Hydrothermal Minerals Mapping using based on Remotely Sensed Data from Sentinel 2 Sattelite: a Case Study in Vinh Phuc Province, Northern Vietnam

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Abstract: This paper presents the experiences obtained in the application of Principal Component Analysis (PCA) method to map hydrothermal minerals based on remotely sensed data. In this study, Sentinel-2B MultiSpectral Instrument (MSI) image is used to detect distribution of hydroxyl-bearing minerals in Vinh Phuc province, northern Vietnam. Four bands of Sentinel-2B image including blue band (band 2), Vegetation Red Edge band (band 8A) and SWIR bands (band 11 and 12) are used to calculate the Principal Components, then and then select the Principal Component, which containing provides information on the hydrothermal minerals information. The obtained results findings show that the methodology and data are effective in detecting and mapping hydrothermal mineralization.

Keywords: Remote sensing, hydroxyl-bearing minerals, Principle Component Analysis, Sentinel 2, Vietnam.

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Картографирование гидротермальных минералов по данным дистанционного (спутникового) зондирования с использованием спектро зонального прибора Сентинель 2 на примере провинции Винь-Пхук, Северный Вьетнам

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Аннотация: В данной статье представлен опыт, полученный при применении метода анализа главных компонентов (PCA) для картографирования гидротермальных минералов на основе данных дистанционного зондирования. В этом исследовании изображения, полученные посредством дистанционного (спутникового) зондирования с использованием спектро зонального прибора Сентинель 2Б, используются для определения распределения минералов, содержащих гидроксий, в провинции Винь Пхук, Северный Вьетнам. Четыре полосы (диапазона) изображения Сентинель 2Б, включая синюю полосу (полоса 2), полосу растительности (красный (длинноволновый) край спектра) (полоса 8А) и полосы SWIR (коротковолновая ИК область спектра, полосы 11 и 12), используются для расчета главных компонентов, а затем выбирается главный компонент, несущий информацию о гидротермальных минералах. Полученные результаты показывают, что рассматриваемые методология и данные эффективны при обнаружении и картировании гидротермальной минерализации.

Ключевые слова: дистанционное зондирование, гидроксий-содержащие минералы, анализ главных компонентов, Сентинель 2 (Sentinel 2), Вьетнам.

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INTRODUCTION

Vinh Phuc province comprises many types of minerals resources, including those with significant reserves such as building stone, granite, kaolin, sand, gravel, and clay. These minerals are of great significance in development of construction industry and other sectors, contributing to the economic development in the province [19].

Remote sensing has been used for hydrothermally altered mineral mapping and mineral prospecting [6]. The Landsat and ASTER data are the most widely used multispectral data for mapping iron oxides and hydroxyl-bearing minerals [1, 2, 4, 5, 8, 11, 12; 16]. There are many technique based on band ratio and Principal Component Analysis (PCA) applicable to detecting and mapping distribution of minerals [2, 17]. In general, these studies showed that the PCA method is able to detect and map hydrothermal minerals better than band ratio–based method.

Fraser and Green [5] developed DPCA (Directed Principal Component Analysis) method for monitoring hydrothermal minerals distribution. The DPCA method is based on the combination of advantages of the band ratio and PCA methods. Trinh and Zablotskii [17] have developed computer program RS-MINERALS to detect and map iron oxide and clay minerals from Landsat 8 OLI data.

Sentinel-2 (2 satellites: Sentinel-2A and Sentinel-2B) carried on-board high-resolution multispectral imager with 13 bands spanning VNIR through SWIR bands. Sentinel-2A data found the first use for geological applications by Van der Meer et al. in 2014 [18]. In study [18], the authors compared the performance of Sentinel-2A MSI imager with that of the ASTER imager in mapping hydrothermal mineral areas. So far, there are a few studies on mapping and detecting minerals using Sentinel 2 MSI data [6, 9, 13, 15]. Spatial and spectral performance characteristics of the Sentinel-2 MSI are similar to those of Landsat data, and the band ratio and PCA methods can be also used to map hydrothermal minerals based on Sentinel-2 MSI data [6].

This study focuses on the application of Sentinel 2 MSI data to detect and map hydroxyl-bearing minerals in Vinh Phuc province, northern Vietnam. In this study, four Sentinel 2 MSI bands (band 2, 8A, 11 and 12) were used to calculate Principal Component (PC). The PC containing information concerning hydroxyl-bearing minerals was selected based on the comparison of eigenvector matrix values and then used to map hydroxyl-bearing minerals.

STUDY AREA

Vinh Phuc is the province in the Red river delta in northern Vietnam. The province is bordered to the north by Thai Nguyen and Tuyen Quang provinces, to the west by Phu Tho province, and to the south by Hanoi capital city (Fig. 1). According to the statistical yearbook 2018, Vinh Phuc province covers area of 1235.87 km² with population of 1,092,424 people. The province is subdivided into 7 districts and 2 cities. The terrain features extend northwest – southeast, that is characteristic for the North and Northeast of Vietnam. The northern part of the province comprises Tam Dao mountain range with the highest peak of 1,592 m, and the southwestern part is surrounded by two large rivers (Red River and Lo River). The terrain altitude descends from northeast to southwest and is divided into 3 regions with characteristic topography: plains, hills, low and medium-altitude mountains [19].

MATERIALS

The Sentinel-2 mission comprises two satellites developed and launched to support vegetation, land cover, and environmental monitoring. The Sentinel-2A satellite was launched by ESA on June 23, 2015 and operates in sun-synchronous orbit at 10 day repeat cycle. The second identical satellite (Sentinel-2B) was launched on March 7, 2017. Together they cover the whole Earth’s land surface, large islands, and inland and coastal waters every five days. The Sentinel-2 MultiSpectral Instrument (MSI) acquires 13 spectral bands ranging from Visible and Near-Infrared (VNIR) to Shortwave Infrared (SWIR) wavelengths along the 290 km orbital swath. Characteristics of Sentinel 2 satellite bands are showed in Tab. 1 [14].
Fig. 1. Study area map, Vinh Phuc province, northern Vietnam

Fig. 2. Sentinel 2B multispectral image in Vinh Phuc province, RGB=B11:B8A:B2
In this study, multispectral cloud-free Sentinel-2B images with spatial resolution of 10 m (bands 2, 3, 4, 8), 20 m (bands 5, 6, 7, 8A, 11, 12) and 60 m (bands 1, 9, 10), produced since December 5, 2019 in the Vinh Phuc province (northern Vietnam) were used for mapping hydroxyl-bearing minerals distribution (Fig. 2). The Sentinel-2B data presented the L2A level product, downloaded from Copernicus Open Access Hub (https://scihub.copernicus.eu) website. The Level-2A product provides Bottom Of Atmosphere (BOA) reflectance images derived from the associated Level-1C products. The comparison of the nominal band centers, bandwidths, and spatial resolution of Sentinel-2 MSI and Landsat 8 OLI bands is presented in Tab. 2 [14].

### METHODS AND FINDINGS

The image processing started with radiometric and geometric correction. At the next step, the Sentinel-2B MSI images were subdivided into subsets for the study area. In this study, image processing was performed using ERDAS Imagine 2014 programs, and hydroxyl-bearing distribution map was created using ArcGIS 10 program.

The PCA method uses the Principal Components transformation technique for reducing dimensionality of correlated multispectral data [10]. The analysis is based on multivariate statistical technique, which selects uncorrelated linear combinations (eigenvector loadings) of variables in such a way that each successively extracted linear combination, or Principal Component...
The eigenvector matrix values and eigenvalues of PCA for 2, 8A, 11, 12 bands of Sentinel-2B MSI images

| Principal Component | Eigen matrix | Eigenvalues (%) |
|---------------------|--------------|----------------|
|                     | B2 | B8A | B11 | B12 |                  |
| PC1                | 0.1081 | 0.5628 | 0.6353 | 0.5176 | 67.442 |
| PC2                | −0.2599 | 0.7834 | −0.2295 | −0.5159 | 29.316 |
| PC3                | −0.9335 | −0.1952 | 0.2980 | 0.0414 | 2.601 |
| PC4                | −0.2222 | 0.1774 | −0.6745 | 0.6813 | 0.941 |

TEХНОЛОГИЧЕСКАЯ БЕЗОПАСНОСТЬ В МИНЕРАЛЬНО-СЫРЬЕВОМ КОМПЛЕКСЕ И ОХРАНА ОКРУЖАЮЩЕЙ СРЕДЫ
Fig. 3. Principal Component Analysis for mapping hydroxyl-bearing minerals in Vinh Phuc province, northern Vietnam

Fig. 4. PC4 reverse, bright pixels represent the hydroxyl-bearing minerals
Fig. 5. Results of mapping the hydroxyl-bearing minerals (blue color) in Vinh Phuc province using Sentinel-2B image.

Fig. 6. Mineral distribution map of Vinh Phuc province [20]
Table 4

| Mine name                        | Hydroxyl-bearing minerals on Sentinel 2B image | Results of mapping based on Sentinel-2B data |
|----------------------------------|-----------------------------------------------|---------------------------------------------|
| Nhan Ly pegmatite mine           | ![Image](image1.png)                          | ![Map](map1.png)                           |
| Dong Dao sedimentary rock mine   | ![Image](image2.png)                          | ![Map](map2.png)                           |
| Xuan Hoa sedimentary rock mine   | ![Image](image3.png)                          | ![Map](map3.png)                           |

**CONCLUSION**

This study attests to the significance and advantages of the application of Sentinel-2 MSI data to detect and map hydrothermal alteration zones. The Sentinel-2B MSI image produced on December 5, 2019 was analyzed to map spatial distribution of hydroxyl-bearing minerals in Vinh Phuc province (northern Vietnam). Four Sentinel-2B MSI bands (2, 8A, 11 and 12) were used to calculated Principal Components, and then select the Principal Component which contains the basic information of hydroxyl-bearing minerals. The 4th Principal Component clearly identifies the area comprising hydroxyl-containing altered minerals in this region. The results obtained in this study show that the Sentinel-2 MSI image with spatial resolution exceeding that of Landsat image can be effectively used in mapping hydrothermal mineral distribution.
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