Utilization of Landsat ETM+ Data for Mapping Gossans and Iron Rich Zones Exposed at Bahrah Area, Western Arabian Shield, Saudi Arabia

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Abstract. Utilization of remote sensing techniques for mapping gossans and iron rich zones exposed at Bahrah area, Western Arabian Shield, Saudi Arabia is the main task of this article. Spatial dimensions of these gossans are favorable to detect by Landsat ETM+ imagery. Gossans at the study area occur within the highly foliated, metavolcanic sequence composed mainly of basalts, basaltic andesites, dacites, rhyolites and their tuffs. Band ratios and density slicing are the main remote sensing techniques used throughout this study to discriminate and map the gossans and iron-rich zones exposed along the NNE-SSW left lateral strike slip faults. 4/5 band ratio image was found to be the most favorable ratio that discriminates the gossans and iron-rich zones. The gossans have a black image signature on this ratio and this signature is attributed to the absorption feature near band-4 exhibited by pyrite, hematite, goethite and magnetite, the main mineral constituents of gossans. On 4/5 band ratio image the DN values of gossans were determined (range between 0 and 14) and used by the density slicing technique to slice the gossans and iron rich zones from other rock units exposed at the study area. Panchromatic Landsat band-8 was prepared for the automatic lineaments extraction using PCI package under the user defined parameters. The results of lineaments analysis revealed that, the main
lineament trends affecting the metavolcanic sequence and the gossans are NE-SW, N-S (NNE-SSW) and NW-SE. These trends were verified in the field and found to coincide largely with the results of the geophysical studies done by many authors on the study area. The information extracted from the lineaments analysis, density slicing technique and the field verification were integrated to produce an image map of scale 1:100 000 shows the distribution of gossans and iron rich zones exposed at the study area.

**Keywords:** Landsat ETM+, Gossan, Band Ratio, Density Slicing, Bahrah area, Saudi Arabia.

**Introduction**

In the western Saudi Arabia, the Neoproterozoic Arabian Shield is composed of at least five geologically distinct terranes separated by four ophiolite-bearing suture zones. Three ensimatic island arc terranes in the western part of the shield (Asir, Hijaz and Midyan) and Afif and Ar Rayn terranes of continental affinity further to the east (Al Shanti and Mitchell, 1976; Bakor et al., 1976; Greenwood et al., 1976; Frisch and Al Shanti, 1977; Gass, 1977 & 1981; Schmidt et al., 1979; Camp, 1984). The Neoproterozoic Arabian Shield host auriferous massive sulphide ore bodies (Al-Shanti and Roobol, 1979). These massive sulphide deposits are Kuroko-type and formed by submarine hydrothermal activity associated with felsic vulcanicity. Primary mineralization which occurs as stock-work or stratabound deposits, were faulted, folded, metamorphosed and intruded. Recent interaction with air and surface water oxidized the sulphides, yielding Fe-rich crusts termed gossans (Sate, 1974).

The area of study lies between Lat. 21° 22' to 21 ° 26' and Long. 39º 30' to 39 ° 37', approximately 40 km east of Jeddah City along the Red Sea coast (Fig. 1). The area is covered by three main rock units namely: schists, metavolcanics and plutonic rocks (Al Shanti, 1967). The metavolcanic sequence is dominated by basalts, andesites, dacites, rhyolites and their tuffs. Two gossan zones namely central and western gossans were discovered by Al-Shanti (1967) within the metavolcanic sequence exposed at the study area. Ground geophysical survey done by ARGAS (1983) and Last et al., (1985) discovered a third alluvium-
covered conductor to the east of central gossan. Sanders and Abdulhay (1987) confirmed the low economic potentially of the western and central gossans and the presence of a board zone of low grade Zn/Ag mineralization for the alluvium covered EM conductor. Copper mineralization associated with brown iron oxide gossans within a volcano-volcanosedimentary sequence was reported by Tawfiq (1977) & Tawfiq and Al-Shanti (1983). They also recorded several smaller mineral occurrences in the vicinity of these gossans. The present study aims to discriminate and map the gossans and iron rich zones exposed at Bahrah area using the processed Landsat ETM+ data and field check.

Several authors utilized the remote sensing techniques for 1) mapping the hydrothermally altered minerals (e.g. Abdelsalam et al., 2000, Ramadan et al., 2001, Madani et al., 2003, and Ramadan and Kontny, 2004), and 2) mapping the local fractures and lineaments that may control the mineralization (e.g. Madani and Bishta, 2002). Hunt (1979) stated that, the remote sensing technique is of valuable use in mapping hydrothermally altered minerals that have distinct absorption features. Abdelsalam et al., (2000) utilized the 5/7, 4/5 and 3/1 band ratios image in RGB for mapping the Beddaho alteration zone in northern Eritrea. Ramadan et al., (2001) mapped the alteration zones associated with gold-bearing massive sulphide deposits, Allaqi suture, South Eastern Desert of Egypt, using Landsat TM color composite ratio images. Ramadan and Kontny (2004), utilized Landsat TM band ratios to study Shalatein District, South Eastern Desert of Egypt, and detected two types of alteration zones controlled by NW-SE structural trend. Salem (2007) utilized the remote sensing techniques for geology and gold mineralization at al Faw - Eqat area, South Eastern Desert, Egypt. He used the PCA and band ratios techniques in tracing the alteration zones possibly gold bearing in the study area. Madani et al., (2008) utilized the band ratio technique for mapping the listwaenite exposures along the southern margin of Jabal Al-Wask serpentinites, western Saudi Arabia.
Geologic Setting of Gossan Zones

Amphibole schist, andesites, andesite porphyries, rhyolites and diabase intruded by plutons of diorites and granodiorites as well as dykes are the main rock units covered the study area (Brown *et al.*, 1963). Gossans and iron rich zones occur within steeply dipping (50°-75°), highly foliated metavolcanics and tuffs sequence composed mainly of basalts, basaltic andesites, dacites and rhyolites. Throughout this study, three field visits were conducted. The following paragraphs describe in detail the geology of both central and western gossans.

The central gossan zone crops out along the NNE-SSW left lateral strike slip fault and occurs as discrete pods of different dimensions Fig. 2(a). These dimensions are favorable for detection and delineation by Landsat imagery (15 and 30m spatial resolution). It is characterized by Fe and Mn stained lenses which occur within steeply dipping (50°-75°), highly foliated siliceous gossans intercalated with andesitic and rhyolitic tuffs. The development of iron staining is variable and increased northward. Lenses rich in sulphides (mainly pyrite) were recorded within
the siliceous gossan and surrounded by a red (hematitic) and yellow (limonitic) iron staining materials Fig. 2(b). The central gossan zone is overlain by thick sequence of metadacite (Sanders and Abdulhay, 1987).

The western gossans Fig. 2(c) consist of brownish limonitic, kaolinitic, sericitic, rhyolitic tuffs of about 6 m thickness underlain by a thick pile of lithic fragments quartz eye rhyolite and grading upward towards the green andesites of about 30 m thickness. Several small exposures of gossan zones were observed northward along the NNE-SSW strike slip fault facing the western gossan zone. Some of them were recorded by the processed Landsat image. The area of study was subjected to low grade metamorphism of green schist facies. The metamorphism event produced locally some quartz veins which cut the volcanic succession in the study area. A NNE-SSW left lateral strike slip fault was observed to displace these veins Fig. 2(d). This trend is the main trend affecting the gossans in the study area.

![Fig. 2](image-url)

**Fig. 2:**

a) Iron (Fe) and Manganese (Mn) staining in siliceous gossan, central gossan.

b) Reddish brown lens embedded within a siliceous gossan rich in pyrite, central gossan.

c) Yellowish brown limonitic gossan (L) overlying the quartz eye rhyolites (R), western gossan.

d) Quartz vein cut by NNE-SSW left lateral strike slip fault, central gossan.
Data Analysis and Discussion

During this study the remote sensing techniques have been applied to discriminate, delineate and map the gossans and iron rich zones which occur within the metavolcanic sequence at Bahrah area, western Saudi Arabia. Results from this study confirm the usefulness of these techniques to discriminate and map these gossan zones. Several iron rich zones were identified in the processed Landsat imagery and verified in the field along the NNE trend and mapped using this approach. Subsets from multispectral and panchromatic Landsat-7 data covering the area of interest were performed using the PCI GeoAnalyst software. Band ratio technique is the most usable technique used to identify and map the alteration zones in several places in the world. In general, Landsat TM band-ratios 5/7 and 3/1 emphasizes clay and Fe minerals that have specific spectral reflectance and absorption features in these bands (Sabins, 1997).

Madani et al., (2003) utilized the Landsat-7 ETM+ data for mapping the hydrothermal alteration zones at Haimur gold mine area, South Eastern Desert, Egypt. They utilized Principal Component Analysis (PCA) and band ratios to map the hydrothermal alteration products. They found that PC5 image represents the altered rock outcrops along the main shear zone at the study area. Also they generated the 5/7, 4/5 and 3/1 band ratio images to discriminate and map the carbonates, Fe-silicates, clay minerals and iron minerals in Haimur gold mine area.

Throughout this study, band ratios and density slicing techniques were used. The following paragraphs describe in detail the discrimination and mapping of the gossans and iron rich zones exposed at Bahrah area.

Mapping Gossan and Iron Rich Zones Using Density Slicing Technique

Density slicing technique was successfully used to map clay- and Fe-rich alteration zones along the the Beddaho Alteration Zone in northern Eritrea using Landsat TM band-ratio 5/7 and 3/1 (Abdelsalam et al., 2000). The density slicing technique converts the continuous grey tone of an image into a series of density intervals, each corresponding to a specific range of digital numbers (DN) (Sabins, 1997). Visual inspection of different band ratio images generated for Bahrah area revealed that the Landsat band ratio 4/5 image is the most favorable ratio that discriminates the gossans and iron rich zones exposed within the metavolcanics sequence at the study area. On 4/5 band ratio image, the gossans and iron rich zones appear to have a black image signature Fig.
3(a). Central and Western gossans have DN values range between 0 and 14. Density slicing technique was performed using these values over a mask area covers the metavolcanic sequence. Fig. 3(b) shows the result of the density slicing of 4/5 band ratio image in which the gossans and iron rich zones were observed as yellow polygons. Visual inspection for the distribution of such polygons revealed that the presence of certain alignment along the NNE-SSW to N-S trends. Field verification revealed the presence of strike slip movement for these trends.

![Image](image_url)

**Fig. 3:**

a) Landsat ETM+ band ratio 4/5 image covers the Bahrah area.

b) Subset image shows the gossans and iron rich zones (yellow) within the metavolcanic sequence generated by density slicing technique.

Under the microscope the siliceous gossan is composed mainly of medium to coarse grained subhedral quartz grains having two different generations. Epidote, apatite, opaques and sericite also occur as accessories and alteration products. Two generations of pyrite having different grain sizes were recorded. The first generation of pyrite is
coarse grained, subhedral and highly fractured Fig. 4(a), whereas the second generation is represented by small tiny crystals occur within gangue minerals. Covellite, chalcocite with little Fe-oxides (goethite) are also observed. The pyrites of western gossan were partially oxidized into Fe-oxide minerals, mainly goethite Fig. 4(b).

Hunt and Salisbury (1970) studied the spectral characteristics of iron minerals and stated the spectral reflectance curves of iron minerals to show low flat spectra. Sabins (1997) stated that the spectra of iron minerals show high red reflectance value around band 3 wavelength region and low reflectance values around blue band. In this study, the gossans have black image signature on 4/5 image which means the low ratio value. Visual inspection of the spectral curves of pyrite and hematite, the main constituents of gossans, Fig. 4 (c and d) show the presence of absorption feature around the wavelength region 0.8 to 0.9 µm which corresponds to the wavelength region of band 4. The presence of such absorption feature may lead to lower the ratio value and yields the black image signature to the gossans.

Fig. 4: a) Highly fractured agglomerated pyrite crystals, P.P.L., P.S., 110X.  
b) Colloform goethite replaced pyrite crystals, P.P.L., P.S., 110X.  
Automatic Lineaments Extraction

The surface expression of geological structures such as, fractures, faults, joints, shear zones and foliations are shown in the form of lineaments on airborne and orbital remote sensing data (Koch and Mather, 1997). Automatic lineament extraction from remote sensing data is an important approach for regional structural studies and mineralization. Recognition of lineaments has been used for mineral exploration studies (Rowan and Lathram, 1980). Madani and Bishta (2002) studied lineaments characterization and their relation to the U-mineralization exposed at Gattar granites, Northeastern Desert, Egypt. The extracted lineament trends are compatible to great extent with the main structural and mineralization trends of the study area.

The lineaments analysis step aims to understand the relationship between the lineament trends (faults) as the main structural element affecting the rock units exposed at the study area and the alignment of the gossan zones. Landsat panchromatic image (15m) was prepared to conduct this test under the user defined parameters of LINE module of PCI software. These parameters produced well defined lineaments compared with those which were produced under the default parameters (Table 1). Automatic lineaments extraction from Landsat panchromatic image was run with three major steps: 1) edge detection, 2) threshold and 3) lineaments extraction. Figure 5, shows the main lineament trends automatically extracted over the metavolcanic sequence contains the gossans and iron rich zones. The main lineament trends are NE-SW, N-S (NNE-SSW, NW-SE constituting the 51.5%, 20.7% and 14.1% respectively. E-W is subordinate direction constitute 13.3% of total lineaments number. On the upper left of Fig. 5 lineament frequency rose diagram shows the high degree of preferred orientation in NE-SW and in NNE-SSW to N-S directions. Result of lineament analysis is in agreement to a large extent with the results of the extensive geophysical studies carried out on the Bahrah area by ARGAS (1983). These studies revealed the presence of two main fault trends (NE and NW) affected the mineralized area. Field investigations revealed that, the strike-slip faults are the most dominating structural fabric in the study area. The strike-slip faults are oriented NNE-SSW (N-S). The NNE–SSW trending lineaments are parallel to the regional Neoproterozoic fabric in the study area and are steeply dipping to the west. The NNE-SSW (N-S) set of strike-slip faults are of left lateral movement. These faults sinistrally offset the east-
west trending quartz veins (Fig. 4d). These quartz veins are good markers indicating the horizontal displacements that vary from a centimeter to meters. Structural information extracted from the lineaments analysis together with the density slicing results and field check were used to generate 1:100 000 image map showing the distribution of gossans and iron rich zones at Bahrah area Fig. 5.

Table 1. User defined and default parameters used for automatic lineaments extraction over Bahrah area.

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<th>Parameter</th>
<th>Default</th>
<th>User defined</th>
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<tr>
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<tr>
<td>Minimum line length</td>
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<tr>
<td>Maximum linkage difference</td>
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</tbody>
</table>

Fig. 5. Image map shows the distribution of gossans, the automatic extracted lineaments and major faults over the Bahrah area with the lineaments frequency rose diagram on the upper left.

Conclusions

This study demonstrates clearly the usefulness of the band ratios and density slicing techniques for mapping the gossans and iron rich zones exposed at Bahrah area, Western Arabian Shield, Saudi Arabia. Visual inspection revealed that, 4/5 band ratio image was found to be the best
discriminator for gossans in which the gossans have black image signature. Spectral curves of pyrite and hematite, the main constituents of gossans, show the presence of absorption feature near band-4, which may be responsible for lowering the ratio value. Several black spots were observed along the NNE-SSW trend parallel to the central and western gossan. To map such spots, the DN values of central and western gossans were determined from 4/5 band ratio image (0-14) and used by density slicing technique to slice the surface gossans and iron rich zones along the NNE-SSW trend. Results of the automatic lineaments extraction using Landsat band-8 revealed that, NE-SW, NNE-SSW (NS) and NW-SE are the main lineament trends affecting the study area. These trends constitute 51.5, 20.7 and 14.1% respectively. E-W trend is subordinate and constitutes 13.3% of the total lineaments number. A map of scale 1:100 000 shows the gossans and iron rich zones distributed over the Landsat (FCC) background was generated by integration of the results of density slicing, field verification and lineament analysis.

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References


استخدام صور اللانداسات في تحرير الجوسان والنقاط الغنية بالحديد بمنطقة بحيرة غرب الدرع العربي، المملكة العربية السعودية

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أستاذ مشارك – قسم الثروة المعدنية والصخور، كلية علوم الأرض، جامعة الملك عبد العزيز، المملكة العربية السعودية

المستخلص: تهدف هذه الدراسة إلى استخدام صور اللانداسات في تحرير صخور الجوسان والنقاط الغنية بالحديد بمنطقة بحيرة غرب الدرع العربي، المملكة العربية السعودية. حيث يظهر الجوسان مصاحباً للرواسب الناعمة المكونة من صخور البازلت، والأيديزيت، والداسيت، والربليت، والتالت البركاني المصاحب.

في هذه الدراسة تم استخدام كل من تقنية قسمة النطاقات وتقنية تقطيع الكثافة لتمييز صخور الجوسان. وأظهرت النتائج أن صورة قسمة النطاقات 5/4 هي الأسبق لتمييز الجوسان والنقاط الغنية بالحديد في منطقة الدراسة حيث تظهر باللون الأسود. وقد أعظم هذه اللون إلى وجود ظاهرة امتصاص لمعدن البيريت والماجنيتيت في النطاقات الطيفية التي تغطي الحزمة رقم 4. ومن هذه الصورة تم استخلاص الأرقام المميزة للجوسان وتم استخدامها في تقنية تقطيع الكثافة لتحرير صخور الجوسان والنقاط الغنية بالحديد بمنطقة الدراسة. وفي هذه الدراسة أيضاً تم استخلاص الظواهر الخصية آلياً باستخدام صورة النطاق رقم 4 بواسطة برنامج PCI. وقد أظهرت النتائج أن الاتجاهات الرئيسية بمنطقة...
الدراسة هي على النحو التالي: شمال شرق-جنوب غرب، وجنوب-شمال، وشمال غرب-جنوب شرق وهذه الاتجاهات تمثل حوالي 51,5%, و70,7% و14,1% من العدد الكلي للظواهر الخطية. ومن نتائج دراسة قسمة النطاقات واستخلاص الظواهر الخطية والتحق الفعلي، تم إنتاج خريطة مصورة بقياس رسم 1:10,000 توضح أماكن وجود الجوسان والنقاط الغنية بالحديد بمنطقة بحرة.