STUDY OF STRUCTURES OF OVOOT KHURAL COAL BEARING BASIN USING OPTICAL AND MICROWAVE REMOTE SENSING

M.Ochirbat[1,3], D.Amarsaikhan[2], N.Boldbayar[3], S.Jargalan[1]
[1] School of Geology and Mining Engineering, Mongolian University of Science and Technology
[2]Institute of Geography and Geoecology, Mongolian Academy of Sciences
[3]Golden Hill LLC, Mongolia

KEY WORDS: Ovoot Khural, geological structure, coal reserve, satellite image

ABSTRACT: The Ovoot Khural coal bearing basin is located at southern part of Mongolia. According to the classification of coal bearing depressions, it belongs to SouthGobi depression and is classified as coal bearing basin. The basin is bounded by Nariin Sukhait thrust fault in the northern part, and sediments of the Ovoot Khural coal bearing basin are folded and faulted, partly shifted along the fault. The aim of this study is to investigate geological structures of the Ovoot Khural coal bearing basin using optical and microwave remote sensing (RS) images. As data sources, high resolution Sentinel-1 synthetic aperture radar (SAR) and Sentinel-2 optical images acquired in 2018 are used. For the analysis of multisource datasets, different standard and advanced image processing techniques are applied. Overall, the study indicates that RS images can be successfully used for the interpretation and analysis of geological structures of the Ovoot Khural area.

1. INTRODUCTION

Mongolia has abundant resources of coal that is about 2,778 million tons of proven coal reserves as of 2016**,** ranking 23rdin the world's total coal reserves. The coal has an important impact on Mongolia's economy as it accounts for 90% of energy production, 40% of export earning, and 10% of the country's budget. Coal deposition in Mongolia has been carried out at 4 different geological periods: Carboniferous, Permian, Jurassic, and Cretaceous. There are 15 coal basins in Mongolia. Ovoot Khural coal bearing basin is a part of SouthGobi coal bearing depression on the basis of a Mongolian coal deposits classification.

According to Mesozoic sedimentation and paleogeographic situation, South Mongolian depression is formed in three main structural settings and Ovoot Khural coal bearing basin belongs to the inter mountainous basin in intracontinental setting. Totally, 16 deposits are distributed throughout Ovoot Khural coal bearing basin, which stretches for over 100km with a width of 20km. Coal-bearing sediments were developed in an intermountain basin during the Lower-middle Jurassic age. Coal seams form monoclonal structure, dip 25 to 80 degrees to south direction. There are 9 coal seams in coal bearing sequence having total thickness of 1350m. The thicknesses of each coal seams range from 5m to 150m. In Ovoot Khural depression, the following three stages coal accumulation is identified:

- Stage 1: Lower coal seams (1-4) are characterized by discrete zones of thin coal layers. Due to strong depression, there is not enough peat coverage. Subsidence rate>sedimentation rate.
- Stage 2: Middle coal seam characterized to be slow rate of depression. There is enough peat coverage in the coal seam-5 and this has the thickest coal layers.
- Stage 3: Upper coal seams (6-9) consist of complex settings of thin conglomerate layers and mostly fine grained sequence (Ochirbat et al. 2016).

Exploration activity started in early 2000 and as a result 6 coal deposits were found, consisting of 16 parts, which can be listed from the west to the east as follows: Bayan Tes, Ovoot Tolgoi, Nariin Sukhait, Khurenshand, Sumber, and Jargalant. The Bayan Tes deposit consists of Elstei, Khurshuut, Khuvd, Gashuu Tolgoi, and Khuren Tsav parts; the Ovoot Tolgoi deposit consists of Sunset and Sunrise parts; the Nariin Sukhait deposit consists of Khuren Tolgoi, Central and East parts; the Sumber deposit consists of Central Sumber, East Sumber, and Biluut part.

The aim of this research is to study geological structures of the Ovoot Khural coal bearing basin using high resolution optical and microwave satellite datasets. The test area and main coal deposits are shown in Figure 1. As data sources, 10m, 20m, and 60m resolution spectral bands of Sentinel-2A and 10m resolution Sentinel-1 data acquired in 2018 have been used. For the analysis and interpretation of the datasets, different standard and advanced RS image analysis techniques such as refined histogram analysis, IHS transformation, band ratios, texture enhancement approach, minimum noise fraction transformation, spectral sharpening, Brovey transform technique (Amarsaikhan, 2017) were applied. The results showed that unlike the Sentinel-1 microwave image, the high resolution Sentinel-2 images could be successfully used for geological structural analysis in the selected test area.

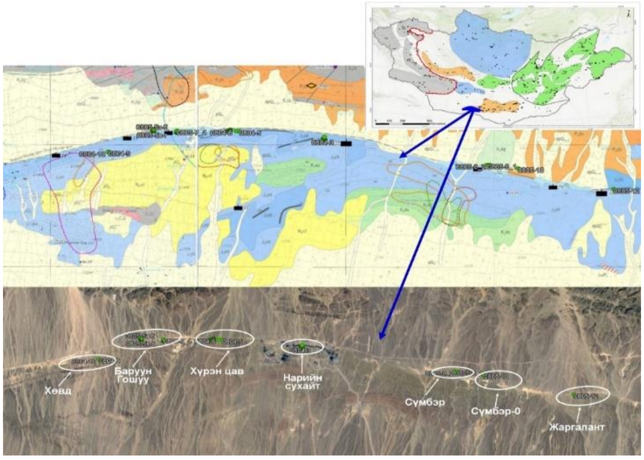

Figure 1. Location of Ovoot Khural coal bearing basin and main coal deposits.

2. GEOLOGIC AND STRUCTURAL OUTLINE OF OVOOT KHURAL BASIN

The Ovoot khural basin district has various types of rocks (Figure 2). At the northern part of district, north from Nariin sukhait fault, there is Toson Bumba mountain range, which is composed of Carboniferous Tost formation dark gray, pinkish and greenish gray, brown, light gray, and gray acidic effusive rocks, and their tuffs of ignimbrite, trachyandesite, andesite, dacite, lava breccia, sandstone, silicified siltstone, partly a few conglomerates, which are intruded by early Carboniferous Tavan Uul complex intrusive bodies of biotite-hornblende diorite, monzo diorite, grnodiorite and granite porphyry. The Tost formation sediments are covered by Lower Permian Togoot khar formation rhyolite, trachy-rhyolite, dacite, ignimbrite, andesite, basalt, and their tuffs and tuff-siltstones, Upper Permian Deliin shand formation greenish-gray, mottled red sandstone, siltstone, conglomerate, and mudstone alternated with this coal seams.

South of Nariin Sukhait thrust fault is distinguished as Ovoot Khural coal bearing basin and filled by Jurassic, Cretaceous, Neogene and Quaternary loose sediments. Middle Jurassic Orgilokh bulag formation sediments distributed at the northern part of coal bearing basin, bounded by Nariin Sukhait thrust fault in the north, and conformably covered by the sediments of the middle to upper Jurassic Esun orlog formation sediment in the south. The Orgilokh bulag formation is composed of gray mudstones containing thin layers of gray and dark gray siltstones, alternated with 3-8 layers of coal with a thickness of about 0.5-50 m and partly interlayered with layers of conlgomerate. Total thickness of sediments of this formation is approximately 1700m.

Middle to Upper Jurassic Eson urlug formation sediments are mainly distributed along the southern and eastern parts of the Ovoot Khural basin, and form monocline structure with inclination of 40-55°. It shows stratigraphic conform cover on the Middle Jurassic Orgilokh bulag formation sediments and its southern part is covered by Lower Cretaceous Ekhen-Us formation and quaternary loose sediments (Ochirbat and Jargalan, 2022). The Eson Urlug formation consists of sandstone, gravel stone, conglomerate, siltstone, and mudstone. Total thickness of sediments of this formation is 110b. The Cretaceous Ekhen-Us formation is distributed in the north-west and south-east of the study area overlying on the Middle Jurassic and Upper Jurassic sediments by very low angle stratigraphic unconformities and are overlain by Neogene and quaternary loose sediments.

The sediments of the Ekhen-Us formation consist of orange-yellow medium-large pebbly conglomerate, gravel stone, fine to coarse grained light yellow colored sandstone, and orange colored sandstone. Total thickness of sediments of this formation is 300-350 m. The Middle Cretaceous Bayan shiree formation is distributed in a relatively limited area and found in intermountain valleys. The Bayanshiree formation consist of siltstone, red-yellow clay, brown-green, light yellow, red-yellow, medium-coarse sand and conglomerate. The pebbles in conglomerate are acidic and intermediate in composition of effusive, sandstone, siltstone, quartz, mana, jasper, pink and variegated chalcedony-type jasper. Quaternary loose sediments distribute along the topographic low lands, overlying Jurassic and Cretaceous sediments.

The Middle Jurassic Orgilokh bulag formation is the main coal bearing sediment in the Ovoot Khural. The formation of Ovoot Khural coal bearing basin is considered that the pressure related to the collision of the terranes affected the territory of Mongolia from the beginning of the Triassic, and the formation of Mesozoic depressions began. It is worth reminding that there is a confusion between the time of formation of depressions and the time of formation of coal deposits. The Jurassic age coal deposits, such as the Noyon and Nariin Sukhait group deposits, were formed in the Triassic depression. Sedimentary deposition is classified as syngenetic, and epigenetic deposition occurs in an already formed depression (Ochirbat and Jargalan, 2021). Geologic map of Ovoot Khural basin and location of main coal deposits are shown in Figure 2.

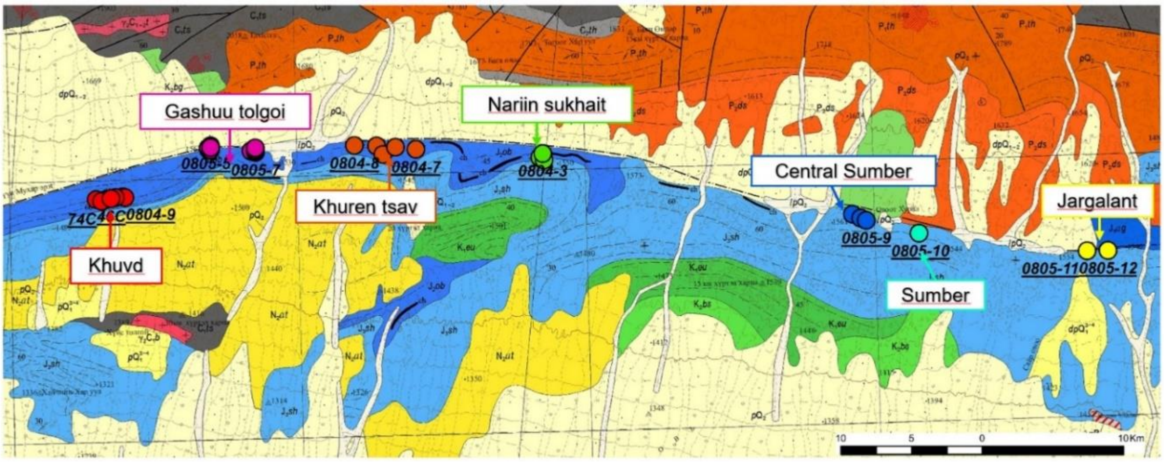

Figure 2. Geologic map of Ovoot Khural basin and location of main coal deposits.

3. COAL DEPOSITS OF OVOOT KHURAL BASIN

There are several coal deposits, each of which contains several parts, along the latitudinal striking Nariin Sukhait thrust fault zone (Figure 2). These are Bayantes (Elstei, Khuvd, Khurshuut, Gashuu Tolgoi, and Khurentsav part), Khuren Shand, Nariin Sukhait (Khuren Tolgoi, Central and East part), Ovoot Tolgoi (Sunset and Sunrise part), Sumber (Central, East and Biluut part), and Jargalant (South Biluut, Jargalant part) deposits.

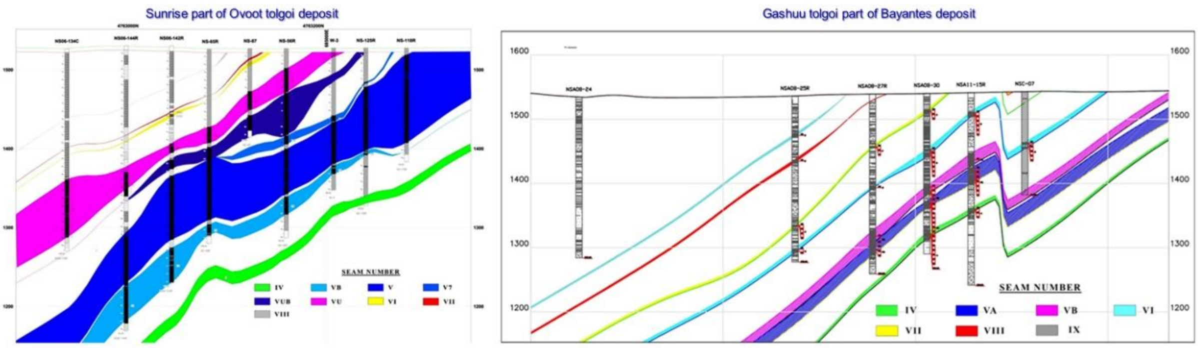

Figure 3. Geologic section of coal seams in Sunrise of Ovoot Tolgoi and Gashuu Tolgoi of Bayantes deposits.

The Bayantes deposit is located in western most part of Ovoot Khural coal basin and contains Elstei, Khuvd, Khurshuut, Gashuu Tolgoi and Khurentsav parts. According to exploration drilling result it has 8 coal seams, from which seams IV, VA, VB, V, VI, VII have an economic importance. Total thickness of coal bearing sediments ranges from 250m to 300m, among which total thickness of coal makes 40-50m. It means that the total thickness of the coal layers is 14-17% of the total coal-bearing sediments, indicating moderately coal bearing deposits. Next to the east of Bayantes deposit, locates Khurenshand deposit, which contains 9 coal seams, from which coal seams V, VI, VII, VIII, IX have an economically important. Coal seams I, II, III, IV are located at the deepest part and were not fully studied. Total thickness of coal seams 76m, which makes 17.3% of total sediment.

The Nariin Sukhait coal deposit is located next to Khurenshand deposit in the east and it was first found, explored and now there is active coal mining activity. This deposit has 5 coal seams and total thickness partly makes up to 180m. Next to Nariin Sukhait in the east exists Ovoot Tolgoi deposit, which consists of Sunrise and Sunset parts. It has coal seams IV, V, VI, VII, VIII and IX, total thickness of which is148.04m, making 12.3% of total sediment. Next to Ovoot Tolgoi deposit, there is Sumber deposit, which consists of Central East and Biluut parts. It has 13 coal seams, which are relatively well studied, except seam XIII. The Jargalant deposit is located in eastern most part of Ovoot Khural coal bearing basin. There are three coal seams with thickness up to 14.2m.

Regarding the general characteristics of stratified coal layers, we can imagine that there are a few coal seams, which are thin and branched a lot in westernmost (Elstei, Khuvd and Khuren tsav part of Bayan tes deposit) and easternmost

(East and Biluut part of Sumber deposit and Jargalant deposit) parts of Ovoot Khural coal beraing basin. At the central part of Ovoot Khural basin, including Gashuu Tolgoi part of Bayantes deposit, Hariin Sukhait, Khuren Tolgoi and Sunset and Sunrise parts of Sumber deposit, a number of coal seam increases and they are thicker compared to the other parts (Ochirbat et al., 2016).

4. RESULTS AND DISCUSSION

In the present study, we used Sentinel-1 microwave and Sentinel-2 optical images downloaded from the ESA's Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home). The radar image provides some information about the geological structure, while the multispectral image provides the information about the spectral variations of geological features. Using the metadata associated with each of the satellite imageries, firstly, radiometric correction has been applied to the Sentinel-2A image to correct pixel brightness values.

It was necessary to georeference the selected multispectral image in a correct referencing system (Amarsaikhan and Saandar, 2011), because the image had some diversions, and all bands with spatial resolutions ranging from 20m to 60m were resampled to a spatial resolution of 10m. Then, a terrain correction was applied to the microwave image presented in a single look complex format. The inspection of the corrected image showed that the result had good geometric accuracy, thus satisfying the requirements needed for the final analysis. In order to improve a radiometric appearance and remove the existing speckle effects in the radar image, a 3x3 size gammamap filtering (ERDAS, 2010) was applied.

Initially, different false color composite images have been created by various combinations of the visible, NIR and SWIR bands as well as SAR image. Most combinations of the NIR and SWIR bands with one of the visible bands gave good results, but the microwave image had insufficient contribution. The reliable result that described rock boundary and spatial variations of the geological structures in the test area was obtained by multichannel Sentinel 4-3-2 color composite image (Figure 4). After creating the image, it was enhanced by the use of piece-wise-linear stretching (Pournamdari et al. 2014). Here, the boundaries and strata of the Lower Cretaceous to older sediments are clearly visible. The Lower Cretaceous sediments are illustrated in alternately brown to dark brown and brownish-brown-dark brown, the Upper Jurassic sediments are appeared in light green to dark green, the Lower Jurassic coal-bearing sediments have green with a light blue tint, and the Carboniferous igneous rocks are highlighted in black with well-defined layers. Modern sediments in the Upper Cretaceous have dark to dark brown background with a greenish glow, and are well distinguished from sediments of other ages by their uniform smooth surface and same level of height.

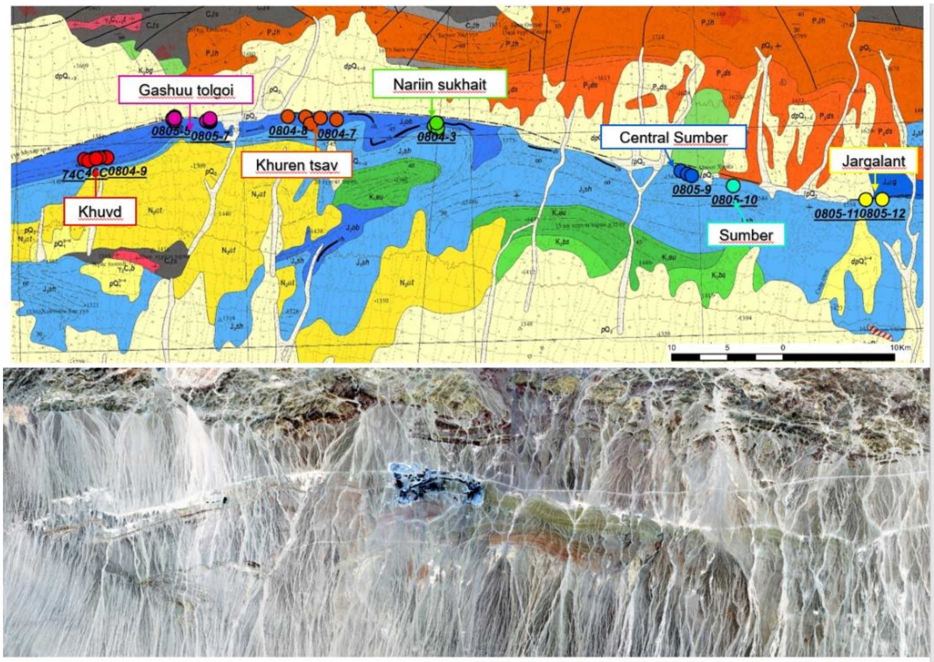

Figure 4. Geological map (upper) and FCC4-3-2 image (lower).

Next reliable output that described spectral and spatial variations of the geological features in the test area was obtained by a Brovey transformed (Richards, 2013) Sentinel 2-3-8a color composite image (Figure 5). This image more clearly separated the boundaries of intrusive and effusive rocks, and transformation zones were distinct. The large bodies of the conglomerate often have a rough surface and a pale yellow-green background color with a bright green color at their outer borders, while the elongated small bodies have a pale violet background. The result also shows a pale background in wind-blown sand. Carboniferous effusive rocks are shown in bright red, while Permian effusive rocks are shown in purple with blue and blue hues.

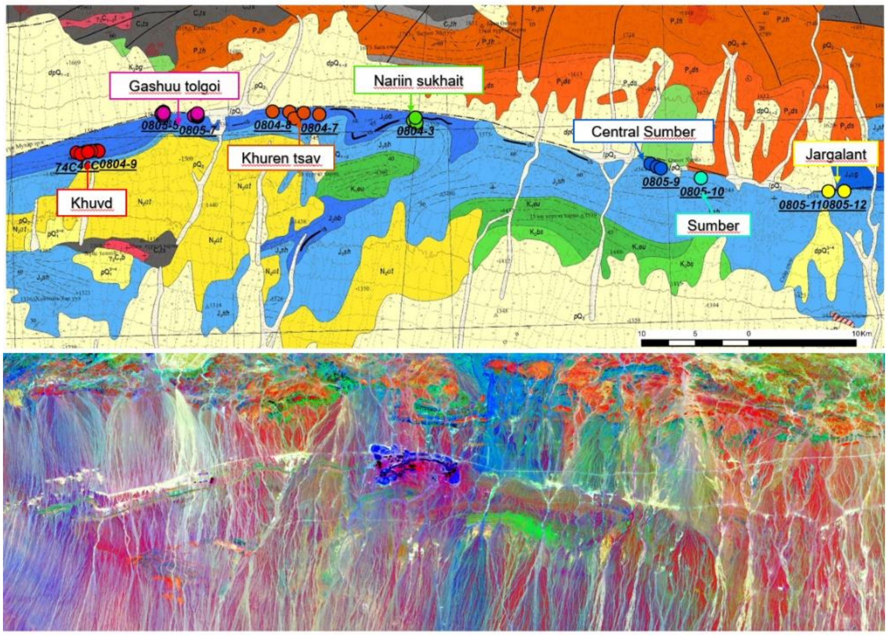

Figure 5. Geological map (upper) and Brovey transformed 2-3-8a image (lower).

To evaluate the spatial variability of different lithological units, a minimum noise fraction transformation (Jensen 2015) has been applied to the optical bands as well as combined bands of optical and microwave datasets. It could be seen that all eigenvalues (Li et al. 2018) of the transformed datasets were greater than 1.0, and in total 8 bands have been selected. The outputs of the transformation have been analyzed individually and in combination. Although, each of the transformed bands contained some information, the combined bands did not include better information than the optical bands. The best results were obtained by the use of the combinations, where fraction band 4 has been included. For example, on the individual fraction band 4, sedimentary rock layers, linear structures, layer transitions, and faults are clearly seen in light to white colors (Figure 6). Moreover, it is seen that vegetated wet areas along the Nariin Sukhait Tokhrol fault standout as light to white linear structures.

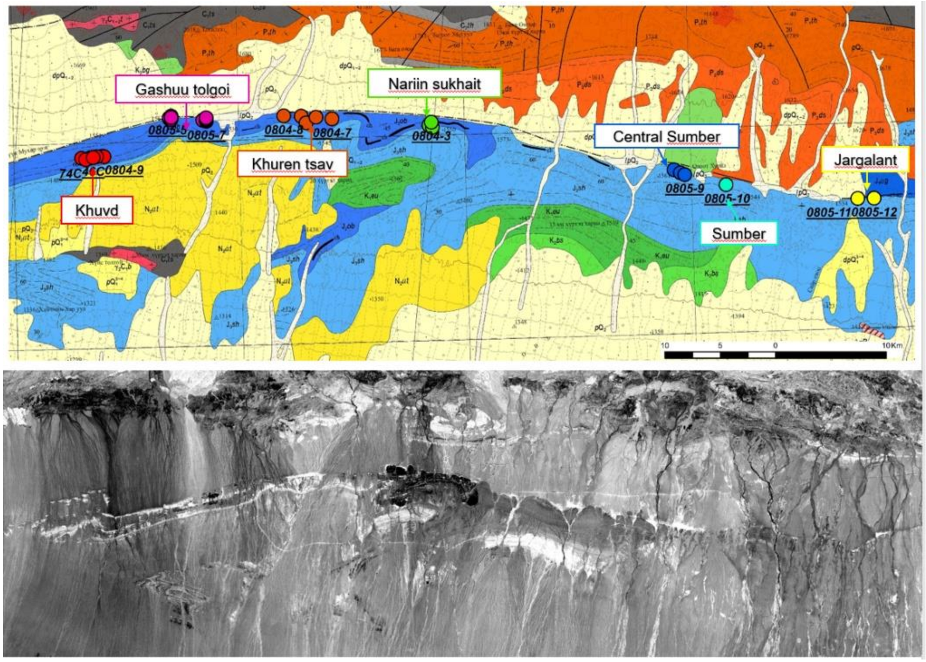

Figure 6. Geological map (upper) and fraction band 4 (lower).

In order to enhance the existing geological structures and other features, different band ratio images have been created by the use of various band combinations. Most of the ratio images illustrated good results. However, among the obtained outputs, a saturation enhanced (Siddiqui, 2003) color composite image of the band ratios of 11/12–4/3–11/7 showed the best result (Figure 7). On the image, the stratification and linear structure of sedimentary rocks are clearly seen. In addition, the wet part of the vegetation along the Nariin Sukhait Tokhrol fault is clearly described, creating a linear structure with aqua blue color.

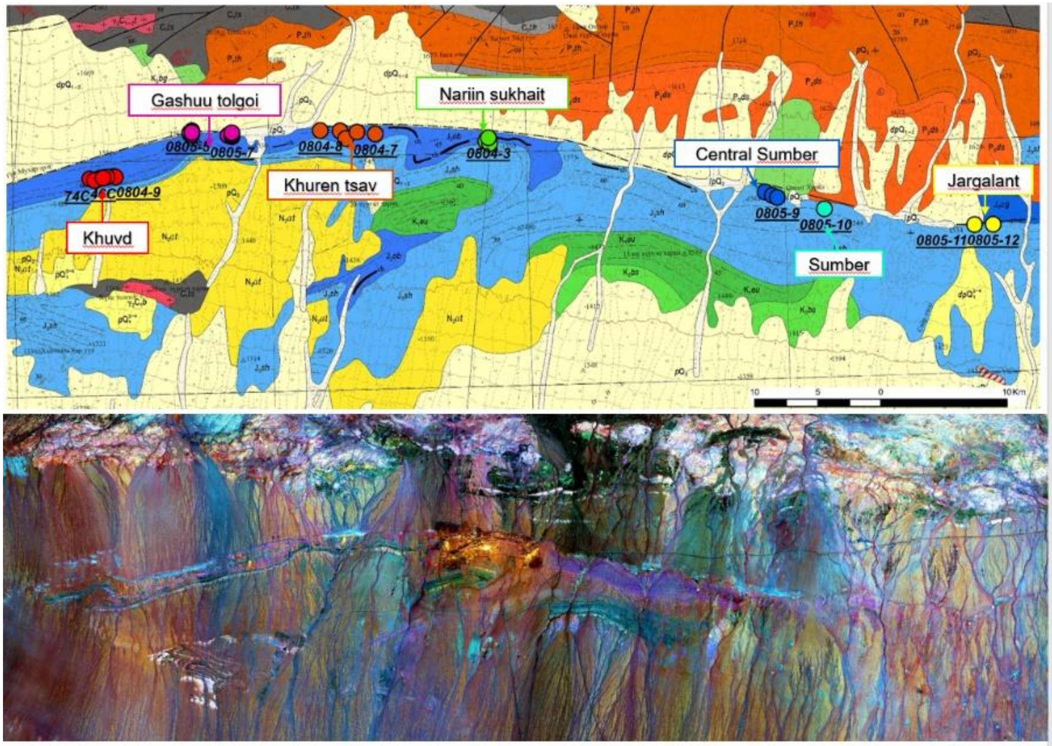

Figure 7. Geological map (upper) and saturation enhanced ratio image (lower).

5. CONCLUSIONS

The aim of this research was to study the geological structures and lithological units of the Ovoot Khural coal bearing basin, one of the largest coal mining area in Mongolia, using optical and microwave RS images. As data sources, high resolution 12 spectral bands of Sentinel-2A and 2 polarization components of Sentinel-1 acquired in 2018 were used. For the analysis of multisource datasets, different RS image processing techniques were applied. Of the applied methods, the superior results were obtained by the uses of the linear-stretched false color image (bands 432), saturation enhanced band ratio (RGB color composite of), minimum noise fraction (fraction output of 4), and Brovey tranform. As could be seen from the analysis, the Sentinel-2 optical image could be effectively used for the interpretation and analysis of geological features in the selcted area.

REFERENCES

Amarsaikhan, D. and Saandar, M., 2011. Chapter 8 - “Fusion of Multisource Images for Update of Urban GIS” in “Image fusion and its applications” Book published by InTECH Open Access Publisher, pp.127-152.

Amarsaikhan, D., 2017. Environmental studies of Mongolia using advanced spatial techniques, *Proceedings of the International Conference on Natural Condition and Territorial Location Aspects,* Ulaanbaatar, Mongolia, pp.280-289.

ERDAS, 2010. New ERDAS Field Guide, ERDAS, Inc. Atlanta, Georgia, pp.776.

Jensen, J. R., 2015. Introductory digital image processing: a remote sensing perspective, Prentice Hall Press.

Li, Y., Meng, Y., Lu, Y., Wang, K., Xie, B., Cheng, Y. & Zhu, K., 2018. Noise removal for airborne time domain electromagnetic data based on minimum noise fraction, Exploration Geophysics, 49:2, 127-133, DOI: [10.1071/EG15072](10.1071/EG15072)

Ochirbat, M., Boldbayar, N, and Namsrai, N., 2016. Coalification of Ovoot Khural basin. Geological Issues 446 (14), ISSN 2313-8408, pp.145-150.

Ochirbat, M. and Jargalan, S., 2021. Geochemistry and depositional environments of coal-bearing strata of Ovoot Khural basin. Geoilogy (36), pp.138-145.

Ochirbat, M. and Jargalan, S., 2022. Coal depositional environment of Ovoot Khural basin. Explorer (64), pp.110-118.

Pournamdari, M., et al., 2014. "Spectral transformation of ASTER and Landsat TM bands for lithological mapping of Soghan ophiolite complex, south Iran." Advances in Space Research 54(4): pp.694-709.

Richards, J. A., 2013. *Remote Sensing Digital Image* Analysis-An Introduction, ISBN-13: 978-3642300615, 5th Edition (Berlin: Springer-Verlag), pp.439.

Sentinel-2 User Handbook, 2015. ESA Standard Document, ESA, pp.64.

Siddiqui, Y., 2003. The modified IHS method for fusing satellite imagery. ASPRS 2003 Annual Conference Proceedings, American Society for Photogrammetry and *Remote Sensing Anchorage*, Alaska (CD publication).