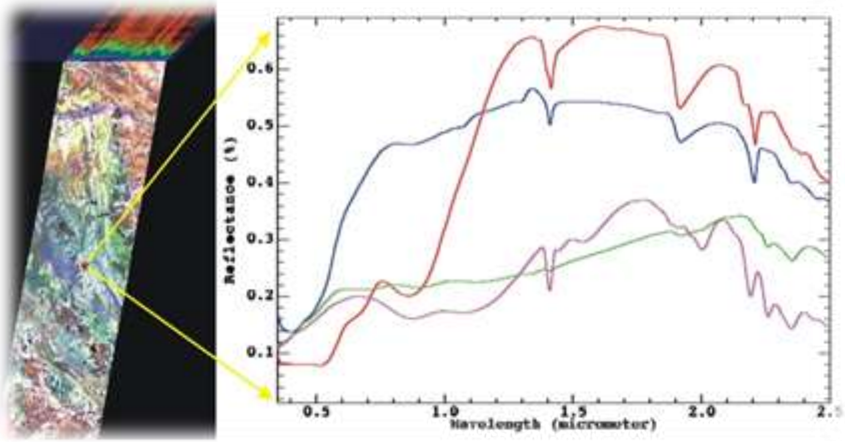
INTRODUCTION TO HYPERSPECTRAL REMOTE SENSING

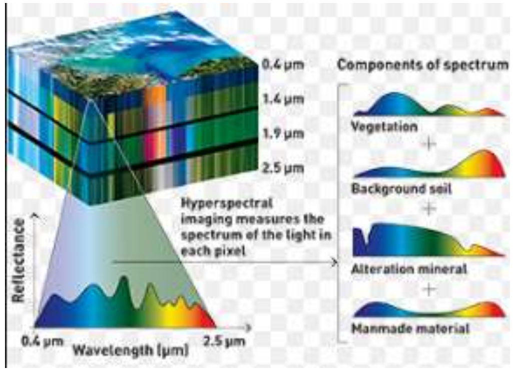
(Hyperspectral & Spectroscopy)

Geological Survey of India
Training Institute
Mission-V

Introduction to Hyperspectral Remote Sensing

(Hyperspectral & Spectroscopy)





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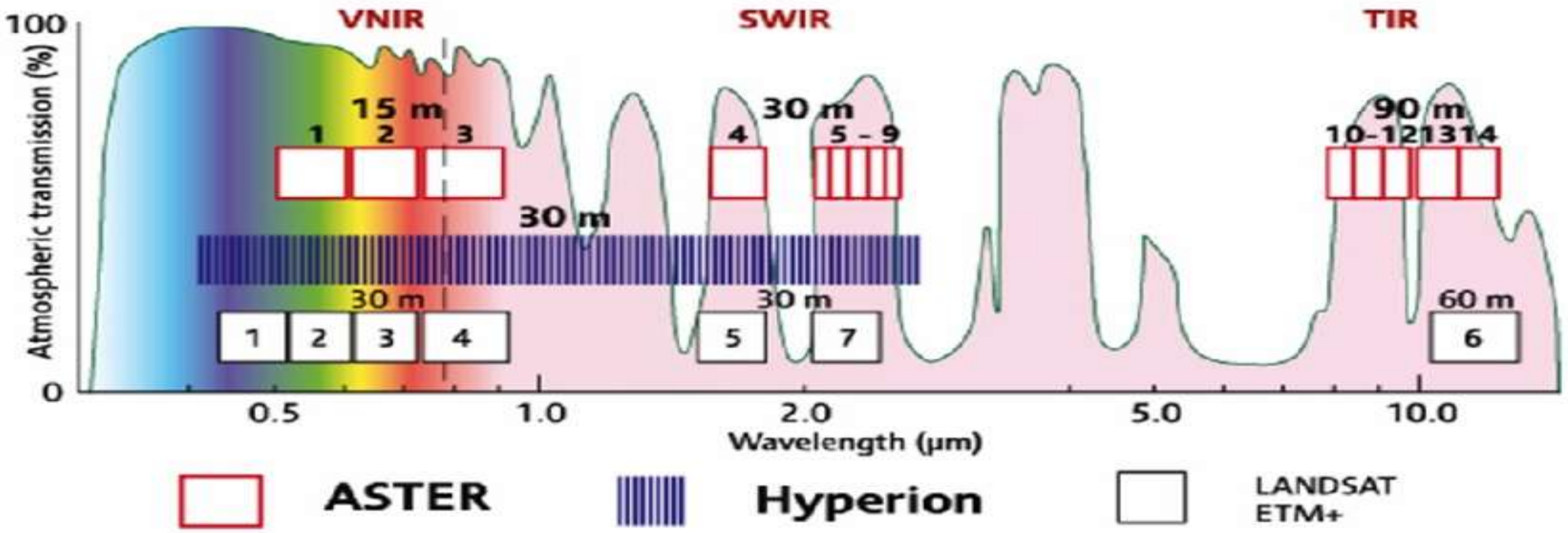
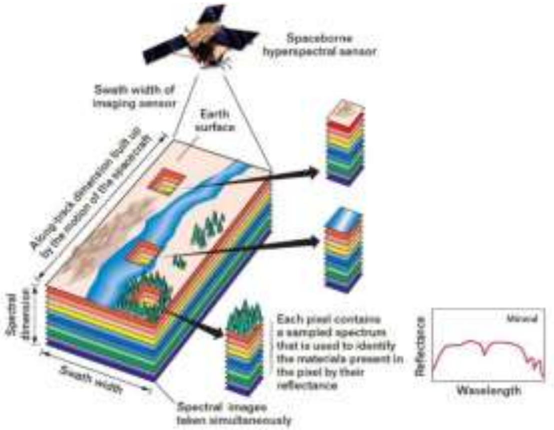
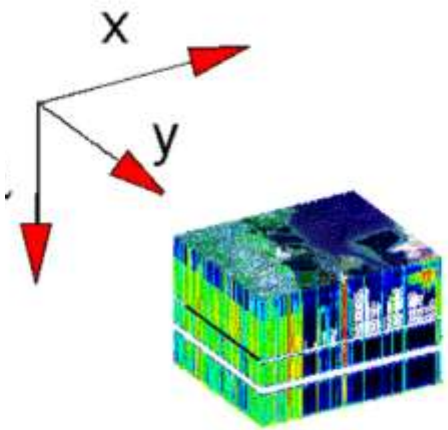
- Hyperspectral Remote Sensing
- Multispectral to hyperspectral
- Concepts of spectroscopy
- Spectroradiometer
- Hyperspectral sensors
- Hyperspectral data processing

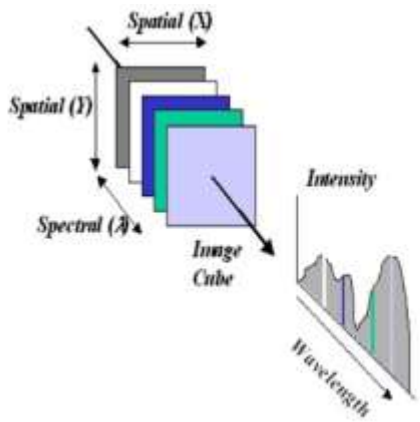
Hyperspectral Remote Sensing

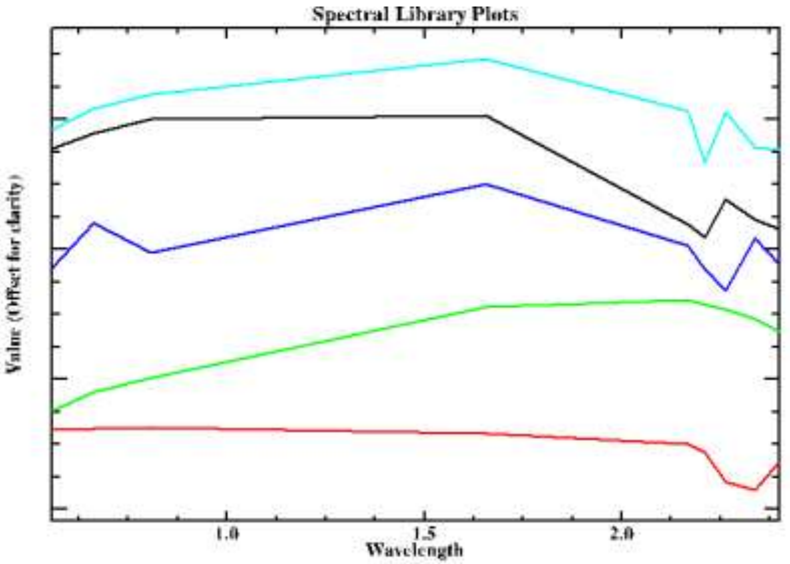
- Hyperspectral sensors acquires image in many narrow contiguous spectral bands throughout the visible, near infrared (VNIR) and shortwave infrared (SWIR) from 0.4 to 2.5 µm wavelength range simultaneously at 5-10 nm band width.
- Hyperspectral remote sensing combines imaging and spectroscopy in a single system, which often includes large data sets and require new processing methods.



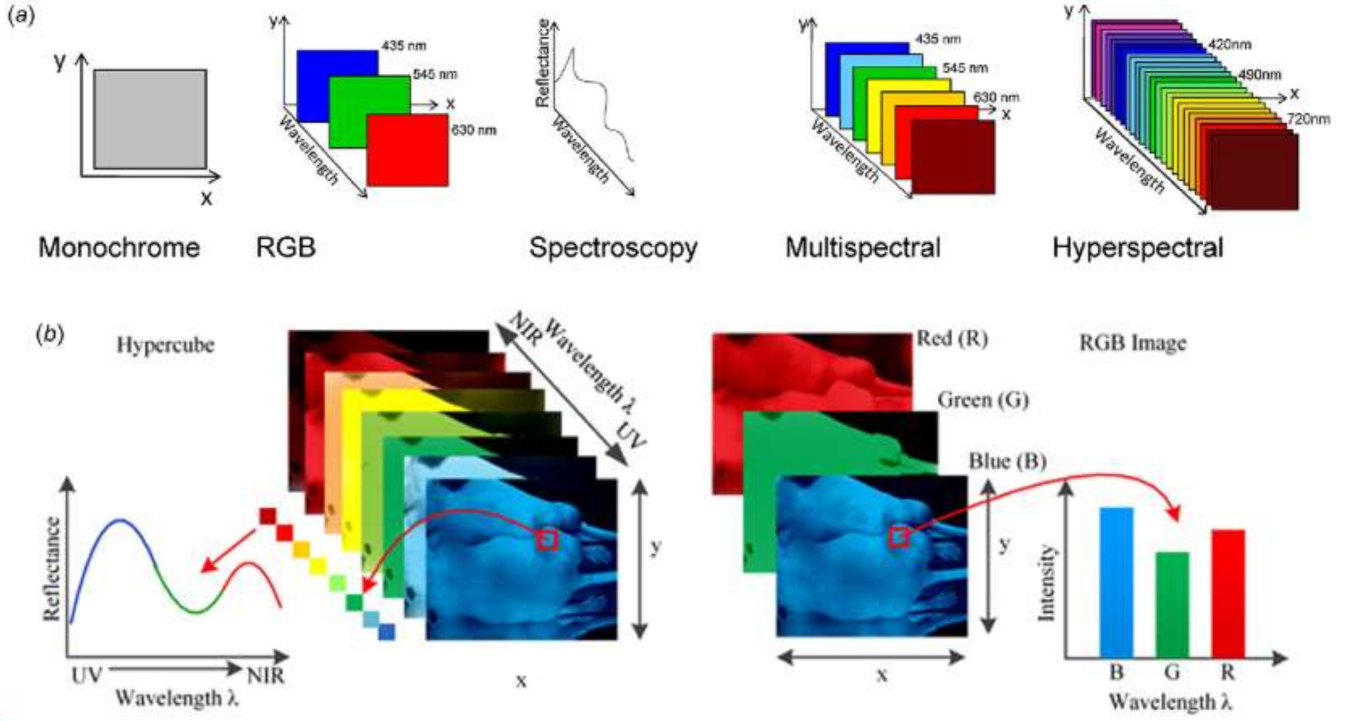


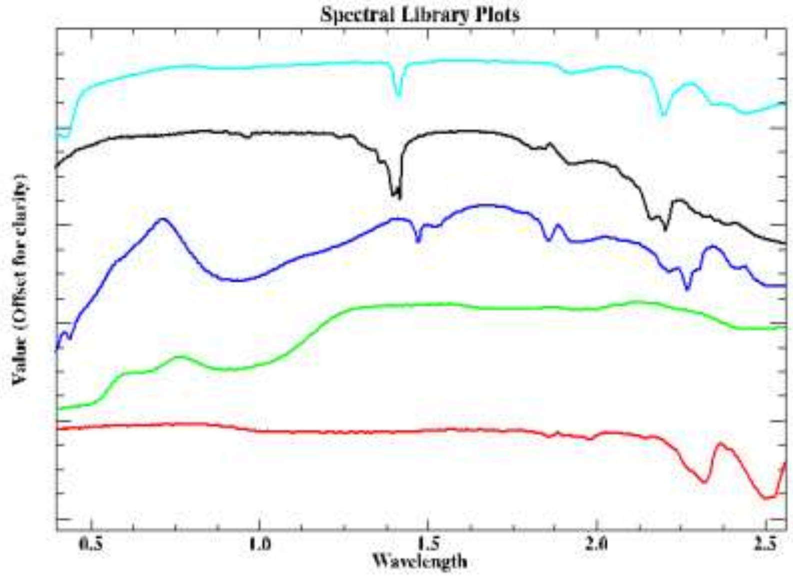




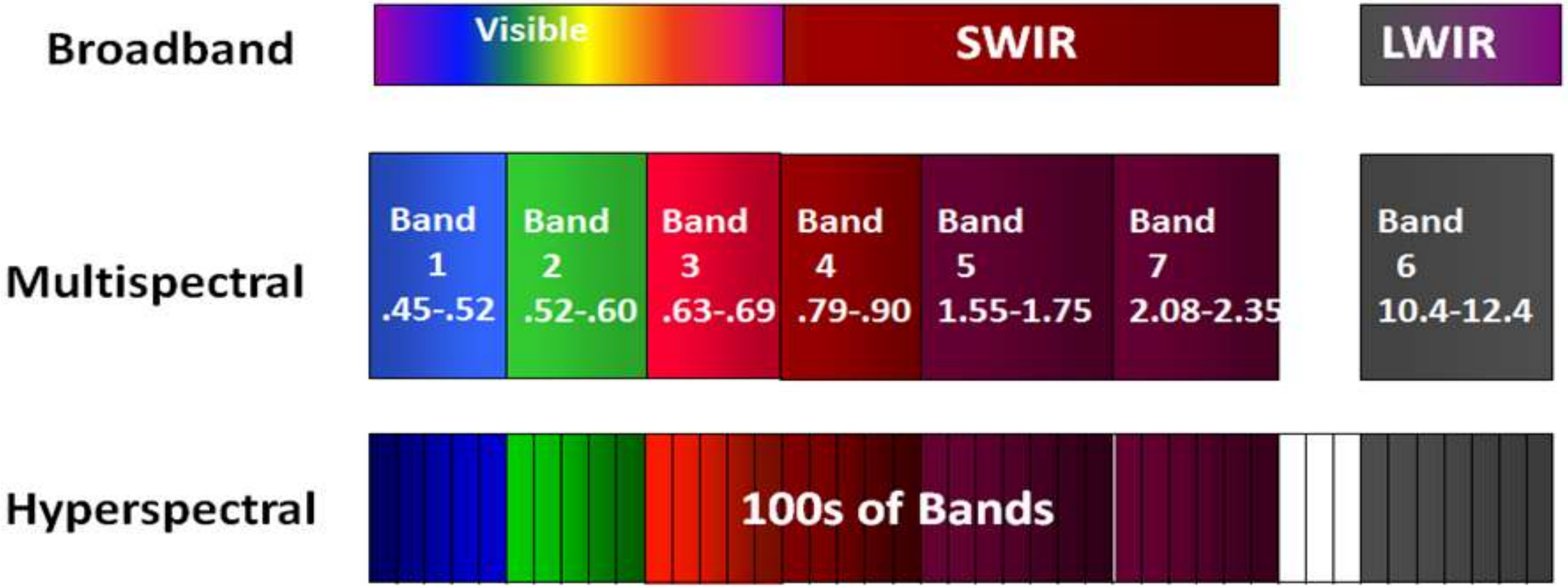


Multispectral Vs Hyperspectral





Multispectral Vs. Hyperspectral

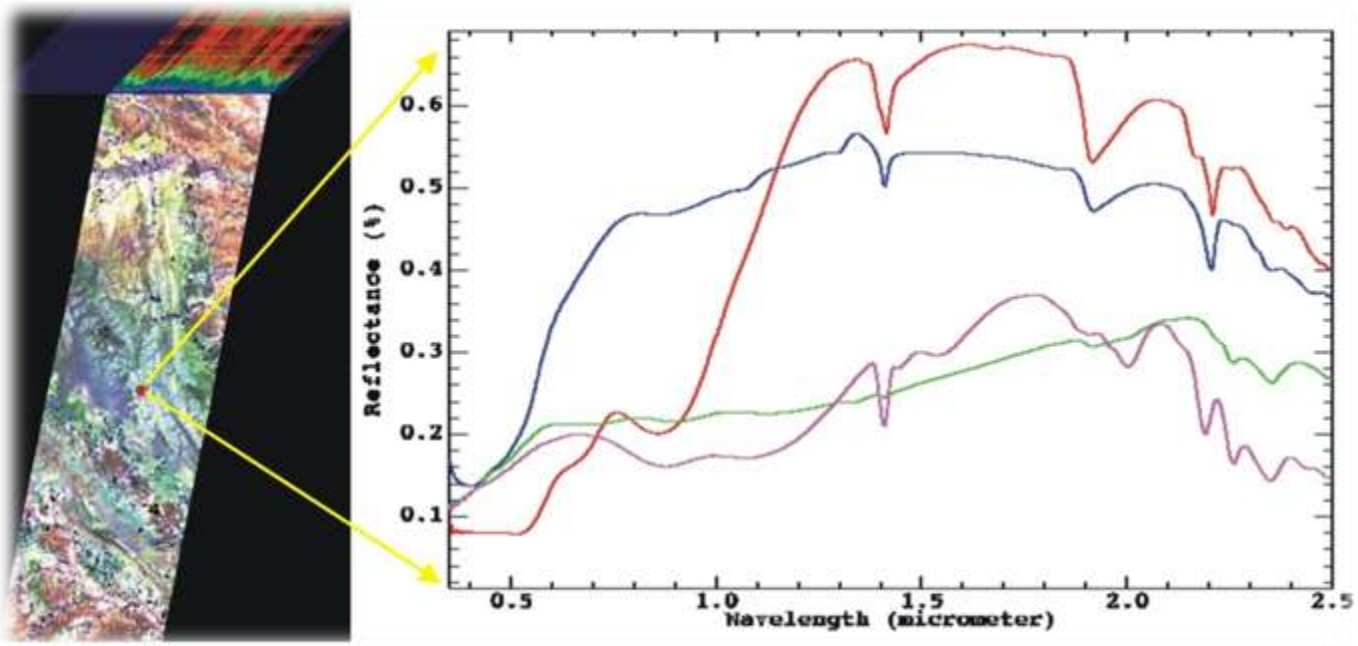


	Multispectral	Hyperspectral
No. of Bands	<100	>100
Wavelength	Discrete	0.4-2.5 µm
Spectral Width	80-100 nm	5-10 nm
Spatial Resolution	30m	30m and 5-8 m for AVIRIS-NG

❖*Hyperspectral imageries are typically collected in 3-D with spatial information in X-Y plane and spectral information in the Z plane.*

❖*Advantage with the hyperspectral data is that it facilitate image analysis as well as spectroscopic study in the form of spectral signature for each pixel*

❖These spectral signatures discriminate individual minerals based on their absorption features.



- Can be *used to delineate a variety of minerals that broadband, low resolution systems such as Landsat are unable to demarcate.*

- Hydrothermal alteration is commonly indicated by iron oxide, hydroxyl bearing minerals, carbonates and sulfate, which produce characteristic signatures throughout the VNIR and SWIR range as an outcome of electronic and vibrational processes .

- Spectral range from 0.4 to 1.0 µm (VNIR) range is important for mapping iron oxides (hematite, goethite, limonite, jarosite).

- Spectral range from 2.0 to 2.5 µm is useful for mapping of hydroxyl-bearing minerals, sulfates and carbonates, common to many geologic units and hydrothermal alteration assemblages

Application of Hyperspectral Remote Sensing

Spectroscopy Of Major Minerals And Spectral Resolution Requirement(cloutis,1996)

Mineral Group	Characteristic absorption depth of absorption signature	Spectral Resolution Required
Olivine	near 1 µm ,0.65 µm	30 nm is required in the 1µm wavelength region to permit the lowest level of quantitative compositional information
Pyroxene	near 1 µm and 2µm	130 nm to 500 nm
Amphibole	absorption features near 1.1 µm, 1·4µm, and 2.3-2.4 µm	Approximately 60 nm
Feldspar	1.1-1.3 µm	At least 200 nm can be used to constrain major (Ca, Na) and minor (Fe) element abundances and grain sizes
Clay	1.4,1.9,2.2 µm	15-20 nm is required to differentiate clay mineral. Spectral resolution on the order of 50-100nm is only useful for identifying the presence or absence of clay minerals.
Carbonate	2.3 to 2.4µm	Approximately 10 nm
Iron Oxides/Hydroxides	0.4µm, 0.7µm	Differences in band positions between different species may be as small as 10nm.

Useful wavelength range for Mineral Exploration

Visible – Near Infrared (VNIR-0.35 to 1 µm)

- Iron Oxides (Fe^{2+}, Fe^{3+})
- Rare Earth Element Oxides

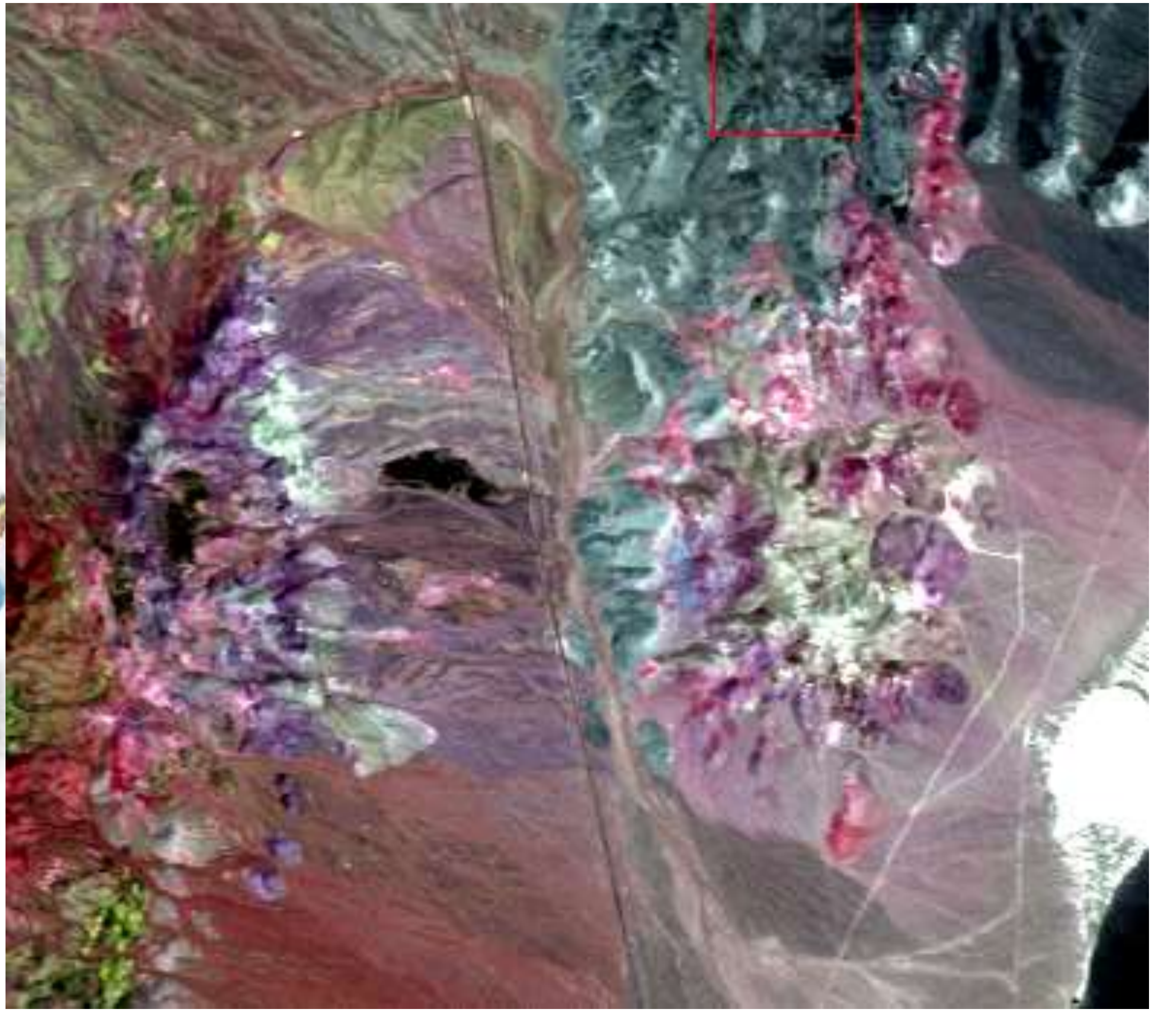
Short Wave Infrared (SWIR- 1 to 2.5 µm)

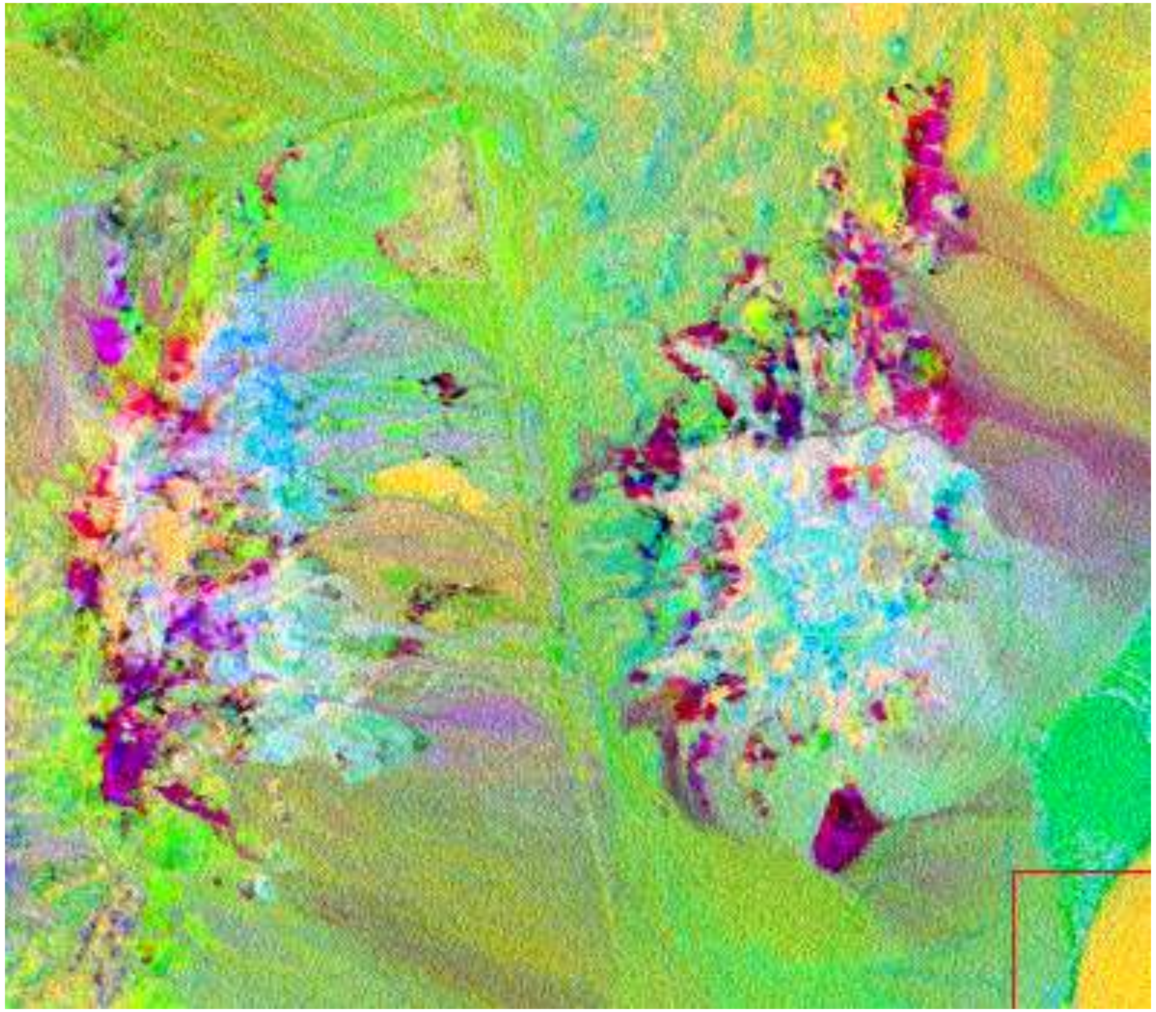
- Carbonates (CO_3- Calc, Magn, Dolo, Fe carb)
- Phyllosilicates
- Sulfates (Alunite, Jarosite)
- Al – OH & Fe – OH (-Clay, Muscovite, Chlorite)
- Mg – OH (Serpentines, Chlorites, Biotite, Phlogopite, Amphiboles)

Long Wave Infrared (Thermal or TIR> 2.5 µm)

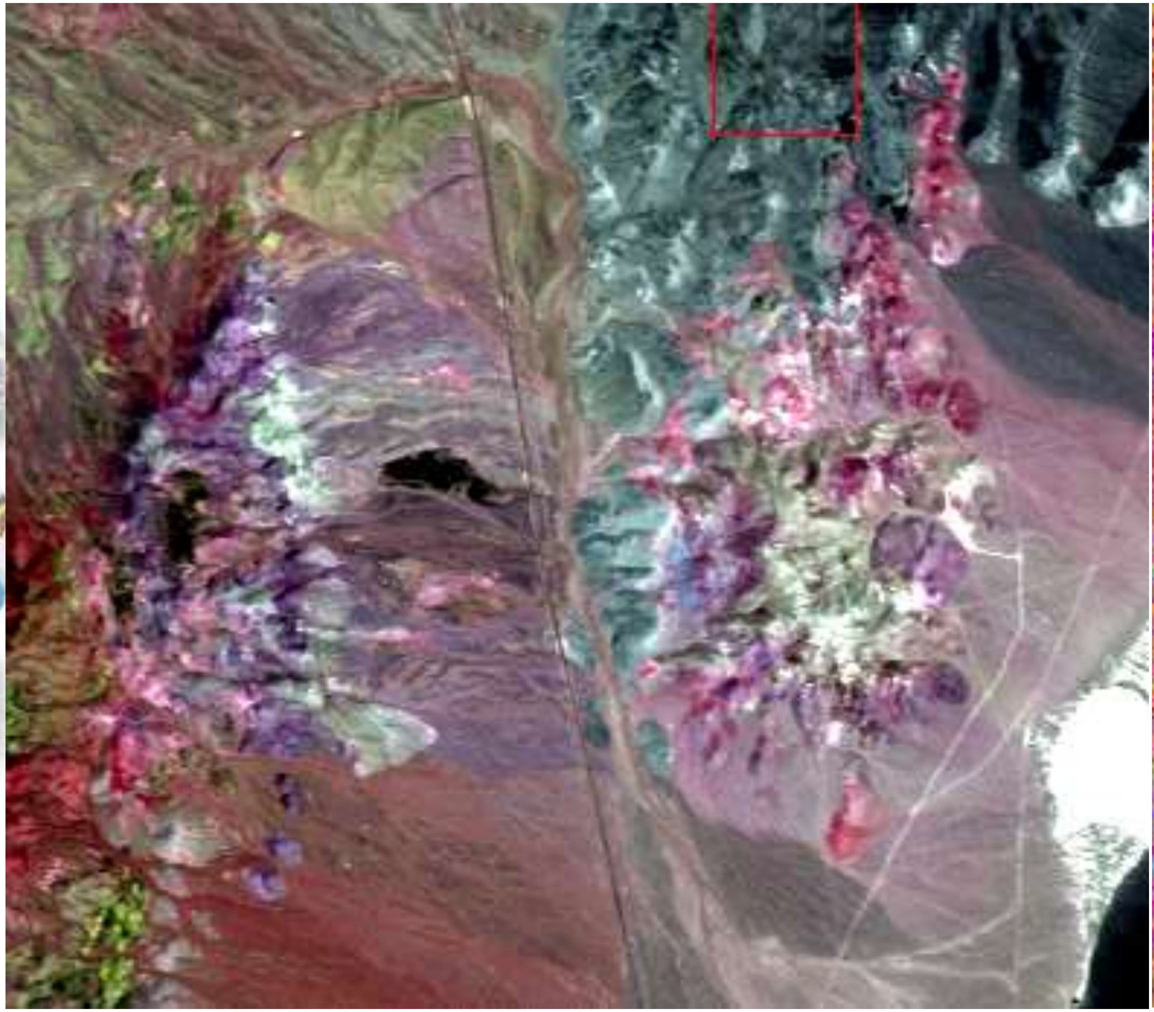
- Silicates (Qtz, Fsp, Gt, Px, Ol, Am, Clays, Micas)
- Sulfates (Alunite, Jarosite, Gypsum, Anhydrite)
- Carbonates (CO_3-Calcite, Magnesite, Dolomite)
- Phosphates (Apatite)

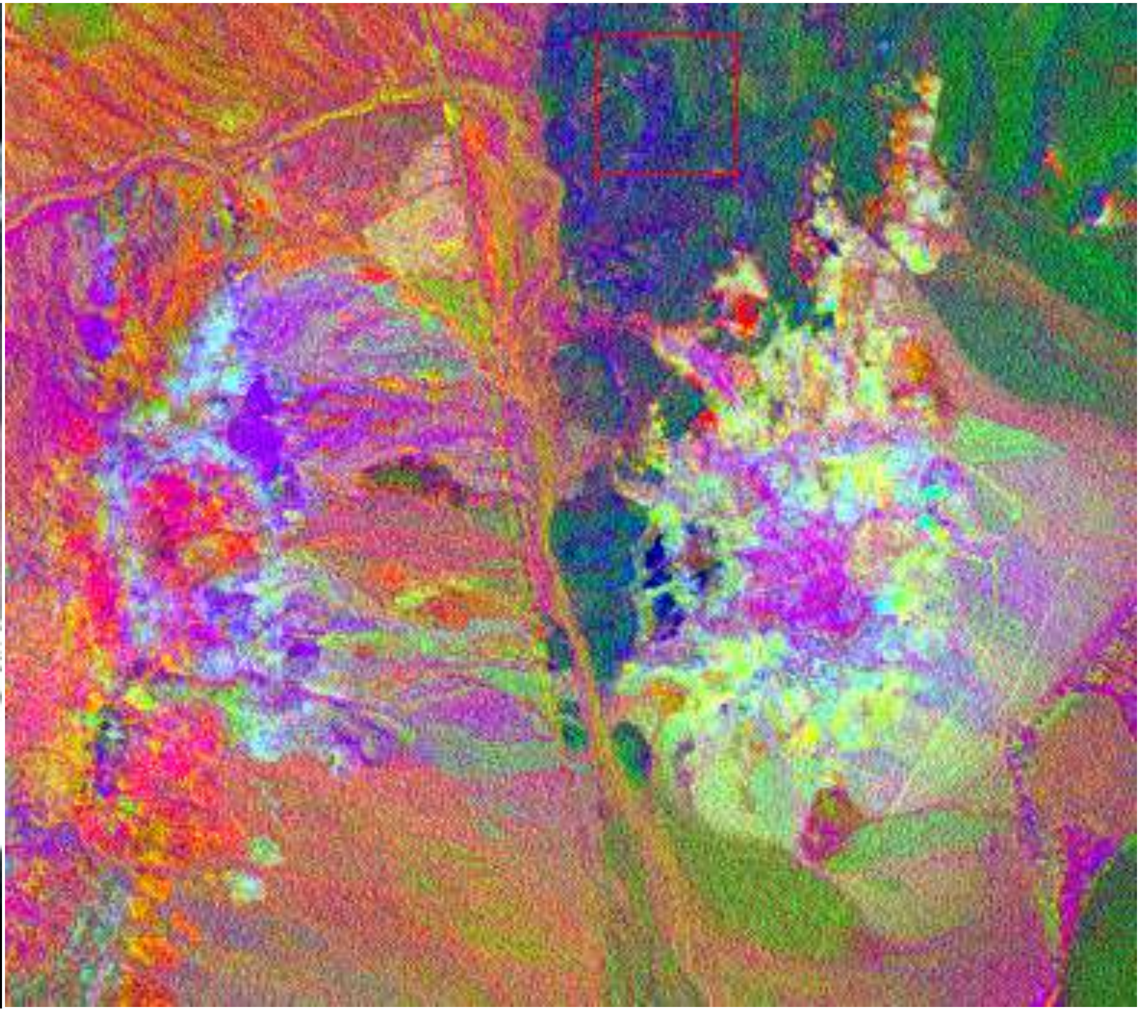
❖ Lithological Mapping



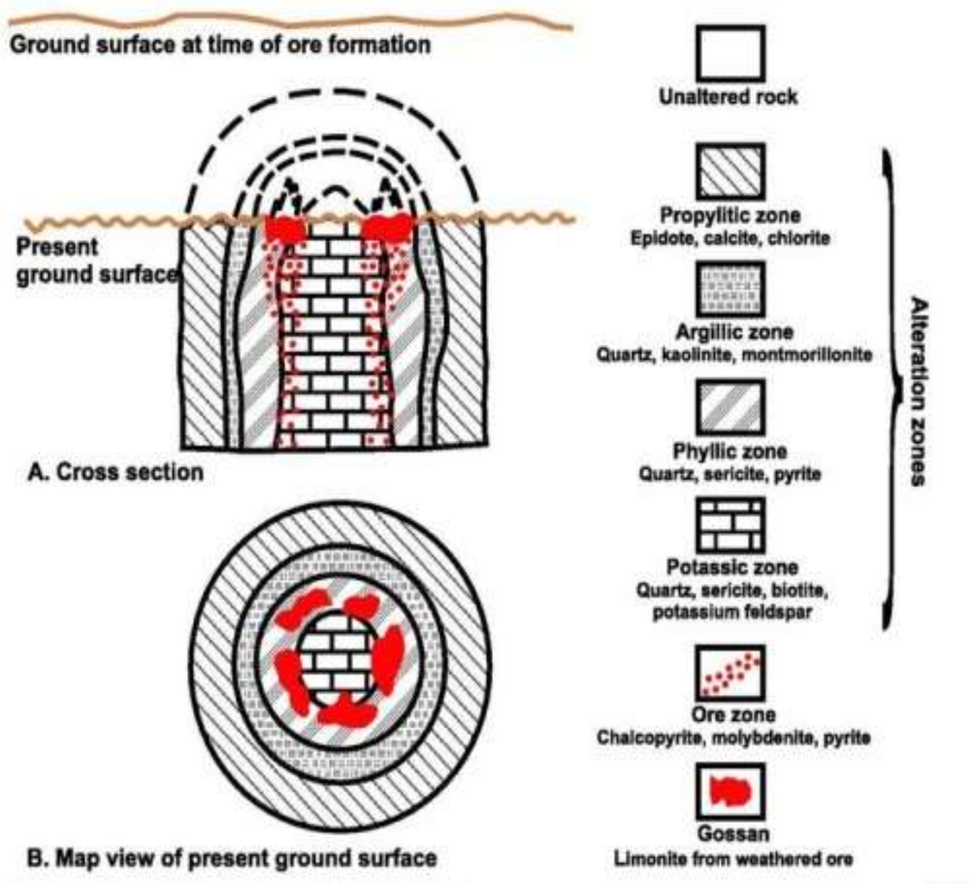


❖ Lithological Mapping





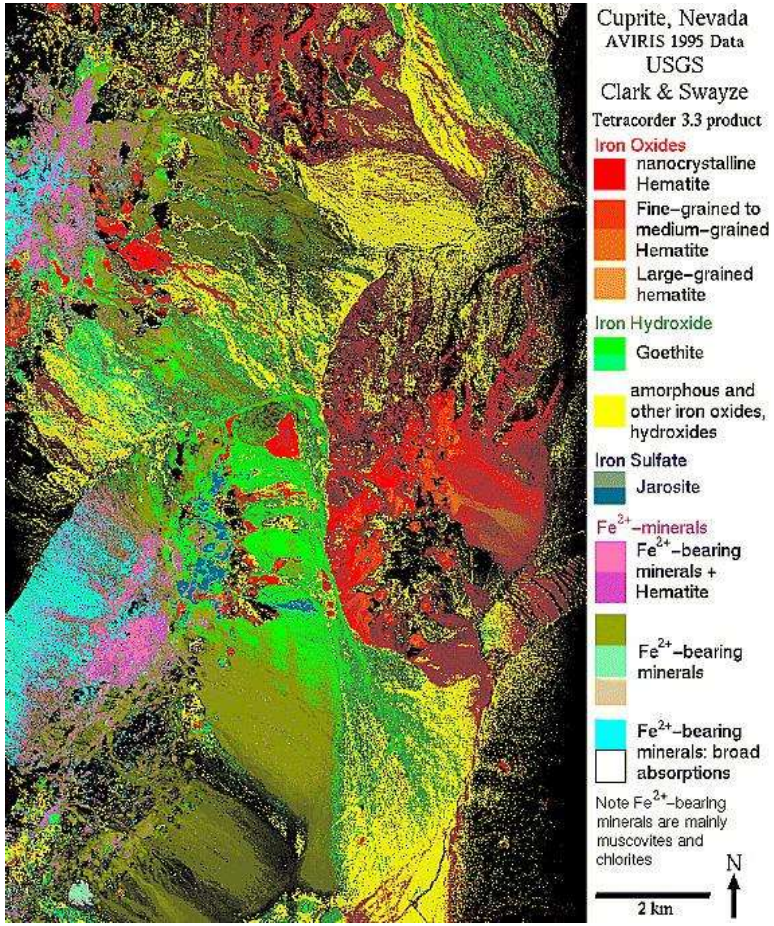
Hydrothermal alteration Zone Mapping/ Mineral Mapping



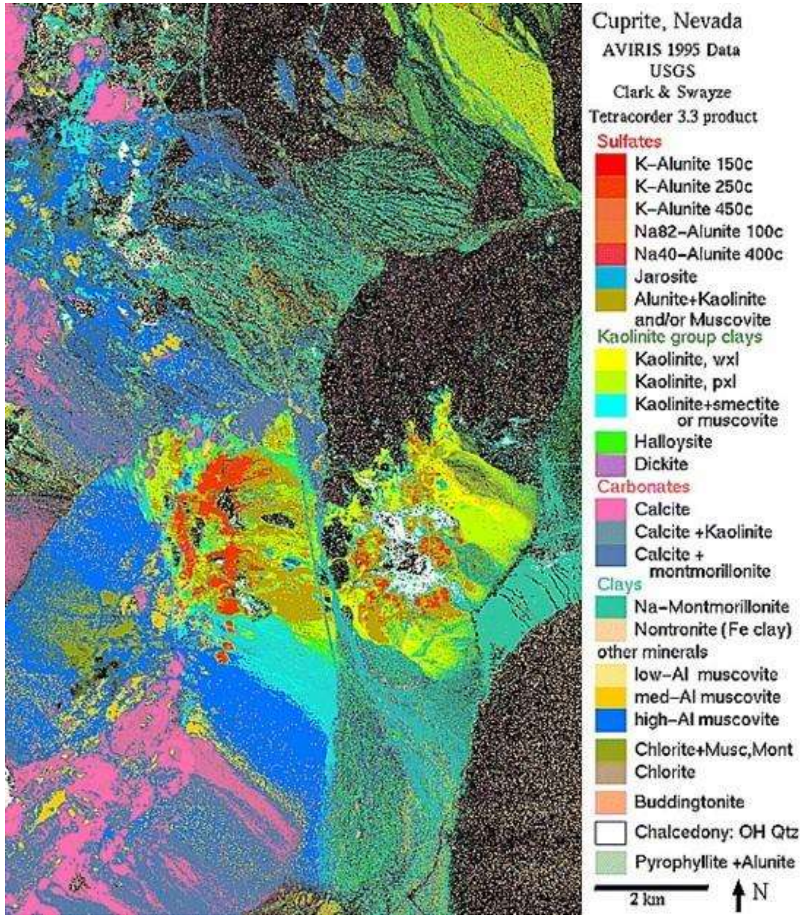
Alteration Zones	Mineral Assemblages
Propylitic Zone	Epidote, Calcite, Chlorite
Argillic Zone	Quartz, kaolinite, montmorillonite
Ad. Argillic Zone	Kaolinite, dickite, pyrophyllite
Phyllic zone	Quartz, sericite, pyrite, muscovite
Potassic zone	Biotite, k-feldspar, quartz, sericite,

CLASSICAL ALTERATION MODELS SHOWING HYDROTHERMAL ALTERATION ZONES (Lowell and Guilbert, 1970)

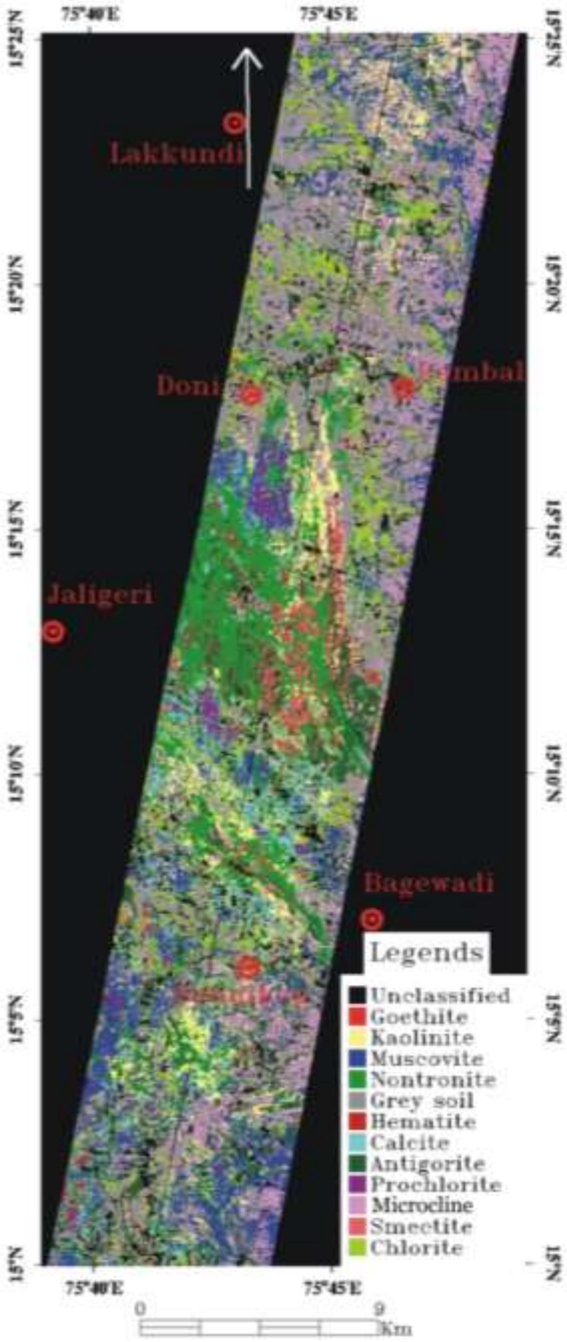
Over the last two decades, like **AVIRIS, HYDICE, DAIS, HyMAP** have been extensively attempted. ***mineral mapping and lithological discrimination using airborne hyperspectral sensors***



Mapping results from the analysis of visible to near infrared (**VNIR**) **AVIRIS** airborne hyperspectral imagery over **Cuprite, Nevada** (from Clark et al., 2003).



Mapping results from the analysis of short-wave infrared (**SWIR**) **AVIRIS** airborne hyperspectral imagery over **Cuprite, Nevada** (from Clark et al. 2003).



•The EO-1 Hyperion sensor was launched in November 2000.

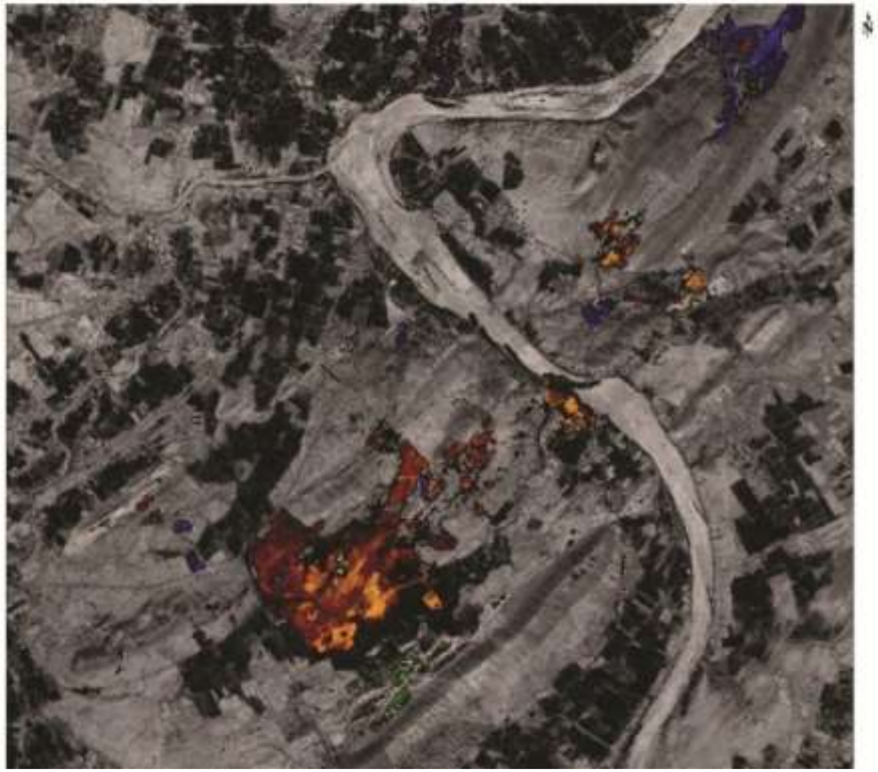
•Hyperion have 242 spectral bands covering VNIR to SWIR region with 7.65 km swath and 185 km long (along-track) region.

•The image consists of 30 m x 30 m pixels, in which the spectrum for each portion is provided

Mapping results from the analysis of Hyperion ((**VNIR-SWIR) spaceborne i**magery over Gadag Schist belt

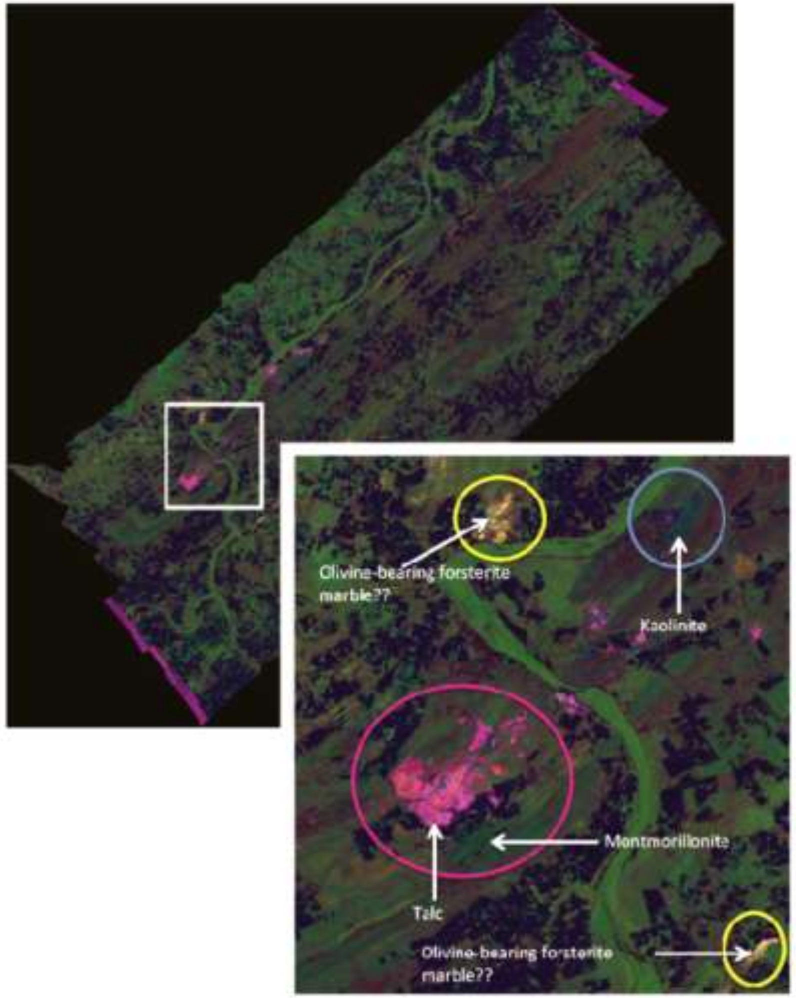
Source: Rani N. 2016

Jahazpur



Magnesium carbonate-bearing host rocks appear in shades of maroon to purple, talc-bearing pixels appear in yellow, kaolinite in blue and montmorillonite in green.

Ambaji



FCC, combined olivine- and carbonate-bearing pixels appear in yellow, **magnesium carbonate in red to orange to maroon**, **soap stones (talc) in magenta,** kaolinite in bluish-green and montmorillonite in dark green.

Source: Bhattacharya et al., 2019

Jahazpur

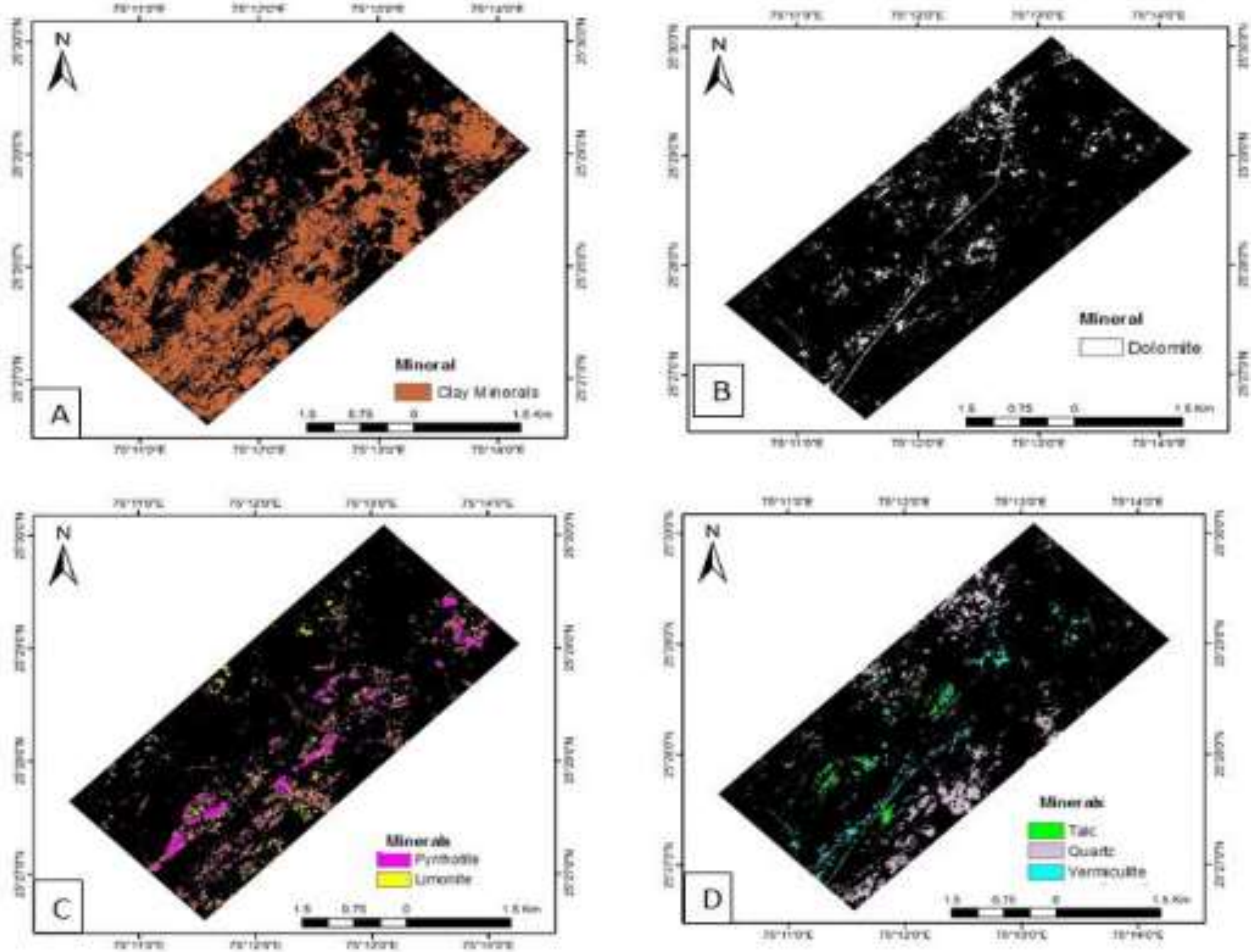


Figure 4: Mineral distribution maps of the different minerals after applying the threshold values on the fit images generated by SFF algorithm. A: Clay minerals, B: Dolomite, C: Iron minerals (pyrrhotite & limonite), D: Other minerals (Talc, quartz & vermiculite).

Source: Jain and Sharma, 2018

Geo-botany

❖Geo-botany has been defined as the study of plants as related specifically to their geologic environment which includes :

❖Spatial distribution of plants and plant communities as related to geology.

❖Vegetation characteristics (physiology, morphology, anatomy, biochemistry) as related to geology.

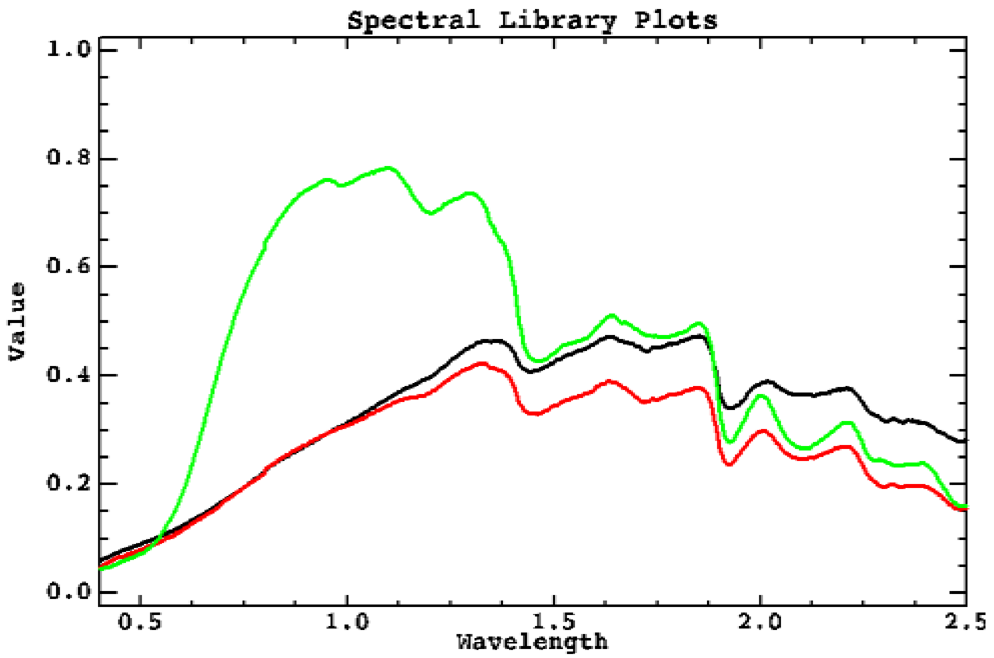
❖**Reflectance spectra of foliage growing over mineralized areas may differ from spectra of foliage in adjacent non-mineralized areas.**

❖Vegetation is often influenced by mineralization, lithology, and rock fracturing.

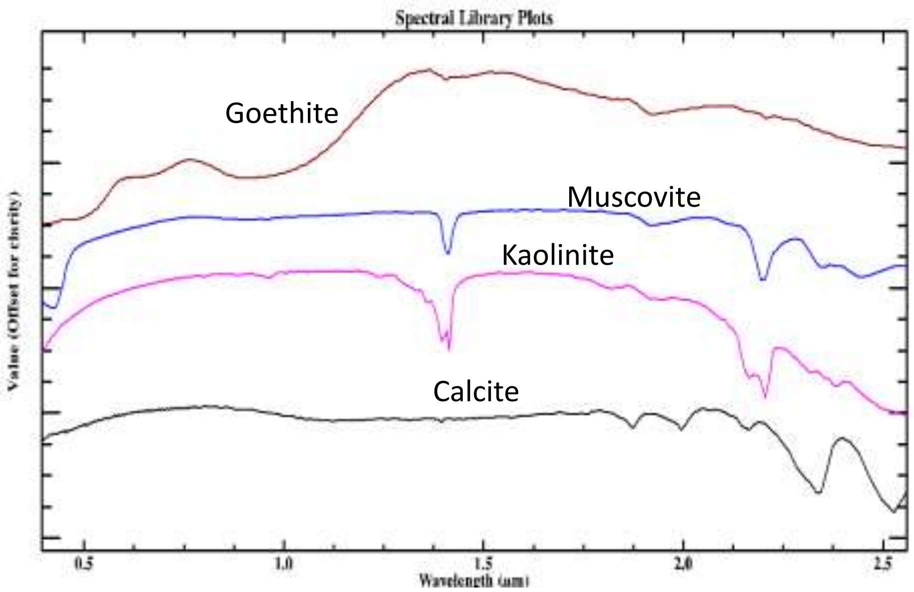
- Sites with high concentration of old mine tailings for lead, copper, zinc, nickel and other metals may develop unique floras because condition is toxic for most species.

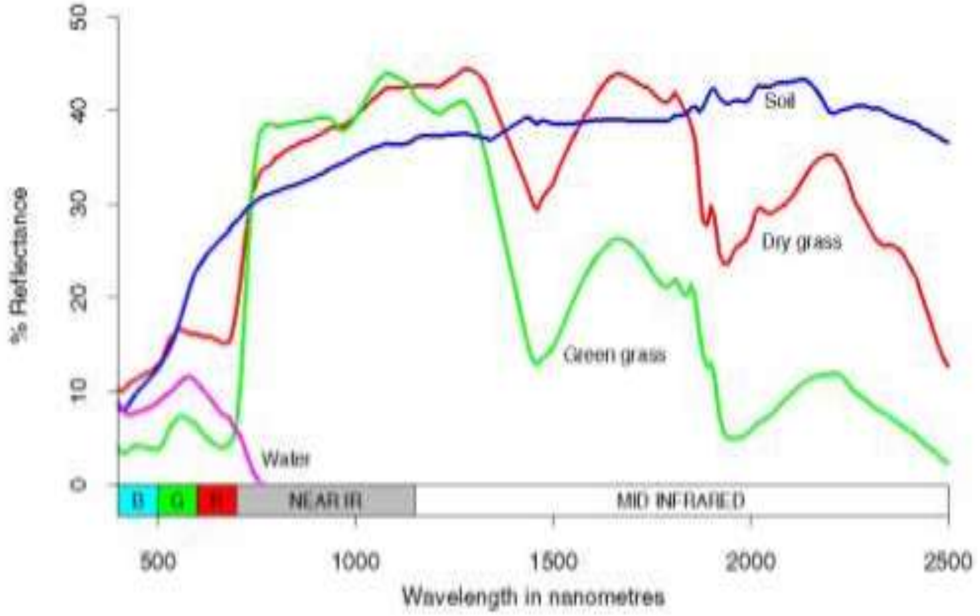
- **Naturally occurring saline or alkaline deposits and serpentine outcrops also develop unique floras.**

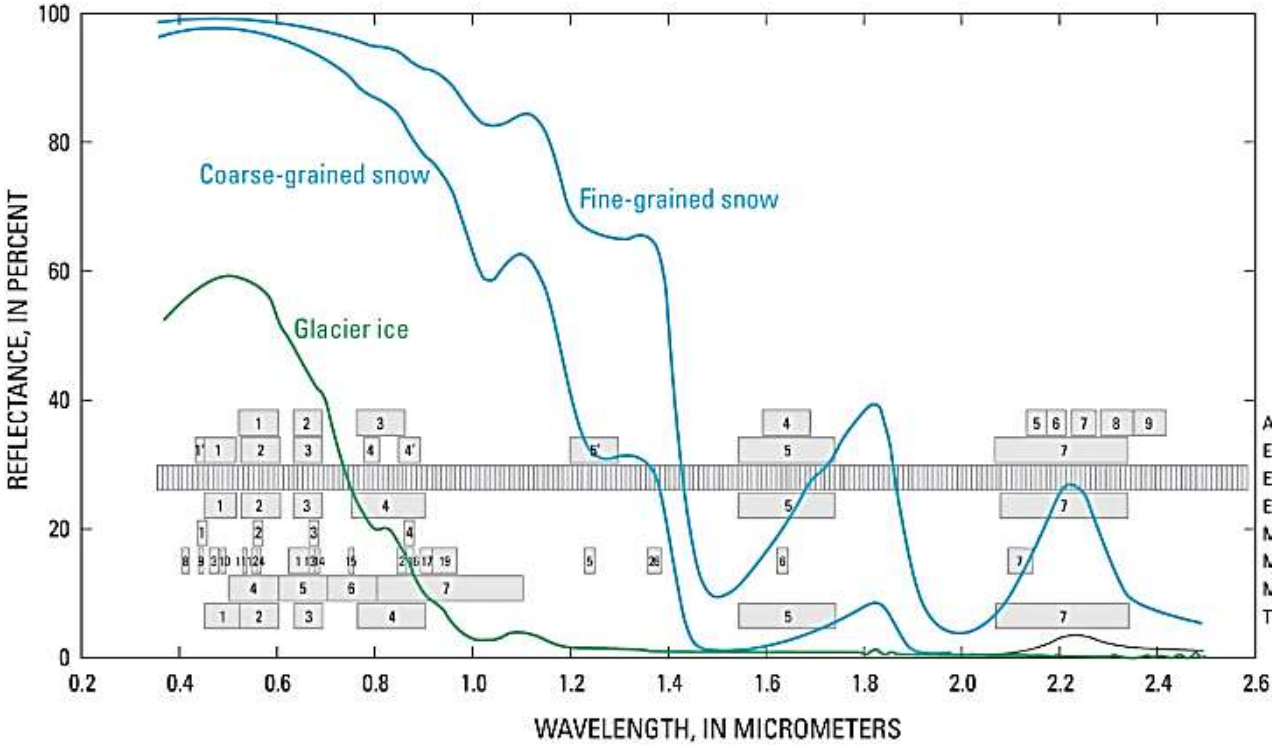
- Leaf concentration of trace metals may indicate the composition of underlying soil and thus may be useful for mineral exploration.



Spectroscopic Study







Other Applications of Hyperspectral data

- **Atmosphere:** water vapor, cloud properties, aerosols.
- **Ecology:** chlorophyll, leaf water, cellulose, pigments, lignin.
- **Geology:** mineral and soil types.
- **Coastal Waters:** chlorophyll, phytoplankton, dissolved organic materials, suspended sediments.
- **Snow / Ice: snow cover fraction, grain size, melting.**
- **Biomass Burning:** sub-pixel temperatures, smoke.
- **Commercial:** mineral exploration, agriculture and forest production.

SPECTROSCOPY

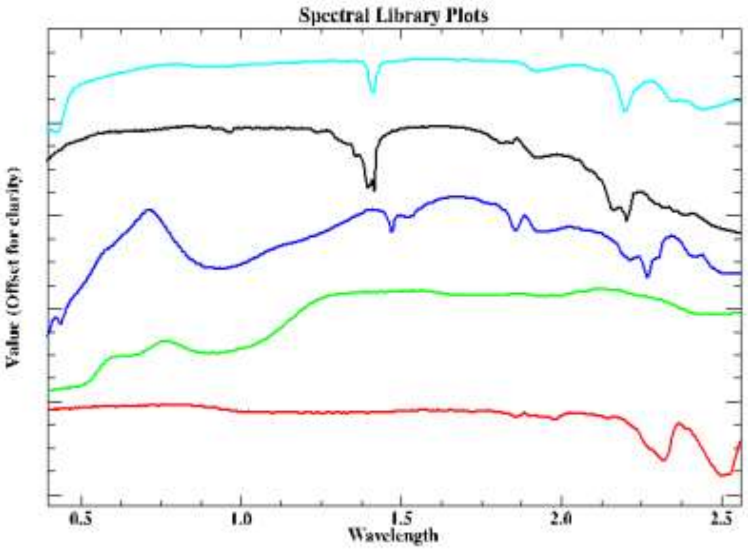
- Contiguous bands of Hyperspectral data allows spectroscopy or spectrometry study of surface material.

- **The spectroscopy is the study of light as a function of wavelength that has been emitted, reflected or scattered from solid, liquid or gas.**

- The Hyperspectral imagery / Spectroscopy can detect individual absorption features, specific chemical bonds in solid or liquid

- Which allows identification of mineral or chemical composition of material or mineral.

- These spectral signatures discriminate individual minerals based on their absorption features.



Spectroscopy / Reflectance Remote Sensing

There are two processes responsible for the absorption of light at certain wavelength:

1. Electronic Process,   2. Vibrational Process

Electronic:

- Mainly occurring in the VNIR (0.3 to 1.0 µm) region.
- When light interacts with any material or mineral, at specific wavelength photon will be absorbed, which causes change in energy from low to higher one.
- Most common electronic process revealed in the spectra of minerals is due to unfilled electron shells of transition elements (Fe, Mn, Ni, Cr, Co etc).
- The absorption bands can also be caused by charge transfers or inter-elemental charge transition where the absorption of photon causes an electron to move between ions or ions and ligands.
- The transition can also occur between the same metal in different valence states, such as Fe^{2+} and Fe^{3+}.

Electronic Processes

- **Crystal field**: absorption due to unfilled electron shells, transition metals are promoted to higher shells, depends on crystal structure.

- **Charge transfer:** electron move between ions -> Fe^{2+} ---> Fe^{3+}.

- **Conduction bands:** two discrete energy levels for electrons, conduction band and valence band.

- **Color centres:** irradiation in UV of a imperfect crystal)
- High energy –High wavelength features

Vibrational Absorption

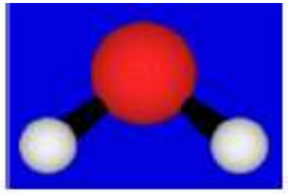
- The vibrational process is dominated in the SWIR (1 to 2.5 µm) region of the electromagnetic spectrum.
- The bonds in a molecule or crystal lattice are like springs with some attached weights: the whole system can vibrate.
- The frequency of vibration depends on the strength of each spring and their attached masses.
- It is called combination tones when they involve different modes of vibrations (Clark, 1999).
- The SWIR (1.0- 2.5 µm) is useful for mapping hydroxyl bearing minerals including clay and sulfate, carbonate minerals.

Vibrational Processes

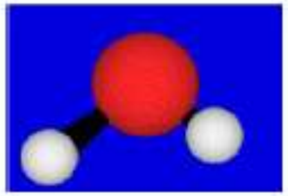
•The bonds in molecule or crystal lattice are like springs with attached weights: the whole system can vibrate

•Low energy-high wavelength features

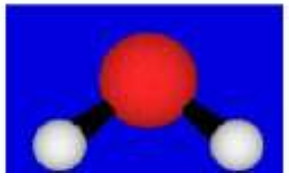
Stretching

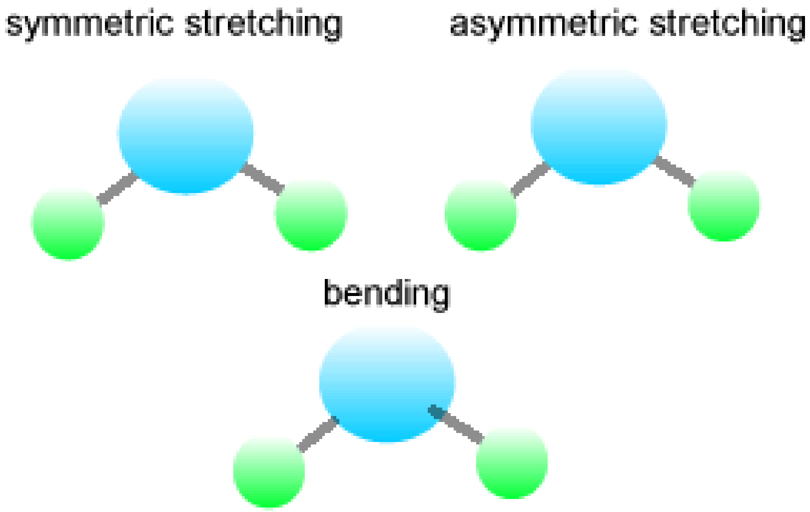


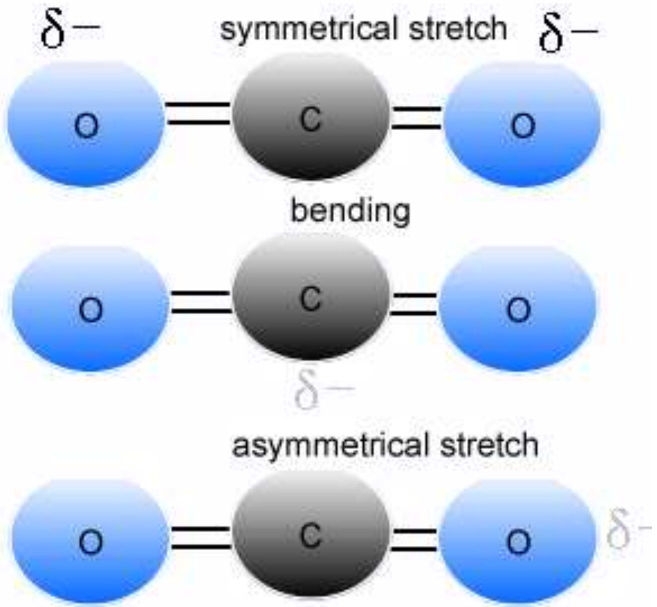
Asymetric Stretching



Bending







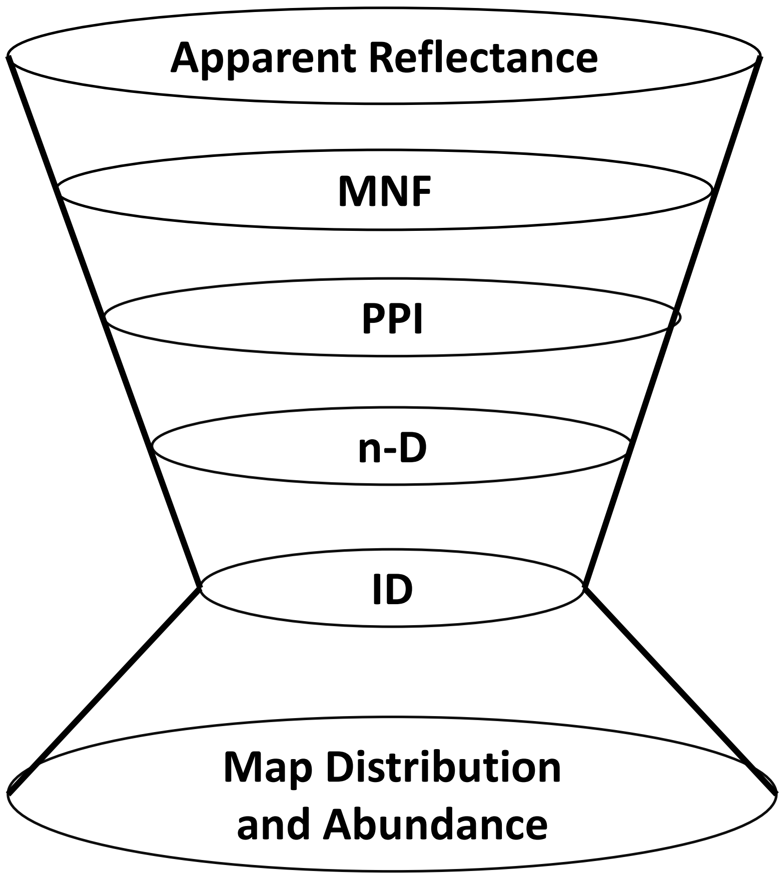
Processing Techniques

For Multispectral

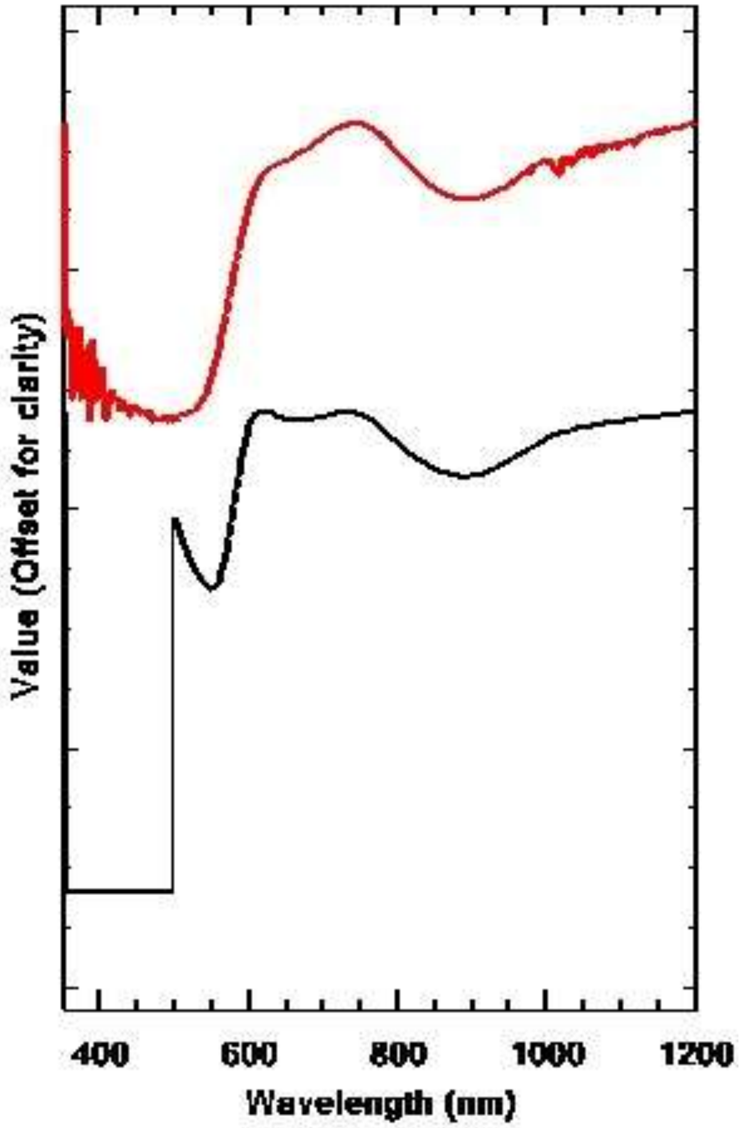
- FCC
- Band Ratio
- PCA
- Classification

Software: ERDAS, ENVI, Arc-GIS

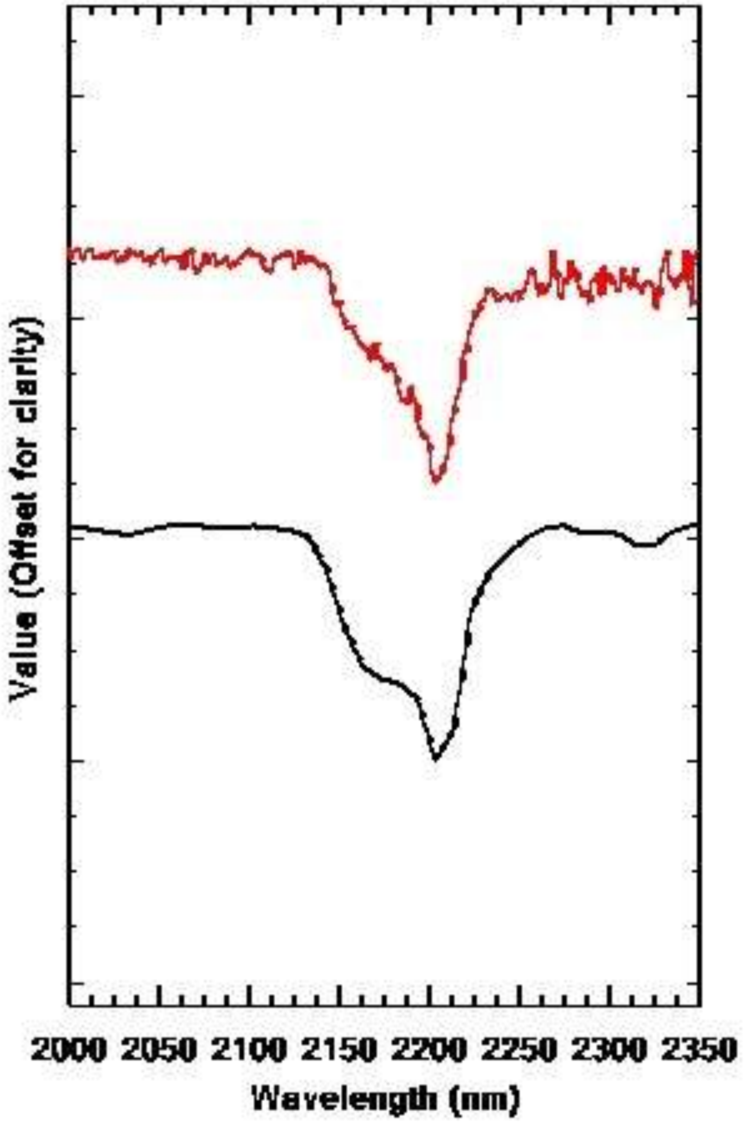
For Hyperspectral Data



Software: ENVI

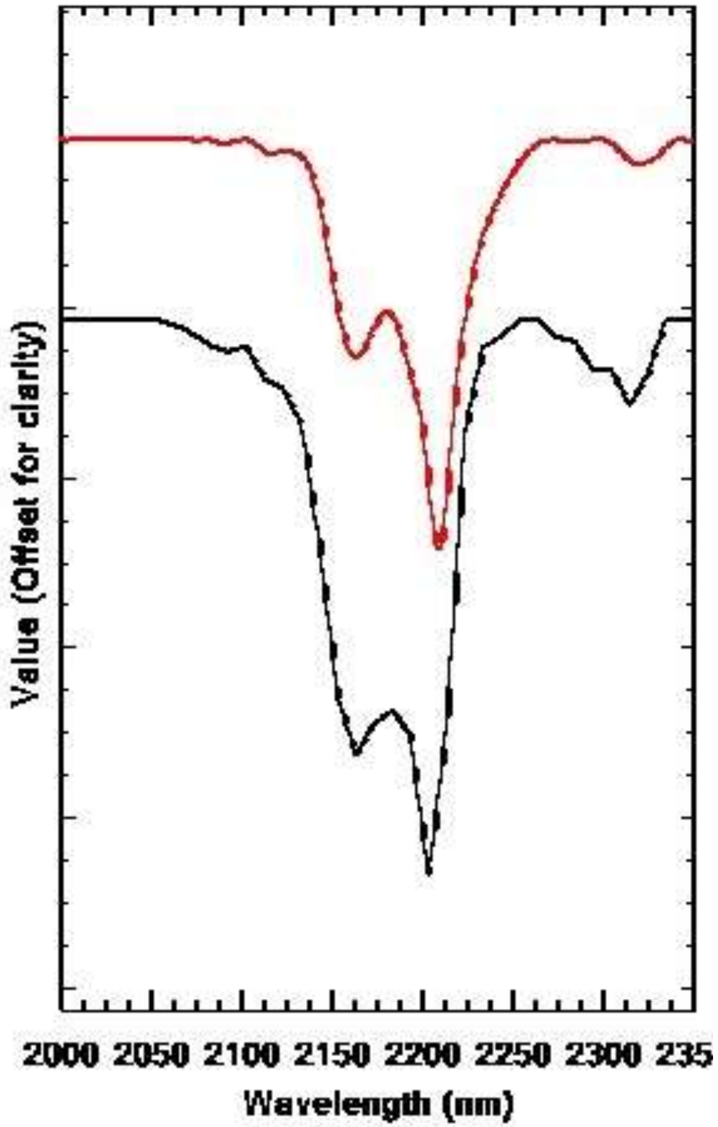


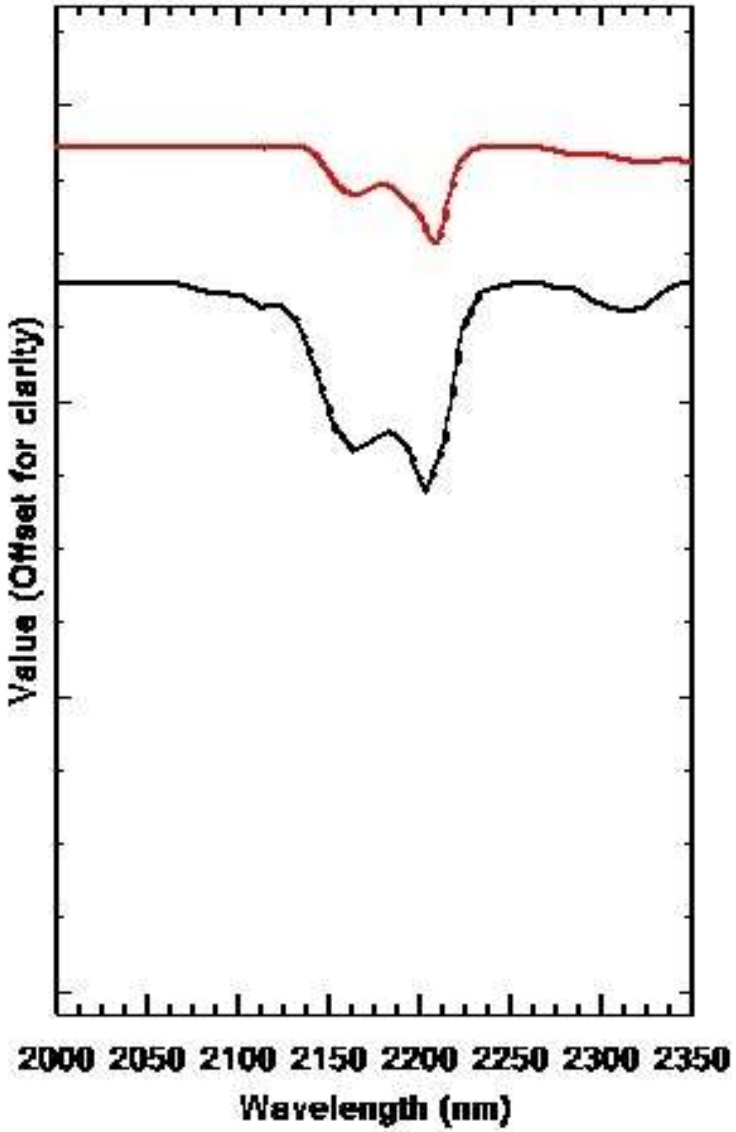
Hematite



Kaosmec

Source: Rani N. 2016

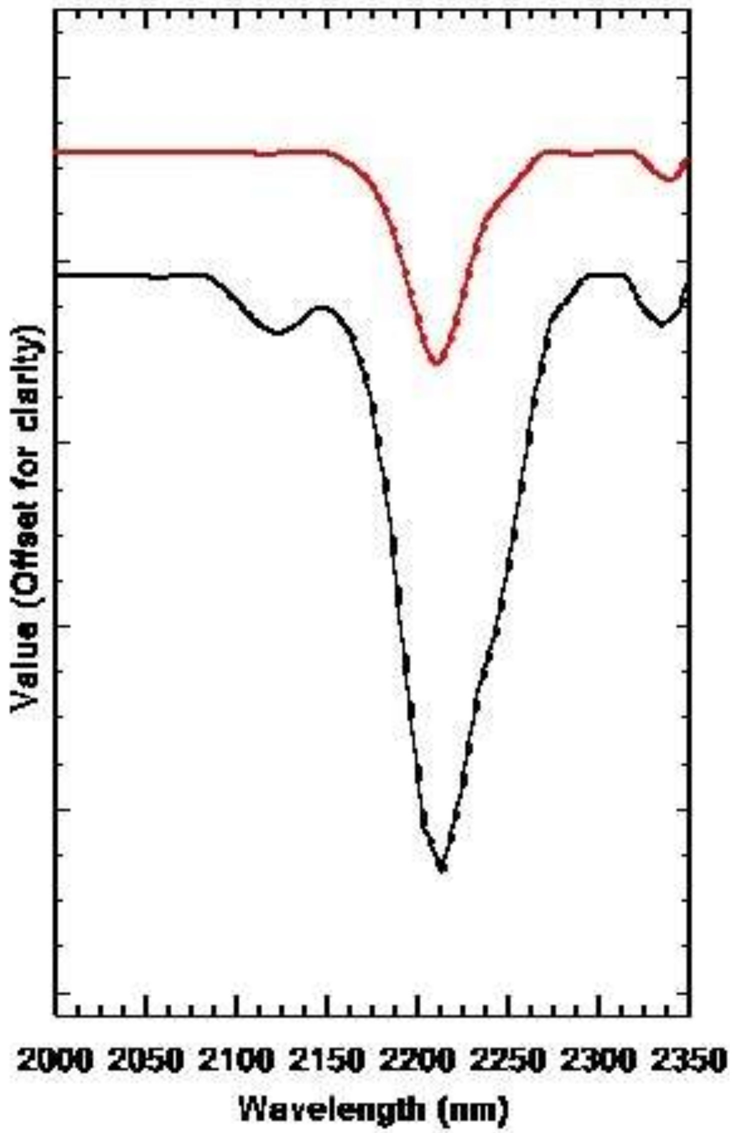




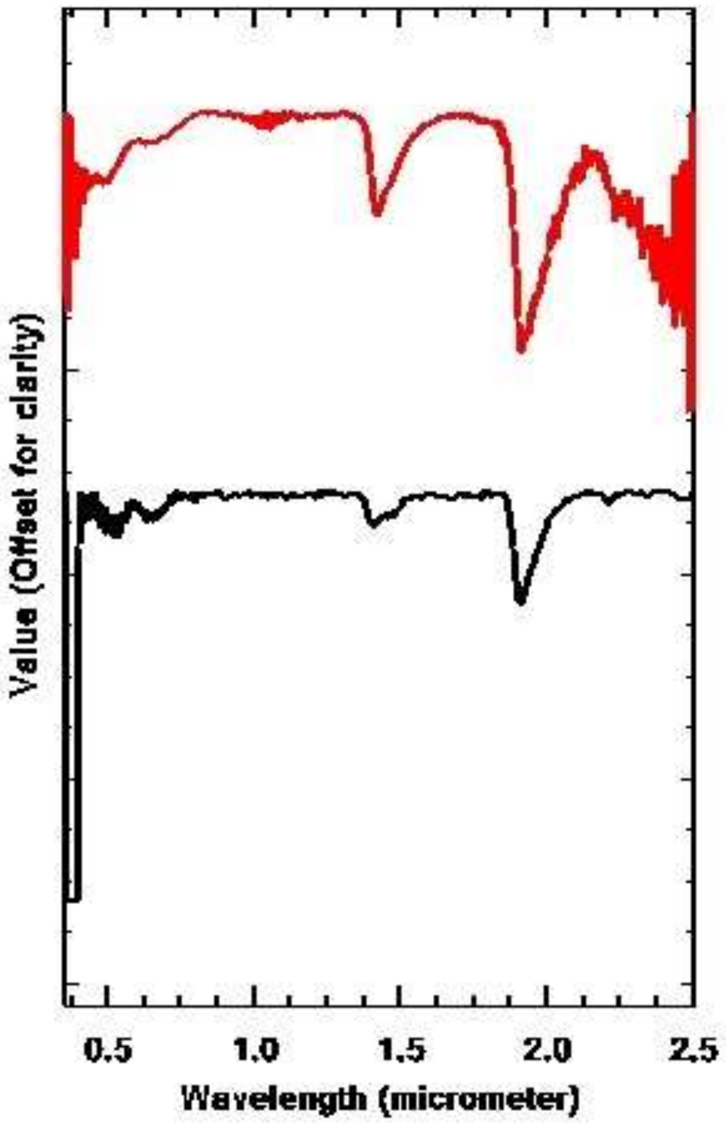
Kaolinite

Kaolinite

Source: Rani N. 2016



Muscovite



Grey soil

Source: Rani N. 2016

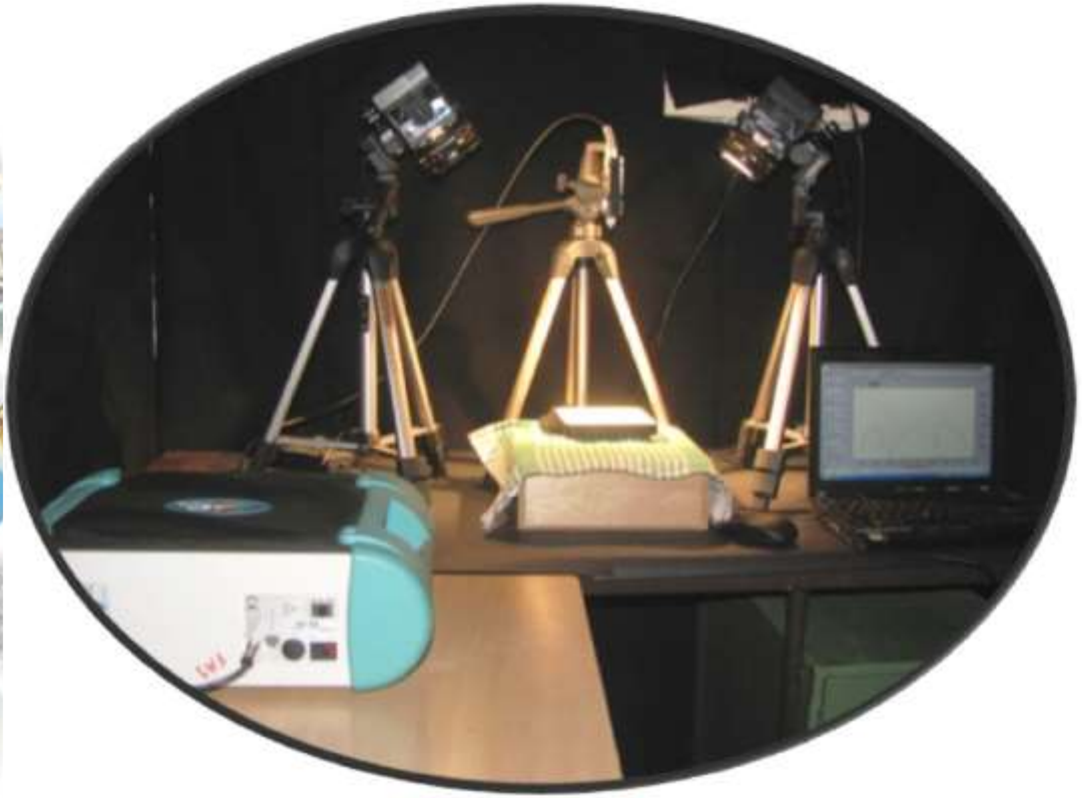
Spectroscopic Study and Collection of Spectra

❖ With the advent of compact and sophisticated spectrometers and spectroradiometers, field spectroscopy is evolving as a robust technique in mineral exploration.

❖ Spectral absorption features of minerals (such as silicates, oxides, hydroxides, carbonates, sulphides, nitrates and borates) are well established and identification of these minerals based on spectra is now possible.

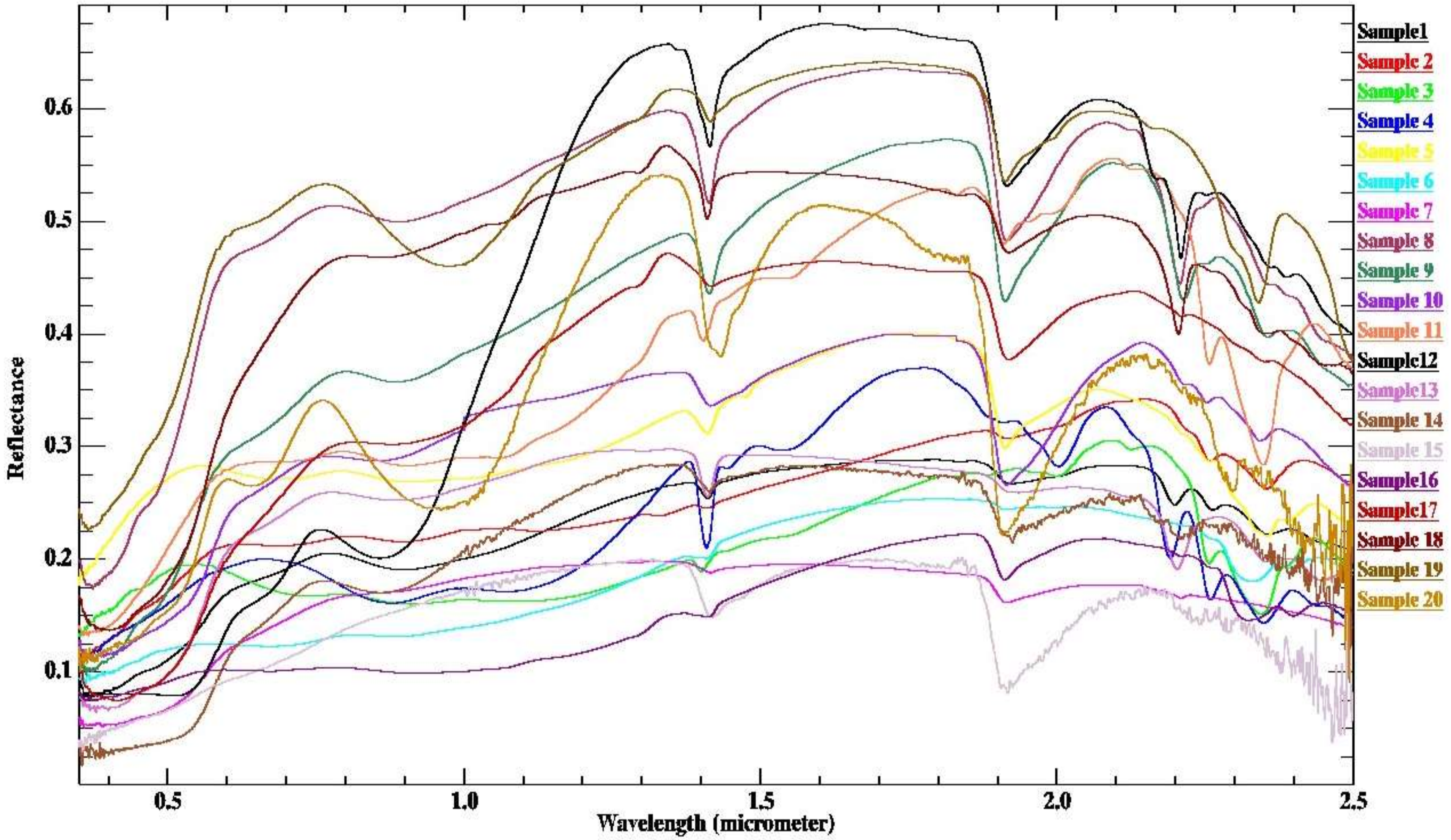
ASD (Analytical Spectral Device) Spectroradiometer:

•The Stpectroradiometer records the spectral reflectance within the wavelength range of 350 nm to 2500 nm and it has a spectral resolution of 3 nm.



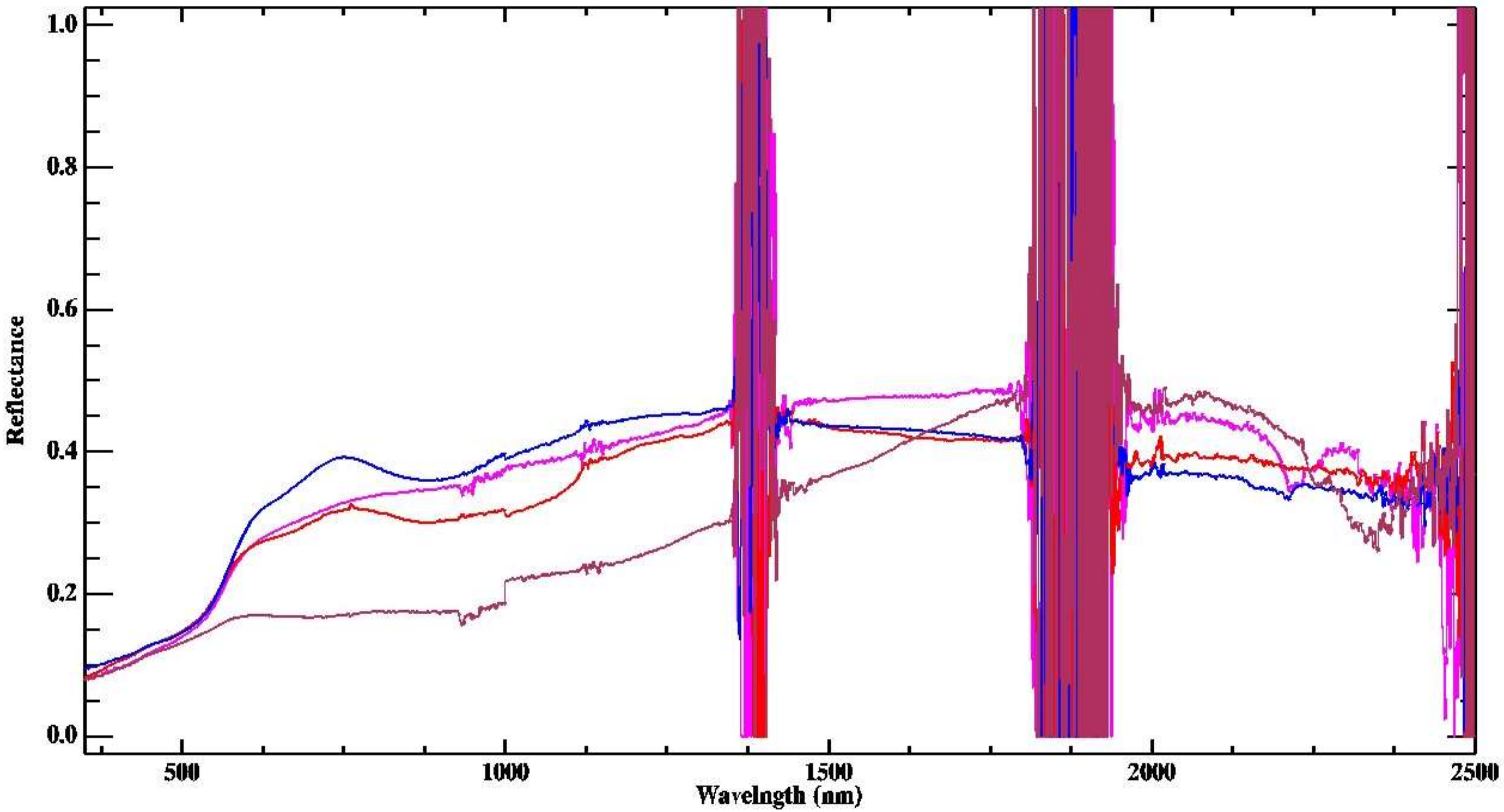
ASD Spectroradiometer, Laboratory

ASD Spectroradiometer, Field

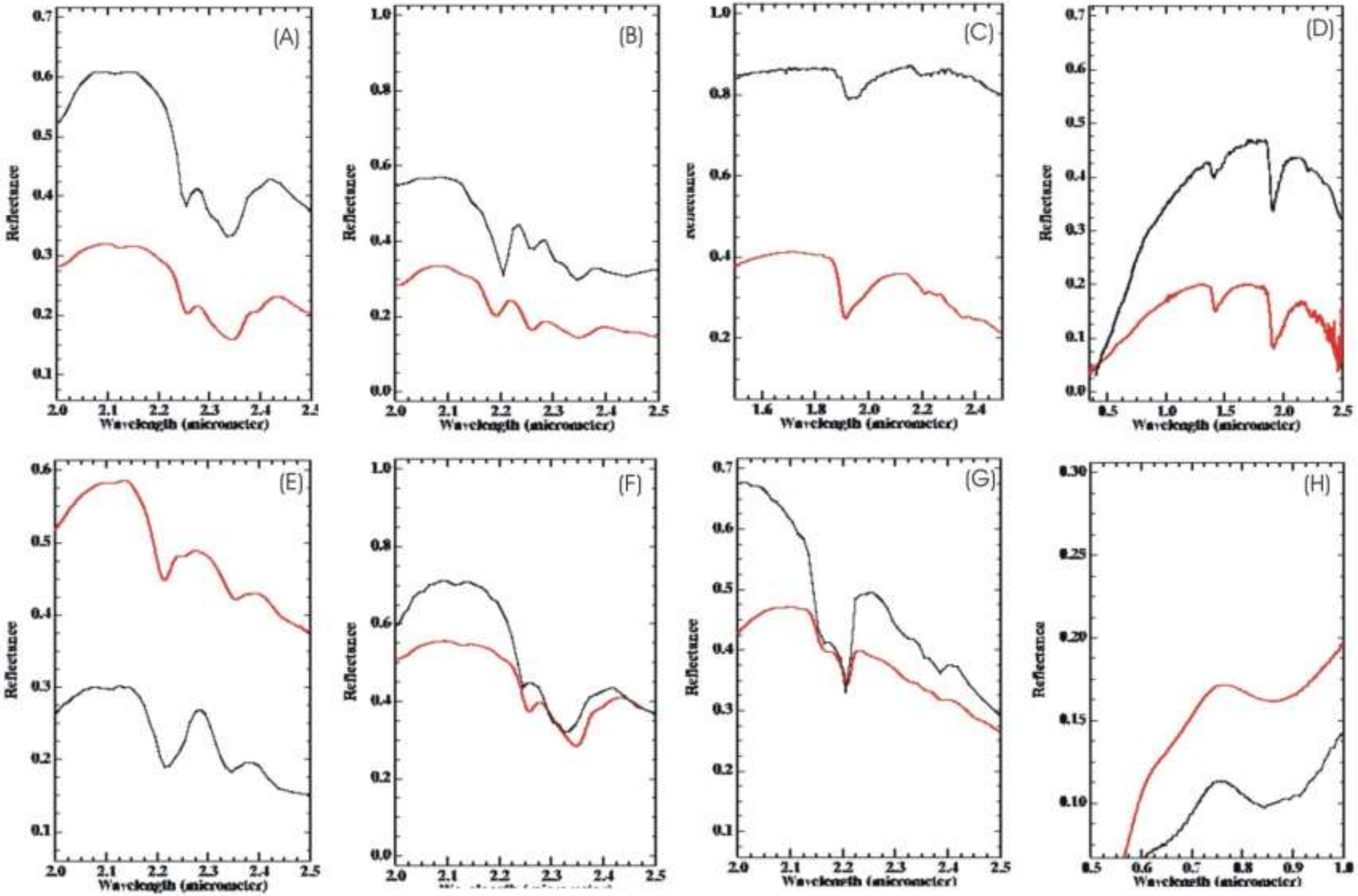


Spectral Signature through Spectroradiometer in the Laboratory condition

Source: Rani, 2016



Spectral Signature of rocks generated through Spectroradiometer in the Field condition



Continuum removed spectra of the samples (red) matched with corresponding USGS and JHU (black) reference spectra for the identification of the former. (A) sample1versus clinochlore; (B) sample 2 versus margarite; (C) sample 3 versus anorthite; (D) sample 4 versus greyish brown loam; (E) sample 5 versus montmorillonite; (F) sample 6 versus chlorite; (G) sample 7 versus kaolinite; (H) sample 8 versus hematite

What is spectral library?

- The spectral library is a collection of spectra of natural and man made materials.
- These libraries provide a source of reference spectra of varieties of targets (minerals, rocks, vegetation species) for remote identification for these targets.

Some important laboratories for spectral signatures

JHU(John Hopkins University) Laboratory

- Minerals(2-25 micrometer)
- Rocks(0.4- 15 micrometer)
- Manmade features(0.3- 12.5 micrometer)
- Lunar rock samples

USGS laboratory

- Minerals
- Vegetation (Visible-near infrared – shortwave domain)

JPL

Thank You