Journal of the Palaeontological Society of India
Volume 58(2), December 2013: 219-228 ISSN 0522-9630

THE DEEP-SEATED COAL DEPOSITS OF THE CHINTALAPUDI SUB-BASIN, GODAVARI VALLEY COALFIELD, ANDHRA PRADESH, INDIA AND THEIR PETROGRAPHIC SIGNIFICANCE

OMPRAKASH S. SARATE

BIRBAL SAHNI INSTITUTE OF PALAEOBOTANY, 53, UNIVERSITY ROAD, LUCKNOW 226 007, INDIA
Email: ossarate@yahoo.co.in

ABSTRACT

The present work has been undertaken to generate coal petrographic database regarding the constitution and rank of the deep-rooted sub-surface coal seam succession encountered in three bore-holes (MCP-1, 2 and 3) at closer vicinity of Chintalapudi area of Godavari Valley Coalfield. Deposition of coal in the valley is mostly confined to the Barakar Formation. However, the recent sub-surface explorations have shown the existence of the Kamthi sediments in the Ramagundam and Chintalapudi areas of the Coalfield. The coal seam encountered at the maximum sub-surface depth of 560.43 m has been petrographically analysed during the present investigations. The study has revealed that coal seam D of (B. H. No. MCP-1), seams, LK-2, LK-3, LK-6, LK-7 and LK-8 (B. H. No. MCP-2) and the seam I and F (B. H. No. MCP-3), contain vitrinite group of macerals in abundance (40-77%). Seam G, despite having comparatively low frequency of vitrinite (35%) but retain dominance. The middle region of seam D (B. H. No. MCP-3), however, contains inertinite in abundance which points towards a distinct change in the climatic scenario in the basin. Liptinite (11-18%) and inertinite (5-7%) macerals in general are sparsely distributed. Mineral matter has been recorded between 16 and 27%, barring seam, LK-2 and D which contain its higher frequency (32-33%). Generally, a wide range of variation in random (R_o mean%) vitrinite reflectance, i.e. 0.43% to 0.59% has been recorded, which indicates the attainment of sub-bituminous B and high volatile bituminous C rank. Abrupt increase in reflectance has been noticed (0.69%) in the coals of seam LK-6 (pellet No. 6), indicating the attainment of high volatile bituminous B stage. Most of the coal seams of this area have vitrinite rich (vitric) constitution. However, a few coal samples viz., seam LK-7 (pellet No. 4), seam D (pellet Nos. 4 & 5) and the coal representing seam G contain mixed type of coal. The palaeo-depositional model, however, has indicated the existence of wet moor with intermittent moderate to high flooding, as the dominating phase with occasional invasions of brackish water influx and a few alternating dry spells, causing oxic and anoxic moor condition.

Keywords : Godavari Valley, Chintalapudi area, Maceral, Reflectance, Depositional Environment

INTRODUCTION

The name Chintalapudi sub-basin is derived from the name of the village Chintalapudi from where the material for the present study has been collected. The Chintalapudi sub-basin covers about 2500 sq. km area of Khammam and West Godavari districts of Andhra Pradesh. It also represents the south-easterly continuation of the Kothagudem sub-basin of the major Pranhita Godavari Valley Coalfield. Both the limbs of the sub-basin are marked by well-defined faults, demonstrating the features of a true Graben (Bhaskar Rao *et al*., 1971). The Gondwana sediments have been laid down on the platform (basement) displaying Archaean gneiss, granites and schists. Recently, SCCL (Singareni Collieries Company Limited, Kothagudem, Andhra Pradesh) has executed drilling operations in the Chintalapudi area, to cut across the entire Lower Gondwana succession laid down in this region. This has provided an opportunity to collect the sub-surface coal-bearing horizons intersected in the Barakar, Barren Measures and its overlying Kamthi formations from the regional bore-holes. The petrographic (maceral composition and rank) information available at present is mostly confined to the coal seams of the Barakar Formation from different localities viz., Kothagudem area (Ramana Rao and Nagmalleswararao, 1965; Rizvi and Ramana Rao, 1969; Ramagundam and Belampalli areas (Ramana Rao and Moiz, 1966; Moiz and Ramana Rao, 1976; Navale *et al*., 1983 and Sarate 1996, 2001a); Tandur area (Ghosh, 1962. Ramana Rao, 1962 and Pareek *et al*., 1964); Koyagudem area (Sarate, 1998); Mauguru area (Sarate, 1999); Yellendu area, (Sarate, 2010). Sarate (2001b) studied the sub-surface coal deposits from the Krishnavaram area, which marks the western end of the Chintalapudi sub-basin; the present work examines its eastern edge and incorporates the coal seams of the Kamthi Formation.

The petrographic information of the coal seams from the Barakar and Kamthi sediments laid down in Chintalapudi area of Godavari Valley is aimed to provide an insight about the depositional scenario, economic and coal bed methane potentials. Constitution of the coal has a direct bearing on their methane holding capacity. The coal macerals, particularly of vitrinite and inertinite groups are actively involved in methane generation; however, inertinite, though having a lesser role to play in methane generation, is known to have greater storage capacity. The cleats in the vitrinite, its micro-porosity, fractures, cracks and cavities provide suitable area for retention of methane in the coal bed. The coal deposits of the Chintalapudi area fulfil both the prerequisites essential for the methane generation and its retention, firstly, they are deep seated (exceeding 300 m) and secondly, their vitrinite reflectance (R_o mean %) also varies from 0.48 to 0.69%.

GEOLOGICAL SETTING

Pranhita Godavari Valley is marked between latitudes 16° 38' and 19° 32' and longitudes 79° 12' and 81° 39', covering the areas of Adilabad, Warangal, Karimnagar, Khammam and Godavari districts of Andhra Pradesh. The valley extends over a length of about 470 km., with NW-SE trend and acquires about 17,000 sq. km area with Boregaon in Maharashtra delimiting its northern limit and extends up to Eluru on the east coast of Andhra Pradesh. The valley preserves about 3000 m thick fluviatile sediments on crevice type of platform, covering the time span of Permian to Lower Cretaceous Period, which also document evidences for the glacial events, well-defined

Table 1: General Geological succession of the Permian sediments exposed in Godavari Valley Coalfield, Andhra Pradesh, India (after, Raja Rao, 1982).

Age	Group	Formation	Maximum Thickness (meters)	Lithology
			500	Upper Member : Coarse-grained, ferruginous sandstones with clay clasts and pebbles and subordinate violet cherty siltstones and pebble beds.
Upper Permian to Lower Triassic		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, grayish white calcareous sandstones with a few coal seams.
Upper Permian	L O W E R G O N D W A N A	Barren Measures	500	Medium to coarse grained, greenish grey to grayish white felspathic sandstones with subordinate variegated and micaceous sandstones.
Upper part of Lower Permian		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 a few thin bands of coal.
Lower Permian		Talchir	350	Fine-grained sandstones, splintery green clays/ shales, chocolate coloured clays, pebble beds and tillite.
				-------------Unconformity------------
? Upper Proterozoic		Sullavai	545	Medium to coarse grained, white to brick red sandstones, at places quartzitic and mottled shales.
				-------------Unconformity------------
Lower Proterozoic		Pakhal	3335	Greyish white to buff quartzites, grey shales, phyllites and marble.
				-------------Unconformity------------
Precambrian		-	-	Granites, banded gneisses, biotite gneisses, hornblende gneisses, quartz magnetite schists, biotite schists, quartz and pegmatite veins.

biozones, reptiles of Upper Triassic to Jurassic Period, palaeosoles, fish remains and the mega as well as microfloral elements (Table 1).

The geomorphic and gravity anomalies of the Coalfield demonstrate it to be a graben, flanked by Precambrian uplands Qureshy *et al*. (1968) and Bhaskar Rao *et al*. (1971). Godavari Valley Coalfield has been divided into four structural sub-basins from north to south, as 1. Godavari, 2. Kothagudem, 3. Chintalapudi and 4. Krishna-Godavari Ramanamurthy and Parthasarathy (1988). Walker (1841) was the first to record existence of coal from Godavari Valley. He collected coal fragments from Godavari river bed, in the neighbourhood of its confluence with river Tal. However, King (1872) discovered coal at Yellandlapad, which proved to be a stepping stone that helped develop coal industry in South India; subsequently, King (1881) recorded the existence of seven coal seams from this area; the last but one seam, having thickness of about 2.1 m and containing steam coal, was named in his honour, as King Seam. Hughes (1878) carried out detailed geological work on the Wardha Godavari Valley coals.

The Gondwana deposits are laid down over the Precambrian platform all along the course of the rivers Pranhita and Godavari covering a length of about 470 km. The Talchir sequence forms the basal part of the Gondwana succession, which encompasses basal boulder bed, fine-grained greenish sandstones and shale sequence, acquiring the thickness of about 200-370 m. The Talchir Formation is overlain by the Barakar Formation, which is marked by cross-stratified sandstones as the most dominant lithofacies. The basal part of this formation has thickness variation from 70 to120 m having predominance of coarse-grained sandstones in association with lenses of conglomerates and the absence of workable coal seams. However, the upper member has attained the thickness of about 200 m and is marked by cyclic repetition of coal, shale and sandstone sequence (Raja Rao, 1982). Earlier, the sediments overlying the Barakar Formation with a normal contact were described as the Kamthi Formation. However, Ramanamurthy (1979) reported about 350-500 m thick Barren Measures Formation from the subsurface of Godavarikhani, Chinnur and Belampalli areas. The Barren Measures sequence is devoid of any coal and gradationally succeeds the Barakar Formation. It contains a succession of cross-bedded, medium to coarse-grained, massive, grey to grayish, felspathic and ferruginous white sandstones with occasional quartz pebbles, thin bands of shale and clay sequence and insignificant carbonaceous matter. In the Sattupalli area, the Barren Measures Formation has shown considerable reduction in its thickness (50 m), as compared to the northern part of the valley (500 m), indicating a gradual uplift during middle Permian Period (Uday Bhaskar, 2006; Uday Bhaskar *et al*., 2002). The lithological succession sandwiched between the Barren Measures and the Maleri Formation in Godavari Valley Coalfield is referred to as the Kamthi Formation. It is divisible into two parts. The lower member which conformably succeeds the Barren Measures sequence with a gradational contact and has a striking resemblance with the Raniganj Formation of the Damodar Valley. Its thickness varies from 40-400 m and contains the dominance of grayish white calcareous medium-grained sandstones, exhibiting greenish tint with alternating shale/ variegated clays and coal sequence, which indicates onset of the favorable conditions for coal formation and transformation of the Valley into flood basin (Uday Bhaskar, 2006). The upper member, however, is marked by coarse-grained arenaceous facies, which displays the existence of bands of pebbles or conglomerates, ferruginous sandstones and brick red sandstones with innumerable clasts of white, violet or yellow shales. This member is considered to be homotaxial with the Panchet Formation of the Damodar Valley (Ramanamurthy, 1979).

COLLECTION SITE

In order to build up a complete succession of sub-surface coal seam sequence encountered from the vicinity of Chintalapudi village, samples have been collected by selecting three bore holes, i.e. B. H. No. MCP - 1, MCP - 2 and MCP – 3, drilled at a distance of nearly 10-12 km north-west of Chintalapudi village (Figs. 1, 2, 3 & 4 and Tables 2, 3 & 4).

METHODOLOGY

Representative coal seam samples were crushed to ± 18 mesh size (1 mm size particles). Mount preparation has been carried out using the mixture of hardener and resin in the proportion of 1:5, using cold setting material without pressure, followed by polishing. Petrographic analyses related to coal composition (maceral) and random vitrinite reflectance measurements (R_o mean %) were carried out using Leica DM 4500D microscope, following the standard procedures and recommendations of ICCP (1963, 1971, 1975, 1998 and 2001) and Stach *et al*. (1982).

MICROSCOPIC CHARACTERISTICS

Vitrinite is recorded as the most conspicuous and dominating maceral group of these coal deposits. Inertinite is the sub-dominant maceral group; however, in some of the coal samples it occupies dominance. Similarly, liptinite group of macerals are also recorded in significant proportion in some of the coal samples. Collotelinite is mostly recorded in the form of thick and thin bands (Pl. I, figs. 1-3). The diagenetic changes in the peat causes its coalification and bituminization besides expulsion of gas (methane) and crude oil. The solid residual

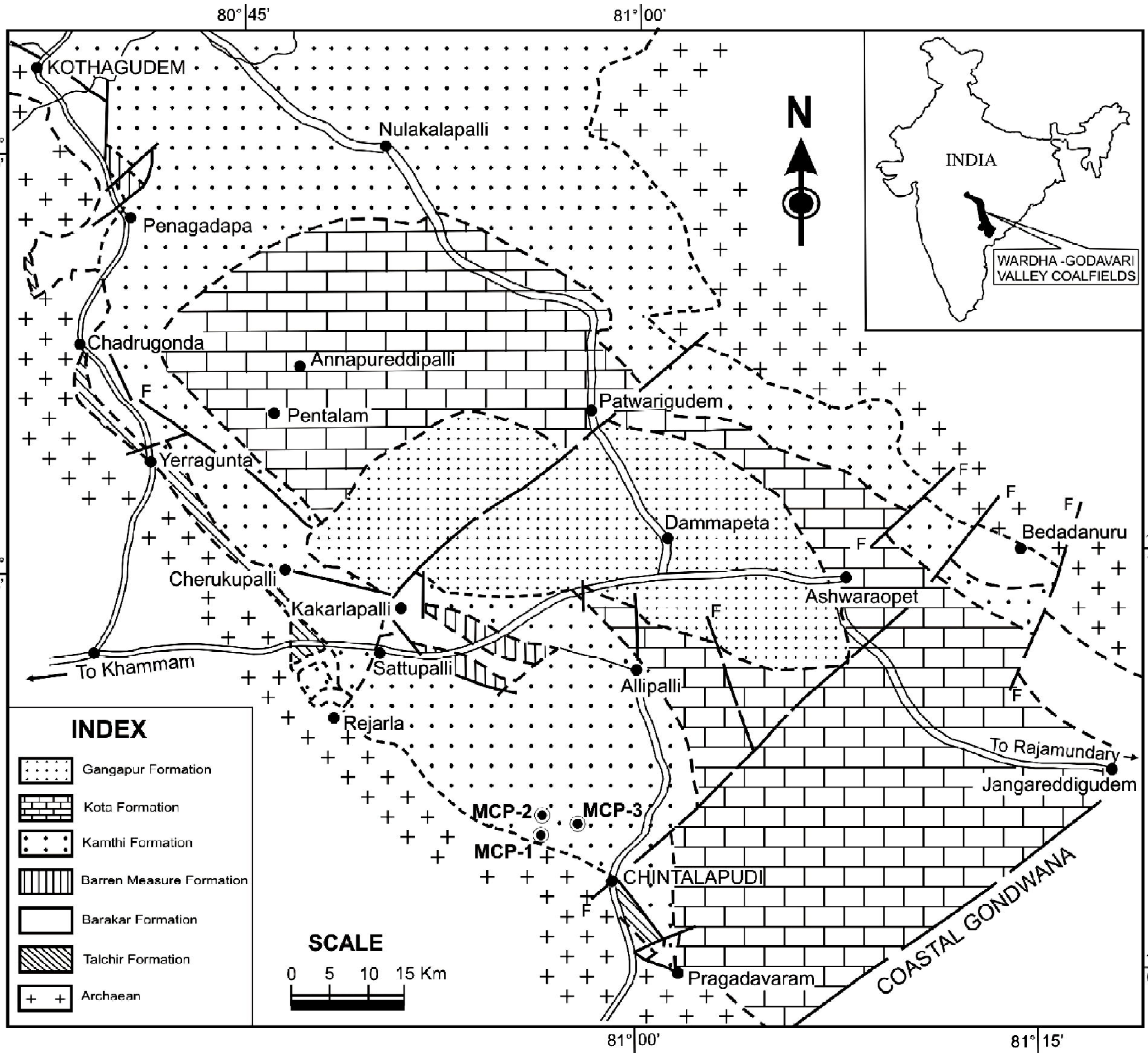


Fig. 1. Geological map of the Chintalapudi area showing location of Bore-hole Nos. MCP-1, MCP-2 and MCP-3 (Courtesy, SCCL).

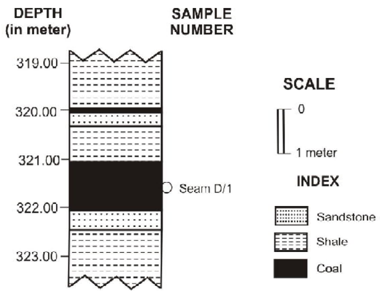


Fig. 1. Litholog of Bore-hole No. MCP-1, showing position of petrological samples analyzed from the Chintalapudi area.

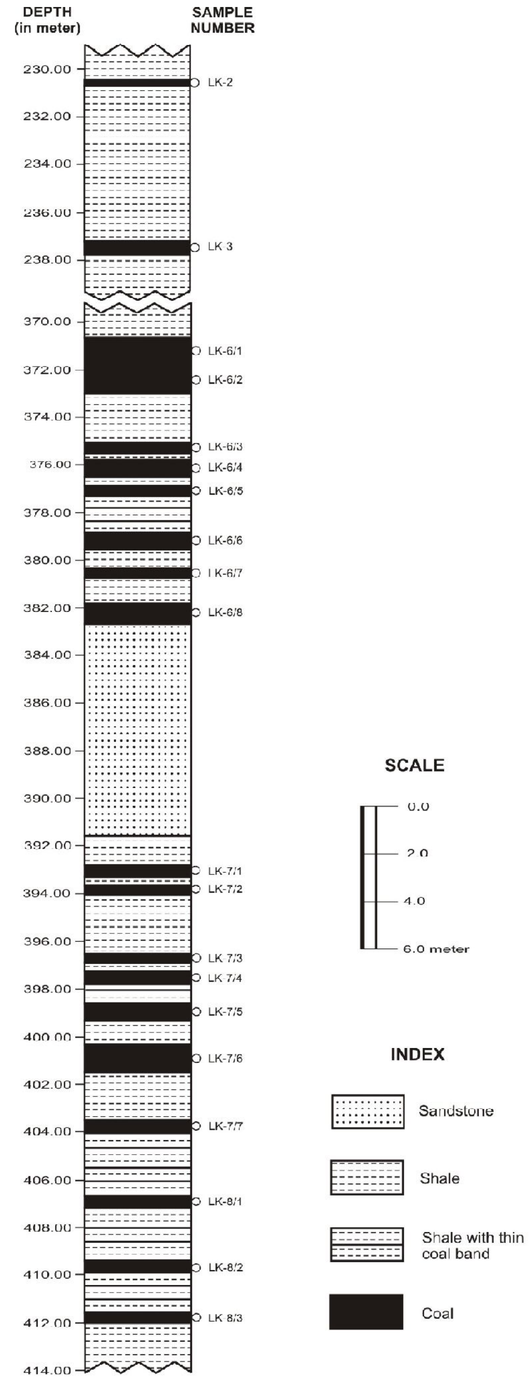


Fig. 3. Litholog of Bore-hole No. MCP-2 showing position of petrological samples analyzed from the Chintalapudi area.

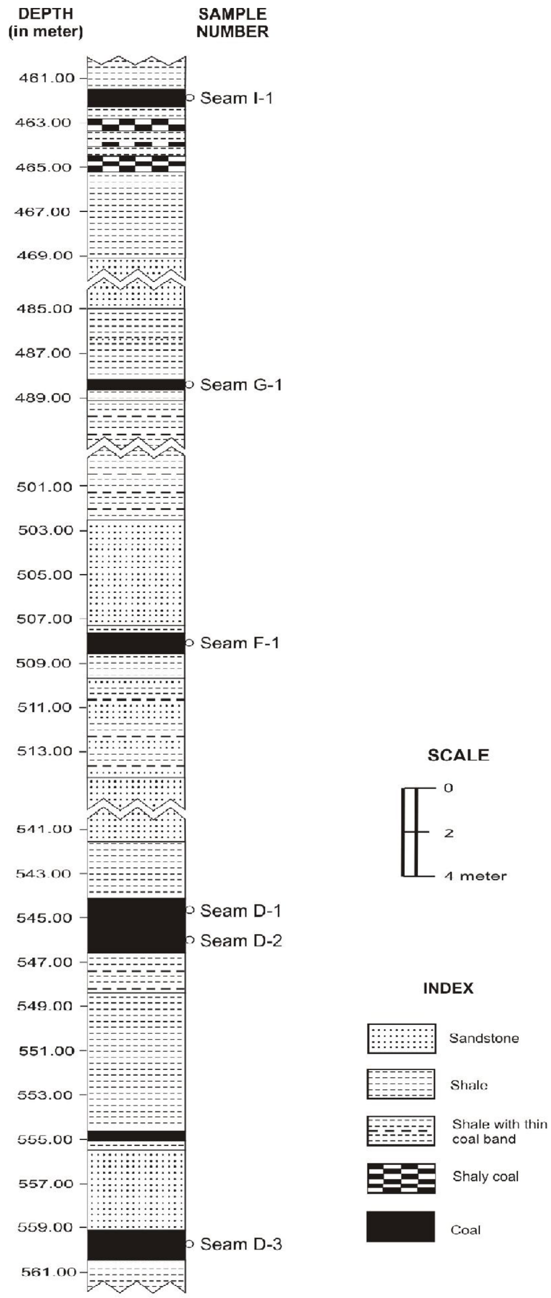


Fig. 4. Litholog of Bore-hole No. MCP-3 showing position of petrological samples analyzed from the Chintalapudi area.

products, however, undergo aromatization and condensation (Coal/Kerogen). The vitrinite and liptinite (exinite) group of macerals are actively involved in the methane and light hydrocarbon generation. During the present study, collotelinites have displayed the expulsion of the hydrocarbons (Pl. I, figs. 16-18), indicating availability of huminite-rich resource during the first coalification jump (Teichmüller, 1974), which has been transformed into vitrinite rich coal constitution. Telinite, however, has scanty distribution. Gelocollinite is mostly recorded as precipitate, from the cell lumens, cavities or cracks. Corpogelinite exists in the form of oval shaped isolated bodies.

Sporinite is generally recorded in the form of linearly arranged thread-like, disc or spindle-shaped bodies dispersed in the vitrinitic ground mass with darker grey shade than the

Table 2: Details regarding the coal samples collected from Bore-hole No. MCP-1 from Chintalapudi area.

Sr. No.	Depth (meters)	Lithology	Name of coal seam	Pellet No.
1.	319.95-320.05	Coal		
2.	320.05-320.30	Sandstone		
3.	320.30-321.05	Shale		
4.	321.05-322.05	Coal	Seam D	MCP 1/ D
5.	322.05-322.46	Sandstone	-	

Table 3: Details regarding the coal samples collected from Bore-hole No. MCP-2 from Chintalapudi area.

Sr. No.	Depth (meters)	Lithology	Name of coal seam	Pellet No.
1.	330.42-330.52	Coal	LK-2	LK-2
2.	330.52-337.15	Grey shale	-	-
3.	337.15-337.81	Shaly coal	LK-3	LK-3
4.	337.81-370.70	Shale	-	-
5.	370.70-371.85	Coal	LK-6/1	LK-6/1
6.	371.85-373.00	Coal	LK-6/2	LK-6/2
7.	373.00-375.10	Shale	-	-
8.	375.10-375.50	Coal	LK-6/3	LK-6/3
9.	375.50-375.75	Shale	-	-
10.	375.75-376.50	Coal	LK-6/4	LK-6/4
11.	376.50-376.86	Shale	-	-
12.	376.86-377.29	Coal	LK-6/5	LK-6/5
13.	377.29-378.86	Shale with thin coal bands	-	-
14.	378.86-379.50	Coal	LK-6/6	LK-6/6
15.	379.50-380.28	Shale		
16.	380.28-380.71	Coal	LK-6/7	LK-6/7
17.	380.71-381.85	Shale	-	-
18.	381.85-382.70	Coal	LK-6/8	LK6/8
19.	382.70-391.63	Sandstone	-	-
20.	391.63-392.89	Shale	-	-
21.	392.89-393.33	Coal	LK-7/1	LK-7/1
22.	393.33-393.60	Shale		
23.	393.60-394.05	Coal	LK-7/2	LK-7/2
24.	394.05-396.51	Shale	-	-
25.	396.51-396.88	Coal	LK-7/3	LK-7/3
26.	396.88-397.18	Shale	-	-
27.	397.18-397.71	Coal	KL-7/4	LK-7/4
28.	397.71-398.69	Shale with thin coal bands	-	-
29.	398.69-399.29	Coal	LK-7/5	LK-7/5
30.	399.29-400.30	Shale	-	-
31.	400.30-401.51	Coal	LK-7/6	LK-7/6
32.	401.51-403.50	Shale	-	-
33.	403.50-404.05	Coal	LK-7/7	LK-7/7
34.	404.05-406.69	Shale with thin coal bands	-	-
35.	406.69-407.18	Coal	LK-8/1	LK-8/1
36.	407.18-409.37	Shale with thin coal bands	-	-
37.	409.37-409.87	Coal	LK-8/2	LK-8/2
38.	409.87-411.60	Shale with thin coal bands	-	-
39.	411.60-412.05	Coal	LK-8/3	LK-8/3
40	412.05- Continue	Shale	-	-

surroundings. Thin walled microspores (tenuisporinite) occur commonly; however, megaspores (Pl. I, fig. 8) and sporangium containing spores are less common. Both the thick and thin-walled cutinite (Pl. I, figs. 4-7), displaying dark grey colour and having cuticular ledges (serrated margins) are seen dispersed in collotelinitic and sporinite-rich ground mass.

Inertinite has emerged as the sub-dominant group of maceral of these coals, barring a few coal seams, where it occupies dominance over vitrinite. This indicates a distinct change in the climatic conditions from wet reducing to dry oxidizing. Fusinite and semifusinites are considered to be the product of peat fire. Both pyro-fusinite and degrado-fusinite are commonly noticed in these coals. The former contains well-preserved cellular structures, yellowish colour and strong relief. Its genesis requires intensive fires which causes depletion in oxygen supply resulting in incomplete combustion of the peat (woody tissues). Thin-walled cells of the degrado-fusinite display high intensity of charring; however, thick-walled cells demonstrates its low intensity. Due to brittle nature, pyrofusinite disintegrates easily. Being lighter it shatters easily and is blown and deposited in the basin as ash, splinters or inertodetrinite. Degrado-fusinite, however, contains ill-preserved cellular structures with white colour, weak to very weak relief and also displays effect of cellular compression as well as disintegration (Pl. I, figs. 9-15). They are also formed due to coal fire or subsurface oxidation and require sufficient oxygen supply for dehydration and oxidation of the peat; they are therefore, also termed the oxyfusinite. Similarly, they may also be the product of decay and degradation caused by the activity of the wood-decaying fungi (Teichmüller, 1950). In such cases, they are represented by indistinct cellular preservation. Semifusinite, however, has comparatively ill-preserved cellular

Table 4: Details regarding the coal samples collected from Bore-hole No. MCP-3 from Chintalapudi area.

Sr. No.	Depth (meters)	Lithology	Name of coal seam	Pellet No.
1.	461. 30-461.43	Shale	-	
2.	461.43-462.26	Coal	Seam I	MCP3/1
3.	426.26-462.85	Shale	-	-
4.	462.85-463.39	Shaly coal	-	-
5.	463.39-463.90	Grey shale	-	-
6.	463.90-464.06	Shaly coal	-	-
7.	464.06-464.51	Grey shale	-	
8.	464.51-465.25	Shaly coal	-	-
9.	465.25-469.10	Shale	-	-
10.	469.10-485.04	Sandstone	-	-
11.	485.04-488.20	Grey shale	-	-
12.	488.20-488.73	Coal	Seam G	MCP3/2
13.	488.73-489.11	Grey shale	-	-
14.	489.11-502.60	Shale with thin coal bands	-	-
15.	502.60-507.37	Sandstone	-	-
16.	507.37-507.60	Grey shale	-	-
17.	507.60-508.60	Coal	Seam F	MCP3/3
18.	508.60-509.63	Grey shale	-	-
19.	509.63-514.60	Shale with thin coal bands	-	-
20	514.60-541.60	Sandstone	-	-
21.	541.60-544.10	Grey shale	-	-
22.	544.10-545.44	Coal	Seam D	MCP3/4
23.	545.44-546.61	Coal	Seam D	MCP3/5
24.	546.61-548.30	Shale with thin coal bands	-	-
25.	548.30-554.61	Shale	-	-
26.	554.61-555.04	Coal	-	-
27.	555.04-555.48	Shale	-	-
28.	555.48-559.11	Sandstone	-	-
29.	559.11-560.43	Coal	Seam D	MCP3/6
30.	560.43-561.20	Grey shale	-	-

structures and lower reflectance than the fusinite and its colour also varies between light grey and white. Micrinite exists in the form of oval or spherical bodies with almost same reflectance as that of the fusinite. Besides, a variety of funginite (fungosclerotinite, fungal hyphae and fungal spores) is also seen dispersed in the inertinite and inertodetrinite ground mass.

Carbonate, clay and sulphides are the minerals which are seen intimately associated with all the coal maceral groups. They may be in the form of ground mass or occupy the empty spaces of the cleats and fissures. Clay minerals display black colour and are characterized by their fine granular nature. Carbonates are witnessed as stringers or exist in the form of groundmass or seen embedded in the fissures. Pyrite is mostly recorded in the form of disseminated particles or as highly reflecting discrete grains. In some of the coal samples, framboidal pyrites (Pl. I, figs. 17 - 18) have been noticed embedded in the vitrinitic ground mass.

MACERAL CONSTITUTION

The petrographic composition of the coal sequence encountered from the sub-surface deposits of the Chintalapudi area has revealed that coal seam D of Bore hole No. MCP 1, seams, LK-2, LK-3, LK-6, LK-7 and LK-8 of Bore hole No. MCP 2 and the seam I and F from Bore-hole No. MCP 3 has displayed the dominance of vitrinite group of maceral, which ranges between 40% and 77%. However, seam G contains quite a low vitrinite (35%) and distribution but retains its domination over other maceral groups. The top part of seam D contains equal proportion of vitrinite and inertinite group of macerals (35%); however, in the middle part, inertinite (34%) gains dominance over vitrinite (27%). Liptinite group of macerals occur with frequency range of 11% to 18%, except for seam D and seam F of Bore hole No. MCP 3 in which the liptinite macerals are sparsely recorded (5% to 7%). Mineral matter association in these coals ranges from 16% to 27%. However, seam LK-2 and Seam G contain higher mineral matter association 32% to 33%, (Table 5, Fig. 5).

REFLECTANCE STUDY

Considerable variation in the vitrinite reflectance (R_o mean %) has been recorded in the coal seam succession of Chintalapudi area, which ranges from 0.43% to 0.69%. however, abrupt increase in the vitrinite reflectivity 0.69% is recorded in one of the coal pellet No. LK- 6/6. The coal of this region has attained high volatile bituminous B stage of the rank. Tectonic activities causing movement along the faults and over thrusts may develop frictional heat causing abrupt rise in vitrinite reflectance Teichmüller and Teichmüller (1966). Chandra and Bond (1956) have also demonstrated that temperature (heat) causes change in the reflectance of the vitrinite of the coals. In the study area thin coal bands have invariably been found associated with persistent shale partings, which indicates the existence periodic intervention of floods in the basin. Changes in the depositional set up of the basin may also have influenced vitrinite reflectance at regular intervals. Thus, the coal seams in general have indicated increasing trend of maturity with respect to depth. Their rank varies from sub-bituminous B to high volatile bituminous C stage (Table 5, Fig. 7).

The ternary mineral matter free (m.m.f.) maceral plotting (Fig. 6) of coal seam succession of the Chintalapudi area has indicated the dominance of vitrinite rich coal constituents (vitric type of coal), barring a few coal of seam samples viz. pellet No. 4 of seam LK-7, pellet Nos. 4 and 5 of seam D and seam G contain mixed type of coal. Singh and Singh (1996) devised facies model signifying the impact of mineral contents of the coal has direct bearing on fluctuations in water table at the depositional site. The facies diagram (Fig. 8) for the present coal deposits has indicated the existence of wet moor with moderate to high flooding prevailed for prolonged period of time with short spells of alternate oxic and anoxic moor.

DISCUSSION

The structural features, palaeobotanical evidences, and the coal constitution suggest that the Gondwana sedimentation initiated in glacially influenced conditions with the gradual development and diversion of the flora. During the Barakar times cold climatic conditions were conducive for accumulation of huge peat deposits, which in due course of time transformed into the present-day coal reserves. During Barren Measures deposition, the flora existed, but the conditions were not suitable for deposition in the form of peat. Scarcity of enough water and the prevalence of warm and oxidizing conditions prevented the initiation of carbonaceous and coal facies. During the Kamthi deposition, shorter spells of alternate dry oxidizing cold and humid climatic conditions existed as indicated by the formation of alternating thin shaly and coaly horizons.

The Chitalapudi sub-basin displays the features of a true graben with both of its limbs marked by well-defined faults. These faults remained activated for a prolonged period of time between Late Carboniferous to Early Permian Period, which resulted in the evolution of slowly sinking basin, in which thick sedimentary deposits could accumulate for a long span. The Gondawana sedimentation commenced coeval with the melting of ice-cap of the Archaean basement. The Talchir deposits mark the basalmost member of the Gondwana succession, which display signatures of glacial influence during their deposition, as evidenced by the existence of thick tillites with pebbles and cobbles of granites and dolomites along with unsorted boulder bed, etc. The plant life initiated and proliferated here, as indicated by fragmentary fossil remains. The Barakar Formation has shown the development of thick coal seams, which indicate that the climate during this regime was conducive for luxuriant vegetation. The Barren Measures Formation is devoid of coal sequence; however, it contains rich palynofloral assemblage, which indicates that the flora existed, but climatic conditions were not conducive for peat formation and its transformation into coal. The overlying thick pile of the Kamthi Formation, however, contains several coaly and shaly horizons, which indicate the existence of shorter spells of cold and humid conditions.

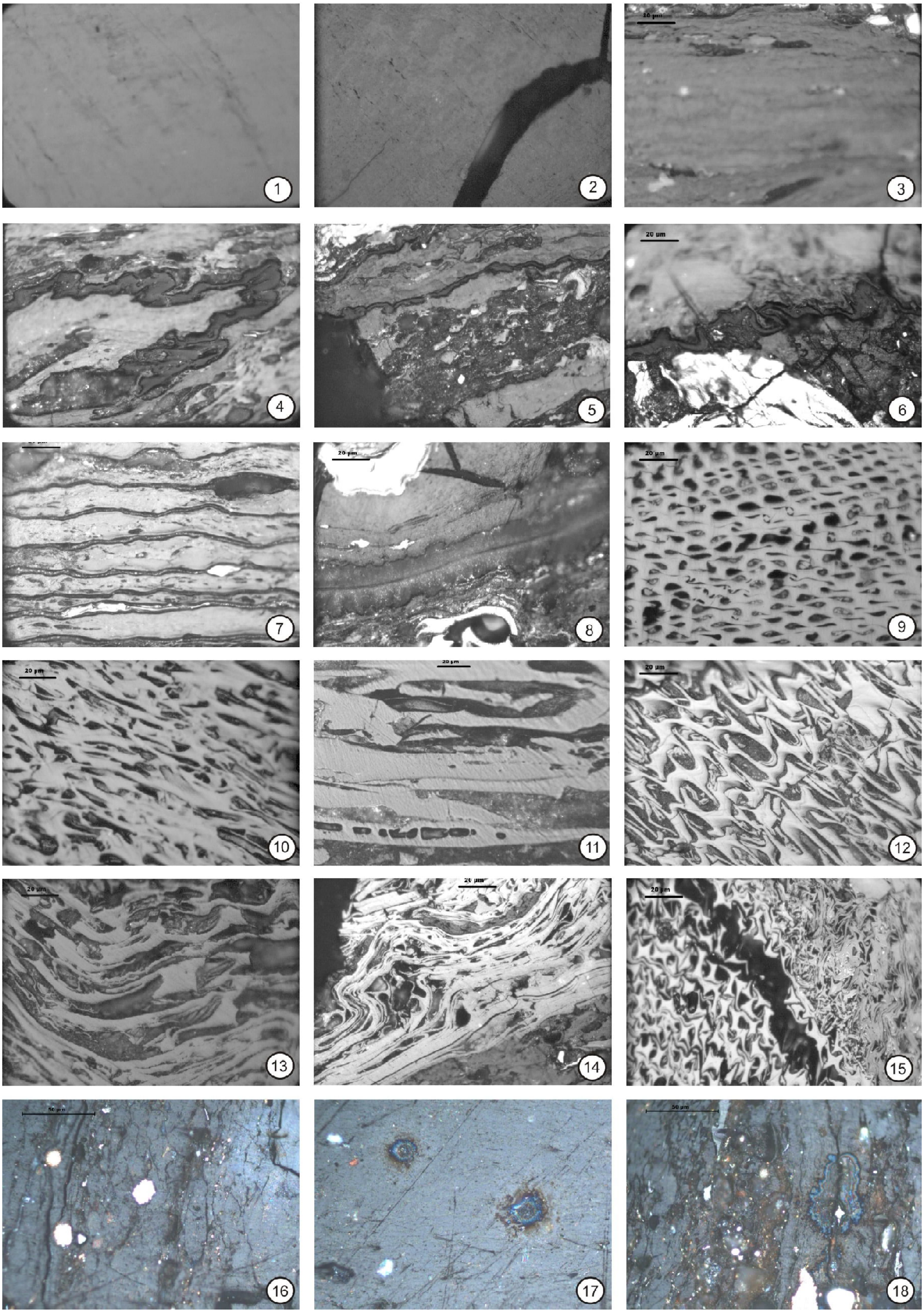
Indian plate during this Period had acquired the palaeogeographic position in and around the arctic regions with cold temperate climatic conditions (King, 1958), intermixed with alternate dry and rainy spells (Kräusel, 1961). The megafloral evidence indicates that these climatic conditions

EXPLANATION OF PLATE I

1-3. Collotelinite bands, 4-7, Cutinite displaying distinct cuticular ledges. 8. Megaspore, 9-15. Fusinite showing effect of cellular compression and disintegration, 16-18. Collotellinite indicating expulsion of hydrocarbons and the existence of Framboidal pyrite.

Journal of the Palaeontological Society of India
Volume 58(2), December 2013

Plate I



SARATE

Table 5. Showing the maceral constitution and reflectance analysis of the coals from Bore-hole No. MCP-1, MCP-2 and MCP-3 of Chintalapudi area.

Sr.No.	B. H. No.	Pellet Nos.	Vitrinite %	Liptinite %	Inertinite %	Mineral Matter %	Reflectance (R_o mean %)
1	MCP - 1	MCP -1/D	77 (87)	7 (8)	4 (5)	12	0.43
2	MCP - 2	LK - 2/1	49 (73)	3 (4)	15 (23)	33	0.45
3	MCP - 2	LK - 3/1	66 (82)	11 (14)	3 (4)	20	0.53
4	MCP - 2	LK - 6/1	22	8	11	59	0.46
5	MCP - 2	LK - 6/2	12	4	15	69	0.35
6	MCP - 2	LK - 6/3	17	5	20	58	0.50
7	MCP - 2	LK - 6/4	70 (77)	12 (13)	9 (10)	9	0.56
8	MCP - 2	LK - 6/5	42 (58)	9 (12)	22 (30)	27	0.48
9	MCP - 2	LK - 6/6	53 (67)	11 (14)	15 (19)	21	0.69
10	MCP - 2	LK - 6/7	60 (78)	9 (12)	8 (10)	23	0.56
11	MCP - 2	LK - 6/8	59 (69)	11 (13)	16 (18)	14	0.45
12	MCP - 2	LK - 7/1	64 (79)	12 (15)	5 (6)	19	0.51
13	MCP - 2	LK - 7/2	61 (73)	15 (18)	8 (9)	16	0.52
14	MCP - 2	LK - 7/3	54 (73)	11 (15)	9 (12)	26	0.61
15	MCP - 2	LK - 7/4	40 (48)	28 (33)	16 (19)	16	0.59
16	MCP - 2	LK - 7/5	62 (75)	18 (22)	3 (3)	17	0.53
17	MCP - 2	LK - 7/6	67 (80)	12 (14)	5 (6)	16	0.55
18	MCP - 2	LK - 7/7	40 (56)	11 (16)	20 (28)	29	0.58
19	MCP - 2	LK - 8/1	56 (75)	8 (10)	11 (15)	25	0.58
20	MCP - 2	LK - 8/2	53 (68)	22 (28)	3 (4)	22	0.57
21	MCP - 2	LK - 8/3	64 (73)	19 (22)	4 (5)	13	0.55
22	MCP - 3	MCP – 3/1	62 (74)	15 (18)	7 (8)	16	0.53
23	MCP - 3	MCP – 3/2	35 (51)	16 (24)	17 (25)	32	0.51
24	MCP - 3	MCP – 3/3	60 (78)	5 (6)	12 (16)	23	0.46
25	MCP - 3	MCP – 3/4	32 (43)	11 (15)	32 (42)	25	0.47
26	MCP - 3	MCP – 3/5	27 (36)	13 (18)	34 (46)	26	0.59
27	MCP - 3	MCP – 3/6	15	6	35	44	0.47

Note : Mineral matter free % is mentioned in the bracket.

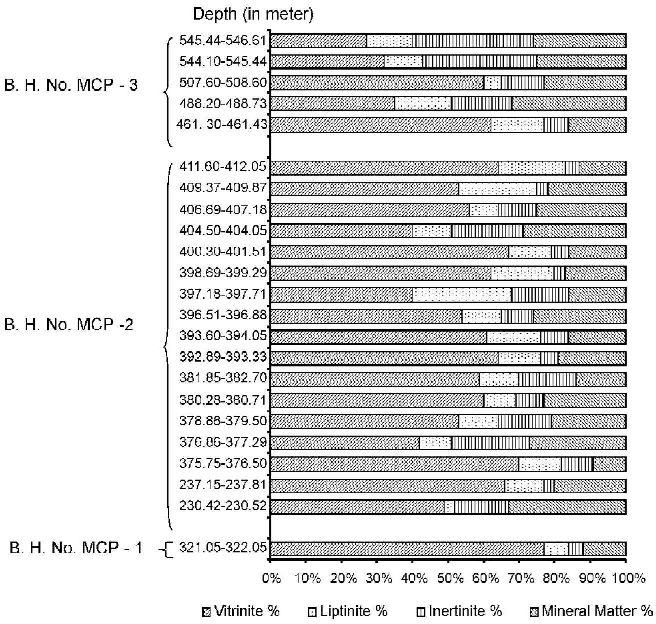


Fig. 5. Maceral composition coal succession intersected in Bore-hole Nos. MCP-1, MCP-2 and MCP-3 from the Chintalapudi area.

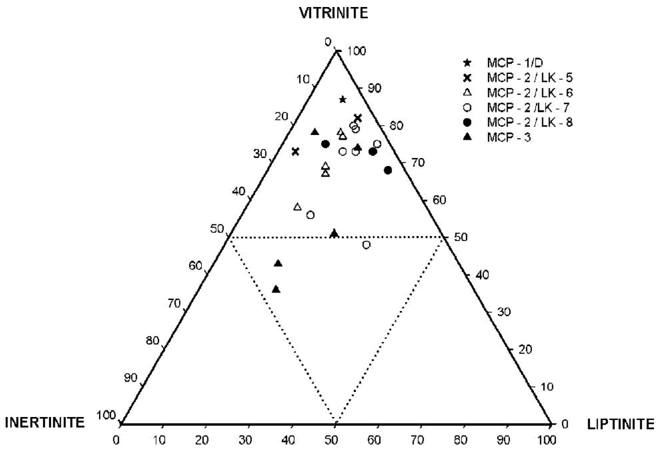


Fig. 6. Ternary diagram showing maceral (m.m.f.) composition of the coal succession intersected in Bore-hole Nos. MCP-1, MCP-2 and MCP-3 from the Chintalapudi area.

were favourable for the development of tongue-shaped, broad leafed dense *Glossopteris* trees, which attained maximum thickness of more than 60 m along with the short stuffed *Gangamopteris* plants, besides *Lepidodendron*, *Sigillaria*, etc. (Chandra and Chandra, 1987). At the base of these plants, grew the aquatic plants of marshy habitat. The petrographic analysis of these coals has shown absolute dominance of vitrinite group of macerals. Vitrinite is derived from humic rich fraction. Existence of anaerobic conditions is the prerequisite for conversion of lignin into humic acid. Thus cold humid climate prevailed during this regime (Fischer, 1952; Welte 1952). The presence of inertinite rich constitution in few samples, however, indicates lowering of the water table and exposure of peat to surface. Similarly, there has been a gradual shift in

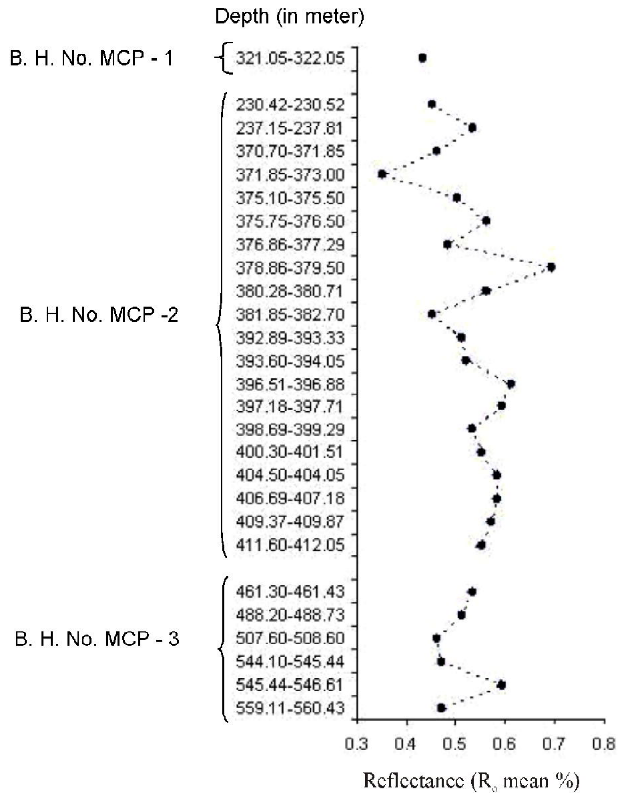


Fig. 7. Reflectance (R_o mean %) analysis of the coal succession intersected in Bore-hole Nos. MCP-1, MCP-2 and MCP-3 from the Chintalapudi area.

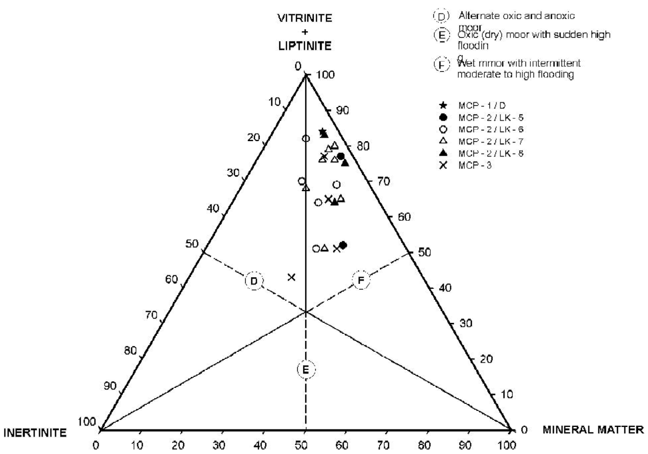


Fig. 8. Depositional conditions of the coals of the Chintalapudi area based on maceral and mineral matter content (after Singh & Singh, 1996)

climatic conditions from cold to warm and oxidizing spells with aggressive fungal activity, resulting in the enhancement of inertinite rich constituents (Cadle *et al*., 1993; Snyman and Botha, 1993; Smyth and Cook, 1976; Mackay, *et al*., 1985 and Moor *et al*., 1996). The existence of pyrite in some of the coal samples either in scattered form or as framboids indicates occasional marine influence conducive for development of marshy plants.

CONCLUSIONS

The ternary mineral matter free maceral plotting (Fig. 6) has indicated the dominance of vitrinite rich coal. Similarly, the facies model (Fig. 8) has also indicated the prevailing cold climatic conditions and wet moor with moderate to high flooding prevailed for prolonged period of time, with short spells of alternate oxic and anoxic moor. These climatic conditions were conducive for transformation of the vegetal resource (peat) into vitrinite rich (vitric) and mixed type of coal deposits in due course of time. The existence of framboidal pyrites and structural features also indicates the development of intermittent brackish water conditions. Since the depth of burial of these coal deposits exceeds 300m and their vitrinite reflectance ($R_o$mean%) also varies between 0.43% and 0.69%, which indicates the existence of ideal depositional set up for coalification, bituminization, coal bed methane generation and its retention in the form of coal-bed methane (Tang *et al*., 1991; Singh and Singh, 1996; Mishra and Cook, 1992).

ACKNOWLEDGEMENTS

The author is thankful to Dr. N.C. Mehrotra, Director, Birbal Sahni Institute of Palaeobotany, Lucknow, for his permission to publish the data. I am indebted to Mr. M. Basava Chari, Chief Managing Director, Exploration Division, Singareni Collieries Company Limited, Kothagudem, Andhra Pradesh for extending help during collection of samples and also for providing the relevant details. The help extended by Mr. V.P Singh for preparing the figures is also being thankfully acknowledged.

REFERENCES

Bhaskar Rao, Murty, V. S. N. and Venkateswarlu, P. D. 1971. Gravity anomalies and tectonics on a part of Lower Godavari Basin. *Gondwana Systems, Aligarh. Muslim.University*: 148-156.

Cadle, A. B., Cairncross., B., Christie, A. D. M. and Roberts, D. L. 1993. The Karoo basin of South Africa : type basin for coal-bearing deposits of South Africa. *International Journal of Coal. Geology,* **23**: 117-157.

Chandra, D., Bond., R. L. 1956. The reflectance of carbonized coals. *Proc. Int. Comm. Coal Petrol.* **2**: 47-51.

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

Fischer, G. 1952. Studien Über den biologischen Abbau des Lignins durch Mikroorganismen. – Diss. Techn. Hochsch. Stuttgart.

Ghosh, T. 1962. Microscopic study of Tandur coal, Godavari valley, Andhra Pradesh. *Quarterly Journal Geological Mining Metallurgical Society of India,* **4** (1): 7-24.

Hughes, T. W. H. 1878. Note on the geology of Upper Godavari Basin between the rivers Wardha and Godavari, near the civil station of Sironcha. *Record Geological Survey of India,* : 11, 30.

International Committee for Coal Petrology, 1963. *International Handbook of Coal Petrology,* Supplement to 2nd ed. Centre de Researche Scientifique. Qual. Antole Paris, unpaginated.

International Committee for Coal Petrology, 1971. *International Handbook of Coal Petrology*, Supplement to 2nd ed. Centre de Researche Scientifique. Qual. Antole Paris, unpaginated.

International Committee for Coal Petrology, 1975. *International Handbook of Coal Petrology*, Supplement to 2nd ed. Centre de Researche Scientifique. Qual. Antole Paris, unpaginated.

International Committee for Coal Petrology, 1998. The new vitrinite classification (ICCP System, 1994). *Fuel,* **77** (5): 349-358.

International Committee for Coal Petrology, 2001. The new inertinite classification (ICCP System, 1994). *Fuel* **80**: 459-471.

King, L. C. 1958. Basic palaeogeography of Gondwanaland during the deposition of Late Palaeozoic and Mesozoic eras. *Quarterly Journal Geological Society* London, **114**: 47-77.

King, W. 1872. Notes on new coalfield in south eastern part of Hyderabad territory. *Record Geological Survey of India,* **5**: 41-47.

King, W. 1881. The geology of the Pranhita Godavari Valley. *Memoir* *of the Geological Survey of India* **18**(3): 150-311.

Kräusel. R. 1961. Palaeobotanical evidence of climate, p. 227-254: In : *Descriptive Palaeoclimatology* (Ed. Nairn, A.E.M.), *Interscience,* New York.

Mackay, G. H., Attwood., D. H., Gaulton., R. J., and Gearge, A. M. 1985. The cyclic occurrence of brown coal lithotypes. State Electricity Commission of Victoria Research and development dept., Brown Coal research division. SO/85/93, 9pp.

Mishra, H. K. and Cook., A. C. 1992. Petrology and thermal maturity of coals in the Jharia Basin. *Implications for Oil and Gas Origins*, **20**: 277-313.

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

Moore, T. A., Shearer., J. C., and Miller., S. L. 1996. Fungal origin of oxidized plant material in the Palangkaraya peat deposit, Kalimantan Tengah, Indonesia: Implications for inertinite formation in coal. *International Journal of Coal, Geology,* **30**: 1-23.

Navale, G. K. B., Misra., B. K. and Anand Prakash. 1983. The microconstituents of Godavri coals, south India. *International Journal of Coal Geology*, **3**: 31-61.

Pareek, H. S., Deekshitulu., M. N., and Ramanamurtthy., B. V. 1964. Petrology of Salaejung and Ross Seam coals Tandur area, Godavari Coalfield, Andhra Pradesh. *Geological. Survey of India.* from Research papers in Petrology by the officers of the pp. 141-158.

Qureshy, M. N., Brahmam., N. K., Gadse., S.C., and Mathur., B. K. 1968. Gravity analysis and Godavari rift, India. *Bulletin Geophysical Society of Americ* **79**: 1221-1230.

Raja Rao, C. S. 1982. Coal resources of Tamil Nadu, Andhra Pradesh, Orissa and Maharashtra. Coalfields Andhra Pradesh. *Bulletins of the Geological Survey of India, Series A.* **45**: 9-40.

Ramanamurthy, B. V. 1979. Report on occurrence of a coal seam in the Kamthi formation, from the Ramagundam area of the Godavari Valley Coalfield, and its stratigraphic significance. *Geological Survey of India, Miscellaneous Publication,* **45**: 89-93.

Ramana Rao., N. 1962. Mikropetrographische Untersuchungen in den Gondwanokohlen von Tondur (India). *Geol. Mitt.* **3**(1): 71-74.

Ramana Rao., N. and Moiz., A. A. 1966. Coalification of coal from the Kothagudem Coalfield. *Metals & Minerals Review*, July.

Ramana Rao, N. and Nagmalleswararao, K. 1965. Petrography of the top seam coal Kothagudem Coalfield. *Journal of the Indian Geoscience Association*, **5**: 87-91.

Ramanamurtthy, B. V. and Parthsarathy, E. V. R. 1988. On the evolution of the Godavari Gondawana graben based on LANDSAT imagery interpretation *Journal of the Geological Society of India*. **32** (5): 417-425.

Rizvi, K. S., Ramana Rao, N. 1969. Nature and distribution of resins in King Seam, Kothagudem coalfields, A. P. *Proceedings of the National Institute of Science of India*, 35A (Suppl.), 2: 210-215.

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

Sarate, O. S. 1998. Biopetrological study of Koyagudem coals, Godavari Basin, Andhra Pradesh, India. *Geophytology*, **27** (1&2): 39-48.

Sarate, O. S. 1999. Manuguru coals – A petrographic evaluation, Godavari Valley Colafields, Andhra Pradesh, India. *Minetech,* **20**(3): 39-48.

Sarate, O. S. 2001a Biopetrological study of the coals from Belampalli Coalfield, Khairagura area, Godavari Basin, Andhra Pradesh, India. Proc. Nat. Seminar on recent advances in Geology of coal and Lignite Basins of India, Calcutta, 1997, *Geological Survey of India, Special. Publication*. **54**: 189-202.

Sarate, O. S. 2001b. Biopetrology of the coals from Krishnavaram area, Chintalapudi Sub-basin, Godavari Valley Coalfields, Andhra Pradesh. *Journal of the Geological Society of India,* **58**: 449-455.

Sarate, O. S. 2010. Study of Petrographic Composition and Depositional Environment of the Coals from Yellendu Area, Godavari Valley Coalfield, Andhra Pradesh. *Journal of the Geological Society of India,* **75**: 488-494.

Singh, M. P. and Singh, P. K. 1996. Petrographic characterization and evolution of the Permian coal deposits of the Rajmahal basin, Bihar. *International Journal of Coal Geology,* **29**: 93-118.

Smyth, M. and Cook., A. C. 1976. Sequence in Australia coal seams. *Mathematical Geology,* **8**(5): 529-547.

Snyman, C. P. and Botha., W. J. 1993. Coal in south Africa. *African Journal Earth Sciences,* **16**: 171-180.

Stach, E., Mackowsky., M.-TH., Teichmüller., M., Taylor., G. H., Chandra., D. and Teichmüller., R. 1982. *Stach's Textbook of Coal Petrology*, 3rd ed. Gebrüder Borntraeger, Berlin, Stuttgard.

Tang, Y., Jendon., P. D. and Teeman., B. C. 1991. Organic Chemistry Advances and Applications in the Natural Environment (Ed. Manning, D. A. C.), Manchester University Press, p. 329-331.

Teichmüller, M. 1950. Zum petrographischen Aufbau und Werdegang der Weichbraunkohle (mit Berücksichtigung genetischer Fragen der Steinkohlenpetrographie). *Geologisches Jahrbuch*, **64**: 429-488.

Teichmüller, M. 1974. Entstehung und Veränderung bituminöser Substanzen in Kohlen in Beziehung zur Entstehung und Umwandlung des Erdöls. Fortschr. Geol. Rheinld. u. Westf., **24**: 65-112.

Teichmüller, M. and Teichmüller, R. 1966. Geological causes of coalification. *Coal Science, Advances in Chemistry Series*, **55**: 133-155. Washington, D.C.

Uday Bahaskar, G. 2006. Electro lithofacies analysis for depositional history and stratigraphy of Manuguru Coalfield using geophysical well logs. *Journal of Indian Geophysical Union*, **10** (3): 241-254.

Uday Bahaskar, G., Srinivasa Rao., A. S., Shanmukha., and Rao, M. 2002. Coal seams correlation and Permian Stratigraphy of Pranhita-Godavari Valley, An example from geophysical logs. *Journal Indian Association of Sedimentologists,* **8**: 89-101.

Walker, W. 1841 On the Coal found at Kotah with a note on the Anthracite of Duntimnapilly (H.H. Nizam's Dominions). *Journal of Asiatic Society of Bengal,* **10**: 341.

Welte, E. 1952. Uber die Entstehung von Huminsäuren und Wege ihrer Reindarstellung. *Z. Pflanzenernähr., Düng., Bodenkde.*, **56** (101): 105-139.

Manuscript accepted July 2013