

## Spectroscopic Study of Rocks of Hutti-Maski Schist Belt, Karnataka

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**Abstract:** Recent developments in sensor technology have given an onset for studying the earth surface features based on the detailed spectroscopic observation of different rocks and minerals. The spectroscopic profiles of the rocks are always quite different than their constituent minerals however, the spectral profile of a rock can be broadly reconstituted from the spectral profile of each constituent minerals. Interpretation of rock spectra using the spectra of constituent minerals based on relative spectral matching can bring out interesting information on the rock. Present study is an effort toward this and it highlights how visible-near infrared-shortwave-infrared (VNIR-SWIR) rock spectroscopy acts as an useful tool for understanding the rock-mineralogy in indirect and rapid way. It has also been observed that spectral signatures of rocks; studied in present case, are related to spectral signatures of constituent minerals although absorption features of constituent mineral in the rock are also modified by the other minerals juxtaposed in the rock fabric. However, each rock of the study area has their significant absorption features, but many of the absorption signatures are closely spaced, as altered rock has significant absorption at 2305 nm whereas amphibolite has its important absorption signature in 2385 nm and metabasalt has its significant absorption at 2342 nm. Therefore spectral measurement of high spectral resolution with appreciable signal to noise ratio (SNR) only can detect rocks from each other based on the absorption signatures mentioned above (each of which is 10 to 20 nm apart from the other) and therefore spectroscopy of rock is an innovative technique to map rocks and minerals based on the spectral signatures.

**Keywords:** Rock fabric, Spectroscopy, Spectral matching, Spectral resolution.

### INTRODUCTION

“Spectroscopy is the study of light as function of wavelength that has been emitted, reflected or scattered from solid, liquid, or gas” (Clark, 2011). Today, spectrometers are being increasingly used in the laboratory, in the field, in aircraft and also in remote sensing satellites. Recent developments in sensor technology have given an onset for studying earth surface features based on the detailed spectroscopic observation. The capability of latest space-borne instruments has been increased manifold due to the development in modern electronics and now it is possible to upscale the laboratory spectroscopic observation to space and identify different minerals based on the “characteristic spectral features” of the concerned minerals.

Reflectance spectroscopy of natural surfaces are sensitive to specific chemical bonds in materials, whether solid, liquid or gas (Clark et al. 1984; Clark et al. 1990; Clark, 2011). Moreover, spectroscopy has the advantage for its sensitivity to both crystalline and amorphous materials, unlike some diagnostic methods, like X-ray

diffraction (Clark, 1990). Spectroscopy's other main advantage is that it can be used close to the target (e.g. in the laboratory) to far away (e.g. observations from the space borne sensors), but it has its own limitations. Main disadvantage of spectroscopic study is its sensitivity to small changes in the chemistry and/or structure of a material. The variations in material composition often cause shifts in the position and shape (depth, asymmetry) of absorption bands in the spectrum. Thus, with the vast variety of chemistry encountered in the real world, spectral signatures can be quite complex. However, it is now changing with the increased knowledge on the natural variation in spectral features and the various causes of those shifts. Laboratory and field spectroscopic studies of rocks and minerals of different varieties help in understanding the entire realm of variability in spectral signatures of particular rocks/minerals and can therefore be used as the basis for hyperspectral/ imaging spectroscopic data interpretation.

Reflectance spectra have been used for last three decades

to obtain compositional information of the Earth surface (Hunt and Salisbury, 1970; Hunt, 1977; Hunt, 1979). Therefore spectroscopy is being used increasingly in geoscientific studies to detect mineralogical compositions of the rocks of earth surfaces and also for rocks and minerals in other planets of the universe.

The present study is taken up to understand the spectroscopy of intimate mixture like rock. The area selected for present study is part of the Hutti-Maski schist belt known for lode type gold occurrence in India. The objectives of the present research are following:

- a) Collection of the spectral signatures of the important rock types of the Hutti-Maski Schist Belt and analyze them with reference to the geochemical data (X Ray Diffraction analysis) and Petrographic data.
- b) Evaluate the optimum sensor requirement for delineating major lithologies of Hutti-Maski Schist Belt and also to understand how mineral spectra behaves in complex nonlinear mixture.

#### **ROCK SPECTROSCOPY (VNIR-SWIR DOMAIN) AND ITS SIGNIFICANCE**

It has been shown that spectral reflectance in visible and near-infrared region offers rapid and inexpensive technique for determining the mineralogy of samples and obtaining information on their chemical composition. Although known spectral libraries on rocks only focus on 2-14 micrometer domain as rocks have more characteristic, unambiguous and non-overlapping spectral signatures within this spectral domain. But atomic processes like electronic transitions produce broad absorption features as it requires higher energy than do vibrational processes, and therefore take place at shorter wavelengths within VNIR (Visible near infrared)-SWIR (Short wave infrared domain) (Hunt, 1979). In addition, vibrational processes in H<sub>2</sub>O and OH-bearing molecule (e.g., small displacements of the atoms about their resting positions) produce fundamental overtone absorptions (Hunt and Salisbury, 1970; Hunt, 1977) at SWIR domain. Spectral features attributed to the electronic process, as is the case, for all iron rich rock forming mafic minerals, for example; hornblende, biotite, Fe-rich pyroxene, Fe-rich olivine, hematite, magnetite have their characteristic absorption features in VNIR etc. domain caused due to the electronic transition taking place in Fe atom. Although it is always difficult to differentiate different iron rich mineral within this domain; it is realized that the shift in the absorption feature of Fe (at 1  $\mu\text{m}$ ) towards higher wavelength due to the increment in Mg component in mineral; helps in distinguishing Fe-rich olivine from Mg-rich olivine.

Similarly Fe-OH mineral has different wavelength position for absorption feature if we compare these signatures with that of the Mg-OH absorption features. These spectral features are quite dominant in SWIR domain. The position, shape, depth, and width of these absorption features are also controlled by the particular crystal structure in which the absorbing species is contained and also by the chemical structure of the mineral. Thus, variables characterizing absorption features would be directly related to the mineralogy of the rock sample. With advances in computer and detector technology, the new field of imaging spectroscopy is developing (Goetz et al. 1985) and is also increasingly being used in different branches of earth sciences.

The spectroscopic profiles of the rocks are always quite different than their constituent minerals but still the spectral profile of a rock can be broadly reconstituted from the spectral signatures of each of the constituent minerals. Although in many cases modeled rock spectra derived from the constituent minerals may not perfectly match with the actual rock spectra as nature of intimate mixing of minerals contributes in shaping the rock spectra. Therefore, the grain size, juxtaposition of a mineral with respect to other i.e. mineral fabric also play important role as contributing factors in evolving the final waveform of the rock spectra.

Modeling a rock spectra from the spectra of its constituent elements is a nonlinear problem; which is very difficult to solve mathematically. In order to understand, how rock spectra can be modeled from mineral spectra and how rock spectra can be used as a tool to delineate one rock from other; integrated analysis of mineral composition, texture of the rock, individual spectrum of constituting the minerals and spectral profiles of rocks are essential. Therefore, interpretation of rock spectra in the light of mineral spectra based on relative spectral matching minerals may derive interesting information on the rock.

#### **STUDY AREA**

The study area belongs to parts of gold mineralized belt of Hutti-Maski schist belt of Dharwar Supergroup and bounded by latitude 15°40'E -16°20'E and longitude 76° 30'N – 76°53'N. The area is located about 80 km west of Raichur, which is also the nearest railway station and accessible from Hyderabad and Bangalore by road (NH-4, 9 and 13).

#### **METHODOLOGY**

It is essential to understand spectroscopic observation of rocks and whether the variability of spectroscopic feature

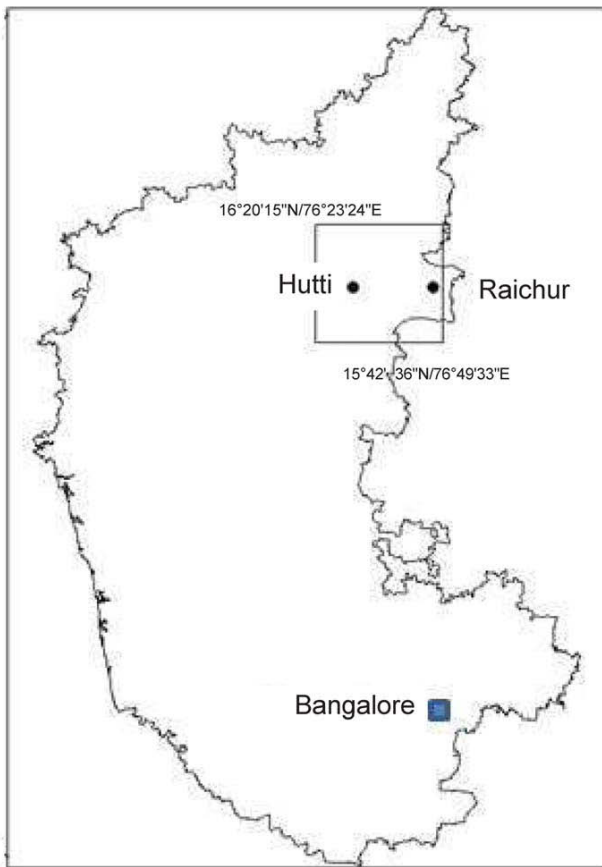


Fig.1. Location of study area.

of a lithovariant is predictive to assess the role of imaging spectroscopy for mapping lithology and alteration minerals associated with different economic mineral deposit. In this regard, laboratory measurement of spectral signature would be the basis for understanding such spectral curves of rocks to use them as “indicator” tool for their delineation from each other using a spectroradiometer; which is capable of spatial observation along multiple scan lines. Most important fact is that collection of spectra for different lithologies require properly documented standardized methodology for repetitive use. Therefore an attempt has been made in this study, to make the spectral measurement and data processing procedures systematic and coherent. In the present study; following factors are considered important for collecting the laboratory spectra and accordingly measurement guidelines are fixed.

#### Spectroradiometer

Spectroradiometer used for present study has very good signal to noise ratio with finer spectral resolution and finer spectral sampling interval (1.4 nm @350-1050nm; 2 nm @ 1000-2500 nm) (FieldSpec, 2011). Spectral resolution is finer enough to detect the subtle absorption features

characteristic of the constituent minerals of the rock. FieldSpec3 spectroradiometer has two types of detectors one 512 element Si photodiode detector operative in 350-1000 nm and two separate, InGaAs photodiodes operative in 1000-2500 nm.

The spectroradiometer is operative in the spectral range of 350 -2500 nm domain and have spectral resolution 3 nm @700 nm and 10 nm @ 1400/2100 nm.

#### Samples

Samples are chosen for the spectral profile collection, they are unique and represent the particular variety of rock. In short, the samples are “type” samples (Fig.2) and ranges from 3"X3" (altered rock) to 5"X7" (amphibolite) in size. Sample size taken in research is comparable with the size of the samples analyzed in NASA's (National Aeronautics and Space Administration, America), JPL (Jet propulsion Laboratory, (Baldrige et al. 2009). Rather samples selected in present research are larger than JPL lab to reduce the ambiguity of contribution of radiance from adjacent portion of measuring platform.

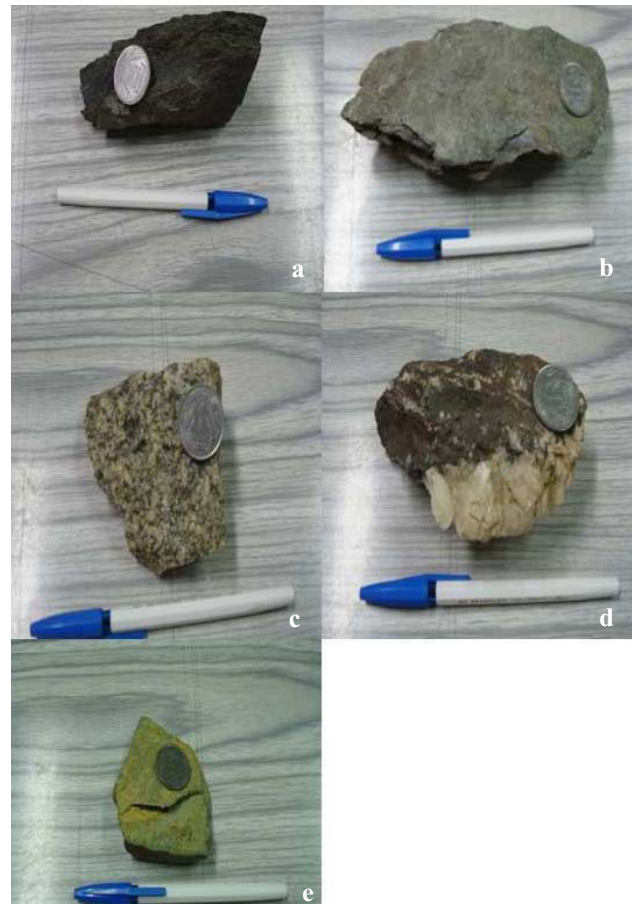


Fig.2. a - Amphibolite; b - Metabasalt; c - Granite; d - Metabasalt with quartz vein; e - Altered rock.

### Surface Alteration Features

Rock Samples are collected with the emphasis to avoid surface alteration features/coatings. For few cases; where the interest is to collect rock samples with alteration; necessary details of alteration signature are recorded by inspecting the megascopic/microscopic textural, mineralogical alteration parameters of the sample. The geochemical analysis of the samples are also carried out to identify the mineral phases and their relative abundance in conjunction to spectral profile collection. In this regard, X-ray diffraction (XRD) method is used for semi-quantitative chemical analysis of the samples. This data is used as a basis for interpreting the absorption signatures imprinted on rock spectra.

### Microscopy

Petrographic analysis of thin sections is important to ascertain the presence or absence of minerals based on the optical property and it helps in supplementing and complementing the spectroscopic observation/information.

### Measurement Procedures

The reflectance of the rock surface is measured based on the “ratio of the radiant flux actually reflected by a sample surface to that which would be reflected into the same reflected-beam geometry by an ideal (lossless) perfectly diffuse (Lambertian) standard surface irradiated in exactly the same way as the sample” (Nicodemus et al. 1977). This approach provided a practical guideline to measure reflectance in the field and laboratory but it also brings the concept of a second reflecting surface into the measurement procedure, the spectral and angular properties of which would affect the resulting reflectance. Despite considerable efforts by technologists, reference panels are neither perfectly reflecting nor perfectly diffuse, and because of the degree to which both these properties vary with wavelength, it is necessary to pay close attention to the properties of the reference panel used (Gu and Guyot, 1993; Bruegge et al. 2001). Spectralon (reference panel) used for the present study has been established as the material of choice. It has a high and stable reflectance throughout the optical region and is washable although it has the disadvantage of generating a static charge such that insects and dust particles cling to it under some conditions. Procedures for the calibration of field/laboratory reference panels were discussed by Biggar et al. (1988) and Bruegge et al. (1991). Sample reflectance is measured by pointing “vertically” the measurement gun which contains the fiber optics of sensor. The light source illuminate the sample at approximately

45 degree phase angle (with respect to the vertical drawn over sample) and measurement is taken by keeping the fore optics vertically over the sample (Phase angle is the angle between the illumination source and measurement point) in order to reduce the specular component of reflected energy in the measured signal. The reflected energy resulted by volume scattering of the rock is the better representative of the internal chemistry whereas specular return from the sample is governed by surface smoothness. Field of view of fore optics, in this case is chosen to standard 25 degree. The measurement gun is adjusted vertically to the sample in such a fashion that field of view of sensor can create a GSD (Ground sampling distance) over sample to incorporate the all the variability of the sample. Twenty observations per sample spot is recorded and averaged to get the characteristic spectral curve for the rock. In cases, where rock fabric variability is more and cannot be described by one sample spot, additional one or two measurements are recorded by laterally moving the sample below the measurement gun. In keeping view the relation,  $D=H*\tan(q/2)$  where D is the radius of the measurement zone or ground sample diameter (GSD) of spectral measurement and H is height of the measurement and q is field of view, one can move up or down the measurement gun to collect representative spectra of the rock unit. For example, If H is fixed 10 cm then the portion with 4.14 cm radius can be sampled by the Spectroradiometer. In Fig.3 the schematic diagram of measurement set up is depicted where S is source, L is fiber optic lens where H refers height of the measurement gun from the sample top and d indicates the field of view (FOV) of the measurement gun.

There are several important and sensitive criteria for

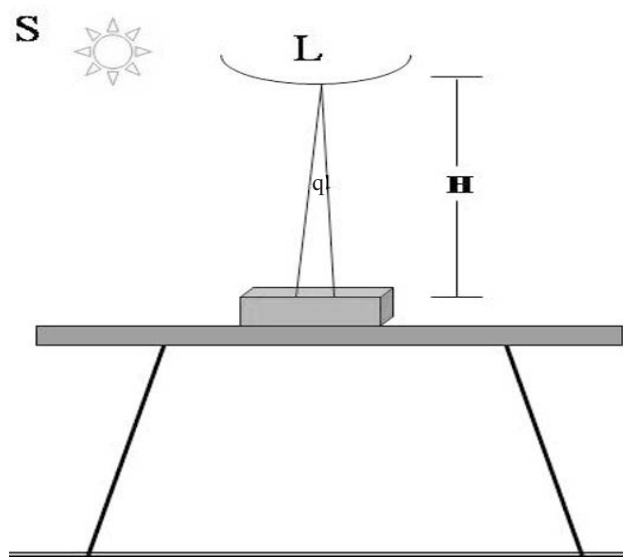


Fig.3. Schematic diagram of measurement set up.

measurement and these are taken into consideration for spectral profile measurement of the rocks.

The reference white panel used for reflectance calibration are well calibrated (Martonchik et al. 2000). This panel is used to convert the measured radiance to reflectance. The fibre optics needs to be optimized using the white reference panel before initiating the measurement.

- Fibre optics (lens) should also be calibrated. The ASD Inc., the manufacturer for reference panel, has calibrated the fibre optics.
- Source of the illumination should also be calibrated so that there is minimal fluctuation in irradiance in successive measurement. Wherever any fluctuation is noticed in illumination of source; reference panel (white panel) radiance has to be recorded time to time to reduce the variance in the relative variation in reflectance in spectra.
- Although orientation angle of the measurement gun influences amount of energy to be received; caution is made to make orientation of measurement gun vertically tipped to the sensor.
- Sample should be larger in length than the GSD of fore optics.
- There should not be any physical blockage of light in any case and shadow of the person measuring the data should not fall over the sample
- The table/platform over which measurements are taken is made dark to reduce the influence of background to minimal. Caution: Background should not influence the signal received at the measurement gun.

#### Processing of Spectral Curve

Spectral curve of the rocks thus collected is processed in standard software to remove the higher order kinks to derive the curve with characteristic "spectral features". In order to improve the signal to noise ratio of the measurements, 50 scan of the samples are taken and then averaged internally before providing the individual spectral measurements of rock samples.

### RESULTS AND DISCUSSION

Archaean granite-greenstone belt from which rock samples are collected is characterized by different low to medium-grained metavolcanics and metasediments flanked by granite-gneiss segment; in most of the cases, granite is basement rock for these metavolcanics/metasediments (Roy, 1979). Hutti-Maski greenstone rocks are important litho-hozions for gold. Main litho-variants of the area, significant for gold mineralization, are metabasalt and amphibolite.

Retrograde metamorphism has made its impact on lithology and low-grade metamorphic minerals are developed in metabasalt along the shear zone where role of retrograde metamorphism has converted pyroxene to low temperature hydrous metamorphic minerals. For spectral measurement, rock samples are collected along and across the shear zone during field survey and spectral profile of few rock samples, which have significant presence in the field with their large outcrops are taken up for spectroscopic study. All the spectral absorption signatures recorded for rocks are interpreted using the spectral signatures of the minerals present in the rocks (these signature are taken from spectral library of minerals prepared by United State Geological Survey). The minerals appeared as dominant phase in these rocks based on the XRD analysis are only used for interpreting the characteristic absorption features of the rock. The details of the spectral profile of each rock unit (Fig.2) are discussed in following sections.

#### Amphibolite

Amphibolites have broad (width 685 nm) absorption feature around 1147 nm (Fig.4 and Table 1). This broad absorption is due to the presence of Fe in amphibole minerals, main constituents of the host rock. The standard mineralogic formula of amphibole is  $\text{Ca}_2(\text{Mg, Fe})_4\text{Al}(\text{Si}_7\text{Al})\text{O}_{22}(\text{OH})_2$ . The electronic transition process of d-orbital electrons in Fe absorbs considerable photon and therefore create such wide absorption feature. There are also Fe-OH bond vibrational absorption band imprinted in amphibolite spectra. Amongst which, wider one is around 2385 nm and another feeble absorption band is at 2496 nm. The spectral signatures of the rock is analyzed using the spectral signature of the constituent minerals. XRD data (Table 2) is used to delineate the major mineral phase present in each rock sample. Major (first four prominent) spectrometric information of absorption parameter calculated using DISPEC 3.2 software is given in Table 1.

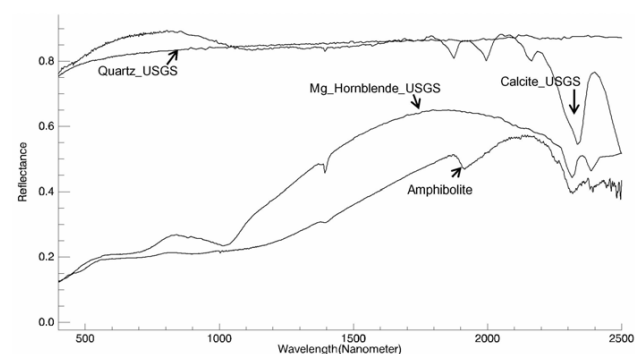


Fig.4. Amphibolite spectra with the spectra of constituent mineral obtained from USGS spectral library.

**Table 1.** Significant absorption parameters for different rock types

Rocks	Wavelength (nm)	Depth (nm)	Width (nm)	Area (sq. nm)	Asymmetry
Amphibolite	2385	0.203209	86	24.85474	-0.28911551
	1147	0.307328	685	218.7717	0.022973205
	1918	0.097424	95	9.353	-0.51117421
Metabasalt	2342	0.092940748	93	9.649032	0.15860207
	950	0.073872823	170	10.491706	0.95561572
	1992	0.048479207	90	4.5214585	-0.082045657
Granite	1406	0.155211	494	93.53493	0.235461
	2103	0.016327	18	0.533841	-0.18423
	2352	0.248489	113	43.55936	0.182325
Amphibolite with quartz vein	2385	0.167653	131	22.17967	0.625723
	1006	0.245982	525	144.9927	0.07374
	1908	0.100719	188	18.78119	-0.24603
Altered rock	2305	0.0297	62.149	23.347	0.0329
	1914	0.115	124.25	15.25	-0.451
	1391	0.0891	24.85	4.25	-0.724

In waveform characterization (Okada and Iwashita, 1992), spectral profiles are normalized for spectrometric analysis to derive the width, asymmetry, area etc of the absorption feature. In this respect, the upper convex hull of a spectral profile (imaginary line joining the highest reflectance values of spectral curve) is calculated as an enveloping curve on the spectra having no absorption features. Next, the hull-quotient reflectance spectrum is derived to characterize absorption features in terms of their position, depth, width, asymmetry, and slope of the upper convex Hull (Van der Meer et al. 2001). The absorption band position or absorption band minimum ( $\lambda$ ) is defined as the band having the minimum reflectance value over the wavelength range of the absorption feature. The relative depth,  $D$ , of the absorption feature is defined as the reflectance value at the shoulders minus the reflectance value at the absorption band minimum. The width of the absorption feature,  $W$ , is derived by

$$W = A_{\text{all}} / 2D$$

where  $A_{\text{all}}$  is the sum of the area left of the absorption band minimum,  $A_{\text{left}}$ , and the area right of the absorption band minimum,  $A_{\text{right}}$ , forming the total area under the convex hull enclosing the absorption feature. The symmetry factor,  $S$ , of the absorption feature is defined as

$$S = 2(A_{\text{left}}/A_{\text{all}}) - 1$$

where  $A_{\text{left}}$  is again the area of the absorption from starting point to maximum point. Values for  $S$  range from -1.0 to 1.0 where  $S$  equals 0 for a symmetric absorption feature. The spectrometric information of absorption signatures of each

rock samples are arranged in terms of their significance to characterize the rock. Absorption signatures; which is having significant width and wavelength of absorption indicating mineral composition of rock well are regarded as significant absorption signature.

Amphibole generally lacks free water molecule in atomic structure. Therefore absorption at 1918 nm is not explainable

**Table 2.** Details of XRD (X-ray diffraction) analysis of rocks

Rocks	Compound Name	Remarks
Metabasalt	Chlorite-Serpentinite	Major
	Quartz	Good amount
	Calcite	Good amount
	Muscovite	Small amount
	Albite	Small amount
	Amphibole	Trace
	Rutile	Trace
Amphibolite	Talc	Trace
	Magnesiohornblende	Major
	Quartz	Major
	Clinochlore	Good amount
	Calcite	Good amount
	Albite	Small amount
	Muscovite	Small amount
Amphibolite with Quartz Vein	Magnesiohornblende	Major
	Quartz	Good amount
	Albite	Good amount
	Clinochlore	Small amount
Alteration Zone	Calcite	Major
	Talc	Good amount
	Clinochlore	Good amount
	Quartz	Trace
	Chromite	Trace likely
	Calcite	Major

based on major minerals such as amphibole and plagioclase (andesine). XRD analysis of the amphibolite shows the presence of the different mineral phases in amphibolite and it is understood presence of Mg in amphibole has caused 2315 absorption feature whereas calcite (as presence confirmed by XRD analysis refer Table 2) may have caused the absorption spectra at 1918 nanometer (nm). In addition to the major absorption feature mentioned, there are absorption around 1400 nm is due to OH molecule stretching. As amphibole is dark rock where mafic (darker) amphibole is dominant mineral; which is intimately associated with minerals like quartz and calcite (please refer XRD analysis of the same rock subjected to spectral analysis in Table 2) and therefore the contribution of dark mineral appeared significant in shaping the spectral response of amphibolites and contribution of other dominant minerals like quartz, calcite (which are leucocratic) are appeared minimal (Fig.4). This is due to the fact that the contribution of darker element dominates to shape the spectral curve of the dark mixture (Clark, 2011). Similar fact is also applicable to amphibolites spectra where the spectral signature of Mg amphibole played the major role in shaping the spectra of amphibolite.

#### Metabasalt

It is the most dominant rock unit of the schist belt. One interesting observation regarding metabasalt (chloritic) spectra is that neither of the major constituent mineral of pure basalt can be referred to infer the spectra of metabasalt (Fig.5).

Sample (Fig.2) characterised as metabasalt are made up of fine grained, green coloured schistose mineral-chlorite, which is formed due to retrograde metamorphism; near the shear zone. XRD analysis of metabasalts also revealed the presence of chlorite and serpentine in the basalt. Therefore, the spectral profile of metabasalt is dominantly constituted by the spectra of chlorite and serpentine. It is quite evident that the metamorphism changes the mineral assemblages and therefore new sets of minerals and their respective spectra can only explain the spectral signature of metamorphosed rock (in present case metabasalt). Mg-OH absorption at 2342 nm (Table 1 and Fig.5) in metabasalt is broader and shallower in comparison to similar absorption signature in serpentine; one of the major constituent of metabasalt and shifted towards higher wavelength in comparison to Mg-OH absorption in chlorite and serpentine (Fig.5). Figure 6 illustrates the photomicrograph of optical thin section under plan polarized light of meta-basalt delineating chlorite (lath-shaped minerals and inequigranular) (marked by greenish yellow outline).

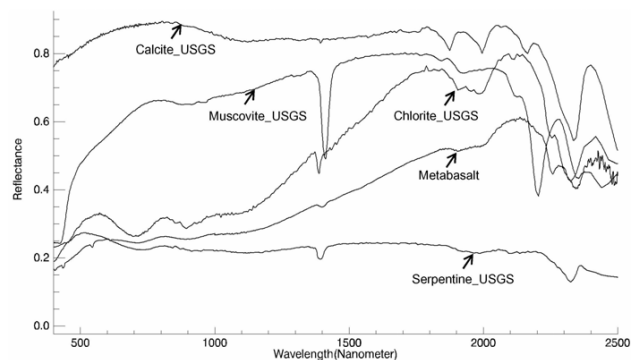


Fig.5. Metabasalt spectra (continuum removed) and spectra of constituent mineral obtained from USGS spectral library.

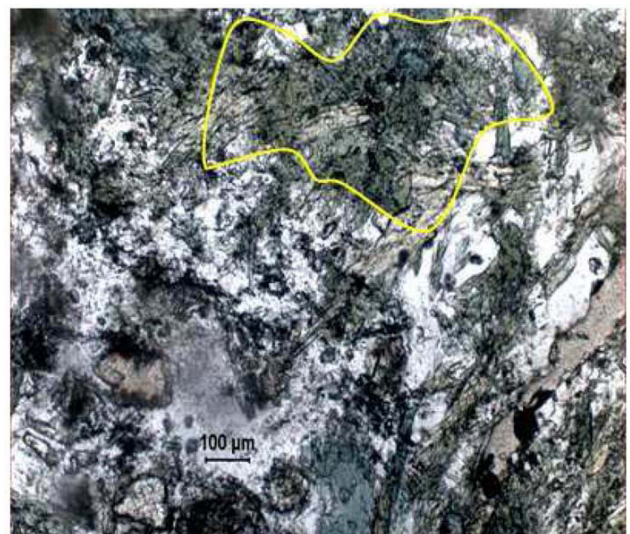
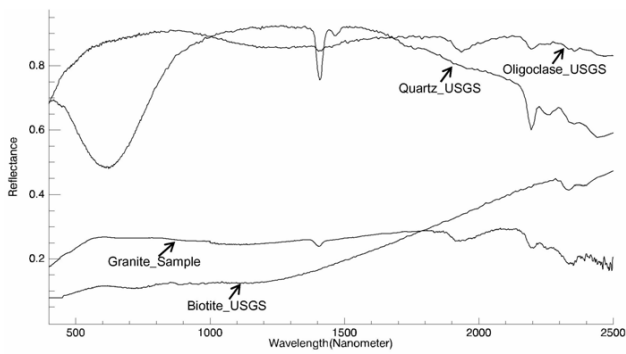


Fig.6. Chloritization in metabasalt.

It is therefore evident that the important absorption feature characteristic for identifying a mineral may shift from its original position due to non-linear mixing with other constituent minerals of the rock. In nonlinear mixture the spectral signature of dominant mineral dominates and therefore 2342 nm due to chlorite is prominent in metabasalt basalt and broad absorption around 700 nm due to the presence of muscovite is suppressed in basalt (Fig.5).

#### Granite/Granite-Gneiss

Granite/Granite-Gneiss spectra is featureless in VNIR-SWIR electromagnetic domain and has broad similarity with the quartz spectra (absorption at 1406 nm) with subdued absorption may be caused by the presence of oligoclase in granite which has high reflectance around 500 nm and subdues the absorption feature of quartz in the same electromagnetic interval. Therefore granite becomes featureless in VIS-SWIR domain (Fig.7). The detail spectrometric observations of the absorption feature of the



**Fig.7.** Laboratory spectra of granite-gneiss and spectra of constituent minerals obtained from USGS spectral library.



**Fig.8.** Granite-gneiss under cross polarized light. Plagioclase (1) and biotite (2) are demarcated in granite.

granite/granite-gneiss rock is given in Table 1. The photomicrograph of granite-gneiss reveals presence of plagioclase (oligoclase), biotite in granite-gneiss (Fig.8). Granite/granite-gneiss spectra is featureless and has broad similarity with quartz (absorption at 1406 nm) but modified by the presence of oligoclase in granite which has high reflectance around 500 nm and therefore subdues the absorption feature of quartz in the same region. The absorption at 2352 nm may be due to the Mg-OH bond vibration in biotite. Biotite also has substantially reduced the overall reflectance of quartz feldspar in the rock and therefore it is once again evident that in intimate mixture darker mineral influences in modifying the relative reflectance of mixture (Clark, 2011). The detail spectrometric observations of the absorption feature of the granite/granite-gneiss rock is given in Table 1.

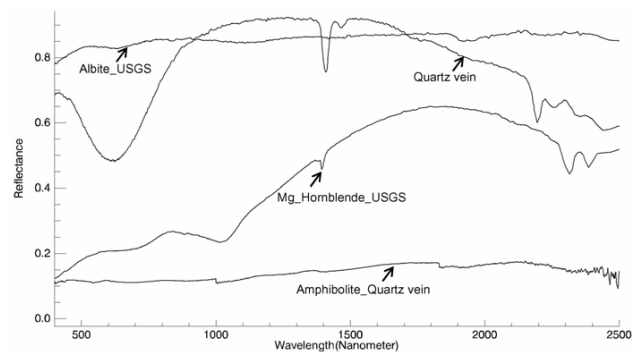
#### Amphibolite with Quartz Vein

Amphibolite is silicified near shear zone. Silicification

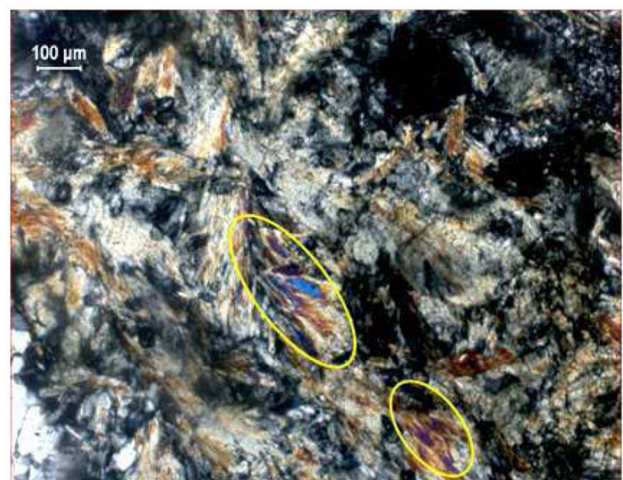
has taken place where quartz reef are emplaced along shear zone. Amphibolites are also found to be stretched in this region as it is observed in cross polarized thin section of the sample (Fig.9). Silicified amphibolite can be regarded as an indicator of mineralization as major lode is emplaced with the emplacement of quartz reef in the schist belt. Therefore understanding the spectral behavior of silicified variant of amphibolite is important. As quartz vein occupied the considerable portion of the sample (Fig.2), spectral profile of the rock is more influenced by the spectral character of quartz but absorption signature due to Mg-rich amphibole still appear significant (Fig.10). The XRD analysis of this rock is illustrated in Table 1.

#### Altered Rock

Isolated old workings are present in the study area. Few altered samples are also collected from these older mines and also from limited surface exposures of the rock from places like Wandali, Mallapur etc. These rocks are believed to be the alteration product associated with mobilization

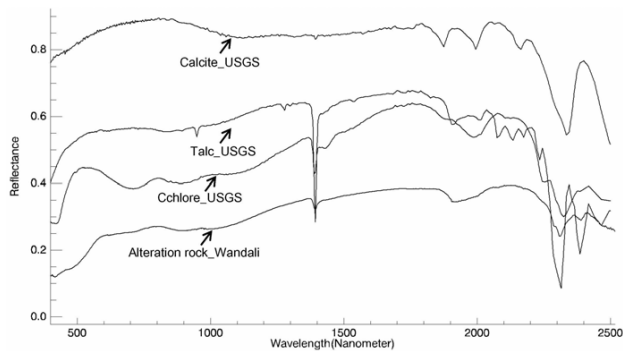


**Fig.9.** Spectral profile of amphibolite intruded by quartz vein and spectra of constituent minerals obtained from USGS spectral library.

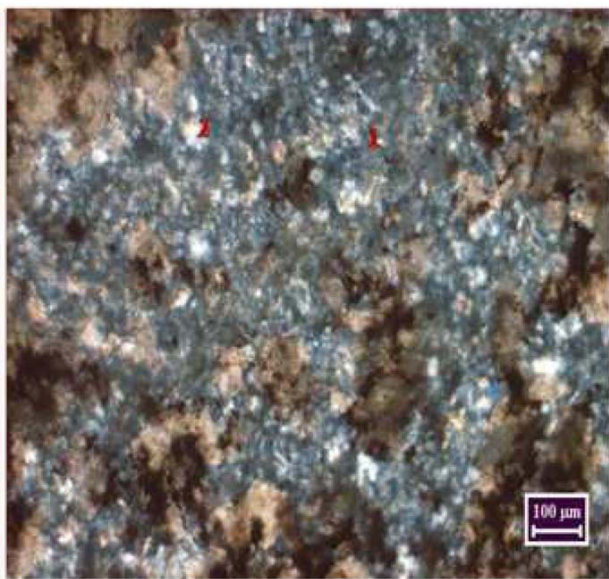


**Fig.10.** Stretched amphibolite minerals due to deformation.





**Fig.11.** Spectral profile of altered rock and spectra of constituent minerals obtained from USGS spectral library.

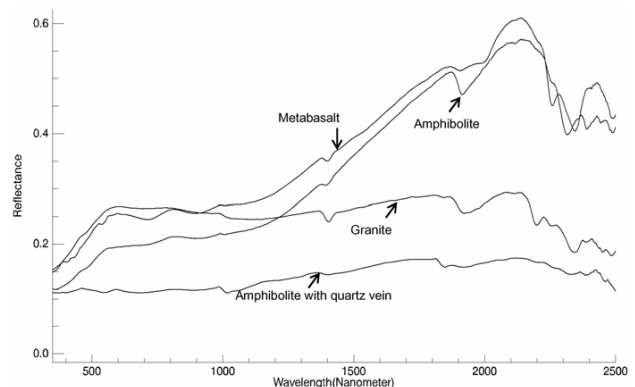


**Fig.12.** Photomicrograph of altered rock (under cross polarized observation). Calcite is brighter (1) in groundmass whereas Mg-rich mineral matrix (talc?) with greyish blue colour.

and mineralization. The spectra (Fig.11) of the altered rock can be analyzed based on the spectra of the mineral phases of this rock determined in XRD analysis (Table 2). The absorption signature of the altered rock at 2305 nm wavelength appear characteristics for the same rock as the rock is dominated by calcite as evident from XRD analysis (Table 2). The petrographic analysis of altered rock revealed that the rock is made up of Mg-rich mineral and calcite (Fig.12). Calcite appears as bright colour and Mg-rich mineral is greenish grey coloured under cross polarization of photomicrograph.

The aforesaid analysis of rock spectra in light of their mineral spectra can be summarized as follows and can be considered as the basis for designing space/airborne sensor for geological application and also setting up the approach for geological studies using imaging spectroscopy

- Spectral signatures of rocks are related to spectral signature of constituent minerals although absorption feature of particular mineral in the rock can be modified or displaced (i.e. displacement of wavelength of absorption) a little due to non-linear mixing in the rock fabric.
- Each rock has significant absorption features (refer Table 1). But many of these absorption signatures are closely spaced to each other. If we study rock spectra conjugately, altered rock has significant absorption at 2305 nm whereas amphibolite has its important signature in 2385 nm and metabasalt has its significant absorption 2342 nm. Granite is almost featureless and has its absorption feature at 1406 nm may be due to quartz (Fig.13). As it is evident that the delineation of the lithologies is possible within the short spectral domain of 2305 nm to 2385 nm and these rocks can be delineated if we can measure with at least 20 nm or better spectral bandwidth for these specific rock samples. Therefore spectral measurement of high spectral resolution with appreciable signal to noise ratio only can detect rocks from each other and further we require high spectral resolution in SWIR domain to make VNIR-SWIR spectroscopy effective for geological applications.
- Absorption signatures of the minerals imprinted on the



**Fig.13.** Spectral signature of the rocks superimposed to each other.

rock spectra matches well with the result of the XRD analysis or vice versa. Therefore if rock spectra are analyzed using mineral spectra they can give quick and satisfactory idea about the presence of major minerals in the rock. Therefore, it can be concluded that spectral signatures of the rocks are useful in detecting the presence of abundant minerals as it is seen while compared these signatures with the XRD data.

## CONCLUSIONS

Spectral analysis of rocks in conjunction with

petrographic and XRD analysis has been used to illustrate the following significant facts:

1. Spectral signature of rocks are complex but can be better analyzed in conjunction with the geochemical data (estimates relative abundance of minerals) and petrographic data (provides supplementary information on mineralogy and texture) of same rock.
2. Research also illustrated that spectral signatures of dominant one or two minerals significantly influence the shape of the rock spectra but original mineral spectra cannot be replicated in the rock spectrum. For e.g. Mg-Hornblende has absorption signature 2315 nm; while Mg-hornblende occur in amphibolite juxtaposed with other mineral variants has absorption at 2385 nm. The absorption signature of calcite in calcite rich altered rock is at 2305 nm while calcite has its absorption at 2335 nm. Therefore, it is evident that rock spectra should be regarded as end member instead of its dominant mineral spectra for mapping lithology using imaging spectroradiometer.
3. It is also observed that the absorption signatures occur within the rock are few in number in comparison to number of minerals present in the rock. Identification of the most significant absorption signature amongst them requires geochemical and petrographical data. The absorption signature of the rocks are closely spaced in many occasion. For example amphibolite has absorption at 2385 nm whereas metabasalt has characteristic absorption 2342 nm. Therefore closely spaced and contiguous spectral channels only can demarcate different lithologies from each other.

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