

## Using SWIR Bands from ASTER for Discrimination of Hydrothermal Altered Minerals in the Northwest of Iran (Se-Sanandaj City); A Key for Exploration of Copper and Gold Mineralization

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**Abstract:** We used SWIR bands from ASTER sensor data for mineral explorations in the west of Iran in Kurdistan Province in the southeast of Sanandaj city. The wavelength of SWIR bands is situated between 1.6-2.43  $\mu\text{m}$ . In these range, hydroxides minerals which have been produced by hydrothermal alteration have a good absorption compared to lower or upper wavelengths. Based on PCA and Band Ratios (BR) methods and so comparing reflectance-wavelength curves with NASA/JPL standard curves, we distinguished two Propylitic and Phyllic alteration zones; in Propylitic zone is rich in chlorite and epidote minerals and Phyllic zone is rich in white mica and kaolinite minerals. These 2 alteration zones are important for copper and gold mineralization in this part of Iran. In the last decade some gold mineralizations such as Kervian and Dashkasan have been explored in the northwest and northeast of study area, respectively.

**Key words:** Iran, ASTER data, alteration zones, gold mineralization, copper mineralization

### INTRODUCTION

ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) is an imaging instrument that is flying on the NASA's Terra satellite launched in December 1999. ASTER acquires 14 spectral bands and can be used to obtain detailed maps of land surface temperature, emissive, reflectance and elevation. ASTER data has been used to map silicate and carbonate rocks (Hewson *et al.*, 2001) and has been used to carry out volcanic studies, urban studies, lithologic mapping, monitoring of coastal environments (Yamaguchi *et al.*, 1998). Reflection Radiometer (ASTER), identification of specific alteration assemblages becomes feasible, since it has 6 spectral bands in the SWIR (bands 4-9) (Abrams, 2000) a region where many clay and carbonate minerals show diagnostic spectral features, compared to only 2 TM bands (TM5 and TM7).

The 14 ASTER spectral bands are saved into three groups; 3 bands with 15 m resolution in VNIR, 6 bands with 30 m resolution in SWIR and 5 bands with 90 m resolution in TIR. They are co-registered to WGS84 and a common NUTM zone. In this study, we used L1B ASTER SWIR data in date 23/8/2001 for discrimination of alteration zones in the east of Kurdistan province in the northwest of Iran.

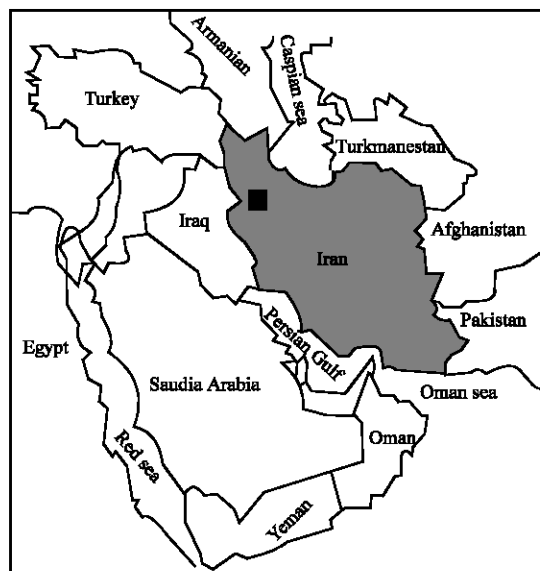


Fig. 1: Black rectangle show study area

**Geology setting:** The study area is located in the west of Iran in longitude 47° 25'-47° 43' eastern and latitude 35° 00'-35° 08' northern in the southeast of Sanandaj (Fig. 1). The region has semi-tropical climate with an annual rainfall around 300 mm. This area is composed of Jurassic

shale and andesite rocks that have been affected by cretaceous or younger granitoid bodies (Zahedi *et al.*, 1987). In some parts it is overlaid by Quaternary alluvial deposits. These granitoid rocks have been generated in the active continental margin with calc-alkaline nature. Most of copper porphyry and gold mineralization have been generated in this tectonic setting. Some of major porphyry copper deposits such as Songoon (NW-Iran) and Sarcheshmah (SW-Iran) are situated on volcano plutonic belts that extend in NW to SE trend in the west of Iran. Some of gold mineralization such as Kervian and Dashkasan in Kurdistan province had been explored in the last decade. Also we think there are some hopeful points for precious metals in Kurdistan province. Satellite data such as ASTER data, will be important for this subject. Furthermore, we know alteration zone is a key for exploration. In this case we used some ASTER data for this subject, because one of the primary applications of SWIR Reflectance Spectroscopy is the identification and characterization of alteration minerals and their distribution within zoning patterns around mineral deposits. Porphyry copper deposits have very complex alteration systems containing several types and combinations of alteration suites. Therefore, SWIR bands are ideal analytical tools to identify and characterize the zones around the porphyry.

**Alteration zones:** We used ASTER LIB data, which have been done geometric and atmospheric correction; also we apply Log residual method for atmospheric and topographic correction. In this method pixel DN's value is near to ground reflection.

Each alteration type in a porphyry copper deposit has fairly distinctive mineralogy. Following is a summary of the common alteration types and the major minerals seen in each type (Spectral International Inc).

- Propylitic (Chlorite, Epidote, Zeolites, Montmorillonite, Illite, Carbonate).
- Potassic (Feldspars, Biotite, Phlogopite, Chlorite, Vermiculites, Anhydrite, Gypsum).
- Phyllic (Illite, Muscovite, Kaolinite, Quartz).
- Argillic (Kaolinite, Smectite/montmorillonite, Zunyite, Diaspore, Topaz).
- Advanced Argillic (Pyrophyllite, Dickite, Alunite, Zunyite, Diaspore, Topaz).

The development of methods for mapping rock types has been one of the main goals of geological

remote sensing research. Hydrothermal altered rocks have received considerable attention because of their potential economic implications and favorable spectral characteristics for remote identification (Rowan *et al.*, 2003; Abrams *et al.*, 1977, 1983; Goetz *et al.*, 1983; Podwysocki *et al.*, 1983; Kruse *et al.*, 1993; Swayze *et al.*, 1998; Crosta *et al.*, 2003; Galvao *et al.*, 2005).

Porphyry type deposits are associated with hydrothermal alterations such as Phyllic, argillic, potassic and Propylitic. Hydroxyl minerals are abundant in the Phyllic, argillic and potassic zones. At the same time, an oxide zone is developing over many of the porphyry bodies, which are rich in iron oxide minerals. These alteration minerals can be detected by remote sensing techniques. Hydroxyl and iron oxide minerals can be identified through remote sensing techniques (Ruiz and Prol, 1998; Tangestani and Moore, 2001). Landsat data has been used for a number of years in arid and semi-arid environments to locate areas of iron oxides and/or hydrous minerals which might be associated with hydrothermal alteration zones. ASTER sensor onboard Terra platform has more capability in terms of spatial and spectral resolution than Landsat. Theoretically, the SWIR bands of ASTER have more capability than the Landsat for the recognition of areas with hydrothermal alteration.

Experimental analyses shows 468 colors composite combination is a good RGB for distinguishing alteration zones. In this color composite, Propylitic alteration will be green and Phyllic alteration will be pink to yellowish color (Fig. 2) because in b4 band alunite, kaolinite and white mica minerals have more reflection than two b6 and b8 bands.

**Comparing spectral reflections to NASA/ JPL standard curves:** Before comparing Reflection-wavelength curve in the study area with NASA/JPL standard curves, we resampled NASA/ JPL curves for ASTER sensor.

In the early studies, we determined two alteration probable zones, which will be important for mineral explorations described below:

**Zone 1:** This zone is limited in the north-northeast of study area. Comparing its reflection curve with NASA/JPL standard curves, we have tried to select homogenous locations (green circle in Fig. 2). Compared to Al-OH minerals such as alunite, kaolinite, Illite and white mica (muscovite), absorption of this zone occurs in b6 (Fig. 3) which is not compatible with alunite, because alunite absorption occurs in b5 band. This region of absorption is compatible to Kaolinite and white mica in band6. Meanwhile, low slope gradient reflection of between two

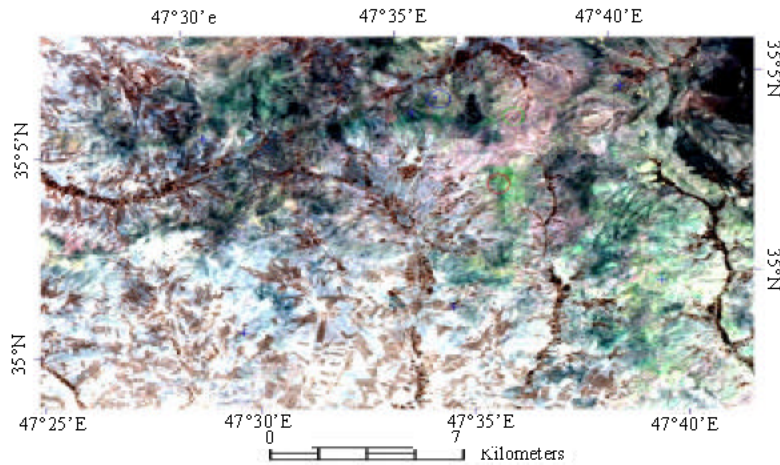


Fig. 2: Color composite in RGB mode, (R=4, G=6, B=8). Propylitic alteration will be green and Phyllic alteration will be pink to yellowish color. Circles show homogenous locations for Z- profile in these two alteration zone

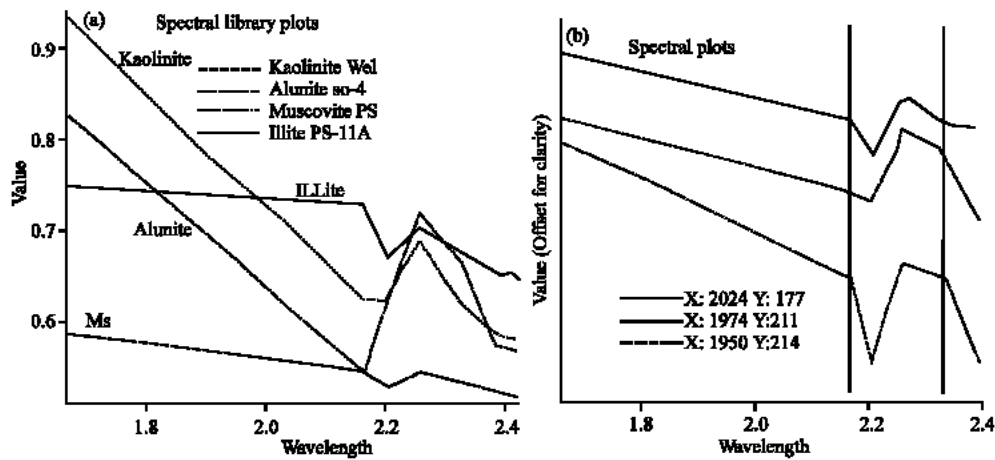


Fig. 3: NASA/JPL standard curves that have been resampled from ASTER sensor, showing some Phyllic alteration minerals. b; the curve of reflection in zone 1

b4 and b5 and high slope gradient between reflection of two b5 and b6 bands (Fig. 2) shows that this probably zone is rich in white mica. Also the curves of this zone is not completely the same as kaolinite, because of high slope between two b4 and b5 bands and moderately slope between two b5 and b6 bands. Compared to with illite groups, there is a different slope between b4 and b5 also b5 and b6 bands. We believe this reflection is a complex of Al-OH minerals that have been created by hydrothermal alteration.

This alteration zone is rich in some mineral such as kaolinite, illite and whit mica (muscovite). Among of them the latter is more than the other minerals. Based on the evidences, we believe this

zone is a Phyllic alteration zone, whose end-members can be distinguished by Hyperspectral sensor.

**Zone 2:** This zone with greenish color composite (R = 4, G = 6, B = 8) is surrounding zone1 extensively and has been developed in the east and southeast of zone 1. After pre-processing, we selected pure parts (red and blue circles in Fig. 2) for drawing of Z-profile (Reflection-wavelength curve). In the first view, these curves show a good absorption in band5 in 2.33  $\mu\text{m}$  and positive slope between b4 and b5 bands. This absorption restriction is compatible with minerals which have Mg-OH, Fe-OH, Al-OH bonds in their compositions.

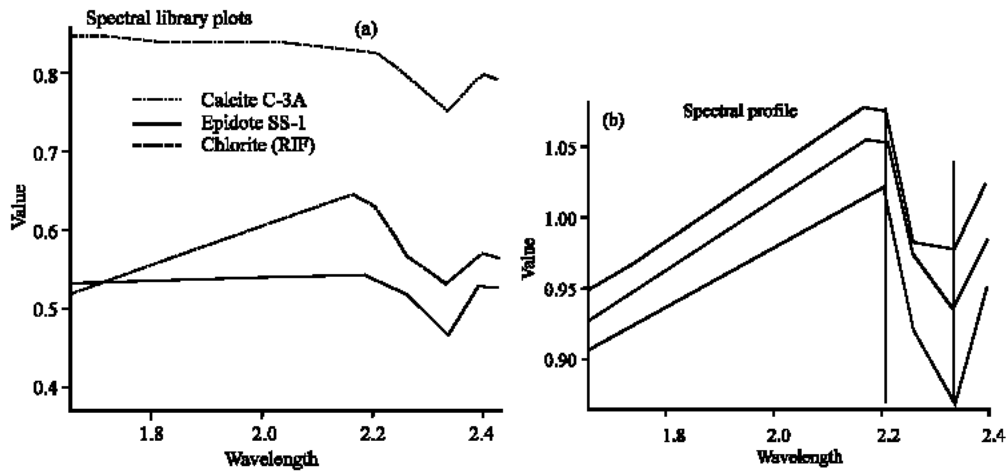


Fig. 4a: NASA/JPL standard curve that have been resample from ASTER sensor, showing some Propylitic alteration minerals. b; the curve of reflection in zone 2

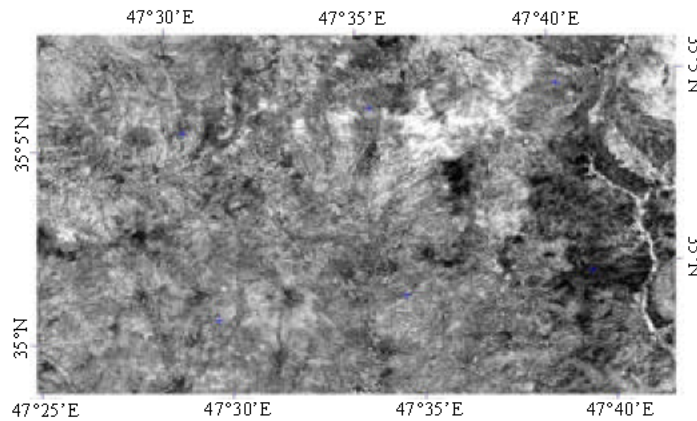


Fig. 5: Band ratios from study area, in the rationing of  $(B5+B7)/B6$  bands Phyllic zone is white and Propylitic is black

In this relation, we compared these curves to standard NASA/JPL diagrams of epidote, Chlorite and calcite minerals. These curves are much more compatible to chlorite than epidote and calcite minerals, because of positive slope between b4 and b5 bands and negative slope between b6 and b7 bands (Fig. 4 a, and b).

Chlorite and epidote mineral standard diagrams shows each of them have a good absorption in b8 band, but slope curve between b4 and b5 is moderate in chlorite and low moderate in epidote. In this case, we believe this zone is composed on chlorite and epidote minerals, but the amount of chlorite is more than epidote mineral. Compared to alteration zones, this zone is a good Propylitic zone.

**Band ratios:** Band ratio is a good method for removing albedo and topographic effects. In the rationing of  $(B5+B7)/B6$  bands, Phyllic zone because of high reflection

in band5 and band 7 and low reflection in band6 will be white. In opposite of, Propylitic alteration zone because of low reflection in b5 and b7 and high reflection in b6 will be darker than Phyllic alteration (Fig. 5). In this figure, the white part is Phyllic zone and the black part is Propylitic zone:

**PCA analysis:** Crosta and Moore (1989) developed a technique based on PCA for mapping iron oxide/hydroxides related to sulphide ore bodies in granite-greenstone belt Terrains using Landsat TM. The relationship between the Spectral responses of target materials (ferric-oxide-rich soils) and numeric values extracted from the eigenvector matrix used to calculate the Principal Component (PC) images. Using this relationship, they were able to determine which PCs contained the spectral information due to iron minerals

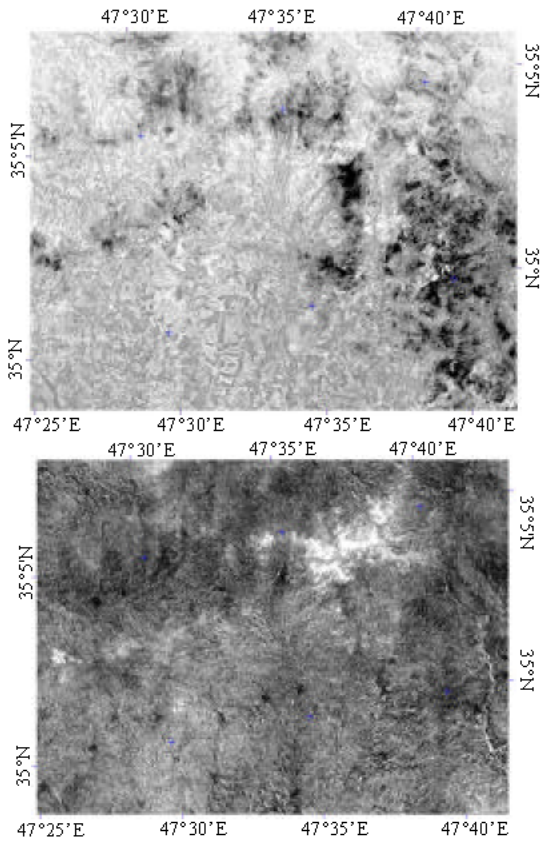


Fig. 6 (left): It shows PC3, in this figure Propylitic alteration will be appear in black and in the PC5(right) phyllic zone will be appear in white color(b)

and whether the Digital Numbers (DNs) of pixels containing the target materials had high (bright) or low (dark) values.

Principal Component Analysis (PCA) is an image processing technique that has been commonly applied to Landsat Thematic Mapper (TM) data to locate hydrothermal alteration zones related to metallic deposits. With the advent of the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER), a 14-band multispectral sensor operating onboard the Earth Observation System (EOS)-Terra satellite, the availability of spectral information in the Shortwave Infrared (SWIR) portion of the electromagnetic spectrum has been greatly increased(Crosta *et al.*, 2003). This allows detailed spectral characterization of surface targets, particularly of those belonging to the groups of minerals with diagnostic spectral features in this wavelength range, including phyllosilicates (clay minerals), sulphates and carbonates, among others.

Table 1: The matrix of eigenvectors for 6 SWIR bands

SWIR	PC1	PC2	PC3	PC4	PC5	PC6
b4	0.396	-0.856	0.23	0.195	0.117	0.069
b5	0.411	0.014	-0.604	-0.42	0.52	0.135
b6	0.411	0.015	-0.499	0.237	-0.723	0.043
b7	0.412	0.101	0.266	-0.366	-0.113	-0.776
b8	0.41	0.273	0.499	-0.331	-0.177	0.606
b9	0.408	0.426	0.188	-0.697	0.384	-0.071

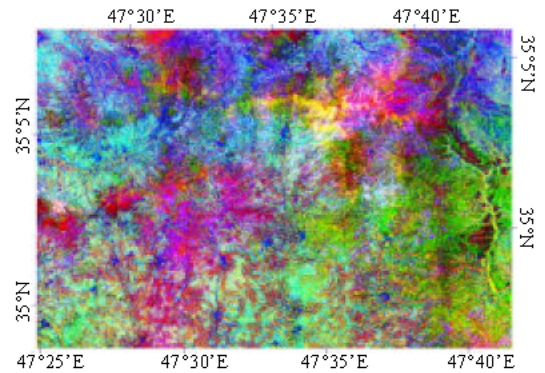


Fig. 7: False color composite in RGB mode(R=PC5, G=P4, B=PC3) mode. in this composite Propylitic zone is green and Phyllic zone in which appear in yellow to red color

We used 6 SWIR bands for the calculation of eigenvector and eigenvalue for determining Phyllic and Propylitic alterations in the study area. The results illustrate ASTER's ability to provide information on alteration minerals which are valuable for mineral exploration activities and support the role of PCA as a very effective and robust image processing technique for that purpose.

After applying PCA, the eigenvector matrix was used to calculate of PCA for the study area and to identify which PC contained the mineral information and which PC that has the highest eigenvector is important for discrimination of alteration zone (Table 1). Because of high reflection in b5 and b6 and good absorption in b8 and b7; PC3 is a useful for illustration of Propylitic zone (Fig. 6a), also because of good absorption in b6 band, PC5 will be a good indicator for discrimination of Phyllic zone (Fig. 6b). In PC3 Propylitic alteration will be appear in black color and in the PC5, Phyllic zone will be appear in white color.

Also in 543 color composite in RGB mode (R = PC5, G = P4, B = PC3) Propylitic zone is green and Phyllic zone in which appear in yellow to red color (Fig. 7). Two color in Phyllic zone shows this zone is not pure composition. For illustration of its composition, we need to some filed works and so some hyper spectral data.

## CONCLUSION

Some minerals associated with hydrothermal processes (e.g., kaolinite and K-micas) usually show spectral features that allow their remote identification (Clark, 1999). Remote sensing detection of these minerals has been conducted in arid and semi-arid terrains. Based on PCA analyses, band ratios and NASA/JPL standard curve, we distinguished two alteration zones: Propylitic and Phyllic alterations. These two alteration zone is a key for gold and copper mineralization, especially porphyry copper deposits and epithermal gold mineralization. Also we need some hyper spectral data for determining end-members in these alteration zones, although it is necessary to do some analyses with PIMA spectrometer.

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