Prospecting Fe-Skarn mineralization using ASTER satellite data: case study from Ravanj village, Markazi Province, Iran

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Abstract. The study area is located in Iran central zone and Urumieh-Dokhtar volcanoplutonic belt. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite data was used to identify alteration zones associated with Fe-Skarn mineralization in the Ravanj village, Markazi Province, Iran. Argillic, phyllic and propylitic alteration zones are typically associated with Fe-Skarn mineralization in the study area. In this research, the Selective Principal Component Analysis (SPCA) method was applied to VNIR + SWIR bands of ASTER remote sensing data. Bands 1, 4, 6 and 8 were designated for identification clay minerals. Bands 4, 5, and 6 were selected for argillic alteration mapping. Bands 1, 2, and 4 were used to identification iron oxides/hydroxide minerals. Bands 5, 6, and 7 were chosen to map phyllic alteration zones. Bands 7, 8, and 9 were nominated to specify propylitic alteration mapping. According to the eigenvector statistics calculated using SPCA for ASTER, inverse SPC4 image identified clay minerals and SPC2 images detected argillic alteration, oxides/hydroxide minerals, phyllic alteration and propylitic alteration. In this paper, SPCA technique is an appropriate method because of the distinction between alteration minerals, vegetation for Fe-Skarn mineralization exploration.

1. Introduction

Remote sensing (RS) is a tool for collecting raster data or images. The RS tool to geological mapping and hydrothermal alteration and associated minerals is a valuable method detecting distinctive absorption features related to hydrothermally altered minerals [1]. In the other words, RS is a valuable tool for mineral exploration that provides a rapid technique to identify hydrothermal alteration zones in a vast region. Due to the rapid growth of technologies, low assay mineral deposits have economic value, recently. Therefore, the identification and exploration of ore minerals has increased for intense the skarn deposits.
Törnebohm (1875) was first published the word ‘skarn’ and was specified as peculiar, dark ore hosting rock and subordinate layer in feldspar-poor felsic volcanic rock. Skarn dominated by calc-silicate mineral groups, such as garnet and pyroxene, is known as a relatively simple rock type that is defined by its mineralogy and generally occurs along the contact between intrusion and carbonate rock [2]. In the other words, skarns or tactites are hard, coarse-grained metamorphic rocks that form by a process called metasomatism. Skarns tend to be rich in calcium-magnesium-iron-manganese-aluminum silicate minerals, which are also referred to as calc-silicate mineral [3]. Skarns are composed of calcium-iron-magnesium-manganese-aluminum silicate minerals. Skarn deposits are economically valuable as sources of metals such as Cu, W, Sn, Mn, Au, Zn, Pb, Ni, Mo and Fe [4]. Dashkesan mine, Russia is an example of iron skarn ore deposits. Previous remote sensing researches to skarn deposits were generally focused on identify alteration zones associated with skarn mineralization. Spectral features of alteration minerals were extract using remote sensing imagery [5][6]. The study area is located in Iran central zone and Urumieh-Dokhtar volcanoplutonic belt, the southeast Delijan, the Ravanj Village. According to the geological map of 1:250000 Qom and 1:100000 Kahak, the rock outcrops in the study area consist of a series of sedimentary, pyroclastic and volcanic rocks intersected by dykes, intrusive and semi-deep. Emplacement of intrusive bodies within calcareous sediments and pyroclastic rocks generated iron Skarn mineralization as veins in the Cenozoic units. In this study, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is used for mapping hydrothermal alteration zones associated with iron Skarn in the the Ravanj Village. Selective Principal Component Analysis (SPCA) method was applied to VNIR + SWIR bands of ASTER remote sensing data to detect argillic alteration, oxides/hydroxide minerals, phyllic alteration and propylitic alteration zones.

2. Materials

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a high spatial, spectral and radiometric resolution multispectral remote sensing sensor [7]. ASTER data is the result of a joint cooperation between the U.S.A. and Japan, with a prominent focus on geological and mineral exploration applications. This sensor has nine bands in the visible and near infrared (VNIR) and shortwave infrared (SWIR) spectral domain and five bands in the thermal infrared (TIR) domain [8][9]. ASTER comprises three separate instrument subsystems. The first sensor images data in the first three bands between 0.52 and 0.86 micrometer in the VNIR region (green, red, and near-infrared) with a spatial resolution of 15
The second sensor images data in the next six bands between 1.6 and 2.43 micrometer in the SWIR region with a spatial resolution of 30 m, and the third sensor images data in the next five bands between 8.125 and 11.65 micrometer in the TIR region with a spatial resolution of 90 m.

In this research, a cloud-free level 1T ASTER (Precision Terrain Corrected Registered At-Sensor Radiance) (AST_L1T_00307042004073158_20150505022450_1007) was obtained from the U.S. Geological Survey Earth Resources Observation and Science Center (USGS EROS) (https://earthexplorer.usgs.gov), acquisition date is 4 July 2004 and was georeferenced to the UTM zone 39 North projection with the WGS-84 datum. The ENVI (Environment for Visualizing Images, http://www.exelisvis.com) version 4.8 software package was used to process the ASTER imagery.

3. Methods

The vegetation in the case study create a negative effect on the final result, causing mistakes in data processing and subsequently, it causes disruption identifying spectral response from alteration minerals. So, we used the Normalized Difference Vegetation Index (NDVI) that was calculated using the formula given below (Eq. (1)).

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$$  \hspace{1cm} (1)

Principal Component Analysis (PCA) converts multispectral images to principal component images. This process will help to focus maximum useful information on fewer principal components and to reduce the redundancy among highly correlated bands and data dimensions. PCA selects the uncorrelated linear combination (eigenvector loadings) of variables, and each principal component is a linear combination that has a small variance [10] [11].

Principal component analysis (PCA) is often employed in the earth sciences [12] [13]. In the other words, Principal Components Analysis (PCA) is a technique to indicate data as a linear recombination of features, where the resulting eigenvectors and eigenvalues relate to dataset variance [14]. For the area, ASTER data indicate that the image processing techniques such as FCC (False Color Combinations), BR (Band Ratio) and PCA method have appropriate results for identifying the vegetation and iron oxide/hydroxide minerals using the VNIR bands and hydrothermal alteration mineral zones such as phyllic, argillic and propylitic alterations, which are associated with Fe-Skarn mineralization using the SWIR bands [15].

In this paper, the Selective Principal Component Analysis (SPCA) was applied on VNIR +SWIR bands for identification alteration zones associated with Fe-Skarn mineralization. In the SPCA only a number of bands are selected depending on the purposes that plan to be achieved. In this analysis, considering the known ASTER bands indices for hydrothermal alteration mineral mapping. Some subsystems (specific bands) were selected for SPCA analysis [16] [17]. Bands 1, 2, and 4 were selected for identification iron oxides/hydroxide minerals. Bands 1, 4, 6 and 8 were designated for identification clay minerals. Bands 4, 5, and 6 were used to argillic alteration mapping. Bands 5, 6, and 7 were chosen to specify phyllic alteration mapping and bands 7, 8, and 9 were nominated to map propylitic alteration zones.
4. Results and Discussion

The first process was the implementation of the NDVI technique. NDVI is a common and widely used index [18]. It is an important and substantial vegetation index [18]. NDVI is computed as a ratio difference between measured canopy reflectance in the red (R) and near infrared (NIR) bands respectively [19]. The NDVI index was used to identify the vegetation. NDVI image showing vegetation as green pixels. Also we used the density slice tool to show better the alteration. For that reason, the green pixels showing vegetation (Figure 1).

![Figure 1. NDVI index image derived from ASTER data. NDVI image shows vegetation as green pixels in the study area.](image)

After identifying the vegetation, alterations zones associated with iron-skarn mineralization were identified in this study. As previously mentioned, the SPCA was applied on VNIR and SWIR ASTER bands for identification alterations zones associated with Fe-Skarn mineralization. The first process was to identify clay minerals. In the following, due to the spectral range of the target minerals, clay minerals were to identify by SPCA method.
Clay minerals have absorption features in bands 6 and reflectance features in band 4 of ASTER. Thus, the inverse SPC4 is able to enhance clay minerals as blue pixels (we used the density slice tool to depict the alteration minerals. The detected pixels shows clay minerals (Figure 2) due to opposite signs of the eigenvector loadings in in band 6 (absorption band) (0.790) and in bands 4 (reflection band) (-0.457) (Table1).

**Table 1.** Eigenvector statistics calculated using SPCA for ASTER bands 1, 4, 6, and 8.

| Eigenvector | Band 1 | Band 4 | Band 6 | Band 8 |
|-------------|--------|--------|--------|--------|
| PC1         | -0.356 | -0.557 | -0.550 | -0.509 |
| PC2         | -0.921 | 0.277  | 0.267  | 0.052  |
| PC3         | -0.138 | -0.635 | 0.030  | 0.759  |
| PC4         | 0.069  | -0.457 | 0.790  | -0.402 |

**Figure 2.** The SPC4 image shows clay minerals in the study area as blue pixels.
The third process is identifying argillic alteration zone. Hence, analyzing the eigenvector loadings shows that the SPC2 contains a strong to moderate contribution of band 4 (0.804) with positive sign and a strong contribution of band 5 (-0.385) and band 6 (-0.450) with a negative signs, respectively (Table 2). Argillic alteration (kaolinite and alunite) has reflectance features in band 4 [17] and absorption features in bands 5 and 6 of ASTER [20], respectively. Therefore, the argillic alteration zone appears as bright pixels in the SPC2 image, which color coded as orange using density slice tool (Figure 3).

### Table 2. Eigenvector statistics calculated using SPCA for ASTER bands 4, 5, and 6.

| Eigenvector | Band 4 | Band 5 | Band 6 |
|-------------|--------|--------|--------|
| PC1         | 0.592  | 0.551  | 0.587  |
| PC2         | 0.804  | -0.385 | -0.450 |
| PC3         | 0.021  | -0.739 | 0.672  |

**Figure 3.** SPC2 image shows argillic alteration in the study area as orange pixels.
The fourth process is about identifying iron oxide/hydroxide minerals. Table 3 shows the eigenvector loadings for mapping iron oxide/hydroxide minerals. The SPC3 shows strong eigenvector loadings for band 1 (-0.559) and band 2 (-0.341) with negative signs and a strong contribution of band 4 (0.755) with a positive sign. Table 3 depicts eigenvector values for mapping iron oxide/hydroxide minerals. Iron oxide minerals have absorption features in bands 1 and 2 and reflectance features in band 4 of ASTER, respectively [21] [22]. Accordingly, the SPC2 is able to enhance oxide/hydroxide minerals as bright pixels due to opposite signs of the eigenvector loadings in the reflection band (positive sign in band 4) and absorption bands (negative sign in bands 1 and 2). We used the density slice tool to show better the alteration. For that reason, the red pixels showing oxide/hydroxide minerals (Figure 4).

**Table 3.** Eigenvector statistics calculated using SPCA for ASTER bands 1, 2, and 4.

| Eigenvector | Band 1 | Band 2 | Band 4 |
|-------------|--------|--------|--------|
| PC1         | -0.478 | -0.611 | -0.630 |
| PC2         | -0.559 | -0.341 | 0.755  |
| PC3         | -0.676 | 0.714  | -0.178 |

**Figure 4.** SPC2 image shows oxide/hydroxide minerals in the study area as red pixels.
The next process is to identify phyllic alteration zone. Thus, looking at the eigenvector loadings in Table 4 for mapping phyllic alteration indicates that the SPC3 has a strong contribution of band 6 (-0.522) with negative sign, while band 7 (0.806) with opposite sign. The phyllic alteration zone produces an intense Al-OH absorption and reflectance feature at band 6 and 7 of ASTER data, respectively. Thus, phyllic alteration zone in the study area displays in yellow pixels in the SPC2 image (Figure 5).

Table 4. Eigenvector statistics calculated using SPCA for ASTER bands 5, 6, and 7.

| Eigenvector | Band 5 | Band 6 | Band 7 |
|-------------|--------|--------|--------|
| PC1         | -0.559 | -0.595 | -0.576 |
| PC2         | -0.275 | -0.522 | 0.806  |
| PC3         | -0.781 | 0.610  | 0.128  |

Figure 5. SPC2 image shows phyllic alteration in the study area as yellow pixels.

Propylitic alteration was identified in the study area based on the eigenvector loadings presented in Table 5. The SPC2 contains strong loadings of band 8 (-0.628) with negative sign and band 9 (0.775) with opposite sign. The propylitic alteration zone consisting of
epidote, chlorite, and calcite display strong absorption features in band 8 of ASTER [17]. Band 9 of ASTER also shows maximum reflectance features in the propylitic alteration zone. Therefore, the SPC2 image displays propylitic alteration zone as magenta pixels in the study area (Figure 6).

### Table 5. Eigenvector statistics calculated using SPCA for ASTER bands 7, 8, and 9.

| Eigenvector | Band 7 | Band 8 | Band 9 |
|-------------|--------|--------|--------|
| PC1         | 0.613  | 0.586  | 0.528  |
| PC2         | -0.067 | -0.628 | 0.775  |
| PC3         | 0.786  | -0.510 | -0.346 |

Figure 6. SPC2 image shows propylitic alteration in the study area as magenta pixels.

5. Conclusions

The image processing algorithm used in this research was the SPCA technique. It helped to identify and map hydrothermal alteration zones using the ASTER satellite data in Ravanj village, Markazi Province, Iran. The SPCA transformation algorithm used in this
research was capable of mapping iron oxide/hydroxide minerals, argilllic alteration zone, phyllic alteration zone, and propylitic alteration zone. According to the selective ASTER bands and eigenvector statistics calculated using SPCA, inverse SPC4 image showing clay minerals and SPC2 image showing oxides/hydroxide minerals, argilllic, phyllic, and propylitic alteration, respectively. The SPCA method is an appropriate method for mapping the distinction between alteration minerals for Fe-Skarn mineralization exploration target in other analogue regions.

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