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**Original Article**

## Maceral composition, coal quality and depositional environments of the middle Permian Ukhaakhudag coal deposit, South Mongolia

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**ABSTRACT**

The Ukhaakhudag coal deposit is located c. 560 km SSE of the city of Ulaanbaatar in the northeastern sector the South Gobi Basin. The coal-bearing strata is part of the middle Permian Tavantolgoi Formation. This study aims to determine the coal petrographic composition and depositional environments of five coal seams in the lower part of the deposit based on petrographic and chemical analyses of 106 composite samples. Vitrinite ranges from 12 to 64 vol.%, and inertinite varies between 9 and 68 vol.%. Liptinite ranges from 1 to 7 vol.%. Microlithotype analyses indicate that coals are primarily vitrinertite, few coals are classified as trimaceralic microlithotypes duroclarite and clarodurite. The inorganic fraction in the studied coals is mainly composed of clay, small amounts of silica, carbonate, and pyrite minerals. The vitrinite random reflectance values of the samples vary between 0.93-1.16 %. Volatile matter content varies from 26.10 to 41.48 wt.% (dry ash free basis). Ash, moisture, and sulfur contents vary between 11.20-44.76 wt.%, 1.63-6.03 wt.% and 0.49-1.67 wt.%, (air dried basis) respectively. Based on random vitrinite reflectance values and volatile matter content, the studied coals are classified as coking (Ch4), fat (Ch5), 1/3 coking (Ch6), gas fat (Ch7) based on the Mongolian system and medium to high volatile bituminous coal when using the ASTM system. The Gelification Index and Tissue Preservation Index of the studied samples suggest most seams accumulated in wet forest swamps with a high tree density. The Middle Permian peats from this location accumulated in mostly alternate oxic and anoxic mire conditions. The climate was drier during the peat accumulation of Seam 0, but it became warmer, and humidity increased starting from Seam 3 accumulation.

***Keywords:*** Coal measures, organic petrology, coal facies, depositional setting

## INTRODUCTION

The Ukhaakhudag coal deposit is located c. 560 km southeast of Ulaanbaatar city, c. 90 km east of Dalanzadgad the provincial capital of the South Gobi and c. 10 km SW of Tsogttsetsii soum. The Ukhaakhudag coal deposit represent the northern 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) (Fig. 1a).

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 of 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, 14 coal seams and 49 coal plies are preserved in the Ukhaakhudag deposit

(Byambaa et al., 2022). Most seams of the Ukhaakhudag coal deposit have coking properties. The coals were analyzed for petrographic composition, vitrinite reflectance and proximate analyses. At the Ukhaakhudag mine site, coal seams are blended and washed by using heavy medium cyclone, spiraling, and froth flotation methods.

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 (Díez et al., 2002). One of the most important factors on coal properties is the depositional environment, which determines the composition and preservation of the peat (Lin and Tian, 2011; Dai et al., 2020). Teichmüler (1982) defined 'coal facies' as primary genetic types of coal, which are dependent on the paleoenvironmental conditions under which precursor peats accumulate. Therefore, by identifying the coal petrographic composition and determining the paleoenvironment of the peat accumulation, it is possible to understand coal composition and quality variation.

Beginning 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 conducted a study of the coal petrographic composition of the Baruunnaran deposit (Byambaa et al., 2022). Beginning in 2017, paleoenvironmental studies of peat accumulation began in the Baruunnaran deposit (Demberelsuren, 2021). Previous coal petrographic, chemical and coal ash chemical analysis of plies H500, T500 and U500 of the Baruunnaran deposit determined the

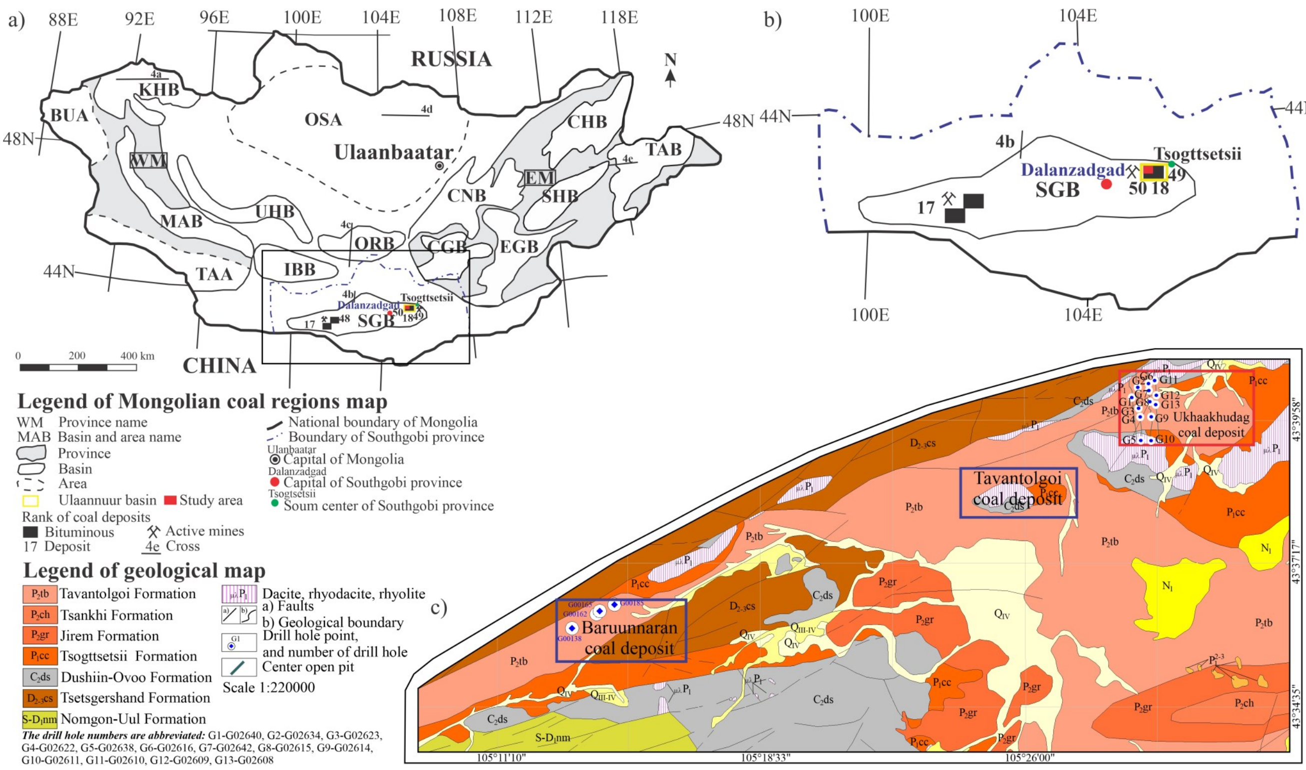



**Fig. 1.** a) Location map of the study area and Mongolian coal-bearing provinces, basins, and deposits (modified after Bat-Erdene, 1992). Provinces: WM-Western Mongolia; EM-Eastern Mongolian; Basins; KHB-Kharkhiraa; MAB-Mongol-Altai; SGB-South Gobi; UHB-South Khangai; IBB-Ikh Bogd; ORB-Ongi River; 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)

paleoenvironment of peat accumulation. Previous results of coal petrography revealed that Seams III and IXG of Baruunnaran deposit are composed of vitrinite (48-71 % and 47-80 % mmf. basis, respectively) and inertinite (14-39 % and 19-48 % mmf. basis, respectively). The concentration of liptinite range from 1 to 9 % and 4 to 15 % (mmf. basis, respectively). Compared to other seams, seam X is characterized by lower content of inertinite (12-25 % mmf. basis) and higher content of liptinite (3-18 % mmf. basis). The vitrinite content varies from 60-81 % (mmf. basis). The average mean of the vitrinite reflectance is 0.81 % in Seams IXG and X, and 1.02 % in the lower Seam III of the Baruunnaran deposit (Demberelsuren, 2021).

Most seams of the lower section of the Ukhaakhudag deposit have coking properties. Therefore, this study was conducted to identify coal petrographic and chemical compositions of Seams 0, 3, 4, 5 and 6 and to explain the composition in relation to paleoenvironments.

## GEOLOGICAL SETTING

The Ukhaakhudag deposit represents the northern part of the Tavantolgoi deposit, situated in the northeastern sector of the South Gobi Basin (ie. a concentration of Permo-Triassic transtensive sub-basins, see Michaelsen and Storetvedt (2023) (Fig. 1a). 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 is folded and faulted by normal, wrench and thrust faults (Fig. 1c).

The coal of the Ukhaakhudag deposit is located

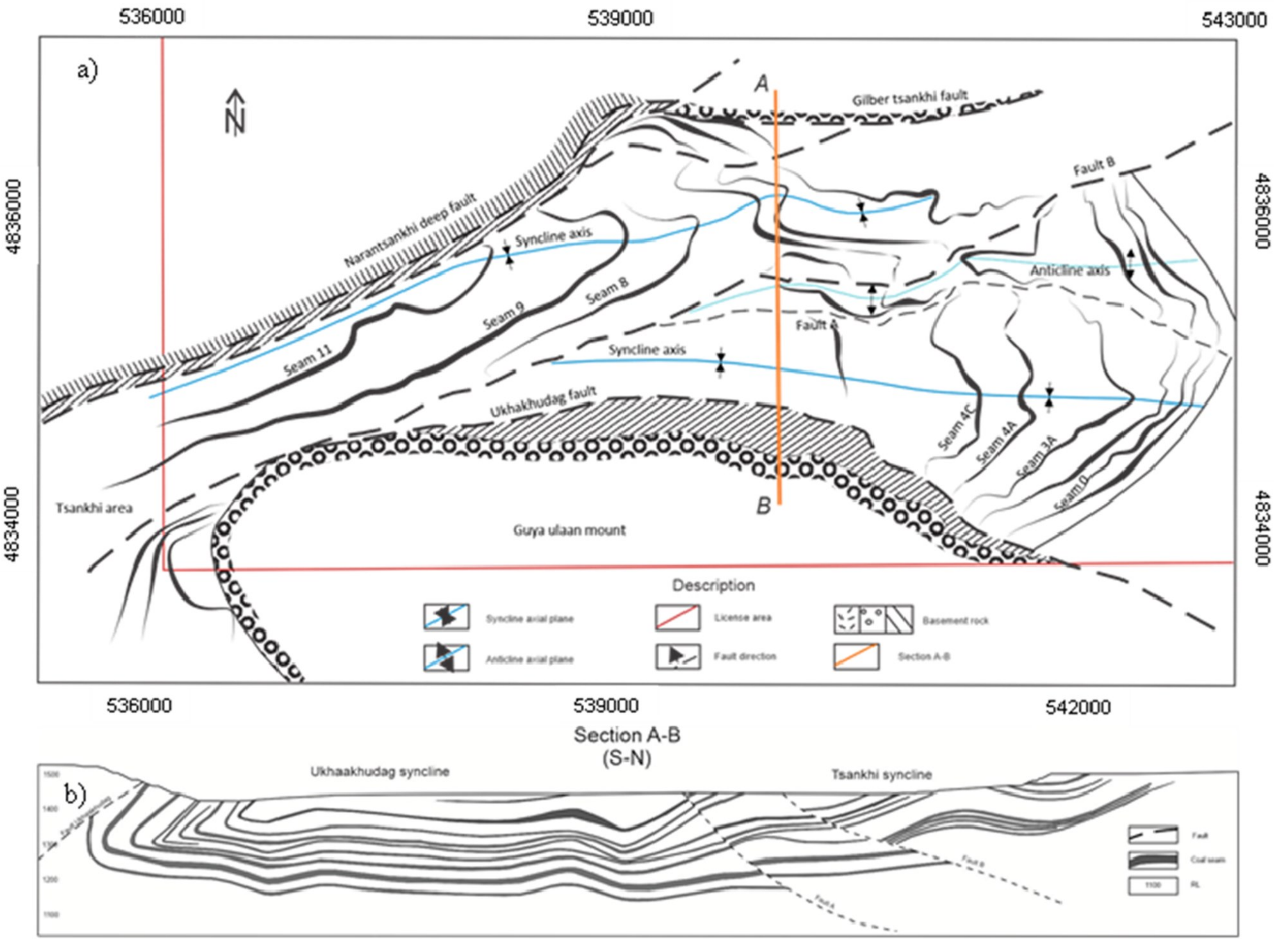



**Fig. 2.** a) Structural outline of the Ukhaakhudag deposit. b) Cross-section line A-B

in an asymetrical synclinal structure. The Ukhaakhudag micro-basin is controlled by the deep Naran Tsankhi fault in the west, the Gilber Tsankhi fault in the north and the Ukhaakhudag fault to the south. The Ukhaakhudag deposit is cut by several reverse B faults, and the deposit is further divided into two: the northern and southern part of the Tsankhi micro-basin (Fig. 2). The Tsankhi micro-basin is bounded by the deep Naran Tsankhi fault to the northwest, and reverse B fault and the Ukhaakhudag fault to the southeast. The Ukhaakhudag deposit is bounded by the Ukhaakhudag wrench fault to the south.

In the eastern part of the deposit the limb dips at c. 5-15o from east to west, while the western limb dips at c. 20-35$^{o}$ to the northwest (Fig. 2). The NE and SE margins of the Ukhaakhudag micro-basin is in contact with volcano-sedimentary units of the lower Permian Tsogttsetsii Formation (Fig. 3) and it borders volcano-sedimentary upper Carboniferous Dushiin-Ovoo Formation and volcanic lower Permian rocks to the NW and SW (Fig. 1c). Fig. 3 shows the stratigraphy of the Ukhaakhudag deposit.

The coal of the Ukhaakhudag deposit is

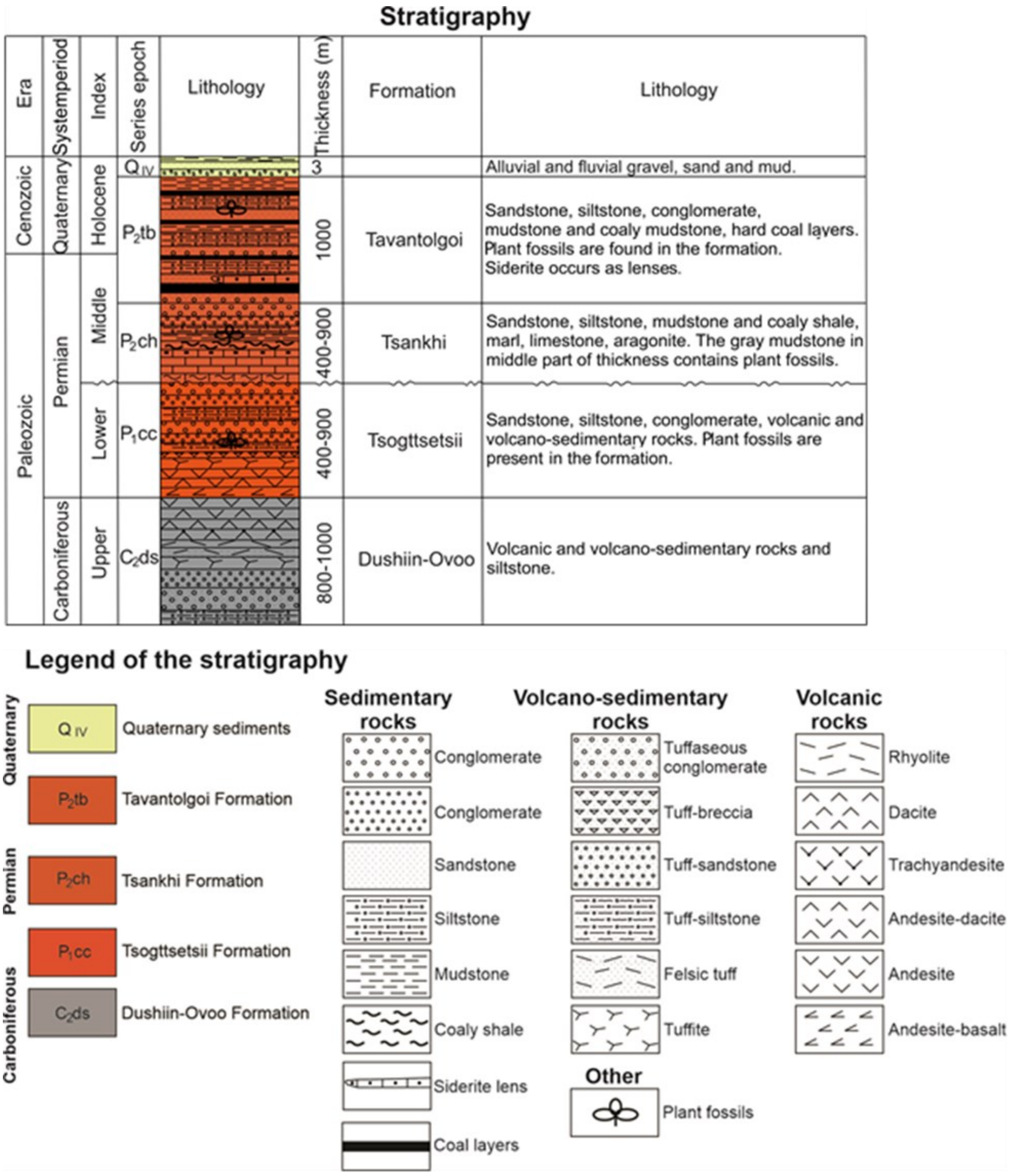



**Fig. 3.** Stratigraphy within the Ukhaakhudag deposit

contained within the coal-bearing middle Permian Tavantolgoi Formation (cf. Erdenetsogt et al., 2009, Michaelsen and Storetvedt, in press). The coal-bearing middle Permian Tavantolgoi Formation has a thickness of c. 650 to 1,200 m in the Ukhaakhudag deposit (Fig. 4). A total of 14 coal seams are developed within the deposit (i.e,. Seams 0, 1, 2, 25, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12) and 49 coal plies. The coal seams are classified by number in ascending order. The true thickness of the 14 economically important coal seams range from 0.23 to 19.2 m. The coal seams include clastic partings of coaly mudstone, siltstone, sandstone and sometimes pebble conglomerate.

Siderite appears to be abundant in the studied lower section (Seams 0-6) compared to the middle and upper units (Fig. 4). Previous work shows the contents of the vitrinite varies from 32-72 vol.%, inertinite from 23-48 vol.%, liptinite from 2-5 vol.%, mineral matter from 5-23 vol.%. The maximum vitrinite reflectance values range from 0.97% to 1.21% (Byambaa et al., 2022).

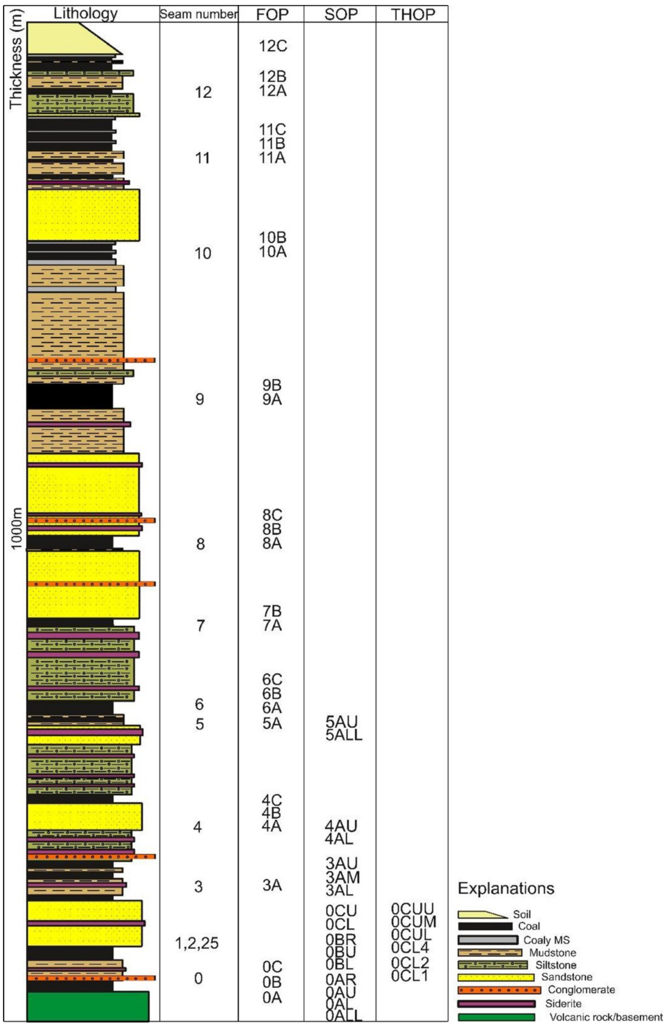



**Fig. 4.** General lithostratigraphy of the Ukhaakhudag deposit. Abbreviation: FOP-first order ply, SOP-second order ply, THOP-third order ply

Previous work has reported total moisture content of coals range from 0.30-59.50 wt.%, with an average 3.59 wt.% (ad. basis), respectively. Ash content ranges from 3.80-49.90 wt.%. The average ash content is relatively low at 22.21 wt.% (ad. basis). The studied coals have a calorific value ranging from 595 to 9,650 kcal/kg (average of 6,433 kcal/kg) (ad. basis) and volatile matter content ranging from 9.72-72.22 wt.% (average 27.30 wt.%) (daf. basis). Total sulfur content value ranges from 0.01-2.8 wt.% with an average of 0.87 wt.% The studied coals 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 bituminous when using the ASTM system in rank (Byambaa et al., 2022).

## MATERIALS

This research is based on 106 composite coal samples from 13 holes drilled during 2019 and 2020 (Fig. 1). They were sampled separately based on brightness and each sample was sealed in a plastic bag with sample number, hole number, and depth interval. First, second and third order plies were further subsampled based on brightness. Samples distinguished by brightness were divided into 4 equal parts and the calculated weight was taken to form the composite sample. The composite sample was approximately 200-300 grams each. Subsequently, the composite sample was crushed to a diameter of 1 millimeter, and a 10 gram sample was taken by dividing it with a split divider. ISO 7404-2 (2009) standard was followed for the preparation of briquettes, and 10 gram of the coal sample (crushed 1 mm) was mixed with resin and hardener in a ratio of 6.5:2, then pressed into a mold and dried in an oven (Binder). After, the dried samples were polished in a half automatic machine with silicon carbide foils, diamond, and silica colloidal solution.

The briquettes preparation, maceral group composition analysis, measurement of vitrinite reflectance and the proximate analysis were all completed at the Central Laboratory of Energy Resources LLC.

*Microscopic analysis:* ISO 7404-3 (2009) was used to determine maceral group composition. And ISO 7404-5 (2009) guidelines were followed for vitrinite reflectance measurements. The maceral group composition analysis was carried out on prepared briquettes under reflected light using a LEICA DM4P. The spacing between the counts was maintained at 0.2 mm and 500 counts were taken on each sample. The ICCP (International committee for Coal and Organic Petrology) classification system 1994 was used to distinguish maceral groups of vitrinite, the liptinite classification system from 1998 and 2001 were used to distinguish inertinite and the system developed by Pickel et al. (2017) was used to distinguish liptinite. Clay, carbonate, silica, pyrite and other minerals were determined. The vitrinite reflectance was measured on a FOSSIL #10 726 microscope with a LEICA DM4P camera. The examination was conducted using a 50x magnification ocular lens under Zeiss oil immersion (518 N). The random vitrinite reflectance was measured from 50 to 100 points in each sample. The mean random vitrinite reflectance values were then calculated using a FOSSIL #10 computer program.

Proximate analysis: proximate analysis was analyzed on each sample to determine moisture, ash, volatile matter, and sulfur content. MNS GB/T 212:2015 was used to determine moisture, ash yield, and volatile matter content, and ISO 351:2001 was used to determine the sulfur content.

## RESULTS AND DISCUSSION

The basal Seam 0 is subdivided into 0A, 0B and 0C first order plies, L (L-lower), M (M-middle) U (U-upper), R (R-rider) second order plies, LL (lower lower), UM (upper middle) and UU (upper upper) third order plies separated by their rock partings (Fig. 4). Coals from Seam 0 contain a wide range of vitrinite from 12 to 62 vol.% and more abundant inertinite from 16-68 vol.%. The liptinite group varies from 0 to 14 vol.%. Coals, which were interested in boreholes numbered G02610 and G02634 drilled along the fault in the northern part of the coal deposit contain slightly higher amounts of the liptinite group (6-14 vol.%). Mineral matter content occurred in the range of 6 to 32 vol.% in coals from Seam 0. Mineral matter content is slightly high at 39-40 vol.% in some coal samples from 0AU second and 0CL3 and 0CL4 third order plies (sample numbers G02642_61-62 and G02616_31-32).

Seam 3 is subdivided into 3AL (L-lower), 3AM (L-lower), 3AU (U-upper) second order plies (Fig. 4). In coals from Seam 3, the content of the vitrinite varies from 26 to 50 vol.%, inertinite content slightly decreases from 10 to 41 vol.%, except for two samples (52 vol.%), liptinite content ranges from 1 to 4 vol.% except for two samples (7 and 11 vol.% in samples number G02634_145 and G02634_58-65). Mineral matter content ranges from 9 to 29 vol.%.

Seam 4 is subdivided into 4A, 4B, 4C first order plies. The first order ply of 4A is further sub-divided into 4AL (L-lower) and 4AU (U-upper) second order plies (Fig. 4). The vitrinite content ranges from 49 to 65 vol.%, inertinite content ranges from 11 to 36 vol.%. The liptinite content is low, ranging from 1 to 5 vol.%. Liptinite content was found to be 10 vol.% (sample number G02634_136-144) in coal from 4AL second order ply and 11 vol.% in coal (sample number G02634_101-132) from the 4B first order ply. Mineral matter content occurred in the range of 9 to 19 vol.%.

Seam 5 is subdivided into 5ALL (LL-lower lower), 5AU (U-upper) second order plies, 5AU, 5AL and 5ALL (LL-lower lower) third order plies respectively (Fig. 4). Vitrinite content varied from 42 to 64 vol.%, inertinite ranges from 9 to 31 vol.%, liptinite content is low and varies from 1 to 5 vol.%, while mineral matter contents ranging from 17 to 34 vol.%.

Seam 6 is subdivided into 6A, 6B and 6C first order plies (Fig. 4). The contents of the vitrinite varies from 56 to 63 vol.%, inertinite from 18 to 30 %, liptinite from 5 to 7 vol.%, and mineral matter from 7 to 15 vol.%.

The coals from Seams 0 and 3 are dominated by vitrinite, specifically collotelinite (Fig. 5a, d, 6a,

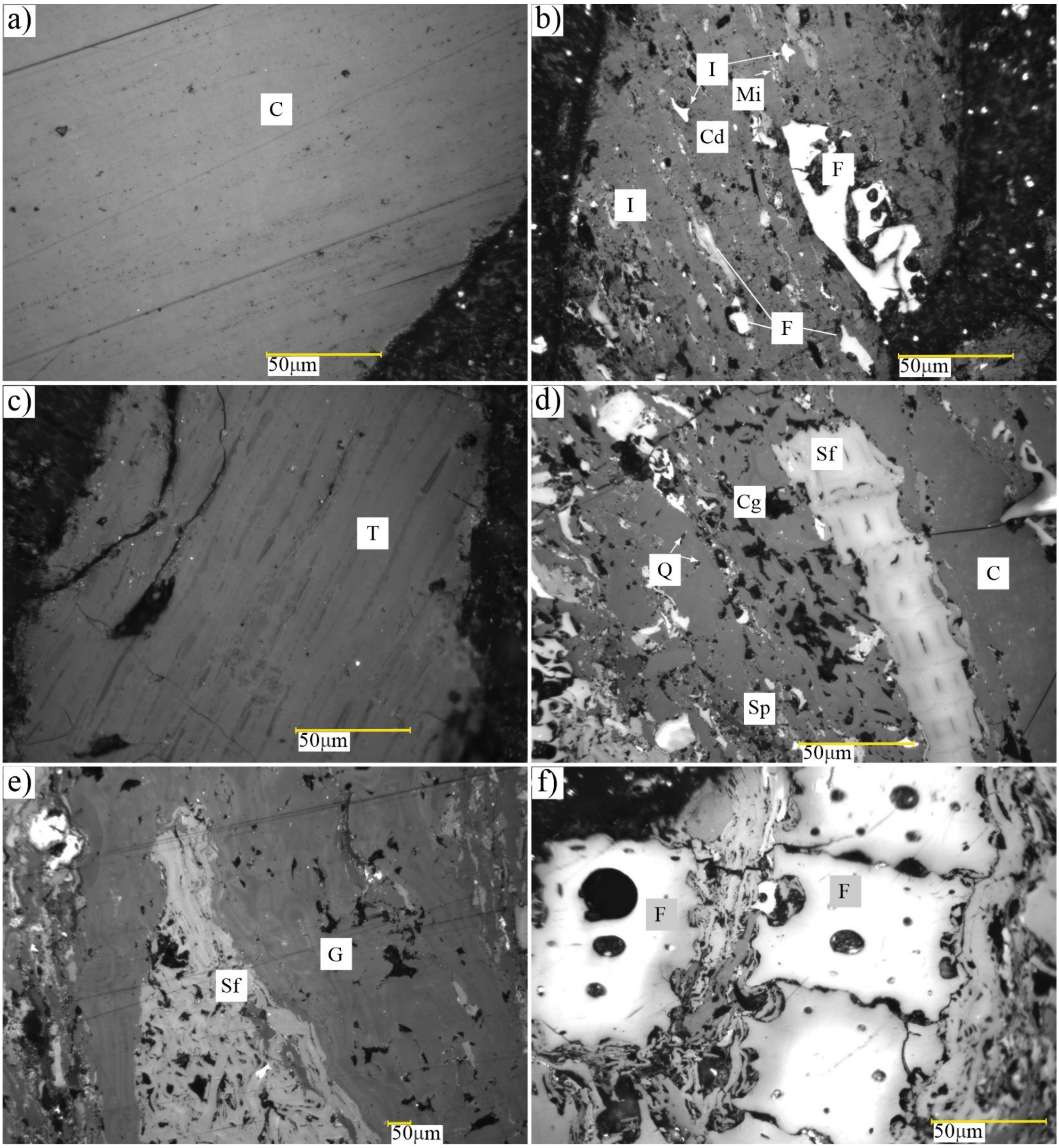



**Fig. 5.** Photomicrographs of representative macerals in coals from Seam 0 and 3 under reflected white light and oil immersion. a) C-collotelinite in coal from 0A ply. b) Cd-collodetrinite in coal from 0B ply. c) T-telinite in coal from 3A ply. d) Cg-corpogelinite, f) F-fusinite in coal from 0C ply. e) G-gelinite and Sf-semifusinite in coal from 0B ply.

f, 8b) and collodetrinite (Fig. 5b, c, d, 7f) and small amounts telinite (Fig. 5c, 6e). However, an increase in telinite and collotelinite contents were observed in coals from Seams 4, 5 and 6. Corpogelinite (Fig. 5d), gelinite (Fig. 5e) and vitrodetrinite (Fig. 6f) were rarely found in the studied coals. For inertinite, mainly semifusinite were found (Fig. 5d, e, 6a, e, 7b, c, e, d, 8a) and fusinite (Fig. 5b, f, 6b, f, 7b) with cellular structure, small amounts of inertodetrinite (Fig. 5b, 6a, b, 7f, 8b), secretinite, funginite, and macrinite; micrinite (5B) were rarely observed

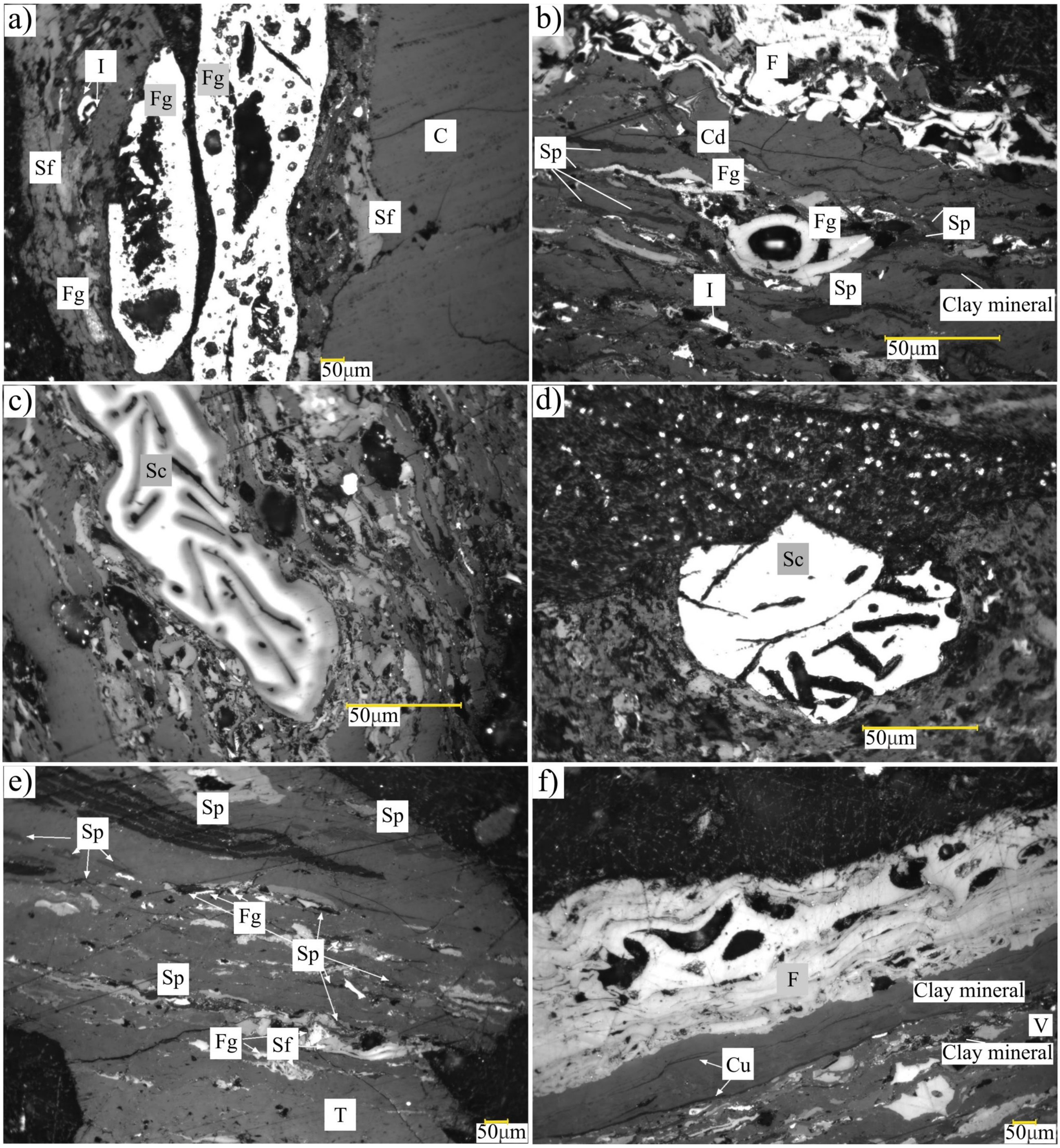



**Fig. 6.** Photomicrographs of representative macerals in coal from Seam 0 under reflected white light and oil immersion. a) Fg-funginite of sclerotia, c) Sc-secretinite with oblong form, e) Sp-sporinite, f) Cu-cutinite in coal from 0B ply. b) Fg-funginite of fungal spore (single cellular) and sclerotia, F-fusinite, I-inertodetrinite, Sp-sporinite, d) Sc-secretinite with ovel form in coal from 0A ply.

in coals from Seams 0, 3, 4, 5 and 6. Funginite occurs as single cellular fungal spores (Fig. 6b), roundish and elongated forms sclerotia (Fig. 6a, b, e). Secretinite occurs as round (Fig. 6d) and oblong forms (Fig. 6c). The liptinite is not constant and ranges from 0 to 14 vol.% in coals of Seam 0. Also, liptinite ranges from 1 to 7 vol.% in coals from Seams 3, 4, 5 and 6. Liptinite is represented mainly as sporinite (Fig.

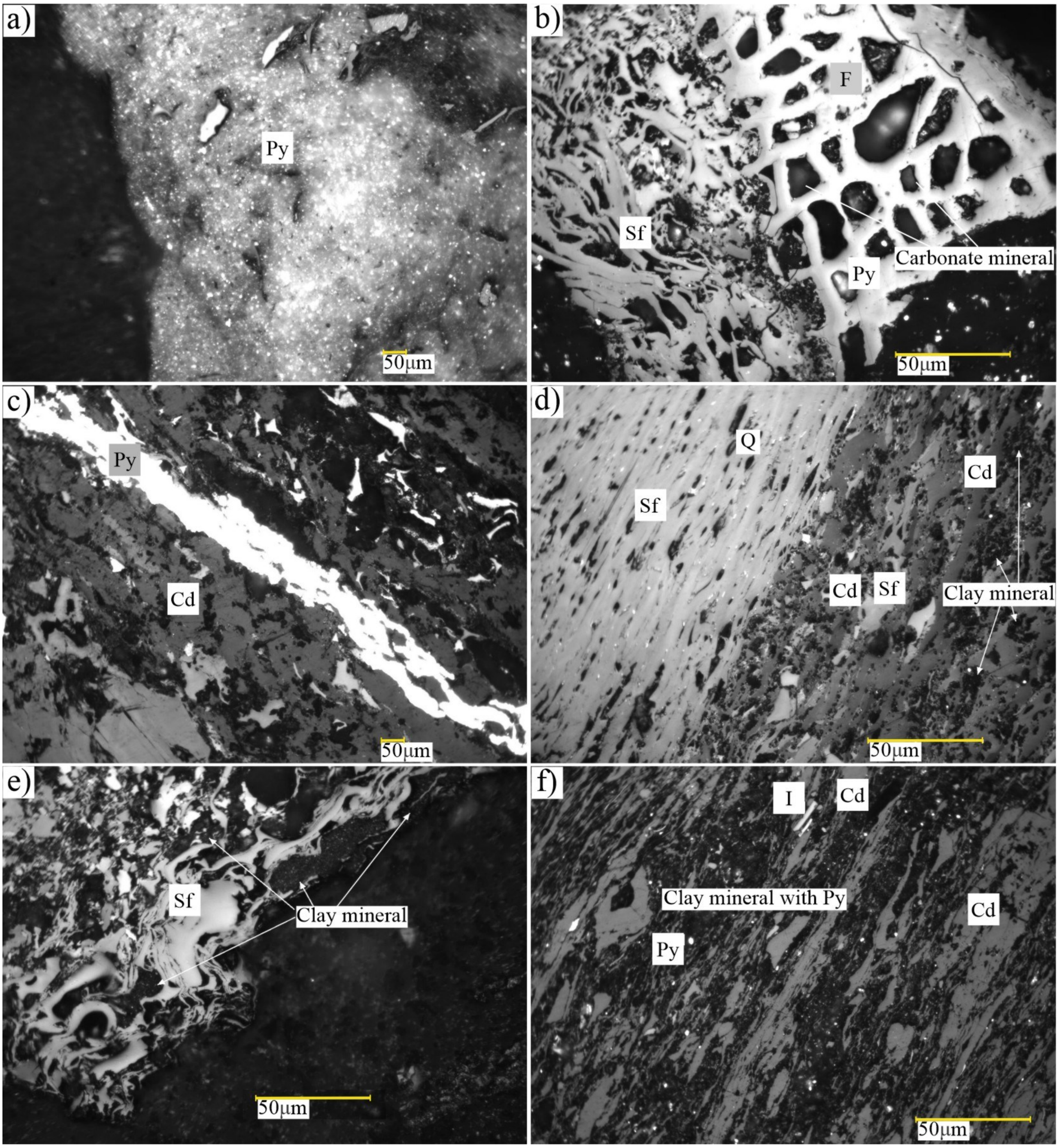



**Fig. 7.** Photomicrographs of representative macerals in coal of Seam 0 under reflected white light and oil immersion. a) Py-pyrite concretion in coal from 0C ply. b) Py-pyrite and carbonate minerals filled in cell cavities of semifusinite, c) Py-pyrite filling the fractures of vitrinite, d) Finely crystalline quartz filled in cell cavities of semifusinite, and clay minerals dispersed on the collodetrinite in coal from 0B ply. e) Cell cavities of Sf-semifusinite filled up by clay minerals, f) Clay minerals with pyrite (Py) dispersed on the Cd-collodetrinite in coal from 0A ply

5d, 6b, e), cutinite (Fig. 6f), and rarely as resinite.

In general, clay minerals and clay minerals with pyrite (1-21 vol.%) occur predominantly in coals from Seams 0, 3, 4, 5 and 6, filling fractures in collotelinite (Fig. 8b) and collodetrinite (Fig. 7d, f). Small amounts of carbonates (Fig. 7b, 8a), quartz (Fig. 5d, 7d),

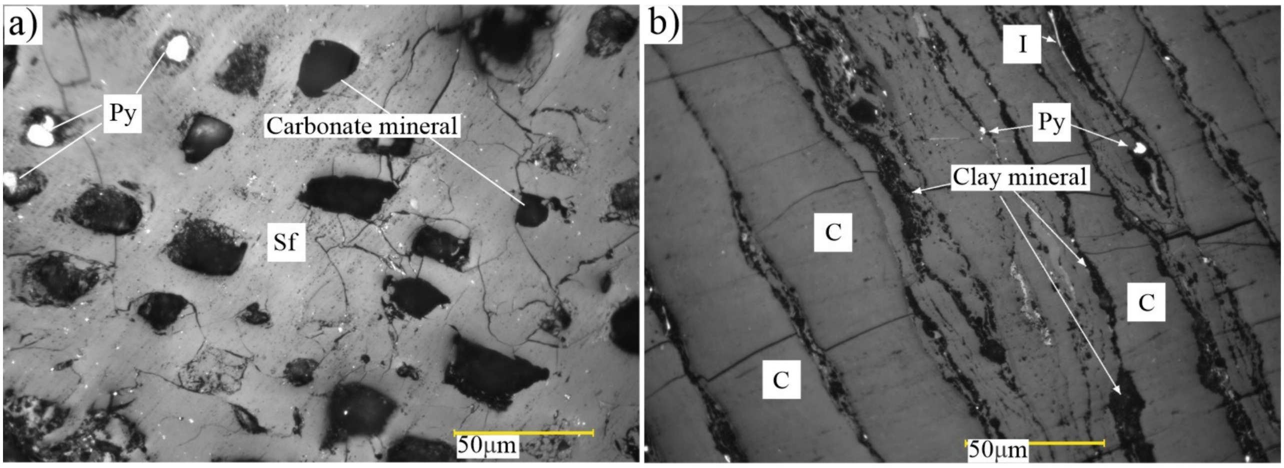



**Fig. 8.** Photomicrographs of representative macerals in coal of Seam 3 under reflected white light and oil immersion. a) Py-pyrite, carbonate minerals in cell voids of Sf-semifusinite, b) Py-pyrite and Clay minerals that fill the cavities and fractures of C-collotelinite in coal from 3A ply.

pyrite (Fig. 7a, b, c, 8a, b), and other minerals fill the cell voids of structured macerals, fractures in macerals, and were also distributed throughout other macerals. However, the content of clay minerals is slightly decreased, and carbonate, pyrite, and quartz are of higher abundance in coals from 4B to 6A, B and C of first order plies. Further, in coal from the 0AL (L-lower) second order ply in borehole G02640 (sample number G02640_169-174) clay minerals infilled the voids of semifusinite (Fig. 7e). The pyrite contents in coals of borehole G02616, drilled in the northern part of the deposit are high, ranging from 9 to 14 vol.%. Pyrite in the coal of borehole numbered G02616 are mostly fine-crystalline concretions and filling in the fractures within vitrinite (Fig. 7a, c). Finely crystalline quartz are rare and fills voids of macerals (Fig 5d), especially the cell cavities of semifusinite (Fig 7d).

In most of Seam 0, the vitrinite content varies from 12 to 62 vol.%. The content of inertinite varies significantly from 16- 68 vol.%. In Seam 3, the content of the vitrinite generally increases from 42 to 68 vol.% (except for five coal samples which vary from 24 to 38 vol.%), the content of the inertinite generally decreased; with a range of 9 to 36 vol.% (with 39 to 52 vol.% in a few coal samples). In coals from basal Seam 0 to Seam 4, the semifusinite is slightly higher than other inertinite macerals. In coals from Seams 5 and 6 the contains a little content of semifusinite and fusinite. The content of the liptinite is generally low from 0 to 8 vol.% (with 11-14 vol.% in four coal samples). The mineral matter content ranges from 6 to 30 vol.%, and 30 to 44 vol.% in seven coal samples (Fig. 9).

Coals from Seams 0, 3, 4, 5 and 6 of the Ukhaakhudag deposit are characterized by vitrinite reflectance values ranging from 0.93-1.13 % (Table 1).

**Microlithotype**

The microlithotypes of the analyzed coal samples from the Ukhaakhudag deposit are classified (i.e., as mmf. basis) using the ternary diagram of Bustin et al. (1983).

The coals are classified as dominantly bimaceralic microlithotype of vitrinertite and low trimaceralic microlithotype of duraclarite and clarodurite (Fig. 10). Using the ternary diagram of Bustin et al. (1983) the coals are classified as vitrinertite microlithotype; which are composed of vitrinite maceral content ranging from 16 to 88 vol.% and inertinite maceral content ranging from 12 to 80 vol.%, while liptinite maceral content is lower than 5 vol.% (i.e., mf. basis).

**Coal quality of the Ukhaakhudag deposit**

The proximate analysis of coals of the Ukhaakhudag deposit is shown in Table 1.

The results of the chemical analysis were expressed as the average value of coals for Seams 0, 3, 4, 5 and 6. The ash content of the

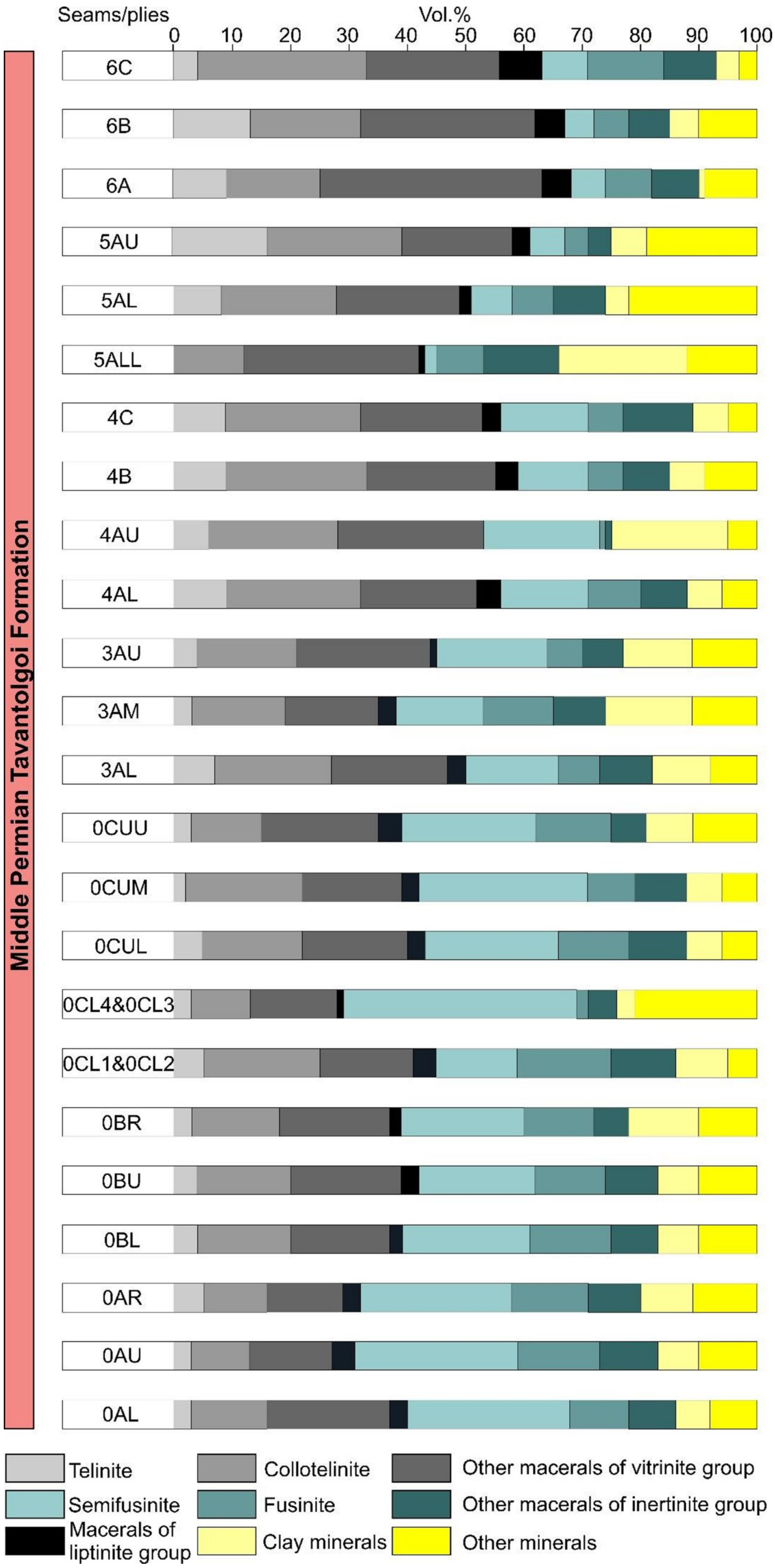



**Fig. 9.** Average petrographic composition of coals from coal plies

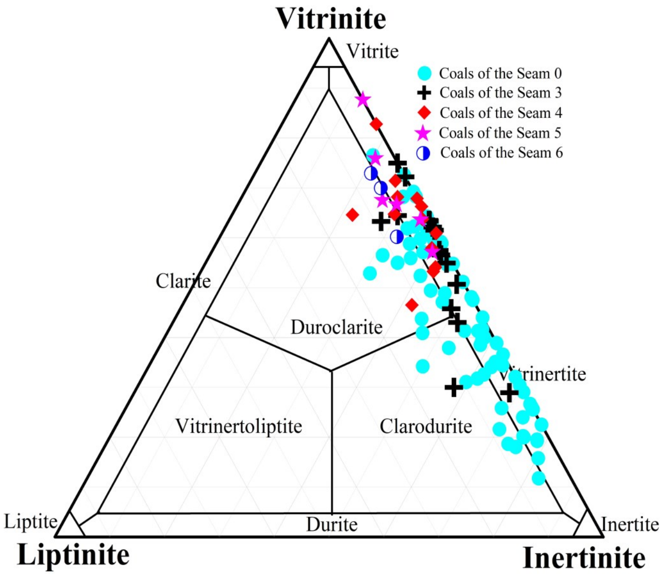



**Fig. 10.** Diagrammatic representation of microlothotype classification showing widely scattered plots along the Vitrinite-Inertinite axis (Bustin et al., 1983)

studied coals range from 11.2 to 44.8 wt.% and the average is 31.97 wt.% (ad. basis). Moisture and volatile matter contents vary from 0.7 to 5.6 wt. % (ar. basis) and from 19.32 to 41.57 wt.% (daf. basis) respectively. Sulfur content is low in most coals with values of 0.22 to 0.99 wt.% (ad. basis). Sulfur content is >1% in some coals of Seams 4 and 6.

Coal rank: Coals from the Ukhaakhudag deposit are classified as coking (Ch4), fat (Ch5), 1/3 coking (Ch6), gas fat (Ch7) coals based on the Mongolian system and medium to high volatile A bituminous coal when using the ASTM system.

**Paleoenvironmental condition of peat accumulation**

The facies, depositional settings, and mire type of the Ukhaakhudag coal deposit is 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). Diesel (1986) suggested that GI is a measure of the degree and persistence of wet condition, whereas TPI is essentially a measure of the degree of tissue breakdown and the proportion of woody plants in the original peat forming assemblages. The GI and TPI in the present case are derived from:

**Table 1.** Average mains from proximate analyses, random vitrinite reflectance of coals from first, second and third order plies

| First, second and third order plies | Tm (ar, wt.%) | A (ad, wt.%) | VM (daf, wt.%) | S (ad, wt.%) | $R_{0random}$ (%) |
|---|---|---|---|---|---|
| 6C | 4.40 | 11.20 | 29.94 | 0.49 | 0.95 |
| 6B | 5.50 | 21.30 | 32.82 | 1.41 | 0.97 |
| 6A | 4.20 | 26.30 | 33.47 | 1.67 | 0.96 |
| 5AU | 5.25 | 36.70 | 34.68 | 0.78 | 0.99 |
| 5AL | 3.87 | 32.33 | 36.41 | 0.96 | 0.97 |
| 5ALL | 3.90 | 52.90 | 35.29 | 0.49 | 0.98 |
| 4C | 4.20 | 18.17 | 31.27 | 1.14 | 0.97 |
| 4B | 3.21 | 24.78 | 41.48 | 1.55 | 0.94 |
| 4AU | 3.25 | 39.70 | 32.85 | 0.48 | 0.98 |
| 4AL | 2.73 | 28.97 | 31.13 | 0.51 | 1.01 |
| 3AU | 3.92 | 44.76 | 35.27 | 0.99 | 0.97 |
| 3AM | 2.92 | 40.26 | 32.22 | 0.57 | 0.96 |
| 3AL | 2.38 | 36.67 | 31.91 | 0.50 | 0.97 |
| 0CUU | 2.58 | 31.70 | 38.79 | 0.93 | 0.93 |
| 0CUM | 1.63 | 34.55 | 37.95 | 0.58 | 0.98 |
| 0CUL | 2.13 | 25.82 | 40.74 | 0.87 | 1.04 |
| 0CL4&0CL3 | 3.10 | 46.20 | 32.48 | 0.51 | 1.00 |
| 0CL1&0CL2 | 2.65 | 29.73 | 33.71 | 0.59 | 0.99 |
| 0BR | 2.30 | 37.82 | 36.00 | 0.63 | 1.06 |
| 0BU | 3.14 | 31.40 | 27.89 | 0.62 | 1.04 |
| 0BL | 2.12 | 35.34 | 37.02 | 0.65 | 1.04 |
| 0AR | 6.05 | 35.55 | 26.10 | 0.35 | 1.11 |
| 0AU | 3.58 | 37.30 | 27.67 | 0.49 | 1.02 |
| 0AL | 2.24 | 32.05 | 38.07 | 0.61 | 1.13 |

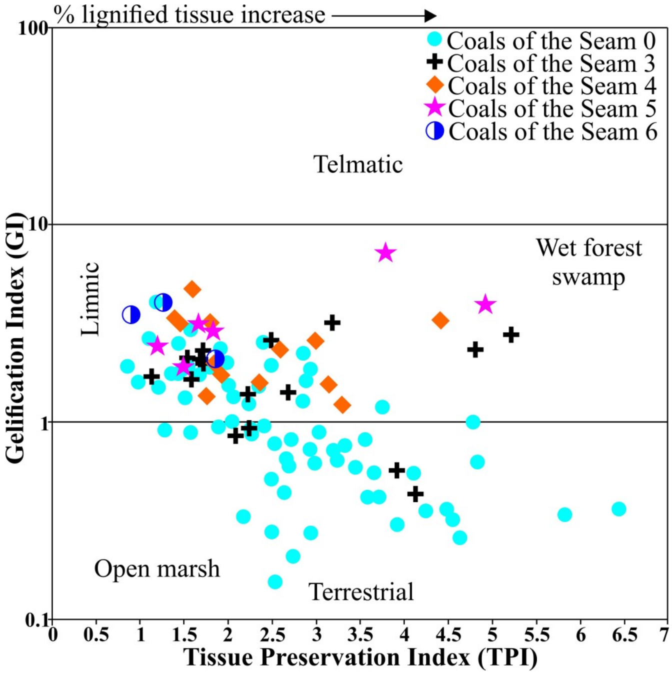
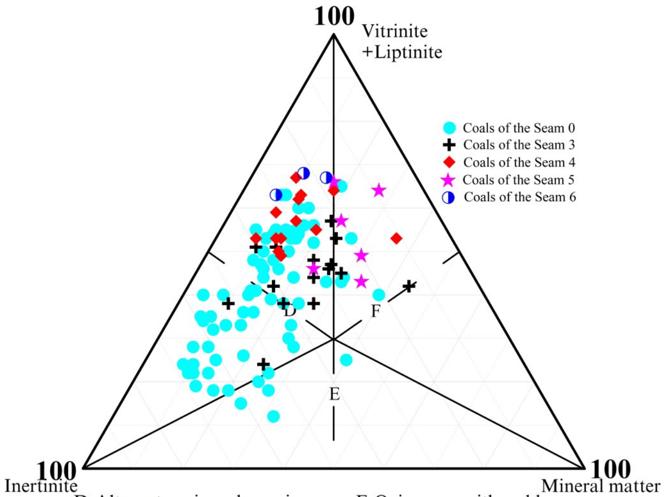



**Fig. 11.** Coal facies of Seams 0, 3, 4, 5 and 6 interpreted from the Gelification Index (GI) and Tissue Preservation Index (TPI) in relation to depositional setting and type of mire (after Diessel, 1986).




D-Alternate oxic and anoxic moor. E-Oxic moor with sudden high flooding. F-Wet moor with intermittent moderate to high flooding.

**Fig. 12.** Depositional condition of coals from Seams 0, 3, 4, 5 and 6 based on widely scattered maceral and mineral matter content (modified from Singh and Singh, 1996).

GI = Vitrinite + Macrinite/Semifusinite + Fusinite + Inertodetrinite

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

Coal facies diagrams for coals of Seams 0, 3, 4, 5 and 6 are illustrated in Fig. 11. Most coals have moderate GI and high TPI. The data suggests that peats of the Ukhaakhudag deposit were dominated by wet forest swamp, with high tree density and rare herbaceous plants. However, some samples from the lower Seams 0 and 3 may be dry forest swamp, indicating that the peat precursor of these seams sometimes accumulated in wet conditions.

In another facies model (Fig. 12) proposed by Singh and Singh (1996) based on macerals and mineral matter content, most coal samples from Seams 0, 3, 4, 5 and 6 suggest the peats were developed in alternating oxic and anoxic mire conditions. In addition, results from some samples taken from Seams 0, 3, 4 and 5 indicate that they formed from wet mires with moderately high flooding (Fig. 12). Further, a few coal samples from Seam 0 indicated an oxic (dry) moor with frequent flooding.

Therefore, it can be concluded that at the beginning of peat accumulation (ie. basal Seam 0), the peat mire was either a forested raised bog or a dry mire with a low groundwater level (depending on the climate). Diessel (1992) based palaeoenvironmental studies on Permian Sydney Basin of New South Wales with coal seams whose depositional setting had been established over many years of field and laboratory investigations. Both GI and TPI define four coal facies whose palaeo-environmental characteristics are summarized in Table 2. Coal samples from Seams 0 and 3 have low GI values and high TPI values, with telo-inertinite of 31-64 vol.% and high ash contents >20 wt.%. Compared with the results shown in Table 2, the results of the Ukhaakhudag deposit can be distinguished as wood-derived telo-inertinite, and its origin is in intermittently dry forested swamps with high ash.

The results of coal petrography revealed that the seams III and IXG of the Baruunnaran deposit are composed of vitrinite (48-71% and 47-80 % mmf. basis) and inertinite (14-39 % and 19-48 % mmf. basis). The concentration of liptinite ranges from 1 to 9% and 4 to 15% (mmf. basis). Compared to other seams, seam X is characterized by lower content of inertinite (12-25 % mmf. basis) and higher content of liptinite

**Table 2.** Summary of the relationship between coal facies indices and conditions of coal formation

| | High TPI | Low TPI |
|---|---|---|
| **High GI** | Coal type: Bright (vitrain) to banded bright (clarain); wood- and bark derived telovitrinite<br><br>Origin: In forested peatlands (telematic swamps), when relatively high in coal ash and/or interbedded with epiclastic stone bands. In forested, continuously wet raised bogs, when low in ash. Mild humification and strong gelification of plant tissues due to high rate of subsidence. | Coal type: banded bright (clarain); tissue-derived detrovitrinite plus some gelovitrinite<br><br>Origin: (I) In forested peatlands from strongly decomposed wood under conditions of slow subsidence in telmatic or limnotelmatic settings (high ash and epiclastic bands). (2) From herbaceous plants in tree-less marshes (high ash and epiclastic bands). (3) From herbaceous plants in continuously wet raised bogs (low ash, no bands). Telmatic or limnotelmatic. Advanced humification and strong gelification of plant tissues. |
| **Low GI** | Coal type: Banded dull (clarodurain); wood-derived telo-inertinite<br><br>Origin: In intermittently dry forested swamps when high in ash, or in forested raised bogs, when coal ash is low or moderate. Mild humification and gelification of plant tissues | Coal type: Dull (durian) to banded dull (clarodurain); tissue-derived inertodetrinite<br><br>Origin: (I) In slowly subsiding, intermittently dry swamps from aerobically decomposed autochthonous plants. (2) Redistributed as subaqueous sediment. (3) In slowly subsiding relatively dry raised bogs |

(3-18 % mmf. basis). The vitrinite content varies from 60-81 % (mmf. basis). The Gelification Index (GI) and the Tissue Preservation Index (TPI) suggest that coals of seams III, IXG and X of the Baruunnaran deposit have a limnic origin with high tree density. The peat of seams III, IXG and X developed in alternate oxic and anoxic mire conditions. The inertinite contents of the Baruunnaran deposit are explained by their possible dry climate conditions during the peat accumulation period (Demberelsuren et al., 2021).

The macroflora of Ukhaakhudag and the wider Tavantolgoi deposit is identical to the central part of the Angara floral realm (Durante, 1976, Michaelsen and Storetvedt, in press). The Angaran province contains the first extensive non-tropical peats (Dai et al., 2020). Thus, during peat accumulation in the middle Permian, Mongolia might have been characterized by relatively dry and cool climatic conditions interrupted by warm periods. This is in agreement with the work by Manankov (2012), Michaelsen and Storetvedt (2023) on the middle-late Permian deposits of the Mongol-Transbaikalian Seaway in the central and northern part of Mongolia which indicate a general cool (boreal) setting interrupted by warmer periods.

In summary it can be concluded that the peats of the lower part of the Ukhaakhudag deposit accumulated in mostly alternate oxic and anoxic mire conditions. The climate was drier during accumulation of the basal Seam 0, but warmed from the onset of Seam 3 deposition, with increased humidity.

In brief, the inertinite content decreases and the vitrinite content increases (Fig. 9) from the base to the top of the lower part of the Ukhaakhudag deposit. This can also be observed based on the GI and TPI ratio of peat accumulation, from the dry climate of Seam 0 to a humid warm climate during accumulation of seam 3 and overlying seams 4, 5 and 6.

It is noted that plant degradation is dependent only on the water table level of the peat mire. This was shown by research on four 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, the paleoenvironment of peat deposition requires an integrated approach including geochemistry of host rock and coal ash as well as detailed sedimentological, structural and palynological research.

## CONCLUSIONS

Petrographic and chemical analyses of coal samples obtained from Seams 0, 3, 4, 5 and 6 of the middle Permian Ukhaakhudag deposit yielded the following results:

1. The coals of the lower part of the Ukhaakhudag deposit are characterized by a wide range of vitrinite (12-64 vol.%) and inertinite (9-68 vol.%). The liptinite is generally around 1-7 vol.% in the studied coal samples. In the 0 seam, fusinite and semifusinite of the inertinite group are more abundant than the overlying seams (ie. 3, 4, 5 and 6) analyzed in this study.
   The samples from Seams 0, 3, 4, 5 and 6 are classified as dominantly bimaceralic microlithotype of vitrinite, with other samples from Seams 0, 3, 4 and 6 classifieds as trimaceralic microlithotype of duroclarite and clarodurite. Clay, silica, carbonate minerals, pyrite and other minerals range from 9 to 30 %. The random vitrinite reflectance values range from 0.93 % to 1.16 %.
1. The studied coals are characterized by a medium to high volatile matter content ranging from 26.10-41.48 wt.% (daf. basis). Ash yield ranges from 11.20 to 44.76 wt.%, ad. basis). Moisture contents range from 1.63-6.03 wt.% (ar. basis), sulfur contents range from 0.49-1.67 wt.% (ad. basis). The coals are classified as coking (Ch4), fat (Ch5), 1/3 coking (Ch6), gas fat (Ch7) based on the Mongolian classification system, and medium - high volatile A bituminous coal when using the ASTM classification system.
2. The peats accumulated in mostly alternating oxic and anoxic mire conditions and were mainly composed of closely spaced trees with rare herbaceous plants. The climate is thought to here been dominated by drier conditions during accumulation of the basal Seam 0 but warmed, as humidity increased with the accumulation of Seam 3. It is considered that it is necessary to further clarify the results of this study by using an integrated approach including geochemistry of the clastic sediments and coal ash as well as sedimentological, structural and palynological research.

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