Mongolian Geoscientist

Original Article

Coal facies of the Middle Permian Baruunnaran deposit, South Mongolia

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ARTICLE INFO

***Article history*:**
Received 12 March, 2023
Revised 22 December, 2023
Accepted 30 December, 2023

ABSTRACT

The Baruunnaran coal deposit is located in the northeastern part of the South Gobi Basin, southern Mongolia, and hosted in the middle Permian Tavantolgoi Formation. In this paper we present indices of coal facies determined from 34 coal samples obtained from three seams in the lower and upper part of the formation (III, IXG and X), by studying their organic petrography and the geochemistry of the coal ash. The results of coal petrography revealed that seams III, IXG and X are composed of 46.9 -80.9 vol.% vitrinite, 11.6-47.5 vol.% inertinite and 1.2-18.2 vol.% liptinite. In samples from seams III and X the average content of mineral matter is low at 11 and 13.4 vol.%, respectively, and 6.3 vol.% in seam IXG, and consists of clay, silica, pyrite, carbonate, and other minerals. The inorganic content mostly occurs as fillings of cell cavities, cracks, and fissures of vitrinite and inertinite macerals. The vitrinite random reflectance values range from 0.81-1.07%. The Gelification Index and Tissue Preservation Index suggest the peats accumulated in wet forest swamp environments with high tree density. The majority of the seams accumulated in mildly oxic to anoxic conditions with good tissue preservation. The peat mire water ranged from weakly to strongly acidic. Further, it was determined by Al_2O_3/TiO_2 ratios that the clastic sediments were probably sourced from volcanic basement characterized by intermediate felsic composition.

Keywords: Tavantolgoi Formation, South Gobi Basin, Organic matter, organic petrology, paleoenvironment conditions, ancient peat mires.

INTRODUCTION

The Baruunnaran coal deposit is located c. 560 km southeast of the city of Ulaanbaatar, c. 90 km east of Dalanzadgad the provincial capital of South Gobi and c. 20 km southeast of Tsogttsetsii soum (Figs. 1a and 1b). The Baruunnaran coal deposit represent the far western part of the Tavantolgoi deposit, situated in the northeastern sector of the South Gobi Basin (ie. a concentration of Permo-Triassic coal-bearing transtensive sub-basins, Michaelsen and Storetvedt, (2023) (Figs. 1a and 1b). The Tavantolgoi sub-basin includes the Tavantolgoi, Ukhaakhudag and Baruunnaran deposits, which might contain a total of 10 Gt of coal to a basement depth up to c. 1,200 m (Michaelsen and Storetvedt, in press - Fig. 1c).
The coal seams are hosted in the middle Permian coal-bearing Tavantolgoi Formation. In total, 21 coal seams are preserved in the Baruunnaran deposit (Byambaa et al., 2022). The coal seams of the Baruunnaran coal deposit are named in the order the English alphabet in ascending stratigraphic order. The nomenclature

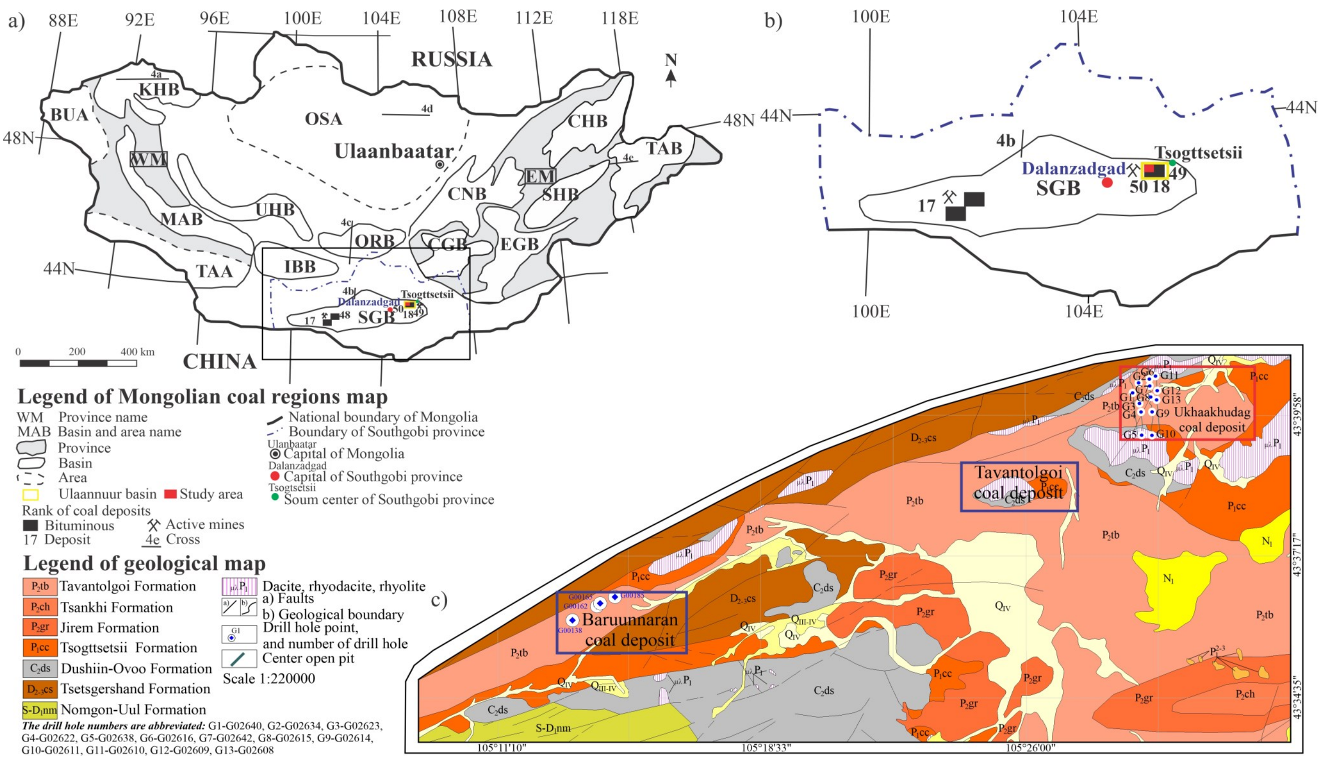


Fig. 1. a) Location map of the study area and Mongolian coal-bearing provinces, basins, and deposits (modified after Bat-Erdene, 1992). Provinces: WM-Western Mongolia; EM-Eastern Mongolian; Basins; KHB-Kharkhiraa; MAB-Mongol-Altai; SGB-South Gobi; UHB-South Khangai; IBB-Ikh Bogd; ORB-Ongi River; CNB-Choir-Nyalga, CHB-Choibalsan; TAB-Tamsag; SHB-Sukhbaatar; EGB-East Gobi; CGB-Central Gobi Basin; Areas: BUA-Bayan-Ulgii; TAA-Trans-Altai; OSA-Orkhon-Selenge; Coal deposits: 17-Nariin Sukhait; 18-Tavantolgoi; 48-Gurvantes; 49-Ukhaakhudag; 50-Baruunnaran. b) A location map of SGB and Ulaannuur Basin, study area. c) Geological map of around Ulaannuur district with study areas (from Khosbayar et al., 1984)

corresponds to the coal seams of the Tavantolgoi and Ukhaakhudag deposits. The coal seams are numbered in ascending order by roman numbers in the Tavantolgoi and Ukhaakhudag coal deposits. The number of coal seams within the Baruunnaran coal deposit is matched by the number of coal seams in the Ukhaakhudag and Tavantolgoi coal deposits. The studied seams III, IXG and X coal seams of the Baruunnaran coal deposit are locally labeled H500, T500 and U500.

Exploration of the Baruunnaran coal deposit started in 1950 by a joint group of Russian and Mongolian geologists and the deposit was identified in 1983. Also, the coals were identified to be of thermal and coking coal type (e.g. by petrographic composition, vitrinite reflectance and proximate analyses). The main coking coal reserves of Baruunnaran coal deposit are seams III (H500) and IXG (T500).

Total reserves are estimated at 411.11 Mt (Byambaa et al., 2022). The coal seams are washed and blended by using heavy medium cyclone, spiraling, and froth flotation methods. The coals are exported to China and as such very important for the economic development of Mongolia.

In 1983, Jargal, Tserensodnom and Erdembat instigated research of the coal petrographic composition of the Tavantolgoi deposit (Jargal et al., 1990). Since 2015, Tsolmon, Ganzorig, Demberelsuren, Saruul-Erdene and Batgerel have been conducting a study of coal petrographic composition at the Ukhaakhudag and Baruunnaran deposits. In 2015, Jargal was conducting a study of the coal petrographic composition of the Baruunnaran deposit (Byambaa et al., 2022). During 2017, paleoenvironmental studies of peat accumulation began in the Ukhaakhudag and Baruunnaran deposits.

The coal quality depends not only on coalification but also on the coal composition, with coal selection and blend composition being major factors controlling coke properties, physical and chemical (Díez et al., 2002). One of the most important factors is the depositional environment which determines the composition and preservation of the peat (Lin and Tian, 2011). The information of accumulation of paleoenvironment is stored in the composition of the coals and associated detrital sedimentary rocks (Johnson et al., 2001). Therefore, by identifying the coal petrographic composition and determining the paleoenvironment of the peat accumulation, it is possible to explain the coal composition and quality. This study was conducted to identify coal petrographic and chemical compositions of Seams III, IXG and X to explain the composition in relation to paleoenvironments.

GEOLOGICAL SETTING

The Baruunnaran coal deposit represents the far western part of the world class Tavantolgoi deposit, situated in the northeastern sector of the South Gobi Basin (ie. a concentration of Permo-Triassic coal-bearing transtensive sub-basins, Michaelsen and Storetvedt (2023) (Figs. 1a and 1b). The transtensive fault-bounded Tavantolgoi sub-basin is V-shaped and trending ENE with the main sub-basin extending for c. 26 km in strike length with a maximum width of c. 12 km (Michaelsen and Storetvedt, in press). It is further subdivided into several sections or micro -basins (Oortsog, Tsanki, Borteeg, Onch Kharaat, Bor Tolgoi, Ukhaakhudag and Baruunnaran) and was folded and faulted by normal, wrench and thrust faults as a result of transpression (Fig. 1c).

Extensive drilling results shows the Baruunnaran coal deposit is part of middle Permian Tavantolgoi Formation in the Naran valley. The NW and SE boundary faults of the Naran valley are aligned with volcano-sedimentary units of the middle and upper Devonian Tsetsgershand Formation and volcano -sedimentary unit of Silurian and lower Devonian Nomgon-Uul Formation to the SW. The basement of the coal deposit is the volcanic -sedimentary lower Permian Tsogttsetsii Formation. Importantly, the coal-bearing middle Permian sedimentary rocks of the narrow Naran valley are faulted and folded to a higher degree compared with the rest of the Tavantolgoi sub-basin. The axis of the syncline is trending approximately 2500, with steep dips of the northern limb (ie. vertical in places), whereas the southern limb dip moderately at c. 500 (Dumitru and Hendrix, 2001; Johnson et al., 2001).

The coal seams are hosted in the middle Permian coal-bearing Tavantolgoi Formation. In total, 21 coal seams) are preserved in the Baruunnaran deposit (Byambaa et al., 2022). The true thickness of the three studied coal seams III, IXG and X varies from 1.4 to 16.2 m.

The coals of the Baruunnaran deposit contain 1.52-3.55 wt.% total moisture content (average of 2.26 wt.%), and 3.64-32.66 wt.%, (average of 23.81 wt.%) ash content (ad. basis). The volatile matter content varies from 26.75 to 70.24 wt.%, average content is 32.61 wt.% (daf. basis). Total sulfur content values range from 0.52 to 1.25 wt.%, (average of 0.99 wt.%) with high calorific values ranging from 5,222 to 7,063 kcal/kg (average of 6,158 kcal/kg) (ad. basis). The coals of the Baruunnaran deposit are classified as coking (Ch4), fat (Ch5), 1/3 coking (Ch6), gas fat (Ch7) coals based on the Mongolian system and medium - high volatile A, B bituminous when using the ASTM system (Byambaa et al., 2022).

Lithostratigraphy of the Baruunnaran coal deposit

The Baruunnaran coal deposit is contained within the middle Permian coal-bearing Tavantolgoi Formation (Byambaa et al., 2022). The Tavantolgoi Formation was studied by Russian geologists in 1966, 1976 and 1978 and later by P.Khosbayar. The formation is divided into two sub-units; a lower and an upper. In this research we use the new integrated lithostratigraphy of the Baruunnaran coal deposit developed by Demberelsuren et al., (2021). The data was collected from four 312 - 882 m deep holes (drilled in 2015), which were drilled along the axis of the syncline (Fig. 1c and 3b). The new integrated lithostratigraphy is generally similar to the Khosbayar (1984) classification but is more detailed (Fig. 2a).

In general, the strata of the lower member consist of relatively fine-grained sedimentary

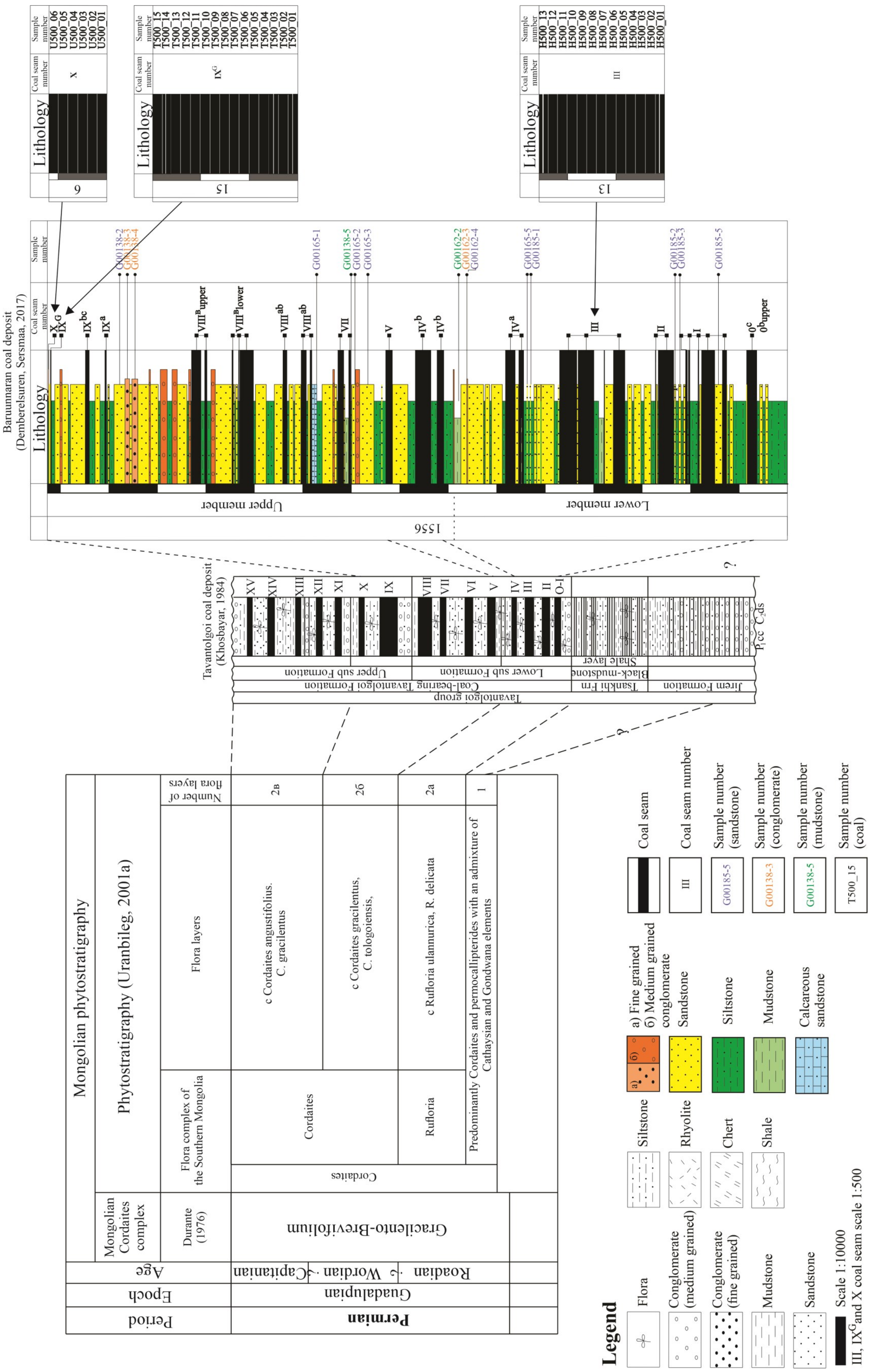
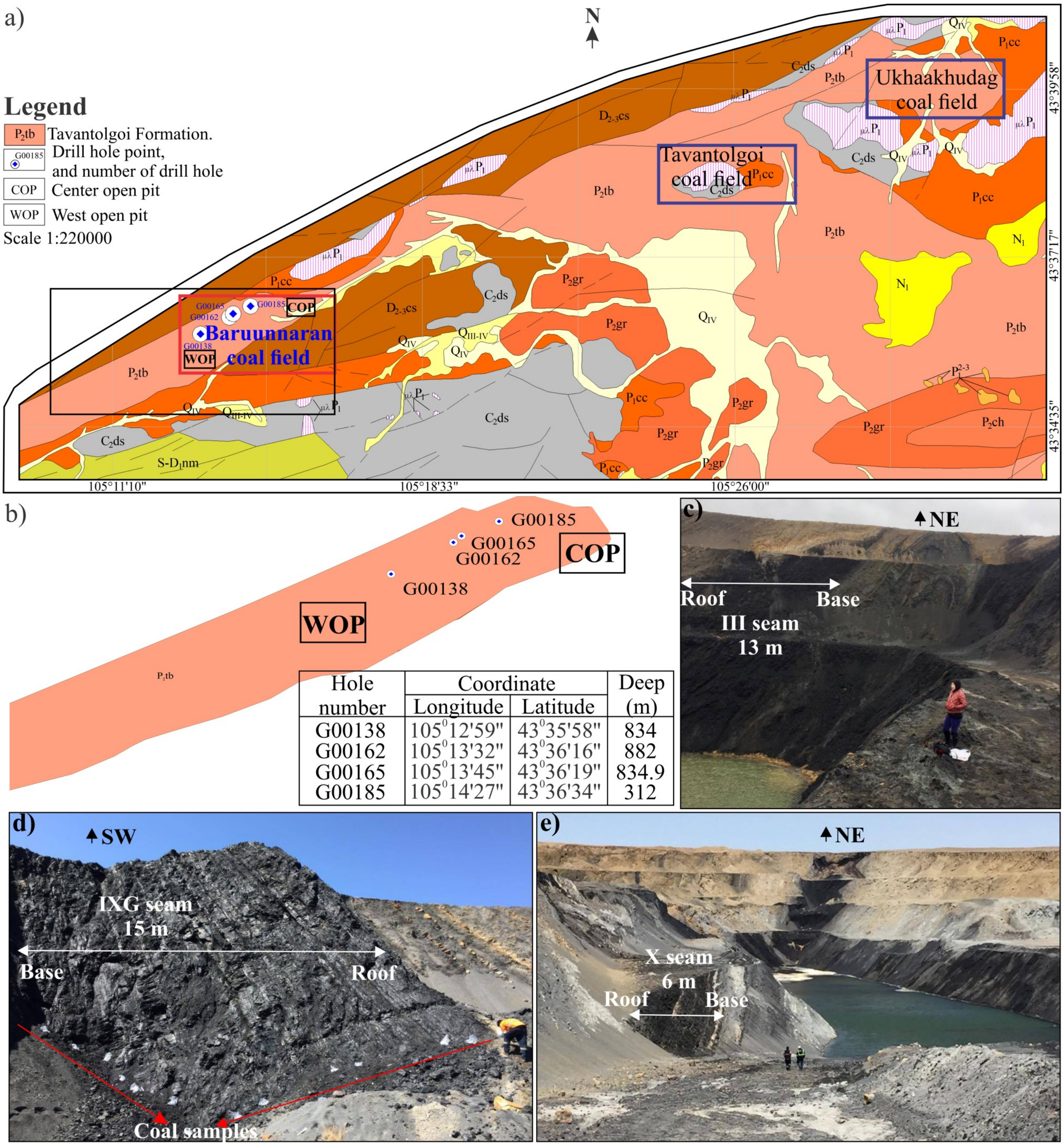


Fig. 2. a. The integrated lithostratigraphy of Baruunnaran coal deposit, which is compared with the Tavantolgoi Formation Lithostratigraphy (Khosbayar et al., 1984).

units interbedded with thick coal seams, whereas the upper member is characterized by coarser grained sediments interbedded with thinner coal seams (Fig. 2a). Seam III is contained within the lower member, and seams IXG and X in the upper member.

The age of Tavantolgoi Formation was established from macroflora, which is in general similar to that found in the central region of Angaraland (Durante, 1976; Uranbileg, 2003, Michaelsen and Storetvedt, in press).



Hole number	Coordinate		Deep (m)
	Longitude	Latitude	
G00138	105°12'59"	43°35'58"	834
G00162	105°13'32"	43°36'16"	882
G00165	105°13'45"	43°36'19"	834.9
G00185	105°14'27"	43°36'34"	312

Fig. 3. a) A location map of the Baruunnaran coal field; b) location map of Central and Western open pits; c) picture of seam III outcrop in the Central pit; d) picture of seam IXG outcrop in the Western pit, and e) picture of seam X seam in the Western pit.

SAMPLING AND METHODS

A total of 34 coal samples were collected from seams III, IXG and X. Seam III is exposed in the central open pit and seams IXG, and X are exposed in the western open pit of the Baruunnaran coal deposit (Fig. 3). Seam III is c. 13 m in true thickness. The true thickness of seams IXG and X are c. 15 and six m, respectively (Fig. 2a). The coal samples were collected from the base to the roof in one-meter intervals (Fig. 3). Thirteen coal samples (sample numbers H500_01-H500_13) were taken from seam III and 15 and six coal samples (sample numbers T500_01-T500_15 and U500_01-U500_06) were taken from seams IXG and X, respectively (Figs. 2a and 3).

The coal briquettes were prepared at the Mongolian Geological Central Laboratory and chemical composition (major elements) of coal ash were determined by X-ray fluorescence (XRF) analysis at the SGS Laboratory in Ulaanbaatar. Proximate analysis was performed in the laboratory of “Energy Resources” LLC.

The maceral analysis was carried out on prepared briquettes under reflected light using a MOTIC BA310 Pol Microscope in the laboratory of the Department of Geology and Geophysics, Faculty of Earth Sciences, National University of Mongolia. The coal sample ISO 7404-3 was used to determine maceral group content. The ICCP 1994 classification system for vitrinite, inertinite and liptinite was used to differentiate the macerals. The spacing between the counts was maintained at 0.2 mm and 400 counts were taken on each sample. ISO 7404-5 was used to measure vitrinite random reflectance.

The vitrinite random reflectance was measured on a FOSSIL #10 726 microscope with a LEICA DM4 P camera in the laboratory of “Energy Resources” LLC. The examination was conducted using a 20x magnification ocular lens under Zeiss oil immersion (518 N). The random vitrinite reflectance was measured from fifty points in each sample. The mean vitrinite random reflectance values were then calculated using the FOSSIL #10 computer program. The samples subjected to proximate analysis were analyzed to determine moisture, ash, volatile matter, and sulfur content. MNS GB/T 212:2015 was used to determine moisture, ash, and volatile matter content, and ISO 351:2001 was used to determine sulfur content.

RESULTS - MACROSCOPIC CHARACTERISTICS

Generally, bright, and dull banded coals are relatively rare within the Baruunnaran coal deposit and predominantly observed in coal seams III and IXG, X. The banded bright coals are contained in upper and lower part of seam III, in the lower part of seam IXG and the upper part of seam X, while the banded dull coal appears only in the middle part of seam IXG (Fig. 4).

Coal petrographic composition

The samples from seams III, IXG, and X are dominantly rich in macerals of vitrinite and inertinite, with subordinate liptinite macerals (ie. vitrinite 39.7-69.8 vol.%; inertinite 1.6-46.3 vol.%; liptinite 1.2-18.2 vol.%). Mineral matter in the studied samples are made up of clay, pyrite, carbonate, quartz and other minor components and varies from 1.5 to 17.5 vol.%.

Petrography of the Baruunnaran coal deposit presents follow-up of sequence results: telinite, collotelinite, vitrodetrinite and collodetrinite were identified from vitrinite maceral group; fusinite, semifusinite, funginite, secretinite, macrinite, micrinite and inertodetrinite were determined from inertinite maceral group and structured sporinite, cutinite and unstructured liptodetrinite were determined from the liptinite maceral group.

Vitrinite. Within the vitrinite group, macerals of telovitrinite and detrovitrinite subgroups were identified. Collotelinite is the most abundant maceral in the telovitrinite subgroup. Gelinite of the gelovitrinite subgroup was rarely observed. Collotelinite occurs as a structureless, homogeneous mass in thin and thick bands or lenses and its color ranges from light gray and gray (Figs. 5d and 7a). Telinite of the telovitrinite subgroup represent a minor part of seams III, IXG and X and occurs mostly as cell walls of variable sizes and shapes (Figs. 6d and 7b). Collodetrinite and vitrodetrinite in the subgroup of detrovitrinite are appeared.

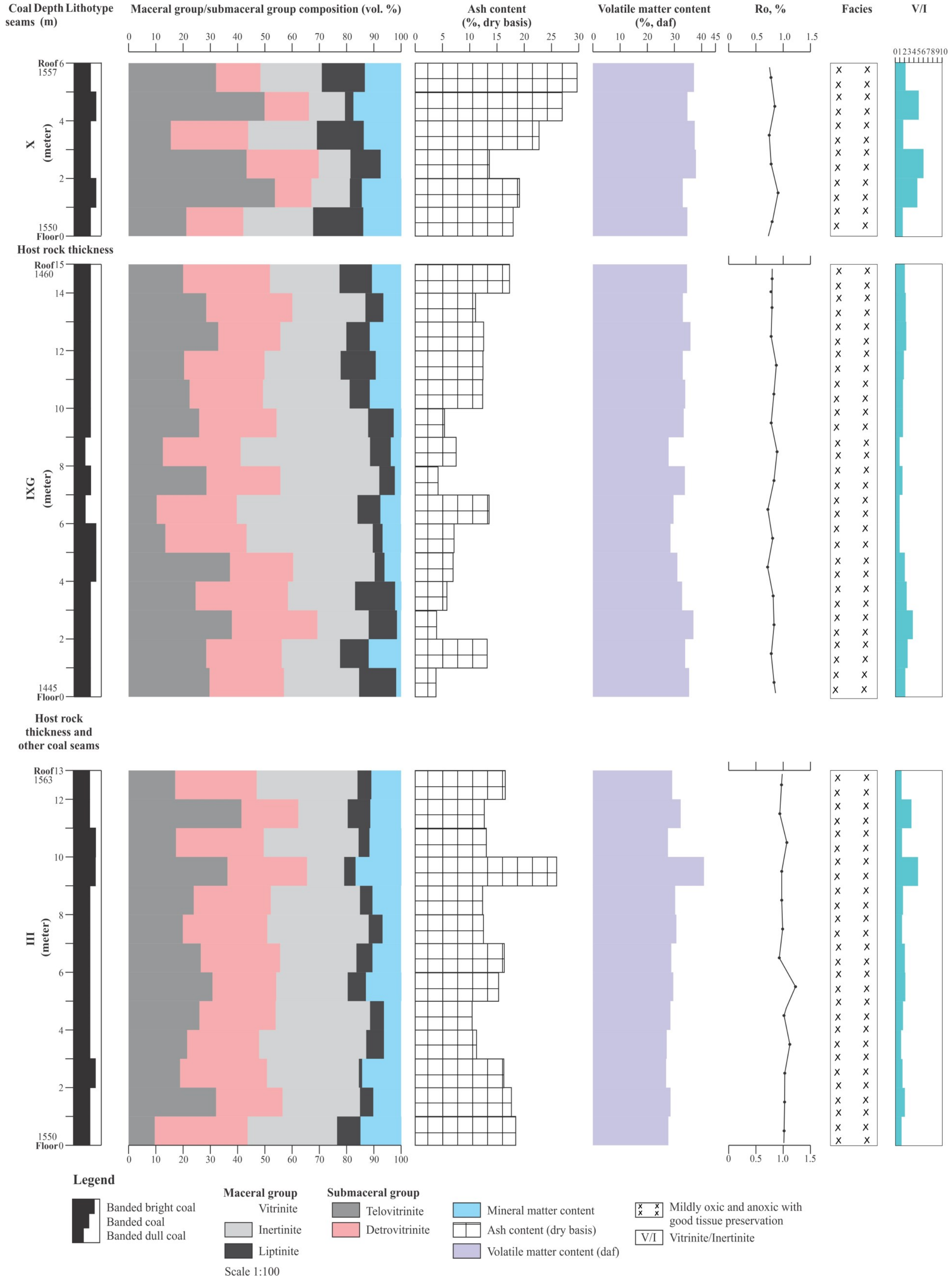


Fig. 4. Macropetrographic and microscopic (maceral and microlithotype) seam profiles, range of mean vitrinite reflectance (in oil), mean volatile matter content and variation in coal seam facies in coals of seams III, IXG and X.

Collodetrinite occurs in mottled structures and in the ground mass (Figs. 5a and 6B). Vitrodetrinite mostly occurs as rounded and elongated shapes in minor amounts.

Inertinite. fusinite is characterized by well-preserved cell structures with higher reflectance than other macerals of inertinite (Fig. 5c). Semifusinite cell lumens are filled with mineral matter, (mostly clay minerals (Fig. 6a). Funginite is rare in seams III and IXG and not present in seam X. It occurs mostly as single-celled structures and is oval rounded in shape (Fig. 7c). Macrinite occurs amorphous and structureless in the seams (Fig. 5d). Micrinite appear mostly as small elongated round shapes with high reflectance. Secretinite content is high in coals of of the Baruunnaran deposit. Secretinite occurs as angular elongated shapes in seam III and oval and rounded shapes in seams IXG and X. Also, it shows very high relief (Figs. 5b and 6e). Inertodetrinite occurs in small various shapes in seams III and IXG, and in eam X as white colored with high reflectance (Fig. 5b).

Liptinite. Generally, sporinite dominated in seams III and IXG, X and occurs as narrow elongated forms. The color of sporinite (ie. bright gray in seam III and gray in seams IXG and X suggest some degree of metamorphism (Figs. 5d and 6f). Cutinite occurs as elongated thread structures (Fig. 6c). Liptodetrinite occurs in small varying shapes.

The petrographic composition of seams III and IXG, X are briefly documented in the following.

Petrographic composition of seam III

The thirteen samples obtained from seam III were studied by coal petrography. The samples have attrite-fragmentary and fragmentary-basal structures and are dominated by vitrinite (43.6-65.5 vol.%), with subordinate inertinite (13.6-

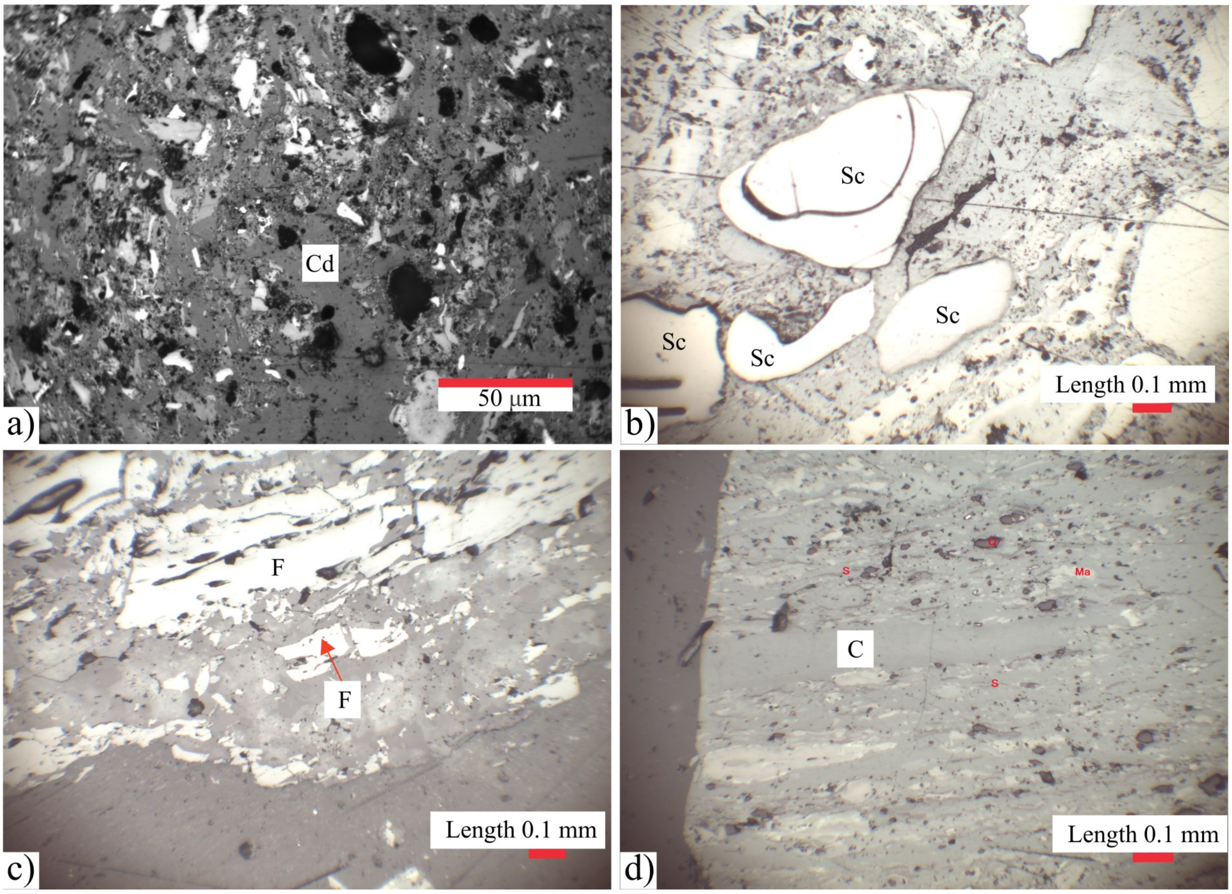


Fig. 5. Photomicrographs of macerals in coals of seam III. a photomicrographs representative under reflected white light and oil immersion. b, c and d photomicrographs representative under reflected white light. a) Cd-collodetrinite, b) Sc-secretinite, c) F-fusinite, d) C-collotelinite.

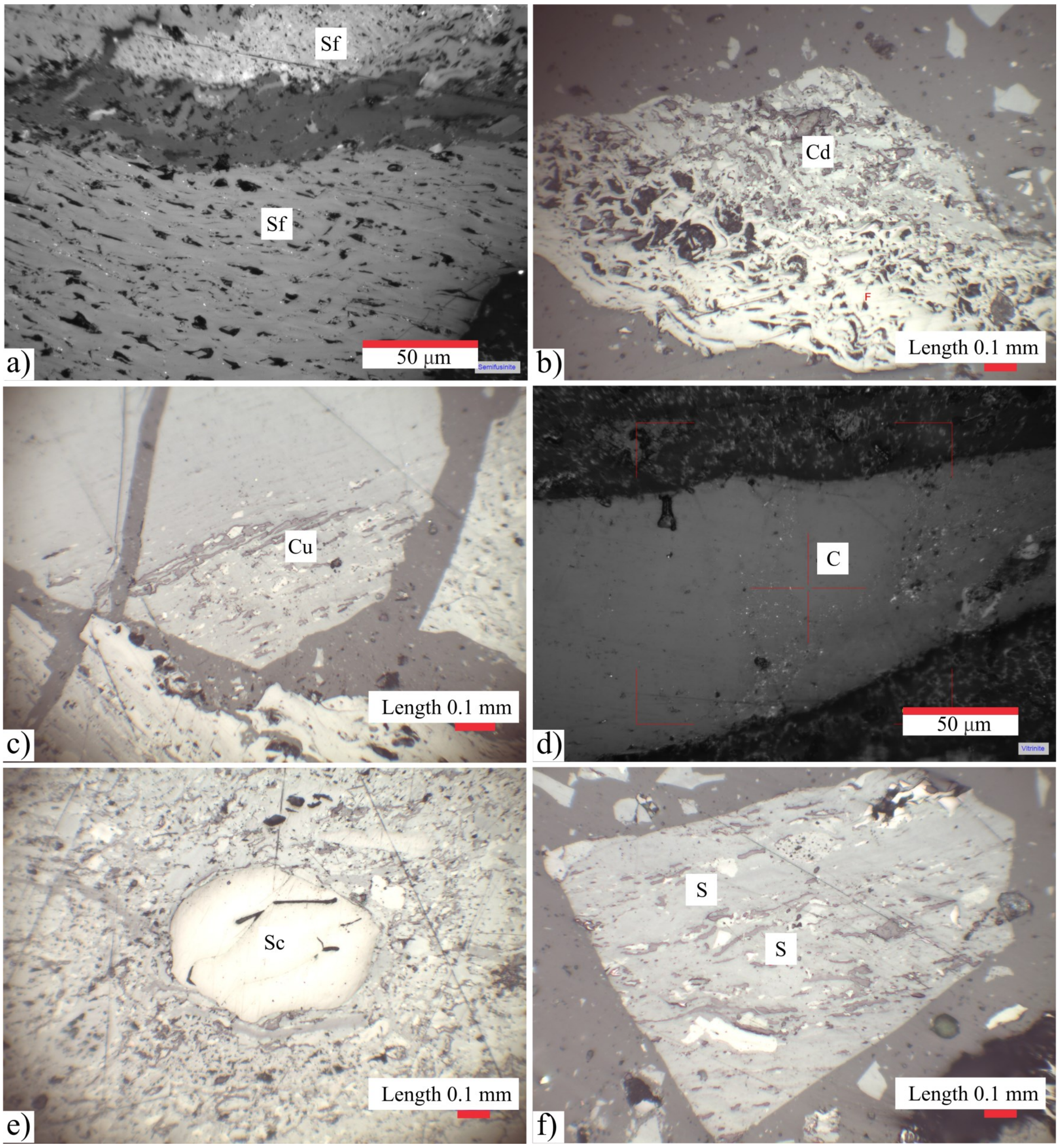


Fig. 6. Photomicrographs of macerals in coals from seam IXG. a, d photomicrographs representative under reflected white light and oil immersion. b, c, e and f photomicrographs representative under reflected white light. a) Sf-semifusinite, b) Cd-collodetrinite, c) Cu-cutinite, d) T-telinite, e) Sc-secretenite and f) S-sporinite.

39.3 vol.%) and liptinite (1.2-8.6 vol.%). Mineral matter ranges from 6.3-16.8 vol.% (Table 1 and Fig. 4).

Vitrinite. The vitrinite maceral group is dominated by collotelinite (6.8-39.0 vol.%) (Fig. 5d) and collodetrinite (21.7-34.5 vol.%) (Fig. 5a). Telinite (1.8-8.7 vol.%) and vitrodetrinite (0.3-1.6 vol.%) are less abundant.

Inertinite. From the inertinite macerals fusinite dominate (3.6-20.8 vol.%), (Fig. 5c). Funginite appears in minor amounts (0.2-0.3 vol.%). Secretinite ranges from 1.5-11.8 vol.% and generally decreases upwards in seam III (Fig. 5b). Semifusinite ranges from 1.8-6.1 vol.% and macrinite between 1.2 to 6.8 vol.% (Fig. 5d). Micrinite varies between 1.2-7.3 vol.%, inertodetrinite varies from 1.0 to 6.2 vol.% (Fig.

5b). Inertinite macerals are affected by partial allochthon processes.

Liptinite. Sporinite ranges from 0.6 to 4.4 vol.% (Fig. 5d), cutinite varies from 0.3 to 2.2 vol.%, and liptodetrinite varies from 0.5 to 3.4 vol.%. The sporinite appears with bright gray colors in the studied coal samples. It is noted that the color of sporinite, which suggests metamorphism, is higher than in seams IXG and X.

Petrographic composition of seam IXG

The petrographic analysis was completed on 15 coal samples taken from seam IXG and identified three different structures in the coal: structures of attrite-fragmentary, basal-fragmentary, and fragmentary-basal. The result of maceral group analysis for seam IXG are shown in Table 1 and Fig. 4. The samples from seam IXG show they are comprised of a large amount of vitrinite (39.7-69.2 vol.%) and inertinite (18.9-46.3 vol.%), as well as minor amount of liptinite macerals (3.6-14.3 vol.%). Minerals are found in a wide range between 1.5 and 11.9 vol.%.

Vitrinite. Collotelinite dominates in this group and varies from 1.9-32.5 vol.%; collodetrinite varies from 21.9-33.3 vol.% (Fig. 6b) with only minor telinite of 0.9-11.2 vol.% (Fig. 6d) and vitrodetrinite of 0.3-0.8 vol.%.

Inertinite. Fusinite varies from 2.0-18.3 vol.%, secretinite ranges from 2.1-11.8 vol.% (Fig. 6e) and macrinite varies from 2.6-17.6 vol.%. Only minor funginite was observed (0-0.3 vol.%). The low content of macrinite (0.5-0.9 vol.%) was identified in the lower part of this coal seam. Inertodetrinite content ranges from 0.6-5.6 vol.%.

Liptinite. Sporinite macerals dominate at 0.6-10.4 vol.% (Fig. 6f). Liptodetrinite varies from

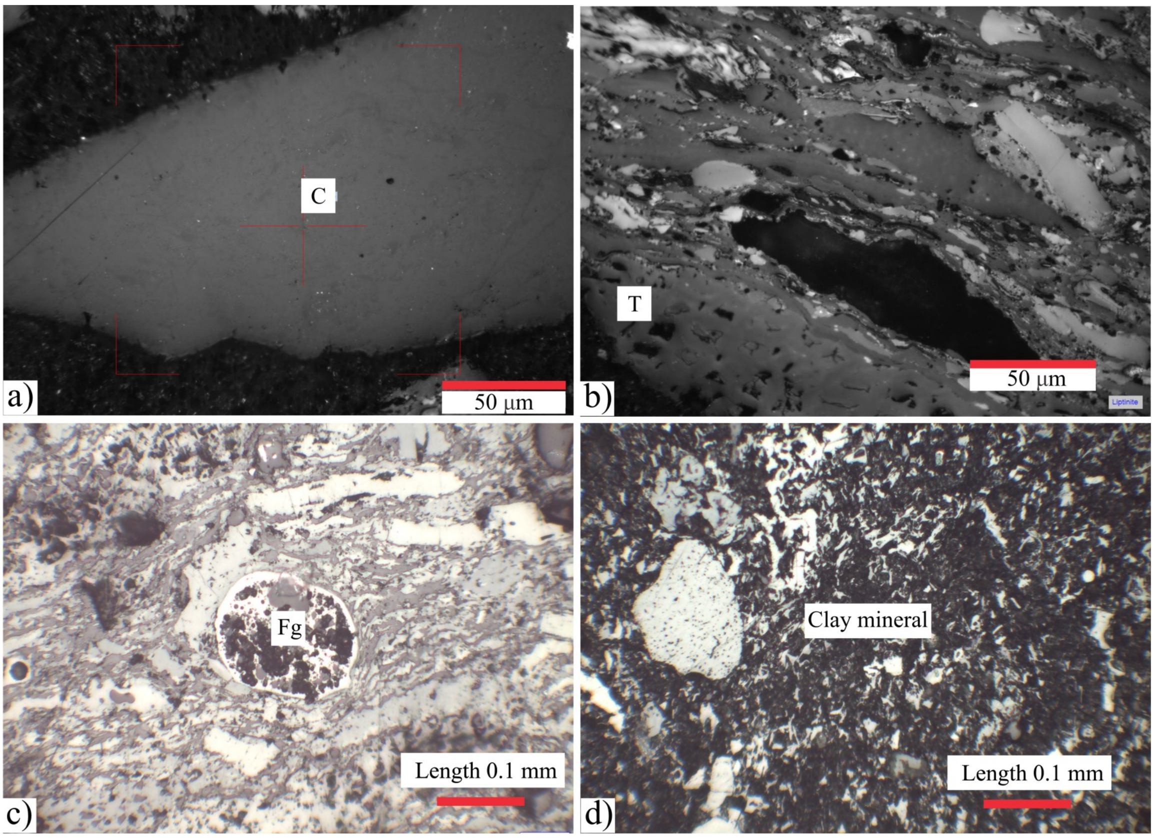


Fig. 7. Photomicrographs of macerals in coals from seam X. a and b photomicrographs representative under reflected white light and oil immersion. c and d photomicrographs representative under reflected white light a) C-collotelinite, b) Cd-collodetrinite, T-telinite, c) Fg-funginite and d) Clay minerals.

0.6-4.7 vol.% and cutinite ranges from 0.3-3.3 vol.% (Fig. 6c).

Petrographic composition of seam X

The result of coal petrography from the six studied samples from seam X identified basal-fragmentary and fragmentary-basal structures in the coal.

Vitrinite macerals dominate with 42.0-69.8 vol.%. Inertinite and liptinite macerals are low to moderate at 11.6-25.6 vol.% and 3.1-18.4 vol.%, respectively. The inertinite macerals of this seam are lower than inertinite macerals in seams III and IXG (Table 2 and Fig. 4). Mineral matter range from 7.5 to 17.5 vol.%. The vitrinite macerals content is generally similar to vitrinite macerals content in the two other studied seams. Collotelinite are abundant at 9.6-50.8 vol.% (Fig. 7a) with common collodetrinite (11.3-26.2 vol.%), while telinite are present in smaller amounts (2.5-7.3 vol.%) (Fig. 7b) and minor vitrodetrinite (0.3-1.9 vol.%).

Inertinite. Fusinite dominates in this group with 5.1-13.9 vol.%, with subordinate micrinite 2.6-5.2 vol.%, macrinite (0.3-3.0 vol.%), inertodetrinite (1.0-2.8 vol.%), semifusinite (0.3 -4.3 vol.%), secretinite (0.5-4.7 vol.%) and funginite (0.5-4.7 vol.%) (Fig. 7c).

Liptinite. Sporinite (1.5-9.5 vol.%) and cutinite (0.5-9.1 vol.%) are dominant with relatively minor liptrodetrinite (0.8-4.9 vol.%).

Mineral matter

Mineral matter content in the studied samples is in general low to moderate, ranging from 6.3 to 15.0 vol.% in seam III, 7.5-17.5 vol.% in seam X and 1.5-11.9 vol.% in seam IXG (Table 1 and Fig. 4). Clay, silica, carbonate minerals, pyrite and other minerals were observed in the studied samples from the three seams. The mineral matter mostly occurs as fillings of cell cavities, cracks, and fissures of vitrinite and inertinite macerals (Fig. 5d and 7d).

Table 1. Petrographic composition and ash content of coals from the Baruunnaran coal deposit

Petrographic composition	III coal seam	IXG coal seam	X coal seam
Maceral (vol.%)			
Telinite	1.8-8.7	0.9-11.2	1.7-5.9
Collotelinite	6.8-39.0	1.9-32.5	9.6-50.8
Total telovitrinite	9.6-41.4	10.3-37.9	15.5-53.7
Vitrodetrinite	0.3-1.6	0.3-0.8	0.3-1.9
Collodetrinite	21.9-34.5	22.5-35.5	12.3-27.9
Total detrovitrinite	20.9-34.1	22.8-33.9	13.4-28.4
Total vitrinite	43.6-65.5	39.7-69.2	42.0-69.8
Sporinite	0.6-4.4	0.6-10.4	1.5-9.5
Cutinite	0.3-2.2	0.3-3.3	0.5-9.1
Liptodetrinite	0.5-2.3	0.6-4.7	0.8-4.9
Total liptinite	1.2-8.6	3.6-14.7	3.1-18.2
Fusinite	3.6-20.8	2.0-18.3	4.9-13.9
Semifusinite	1.8-6.1	1.2-8.9	0.3-4.3
Funginite	0.2-0.3	0.3	0.0
Secretinite	1.5-11.8	2.1-11.8	0.5-5.7
Macrinite	1.2-6.8	0.5-3.6	0.3-3.0
Micrinite	1.2-7.3	2.6-17.6	2.6-5.2
Inertodetrinite	1.0-6.2	0.6-5.6	1.0-2.8
Total inertinite	13.6-39.3	18.9-47.5	11.6-25.3
Mineral matter (vol.%)			
Clay mineral	1.3-4.6	1.0-7.5	1.0-13.8
Siliceous mineral	0.5-5.5	0.3-3.4	1.3-4.0
Carbonate	1.0-11.3	0.3-4.6	0.8-6.7
Pyrite	0.3-3.8	0.3-2.9	0.7-2.3
Other minerals	0.1-0.6	0.1-0.3	0.3-0.4
Total mineral	6.3-16.8	1.5-11.9	7.5-17.5
Ash content (wt.%)	10.4-25.9	3.8-17.3	13.6-26.9

Carbonate minerals (1.0-11.3 vol.%) are common in coals of seam III, while siliceous minerals (0.5-5.5 vol.%) and pyrite (0.3-3.8 vol.%) appear to be higher in seam III than in seams IXG and X. Clay minerals in seam III (1.3-4.6 vol.%) are less than in the samples from seams IXG and X. Minor other minerals (0.1-0.6 vol.%) in seam III appear to be nearly equal to the content in seams IXG and X (Table 1). Clay (1.3-4.6 vol.%) and carbonate minerals (1.3-4.6 vol.%) dominate, while some minerals such as pyrite (1.3-4.6 vol.%), silica (1.3-4.6 vol.%) and other minerals (1.3-4.6 vol.%) in seam IXG are found in minor amounts (Table 2).

The clay (1.0-13.8 vol.%) and carbonate minerals (0.8-6.7 vol.%) are observed in higher amounts in seam X, whereas the content of pyrite, silica and other minerals are mostly the same as those in seam IXG (Table 1).

Microlithotype

The microlithotype of seams III, IXG, and X were determined by the ternary diagram of Bustin et al., (1983), which is classified on mineral matter free (mmf) basis. The coals of seams III IXG and X are classified as dominant trimaceralic microlithotype of duroclarite with low clarodurite, with a few coals classified as bimaceralic microlithotype of vitrinertite (Fig. 8).

Using the ternary diagram of Bustin et al. (1983) seams III, IXG, and X are classified as duroclarite microlithotypes; with those composed of high vitrinite maceral content ranging from 48.9-75.5 vol.% and inertinite maceral content from 12.6 to 40 vol.%, while liptinite maceral content ranges from 5.2 to 21.4 vol.% (ie. reported on mmf. basis).

The two samples from seam IXG plot in the field of clarodurite microlithotype, which is composed of vitrinite, inertinite and liptinite macerals. Nonetheless, coals of clarodurite microlithotype are composed of higher inertinite macerals than vitrinite macerals. While liptinite macerals contain higher than 5 vol.% in coals of clarodurite microlithotype. Also, three samples from seams III and X and two samples from seam IXG are classified as bimaceralic microlithotype of vitrinertite, which are characterized by dominant macerals of vitrinite and inertinite. Results show that the samples are composed of lower than 5 vol.% of liptinite macerals (Fig. 8).

The classification of microlitotype corresponds with the classification of lithothypes. Generally, the duroclarite microlithotype of seams III, IXG and X corresponds to the banded coals by maceral composition. It is noted that when vitrinite decreases, inertinite increases with liptinite around 5 vol.%. Otherwise, banded dull coals corresponds with clarodurite microlithotype coals. Also, banded bright coals conform with vitrinertite microlithotype coals. The coals are dominantly composed of vitrinite and generally the same in percentage as inertinite and lower <5 vol.% of liptinite macerals.

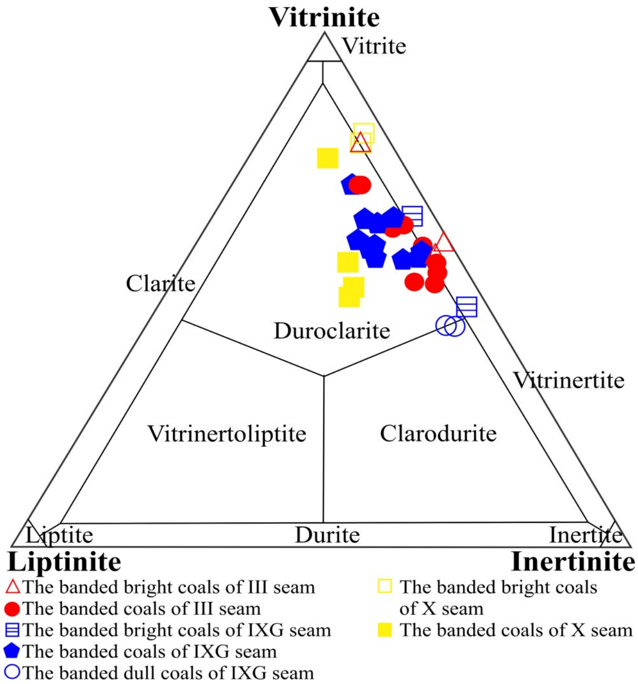


Fig. 8. Diagrammatic representation of microlothotype classification (Bustin et al., 1983).

Chemical composition

Seams III, IXG and X are chemically characterized by low moisture (0.61-2.07 wt.%) moderate to high volatile matter content (26.89-40.79 wt.%) and low to moderate ash content (3.81-26.97 wt.%). The proximate analysis is shown in Table 2 and Fig. 4.

The ash content ranges from 11.25 to 18.44 wt.% in seam III, whereas the ash content is

Table 2. Proximate analysis data from seams III, IXG and X

Sample №	Proximate analysis (ad. basis)		(daf. basis)
	M (wt.%)	A (wt.%)	VM (wt.%)
		III coal seam	
H500_01	1.32	18.44	27.71
H500_02	1.28	17.65	28.51
H500_03	1.08	16.25	26.89
H500_04	1.28	11.25	27.11
H500_05	1.35	10.44	28.46
H500_06	0.80	15.30	29.52
H500_07	0.85	16.34	28.79
H500_08	0.90	12.52	30.67
H500_09	1.00	12.36	30.21
H500_10	0.61	25.95	40.79
H500_11	1.17	13.05	27.57
H500_12	1.00	12.67	32.23
H500_13	1.00	16.52	29.11
		IXG coal seam	
T500_01	1.49	3.81	35.32
T500_02	0.92	13.20	33.87
T500_03	1.19	3.92	36.90
T500_04	1.35	5.82	32.74
T500_05	1.64	6.94	31.00
T500_06	1.84	7.12	28.47
T500_07	2.07	13.55	29.60
T500_08	1.68	4.19	33.77
T500_09	1.66	7.51	27.80
T500_10	1.66	5.37	33.35
T500_11	1.60	12.37	33.90
T500_12	1.63	12.43	32.99
T500_13	1.28	12.55	35.82
T500_14	1.41	11.06	33.03
T500_15	1.43	17.30	34.56
		X coal seam	
U500_01	1.51	17.97	34.67
U500_02	1.64	19.13	33.00
U500_03	1.31	13.60	37.82
U500_04	1.05	22.72	37.39
U500_05	1.64	26.97	34.71
U500_06	1.04	19.14	37.12

M-moisture, A-ash, VM-volatile matter

slightly higher in seam X at 13.6 to 26.97 wt.%, and Seam IXG has a wide range of ash content (3.81-17.30 wt.%) with high ash content found in the upper part of the seam (Table 2).

The samples from seams IXG and X have nearly the same percentage of volatile matter, varying from 27.8 to 36.9 wt.% and from 33.0 to 37.12 wt.%, respectively. The samples from seam III have lower volatile content (26.89-32.23 wt.%) compared with the other coal seams. The lower volatile content might be caused by metamorphism. The vitrinite reflectance is higher in the samples from seam III than seams IXG and X.

Coal rank

Seam III is preserved in the lower part of the Baruunnaran coal deposit (Fig. 2). In terms of metamorphism, the vitrinite reflectance of the samples from seam III is higher than in the overlying seams IXG and X (Table 3). Further, samples from seam III have vitrinite random reflectance values varying from 0.93 % to 1.23 % (mean value 1.02 %). That suggests that the samples from seam III, according to the ASTM system range between high volatile A bituminous and medium volatile bituminous rank, and in terms of the Mongolian system, 1/3 coking coal (Ch6), fat coal (Ch5), and coking

Table 3. Volatile matter content and vitrinite reflectance values coals from III, IXG and X seams

Coal seam number	Volatile matter (wt.%) (daf. basis)		R_{rand} (mean %)	
	Range	Mean	Range	Mean
III	26.86-40.79	29.81	0.93-1.23	1.02
IXG	27.80-36.90	32.87	0.71-0.88	0.81
X	33.00-37.82	35.79	0.74-0.91	0.81

coal (Ch4) (Table 4). Coals with slightly higher vitrinite reflectance are found in the lower part of seam III (Table 3 and Fig. 4).

The samples from seams IXG and X tend to be characterized by similar varieties of vitrinite random reflectance ranging from 0.71 % to 0.88 % (mean value 0.81 %) and from 0.74 % to 0.91 % (mean value of 0.81 %), respectively. Therefore, seams IXG and X are classified as gas fat coal (Ch7), 1/3 coking coal (Ch6), fat coal (Ch5), and coking coal (Ch4) by Mongolian standards, and high volatile B and high volatile A bituminous by the ASTM system (Table 3).

Major element composition of coal ash

The major elements data for the coal ash of the three studied seams is shown in Table 4. The ash of seam III is dominated by SiO_2 (21.3-56.2 wt.% and average of 42 wt.%), with subordinate Al_2O_3 (8.6-22.3 wt.% and average of 16.1 wt.%), SO_3 (2.9-7.7 wt.% with an average of 4.5 wt.%), CaO (6.9-31.4 wt.% and average of 15.3 wt.%), MgO (4.7-21.7 wt.% averaging 9.1 wt.%), TiO_2 (0.5-1.3 wt.% with an average of 0.9 wt.%) and P_2O_3 (0.1-14 wt.% averaging 2.6 wt.%). Minor content of K_2O (0.3-1 wt.% averaging 0.5 wt.%), Na_2O (0.01-0.3 wt.% with an average 0.03 wt.%) and Fe_2O_3 (0.7-6.5 wt.% and average of 2.9 wt.%). It was found that the content of MnO in this seam is just 0-0.1 wt.% and average 0.1 wt.% (Table 4).

In seam IXG the average contents of SiO_2 (40.1-83.9 wt.% and average 57.7 wt.%) and Na_2O (0.1-0.3 wt.% with average of 0.2 wt.%) which are higher than the average contents of SiO_2 and Na_2O in seam III. However, it is lower than the average SiO_2 and Na_2O content in the overlying seam X. The average contents of Al_2O_3 (12-36.6 wt.% and average 25.3 wt.%), Fe_2O_3 (2.3-13.8 wt.% average of 8.2 wt.%) and MnO (0.01-0.3 wt.% averaging 0.2 wt.%) in seam IXG are higher than the average contents of above oxides in seam III. However, the average contents of SO_3 (0.2-3.2 wt.% average 0.9 wt.%), CaO (0.2-3.7 wt.% averaging 1.7 wt.%), and MgO (0.2-0.5 wt.% with average of 0.4 wt.%) is lower compared to the average contents of SO_3, CaO and MgO in seam III. The average contents of TiO_2 (0.5-1.3 wt.% average of 0.9 wt.%) and P_2O_3 (0.1-14 wt.% averaging 2.6 wt.%) in seam IXG are close to the average contents of TiO_2 in seam III and lower than the average content of P_2O_3.

In seam X the average content of SiO_2 (77.7-86.5 wt.%, average 80.6 wt.%) in is relatively higher compared to the average content of SiO_2 in seams III and IXG. Al_2O_3 varies from 10-14.9 wt.% with an average of 13.2 wt.%, SO_3 ranges from 0.1-0.8 wt.% and average 0.3 wt.%, CaO varies from 0.2-0.3 wt.% and average 0.4 wt.%, Fe_2O_3 varies from 1.4-4.6 wt.% and average 2.4 wt.% and MnO ranges from 0-0.1 wt.% with average of 0.03 wt.%. The average values of Al_2O_3, SO_3, CaO, Fe_2O_3 and MnO are less than in seams III and IXG. TiO_2 varies from 0.5-0.9 wt.% and average 0.7 wt.%, P_2O_3 ranges from 0.1-0.7 wt.% and average 0.3 wt.%, MgO varies from 0.2-0.5 wt.% and average 0.3 wt.% in seam X, which is lower compared to the average values in seams III and IXG. The average content of Na_2O (0.1-0.2 wt.% and average of 0.2 wt.%) of seam X is close to the average content of this oxide in seam IXG, while it is slightly higher than the average content of Na_2O in seam III. The average contents of K_2O in seams III, IXG and X are similar (0.49 wt.%, 0.36 wt.% and 0.48 wt.%, respectively, Table 4).

In summary, seam III is characterized by relatively high values of CaO, MgO and SO_3, while seam IXG is characterized by high contents of Al_2O_3 and Fe_2O_3 which are probably due to clay-mica minerals, while seam X is characterized by high SiO_2 values due to siliceous and clay-mica minerals.

Table 4. Major elements concentration in weight percent for coal ash from seams III and IXG and X

Sample number	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	P_2O_5	SO_3	CaO	MgO	Na_2O	K_2O	MnO
					III coal seam (wt.%)						
H500_01	55.2	15.6	1	1.35	0.2	2.9	10.5	7.85	0.01	0.7	0.05
H500_02	54.1	16.9	1	5.15	0.15	4.55	7.7	5.65	0.01	0.95	0.1
H500_03	56.15	16.6	1	3.7	0.45	3.55	7.95	5.95	0.05	0.6	0.05
H500_04	54.3	20.1	1.15	1.85	1.3	5.55	6.85	4.7	0.05	0.55	0.05
H500_05	40.75	18.45	0.85	6.45	10.45	3.2	15.05	1.55	0.25	0.5	0.05
H500_06	37.4	13.95	0.85	1	0.9	4.85	18.1	13.35	0.01	0.35	0.05
H500_07	28.9	13.75	0.75	0.7	0.75	3.3	23.15	17	0.01	0.4	0.05
H500_08	54.1	22.25	1.25	1.35	0.3	4.15	7.2	5.3	0.01	0.55	0
H500_09	24.9	12.65	0.55	3.7	4.4	6.7	22.15	12.65	0.01	0.2	0.1
H500_10	21.35	8.6	0.5	3.25	0.1	3.35	31.4	21.65	0.01	0.4	0.1
H500_11	46.1	20.8	0.9	5.2	0.1	7.7	8.85	6.15	0	0.45	0.05
H500_12	36.25	19.3	0.7	2.6	0.8	5.75	15.75	11.15	0.01	0.45	0.05
H500_13	36.75	10.8	0.55	1.15	14	3	24.45	4.9	0.01	0.25	0.05
Average	**42.02**	**16.13**	**0.85**	**2.88**	**2.61**	**4.50**	**15.32**	**9.07**	**0.03**	**0.49**	**0.06**
					IXG coal seam (wt.%)						
T500_01	55.25	30.85	0.95	4.85	0.4	0.45	0.8	0.35	0.1	0.4	0.1
T500_02	56.85	34.15	0.95	5.55	0.25	0.2	0.3	0.25	0.1	0.55	0.1
T500_03	49.85	29	1	8.2	2.8	1.25	3.65	0.3	0.15	0.2	0.15
T500_04	52.35	30	1.3	11.6	0.7	0.55	0.7	0.3	0.2	0.25	0.3
T500_05	41.9	28.85	0.65	8	4.75	2.45	7	0.25	0.15	0.15	0.15
T500_06	40.05	25.8	0.8	13.45	1.6	0.6	2.25	0.45	0.2	0.2	0.4
T500_07	53.4	36.55	0.95	5.5	0.55	0.3	0.3	0.2	0.1	0.25	0.1
T500_08	47.9	25.15	1.3	13.8	1.35	3.15	4.2	0.35	0.15	0.35	0.4
T500_09	55.55	25.55	1.15	8.65	1.15	0.35	0.5	0.35	0.15	0.2	0.1
T500_10	62.15	20.9	1.05	10.85	0.7	0.95	1.1	0.4	0.2	0.35	0.05
T500_11	62.05	26.3	0.95	6.7	0.2	0.4	0.45	0.25	0.2	0.45	0.15
T500_12	63.95	20.95	0.95	8.8	0.3	0.45	0.45	0.3	0.1	0.45	0.2
T500_13	77.15	16.3	0.9	3.4	0.3	0.35	0.55	0.25	0.1	0.55	0.05
T500_14	62.85	16.75	0.7	11.25	0.8	1.8	3	1.15	0.25	0.65	0.15
T500_15	83.85	12	0.5	2.25	0.05	0.15	0.2	0.15	0.15	0.35	0.01
Average	**57.67**	**25.27**	**0.94**	**8.19**	**1.06**	**0.89**	**1.70**	**0.35**	**0.15**	**0.36**	**0.16**
					X coal seam (wt.%)						
U500_01	77.65	14	0.85	2.6	0.1	0.25	0.25	0.3	0.2	0.4	0.05
U500_02	81.6	14.45	0.7	1.85	0.1	0.15	0.15	0.25	0.1	0.35	0.05
U500_03	79.9	10.65	0.55	4.55	0.7	0.8	1	0.4	0.15	0.25	0.1
U500_04	86.45	10	0.45	1.35	0.25	0.15	0.25	0.2	0.15	0.3	0
U500_05	78.8	14.9	0.7	2.5	0.15	0.3	0.3	0.45	0.15	0.85	0
U500_06	79.2	14.85	0.8	1.75	0.35	0.1	0.3	0.35	0.2	0.7	0
Average	**80.60**	**13.14**	**0.68**	**2.43**	**0.28**	**0.29**	**0.38**	**0.33**	**0.16**	**0.48**	**0.03**
UCC	**66.6**	**15.4**	**0.6**	**5**	**0.1**		**3.6**	**2.5**	**3.7**	**2.8**	**0.1**

UCC-Upper Continental Crust (Rudnick and Gao, 2005)

Source rock composition of sedimentary rocks was determined by the ratio of oxides of Al and Ti, which are less soluble in natural water. If the Al_2O_3/TiO_2 ratio is <8, the source is considered to be mafic, if >20 it is felsic, and if it is between 8 and 21, the source rock is considered to have an intermediate composition (Hayashi et al., 1997). The value of Al_2O_3/TiO_2 ratio is 15-21 in 10 samples, 23-27 in 3 samples from seam III, 22-44 in 12 samples, 19-21 in 3 samples from seam IXG seam and 16-22 in samples from seam X ash. Based on this, it can be assumed that during the peat accumulation of seams III, IXG and X, weathering, and transport products (minerals and detrital sediments) were accumulated from volcanic source rock with intermediate and felsic composition.

Paleoenvironmental depositional conditions

The paleofacies, depositional settings and mire type of the three studied seams of the Baruunnaran coal deposit were determined in accordance with the scheme of Diessel (1986), which is based on petrographic facies indices.

This scheme has two parameters: Gelification Index (GI) and Tissue Preservation Index (TPI). The GI is a measure of the degree and persistence of wet conditions, whereas TPI is essentially a measure of the degree of tissue breakdown and the proportion of woody plants in the original peat forming assemblages (Diessel, 1986). As an example, if the Gelificatin Index (GI) value greater than one (>1) and Tissue Preservation Index (TPI) value greater than one (>1) in peat deposited under moist conditions and indicates that it originated from a woody plant.

The GI and TPI are derived from:

GI = Vitrinite + Macrinite/Semifusinite + Fusinite+Inertodetrinite

TPI = Telinite + Collotelinite + Semifusinite + Fusinite/Collodetrinite+Macrinite+Inertodetrinite

Coal facies diagrams for the samples from seams III, IXG and X are illustrated in Fig. 9. Based on the above calculations, the values of GI from seams III, IXG and X were determined to be between 1.70 and 10.0, and the TPI value between 1.0 and 5.0, respectively. That strongly

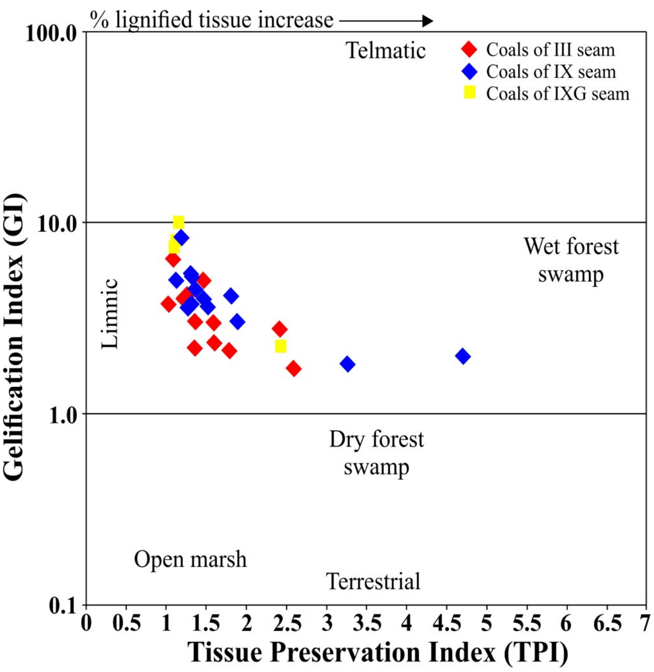


Fig. 9. Coal facies of seams III and IXG, X interpreted from the Gelification Index (GI) and Tissue Preservation Index (TPI) in relation to depositional setting and type of mire (after Diessel, 1986).

indicate that the peat was made up of wet forested swamp and woody plants with fluctuating water levels.

In another facies model (Fig. 10) proposed by Mukhopadhyay (1986) all coals are determined by maceral content and character of weak and strong gelification. Using this model, it was discovered that the peat developed in a mildly oxic to anoxic forest swamp characterized by good tissue preservation (Figs. 4 and 10).

SAL and IV factors: Estimates of the relationship between the content of silica-aluminum in coal ash and macerals of the inertinite and vitrinite groups were used to determine the ancient conditions of peat accumulation (Warbrooke, 1987). Table 5 shows the types of ancient peat mire of the Baruunnaran coal deposit determined by this calculation.

Silica-aluminum (SAL) and inertinite, vitrinite (IV) factors were determined by the calculation below.

$SAL=SiO_2 x100/SiO_2+Al_2O_3$

IV=Inertinite x 100/(Inertinite+Vitrinite)

The value of the silica-aluminum factor in seam III varies from 65.3 to 78.0 wt.%, whereas in seam IXG it ranges from 59.2 to 87.5 wt.%, and 84.2 to 89.6 wt.% in seam X. The value of the IV factor varies from 17.2 to 44.1 vol.% in seam III, from 21.5 to 53.6 vol.% in seam IXG and from 14.3 to 37.8 vol.% in seam X. From these values it was determined that the peats of seams III and IXG accumulated in forest swamps with alternating wet and dry conditions, while the peat of seam X seam was accumulated in wet forest swamps (Table 5).

Acidity of the peat mire (pH)

The environmental acidity in the ancient peat mires of Baruunnaran coal deposit was determined through the chemical composition of the coal ash and the acidity diagram of Kortenski (1986).

The pH coefficient (KA) was calculated using the following formula:

$KA=(SiO_2+Al_2O_3+SO_3+P_2O_5)/(CaO+MgO+Fe_2O_3+K_2O+Na_2O+MnO+TiO_2)$

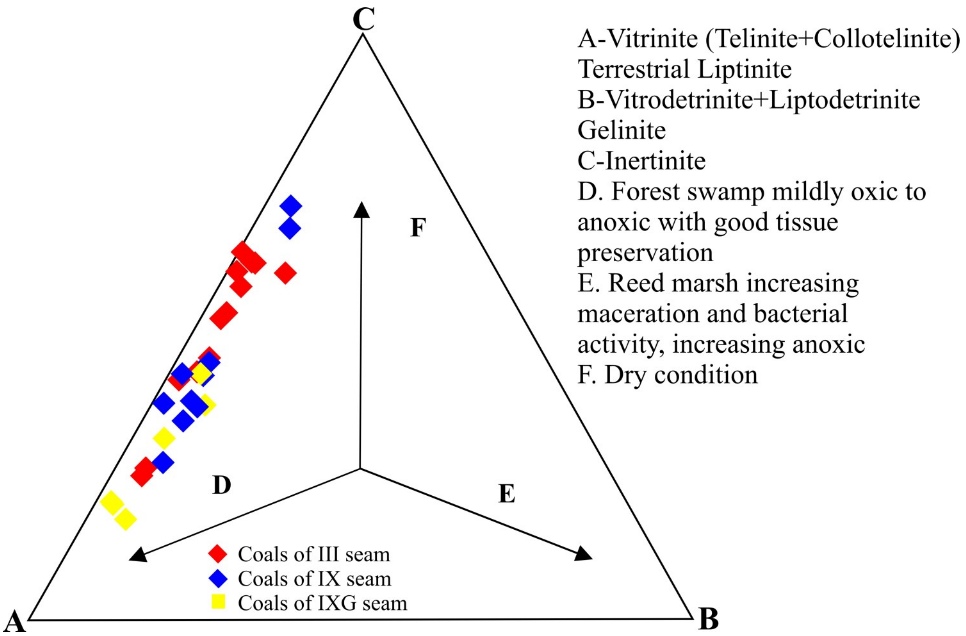


Fig. 10. Ternary diagram illustrating facies-critical maceral associations of the studied seams III, IXG and X and suggested peat forming environments (modified from Mukhopadhyay, 1986).

Table 5. Correlation of SAL and IV factors in ancient peat mire types of the Baruunnaran coal deposit (after Warbrooke, 1987)

Accumulation condition	Baruunnaran coal deposit	IV	SAL
Reed marsh		15-35	45-60
Fen		5-35	60-80
Wet forested swamp	Coals of X seam	5-35	80-90
Wet/dry forested swamp	Coals of III, IXG seams	35-65	65-85
Dry forested swamp		45-85	55-75

According to the calculation, the pH value of the ancient peat mire of seam III was 4-7, and the average value was 6. The pH value of seam IXG seam varies from 1.8-4.5, with an average of 2.9, and the pH of seam X varies from 1.8-2.9 and average 2.3. The results from the three studied seams show a general increase in acidity upward. The pH of the peat mire water of seam III was weakly acidic to neutral, the acidity of the IXG seam was acidic, and seam X seam was strongly acidic (Fig. 11).

It may be concluded that, the predominated carbonate and pyrite were precipitated in peat mires with weakly acidic to neutral (pH), when the peat of seam III accumulated. Clay-mica minerals were precipitated in peat mires with strong pH acidity during peat accumulation of seams IXG and X.

Some minerals can be introduced in a post-depositional type, for example $CaCO_3$, which can enter cleats after formation of the peat, so could be unrelated to the original peat acidity, but will still show up in the coal ash analysis. Therefore, Kortenski acidity estimation should be used with awareness. The samples from the studied Baruunnaran deposit were taken in small quantities (1-2 kg) from the mine wall and were crushed by hammering, thus it is likely that the minerals in the cleat were discarded. Also, the petrographic analysis shows that the carbonate minerals in the coal of III seam are associated with organics. Therefore, it is believed that the pH conditions of the peat mires of the III, IXG and X seams of Baruunnaran deposit are accurately determined by the Kortenski's calculation. In the future, using the Kortensky's calculation, pH conditions of the peat mire accumulation of the studied coals from the III, IXG and X seams of the Baruunnaran deposit can be tested using processed and unprocessed coal.

According to the ratio of macerals from seams III, IXG and X, the peat formed from woody plants, the peat of seams III and IXG accumulated in wet/dry forest swamps, and the peat of seam X accumulated in wet forest swamps. Also, peat forming condition of all the coal seams evolved under mildly oxic to anoxic conditions with good tissue preservation.

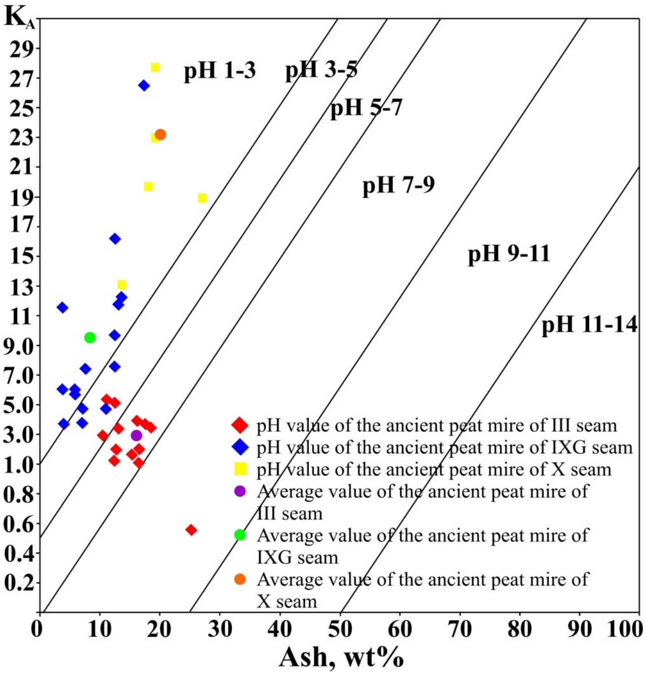


Fig. 11. Diagram of environment acidity in ancient peat mires (Kortensкi, 1986).

The ratio of vitrinite and inertinite (Fig. 4) from the three studied seams indicates the climate was humid during peat accumulation of seam III of the lower member. Later the climate changed and became relatively arid during accumulation of seam IXG from the upper stratigraphic member. However, during accumulation of the overlying seam X the climate appears to have changed again and became more humid. However, recent studies by Demberelsuren et al., (2021) of associated sandstone units (Fig. 2a), which included petrographic and geochemical analysis of whole rocks, suggest the lower stratigraphic member accumulated in semi-humid to semi-arid conditions whereas the upper member accumulated during semi-arid conditions.

Given the conflicting data from coal and sandstone samples it is noted that plant degradation is dependent only on the water table level of the peat mire. Moreover, no correlation was found between peat type, tectonic and/or climatic settings. Water table level and the degree of fluctuations are the only parameters which seem to have a good causative relationship with peat types. Climate can play a significant role in influencing mire type, however, there are no diagnostic effects of climate that can be ascribed to forming particular peat and thus coal types. This was shown by research on four modern bogs in New Zealand (Moore and Shearer 2003). Further, according to a study of the petrographic composition of tropical peat deposits from the Tasek Bera Basin, Malaysia, GI and TPI maceral ratio model illustrated erroneously that samples from the same depositional environment accumulated in different environments (Wüst et al., 2001). Therefore, it is advisable to clarify the climatic condition of the peat mire by palynological and other studies.

CONCLUSION

We have completed coal petrographic, chemical and coal ash geochemical analyses on coal samples taken from seams III, IXG and X of the middle Permian Baruunnaran coal deposit in southern Mongolia.

1. The content of the vitrinite group is similar in the three studied seams III, IXG and X (ie. averages of 53.1, 53.5 and 56.2 %, respectively). The average content of the inertinite group is 30.5 vol.% in seam III, increasing to 31.3 vol.% in seam IXG and decreasing to 18.7 vol.% in seam X. The content of liptinite group is 9 and 11.6 vol.% in seams IXG and X, and slightly lower (5.4 vol.%) in seam III. In seams III and X the average content of mineral matter is c. 11 and 13.4 vol.%, and lower in seam IXG (6.3 vol.%).
2. The vitrinite reflectance value of the three studied seams varies from 0.81-1.07 %, indicating the degree of coalification has increased with depth. Moisture content in

seams III, IXG and X varies from 0.61-2.07 wt.%, ash content ranges from low to moderate (3.8-26.97 wt.%) and volatile matter from 26.89-40.79 wt.%. The seams are classified as gas fat coal (Ch 7), 1/3 coking coal (Ch6), fat coal (Ch5), and coking coal (Ch4) by Mongolian standards, and range between high volatile B, A and medium volatile A bituminous by the ASTM system.

3. The three studied coal seams III, IXG and X of the Baruunnaran deposit were classified into vitrinertite, duroclarite and clarodurite microlithotype, which are dominated by the vitrinite group and contains a certain amount of inertinite and liptinite groups. The peat formed from woody plants with the peat of seams III and IXG accumulated in wet/dry forest swamp, and the peat of seam X accumulated in a wet forest swamp. Therefore, peat forming conditions for most of the coal seams evolved under mildly oxic to anoxic conditions with good tissue preservation. The content of CaO, MgO and SO_3 in coal ash of seam III was considered to be related to the content of carbonate (4.3 vol.%) and pyrite (1.2 vol.%), while the high content of Al_2O_3, Fe_2O_3 in coal ash of seam IXG was related to the content of clay-mica minerals (3.8 vol.%). Moreover, the high content of SiO_2 in coal ash of seam X was considered to be related to high content of clay-mica minerals. It may be concluded that, the dominating carbonate and pyrite were precipitated in the peat mire water of seam III with weakly acidic to neutral pH, with clay-mica minerals precipitated in the peat mire water of seams IXG and X with strong acidity (pH).
4. It was determined that the source rock of minerals and detrital sediments using the Al_2O_3/TiO_2 ratio was volcanic rocks with intermediate and felsic composition. However, the content of gelified and fusinized macerals in seams III, IXG and X and composition and amount of minerals and detrital sediments transported to the peat mire differed due to climatic conditions during accumulation. The climatic conditions during peat mire deposition should be further clarified by palynological and other studies.

ACKNOWLEDGEMENTS

We are grateful to Associate professor, Dr. G.Sersmaa and Dr. B.Erdenetsogt for their discussions and helpful suggestions. We also thank managers and specialist 'SGS' laboratory for their help with analysis of the chemical composition of coal ash. We are grateful to Dr. M.Ariuntogos for teaching us about some professional programs which were a great help for making this paper. Further, we greatly acknowledge Dr. P.Michaelsen, Geoscience center, MUST, for discussions and review of the manuscript.

REFERENCES

Bat-Erdene, D. 1992. Nature of distribution and formational condition of coal basins in the Mongolian orogenic belt. Summary of Sc.Dr. thesis. Moscow, p. 6-52 (in Russian)

Bustin, R.M., Cameron, A.R., Grieve, D.A., Kalkreuth, W. 1983. Coal Petrology Its Principles, Methods, and Applications: Geological Association of Canada. Short Course Notes, v. 3, p. 248.

Byambaa, B., Tsolmon, A., Uranbayar, Ch., Bekhbat, P., Avirmed, Kh. 2022. Report on the results of additional exploration work and reserve of resources performed in 2018 and 2020 in the Ukhaakhudag coking coal deposit, v. I, p 130-138.

Demberelsuren, B., Jargal, L., Munkhtsengel, B. 2021. The coal facies interpretations in the Baruunnaran coal deposit, Southern Mongolia. Geology journal of School of Geology and Mining Engineering, Mongolian University of Science and Technology, v. 36, p. 120-137. (in Mongolian)

Diessel, C.F.K. 1986. On the correlation between coal facies and depositional environments. Advances in the study of the Sudney Basin, Proceedings 20th symposium, Newcastle, Australia, p. 19-22.

Díez, M.A., Alvarez, R., Barriocanal, C. 2002. Coal for metallurgical coke production: Predictions of coke quality and future requirements for cokemaking. International Journal of Coal Geology, v. 50(1-4), p. 389-412. https://doi.org/10.1016/S0166-5162(02)00123-4

Dumitru, T.A., Hendrix, M.S. 2001. Fissiontrack constraints on Jurassic folding and thrusting in southern Mongolia and their relationship to the Beishan thrust belt of northern China. In Hendrix, M.S., Davis, G.A. (eds), Paleozoic and Mesozoic tectonic evolution of central Asia: From continental assembly to intracontinental deformation. Geological Society of America Memoir 194, p. 215–229. https://doi.org/10.1130/0-8137-1194-0.215

Durante, M.V, 1976, Carboniferous and Permian stratigraphy of Mongolia on the basis of paleobotanical data: Nauka, Moscow, v. 19, p. 279 (in Russian).

Hayashi, K.L., Fujisawa, H., Holland, H.D., Ohmoto, H. 1997. Geochemistry of approximately 1.9 Ga sedimentary rocks from northeastern Labrador, Canada. Geochemica et Cosmochimica Acta, v. 61 (19), p. 4115-4137. https://doi.org/10.1016/S0016-7037(97)00214-7

ICCP system 1994. International Committee for Coal and Organic Petrology, 1998. The new vitrinite classification Fuel 77, 349-358. https://doi.org/10.1016/S0016-2361(98)80024-0

ICCP system 1994. International Committee for Coal and Organic Petrology, 2001. The new inertinite classification. Fuel 80, 459-471. https://doi.org/10.1016/S0016-2361(00)00102-2

ISO 351, 2001. International Standard. Method of determining sulfur content.

ISO 7404-2, 2009. International Standard. Methods for the petrographic analysis of coals-Part 2: Methods of preparing coal samples.

ISO 7404-3, 2009. International Standard. Methods for the petrographic analysis of coals-Part 3: Method of determining maceral group composition.

ISO 7404-5, 2009. International Standard. Methods for the petrographic analysis of coals-Part 5: Method of determining microscopically the reflectance of vitrinite.

Jargal, L., Kuznetsova, A. A., Tserensodnom, P., Erdembat, L., 1990, Petrographic character of coals from major coal seam of Tavan Tolgoi deposit, in Geology and Mineral deposits of Mongolian People's Republic: Nedra, Moscow,158–163 (in Russian)

Johnson, C.L., Webb, L.E., Graham, S.A., Hendrix, M.S., Badarch, G. 2001. Sedimentary and structural records of late Mesozoic high-strain extension and strain partitioning, East Gobi basin, southern Mongolia. In Hendrix, M.S., Davis, G.A. (eds), Paleozoic and Mesozoic tectonic evolution of central Asia: From continental assembly to intracontinental deformation. Geological Society of America Memoir 194, p. 413–433. https://doi.org/10.1130/0-8137-1194-0.413

Khosbayar, P., Byambaa, B., Dorj, Ts., Tumurbaatar, P. 1984. Results of geological mapping 1:50000 scale conducted in the territory around coal deposit Tavan Tolgoi, South Gobi during 1982-1983. Geological Information Center, Mongolia, Report #3740.

Kortenski, J. 1986. Opredelyane na mineralite vav vaglistata ot Sofiiskiya basein chrez rezultatite ot silikatniya analiz. (Determination of the mineral types from the Sophia Basin through the result of the silicate analysis). Annual Book of Higher Institute of Mining and Geology, 32 (2), 179-191 (in Bulgarian with English and Russian abstract).

Lin, M.Y., Tian, L. 2011. Petrographic characteristics and depositional environment of the No. 9 Coal (Pennsylvanian) from the Anjialing Mine, Ningwu Coalfield, China. Energy Exploration & Exploitation, v. 29(2), p. 197-204. https://doi.org/10.1260/0144-5987.29.2.197

Michaelsen, P. and Storetvedt, K.M. (in press). Protracted destabilization and collapse of peat mire ecosystems at the Permo-Triassic boundary recorded by a sequence of related transtensive sub-basins in central and southern Mongolia. Permophiles.

Michaelsen, P., Storetvedt, K.M. 2023. Tectonic evolution of a sequence of related late Permian transtensive coal-bearing sub-basins, Mongolia: A global wrench tectonics portrait. Mongolian Geoscientist, v. 28(57), p. 1-53. https://doi.org/10.5564/mgs.v28i57.3200

MNS GB/T 212, 2015. Mongolian standard. Proximate analysis of coal. Methods of determining moisture, ash, and volatile matter contents.

Moore, T.A. Shearer, J.C. 2003. Peat/coal type and depositional environment-are they related? International Journal of Coal Geology, v. 56(3-4), p. 233-252. https://doi.org/10.1016/S0166-5162(03)00114-9

Mukhopadhyay, P.K. 1986. Petrography of selected Wilcox and Jockson Group lignites from Tertiary of Texas. In Finkelman, R.B., Casagrade, D.J (Eds.), Geology of Gulf Coast Lignites. United Kingdom, p. 126–145.

Rudnick, R.L, Gao, S. 2005. Composition of the Continental Crust. Treatise on Geochemistry. v. 3, p. 1-64. https://doi.org/10.1016/B0-08-043751-6/03016-4

Uranbileg, L. 2003. The new plants of Upper Permian coal deposits in southern Mongolia. Mongolian Geoscientist, v. 23, p. 47-50.

Warbrooke, P.R. 1987. Depositional and chemical environments in Permian coal forming swamps from the Newcastle area. Advances in the Study of the Sydney Basin, 21 Symposium Proceedings, Newcastle. p. 1-10.

Wüst, R.A.J., Hawke, M.I., Bustin, R.M. 2001. Comparing maceral ratios from tropical peatlands with assumptions from coal studies: do classic coal petrographic interpretation methods have to be discarded? International Journal of Coal Geology, v. 48(1-2), p. 115-132. https://doi.org/10.1016/S0166-5162(01)00050-7