Utilization of USGS Spectral Signature Processing in Croatian Gypsum Exploration

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Abstract: A detailed previous study of the potentiality of mineral raw materials in the Vrlika karst polje showed a high geological gypsum potential that was not precisely determined on existing geological maps. This serves as the primary scientific reason for selecting this study area. The second reason arises from market demands for an increased supply of gypsum, recognized as an environmentally friendly mineral raw material by the Eurogypsum Association. To rapidly assess the 25 km^2 area, remote sensing methods were employed. Data collected from the USGS (the United States Geological Survey) was used, with their scientists having created a database of spectral signatures. By using spectroscopy to study materials, measurements can be compared to the spectral records of sensors located on different platforms, in this case, the ESA´s (the European Space Agency) MSI-Sentinel-2A. The K-means algorithm and NDVI based on WV3 sensor were also used. Comparative analysis of the obtained data with field data led to the conclusion that spectral signatures of gypsum from USGS samples align closely with those from Croatia due to their very similar chemical composition, taking into account the spatial resolution of MSI-Sentinel-2A.

Keywords: USGS Spectral Library data; gypsum; MSI-Sentinel 2-A; WV3; K-means.

1 Introduction

Gypsum is a mineral composed of calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$). According to Wilson et al. (2014) the structure of gypsum is formed from layers of CaO 8 polyhedra consisting of “zig-zag” chains bound by similar “zig-zag chains” of SO_4^{2-} units. These double-sheet polyhedral layers are linked by an O(1)–H(2) hydrogen bond. Gypsum forms in sedimentary environments through the evaporation of seawater or saline lakes. When water containing dissolved calcium sulfate evaporates, gypsum precipitates out of solution and accumulates as layers or beds within sedimentary basins. It can be found in various sedimentary settings, including marine basins, evaporite deposits, and continental rifts. Gypsum deposits are economically significant as they are a major source of calcium sulfate, which is used in various industries such as construction, agriculture, and chemical manufacturing. Understanding the geological processes involved in gypsum formation and its occurrence within sedimentary basins is crucial for exploration and exploitation purposes (Warren 2016). According to Shuai et al. (2022), the basis for remote sensing of gypsum lies in the spectral characteristics of calcium sulfate, which exhibit distinctive properties in the VNIR, SWIR, and TIR regions. Gypsum, as a hydrated calcium sulfate, shows characteristic absorption features in the VNIR and SWIR regions. Specifically, it is characterized by a "triplet" at wavelengths of 1446 nm, 1490 nm, and 1538 nm, as well as at 1750 nm, 1900 nm, and a triplet at 2178 nm, 2217 nm, and 2268 nm (Figure 1). The reason for this lies in the vibrations of hydrogen bonds in the molecular structure of water (Crowley 1991). Due to this reason, these properties are not characteristic for "anhydrous" calcium sulfate types such as anhydrite, nor other evaporites (halite, thenardite, etc., Bishop et al. 2014, Figure 1).

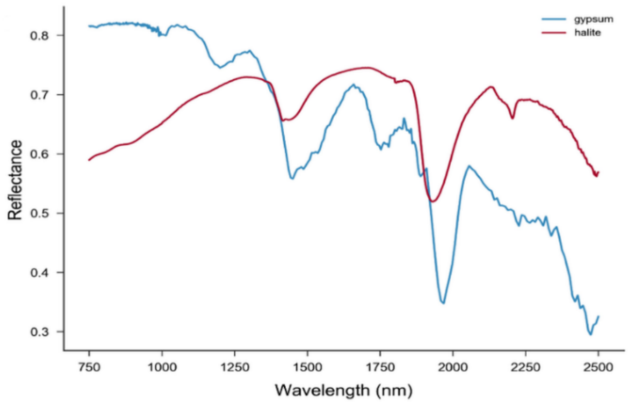

Figure 1. Comparison gypsum and halite spectral signatures (according to Howari et al. 2018).

2 Materials and methods

2.1 Study area and geological settings

Geological exploration of gypsum was conducted in the territory of the Republic of Croatia, Split-Dalmatia County (Figure 2 Left), the area of the Town of Vrlika, south of Vrlika karst polje, within the previous gypsum exploration field "Vranjkovići", and in the area of the former gypsum exploitation field "Vranjkovići" with its immediate vicinity (Figure 2 Right).

According to Dedić (2018), referencing OGK SFRJ sheet Drniš (Ivanović et al. 1977, Ivanović et al. 1978), the geological structure of the Vrlika area highlights two types of sedimentary deposition. One is predominantly carbonate, represented by limestone, dolomite, and Jurassic-Cretaceous breccias, while the other is characterized by a Permian evaporite complex. Permian deposits are characterized by the distinctive development of an evaporite complex: anhydrite, gypsum, fine-grained clastics, carbonates, as well as occasional occurrences of eruptive formations (Figure 2. Right). However, due to the scale of the map and the size of gypsum outcrops, they are not specifically marked on the OGK SFRJ. Therefore, the

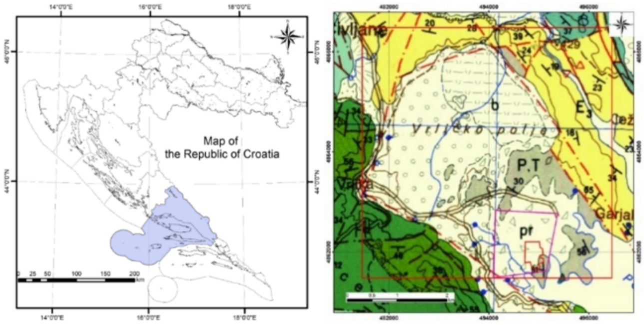

Figure 2. Left: Map of the Republic of Croatia. Split – Dalmatia County is highlighted in blue. Right: Geological Map of Yugoslavia at a scale of 1:100,000 (OGK SFRJ), sheet Drniš clip. Red rectangle represents study area; magenta polygon is a former exploration field "Vranjkovići", red polygon is a former exploitation field "Vranjkovići".

idea is to attempt to identify them through remote sensing methods.

Gypsum deposits are studied on a number of locations, and they are partly exploited. The thickness of gypsum layers is approximately 30 m and they gradually transition into anhydrite which is always located in their base. Dedić (2018) wrote on geochemical and mineralogical characteristics of Upper Permian evaporite sediments from central Dalmatia. Gypsum is made up of 93-96% $CaSO_4 \cdot 2H_2O$.

2.2 Geological mapping

A 38 ha area underwent geological mapping using hand-held GPS devices. The data, initially recorded in the WGS84 system, was subsequently converted to the HTRS96TM system using GIS, ensuring compatibility with digital dataset. The mapping primarily focused on the former exploitation and exploration fields of "Vranjkovići" and their vicinity (Figure 3).

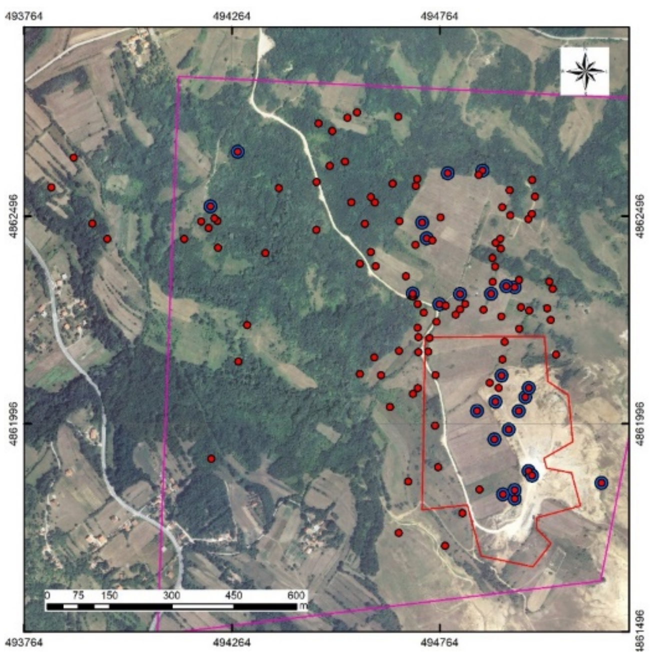

Figure 3. Geological mapping field points. Red dots are all observed points. Blue – red dots are gypsum occurrences.

2.3 Datasets and imagery processing

Publicly available images from the European Space Agency's Copernicus program, specifically the MSI-Sentinel 2A sensor (MSI-S2A), and a commercial image from the WorldView 3 sensor (WV3) sponsored by ESA, were employed in this study. The MSI-S2A sensor offers 13 spectral bands of wavelengths spanning from 443 to 2190 nm, with spatial resolutions of 10 m for four bands, 20 m for six bands, and 60 m for three bands. Conversely, the commercial WV3 image sponsored by ESA encompasses only 5 bands: blue (478 nm), green (546 nm), red (659 nm), NIR1 (831 nm), and Pan (625 nm), with spatial resolutions ranging from 0,31 m to 1,24 m. In this context, the WV3 image was exclusively utilized for more precise discrimination between vegetation and rocks (geological formations) using NDVI (Rouse et al. 1973). After NDVI analysis, 6 raster datasets on USGS Spectral signatures on gypsum were used (Kokaly et al. 2017) which were classified by Kmeans algorithm.

3 Results

The final outcome of geological mapping along with the processing of existing archival data, undoubtedly contributes to a better understanding of results obtained through remote sensing methods. Therefore, an attempt was made to work with this data. The application of NDVI on the MSI-S2A image is shown in Figure 4. In this case only 5 WV3 bands were available, so the NDVI that can distinguish rocks and vegetation was calculated. K-means algorithm (Hartigan 1975, Hartigan and Wang 1979) was used on USGS gypsum raster data fusion (20 classes, 60 iterations, 60,000 random seed). All classes were analyzed in GIS by comparing them to ground truth data and NDVI, and one class was selected that could correspond to gypsum (Figure 4). All obtained results are shown in Figure 4. In the background is the NDVI analysis based on the WV3 sensor. The red areas represent rocks, in this case field terrain marked gypsum. Green indicates vegetation. Blue polygons represent gypsum obtained through analysis of USGS data and the K-means algorithm. White dots are gypsum occurrences (ground truth data). Attached aerial photographs were obtained by an unmanned aerial vehicle (UAV), and gypsum occurrences are clearly visible as white outcrops.

4 Discussion

According to the OGK SFRJ, it is evident that gypsum is not particularly isolated, but it is found within the evaporite complex together with other types of rocks. There are two reasons for that. The first reason is the scale of the map (1:100,000), and the second is the submeter size of gypsum outcrops (Figure 4). Therefore, data digitization and machine learning were approached. Regarding purity, it has been investigated that outcrop in the Republic of Croatia contain 93–96% gypsum (Dedić 2018), while the USGS worked on samples containing 100% gypsum (Kokaly et al. 2017). Therefore, certain deviations are possible in the index processing, and for this reason the K-means algorithm was applied to further narrow down the

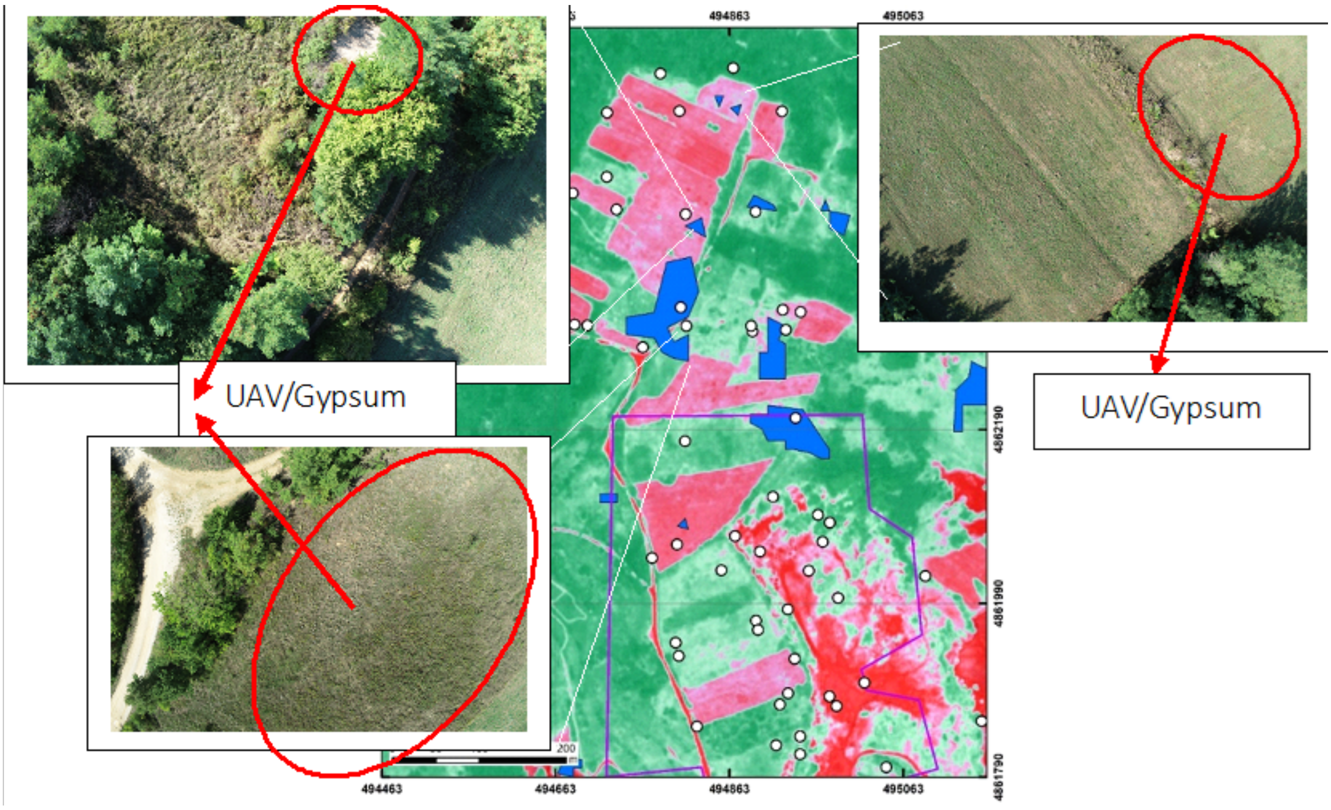

Figure 4. All obtained results; WV3-NDVI; MSI-S2A/USGS/K-means, GT, UAV/gypsum.

possible error. Among other authors who have conducted research on gypsum deposits in the territory of the Republic of Croatia are Šćavničar (1973), Šušnjara (1991), Tišljar (1992), Lukšić and Gabrić (1997), Gabrić et al. (2002), Lukšić and Pencinger (2004), and Dedić (2018). However, the potential of gypsum has not been fully defined regarding its spatial distribution. Therefore, remote sensing techniques were applied to attempt to define its surface potential, with the Vrlika karst polje area being taken as an example. Van der Meer et al. (2014) wrote about the potential of the Sentinel-2A sensor in geological research. They concluded that the results of processing these images support the geological model depicted on the geological map. On the other hand, Kruse and Perry (2013) wrote about the capabilities of the WV3 sensor in mineral mapping. The spectral bands of WV3 should enable the identification and mapping of essential minerals, while the enhanced spatial resolution will enhance the discrimination of intricate alteration mineral patterns. The promising results from WV3 suggest that this sensor will serve as a valuable tool for geological remote sensing.

5 Conclusions

Modern studies on gypsum deposition and sedimentary basins often involve a combination of field mapping, geochemical analysis, remote sensing, and geophysical methods. From the previous chapters, it is evident that research on gypsum in the Republic of Croatia has been continuous for the past 50 years. The obtained results certainly point to the continuation of research using the most modern methods of remote sensing and machine learning which have not been implemented so far. These results will be part of the methodological solutions that integrate remote sensing with field and laboratory verification, improving the accuracy of assessing the geological potential of mineral raw materials in karst Dinarides, and carbonate terrains overall.

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