Proximate Analysis of Bituminous Coals from Various Gondwana Basins of India: A Comparative Study

Vikram Pratap Singh [1,*], Rahul Dwivedi[1], Shivani Pathak [1], Kirti Ranjan Mallick[2], Pravat Kumar Nayak[2]

[1] *Department of Geology, Indira Gandhi National Tribal University, Amarkantak 484887, Madhya Pradesh, India*
[2] *PG Department of Geology, Utkal University, Bhubaneshwar 751004, Odisha, India*

ABSTRACT

The Gondwana coal deposits account for more than 98% of the Indian coal reserves. The geochemical characterization of these coals is important for the determination of their use in various industries. In the present study, we have conducted proximate analysis on bituminous coals collected from five mines, namely Lalmatia Coal Mine, Rajrappa Coal Mine (both in Jharkhand), Mohan Colliery, Dhanpuri Coal Mine (both in Madhya Pradesh) and Ananta Opencast Mine (Odisha) in the different Gondwana Basins. The study attempts to show the useful heat value generated with the help of proximate analysis as a preliminary parameter to fix the commercial viability of the bituminous coals. We collected ten samples from one seam each, using the pillar sampling method, from the coal-bearing unit in all five mines, which belong to the Barakar Formation. The moisture and volatile matter content of these coals show comparable values, but the ash content and fixed carbon content show a significant variation in these coals. The useful heat values calculated by using these proximate constituents show that the coals of Mohan Colliery have the lowest useful heat values (1307.24 kCal/kg), while the coals of Lalmatia Coal Mine have the highest useful heat values (5587.47 kCal/kg) even though all these coals belong to the same geological horizon. The gross calorific values of these coals were also calculated to identify the grade of the coals. Based on the UHV and GCV, the Lalmatia coals are of the highest grade and show the maximum commercial viability.

ARTICLE HISTORY
Received 12 April 2024
Revised 5 June 2024
Accepted 15 June 2024

KEYWORDS
Gondwana basin
Barakar Formation
Bituminous coal
Proximate analysis
Useful Heat Value
Gross Calorific Value

1. INTRODUCTION

The various Gondwana basins were formed after the rivers brought sediments to fill the elongate depressions which were formed due to the reactivation of shear zones, faults and rift valleys of the Precambrian times (Valdiya, 2010). These sedimentary sequences, which occur across Rajamahal, Son-Mahanadi, Satpura, Rewa, and Godavari basins, were deposited during Permian to early Cretaceous (King, 1958). The climate during the deposition of these sediments ranged from cold temperate with alternating dry and wet seasons (Kräusel, 1961) to warm temperate (King, 1961), leading to luxuriant growth of flora (Stach et al., 1982).

The Gondwana coals have been extensively studied for their petrographical and geochemical characterization since the late nineteenth and early twentieth centuries. The Rajmahal Basin coals were first reported by Twiner in 1829, while the systematic studies started in 1851 after the Geological Survey of India was established (Singh and Singh, 1996). The coals of Mahanadi Valley were systematically surveyed by Blanford et al. (1856). The Damodar Valley holds

*Corresponding author. Email: vikram.singh@igntu.ac.in (VPS)

the distinction for being the first coal mine in India where mining started in 1774 (Chandra et al., 2000). The Satpura Basin coal deposits were first reported by Quseley (1835) and extensive surveys were conducted by Medlicott (1871, 1875, 1879) and Jones (1887). Later the research advanced to higher levels of elemental analysis.

The present work focuses on the geochemical characterization (proximate analysis only) and comparison of the results from the five locations, Lalmatia opencast mine, Jassidih (Jharkhand) in the Rajmahal Basin, Rajrappa opencast mine, Ramgarh (Jharkhand) in the Damodar Valley, Mohan Colliery, Chhindwara (Madhya Pradesh) in the Satpura Basin, Dhanpuri opencast mine, and Shahdol in the Rewa Basin.

2. GEOLOGY OF THE STUDY AREA

The study areas are located in the different Gondwana Basins (Fig. 1). The geology of each area is discussed below:

2.1. Lalmatia Opencast Mine, Jassidih District (Jharkhand)

The Lalmatia Opencast mine (24°13′N; 87°20′E) is situated in the Hura Coalfield, which is one of the five coalfields Rajmahal Coalfield located in the Jassidih District, belonging to the coal-bearing Barakar Formation, in the Rajmahal Basin. Rajmahal Basin constitutes a minor part of the Gondwana Basin and comprises of Talchir, Barakar and Dubrajpur formations, overlain by the Rajmahal Volcanics (Singh and Singh, 1996; Vaidyanadhan and Ramakrishnan, 2010). The Barakar Formation exposed here is divided into a thin lower and more thick upper part (Singh and Singh, 1996). The Lower Barakar Formation consists mainly of arkosic sandstones and is devoid of coal seams, while the Upper Barakar Formation has interbedded sequences of coal, coaly shales, carbonaceous shales, claystone and sandstones (Metchem, 1987). Samples were collected from the seam-III of the Upper Barakar Formation in the Lalmatia opencast mine.

2.2. Rajrappa Opencast Mine, Ramgarh District (Jharkhand)

The Rajrappa opencast mines (23°06′15″N; 85°06′82″E) are a part of the Ramgarh Coalfield in the Damodar Valley Basin (Mahadevan, 2002). The study area comprises of Archean basement, unconformably overlain by Talchir and Barakar formations of early Permian age (Mahadevan, 2002). The main lithounit of the Barakar Formation is the coal bearing strata, having a thickness of approximately 600 m (GSI, 1963). The sampling was done from the seam-VII of the Barakar Formation in the Rajrappa opencast mine.

2.3. Mohan Colliery, Chhindwara District (Madhya Pradesh)

The Mohan Colliery (22°10′N; 78°40′E) is located in the Satpura Basin, which has rocks of Lower Gondwana exposed in a syncline (Singh and Shukla, 2004). The Upper Gondwana rocks are located on the edge of this syncline (Raja Rao, 1983). The lithology consists of Archean basement, unconformably overlain by the Talchir, Barakar and Motur formations (Late Carboniferous to Jurassic age) (Samaddar and Banerjee, 1978). In this region, the 450 m thick Barakar Formation is the only coal bearing unit, with sandstones interbedded with carbonaceous shales and coal seams (Singh and Shukla, 2004). Sampling was done from the seam-III of the Barakar sandstone in the Mohan Colliery.

2.4. Dhanpuri Opencast Mine, Shahdol District (Madhya Pradesh)

Dhanpuri opencast mine (23°08′30″N; 81°32′ 20″E), located within the Burhar-Amlai sub- basin (Agnihotri et al., 2018), comes under the Sohagpur Coalfield in the Shahdol district, which is the second highest producing coalfield in Madhya Pradesh (Coal Directory of India, 2014-15). Sohagpur coalfield has Precambrian basement, unconformably overlain by Talchir and Barakar Formations (early Permian age), Pali Formation (middle Permian-middle Triassic age), Parsora Formation (early Jurassic), and Lameta Beds (late Cretaceous age) (Raja Rao, 1983). The sampling was done from the seam-VI, which is the only workable seam in the Dhanpuri opencast mine.

2.5. Ananta Opencast Mine, Angul District (Odisha)

The Ananta Opencast Mine (20°56′32.79″N; 85°09′32.34″E) is a part of Talcher Coalfield in the Brahmani River Valley. This basin has Archean basement, unconformably overlain by the Talchir, Karharbari, Barakar and Kamthi formations (Raja Rao, 1982). In the study area, the coal-bearing successions belong to the Barakar Formation, consisting

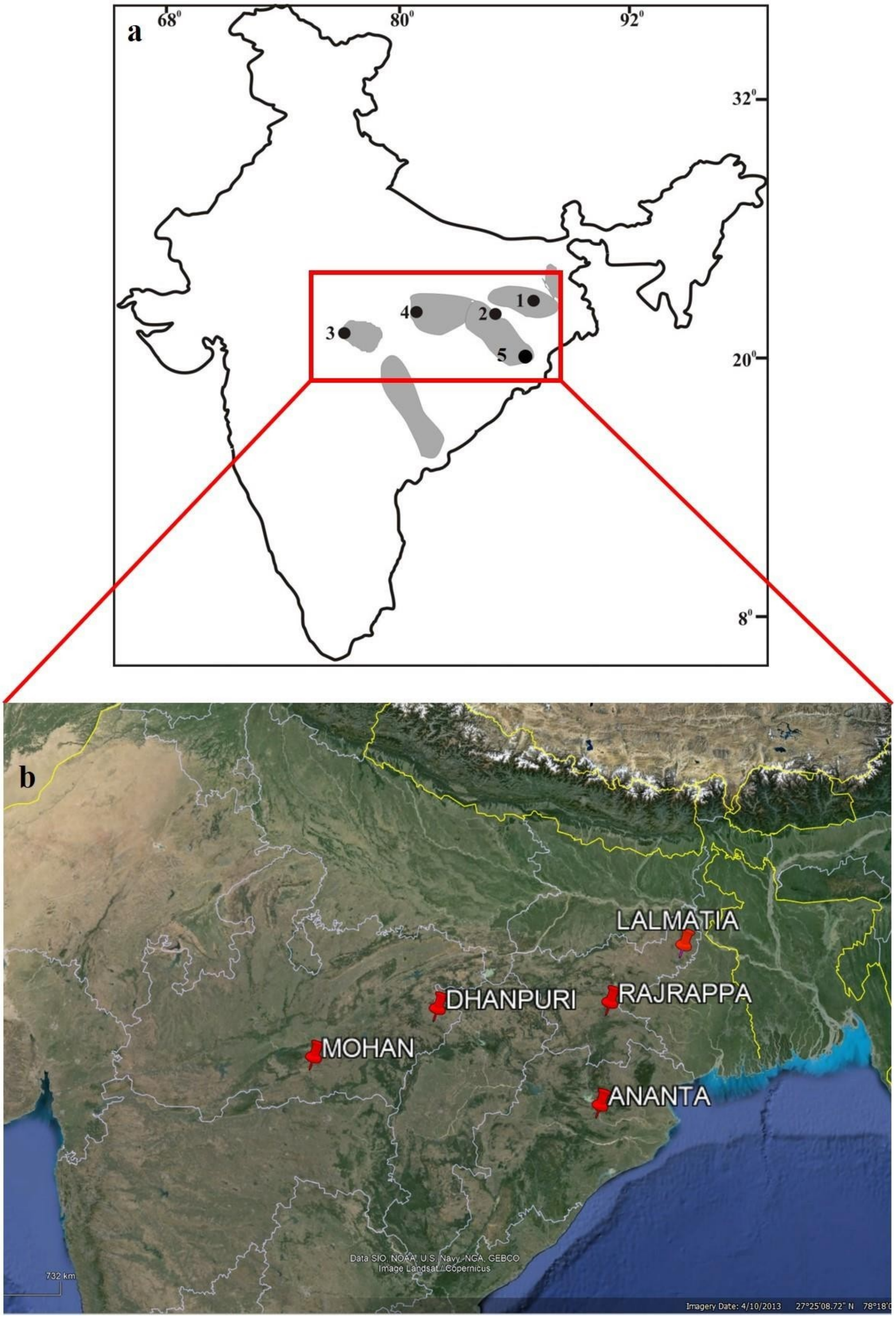

Fig. 1. a. The location map of the study sites: a. the various Gondwana basins (after Vaidyanadhan and Ramakrishnan, 2010). The numbers show the five mines in the different basins: 1. Lalmatia Opencast mine, 2. Rajrappa Opencast mine, 3. Mohan Colliery, 4. Dhanpuri Opencast mine and 5. Ananta Opencast mine; b. the location of the five mines marked in the various states. b. Basemap is from Google Earth.

of medium to coarse grained sandstones, shales, coal seam with a conglomeratic base (Raja Rao, 1982).

The Barakar Formation of early Permian age, unconformably overlying the Precambrian basement, are exposed in all the five study areas. The Barakar Formation is the main lithounit where the coal bearing strata provide the thickest and workable coal seams.

3. MATERIALS AND METHODS

Ten composite coal samples were collected from each seam using the pillar sampling method. The analytical technique applied for geochemical characterization was proximate analysis. In this technique, the coals samples were crushed to a preferable size of 70 mesh and the powder was heated in hot air oven and muffle furnace (BIS, 2003). The parameters determined in this study were the moisture content, volatile matter content, ash content and fixed carbon content of the coals. The results for proximate analysis are discussed for air dried and dry ash free basis.

Table 1 presents a generalised classification and correlation of strata exposed in the five study areas.

3.1. Moisture Content

One gram of air-dried coal powder of 70 mesh size was weighed and spread uniformly over a petri dish. The dish was then heated in an oven at a temperature of 108°C for 90 minutes. The dish was then removed from the oven and staked in a desiccator for nearly 30 minutes for cooling. The residue was then weighed to calculate the weight lost as a result of heating. The moisture content in the coal was calculated as weight percent.

$$Moisture\ wt.\% = \frac{wt.\ of\ coal\ powder - wt.\ of\ residue\ after\ heating}{wt.\ of\ coal\ powder} \times 100$$

(Chandra et al., 2000)

3.2. Volatile Matter (VM)

The VM comprises of all the volatile components, excluding the moisture, released during the heating of coal (Speight, 2005). The VM not only comprises of volatiles present in organic matter, but also volatiles from the mineral matter, e.g. carbon dioxide, hydrogen chloride, and sulphur from carbonate, chloride and pyrite minerals respectively. To find the VM content, one gram of air-dried coal powder of 70 mesh size was placed in a silica crucible, covered with a lid. It was then placed in Muffle Furnace and temperature was allowed to rise to 900°C. The crucible was then heated at this temperature for 7 minutes. After heating, the crucible was placed in a desiccator for cooling. The residue was then weighed to note the loss in weight. The VM is represented as weight per cent.

$$VM\ wt.\% = \left(\frac{wt.\ of\ coal\ powder - wt.\ of\ residue\ after\ heating}{wt.\ of\ coal\ powder} \times 100\right) - Moisture\ wt.\%$$

(Chandra et al., 2000)

3.3. Ash Content

The coal ash is the residue which remains after the combustion of coal under specific conditions and comprises primarily of oxides and sulphates (Speight, 2005). Ash formation is a result of several chemical changes taking place in mineral matter during combustion, for example, loss of water from silicate minerals, carbon dioxide from carbonate minerals, and oxidation of pyrite to iron.

To determine the ash content, one gram of air-dried coal powder of 70 mesh size placed in a silica crucible and left uncovered initially at room temperature in a Muffle Furnace. The temperature was allowed to rise to 500°C in 30 minutes and then gradually to 815°C in the next 30-60 minutes. This temperature was then maintained for next 60 minutes. Later the crucible was placed in a desiccator and the residue was then weighed to know the loss in weight. Ash content is represented as weight per cent.

$$Ash\ wt.\% = \frac{wt.\ of\ residue\ after\ heating}{wt.\ of\ coal\ powder} \times 100$$

(Chandra et al., 2000)

3.4. Fixed Carbon (FC)

The FC is defined as the solid combustible residue remaining after expulsion of VM (Speight, 2005). It can be calculated in weight per cent as

$$FC\ wt.\% = 100 - (Moisture\ wt.\% + VM\ wt.\% + Ash\ wt.\%)$$

(Chandra et al., 2000)

The dry ash free (d.a.f.) basis values of VM can be calculated as

$$VM\ wt.\%_{(d.a.f.)} = \frac{VM\ (air\ dried) \times 100}{100 - (Moisture + Ash)}$$

(Chandra et al., 2000)

e-ISSN: 2583-6900

Table 1. Generalized classification and correlation of strata exposed in the study areas of various Gondwana basins.

Age	**Lalmatia Opencast Mine, Hura Coalfield, Rajmahal Basin** (*Metchem, 1987*)	**Rajrappa Opencast Mine, Ramgarh Coalfield, Damodar Valley** (*Vaidyanadhan and Ramakrishnan, 2010*)	**Mohan Colliery, Chhindwara, Satpura Basin** (*Samaddar and Banerjee, 1978; Vaidyanadhan and Ramakrishnan, 2010*)	**Dhanpuri Opencast Mine, Sohagpur Coalfield, Rewa Basin** (*Agnihotri et al., 2018*)	**Ananta Opencast Mine, Brahmani River Basin** (*Raja Rao, 1982*)
Recent	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium
Pleistocene	-Unconformity-		Dolerite Intrusives		
			-Unconformity-		
			Deccan Flood Basalts	Deccan Traps	
Late Cretaceous					
				Lameta Beds	
Early Cretaceous					-Unconformity-
Late Jurassic	Rajmahal Traps			-Unconformity-	
Middle Jurassic					
Early Jurassic		Mahadeva Formation (Supra Panchet Formation)	-Unconformity-	Parsora Formation	
					Kamthi Formation
Late Triassic	Dubrajpur Formation			-Unconformity-	
Middle Triassic	-Unconformity-				
Early Triassic		Panchet Formation			
Late Permian		Raniganj Formation	Motur Formation	Pali Formation	Barakar Formation
Middle Permian		Barren Measures	-Unconformity-		
	Barakar Formation	Barakar Formation	Barakar Formation	Barakar Formation	Karharbari Formation
Early Permian	Karharbari Formation	Talchir Formation	Talchir Formation	Talchir Formation	Talchir Formation
	Talchir Formation				
	-Unconformity-	-Unconformity-	-Unconformity-	-Unconformity-	-Unconformity-
Proterozoic			Metamorphics and intrusives	Basement	Basement
		Basement			
Archean	Basement		Basement (not exposed)		

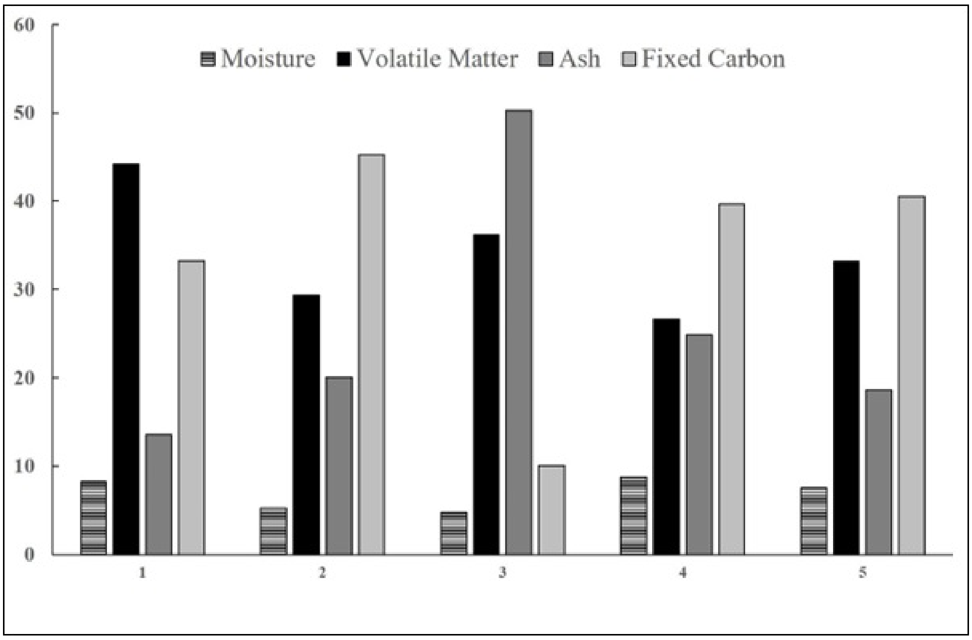

Fig. 2. Proximate analysis of coal from the study areas. 1. Lalmatia Opencast Mine, 2. Rajrappa Opencast Mine, 3. Mohan Colliery, 4. Dhanpuri Opencast Mine and 5. Ananta Opencast Mine. The vertical axis represents values in wt%.

The weight percent of ash and moisture were then used to calculate the useful heat value (UHV) of the coal using the empirical formula

$$UHV = 8900 - 138 \times (wt.\%\ of\ Ash + wt.\%\ of\ Moisture)$$
(Ghosh et al., 2016)

The gross calorific value (GCV) was calculated using the following empirical formula for high moisture coals (>2% moisture):

$$GCV = 85.6[100 - (1.1A + M)] - 60M$$
(Mazumdar, 1954)
$(A:\ wt\%\ of\ Ash;\ M:\ wt\%\ of\ Moisture)$

4. RESULTS AND DISCUSSION

The values derived from the proximate analysis were analysed for all the samples recovered from the seam to study the variation of these constituents from bottom to top. Further, the mean value was calculated (Fig. 2).

In the coals of Lalmatia opencast mine, the moisture content varies from 7.19 to 9.92%, VM from 23.35 to 43.07%, ash from 13.01 to 30.09% and FC from 27.94 to 53.73% on air dried basis. The VM and FC on dry ash free basis vary from 49.90 to 69.76% and 30.24 to 50.1% respectively.

In the coals of Rajrappa opencast mine, the moisture content ranges from 4.01 to 7.71%, VM from 38.96% to 54.07%, ash from 10.77 to 16.93% and FC from 23.44 to 39.79% on air dried basis. The VM and FC on dry ash free basis range from 31.18 to 50.80% and 8.76 to 43.85% respectively.

In the coals of Mohan colliery, the moisture content ranges from 1.68 to 7.30%, VM from

25.43 to 44.4754.07%, ash from 37.35 to 67.79% and FC from 5.38 to 13.43% on air dried basis. The VM and FC on dry ash free basis range from 71.57 to 87.76% and 12.23 to 28.425% respectively.

In the coals of Ananta opencast mines, the moisture content ranges from 5.48 to 9.30%, VM from 27.25 to 47.63%, ash from 9.6 to 38.05% and FC from 29.1 to 48.06% on air dried basis. The VM and FC on dry ash free basis range from 40.02 to 52.07% and 47.93 to 59.98% respectively.

The average values of the results of proximate analysis are presented in Table 2.

The mean values were then used to calculate the Useful Heat Values (UHV) of coals of each area (Table 3).

We also calculated the Gross Calorific Values (GCV) based on proximate analysis data (Table 4) to identify the grade of the coals.

The bituminous coals analyzed in this study have less than 10% moisture. The VM content, which helps in judging the behaviour of coal on combus-

Table 2. Composite result of proximate analysis of the coal samples.

Proximate Constituents	Lalmatia Opencast Mine Mean wt.%	Rajrappa Opencast Mine Mean wt.%	Mohan Colliery Mean wt.%	Dhanpuri Opencast Mine Mean wt.%	Ananta Opencast Mine Mean wt.%
Air-dried basis					
Moisture	8.24	5.30	4.77	8.80	7.59
Volatile Matter	44.21	29.38	36.15	26.69	33.19
Ash	13.59	20.06	50.25	24.85	18.67
Fixed Carbon	33.24	45.24	10.08	39.67	40.5
Dry Ash Free basis					
Volatile Matter	56.69	39.36	78.02	40.36	45.19
Fixed Carbon	43.38	35.28	21.98	25.99	54.8

Table 3. Useful heat value for coals from the study areas.

Study Area	Useful Heat Value (kCal/kg)
Lalmatia Opencast Mine	5887.46
Rajrappa Opencast Mine	5400.32
Mohan Colliery	1307.24
Dhanpuri Opencast Mine	4256.3
Ananta Opencast Mine	5275.53

Table 4. Gross Calorific Values for coals from the study areas.

Study Area	Gross Calorific Value (kCal/kg)
Lalmatia Opencast Mine	6080.62
Rajrappa Opencast Mine	5899.47
Mohan Colliery	3133.95
Dhanpuri Opencast Mine	4938.84
Ananta Opencast Mine	5696.93

tion, carbonization and gasification (Chandra et al., 2000), shows quite variable values in all the areas, the highest in Lalmatia coals (44.21%) while the lowest in Dhanpuri coals (26.69%). The values of VM suggest that the coals of Rajrappa and Dhanpuri opencast mines are of coking quality, while the Lalmatia opencast mine, Mohan Colliery and Ananta opencast mine are of non-coking variety.

The ash content of coal, which is the result of the complete combustion of inorganic mineral matter in the coal, which may be inherent mineral matter incorporated during the early stage of coal formation or epigenetic mineral matter deposited subsequent to the formation of the coal (Chandra et al., 2000). The ash content in the coals from Mohan Colliery has the highest values among the five study areas. This provides the evidence for high epigenetic mineral matter in the Mohan Colliery coals. Thus, the FC content of the four study areas, viz. Lalmatia, Rajrappa, Dhanpuri and Ananta opencast mines show comparable values, while the Mohan Colliery shows the lowest value.

The Lalmatia opencast mine coals have the highest UHV of 5887.46 kCal/kg as well as highest GCV of 6080.62 kCal/kg, while those of Mohan Colliery have 1307.24 kCal/kg UHV and 3133.95 kCal/kg. Based on the GCV, the Mohan Colliery coals are of G14 grade, Dhanpuri coals lie in G8 grade, Ananta coals in G6 grade while the Rajrappa and Lalmatia coals belong to G5 grade.

5. CONCLUSIONS

Based on a comparative study of coal samples collected from the coal seams belonging to Barakar Formation in various mines of five locations in the Gondwana basins, we deduce that the high rank coals are affected by the local sedimentation, groundwater and tectonic conditions to a large extent, which may cause a variation in their proximate constituent contents as well as useful heat values. It is concluded that of the five study areas, the Mohan Colliery coals have the highest ash content and lowest UHV and GCV, which makes them commercially least viable while the Lalmatia opencast mine coals, on the basis of UHV and GCV have the highest grade and commercial value.

ACKNOWLEDGEMENTS

VPS gratefully acknowledges the Professor incharge, Coal and Organic Petrology Lab, BHU for extending support to work on the Lalmatia and Ananta opencast mine samples, officials of Lalmatia Coal Mines, Jassidih (Jharkhand) for permitting to carry out fieldwork and collect samples; St. Xavier's College, Mumbai to extend lab facilities to work on Mohan Colliery coal samples, officials of Mohan Colliery, Junnardeo (Madhya Pradesh) to permit the fieldwork and collection of coal samples; Head Department of Geology, IGNTU, Amarkantak for extending lab facilities to work on Rajrappa and Dhanpuri coal samples, officials of Rajrappa Opencast Mines, Ramgarh (Jharkhand) and SECL, Sohagpur and Dhanpuri Opencast Mine for permitting the fieldwork and collection of coal samples. VPS also gratefully acknowledges the efforts of his students Angana Chaudhuri, Eram Shaikh, Rajvardhan Sharma, Prakash Tiwari and Biplab Kumar Mahanta during the fieldwork and lab studies. RD and SP thank IGNTU for financial support. KRM and PKN thank the PG Department of Geology, Utkal University, Odisha. Two anonymous reviewers are thankfully acknowledged for their comments which have greatly improved the manuscript.

References

Agnihotri, D., Pillai, S.S.K., Neha, A., Rajni, T., Jasper, A., Uhl, D., 2018. Palynomorphs from the Barakar Formation of Dhanpuri Open Cast Mine, Sohagpur Coalfield, Madhya Pradesh, India. *The Paleobotanist* 67, 171–184. https://doi.org/10.54991/jop.2018.56.

BIS, 2003. *Methods of test for coal and coke (2nd revision of IS: 1350). Part I, Proximate analysis.* Bureau of Indian Standard.

Blanford, W.T., Blanford, H.F., Theobald, T., 1856. On the geological structure and relations of Talcher coalfield in the district of Cuttack. *Mem. Geol. Surv. India* 1(1), 1–98.

Chandra, D., Singh, R.M., Singh, M.P., 2000. *Textbook of Coal (Indian Context).* Tara Book Agency.

GSI, 1963. Report on the investigation by drilling in the south –eastern part of the Ramgarh coal field, Hazaribagh district, Bihar, Unpublished Geological Survey of India Report. GSICHQ-1587.

Coal Directory of India (2014-15), Coal.Statistics, 2016. Ministry of Coal, Government of India.

Ghosh, S., Chatterjee, R., Shanker, P., 2016. Estimation of ash, moisture content and detection of coal lithofacies from well logs using regression and artificial neural network modelling. *Fuel* 177, 279–287. https://doi.org/10.1016/j.fuel.2016.03.001.

Jones, E.J., 1887. The southern coalfields of Sarpura Gondwana Basin. *Mem. Geol. Surv. India* 24(I), 1–58.

King, L.C., 1958. Basic palaeogeography of Gondwanaland during the late Palaeozoic and Mesozoic eras, Geol. *Soc. London Quart. Jour.* 114, 53. https://doi.org/10.1144/gsjgs.114.1.0047.

King, L.C., 1961. The palaeoclimatology of Gondwanaland during the Late Palaeozoic and Mesozoic eras, in: Nairn, A.E.M. (Ed.), Descriptive Palaeoclimatology. Interscience, New York, p. 307–331.

Kräusel, R., 1961. Palaeobotanical evidence of climate, in: Nairn, A.E.M. (Ed.), Descriptive Palaeoclimatology. Interscience, New York, p. 250.

Mahadevan, M.T., 2002. Geology of Bihar and Jharkhand. *Geol. Soc. of Ind.* .

Mazumdar, B.K., 1954. Coal systematics: deductions from proximate analysis of coal Part I. *Jour. Sci. Indian Res.* 13B(12), 857–863.

Medlicott, H.B., 1871. Note on the Narbada coal basin. *Rec. Geol. Surv. India* 4, 66– 69.

Medlicott, H.B., 1875. The Shahpur Coalfield with notice of coal exploration in the Narbada Region. *Rec. Geol. Surv. India* 8, 65–86.

Medlicott, H.B., 1879. Note on the Mohpani Coalfield. *Rec. Geol. Surv. India* 12, 95– 140.

Metchem, 1987. *Project Document.* Rajmahal OCP, Eastern Coalfield Ltd., Coal India.

Quseley, J.R., 1835. Notice of two beds of coal, discovered near Barakar Garabwara in the valley of the Narbada. *J. Asiat. Soc. Bengal* 4, 648.

Raja Rao, C.S., 1982. Bulletins of the Geological Survey of India, series A, No. 45, Coalfields of India, Coal resources of Tamil Nadu, Andhra Pradesh, Orissa and Maharashtra.

Raja Rao, C.S., 1983. Coal resources of Madhya Pradesh, Jammu and Kashmir. *Bull. Geol. Surv. India, Ser. A* III(45), 155– 178.

Samaddar, D., Banerjee, S.P., 1978. Geology and coal resources of central part of the Pench-Kanhan Tawa Valley coal field, Chhindwara and Betul district, Madhya Pradesh. Unpublished GSI Prog. Rept. for FS 1970-71.

Singh, M.P., Shukla, R.R., 2004. Petrographic characteristics and depositional conditions of Permian coals of Pench, Kanhan, and Tawa Valley Coalfields of Satpura Basin, Madhya Pradesh, India. *Inter. Jour. of Coal Geol.* 59, 209–243. https://doi.org/10.1016/j.coal.2004.02.002.

Singh, M.P., Singh, P.K., 1996. Petrographic characterization and evolution of the Permian coal deposits of the Rajmahal Basin, Bihar, India. *Inter. Jour. of Coal Geology* 29, 93–118. https://doi.org/10.1016/0166-5162(95)00005-4.

Speight, J.G., 2005. *Handbook of Coal Geology.* Wiley and Sons.

Stach, E., Mackowsky, M.Th., Teichmüller, M., Taylor, G.H., Chandra, D., Teichmüller, R., 1982. *Stach's Textbook of Coal Petrology.* Gebrüder Borntraeger, Berlin, Stuttgart.

Vaidyanadhan, R., Ramakrishnan, M., 2010. *Geology of India.* volume 2. Geological Society of India.

Valdiya, K.S., 2010. *The Making of India- Geodynamic Evolution.* Macmillan Publishers India Ltd.