JOURNAL INDIAN ASSOCIATION OF SEDIMENTOLOGISTS ISSN NO 2582 – 2020
Vol. 41, Issue II, 2024, pp. 52 – 62
DOI: https://doi.org/10.51710/jias.v41iII.384

Tertiary Coal Deposits from the North-eastern Region of India – A review

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ABSTRACT

This review paper aims to provide a comprehensive account of the Tertiary coal resources of north-eastern region of India. The coal belt of North-East India developed in two different geo-tectonic settings – one is the foreland basin (Assam, Arunachal Pradesh, Nagaland Oligocene coals) and the other platform areas (Meghalayan Eocene coals). The rank of eastern Himalayan coals varies from sub-bituminous to high volatile bituminous C. The carbon content of Oligocene coal is much higher and show caking characteristics. The coals of this part of India have low ash (<8%), low moisture (<5%), high volatile matter (>40%), high sulphur (>3%), high hydrogen content (>4%), low nitrogen (<1%) and oxygen (<12%). Petrographically they are rich in vitrinite, moderate Liptinite and low inertinite. High concentrations of trace elements (like Cu, Cr and Ni) and sulphur content indicate marine influence in the depositional basin. In the north-eastern coals the dominance of typical Tertiary angiosphermic floral assemblage is well indicated by the occurrence of single, double and triple celled telutospores.

Keywords: Sulphur deposits, petrography, coal, India

INTRODUCTION

Coal is a naturally occurring fossil fuel that contributes immensely to the energy and power sectors. This fossil fuel is abundant and most important in India and other parts of the world like China, USA, Australia and Indonesia. It contributes about 37% and 73% of the global and Indian electricity supply (Indian Bureau of Mines, 2019) (Fig.1a and b). Indian coal resources belong to two principal stratigraphic horizons viz Permian sediments deposited in intra-cratonic lower Gondwana basins and Tertiary coal in near-shore basins and shelf having mainly peri-cratonic set-up. Major coal resource occurs within the Gondwana basins that are preferentially located in the eastern and southeastern parts of the country in the states of Jharkhand, Bihar, West Bengal, Odissa, Madhya Pradesh, Andhra Pradesh and Maharashtra (Kumar, 2022). Only a small portion of the total coal resources constitute the Tertiary coal of northeastern states of Assam, Arunachal Pradesh, Nagaland and Meghalaya (Fig. 2) (Kumar, 2022). However, Tertiary coal contribute (0.5%) meagre amount to the total coal reserve of India (1655.54 M.T., G.S.I, 2022). However, these coal resources are still important because they are quite far distant from the principal coal-producing zones of the country (in the extra-peninsular part). Hence these resources have a crucial role in meeting the local and regional coal demands of the north-eastern states of India. The Tertiary coals invariably have low ash content but high sulphur intimately intermingled with the coal. Industrial use of these coals is thus restricted as the latter causes deleterious effects on the furnace. The Geological Survey of India has provided detailed the stratigraphic sequences, structural elements and tectonic settings of North–East India in the year 1974, 1981, 1989, 1994 and 2009. The coal

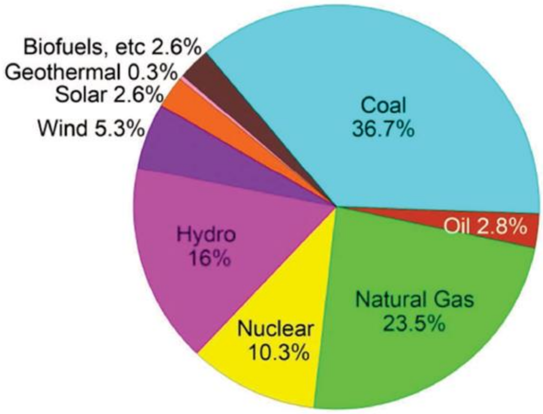

Fig. 1 (a): World Electricity Generation

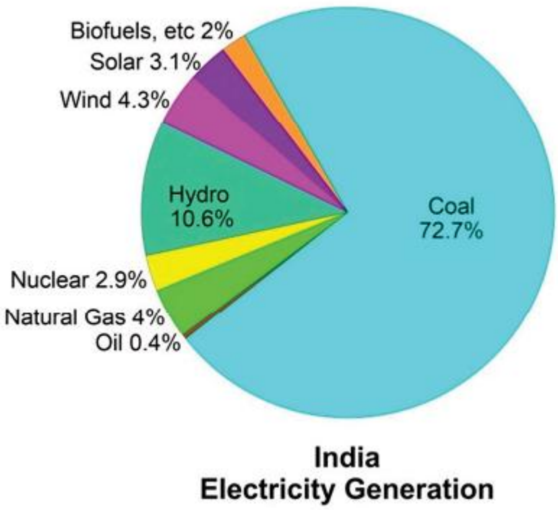

Fig. 1 (b): India Electricity Generation

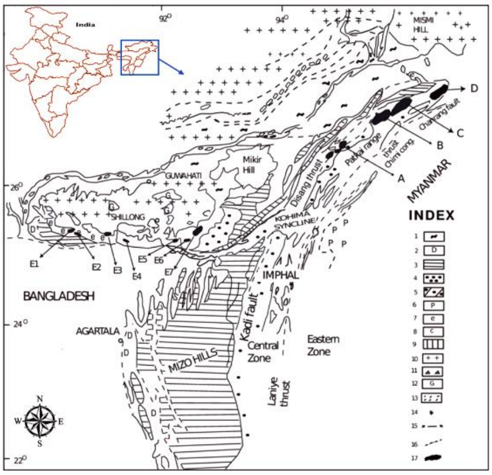

Fig. 2. Geological Map of Coalfields of North Eastern region of India modified after Singh and Singh 2022
1). Alluvium **2)**. Dihing and Dupi Tila Group **3).** Tipam and Surama Group **4).** Barail Group **5).** Undifferentiated Sandstone Group **6).** Pondaungs and Younger Sediments **7).** Jaintia and Disand Group **8).** Langpar and Mahadek Formation **9).** Lower Gondwana System **10).** Metamorphic and Igneous Rocks **11).** Granite **12).** Serpentine Intrusion Result **13).** Basalt **14).** Salt Springs **15).** Line Of Demarcation between High And Low Intensity Foldings **16).** Faults **17).** Coldfields [**A.)** Borjan Coalfield **B).** Dilli Jeypore Coldfield **C).** Makum Coldfield **D).** Namchik Namphuk Coalfield **E1).** West Daranggiri **E2).** Siju **E3).** Langrin **E4).** Mawlong-Shella **E5).** Cherrapunji **E6).** Laitryngew **E7).** Bapung)

resources of the North-Eastern Region of India have been studied by various authors from time to time concerning their geology, chemical and petrographic characteristics, trace elements, hydro-carbon generation potential and depositional set-up along with utilization potential (Ahmed, 1971; Ahmed and Bharali, 1983; Goswami, 1985; Singh, 1989; Mishra, 1991; Mishra, 1992; Chandra and Behera, 1992; Mukherjee et al., 1992; Ahmed and Rahim, 1996; Mishra and Ghosh, 1996; Rajanathnam et al., 1996; Ahmed and Phukan, 1999; Singh et al., 2000; Singh et al., 2003; Mukherjee and Srivastava, 2005; Singh et al., 2012; Singh et al., 2013; Nayek, 2013; Singh, 2015; Nath, 2017; Singh, 2018; Gogoi et al., 2020; Nath, 2021; Kumar et al., 2021; Nath et al., 2022; Adsul, 2024). Though the report of first occurrence of coal in North-East India made by Medlicott (1865) for Assam coals and Medlicott (1868) for Maghalaya coals followed by Mallet (1875), La Touche (1889), Bose (1904), Erans (1932), Fox (1934), Ghosh (1940; 1964), Goswami and Das (1965), Chakraborty and Bhatacharyya (1969), and Raja Rao (1981).

In this study, an attempt has been made to summarise and compile all the published papers in order to get an in-depth overview of the coal resources of the north-eastern part of India.

GEOLOGY OF THE PLATFORM AREAS

The Shillong Plateau, bordered by Brahmaputra lineament to the north, Dauki fault to the South, Naga-Disang thrust to the east and

Table 1. Geological succession of coalfields of Platform areas (Meghalaya) (modified after Raja Rao, 1981 and GSI, 2009)

Age	Group		Formation and member	Thickness (in m)	Lithology/Rock type	
Late Eocene			Kopoli	-	Ferruginous Sandstone, grey siltstone and shale	
Middle Eocene			Sylhet limestone: Prang limestone/Siju limestone	60 – 150	Bluish massive to thinly bedded limestone with marly interbands	
Early Eocene			Nurpuh sandstone	15 – 26	Coarse to medium grained ferruginous sandstone with bands of sandy limestone	
Early Eocene		SHELLA FORMATION	Umlatdoh limestone	70 – 110	Grey to pinkish grey limestone, sandy limestone and calcareous sandstone	TURA SANDSTONE
Early Eocene to Palaeocene	Jaintia Group		Lakadong sandstone	35 – 250	Predominantly buff coloured medium grained arkosic sandstone with thin grey and carbonaceous shale and coal seams	
Early Eocene to Paleocene			Lakadong limestone	25 – 60	Grey to brownish grey limestone, siliceous limestone	
Early Eocene to Paleocene			Therria sandstone	20 – 80	Buff colured medium to coarse grained arkosic sandstone with thin hands of yritic rich silty sandstone	
Late Cretaceous (Danian)			Langpar	10 – 50	Buff coloured calcareous-ferruginous sandstones, earthy limestones etc.	
Late Cretaceous (Maastrichtian)			Mahadek	160 – 335	Massive coarse grained glauconitic sandstones containing dark grey shales and calcareous horizons	
Jurassic to Early Cretaceous			Sylhet Trap	250 – 400	Aa and pahoehoe type basalts	

Dhubri-Yamuna lineament to the west, represents the Precambrian cratonic – the extension of which goes up to Shillong Plateau of NE India. The Plateau is tectonically sensitive and seismically very active due to continued north-north-eastward counter clockwise movement of the Indian plate producing severe compression tectonics. (*Harijan et al., 2003; Ramesh et al. 2005*)

The platform areas developed in the Shillong Plateau of Meghalaya, where Eocene-age coal deposits were deposited in the peripheral margins. During the cretaceous period, this shield got uplifted to form host structure and finally the plateau formed because of its peneplanation. Later on along the peripheral region of the Plateau, deposition of coal took place. The lateral variation of lithofacies occurred because of the sediments deposited on the shallow marine shelf, which extended as an embayment. The stratigraphic succession of the coalfields of Meghalaya is presented in Table-1 (after Raja Rao, 1981). The principal coal-bearing formation of Garo Hill is the Tura Formation of the Jaintia Group while in Khasi (both East and West) & Jaintia (East) Hills the coal-bearing horizon occurs in the Lakadong Sandstone Member of the Shella Formation of Jaintia Group which was developed because of intermittent transgression & regressions of during Eocene times. The oldest rock encountered in the platform area is the Sylhet trap which forms the basement of Cretaceous-Tertiary sedimentation.

GEOLOGY OF THE ZONE OF SCHUPPEN (FOREDEEP BASIN)

In pericratonic down warps in the 'belt of schuppen' over the northern flank of Naga-Patkai range the Oligocene coal deposits occur and spread over the states of Upper Assam, Arunachal Pradesh and Nagaland (Evan, 1932; Biswas et al., 1994; Mishra and Ghosh, 1996; Srivastava et al., 2004). Dasgupta and Biswas (2000) observed that shallow brackish water condition prevailed during the Oligocene period when the stratigraphic formation of Barail took place. Arranged in imbricately along the Naga Hills the belt of Schuppen has been characterised by a series of at least eight complex thrust faults. To the foreland ridges the Naga Hills have moved towards north-west by fault activity. Extending from Nagaland through Assam up to Arunachal Pradesh (with thick coal seams) developed large molasses basins during Oligocene-Miocene times. Large-scale, open, upright folds have occurred due to vertical block movements eventually forming the major thrust faults. In the flanks of trough of the Indo-Burmese range a thick sequence (2-6 km) of Tertiary sediments has accumulated which was deposited in deltaic facies. Makum and Namchik-Namphuk coalfield encloses the northern part of the belt where coal seams are thick (18 m in Makum coalfield) whereas the southern part of belt includes Dilli-Jeypore of Assam, Borjan and Tiru Valley of Nagaland and also includes some minor coalfields where the thickness of coal seams are of 1.5 m. The stratigraphic succession of coalfields of the foreland basin is shown in Table-2 (after Raja Rao, 1981). Here principal coal-bearing sequence is the Tikak Parbat Formation (alternate bands of sandstone, sandy shale and coal seam) of the Barail Group of the Oligocene age. The Barail group is underlain by Disang group. In the Barail group lower Naogaon formation also developed in Makum, Dilli-Joypore of Assam, Borjan, Tiru Valley of Nagaland and Namchik-Namphuk of Arunachal Pradesh. Above Barail Group lies Tipam Group. Tipam Group of rocks also developed in Dilli-Joypore, Namchik-Namphuk, Borjan and Tiru valley coalfields. Above Tipam lies Namang Formation and at the top is Dihing.

DISTRIBUTION PATTERN OF TERTIARY COALS

The Tertiary coal measures of the north-eastern region of India are unevenly distributed in the four states of Assam, Arunachal Pradesh, Nagaland and Meghalaya which enclose 67

Table 2. Geological succession of coalfields of zone of Schuppen (Assam, Arunachal Pradesh, Nagaland) (modified after Raja Rao, 1981)

Age	Group & Formation	Thickness	Rock Types
Pliocene	Dihing Group	1800 m	Mostly pebbly sandstone with thin greyish clay beds
	…………… Unconformity ………………..		
Mio-Pliocene	Namsang Formation	800 m	Fine to coarse grained sandstone with bands of clay
	…………… Unconformity ………………..		
Miocene	Tipam Group (i) Girujan Clay (ii) Tipam Sandstone	 1800 m 2300 m	 Mottled clay with greyish soft sandstone Ferruginous, fine to coarse grained micaceous to felspathic sandstone
	…………… Unconformity ………………..		
Oligocene	Barail Group (i) Tikak Parbat Formation (ii) Baragolai Formation (iii) Naogaon Formation	 600 m 3500 m 200 m	Greyish to yellowish sandstone, sandy shale, coal seams. Greyish to bluish grey or yellowish red mudstone, shale, sandstone, carbonaceous shale and thin coal seam Compact, fine grained, dark grey sandstone with bands of splintery shale
Eocene	Disang Group	3000 m	Splintery dark grey shales and thin sandstone interbands

individual minor to moderate coal deposits (Mishra and Ghosh, 1996). The coal belts in this region are sub-divided into two areas viz. (i) coalfields of upper Assam, Arunachal Pradesh, Nagaland and (ii) coalfields of central and lower Assam comprising the coal measures of Karbi-Anglong and Meghalaya.

Tertiary coal formed near marine milieu like estuarine, lagoonal or deltaic environments. The migration of marine pump related to transgressive and regressive events controlled the development of coal swamps and the formation of coal deposits. The coal belts of Garo, Khasi and Jaintia Hills of Meghalaya and Mikir Hills of Assam occur within the Early Eocene sediment package. They generally formed thin, splitting and pinching coal seams in the coastal parts of the shelf zone of the early Eocene sea, close to the peripheries of and over the Meghalaya-Assam crystalline massif. On the other hand, the coal deposits of Upper Assam, in Makum, Dilli-Jeypore coalfields and those of adjacent Nagaland and Arunachal Pradesh were formed within the Barail Group during the Oligocene in the peri-cratonic molassic basins. In the Assam shelf, the locally thick Barail coal seams are disposed of as lenses because of close interaction of fluvial, lagoonal and shallow marine environments. The molasse basin slowly and was flanked by the rising Indo-Burma ranges. The Barail sediments along this belt develop persistent thick coal seams. These were later unconformably superposed by the Neogene sediments and were subsequently affected by folding and thrusting. They occur now at the floor of several often-anastomosing thrust slices that cut through the overlying Neogene mollasse sequence within the "belt of schuppen".

The most important coalfields in these areas where exploitation or prospecting of coals carried out/going on are shown in Table 3 and Table 4.

CHARACTERISTICS OF TERTIARY COAL

The coals from the 'Zone of Schuppen' and 'Platform areas' are non-bonded and bright with humic components strongly decomposed Megascopically the north-eastern coals are soft, friable, dark black and highly vitrain-rich and exhibit sub-conchoidal to conchoidal fracture and on weathering they break parallel to bedding plane. The coals show greasy to vitreous lustre. These coals also show cleat. Pyrite is the dominant mineral in those coals as bleds, nodules, veins and specks. The coal seams of Meghalaya are relatively thin (0.3 – 2.0 m) because of the development of encroachment of fast shifting of distributary channels over swamp abating the development of peat (Raja Rao, 1981). The coal seams are sometimes characterised by pinching and swelling character.

Both Eocene and Oligocene coals are chemically almost the same but the only difference is that Eocene coals are slightly less mature (Mishra and Ghosh, 1996). Coals of both areas are low in moisture (<5%), low ash (<8%) but volatile matter is quite high (>40% average). Oligocene coals average carbon content (74% to 83%) is higher than the Eocene coals (67% to 78%). The north-eastern coals are generally non-caking based on carbon and volatile matter content. However, coals from Makum of upper Assam and Namchik-Namphuk of Arunachal Pradesh show strong swelling index ranging from 3 to 9 (Ghosh & Mishra, 1996). Coals of this region vary from sub-bituminous type C to high volatile bituminous type C in rank as per German (DIN) and North American clarification (Singh et al 2000, 2013) based on vitrinite reflectance and volatile matter. As per Seyler's diagram, the coals of Meghalaya fall within the 'Ortholignitous' to 'para-bituminous' rank (Singh, 2018).

The north-eastern coals have higher sulphur content (generally > 3%) which even reaches upto 7% (Nath, 2021). All forms of sulphur-sulphate, pyritic and organic sulphur are recognised where organic sulphur (>80%) predominates the other forms of sulphur. Chandra et. al. (1983) observed that coals of Meghalaya show an increasing sulphur content from bottom to the top of

Table 3. Coalfields of platform areas of Meghalaya of Northeastern region of India

A. East Jaintia Hills (latitude $25^0 10'$ – $25^0 28'$N and longitude $92^0 08'$ – $92^0 33'$ 30" E)

1. Bapung
2. Sutunga
3. Jarain – Tkentalang
4. Lakadong
5. Mutang
6. Loksi
7. Umlatdoh
8. Musiang Lamare

B. Khasi Hills (latitudes 25^0 10' – 25^0 42' N and longitudes 91^0 40' – 91^0 55' E)

1. Langrin
2. Umrileng
3. Mawsynram
4. Mawlong – Shella – Isamati
5. Cherrapunji – Mawkma – Laitryngew
6. Mawpholong
7. Pynursla – Lyngkyrdn – Thangjinath
8. Lundidom
9. Laitduh
10. Mawbehlarkar

C. Garo Hills (latitudes 25^0 12' – 25^0 44' N and longitudes 89^0 58' – 90^0 58' E)

1. West Daranggiri
2. East Daranggiri
3. Siju
4. Karaibari
5. Rongrenggiri
6. Balphakram – Pendengru

the seam. They opined that pH values decreased with depth and alkalinity increased from the bottom to the top, thereby bringing highest sulphur content at the top of a sequence because the alkaline condition is conducive to sulphide deposition. Again Chandra et al. (1983) observed that a gradual increase in the total sulphur content from west to east in the coals of Meghalaya within the basin of deposition is due to the increasing marine influence of the peat forming swamps of Khasi and Jaintia Hills (i.e. Langrin, Bapung coalfields) in the eastern part of the Meghalaya as compared to the Garo Hills in the West (West Daranggiri, Siju coalfields). The total sulphur content of Tiru Valley of Nagaland even reaches upto 11% (Sing et al., 2012) which places them as super high organic sulphur (SHOS) (as per Chou classification, 2012, 1990). Many researchers like Ahmed et al. (1981, 1985, 1992, 1996), Gogoi et al. (2020) Nath (2021) have shed light on the distribution/abundance of sulphur of north-eastern coal. Saikia et al. (2014) studied the geochemistry and nano-mineralogical studies of medium sulphur coals of Assam whereas Choudhury et al. (2016) contributed on the multi-analytical study on sulphur components in some sulphur-rich Assam coals.

These coals have relatively less oxygen (< 12% average) because of the replacement of oxygen by sulphur (Lahiri, 1965). The hydrogen content is high (>5%). The nitrogen content is quite low (< 2%) in all the coals of the belt.

Mukherjee et al. (1992) studied the geochemistry of trace elements of Tertiary coals of North-East India. The concentration of trace elements (in ppm) of west Daranggiri, Siju and Langrin coals of Meghalaya are Ge → 229 to 395, less than 5, Ni → 42 to 64, 20 to 40, 20 – 90, Co → 25 to 51, 15 to 25, less than 10 to 80, Cu → 23, 5 to 80, 25 to 800, Pb → 110 to 280, less than 5 to 50, less than 10 to 24, Mo → less than 5 to 13, less than 5, less than 5 to 15, Zr → 57 to 88, 60 to 70, 80 to 115, Mn → 290 to 483, 90 to 200, 180 to 400, Cr → 66 to 106, 40 to 150, 70 to 130, Ba → 147 to 162, 30 to 400, 60 to 118, Ga → 7 to 14, less than 10 to 15, less than 10 to 63, V → 25 to 66, 40 to 500, 30 to 200, Sr → 105 to 120, less than 10 to 150, 70 to 373 respectively. Here germanium (Ge) concentration is significantly higher (229 to 395) in West Daranggiri coals and lesser in Siju and Largin coals (less than 5). Maximum concentration of Mn in all the coalfields suggest possible association of organic matter. The high Cu, Ni and V concentration in Langrin coals show affinity with organic matter. Upward increase (from bottom to top seam) of elements such as Pb, Mn and V further suggest the conformity of increase of sulphur content from bottom to top seam as per Chandra et al. (1983) because the alkaline condition is favourable to the deposition of sulphide. Again Chandra et.al (1983)'s observation of the increase of sulphur content from the western to the eastern part of Meghalaya is corroborated by the accumulation trend of Cu (80 to 800 ppm), Zr (88 to 115 ppm), Sr (150 to 373 ppm) which also suggest marine environment contributed to the deposition of Lithophile (Zr) and Chalcophile (Cu and Zn) elements.

In case of Assam Oligocene coals the concentration of trace elements in ppm of Makum and Dilli – Jeypore coalfields are Ge → 69 to 72, 40 to 60, Ni → 504 to 754, 120 to 450, Co → 18 to 77, 150 to 450, Cu → 948 to 1264, 150 to 400, Zr → 126 to 174, 80 to 250, Mn → not detected, negligible, Cr → 1169 to 1641, 300 to 1000, Ba → 783 to 1110, 400 to 700, V → 209 to 533, 200 to 600, Y → 22, less than 20 to 50, La → nil, less than 30, Nb → not detected, 150 to 450, Pb → 82 to 198, 30 to 110 (Mukerjee et al., 1992).

Here Mn is negligible and not even detected in Makum coal and Ge is also very less in both coals. Nb concentration is higher in Dilli-Jeypore coals and not detected in Makum coals. The high concentration of Cu, Ni, Cr, V strongly suggest their association with the organic fraction of the coal and also indicate marine influence in the depositional basin because these elements are more abundant in marine water (Nichols, 1968). Also, this

Table-4 Coalfields of Foredeep basins of northeastern region of India

Assam:
1. Makum coalfield (five coal seams recorded in this area. These are 5 ft. seams, 8 ft. seams, 20 ft. seams, 60 ft. seams and new seam. Only 20 ft. and 60 ft. seam is persistent throughout the area).
2. Dilli – Jeypore

Arunachal Pradesh:

(Eight persistent coal seams ranging in thickness from 1 to 17.4 m)
1. Namchik – Namphuk (latitudes 27^0 18' and 27^0 28' N and longitudes 95^0 58' and 96^0 14' E) – eastern part of the Tirap district and is the extension of Makum coalfield of Assam.

Nagaland:
1. Borjan (2 seams)
2. Tiru valley (1 seam)
3. Moulong Kimong (latitude $26^0$19'7'N; longitude 94^0 30'44''7'E)

high value indicates that Oligocene Assam coals are significantly different from those of Eocene Meghalayan coals.

The reflectance of Oligocene and Eocene coal varies from 0.53% to 0.74% and 0.37% to 0.67% respectively, indicating that Oligocene coals are of deeper burial (Ghosh and Mishra, 1996).

Petrological studies made by various workers like Lahiri and Bhattacharya (1961), Ahmed and Bharali (1983), Goswami (1985), Ahmed and Rahim (1996), Singh (1989), Mishra (1992), Chandra and Behra (1992), Mishra and Ghosh (1996), Rajaratham et al. (1996), Singh and Singh (2000), Pareek (2004), Singh et al. (2012), Singh et al. (2013). Sharma et al. (2016), Gogoi et al. (2020), Nath et al. (2021), Kumar et al. (2022), Nath (2022), and Adsul et al. (2022) on the north-eastern coal show that they are rich in vitrinite with moderately high concentration of Liptinite and low inertinite. The mineral matter content is also quite high. Singh et al. (2006) also suggested a proposal for the distribution of pyrite of Tertiary coals of Northeast India.

The details of micro-petrographic characteristic of both Oligocene and Oligocene coal are given below:

COAL FROM THE SCHUPPEN ZONE NORTH-EAST INDIA

Singh et al. (2013, 2012) studied the coal deposits of Makum, Dilli Jeypore of upper Assam, Nanchik – Namphuk of Arunachal Pradesh, Borjan and Tiru Valley of Nagaland. Makum coals are rich in vitrinite which ranges from 81.7 to 94.7 vol. % (84.6 to 96.6 vol. % mmf basis) while Liptinite and inertinite content varies from 2.6 to 14.4 vol. % (2.7 to 14.9 vol. % mmf basis), 0.4 to 2.2 vol. % (0.4 to 3.3 vol. % mmf basis). In Dilli-Jeypore coal vitrinite, Liptinite and inertinite ranges from 71.4 to 95.2 vol. % (81.7 to 95.8 vol. % mmf basis), 2.9 to 12.7 vol. % (3.1 to 15.7 vol. % mmf basis), 0.1 to 3.1 vol. % (0.1 to 3.3 vol. % mmf basis), respectively. In Namchik-Namphuk coals vitrinite, Liptinite, inertinite varies from 41.3 to 77.3 vol. % (68.8 to 84.4 vol. % mmf basis), 13.9 – 32.9 vol. % (15.9 – 35.4 vol. % mmf basis), nil to 1.4 vol. % (nil to 1.5 vol. % mmf basis). In Borjan coals vitrinite, Liptinite, inertinite content spreads from 53.2 to 81.4 vol. % *0.6 to 89.7 vol. % mmf basis), 8.5 to 16.1 vol. % (9.3 to 21.8 vol. % mmf basis), nil to 1.3 vol. % (nil to 1.6 vol. % mmf basis). In Tiru Valley coals the macerals are varies from 95 to 99 vol. %, 1 to 3 vol. %, nil to 2 vol. %.

In vitrinite group the identified macerals are collotelinite, gelinite, corpogelinite, collodetrinite, dark-vitrinite and phlobaphinite in all coals of foreland basins. Amongst them collotelinite predominates the other form while telinite is rare but occurs with well-preserved cell structure in all the coals while gelinite is absent in Arunachal and Nagaland coals, collodetrinite absent in Arunachal Pradesh coals. Vitrodetrinite, pseudovitrinite and phlobaphinite are absent in upper Assam coals and phlobaphinite is absent only in Arunachal Pradesh coals.

In Liptinite group identified macerals are sporinite, cutinite, resinite, suberinite, alginite, butuminite, fluorinite, exsudatinite, liptodetrinite. Resinite is the most dominant Liptinite maceral in these coals.

Inertinite macerals are fusinite, semi-fusinite, macrinite, funginite, interto detrinite. Fusinite, semifusinite with well preserved and less preserved cell structure found only in Dilli-Jeypore coals of upper Assam. Macrinite occurs as fine particulate matter in the form of lenses found only in upper Assam coals. Funginite is the most common maceral in these coals. Inertodetrinite derived from crushing of teleutospores are only seen in Dilli-Joypore coals.

Observed mineral matter varies from 0.9 – 9.2 vol. % (3.26 vol. % average), 0.7 – 13.5 vol. %. (3.88 vol. % average), 4.8 – 38.8 vol% (18.5 vol. % average), 9.2 to 37.9 vol. % (23.55 average), 1-86% (19.55 vol. % average) in upper Assam, Arunachal Pradesh and Nagaland coal deposits. Observed mineral matter in these coals are clay, carbonate and sulphides of which clay dominance the other. As ground mass both clay mineral and carbonates occur and also as fissure, crack, cleat filings, strings and fissure fillings. Pyrite is classified here as framboidal, disseminate, cavity and fisher filling, massive, discrete grain of which framboidal is the dominant form. Vitrite is the dominant microlithotype in these coals.

Further Singh et al (2012) observed that high GI and TIP values suggest peat growth under telmatic conditions with prolonged wet conditions and high tree density. Highly gelified peat results from high GI indicates a continuous influx of calcium-rich waters in the swamp. The value of GWI and VI also indicates that the peat formed in bog forest under mesotrophic to ombotrophic hydrological conditions.

COALS OF MEGHALAYA (PLATFORM BASIN), NORTH EAST INDIA

Singh et.al (2000) studied in detail the coal deposits of the three Hills of Meghalaya (Garo, Khasi and Jaintia). The analysed major coalfields are west Daraggiri, Siju of Garo Hills, Langrin, Mawlang – Shella of Khasi Hills while minor coal fields include Cherrapungi, Laitryangew (Khasi Hills) and Bapung (Jaintia Hills)

GARO HILLS

Daranggiri coals are rich in vitrinite which, ranging from 20.9 to 69.6 vol. % (56.8 to 86.6 vol. % mmf basis). Collotellinite is the dominant maceral in this group while telinite is absent in this coal while other macerals are gelinite, corpogelinite, collodetrinite, dark vitrinite and vitro-detrinite. The frequency distribution of Liptinite and inertinite macerals are 9.1 – 22.2 vol. % (13.0 to 36.7 vol. % mmf basis), 0.2 – 4.6 vol. % (0.4 to 7.4 vol. % mmf basis). The identified macerals are sporinite, cutinite, resinite, suberinite, alginite, bituminite, fluorinite, exsudatinite, liptodetrinite (tiptinites) where resinite is the dominant one. Inertinite includes fusinite, semifusinite and inertodetrinite while sclerotinite and macrinite are not observed here. Mineral matter (MM) varies from 7.7 to 66.5 vol. % (46.8 vol. % mean values). Among MM, clay minerals dominate the other sulphide and carbonate minerals. Both clay & carbonate minerals occur as ground mass plus cracks, cleats, fishers, cell fillings. The dominant sulphide mineral is pyrite.

The Siju coals the vitrinite, Liptinite, inertinite and mineral matter varies from 29.2 to 58.2 vol. % (59.9 to 80.6 vol. % mmf basis), 7.5 – 27.2 vol% (14.2 to 35.2 vol. % mmf basis), 1.2 – 6.6 vol. % (1.9 to 9.4 vol. % mmf basis), 23.4 – 50.2 vol% (37.3 vol. % average). All the macerals like Daranggiri coals are present here.

KHASI HILLS

The frequency distribution of maceral and mineral matter composition of Langrin, Mawlong-Shella,Cherrapunji and Laitryngew coals are vitrinite – 19.6 to 78.0 vol% (45.0 to 87.5 vol. % mmf basis), 48.5 to 97.9 (65.7 to 2.9 vol. % mmf basis), 56.9 to 71.8 (68.3 to 79.5 vol. % mmf basis), 51.7 to 83.1 (62.4 to 86.3 vol. % mmf basis), Liptinite – 6.2 to 27.5 (11.8 to 53.1 vol. % mmf basis), 5.4 to 24.8 (5.5 to 32.4 vol. % mmf basis), 9.1 to 23.0 (9.1 to 23.0 vol. % mmf basis), 8.8 to 27.5 (9.1 to 31.7 vol. % mmf basis), interdinite – nil to 13.1 (0.0 to 13.8 vol. % mmf basis), nil to 3.7 (0.0 to 4.1 vol. % mmf basis), 2.2 to 5.9 (2.2 to 5.9 vol. % mmf basis), 1.3 to 5.7 (1.4 to 6.6 vol. % mmf basis) and mineral matter – 2.8 to 67.6 vol% (34.7 vol. % mean values), 1.9 to 27.8 vol% (15.2 vol. % mean values), 10.0 to 26.9 vol% (16.4 vol. % mean values), 3.6 to 30.8 vol. % (17.4 vol. % mean values). The identified macerals of vitrinite group are collotelinite (dominant) followed by gelinite, corpogelinite, collodetrinite, pseudoritrinite, dark vitrinite, vitrodetrinite. Telinite is rare while gelinite is absent in Laitrygew coal. In Liptinite group the macerls found are sporinite, cutinite, resinite, suberinite, alginite, liptodetrinite (structured) bituminite, fluorinate and exsudatinite (secondary). Amongst Liptinite resinite is the dominant maceral which occurs in oral to spherical or elliptical shape. Cutinite occurs as thread-like bodies. Inertinite group includes fusinite, semifusinite, sclerotinite, macrinite, inertodetrinite. Fusinite is characterized by well-preserved cell structure and sometimes showing bogan structure. Rounded to oval bodies of macrinite have been observed only in Langrin coal. In these coals, visible mineral matters are clay, carbonate and sulphide while clay is the dominant mineral. Clay minerals occurs as groundmass alongwith fissure, crack, cleat and cell infillings of fusinite, semifusinite and sclerotinite. Carbonate minerals also appear as ground mass, as stringers, as fissure fillings. The sulphide in the form of pyrite occurs as disseminated, blebs, discrete grains, framboidal bodies, massive replacement and fissure fillings.

JAINTIA HILLS

The frequency distribution of maceral and mineral matter composition (in vol%) of Bapung coals (which includes Sutunga, Jarain, Musiang, Lamare, Loksi, Khliehriat) are vitrinite – 49.4 to 68.4 vol. % (71.2 to 81.1 vol. % mmf basis), Liptinite – 10.9 to 23.5 vol. % (17.8 to 27.5 vol. % mmf basis), inertinite – 0.3 to 1.2 vol. % (10.3 to 1.7 vol. % mmf basis), mineral matter – 14.6 to 38.6 vol. % (23.6 vol% mean values). Here all the maceral groups are observed with collotellinite being the dominant maceral in the vitrinite group. Collodetrinite in the vitrinite group, bituminite and fluorinite in Liptinite group, fusinite, semifusimite, selerotinite, macrinite, inertodetrinite are absent here. Nayak (2013) studied the mineral matter and nature of pyrite of these coals and observed that the minerals in these coals are sulphide (pyrite, marcacite), sulphates, oxides, hydroxides, phosphate, carbonate, silicates and kaolinitic clay. The disulphides occur in 2 modes like pyrite and occasionally marcasite and in various forms like framboids, colloidal precipitate, colloform banded, fine dissemination, discreate grains, dendritic (feathery), recrystallized, nuggests, discoidal, massive, cavity-fracture and cleat-fillings. In the early stages of coalification framboidal pyrite has formed primarily due to biological activities of sulphur reducing bacteria. He found from sulphur isotopic values that pyrites are of biogenic origin.

In Meghalayan coals common occurrence of one, two and three-celled teleutospore in collotelinite corroborates the view that these coals have evolved from angiospermic floral assemblages. Further Singh et al. (2000), plotted microlithotypes in the double diamond diagram of Hacquebard and Donaldson (1969) suggesting that these coals have evolved from wet forest moor, reed moor and open moor facies. The Khasi and Jaintia Hills coals plot in the forest moor facies of the telmatic to limnotelmatic zones, while the coals of Garo Hills plot mainly in the open moor and need moor facies of the telmatic and limmic zones. To corroborate this by plotting in the Diessel (1986) facies model of GI and TIP, these coals show high GI and high TPI values that evolved under telmatic conditions with high tree density under prolonged wet conditions. Also, abundance of microlithotype strongly suggests that during pet formation wet condition prevails. A constant influx of calcium-rich water into the coal swamps occur because of high GI. The decomposition of organic matter & formation of humates accelerate because of the high concentration of calcium ions. Marine-influenced coals have this typical property. Further Singh et.al opined that terpene type primary resins (in high concentration) of very large dimensions suggest abundant growth of conifers in the basin & temperate climatic conditions during the evolution of these coals.

Singh et al. (2001) observed that north-eastern coals are oil-prone where H/C>0.8. Also, Gogoi et al. (2008, 2020), Nath (2022, 2023) based on geochemical and rock eval investigation indicate they contain type II kerogen and grade to mixed kerogen (type II/III), with mainly gaseous hydrocarbons potential and few amounts of liquid hydrocarbon generation. The source rock is good for hydrocarbon generation in these coals.

POTENTIAL UTILIZATION OF TERTIARY COALS

The Tertiary coals of North-Eastern states are generally very low in ash which can be used as blends and per hydrous in nature. Besides their normal use as fuels for general industries they are ideally suitable for direct hydrogenation for the production of synthetic oil on which the coals of upper Assam have a major role. In spite of their high sulphur content, these coals are profitably used (10% even more) as blends in metallurgical coke making and for the production of Ferro-Silicon. Due to high percentage of sulphur these coals also best utilized for cement manufacturing (presently going on in Meghalayan cement industries). Most of these coals are used in brick industries, domestic fuel and also exported to Bangladesh. The high volatile matter concentration and hydrogen content make its suitable for liquefaction and garification. (Singh, 2018) which was initiated by CSIR, Jorhat where it showed that 80-90% of the coal can be liquefied despite the hurdles of sulphur (Lahiri, 1965). High sulphur Tertiary coal has wide scope of utilisation in fertiliser industry. They are good source rock for hydrocarbon generation (Gogoi et al., 2008; Gogoi et al., 2020; Nath et al., 2023). The desulphurization of this coal with bacterial biomass was initiated recently and if it comes out successful then these coals will be a real asset for the people of north-eastern India. Though desulphurization techniques of (Sakia et al., 2014) showed that the organic sulphur content of coal could be removed which generally intermingled with coal.

Among the Tertiary coal deposits, the Makum coals of Assam, Namchik-Namphuk coals of Arunachal Pradesh and Bapung and Langrin coals of Meghalaya are the most potential.

CONCLUSIONS

1. The coals of Meghalaya (Eocene age) formed in platform areas whereas coals of Assam, Arunachal Pradesh and Nagaland (Oligocene age) formed in foredeep basins in the eastern part of Himalaya.
2. The north-eastern coals have low moisture, low ash, high volatile matter, high sulphur (mostly organic), high carbon, high hydrogen, low nitrogen and low oxygen chemically whereas petrographically they have high vitrinite, moderately high content of Liptinite and low inertinite. The mineral matter represented by clay minerals, sulphides and carbonates are also quite high.
3. In the Eocene and Oligocene coals of north-eastern India, the concentration and distribution of trace elements (Ge, Ni, Co, Cu, Pb, Mo, Mn, etc.) indicate marine conditions/or inclusion which is corroborated with high content of sulphur.
4. Coals of this region range from sub-bituminous type C to high volatile bituminous type C in rank.
5. Meghalaya (Platform basin) coal-bearing sequence indicates intermittent transgression and regression during Eocene. Further occurrence of single, double and three-celled teleutospores suggests mangrove-rich angiosperm that grew in tropical humid climate and the presence of large resins suggests growth of conifers. In the eastern Himalayan foreland coal basin due to the regression of sea prograding delta emerged and subsequently grew of angiospermic flora in dominance, which occurred in the form of coal-bearing sequences. In mesotrophic to ombrotropic hydrological conditions bog forest developed here.
6. The high sulphur content (>3% and reaching up to 12%) of north-eastern coal suggest for further research regarding desulphurization whereby it can be utilized in a better way for industrial purpose in near future.

DECLARATION OF CONFLICTING INTEREST

The author declares no competing interest

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Received on: July 9, 2024
Revised accepted on: Sept 28, 2024