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A study of geochemical and petrographic characteristics of Eocene coal from Bapung coalfield, East Jaintia Hills, Meghalaya, North East India

Manabendra Nath[1] · Alok Kumar[2]

Abstract

The Bapung coalfield in the East Jaintia Hills of Meghalaya was studied in order to know the physicochemical character and depositional environment of the coal-based on geochemical and petrographic analysis. The Bureau of Indian Standards procedure followed for proximate and ultimate analysis. Whereas for petrographic analysis, polished blocks were studied under reflected light with an oil immersion lens using a Leitz microscope (magnification × 200) following the ICCP system. The study reveals that the coal has low ash (1.1 to 4.2%), low moisture (1.5 to 2.1%), high volatile matter (40.02 to 45.25%), high carbon (74.30 to 79.65%), high hydrogen content (more than 5%), and high sulphur above 3%. In reflected light, the dominant maceral identified is vitrinite (75.5 to 82.6%), while inertinite occurs in subordinate amounts, and liptinite concentration is low. This coal is sub-bituminous A to high volatile bituminous C in rank. The petrography-based ternary facies model used to decipher the paleodepositional environment suggests that anoxic condition dominantly prevailed in the paleomire, and there was an association of peat with brackish water condition that allowed the sulphate-reducing bacteria to thrive.

Keywords Bapung coal · Meghalaya · Coal petrography · Geochemistry · Depositional environment

Introduction

The coal resources of India occur in two distinct stratigraphic horizons, the Gondwana coals of the Permian age and the Paleogene coal resources. Gondwana coals account for over 99% of India's coal resources, whereas Paleogene coal contributes the rest. The Paleogene coal deposits in the North-Eastern region of India mainly occur in the States of Assam, Arunachal Pradesh, Meghalaya, and Nagaland. The coal-bearing sequences of Meghalaya were deposited over a stable platform basin. This took place, especially along the peripheral margins of the Shillong Plateau. Raja Rao (1981)

reported three groups of coalfields in Meghalaya, which are located in the Garo Hills, Khasi Hills, and Jaintia Hills.

The coalfields of North-Eastern India have been petrologically studied by several workers, and significant contributions have been made by Mishra and Ghosh, 1996; Singh and Singh (2000, 2001); Singh et al. (2012c, 2013a); Singh (2018); Gogoi et al. (2020); Kumar et al. (2021). Nath et al. (2022) recently investigated the source rock potential of the Garo Hills coal deposits of Meghalaya using the advanced geochemical tool. The research done by him shows the hydrocarbon generation potential of coal of the region, which is mixed-type kerogen-II-III, and it is a good source rock for hydrocarbon generation. In addition, the evolution of the coal deposits of North East India and its source rock potential has been studied by several researchers using petrological and geochemical techniques (Gogoi et al. 2022, 2021, 2020; Banik et al. 2021; Sharma et al. 2018).

Medlicott (1868) first reported the occurrence of coal in Meghalaya, and subsequent studies were carried out by Evans (1932), Fox (1934), Ghosh (1940), Raja Rao (1981), Singh (1989), Chandra and Behera (1992), Ahmed and Rahim (1996), Mishra and Ghosh (1996), and Rajarathnam et al. (1996). The present study has been carried out on coals

✉ Manabendra Nath
  dr.manabendra.nath@gmail.com

1   Department of Geology, Gurucharan College,
    Silchar 788004, Assam, India

2   Department of Petroleum Engineering and Geoengineering,
    Rajiv Gandhi Institute of Petroleum Technology, Jais,
    Amethi 229304, India

of Bapung coalfield (Fig. 1). It is a minor but important coalfield of Jaintia Hills. The coal seams occur in the Shella Formation of Eocene age and belong to the Jaintia Group. The objective of the present paper is to provide comprehensive information on the composition and evolution of Bapung coals from Jaintia Hills of Meghalaya using coal petrography and geochemistry.

Geology of the study area

The Bapung coalfield lies in the south-eastern part of the Jaintia Hills of Meghalaya. In the coalfield, the sediments of Eocene age rest unconformably on the deeply weathered Precambrian basement. The geological formations in Jaintia Hills comprise mostly rocks of the Jaintia Group, unconformably overlying the Archaean gneisses and granites (PMB). The Lakadong sandstone member of the Shella Formation is extensively exposed throughout the Bapung area, and it includes a few coal seams. The Lakadong sandstone member chiefly comprise sandstones and shales of varying nature, from ferruginous pyriteous and carbonaceous and contain three coal seams. The top seam ranges in thickness from 0.50 to 0.78 m., the middle seam from 0.38 to 0.90 m, and the bottom seam from 0.80 to 1.00 m. Below the top seam, 0.40 to 0.60 m carbonaceous shales occur with thin lenses of coal. The three coal seams are persistent in nature

and are associated with bands of carbonaceous shale. The sandstone bed has a general strike in the NE-SW direction with a common southerly dip of 2 to 5°. The sandstones are medium to fine-grained and greyish white to yellowish-brown to buff-colored. Overlying the sandstone are the beds of pale grey to white shales, ferruginous sandstone, current-bedded sandstone, and coal seams. The grey-white shales overlying the top seam at places thin out where sandstone beds develop. Occasionally, the shale bed contains thin layers of coal. In between the lower two seams, the sandstone shows pinching and swelling. The coal seams are nearly horizontal and sub-horizontal.

They have a rolling dip and vary from 2 to 5°. The common dip direction is towards SE. The generalised stratigraphic succession (modified after GSI 2009) of the coalfield is given in Table 1.

Materials and methods

Channel coal samples were collected from all the working/exposed coal seams from the Bapung area. The samples of coal collected were air-dried to remove the free moisture. After drying, the required amount (250 gm) was taken from each sample by coning and quartering method. The portion selected was crushed and passed through 72 mesh (211 µ) sieve for proximate analysis. Polished blocks were prepared
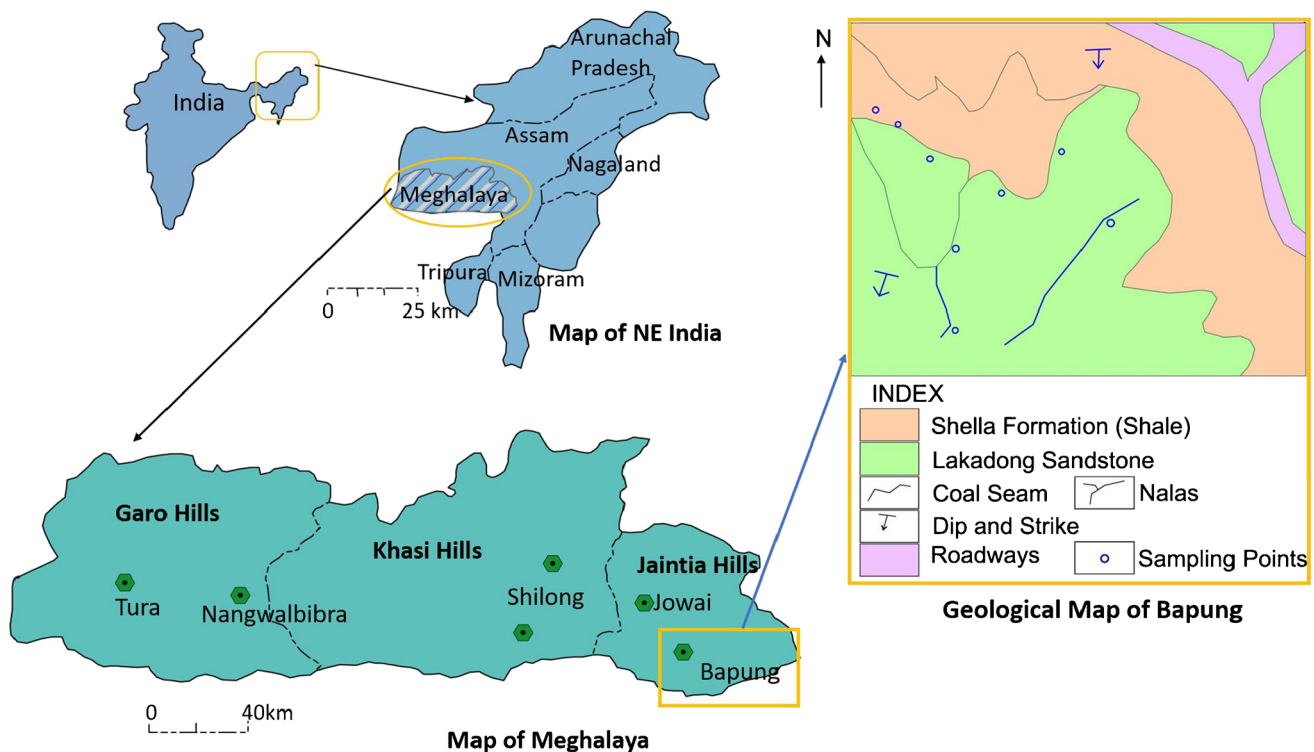

Fig. 1 Map of Meghalaya showing the geological map of Bapung coalfield and sampling locations

Table 1 The stratigraphic succession of the study area, Bapung Coalfield (modified after GSI 2009)

Age	Group name	Formation	Member	Lithology
Pleistocene to Holocene	Alluvium (thickness not known)	Unclassified		Mostly sands silt and clay
Uncomformity				
Eocene	Jaintia group	Shella Formation	Lakadong Sandstone member	Medium to coarse grained ferruginous quartzitic sandstone, containing thin coal seams, carbonaceous shales, and occasionally thin clay bed
Uncomformity				
Archaean	Meghalaya Gneissic Complex			Gneisses, schists, and granites

from the channel samples selecting hand lumps of coal. In order to prepare polish blocks to study the coal under reflected light, two alternate faces (vertical and horizontal) were selected. The maceral analysis was carried out on polished blocks under reflected light with an oil-immersion lens using a Leitz microscope (magnification × 200). Coal petrography was studied as per the ICCP system 1994 (ICCP 1998, 2001; Pickel et al. 2017).

The procedure recommended by the Bureau of Indian Standard (BIS 2003, 1974, 1975) was followed for proximate and ultimate analysis. The vitrinite reflectance measurements were carried out in the KDMI institute, Dehradun, using a Leitz MPV-2 microscope with an oil immersion lens.

Results

Megascopic characteristics

The Bapung coal is dark gray to black in colour. The coal is hard and compact, but some portion of the seam also has soft and friable varieties. The coals break with cubical fracture, but the hard ones break with sub-conchoidal to conchoidal fracture. The coal depicts a dull to glossy luster and at places, thin pyrite bands are also observed.

Chemical attributes

The proximate and ultimate analysis data are summarised in Table 2. The Bapung coals are chemically characterised by a low ash yield (1.1 to 4.2%), low moisture (1.5 to 2.1%), and high volatile matter (40.02 to 45.25%). The ultimate analysis shows that these coals have carbon contents ranging from 74.30 to 79.65%, while hydrogen content is moderately high with more than 5% in all the samples. The sulphur content is also high and ranges from 3.58 to 5.03%. H/C and O/C atomic ratios have been calculated with the H/C varying between 0.84 and 0.94 (mean 0.90), while O/C ranges from 0.07 to 0.13 (mean 0.10). Generally, marine-influenced coals

are rich in sulphur, hydrogen, and nitrogen contents and have a characteristically higher volatile matter than other coals (Teichmüller 1962). This generalisation was further substantiated by Price and Shieh (1979), Chou (1990), and Singh et al. (2010a, b, 2016), who confirmed that this increased proportion of sulphur (usually > 1%) comes from seawater. Under such a situation, the hydrogen and nitrogen are retained in the humic materials and finally appear as perhydrous vitrinite (Taylor et al. 1998). This condition could also have been with Bapung coal which has relatively high sulphur and volatile matter contents and shows its perhydrous nature (Fig. 2). The plots of the Bapung coal in the Van Krevelen diagram (Fig. 3) suggest that the coal was derived essentially from continental plants, whose microbial degradation in the basin of deposition was limited due to Sedimentation and rapid burial.

Petrographic composition

The maceral composition of Bapung coals is summarised in Table 3. The Bapung coals of Meghalaya, in general, are poor in liptinite and moderate in inertinite, while vitrinite is the most abundant maceral. The vitrinite content ranges from 76.50 to 82.62% (mmf basis), dominated by telovitrinite, which is mainly represented by collotelinite. It occurs as groundmass and bands. Liptinite ranges from 1.25 to 3.25% (mmf basis) and is represented mainly by sporinite and resinite. Sporinite occurs as thread-like bodies within vitrinite. Resinites include the plant resins and waxes occurring as rodlets in the vitrinitic groundmass. Inertinite also occurs in a moderate amount (8.6 to 18.0%, mmf basis), and it is mainly represented by fusinite, semifusinite, macrinite, and inertodetrinite. Fusinite is characterised by the presence of a well-preserved cell structure. In a few sections, cell structure was crushed producing 'Bogen structure'. Semifusinite is characterised by cell structures less preserved than fusinite and higher reflectivity than vitrinite. Macrinite occurs as fine particulate matter in the form of lenses. It shows the white colour and high reflectance. Inertodetrinite is seen

Table 2 Geochemical analyses of proximate and ultimate with the calculated H/C and O/C atomic ratios of Bapung coals

Sl. No	Proximate analysis				Ultimate analysis					Atomic ratios	
	Moisture (Wt.%)	Ash (Wt.%)	VM (Wt.%)	FC (Wt.%)	C (Wt.%)	H (Wt.%)	N (Wt.%)	S (Wt.%)	O (Wt.%)	H/C	O/C
1	1.8	1.5	42.15	54.55	77.06	5.83	2.66	4.11	10.34	0.08	0.14
2	2.0	1.6	40.25	56.15	74.30	5.32	2.82	4.25	13.31	0.07	0.19
3	1.9	2.8	41.20	54.10	79.15	5.69	2.95	4.45	7.76	0.07	0.11
4	2.0	1.6	42.30	54.10	-	-	-	-	-	-	-
5	1.7	2.7	44.70	50.90	-	-	-	-	-	-	-
6	1.8	2.4	44.25	51.55	-	-	-	-	-	-	-
7	1.6	1.5	43.70	53.20	-	-	-	-	-	-	-
8	1.8	2.4	40.10	55.70	78.32	6.15	1.76	4.40	9.37	0.08	0.14
9	1.5	2.2	42.75	53.55	76.58	5.37	2.20	3.58	12.27	0.07	0.17
10	1.7	4.2	44.10	50.00	78.13	6.11	1.92	5.02	8.82	0.08	0.13
11	2.0	2.4	40.25	55.35	79.65	5.95	1.39	4.69	8.32	0.07	0.12
12	1.9	3.4	42.35	52.35	76.63	5.90	2.23	4.71	10.53	0.08	0.15
13	1.6	1.1	44.20	53.10	76.85	5.74	2.80	4.38	10.23	0.07	0.14
14	1.5	1.6	42.23	54.67	-	-	-	-	-	-	-
15	1.7	1.5	40.02	56.78	-	-	-	-	-	-	-
16	1.5	1.7	40.02	56.78	-	-	-	-	-	-	-
17	1.7	2.2	42.32	53.78	74.68	5.86	1.99	4.20	13.27	0.08	0.19
18	1.6	2.1	42.02	54.28	75.74	5.81	2.67	4.27	11.51	0.08	0.16
19	1.7	2.5	43.67	52.13	78.47	5.81	2.84	3.37	9.51	0.07	0.13
20	2.1	2.7	45.25	49.95	-	-	-	-	-	-	-
21	1.8	2.5	43.07	52.63	-	-	-	-	-	-	-
22	1.6	3.7	44.25	50.45	-	-	-	-	-	-	-
23	1.9	3.1	42.02	52.98	-	-	-	-	-	-	-
24	1.5	3.2	42.07	52.43	76.39	5.77	2.35	4.97	10.52	0.08	0.15

VM, volatile matter; *FC*, fixed carbon; *C*, carbon; *H*, hydrogen; *N*, nitrogen; *S*, sulphur; *O*, oxygen
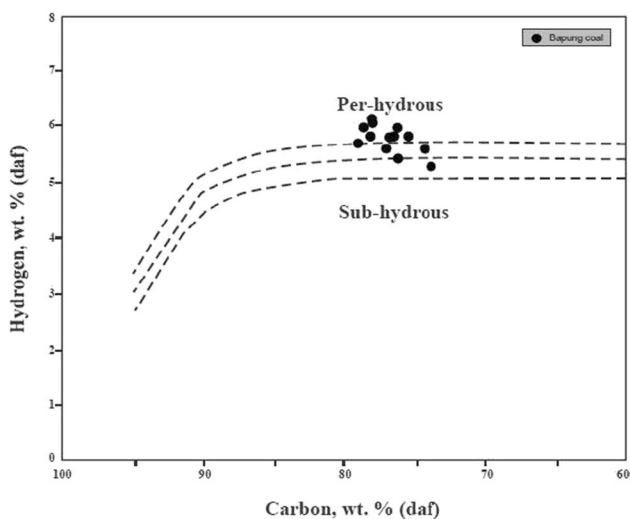

Fig. 2 Simplified Seylers chart with the bright coal band indicated by dashed lines. The sulphur-rich Bapung coals of Meghalaya are at the upper limit of the bright coal band and in the area of per-hydrous coals

with cracks and cavities. Funginite, occurring as circular to oval single and multi-chambered bodies.
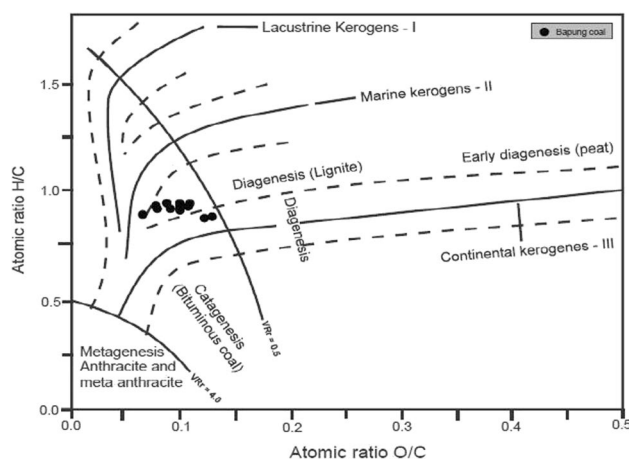

Fig. 3 Position of Bapung coal, Meghalaya in Van Krevelen diagram of H/C versus O/C atomic ratios (after Van Krevelen 1961)

Table 3 Maceral composition with mineral matter content (in vol %), random vitrinite reflectance, gelification index (GI), and tissue preservation index (TPI) of Bapung coal samples

Sample no	CC1 (Vol %)	CC2 (Vol %)	CC3 (Vol %)	CC4 (Vol %)	CC5 (Vol %)	CC6 (Vol %)	CC7 (Vol %)	CC8 (Vol %)	CC9 (Vol %)
Telinite	0.0	0.1	0.3	0.7	0.5	0.0	0.4	0.3	0.8
Collotelinite	78.2	76.2	77.5	75.2	76.0	81.5	73.5	80.2	79.5
Gelinite	1.1	0.1	1.1	0.0	0.5	0.0	2.1	0.0	0.0
Corpogelinite	0.1	1.8	0.7	0.5	1.6	<1	0.2	0.1	1.3
Collodetrinite	2.3	<1	0.5	0.2	0.1	1.7	0.1	2.1	<1
Vitrodetrinite	<1	1.1	<1	0.7	0.2	0.6	0.2	0.5	0.2
Total Vitrinite	81.7	78.2	80.1	77.3	78.5	82.6	76.5	82.2	81.8
Sporinite	2.23	1.12	1.94	1.07	0.68	1.46	1.88	1.4	0.75
Resinite	1.02	0.4	1.01	0.2	0.6	0.7	0.1	0.3	0.5
Cutinite	0.0	<1	0.0	0.0	<1	<1	0.0	0.0	<1
Total liptinite	3.25	1.52	2.95	1.27	1.28	2.16	1.98	1.70	1.25
Fusinite	1.1	1.2	1.0	0.9	0.2	0.1	0.8	3.0	0.3
Semifusinite	1.0	0.4	1.1	0.4	1.5	0.8	2.0	1.0	1.0
Macrinite	6.2	12.8	9.2	16.5	14.5	10.2	15.0	9.0	12.1
Inertodetrinite	0.2	0.2	0.1	0.1	0.0	0.0	0.1	0.0	0.2
Sclerotinite	0.1	0.2	0.0	0.1	0.3	0.0	0.1	0.0	0.1
Total inertinite	8.6	14.7	11.4	18.0	16.4	11.1	18.0	13.0	13.7
Sulphide	6.2	5.3	5.3	3.2	4.0	4.0	3.2	3.0	3.0
Carbonates	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0
Argillaceous	0.0	0.2	0.2	0.1	0.1	0.0	0.2	0.1	0.1
Mineral matter	6.3	5.5	5.6	3.3	4.2	4.0	3.4	3.2	3.1
%VRr	0.66	0.62	0.58	0.67	0.59	0.61	0.65	0.63	0.57
TPI	12.54	5.98	8.55	4.61	5.36	8.07	4.93	9.35	6.57
GI	9.5	5.3	7.0	4.2	4.8	7.4	4.2	6.3	5.9

Minerals matter ranges from 3.1 to 6.3% and is represented mainly by pyrite. Pyrite occurs as disseminated grains and specks within vitrinite and as framboidal pyrite bodies occurring as single or clustered bodies or also in the cavities. Argillaceous minerals and carbonates are next in abundance (Table 3). The vitrinite random reflectance (Rr) ranges from 0.57 to 0.67% (avg. 0.62%), which places the coal as sub-bituminous A to high volatile bituminous C in rank. The details of reflectance measurements are summarised in Table 3. The petrographic photographs are given in Fig. 4.

Discussion

Teichmüller (1962) believed that the coals formed under the marine influence are generally rich in sulphur, hydrogen, and nitrogen contents and are also characterised by relatively high volatile matter. This fact has also been substantiated by Price and Shieh (1979) and Chou (1990), who demonstrated that increasing sulphur proportion (usually > 1%) of such coals comes from seawater. Taylor et al. (1998) showed that hydrogen and nitrogen are retained in the humic materials and are consequently manifested as perhydrous vitrinite. Similar conditions were also recorded in the nearby coal seams of Nagaland (Singh et al. 2012a, b, c) and could also

be applicable with coals that have relatively high sulphur content and volatile matter as in the Bapung coals. Bapung coal in the Van Krevelen diagram (Fig. 3) indicates that the coal was derived mainly from continental plants, whose microbial degradation in the basin of deposition was controlled by sedimentation and rapid burial. However, the marine influence cannot be ruled out as few plots also show some deviation from the pure continental path (Fig. 3).

Teichmüller (1962) noted that 'coal facies' depend on the paleo-environmental conditions under which the precursor peats accumulate. Thus, plants are sensitive and react to the changes in the environmental conditions, and therefore, the petrographic study provides a precise tool for facies studies (Teichmiiller and Teichmiiller 1982). Moreover, several researchers have related the petrographic components of coal with the paleoecological setting (Cohen and Spackman 1972; Cohen et al. 1987; Grady et al. 1993; Singh and Singh 1996; Hawke et al. 1999; Shearer and Clarkson 1998; Styan and Bustin 1983; Singh et al. 2003, 2010a, b, 2012a, b, c, 2013a, b, 2014, 2016, 2017a, b, c, d, 2019; Naik et al. 2016; Rajak et al. 2019). For this purpose, different maceral indices have been used. Initially, gelification index (GI) and tissue preservation index (TPI) were introduced by Diessel (1986) to characterise the depositional environments of Australian Gondwana coals. However, some scientists raised critical
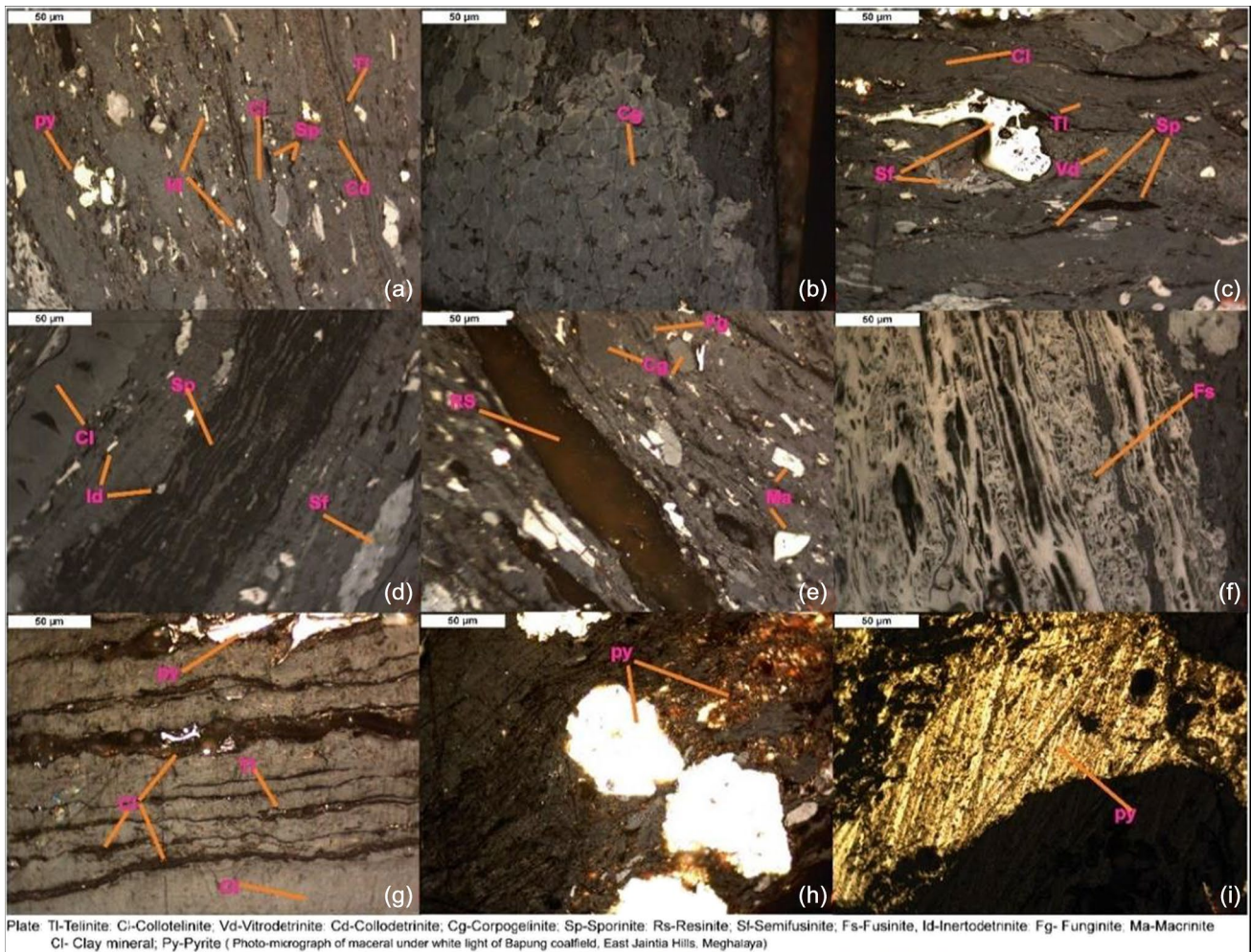
Plate: Tl-Telinite; Cl-Collotelinite; Vd-Vitrodetrinite; Cd-Collodetrinite; Cg-Corpogelinite; Sp-Sporinite; Rs-Resinite; Sf-Semifusinite; Fs-Fusinite; Id-Inertodetrinite; Fg- Funginite; Ma-Macrinite Cl- Clay mineral; Py-Pyrite (Photo-micrograph of maceral under white light of Bapung coalfield, East Jaintia Hills, Meghalaya)

Fig. 4 Microphotographs showing the representative macerals observed in Bapung coal

comments against the usage of such indices, especially for Cenozoic coals and lignites (Lamberson et al. 1991; Crosdale 1993; Dehmer 1995; Scott 2002; Moore and Shearer 2003; Amijaya and Littke 2005). Modifications were subsequently made in the indices by some researchers to make it applicable for other coals (Calder et al. 1991), Kalkreuth et al. (1991), and Petersen (1993) further modified these indices used them for low-rank coals. For Bapung coals of Meghalaya, the modified indices have been calculated using the following formulae:

maceral subgroup is derived from partially gelified woody tissue and indicates wood-producing plants as well as biochemical gelification. Marchioni and Kalkreuth (1991) relate biochemical gelification to high moisture conditions. Furthermore, Diessel (1982) indicated that brighter components of coal are formed under wet conditions. The present study is also in agreement with the earlier work (Mishra and Ghosh 1996; Singh et al. 2012c, 2013a), which has demonstrated that the coals of NE India evolved under wet forest swamps

$$GI = vitrinite/inertinite$$
$$TPI = (telinite + collotelinite + fusinite + semifusinite)/(collodetrinite + macrinite + inertodetrinite)$$

The Bapung coals are characterised by moderate GI and TPI values. A moderate GI indicates a continuous presence of water cover in the basin when Bapung peat was deposited. The facies model shows that these coals evolved mainly from wet forest peats (Fig. 5). The presence of a high telovitrinite content in these coals also reveals this fact because this

in marshy environments. Misra (1992) has revealed through palynological records that during Palaeocene and Oligocene periods, there was the growth of green forest vegetation under humid tropical conditions in India. Lack of forest fire could have been the reason for low inertinite content in these coals. To understand the peat-forming environment, a

Fig. 5 Coal facies deciphered from gelification index (GI) and the tissue preservation index (TPI) in relation to depositional setting and type of mire for Bapung coal (after Diessel 1986 and modified by Kalkreuth et al. 1991) [Li, limited influx; O marsh, open marsh; Vit, vitrinite; Inert, inertinite; Semifus, semifusinite; Fus, fusinite; Idet, inertodetrinite; Struct, structured; Deg, degraded
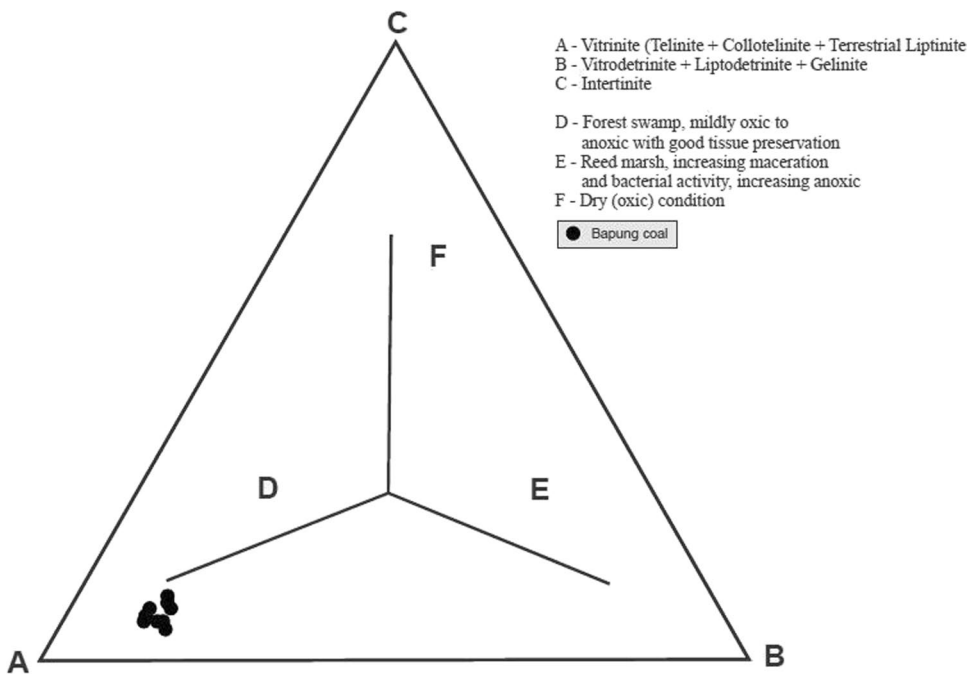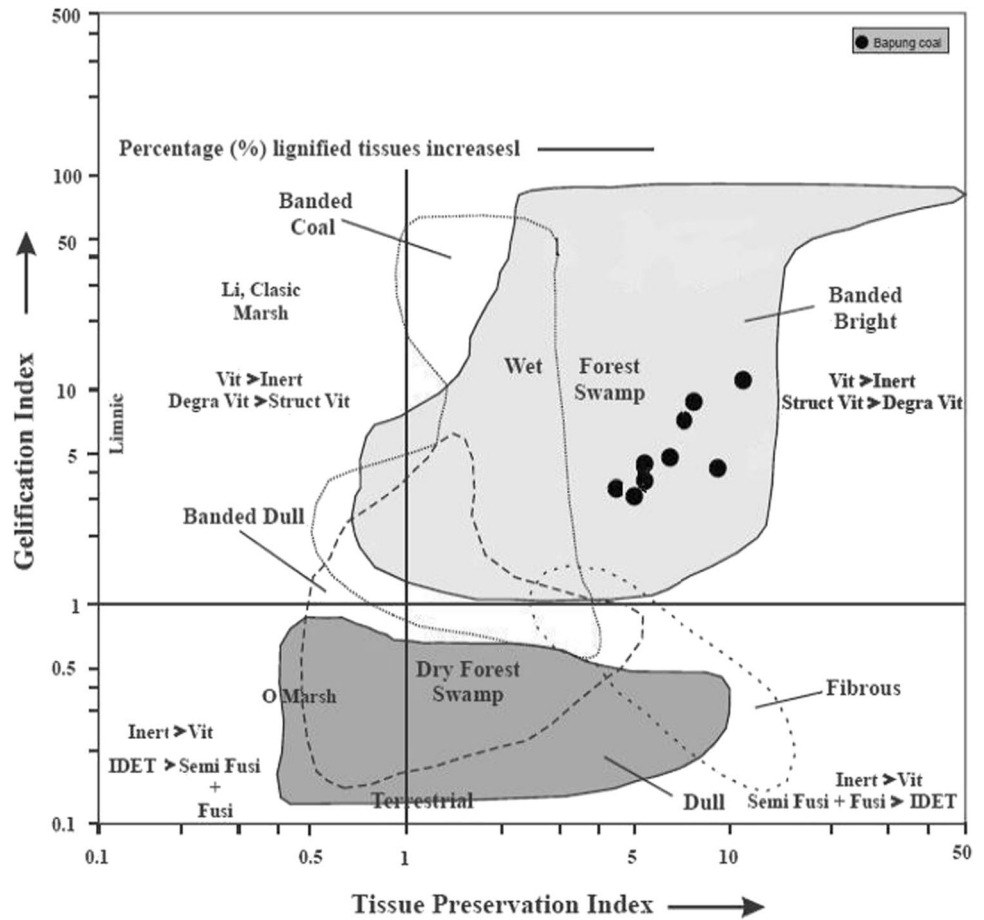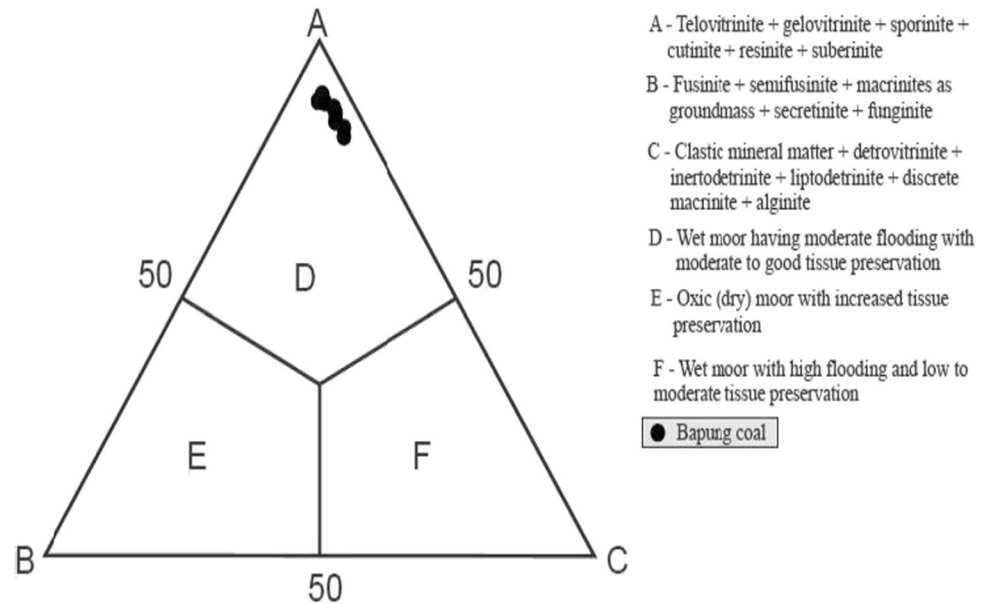

Fig. 6 Ternary diagram illustrating facies-critical maceral association in Bapung coal, Meghalaya, and suggested peat environments (modified from Mukhopadhyay 1986)

Fig. 7 Depositional condition of Bapung coal, Meghalaya based on maceral and mineral matter content (modified from Singh et al. 2012a)

A - Telovitrinite + gelovitrinite + sporinite + cutinite + resinite + suberinite

B - Fusinite + semifusinite + macrinites as groundmass + secretinite + funginite

C - Clastic mineral matter + detrovitrinite + inertodetrinite + liptodetrinite + discrete macrinite + alginite

D - Wet moor having moderate flooding with moderate to good tissue preservation

E - Oxic (dry) moor with increased tissue preservation

F - Wet moor with high flooding and low to moderate tissue preservation

● Bapung coal

petrography-based ternary model given by Mukhopadhyay (1986, Fig. 6) is taken into account. The samples of Bapung coals are located close to A corner of the plot, which is dominated by telovitrinite (telinite and collotelinite) and terrestrial liptinite indicating forest swamp has a more anoxic environment with good tissue preservation. This is further confirmed in a model proposed by Singh et al. (2012a), which is based on maceral composition and clastic mineral matter content. They have shown that the amount of clastic minerals directly relates to the water cover in the basin and the plots of Bapung coal indicates that this coal evolved under wet moor condition, having moderate flooding with moderate to good tissue preservation (Fig. 7).

Moreover, the Bapung coals are enriched in sulphur (3.58–5.03%; mean 4.31 wt.%), and elevated pyrite content is commonly seen under the microscope, indicating

the association of peat with brackish water conditions. Such association is reported by several workers (Bustin and Lowe 1987; Casagrande 1987). Dasgupta and Biswas (2000) reported the prevalence of a shallow brackish water condition during the deposition of the Barail Formation. This has been further substantiated by the studies on modern peats under the marine influence (Querol et al. 1989; Phillips et al. 1994). The field photographs of the Bapung area are placed in Fig. 8.

Conclusion

Based on the detailed geochemical and petrographic study, the following conclusions are drawn:

1. These coals have low ash (1.12 to 4.2%), low moisture (1.5 to 2.1%), and high volatile matter (40.02 to 45.25%).
2. The sulphur content (more than 3%) in the seams of the Bapung field is high, but there is no definite trend of variation of sulphur from the bottom to the top of the seam.
3. Bapung coals are sub-bituminous A to high volatile bituminous C in rank.
4. They are dominantly rich in vitrinite (mainly collotelinite—76.5 to 82.6%) with low contents of liptinite and subordinate/moderate inertinite.
5. A continuous wet condition prevailed in the basin as revealed by moderate gelification and tissue preservation indices.
6. Maceral-based ternary plots also support the prevalence of a wet moor environment having moderate flooding with bacterial activity. There was a marine influence

Fig. 8 Field photographs of Bapung coal seam

in the Bapung basin where pyrite framboids formed through bacterial activity.

Limitations

The carbon, hydrogen, nitrogen, and sulphur content of all the samples could not be determined because of the lack of instrumental facilities of high accuracy. Moreover, a reflectance study was not available, so it was hired for a limited number of samples analyzed. Again, a high-quality petrological microscope is required for a more accurate result.

Declarations

Conflict of interest The authors declare that they have no competing interests.

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