Comparison of remote sensing techniques in mapping hydrothermal alteration associated with Ovacik epithermal gold-silver mineralization

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Abstract

The use of remote sensing and geographic information system techniques in mineral exploration is still underutilised. There is a need to explore the potential of new robust remote sensing and geographic information system techniques in the field of mineral exploration. In this study, we mapped the argillic alteration associated with epithermal gold-silver mineralisation. A band ratio of band5/band6 and Crósta technique on Advanced Spaceborne Thermal Emission and Reflection Radiometer within the Google Earth Engine Environment was applied. The bands 5 and 6 were selected for the band ratio after critically analysing and comparing the illite spectral extracted from the Advanced Spaceborne Thermal Emission and Reflection Radiometer image and the illite spectral obtained from the United States Geological Survey spectral library. The band ratio and Crósta technique identified and mapped the Ovacik goldmine and other argillic alteration zones. Even though both methods mapped out the argillic alteration zones associated with gold-silver mineralisation, the Crósta technique produced the optimal argillic alteration. The study demonstrates the analytical capabilities of Google Earth Engine in image processing and analysis for mineral exploration, such as discovering hydrothermal alteration associated with mineralisation.

Keywords

band ratio, Crósta technique, argillic alteration, epithermal gold-silver deposit

Introduction

Minerals and metals are vital for the sustainability of humanity on Earth and are used in innumerable and diverse applications, for instance, from building aircraft to producing ornaments for human use. Economically, mineral resources contribute to gross domestic product and offer employment opportunities. According to Creamer (2012), mining's contribution to the world's gross domestic product is approximately 45 per cent. Thus, sustainable mining of minerals and metals remains paramount. in most instances, mining usually only commences after extensive mineral exploration.

Despite the benefits, mineral exploration is one of the highest risk ventures in recent times in terms of the associated cost and failure (Gandhi, Sarkar, 2016). Modern technologies, such as remote sensing and geographic information systems (GIS), have been used as an alternative approach for mineral prospecting to reduce the cost and failure of new minerals' discovery. Remote sensing and GIS have yielded many successful mineral exploration works (Ninomiya et al., 2006; Chen et al.; 2007; Tangestani et al., 2011; Hede et al., 2015; Salehi et al., 2017; Rajendran, Nasir, 2017; Wang et al., 2017). Therefore, the objective of the study was to use Google Earth Engine as a working environment for the identification and mapping of the argillic alteration zones associated with epithermal gold-silver deposits in Izmir, Turkey.

Geological setting of the study area

The Ovacik gold mine is located in the northern part of Izmir in Turkey, lying adjacent to the east-northeast (ENE) trending Bergama graben (Figure 1).

The first economic epithermal deposit found in Turkey using modern exploration technology is the Ovacik gold-silver deposit (Yilmaz, 2002). The principal rock types within the Ovacik mine and its environment include limestones, palaeozoic metamorphic rocks, and intrusive andesitic rocks (Yilmaz, 2002), as illustrated by Figure 2. The main minerals associated with the argillic alteration of the Ovacik epithermal deposit are illite, interlayered illite/smectite, illite/chlorite, adularia, smectite, chlorite, and chalcedonic quartz (Yilmaz, 2002). This study area also confirms illite minerals as one of the main argillic alteration minerals in Ovacik.

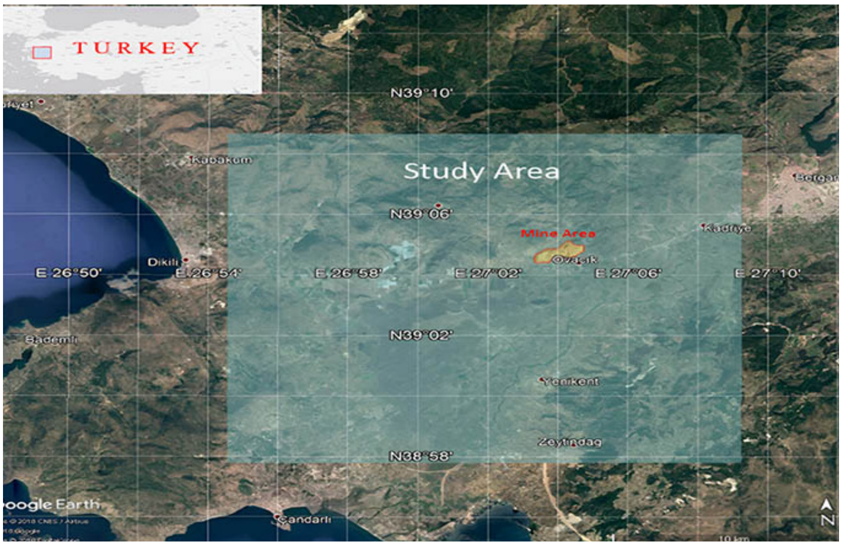

Figure 1—Google Earth Image of the Ovacik gold mine

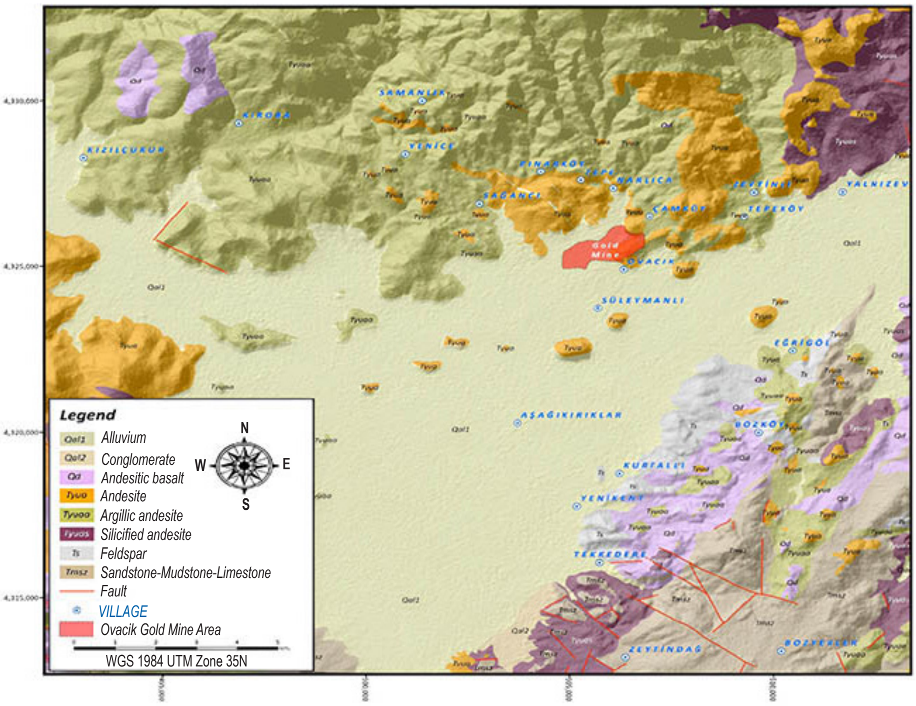

Figure 2—Geological map of the Ovacik area. Source: (MTA, 2018)

Material and methods

The materials used in this study include an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) image, a geological map of the Ovacik Mine, and Google Earth Engine Application Programming Interface (API). In order to identify and map the argillic alteration associated with gold-silver mineralisation within the study area, Google Earth Engine API was used to extract the image spectra, perform the band ratio, and the Crósta technique was applied to the image. Google Earth Engine has reduced the burden of downloading satellite images before performing image processing and analysis. Google Earth Engine can process broad coverage areas image analysis faster and easier than most commercial remote sensing and GIS software (Gorelick et al., 2017).

The Ovacik gold mine was selected because its characteristics are similar to the other gold-silver mineralisation locations in Turkey. The ASTER image captured on 23 September 2006, was first loaded on the Google Earth Engine environment. Owing to its diagnostic characteristics and predisposition to clay minerals detection and mapping, shortwave infrared bands were selected. In brief, the image was transformed from radiance to reflectance using gain and offset values of bands of the image before the band ratio operation was performed. The geological map of the Ovacik gold mine was also imported to Google Earth Engine, and sample points were extracted from known mineralised locations. Sample points extracted from the known mineralised locations in the geological map were used to obtain image spectra from the ASTER image. The illite mineral spectra obtained from the United States Geological

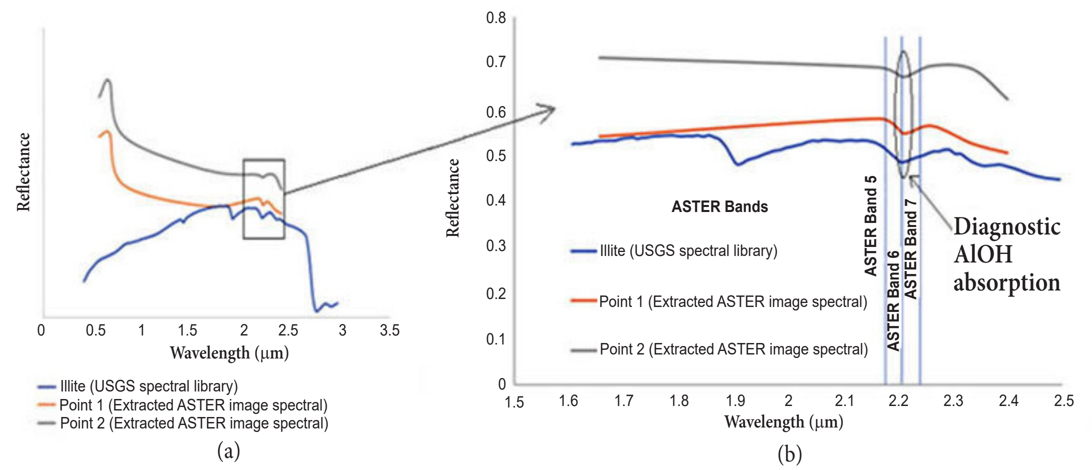

Figure 3—The extracted ASTER image spectra within the (a) VNIR-SWIR and (b) SWIR region and the USGS illite spectra

Survey (USGS) spectral library was compared with that of the spectra acquired from the ASTER image, as illustrated in Figure 3. The extracted image spectrum shows the diagnostic characteristics of the illite mineral, which is a known mineral of argillic alteration. In Figure 3, the illite mineral showed high reflectance in Band 5 and strong absorption, or low reflectance in Band 6, which were vital diagnostic characteristics for its identification and mapping using the band ratio method.The presence of argillic alteration characterised by illite mineralisation was also identified by performing the Crósta technique using bands 1, 3, 5, and 6, as suggested by Crósta et al. (2003). All the processed images were exported from the Google Earth Engine as Geographic Tagged Image File Format (GeoTIFF) images for map creation.

Band ratio

Minerals and rocks do not show similar reflectance responses at different ranges of spectral wavelengths (Chandrasekar et al., 2011). Band ratio operation can be easily performed to map hydrothermal alteration by using the spectral diagnostic characteristics exhibited by rock and minerals. For instance, in 800–1000 nm, iron oxide minerals portray high absorption features and high reflectance in other wavelength regions (Pontual et al., 2008). In mapping hydrothermal alteration zones associated with mineralisation, the most common techniques applied are the band ratio and principal component analysis (PCA) (Yajima, 2014). There is a reduction in the effect of the seasonal changes, slope shadows, and the elimination of sunlight angles effect when band ratio analysis is applied on satellite imagery (Jensen, 1986).

Crósta technique

The Crósta technique is a modified version of the standard PCA, and it utilises four image bands (Loughlin, 1991). The Crósta technique uses the linear combinations of the PCA to determine which principal component (PC) image best describes the theoretical spectral response of the mineral under investigation (Loughlin, 1991). The Crósta technique has the advantage of determining whether the target feature type has been enhanced in the previous principal component image as dark or bright pixels. Other image analyses, such as band colour combination and band ratio, were performed to decide the band that could best show the argillic alteration within the study area before choosing the bands for the Crósta technique.

Results and discussion

The short-wave infrared (SWIR) bands offer a moderate spatial and spectral resolution for detecting and identifying clay and hydrous minerals. Within the SWIR bands, the clay and hydrous minerals reveal diagnostic spectral characteristics. In the SWIR region of the electromagnetic spectrum, illite minerals portray different absorption features. The wavelengths of distinct absorption features identified within the SWIR include 1.900 µm (water absorption), 2.180-2.228 µm (AlOH), 2.342 µm, and 2.435 µm (Pontual et al. 2008). Field studies of the hydrothermal alteration of the Ovacik gold deposit reveal the abundance of illite minerals and its association with epithermal gold-silver mineralisation. The image spectra, as shown in Figure 3, revealed the diagnostic feature of illite mineral as 2.180-2.228µm (AIOH) after being critically examined. At a wavelength of 2.185-2.225µm, the AI-OH molecular vibration process obtained the high AIOH absorption feature (Pontual et al., 2008) corresponding to band 6 of the ASTER image.

Table1 shows eigenvector loadings, eigenvalues, the percentage variances of individual principal component images of the bands used in the Crósta technique, and statistics of individual bands used to calculate the eigenvector of the Crósta technique. Each of the individual principal components (PC) in Table1

Table 1

The eigenvector loadings, eigenvalues, and percentage variance of bands (1, 3, 5, and 6)

	PC1	PC 2	PC 3	PC 4
Band 1	-0.69	0.25	-0.44	-0.50
Band 3	-0.00	0.93	-0.22	-0.26
Band 5	-0.72	0.23	0.40	0.50
Band 6	0.02	-0.00	-0.76	0.64
Eigenvalues	582.84	222.06	43.34	1.12
%Variance	73.61	22.63	3.64	0.12

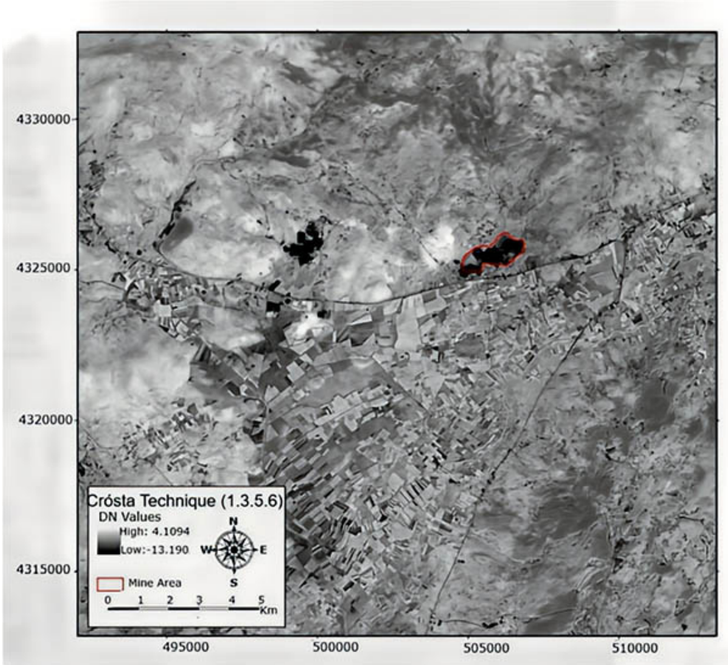

Figure 4—PC3 image of Crósta Technique for argillic alteration zones detection

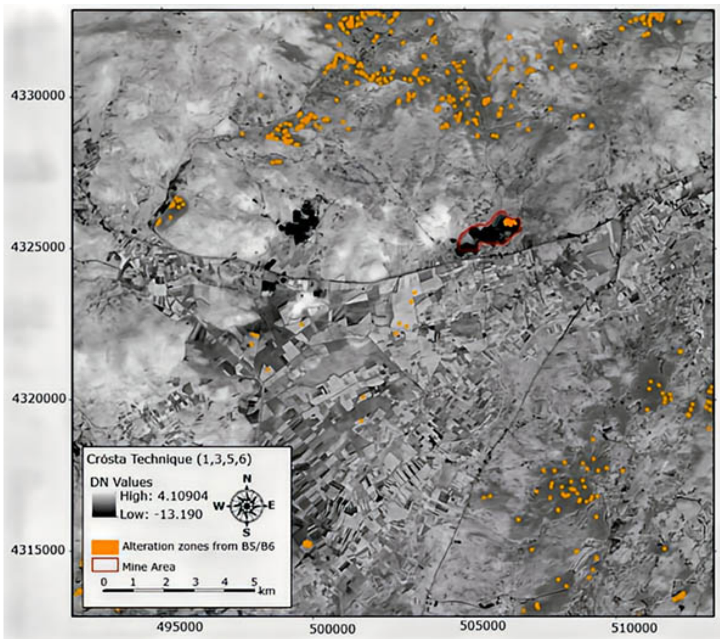

Figure 5—Comparison of the Argillic alteration zones from band ratio (b5/b6) and Crósta technique (1, 3, 5, and 6)

has a corresponding principal component image. The principal components in Table1 indicate the numeric values of argillic minerals. Principal component images display spectral information of the argillic minerals as grey in colour. Principal components, which contained the argillic alteration characterised by illite mineralisation were based on Loughlin's (1991) criterion, which states that "PC that contains the target spectral information shows the highest eigenvector loadings from the image bands, coinciding with the target's most diagnostic features, but with opposite signs (+ or -)". Based on Loughlin's criterion, PC3 was selected as it has the highest value with high opposite loadings values. The PC3 has a high eigenvector loading value for bands 5 (0.4) and 6 (-0.76). The high and negative eigenvector loading of band 6 and the low positive value of band 5 are the main reasons why argillic alteration zones in Figure 4 appeared as dark rather than bright pixels. In order to display the argillic alteration zones as bright pixels, the spectral values of PC3 were multiplied by negative 1 (Tangestani, Moore, 2000). Figure 3 shows high absorption of illite in band 6 and high reflectance in band 5.

A threshold value of 1.08, calculated by using the mean plus twice the standard deviation, was applied at a 95% significance level on the image processed with the Crósta technique method to separate altered from non-altered argillic zones.The orange colour in Figure 5 shows zones with reflectance values above the threshold value, and these are the most likely argillic zones associated with gold-silver mineralisation. When the argillic alteration zones extracted from the band ratio of band 5/band 6 were overlaid with alteration zones produced from the Crósta technique, most of the argillic alteration zones from band ratio did not coincide with alteration zones of the Crósta technique. The argillic alteration zones obtained from the band ratio were affected by vegetation cover, while in the Crósta technique, the effect of vegetation was suppressed. Suppression of the vegetation effect helped enhance spectral reflectance of the illite mineral.

The spectral characteristics of minerals are not vastly distinctive, and this must be considered when mapping hydrothermal alteration. Although the wavelength for reflectance bands may vary, many clay minerals' diagnostic absorption features fall within almost the same wavelengths. This suggests that the same band ratio index may not produce optimal hydrothermal alteration zones in all geographic locations. Band combinations can aid in selecting suitable bands for hydrothermal alteration identification and mapping. By comparing the argillic alteration zones produced from two methods, the Crósta technique produced better alteration results than the band ratio method. However, both the band ratio and Crósta technique identified the Ovacik goldmine within the argillic alteration zones.

Conclusion

This study demonstrates the use of Google Earth Engine (GEE) for detecting and mapping argillic alteration zones associated with gold-silver mineralisation in Izmir using the band ratio and Crósta techniques. Despite its potential for handling large geospatial datasets efficiently, the use of GEE in mineral exploration remains limited.

The study evaluated methods for identifying and mapping argillic alteration zones linked to epithermal gold-silver mineralisation. Specifically, it assessed the performance of Landsat bands 5 and 6 for band ratio analysis and bands 1, 3, 5, and 6 for the Crósta technique. The findings indicate that the Crósta technique outperformed the band ratio method, as it leverages spectral bands associated with alteration minerals, providing greater accuracy and reliability in delineating areas with potential gold-silver deposits.

Furthermore, this study underscores the transformative potential of Google Earth Engine as a powerful geospatial tool for advancing mineral exploration. Its ability to process and analyse large-scale satellite imagery enhances the efficiency and precision of remote sensing-based mineral prospecting, offering a valuable approach for future exploration initiatives.

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