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Exploration of Hydrothermal Alteration Zones Using ASTER Imagery: A Case Study of Nuqrah Area, Saudi Arabia

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Abstract: This study aims at exploiting multi-spectral data, acquired from ASTER, satellite to explore areas of hydrothermal alteration and Gossan including massive sulphide deposits. Auger sulphide is a good source of raw materials such as economic copper, silver, gold and zinc. Major steps involved in the analysis of ASTER satellite data have been discussed using ERDAS Imagine Software. The extent of interdependence among spectral regions, hydrothermal alteration and Gossan has been studied through digital image analysis and classification. The visual interpretation techniques have been employed to identify and earmark hydrothermal alteration and Gossan zones on the satellite image for carrying out subsequent supervised image classification. Imagery analysis was supported by the color composite, developed by exposing bands 4, 6 and 9 with red, green and blue radiations respectively, to make iron-rich cap or Gossan and hydrothermal alteration zones are prominent. The Gossan-laden regions appeared in red color while the hydrothermal alteration zones took color range from reddish green to light green. Image enhancement has also been achieved through the application of image ratioing techniques and an improved color composite was developed by exposing results of band ratios of band 5 and 7, band 5 and 4 and band 2 and 1 with red, green and blue radiations, respectively. The combination of visual interpretation, previous knowledge of the landcover and digital image processing techniques applied on the ASTER satellite imagery in multi-spectral mode, has proved beneficial in studying hydrothermal alteration zones and Gossan in the Nuqrah area.

Key words: ASTER, Gossan, hydrothermal alteration, digital image classification, colour composite

INTRODUCTION

Geological Setting

The Nuqrah belt lies within the Hulayfah group of volcanic and volcano-sedimentary rocks. This group comprises two formations, the lower or Afna formation and the upper or Nuqrah formation. The Afna formation is mostly andesitic, where basaltic flows exist containing the agglomeration of mafic tuff and breccia. Units of rhyo-andesitic quartz-crystal tuffs are found near the top of Afna formation. The upper, or Nuqrah formation, is a sequence of alternating volcanic and sedimentary rocks in which three subunits are recognized:

- The lower subunit begins with an alternating sequence of andesitic crystal tuff and rhyolitic crystal tuff. This is followed by massive felsic tuff, containing lithic fragments of rhyolite and subordinate andesite, intercalated with rhyolite flows

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- A middle subunit composed of lenticular beds of graphitic tuff, calc-dolomitic marble and subordinate jasper with local concentrations of base metal sulfides. Above this basal complex, the dominant facies is bedded crystal and lapilli tuffs and individual flows of Na-rhyolite
- The upper subunit is mainly composed of volcaniclastic rocks beginning with a thick conglomerate containing cobbles and of rhyolite and granophyre. This grades upward to alternating beds of conglomerate and carbonate-cemented felsic tuffite. Syntectonic intrusions include layered gabbro, diorite and migmatite. Delfour (1977) considered all of these to be essentially contemporaneous with Hulayfah group volcanism. Late- and posttectonic intrusions include calc-alkaline, alkalic and peralkalic granites.

Local Geology

In the immediate Nuqrah district, Delfour (1977) noted large variations in the rock assemblages of the lower and middle subunits of the Nuqrah formation, which he attributed partly to deformation but mostly to the variability of the original paleovolcanic environment. The succession begins with about 2000 m of andesite, basaltic flows and related pyroclastics of the Afna formation. These are succeeded by the Nuqrah formation, the lower part of which is a rhyolitic and/or lapilli tuff grading laterally to andesitic and basaltic tuff and breccia intercalated with rhyolite andesite and basaltic flows. The top of this unit is composed of bedded rhyolitic tuff, graphitic shale, marble, jasper and local lenses of base metal sulfides. Above this is a succession of alternating Na-rhyolite flows, rhyolitic tuff, graphitic tuff and carbonate-rich tuff and cherty tuffite. In this area, Nuqrah formation rocks are intruded by porphyritic rhyolite, small stocks and sills of gabbro and diabase all of which were regarded by Delfour (1977) as being subvolcanic.

Location of Study Area

The study area, Nuqrah district, is located in the North-Eastern part of the Arabian Peninsula (Fig. 1). The geographic coordinates range from 40 to 42° East longitude and 25 to 26° North latitude. The Nuqrah village is situated along a road linking the cities of Buraydah and Medina. The village is about 230 km South West of the city of Buraydah and 300 km North-East of Medina.

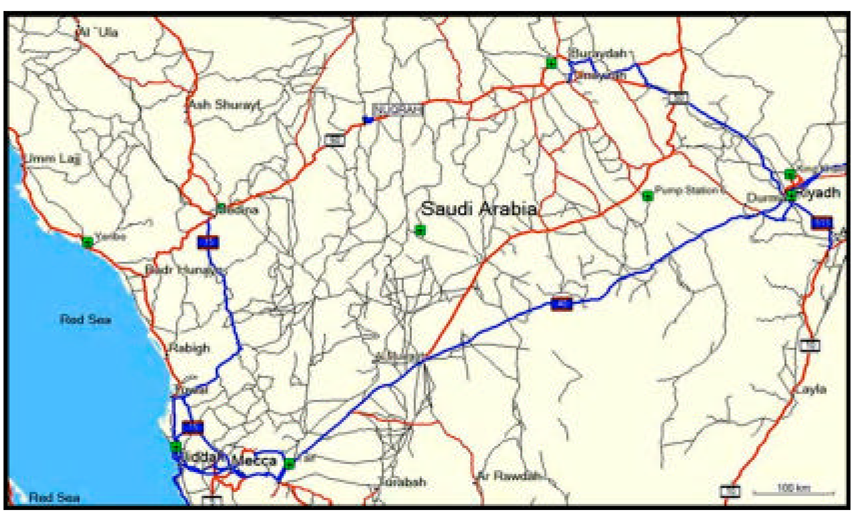

Fig. 1: Location of study area, (GPS-acquired geographic coordinates: 25°36.218' N, 41°30.875' E)

MATERIALS AND METHODS

A combination of geological, landcover and ASTER satellite datasets has been studied to accomplish the present research. The Geo-science datasets included the geo-referenced thematic layers of lithology, geomorphology and structural geology.

In addition to visual interpretation, digital processing of multi-spectral imagery datasets has been carried out to classify features of geological significance in the study area. Image processing operations are algorithms that map input images into output images. The mapping of hydrothermal alteration has been an important outcome of the present research effort carried out with the application of various image processing operations.

The addition of two shot-wave infrared bands in Thematic Mapper Sensor of the LANDSAT System, many clay minerals have been found to have their more diagnostic absorption features (Hunt and Salisbury, 1970).

Since 2000, Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) multispectral data have been used in mineralogical and lithological studies (Rowan and Mars, 2001) and (Ninomiya, 2004). ASTER is a cooperative effort between NASA and Japan's Ministry of Economic Trade and Industry (METI). The instrument was launched on board NASA's TERRA spacecraft in December 1999. ASTER is an advanced multispectral imager which covers a wide spectral region of the electromagnetic spectrum from the Visible near Infrared (VNIR) to the Thermal Infrared (TIR).

Terra has an orbital path similar to Landsat 7's. Five instruments on the spacecraft, including ASTER, can be combined to monitor all earth systems (Abrams *et al*., 2002) and generate data in 60×60 km scenes.

ASTER data are used for a range of applications, including land-use studies, mapping, water resources, coastal resources, environmental monitoring, generation of Digital Elevation Models (DEMs) and mapping alteration patterns or specific mineral assemblages known to be associated with mineral systems. ASTER consists of three separate instrument subsystems (Table 1):

- Visible and Near Infrared (VNIR)
- Shortwave Infrared (SWIR)
- Thermal Infrared (TIR)

Data Processing

The remote sensing operations are applied to the satellite imagery to digitally enhance the feature details and render it more interpretable in comparison to its raw state. As any image involves radiometric errors as well as geometric errors, these errors should be corrected. Radiometric correction is to avoid radiometric errors or distortions, while geometric correction is to remove geometric distortion. When the emitted or reflected electro-magnetic energy is observed by a sensor on board an aircraft or spacecraft, the observed energy does not coincide with the energy emitted or reflected from the same object observed from a short distance. This is due to the sun's azimuth and elevation, atmospheric conditions such as fog or aerosols, sensor's response etc. which influence the observed energy. Therefore, in order to obtain the real irradiance or reflectance, those radiometric distortions must be corrected.

Table 1: ASTER statistics along with 14 bands for data acquisition

Instrument	VNIR	SWIR	TIR
Spectral bands	1-3	4-9	10-14
Spatial resolution	15 m	30 m	90 m
Swath width	60 km	60 km	60 km
Radiometric resolution (Quantization)	8 bit	8 bit	12 bit
Cross track pointing	±318 km (± 24°)	±116 km (±8.55°)	±116 km (± 8.55°)

At first, radiometric correction was applied to remove the atmospheric effects. The correction was achieved by subtracting the minimum values, corresponding to atmospheric haze, from each band.

To eliminate influence of water in the imagery, water bodies were masked. The procedure involved band ratioing, where a ratio of band 4 to 2 was computed and a threshold value was selected for masking the water features. It was found that all pixel values below 0.6 represented water features. The ratioed-image was displayed containing only the values greater than 0.6. The image represented all landcover features except the water feature. That is how water features were masked out of the imagery dataset.

Image Analysis Through Digital Processing Techniques

An image of Aster for area of interest was processed for subsequent analysis. Analysis of Aster data for lithological discrimination is based on relationship between the spectral absorbance or emittance and the mineral composition of rock units under investigation. Various image enhancement and spatial filtering techniques were applied to the ASTER Imagery for making the features visually prominent.

Processing of Imagery Dataset Comprising SWIR Bands

ASTER Imagery Dataset containing Short Wave Infra Red (SWIR) bands were processed and analyzed for the investigation of Hydrothermal Alteration and Gossan. The application of digital processing techniques on color composite, developed from the combination of bands 4, 6 and 9, revealed the existence of Gossan in the areas of hydrothermal alteration. The Gossan appeared in red color while other areas of hydrothermal alteration appeared in a range of colors from Verde reddish to light green. Figure 2 showed hydrothermal alteration zones and the Gossan in the processed ASTER Imagery. It can be asserted by saying that all the SWIR bands can be exploited for the investigation of the Gossan and the hydrothermal alteration zones because data is captured at these bands in optical spectroscopy.

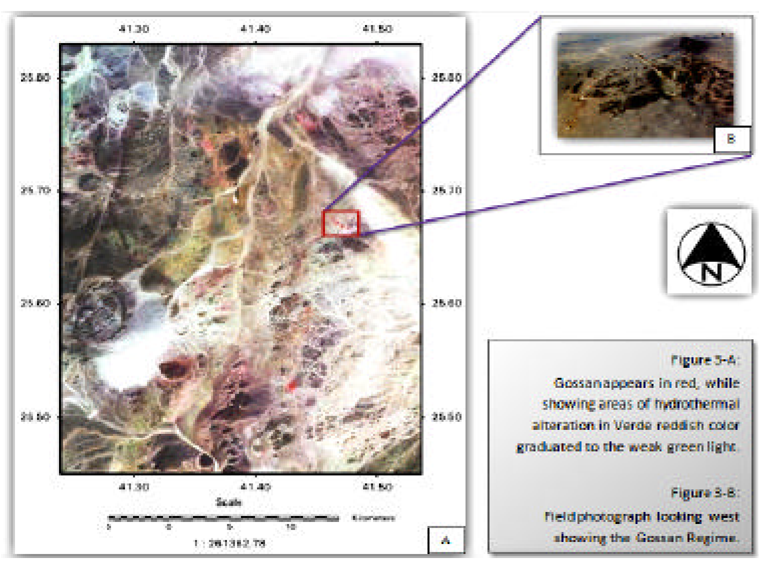

Fig. 2: SWIR color composite (bands 469-RGB) in 3-A and field photograph in 3-B

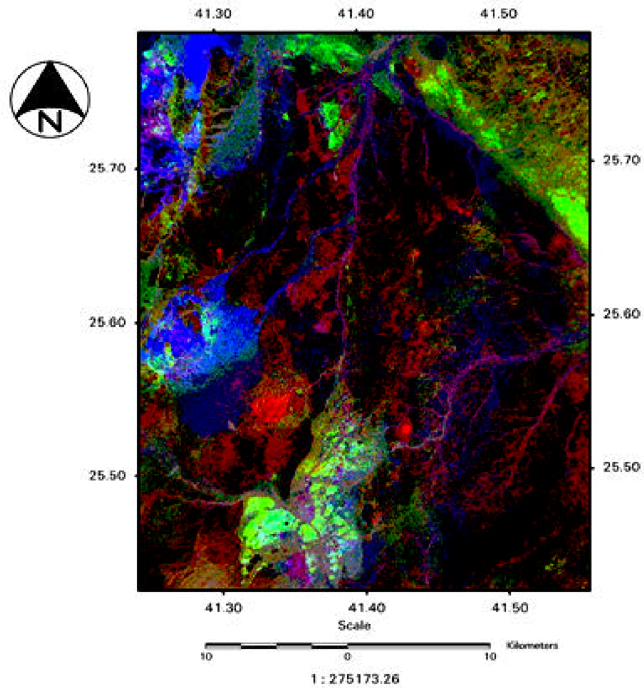

Fig. 3: Color composite of ratio images 1/2, 4/5 and 7/5 (RGB) Prepared from ASTER, showing Gossan in bright red, while areas of Hydrothermal alteration from pink to red

Image Rationing Technique

For identification and classification of Gossan and hydrothermal alteration zones, ratio images were prepared for the study area. The ratio images were created by dividing the Digital Number (DN) in one band by the corresponding DN in another band for each pixel, stretching the result value and plotting the new values as an image. The method is used by (Cappaccioni *et al*., 2003) to extract spectral information from multispectral imagery. Color Composite of ratio images 1/2, 4/5 and 7/5 (RGB) that revealed Gossans in red while showing the hydrothermal alteration zones from pink to red (Fig. 3). This band combination is recommended because many other rocks also have the resembling appearance.

RESULTS AND DISCUSSION

This study demonstrates the application of image processing techniques, coupled with allied geo-spatial datasets, for the exploration, identification and classification of Iron-rich Cap or Gossan and associated Hydrothermal alteration zone, which forms clay Kaolinite, Montmorillonite, calcite and chlorite-rich zones at Nuqrah area. The hydrothermal alteration which usually consists of acid and some of the riolite and covers massive sulphide deposits, is considered a good source of the raw material.

ASTER data processing shows good correlation with field data for the appraisal of ore deposits. The analysis of ASTER's SWIR datasets has been found suitable for the detection and mapping of hydrothermal alteration zones and Gossan. The research effort has produced fairly reliable and accurate results and can therefore, be recommended for mineral exploration.

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