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# Spectroscopy of Gossans and associated lithology and its implication in geo exploration- A Case Study in the Parts of Rajpura-Dariba Group, Rajasthan, India

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**Abstract: The gossan exposures are sparsely distributed in the Dariba area and for detection and mapping of gossan and its associated lithology, spectral signatures have been used. Spectral reflectance and absorption features in VNIR-SWIR (visible and near-infrared - shortwave infrared) domain provide the scope for delineating the mineralogy of rocks. In the study, a few spectral mapping methods like Spectral angle mapper, Spectral information divergence and Band ratio indices were applied to ASTER (Advanced Space borne Thermal Emission Reflection Radiometer) calibrated data for delineating the lithology. These mapping methods could delineate boundaries for gossan and its associated rocks of Dariba; but above out of all mapping methods, spectral angle mapper spatial map has been validated with base detailed geological map in quantitatively and accuracy much better than spectral information divergence indices. The band ratio can demarcate the boundaries for gossans in the 4/2 ratio map, in the same way for associated rocks of Carbonates were well delineated in the (7+9)/8 ratio map and Quartzite 4/6 ratio map. Finally, the overextended boundaries of Dariba gossans and associated units found in the above validated spatial map, can be confirmed with field evidence can be helpful to update the base map of Dariba.**

**Index Terms:Spectral signature, Band ratio, Spectral mapping, ASTER, Kappa coefficient**

## I. INTRODUCTION

Gossan is intensely oxidized, weathered or decomposed rock and indicates enrichment of sulphide minerals underneath. Gossans are usually restricted to the upper and exposed part of an ore deposit (mostly lead-zinc deposits). The chief minerals constituted in Dariba gossan deposits are iron oxides of Limonite (FeO (OH).n$H_2O$), Goethite ($Fe_3O(OH)$), Jarosite ($KFe_3(So_4)_2(OH)$), Hematite ($Fe_2O_3$) etc. The gossan/leached cap formation process commences by ore assemblages and their associated wall rocks encounter to interface between the water table and the overlying surficial zone, this is, in essence the transition from a deducing to an oxidizing environment (Roger, Taylor., 2012). Dariba area sulphide ore mineral assembles transition from the water to surface via weathering; there are numerous factors which contribute to the final surface exposures as gossan caps. The main objective of the work includes the usage of the spectral signatures for generating a spatial map by different mapping methods for delineating the gossan and associated lithology of the Dariba group and understanding the rock spectra variations in material composition, to find accuracy in the spatial map for gossan distribution over the area and to identify mapping method suitable for easily mapping of the gossans distribution and associated lithounits.Noori et al (2019) delineated alteration zones allied with polymetallic vein-type mineralization in Northern Iran using Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER).Gahlan and Ghrefat (2018) utilized Landsat 8 OLI imagery for detecting gossans/alteration zones in arid regions of Eastern Arabian Shield and for further investigations using remote sensing tools like pan sharpening, PCA, minimum noise fraction (MNF), and band ratio. Clabaut et al (2018) analyzed Gossans of the Canadian Arctic by using band rationing, PCA and neural networks and geo big data (Landsat-8, Arctic digital elevation model lithological maps). Amin Beiranvand Pour et al (2013) confirmed hydrothermal alteration zones allied with gold mineralization of East Malaysia using remote sensing tools.

## II. Study Area

Dariba is well known for lead-zinc deposits of Rajpura-Dariba group, BhilwaraSupergroup and lies between longitudes 74°05'49" &74°10'06" and latitudes 24°55'40"&25°0'34" (Fig. 1). Dariba has located around 45km from NE of Udaipur city, 15 km NNE of Fatehnagar.

## III. GEOLOGY OF THE DARIBA

The Rajpura-Daribagossan belt is a polymetallicsulphide mineralization zone that lies between Dariba and Rajpura hamlets in Rajsamand dist., Rajasthan has a length of 4.5 km with 2-40 m in width (Raja Rao et al., 1971). The strike of the belt is NNE-SSW to N-S direction, the dip is steeply towards East with more than 64°. The chief ore minerals in the Dariba area are Sphalerite, Galena, Pyrite and Pyrrhotite and other minor minerals like Arsenopyrite, Cubanite, Mackinawite, Polybasite etc. The Dariba gossan mineralization is associated with Calc-Carboniferous schist, Quartzites, Marble/Dolomite of Rajpura-Dariba group and Bhilwara super group of Archean age.

## IV. METHODOLOGY

The present study has been carried out based on the spectral signatures collection from the Dariba group of rocks and mapping of gossan and associated parts through calibrated ASTER data over the area for achieving the objectives. The data used in the work include ASTER (Advanced Spaceborne Thermal Emission Reflection Radiometer) Level 1B data for mapping of Gossans and associated lithology in parts of Dariba area, ground spectroradiometer (Fieldspec3) for spectral library generation, spectral parameters of Dariba rock samples and geological map of the Dariba area. The visible and near infrared, short wave infrared (VNIR-SWIR) helped to identify the mineral components in rock samples (Marble/Dolomite and Quartzites), which are major lithounits of Gossans of the area. Spectro radiometer with detectors - 512element Si photodiode operates in 350-1000nm and InGaAs photodiode operative in 1000-2500nm and Spectral information divergence (SID) have been employed in the work. The ASTER collected information by spectral domains of Visible and Near Infrared (VNIR), Short wave Infrared (SWIR) and Thermal Infrared (TIR), which are having 14 spectral bands. Other details of the methods and materials are explained under Spectroscopic studies and Satellite data processing.

## IV. SPECTROSCOPIC STUDIES

Spectroscopy is the study of light as a function of wavelength that has been emitted, reflected/scattered from matter (Clark, 1999). In the recent development of sensor technology, spectroscopy has been used for studying the earth’s surface exposures (rocks/minerals). In a geological point of view, VNIR-SWIR (visible and near infra-red, short wave infrared) domain helps to identify the mineral components in rock samples. In this work, three different rock samples were collected from the field, which are major litho units like Gossan and its associated rocks, carbonate rock (Marble/Dolomite) and Quartzite rock. The spectral profiles have been generated for the Dariba group of rocks (Fig. 2) using the ASD field Spectroradiometer in the laboratory, which is having wavelength 350-2500 nm range with a spectral resolution of 3@700nm and 10nm@1400/2100nm (ASD Fieldspec3, 2011). The reflectance values of Gossans, associated carbonate rock (Marble/Dolomite) and Quartzites are around 0.2, 0.4 and 0.6 respectively. The reflectance values of Gossans, associated carbonate rock (Marble/Dolomite) and Quartzites with that of Goethite-USGS, Calcite-USGS and Quartz-USGS. The reflectance values of Goethite-USGS, Calcite-USGS and Quartz-USGS with values of around 0.60, 0.85 and 0.90 respectively. Spectro radiometer has two detectors - 512element Si photodiode operate in 350-1000nm and InGaAs photodiode operative in 1000-2500nm. The rock samples are giving different spectral signatures because of mineralogically aggregation and composition wise different from each other. These spectral signatures help to understand the atomic processes involving the shape of absorption features of each mineral in a particular rock. In generally the absorption feature of rock or minerals which are less than 1.0 μm range is useful for spectral identification of minerals containing $Fe^{+2}$ and $Fe^{+3}$ in the VNIR domain (Kruse, 2011); and molecular vibrational features, occurring between 1.0 and 2.5 μm in the SWIR, are diagnostic of minerals containing anion groups such as Al-OH, Mg- OH, Fe-OH, Si-OH, $CO_3$ (Clark et al., 2007). The VNIR-SWIR electromagnetic domain is characterized by the absorption features resulting either due to electronic processes or vibrational processes and therefore these absorption signatures delineate minerals in rocks successfully (Cloutis et al. 2006, Cloutis et al. 2010, Kruse, 2011). In the present study rock samples show absorption features at 490 and 900 nm for Gossans, 2206 nm for Quartzites and 2336 nm for carbonates of marble/calcite rich. These signatures can be predicted to assess the mapping of lithology and any alterations of the Dariba area.

## IV. SATELLITE DATA PROCESSING

The work has been carried out by using the ASTER level 1B multispectral data for mapping of Gossans and associated lithology in parts of the Dariba area. The ASTER acquires the information through three major spectral domains i.e. Visible and Near Infrared (VNIR), Short wave Infrared (SWIR) and Thermal Infrared (TIR), which are having 14 spectral bands, VNIR domain having 3bands, 6bands in SWIR and 5bands for TIR with the spectral resolution is 15, 30, 90m respectively, with total coverage of the scene is 60 sq.km area. From a geoexploration point of view in this study, data has resized to ASTER spectral bands of the VNIR-SWIR domain (9 spectral bands) for delineation of the gossan and associated lithology in parts of the Dariba group.

ASTER level 1B data has been empirically calibrated by the ratio between the image spectra of one unit on the image and its corresponding field or lab spectra for the calibrated data. The empirical line calibration forces spectral data to match selected field reflectance spectra. This empirical correction derives the constant gain and offsets for each band to force the best fit between sets of field/lab spectra and its corresponding image spectra characterizing the same ground areas thus removing atmospheric effects, this noise due to instrument artefacts and viewing geometry (Vander Meer, 2001) after calibrated data product can be used to generate spatial maps using spectral signatures as endmember to different mapping methods like spectral angle mapper (SAM) and spectral information divergence (SID).

The SAM is a physically based spectral classification that uses an n-D angle to match pixel to reference spectra. This supervised classification method could be determined the spectral likeness between two spectra by recording the angle between the spectra in a space with dimensionality equivalent to illumination and albedo effects (Kruse, F. A., etal 1999). The ASTER Level 1B calibrated data which helps to correlate the spectra of any unit in image spectra and its corresponding rock spectra of laboratory based spectra (image spectra of vegetation and its corresponding ASTER convolved USGS deciduous spectra). This calibrated data can be directly used for mapping of gossan and its associated lithology using mapping method of SAM. The end member has been collected from image for different geological units like Gossan, Carbonate rock and Quartzites. The above rock spectral signatures treated as end members and these end members have given to calibrated data for SAM (Fig. 3). The spatial map of SAM has been validated with base geological map of the Dariba area. The quantitative validation of SAM spatial map with base geological boundaries as a region of interest is 65.942% (Table 1).

Spectral information divergence (SID) is a spectral classification method that utilizes a divergence measure to match pixels to reference spectra. In the SID results finding the smaller divergence between pixels to corresponding spectra, it indicates the pixels are similar. This SID spatial map (Fig. 4) has been generated for the Dariba deposits using the same end members to ASTER calibrated data. This SID spatial map has been quantitatively validated with a base geological map, the accuracy for the SID map with the base map is 49.0262% (Table 2).

The Band Ratio technique is to produce the mineral map to display the spectral contrast of specific absorption features for each major mineral of rocks (Junek, 2004). The band ratio is to enhance the spectral differences between the bands and reduce the effects of topography. Dividing one spectral band by another spectral band of calibrated ASTER spectral band data, enhances the mineral image for different litho units of the Dariba area. In this study, based on the spectral absorption features of ASTER spectral band were chosen for mapping of gossan and its associated rock (Freek D. van der Meer, et al., 2012). The spectral bands have used 4/2 for Gossan, (7+9)/8 Carbonate rocks and 4/6 Quartzites mapping. The above band ratios are given the best mapping ratios for gossan and its associated rocks distributed in the Dariba (Fig. 5).

## V. RESULTS AND DISCUSSIONS

The rock samples which are collected from the Rajpura-Dariba group, are geochemically different. The Gossans are dominated by minerals of Goethite / Jarocite / Limonite etc with limited silica particles. As per the observation of results in spectral profiles of the Dariba rocks, the absorption features (spectral signatures) are explained for each sample. The gossan is showing the absorption feature at 494 nm because of goethite mineral domination (USGS Goethite mineral at 484); water absorption features for gossans were found approximately at 1435nm,1931nm and another absorption feature was observed at 2207nm, this signature due to the presence of Quartz. The monitoring of gossan absorption results shows that Gossans are mainly composed of Goethite and a minor quantity of Quartz (silica). The Dariba gossans are formed along with silicification processes (best example we can see Gossans at Rajpura village, showing the silicification within the gossan belt). Another rock sample collected from the Dariba area was carbonate rock (dolomite) variety, this carbonate rock sample showed the absorption signatures at 2336nm because of calcite mineral dominant (USGS calcite mineral absorption signature at 2337nm), and water absorptions for this carbonated rock at 1414nm, 1915nm. Quartzites is another sample, which is showing the absorption feature at 2209 nm, due to Quartz mineral presence(USGS Quartz mineral signature at 2198nm), and other absorption features like water absorption feature at 1438 and 1931nm. The spectral parameters for the Dariba group of rocks and its corresponding minerals are compiled (Table 3). These spectral properties are depth, width, asymmetry, area and wavelength absorption features, all parameters help to understand the pattern of absorption feature, asymmetry calculation, the grain size difference in rock/mineral samples etc. The spectrometric properties like depth of spectral profiles of one rock can be calculated as the reflectance value at the shoulders (high reflectance value) minus the reflectance value of absorption band minimum value (low reflectance value), which explains the mineral/aerosol abundance in the rock. The width of the absorption feature can be derived by the ratio of the sum of the area absorption feature at left and right side values ($A_{all}$) (reflectance values) to the depth of the absorption multiplied by 2. The Asymmetry calculation based on the formula $S= 2(A_{left}/A_{all}) - 1$, which understand based on the range between -1 to 1, if it is S is equal to zero which is a symmetrical curve and if the S value is -1 to-1 but not zero, which explains the spectral curve is asymmetry. The absorption feature of rock indicates the mineral composition (Arindam et al. 2012). Those above spectral signatures were used for mapping gossan and its associated rock.

The SAM and SID maps were generated for the Dariba rocks using the spectral signatures, those spatial maps are quantitatively validated with based geological maps in different amounts. Computed the change detection statistics for SAM and SID images to understand the changes between the two classification images and this analysis identifies the different classes into which pixels changed in the final state image (Table 4). Here the spectral angle in radiance 0.05 value sustained for SAM and SID spatial mapping.

The Band Ratio technique used in this study for mapping individual rocks of the Dariba using ASTER convolved spectral signatures (Fig. 6). The band ratio maps were generated for gossan using spectral bands 4/2, (4+5)/2 and 4/1; for carbonate rock mapping using (7+9)/8 and 5/8; and for Quartzite mapping 4/6 and (4+5)/6. The above spectral bands have used maps for mapping individual rocks, these ratio maps for gossan and its associated rocks has explained in Table 5, which were validated with a base geological map of the Dariba area. The outcome for gossan mapping is a 4/2 ratio map for gossan distribution over the area than other gossan ratio maps. In the same case associated rocks, like carbonate rock mapping delineated in ratio map of (7+9/8) than 5/8 ratio map; and another rock Quartzite mapping well-extracted boundaries in 4/6 ratio map than ratio map of (4+5/6).

## V1. LIMITATION OF THE STUDY

In the present work, the authors tried to identify the Gossan exposures using spectroscopy and RS techniques as Gossans are pathfinders for sulphide minerals (Pb-Zn deposits). In the study, the main limitation faced was the lack of the best Indian hyperspectral data sets. In place of this, the authors used ASTER multi-spectral data which can give best results for mineral or rocks mapping. India launched hyperspectral data sets in previous years but that was having calibration and noise problems. That is why no researchers are using this data for their research works. The main limitation is that gossans are very limited in distribution in India and RajpuraDariba is the best monument place for Gossans in India, which are lining on ASTER data 1 to 3 pixels only for mapping. Using these pixels, tried to identify and mapping of gossans and their associated rocks in the present study. The present results are not perfectly matching with the ground boundary of maps published by the Geological survey of India.

## VII CONCLUSIONS

The study reveals that SAM and SID spatial maps were generated using the spectral signatures of the Dariba rocks. The accuracy of the SAM spatial map is much better than SID spatial map, the SAM spatial map of gossan and its associated lithology of the Dariba has been validated with ground based geological map. Band ratio maps were generated for gossan and its associated rocks of the Dariba using the ASTER spectral bands. In those ratio maps, one of them has been validated with ground-based geological map, those are selected for mapping of gossan well demarcated in 4/2 ratio map and other rocks like carbonate rock, Quartzite were well-delineated boundaries in (7+9/8) and 4/6 respectively. In all spatial maps of SAM, the SID band ratio showing the overextended boundaries, can be conformed to field evidence or could be a mixture of weathered products of the above rocks.

## References


Amin Beiranvand Pour, MazlanHashim&JohnvanGenderen (2013). Detection of hydrothermal alteration zones in a tropical region using satellite remote sensing data: Bau goldfield, Sarawak, Malaysia. Ore Geology Reviews, Volume 54, pp.181-196

ArindamGuha, DebashishChakraborty, Ekka, A. B., Kaushik, P., VinodKumar, K., Chatterjee, S., Subramanium, S., &Ananthrao, D. (2012). Spectroscopic Study of Rocks of Hutti-Maski Schist Belt, Karnataka. Journal Geological Society of India, 79, pp.335-344.

Clabaut, E., Lemelin, M., Germain, M., Williamson, M.C.,& Brassard, E. (**2020**). A Deep Learning Approach to the Detection of Gossans in the Canadian Arctic. Remote Sens. 12, 3123. https://doi.org/10.3390/rs12193123

Clark, R. N. (1999). Spectroscopy of Rocks and Minerals, and Principles of Spectroscopy, in Manual of Remote Sensing, 3, Remote Sensing for the Earth Sciences (Chapter 1), (A.N. Rencz, ed.) John Wiley and Sons, New York, pp.3-58, http://speclab.cr.usgs.gov/PAPERS.refl-mrs/refl4.html (accessed online on 15. 06.2012).

Clark, R.N., Swayze, G.A., Wise, R., Livo, E., Hoefen, T., Kokaly, R., &Sutley, S.J. (2007). USGS digital spectral library splib06a: U.S. Geological Survey, Digital Data Series 231.

Cloutis, E., Klima, R. L., Kaletzke, L., Coradinia, Golubeva, L. F.,& McFadden, L. (2010). The 506nm absorption feature in pyroxene spectra: Nature and implications for spectroscopy-based studies of pyroxene-bearing targets. Icarus, 207(1), pp.295-313. Elsevier Inc. doi: 10.1016/j.icarus.2009.11.025.

Cloutis, E., Hawthorne, F., Mertzman, S., Krenn, K., Craig, M.,&Marcino, D. (2006). Detection and discrimination of sulfate minerals using reflectance spectroscopy. Icarus, 184(1), pp.121-157. doi: 10.1016/j.icarus.2006.04.003.

Envi 4.8, (2011). Tutorials/band ratios

Freek D. van der Meer, Harald M.A. van der Werff, Frank J.A. van Ruitenbeek, Chris A. Hecker, Wim H. Bakker, Marleen F. Noomen, Mark van der Meijde, E. John M. Carranza, J. Boudewijn de Smeth&TsehaieWoldai. (2012). Multi- and hyperspectral geologic remote sensing: A review., International Journal of Applied Earth Observation and Geoinformation., 14, pp.112-128.

Freek, D., van der Meer., Harald, M.A., van der Werff, Frank, J.A., van Ruitenbeek, Chris A. Hecker, Wim H. Bakker, Marleen F. Noomen, Mark van der Meijde, E. John M. Carranza,J. Boudewijn de Smeth&TsehaieWoldai. (2012). Multi- and hyperspectral geologic remote sensing: A review; International Journal of Applied Earth Observation and Geoinformation, 14, pp.112-128.

Gahlan, H., Ghrefat, H. (2018). Detection of Gossan Zones in Arid Regions Using Landsat 8 OLI Data: Implication for Mineral Exploration in the Eastern Arabian Shield, Saudi Arabia. Nat Resour Res **27**, pp.109–124. https://doi.org/10.1007/s11053-017-9341-8

http://www.ga.gov.au/image cache/GA7833.pdf.

http://en.wikipedia.org/wiki/Gossan

http://www.asdi.com/products/fieldspec-spectroradiometers/fieldspec-3-hi-res-portable-spectroradiometer

http://www.portal.gsi.gov.in/portal/page?_pageid=127,529429&_dad=portal&_schema=PORTAL

Junek, P. (2004).Geological Mapping in the Cheleken Peninsula, Turkmenistan Area Using Advanced Spaceborne Thermal Emission and Reflection Radiometer (Aster) Data.

Kruse, F. A. (2011). Mapping surface mineralogy using imaging spectrometry, Geomorphology, Elsevier B.V. doi: 10.1016/j.geomorph.2010.09.032.

Kruse, F. A., Lefkoff, A. B., Boardman, J. B., Heidebrecht, K. B., Shapiro, A. T., Barloon, P. J., & Goetz, A. F. H. (1993). The Spectral Image Processing System (SIPS) - Interactive Visualization and Analysis of Imaging spectrometer Data. Remote Sensing of the Environment, 44, pp. 145-163.

Noori, L.,Pour, A.B. , Askari, G. , Taghipour, N. , Pradhan, B. , Lee, C.W., &Honarmand, M. (2019).Comparison of Different Algorithms to Map Hydrothermal Alteration Zones Using ASTER Remote Sensing Data for Polymetallic Vein-Type Ore Exploration: Toroud–Chahshirin Magmatic Belt (TCMB), North Iran. Remote Sens., 11, 495. https://doi.org/10.3390/rs11050495

Raja Rao, C.S., Poddar, B.C., Basu, K.K., & Dutta, A.K. (1971). Precambrian stratigraphy of Rajasthan: a review. Records Geological Survey of India, 101(2), pp. 60-79.

Roger Taylor. (2012). Gossans and leached capping, Field assessment. 1st Edition, Book, Spinger, pp.33.

Van der Meer, F. D., & De Jong, S.M. (2001). Imageingspectraometry: Basic principles and prospective application, 4, pp.403.

http://reslib.com/book/Imaging_spectrometry__Basic_principles_and_prospective_applications#8.

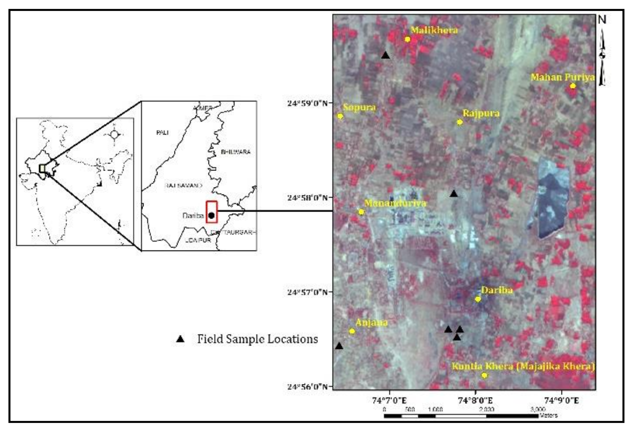


**Fig. 1: Study area of Dariba-Rajpura in Rajasthan**

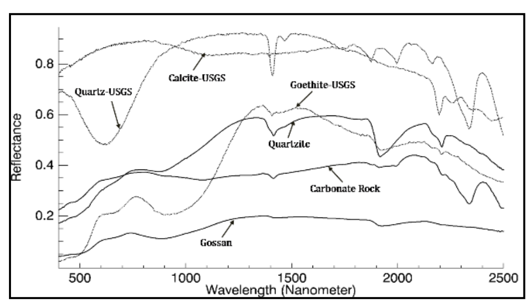


**Fig. 2: Spectral profiles of Dariba rocks and its comparison with USGS minerals**

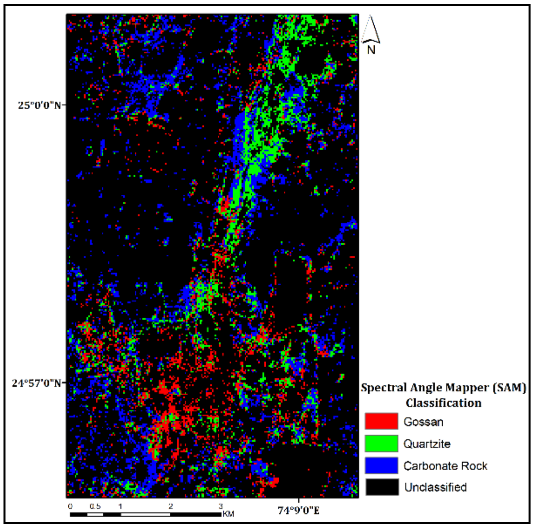


**Fig. 3: Dariba rocks classification from spectral angle mapper (SAM)**

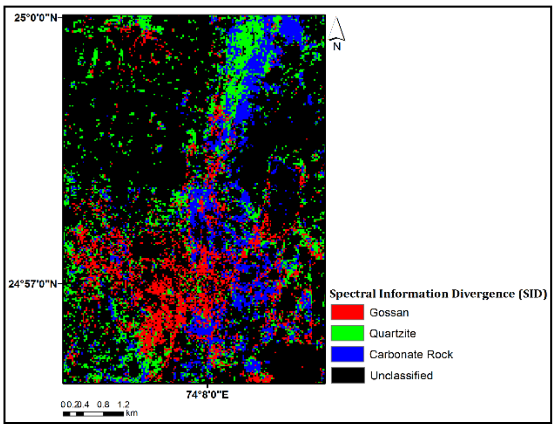


**Fig. 4: Dariba rocks classification from spectral information divergence (SID)**

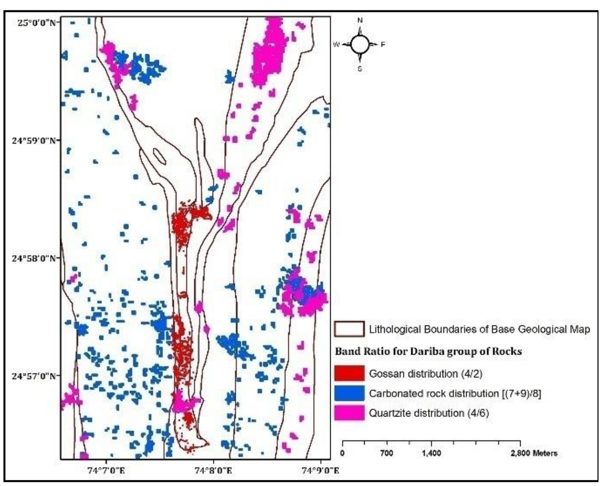


**Fig. 5: Band ratio technique applied for Dariba rocks and its distribution comparison with base geological map**

**Table 1: The quantitative validation of Spectral Angle Mapper with base map**

Overall Accuracy = (91/138) 65.9420%
Kappa Coefficient = 0.5077

| Class | Ground Truth (Pixels) Gossan | Carbonate roc | Quartzite | Total |
|---|---|---|---|---|
| Unclassified | 8 | 22 | 2 | 32 |
| Gossan [Red] | 7 | 8 | 0 | 15 |
| Carbonate Roc | 0 | 45 | 4 | 49 |
| Quartzite [Gr | 2 | 1 | 39 | 42 |
| Total | 17 | 76 | 45 | 138 |

| Class | Ground Truth (Percent) Gossan | Carbonate roc | Quartzite | Total |
|---|---|---|---|---|
| Unclassified | 47.06 | 28.95 | 4.44 | 23.19 |
| Gossan [Red] | **41.18** | 10.53 | 0.00 | 10.87 |
| Carbonate Roc | 0.00 | **59.21** | 8.89 | 35.51 |
| Quartzite [Gr | 11.76 | 1.32 | **86.67** | 30.43 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 |

| Class | Commission (Percent) | Omission (Percent) | Commission (Pixels) | Omission (Pixels) |
|---|---|---|---|---|
| Gossan [Red] | 53.33 | 58.82 | 8/15 | 10/17 |
| Carbonate Roc | 8.16 | 40.79 | 4/49 | 31/76 |
| Quartzite [Gr | 7.14 | 13.33 | 3/42 | 6/45 |

| Class | Prod. Acc. (Percent) | User Acc. (Percent) | Prod. Acc. (Pixels) | User Acc. (Pixels) |
|---|---|---|---|---|
| Gossan [Red] | 41.18 | 46.67 | 7/17 | 7/15 |
| Carbonate Roc | 59.21 | 91.84 | 45/76 | 45/49 |
| Quartzite | 86.67 | 92.86 | 39/45 | 39/42 |

**Table 2: The quantitative validation of Spectral Information Divergence with base map**

| Sample No | Wavelength (nm) | Depth | Width (nm) | Area | Asymmetry (DN) |
|---|---|---|---|---|---|
| Gossan | 2207 | 0.10399252 | 92 | 10.520581 | -0.33588925 |
| | 1921 | 0.10846602 | 99 | 11.186326 | -0.49083263 |
| | 1415 | 0.048354428 | 41 | 2.76006 | -0.25341417 |
| | 901 | 0.11281818 | 74 | 9.108449 | 0.80040892 |
| | 494 | 0.10745832 | 92 | 9.4724579 | -0.18415361 |
| Goethite (USGS) | 505 | 0.587256 | 42 | 24.632 | -0.85396 |
| | 2214 | 0.011756 | 19 | 0.202684 | 0.10757 |
| Quartzite | 2209 | 0.042377393 | 77 | 3.2546239 | -0.30154336 |
| | 1932 | 0.41159396 | 136 | 58.785782 | -0.38199479 |
| | 1439 | 0.20934009 | 126 | 29.405104 | -0.35720466 |
| Quartz (USGS) | 2197 | 0.165794 | 35 | 6.134557 | -0.04718 |
| Carbonate Rock | 2336 | 0.30610459 | 91 | 29.742375 | 0.37183846 |
| | 1414 | 0.13966914 | 238 | 29.996678 | -0.63101476 |
| | 1915 | 0.093108638 | 64 | 5.3765558 | -0.13590969 |
| Calcite (USGS) | 2336 | 0.327528 | 87 | 28.97351 | 0.412264 |

**Table 3: spectral parameters of Dariba group of rocks and its corresponding USGS minerals**

| Pixel Counts | Gossan [Red] 260 points | Quartzite [Green] 3155 points | Carbonate Rock [Blue] 814 points | Unclassified | Row Total | Class Total |
|---|---|---|---|---|---|---|
| Unclassified | 314 | 353 | 504 | 162937 | 164108 | 164108 |
| Gossan [Red] 260 points | 5189 | 887 | 1484 | 3721 | 11281 | 11281 |
| Quartzite [Green] 3155 points | 1743 | 3126 | 16643 | 7522 | 29034 | 29034 |
| Carbonate Rock [Blue] 814 points | 390 | 5963 | 10842 | 6709 | 23904 | 23904 |
| Class Total | 7636 | 10329 | 29473 | 180889 | 0 | 0 |
| Class Changes | 2447 | 7203 | 18631 | 17952 | 0 | 0 |
| Image Difference | 3645 | 18705 | -5569 | -16781 | 0 | 0 |
| **Percentages** | **Gossan [Red] 260 points** | **Quartzite [Green] 3155 points** | **Carbonate Rock [Blue] 814 points** | **Unclassified** | **Row Total** | **Class Total** |
| Unclassified | 4.112 | 3.418 | 1.71 | 90.076 | 100 | 100 |
| Gossan [Red] 260 points | 67.954 | 8.587 | 5.035 | 2.057 | 100 | 100 |
| Quartzite [Green] 3155 points | 22.826 | 30.264 | 56.469 | 4.158 | 100 | 100 |
| Carbonate Rock [Blue] 814 points | 5.107 | 57.731 | 36.786 | 3.709 | 100 | 100 |
| Class Total | 100 | 100 | 100 | 100 | 0 | 0 |
| Class Changes | 32.046 | 69.736 | 63.214 | 9.924 | 0 | 0 |
| Image Difference | 47.734 | 181.092 | -18.895 | -9.277 | 0 | 0 |
| **Area (Square Meters)** | **Gossan [Red] 260 points** | **Quartzite [Green] 3155 points** | **Carbonate Rock [Blue] 814 points** | **Unclassified** | **Row Total** | **Class Total** |
| Unclassified | 282600 | 317700 | 453600 | 146643300 | 147697200 | 147697200 |
| Gossan [Red] 260 points | 4670100 | 798300 | 1335600 | 3348900 | 10152900 | 10152900 |
| Quartzite [Green] 3155 points | 1568700 | 2813400 | 14978700 | 6769800 | 26130600 | 26130600 |
| Carbonate Rock [Blue] 814 points | 351000 | 5366700 | 9757800 | 6038100 | 21513600 | 21513600 |
| Class Total | 6872400 | 9296100 | 26525700 | 162800100 | 0 | 0 |
| Class Changes | 2202300 | 6482700 | 16767900 | 16156800 | 0 | 0 |
| Image Difference | 3280500 | 16834500 | -5012100 | -15102900 | 0 | 0 |

**Table 4: Band ratio techniques for delineation of Gossan and its associated rocks of Dariba group with existence in base geological map**

| Litholog y | Ratio Maps | Mapping |
|---|---|---|
| Gossan | 4/2 | Map is in accordance with existing geological map |
| | 4/1 | Not in accordance with existing the geological map |
| | (4+5) /2 | Not in accordance with existing the geological map |
| Carbonat ed Rock | (7+9) /8 | Map is in accordance with existing geological map |
| | 5/8 | Not in accordance with existing the geological map |
| Quartzite | 4/6 | Map is in accordance with existing geological map |
| | (4+5) /6 | Not in accordance with existing the geological map |

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