal seams of this area has tendency to split in several seams through partings of shale or sandstone. The lithologies demarcating the roof and floor of coal seams have shown great variation from one horizon to the other. The roof and floor are marked by sandstone or shale or combinations of sandstone and shale, shale and clay.

MICROSCOPIC CHARACTERISTICS

Microscopically these coals are characterized by the dominance of vitrinite and inertinite maceral groups in association with exinite and mineral matter. Resinite is also persistently observed in the coal seams.

Vitrinite—It is mostly recorded in association with trimacerite, durite and vitrinertite microlithotypes as irregular shreds and fragments of light to dark grey colour. Thick microbands of telinite are more frequent than the collinite microbands. The collinite microbands constitute telocollinite, desmocollinite and corpocollinite. Vitrodetrinite is generally recorded from the dull coal bands. The cracks in the vitrinite bands are filled with clay mineral, however, pyrite filling is relatively a rare phenomenon.



Map 1—Location map of bore-hole no. 732, with geological details of the area (after Raja Rao, 1982).

Exinite—It mainly includes tenuispores distributed in some of the vitrinites, however, sporangia, spore masses, crassi and tenui cutinites, resin bodies, megaspores having different size and shapes, alginite (*Botryococcus*) and seeds are relatively less common and are mostly confined to the lowermost IV seam.

Inertinite—Transition of semifusinite to fusinite is frequently observed in Ramagundam coals. Fusinite is mostly recorded in the pyo- or degrado stages alongwith occasional impregnation of pyrite. Presence of well preserved fusinised cellular tissues, bogen structures and disintegrated cells is a regular feature observed in these coals. The cellular cavities and cracks are usually filled by carbonate or clayey mineral matter. However, in some of the samples pyrite impregnations have also been recorded.

Inertodetrinite—Inertodetrinite is constituted by small, strongly reflecting broken particles of fusinite, semifusinite, micrinite and sclerotinite. Sometimes, it is very difficult or even impossible to assign their affinity with a particular maceral.

Micrinites and macrinites—The micrinites and macrinites have scanty distribution in Ramagundam coals. They are generally found associated with vitrinites and exinites as strongly reflecting structureless bodies. Micrinites are commonly distributed in durite and trimacerite fractions of the dull coal bands in the form of homogeneous bodies of different shapes and size.

PLATE 1

(All magnifications x 250)

1. Vitrinite band.
2. Vitrinite bands with cracks.
3, 4. Vitrinite bands with pyrite impregnations.
5. Trimacerite containing calcite.
6. Pyrite grains in inertodetrinite.
7. Vitrinite to semifusinite transition with cracks filled by pyrite grains.
8. Telinite in inertodetrinite band.

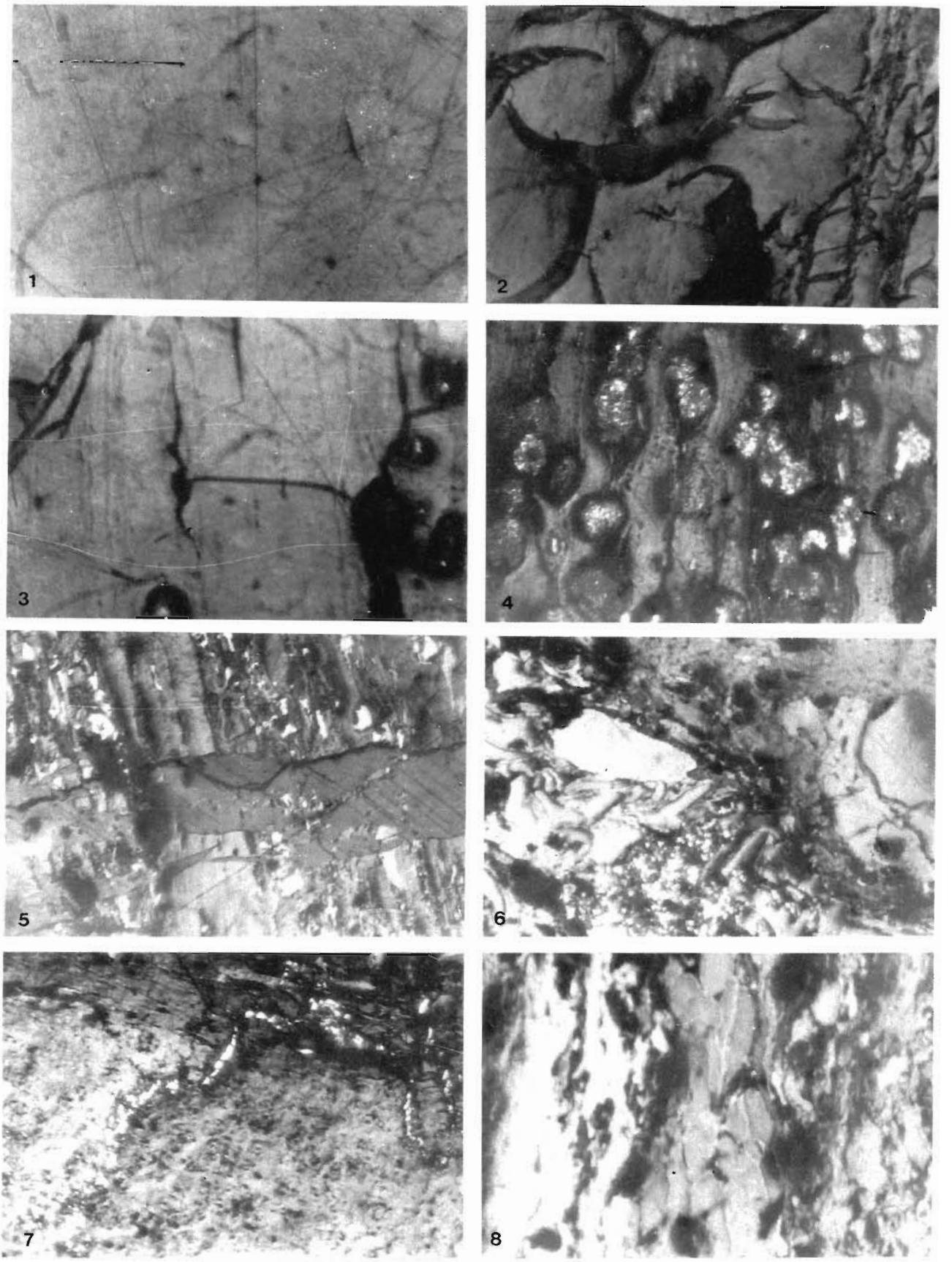


PLATE 1

Mineral matter—In Ramagundam coals carbominerite is the dominant mineral matter as compared with other minerals like pyrite, siderite and calcite which are observed but their frequency is comparatively low.

MACERAL STUDY

The data presented here is based on the detailed maceral composition of all the eight coal seams encountered in bore-hole no. 732 (for details please see Text-figure 2).

I A seam (Top section)—This coal seam is characterized by the dominance of vitrinite (57-47%) and mineral matter (21-27%). Both vitrinite and mineral content show decreasing trend towards the bottom of the seam. However, exinite (10-23%) and inertinite (12-13%) have shown increasing trend towards the bottom portion.

I A seam (Middle section)—The top and middle part of this section is occupied by the dominance of vitrinite (38-58%) with an increasing trend towards the middle part. Inertinite (29-20%) and exinite (18-7%) decrease towards the bottom. However, mineral matter has constant frequency distribution (15%). The coal at the bottom is inertinite rich (46%) containing mineral matter (38%), vitrinite (8%) and exinite (8%).

I A seam (Bottom section)—The coal representing top part of the section contains vitrinite (52%) intimately associated with exinite (17%), inertinite (17%) and mineral matter (14%). The coal at the bottom part is also characterized by the dominance of vitrinite (49%) as observed at the top of the section. However, the coal of the bottom section differs in having low exinite (4%) and high mineral matter (32%) association.

I seam—This is a composite seam having 5.91m thickness. The coal seam has been divided into top (pellet nos. 8-12) and bottom (pellet nos.13-20) parts to describe the average maceral composition. The coal representing the top part is characterized by the dominance of vitrinite (33-55%) intimately associated with exinite (17-26%), inertinite (10-20%) and mineral matter (20-23%). However, a shaly coal band (pellet no. 11) is present in this section having the dominance of inertinite (44%) and mineral matter (44%) in association with exinite (11%) and very scanty distribution of vitrinite.

The coal in the bottom part of I seam has a number of dull, bright and shaly coals. Vitrinite rich coal band contains the dominance of vitrinite (35-63%) whereas, the subdominance is occupied by inertinite (24-31%) and exinite (14-15%). The mineral matter (19-41%) association has shown an increasing trend towards the bottom. However, fusic coal contains the dominance of inertinite (34-37%), vitrinite (13-24%) and exinite (9-23%). High frequency of mineral matter (19-54%) has been recorded in some of the coal bands imparting shaly nature to these coals.

The thin (7-16 cm) bright and shaly coal bands lying below I seam are constituted by vitrinite (9-53%) associated with inertinite (9-33%), exinite (3-16%) and mineral matter (27-64%).

II seam—The coal seam contains alternate bands of vitric, fusic and shaly coal constituents. Vitric coal comprises vitrinite (41-51%) associated with inertinite (19-26%), exinite (9-10%) and mineral matter (20-24%). Shaly coals are characterized by mineral matter (43-65%) in association with inertinite (21-47%), vitrinite (8-13%) and exinite (1-2%). The bottom of this seam is characterized by a fusic coal band containing the dominance of inertinite (31%), followed by vitrinite (28%) and mineral matter (18%).

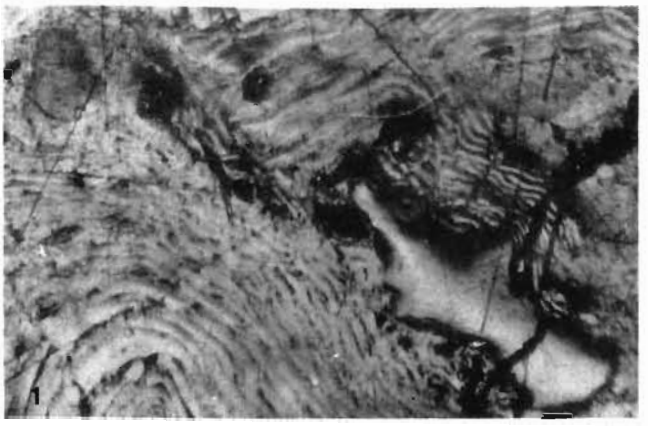
III B seam—The coal representing the top part is characterized by vitrinite (42%) dominance in association with exinite (37%), inertinite (13%) and mineral matter (12%). Such a high frequency of exinite is not recorded in the overlying I A, I and II seams. The coal at basal part is exclusively composed by inertinite (42%) and mineral matter (58%).

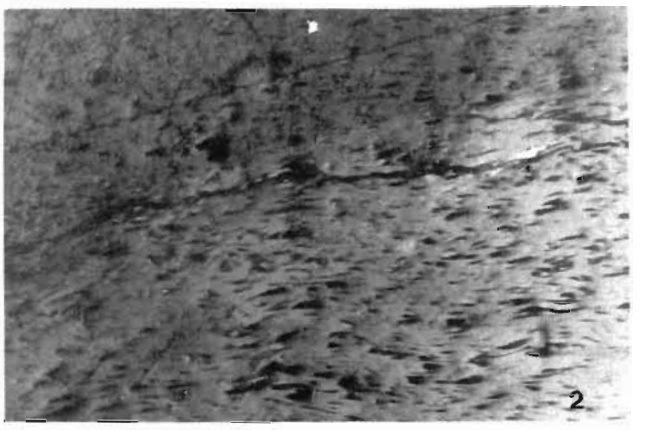
Index seam—The top of this seam has the dominance of exinite (33%) alongwith inertinite (30%), vitrinite (19%) and mineral matter (18%). However, the coal at the bottom constitutes inertinite

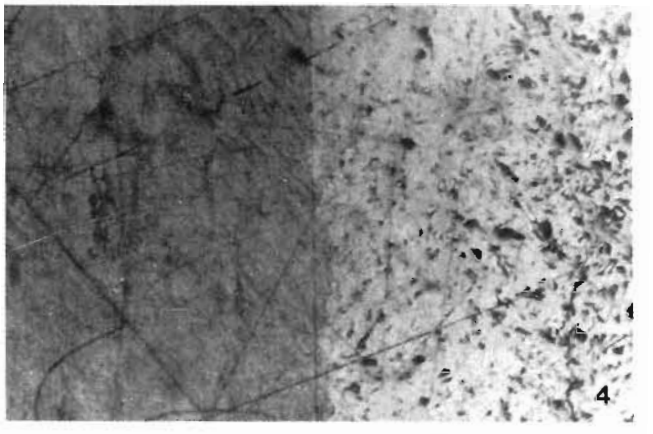
PLATE 2

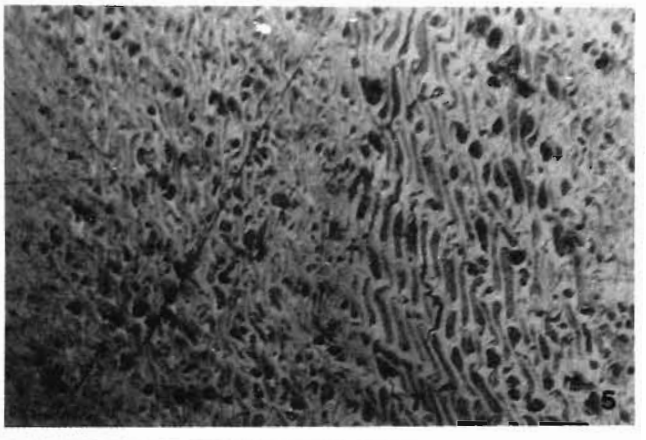
(All magnifications x 250)

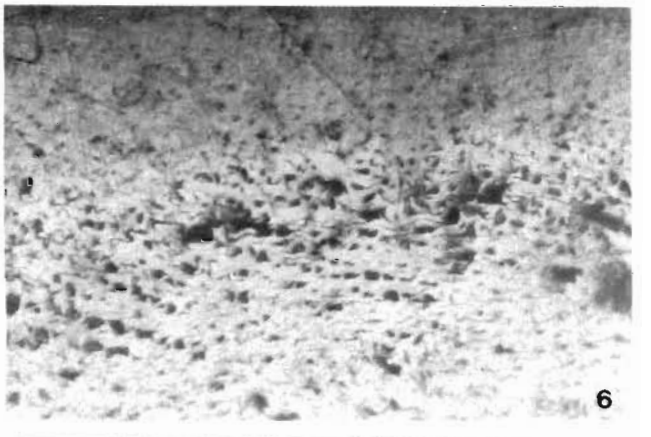
1. Semi-fusinite showing cellular folding.
2, 4-8. Transition from vitrinite to semifusinite.
3. Fusinite showing cellular folding.

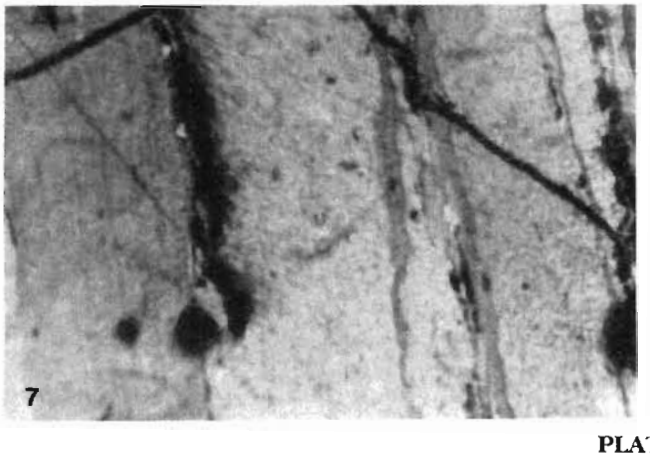












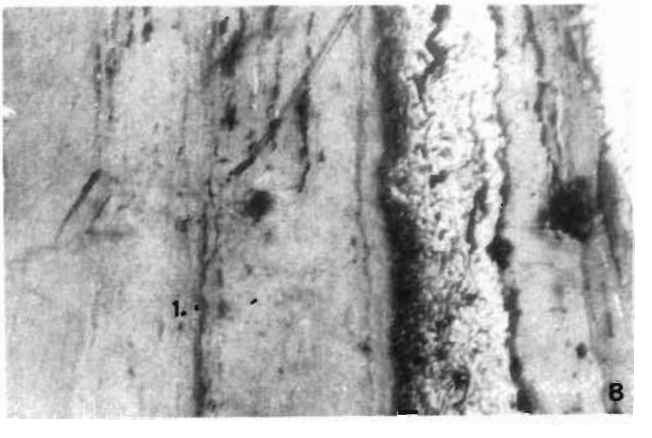


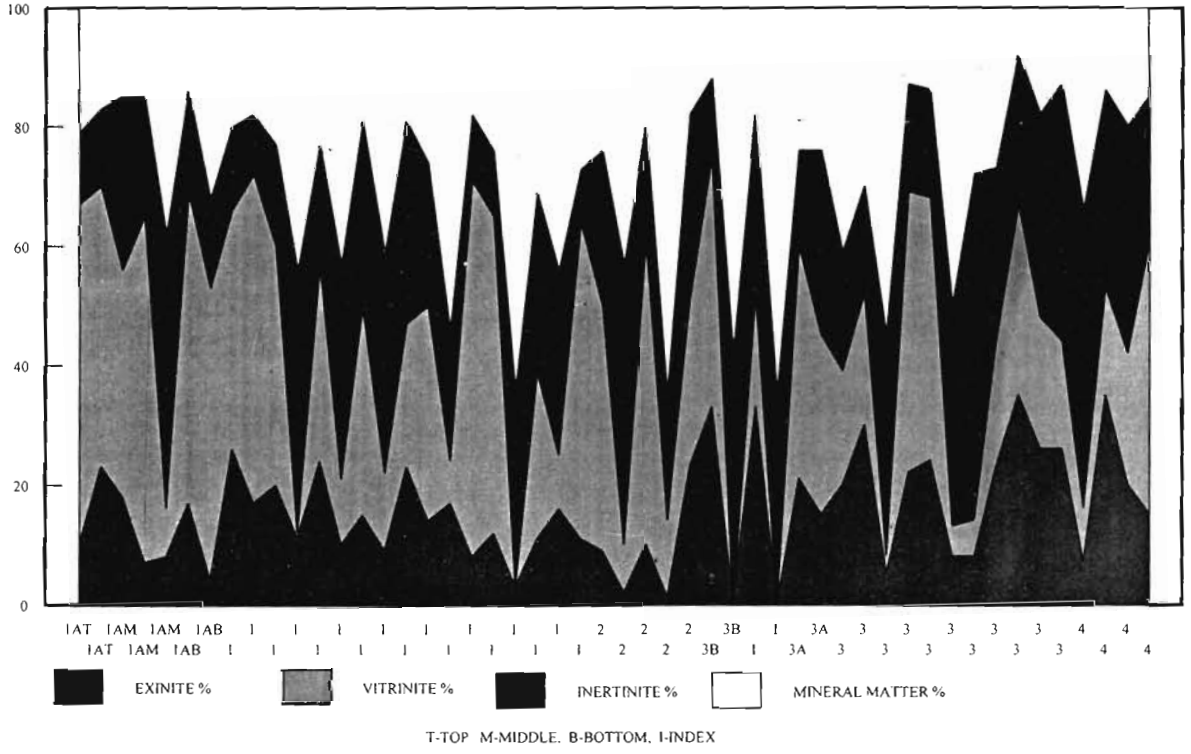
PLATE 2

(42%) and mineral matter (58%). The coal seam is closely comparable to the overlying III B seam in having high frequency of exinite at the top and inertinite and mineral matter at the bottom.

III A seam—The upper part of III A seam contains vitrinite (39%), exinite (21%) and inertinite (16%) associated with mineral matter (24%). However, the coal at the bottom is characterized by the dominance of vitrinite and inertinite (30-31%) alongwith exinite (15%) and mineral matter (24%).

III seam—The average maceral composition at the top of this coal seam reveals the existence of high frequency of mineral matter (30-55%) in association with inertinite (20-37%), vitrinite (3- 22%) and exinite (3-30%). The middle part, however, is characterized by vitrinite (44-47%), exinite (22-24%) and inertinite (18%) with mineral matter (13%). The bottom of the seam is marked by alternate bands of fusic and vitric coal constituents. Vitric coals contain high frequency of exinite (35%) and vitrinite (32%) in association with inertinite (25%) and mineral matter (8%). However, fusic coals are represented by the dominance of inertinite (34-43%) in association with exinite (26%) and vitrinite (18-22%). Some of the fusic coals have been found containing inertinite (29-58%), mineral matter (27-58%) associated with low percentage of vitrinite (5-9%) and exinite (7-8%). The high representation of mineral matter points towards the shaly nature of these coals.

IV seam—The coal at the top contains the dominance of exinite (35%) and inertinite (33%) alongwith vitrinite (18%) and mineral matter (14%). Similar coal composition has been observed in the upper part of Index seam. The coal in the middle portion contains inertinite (38%), vitrinite (22%), exinite (20%) and mineral matter (20%). The coal at the

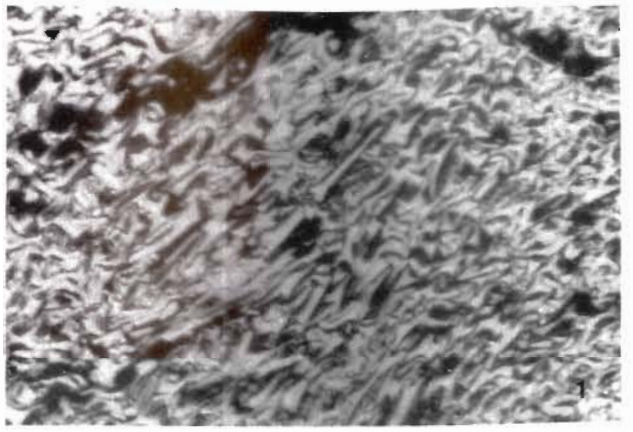


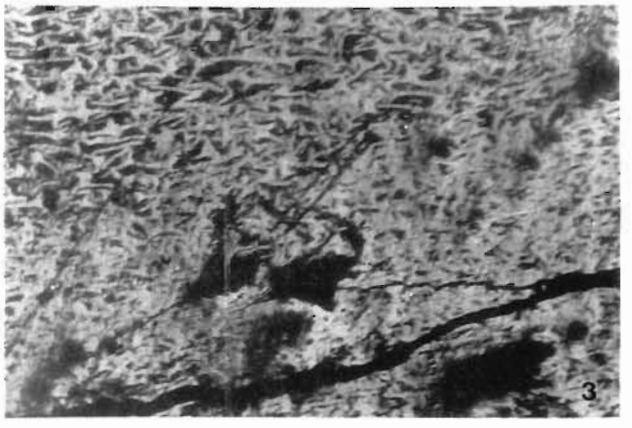
Text-figure 2—Maceral composition of coal seams from Bore-hole no. 732, Ramagundam Coalfield.

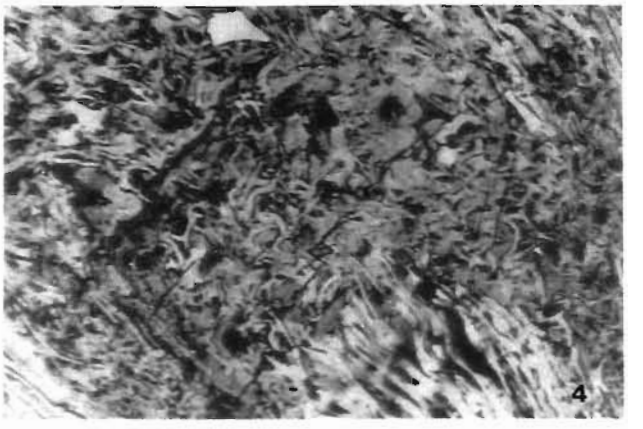
PLATE 3

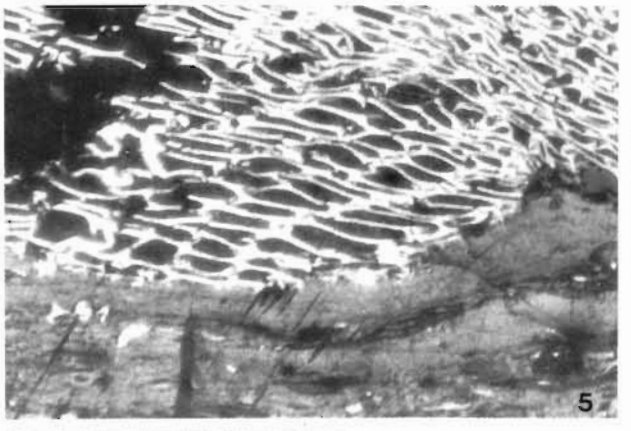
(All magnifications x 250)

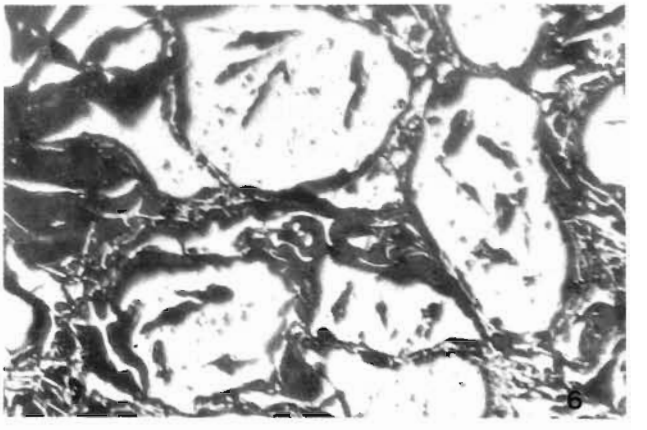
1. Inertinite showing bogen structures.
2. Inertinite showing cellular disintegration.
3, 5, 7. Fusinised cells.
6. Fusinised resins.
4, 8. Semi-fusinised and fusinised tissues showing folding.

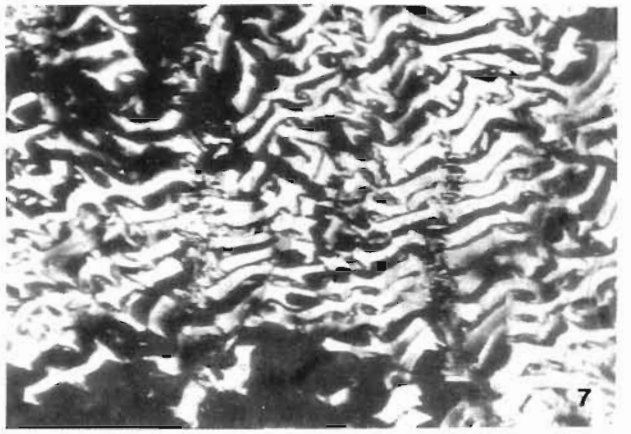












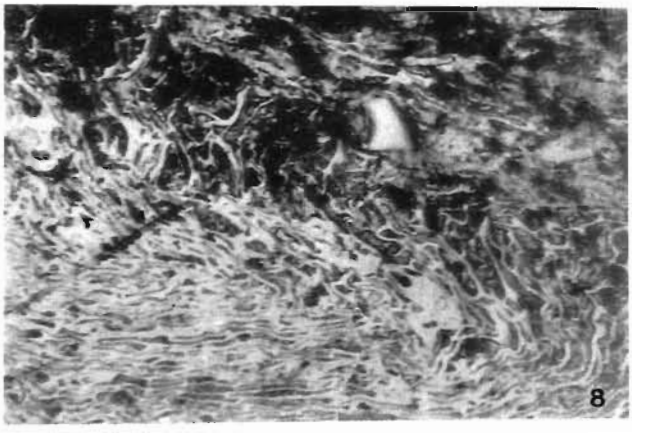


PLATE 3

bottom is constituted by the dominance of vitrinite (46%) intimately associated with inertinite (24%), exinite and mineral matter (15%).

MICROLITHOTYPE STUDY

IA seam (Top section)—The coal from the upper portion of this section contains the dominance of clarite (38%) and vitrite (35%) in association with inertite (10%), duroclarite (6%), carbominerite (4%), vitrinertite, durite and clarodurite (2-3%). The bottom portion is characterized by the dominance of duroclarite (47%), clarite (30%), inertite (7%), vitrite (7%) and clarodurite (5%). Vitrinertite, carbominerite and durite are restricted to (1-2%) in distribution (see Table 2).

I A seam (Middle section)—The coal at the top of this section is represented by inertite (34%) and clarite (33%) in association with duroclarite (9%), vitrite (9%), vitrinertite (6%), and clarodurite (6%). However, carbominerite and durite have a frequency range of 2-1 per cent. The underlying coal band is vitrite rich (33%) containing duroclarite (20%), clarite (17%), inertite (16%) and carbominerite (8%). However, clarodurite (4%) and vitrinertite (2%) have lesser distribution.

I A seam (Bottom section)—The coal representing the upper part of this section is characterised by the dominance of inertite (53%) associated with clarite (15%), durite and duroclarite (10-11%), clarodurite (8%) and vitrinertite (3%). The underlying coal is constituted by duroclarite (26%) alongwith vitrite (23%), clarite (18%), inertite (14%) and carbominerite (12%). However, clarodurite (6%) and vitrinertite (1%) occur rarely. The coal at the base shows the dominance of duroclarite (46%) invariably associated with carbominerite (20%) and clarite (16%). Besides, vitrite (6%), inertite (5%), vitrinertite (4%) and clarodurite (3%) are also present.

I seam—The coal at the top of this seam is represented by the dominance of duroclarite (25-58%) in association with clarodurite (8-14%), inertite (3-1%), vitrinertite (2-8%), vitrite (4-8%), durite (3-7%) and clarite (5%). However, two coal bands (pellet nos. 9 and 12) are characterized by the dominance of clarite (41-43%) in association with duroclarite (25-31%). The coal represented by pellet no. 11 contains durite (44%) and inertite (43%). Thus, it appears that different coal bands have distinct microlithotype composition at the top of I seam.

The bottom part of I seam is constituted by a number of bright and shaly coals, each having characteristic microlithotype composition, e.g., the coal of pellet nos. 13 and 18 constitutes inertite (61%) intimately associated with carbominerite (3-15%), clarodurite (2-7%), duroclarite (7-14%), durite (10%), vitrinertite (4-7%) and clarite (1-4%). However, pellet nos. 14 and 19 contain the dominance of vitrite (33-47%) and the subdominance of duroclarite (27%) and clarite (24%). The coal of pellet nos. 15, 16 and 17 is constituted by duroclarite (32-49%), vitrinertite (5-11%), inertite (4-23%), clarite (4-30%), clarodurite (6-32%) besides, carbominerite, durite and vitrite (1-3%) having scanty distribution.

Four thin coal bands occuring below I seam are represented by the dominance of inertite (78%), duroclarite (28%) and clarite (35%) from top to bottom. However, durite (19%), clarite and inertite (22-23%), carbominerite (18%), and duroclarite (18%) are the subdominant associate in each coal band.

II seam—This coal seam is constituted by four bands each distinguishable on the basis of characteristic microlithotype composition from top to bottom. The coal at the top and bottom contains the dominance of clarite (27%) in association with vitrite ((19%), inertite, vitrinertite, carbominerite (15-16%) and duroclarite (7%) at the top and inertite (28%), duroclarite (20%) vitrinertite and clarodurite (10-11%) at the bottom. However, the coal in the middle and bottom parts has the dominance of inertite (49%), carbominerite (21), durite (45%) and vitrite (18%) and clarite (19%), inertite (44%), durite (26%) and vitrinertite (22%).

III B seam—The upper part of the coal seam has the dominance of clarite (44%) alongwith duroclarite (25%), inertite (10%), clarodurite (8%), vitrinertite and vitrite (5-6%) and durite (2%). However, the coal at the bottom is mainly constituted by inertite (83%), durite (16%) and carbominerite with rare occurrence.

Index seam—The coal at the top is characterized by inertite (26%) and duroclarite (24%) in association with clarite (17%), clarodurite (15%), durite (10%) and vitrinertite (6%) besides, inertite and carbominerite having scanty representation of 1 per cent each. The coal at the bottom is constituted of a

Table 2—Microlithotype analysis of the coal seams from Bore-hole no. 732, Ramagundam Coalfield, Godavari Basin, Andhra Pradesh

Name of coal seam	Sample no.	Vitrite %	Clarite %	Inertite %	Vitrinertite %	Durite %	Duroclarite %	Clarodurite %	Carbominerite %
I A	1	35	38	10	2	2	6	3	4
(Top)	2	7	30	7	2	1	47	5	1
I A	3	9	33	34	6	1	9	6	2
(Middle)	4	33	17	16	2	-	20	4	8
I A	5	-	15	53	3	11	10	8	-
(Bottom)	6	23	18	14	1	-	26	6	12
--do--	7	6	16	5	4	-	46	3	20
I(Top)	8	7	15	5	5	-	56	7	5
--do--	9	8	43	3	3	7	31	5	-
--do--	10	4	5	11	2	-	58	14	6
--do--	11	-	-	43	-	44	2	6	5
--do--	12	5	41	10	8	3	25	8	-
I(Bottom)	13	-	4	61	4	-	14	2	15
--do--	14	33	1	4	10	1	27	14	10
--do--	15	-	4	23	6	3	32	32	-
--do--	16	1	31	16	11	-	34	6	1
--do--	17	3	30	4	5	-	49	8	1
--do--	18	-	11	61	1	10	7	7	3
--do--	19	47	24	6	7	2	8	2	4
--do--	20	15	52	3	3	1	20	6	-
Below I	21	-	-	78	-	19	1	-	2
--do--	22	2	23	22	4	4	28	17	-
--do--	23	-	4	44	3	8	14	9	18
--do--	24	7	35	12	9	4	26	7	-
II	25	19	27	16	15	-	7	1	15
--do--	26	-	3	49	4	5	5	13	21
--do--	27	19	18	3	5	45	6	4	
--do--	28	-	-	44	22	26	8	-	-
--do--	29	2	27	28	11	-	20	10	2
III B	30	5	44	10	6	2	25	8	-
--do--	31	-	-	83	-	16	-	-	1
Index	32	1	17	26	6	10	24	15	1
--do--	33	-	-	76	-	23	-	-	1
III A	34	16	31	7	3	4	34	5	-
--do--	35	2	23	22	7	17	19	9	1
III(Top)	36	-	27	44	3	11	12	3	-
--do--	37	1	5	25	1	1	42	8	17
--do--	38	-	-	78	-	18	-	1	3
III(Middle)	39	9	40	4	6	2	29	9	1
--do--	40	8	51	15	5	-	17	4	-
III(Bottom)	41	-	-	60	5	16	3	16	-
--do--	42	-	-	48	2	34	3	13	-
--do--	43	1	7	21	9	9	22	31	-
--do--	44	5	27	17	21	4	22	4	-
--do--	45	5	21	41	5	10	8	10	-
--do--	46	-	1	36	2	1	31	25	4
--do--	47	-	12	60	6	1	14	5	2
IV	48	2	9	8	8	-	31	42	-
--do--	49	10	2	31	8	11	19	18	1

mixture of inertite (76%) and durite (23%) with rare occurrence of carbominerite (1%).

III A seam—The coal from the upper horizon of III A seam is characterised by the dominance of duroclarite (34%) followed by clarite (31%), vitrite (16%) and inertite (7%), clarodurite, durite and vitrinertite (3-5%). The coal at the bottom horizon contains clarite and inertite (22-23%) intimately associated with duroclarite (19%), durite (17%), clarodurite and vitrinertite (7- 9%) besides, vitrite and carbominerite (2-1%).

III seam—The coal at the top of this seam is characterised by three alternate bands of inertite (44%) and vitrite (27%) associated with durite and duroclarite (11-12%). The underlying coal band contains duroclarite (42%), inertite (25%) and carbominerite (17%). The coal at the base is characterized by the dominance of inertite (78%) intimately associated with durite (18%), clarodurite and carbominerite (1-3%). The coal in the middle part contains the dominance of clarite (40-51%) in association with duroclarite (17-29%), clarodurite (4-9%), vitrite (8-9%), vitrinertite (5-6%) and inertite (4-15%). However, durite and carbominerite (1-2%) have scanty distribution. The coal at the base of III seam is characterized by a number of coal bands. The uppermost coal band is inertite rich (48-60%) containing durite (16- 34%) and clarodurite (13-16%). Inertite (36-60) rich coal follow this sequence alongwith the subdominance of clarite (21%), duroclarite (31%), clarodurite (25%) and duroclarite (14%).

IV seam—The coal at the top is characterized by high frequency of clarodurite (42%) in association with duroclarite (31%), clarite, inertite and vitrinertite (8-9%) and vitrite (2%). The coal in the middle part is inertite (31%) rich invariably associated with clarodurite and duroclarite (18-19%), vitrite and durite (10-11%) and vitrinertite (8%). Clarite and carbominerite, however, have low frequency distribution (2-1%). The coal at the bottom is constituted by the dominance of duroclarite and clarite (32-31%) intimately associated with vitrinertite and inertite (12%) each, vitrite (8%), clarodurite (4%) and durite (1%).

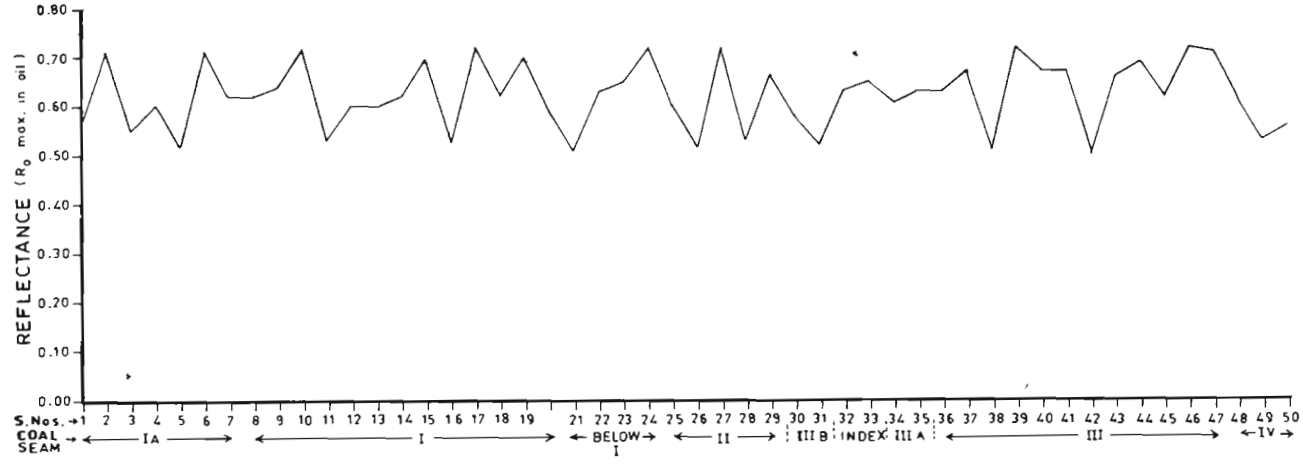
REFLECTANCE STUDY

The details regarding reflectance properties of each coal seam are given in the Table and Text-figure 3 for correlation.

I A seam (Top section)—The coals have attained vitrinite R_O max. values of 0.71 per cent in the bottom and 0.57 per cent in the top parts of this sections of the seam.

I A seam (Middle section)— The coals of this section are characterized by the vitrinite reflectance (R_O max.) of 0.55 per cent in top part, 0.60 per cent in middle part and 0.52 per cent in the bottom part.

I A seam (bottom section)— In this section the coal shows reflectance R_O max. values 0.71 per cent and 0.62 per cent, equivalent to high volatile bituminous B rank in the top part and high volatile bituminous C rank in the bottom part.



Text-figure 3—Reflectance analysis of different coal seams of bore- hole no. 732, Ramagundam Coalfield, Andhra Pradesh.

I seam—The coal of this seam contains bands of high volatile bituminous C and high volatile bituminous B rank with (R_o max.) ranges between 0.53-0.72 per cent in oil.

Four thin coal bands present below I seam show reflectance range (R_o max.) between 50 to 72 per cent which indicates that different coal bands have reached different stages of coalification which varies from the intermediate stage between high volatile bituminous C to sub-bituminous A stage, high volatile bituminous C and high volatile bituminous B stages.

II seam—This seam is constituted by the coal of high volatile bituminous C rank at the top and bottom portions having reflectance (R_o max.) range of 0.52-0.62 per cent and 0.53-0.66 per cent. The coal in the middle portion, however, has attained the rank of high volatile bituminous B stage (R_o max.) 0.72 per cent.

III B seam—The coal shows maximum reflectance range (R_o max.) of 0.58-0.52 per cent with increasing trend towards the top portion. Thus, the coal is of high volatile bituminous C rank.

Index seam—Index seam is constituted by coal containing reflectance range of (R_o max.) 0.50-0.63 per cent with an increasing trend towards the bottom indicating high volatile bituminous C rank.

III A seam—The coal of this seam shows a reflectance value (R_o max.) range of 0.61-0.63 per cent with increasing trend towards the bottom. Thus, the coal seam has attained high volatile bituminous C rank.

III seam—The coal at the top of III seam has attained high volatile bituminous C rank. However, the middle part is constituted by two coal bands. The upper band contains the coal of high volatile bituminous B rank (R_o max.) 0.72 per cent and at the basal part the coal band of high volatile bituminous C rank (R_o max.) 0.67 per cent. The coal representing bottom part of this seam has three bands, at the top it contains intermediate stage between high volatile bituminous C to sub-bituminous A rank (R_o max.) 0.59 per cent at the middle and bottom levels it contains high volatile bituminous C and high volatile bituminous B rank coal with (R_o max.) range of 0.62-0.72 per cent.

IV seam—The maximum reflectance values recorded for this coal seam are 0.56 per cent at the bottom, 0.53 per cent in middle and 0.62 per cent at the top portions. Thus, the coal has attained high volatile bituminous C rank.

SEAM CORRELATION

The variation in the reflectance of vitrinite observed from the different bands of coal in the seam appears to have been caused mainly by the difference in the source material or by the association of mineral matter content. Generally, the vitrinites found in mineral matter rich coals have lesser reflectance as compared to the coals having low representation of mineral matter. This seems to be the probable reason for the variation in the rank values of different bands of Ramagundam coals. The comparatively dull bands generally show lesser maturation levels.

Coal seam	R_o max.	Rank of coal
IA (Top)	0.57	* HVB C
IA --do--	0.71	* HVB B
IA (Middle)	0.55	* HVB C
IA --do--	0.60	* HVB C
IA --do--	0.52	* HVB C
IA (Bottom)	0.71	* HVB B
IA --do--	0.62	* HVB C
I (Top)	0.62	* HVB C
I --do--	0.64	* HVB C
I --do--	0.72	* HVB B
I --do--	0.53	* HVB C
I --do--	0.60	* HVB C
I (Bottom)	0.60	* HVB C
I --do--	0.62	* HVB C
I --do--	0.70	* HVB B
I --do--	0.53	* HVB C
I --do--	0.72	* HVB B
I --do--	0.62	* HVB C
I --do--	0.70	* HVB B
I --do--	0.59	* HVB C
Below I seam	0.51	* HVB C
--do--	0.63	* HVB C
--do--	0.50	* HVB C / SB A
--do--	0.72	* HVB B
II	0.60	* HVB C
II	0.52	* HVB C
II	0.72	* HVB B
II	0.53	* HVB C
II	0.66	* HVB C
III	B 0.58	* HVB C
III	B 0.52	* HVB C
Index seam	0.63	* HVB C

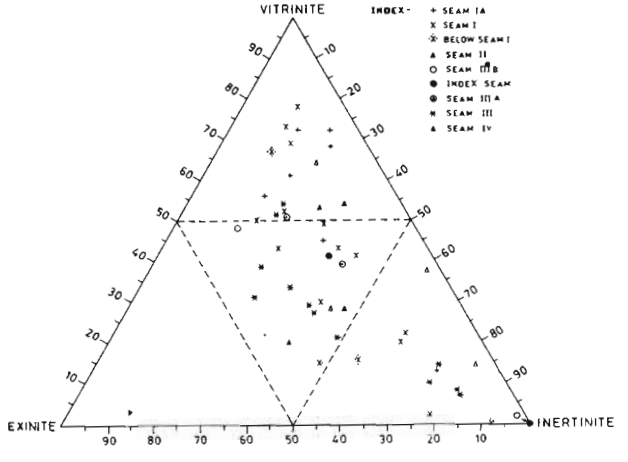
Contd.

Coal seam	R_o max.	Rank of coal
--do--	0.50	* HVB C / SB A
III A	0.61	* HVB C
III A	0.63	* HVB C
III (Top)	0.64	* HVB C
III --do--	0.67	* HVB C
III --do--	0.51	* HVB C
III (Middle)	0.72	* HVB B
III --do--	0.67	* HVB C
III --do--	0.67	* HVB C
III (Bottom)	0.50	* HVB C / SB A
III --do--	0.66	* HVB C
III --do--	0.69	* HVB C
III --do--	0.62	* HVB C
III --do--	0.72	* HVB B
III --do--	0.71	* HVB B
IV	0.61	* HVB C
IV	0.53	* HVB C
IV	0.56	* HVB C

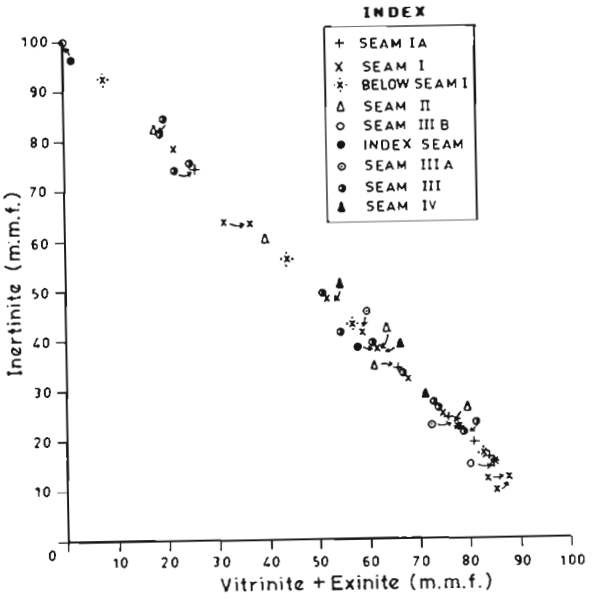
* HVB - High volatile bituminous

SB - Sub-bituminous

The reflectance analysis has indicated that the coal seams IA (middle portion), III B, III A, III (Top) and VI have attained high volatile bituminous C rank. However, top and bottom portions of IA, the entire I and II seams and middle part of III seam is constituted by alternate bands of high volatile bituminous C and high volatile bituminous B rank. However, III seam and the coal bands present below I seam are characterized by bands of high volatile bituminous B, high volatile bituminous C and an intermediate (between high volatile bituminous C and sub-bituminous A) stage of rank. Index seam is characterized by a band of high volatile bituminous C and a band of intermediate stage coal.



Text-figure 4—Triangular data (m.m.f.) of vitrinite, exinite and inertinite macerals in different coal seams of Ramagundam Coalfield.



Text-figure 5—Biaxial (m.m.f.) maceral data plotting of different coal seams of Bore-hole no. 732, Ramagundam Coalfield.

The maceral study has revealed that the top and bottom parts of IA and the middle part of III seam is vitric in nature. However, III A seam is constituted by vitric and the coal of mixed (vitro-fusic and fuso-vitric) nature. The seams IA (middle) and IV contain the coal of both vitric and fusic nature. Besides, the top part of III seam and the index seam contain bands of exinite rich coal and shaly coal. The top part of I seam and the entire III B seam contain bands of vitric and shaly coal. However, the coal seams I (Bottom), II and bottom part of III seam and the coal bands present below I seam contain vitric, fusic and shaly coal bands.

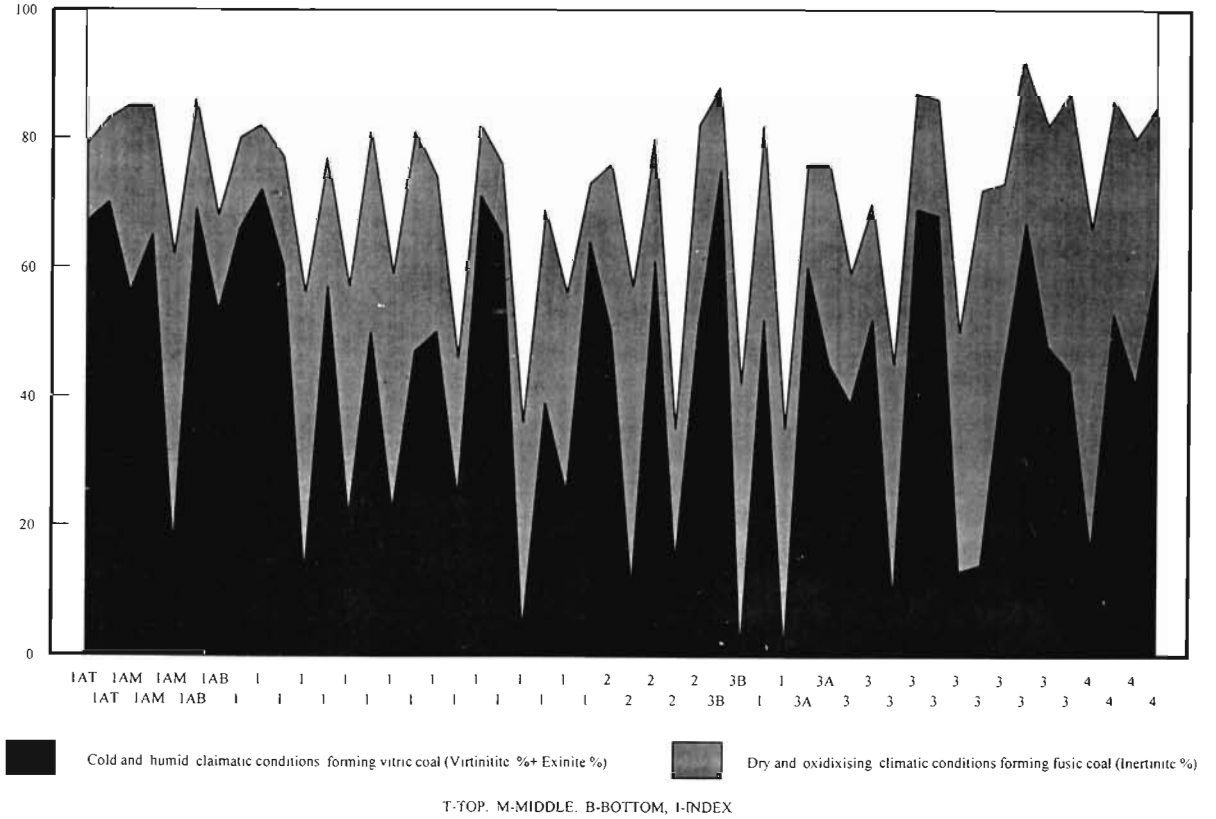
The triangular (m.m.f.) data plotting of vitrinite, exinite and inertinite (Text-figure 4) has indicated the existence of vitric, fusic and mixed (vitro-fusic and fuso-vitric) type of coals in Ramagundam Coalfield. The coal seams I A, I, II, III A and the coal bands below I seam contain vitric, fusic and mixed type of coal. The seams IA and IV are constituted by vitric and mixed coal types. However, index seam is constituted by both fusic and mixed (vitro-fusic and fuso-vitric) type of coal and III B seam by vitric and fusic coal types.

The biaxial mineral matter free (m.m.f.) data plotting (Text-figure 5) has also indicated the existence of three coal types (i) vitric, (ii) mixed (vitro-fusic and fusovitric), and (iii) fusic.

COMPARISON AND DISCUSSION

Navale *et al.* (1983) studied biopetrology of three coal seams (seam I and II of Incline 3 and seam III from Incline 7) from Ramagundam Coalfield which are closely comparable in maceral and microlithotype characteristics of I A (Top and Bottom sections) of present study. Seams IV, IV (below index) and IV A of Mulug area, contain similar maceral and microlithotype constitution and rank as observed in IV seam of Ramagundam Coalfield (Sarate, 1996). This indicates that the IV seam of Ramagundam Coalfield splits into IV, IV (below index) and IV A seams in Mulug area. In general, the Ramagundam coals contain higher amount of mineral matter than the coals of Kothagudem, Yellendu, Ramakrishnapuram, Belampalli and Tandur areas of Godavari Basin (Pareek *et al.*, 1964; Ghosh, 1962; Moiz & Ramana Rao, 1976). The coals of Ramanwara Khas colliery seam nos. I, II and Chandąmeta III seams are inertinite rich, however, seam III of Ramanwara Khas colliery has the dominance of vitrinite (Bharadwaj *et al.*, 1974). The coals from Wardha Valley coalfields and Pathakhera Coalfield, Satpura Basin (Anand Prakash & Khare, 1976; Aanand Prakash & Sarate, 1993) also contain vitrinite and inertinite rich coals as observed in Ramagundam coals. Thus, it appears that the Lower Gondwana sediments in Satpura, Wardha and Godavari basins were laid down under similar climatic conditions.

It is evident that the coaliferous basins of the Gondwanaland were located in and around subarctic regions at the initial stages of the Gondwana sedimentation. The flora at present growing in the subarctic regions is similar to the Glossopteris flora characterized by broad tongue-shaped leaves with stunted growth and short tufted Gangamopteris plants that existed in the Gondwanaland forests. The vegetal matter responsible for the formation of coal in Ramagundam area seems to have accumulated in



Text-figure 6—Demonstrating the climatic conditions.

a tectonically controlled slowly sinking basin. The presence of alternate vitrinite and inertinite rich coal bands indicates the prevalence of two distinct periods of deposition characterized by cold and humid conditions during which the vegetal matter remained submerged in water enhancing the process of vitrinization and drier conditions responsible for the formation of inertinites. The fusic coal, however, indicates the stage when the vegetal matter remained exposed to the surface (dry conditions) causing churning effect on the coal microconstituents. The high incidence of mineral matter suggests periodic flooding in the Basin of deposition. Krausel (1961), King (1958), Chandra and Chandra (1987), Laskar and Mitra (1976), Shah (1976) and Lele (1976) also expressed similar views regarding the climatic conditions during the Lower Gondwana sedimentation.

ECONOMIC POTENTIAL

Bore-hole no. 732 intersects a succession of 8 coal seams. However, I A (Top section), I, II, III A and IV seams have attained workable thickness. The coal representing the lowermost IV seam may be used for blending or for other allied purposes in view of its high vitrinite and exinite constituents and low mineral matter association.

ACKNOWLEDGEMENTS

I am thankful to Dr Anand-Prakash for critically going through the manuscript and Shri Venkatappayah, Chief Geologist, Singareni Collieries Company Limited, Kothagudem, Andhra Pradesh for permission to collect the samples. I also thankfully acknowledge the help of Shri V.P. Singh for preparing 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.

Blanford WT 1871 Additional note of plant-bearing sandstones of Godavari Valley. *Rec. geol. Surv. India* **4**(3) : 59-88.

Chandra S & Chandra A 1987. Vegetational changes and their climatic implications on coal bearing Gondwana. *Palaeobotanist* **36** : 74-86.

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 petrography*. Supl. 2nd., ed., C.N.R.S., Paris.

King LC 1958. Basic palaeogeography of Gondwanaland during Late Palaeozoic and Late Mesozoic eras *Q. J. geol. Soc. Lond.* **114** : 47-88.

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

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

Krausel R 1961. Palaeobotanical evidence of climate. *In* : Nairn AEM (Editor)- *Descriptive palaeoclimatology*: 227-254. Interscience, New York.

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.

Laskar B & Mitra ND 1976. Palaeoclimatic vicssitudes in India during the Lower Gondwana sedimentation. *Geophytology* **6** : 162-169.

Lele KM 1976. Palaeoclimatic implications of Gondwana flora. *Geophytology* **6** : 162-169.

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

Moiz AA & Ramana Rao N 1976 Mineral matter in coals of Ramagundam, Belampalli coal belt, Andhra Pradesh. *J. Mines Metals Fuels* **24**(2) : 63-65.

Pareek HS, Deekshitulu MN & Ramanamurthy BV 1964. Petrology of Salarjung and Ross seam coal, Tandur area, Godavari Valley Coalfield, Andhra Pradesh. *Research papers 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 1985. Permian palynostratigraphy of Ramagundam Mantheni area, Godavari Valley Coalfield, Andhra Pradesh. *Geophytology* **15**(2) : 119-136.

Shah SC 1976. Climate during Gondwana era in peninsular India : Faunal evidences. *Geophytology* **6** : 186-206.

Sarate OS 1996. Biopetrological study of Mulug coalbelt, Godavari Basin, Andhra Pradesh, India. *Palaeobotanist* **43**(3).

Walker 1841. Coal resources of India. *Mem. geol. Surv. India* **88** : 336.

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