J. Asiat. Soc. Bangladesh, Sci. **49**(1): 101-119, June 2023 DOI: https://doi.org/10.3329/jasbs.v49i1.67599

A PALEO-BIOCLIMATOLOGICAL STUDY ON GONDWANA COAL DEPOSITS IN NORTHWESTERN BANGLADESH AND THE ASSOCIATED ENVIRONMENT REFLECTED BY POLLEN AND GEOCHEMICAL ANALYSIS

SONJITA SINGH AND SUBROTA KUMAR SAHA*

Department of Geology, University of Dhaka, Dhaka, Bangladesh

Abstract

To comprehend the realistic paleo-bioclimate and depositional environment, we need to clearly grasp the methods that can be used to track paleoclimate in the past. The present research has focused on palynological investigation, X-ray Diffraction analysis, and elemental analysis of the core coal samples of the Gondwana coal of the Barapukuria Basin. The palynological study identifies two Palynoassemblage zones (Zone I and Zone II). A non-striate desiccate *Scheuringipollenite, Crucisaccites, Parasaccites* palynoassemblages are identified as Zone I and denotes as Lower Barakar Palynozone in the Early Permian where Zone II is dominated by striate desiccate *Barakarites, Faunipollenites, Callumispora* Palynoassemblages in the Late Permian. The Glossopterid plant family ruled the botanical affinity of Zone I and Zone II. It rendered the Gymnosperm group of plants as the rapid deglaciation assisted dissemination of Glossopteris flora. Higher percentages of clay minerals in X-ray diffraction (XRD) analysis and higher amounts of carbon content, lower sulfur, and higher C/S>10 ratio in the elemental analysis have been identified. All evidence from the research suggests that coals were deposited when glaciers retreated in the Early Permian, and the Gymnosperm group of plants prevailed and accumulated in the warm and humid climatic conditions under the braided fluvial influence in the terrestrial environment.

Keywords: Palynoassemblages, Paleo-bioclimatology, Gymnosperm, Terrestrial Environment, X-ray diffraction (XRD) analysis, Elemental (CHNS) analysis.

Introduction

The name Gondwanaland was introduced by E-Suess (Fox, 1931) for the southern supercontinent. The name Gondwana in itself is self-explanatory. It reflects the historical geographic locality in the Indian sub-continent. Gondwana sediments are one of the world's most important coal-bearing sequences. The actual storage of coal is located in the Gondwana supergroup of rocks, ranging in age from Early Permian to Early Cretaceous (Hossain, 2016). The sedimentation in Gondwana Basin was controlled mainly by sedimentary tectonics, as these shallow basins were being- filled by the incoming sediments, and along with these sediments, the vegetal matter in very large

*Corresponding author: sks@du.ac.bd

quantities was also transported to the basin of deposition, which has later transformed into coal under favorable conditions. India’s Gondwana sequence is notable for its abundant plant fossils, Palynomorphs, leaves, roots, and seeds are all examples of palynomorphs (Tewari, 1991; Bajpai and Singh, 1986; Rajinikanth and Parakash, 1994) examined Permian megaspores in Indian in depth from several sedimentary basins. Barakar formation represents one of the most coal-bearing litho units in the Gondwana sequence.

In changing energy infrastructure, coal will play an important role in Bangladesh, particularly coal in the country's northwestern region (Imam, 2006). Coal fields in Bangladesh are demarcated in the Bogra shelf and Rangpur saddle area of the Stable platform and have a geological connection with coal fields in the Assam and Raniganj areas of West Bengal. Coal fields in Bangladesh mainly belong to Gondwana coal of the Permian age (Imam, 2006). In Bangladesh, the Gondwana deposits are identified in the Kuchma, Jamalganj, Barapukuria, Khalaspir, Singra, Phulbaria, Dighipara, and Burirdoba Basin (Uddin and Islam, 1992; Hossain *et al*., 2002).

Bangladesh's most notable and well-researched sedimentary deposits are only found in these basins and are part of the Barapukuria Gondwana succession. The Barapukuria coalfield, one of Bangladesh's largest coalfields, was discovered in 1985 in the drill hole GDH-38 in Dinajpur District by the GSB (Geological Survey of Bangladesh) (Imam, 2006). The Barapukuria coal basin is a half-graben type asymmetric cratonic basin located in the tectonic unit of the Rangpur saddle of the stable platform in the northwestern region of Bangladesh. It is surrounded in the east by a large fault known as the Eastern Boundary Fault (Hossain, 2016; Imam, 2006). There are several structural and sedimentological studies on the Gondwana sequence of the Barapukuria coal field (Islam *et al.*, 1987; Wardell Armstrong, 1991; Islam *et al.*, 1992; Uddin and Islam, 1992; Islam and Hossain, 2006; Farhaduzzaman *et al*., 2012), but no systematic palynological, mineralogical research has been documented from the basin so far.

Palynological investigation of borehole GDH-42 from Barapukuria Basin Bangladesh closely resembles the palynoflora described from Barakar formation in Raniganj, India. A good number of monosaccate genera at this level also strengthens its placement in the basal part of the Barakar Formation. The floristic research also reveals evidence of distinct plant fossil distributions in different Barapukuria Basin coal seams. The climatic variation in the Barapukuria sequence is also strongly associated with the Gondwana successions of Raniganj, India, and records climatic oscillations and the extent of climatic impact in Gondwanaland. According to (Roy and Roser, 2012) Glossopteris dominated the coal-forming forests that covered Gondwana's floodplains in the Early and Later Permian. Using CHNS elemental analysis, organic matter sources and depositional environments of Permian Gondwana coals in the coal seam-VI in the Barapukuria coalfield have been investigated (Tahsin *et al*., 2016). To understand the realistic paleoclimate, we need to clearly understand the tools that can be used for tracking paleoclimate in the past. Commonly used proxies include spore pollen, charcoal, foraminifera, coral, XRD, and elemental analysis (CHNS). The present study on the palynological investigation, X-ray diffraction (XRD), and elemental Analysis (CHNS) highlighted to understand the paleoenvironment conditions of Gondwana deposits in the Barapukuria coal field.

Materials and Methods

The Barapukuria coalfield is located near the Hamidpur Union's Barapukuria village in the Parbatipur Thana of Dinajpur district. Regionally the research region is situated between latitudes 25°21'0" N and 25°34'00" N and longitudes 88°57'00" E and 88°59'00" E (Fig. 1). For this research work, a total of 11 coal samples are collected from different Geological Drill Holes (GDH-40, 41, 42, 43) at different depths using a hand cutter that covers the area of the Barapukuria coal Basin. Samples are collected from the Geological Survey of Bangladesh (Bogra Branch) repositories for analyzing their palynological studies, elemental analysis (CHNS) for determining the depositional environment of the coal samples, and XRD analysis for identifying minerals in the coal samples.

Table 1. Geological Drill Hole Samples of Coal.

GDH-No.	Depth in meter	Core sample of Coal
GDH-40	194.15	
GDH-40	250.24	
GDH-40	334.36	
GDH-40	489.81	
GDH-41	135.94	
GDH-41	306.01	
GDH-42	187.60	
GDH-42	231.30	
GDH-43	166.11	
GDH-43	290.16	
GDH-43	317.90	

Palynology and Extraction of Palynofossils

To extract the palynofossils, 10gm samples were treated with 5% Hydrochloric acid (HCl) and kept for 1 hour to dissolve calcareous materials. After that, I added conc. nitric acid (HNO_3) kept the residue for 2 days to dissolve organic matter and carbonates, if any. The maceral was screened through a series of 270 and 400-grade meshes and allowed to dry in the respective sieves at room temperature. We finally added Sodium hydroxide (NaOH) to clean the dark coating from the pollen body. Double-mount slides were made after maceration and ready for microscopic studies. The remaining original samples and treated and single-mount specimens are preserved in the Department of Geology, University of Dhaka laboratory.

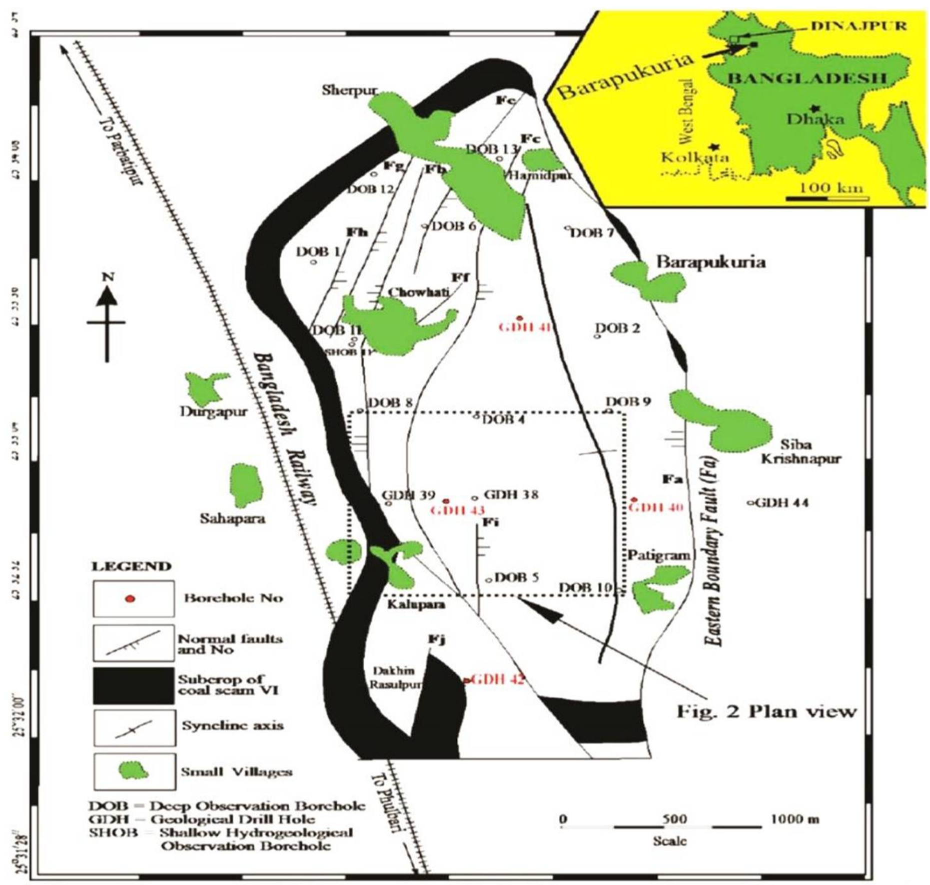

Figure 1. Location of the boreholes, major faults, and structural pattern of the Barapukuria Coal Basin, Dinajpur, Bangladesh (Wardell Armstrong, 1991; Bakr et al., 1996).

XRD Analysis

The X-ray diffraction data were taken using a step scanning technique on a Rigaku Ultima IV X-ray Diffractometer at the University of Dhaka's Centre for Advanced Research in Science (CARS) utilizing Cu K radiation in the range 2=10-41°.

Coal samples are subjected to XRD examination. First, make a fine powder out of the coal sample. Place the sample in the sample holder's glass depression. The glass sample holder had a depth of 0.2mm. Vertical loading must be avoided at all costs. X-ray diffraction pattern has been obtained, and the strongest reflection peaks converted from 2θ angles to d-spacing value. Using Bragg's equation, we calculate the d-spacing value from 2θ angles.

Proximity Analysis (CHNS)

MAS Plus and AS 1310 Liquid Autosamplers method describes the procedure for determining CHNS from the Centre for Advanced Research in Science (CARS), University of Dhaka. The approaches involve the analytical determination of nitrogen, carbon, hydrogen, and sulfur. The CHNS analyzer, varioMicro V1.6.1GMbH, Germany, was used for the analysis. The varioMicro V1.6.1 GMbH uses dynamic flash combustion of the samples for CHNS assessment, allowing for automated and simultaneous CHNS determination in a single test session.

Results and Discussion

Palynological assemblage: The Palynological investigation of the Barapukuria coal (GDH-40, GDH-41, GDH-42, and GDH-43) suggests the following information.

The palynological assemblage in GDH-40, GDH-41, and GDH-43 comprises 37 genera, and GDH-42 comprises 27 genera belonging to trilete, monolete, monosaccate, striate bisaccate, non-striate bisaccate, polysaccate, monocolpate, and polyplicate types through this study.

In the GDH-40 Coal sample, the palynological assemblage at 194.15m depth in this study demonstrates an overwhelming dominance of Scheuringipollenites (23%) closely followed by *Crucisaccites* (21%), *Parasaccites* (21%). The sample at a depth of 250.24m exhibits more or less equal dominance of *Scheuringipollenites* (34%) and *Faunipollenites* (18%). At 334.36 m depth, *Callumispora* (23%) is most abundant and closely followed by *Scheuringipollenites* (21%) and *Faunipollenites* (20%). Apart from that, a number of monosacate genera can be found across the assemblage. The palynological assemblage collected from borehole GDH 40 is thus characterized by a non-striate desiccate *Scheuringipollenite* dominance and a striate desiccate sub-dominance.

In the GDH-41 coal sample at 135.94 m depth, the palynological assemblage shows the dominance of *Faunipollenites* (18%) followed by *Parasaccites* (14%). The sample at a depth of 306m exhibits dominance of *Callumispora* (22%) followed by *Crucisaccites* (10%). Besides, a number of monosacate genera are quite common throughout the assemblage. The overall palynological assemblage recovered from borehole GDH 41 is thus characterized by the dominance of striate desiccate *Callumispora* followed by *Faunipollenites* and non-striate desiccates as a sub-dominant.

In the GDH-42 coal sample, at 187.60m depth, the palynological assemblage shows an overwhelming dominance of *Scheuringipollenites* (56%) followed by *Faunipollenites* (18%). The sample at a depth of 213.30m exhibits more or less equal dominance of *Scheuringipollenites* (27%), *Striatopodocarpites* (25%), and *Faunipollenites* (20%). Besides, several monosacate genera are quite common throughout the assemblage. The palynological assemblage retrieved from borehole GDH 42 is thus characterized by a nonstriate desiccate Scheuringipollenite dominance and a striate desiccate subdominant.

In the GDH-43 study, at 166.97m depth, the palynological assemblage shows a dominance of *Scheuringipollenites* (14%) followed by *Faunipollenites* (14%), closely followed by *Callumispora* (12%), *Barakarites* (12%). The sample at a depth of 290.16m exhibits dominance of Barakarites (23%), and at a depth of 317.9 m, the sample shows complete dominance of *Faunipollenites* (23%) and *Callumispora* (23%). The total palynological assemblage obtained from borehole GDH 43 is characterized by the prevalence of striate desiccate *Barakarites* (23%), *Faunipollenites* (23%), *Callumispora* (23%), and sub-dominance of non-striate desiccate.

Palynoassemblages of nonstriate desiccate *Scheuringipollenites, Crucisaccites,* and *Parasaccites* have been distinguished in the GDH-40, and GDH-42, which are denoted as Zone I and Palynoassemblages of striate desiccate *Barakarites*, *Faunipollenites*, *Callumispora* have been recorded as Zone II in the GDH-41 and GDH-43. Besides, several monosacate genera are common throughout the assemblage in all coal samples. The monosaccate genera are found in abundance in the lower part of the Gondwana sequence (Talchir and Karharbati formation), and their numbers gradually come down in the upper part (Kulti and Raniganj formation) (Jha and Aggarwal, 2011).

The palynoassemblages in the GDH-40 and GDH-42 show nonstriated desiccate *Scheuringipollenites* dominance, *Faunipollenites* sub–dominance, and other genera, indicating an early Permian age. It suggests that the sediments are from the Barakar

Formation's lower portion. The Barakar formation has been palynologically divided into the older *Scheuringipollenites* dominant complex and the younger striate desiccate dominant complex (Jha and Aggarwal, 2011; Mukhopadhyay *et al*., 2010; Prasad and Pundir, 2020). The palynological assemblage recorded in borehole GDH 42 from the Barapukuria basin is equivalent to the palynoflora described from the Barakar formations of various Indian Gondwana sequences such as the Son-Mahanadi, Damodar,

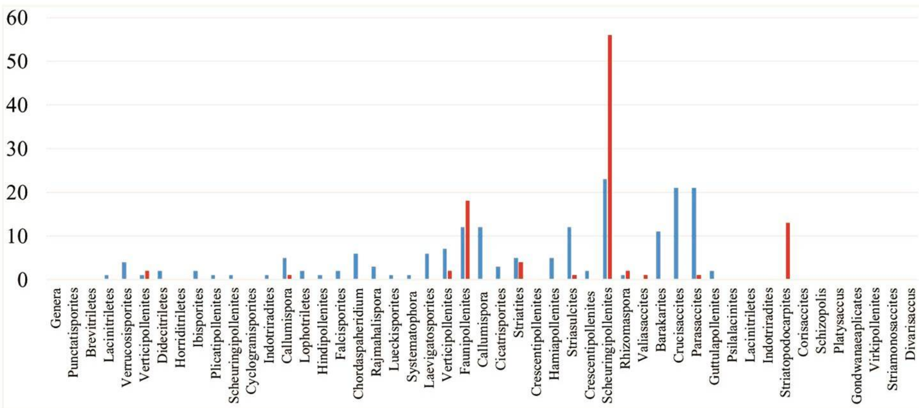

Figure 2. Palynoassemblages (Zone 1) of nonstriate desiccate *Scheuringipollenites*, *Crucisaccites*, and *Parasaccites* have been distinguished in the GDH-40, and GDH-42.

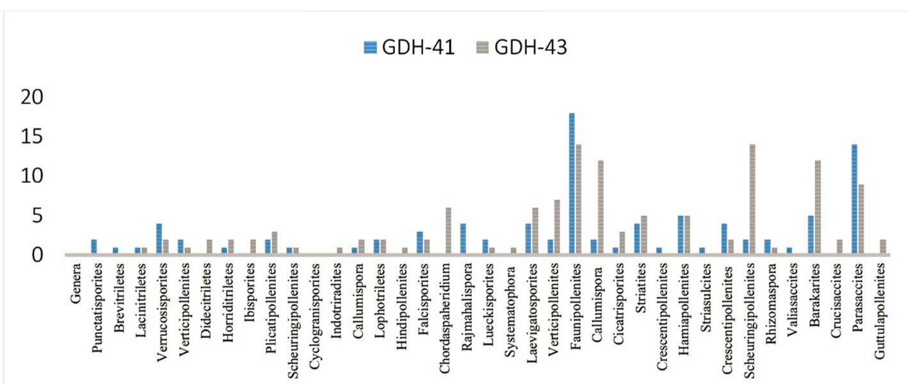

Figure 3. Palynoassemblages (Zone 2) of striate desiccate *Barakarites*, *Faunipollenites*, and *Callumispora* have been recorded in the GDH-41 and GDH-43.

And Godavari valley basins are comparable to the *Scheuringipollenites*- *Faunipollenites* Assemblage Zone, which represents the Lower Barakar palynozone. The palynoassemblages from the GDH-41 and GDH-43 show striate desiccate *Barakarites, Faunipollenites* dominance, and *Scheuringipollenites* sub-dominance, indicating late Permian age, which denoted that the sediments are from Barakar formation. Striate bisaccates are found in large numbers in Indian Lower Gondwana (lower Barakar), persisting as a dominating palynofloral component in the late Permian. Stratigraphically significant species are crucial when recognizing palynoassemblages in the late Permian succession. From the early to late Permian, quantitative analysis of distinct palynoflora reveals substantial changes in microflora.

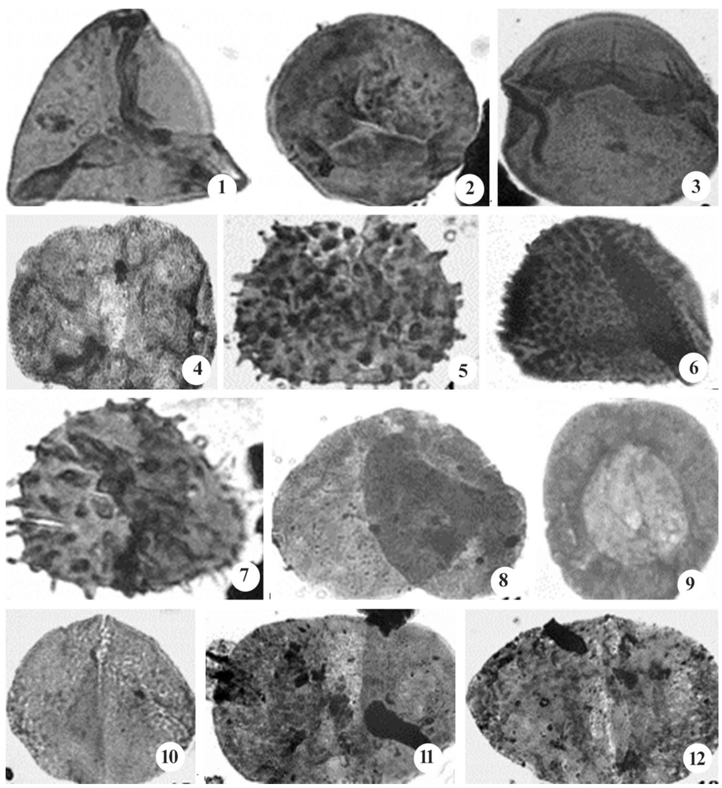

Plate 1. Miospore (x200) identified from Gondwana Coal deposits, Bangladesh. 1. ***Lacinitriletes badamensis*****; 2.** ***Punctatisporites uniformis*****; 3.** ***Callumispora barakarensis*****; 4.** ***Crucisaccites latisulcatus*****; 5.** ***Brevitriletes unicus*****; 6.** ***Didecitriletes horridus*****; 7.** ***Horriditriletes curvibaculosus*****; 8.** ***Ibisporites diplosaccus*****; 9.** ***Plicatipollenites gondwanensis*****; 10.** ***Scheuringipollenites tentulus*****; 11.** ***Circumstriatites talchirensis*****; 12.** ***Scheuringipollenites barakarensis*****.**

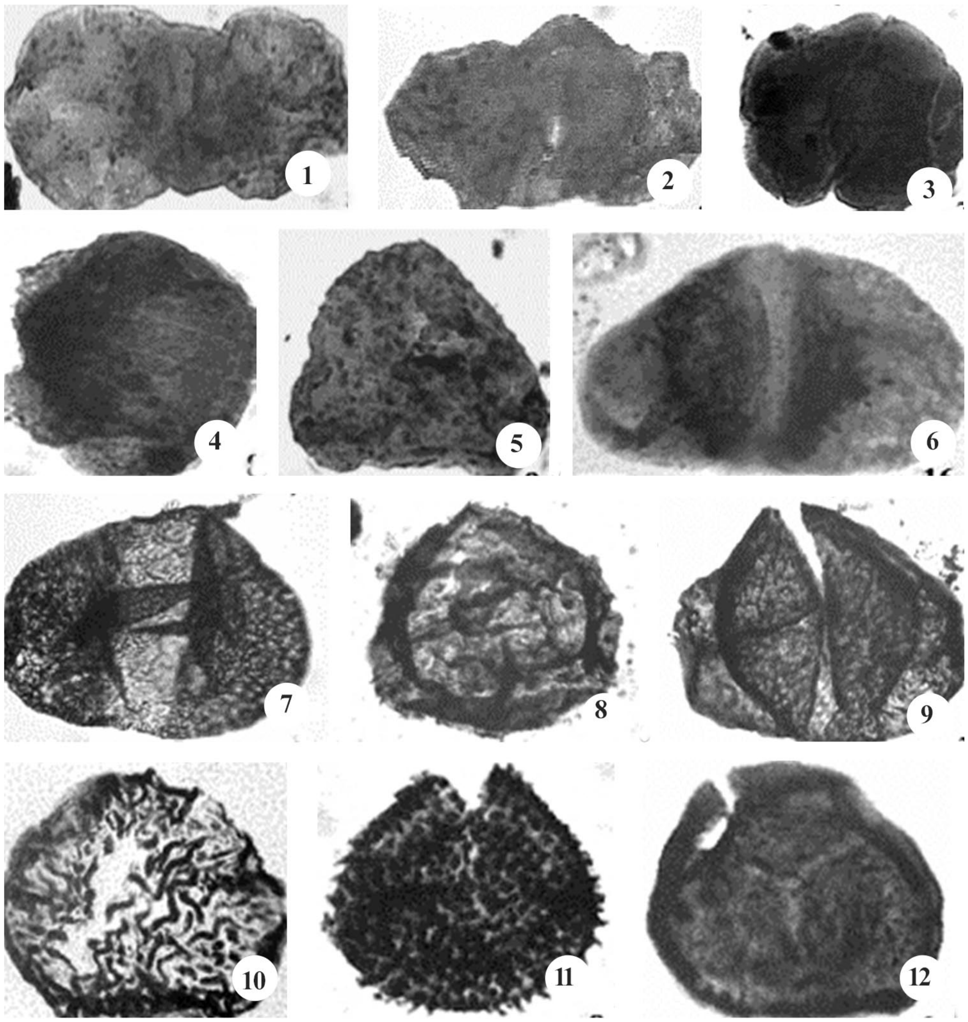

Plate 2. Miospore (x200) identified from Gondwana Coal deposits, Bangladesh. 1. *Verticipollenites gibbosus*; 2. *Hindipollenites indicus*; 3. *Guttulapollenites hannonicus*; 4. *Guttulapollenites gondwanensis*; 5. *Lophotriletes rectus*; 6. *Falcisporites stabilis*; 7. *Chordaspaheridium australiensis*; 8. *Rajmahalispora triassicus*; 9. *Lueckisporites junior*; 10. *Rajmahalispora rugulata*; 11. *Ceratosporites helidonensis*; 12. *Aratrisporites granulatus*.

Botanical Affinity

The palynomorphs recovered from the three samples (GDH-40, GDH-41, and GDH-43) comprise 37 genera, and GDH-42 comprises 27 genera belonging to Glossopteridales (6 taxa represented by *Faunipollenites, Scheuringipollenites, Cyclogranisporites*, *Striatites,* *Striasulcites, Striamonosaccites*), Coniferales (8 taxa represented by *Verticipollenites, Ibisporites, Striatopodocarpites, Crescentipollenites, Falcisporites, Chordaspaheridium, Lueckisporites, Striatites*), Ginkgoales (6 taxa namely, *Verticipollenites, Crescentipollenites, Hamiapollenites, Striasulcites, Gondwanaeaplicates, Barakarites),* Filicales (2 taxa, viz., *Verrucosisporites, Cyclogranisporites*), Equisetites (3 taxa, viz., *Callumispora, Hamiapollenites*), Malvaceae (2 taxa, viz., *Brevitriletes, Rhizomaspora*), Clathropteris (2 taxa, viz., *Guttulapollenites*, *Cicatrisporites*) and Cycadales (1 taxon, viz., *Valiasaccites*).

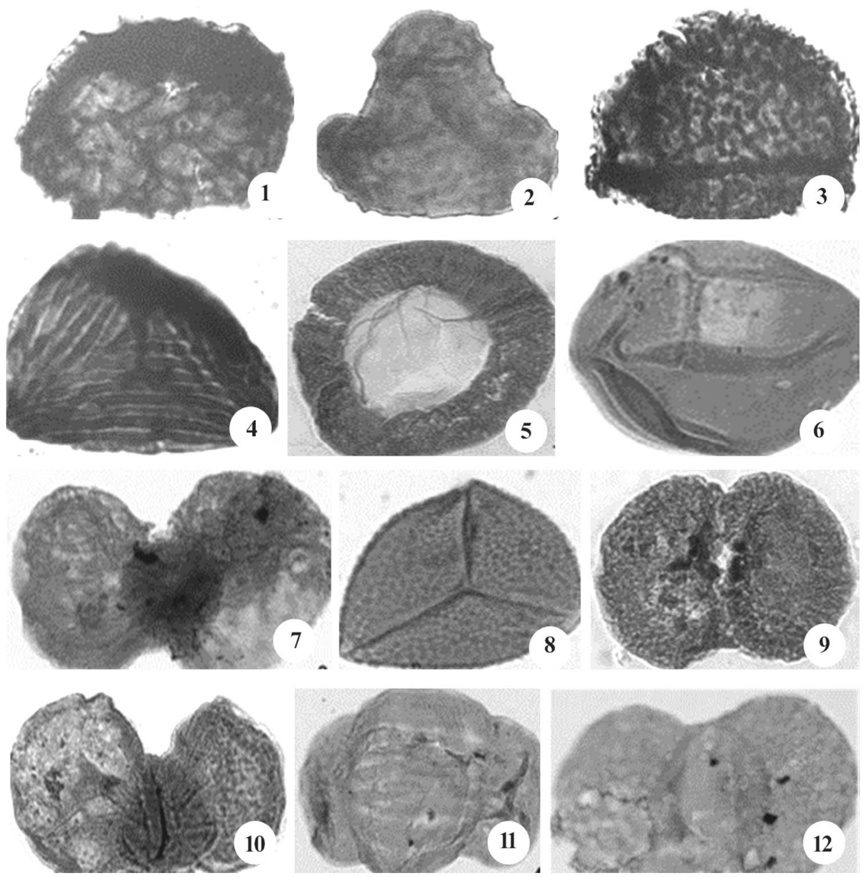

Plate 3. Miospore (x200) identified from Gondwana Coal deposits, Bangladesh 1. *Systematophora areolata*; 2. *Impardecispora apiverrucata*; 3. *Kalyptea* sp. *cf. K. wisemaniae*; 4. *Striatriletes sp*; 5 *Barakarites indicus*; 6. *Callumispora sp*. 7. *Cicatrisporites australiensis*; 8. *Microbaculispora karensis*; 9. *Ibisporites* sp.; 10. *Verticipollenites gondwanensis*; 11. *Hamipollenites striatus*; 12. *Crescentipollenites* sp.

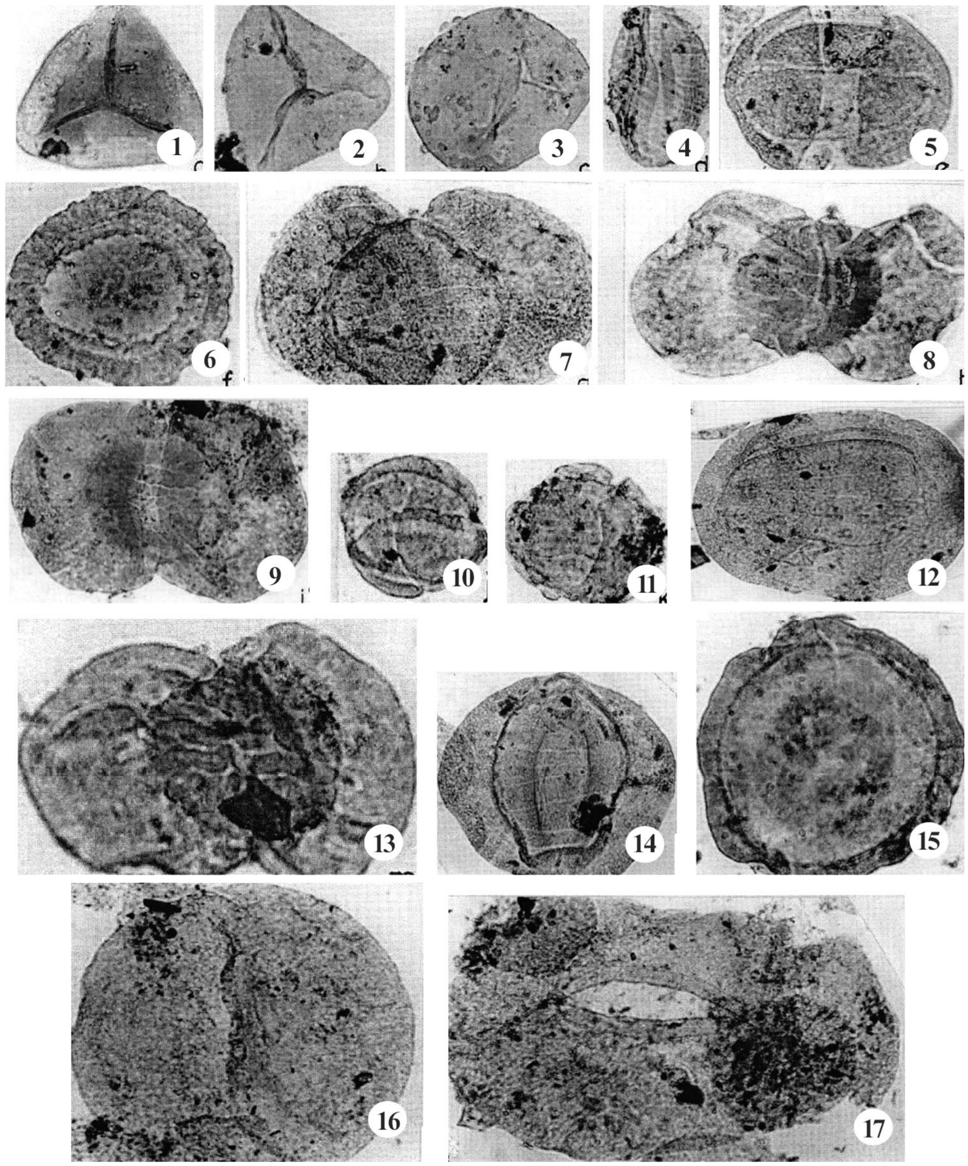

Plate 4. Miospore (x200) identified from Gondwana Coal deposits, Bangladesh 1. *Psilalacinites*, 2. *Lacinitriletes badamensis*, 3. *Verrucosisporites* sp., 4. *Striasulcites tectus*, 5. *Coricasaccites alutus*, 6. *Virkkipollenites triangularis*, 7. *Striatites notus*, 8. *Verticipollenites gibbosus*, 9. *Striatopodocarpites decorus*, 10. *Guttulapollenites hannonicus*, 11. *Schizopollis woodhousei*, 12. *Faunipollenites various*, 13. *Rhizomaspora radiate*, 14. *Crescentipollenites* sp., 15. *Barakarites indicus*, 16. *Scheuringipollenites barakarensis*, 17. *Divarisaccus lelei*.

The palaeovegetation in the Palynoassemblage Zone-I was dominated by Glossopteridales and sub-dominated by Coniferales vegetation during the early Permian.

Palynoassemblage Zone II was characterized by the dominance of Glossopteridales and sub-dominance of Ginkgoales vegetation during the late Permian. Coniferales were uncommon, while Filicales and Cycadales were unusual in occurrence.

The megafloral assemblage recovered from the Barapukuria basin displays a dense and swampy forest growing in low-lying river valleys, with rich green vegetation subjugated by arborescent deciduous trees with Glossopteris leaf and some equisetales. Except for a few herbaceous plants, most Glossopteris plants were arborescent trees. Palynomorphs also suggest that Glossopteridales dominate the forest, with Coniferales and Cordaitales as sub-dominants. It also indicates that Filicales and Ginkgoales were restricted to specific areas.

The major Flora of the Gondwana coals in Bangladesh was coniferous gymnosperms, and the Flora closely matched that of other Gondwana assemblages globally (e.g., India, South Africa, South America, Russia, Australia, and Antarctica (Akhtar and Kosanke, 2000). Glossopteris Flora plant fossils discovered in Gondwana rocks give compelling evidence for ecological and climatic circumstances (Anderson *et al*., 1999). The Glossopteris Flora arrived rather unexpectedly and energetically as the glaciers receded in the early Permian. The Glossopteris Flora's temporal and spatial distribution was aided by the improved climate caused by rapid deglaciation. Bryophyta, Lycophyta, Arthrophyta, Filicophyta, and Gymnospermophyta are all represented in the Flora. The gymnosperms, which included the divisions Cordaitopsida, Cycadopsida, Coniferopsida, Ginkgopsida, and Glossopteridopsida, were the most prevalent group of plants (Phillips and Hayman, 1970). The Glossopterid plant family was the most important.

Glossopterids represent mesophilous palaeoenvironment and proliferate in lowland peats. At the same time, conifers were carried out from more far-away parts to the swamps and are measured to be extramarital elements which typically show numerous adaptations for subsistence in drier habitats (Knoll and Niklas, 1987). Based on botanical affinity, the pre-eminence of Glossopteridales and contributory presence of Cordaitales, Coniferales, and scare presence of spores in the present palynoflora represents a warm and humid climate in a telematic environment (forest moor).

Zone (Palynoassemblage)-I (abundance of Glossopteridales along with subdominant of Coniferales) represents a more humid climate as compared to Zone (Palynoassemblage)-II (abundance Glossopteridales and sub-dominance of Ginkgoales), which is also advocated by the presence of a thick succession of shale during the deposition of

Palynoassemblage-I. The presently studied palynoassemblages (I and II) demonstrate a warm, humid (high) temperate climate with sufficient water supply.

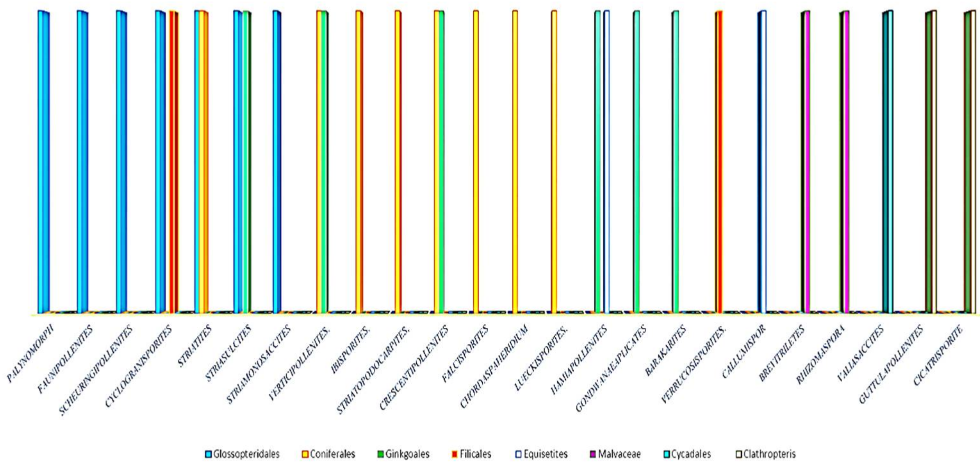

Figure 4. The Botanical affinity of the identified palynomorphs (Balme 1995, Gould and Delevoryas 1977 and Jasper *et al*. 2006)

XRD data analysis

The graphs below show XRD's intensity (cps) vs. 2-theta (deg) data. Various minerals have been identified from 2θ angles and the corresponding d- spacing values as shown in the graph.

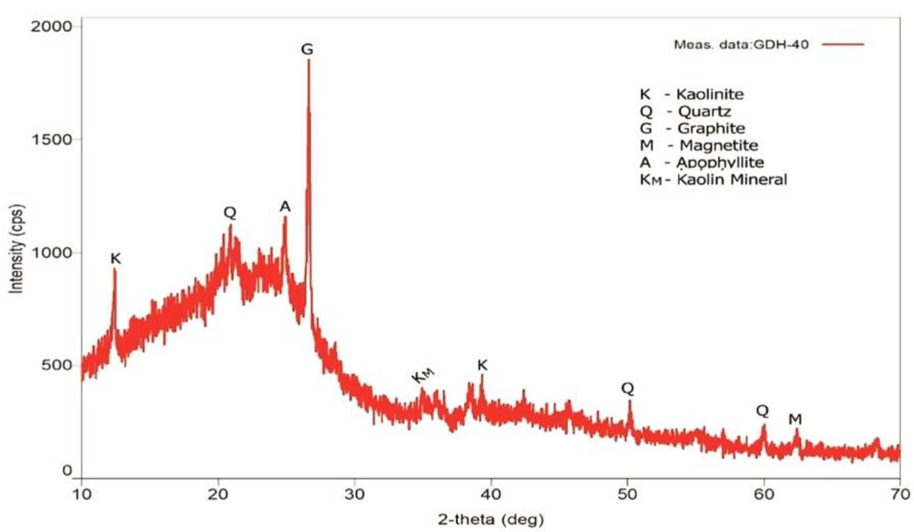

Figure 5. Identified minerals in GDH-40 coal samples from the 2θ/d-spacing value.

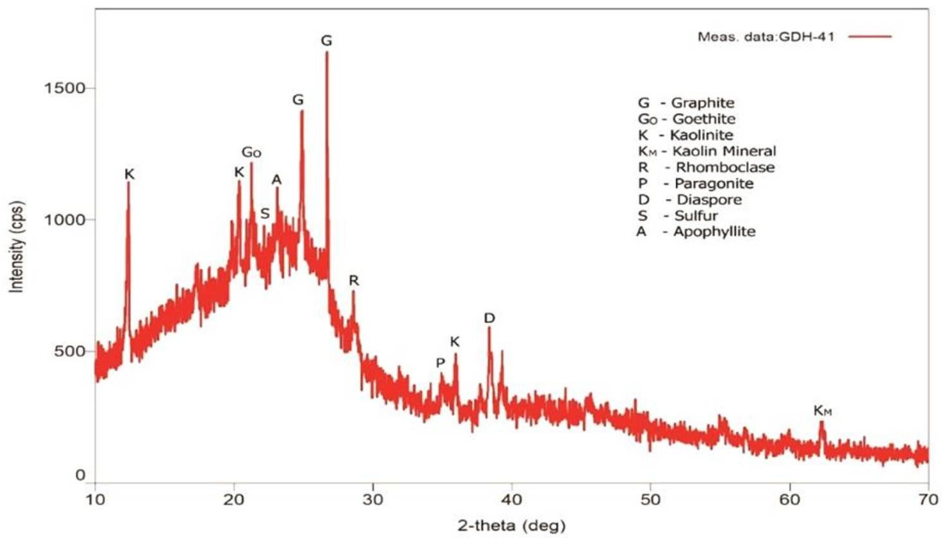

Figure 6. Identified minerals in GDH-41 coal samples from the 2θ/d-spacing value.

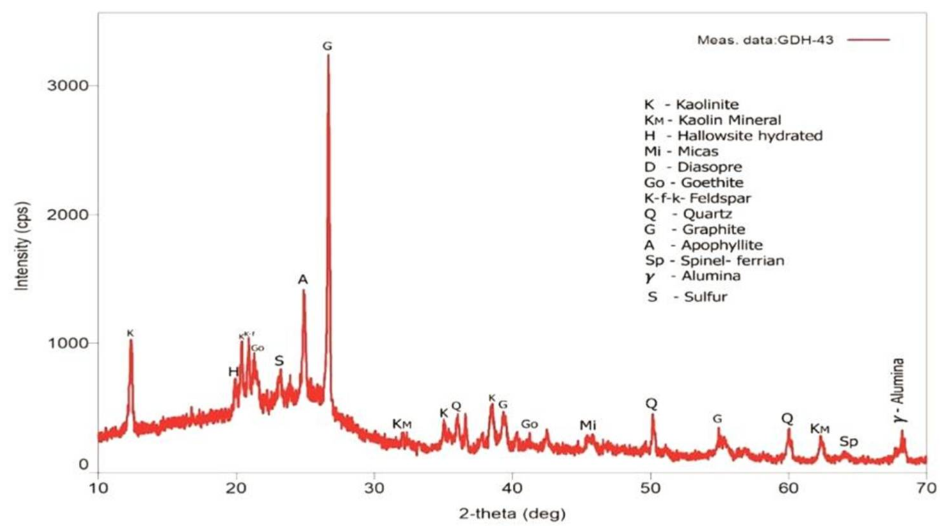

Figure 7. Identified minerals in GDH-43 coal samples from the 2θ/d-spacing value

From the XRD data analysis (Fig. 5-7), it has been determined that all coal samples are mostly constituted of different types of Clay minerals, Quartz, Various organic sources of minerals, and miscellaneous. Identified clay minerals are Kaolinite, Kaolin minerals, Hallowsite hydrated, and Apophyllite. Graphite, Sulfur, Diaspore, Goethite, and Magnetite are encountered as organic minerals. K-feldspar, Rhomboclase, Paragonite, Micas, Spinel Ferrian, and Gamma-Allumina fall into the miscellaneous group.

The percentage of clay minerals ranges from 34%-44%, organic minerals are 22-36%, Quartz 9-33%, and miscellaneous are about 9-17% in the coal samples.

Aluminium silicate minerals like feldspar undergo chemical weathering to create kaolinite, kaolin minerals (hydrated aluminum silicate crystalline minerals), and hydrated halloysite. They are common in soils generated by the chemical weathering of rocks in hot, humid climates. They can be found in regions that see marked seasonal changes between dry and wet, such as tropical rainforest areas (Bhattacharya and Bhattacharya, 2007). A particular class of phyllosilicate minerals known as apophyllite is generally found as secondary. The silicate mineral family includes micas. Mica often occurs in igneous and metamorphic rock and can emerge from various processes under various circumstances, including fluid deposition from directly related magmatic activity and crystallization from consolidating magmas. Low- to medium-grade metamorphic rocks include the mica-group mineral paragonite. The rock's feldspar underwent hydrothermal alteration to generate a metastable white mica, which later changed into paragonite. Quartz is the silicate mineral and the most prevalent, plentiful, and extensively distributed mineral on the planet's surface.

It is also a component of the majority of soil parent materials. Due to its poor capacity for weathering, quartz is a frequent residual mineral in residual soils and stream sediments. It is a fundamental component of many rocks and may be found in virtually all mineral settings. Rhomboclase, an acidic iron sulfate mineral, has been identified as an arid-region post-mine mineral.

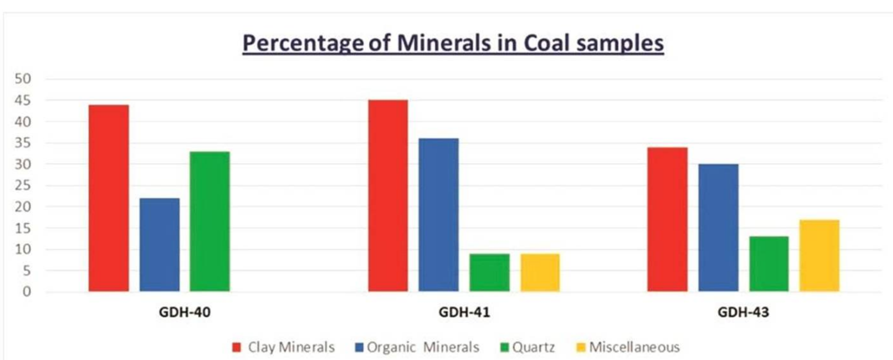

Figure 8. Percentage of minerals in GDH-40, GDH-41, and GDH-43 coal samples.

Graphite may be found in organic-rich coal beds created by transforming dead plant and animal components in the identified organic minerals. A member of the diaspore group, goethite is an oxide-hydroxide of iron (III). It may be discovered in sediments and other low-temperature settings like soil. It may commonly be seen in the swampy regions near spring waters. It has been discovered that certain types of bacteria's excretion processes create goethite.

Samples of the minerals encountered in the coal indicate that Barapukuria coals are argillaceous because of many clay minerals and indicate terrestrial paleoclimate. It suggests that coal samples are deposited with a braided fluvial environment immediately following the glacial amelioration stage to a humid, warm climate. During the deposition of Barapukuria coal, known as Gondwana coal, there was a dense and swampy forest growing in low-lying river valleys and demonstrating a warm, humid temperate climate with a sufficient water supply and land plant-derived organic matter subsequently deposited in entirely terrestrial environments.

Table 2. CHNS elemental analysis (wt %) of Permian Gondwana coals in the (GDH-40, GDH-41, GDH-43) Barapukuria coal field, northwestern Bangladesh.

GDH-No.	Depth (m)	Weight (mg)	N%	C%	H%	S%	C/S
GDH-40	194.15	3.816	8.84	41.69	3.998	0.512	81.4
GDH-40	250.24	2.3580	14.49	78.30	4.653	0.682	114.8
GDH-40	334.36	2.8370	12.90	47.06	5.091	0.445	105.7
GDH-40	489.81	3.2220	12.04	61.49	4.757	0.358	171.75
GDH-41	135.94	4.2910	8.64	38.73	5.642	0.969	39.96
GDH-41	306.0	4.6130	8.24	29.49	4.321	0.296	99.6
GDH-43	156.97	5.3450	7.42	49.69	5.220	0.614	80.92
GDH-43	290.16	4.3030	9.75	38.08	3.241	0.562	67.75
GDH-43	317.9	3.6580	11.95	56.59	3.418	0.273	207.28

Elemental compositions

CHNS analysis (C, H, N, and S) of the studied coal samples are listed in Table 2. The carbon content of the coal samples varies from 29.49-78.30 wt%. Hydrogen and Nitrogen abundances for the coal samples range from 3.24-5.642 wt% and 14.49-7.42 wt%, respectively. The Coals are characterized by low sulfur content ranging from 0.273-0.969 wt%. C/S ratio range between 39.96 to 207. The C/S ratio is widely used to infer depositional conditions of organic matter accumulated in marine or non-marine water bottom environments (Berner 1984; Hossain *et al*., 2009).

Since the biogeochemical cycle of sulfur in sediments is inseparable from that of carbon, the relationship depends largely on the depositional environment during or after the burial of organic matter. Sediments deposited in marine environments have low C/S values of 0.5 to 5, whereas freshwater sediments have relatively high C/S values >10 (Berner and Raiswell, 1984). In the studied coals, sulfur content is relatively low, and the C/S ratio is > 10, which indicates a freshwater influence and suggests that the coaly organic matters were communicated with a non-marine environmental condition. Hossain *et al.* (2015) also mentioned that the lower part of the Gondwana succession was accumulated in dominantly oxic conditions with abundant input of terrestrial-derived organic matter. Plant production is relatively high in hot, humid climatic conditions and low in dry/cool climatic conditions. Islam and Hossain (2006) stated that low- to moderately-sinuous stream channel is commonly associated with peat-forming mire complexes in the Gondwana Barapukuria basin.

Conclusion

The Gondwana Coal Deposits in Northwestern Bangladesh are equivalent to the palynoflora described from the Barakar formations of various Indian Gondwana sequences, representing the Early Permian age and being Lower Barakar Palynozone. Zone II indicates the Late Permian age, which denoted that sediments are from Barakar formation and persist in dominating the palynofloral component in the Late Permian. According to Botanical affinity, Palynoassemblage Zone I was dominated by Glossopteridales and sub-dominated by Coniferales vegetation during Early Permian. On the other hand, Palynoassemblage Zone II was characterized by the dominance of Glossopteridales and sub-dominance of Ginkgoales vegetation during the Late Permian. Glossopteris plant fossils found in Gondwana rocks strongly support ecological and climatic conditions. As the glacier retreated in the Early Permian, the Glossopteris Flora appeared abruptly and vigorously. The favorable climate brought on by rapid deglaciation assisted the temporal and spatial dissemination of the Glossopteris Flora. From XRD analysis, it has been determined that all coal samples are mostly constituted of different types of clay minerals, quartz, organic sources of minerals, and miscellaneous components. The percentage of clay minerals ranges from 34%-44%, organic minerals are 36-22%, quartz 9-33%, and miscellaneous are about 9-17% in the coal samples. A relatively higher percentage of clay minerals and organic sources of minerals indicate that these coal samples are argillaceous coal. A higher percentage of carbon content (29.49-78.30 wt %), low sulfur content (0.273-0.969 wt %), and C/S ratio (139.96 to 207) indicate a non-marine freshwater environmental condition.

Barapukuria basin suggests that Barapukuria coal samples are deposited in freshwater influence and sediments accumulated in dominantly oxic conditions. During the deposition of Barapukuria coal samples, a dense and swampy forest grew in low-lying river valleys. It is deposited in a warm, humid (high) temperate climate in the terrestrial environment.

References

Akhtar, A., and R.M. Kosanke. 2000. Palynomorphs of Permian Gondwana coal from borehole GDH-38, Barapukuria Coal Basin, Bangladesh. *J. African Earth Sci.* **31**(1)**:** 107-117.

Anderson, J. M., H. M. Anderson, S. Archangelsky, M. Bamford, S. Chandra, M. Dettmann, R. Hill, S. Mcloughlin, and O. Rosler. 1999. Patterns of Gondwana plant colonization and diversification. *J. African Earth Sci.* **28:** 145-167.

Bajpai, U, and VK Singh. 1986. Araucarioxylon kwnarpurensis, a new gymnospermous wood from the Upper Permian of West Bengal. *Palaeobotanist* **35:** 53-56.

Berner, RA 1984. Sedimentary pyrite formation: an update. *Geo chim. Cosmochim. Acta*. **48:** 605-615.

Berner, RA and R. Raiswell, 1984. C/S method for distinguishing freshwater from marine sedimentary rocks. *Geology* **12:** 365-368.

Farhaduzzaman, Md., Wan Hasiah Abdullah, and Md. Aminul Islam. 2012. Depositional environment and hydrocarbon source potential of the Permian Gondwana coals from the Barapukuria Basin, Northwest Bangladesh. *Int. J. Coal Geol.* **90-91:** 162-179.

Fox, C S. 1931. The Gondwana System and related formations, *Geol. Surv. India Memoir* **58** 1–241.

Hossain, H.M.Z., M.S.U. Islam, S.S. Ahmed and I. Hussain, 2002. Analysis of Sedimentary Facies and Depositional Environments of Permian Gondwana Sequence in borehole GDH-45, Khalaspir Basin, Bangladesh, *Bangladesh Geosci. J.* **6:** 227-236.

Hossain, HMZ., Y Sampei and BP. Roser, 2009. Characterization of organic matter and depositional environment of Tertiary mudstones from the Sylhet Basin, *Bangladesh. Org. Geochem.* **40**: 743-754.

Hossain, HMZ., Y. Sampei, QH Hossain and BP. Roser, 2015. Organic geochemical characterization of Carboniferous-Permian Gondwana coaly shales intercalated in coals/sands of the Barapukuria basin, *Bangladesh. Org. Geochem.*

Hossain, Md. Mosharrof. 2016. *Coal Bangladesh*. Adorn Publication. Dhaka, Bangladesh.

Imam, Badrul. 2006. *Energy Resources of Bangladesh*. University Grant Commission of Bangladesh.

Islam, M.N, M.N. Uddin, S.A. Resan, M.S. Islam and M.W Ali. 1992. Geology of the Khalaspir Coal Basin, Pirganj, Rangpur, Bangladesh. *Geological Survey of Bangladesh* **6. 5**.

Islam, M.S. 1993. Anatomy and environment of deposition of the abnormally thick coal seam VI in the Barapukuria basin, Dinajpur, Bangladesh. *Bangladesh J. Geol.* **12**: 27-38. (published in 1996).

Islam, MS and I. Hossain, 2006. Lithofacies and Embedded Markov Chain analyses of Gondwana sequence in boreholes GDH-40 and 43, Barapukuria coal field, Bangladesh. *Bangladesh J. Geol.* **25**: 64-84.

Jha, Neerja, and Neha Aggarwal. 2011. Palynological correlation of coal-bearing horizons in Gundala area, Godavari Graben, India. *J. Earth Syst. Sci.* **120**: 663-679.

Knoll, A H and K j Niklas. 1987. Adaptation, plant evolution, and the fossil record. *Review of Palaeobotany and Palynology* **50**: 127-149.

Mukhopadhyay, G., S. K. Mukhopadhyay, Manas Roychowdhury, and P. K. Parui. 2010. Stratigraphic Correlation between Different Gondwana Basins of India. *Geological Society of India* **76**: 251-266.

Phillips, JM, and DS Hayman. 1970. Improved procedures for clearing roots and staining parasitic and vesicular arbuscular mycorrhizal fungi for rapid assessment of infection. *Trans. Br. Mycol. Soc.* **28**: 145-167.

Prasad, Bijai, and B S Pundir. 2020. Gondwana biostratigraphy and geology of West Bengal Basin, and its correlation with adjoining Gondwana basins of India and western Bangladesh. *J. Earth Syst. Sci.* **129**.

Roy, Dhiman Kumer, and Barry P Roser. 2012. Climatic control on the composition of Carboniferous–Permian Gondwana sediments, Khalaspir basin, Bangladesh. *Elsevier, Gondwana Research* **23**: 1163-1171.

Tahsin, S., H. M. Z. Hossain and M.M Hossain. 2016. Organic matter in coal seam-VI of the Barapukuria coal field in Bangladesh. *Bangladesh J. Sci. Indust. Res.* **51**(3): 221-230.

Tewari, Ram Chandra. 1991. Structures and sequences in fine-grained point bars of Yamuna River near Etawah, Uttar Pradesh. *J. Geol. Soc. India* **38**: 303- 311.

Uddin, M.N., M.S.U. Islam, 1992. Depositional environments of the Gondwana rocks in the Khalashpir basin, Rangpur District, Bangladesh. *Bangladesh J. Geol.* **11**: 31-40.

Wardell-Armstrong Ltd. 1991. Techno-economic feasibility study, Barapukuria coal project, Dinajpur, Bangladesh. **12**. Report submitted to Ministry of Energy and Mineral Resources, Government of the People's Republic of Bangladesh (unpublished).

(Revised copy received on 30.05.2023)