Mongolian Geoscientist

Original Article

Maceral composition, coal characteristics and depositional environment of the Middle Jurassic Nariinsukhait coal deposit, Southern Mongolia

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ARTICLE INFO

Article history:

Received: 12 September, 2024
Revised: 26 October, 2024
Accepted: 28 October, 2024

ABSTRACT

The Nariinsukhait deposit is the largest Jurassic coal deposit in southern Mongolia. A total of 90 core samples were obtained from a 493.1 m deep borehole in the central part of the deposit and tested for proximate analysis and caking properties, while 29 composite samples were analyzed for maceral composition and random vitrinite reflectance. The thick seam V stands out for its better quality compared to the upper seams, with an average ash content of 12.4% (ad), total sulfur of 0.5% (ad), volatile matter of 36.7% (daf), inherent moisture of 0.6% (ad), calorific value of 6,600 kcal/kg (ar), and a G index of 84 (ad). Seam V is characterized by higher inertinite content (32.2 vol.%), and lower vitrinite (58.0 vol.%) and mineral matter contents (6.7 vol.%) relative to the upper seams. Additionally, this seam has a higher rank, with random vitrinite reflectance (Rrand) of 0.77%, compared to 0.65-0.70% for the upper seams. According to MNS 6457:2023 standards, seam V is classified as “1/3 coking coal”, while the upper seams are classified as “high volatile gas coal”. Based on TPI, GI and A/I indices, seam V was deposited in oxic, ombrotrophic mire, whereas the upper seams were formed in mesotrophic and rheotrophic mires with high water tables and less oxic conditions. Due to these depositional environments, seam V exhibits higher inertinite, lower ash, and lower sulfur contents than the upper seams. The rank of the Nariinsukhait coals is comparable to that of Jurassic coals in central Mongolia, while the maceral composition and coal quality of the upper seams align with those of Jurassic coals. Seam V is distinct in its high inertinite and low total sulfur contents. The Nariinsukhait coal is primarily semi-soft coking coal (2/3 of total coal resources) and is also suitable as high-quality PCI coal. Further detailed studies are recommended to evaluate its potential for liquefaction and as a coking coal blend.

Keywords: coal petrology, peat mires, ombrotrophic, 1/3 coking coal

INTRODUCTION

The Nariinsukhait coal deposit is located in the South Gobi coal-bearing Region in Southern Mongolia (Bat-Erdene, 1992) and holds significant economic importance due to its significant coking coal resources and proximity to China, the main coal market. In 2023, Mongolia extracted 85.2 million tons of coal and exported 69.6 million tons to China. Significantly, coal production accounts for 36.8% of Mongolia’s gross industrial output (NSM, 2024), and coal export accounts for 58.6% of the country’s total export income (MMIH, 2024). The vast majority of the exported coal is exploited from the South Gobi coal-bearing Region. In 2020, the five mines operating within the Nariinsukhait deposit produced 29% of Mongolia’s total coal exports (Batgerel et al., 2021).

Previously, it was thought that all coals in the South Gobi coal-bearing region were of Permian age (Bat-Erdene et al., 2001; Jargal et al., 2002; Bat-Erdene, 2009; Erdenetsogt et al, 2009). However, Baatarkhuyag et al. (2010, 2012) revised the age of the Nariinsukhait deposit to the Jurassic, and later studies by Kostina and Herman (2013, 2016) confirmed a middle Jurassic (Bajocian) age. Several other coal deposits within Jurassic sequences have been discovered around Nariinsukhait, such as Bayantes, Sumber, Biluut and Jargalant (Baatarkhuyag et al., 2021). Additionally, the Khuuraital coal deposit was discovered to the west, outside of the South Gobi coal-bearing Region boundary, with coal characteristics similar to those of Nariinsukhait (Bakhdal and Jargal, 2021). However, the coal at Khuuraital is thought to be of Upper Triassic-Lower Jurassic age. Furthermore, Ochirbat (2024) proposed a new Jurassic coal-bearing region, covering the Ovootkhural depression, which is a part of South Gobi Region. These findings, supported by accumulated data from coal exploration and geological research, including new age dating, indicate that the geological setting and coal characteristics in this region require comprehensive revision and compilation.

Jurassic coals are widespread in Mongolia, characterized by high concentration of vitrinite and liptinite (Bat-Erdene, 2009; Erdenetsogt et al., 2009). However, the rank of these coals varies from subbituminous to medium volatile bituminous. The pattern of the rank changes and the factor influencing them are not fully understood (Erdenetsogt and Barsbold, 2012; Erdenetsogt and Jargal, 2021; Erdenetsogt, 2022). Due to their high vitrinite content, Jurassic coals of higher rank exhibit high fluidity, good plasticity and caking properties (Erdenetsogt and Narangerel, 2014; Erdenetsogt, 2022). As the largest Jurassic coal deposit in southern Mongolia, studying the geology, tectonics, coal quality and maceral composition of the Nariinsukhait deposit can provide valuable insights into the overall patterns of Jurassic coal rank changes in Mongolia.

The peat forming environment is a key factor controlling coal seam thickness, lateral continuity, maceral composition, and ash content within a coal deposit. The rank, however, is the one characteristic not affected by the mire condition (Teichmuller, 1989; Calder et al., 1991; Diessel, 1992; Kalkreuth et al., 1991; Singh and Singh, 1996; Suarez-Ruiz et al., 2012; O'Keefe et al., 2013; Dai et al., 2020). Research methods such as paleobotany, palynology, sedimentology, mineralogy, geochemistry, and organic petrography are employed to interpret depositional environment (Wang et al., 2011; Jasper et al., 2010; Ward, 2016; Dai et al., 2020; Sosnowski and Jelonek, 2022). Among these, organic petrography is one of the most straightforward and widely used approaches (Suarez-Ruiz et al., 2012). A detailed study of the depositional paleoenvironment of the Nariinsukhait coals can assist to predict the coal quality and economic value of the discovered Jurassic coals in the South Gobi coal-bearing region (Baigalmaa et al., 2021; Batgerel et al., 2021).

Previous studies have revealed various aspects of the Nariinsukhait deposit, including its geological setting, coal quality, coal resources (Dashkhorol and Baatar, 1992; Munktogoo and Gantulga, 2006; Baatarkhuyag et al., 2015; Baatarkhuyag et al., 2021; Ochirbat, 2024), maceral compositions of certain coal seams (Jargal et al., 2019), peat-forming floras (Kostina and Herman, 2013, 2016), depositional environment of coal-hosting sedimentary rocks, paleoclimate, and tectonics of the Nariinsukhait depression (Kostina and Herman, 2016; Baigalmaa et al., 2021; Batgerel et al., 2021; Ochirbat, 2024). However, no research has yet been conducted on reconstructing the peat-forming paleoenvironment of these coals. The purposes of this study are to reconstruct the depositional environment of the Nariinsukhait coal and to reveal the impact of paleomire conditions on coal quality. Significantly, this is the first study on the depositional environment of Jurassic coals in Mongolia.

GEOLOGICAL SETTING

The Nariinsukhait coal deposit is situated in the Nariinsukhait basin, which is oriented east-west, approximately 160 km long and 10-25 km wide, and has been subjected to intense faulting as well as folding in places (Baatarkhuyag et al., 2021). The coal-bearing Middle Jurassic

Orgilokhbulag, Upper Jurassic Sharkhotgor Formation (J_3sh) and Cenozoic sediments are preserved within the basin (Fig. 1).

The Middle Jurassic Orgilokhbulag Formation (J_2ob), the focus of this work, conformably overlies the brown conglomerate-breccia of the Lower Jurassic Aguit Formation and is in turn overlain by the Upper Jurassic Sharkhotgor Formation (J_3sh).

The coal-bearing Orgilokhbulag Formation, up to 1360 m thick, is divided into two members - Lower and Upper - based on lithological features and paleobotanical description (Baatarkhuyag et al., 2021). The Lower member consists of predominantly coarse-grained sediments, while the Upper member is mainly composed of fine-grained sediments. The Lower member contains coal seams I-VI, and the Upper member contains seams VII-XII (Fig. 2). Seams I-IV are not economically viable.

According to Baatarkhuyag et al. (2021), the base of the Lower member is composed of conglomerate, followed by sandstone, and the coal seam V, which is the thickest seam

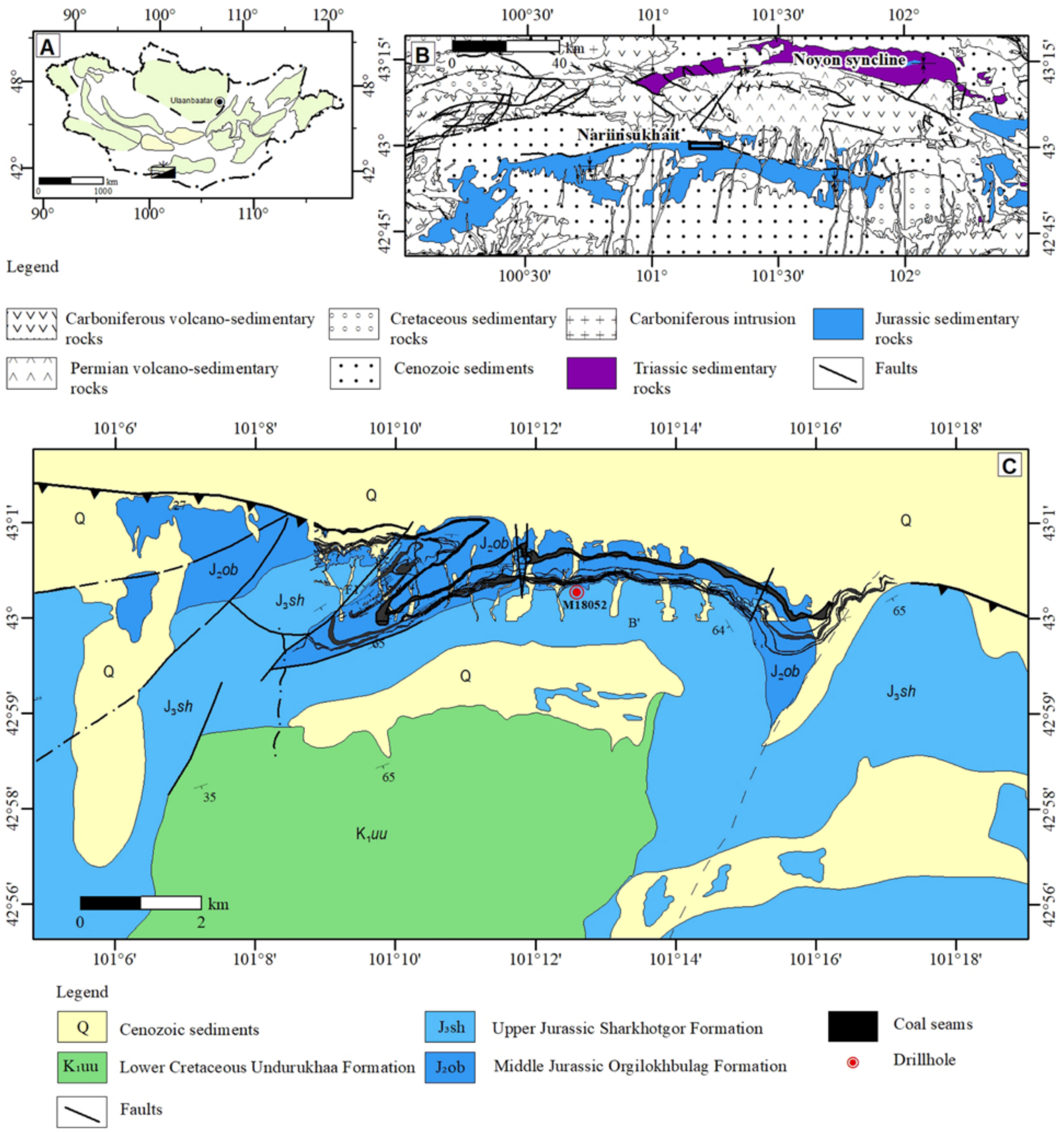

Fig. 1. Geological map of the Nariinsukhait deposit (modified after Baatarkhuyag et al., 2015)

in the deposit. The upper part of the Lower member is characterized by intercalation of conglomerate and sandstone, followed by coaly siltstone with abundant flora, and intercalations of sandstone, coaly siltstone, mudstone, and thin coal layers. The thickness of the Lower member ranges from 430 to 520 m. The Upper member begins with thin conglomerate layer, followed by intercalation of siltstone, coaly siltstone, and coal seams. The middle part of the

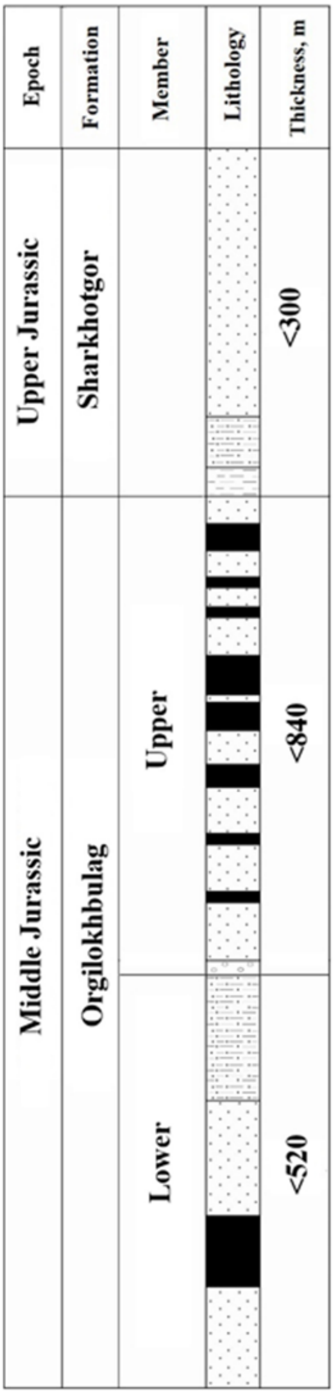

Fig. 2. Generalized stratigraphic column of the Middle Jurassic Orgilokhbulag and Upper Jurassic Sharkhotgor Formations (Baatarkhuyag et al., 2015)

Upper member section consists of sandstone with layers of siltstone and coal. The upper section of the member includes intercalations of sandstone, siltstone and coal seams. The Upper member has total thickness ranging from 360 to 840 m. The age of the formation was dated to the Bajocian stage based on plant fossils (Baatarkhuyag et al., 2010, 2012; Kostina and Herman, 2013, 2016).

The Upper Jurassic Sharkhotgor Formation unconformably overlies the Middle Jurassic Orgilokhbulag Formation. The contact is characterized by a very low angle and the Jurassic strata is in turn unconformably overlain by Cenozoic sediments. The Upper Jurassic Sharkhotgor Formation consists of conglomerates, light green sandstone, green siltstone, and mudstone. The thickest section of the Formation, 307 m, was intersected at NWS-08-37 borehole (Baatarkhuyag et al., 2021). A more detailed description of the Middle Jurassic Orgilokhbulag and Upper Jurassic Sharkhotgor Formations can be found in Baatarkhuyag et al. (2021).

MATERIALS AND METHODS

Samples

A total of 90 core samples were collected from coal seams V to XII at depths ranging from 93.7 m to 493.1 m from exploration borehole #M18-52C (N101°12’35.4”; E43°0’16.6”), drilled in 2018 at the central part of the Nariinsukhait deposit (Fig. 3).

The sample length averaged 1 m but varied between 0.4 and 1.5 m depending on the thickness of the coal seam. Each sample was instantly sealed in a plastic bag and delivered to the Mongolyn Alt (MAK) LLC’s laboratory. In the laboratory the samples were crushed to a size of 1.0 mm, blended, and divided into two equal parts. One half analyzed for proximate analysis and G index test, while the remaining half was sealed in a plastic bag and sent to Energy Resource Laboratory at the National University of Mongolia for organic petrographic analysis. The coal samples for petrographic analysis were crushed to 0.5 mm, and 29 composite samples were prepared. An overview of the sampled seams, the number of samples, coring depth, and results of the proximate analysis and G index test are provided in Supplement 1. The details of composite samples for organic petrography and the results of the analysis are presented in Fig. 3 and Supplement 2.

Proximate analysis and caking property test

The proximate analysis and G index test were performed at the Coal Analysis Laboratory of Mongolyn Alt (MAK) LLC, in accordance with

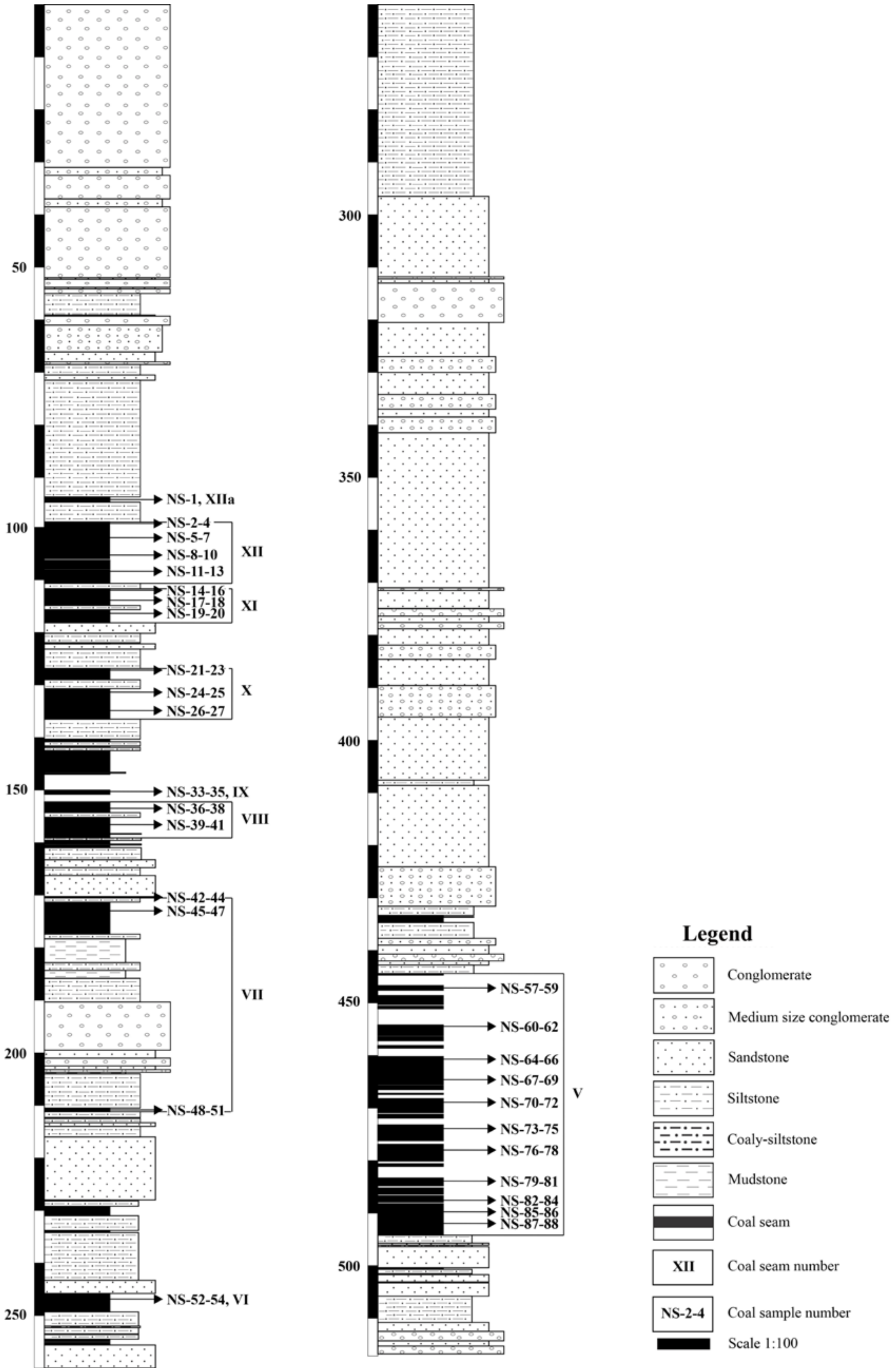

Fig. 3. Composite samples for maceral analysis and the geological section of the M18-52C borehole

MNS-ISO and ASTM standards. The total and inherent moisture contents were determined using MNS 0655:1979, ASTM D3173, total sulfur contents using ASTM D4239, ash contents using MNS 0652:1979, ASTM D3174, volatile matter contents using MNS 0654:1979, ASTM D3175, and calorific values using ASTM D5865. The G index was tested according to ISO 15585:2019 standards.

Organic petrography

Polished sections were preperad according to MNS ISO 7404-2:2016 for maceral analysis and random vitrinite reflectance (Rrand, %) measurements. Maceral analyses were carried out in accordance with MNS ISO 7404-3: 2016 using a MOTIC BA310 Pol reflected light microscope. Point counting at least 400 points was performed on all samples. Maceral classification followed the International Committe for Coal and Organic petrology (ICCP) nomenclature (ICCP 1998, 2001). Random vitrinite reflectance measurments with 20 readings collected per samples, were carried out at Central Geological Laboratory in Ulaanbaatar. Saphare (0.588%) and glass (3.26%) standards were used for calibration, with standard deviations of the measurements ranging from 0.04 to 0.09.

RESULTS

Proximate analysis and G index test

The total moisture content of the samples varies from 1.1 to 19.2%, with the highest contents found in Seams VIII and IX at depths of 149.5 to 156.5 m. The inherent moisture content varies between 0.3 and 1.6%, with the basal seam V characterized by the lowest average content of just 0.6%. Net calorific values (as received basis) ranges from 3,484 to 7,257 kcal/kg. The uppermost seam XII has an average net calorific value of 5,970 kcal/kg, while the lowermost seam V averages 6,599 kcal/kg. There is a downward decreasing trend in volatile matter content from the upper to the lower seams. Seams XII and VIII have the highest average volatile matter contents at 42.8 and 42.1% (dry, ash free basis), respectively, while seam V has the lowest average volatile matter content of 36.7% (dry, ash free basis) (Table 1, Supplement 1).

The ash content of the analyzed samples varies significantly from 3.7 to 48.7% (air dry basis). The lowermost seam V has the lowest average ash content of 12.4%, while seam X has the highest of 21.3%. The total sulfur content (air dry basis) is highly variable, ranging from 0.2 to 3.9%. Sulfur content is lower in seam V averaging 0.5%, and higher in the upper seams, with seam VIII averaging 2.1%, and peaking at 3.9% (Table 1, Supplement 1).

The G index test was used to evaluate the caking properties of the samples. Three samples recorded a G index value of 0, while the remaining samples had G index values ranging from 32 to 99. Seam V has the highest average G index at 84, compared to other seams. Seams VI and IX have the lowest average G index values of 57 and 54, respectively. The average G index of the other seams ranges from 70 to 77 (Table 1, Supplement 1).

Table 1. Average values of coal characteristics of the Nariinsukhait coal deposit

Seam #	# of samples	Total moisture, %	Inherent moisture %	Total sulfur, %	Ash%	Volatile matter %	Calorific value kcal/kg	G index	Rrand, %
		ar	ad	ad	ad	daf	ar	ad	
XII/XIIa	13 (3)*	3.3	0.8	1.2	19.9	42.8	5970	63	0.65
XI	7 (2)	3.1	0.8	1.1	17.0	38.0	6251	72	0.68
X	8 (1)	3.0	1.0	1.1	21.3	41.4	5843	54	0.65
IX	9 (1)	6.9	0.8	1.3	12.8	38.7	6540	70	0.69
VIII	6 (1)	9.5	0.9	2.2	17.4	42.1	5712	75	0.67
VII	10 (1)	2.4	0.7	1.2	15.9	40.8	6302	77	0.70
VI	4 (1)	4.0	0.9	0.8	15.3	38.2	6303	57	0.73
V	33 (4)	3.8	0.6	0.5	12.4	36.7	6599	84	0.77

*Note: *number of samples used to calculate average random vitrinite reflectance (Rrand) is in parentheses. Abbreviations, ar -as received, ad -air dried, daf -dry ash free*

Random vitrinite reflectance value (Rrand,%)

Random vitrinite reflectance values (Rrand, %) varies from 0.61 to 0.84%. As expected, the average vitrinite reflectance increases from 0.65% in the uppermost seam XII to 0.77% in the lowermost seam V (Table 1, Supplement 2). However, seams X and VIII show slightly lower average values than expected in the downdip increasing trend in vitrinite reflectance.

Organic petrography

Table 2 summarizes the results of organic petrographic analysis. Figs. 4-6 show the photomicrographs of the coal macerals and mineral matter observed in the samples. Detailed maceral data are disclosed in Supplement 2.

The studied samples exhibited a variable composition of vitrinite group macerals (48.8-78.1 vol.%), followed by inertinite (7.7-39.7 vol.%) and liptinite (2.4-6.1 vol.%), along with mineral matter (3.14-24.2 vol.%). Vitrinite content decreases down dip towards the lower seams, while inertinite content increases. No consistent trend in liptinite content was observed.

The vitrinite group primarily consists of collodetrinite (avg. 38.4 vol.%) and collotelinite (avg. 23.0 vol.%). Telinite and vitrodetrinite are present in lower concentrations (avg. 0.7 vol.% and 0.2 vol.%, respectively), mainly found in the upper seams. The inertinite group is dominated by fusinite (avg. 7.2 vol.%), inertodetrinite (avg. 4.4 vol.%), macrinite (avg. 4.2 vol.%), and semifusinite (avg. 3.9 vol.%). Secrinite and macrinite are present in minor amounts, averaging 1.9 vol.%. The liptinite group is composed of cutinite (avg. 2.8 vol.%) and sporinite (avg. 1.0 vol.%). No other macerals were observed.

Mineral matter content is higher in the upper seams and lower in the lower seams. Mineral matter is mainly composed of carbonate (avg. 4.7 vol.%) and clay (avg. 3.2 vol.%) minerals. Sulfide minerals, primarily pyrite, average 1.5 vol.%, while silicate minerals average 1.1 vol.%.

Table 2. Average maceral composition and mineral matters of the Nariinsukhait coal seams

Seam #	XII/XIIa	XI	X	IX	VIII	VII	VI	V
# of samples	5	3	3	1	2	3	1	11
Vitrinite	61.2	65.7	68.2	62.2	67.6	67.7	65.4	57.5
Telinite	1.5	1.5	0.9	0.2	1.2	0.7	0.2	0.1
Collotelinite	27.7	24.8	24.8	18.5	31.2	29.0	26.7	17.4
Vitrodetrinite	0.6	0.2	0.2	0.4	0.0	0.1	0.0	0.0
Collodetrinite	31.5	39.2	42.3	43.1	35.2	37.9	38.5	40.0
Inertinite	21.6	17.6	15.1	25.6	14.3	18.1	21.2	30.6
Fusinite	6.4	4.6	3.3	9.5	4.3	5.7	6.3	9.9
Semifusinite	2.0	2.9	1.3	2.1	1.6	3.1	5.3	6.2
Secretinite	1.9	1.0	1.2	1.1	2.1	1.9	1.6	2.3
Macrinite	4.3	3.4	4.1	1.3	1.9	1.5	2.4	5.7
Micrinite	0.9	0.9	2.0	6.1	1.4	1.3	2.4	2.4
Inertodetrinite	6.1	4.6	3.2	5.5	3.0	4.5	3.2	4.2
Liptinite	3.7	3.9	3.5	2.7	4.0	3.8	4.3	3.9
Sporinite	1.0	1.0	1.0	0.8	0.7	0.7	0.7	0.9
Cutinite	2.7	3.0	2.9	2.1	2.5	2.5	3.1	3.0
Total organic	86.6	87.2	86.9	90.5	85.9	89.6	90.9	92.1
Mineral matter	13.4	12.8	13.1	9.5	14.1	10.4	9.1	7.9
Clays	3.0	5.1	7.0	1.9	3.8	3.3	5.1	1.9
Silicates	1.4	2.3	0.8	0.4	1.1	1.1	1.8	0.9
Carbonates	6.4	3.6	3.8	5.1	4.9	3.9	1.8	4.8
Sulphides	2.6	1.7	1.5	2.1	4.2	2.2	0.4	0.4
Others	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Total mineral matter	13.4	12.8	13.1	9.5	14.1	10.4	9.1	7.9

Seam XII/XIIa (93.7-110.1 m): Four samples from seam XII were studied. Samples were dominated by collodetrinite (27.7-34.5 vol.%), and collotelinite (14.3-35.8 vol.%) with minor amount of telinite and vitrodetrinite. The most abundant maceral of the inertinite group is fusinite (3.1-10.3 vol.%), with minor inerttodetrinite (4.1-11.3 vol.%), macrinite (1.5-5.9 vol.%), secretinite (0.2-3.5 vol.%), and semifusinite (0.7-3.3 vol.%). Liptinite group macerals include cutinite and sporinite. Cutinites predominate (2.2-2.8 vol.%). The mineral matter contents of seam XII ranges from 7.5 to 24.2%. The upper part of the seam has high mineral matter contents (24.2 vol.% at 98.5-101.5 m), which decreases significantly downwards (7.5-12.7 vol.% at 101.5-110.1 m). Carbonates predominate in mineral matter, which also includes clay minerals, sulfides (pyrites), and silicates (Table 2).

A sample was studied from sub-seam XIIa. The sample is dominated by collotelinite (32.6 vol.%) and collodetrinite (33.0 vol.%), with minor amounts of telinite and vitrodetrinite. The inertinite maceral group accounts for 10.1 vol.% and is mainly composed of fusinite (2.6 vol.%) with subordinate inertodetrinite (2.8 vol.%), secretinite (2.0 vol.%), and macrinite (1.7 vol.%) (Fig. 4a). Semifusinite and macrinite are rare. Liptinite maceral groups are composed of cutinite (4.8 vol.%), and sporinite (1.3 vol.%) (Fig. 4b). Mineral matter content of sub-seam XII is 11.7 vol.% and includes clays, carbonates, siliceous minerals, and pyrite (Fig. 4c). They are disseminated over organic macerals, and particularly pyrite is frequently found along the cracks (Fig. 4d).

Seam XI (111.1-117.5 m): Three samples from seam XI were analyzed. The coal is composed of vitrinite (62.4-68.8 vol.%), inertinite (14.2-22.7 vol.%), liptinite group macerals (3.0-5.0 vol.%), and mineral matter (8.7-17.1 vol.%). Collodetrinite (34.1-39.7%) and collotelinite (20.4-26.6%) are the most common macerals of the vitrinite group, with minor telinite

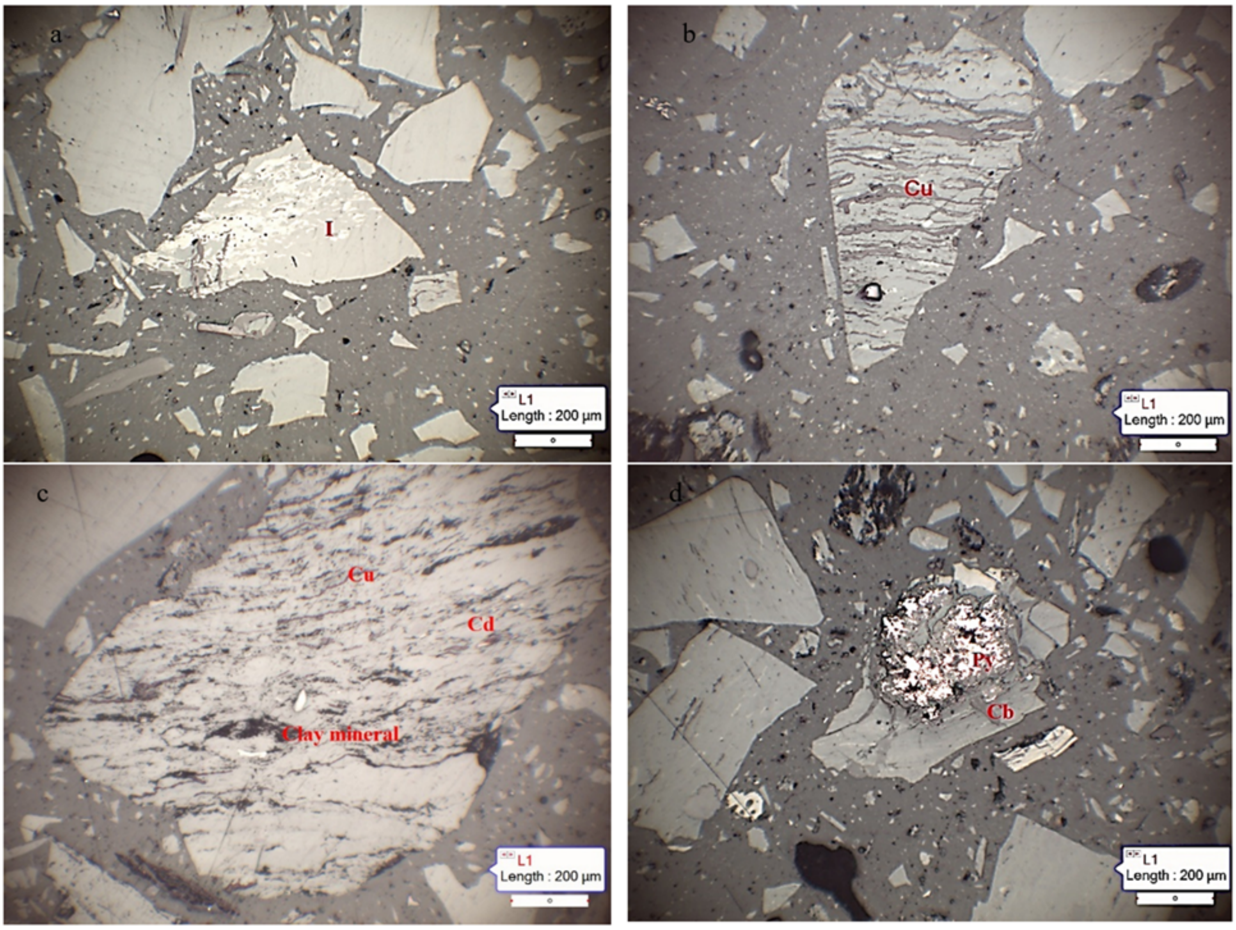

Fig. 4. Microphotographs showing a) inertodetrinite (I), b) cutinite (Cu), c) clay minerals, d) pyrite (Py) and carbonates (Cb) from seam XII/XIIa

(0.4-2.6%) and vitrodetrinite (0.2-0.4%) appearing infrequently. The inertinite group is characterized by fusinite (3.5-6.4%) and inertodetrinite 3.2-6.5%), whereas macrinite, semifusinite, and secrinite are rare. Mineral matter content ranges between 8.7 and 17.1 vol.%. It consists of clay (2.6-8.1 vol.%), carbonate (2.1-4.5 vol.%), silicate (0.2-3.6 vol.%), and sulphide (1.5-1.9 vol.%) minerals. Rarely, ore minerals with titanium are found (0.2 vol.%). Minerals are dispersed throughout the organic mass and sometimes filling the pores of the macerals (Table 2).

Seam X (126.2-135.2 m): A total of 3 samples were taken from seam X and analysed. The samples consist of vitrinite (63.2-78.1%), inertinite (7.7-19.1%), and liptinite group macerals (3.1-4.7%), with mineral matter of 6.4 -16.4%. Collodetrinite makes up the majority of the vitrinite group macerals, with subordinate telinite, collotelinite and vitrodetrinite. Fusinite and inertodetrinite are the predominant macerals from the inertinite group, with macrinite, semifusinite, and secretinite also present. Cutinites are the most common liptinite group macerals and make up the outer framework of leafy parenchyma. The mineral content varies from 6.4 to 16.4%, consisting of clay (1.4 to 9.6%), carbonate (2.6 to 7.3%), silicate (0.5-1.5%), and sulfides (1.3-2.0%) (Table 2).

Seam IX (149.5-152.5 m): A single sample was studied from this seam. The sample consists of vitrinite (62.2%), inertinite (25.6%), and liptinite group macerals (2.7%). Mineral matter content is 9.5 vol.%. Collodetrinites (43.1 vol.%) and collotelinite (18.5%) dominate the vitrinite group with a minor amount of telinite (0.2%). The inertinite group is mainly composed of fusinite (9.5%), micrinite (6.1%), and inertodetrinite (5.5%), with macrinite, semifusinite and secretinite. Cutinite and its fragments are the most common maceral of

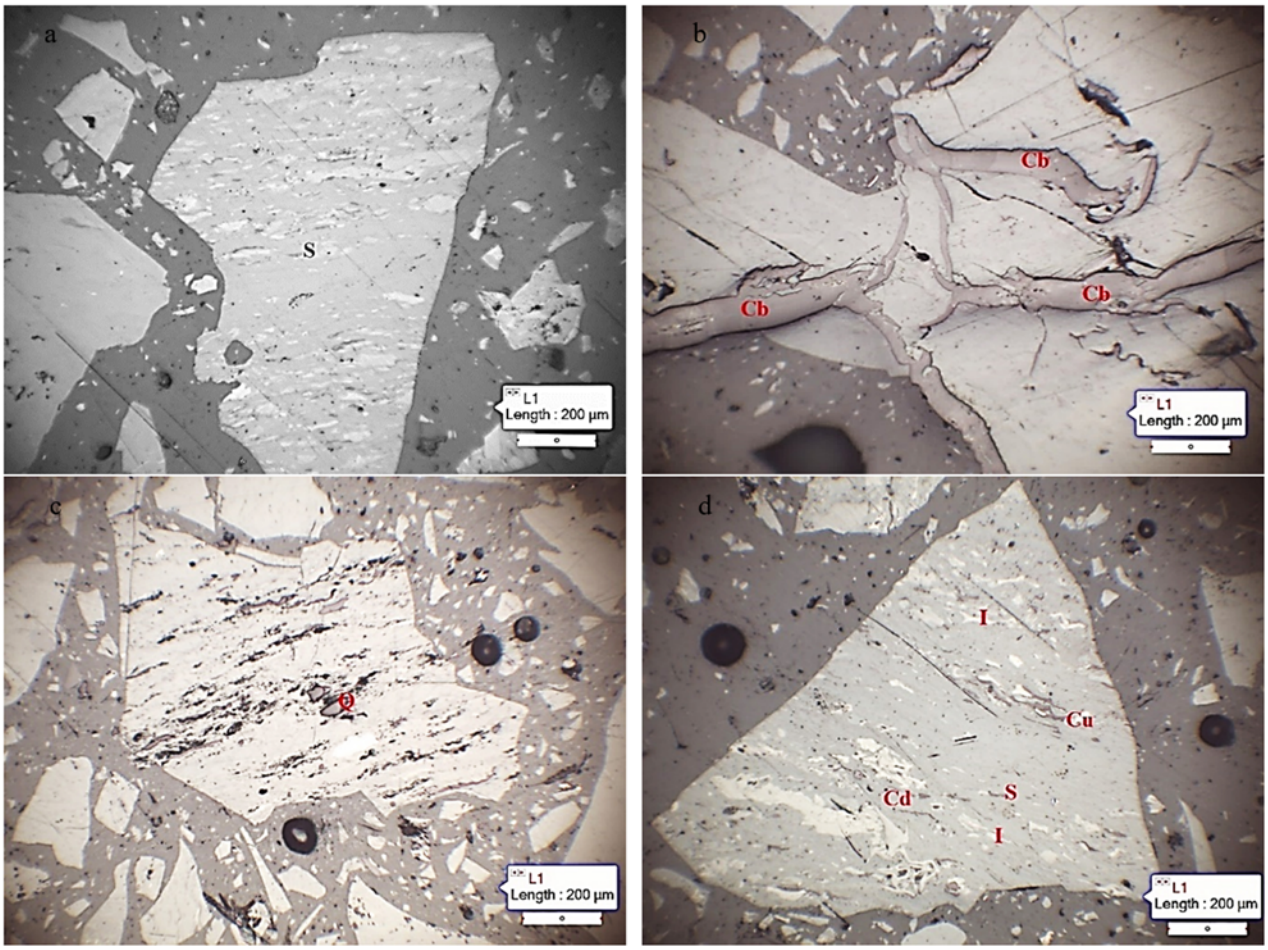

Fig. 5. Microphotographs showing a) sporinite (S); b) carbonates (Cb); c) quartz (Q); d) collodetrinite (Cd); inertodetrinite (I); cutinite (Cu) and sporinite (S) from seams VII and VIII

the liptinite group, with minor sporinite. The mineral matter content is 9.5%. Carbonates (5.1%), sulfides (2.1%), clays (1.9%), and occasional silicate minerals (0.4%) make up the the mineral matter (Table 2).

Seam VIII (153.5-159.2 m): Two samples were obtained from seam VIII and analyzed. Vitrinite (64.4-71.5%), inertinite (13.3-15.1%), and liptinite group macerals (3.5-4.6%), as well as mineral matter (10.6-17.0%) were observed. Collodetrinite and collotelinite are the dominant macerals of the vitrinite group, with minor telinite. Inertinite group macerals are often contained within collodetrinite and characterized by fusinite, inertodetrinite, macrinite, semifusinite, and secretinite. The liptinite group is composed of cutinite, its pragments, and sporinite (Fig. 5a). The mineral matter content varies between 10.6 and 17.0%.

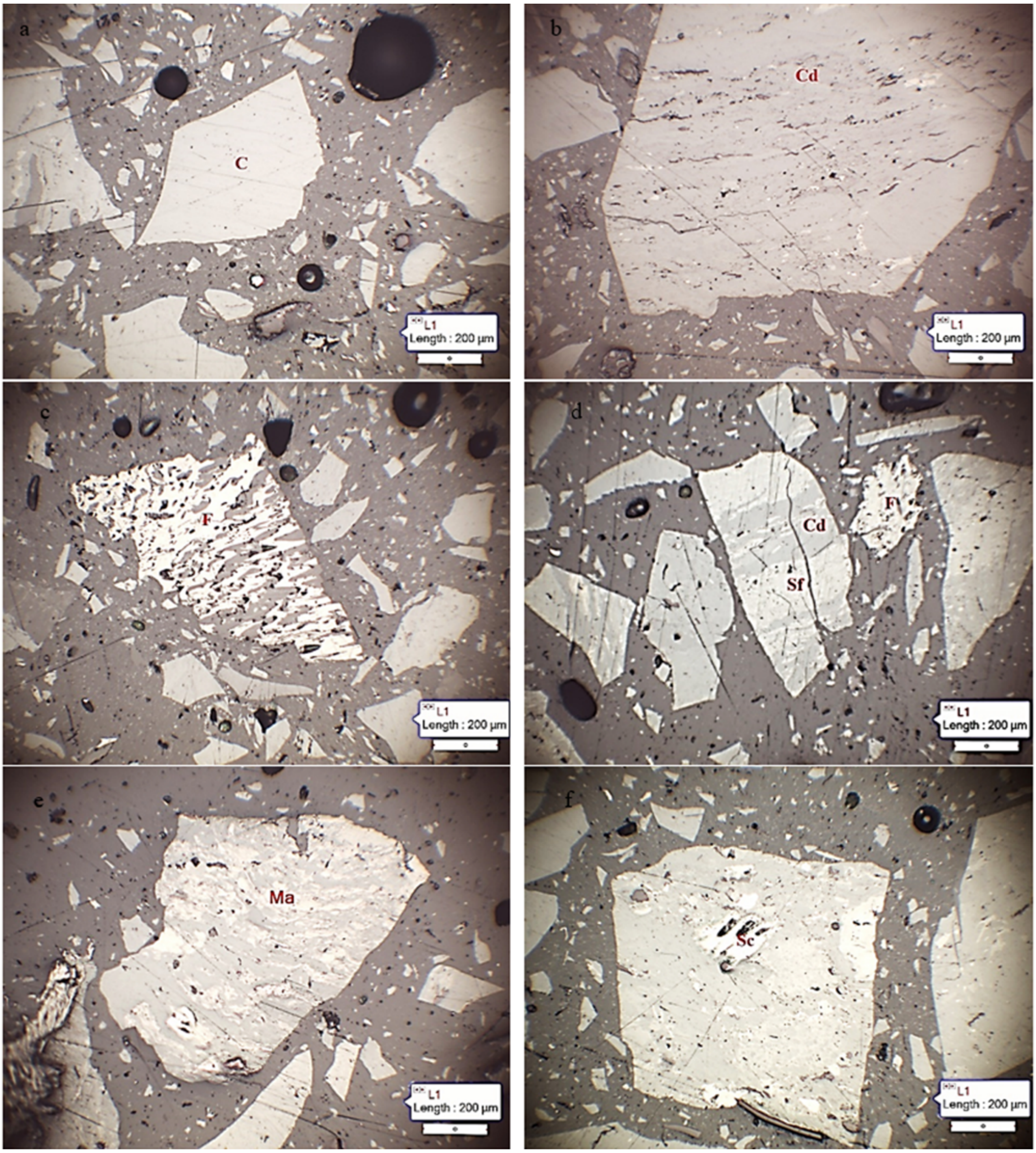

Fig. 6. Microphotographs showing a) collotelinite (C); b) collodetrinite (Cd); c) fusinite (F); d) semifusinite (Sf); e) macrinite (Ma); f) secrinite (Sc) from seam V

Carbonates, clays and sulfides are abundant with some silicate minerals (Fig. 5b, c; Table 2). Seam VII (169.5-233.4 m): Three samples from Seam VII were analyzed for organic petrography. The coal samples are characterized by vitrinite (64.9-72.3%), inertinite (14.9-20.8%), and liptinite group macerals (3.5-4.1%), with mineral matter content of 5.3-14.9 vol. %. Among the vitrinite group macerals, collodetrinite (36.1-42.1%) and collotelinite (28.4-30.0%) dominate, and telinite and vitrodetrinite are rare. Inertinite group macerals consist of fusinite, inertodetrinite, macrinite, semifusinite, and secretinite (Fig. 5d). Liptinite group macerals are cutinite, its fragments, and sporinite. Mineral matter is characterized by carbonate, clay, and sulfide minerals, with minor amount of silicate minerals (Table 2).

Seam VI (244.8-248.5 m): A single sample from seam VI was studied. Vitrinite (65.4%), inertinite (21.2%), and liptinite group macerals (4.3%), and mineral matter (9.1%) were determined in the coal sample. Collodetrinites and collotelinites were the most abundant vitrinite macerals with minor telinite. Inertinite group macerals are composed of fusinite and semifusinite, with minor inertodetrinite, micrinite, macrinite, and secretinite. The liptinite group is characterized by cutinite, its fragments, and sporinite. A partial allochthonous process were observed in the sample characterized by low mineralization and carbonates, clays, and sulfides with trace amount of silicate minerals (Table 2).

Seam V (446.5-493.1 m): 11 samples were obtained from the important basal seam V and analyzed. The seam has higher inertinite content compared with the overlying Jurassic seam package. The concentration of vitrinite, inertinite, and liptinite group macerals are 50.4-65.9%, 16.2-39.7%, and 2.4-6.1%, respectively. Mineral matter content varies from 3.4 -13.7% with an average of 8%. The most abundant macerals of the vitrinite group are collodetrinite (32.7-47.3%) and collotelinite (8.5-24.2%) (Fig. 6a, b). Telinite (0.2-0.3%) is found in small amounts. The inertinite group is characterized by fusinite (6.1-13.9%), semifusinite (1.8-11.4%), macrinite (2.9-10.0%) and inertodetrinite (1.8-6.5%). Secretinite (1.1-3.5%) occurs in minor amounts (Fig. 6c-f). Rarely, transitions from semifusenite to fusinite were observed. On secretinite, desiccation cracks were occasionally observed. The coal has a higher concentration of liptinite group macerals, primarily cutinite, its fragments (1.1-4.6%) and sporinite (0.3-1.5%). The leaf parenchyma's outer framework is composed of cutinite. Seam V has low mineral matter, mainly comprised of carbonate (2.0-7.6%), and clay minerals (0.4-5.4%). Sulfide and silicate mineral contents are minor, 0.2-1.4%, and 0.4-1.6%, respectively (Table 2). Minerals containing titanium occurs rarely. Structured maceral pores and cleats are filled with minerals.

DISCUSSION

Coal rank and classifications

The vitrinite reflectance values of the studied samples range from 0.61 to 0.84%, generally increasing with depth. However, samples from seams VIII and X exhibit slightly lower reflectance values than expected for their depth. It is evident that seam V, the basal seam, has a higher rank compared to the other seams (Table 1). This is reflected in its lower volatile matter content (avg. 36.7%, daf), lower inherent moisture (avg. 0.6%, ad), and higher vitrinite reflectance (Rrand, avg. 0.77%) (Fig. 7a-c). The average net calorific value of seam V is 6,599 kcal/kr (ar). This elevated calorific value is partially attributed to its higher rank, with the lower ash content also playing a significant role. Based on the samples studied, seam V in the central part of the Nariinsuhait deposit can be classified as '1/3 coking coal', while all other seams are classified as 'high volatile gas coal' according to MNS 6457:2023 classification. According to Baatarkhuyag et al. (2015), the ranks of the upper seams of the Nariinsukhait deposit vary from seam to seam, indicating lateral rank changes, particularly in the upper seams. Such rank variations within individual seams are common in folded coal seams, especially coalification occurred after folding or concurrent with folding (e.g., Pearson and Grieve, 1985). This is because active tectonism causes uneven burial depths for the peat, leading to asymmetrical coalification across individual seams.

Coal characteristics

Seam V is characterized by higher coal quality compared to other seams due to its higher rank, and lower ash content (avg. 12.4%, ad) (Table 1). This seam also has relatively lower inherent moisture and volatile matter, as well as higher calorific value (Fig. 7a-b). Moreover, the G index of seam V averages 85, indicating coking potential (Table 1). Generally, a G index greater than 65 suggests suitability for coke manufacturing (Chen, 1989; Thomas, 2020). Although this study did not analyze dilatation and plasticity, the Sapozhnikov plastometer index, y (mm), for seam V ranges from 10 to 13 mm, as reported by Baatarkhuyag et al. (2015). In contrast, the upper seams have an average G index ranging from 54 to 77. Higher ash contents result in lower G index. For instance, seams X and XII have an average G index of 54 and 69, respectively, with an average ash content of 21.3% and 19.9% (ad). Other upper seams exhibit a higher G index, ranging from 70 to 77, indicating that they also possess coking potential. Furthermore, the quality of the upper seams can be improved to '1/3 coking coal' through washing as noted by Baatarkhuyag et al. (2015). This beneficiation is expected as lower ash content enhances caking properties and calorific value (Fig. 7d-e).

Due to its lower rank, Nariinsukhait coals are not classified as hard coking coal. However, coal from seam V is classified as semi soft coking coal and used for the coking coal blends. Seam V contains 66% of the total coal resources of the deposit (Baatarkhuyag et al., 2015). Coals from

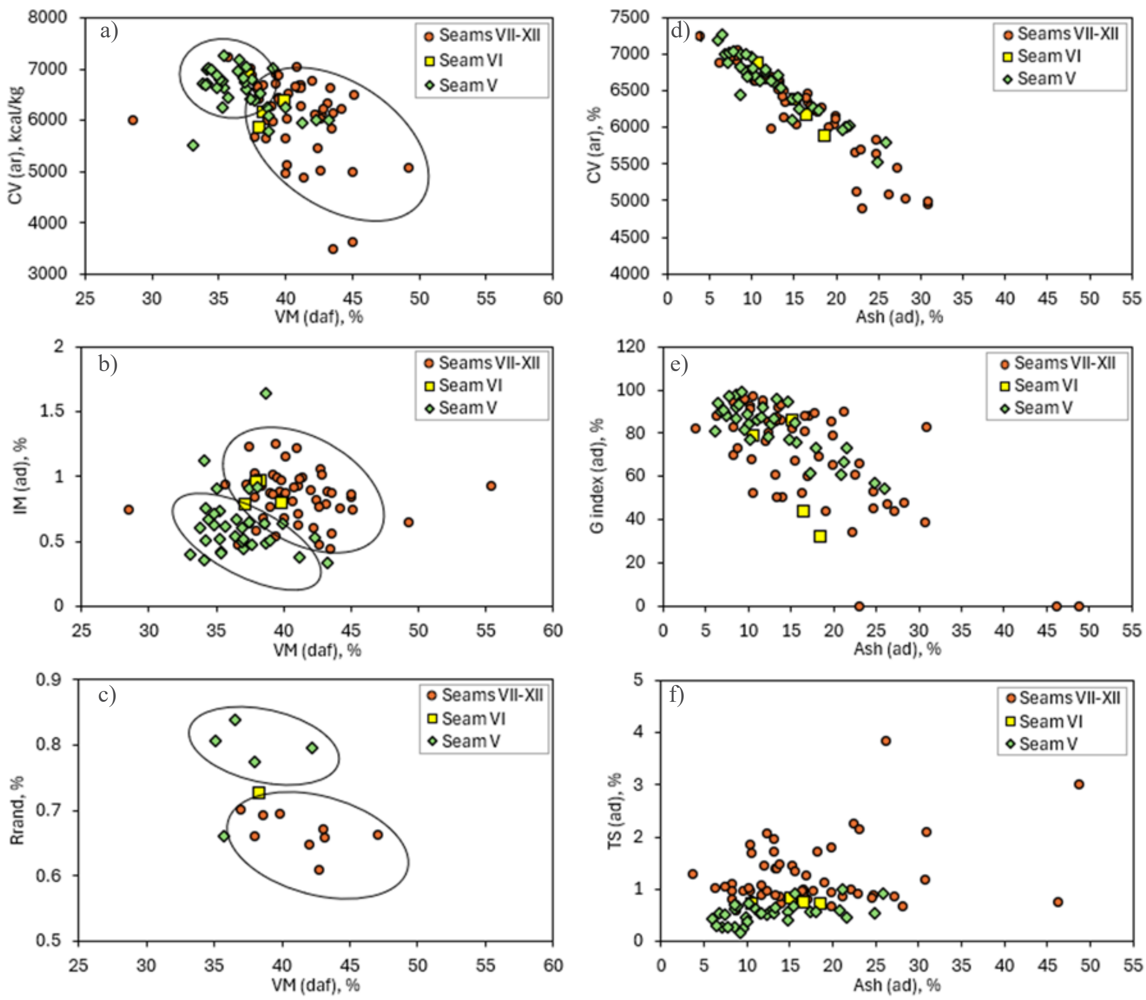

Fig. 7. Basic characteristics of the Nariinsukhait coal seams. The coal quality of seam V is distinguishable from the other seams (see text for discussion). Volatile matter contents of the samples are compared with a) calorific value; b) inherent moisture; c) Rrand, %. Ash contents are compared with d) calorific value; e) G index; f) total sulfur content.

upper seams with high ash can also be washed and utilized as semi-soft coking coal. Another primary use of Nariinsukhait coals is high-quality pulverized coal injection (PCI) coal.
Sulfur content is a critical characteristic for both coal reserve estimation and coal utilization (Munkhtogoo, 2019; Thomas, 2020) and provides insights into peat-forming environments (Chou, 2012). The total sulfur contents of seam V are relatively low, averaging 0.5% (ad basis), while the upper seams show higher sulfur contents, averaging from 1.1 to 2.2% (Table 1, Fig. 7f). Notably, seam VI has an average total sulfur content of 0.8% (ad basis). Low sulfur content (<1%), typically indicates sulfur sourced mainly from the parent plant (organic sulfur), whereas medium (1-3%) and high (>3%) sulfur contents include contributions from both organic sulfur and seawater sulfate (Chou, 2012). In the Nariinsukhait coals, organic sulfur does not exceed 0.02%, suggesting that most of the total sulfur is in sulfide and sulfate forms (Baatarkhuyag et al., 2015). The relatively low sulfur and ash contents of seam V are hypothesized to be influenced by the conditions of feat-forming environment (Mccabe, 1984; Hunt and Smyth, 1989). The depositional environment of the Nariinsukhait paleomire is further discussed in the subsection; *Peat forming depositional environment.*

Maceral composition

Maceral composition and vitrinite reflectance are widely used coal characteristics to measure coal rank and to design specific coal blends (Diez et al., 2002; Suares-Ruiz and Ward, 2008; Suarez-Ruiz et al., 2012). Additionally, the maceral composition of coal is controlled by factors such as the type of peat-forming plant, water table levels, and nutrient supply among others. Therefore, organic petrography is routinely employed to reconstruct the peat-forming depositional environment (Diessel, 1986; Calder et al., 1991; Diessel, 1992; Kalkreuth et al., 2000; Suarez-Ruiz et al., 2012; O'Keefe et al., 2013; Sosnowski and Jelonek, 2022).
The results from organic petrography reveal that coals from seam V are characterized by high inertinite content and low mineral matter. In contrast, coals from the upper seams display high vitrinite content and high mineral matter (Table 2, Figs. 8 and 9b). An inverse correlation exists between the average inertinite content and average mineral matter content (Fig. 10). No significant trend in liptinite concentration has been observed (Table 2, Fig. 9a). These variations in maceral composition and

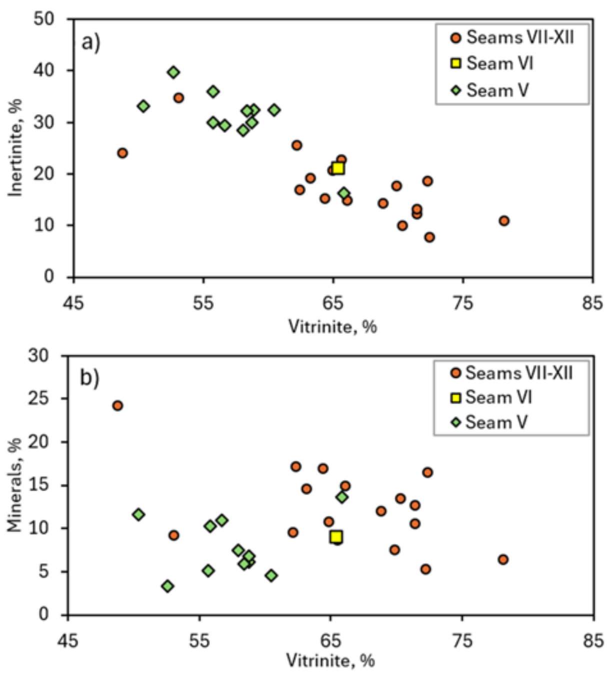

Fig. 8. Maceral composition of the Nariinsukhait coal seams. Vitrinite contents are compared with a) inertinite and b) mineral matter contents.

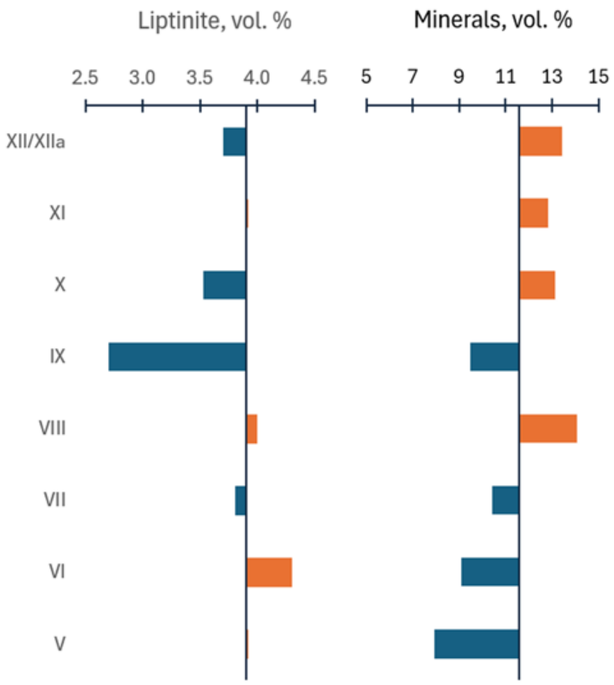

Fig. 9. Changes in a) liptinite and b) mineral matter contents of the Nariinsukhait coal seams.

mineral matter content are influenced by the depositional environment of the peat-forming paleomires (*see subsection Peat forming depositional environment*). For example, seam V was accumulated in a raised bog. Such bogs are mainly fed by rainfall, with limited influence from ground water (Moore, 1989). On the other hand, the bog's surface is elevated relative to the surrounding area, causing the upper peat to be above the water table and thus more prone to oxidation into inertinite (ICCP, 2001). Additionally, the elevated topography restricts sediment input into the peat, leading to lower mineral matter (ash) contents in the coal (Diessel, 1986; Moore, 1989; Calder et al., 1991; Diessel 1992; Zieger and Littke, 2019).

When coking coal (or blend) is heated in the absence of oxygen, vitrinite and other reactive macerals melt and form coke. However, a certain amount of inertinite is necessary to produce strong coke (ICCP, 2001; Diez et al., 2002; Crelling, 2008; Thomas, 2020). Fig. 11 shows the relationship between inert contents (inertinite and ash) and vitrinite reflectance values of various coking coals traded on the world market. The "optimum inert" line indicates the ideal amount of inert contents required to produce the strongest coke for each rank. Coals positioned to the left of this line are rich in inertinite, while those to the right are rich in vitrinite (Pearson, 1980). It is evident that Nariinsuhait coals are rich in inerts, suggesting a need to blend them with coals that are rich in reactive macerals.

The concentrations of collodetrinite and collotelinite in Nariinsukhait coals varies significantly from 40 to 93.4 vol.%, with an average of 68.7 vol.% (Table 2, Supplement 2). The bitumen content in collodetrinite

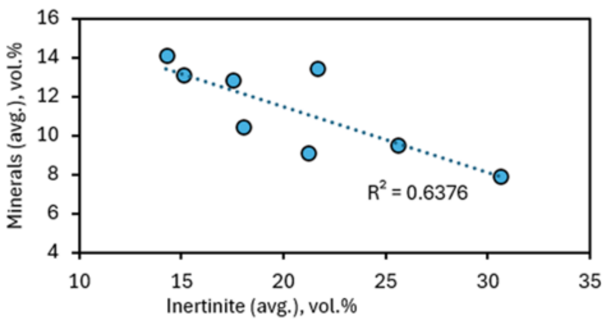

Fig. 10. Relation between average contents of inertinite and mineral matter of the Nariinsukhait coal seams.

significantly influences caking and coking properties of coal, and collodetrinite also plays a major role in the liquefaction products (ICCP, 1998). The upper seams of the Nariinsukhait coal-bearing package exhibit high concentrations of collotelinite, which is a key reactive maceral for coke production and liquefaction. Furthermore, high volatile medium rank coals typically show optimal conversion rates to liquid and gaseous products (ICCP, 1998). Therefore, Nariinsukhait coals may be suitable for liquefaction processes.

Peat forming depositional environments

Types of peat forming mires

Peat accumulates only in specific types of ecosystems (Moore, 1989) that meet certain geological conditions, such as appropriate subsidence rate, and minimal sediment input etc (McCabe, 1984; Diessel, 1986, 1992; Calder et al., 1991; Suarez-Ruiz et al., 2012). Peat-forming mires can be classified based on their hydrology into two primary types (Table 3). Rheotrophic mires are fed by both rain- and ground-water flow. In contrast, ombrotrophic

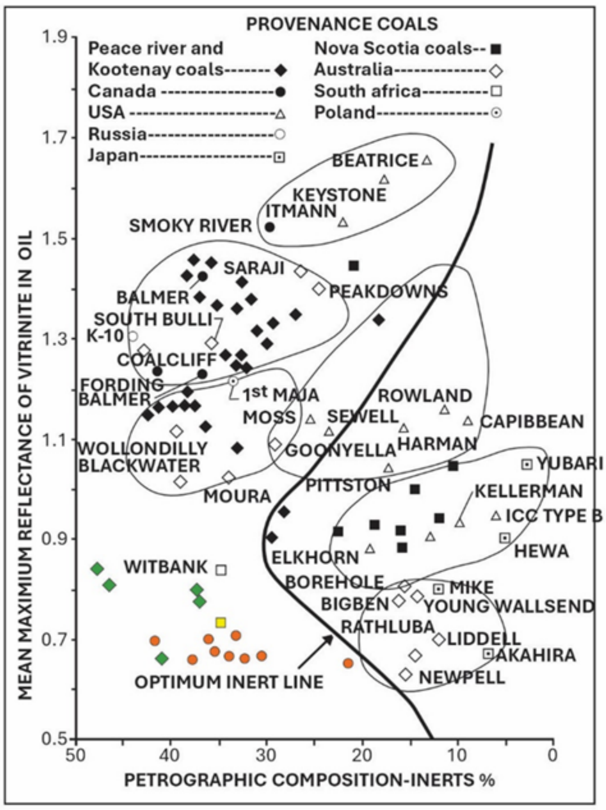

Fig. 11. Petrographic compositions of some coking coals traded in the World market (Pearson, 1980), with plots of Nariinsukhait coal samples showing high inert composition.

mires receive water input only from rainfall (Moore, 1989). An intermediate classification of mesotrophic mires applies to transitional peat mires tending toward ombrotrophic conditions (Calder et al., 1991). Ombrotrophic mires are commonly called bogs. Rheotrophic mires can be further subdivided into fens and swamps depending on degree of flooding. When covered by forest, these mires are termed bog forest and swamp forest, respectively (Calder et al., 1991). Diessel (1992) identified two major types of depositional systems for peat accumulation. The first is freshwater peatlands, including alluvial plain, and delta plain. The second is coastal lowlands protected by barrier beaches or sand bars. Alluvial plains are extensive, gently sloping flat landforms commonly found in intracratonic basins or between highlands and coastal plains (Diessel, 1992). Deltas are typically triangular landforms consisting of delta plain (landward) and delta front (below sea/lake)., with the delta plain further subdivided into upper and lower delta (Suarez-Ruiz et al., 2012; Dai et al., 2020). Diessel (1992) also defined four types of zones associated with coal facies based on mire water levels: (i) terrestrial - relatively dry, wooded mire; (ii) telmatic - water level is controlled and fluctuated by sea level and water table variations; (iii) limnic - underwater environment; (iv) limno-telmatic - transition zone between telmatic and limnic environment.

Reconstruction of depositional environment based on organic petrography

Organic petrographic studies have been extensively applied to infer the depositional environments of peat-forming mires and their paleoecology (Diessel, 1986; Mukhopadhyay, 1986; Calder et al., 1991; Suarez-Ruiz et al., 2012). Diessel (1986) introduced the Tisue preservation index (TPI) and Gelification index (GI) based on maceral composition. Subsequent research has developed additional indices for paleoenvironmental interpretation based on coal petrography and those indices have been used (Calder et al., 1991; Kalkreuth et al., 2000; Petersen and Ratanasthien, 2011; Silva and Kalkreuth, 2005; Singh et al., 2012, 2013, 2016; Stock et al., 2016; Zieger and Littke, 2019; Sosnowski and Jelonek, 2022; Zamani et al., 2023). In constructing the depositional paleoenvironment of the Nariinsukhait paleomire, A/I index (Zieger and Littke, 2019), the facies diagram by Singh and Singh (1996), and the foreland diagram by Hunt and Smyth (1989) were used in conjunction with the TPI and GI indices.

The TPI measures the ratio of structured to unstructured tissue derived macerals, reflecting the degree of humification, and the contribution of wood to the peat (Diessel, 1992). Under relatively dry conditions, fusinite and semifusinite are formed, while moist conditions favor the formation of telinite and collotilinte. Herbaceous plant tissues, which lack structure and decompose more readily than wood cells, contribute to lower TPI values. A TPI value <1 indicates a higher contribution from herbaceous plants, while a value >1 suggests a predominance of arborescent plants. The GI is the ratio of gelified to non gelified macerals, indicating relative humidity and oxidation in paleomires. A GI value >1 suggest high water table conditions, while a value <1 indicate a low water table (Diessel, 1992). In this study, the TPI and GI ratio were slightly modified according to Kalkreuth et al. (2000) and Silva and Kalkreuth (2005) (Eq.1).

$$TPI = \frac{\text{telinite} + \text{collotelinite} + \text{fusinite} + \text{semifusinite}}{\text{vitrodetrinite} + \text{collodetrinite} + \text{macrinite} + \text{inertodetrinite}}$$

$$GI = \frac{\text{vitrinite} + \text{macrinite}}{\text{fusinite} + \text{semifusinite} + \text{inertodetrinite} + \text{micrinite}}$$

Table 3. Types of mires based on hydrological conditions (Calder et al., 1991)

Criterion:	Wetland ecosystem			
Peat accumulation:	Peat-forming (mires)			Non peat-forming
Water source:	Ombrotrophic (rain-fed)	Rheotrophic (flow-fed)		
Water level:	Bog (Bog forest)	Dry season water table		
		Below surface	Above surface	Near surface
Ecosystem:		Fen	Swamp (Floating swamp, swamp forest)	Marsh
Vegetational varieties:				

The A/I ratio, proposed by Zieger and Littke (2019), is the ratio of ash to fusinite and semifusinite (Eq. 2). This ratio differentiates between depositional environments. An A/I ratio >0.5 indicate a rheotrophic environment with a high-water table, whereas <0.5 suggest a relatively dry ombrotrophic environment.

(Eq. 2)

$$A/I = \frac{\text{ash yield}}{\text{ash yield} + \text{semifusinite} + \text{fusinite}}$$

Singh and Singh (1996) developed a facies diagram based on maceral compositions and mineral matter, which relates to the influx of surface water in the mire. The diagram helps to identify oxic and unoxic conditions in the paleomire.

Due to the different subsidence rates in foreland and cratonic basins, the maceral compositions of coals from these basins can vary significantly. Based on this assumption, Hunt and Smyth (1989) proposed a model that uses two parameters: vitrinite contents and semifusinite ratio. Vitrinite content, which includes both vitrinite and liptinite, reflects organic material deposited under reducing conditions. The semifusinite ratio is the ratio of inertinites with at least one complete cell structure to other inertinites, which indicates the degree of oxidation of organic components during mire deposition.

Despite criticism of using petrographic indices for reconstructing depositional environments (Moore and Shearer, 2003; Dai et al., 2020), these indices remain valuable for identifying variations within coal seams with different depositional conditions, especially when integrated with other characteristics such as ash and sulfur contents etc. (Zieger and Littke, 2019; Sosnowski and Jelonek, 2022; Zamani et al., 2023). A more accurate peat-forming model requires complex studies such as paleontology, sedimentology, paleobotany, petrology, and mineralogy etc. (Dai et al., 2020).

Depositional environment of the Nariinsukhait paleomire

The TPI values in the Nariinsukhait coals range from 0.5 to 1.1 with an average of 0.8, while GI values vary from 2.2 to 12.3 with an average of 4.6. Most samples from the upper seams fall within an upper delta plain environment (Fig. 12). In contrast, samples from seam V are plotted in an area associated with back barrier coals. However, a back-barrier setting for Nariinsukhait coal is unlikely, as by the Permian southern Mongolia had collided with the north China craton, and the Paleo-Asian Ocean was closed already (Badarch et al., 2002; Lamb et al., 2008; Johnson et al., 2008; Gerel, 2021). Only a remnant ocean, called Sulinkheer ocean, existed in southeastern Mongolia until the end of Permian (Johnson et al., 2008). It is more

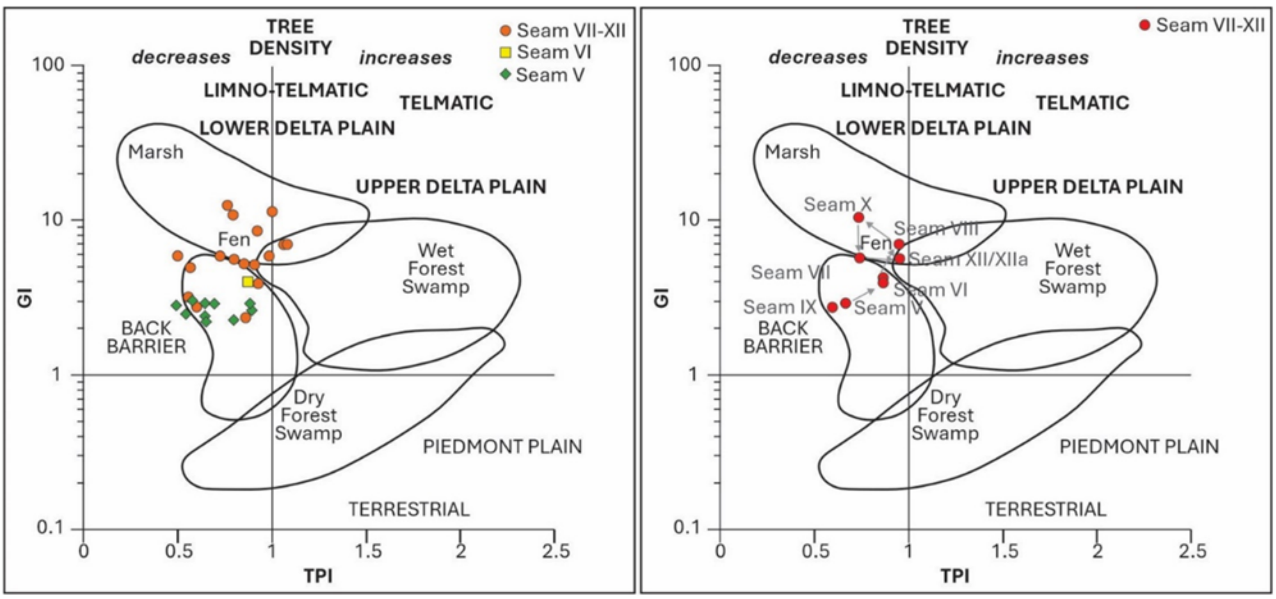

Fig. 12. TPI-GI depositional facies diagram for Nariinsukhait coal sample (Diessel, 1986). a) all samples; b) the averages of coal seams

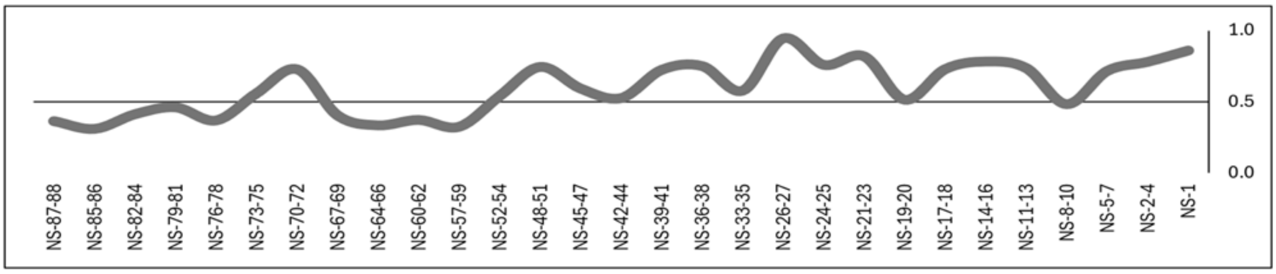

Fig. 13. A/I variations of Nariinsukhait coal seam samples. Seam V has lower A/I, whereas the overlying seams are characterized by higher A/I.

plausible that the paleomire developed in upper delta plain environment, characterized by a flat, relatively wide valley bordered by upland areas and topographic highs. This type of depositional environment was reconstructed for Canadian Minto coals (Kalkreuth et al., 2000). Coals from the upper seams might have accumulated in a lower delta plain environment with a relatively higher water table compared to seam V.

Fig. 12b shows the average TPI and GI values for each seam, reflecting variations in the water table of the paleomires. Seam V developed in a mire with the lowest water table, whereas seams VI, VII, and VIII accumulated in wetter conditions. In contrast, seam IX was deposited in a dry mire, similar to seam V. However, seam X accumulated in a mire with the highest water table. Subsequently, the water tables for the mires of seams XI, and XII were lower once again.

The A/I ratio of the Nariinsukhait coals increases towards the upper seams (Fig. 13). Samples from seam V exhibit AI ratios of <0.5, indicative of ombrotrophic mire with relatively dry conditions during most of the peat accumulation. Additionally, the low contents of total sulfur and mineral matter supports the presence of an ombrotrophic mire (Hunt and Smyth, 1989; Calder et al., 1991; Diessel, 1992; Zieger and Littke, 2019). Samples from the middle part of seam V show A/I values of >0.5, suggesting paludification of the mire. In contrast, most samples from the upper seams have A/I values of >0.5, with some variability, indicating mesothrophic and rheotrophic mire conditions. The higher ash and total sulfur contents in the upper seams are consistent with these mire types.

Plots of the studied samples on the facies model proposed by Singh and Singh (1996) suggest that the Nariinsukhait coals were deposited in alternating oxic and anoxic mires (Fig. 14a). Seam V accumulated in a more oxic mire, whereas the upper seams developed in less oxic and more moist mires.

The model proposed by Hunt and Smyth (1989) indicates that the Nariinsukhait coals evolved in a foreland basin setting. The samples, characterized by low semifusinite ratio and high vitrinite contents, are plotted within the foreland field (Fig. 14b). Samples from seam V show lower vitrinite content and higher semifusinite ratios compared to the upper seams. Unlike cratonic basins, the subsidence rate of foreland basins is high, resulting in a lower coal:clastic ratio in the coal-bearing sedimentary package and more frequent initiation and termination of peat formation. Additionally, coals from foreland basins typically have higher vitrinite content due to wetter conditions (Hunt and Smyth, 1989). The higher semifusinite ratio in seam V may reflect not only dry and oxic conditions but also the influences of the tectonic regime of the sedimentary basin on the peat-forming paleomires.

The Nariinsukhait basin is interpreted here as a collisional foreland basin, developed parallel to the Noyon basin to the north, both formed by north-south directed compression (Hendrix et al., 1996, 2001; Lamb et al., 2008; Baigalmaa et al., 2021; Batgerel et al., 2021). However, the basin may also be interpreted as strike-slip or transtensive basin (Hendrix et al., 1996; Michaelsen and Storetvedt, 2023). Prior to peat accumulation, coarse grained clastic sediments of the basal section of the Orgilokhbulag Formation accumulated in the Nariinsukhait basin during a period of accelerated subsidence. Following this, tectonic conditions stabilized, leading to the formation of large, flat valleys

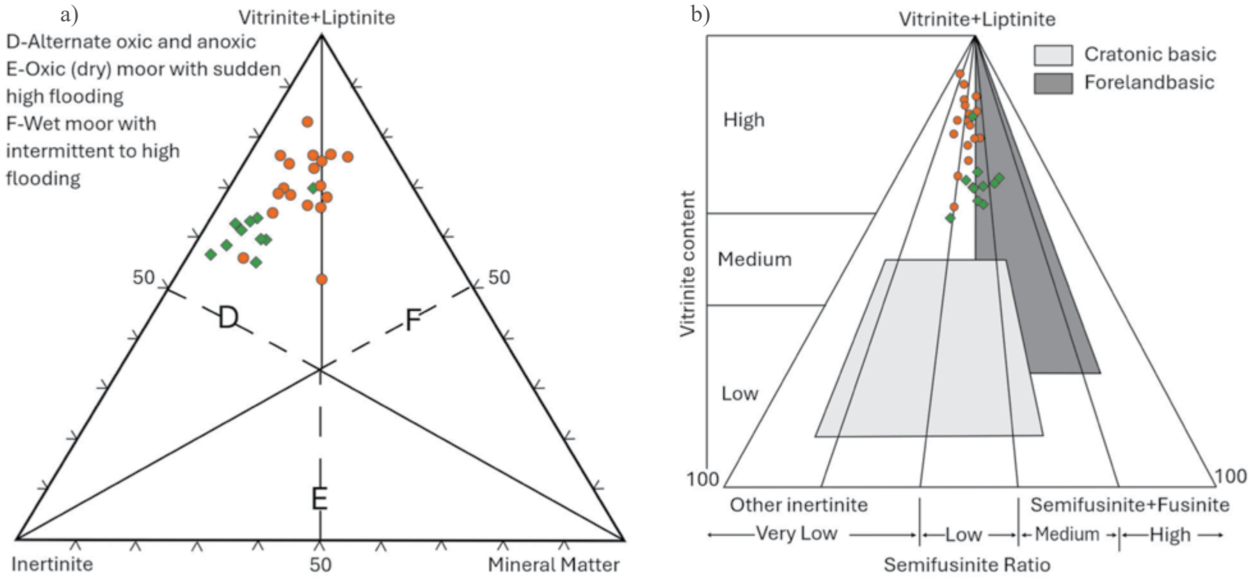

Fig. 14. a) Depositional conditions of the Nariinsukhait coals based on maceral and mineral matter contents (Singh and Singh, 1996), b) Maceral composition of the Nariinsukhait coals in foreland and cratonic basins proposed by Hunt and Smyth (1989)

bounded by high mountains, where mobile braided river channels drained into relatively small lakes. The climate during this time was warm and humid (Baigalmaa et al., 2021), and the flora was associated with the Siberian paleofloristic Region (Kostina and Herman, 2016).

The peat of seam V accumulated in an ombrotrophic mire on the upper delta plain. The depositional conditions were suitable for the formation of thick peat, and the mire quickly developed into a raised bog. The central part of this raised bog remained unflooded, and clastic sediment flux ceased, resulting in a thick coal with low ash and sulfur content (Moore, 1989; Hunt and Smyth, 1989; Calder et al., 1991; Diessel, 1992). However, because the upper part of the peat was exposed above the water table, the inertinite content in seam V increased upwards due to oxidation and wildfire (Diessel, 1992; Scott, 2000; ICCP, 2001). During this period, the climate was hot, and the water salinity was relatively high (Batgerel et al., 2021).

Generated by changes in the tectonic regime, peat accumulation was terminated, and conglomerates and sandstone with coaly shale and mudstone were deposited. The climate during this period was relatively cooler (Baigalmaa et al., 2021). Subsequently, the tectonic and depositional conditions became favorable for peat accumulation again, leading to the formation of upper seams in a lower delta plain environment. The hydrological conditions varied, and mesotrophic and rheotrophic mires formed. The increased concentration of collotelinite in the upper seams suggests that these mires had high water tables, low pH water and were only partially forested (ICCP, 1998).

After the accumulation of the upper seams, peat accumulation ended, and conglomerates, green sandstone, and siltstones of the Upper Jurassic Sharkhotgor Formation were deposited (Baatarkhuyag et al., 2021). During this period, the climate became significantly cooler compared to the preceding peat-forming period of the Middle Jurassic (Baigalmaa et al., 2021).

Coalification and coal quality of Jurassic coals in Mongolia

Coal accumulation in Mongolia began in the western region and shifted eastward over time. Pennsylvanian coals are found in western Mongolia, Middle and Upper Permian in southern and central Mongolia, and Lower Cretaceous coals in eastern Mongolia (Bat-Erdene, 1992, Michaelsen and Storetvedt, 2023). Coal rank correlates with the age of the coal-bearing rocks: Pennsylvanian coals are low volatile bituminous, Permian coals are medium volatile bituminous, and Lower Cretaceous coals are lignite (Bat-Erdene, 1992;

Erdenetsogt et al., 2009). In contrast, Jurassic coals are widespread in Mongolia and range in rank from subbituminous to medium volatile bituminous (Erdenetsogt, 2022).

In western Mongolia, Lower-Middle Jargalant coal has a vitrinite reflectance of 0.4%, while in northwestern Mongolia, Lower-Middle Mogoingol coal has a reflectance of 1.2%. Conversely, vitrinite reflectance values for Middle-Upper Jurassic coals such as Sharyngol, Ulaan-Ovoo and Khujirt coals in northern Mongolia range from 0.44 to 0.55%. In central eastern Mongolia, Middle Jurassic Alagtogoo coals have vitrinite reflectance of 0.41%, whereas Middle Jurassic Ailbayan coals in southeastern Mongolia have reflectance of 1.4%. In central Mongolia, Lower-Middle Jurassic Bayanteeg and Khotgor coals have reflectance values of 0.55%, and 0.79%, respectively (Bat-Erdene et al., 2001; Erdenetsogt and Barsbold, 2014; Jargal et al., 2017; Erdenetsogt and Jargal, 2021; Tserenbat and Jargal, 2023). These variations in rank are likely related to post-depositional tectonic conditions or difference in burial depth (Erdenetsogt and Barsbold, 2012). Nariinsukhait coals have random vitrinite reflectance values ranging from 0.61 to 0.84%, similar to the coalification rank of coals in Central Mongolia.

Jurassic coals in Mongolia are characterized by low ash content and high vitrinite content (Bat-Erdene, 2009; Jargal and Erdenetsogt, 2022). This unique characteristic is primarily explained by regional paleoclimate (Erdenetsogt et al., 2009; Erdenetsogt and Barsbold, 2012). However, total sulfur contents in Jurassic coals are high (0.9-1.6%) compared to other coals in Mongolia (Erdenetsogt and Jargal, 2021). Jurassic coals from adjacent Russian regions such as Irkutsk and Ulugkhem, exhibit similar characteristics to those in Mongolia (Erdenetsogt and Barsbold, 2012; Zolotukhin and Kraskovskaya, 2016). In contrast, Jurassic coals from Hami-Turpan and Junggar basins in western China are characterized by significantly higher inertinite contents, likely due to extensive paleo wildfire across northwestern China (Xu et al., 2020; Wei et al., 2023).

While the elevated sulfur content generally poses challenges for utilizing Jurassic coals, Nariinsukhait coals present a different scenario. Seam V has low sulfur content, although the upper seams have higher sulfur contents, these can be mitigated through washing (Baatarkhuyag et al., 2015). The inertinite content of seam V is higher compared to other Jurassic coals in Mongolia (Erdenetsogt and Jargal, 2021; Jargal and Erdenetsogt, 2022). Additionally, coals from Khuuraital, located outside the South Gobi coal-bearing region, exhibit a similar maceral composition to Nariinsukhait coals (Bakhdal and Jargal, 2021). High rank Jurassic coals, due to their high vitrinite content and fluidity, can be used as blend coals with lower quality coals (Erdenetsogt and Narangerel, 2014; Erdenetsogt, 2022). Nariinsukhait coals can be used as semi soft coking coal and high-quality PCI coal owing to their lower rank and lower vitrinite content. Further detailed investigations are recommended to assess their potential for liquefaction.

SUMMARY AND CONCLUSION

A total of 90 core samples collected from a borehole drilled in the central part of the Nariinsukhait deposit were studied in order to determine the coal characteristics. Additionally, 29 composite samples were analyzed for maceral composition and random vitrinite reflectance.

Average vitrinite reflectance of seam V, the lowermost seam, is 0.77%, while that of upper seams range from 0.65 to 0.70%. According to Mongolian standard (MNS 6457:2023), seam V is classified as "1/3 coking coal", whereas all other seams are classified as "high volatile gas coal".

Seam V has better quality compared to the upper seams, with an average ash content of 12.4% (ad), total sulfur of 0.5% (ad), volatile matter of 36.7% (daf), inherent moisture of 0.6% (ad), calorific value of 6600 kcal/kg (ar), and a G index of 84 (ad). The depositional environment influenced the ash, and sulfur contents, while burial and subsequent rank affected the volatile matter and inherent moisture. Both depositional environment and rank influenced the G index and calorific value.

Seam V is characterized by higher inertinite content (32.2 vol.%), lower vitrinite content (58.0 vol.%) and lower mineral matter content

(6.7 vol.%). In contrast, the upper seams contain lower inertinite (10.8-25.6 vol. %), higher vitrinite (62.2-72.4 vol. %), and mineral matter (9.5-14.6 vol. %).

Based on TPI and GI indices, seam V was probably deposited in an upper delta plain environment, whereas the upper seams might have accumulated in a lower delta plain setting. The paleomire of seam V was a raised bog (ombrotrophic) with oxic conditions (A/I <0.5), resulting in high inertinite and low ash and sulfur contents. In contrast, the paleomires of the upper seams were mesotrophic and rheotrophic with high water table and less oxic conditions (A/I >0.5), leading to higher vitrinite, increased ash and sulfur contents. The rank of the Nariinsukhait coal is similar to that of Jurassic coals in central Mongolian coal-bearing Regions. Furthermore, the upper seams exhibit characteristics comparable to Mongolian Jurassic coals: high vitrinite, low inertinite and high sulfur contents. However, seam V has higher inertinite and lower sulfur content. Additionally, the coal has low organic sulfur (0.2%), indicating that the sulfur content can be significantly reduced through washing. Nariinsukhait coals can be classified as semi-soft coking coal and high-quality PCI coal. Further, detailed studies are recommended to evaluate the potential for liquefaction and as a coking coal blend.

ACKNOWLEDGEMENTS

Authors thank Professor B.Batkhishig (editor-in-chief) for handling the manuscript and Per Michaelson for her English editing. Special thanks go to A.Battushig, B.Bilguun, and Ts.Minjinsor for kind assistance with the illustrations.

This research has received funding from the National University of Mongolia under grant agreement P2020-3939.

REFERENCES

Baatarkhuyag, A., Altantsetseg, D., Baigalmaa, N., Bolormaa, B. 2021. Geological setting of Narynsukhait depression. Institute of Geology of MAS, Journal of Geology Research, 25, p. 91-119. (in Mongolian)

Baatarkhuyag, A., Altantsetseg, D., Ichinnorov, N. 2012. New data on fossil flora and spore-pollen assemblage of the Narynsukhait deposit. Khaiguulchin 46, p. 192-199. (in Mongolian)

Baatarkhuyag, A., Altantsetseg, D., Nyambayar, O., Gerelkhuu, Ch. 2015. Coal reserve estimation report of Naryn Sukhait hard coal deposit located in the territory of Gurvantes soum, Umnugobi aimag, based on the results of exploration, conducted during the period from 2008 to 2013. Geological Information Center, Mongolia, Geological Report #7860. (in Mongolian)

Baatarkhuyag, A., Altantsetseg, D., Uranbileg, L., Baigalmaa, N. 2010. New data on the age of Narynsuhait coal. Khaiguulchin 1, p. 81-83. (in Mongolian)

Badarch, G., Cunningham, W.D., Windley, B.F. 2002. A new terrain subdivision for Mongolia: implications for the Phanerozoic crustal growth of central Asia. Journal of Asian Earth Sciences, vol. 21, p. 87-110. https://doi.org/10.1016/S1367-9120(02)00017-2

Baigalmaa, N., Erdenechimeg, D., Erdenetsogt, B., Jargal, L., Ogata, T., Erdenebayar, J., Baatarkhuyag, A., Nansalmaa, D., Bilguun, B. 2021. Geodynamics and paleoclimate of Southern Mongolia during Middle Jurassic. Part I. Inferences from sandstone geochemistry of Nariinsukhait. National University of Mongolia, Journal of Geological Issues, vol. 19(554), p. 46-62. (in Mongolian with English abstract)

Bakhdal, L., Jargal, L., 2021. Geological settings and provenance analysis of sandstone of Khuuraital coal deposit. National University of Mongolia, Journal of Geological Issues, vol. 19(551), p. 24-33. (in Mongolian with English abstract)

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

Bat-Erdene, D. 2009. Fossil fuel deposits. In Byamba, J. (ed.), Geology and Mineral Resources of Mongolia, vol. V, Soyombo Printing, Ulaanbaatar, p. 27-174, (in Mongolian)

Bat-Erdene, D., Jargal, L., Erdenetsogt, B.

2001. Synthesis on Mongolian fossil fuel research and its results. Mongolian University of Sciences and Technology, Journal of Geology, vol. 2/3, p. 334-344. (in Mongolian)

Batgerel, S., Erdenetsogt, B., Baigalmaa, N., Altantsetseg, D. 2021. Geodynamics and paleoclimate of Southern Mongolia during Middle Jurassic. Part II. Inferences from coal geochemistry of Nariinsukhait. National University of Mongolia, Journal of Geological Issues, vol. 19(554), p. 63-74. (in Mongolian with English abstract)

Calder, J., Gibling, M., Mukhopadhyay, P. 1991. Peat formation in a Westphalian B piedmont setting, Cumberland Basin, Nova Scotia, Nova Scotia: implications for the maceral-based interpretation of rheotrophic and raised paleomires. Bulletin of the Geological Society of France, vol. 162(2), p. 283-298.

Chen, P. 1989. Significance and application of the caking index of coal - Ten years' review. International Journal of Coal Geology, vol. 21, p. 99-115. https://doi.org/10.1016/0378-3820(89)90064-7

Chou, Ch-L. 2012. Sulfur in coals: A review of geochemistry and origins. International Journal of Coal Geology, vol. 100, p. 1-13. https://doi.org/10.1016/j.coal.2012.05.009

Crelling, J.C. 2008. Chapter 7 - Coal carbonization. In Suárez-Ruiz, I., Crelling, J.C. (ed.), Applied Coal Petrology, p.173-192. https://doi.org/10.1016/B978-0-08-045051-3.00007-5

Dai, S., Bechtel, A., Eble, C.F., Flores, R.M., French, D., Graham, I.T., Hood, M.M., Hower, J.C., Korasidis, V.A., Moore, T.A., Püttmann, W., Wei, Q., Zhao, L., O'Keefe, J.M.K. 2020. Recognition of peat depositional environments in coal: A review. International Journal of Coal Geology, vol. 219, 103383. https://doi.org/10.1016/j.coal.2019.103383

Dashkhorol, J., Baatar, G. 1992. Report of coal exploration and infill drilling of Narynsukhait hard coal deposit located in the territory of Gurvantes soum, Umnugobi aimag. Geological Information Center, Mongolia, Geological Report #4613. (in Mongolian)

Diessel, C.F.K. 1986. On the correlation between coal facies and depositional environments. In: Advances in the Study of the Sydney Basin, Proceedings, 20th. Newcastle, Australia, p. 19-22. https://doi.org/10.1007/978-3-642-75668-9_5

Diessel, C.F.K. 1992. Coal Facies and Depositional Environment. Coal-bearing Depositional Systems. Springer-Verlag, Berlin, p. 161-264. https://doi.org/10.1007/978-3-642-75668-9_5

Diez, 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 vol. 50(1-4), p. 389-412. https://doi.org/10.1016/S0166-5162(02)00123-4

Erdenetsogt, B. 2022. Recent advances in geological studied of Mongolian sedimentary basins and fossil fuel deposits. National University of Mongolia, Journal of Geological Issues, vol. 21(02), p. 212-226. (in Mongolian with English abstract)

Erdenetsogt, B., Barsbold, Ts. 2012. Issues on coal geology of Orkhon-Selenge coal-bearing area. National University of Mongolia, Journal of Geological Issues, vol. 339(12), p. 51-60. (in Mongolian)

Erdenetsogt, B., Barsbold, Ts., 2014. Geological setting and coal quality of Ovoot deposit. National University of Mongolia, Journal of Geological Issues, vol. 416(13), p. 121-132. (in Mongolian)

Erdenetsogt, B., Lee, I., Bat-Erdene. D, Jargal, L. 2009. Mongolian coal-bearing basins: geological settings, coal characteristics, distribution, and resources. International Journal of Coal Geology, vol. 80(2), p. 87-104. https://doi.org/10.1016/j.coal.2009.08.002

Erdenetsogt, B., Narangerel, J. 2014. Study on blending of Tavantolgoi and Ovoot coals. Part II: Quality of coal blends. Mongolian Geoscientist, vol. 41, p. 85-93. (in Mongolian)

Erdenetsogt, B-O, Jargal L. 2021. Coal Deposits. In Gerel, O., Pirajno, F., Batkhishig, B., Dostal, J. (eds.), Mineral Resources of Mongolia. Modern Approaches in Solid Earth Sciences, vol 19. P. 427-461. https://doi.org/10.1007/978-981-15-5943-3_14

Gerel, O. 2021. Geology and Metallogeny of Mongolia. In Gerel, O., Pirajno, F., Batkhishig, B., Dostal, J. (eds.), Mineral Resources of Mongolia. Modern Approaches in Solid Earth Sciences, vol 19, p.1-21. https://doi.org/10.1007/978-981-15-5943-3_1

Hendrix, M.S., Beck, M.A., Badarch, G., Graham, S.A. 2001. Triassic synorogenic sedimentation in southern Mongolia; early effects of intracontinental deformation. 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, pp. 389-412. https://doi.org/10.1130/0-8137-1194-0.389

Hendrix, M.S., Graham, S.A., Amory, J.Y., Badarch, G. 1996. Noyon Uul Syncline, southern Mongolia: lower Mesozoic sedimentary record of the tectonic amalgamation of Central Asia. Geological Society of America Bulletin, vol. 108, p. 1256-1274. https://doi.org/10.1130/0016-7606(1996)108<1256:NUSSML>2.3.CO;2

Hunt, J.W., Smyth, M. 1989. Origin of inertinite rich coals of Australian cratonic basins. International Journal of Coal Geology, vol. 11(1), p. 23-46. https://doi.org/10.1016/0166-5162(89)90111-0

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

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

Jargal, L., Bat-Erdene, D., Erdenetsogt, B. 2002. Petrographical study on Mongolian coal and its results. National University of Mongolia, Journal of Geological Issues, vol. 5, p. 53-78. (in Mongolian)

Jargal, L., Erdene, A., Dashkhorol, A., Nansalmaa, D. 2017. Petrographical composition and coal quality of Khujirt deposit. National University of Mongolia, Journal of Geological Issues, vol. 473(15), p. 36-45. (in Mongolian)

Jargal, L., Erdenetsogt, B. 2022. Recent advances in organic petrological study of Mongolia coal deposits. National University of Mongolia, Journal of Geological Issues, vol. 21(02), p. 227-247. (in Mongolian with English abstract)

Jargal, L., Erkhembayar, E., Baigalmaa, N., Batgerel, S., Enkhtuvshin, R. 2019. Results of petrographic analysis of coal and coal hosting rocks from Ovoottolgoi deposit. National University of Mongolia, Journal of Geological Issues, vol. 17(519), p. 124-143. (in Mongolian with English abstract)

Jasper, K., Hartkopf-Froder, C., Flajs, G., Littke, R. 2010. Evolution of Pennsylvanian (Late Carboniferous) peat swamps of the Rhur Basin, Germany: Comparison of palynological, coal petrographical and organic geochemical data. International Journal of Coal Geology, vol. 12(4), p. 346-365. https://doi.org/10.1016/j.coal.2010.05.008

Johnson, C.L., Amory, J., Zinniker, D., Lamb, M., Graham, S., Affolter, M., Badarch, G. 2008. Sedimentary response to arc-continent collision, Permian, southern Mongolia. In Draut, A.E., Clift, P.D., Scholl, D.W. (eds.), Formation and Applications of the Sedimentary Record in Arc Collision Zones: Geological Society of America Special Paper, vol. 436, p. 363-390. https://doi.org/10.1130/2008.2436(16)

Kalkreuth, W., Marchioni, D., Calder, J., Lamberson, M., Naylor, R., Paul, J. 1991. The relationship between coal petrography and depositional environment from selected coal basins in Canada. International Journal of Coal Geology, vol. 19(1-4), p. 21-76. https://doi.org/10.1016/0166-5162(91)90014-A

Kalkreuth, W., Marchioni, D., Utting, J. 2000. Petrology, palynology, coal facies, and depositional environments of an Upper Carboniferous coal seam, Minto Coalfield, New Brunswick, Canada. Canadian Journal of Earth Sciences, vol. 37, p. 1209-1228. https://doi.org/10.1139/e00-039

Kostina, E., Herman, A. 2016. Middle Jurassic Floras of Mongolia: Composition, Age, and Phytogeographic Position. Paleontological Journal, vol. 50, p. 1437-1450. https://doi.org/10.1134/S0031030116120108

Kostina, E.I., Herman, A.B. 2013. The Middle Jurassic flora of South Mongolia:

Composition, age and phytogeographic position, Review of Palaeobotany and Palynology, vol. 193, p. 82-98. https://doi.org/10.1016/j.revpalbo.2013.01.009

Lamb, M.A., Badarch, G., Navratil, T., Poier, R. 2008. Structural and geochronologic data from the Shin Jinst area, eastern Gobi Altai, Mongolia: Implications for Phanerozoic intracontinental deformation in Asia. Tectonophysics, vol. 451, p. 312-330. https://doi.org/10.1016/j.tecto.2007.11.061

McCabe, P.J. 1984. Depositional environments of coal and coal-bearing strata. In Rahmani, R.A., Flores, R.M. (eds.), Sedimentology of Coal and Coal-bearing Sequences. International Association of Sedimentologists Special Publication, 7, p. 13-42. https://doi.org/10.1002/9781444303797.ch2

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

MMHI. 2024. Statistical data on Mineral resources sector (2023 I-XII), Ministry of Mining and Heavy Industry of Mongolia (MMHI), https://mmhi.gov.mn/ accessed 24 August 2024 (in Mongolian)

MNS 6457:2023. Coal quality classification (in Mongolian)

Moore, P.D. 1989. The ecology of peat-forming processes: a review. International Journal of Coal Geology, vol. 12(1-4), p. 89-103. https://doi.org/10.1016/0166-5162(89)90048-7

Moore, T.A., Shearer, J.C. 2003. Peat/coal type and depositional environment are they related? International Journal of Coal Geology, vol. 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 Jackson Group lignites from the Tertiary of Texas. In Finkelman, R.B., Casagrande, D.J. (eds.), Geology of Golf Coast Lignites, Field Trip Guidebook. Geological Society of America, Boulder, Colo, p. 1126-145.

Munkhtogoo, L. 2019. Coal. In Altankhuyag, D. (ed.), Guideline for using classification of mineral reserve and resources. Ministry of Mining and Heavy Industry, Mongolia. Ulaanbaatar, p. 95-156. (in Mongolian)

Munkhtogoo, L., Gantulga, B. 2006. Report on infill drilling of the Narynsukhait hard coal deposit located in the territory of Gurvantes soum, Umnugobi aimag. Ulaanbaatar, (in Mongolian)

NSM. 2024. Mongolian statistical yearbook 2023. National Statistics office of Mongolia (MSM), Ulaanbaatar, 500 p.

O'Keefe, J.M.K., Bechtel, A., Christianis, K., Dai, S., DiMichele, W.A., Eble, C.F., Esterle, J.S., Mastalerz, M., Raymond, A.L., Valentim, B.V., Wagner, N.J., Ward, C.R., Hower, J.C. 2013. On the fundamental difference between coal rank and coal type. International Journal of Coal Geology, vol. 118, p. 58-87. https://doi.org/10.1016/j.coal.2013.08.007

Ochirbat, M. 2024. Study on geology, depositional environment, and coal quality of Ovootkhural depression. Summary of unpublished PhD. thesis, Mongolian University of Science and Technology, Ulaanbaatar (in Mongolian)

Pearson, D.E. 1980. The quality of Western Canadian coking coal. Canadian Mining and Metallurgical Bulletin, January, p. 1-15.

Pearson, D.E., Grieve, D.A. 1985. Rank variation, coalification pattern and coal quality in the Crowsnest coalfield, British Columbia. Canadian Mining and Metallurgical Bulletin, vol. 78(881), p. 39-46

Petersen, H.I., Ratanasthien, B. 2011. Coal facies in a Cenozoic paralic lignite bed, Krabi Basin, southern Thailand: Changing peat-forming conditions related to relative sea-level controlled watertable variations. International Journal of Coal Geology 87(1), p. 2-12. https://doi.org/10.1016/j.coal.2011.04.004

Scott, A. 2000. The Pre-Quaternary history of fire. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 164, p. 281-329. https://doi.org/10.1016/S0031-0182(00)00192-9

Silva, M.B., Kalkreuth, W. 2005. Petrological and geochemical characterization of Candiota coal seams, Brazil - Implication for coal facies interpretations and coal rank. International Journal of Coal Geology, vol.

64(3-4), p. 217-238. https://doi.org/10.1016/j.coal.2005.04.003

Singh, A.K., Singh, M.P., Singh, P.K. 2013. Petrological investigations of Oligocene coals from foreland basin of northeast India. Energy exploration and exploitation, vol. 31, p. 909-936. https://doi.org/10.1260/0144-5987.31.6.909

Singh, M.P., Singh, P.K. 1996. Petrographic characterization and evolution of the Permian coal deposits of the Rajmahal basin, Bihar, India. International Journal of Coal Geology, vol. 29(1-3), p. 93-118. https://doi.org/10.1016/0166-5162(95)00005-4

Singh, P.K., Rajak, P.K., Singh, M.P., Singh, V.K., Naik, A.S., Singh, A.K. 2016. Peat swamps at Giral lignite field of Barmer basin, Rajasthan, Western India: understanding the evolution through petrological Modelling. International Journal of Coal Science and Technology, vol. 3(2), p. 148-164. https://doi.org/10.1007/s40789-016-0137-y

Singh, P.K., Singh, M.P., Prachiti, P.K., Kalpana, M.S., Manikyamba, C., Lakshminarayana, G., Singh, A., Naik, A.S. 2012. Petrographic characteristics and carbon isotopic composition of Permian coal: implications on depositional environment of Sattupalli coalfield, Godavari Valley, India. International Journal of Coal Geology, vol. 90–91, p. 34–42. https://doi.org/10.1016/j.coal.2011.10.002

Sosnowski, P., Jelonek, I. 2022. Facies development of coal seams in the Knurow deposit (Upper Silesia, Poland). International Journal of Coal Geology, vol. 261, 104073. https://doi.org/10.1016/j.coal.2022.104073

Stock, A.T., Littke, R., Lücke, A., Zieger, L., Thielemann, T. 2016. Miocene depositional environment and climate in western Europe: the lignite deposits of the lower Rhine Basin, Germany. International Journal of Coal Geology, vol. 157, p. 2-18. https://doi.org/10.1016/j.coal.2015.06.009

Suares-Ruiz, I., Ward, C.R. 2008. Basic factors controlling coal quality and technical behavior of coal. In Suárez-Ruiz, I., Crelling, J.C. (ed.), Applied Coal Petrology. The Role of Petrology in Coal Utilization. Elsevier, Amsterdam. p.19-59. https://doi.org/10.1016/B978-0-08-045051-3.00002-6

Suarez-Ruiz, I., Flores, D., Filho, J.G.M., Hackley, P.C. 2012. Review and update of the applications of organic petrology: Part 1, Geological applications. International Journal of Coal Geology, vol. 99, p. 54-112. https://doi.org/10.1016/j.coal.2012.02.004

Teichmüller, M. 1989. The genesis of coal from the viewpoint of coal petrology. International Journal of Coal Geology, vol. 12(1-4), p. 1-87. https://doi.org/10.1016/0166-5162(89)90047-5

Thomas, L. 2020. Coal geology. 3rd edition, Wiley. p.113 https://doi.org/10.1002/9781119424307

Tserenbat, B., Jargal, L. 2023. The study on coal petrography and quality of North Eldev deposit. National University of Mongolia, Journal of Geological Issues, vol. 22(01), p. 63-77. (in Mongolian with English abstract)

Wang, H., Shao, L., Hao, L., Zhang, P., Glasspool, I. J., Wheeley, J.R., Wignall, P.B., Yi, T., Zhang, M., Hilton, J. 2011. Sedimentology and sequence stratigraphy of the Lopingian (Late Permian) coal measures in southwestern China. International Journal of Coal Geology, vol. 85(1), p. 168-183. https://doi.org/10.1016/j.coal.2010.11.003

Ward, C.R. 2016. Analysis, origin and significance of mineral matter in coal: An updated review. International Journal of Coal Geology, vol. 165, p. 1-27. https://doi.org/10.1016/j.coal.2016.07.014

Wei, J., Wei, Y., Qin, G., Ning, S., Cao, D., Wang, A. 2023. Geochemistry, Mineralogy, and Coal Petrology of No. 4 Coal in Sandaoling Mine, Turpan-Hami Basin, Northwest China: Provenance and Peat Depositional Environment. Minerals, vol. 13(7), p. 837. https://doi.org/10.3390/min13070837

Xu, Y., Uhl, D., Zhang, N., Zhao, C., Qin, Sh., Liang, H., Sun, Y. 2020. Evidence of widespread wildfires in coal seams from the Middle Jurassic of Northwest China and its impact on paleoclimate. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 559, 109819. https://doi.org/10.1016/j.palaeo.2020.109819

Zamani, Z., Bonab, H.R., Littke, R. 2023. Coal petrology, sedimentology and depositional environment of the Parvadeh coals in the Upper Triassic, Tabas Block of Central-East Iran. International Journal of Coal Science and Technology, vol. 10, 40. https://doi.org/10.1007/s40789-023-00600-w

Zieger, L., Littke, R. 2019. Bolsovian (Pennsylvanian) tropical peat depositional environments: The example of the Ruhr Basin, Germany. International Journal of Coal Geology, vol. 211, 103209. https://doi.org/10.1016/j.coal.2019.103209

Zolotukhin, Yu. A., Kraskovskaya, T.F. 2016. Properties of Ulug Khem Coal. 1. Types of Vitrinite and Its Associations with Microcomponents and Minerals. Coke and Chemistry, vol. 59, p. 1-7. https://doi.org/10.3103/S1068364X16010075