Identification of hydrothermal alteration minerals for exploring porphyry copper deposit using ASTER data: a case study of Varzaghan area, NW Iran

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ABSTRACT
Alteration is regarded as significant information for mineral exploration. In this study, ASTER image data are used for recognizing and extracting alteration zones in Varzaghan area, northwestern Iran, which is located in the northern part of the Cenozoic Urumieh–Dokhtar magmatic arc. This belt was formed by subduction of the Arabian plate beneath central Iran during the Alpine orogeny and hosts many porphyry copper deposits. The principal component analysis (PCA), Minimum Noise Fraction (MNF) and Band Ration TIR and SWIR ASTER bands were employed for hydrothermal alteration zone extractions such as argillic, phyllic and propylitic alterations. The alteration zone that identified from remote sensing were evaluated and compared in detail along with Sungun copper porphyry mine. The results show that the OH—alteration is a main indicator of argillic, phyllic, and propylitic alterations. These alterations are closely related to porphyry copper deposits. Results show that PCA and band ratio methods clearly manifest different altered zones of the region. However, band ratio more effectively shows the alterations. Also, ASTER images provide preliminary mineralogy information and geo-referenced alteration maps at low cost and with high accuracy for reconnaissance porphyry copper mineralization.

1. Introduction
Since 2000, Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) multispectral data have been used in mineralogical and lithological studies (Tommaso & Rubinstein, 2007). ASTER captures high spatial resolution data in 14 bands from the visible and near infrared radiation (VNIR), shortwave infrared radiation (SWIR) and thermal infrared radiation (TIR) wavelengths. The technical characteristics of ASTER data are shown in Table 1. In this study, both VNIR and SWIR subsystems were used to extract hydrothermal alterations.

Previous studies documented identification of specific hydrothermal alteration minerals, such as alunite, kaolinite, calcite, dolomite, chlorite, talc, pyrite, and muscovite, as well as mineral groups, through analysis of ASTER VNIR and SWIR data, which have been proven using in-situ field spectral measurements (Ducart et al., 2006; Rowan et al., 2006; Tommaso & Rubinstein, 2007). Therefore, these properties making these subsystems of ASTER data suitable for detailed mineralogical alteration mapping, that is important to distinguish the high-potential areas of economic mineralization of ore deposits such as epithermal gold and hydrothermal porphyry copper deposits (Pazand et al., 2012). Each ideal porphyry copper deposit is typically characterized by hydrothermal alteration mineral zones (Figure 1). A core of quartz and potassium-bearing minerals is surrounded by broad phyllic zone and narrower argillic and the outer propylitic zones. In hydrothermal alterations, montmorillonite, muscovite and epidote represented argillic, phyllic and propylitic alterations.

Montmorillonite displays a secondary Al-OH absorption feature at 2.17 µm; muscovite indicates an intense, Al-OH absorption feature centered at 2.20 µm and epidote exhibit absorption features situated in the 2.35 µm (Figure 2).

In this paper, spectral mapping techniques such as principal component analysis (PCA) and Minimum Noise Fraction (MNF) were applied on VNIR and SWIR of ASTER data to discriminate the specific hydrothermal alteration zones associated with porphyry copper mineralization in the Sungun mine district in NW Iran. The results can be as a guide in delimiting the higher potential mineralized lithological units with respect to the surrounding country rocks.

2. Material and methods
2.1. Geological setting
Study area is a part of Varzaghan sheet in the northwestern Iran. It is located in eastern Azerbaijan
province, between latitudes 38° 30’ and 38° 50’N and longitudes 46° 30’ and 47°E (Figure 3).

It is situated in the NW part of a NW–SE trending Urumieh-Dokhtar Cenozoic magmatic belt of Iran. The oldest rocks exposed in the study area are a 500 m sequence of Cretaceous limestone with intercalations of shale, and a 1500 m thick sequence of Middle to early late Tertiary, intermediate, calc-alkaline lavas, and tuffaceous rocks, intruded by numerous calc-alkaline andesitic dykes (Mehrpartou et al., 1992). There is several porphyry and skarn indexes in study area that one of the porphyry copper deposits are mined (the sungun deposit). The Sungun intrusive complexes intruded along the Sungun anticline into Cretaceous limestone and trachy andesite Eocene tuff and agglomerate along the Sungun anticline (Hezarkhani, 2003; Hezarkhani & Williams-Jones, 1996). The Sungun stock has a plan area of approximately 3.45 km² (1.5 × 2.3 km), elongated NW–SE, and consists of three different intrusive phases (Figure 4) (Hezarkhani, 1997, 2002). Almost all intrusive units contain the same assemblage of minerals: plagioclase, K-feldspar, quartz, biotite, hornblende (typically altered to biotite and/or chlorite), titanite, rutile, scheelite, apatite, minor magnetite, and zircon (Hezarkhani, 2006). The intrusive rocks at Sungun are: 1. monzonite/quartz monzonite; 2. diorite/granodiorite; and 3. andesitic and related dykes, in order of emplacement (Figure 4). The monzonite/quartz-monzonites are mainly porphyritic, and exposed to the west of the diorite/granodiorite intrusion, and in a small body in the southeast. The diorite/granodiorite forms the central part of the stock

| Module     | VNIR          | SWIR          | TIR           |
|------------|---------------|---------------|---------------|
| Spectral range(µm) | Band1: 0.52–0.6 | Band4: 1.6–1.7 | Band10: 8.125–8.475 |
|            | Band2: 0.63–0.69 | Band5: 2.185–2.185 | Band11: 8.475–8.825 |
|            | Band3N: 0.76–0.86 | Band6: 2.185–2.225 | Band12: 8.925–9.275 |
|            | Band3B: 0.76–0.86 | Band7: 2.235–2.285 | Band13: 10.25–10.95 |
|            | Band4: 1.6–1.7 | Band8: 2.295–2.365 | Band14: 10.95–11.65 |
|            |                | Band9: 2.36–2.43 |               |

Ground resolution(m) | 15 | 30 | 90 |
Swath Width(km) | 60 | 60 | 60 |

Figure 1. Hydrothermal alteration zones associated with porphyry copper deposit (Lowell & Guilbert, 1970).
Figure 2. Convolution of USGS spectral library profiles with Aster Spectral response function using ENVI: refers the USGS spectra for alteration minerals.

Figure 3. Location and geological map of Varzaghan area (simplified after Mehrpartou et al., 1992).
and intrudes the monzonite/quartz-monzonite (Hezarkhani, 2006). The intrusives are generally unfoliated and commonly porphyritic, suggesting a shallow level of emplacement. This interpretation is supported by a stratigraphic reconstruction, which shows that the maximum depth of intrusion was 2000 m.

### 2.2. Methods

One cloud-free level 1B ASTER scenes have used in this study to extract the main hydrothermal alteration mineral spectral features in part of 1:100000 Varzaghan geological map. To remove atmospheric and topographic effects from ASTER VNIR and SWIR data, the Internal Average Relative Reflectance method (IAR) was used.

#### 2.2.1. Principal Component Analysis (PCA) method

Principal Component Analysis (PCA) is a commonly used enhancement technique in various lithological and alteration mapping studies in metallogenetic provinces (Ruiz-Armenta & Prol-Ledesma, 1998). The technique involves a mathematical transformation of the original data, which are rearranged according to the axes of greatest variability, creating new non-correlated components. The lengths of the principal axes are defined by a set of quantities called eigenvalue, which measure the variability of the data along the orthogonal directions. The direction of each axis is defined by another set of data called eigenvectors, which defines the correlation between the principal components (PC) and the original bands. Sign and magnitude of eigenvector loadings indicate which spectral properties from vegetation, rocks, and soils were responsible for the statistical variance mapped onto each PC. The principal components can be analyzed using the standard or selective method. In the standard analysis, all available bands of an image are used as input for the principal component's calculation, while in the selective analysis, only certain bands are chosen (Loughlin, 1991).

#### 2.2.2. Minimum Noise Fraction (MNF) method

MNF (Minimum Noise Fraction) rotation (using principal component calculations) is used to show the variation between bands in an image. This is a statistical method which works out differences in an image based on pixel DNs in various bands. Mathematically, this uses eigenvectors and eigenvalue to work out the principal vectors and directions of the data cloud (collection of data values for the image). The idea is to show the similarities between the bands. So in principal component images you are looking at the maximum differences between what the sensor is picking up in different bands rather than where separate bands are recording the same thing, i.e., reducing redundancy. The calculations also identify noise in the image. After doing this analysis you can then go and do some band ratios, compare to your MNF or principal component image, and perhaps assign each MNF band to some feature or characteristic. Remember that these are statistics and do not indicate any specific mineral, merely differences between areas of the image. This works best for SWIR images (Kalinowski & Oliver, 2004).

**Figure 4.** Geological map of the Sungun deposit area, showing field relationships among the various subtypes of Sungun intrusive rocks, and the outline of the mineralized zone (Hezarkhani, 2006).
2.2.3. Band ratio method

Band ratio was used to enhance the spectral difference between bands and to reduce the topographic effects. Dividing one spectral band by the other produces an image that provides relative band intensities. A thorough description of the selection of sensitive bands of minerals can be found in relevant publications (Sabins, 1997).

3. Result and discussion

We applied spectral mapping techniques (PCA, MNF and band ratio) on the SWIR subsystem of ASTER data to map the surface mineralogy of hydrothermal alteration zones related to porphyry copper mineralization in Varzghan region. The main aim of PCA is to remove redundancy in multispectral data. This technique indicates whether the materials are represented bright or dark pixels in the principal components according to the magnitude and sign of the eigenvector loadings. The principal component transformation (eigenvectors and eigenvalue) described in Tables 2 and 3, is performed by using nine aster bands as input bands (bands 1–9).

After performing a principal component analysis on satellite imagery bands, gray scale image is created that each pixel has its own component. By comparing the principal components of every band to gather (Table 2), it can distinguish bands that have especial property, for example, the forming main minerals of hydrothermal alteration. In this paper, image relating to PC7 in (−1) was multiplied. A new image is created that its bright pixel separate regions, including phyllic alteration. If image relating to PC8 in (−1) was multiplied bright pixels distinguish zones, including argillic alteration. In image relating to PC9, bright pixels indicate regions including propylitic alteration. Figure 5 displays color composite from 3 above PC image. Argillic, phyllic and propylitic alterations separate by yellow, orange and dark-blue colors.

The Minimum Noise Fraction (MNF) transformation is used to determine the inherent dimensionality of image data, especially in hyperspectral data, to segregate noise in

Table 2. Basic statistics of ASTER image bands.

| Band | Min     | Max     | Mean   | Stdev  | Eigenvalue |
|------|---------|---------|--------|--------|------------|
| 1    | 0.774024| 3.51075 | 1.569796| 0.314633| 0.846494   |
| 2    | 0.530732| 3.964878| 1.55406 | 0.424337| 0.067852   |
| 3    | 0.703083| 3.317111| 1.636837| 0.206145| 0.038542   |
| 4    | 0.896411| 3.03254 | 1.669535| 0.249033| 0.006109   |
| 5    | 0.750732| 2.745535| 1.641285| 0.208726| 0.001621   |
| 6    | 0.668491| 2.855213| 1.640031| 0.225368| 0.001248   |
| 7    | 0.693487| 2.990661| 1.630147| 0.344433| 0.000939   |
| 8    | 0.623387| 3.050145| 1.628526| 0.379824| 0.000612   |
| 9    | 0.714192| 2.856768| 1.631942| 0.340822| 0.003888   |

Table 3. Eigenvector matrix for PCA on 9 bands of ASTER image bands.

| Eigenvector | PC 1     | PC 2     | PC 3     | PC 4     | PC 5     | PC 6     | PC 7     | PC 8     | PC 9     |
|-------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Band 1      | 0.305966 | 0.427981 | 0.011455 | 0.246288 | 0.330579 | 0.346023 | 0.370174 | 0.407629 | 0.360864 |
| Band 2      | 0.502379 | 0.54196  | 0.485967 | −0.136913| −0.171733| −0.223346| −0.165211| −0.19224 | −0.233352|
| Band 3      | −0.209426| −0.33841 | 0.818948 | 0.383683 | 0.079985 | 0.103005 | 0.075266 | 0.032046 | 0.00561 |
| Band 4      | 0.060607 | 0.126156 | −0.285602| 0.756435 | 0.034588 | 0.108068 | −0.040552| −0.284027| −0.481097|
| Band 5      | −0.502725| 0.467751 | 0.024654 | 0.20352 | −0.063995| −0.093021| −0.324226| −0.28614 | 0.535445 |
| Band 6      | −0.593626| 0.415089 | 0.078674 | −0.218915| 0.081369 | 0.028036 | 0.279233 | 0.256476 | −0.519645|
| Band 7      | 0.000981 | 0.004293 | 0.067317 | −0.227186| 0.422281 | 0.671561 | −0.210144| −0.453705| −0.085175|
| Band 8      | −0.012186| 0.037578 | 0.008685 | 0.027799 | −0.698688| 0.575019 | −0.277624| 0.316671 | −0.037725|
| Band 9      | −0.017   | 0.012119 | 0.007471 | −0.063428| −0.420033| 0.130428 | 0.723905 | −0.50949 | 0.135748 |

Figure 5. Principal components color composite with – PC7(R), -PC8 (G), and PC9 (B).
the data, and to reduce the computational requirements for subsequent processing (Boardman & Kruse, 1994). The MNF technique is applied to the nine ASTER bands 1–9 of the study area to enhance the spectral variability of the content of the image. MNF technique was applied for satellite image. As the principal component method, 9 MNF image was created. RGB image was created to combine bands 1, 2 and 3 relating to MNF image (Figure 6). In this color composite, Argillic alterations are characterized by bright green pixels and propylitic alteration by dark-blue pixels.

A simple way to separate alteration zones is by using Band Ratio images. In this way to display and manifest index mineral any alteration, in the numerator put band or sum of the bands that have most reflection of specific mineral. In the denominator put a band that has a most absorbance for same mineral. In this paper, to manifest chlorite or epidote as an index mineral for propylitic alteration used band ratio (band7 + band9) / band8, to characterize kaolinite as index mineral for argillic alteration used band ratio (band4 + band7) / band6 and finally to separate muscovite as index mineral for phyllic alteration applied band ratio (band5 + band7) / band6 (HashemiTangestani and Mazhari, 2005). Color composite image was created from above band ratio images (Figure 7). In this figure, Zones with argillic alteration by yellow color, regions with phyllic alteration by brown color and zones with propylitic alteration by dark-blue color was distinguished.
4. Conclusion

This research investigates mapping altered zones by using advanced methods. Since the ability of ASTER data and performing advanced methods, three altered zones extracted from remote sensing image: 1-argillic alteration 2-phyllic alteration 3-propylitic alteration. According to the results of this study, Color composite of Principal component analysis and band ratio methods clearly manifest different altered zones of the region. However, band ratio more effectively shows the alterations. It is suggested that this study be performed in other areas and the results compared. The results of this study can also be used in the exploration of porphyry copper deposits.

Disclosure statement

No potential conflict of interest was reported by the authors.

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