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INVESTIGATION OF GEO-STRUCTURE OF THE KHAN BOGD MASSIVE USING OPTICAL AND MICROWAVE RS

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ABSTRACT: The Khan Bogd alkaline granite complex is situated in the south of Mongolia near the Oyu Tolgoi copper-gold-molybdenum porphyry deposit. It has a ring shaped structure and consists of two ring bodies. The main part is composed of medium to fine grained alkaline granite and includes layered granite, orbicular granite, boulder granite and intruded by dikes of ekerite, pantellerite, mafic porphyrite, and monzonite. The massive has clear contact with host volcanogenic and sedimentary-volcanogenic sequence and it makes distinct ring shape with blackish colored marginal border. The aim of this study is to investigate geological structures of the Khan Bogd area using optical and microwave images. As data sources, high resolution Sentinel-1 and 2 images acquired in 2019 are used. For the analysis of multisource datasets, different standard and advanced remote sensing (RS) techniques have been applied. Overall, the study indicated that a combined use of multispectral and synthetic aperture radar (SAR) images could be successfully used for the interpretation and analysis of geological features.

1. INTRODUCTION

The Khan Bogd alkaline granite complex one of the largest massifs in the world (Gerdes et al. 2017) is situated in southern Mongolia near the Oyu Tolgoi copper-gold-molybdenum porphyry deposit. The granite massive has a ring shaped structure occupying about 1000 sq.km and consists of two rings with sizes of 30 km and 14 km in diameters. The inner ring structure is typical of the western body and accentuated by ring dikes and roof pendants of the country island-arc complex (Kovalenko et al. 2006). In regional geologic setting, it is located within Permian Gobi-Tian Shan Rift Zone developed at the south and south-eastern parts of the Paleozoic Gurvansaikhan island arc terrain. The granite body is intruded into Devonian Alagbayan formation sedimentary and volcanogenic sedimentary sequences. Surrounding area is covered by Cretaceous loose sediments which partly contains dinosaur eggs and bones.

In general, it consists of different intrusive phases including, (i) elpidite-bearing aegirine-arfvedsonite alkaline granite of the main intrusive phase, making up the majority of the western body, (ii) aegirine (-arfvedsonite) granite, sometimes with greisen type alteration and fluorite, making up the majority of the eastern body, (iii) ekerite dikes, layered ekerite-pegmatite-aplite, and pegmatite bodies in the western body, (iv) pantellerite dikes, (v) dikes of alkali leucogranite porphyry, and (vi) red microgranosyenite and micromonzonite dikes in the western body (Kovalenko et al. 2006). The alkaline granite pluton contains many xenoliths, whose abundance increases approaching the contact of the complex with the roof consisting of either dark grey volcanic rocks of the island arc complex or a pink porphyritic granite (Vaglio et al. 2007).

For several decades, RS has been efficiently used for different geological studies. It has become an important tool in geological analysis and interpretation, mineral and hydrocarbon exploration, geomorphological study, and geo-structural investigation. Recent advances in both optical and microwave RS and availability of large image archives can support the scholars in exploring and analyzing extensive geological structures and the related characteristics within a short time, and delivering various high-level research outputs. Due to emergence of the latest refined multisource sensors, different advanced image processing and analysis methods and algorithms having enormous practical applications are being developed. It is evident that multisource datasets will greatly improve any RS-related analyses, because specific information which is not observed by one sensor may be observed by other sensors (Amarsaikhan et al. 2012).

The aim of this study is to investigate geological structures of the Khan Bogd alkaline granite massive using optical and SAR datasets. For this purpose, Sentinel-1 and Sentinel-2 images acquired in 2019 have been used. For the analysis and interpretation of multisource datasets, different standard and advanced RS techniques were applied. The results indicated that a combined use of optical and microwave RS could be effectively used for geological analysis in the selected test site.

2. TEST SITE AND DATA SOURCES

As a test site, the Khan Bogd alkaline granite massive has been selected. It is situated in the southern Gobi, Mongolia being localized in the core of the Late Paleozoic Syncline, where island-arc calc-alkaline differentiated volcanics of variable alkalinity give way to the rift-related bimodal basalt-comendite-alkali granite association. The tectonic setting of the area is controlled by intersection of the near-latitudinal Gobi-Tian Shan Rift Zone with an oblique transverse fault, which, as the rift zone, controls bimodal magmatism. The massive consists of the eastern and western rings and comes into sharp intrusive contact with rocks of the island-arc complex and tectonic contact with rocks of the bimodal complex (Kovalenko et al. 2006).

As data sources a combined use of multispectral Sentinel-2A and Sentinel-1 SAR images acquired in 2019 has been applied. Sentinel-2A images have 13 spectral bands, including blue, green, red, red-edge, near infrared (NIR), and short-wave infrared (SWIR) bands with spatial resolutions ranging from 10m to 60m. Meanwhile, Sentinel-1 datasets include VV and VH polarization components with a pixel resolution of 10m. In the present study, 12 spectral bands of Sentinel-2A (excluding band 1) and both polarization components of Sentinel-1 have been selected. In addition, a large scale geological map and some ground truth data were available. Figure 1 shows the test area illustrated in optical and radar image frames.

(a)

(b)

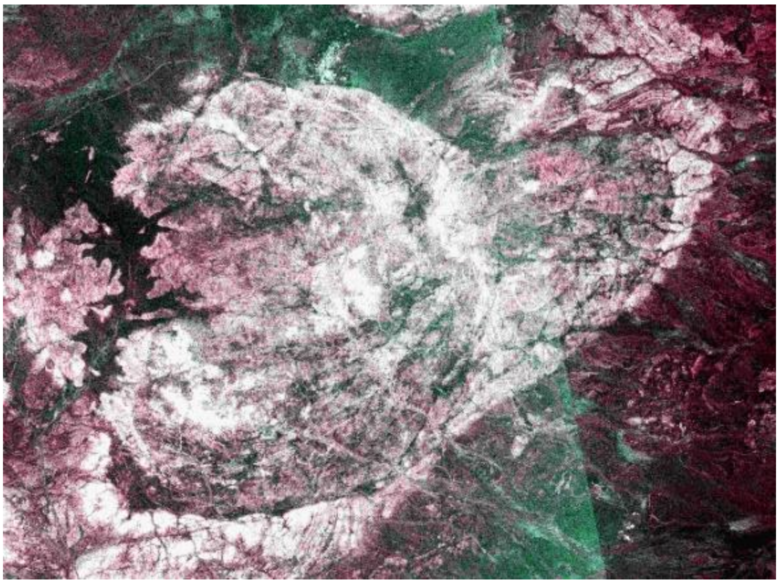

Figure 1. RS images of the Khan Bogd alkaline granite complex: (a) Natural colour image, (b) SAR image.

3. SATELLITE DATA PREPROCESSING

Both Sentinel-1,2 images have been downloaded from the ESA's Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home). Using the metadata associated with the satellite imagery, initially, radiometric correction was applied to the Sentinel-A datasets to improve the quality of the image. It was not necessary to systematically georeference the selected multispectral image, because it was in a correct WGS84/UTM48 system. Then, all bands with spatial resolutions ranging from 20m to 60m were resampled to a pixel resolution of 10m. After that a terrain correction has been applied to the Sentinel-1 SAR image presented in a single look complex format. Visual inspection of the obtained image showed that the result had a very high geometric accuracy, thus satisfying the requirements needed for the final analysis. In order to improve a radiometric quality and reduce some speckle effects in the microwave image, a 3x3 size gammamap filtering (ERDAS, 2010) was applied.

4. RESULTS AND DISCUSSION

Satellite RS has been frequently used for geological analysis and mapping in desert or semiarid areas, and different exceptional results have been obtained during the past years. In case of the present study, the SAR image provides some information about the geological structure, while the multispectral image provides the information about the spectral variations of different features. Over the years, different techniques have been developed and applied, individually and in combination, providing users and decision-makers with various levels of information. In this study, the following techniques were compared: convolution filtering of different sizes, low pass filtering of different sizes, piece-wise (non) linear stretching, band ratios, IHS transformation, Gram-Schmidt fusion, wavelet-based method, and minimum noise fraction. Detailed descriptions of these methods are given in Siddiqui (2003), Pajares and Cruz (2004), Amarsaikhan and Saandar (2011), and Richards (2013) Luo et al. (2016).

Band combinations

At the beginning, different false color composite images have been created by various combinations of the visible, NIR and SWIR bands. Most combinations of the NIR and SWIR bands with one of the visible bands gave good results. However, the reliable results that described both spectral and spatial variations of the geological features in the selected test area were obtained by multichannel Sentinel 9-4-3 RGB and 11-4-3 RGB color composite images. Especially, the image enhanced by the use of the piece-wise non-linear stretching represented the best result among the false color composite images. Here, the stretching was applied in between the lower and upper values of the histograms of all available bands. These images (i.e. 9-4-3 combination and enhanced 11-4-3 bands) are shown in Figure 2.

(a) (b)

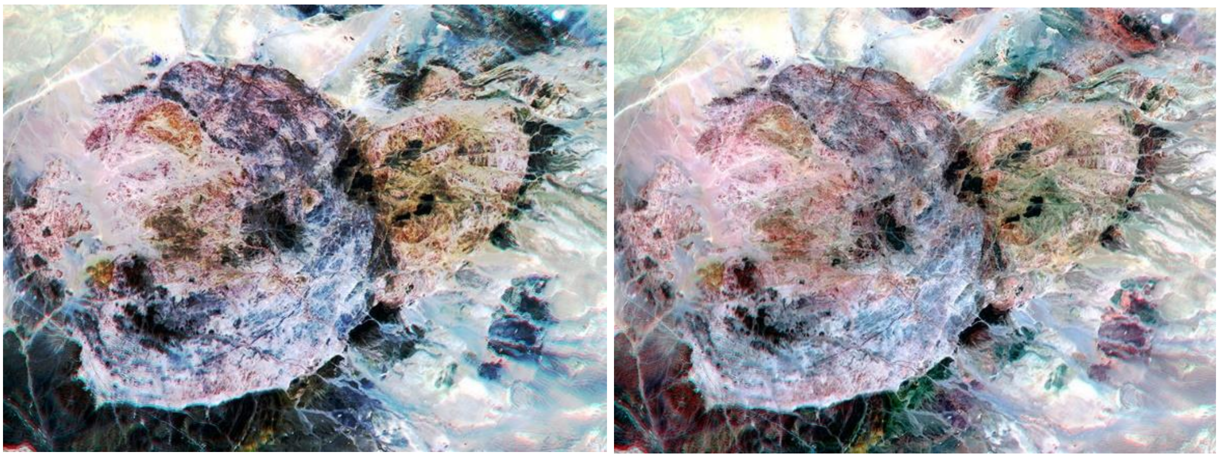

Figure 2. The false color composite images of the test area: (a) Combination of 9-4-3 bands, (b) Combination of enhanced 11-4-3 bands.

Band ratio analysis

Band ratio analysis is considered one of the most efficient methods for lithological discrimination (Pournamdari et al. 2014). In the current study, for the enhancement of the available geological features, a total of 15 combinations have been performed using blue, green, red, red-edge, NIR, and SWIR bands of the Sentinel-2 image as well as 2 radar channels. Of the selected band ratios, the following combinations were the most relevant for the geological analysis and enhancement of the spectral differences of relevant lithological units in the Khan Bogd alkaline granite complex:

a) RGB color composite of the band ratios: 11/12–4/3–11/7
b) RGB color composite of the band ratios: 11/12–11/2–12/3
c) IHS-enhanced RGB color composite of the band ratios: 11/4–11/3–11/2
d) RGB color composite of the band ratios: 12/8–12/11–12/9.

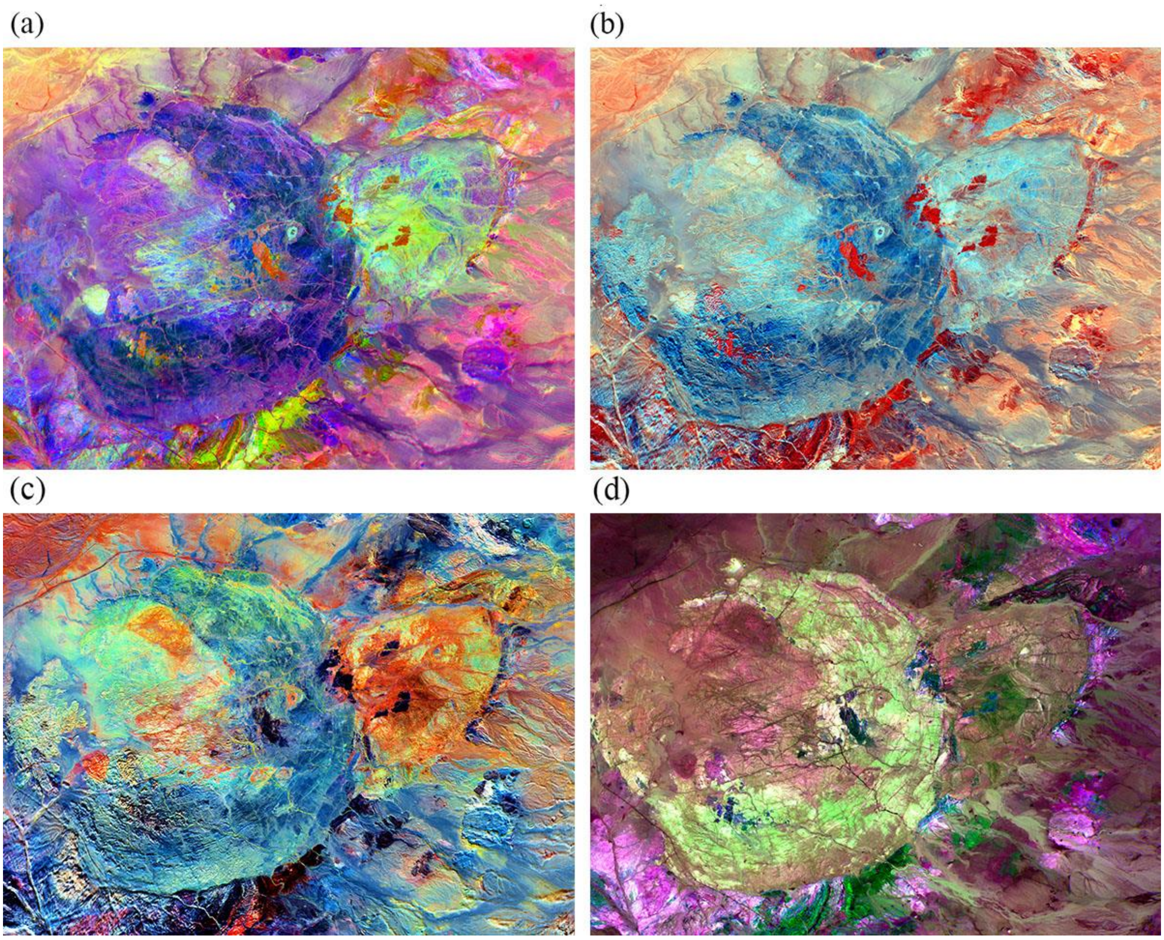

Figure 3. Ratio images of the Khan Bogd area: (a) Combination of 11/12–4/3–11/7, (b) Combination of 11/12–11/2–12/3, (c) Combination of 11/4–11/3–11/2, (d) Combination of 12/8–12/11–12/9.

As can be seen from the above ratios, combinations of the SWIR and other bands gave better results compared to the other combinations. The selected band ratio images are illustrated in Figure 3. As seen from the Figure 3, the ratio images clearly show the geo-structures and spectral differences between different lithological units.

Convolution and low pass filtering

Traditionally, convolution filtering has been efficiently used for the spatial enhancement of different geological structures. It includes various types of high pass filters along with Robert, Sobel, and Laplacian type filters (Amarsaikhan and Khosbayar 1996). Likewise, low pass filters of different sizes have been widely used for the geological interpretation and analysis (Ganzorig at el. 1999). In the present study, 26 convolution and low pass filters of different sizes were applied to the optical and SAR bands. Among the outputs, the following 2 combinations demonstrated the best results in terms of the spatial and spectral enhancements of the geo-structures in the test area:

a) RGB color composite: b9*highpass (3x3)-b5*highpass (5x5)-b2*lowpass (7x7) (Output 1)
b) RGB color composite: b4* highpass (3x3)-b2* lowpass (7x7)-b11* highpass (5x5) (Output 2).

As seen from outcomes of the convolution and low pass filtering, the outputs of spatial enhancement techniques obtained by the use of blue, red, NIR, and SWIR bands of Sentinel-2 image illustrated the best results. The images are shown in Figure 4.

(a) (b)

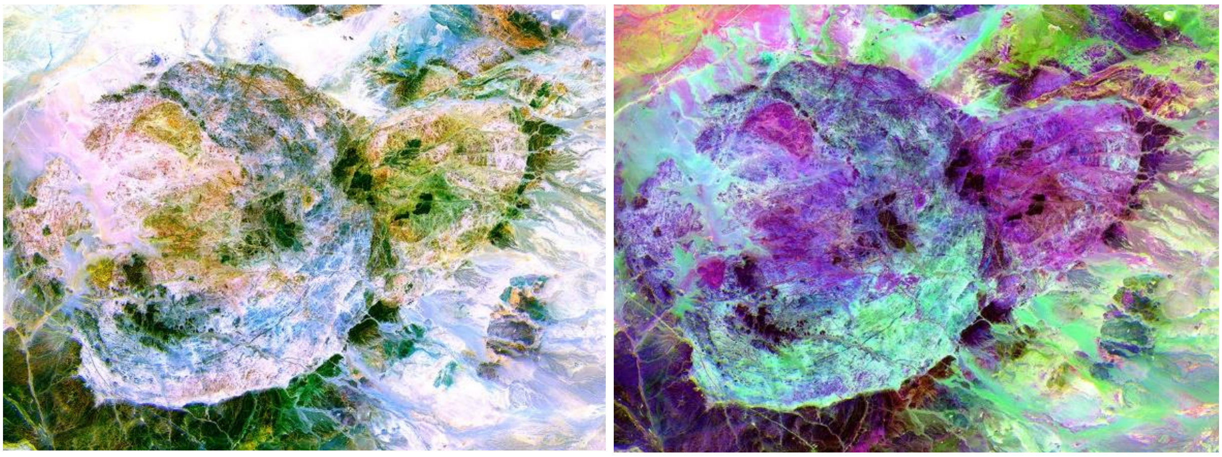

Figure 4. Results of the convolution and low pass filtering: (a) Output 1, (b) Output 2.

Minimum noise fraction transformation

To assess the spatial variability of different lithological units, a minimum noise fraction transformation has been applied to the combined bands of optical and microwave datasets. The method involves two cascaded principal component transformations. The first transformation de-correlates and rescales the noise in the data based on an estimated noise covariance matrix. Then, noise-reduced data is fed onto a standard principal component transformation. The final outputs are uncorrelated and are arranged in terms of decreasing information content. The minimum noise fraction components with eigenvalues less than 1.0 are usually excluded from the data in order to improve the subsequent spectral processing results (Jensen 2015). In our study, all eigenvalues of the transformed multisource datasets were greater than 1.0 and in total 9 bands have been obtained. The outputs of the minimum noise fraction have been analyzed individually and in combination. The best results were obtained by the use of the below combinations:

a) RGB color composite of fraction outputs of 5-3-2 (Image 1)
b) RGB color composite of fraction outputs of 3-2-1 obtained by applying a 7x7 size low pass filter to the bands 2,3,6 and 5x5 size convolution filter to the bands 2,5,10 (Image 2).

As seen from outputs of the minimum noise fraction transformation, in the first case, a combination of the fraction outputs of 5-3-2 delivered the best outcome, while in the second case, fraction results of 3-2-1 obtained by applying the 7x7 size low pass filter to the visible bands and 5x5 size convolution filter to the visible and SWIR bands exhibited the best output. Also, it could be seen from Figure 5, the illustrated images contain some structural information available in the microwave image.

(a) (b)

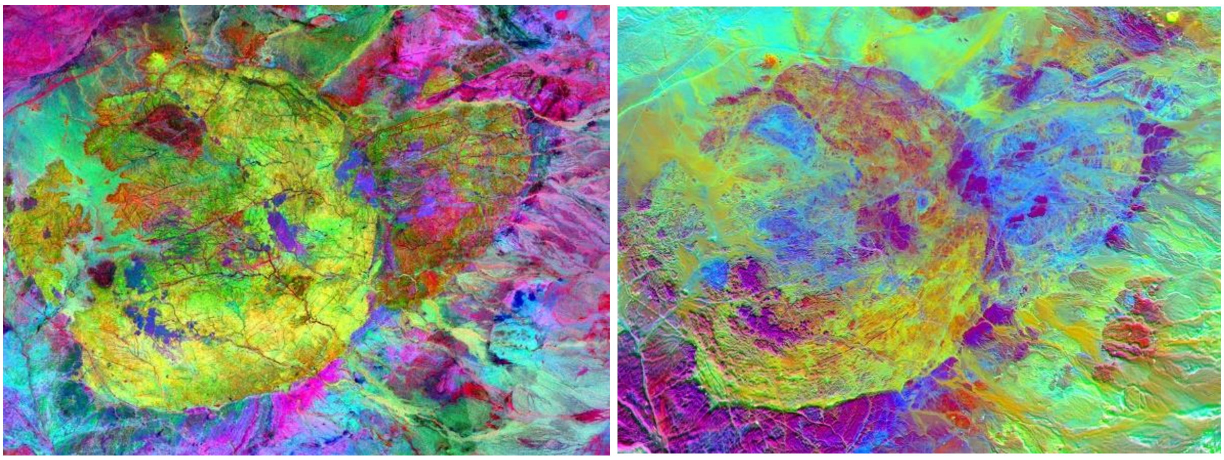

Figure 5. Results of the minimum noise fraction transformation: (a) Image 1, (b) Image 2.

5. CONCLUSIONS

The aim of this research was to study the geological structures and lithological units of the Khan Bogd alkaline granite complex, one of the largest massifs in the world, using optical and microwave RS. As data sources, high resolution 12 spectral bands of Sentinel-2A and 2 polarization components of Sentinel-1 acquired in 2019 were used. For the analysis of multisource datasets, convolution filtering of different sizes, low pass filtering of different sizes, piece-wise (non) linear stretching, band ratios, IHS transformation, Gram-Schmidt fusion, wavelet-based method, and minimum noise fraction transformation were applied. Of the applied methods, the superior results were achieved by the uses of the piece-wise non-linear stretching, band ratios (RGB color composites of 11/12–4/3–11/7, 11/12–11/2–12/3, 11/4–11/3–11/2, 12/8–12/11–12/9), IHS transformation, convolution and low pass filters of different sizes (RGB color composites of b9*highpass (3x3)-b5*highpass (5x5)-b2*lowpass (7x7), b4* highpass (3x3)-b2* lowpass (7x7)-b11* highpass (5x5)), and minimum noise fraction method (RGB color composites of fraction outputs of 5-3-2 and 3-2-1 obtained by applying different filters). As seen from the analysis, the combined use of multisource Sentinel datasets could be effectively used for the interpretation and analysis of geological features.

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