

몽골 돈디고비지역에서 산출되는 오일셰일의 광물조성, 퇴적환경 및 분광학적 특성

Mineral Composition, Depositional Environment and Spectral Characteristics of Oil Shale Occurring in Dundgobi, Mongolia

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요약 : 본 연구는 몽골 돈디고비(Dundgobi)지역에서 채취한 오일셰일과 석탄 시료들의 유기물 기원, 광물조성 및 분광학적 특징에 대해 조사하였다. 채취한 오일셰일 및 석탄시료들은 Rock/Eval과 총유기탄소(Total organic carbon; TOC) 분석을 통해 케로젠(Kerogen) 종류, 수소 함량, 열적 성숙도, 퇴적환경을 확인하였으며, X-선회절 분석과 분광분석을 이용하여 광물조성을 정의하였다. Rock/Eval과 TOC 분석결과, 에덴트(Eedemt) 광상에서 채취한 샘플들은 미성숙-성숙 단계의 근원암에 해당하며, 풍부한 수소함량을 보이고, I-형, II-형 and III-형의 케로젠 종류를 가진다. 반면 샤인 어스 쿠닥(Shine Us Khudag) 광상에서 채취한 샘플들의 경우 성숙단계의 근원암으로써, I-형, II/III-형 또는 III-형의 케로젠을 함유하는 잠재성을 가진다. 또한 탄소와 황의 함량에 따르면 두 지점의 퇴적환경은 담수성의 퇴적환경인 것으로 확인되었다. X-선회절 분석으로부터 확인한 오일셰일과 석탄시료들의 광물조성은 석영, 방해석, 고회석, 일라이트, 고령토, 몬모릴로나이트, 아놀소클레이스, 조장석, 미사장석, 정장석, 방비석으로 확인되었다. 가시광선-근적외선-단파적외선 분광분석을 통해 오일셰일 시료로부터 1412 nm, 1907 nm의 점토광물 및 수산화성분에 의한 흡광특성, 2206 nm에서 고령토와 몬모릴로나이트에 의한 흡광특성, 탄산염광물인 고회석에 의한 흡광특성이 2306 nm에서 확인되었다. 그러나 오일셰일의 원격탐사적 탐사를 위해서는 유기물 함량에 따른 분광특성에 대한 연구가 수행되어야 할 것으로 사료된다.

주요어 : 돈디고비, 오일셰일, 퇴적환경, 광물조성, 분광분석

ABSTRACT : This study investigated genetic, mineralogical and spectral characteristics of oil shale and coal samples in Dundgobi area, Mongolia. Based the Rock/Eval and Total organic carbon (TOC) analysis, kerogen type, hydrogen quantity, thermal maturity and depositional environment were confirmed. Moreover, the mineral composition of oil shale and coal samples were analyzed by XRD and spectroscopy.

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The result of Rock Eval/TOC analysis revealed that the samples of Eedemt deposit are immature to mature source rocks with sufficient hydrocarbon potential, and the kerogen types were classified as Type I, Type II and Type III kerogen. On the other hand, the samples from Shine Us Khudag deposit were mature with good to very good hydrocarbon potential rocks where kengen types are defined as Type I, Type II/III and Type III kerogen. According to the carbon and sulfur contents, the depositional environment of the both sites were defined as a freshwater depositional environment. The XRD analysis revealed that the mineral composition of oil shale and coal samples were quartz, calcite, dolomite, illite, kaolinite, montmorillonite, anorthoclase, albite, microcline, orthoclase and analcime. The absorption features of oil shale samples were at 1412 nm and 1907 nm by clay minerals and water, 2206 nm by clay minerals of kaolinite and montmorillonite and 2306 nm by dolomite. It is considered that spectral characteristics on organic matter content test must be tested for oil shale exploration using remote sensing techniques.

Key words : Dundgobi, Oil shale, depositional environment, mineral composition, spectroscopy

Introduction

Oil shale is a hot issue in energy and oil exploration industries after the development of oil extraction technology from oil shale layers. Due to its economic value, exploration of oil shale is very critical to for national resources security. Mongolia is well known for its tremendous amount of oil shale resources with more than 60 deposits over 788 billion tons of oil shale reserves. Most of the oil shale resources are generally inter-bedded with the coal deposits (Savel, 2011). Although the oil shale exploration in Mongolia had begun since 1920s, the systematic exploration and analyses only started in 1990s by Japanese organization (Speight, 2012). As a result of the exploration, 13 oil shale basins were defined based on their geological formation. In general, oil shale basins are located in large Mesozoic depressions, occupying several thousand square kilometers of territory. The major oil shale basins are Saikhan-Ovoo, Gobi-Altai, Ugii-Nuur, Nyalga, Choir, Dornogobi, Dundgobi, Choibalsan, and Tamsag (Bat-Erdene, 2009).

Because of Mongolia's oil shale reserves and undeveloped socio-economic situation, the participation of Korean industries in oil shale exploration and development contains a great potential. However, the characteristics of Mongolian oil shale deposits has not been reported in Korean science community,

and most of literatures of previous studies are written in Mongolian. On the other hand, the wide land area, brutal environment, and undeveloped traffic network burdens activities in new resources exploration, and, thus, it is necessary to narrow down the target areas for optimal exploration. A remote sensing approach as a preliminary step for mineral resources exploration could save both men and monetary effort significantly. However, oil shale exploration employing remote sensing approaches is still immature. This study investigated genetic, mineralogical, and spectral characteristics of different types of oil shale and coal samples occurring in Dundgobi area of Mongolia. Based on the bulk analysis techniques of the Rock Eval pyrolysis and Total organic carbon analysis (Rock Eval/TOC), their kerogen type, thermal maturity and depositional environment were analyzed. Additionally, their mineral composition is defined by X-ray Diffraction (XRD). The spectral characteristics of oil shale samples are analyzed to test possible application of remote sensing techniques for oil shale exploration. Moreover, additional information from previous studies were introduced and compared with our study results.

Study area and geology

We selected two study sites in Dundgobi province of Mongolia where Site 1 is located near the

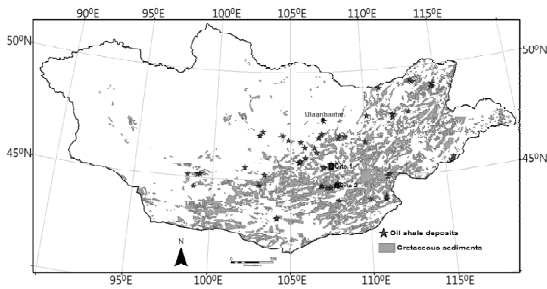


Fig. 1. Location map of study sites and oil shale deposits in Mongolia.

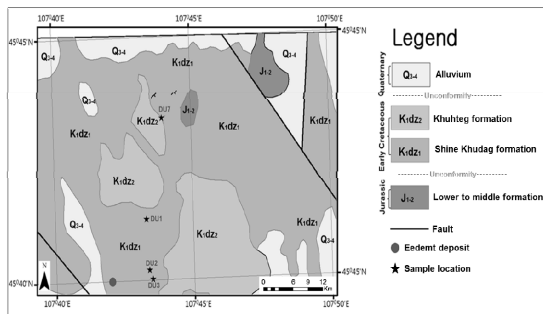


Fig. 2. Geological map of study site 1 related to the Eedemt oil shale deposit (modified from Varzalov *et al.*, 1949).

Eedemt oil shale deposit (107°42'E, 45°40'N) and Site 2 is located near the Shine Us Khudag oil shale deposit (107°57'E, 44°43'N). These sites are located approximately 245 kilometers south of capital city Ulaanbaatar (Fig. 1).

The geology of study site 1 consists of lower to middle Jurassic sedimentary rock, Lower Cretaceous Shine Khudag formation and the Khuhteg formation (Fig. 2). The lower to middle Jurassic sedimentary rock (J₁₋₂) is mainly composed of mudstone, conglomerate, and sandstone with thickness of 150 to 200 m. The Shine Khudag formation (K_{1dz1}) unconformably overlays the lower to middle Jurassic sedimentary rock (J₁₋₂), and bears oil shale layers. The lower part of the formation is composed of 100 meter thick sandy conglomerates, while the upper part is composed mainly of oil shale, dolomite, limestone, marl, mudstone with subordinate sandstone, siderite and siltstone. The Khuhteg coal bearing formation is

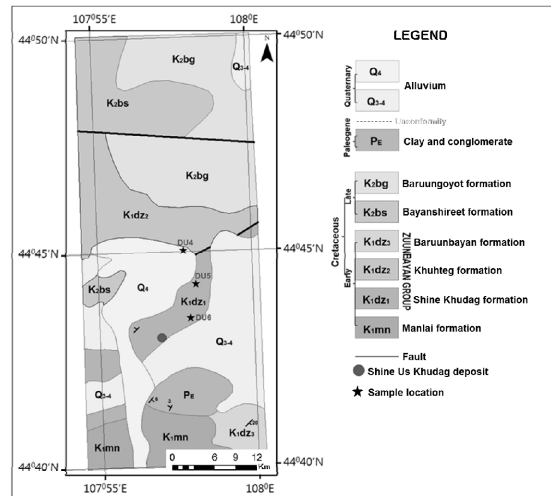


Fig. 3. Geological map of study site 2 related to the Shine Us Khudag oil shale deposit (modified from Bumburuu *et al.*, 1990).

composed of conglomerate, coaly shale with thick coal measures, sandstone and siltstone (Yamamoto *et al.*, 1993)(Fig. 2).

Geologically, study site 2 is composed of Cretaceous Manlai formation (K_{1mn}), Shine Khudag formation (K_{1dz1}), Khuhteg formation (K_{1dz2}), Baruunbayan formation (K_{1dz3}), Bayanshireet formation (K_{2bs}), and Baruungoyot formation (K_{2bg}) (Fig. 3). The Manlai formation (K_{1mn}) consists of breccias, conglomerate, clay and gravelite, and the Shine khudag formation (K_{1dz1}) is composed of oil shale, dolomite, limestone, marl, mudstone with subordinate sandstone, siderite and siltstone.. Thickness of the oil shale layers in the Shine khudag formation is estimated to be 80 m. The Khuhteg formation (K_{1dz2}) is a coal bearing formation lithologically similar to site 1. The Baruunbayan formation (K_{1dz3}) is composed of sandstone alternating with conglomerate, fine grained sediment sand tuffaceous sediments. The Bayanshireet formation (K_{2bs}) is composed of clay, conglomerate, gravelite, gray sandstone, limestone and mudstone. The Baruungoyot formation (K_{2bg}) overlying the Bayanshireet formation consists of clay, conglomerate, marl, sandstone and sand. Paleogene clay and conglomerate formation is

also distributed in south of the study area (Yamamoto *et al.*, 1993)(Fig. 3).

Methodology

Three oil shale samples from Shine Khudag formation (DU1, DU2 and DU3) and one coal sample (DU7) from the Khuhteg formation were collected in the study site 1, and three oil shale (DU4, DU5 and DU6) samples near the Shine Us Khudag oil shale deposit were collected in the study site 2. Organic, spectral and mineralogical analyses were conducted for the collected samples.

Basically, oil shale is a mixture of organic material called kerogen and inorganic materials which contain various minerals. The Rock Eval pyrolysis has been widely used for an assessment of hydrocarbon potential of a source rock. It provides information about quantity, type and thermal maturity of the associated organic matter (Peters, 1986). The seven samples were analyzed by Rock-Eval Turbo 6 in Korean Institute of Geoscience and Mineral Resources (KIGAM). All samples were weighed to 100 mg and subjected to Rock-Eval 6/TOC analysis in order to determine the kerogen type, TOC content and thermal maturity. The Rock Eval/TOC analysis results were cross-validated with the previous studies about Eedemt oil shale deposit in Dundgobi area, Mongolia (Yamamoto *et al.*, 1993; Yamamoto *et al.*, 1998).

Moreover, X-ray diffraction (XRD) analysis is carried out for selected oil shale and coal samples with the Rigaku/Rint 2002 at KIGAM. Samples ran from 2 to 60 degrees on continuous scan at 2 degrees 2-theta per minute with a step size of 0.02. "Crystallographica Search-match" and "Match!" software were used in XRD analysis. The spectral characteristics of oil shale and coal samples were measured with a LabSpec 5100 spectrometer of Analytical Spectral Devices (ASD) at laboratory condition. The spectrometer covers spectral range of 350-2500 nm with a 3-6 nm spectral resolution. The measured spectra were analyzed with The Spectral Geologist 7.5

(TGS 7.5) and ENVI 4.8 software. USGS (United States Geological Survey) spectral library 06 (Clark *et al.*, 2007) and JPL (Jet Propulsion Laboratory, NASA) ASTER spectral library 2.0 (Baldrige *et al.*, 2009) were used as reference spectra.

Results and discussion

The Rock Eval/TOC pyrolysis measured the amount of free hydrocarbon (S1, mg HC/g rock), pyrolyzed hydrocarbon (S2, mg HC/g rock), amount of CO₂ (S3, mg CO₂/g rock), the temperature at which maximum release of hydrocarbons from cracking of kerogen occurs during pyrolysis (Tmax, °C) and the amount of total organic carbon (TOC, wt. %). These five parameters were used to calculate the following parameters (McCarthy *et al.*, 2011):

HI(mg HC/g TOC), hydrogen index

$$[HI=(S2/TOC) \times 100]$$

OI(mg CO₂/g TOC), oxygen index

$$[OI=(S3/TOC) \times 100]$$

PI, production index $[PI=S1/(S1+S2)]$

Rock Eval/TOC results for this study are summarized and compared with previous study (Yamamoto *et al.*, 1993; Yamamoto *et al.*, 1998) in Table 1.

Hydrocarbon Potential

The hydrocarbon potential was estimated using the total organic carbon (TOC) and S2 values of the samples (Table 2). The Total Organic Carbon content (TOC, %) of oil shale samples from site 1 ranges from 7.56% to 20.58%, and S2 values varied widely ranging from 35.81 mg HC/g rock to 176.99 mg HC/g rock (Table 1). On the other hand, different from oil shale samples, the coal sample DU7 showed the highest TOC content of 62.14% and S2 of 107.28 mg HC/g rock. This inferred that the coal contains a higher percentage of organic matter than oil shale. Yamamoto *et al.*(1998) examined that TOC content of oil shale

Table 1. Rock-Eval Pyrolysis results compared with previous study (Yamamoto et al., 1993; Yamamoto et al., 1998)

	Sample ID	TOC, (wt %)	S1 (mg HC/g rock)	S2 (mg HC/g rock)	S3 (mg CO ₂ /g rock)	OI (mg CO ₂ /g TOC)	PI (S1/(S1+S2))	HI (mg HC/g TOC)	Tmax (°C)
Eedemt deposit (Yamamoto et al., 1993; Yamamoto et al., 1998)	no 1	13.03	1.21	95.79	3.73	29	0.01	735	446
	no 2	10.82	1.96	67.94	4.44	41	0.03	628	449
	no 3	15.6	10.19	113.23	5	32	0.08	726	422
	no 4	21.31	10.52	159.82	8.07	38	0.06	750	429
	no 5	5.83	0.42	38.72	1.77	30	0.01	664	450
	no 6	14.6	2.81	103.59	5.82	40	0.03	710	445
	no 7	17.5	4.41	135.58	5	29	0.03	775	445
	no 8	7.97	1.35	48.64	3.38	42	0.03	610	446
	no 9	13.07	3.86	87.83	3.86	30	0.04	672	444
	no 10	17.37	7.52	139.8	6.23	36	0.05	805	442
Eedemt deposit in this study	DU1	7.56	0.43	35.81	4.52	60	0.01	474	433
	DU2	11.07	0.38	77.21	5.81	52	0	697	437
	DU3	20.58	1.85	176.99	9.04	44	0.01	860	445
	DU7	62.14	0.53	102.28	11.87	19	0.01	165	419
Shine Us Khudag deposit in this study	DU4	1.68	0.05	2.53	1.7	101	0.02	151	440
	DU5	8.4	0.36	56.11	4.3	51	0.01	668	435
	DU6	2.53	0.09	6.52	2.34	92	0.01	258	444

Table 2. Geochemical parameters describing hydrocarbon generation potential of source rocks (modified from Peters, 1986)

Potential	TOC (wt%)	S1 (mg HC/g Rock)	S2 (mg HC/g Rock)
Poor	0.5	0-0.5	0-2.5
Fair	0.5-1	0.5-1	2.5-5
Good	1-2	2	5-10
Very good	>2	>2	>10

samples from Eedemt deposit ranged from 5.83% to 21.31% and S2 values ranged from 38.72 to 139.8 mg HC/g rock where both this study and previous study coincided well. The TOC and S2 values indicates that the oil shale of the Eedemt deposit can be considered as a very good hydrocarbon potential source rock (Yamamoto *et al.*, 1993; Yamamoto *et al.*, 1998).

On the other hand, the TOC and S2 values of study site 2 samples representing Shine Us

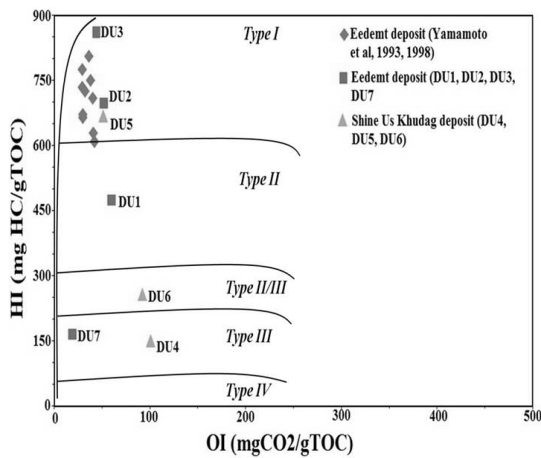
Khudag deposit are relatively lower than the Eedemt deposit ranging 1.68% to 2.53% of TOC and 2.53 HC/g rock to 56.11 mg HC/g rock of S2, respectively (Table 1). According to Table 2, the samples of the Shine Us Khudag deposit belonged to a good to very good hydrocarbon generation potential source rocks.

Type of organic matter

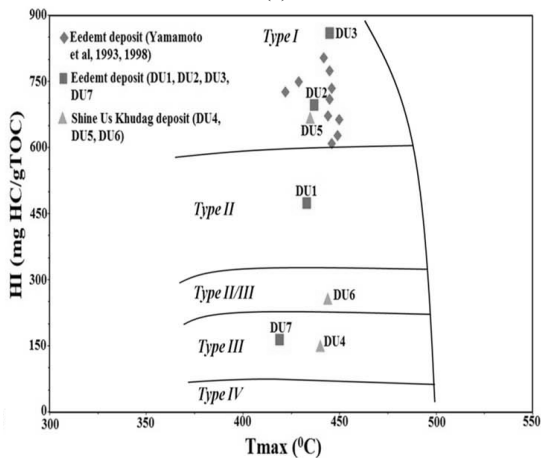
Based on the Rock Eval pyrolysis measurements,

Table 3. Classification parameters for Kerogen type (modified from Peters et al., 1994)

Kerogen type	Organic matter	Environment	HI (mg HC/g TOC)
I	highly oil-prone, hydrogen rich	mainly in lacustrine and some marine	>600
II	oil prone hydrogen rich	marine	300-600
II/III	mixed oil/gas prone	marine and some terrestrial	200-300
III	low in hydrogen and generates mainly gas	terrestrial	50-200
IV	dead or inert carbon	-	<50



(a)



(b)

Fig. 4. (a) van Krevelen plot of Rock Eval data (the relationship between HI and OI), (b) The relationship between HI and Tmax plot. The lines describe the boundaries of the different kerogen types.

the hydrogen index (HI) and oxygen index (OI) were calculated. Moreover, the van Krevelen diagram (HI vs. OI) and HI vs. Tmax diagram were drawn to figure out types of the organic matter for the oil shale and coal samples. The HI is derived from the ratio of hydrogen to TOC which is defined by $100 \times (S_2/TOC)$ (McCarthy *et al.*, 2011). The OI is calculated from the ratio between CO₂ and TOC which can be defined as $(100 \times S_3) / TOC$ (McCarthy *et al.*, 2011). The HI is proportional to the amount of hydrogen contained within kerogen indicating the oil generation potential. The OI is related to the amount of oxygen contained in the kerogen and can be used for defining types and maturation levels of kerogen (McCarthy *et al.*, 2011). Based on Table 3 (Peters *et al.*, 1994), the kerogen types were determined by plotting the van Krevelen diagram and Tmax vs. HI diagram (Fig. 4).

Because of large variations in HI values ranging from 474 to 860 mg HC/g TOC, the oil shale samples of study site 1 were plotted in the region of kerogen type I and II. The coal sample (DU7) of the study site 1 was classified as type III kerogen (Table 3 and Fig. 4). Yamamoto *et al.* (1998)'s results on Eedemt deposit oil shale samples were mostly plotted within the type I kerogen. It infers that the oil shale samples of Eedemt deposit are mostly highly oil-prone. DU1 oil shale sample indicated oil prone Type II kerogen because of its lower HI value than other oil shale samples. On the other hand, oil shale samples of study site 2 showed a mixed kerogen types showing Type I, II/III, and III kerogen

Table 4. Total organic carbon and sulfur content for Dundgobi oil shale samples

	Sample ID	TOC (wt%)	TS (wt%)
Site 1	DU1	7.56	0.14
	DU2	11.07	0.296
	DU3	20.58	0.71
	DU4	1.68	0.117
Site 2	DU5	8.4	0.205
	DU6	2.53	-

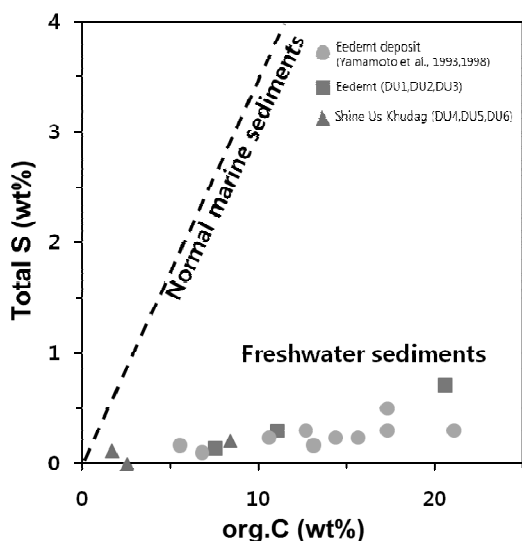


Fig. 5. Distribution of total organic carbon and sulfur contents. The dashed line describes normal marine sediments (C/S ratio=2.8). Areas of normal marine and freshwater sediments refer to Berner and Raiswell (1984).

which requires further study to define the kerogen type for the study site 2 (Table 3 and Fig. 4).

Maturity of organic matter

The source rock maturity containing organic matters is determined by the degree of thermal alteration on organic matters in the source rock. The degree of thermal maturity on the organic matter can be defined by Tmax (°C) and Production index (PI=S1/(S1+S2)) (Bordenave *et al.*, 1993). All samples of Dundgobi area show Tmax values less than 445°C (419-445°C), and PI value

ranges of 0 to 0.02 (Table 1). Following Peters *et al.* (1994), five samples (DU2, DU3, DU4, DU5 and DU6) were considered as mature organic matters while two samples from site 1 (DU1 and DU7) were classified as immature organic matters due to the low Tmax values. Previous study defined the oil shale of the Eedemt deposit as mature organic matter (Yamamoto *et al.*, 1998), and it generally coincided with this study.

Depositional environment

The relationship between organic carbon and sulfur has been used to characterize the depositional environment of the source rocks. For site 1, total sulfur value of study site 1 ranged from 0.140% to 0.676%, and TOC value of 7.56% to 62.14% (Table 4). Comparing with site 1, the samples of site 2 had lower organic carbon and sulfur content. An organic carbon-total sulfur diagram (Berner and Raiswell, 1984) indicated that the depositional environment of the both study sites was freshwater environment (Fig. 5).

Spectral Characteristics and Mineral Composition

As a result of the XRD analysis, mineral composition of the oil shale samples were identified. The peaks of quartz were the most obvious at all samples of the study sites. Clay minerals including illite, kaolinite and montmorillonite were also abundant next to quartz (Table 5). Carbonate minerals including calcite and dolomite were also identified in a few oil

Table 5. Mineral composition of the oil shale and coal samples based on XRD analysis

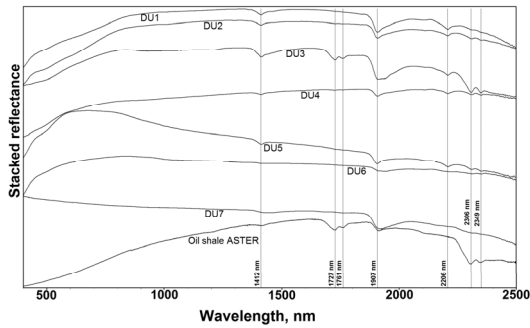
Name of minerals	DU1	DU2	DU3	DU4	DU5	DU6	DU7
Quartz	○	○	○	○	○	○	○
Illite	○	○	○	○	○	○	×
Kaolinite	○	○	○	○	○	×	×
Montmorillonite	○	×	○	×	×	×	×
Calcite	○	○	○	×	×	×	×
Dolomite	×	×	×	○	×	○	×
Analcime	×	○	×	×	×	×	×
Anorthoclase	○	×	○	○	×	×	×
Albite	×	×	×	○	○	×	×
Microcline	×	×	×	×	×	○	×
Orthoclase	×	×	×	×	○	×	×

shale samples. Feldspar group minerals such as anorthoclase, albite, microcline and orthoclase were detected. It infers that most of the oil shale samples are composed of quartz and clay minerals with accessory minerals of feldspars, carbonate minerals and analcime. Different from oil shale samples, quartz was only one mineral that was identified in coal sample (DU7) by XRD. The results of analysis are shown in Table 5.

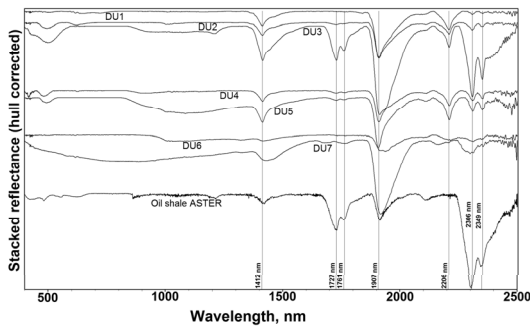
In addition to XRD analyses, spectroscopic analysis of oil shale had been conducted to identify mineral composition and to test possibility of remote sensing application on oil shale exploration. The spectra of five oil shale samples (DU1, DU2, DU3, DU4, DU5 and DU6) were compared with the oil shale spectra from ASTER spectral library (Baldrige *et al.*, 2009) which were collected from Green River Formation in Colorado and Utah, USA. The spectral characteristics of oil shale samples showed the common absorption features around 1412 nm, 1907 nm, and 2206 nm. Moreover DU1, DU2, DU4, DU5 and DU6 samples have weak absorption features around at 2306 nm and 2349 nm while DU3 and Oil shale ASTER spectra have strong absorption features around at 1727 nm, 1761 nm, 2306 nm and 2349 nm. The absorption features centered near 2206

nm are attributed to Al-OH molecule in clay minerals and micas. The absorption features near 2306 nm might be due to CO₃ molecule caused by calcite and dolomite. The absorption features near 1907 nm and 1412 nm are related to OH-water molecule, mainly caused by smectite (Hauff, 2008; Pontual *et al.*, 2012)(Fig. 6). In addition, the spectral signatures of coal and oil shale samples were compared for possible application on distinguishing between oil shale and coal. Compare to oil shale samples, coal spectrum was more featureless in VNIR-SWIR region. It has weak absorption features at 1429-1441 nm, 1915 nm and 2296-2300 nm which caused by OH-water molecule and CO₃ molecule as described (Fig. 6). The difference between absorption features of oil shale spectra and coal spectrum is shown at 2206 nm which caused by Al-OH molecule (Hauff, 2008; Pontual *et al.*, 2012).

Moreover, spectra of representative oil shale samples (DU1, DU2, DU3, DU4, DU5 and DU6) were compared with major probable minerals from USGS spectral library (Fig. 7). It is well known that absorption feature at 1412 nm and 1907 nm are caused by OH-water molecule, 2206 nm by Al-OH, and 2306 nm by Mg-OH and carbonate (CO₃) where commonly found minerals



(a)

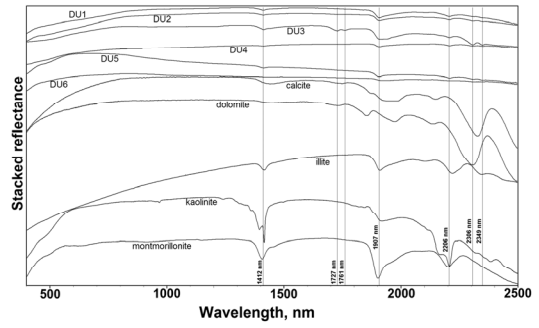


(b)

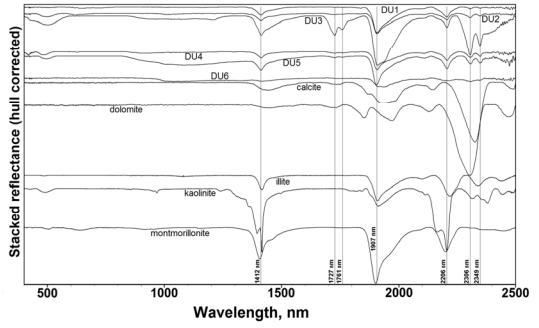
Fig. 6. VNIR-SWIR stacked plot with representative spectra of oil shale samples (DU1, DU2, DU3, DU4, DU5, and DU6), coal sample (DU7) and oil shale spectra from ASTER spectral library; (a) Stacked reflectance spectra of oil shale, coal samples and oil shale ASTER (b) Stacked hull corrected spectra of oil shale, coal samples and oil shale spectra from ASTER.

are clay minerals and carbonate minerals (Hauff, 2008; Pontual *et al.*, 2012). The spectroscopic analyses identified clay and carbonate minerals as major minerals composing oil shale samples. Different from XRD analysis, spectral analyses could not identify quartz and feldspar because anhydrous silicate minerals have limited spectral features in VNIR-SWIR region (Kerr *et al.*, 2011).

The spectral analyses revealed that oil shale samples may show distinctive absorption features in shortwave infrared region due to its mineral composition while coal samples can not be distinguished due to featureless spectral charac-



(a)



(b)

Fig. 7. (a) VNIR-SWIR stacked reflectance spectra of oil shale samples (DU1, DU2, DU3, DU4, DU5 and DU6) with reference spectra of clay minerals (illite, kaolinite, montmorillonite), and carbonate mineral (calcite, dolomite) (b) Stacked hull corrected spectra of oil shale samples (DU1, DU2, DU3, DU4, DU5 and DU6) with reference spectra of clay minerals (illite, kaolinite, montmorillonite) and carbonate minerals (calcite and dolomite).

teristics. However, as the composition of oil shale samples is mainly controlled by organic matter, further studies must be conducted to extract geological distribution of oil shale deposits focused on identification of organic content for oil shale exploration using remote sensing techniques.

Conclusions

This study analyzed organic matter (kerogen), mineralogical and spectral characteristics of oil shale and coal samples in Dundgobi area, Mongolia. Rock Eval pyrolysis/TOC analysis

revealed that the samples near Eedemt deposit are immature to mature source rocks with a very good hydrogen potential. Moreover, the kerogen types are defined as to Type I, Type II, Type III. The samples from Shine Khudag deposits are from mature source rock with good to very good potential rocks, and are likely to yield Type I, Type II/III and Type III kerogen. The depositional environment of the both study sites is freshwater depositional environment. The mineral composition of oil shale samples is quartz, clay minerals such as illite, kaolinite, and montmorillonite with accessory minerals of feldspars and carbonate minerals. The spectra of oil shale and coal samples were compared with oil shale reference spectra from ASTER library. The oil shale samples had absorption features at 1412 nm, 1727 nm, 1761 nm, 1907 nm, 2206 nm, 2306 nm and 2349 nm. Spectra of coal was more featureless in VNIR-SWIR region with weak absorptions at 1429-1441 nm, 1915 nm and 2296-2300 nm. Oil shale absorption features were found at 1412 nm and 1907 nm by clay minerals and OH-water molecule, 2206 nm by clay minerals, 2306 nm by dolomite. Because the composition of oil shale samples is mainly controlled by organic matter, additional studies about relationship between organic matter (kerogen) and spectroscopic analysis are needed to be tested for exploration of oil shale deposits based on remote sensing techniques.

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REFERENCES

- Baldrige, A.M., Hook, S.J., Grove, C.I., and Rivera, G. (2009) The ASTER spectral library version 2.0: Remote Sensing of Environment, 113, 711-715.
- Bat-Erdene, D. (2009) Geology and Mineral resource of Mongolia. "Fuel resources". Soyombo, Ulaanbaatar, 181-183(in Mongolian).
- Berner, R.A., and Raiswell, R. (1984) C/S method for distinguishing freshwater from marine sedimentary rocks. *Geology*, 12, 365-368.
- Bordenave, M.L., Espotalie, J., Leplat, P., Oudin, J.L., and Vandenbroucke, M. (1993) Screening techniques for source rock evaluation. *Applied Petroleum Geochemistry*, 217-278.
- Bumburuu, G., Lkhundev, Sh., Baatar, Ts., Byamba, B., Baatar, D., Tundev, S., Bukhbat, S., Sergelen, S., Tuuruul, N., Tungalag, P., Amarsaikhan, Ts., and Batmunkh, Ch. (1990) Geological map of Mongolia, Sainshand sheet L-48-XXX (1:200,000). Ministry of Energy, Mining Industry and Geology of Mongolia.
- Clark, R.N., Swayze, G.A., Wise, R., Livo, E., Hoefen, T., Kokaly, R., Sutley, S.J. (2007) USGS digital spectral library splib06a: U.S. Geological Survey, Digital Data Series 231.
- Hauff, P. (2008) An overview of VIS-NIR-SWIR field spectroscopy as applied precious metals exploration. Arvada, Colorado; Spectral Inc., 80001 303 403 8383.
- Kerr, A., Rafuse, H., Sparkes, G., Hinchey, J., and Sandeman, H. (2011) Visible/infrared spectroscopy (VIRS) as a research tool in economic geology: background and pilot studies from Newfoundland and Labrador. Geological Survey, Report 11-1, 145-166.
- McCarthy, K., Rojas, K., Niemann, M., Palmowski, D., Peters, K., Stankiewicz, A. (2011) Basic Petroleum Geochemistry for Source Rock Evaluation. *Oilfield Review Summer*, 23, no.2.
- Peters, K.E. (1986) Guidelines for evaluating petroleum source rock using programmed pyrolysis. *American Association of Petroleum Geologist Bulletin*, 70, 318-389.
- Peters, K.E., and Cassa, M.R. (1994) Applied source rock geochemistry. In Magoon, L.B., and Dow, W.G., (eds.), *The petroleum system-from source to trap*. American Association of Petroleum Geologists, 60, 93-120.
- Pontual, S., Gamson, P., and Merry, N. (2012) Spectral interpretation field manual. *Spectral Analysis Guides for Mineral Exploration, G-Mex Version 3.0*. AusSpec International Pty. Ltd. Vol.1.
- Savel, V.V., Pevneva, G.S., Namkhainorov, Zh., and Golovko, A.K. (2001) Oil Shales of Mongolia. *Solid fuel chemistry*, 45, No.6, 397-403.
- Speight, J.G. (2012) *Shale oil production processes*. (1stEd.), Gulf Publishing Company, Kidlington,

Oxford, 58p.

- Varzalov, Yu.K., and Khayankhyarvaa. (1949) Geological map of Mongolia, Choir sheet L-48-XXIX (1:200,000). Ministry of Energy, Industry and Geology of Mongolia.
- Yamamoto, M., Bat-Erdene, D., Ulziikhishig, P., Enomoto, M., Kajiwara, Y., and Nakajima, T. (1993) Preliminary report on geochemistry of Lower Cretaceous Dsunbayan oil shales, eastern Mongolia. Bulletin of the Geological Survey of Japan, 44, 685-691.
- Yamamoto, M., Bat-Erdene, D., Ulziikhishig, P., Watanabe, Y., Imai, N., Kajiwara, Y., Takeda, N., and Nakajima, T. (1998) Organic geochemistry and palynology of Lower Cretaceous Zunnbayan oil shales, Mongolia. Bulletin of the Geological Survey of Japan, 49, 257-274.

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