MINERAL IDENTIFICATION BY BAND RATIOS AND FEATURE ORIENTED PRINCIPAL COMPONENT SELECTION TECHNIQUES IN THE BHUKIA REGION, RAJASTHAN

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ABSTRACT

The applications of remote sensing are dynamic and ever growing. In the field of mineralogy in particular, the application of remote sensing reached a new dimension with the advent of hyperspectral remote sensing which includes both imaging and spectroscopy in a single system. The basic concept behind this mineral identification through remote sensing lies in the minerals' uniqueness in the reflectance and absorption pattern across different wavelengths.

In this study Band Rationing and Feature Oriented Principal Component Selection (FPCS) have been applied to VNIR-SWIR bands of ASTER data set to identify the minerals in the study area. By studying the spectral signatures of the minerals in the spectral range of the datasets and by referring to certain previous works, appropriate Band Ratios have been operated and the minerals have been identified and matched through the USGS spectral mineral library. With this basic approach, the FPCS technique has also been applied where Principal Component Analysis (PCA) has been functioned on a set of four bands selected by considering the spectral signatures of the minerals and then analyzing the eigenvectors.

Mineral spectra have also been generated from the field samples for the validation purpose and the spectra thus obtained have been matched with the USGS spectral mineral library.

Finally, calcium rich minerals such as Dolomite, Diopside, Calcite, and Talc, clay minerals such as Kaolinite, Illite, Montmorillonite and Nontronite and a few iron rich minerals such as Pyrrhotite, Jarosite and Hematite have been documented. The minerals obtained were in support of the GSI geological map of the area.

Keywords: Band ratio, FPCS, Mineral identification, SAM, Spectroscopy

INTRODUCTION

Minerals are distributed all over the Earth's arena abided by certain specific structural and chemical control. Mineral identification and exploration have been operating since the very early days of remote sensing applications. The methods and the techniques in this niche field have been emerging ever since.

Band rationing and Principal Component Analysis (PCA) have been the important technique of remotely sensed data for mineral exploration (Sabins 1999). The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), has a better spectral resolution with six bands in the SWIR region and three in the Visible Near Infrared region, which helps in obtaining detailed information about the altered zones detected in comparison to the other multispectral data. Mineral assemblages like those including clay and carbonate minerals could easily be documented.

In this paper, the obtained results from these classical techniques have been matched with the recent technique of endmember selection by processing the hyperspectral equivalent data of the area.

BACKGROUND

In this study both Band rationing and PCA operations are used for spectral enhancement. The ratio images thus enhance the spectral contrast among the bands. By applying band ratios, the spectral information is conveyed irrespective of the scene illumination conditions (Lilisand, 2008). On the other hand, Principal Component Analysis is a statistical technique which suppresses the dominant irradiance effects of all the bands and optimizes the imagery by removing the correlation which is inherent to the sensor (Crosta and Moore,1989).

In the Feature oriented Principal Component Selection (FPCS) technique as introduced by Crosta and Moore in 1989 the spectral responses of the concerned target minerals and the respective eigenvector values are studied to calculate the principal components and the relationship thus established helps to determine which principal component has the maximum spectral information about the target minerals and the dark or bright pixels it is contained in. This technique was later modified by Loughlin (1991), in his approach a particular set of bands are selected considering the minerals to be targeted and the Principal Component Analysis is operated on those set of bands. This ensured that certain topographic materials such as vegetation is not mapped and only the target minerals are mapped. This technique has been successfully used for mineral exploration.

STUDY AREA

The study area lies in the Bhukia region of Rajasthan. The area includes parts of Udaipur, Dungarpur and Banswara districts of Rajasthan. The area lies between longitudes 74°0'0" to74°7'1.2" and latitudes 24°7' 1.2" to 23°50'9.6" Geologically the area manifests rocks of Precambrian origin and comprises the Northwestern Indian craton. The area depicts a wide variety of lithological and tectonic units representing the Banded Gneissic complex as the basement rock (Heron, 1953), Proterozoic fold belts (Aravalli and Delhi) and Late Proterozoic igneous suites (Malani, Jalore, and Siwana).

The area under study is a highly metamorphosed patch of land thus the major rock type in the area is depicted by medium to high grade metamorphic rocks. Though in the northern portion there is a significant amount of emplacement of igneous body comprising of granite and also some conglomerate patches of the sedimentary origin. The major rock type in the region is Quartz-chlorite schist, Garnetiferous biotite schist, Phyllite-mica schist, Dolomitic marble, para-gneiss, and amphibolite schist. The geological map of the study area is shown in the figure1.

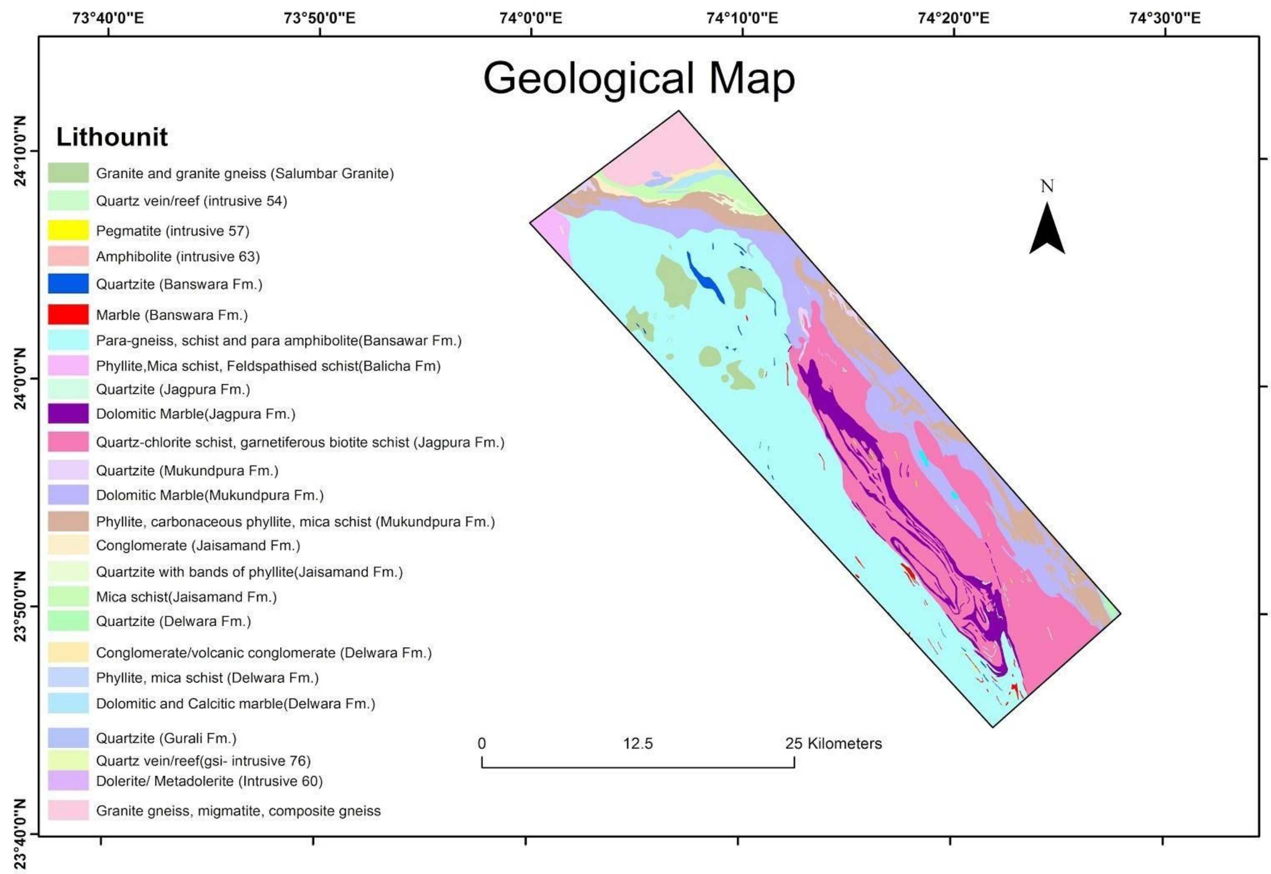

Fig 1: Geological Map of the study area.

BAND RATIOS

ASTER has a total of fourteen spectral bands among these, three are in the VNIR region (0.52-0.86 µm) with a spatial resolution of 15m, six in the SWIR region (1.60-2.43 µm) with a spatial resolution of 30m and five in the TIR region (8.125-11.65 µm) with a spatial resolution of 90m. For the interest of this venture only the bands in the VNIR and the SWIR region in considered.

RGB: 9/8 4/8 5/8

Band 4: 1.600 - 1.700 µm; Band 5: 2.145 - 2.185 µm; Band 8: 2.295 - 2.365 µm; Band 9: 2.360 - 2.430 µm

In this RGB composite 9/8 ratio highlights Epidote, 4/8 highlights Carbonate minerals and 5/8 marks the presence of Fe-Mg rich Mafic minerals (augite, pigeonite, chromite, etc)(Fig: 2). On relating this with the lithology of the area it can be seen that the red colour or 9/8 is predominant in the regions where the rock types are mainly mica schist and phyllite, the green colour i.e, the 4/8 ratio is mainly seen in the area with dolomitic to calcitic marble and finally the 5/8 ratio or the blue colour marks the regions which has pyroxene rich mafic bodies in some meta basalt and basic intrusives. On matching the spectra at certain locations minerals like dolomite [$CaMg(CO_3)_2$)] , epidote [$\{Ca_2\}\{Al_2Fe^{3+}\}[O|OH|SiO_4|Si_2O_7$], augite [$(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$] have been documented (Fig 2.1).

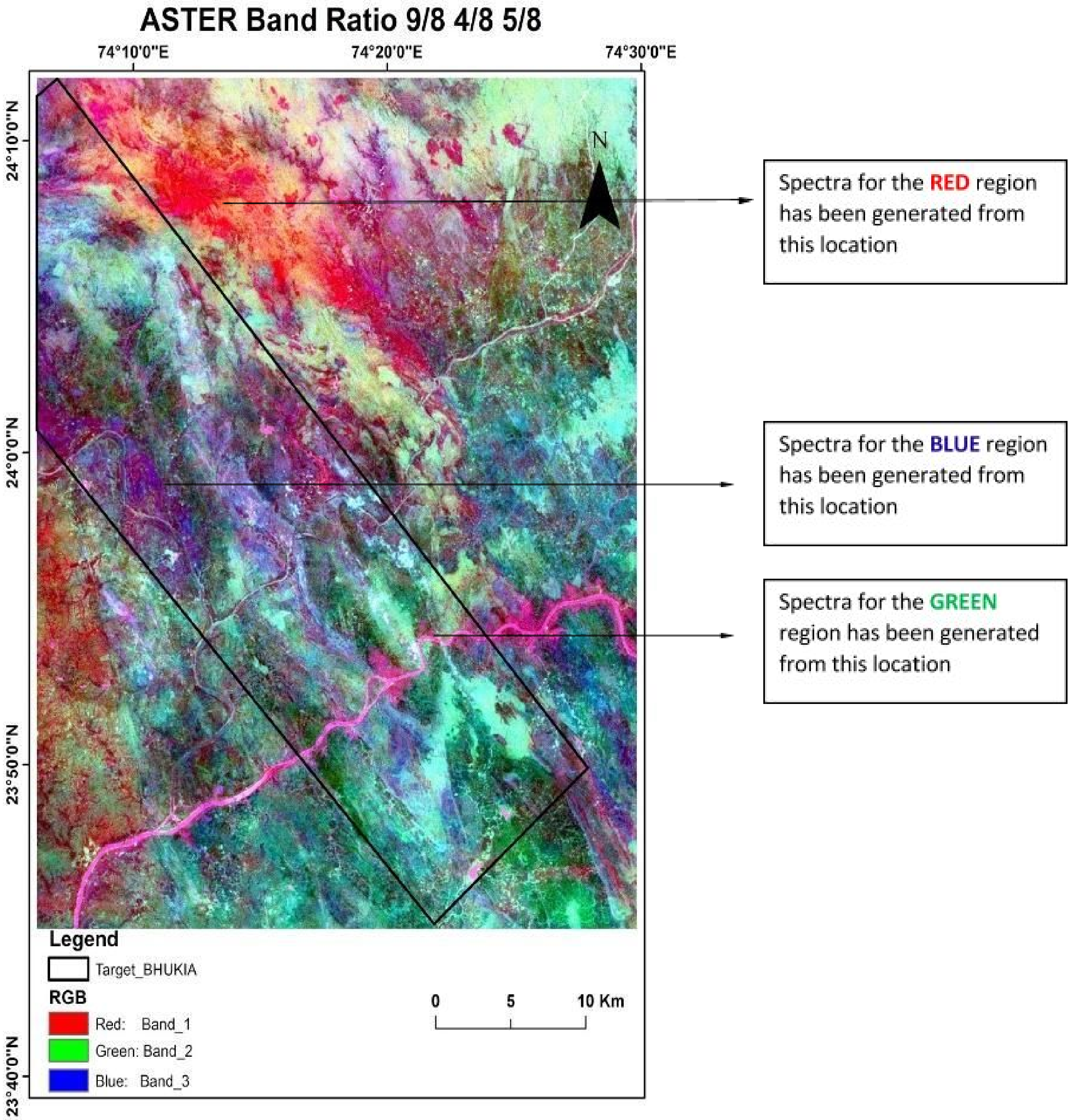

Fig 2: ASTER Band Ratio 9/8 4/8 5/8 highlights the presence of Epidote, Carbonate, Fe, Mg rich minerals

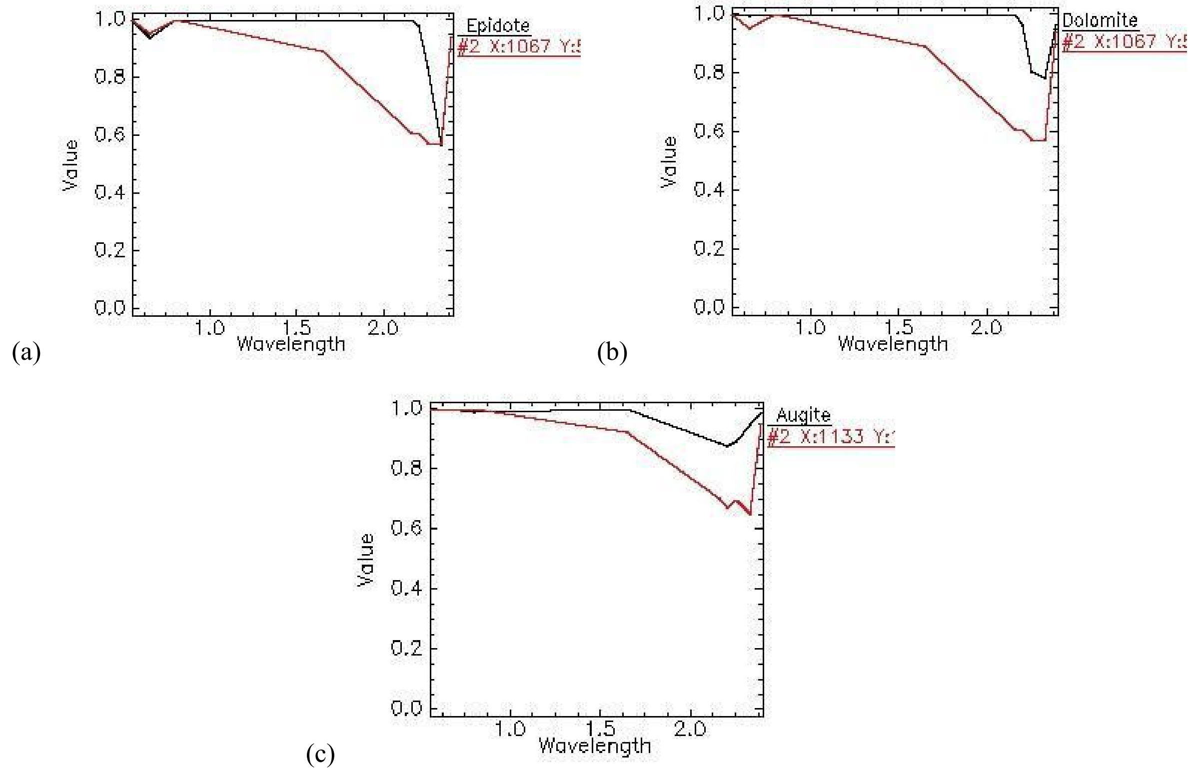

Fig 2.1: The ASTER spectra (red colour) shows match with the USGS spectra (black colour) of (a)Epidote (b)Dolomite and (c)Augite. ; the red spectra shows the spectrum of the particular pixel and the black spectra shows its match with the USGS mineral library

RGB: 9/8 4/8 4/2

Band 2: 0.63 - 0.69 µm; Band 4: 1.600 - 1.700 µm; Band 8: 2.295 - 2.365 µm; Band 9: 2.360 - 2.430 µm

Under this RGB composite the significance of 9/8 and 4/8 band ratios remain the same and highlights more or less the same portions as in the previously mentioned RGB composite. The 4/2 composite is supposed to highlight gossan. Thus, here the blue gun is supposed to highlight areas rich in gossan deposits (Fig:3). The rock type for gossan mainly restricts to schist. The minerals documented are pyrite [FeS_2] and goethite [FeO(OH)](Fig:3.1)

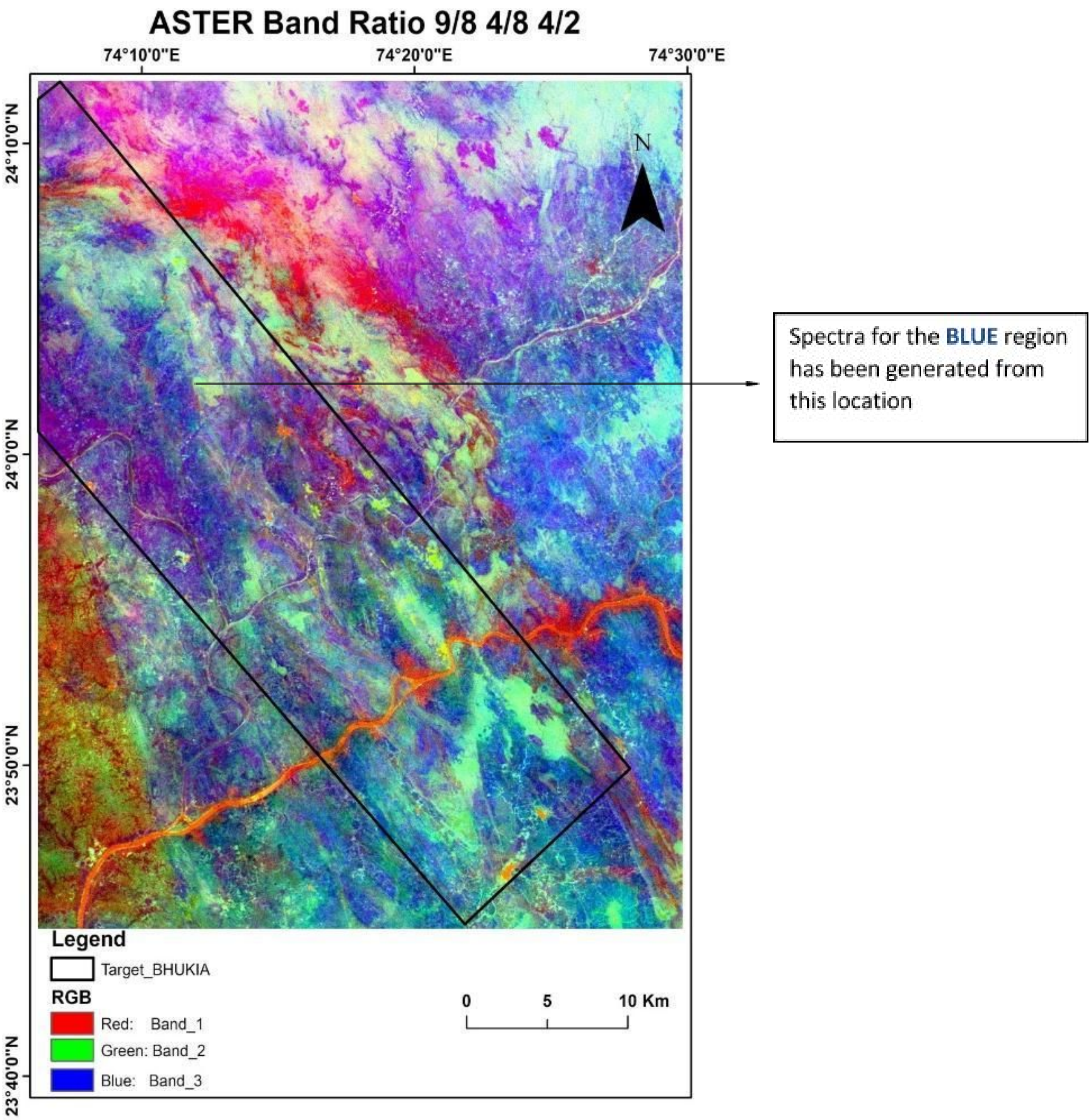

Fig 3: ASTER Band Ratio 9/8 4/8 4/2 highlights the presence of Epidote, Carbonate,Gossan

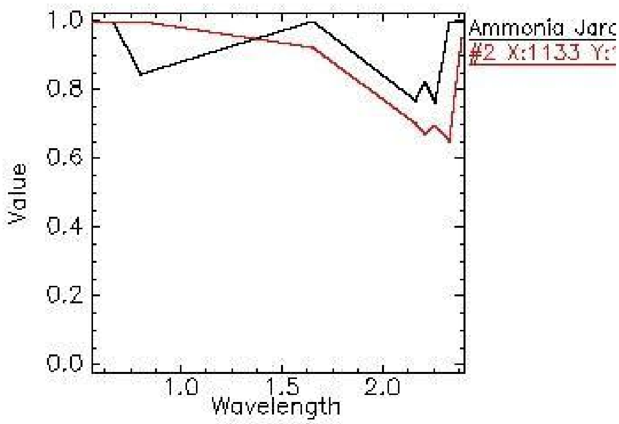

Fig 3.1: The ASTER spectra (red colour) from Gossan region shows match with the USGS spectra (black colour) of Ammonium -rich JarositeJarosite in support of Gossan in ASTER 4/2 ratio: ; the red spectra shows the spectrum of the particular pixel and the black spectra shows its match with the USGS mineral library

RGB: 2/1 4/5 4/2

Band 1: 0.52 - 0.60 µm; Band 2: 0.63 - 0.69 µm; Band 4: 1.600 - 1.700 µm; Band 5: 2.145 - 2.185 µm

This RGB composite theoretically is supposed to demarcate Ferric iron through the 2/1(Red) ratio, laterite through 4/5(Green) and gossan through 4/2(Blue)(Fig:4). In the image a narrow band is clearly highlighted just above the boundary in red marking the dominance of ferric iron, the rock type in this region is mainly mica schist. The rest of the area mainly shows mixed pixels or secondary colour mainly because laterite and gossan both are weathered products and is hard to distinguish distinctly through satellite imagery, although the presence of laterite is clearly seen in the south-western corner of the image where the rock type is mainly gneiss to para-gneiss.

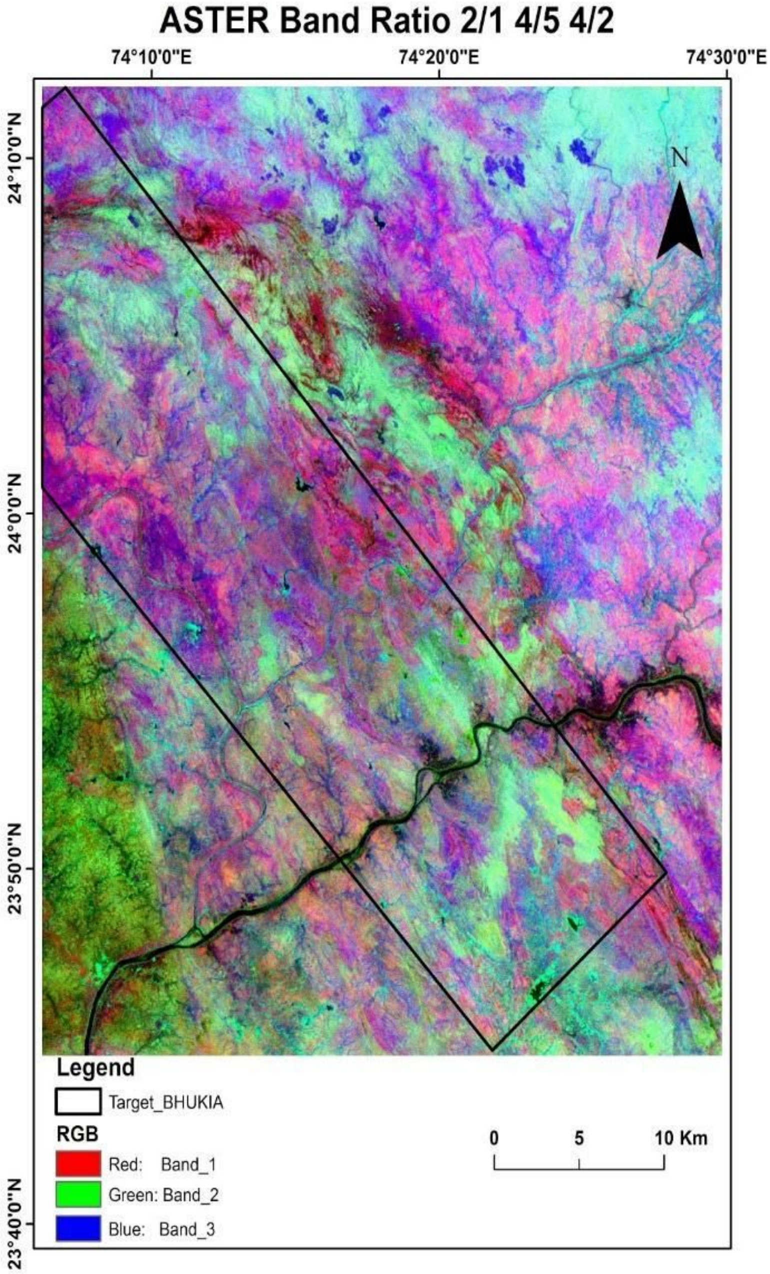

Fig 4: ASTER Band Ratio ASTER Band Ratio 2/1 4/5 4/2 highlights the presence of Ferric Iron ,Laterite and Gossan.

FPCS TECHNIQUE ON ASTER DATA

PCA on Bands 1,2,3 and 4 of ASTER.

Band 1: 0.52 - 0.60 µm; Band 2: 0.63 - 0.69 µm; Band 3: 0.76 - 0.86 µm; Band 4: 1.600 - 1.700 µm

Principal component analysis is applied on bands 1, 2, 3 and 4 of ASTER bands. In the following step, the statistics file is analysed. Here we can see that that the fourth principal component shows the maximum variation in eigenvectors between bands 2 and 1(Table 1). As seen earlier the band ratio of ferric iron for ASTER bands is 2/1 therefore principal component four (Fig 8) will highlight the presence of ferric iron. Eigenvector at band one has a negative loading whereas the eigenvector in band two has a positive loading thus the bright pixels in the component image is supposed to highlight ferric iron. The predominant rock type in the areas of the bright pixels is mainly schist.

Table 1: Eigenvectors for PC1234 and PC4 showing maximum variation in Bands 1 and 2

Eigenvector	Band 1	Band 2	Band 3	Band 4
PC 1	0.226986	0.367835	0.455274	0.778396
PC 2	0.438492	0.484528	0.441335	-0.614964
PC 3	-0.329453	-0.534622	0.771449	-0.102501
PC 4	**-0.804775**	**0.586609**	0.053066	-0.073565

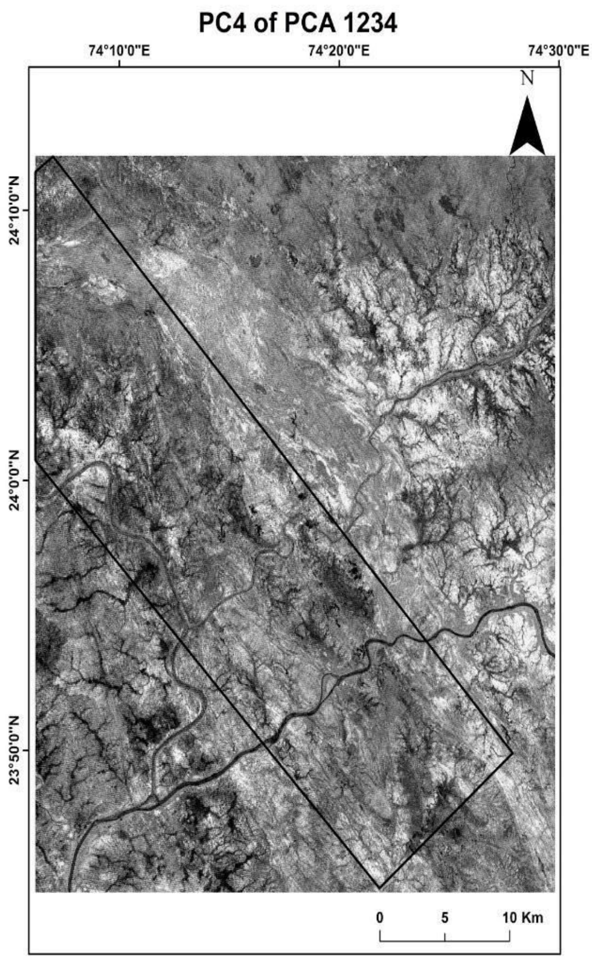

Fig 8: PC 4 of PCA applied on bands 1,2,3 and 4 of ASTER where bright pixels highlight ferric iron

PCA on Bands 1,4,6 and 7 of ASTER

Band 1: 0.52 - 0.60 µm; Band 4: 1.600 - 1.700 µm; Band 6: 2.185 - 2.225 µm; Band 7: 2.235 - 2.285 µm

In this case bands 1, 4, 6 and 7 are considered and the similar procedure is followed. After operating the PCA the eigenvectors in the statistics file is analysed. Here again the fourth component shows the maximum variance in eigenvectors for band 7 and band 6(Table 2). This is related to the presence of the group of minerals including muscovite, kaolinite and montmorillonite whose band ratio is 7/6. Here the fourth principal component (Fig 9) is supposed to highlight the presence of muscovite probably as the area is lithologically mica schist. Unlike the previous combination in this one, the reflectance band of muscovite i.e. band 7 shows a negative loading whereas the absorption band shows a positive loading as a result the dark pixels in the principal component image will indicate the presence of muscovite in the region.

Table 2: Eigenvectors for PC1467 and PC4 showing maximum variation in Bands 7 and 6

Eigenvector	Band 1	Band 4	Band 6	Band 7
PC 1	-0.106780	-0.612442	-0.541007	-0.566414
PC 2	-0.982054	0.165411	0.068579	-0.059219
PC 3	-0.143278	-0.752256	0.267631	0.584770
PC 4	0.060333	-0.177948	**0.794344**	**-0.577678**

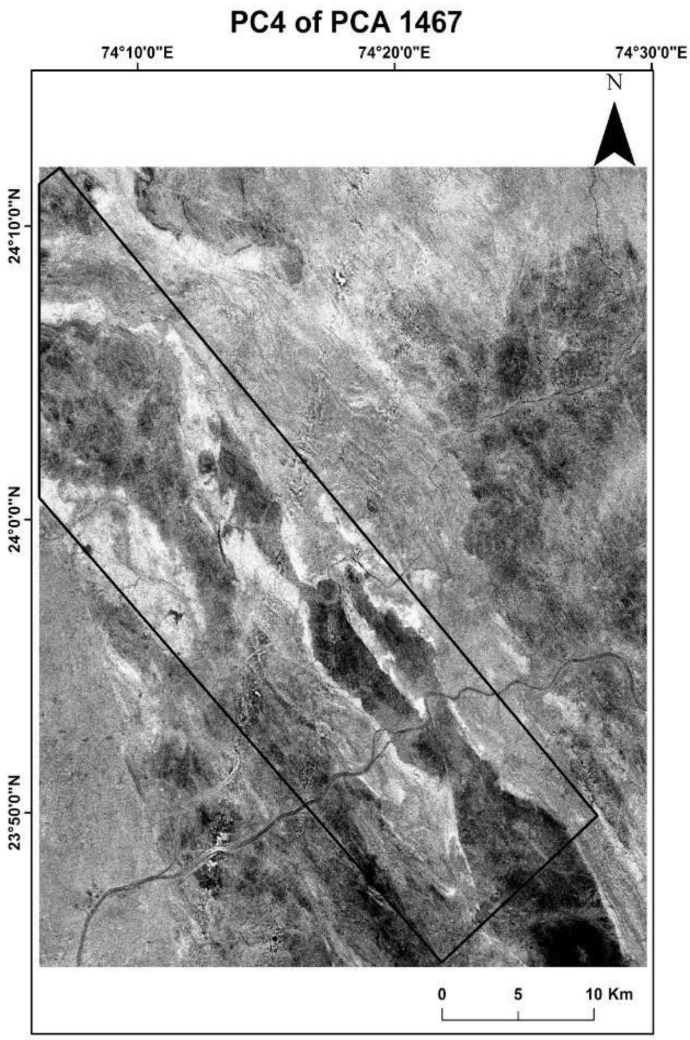

Fig 9: PC 4 of PCA applied on bands 1,4,6,7 of ASTER bands where dark pixels highlight muscovite due to negative loading in band 7

PCA on Bands 1,4,6 and 9of ASTER

Band 1: 0.52 - 0.60 µm; Band 4: 1.600 - 1.700 µm; Band 6: 2.185 - 2.225 µm; Band 9: 2.360 - 2.430 µm

In this approach, the FPCS technique has been repeated taking bands 1,4,6, and 9. The target mineral in this combination being kaolinite whose appropriate band ratio is 4/6. After operating the PCA on the selected bands and analysing the eigenvectors from the statistics file it is found that the fourth principal component(PC4) shows the maximum variation in bands 6 and 9 thus it is likely to highlight the presence of kaolinite (Table 3). The dark pixels in the image of the fourth principal component should highlight kaolinite. But here the first principal component shows positive and pretty high loadings for all the bands, which indicates that the first principal component (PC1) contains information mainly about the surface topography and albedo of the region. So now if the information in the first principal component could be concealed, the information in the rest of the components could come out clearly. In order to obtain this, the rest of the principal components have been multiplied to the first principal component and then the resultant bands have been applied to RGB (Crostaand Moore 1989). As a result it was found that the image went through an overall smoothing effect and the kaolinite in the PC4 was significantly highlighted in the blue band. On comparing the region with the geological map it has been seen that the rock type in this region is feldspar-rich mica schist which supports the presence of kaolinite in the obtained region(Fig 10)

Table 3: Eigenvectors for PC1469 and PC4 showing maximum variation in Bands 4 and 6

Eigenvector	**Band 1**	**Band 4**	**Band 6**	**Band 9**
PC 1	0.087795	0.518506	0.468066	0.710181
PC 2	-0.281325	-0.680284	-0.182500	0.651739
PC 3	0.955241	-0.260074	-0.073557	0.120271
PC 4	-0.025735	**-0.448025**	**0.861509**	-0.237517

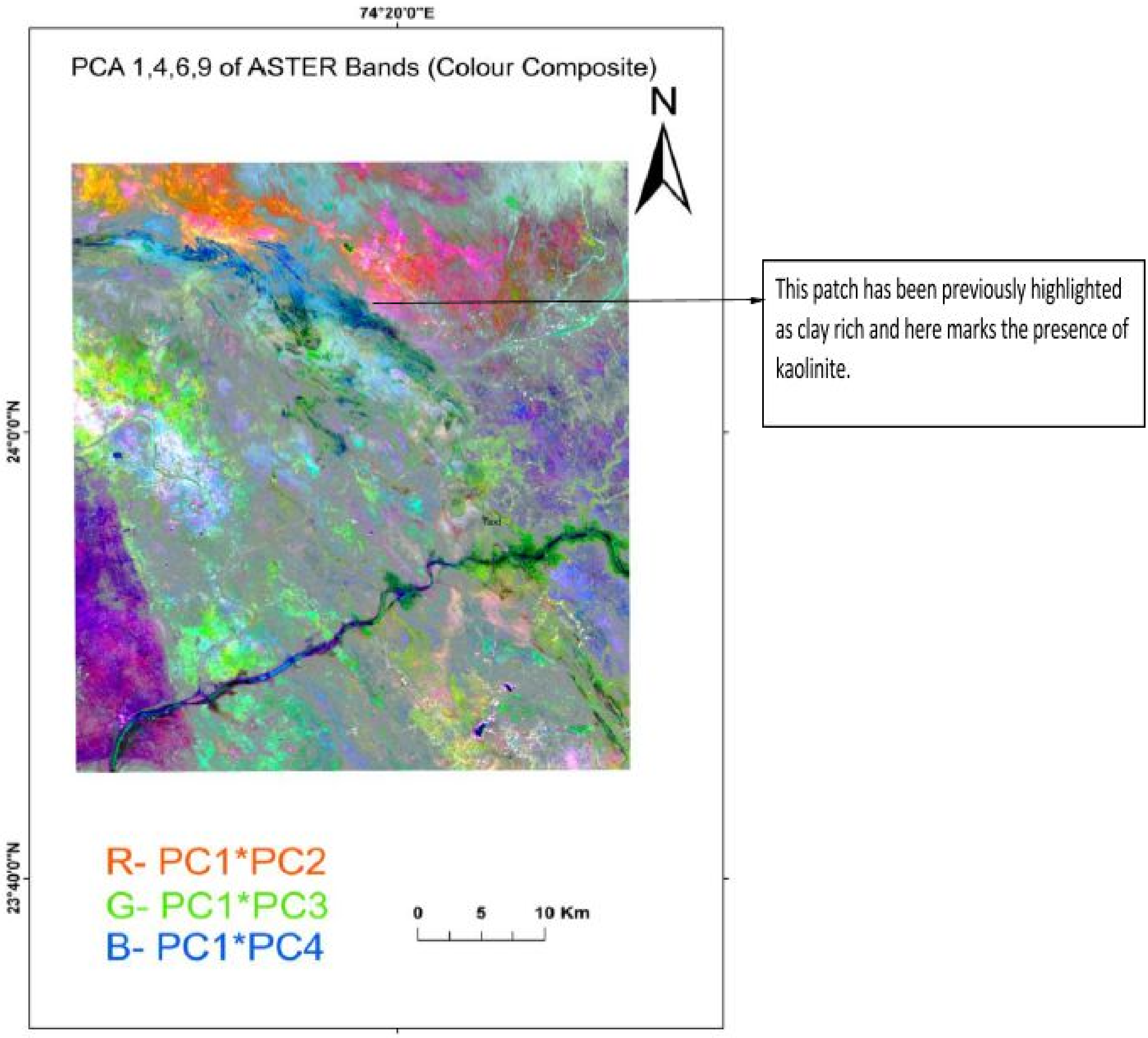

Fig 10: PCA of 1,4,6,9 ASTER bands. PC1*PC2, PC1*PC3, PC1*PC4; Blue bands of Kaolinite and the matching spectra from FCC

Validation Of The Minerals Through Field Spectra

Spectra of the field samples collected were generated with the help of ASD spectro-radiometer. These spectral signatures of each sample were further studied and the minerals thus obtained have been noted. The minerals thus inferred are found to be in support of the ones that have been obtained from the study. To be specific clay minerals such as montmorillonite from the smectitic clay group which incorporates water molecule in between the T-O-T layers and is very commonly found in epithermally altered regions such as this, muscovite also from the phyllo-silicate group of minerals, and iron bearing minerals such as pyrite and jarosite. Occurrence of pyrite is owed to the presence hydrothermal veins and also due to contact metamorphism found in the region, jarosite also owes its presence to the epithermal alteration in the area.

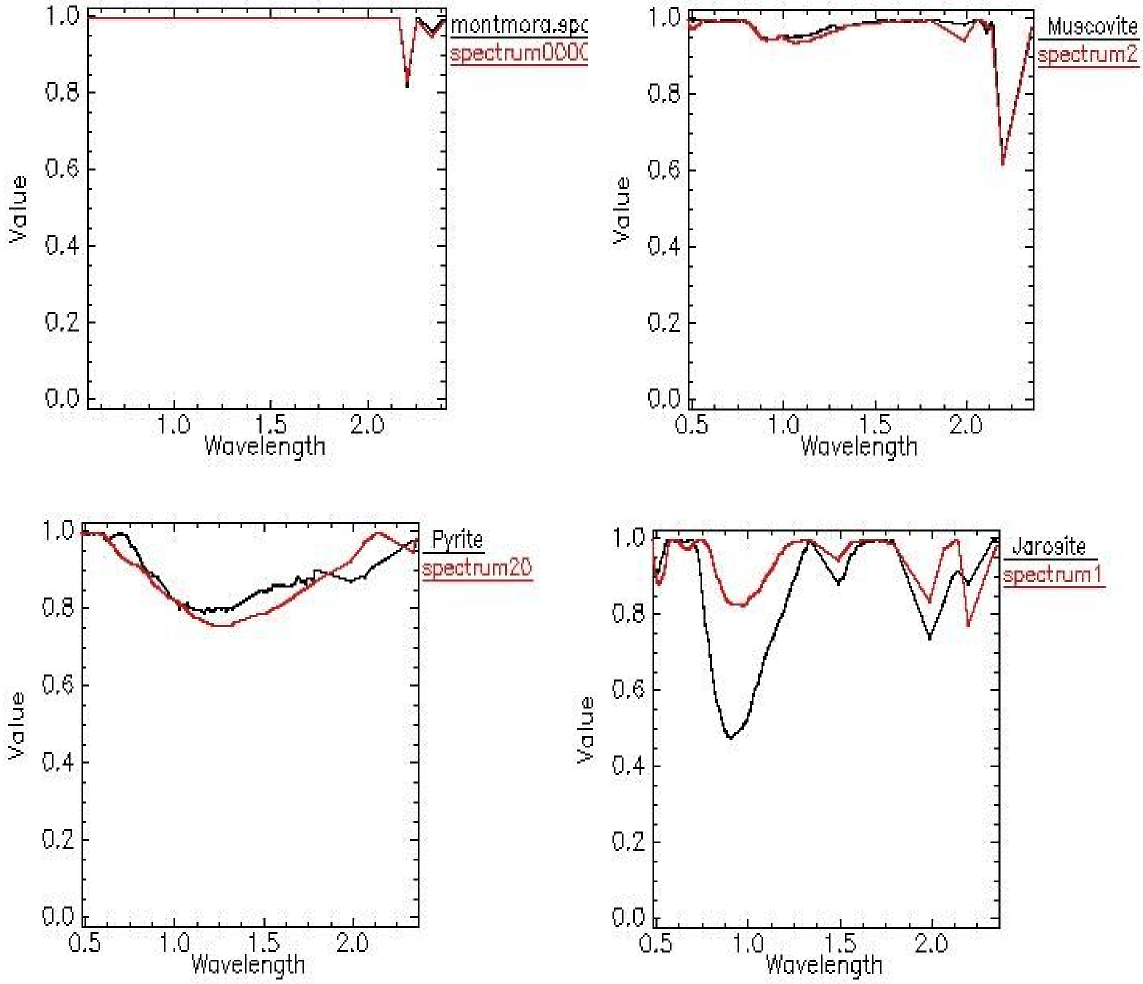

Fig 11: Minerals obtained from the field spectra. In the graphs the red line marks the field spectra and the black line marks the matched minerals from the USGS library i) Monmorillonite ii)Muscovite iii)Pyrite iv)Jarosite

CONCLUSION

Rajasthan as known is a highly mineral prospecting state. Owing to the number of dolomite mines in the study area the occurrence of Ca bearing minerals such as Dolomite, Diopside, Calcite, Wollastonite and Tremolite are found arranged in decreasing order of occurrence. The evidence of occurrence of these minerals have been found in all the datasets along with the field data very prominently. Apart from this phyllosilicate minerals like muscovite, biotite and phlogopite is found in litho units supporting their occurrence added to these clay minerals kaolinite and some other clay minerals of the smectite group such as montmorillonite, nontronite etc is also found to be a common occurrence throughout the area. Certain patches of iron-rich minerals have been found in the various locations where the rock type is mainly schist, both ferric ion rich mineral mainly hematite, goethite, jarosite and also ferrous iron rich minerals such as pyrite and pyrrhotite are quite profound. Thus, the study concludes with successful results showing the presence of the possible minerals in the concerned study area which were in support of the field data.

The further scope of study in the area would be to establish the presence of gold. This could be through looking for the occurrence of indicating minerals such as arsenopyrite and other arsenic bearing minerals or directly gold itself through the spectroscopy study of the minerals.

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