Remote Sensing Techniques for Detection of Gossans and Associated Alteration Zones, Ariab Area, Red Sea Hills, NE Sudan

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Abstract

The massive sulphide deposits in Neoproterozoic Ariab Belt are not exposed at the surface. They have been recognized by a few tens of meters Fe-rich crusts over the surface (gossans) surrounded by a wider zone of clay and Fe-rich alteration. The gossans and surrounding alteration zones in Ariab Belt are identified using Enhanced Landsat Thematic Mapper (ETM). The RGB 742 Landsat ETM image together with ground observations collected from the field better reveals the lithological variations of Ariab area. A saturation stretched has been done to the same RGB (742) image to acquire more clearly image. In this image the lithological variations and the Neoproterozoic structures are well defined. The main lithological units that were identified are: Ariab volcano-sedimentary sequence with which, the gossans were associated; the Oshib ultra-mafic complex; Awat-Asotriba group; and the granitoid intrusives. The volcano-sedimentary rocks occupy the core of the mineralized Ariab Belt. Density slicing is well used to map clay-and iron alteration zones along Neoproterozoic Ariab belt. By comparing clay and/Fe alteration index maps it leads to identification of gossans and outlined well the alteration zone.

Key words: Red Sea Hills, Ariab, remote sensing, gossan, density slicing, alteration zones

1. Introduction

The Ariab Mineral district is located in the central part of the Red Sea State. It is situated between latitudes 18° 20' -19° 00N and longitudes 35° 10' – 36° 00E, midway between Atbara and Port Sudan town (Fig.1). The target area, that contains volcanic massive sulphide (VMS) ore lenses, is located about 220km WSW Port Sudan. The main sulphide deposits are situated around Wadi Ariab, with the two largest outcropping gossans: Hadal Awateb and Adaiamet, which reaching altitudes of 700-725m and 260m above the plain respectively. The study area lies within the Sahelian Zone desert to semi-desert climatic regime and drained mainly by Wadi Amur and Wadi El Humar directly to the Nile.

Outstanding example of auriferous massive sulphide deposits in Arabian-Nubian Shield occur in the Ariab Metallogenic District of the Red Sea Hills (Aye et al., 1985; Cottard et al., 1986; Bakheit, 1993; Wipfler, 1994). The deposits occur in poly-deformed and metamorphosed volcano-sedimentary rocks of Neoproterozoic Nakasib-Bir Umq Suture (Johnson, 1994). Other similar deposits can be expected elsewhere in the vast and poorly known Arabian-Nubian Shield. The massive sulphide deposits in Neoproterozoic Ariab Belt are not exposed at the surface. However, they have been recognized by a few tens of meters Fe-rich crusts over the surface (gossans) surrounded by a wider zone of clay and Fe-rich alteration.

In this work the gossans and surrounding alteration zones in Ariab Belt are identified using Enhanced Landsat Thematic Mapper (ETM). The small size of the gossans makes it difficult to find them with Landsat ETM data, in spite of the fact that gossans have roughen appearance than the surrounding volcano-sedimentary and plutonic rocks (Abdelsalam et al., 2000). By using some processing techniques, it has been possible to use relatively poor spatial Landsat ETM data to locate the gossans.
2. Geology of Ariab Area

Ariab gold-bearing sulphide occurrences are located within the Late Proterozoic Ariab-Arbaat volcanic arc sequences (volcano sedimentary) forming the western extension of a narrow, 250Km, belt parallel to the northeast-striking geological features of the Red Sea Hills. The volcanic arc units comprise a complex upper sequence of rhyolitic and andesitic rocks overlying basaltic lavas. These, together with pyroclastic and epiclastic rocks, are intruded by early granodiorite and tonalite and are capped by thick epiclastic deposits into which the Oshib ultrabasic complex has been tectonically emplaced (Fig. 2). The belt trends generally in an ENE direction parallel to the northern edges of the intraoceanic island arc of the Haya terrane (Kroner et al., 1987).

The Ariab volcano-sedimentary rocks occupy the core of the mineralized belt. They have been subdivided (Bakheit, 1991; Abu Fatima, 2007) into five lithostratigraphic units (The basal greenstone complex, mafic to intermediate volcanic rocks, felsic volcanic rocks, upper basic to intermediate volcanic rocks and predominantly sedimentary rock).

3. Ariab mineralization

There are five mineralization types pertaining to the economic concentration of gold in the Ariab area (Abu Fatima, 2006). They are briefly described below:

(1) Volcanogenic Massive Sulphides (VMS). The main sulphide bodies consist mainly of primary pyrite, in both disseminated to massive form, which occurs in stockworks hosted in hydrothermalized altered felsic volcanic rocks. The sulphide mineralization in these deposits has largely been oxidized and now occurs as gossans, e.g Hadal Awateb, Adaiamet, Oderuk, Talaiiderut, Hassai and Shulai. This mineralization has been also intersected by deep drill holes at Adassidakh and Adaiamet which consist mostly of massive pyrite. The massive sulphides in the Ariab District are noted for their variable Cu (chalcopyrite) and Zn (sphalerite) grades and their fairly high gold grade (0.6–1.2g/ton average (Bakheit, 1991).

(2) Secondary Mineralization Related to Gossans Derived from the Oxidation of Massive Sulphides.

This type of mineralization mainly involves supergene enrichment with economic gold and silver grades occurring in a weathering profile composed predominantly of siliceous barite facies rocks that have been partly preserved down to a depth of about 120m. Gold in these rocks is generally very fine-grained (4–20µ) and is difficult to detect. It is mainly contained in deeply weathered rocks and occurs either between grains or, in places, enveloped by iron oxides. Because of these characteristics this type of gold was undetected during ancient exploration. It is mostly found within silica barite rocks (or SBRs), which are microbreccias of supregene origin, where sulphide minerals have been leached from rocks rich in gangue material. The rocks containing the mineralization occur as lenses intercalated with, or adjoining the gossan rocks. Orebodies belonging to this type are found at Hadal Awateb, Oderuk and Adaiamet (Cottard et al., 1986b).
(3) Mineralization Associated with Baritic Lenses and Without Gossan
Gold in these deposits may be either coarse or fine-grained and the silver content can be high. The mineralized bodies, an example being the Ganaet deposit, are usually quite small;

(4) Mineralization Associated with Quartz Veins. This type, containing of visible or very fine-grained gold, is found at Kamoeb (Cottard et al., 1986b).

(5) Epigenetic Auriferous Deposits. These deposits are related to shearing and metamorphic degassing of ultra-mafic rocks e.g present at Dirbikwan and Hoshib areas (Abu Fatima, 2006). In this case it is suggested that shear zones had focussed the mobile carbon dioxide (CO₂), water (H₂O) sulphur (S) and other chalcophile and gold solute from the ultra-mafic rocks and channeled them uprising into more permeable layers of the volcanoclastic sediments of the Ariab Group. This process may be contemporaneous with emplacement of the granites in Ariab.

Fig. 2. Simplified geological map of the Ariab area showing locations of the main ore deposits. KAM=Kamoeb; HAA= Hadal Awateb; HAS= Hassai; TAL= Talaiderut; ODE= Oderuk; ADK= Adassedakh; ADA= Adaaimet; GAN= Ganaet (modified from BRGM report 86 SDN 110)

4. Remote Sensing Interpretation

4.1 Digital Image Processes for Geological Mapping
Landsat ETM images together with ground observations collected from the field were used in this study.

4.1.1 Colour Composite
False-colour composite of Landsat ETM was produced from three components assigned to the filters red, green and blue (RGB). The interpretation has been started with RGB 742 of Landsat ETM (Fig. 3A), which is recommended for geological studies in arid regions (Sabins, 1997). In the RGB 742 (Fig. 3. A), the volcano-sedimentary sequence appears as alternating dark brown and faint brown. Granitic rocks (late-to post) orogenic igneous bodies are scattered throughout the district. They are well recognized in the northern, western and southeastern parts of the area. The late intrusives appear in brown to dark brown with light blue and white tinges. The ultra-mafic complex occupies the western and northern parts
of the map area. It maintains a linear setting that marks the northern margin of Ariab depositional basin and it appears in dark blue colour.

4.1.2 Saturation stretch
Saturation stretching has been applied to the same RGB (742) image to obtain more clearly image. Saturation stretching is used as one of the most commonly applied methods of image processing to enhance lithological units because it represents the purity of the colour (Sabins, 1997).

In the obtained image (Fig. 3B) the lithological variations and the Neoproterozoic structures are well defined. The main lithological units that were identified are Ariab volcano-sedimentary sequence with which, the gossans were associated; the oshib ultra-mafic complex; Awat-Asotriba group; and the granitoid intrusives. The volcano-sedimentary rocks occupy the core of the mineralized Ariab Belt. The sequence has a strong north-trending, east-dipping foliation, which is steep in the west and becomes more gentle to the east.

Fig. 3. (A) RGB 742 of Landsat ETM image. (B) Saturation stretched of RGB 742 Landsat ETM image showing the interpreted main lithological units and the Neoproterozoic structures of Ariab belt.
4.2 Digital Image Processes for Gossans Delineation

The objective of using remote sensing analysis in this study is to identify gossans within clay-and Fe-rich alteration zones using Landsat ETM. Furthermore, it is used for determining the geologic controls on the Neoproterozoic sulphide mineralization in Ariab mineral district. A number of gossan bodies occur within the Ariab Belt, the largest of which are Hadal Awateb (a length of 3000 m, ranging in width from 20 to 50 m), Hassai (a total length of 1800 m and a width of 10 to 40 m), Talaiderut (covers an area of about 800x200 m), Oderuk (covers an area of 700x200 m) and Adaiamet with a total surface area of some (100x600 m). Most other gossans are very small to be unequivocally identified directly in the Landsat ETM that has 30 m spatial resolution. Below is described how these data were used to locate and map alteration zones and associated gossans.

4.2.1 Density Slicing

The density slicing technique converts the continuous grey tone of an image into a series of density intervals, each corresponding to specific range of digital numbers (Sabins, 1997). Different density slices can be shown as a separate colour and can be dropped over background images. Density slicing of band-ratio 5/7 and 3/1 are used to create clay and Fe alteration index maps (Fig. 4A & Fig. 4B), respectively. The band ratio 5/7 effectively maps clay alteration because clay minerals such as sericite have reflectance maxima within band 5 similar to most minerals (reflected IR; wavelength=1.55-1.75 µm) and reflectance minima within band 7 (reflected IR; wavelength=2.08-2.35 µm; Hunt and Ashley, 1979). Similarly, band ratio 3/1 is effective in mapping Fe alteration because Fe minerals such as limonite and jarosite have reflectance maxima within band 3 (visible red; wavelength=0.63-0.69 µm) and reflectance minima within band 1 (visible blue; wavelength=0.45-0.52 µm; Hunt et al., 1971). Hence, 5/7 and 3/1 band ratios increase the difference between the DN l;

Fig. 4: (A) Clay alteration index map, Ariab area. (B) Fe alteration index map, Ariab area. Enhancement: Density slicing of Landsat ETM band-ratios 5/7 and 3/1 respectively.
(Digital Number) values of clay and Fe alteration zones, respectively, and those of unaltered rocks as well and this leads to a better discrimination between hydrothermally altered and unaltered zones.

The index maps Figures (4.A & 4B) show excellent correlation with field observations. Density slicing was successfully used by Abdelsalam et al. (2000) to map clay-and iron alteration zones along Neoproterozoic Beddaho alteration zone in north Eritrea.

4.2.2 Hydrothermal Composite
RGB 5/7-4/5-3/1 (bands ratio) Landsat ETM image (Fig. 5) was produced by dividing digital numbers (DN) of one band by another to yield an image that both enhances spectral differences and reduces topographic variation in illumination. This image also better reveals the lithological variations and Neoproterozoic structures. The alteration zone is outlined very well in this image where it appears in pinkish blue colour with tinges of purple. In 5/7-4/5-3/1 Landsat ETM image (Fig. 5), the Fe-rich areas appear in dark bluish colour, areas dominated by clay alteration appear in red, and when both mineral species are present the area appears in magenta colour, while gossans appeared in yellow with orange to red tinges. The band-ratios 5/7 and 3/1 emphasizes clay and Fe minerals respectively (Sabins, 1997) which have specific spectral reflectance and absorption features in these bands. Band-ratio 4/5 is used because hydroxyl minerals have reflectance maxima at band 4 and absorption minima at band 5 (Abrams et al., 1983; Ruiz-Armenta and Prol-Ledesma, 1998).

Fig. 5.: Landsat ETM image, showing the alteration zone and the associated gossans Ariab area. Box A & B showing the already known and assumed gossanic areas respectively.
5. Discussions

The alterations detected associated with Ariab volcano-sedimentary sequence are mainly composed of quartz sericite and quartz chlorite schists. Pervasive clay-and Fe-rich hydrothermal alteration is dominantly confined to granodiorite body and they extend into the volcano-sedimentary sequence (Fig. 5). The mineralization is thought to be concentrated at the roof hanging wall because the later pathways for hydrothermal fluid had emanated from the enclosing syn-orogenic granodiorite (Abdelsalam et al., 1997). The alteration is interpreted to postdate the emplacement of the syntectonic grandiorite but predates development of northeast-trending foliation and is, therefore, thought to be a result of Neoproterozoic related hydrothermal activity. The most common manifestations of the Fe alteration is the presence of limonite and jarosite, whereas clay alteration produced widespread sericitisation and kaolinitization.

The Fe alteration is mainly associated with the gossans. These gossans are dominantly massive hematite, magnetite, limonite and goethite.

Landsat ETM data have been used to map alteration zones because of their characteristic spectral properties (Filho and Vitorella, 1997; Ruiz-Amenta and Prol-Ledesma, 1998). This may be partly because the 30 m spatial resolution of Landsat ETM data is too coarse to be used in direct identification of majority of gossans that are only a few tens of metres wide. Since the density slicing technique is useful in overcoming the spatial resolution, disadvantage of the Landsat ETM data in mapping few pixel gossans are the:

i) the density slicing technique produces clay and Fe alteration index maps, which can be used to identify alteration zones that contain gossans; and

ii) by comparing clay and Fe alteration index maps it leads to identification of gossans.

The Fe-rich gossans have characteristic reflectance spectra and surface roughness; they are often very small to be directly detected by Landsat TM that has about 30 m spatial resolution. Band-ratios 5/7-4/5-3/1 of ETM image characteristically portray small (tens of pixels) gossans in yellow-orange and the more extensive alteration zones in pinkish purple.

Furthermore, the Landsat ETM data is important in exploring for Au-bearing massive sulphides in the arid regions because the Landsat ETM images allow large areas to be examined inexpensively (a Landsat ETM scene is 185x175 km) therefore, are affordable for developing countries in arid regions.

6. Summary and Conclusions

The study has combined new field and orbital remote sensing data to study the alteration zones and detect their associated gossans. The RGB 742 Landsat ETM image better reveals the lithological variations and the Neoproterozoic structures of Ariab area. Density slicing is well used to map clay-and iron alteration zones along Neoproterozoic Ariab belt. By comparing clay and Fe alteration index maps it leads to identification of gossans and outlined well the alteration zone. The alteration zone mainly composed of quartz sericite and quartz chlorite schists. The most common sign of the Fe alteration is the presence of limonite and jarosite, whereas clay alteration produced widespread sericitisation and kaolinitization.

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