STRUCTURAL FEATURE STUDY OF KHALZAN-TSAKHIR REE BEARING ORE ZONE USING OPTICAL AND MICROWAVE REMOTE SENSING

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ABSTRACT: The Khalzan-Tsakhir REE bearing ore zone is situated in western part of Mongolia at the southern end of Altan Khukhii mountain range. In regional geologic setting, it is located along the Tsagaan shuvuut deep fault zone. The main goal of this research is to study structural features of the ore zone using high resolution optical and synthetic aperture datasets. As data sources, 10m, 20m, and 60m resolution spectral bands of Sentinel-2A, and two polarization components of Sentinel-1 acquired in 2018 are used. For the analysis and interpretation of the datasets, different remotely sensed image analysis techniques such as convolution and low pass filtering of various sizes, refined histogram analysis, band ratios, texture enhancement approach, minimum noise fraction transformation, principal component analysis, and spectral sharpening techniques are applied. The results show that unlike the microwave data, the high resolution Sentinel-2 bands can be successfully used for the analysis of structural features in the selected test area.

1. INTRODUCTION

The Khalzan-Tsakhir REE bearing ore zone is located in Western Mongolia, in site with excellent exposure of the related alkaline rocks due to the favorable geomorphological characteristics and sparsely distributed vegetation. These features enable accurate and comprehensive investigation of late magmatic processes preceding ore-formation and the detailed examination of Zr–Nb–REE mineralization in different host rocks in the area. Granitic rocks host the Khalzan Burged deposit in the southern part of this area, whereas quartz-rich zones hosting Zr–Nb–REE mineralization of the Tsakhir prospect are mainly developed within dolerite. Moreover, the structures indicative of magmatism and hydrothermal alteration at Khalzan Burged are not further affected by late deformation and metamorphism (Kempe et al. 2015).

The deposit and related prospects in the area are situated adjacent to the north-western end of Khar-Us Nuur, about 45 km northeast from the center of the Khovd aimag. The deposit occurs in spatial association with large intrusions of acidic alkaline rocks. The occurrence of Nb–Zr–REE mineralization at Tsakhir was found during the exploration work led by Minin in the late 1980s near the well Tsakhir Khudag north of Khalzan Burged in altered dolerite (Minin, 1991). Although the potential for recovery of Y and heavy rare earth elements from both deposits was recognised relatively early (Kempe and Dandar, 1995), demand for these elements from the industry initiated a worldwide search for such deposits, was relatively at a later stage (Chakhmouradian and Wall, 2012).

As it is known, remote sensing (RS) techniques, technologies, and methods have been effectively used for different geological and structural studies. Over the years, RS has become an important and essential tool in mineral mapping, geological analysis and interpretation, geomorphological study as well as exploration of structural features. Recent advances in both optical and microwave RS imaging acquisition and accessibility to the multisource images with different spatial and spectral characteristics help the scientists and researchers to map widespread geological structures and accurately analyze and explore them within a short time (Saibi et al. 2018). In addition, the current advanced multisource sensors along with innovative image processing and analysis techniques can significantly can push forward develop of various geology related applications.

The aim of this study is to investigate the structural features of the Khalzan-Tsakhir REE bearing ore zone, Western Mongolia using optical and synthetic aperture radar (SAR) datasets. For this purpose, Sentinel-1 and Sentinel-2 images of 2018 with different spatial resolutions have been selected. For the analysis and interpretation of multispectral and microwave datasets, different standard and advanced image processing techniques were applied. The results indicated that a combined use of optical and microwave images can be used for geological analyses, but compared to the SAR data the high resolution Sentinel-2 image has superior performance for the analysis of structural features in the selected test area.

2. TEST SITE AND DATA SOURCES

The Khalzan-Tsakhir REE bearing ore zone is situated in western part of Mongolia at the southern end of Altan Khukhii mountain range. In regional geologic setting, the site is positioned along the Tsagaan shuvuut deep fault zone and belongs to the lake metallogenic belt. It is has a very complicated geological structure, because its location is along the longitudinal trending Tsagaan shuvuut deep fault zone delineating between Mongolian Altai and Lake tectonic zones. Therefore, the ore zone is divided by north west, north east and longitudinal fault zones. A geological map of the test area is shown in Figure 1.

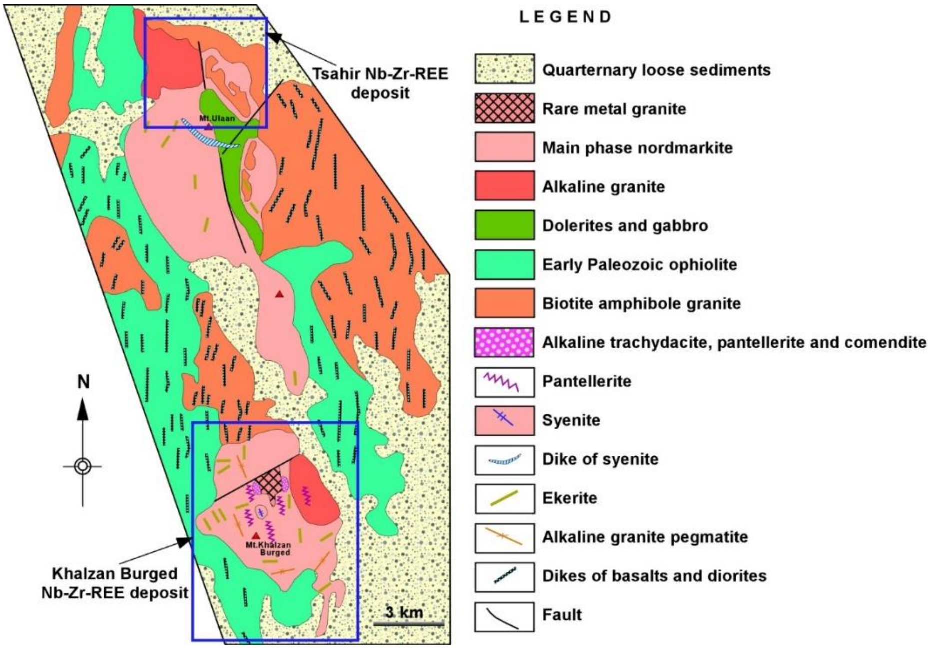

Figure 1. A geological map of the test area.

As data sources, a combined use of multispectral Sentinel-2A and Sentinel-1 radar images acquired in 2018 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 (characteristics are presented in Table 1), while Sentinel-1 datasets include VV and VH polarization components with a pixel resolution of 10m (Sentinel-2 User Handbook, 2015). 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 image frame

Table 1. Characteristics of spectral bands of Sentinel-2A.

Band	Wavelength (μm)	Spatial resolution (m)	Bandwidth (nm)
Band 1	0.443	60	27/45 (2A/2B)
Band 2	0.490	10	98
Band 3	0.560	10	45/46 (2A/2B)
Band 4	0.665	10	38/39 (2A/2B)
Band 5	0.705	20	19/20 (2A/2B)
Band 6	0.740	20	18
Band 7	0.783	20	28
Band 8	0.842	10	115
Band 8A	0.865	20	20
Band 9	0.945	60	20
Band 10	1.375	60	20
Band 11	1.610	20	90
Band 12	2.190	20	180

3. SATELLITE DATA PREPROCESSING

Multichannel Sentinel-2 and Sentinel-1 radar images have been downloaded from the ESA's Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home). By the use of the metadata associated with the optical data, initially, radiometric correction was applied to the Sentinel-2 image to improve the appearance of the image. It was not necessary to systematically georeference the selected multispectral bands, because they were in a correct WGS84/UTM46 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 microwave image presented in a single look complex format. The result showed a very high geometric accuracy, and it was integrated with the optical dataset.. In order to improve a radiometric quality and reduce speckle noise in the microwave image, a 3x3 size frost filtering (ERDAS, 2010) was applied.

4. RESULTS AND DISCUSSION

In the current study, the microwave data provides some information about the structure of different geological features, whereas the optical image provides the information about the spectral variations of different objects. During many years, diverse techniques have been developed and used for different geological applications and analyses. In our study, the below techniques have been compared: convolution filtering of different sizes, low pass filtering of different sizes, piece-wise (non) linear stretching, band ratios, IHS transformation, Gram-Schmidt fusion, minimum noise fraction (MNF), and principal component analysis (PCA). Detailed descriptions of these methods are given in Siddiqui (2003), Amarsaikhan and Saandar (2011), Richards (2013), and Luo et al. (2016).

Band ratio analysis

In geological RS, band ratio analysis is considered one of the most efficient methods for lithological discrimination (Pournamdari et al. 2014). In our study, for the enhancement of the existing structural features, a total of 18 combinations have been carried out using blue, green, red, red-edge, NIR, and SWIR bands of the Sentinel-2 image as well as SAR polarization components. Among the applied band ratios, the following combinations were the most relevant for the geological analysis and enhancement of the spectral differences of structural features in the Khalzan-Tsakhir REE bearing ore zone:

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

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

As seen from the above ratio images, in most cases combinations of the SWIR and visible bands gave better results compared to the other combinations. The selected band ratio images are illustrated in Figure 2. As seen from the Figure 2, these images clearly show the geological structures and spectral differences among different structural features in the test area.

Convolution and low pass filtering

Over the years, 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, 12 different 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: b4*highpass (3x3)-b1*lowpass (7x7)-b10*highpass (5x5) (Result 1)
b) RGB color composite: b4* highpass (3x3)-b2* lowpass (7x7)-b11* highpass (5x5) (Result 2).

As seen from results of the convolution and low pass filtering, the outputs of spatial enhancement techniques obtained by the use of blue, red, and SWIR bands of Sentinel-2 image illustrated the best results. The images are shown in Figure 3.

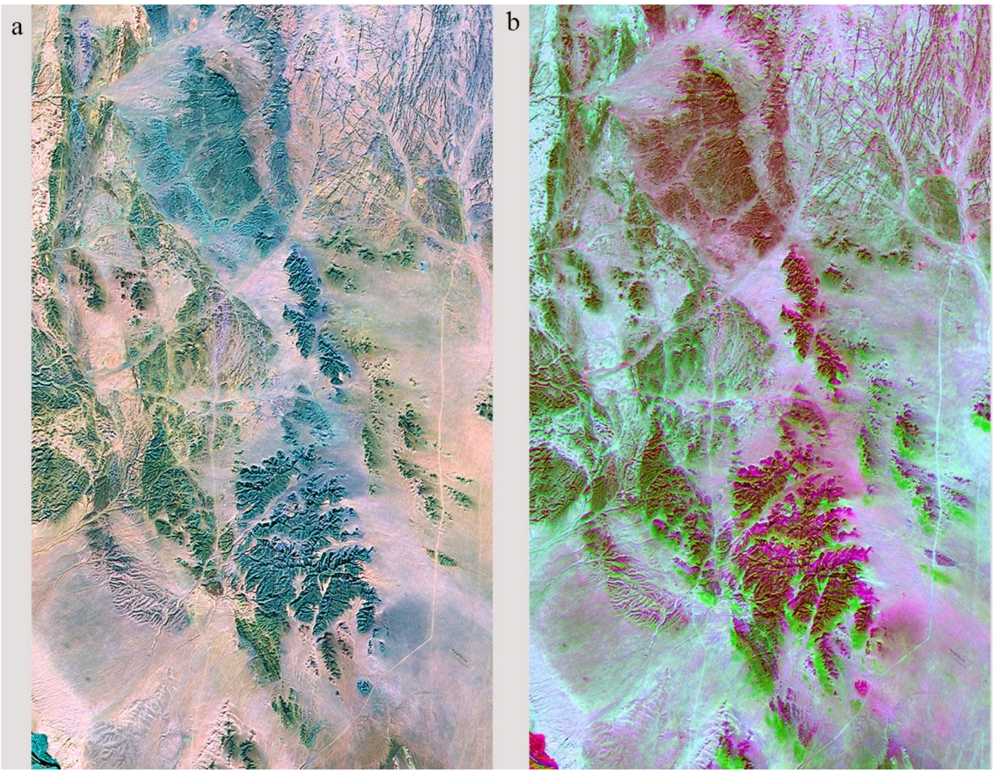

Figure 3. Results of the convolution and low pass filtering: (a) Result 1, (b) Result 2.

MNF transformation and PCA

To assess the spatial variability of different structural features, MNF transformation and PCA techniques have been applied to the optical and microwave datasets. In both MNF and PCA methods, final outputs are orthogonal components and are arranged in terms of decreasing information content. The outputs of the methods have been analyzed individually and in combination. The best results (Figure 4) were obtained by the use of the below combinations:

a) RGB color composite of fraction outputs of 2-3-1 (Figure 4a)
b) RGB color composite of fraction outputs of 1-4-6 (Figure 4b)
c) RGB color composite of fraction outputs of 4-3-5 (Figure 4c)
d) RGB color composite of principal components 7-2-1 (Figure 4d)
e) RGB color composite of principal components 4-5-6 (Figure 4e)
f) RGB color composite of principal components 6-7-8 (Figure 4f).

As seen from the outputs of the MNF, in the first case, a combination of the fraction outputs of 2-3-1 delivered the most reliable outcome, while in the second case, fraction results of 1-4-6 showed the best output. In the third case, a combination of the fraction outputs of 4-3-5 also illustrated an acceptable result.

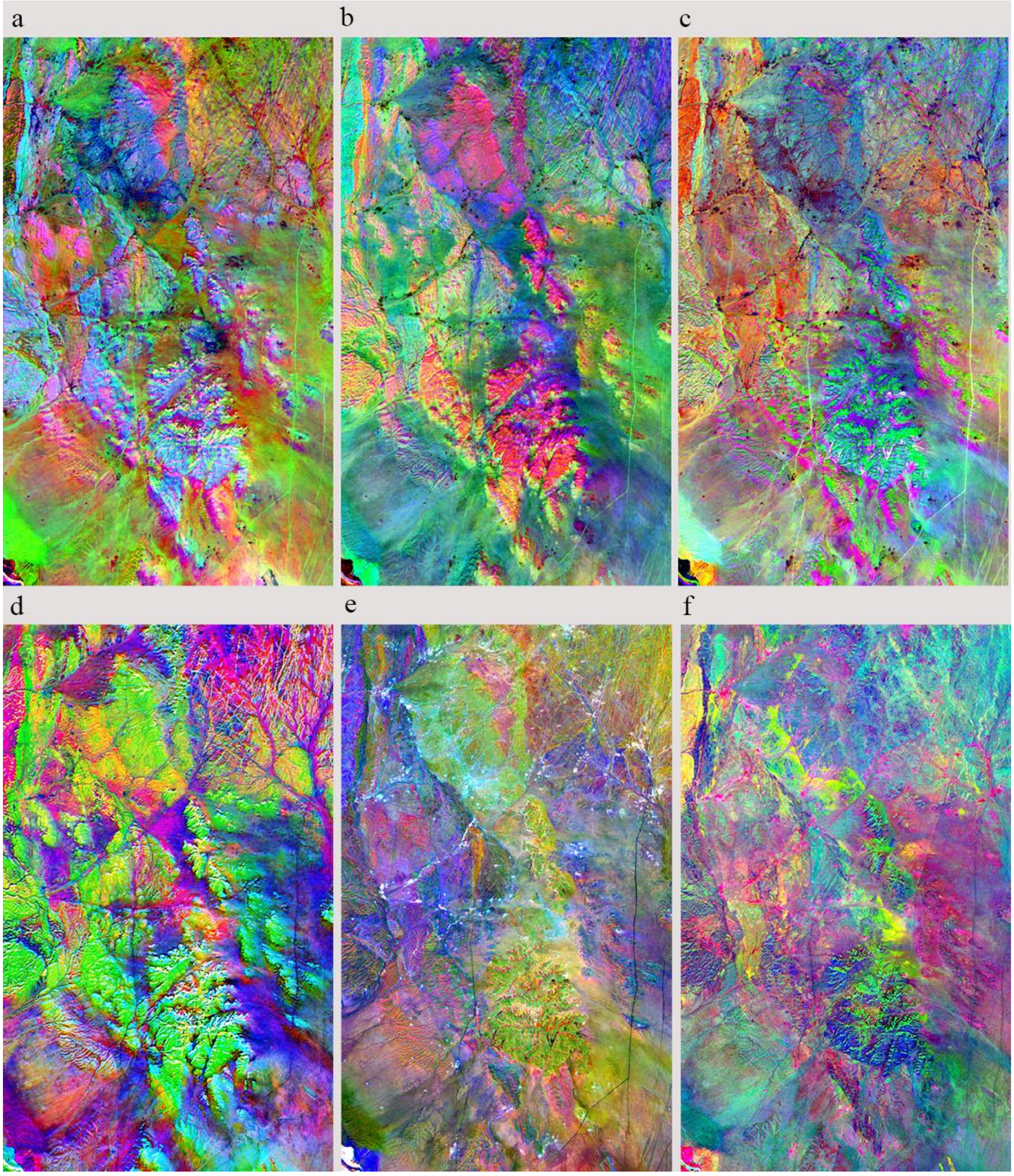

Figure 4. Results of the MNF and PCA: a) Fraction outputs of 2-3-1, b) Fraction outputs of 1-4-6, c) Fraction outputs of 4-3-5, d) Principal components 7-2-1, e) Principal components 4-5-6, f) Principal components 6-7-8.

As could be seen from the results of the PCA, unlike a combination of the first 3 principal components that contained more than 85% of the overall variance, a combination of the 7-2-1 components gave a superior result. Combinations of the principal components 4-5-6 as well as 6-7-8 also delivered good results though they contained less that 10% of the overall variance. This indicates that although the first principal components comprise the majority of the overall information, some of the last components could still contain useful information.

Band combinations

In order to enhance the structural features of the study area, different false color composite images have been created by various combinations of the microwave and optical bands. Many combinations of the NIR and SWIR bands with one of the visible bands gave good results illustrating both spectral and spatial variations of the geological features in the selected test site. Some of the reliable RGB color composite images obtained by multichannel band combinations of 11-4-3, 12-11-8a, 8a-2-12, 8a-11-7 are shown in Figure 5. As seen from the Figure 5, a combination of all infrared bands could give a similar result as a combination of SWIR and visible bands.

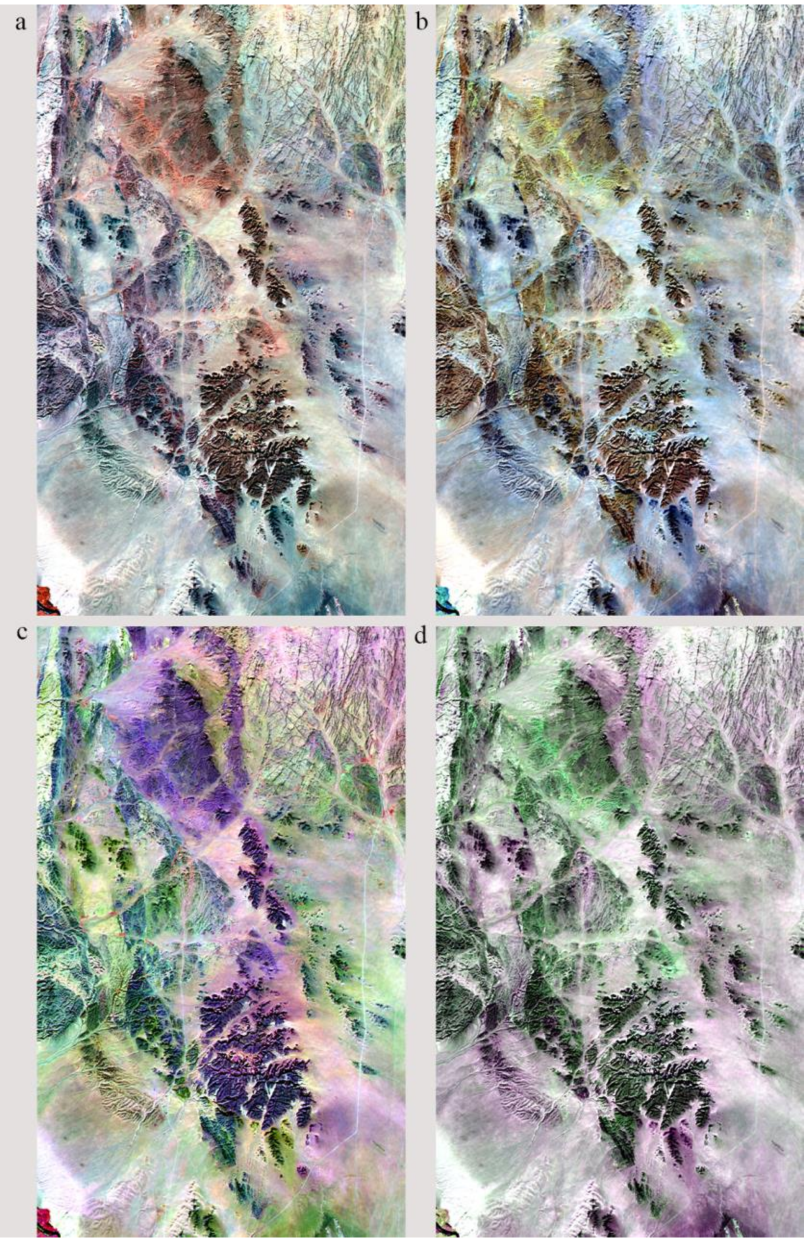

Figure 2. The false color composite images of the test area: (a) Combination of 11-4-3 bands, (b) Combination of 12-11-8a bands, (b) Combination of 8a-2-12 bands, (b) Combination of 8a-11-7 bands.

5. CONCLUSIONS

The aim of this study was to investigate the geological structural features of the Khalzan-Tsakhir REE bearing ore zone situated in western part of Mongolia using multispectral and microwave RS datasets. As data sources, high resolution 12 spectral bands of Sentinel-2A and polarization components of Sentinel-1 acquired in 2018 were used. For the analysis of the combined datasets low pass filtering of various sizes, refined histogram analysis, band ratios, texture enhancement approach, minimum noise fraction transformation, PCA, and spectral sharpening techniques were applied. Among the applied methods, more reliable results were achieved by the uses of the band ratios, convolution and low pass filters, minimum noise fraction method, PCA, and false color composite images. As seen from the analysis, dissimilar to the microwave data, the high resolution Sentinel-2 bands could be successfully used for the analysis of structural features in the selected area.

REFERENCES

Amarsaikhan, D. and Khosbayar, P., 1996. Creation of a lineament layer within a GIS using RS data, *Mongolian articles presented at the 30th World Congress on Geology*, Beijing, China, pp.15-18.

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.

Andreev, G.V. and Ripp, G.S., 1996. Rare-metal epidote-quartz metasomatites in the Khaldzan Buregteg massif. Zapiski Vesrossijskogo Mineralogicheskogo Obshchestva 75 (6), pp.24–30.

Chakhmouradian, A.R., Wall, F., 2012. Rare earth elements: minerals, mines, magnets (and more). Elements 8, pp.333–340.

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

Ganzorig, M., Amarsaikhan, D. and Gan-Ochir, J., 1999. Estimation of the prospective ore-bearing sites using multivariate statistical and image analyses, *Invited full paper published in Proceedings of the 20th Asian Conference on RS*, Hong Kong, pp.519-524.

Kempe, U. and Dandar, S., 1995. Nb–Zr–REE mineralization: a possible source of HREE. In: Pašavá, J., Křibek, T., Žák, P. (Eds.), Mineral Deposits: from Their Origin to Their Environmental Impacts. Balkema, Rotterdam, pp.463–466.

Kempe, U., Möckel, R., Graupner, T., Kynicky, J., Dombon, E., 2015. The genesis of Zr-Nb-REE mineralization at Khalzan Buregte (Western Mongolia) reconsidered. Ore Geology Reviews 64, pp.602–625.

Luo, G., Chen., Tian, L., Qin, K. and Qian, S-E., 2016. Minimum noise fraction versus principal component analysis as a preprocessing step for hyperspectral imagery denoising, Canadian Journal of RS, 42, pp.106-116.

Minin, A.D., 1991. Geology and deposits in the Altan-Khkhei ridge and adjacent eastern territories in Western Mongolia. Unpublished technical report; Ulaanbaatar, Mongolia, pp.240 pp.

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.

Saibi, H. , Bersi, M. , Mia, M. B. , Saadi, N. , Bloushi, K. M. S. A. , W. Avakian, R., 2018. Applications of remote sensing in geoscience. In: Hung, M. , Wu, Y. , editors. Recent Advances and Applications in Remote Sensing [Internet]. London: IntechOpen, Available from: https://www.intechopen.com/chapters/60592.

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).