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Applications of Remote Sensing and GIS in Mineral Exploration

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Abstract: Mineral exploration is a task that we need to approach with maximum information. Missing out on rare metals and minerals can easily occur, and the process of searching for them is a costly risk. That is one of the reasons for remote sensing in mineral exploration being so important. Remote sensing can be used to measure, variations in acoustic wave distributions, force distributions and also electromagnetic energy distributions. The latest progress in the field of remote sensing and origin of new computer software such as Geographical Information System (GIS), ENVIS (Environmental Information Software) have transformed the world and made life much easier for mineral explorers.

I. INTRODUCTION

Industrialization and economic development of a country is largely depends upon the mineral resources of the country. For many countries mineral resources are the main source of national income. Hence mineral exploitation should be guided by the long- term national goal and perspectives. As we aware that rock (which is an aggregate of minerals) was first used by the human as tools for hunting and subsequently different minerals were used for wide range of applications. Expansion of human civilizations could not have been possible without mineral resources. Directly or indirectly human completely depend up on the mineral resources. Minerals are generally classified into three categories: metallic, non-metallic and fuel (energy). Metallic minerals are again categories into two types: a) ferrous (containing iron), e.g., iron, manganese deposits etc.; b) non-ferrous e.g., bauxite, base metal such as copper, lead, zinc etc. Non- metallic deposits also called as industrial minerals e.g., salt, clay, sulfur, limestone etc. Fuel or energy minerals deposits encompass coal, petroleum, natural gas and minerals used for nuclear energy. Some of the minerals are very rare and has various applications; hence it kept under precious mineral categories e.g., gold, silver and platinum etc. Other than above categories, minerals or rock are also used as building stone or road materials. Based on the mineral exploration result mineral deposits of any country are classified into two types a) mineral reserve and b) mineral resource. Mineral deposit which can be economically and legally extracted or produced at the time of the reserve determination is called mineral reserve. Mineral resources are the mineral deposits which will be economical in near or indefinite future. Mineral resources are either measured or indicated.

In India mining sector is an important segment of national economy. Mining activity provides raw materials to many industries such as iron and steel, thermal power, cement, fertilizers, petrochemicals, glass and ceramics, electrical and electronics, building materials, precious and semiprecious stone etc. India is rich in iron, copper, chromite, bauxite, coal, crude oil and gas, base metal, manganese deposits. For many years exploration of various mineral/ore deposits activities was conventional type with restricted input from geochemical, geophysical and remote sensing techniques.

A. Benefits of Remote Sensing

It provides Wide range of accessibility in regional scale.
Ability to save time and money while providing helpful information
Best used for the discovery of high-value commodities such as diamond sand gold, which are becoming more difficult to locate.
Remote Sensing is used to narrow down field surveys to smaller areas.
Application of remote sensing can also provide value by reducing the risk of a project and helps in selecting the sites on priority to explore first.
Expensive operations like drilling and field work can come after information is gathered.
Known drill results can be integrated with topographic maps, air photos, structural maps and ore grade data.
Data synthesis can greatly increase the accuracy and effectiveness of an exploration program and can act as a tool for targeting concealed deposits by integrated study.

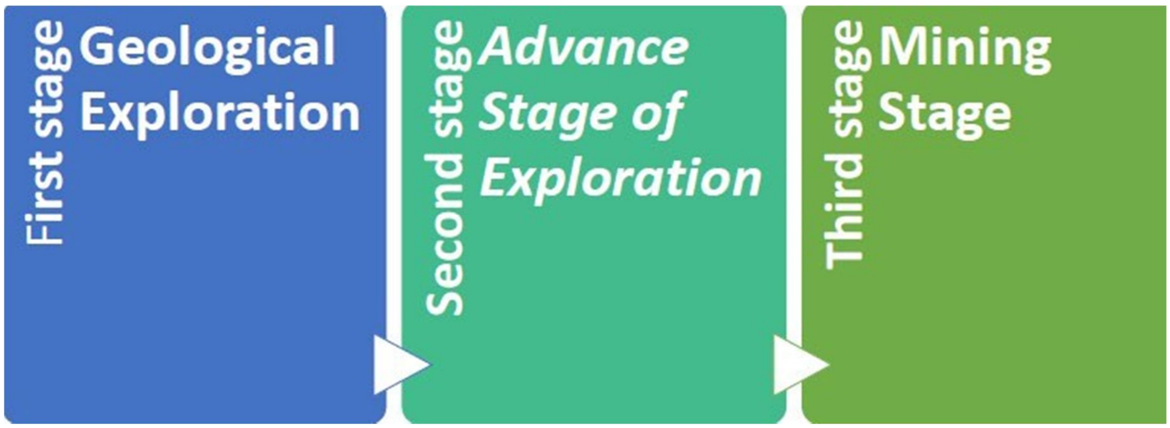
B. Satellite Imagery Have Proved Valuable for Mineral Exploration in Three Ways

Mapping of regional and local fracture systems that controlled ore deposits Detection of surface alteration effects associated with ore deposits Providing basic data for geologic mapping

From exploration perspective, mineral deposits that can be easily targeted using reflectance spectra include:

Epithermal gold, low-,and high-sulphidation deposits; porphyries, kimberlites, iron oxide, copper, gold, skarns and uranium

C. Utilization of Remote Sensing Data



D. Remote Sensing Data in Mineral Exploration

Aerial photographs are useful in identification of surface features like differential erosion, out cropping rock, drainage patterns and folds.

The advent of multispectral imaging and thematic mapping has allowed surface mapping to be performed remotely.

This enables vast areas to be mapped in a short time, at a fraction of the cost of traditional geologic mapping.

Remote sensing and GIS techniques have been widely used in the various fields of geological sciences. Among all, preparation of mineral resource map and exploration are important application. Mineral exploration and lithological mapping is a time consuming, laborious and required extensive field work. But use of remote sensing technique has drastically reduced the field work. In the early days of remote sensing aerial photography was extensively used by the geologists for mineral exploration. The advancement of satellite imagery in the subsequent years provided better opportunity to use remote sensing techniques for mineral exploration even in the inaccessible areas. The lunch of first earth resource satellite (Landsat 1) in 1972 provided a new avenue for the geologist to interpret digital satellite image for mineral exploration. In the recent years using high resolution multispectral satellite and airborne digital image geologist are exploring elusive potential mineral deposits which are cover by the vegetation and Quaternary deposits.

E. Remote Sensing Techniques in Lithological Mapping

A geological map provides information about the boundary of outcropping features, litho units and geologic strata.

Geological mapping methods are undergoing continuous change along with technological and scientific advances in other relevant fields. Mineral resources are products of geological processes and the exploitation strategy is governed by geological factors and environment in which these deposits occur. Geological maps can also provide the basis for exploring the landmass in search of its resources.

II. LITHOLOGY

Lithological mapping and Mineral exploration are the hot domain in the geological investigations at present scenario

Lithological mapping is an essential technique in various mineral prospecting studies, geological studies, hydrogeology etc

Lithological sections help in visualizing spatial, three-dimensional, geological relationships Stratigraphic correlation compares and establishes litho-formation to host economic minerals for future searches The lithologically bound epigenetic deposits are formed due to strong preference of host rocks Stratigraphic (age) criteria refer to the geological setting and the stratigraphical position of the geological unit Since some types of mineral deposits are confined to certain age groups forexample coal, iron manganese, phosphorite etc.

III. REMOTE SENSING IN LITHOLOGICAL MAPPING

Mineral exploration and lithological mapping through conventional geological techniques are tedious, expensive and time-consuming.

To mitigate these problems, the use of remote sensing data can constitute a considerable information source Advances in remote-sensing data analysis techniques have improved the capacity to map the geological structures and regional characteristics and can serve in mineral exploration in complex and poorly understood regions. Remote sensing techniques are now being increasingly used to prepare geological maps and obtain the basic geological information on which further detailed work is based

The accessibility of inexpensive, satellite-borne, multispectral and hyperspectral data has created new opportunities for the regional mapping of lithology An increasing number of bands in the Short wave infra-red (SWIR) region of remote sensing data enhance the surface lithological mapping capability.

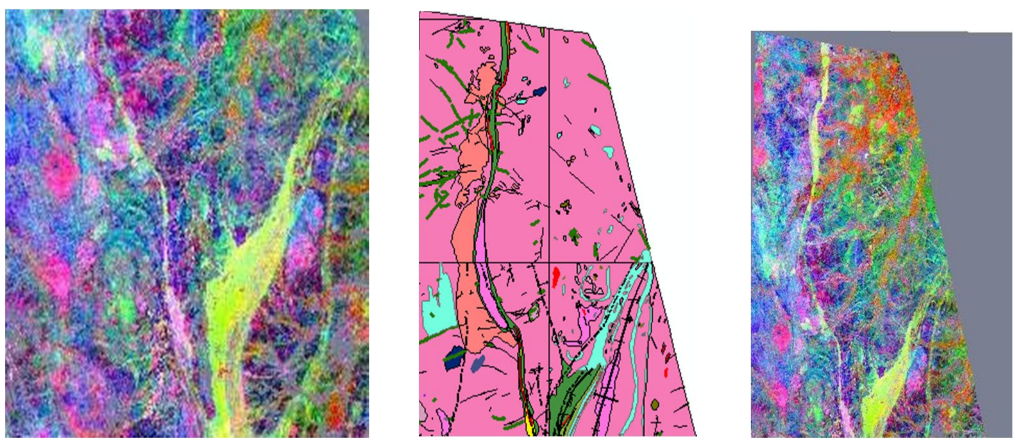
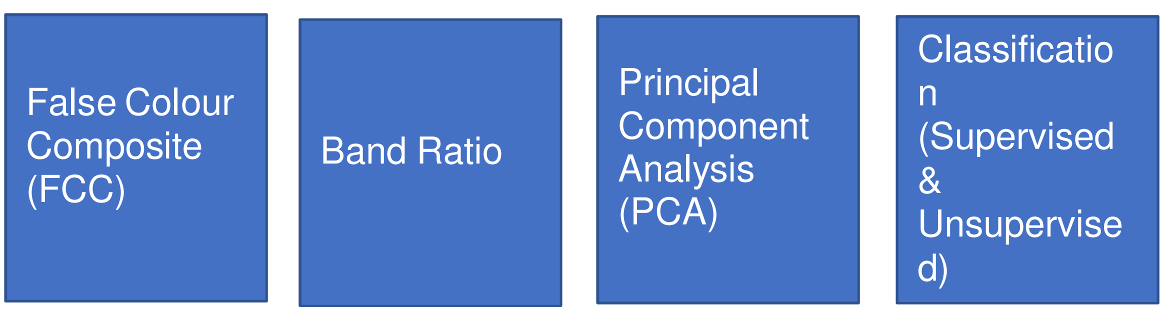


FIG Lithological Mapping

A. *Advantage Of Remote Sensing*

Free availability of remote sensing data such as ASTER, Landsat, Sentinel etc. The ability to get regional views of large areas. Ease of combining information from multiple sensors. Accessibility in covering remote areas. Availability of sophisticated computer analysis programs. A wide selection of energy bands. Vital importance, low cost, and high speed.

1) *Processing Techniques*



2) *Principle Component Analysis (PCA)*

This Transformation technique is used for reducing dimensionality of correlated data. And to compressed information from all bands into fewer bands with little loss of information variance The 'new' bands that result from PCA are called principal components The resulting PCs are more interpretable than are the original images For lithological mapping PCA is very useful technique

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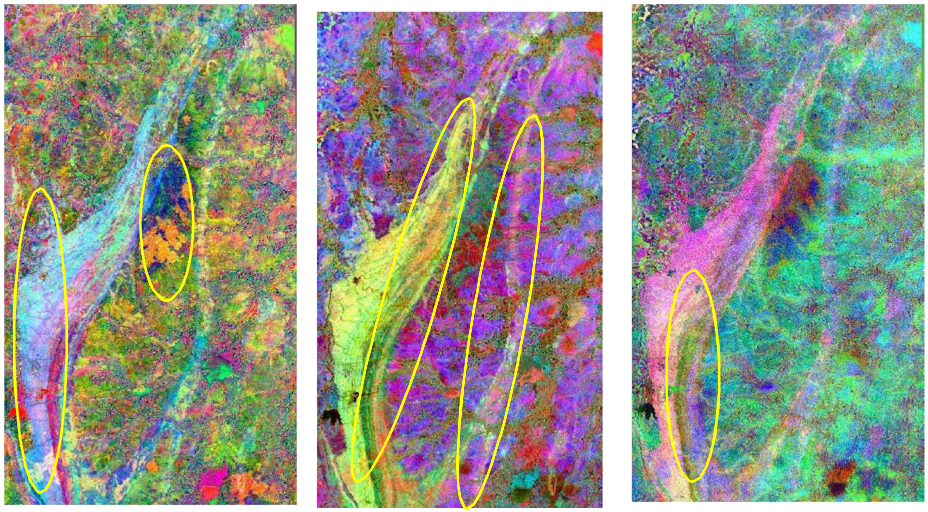

FIG Principal Component Analysis In Mineral Identification

3) Band Ratio Technique

Due to topographic slope, aspect, shadows, or seasonal changes in sunlight illumination angle and intensity, alike surface materials can give different brightness values. The object may have high reflectance value in one spectral band though, it may absorb in another spectral region. Band Ratio is a technique where the values of the brightness of the pixels in a spectral band are divided by another band and as a result, a new image is created Therefore, the Band Ratio method could be able to transform the data, reducing the effects of such environmental conditions.

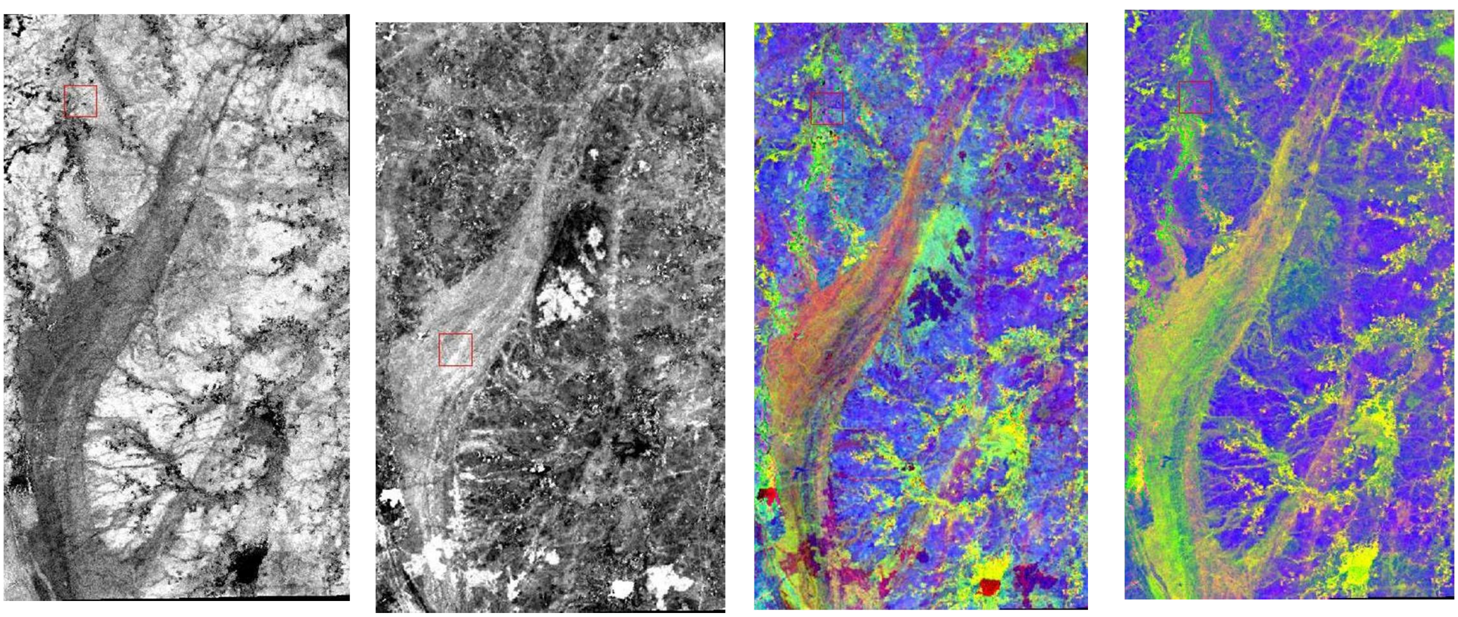

FIG Band Ratio Of Kaolinite And Chlorite Fcc Of Band Ratio Image

B. False Color Composite (FCC)

A false color satellite image is one in which the Red (R), Green (G), and Blue (B) values do not correspond to the true colors of red, green and blue. A standard False Color Composite (FCC) blue is assigned to green radiations (0.5 to 0.6 µm), green is assigned to red radiations (0.6 to 0.7 µm and red is assigned to Near Infrared radiation (0.7 to 0.8 µm). This false color composite scheme allows vegetation to be detected readily in the image. Vegetation appears in different shades of red depending on the types and conditions of the vegetation, since it has a high reluctance in the NIR band.

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Four most common false-color band combinations are

Near infrared (red), green (blue), red (green). This is a traditional and popular band combination useful in seeing changes in plant health.

Shortwave infrared (red), near infrared (green), and green (blue), often used to show foods or newly burned land.

Blue (red), two different shortwave infrared bands (green and blue). We use this to differentiate between snow, ice, and clouds.

Thermal infrared, usually shown in tones of gray to illustrate temperature.

Features	Colour in Standard FCC
Evergreen	Red to Magenta
Deciduous	Brown to Red
Scrubs	Light Brown with Red Patches
Cropped Land	Pink to Bright Red
Fallow Land	Light Blue to White
Wetland Vegetation	Blue to Grey
Clear Water	Dark Blue to black
Turbidity Water Body	Light Blue
High Density	Dark Blue to Bluish Green
Low Density	Light Blue
Rock Outcrops	Light Brown
Sandy deserts/River Sand	Light Blue to White
Salt affected Deep ravines	Dark green
Shallow ravines	Light Green
Water logged/Wet Lands	Modeled black

FIG FALSE COLOR COMPOSITE (FCC)

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C. Image Classification

Classification is the process of assigning pixels of remotely sensed images into groups of homogenous characteristics Image classification refers to the task of extracting information classes from a multiband raster image The resulting raster, from image classification can be used to create thematic Maps Classification technique is useful for Land use and land cover (LULC), Geologic terrains Mineral exploration, Alteration mapping

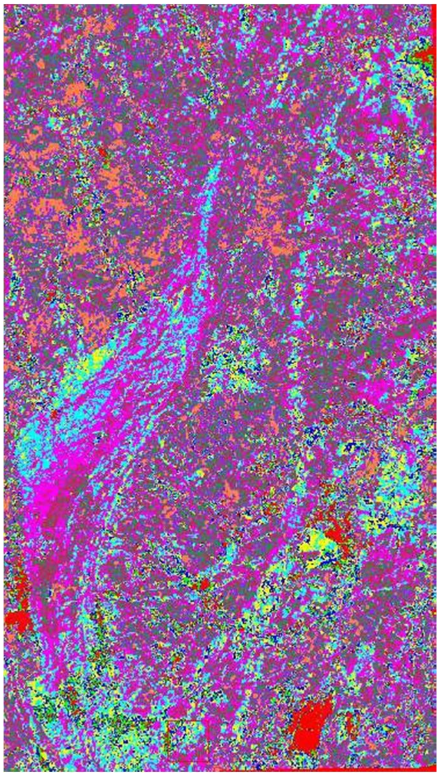

FIG UNSUPERVISED

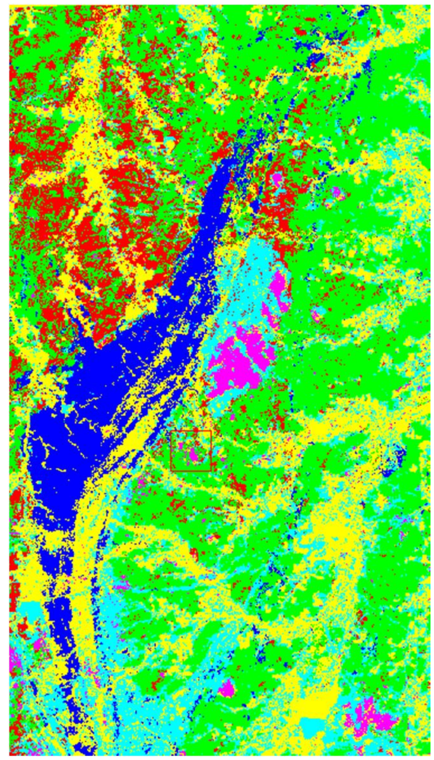

FIG SUPERVISED

Type of sensors used for mineral resource studies: Remote sensing data/information about an area or object were collected by passive or active sensor mounted in a satellite or aircraft.
Passive sensors collect data using reflected or transmitted parts of the electromagnetic
(EM) spectrum (Figure 1), which rely on solar illumination of the ground or natural thermal radiation for their source of energy respectively.
Important sensors for mineral resource studies are Landsat Multispectral Scanner (MSS).
Landsat Thematic Mapper (TM) utilizes additional wavelengths, and has superior spectral and spatial resolution compared with MSS images; ETM – Enhanced Thematic mapper.
Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) on NASA's satellite Terra.
SPOT, a French commercial satellite with stereoscopic capabilities
The Indian remote sensing (IRS) satellite series combine features from both Landsat MSS/TM sensors and the SPOT HRV sensor
Active sensors use their own source of energy. They emit energy and measure the intensity of energy reflected by a target. Some examples are Radar (microwave) and Lasers.
Landsat Satellite series MSS/TM provides multispectral imageries having a wide applicability in geological studies. ASTER sensor provides higher spatial and radiometric resolution for similar part of the electromagnetic spectrum. Remote sensing data gathering system records part of the electromagnetic spectrum . Some part of the EM spectrum get absorbed or interrupted by the atmospheric gas ($O3$, $CO2$, $H2O$ etc.), hence data is restricted to a particular band of the EM spectrum. Part of the ultra violet (UV) radiation gets absorbed by the $O3$ and different segment of reflected & Thermal IR wavelength areinterrupted by the $H2O$ (water vapor) and $CO2$. Each remote sensing satellite systems are designed to record a particular band with different spatial and temporal resolution.

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Hence it decides the applicability of the data to different natural resource studies. These data can be used to extract information about the lithology or rock composition, land surface structure, shallow subsurface rock type etc. For mineral resource study the reflectance / emissivity of the mineral is used and information were extracted from the remote sensing data. When light incident the mineral or rock surface certain wavelength of light gets absorbed and some are reflected depending up on the chemistry and crystal structure. Absorption of energy is mainly due to electronic (presence of color center, charge transfer, conduction band and crystal field effect) and vibration process of molecule.

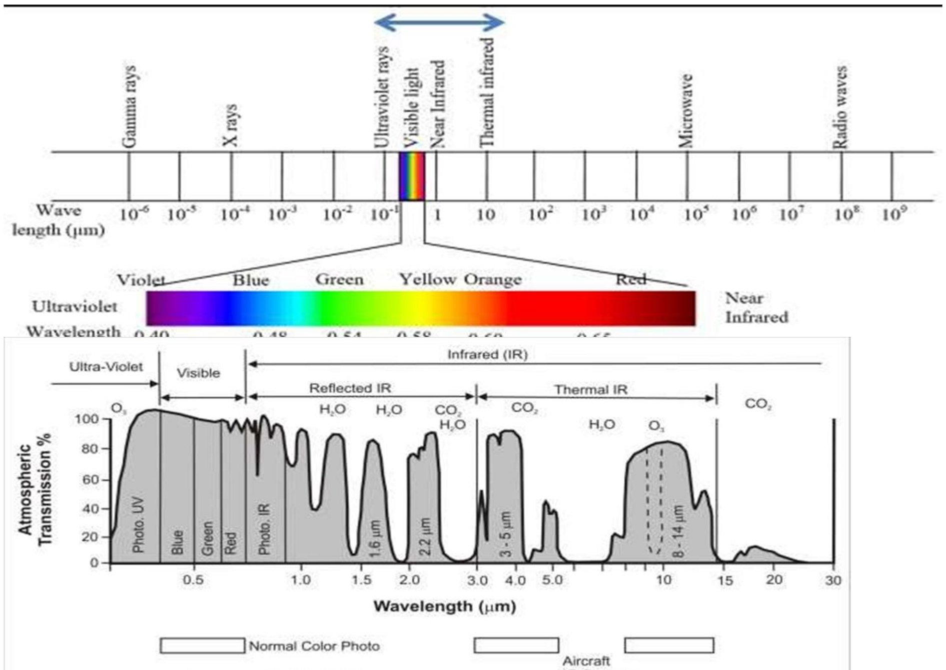

FIG Shows the electromagnetic (EM) spectrum and the wavelength (in µm). Arrow mark on the top indicates the range of wavelength used for multispectral data collection

FIG Some parts of the EM spectrum are wholly or partly absorbed by atmospheric gases. Atmospheric windows where transmission occurs are shown and the sensors of different satellite system that use these wavelengths are indicated. EM Spectrum showing the majority of the data-gathering wavelengths.

D. Reflectance of Different Mineral in VNIR and SWIR

SWIR electromagnetic spectrum is very useful for identification of minerals and minerals group such as silica, clay, carbonates, iron oxides and other silicates. ASTER images have higher spectral resolution in the SWIR compare to Landsat; hence it is used for mineral identification. Complete reflectance and emittance spectra of different minerals / mineral groups for wide range of electromagnetic wavelength are experimentally generated and available at different library data band intervals in the VNIR-SWIR region emittance spectra (Johns Hopkins University (JHU) library) of the studied minerals are superimposed on ASTER data band intervals in the TIR region. This comparison helps us to use selected band for observing a mineral or group of minerals.

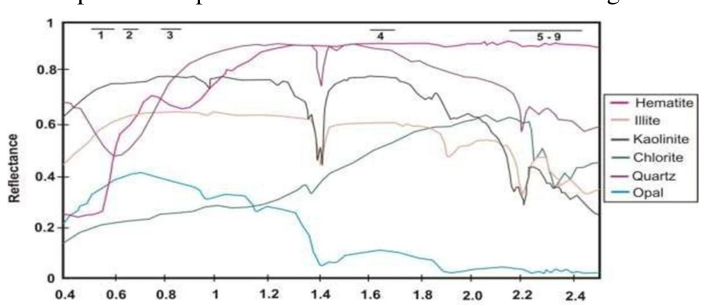

FIG Wavelength of EM spectrum vs. reflectance of different minerals. ASTER channels (1-9) are indicated in the top.

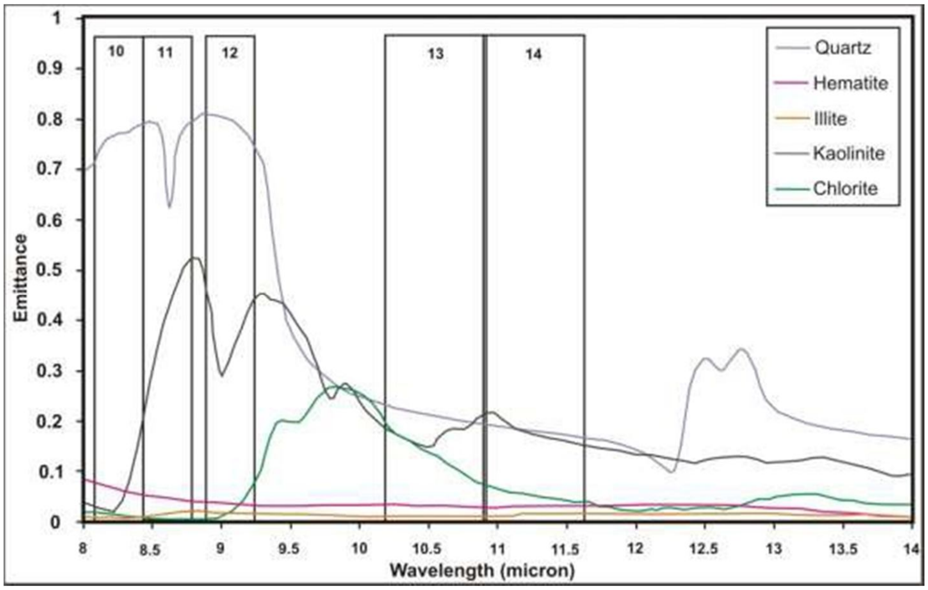

FIG The JHU (Johns Hopkins University) library spectra of the studied minerals superimposed on ASTER data band intervals in the TIR region

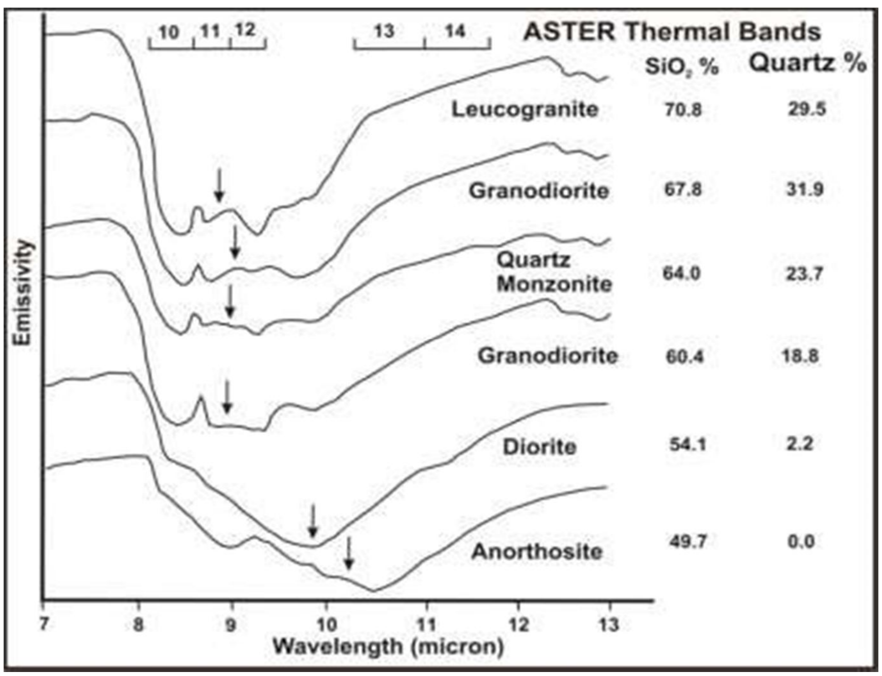

FIG ASTER thermal band indicating how the emissivity of the rock changes with respect to silica content (Shift of minima to shorter wavelength as silica content increases)

Iron oxides, clay, carbonate and sulfide minerals show distinct absorption in the VNIR and SWIR regions. Iron oxide/hydroxide minerals (e.g. limonite, hematite, etc.) shows absorption from 0.4 to 1.1 µm of the electromagnetic spectrum due to the presence of transition elements such as Fe2+, Fe3+, Mn, Cr and Ni in the crystal structure . Minerals bearing Al–O–H, Mg–O–H, Si–O–H, Al-Si-OH, Mg-Si-OH, Ca-Al-Si-(OH), other hydroxyl and CO3group (Clay mineral such as Kaolinite, montmorillonite, chlorite, illite; muscovite; talc; epidote group; carbonates such as calcite, dolomite and sulphate minerals including alunite and gypsum) shows absorption in the SWIR region due to vibrational processes. In the TIR region (between 8 – 14µm) quartz shows strong vibrational absorption due to asymmetric Si- O stretching Similarly carbonate minerals such as calcite and dolomite shows distinct emissivity absorption features are different wavelength of TIR region.

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These characteristics of minerals help to identify and map an area using remotely sensed images with different spectral range. In the figure 5 emissivity spectra of different igneous rocks are plotted for TIR region from 8 – 14 µm. Due to variation of the silica concentration in the rock center of the absorption band (broad emissivity minima in the spectra) change its position. center of the absorption band is indicated by an arrow and it shift to longer wavelength as the silica concentration in the rock decreases

Elements / Ions	Absorption peaks (µm)	Elements / Ions	Absorption peaks (µm)
Visible and near Infrared (VNIR) Region		Thermal Infrared (TIR) Region	
Ferric ion	0.40, 0.50, 0.70 & 0.87	Silicates	9.00 – 11.50 (depending uponthe crystal structure)
Ferrous ion	0.43, 0.45, 0.57, 0.55, 1.00 & 1.80 – 2.00	Carbonates	7 (not used in remote sensing)& 11.30
Manganese	0.34, 0.37, 0.41, 0.45 & 0.55	Sulphates	9 & 16
Copper	0.80	Phosphates	9.25 & 10.30
Nickel	0.40, 0.74 & 1.25	Nitrates	7.20
Chromium	0.35, 0.45 & 0.55	Nitrites	8 & 11.8
Short Wavelength Infrared (SWIR) Region		Hydroxides	11
Hydroxyl ions	1.44 & 2.74 – 2.77	The absorption features of 0.87 m (iron oxide), 1.00m (amphiboles and olivines), 0.70 m, 1.00 m and 1.80 m (pyroxenes) appear to be more common.	
AI – OH	2.20		
Mg – OH	2.30		
Water molecules	1.40 & 1.90		
Carbonates	1.90, 2.00, 2.16, 2.35 & 2.55		

E. Hyperspectral images

So far we have discussed about various multispectral sensors (e.g. ASTER, Landsat) having different bands in the VNIR, SWIR and TIR regions which can be used for mineral mapping, lithological discrimination. But using these data it is difficult to determine the detailed mineral composition and their relative abundance due to lack of finer band width and good spectral contiguity. However hyperspectral sensors acquire images from in contiguous (100-200) spectral bands with narrow bandwidth (10-15 nm spectral resolution). These images will provide a complete reflectance/ emittance spectrum. These spectrums are similar to the laboratory spectra and very useful for discrimination study to identify different mineral and rocks. The important airborne hyperspectral sensors used for mineral mapping and lithological discrimination are AVIRIS, HYDICE, DAIS, HyMAP, Hyperion and ALI etc.In the figure 6, bands and images of hyperspectral and multispectral sensors are compared..

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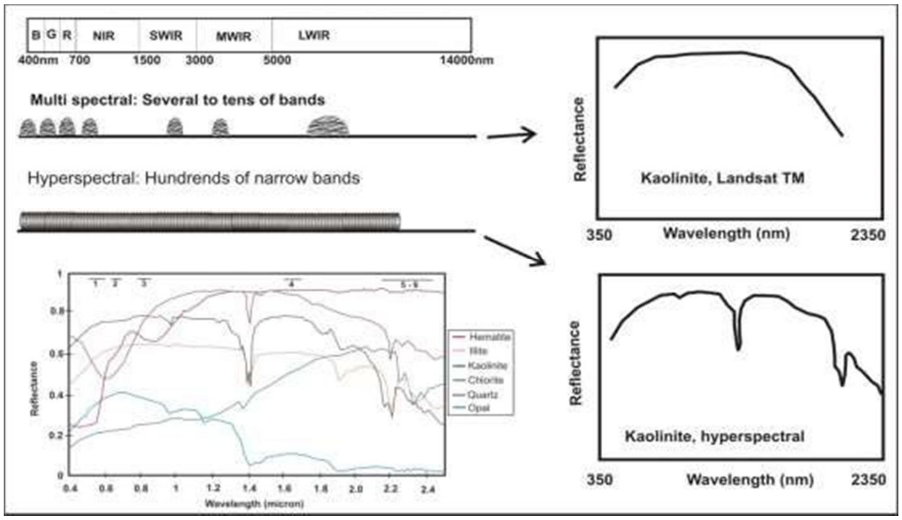

FIG Multispectral vs. hyperspectral images

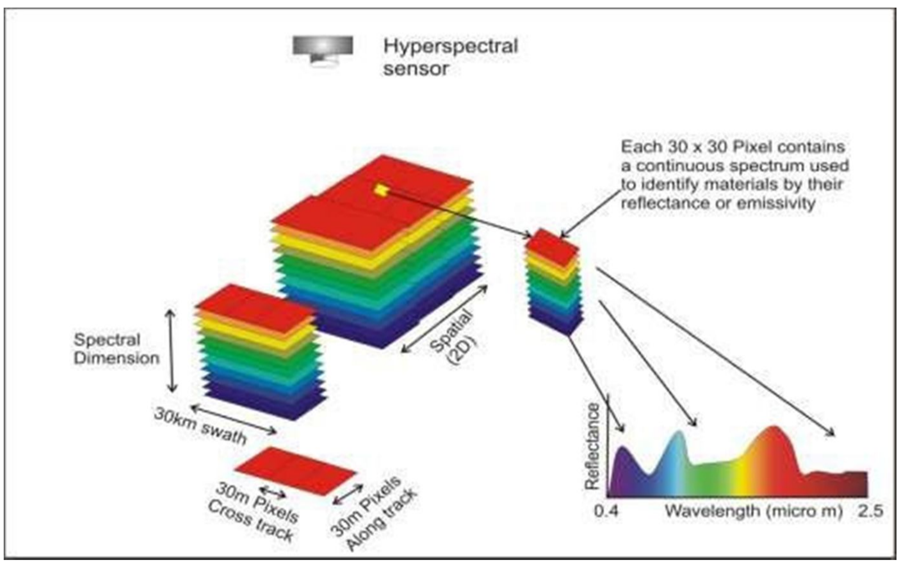

FIG Hyperspectral images contain layers or bands are representing a slice of EM spectrum, each of which contains different information about the surface composition

F. Characteristics of Images

All the remotely sensed images are processed before extracting any information about the object/material. Prior to image processing characteristics of image are needs to beknown.

The characteristics of mages are No. of spectral band, swath, successive paths overlap, temporal resolution etc.

Pixel parameter: Digital images consist of discrete picture elements, or pixels. Each pixel associated with a number that signify the average radiance or brightness which represents reflected radiance from surface and radiation scattered by the atmosphere. Each is grouped as an 8 bit “byte” of information, with each bit used to indicate ascending powers of 2 from 20 (=1) to 27 (=128).

The Instantaneous Field of View (IFOV) is the distance between consecutive measurements of pixel radiance which is called as pixel size. For MSS: 79 m × 79 m, TM and ASTER has 30m x 30m pixel size.

Image parameter: Number of pixels per scene decides the resolution of images. In the multispectral images same scene is imaged simultaneously in several spectral bands. The image intensity level histogram is a useful indicator of image quality which describes the statistical distribution of intensity levels.

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G. Digital Image processing

For mineral resource study important function of digital image processing's are a) image restoration, b) image enhancement, and c) Information extraction.

H. Image Restoration

In this process images are corrected for inherent defects incorporated during data collection.

1) Correction for lost data i.e. dropped lines or bad pixels
2) Atmospheric noise correction
3) Geometric correction

The earth rotates during the time it takes the satellite to scan its swath, resulting in the skewed image. Hence geometric correction is required as images are needs to be integrated with the geophysical, topographical or other map-based data.

I. Image Enhancement

During this process original data of the images were transformed to the suitable form to improve the information content. Important ones are:

1) *Contrast Enhancement:* Contrast stretch (a simple linear transformation) is routinely used to increase the contrast of a displayed image by expanding the original gray level range to fill the dynamic range of the display device.
2) *Spatial Filtering:* It is used to enhance linear surface features such as fractures, faults, joints, etc.
3) *Density Slicing:* It transforms the continuous Gray tone range into a series of density intervals (slices) with a specific digital range. Each slice may be given a separate colour or line printer symbol.
4) *False Colour Composite Images (FCC):* A multispectral false colour image is generated by combining different spectral band and assigning a different colour to each band. It increases the amount of information available for interpretation.

a) *Information Extraction:* After image restoration and enhancement, interpretation of images for extracting valuable information such as rock type, mineral deposits, alteration zone, structure etc. were carried out using spectral signature and other associated features. For image interpretation systematic observation of image elements and terrain elements is required as each of these elements has their geological significance.
b) *Image Elements:* Tone/colour, Texture, Pattern, Shape, Size, Shadows, Site and Association
c) *Terrain Elements:* Drainage patterns drainage density, topography/land form and erosion status Geological mapping and/or mineral exploration based on remotely sensed data required a) image interpretation of terrain element and image element with documentation of geological features (identification of features and judging their significance) based on the variation of spectral signature and b) verifying the result with the existing regional geological maps, reports, guides or by field visit. Generally broad geological information about the terrain is a prerequisite for preparing geological map or map for mineral exploration from air/space borne images. As discussed in the previous section for identification of different rock / mineral group/mineral their spectral signature is very helpful.

Drainage Pattern	Geological Significant
Dendritic	It develops in the area where homogenous rock without structural control, having gentle slope with horizontal to sub-horizontal bedding. Ex. Shales and granitic gneisses
Rectangular	It develops in the area structurally controlled and it follows along joints/fault intersecting at right angles.
Treills	Develops in the area controlled by the structuresuch as: a) Areas with parallel fracture or fault b) Tilted interbeded sedimentary rocks having different rocks with different resistance c) Folded sedimentary sequence
Parallel	Formed due to distinct regional slope or in areas having elongated geomorphic features such as homoclinal ridges
Radial	It is associated with domes, doubly plunging fold or volcanoes etc.
Deranged	It forms in Limestones in humid climate.

Table 4: Drainage pattern and geological significance

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Other than the image element and terrain elements, geological information can be extracted from the image by various methods such as band ratio, spectral angel mapper, multispectral classification, principle component analysis etc.

J. Band Ratio

Gray level of pixel in one band divided a by another band. These ratio help to identify the ferruginous and limonitic capping which also called as gossan. Soils and exposed rocks rich in iron oxides and hydroxides absorb wavelength of <0.55 µm and cause red coloration (Whateley, 2006). And when these minerals mixed with other minerals it masks the coloration hence it is important to discriminate different minerals. Small contribution of iron minerals can be identified/ it can be enhanced by taking ratio of MSS band 4 over band 5. Similarly for discriminating areas of limonite alteration a ratio of MSS band 6 over band 7 will be helpful. Mineralogical spectral characteristics related to alteration are detected by taking ratio of TM bands). ASTER provides better enhanced alteration discrimination due to finer spectral bands. Using this ratio we can also detect the alteration zone. For identifying hydrothermally altered rockLandsat TM bands 5 and 7 are very useful. A complete list of different band ratio (ASTER) used for identification of various mineral is given in the table 5.

K. Spectral Angle Mapper (SAM)

This method determines angle of similarity between the reference spectrum and an image spectrumby calculating spectral angle among them . Here image spectrum for unknown material is compared with reference spectrum of a known material; and spectra treated as multidimensional (*n*) vector while computing by the SAM. Where *n* is the number of bands. This method is widely applied for spectral matching and it is independent of illumination conditions and albedo effects. Therefore it treats all possible illumination equally. The position of each spectrum under all possible illumination condition can be defined by a vector from the origin through each point. Poorly illuminated pixels are plot close to the origin. In the result if angle is small then it indicate the closer match with the reference spectrum. Regardless of the length the angle between the vectors is same. Under this method if the pixels are away from the specified angle (in radians) then they will not be classified. The direction of unit vector will define the color of a material

1) Multispectral Classification

In this process (digitally) a symbol or color is assign to a pixel or small group of pixels representing similar surface material. These selected pixels have high probability to represent same kind of material. To the large extent variation in the vegetation cover mimic the underlying geology, hence using multispectral classification this can be detected and the information about the geology can be extracted. For the large areamultispectral classification is also used to extract information

2) Principal Component Analysis (PCA)

Spectral variations among different rock type are more visible in the principal component image compare to single bands. Therefore principal componentanalysis helps to enhance or distinguish lithological differences. Very good correlation is observed in the reflectance of different bands of MSS, TM, or ASTER images.

To improve the spread and to exaggerate differences in the data principal componentanalysis is applied by redistributing data on another set of axes.

Features	Band or ratio	feature	Band or ratio
Iron		muscovite	7/6
Ferric iron, Fe3+	2/1	kaolinite	7/5
Ferrous iron, Fe2+	5/3+1/2	Clay	(5x7)/(6x6)
Laterite	4/5	Alteration	4/5
Gossan	4/2	Host rock	5/6
Ferrous Silicates (biotite, chlorite, amphibolite)	5/4	silica	
Ferric Oxides	4/3	Quartz Rich Rocks	14/12
Carbonates/ Mafic Minerals		Silica	(11x11)/10/12

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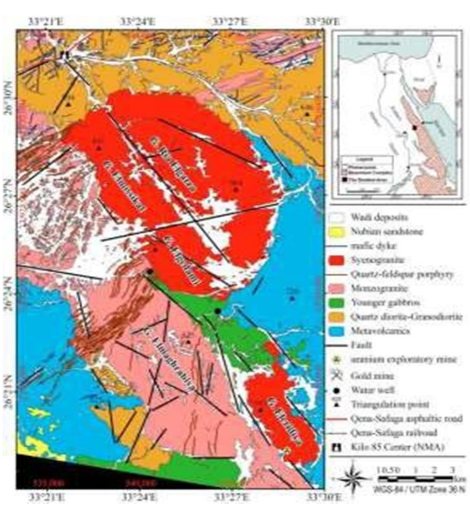
Carbonate / Chlorite / Epidote	(7+9)/8	Basic Degree Index (garnet, clinopyroxene, epidote, chlorite)	12/13
Epidote / chlorite / Amphibole	(6+9)/(7+8)	Sio2	13/12
Amphibole / MgOH	(6+9)/8	Sio2	12/13
Amphibole	6/8	Siliceous Rocks	(11x11)/(10x12)
Dolomite	(6+8)/7	Silica	11/10
Carbonate	13/14	Silica	11/12
Silicates		Silica	13/10
Sericite / Muscovite /Illite /Smectite	(5+7)/6	Others	
Alunite / Kaolinite /Pyrophyllite	(4+6)/5	Vegetation	3/2
Phengitic	5/6	NDVI	(3-2)/(3+2)

L. Case Study

To learn how this technique can be used for mineral exploration, an example is given here. This case study is directly quoted from " Elsaid, et al. (2014): Processing of Multispectral ASTER Data for Mapping Alteration Minerals Zones: As an Aid for Uranium Exploration in Elmissikat – Eleridiya Granites, Central Eastern Desert, Egypt, Here author tried to map the alteration mineralization and/or zones as pathfinders for uranium mineralization within Elmissikat - Eleridiya younger granite (Central Eastern Desert, Egypt), which may assist in developing a uranium exploration program using ASTER imagery.

With above objective author used ASTER image followed by ortho-rectification using SRTM topographic data. Author also converted the pixel radiance to the reflectance at surface data using FLAASH (fast line of sight atmospheric analysis of spectral hypercubes) module of ENVI software and thermal atmospheric correction of ASTER- TIR emittance bands were also applied.False color composite of ASTER bands (9:R, 8:G, 1:B) was prepared to discriminates the different rock units of the study area The feature oriented principal component selection (FPCS) and spectral angle mapper (SAM) is the main image processing techniques was used by the author. The input bands for FPCS analysis of selected minerals (type of minerals will vary as per the aim of the study) are listed in the Format for result of principal component analysis for selected bands (VNIR-SWIR and TIR separately) and for a mineral is given in the. For the selected minerals separate analysis is required. Based on the result anomaly maps will be prepared for each selected minerals. Few maps are given in the For SAM classification computed maximum angle in radians are listed in the table A 3 for selected endmember minerals



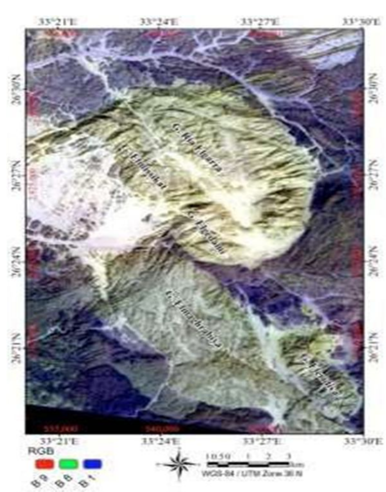


FIG Geologic map of the study area, Elmissikat - Eleridiya district, Central Eastern Desert, Egypt Blue circle indicate the uranium exploratory mine. **b)** False color composite of ASTER bands discriminates the different rockunits in the study area.

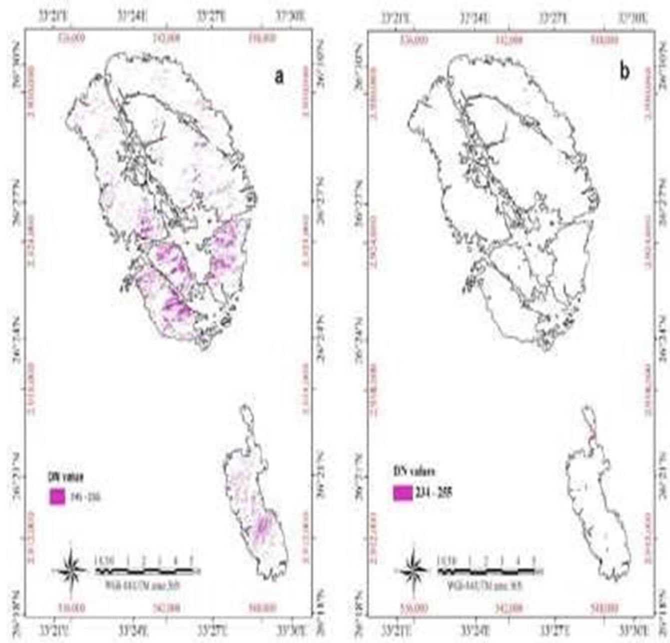


FIG Image for Kaolinite based on the PC3 of FPCS technique for the input VNI SWIR bands applied on the study area. Magenta pixels represent ***kaolinite*** anomalies

Image for Kaolinite based on the PC3 of FPCS technique for the input thermal emissivity bands applied on on the study area. Magenta pixels represent thresholded *kaolinite* anomalies. Image forIllite based on the PC4 of FPCS technique for the selected input VNIR-SWIR bands applied on the study area. Blue pixels represent thresholded *illite* anomalies Image forHematite based on the PC1 of FPCS technique for the input VNIR-SWIR bands applied onthe study area. Red pixels represent Hematite anomalies. Image forQuartz based on the PC5 of FPCS technique for the input thermal emissivity bands applied on the study area. Cyan pixels represent threshold quartz anomalies

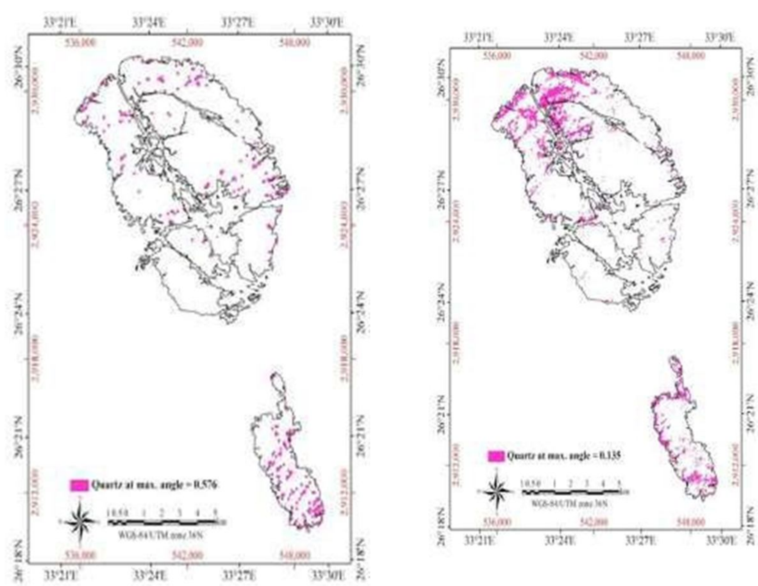
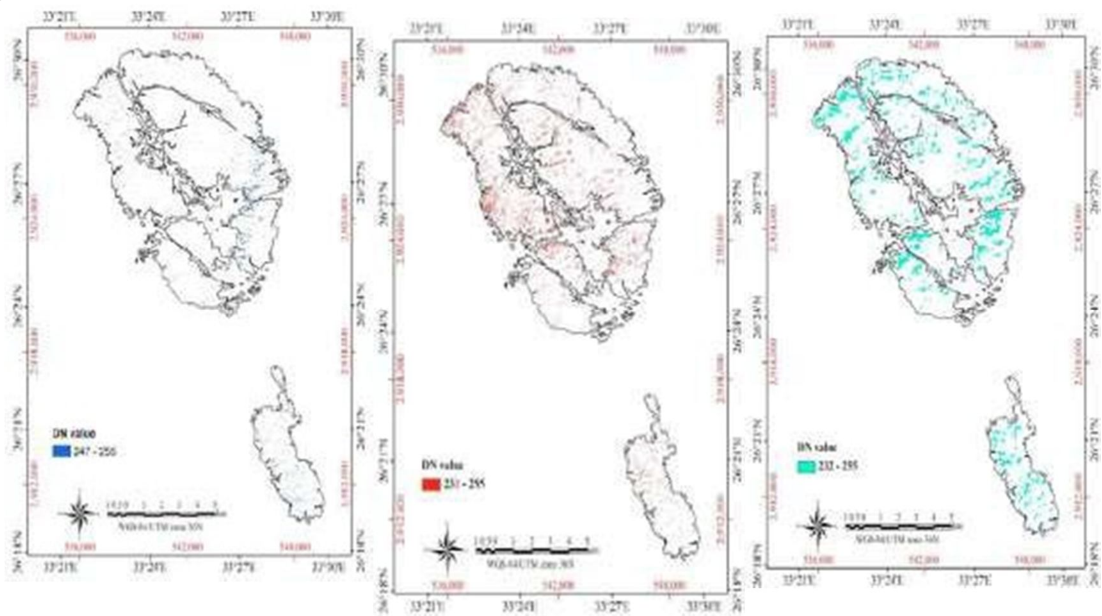


FIG separated SAM classification for end-member (***Quartz***) using ASTER VNIR-SWIR stack and the USGS ASTER resampled spectral library applied on the study area, **b)** separated SAM classification end-member (***Quartz***) using ASTER TIRstack and the USGS ASTER resampled spectral library applied on the study area



IV. CONCLUSION

This module introduces the importance of mineral resource study and an example was given that for a person how much mineral, metal or stone required in his or her lifetime. Here we also learned how remote sensing and GIS techniques can be used for mineral exploration, preparing/ updating lithological map of an area. Using reflectance and/or absorbance of different wavelength of electromagnetic radiation, minerals/rocks can be identified and this property of mineral will also help us to use remote sensing technique more efficiently in the various fields of mineral exploration and mapping. Usefulness of remotely sensed images from different sensor is also discussed here to guide or select suitable image for mineral resource study. In this module only selected digital image processing and image interpretation techniques are discussed as detailed discussion is beyond the scope of this module. The case study presented here is only to demonstrate that how one can use this technique and what are the steps involved for mineral exploration study.

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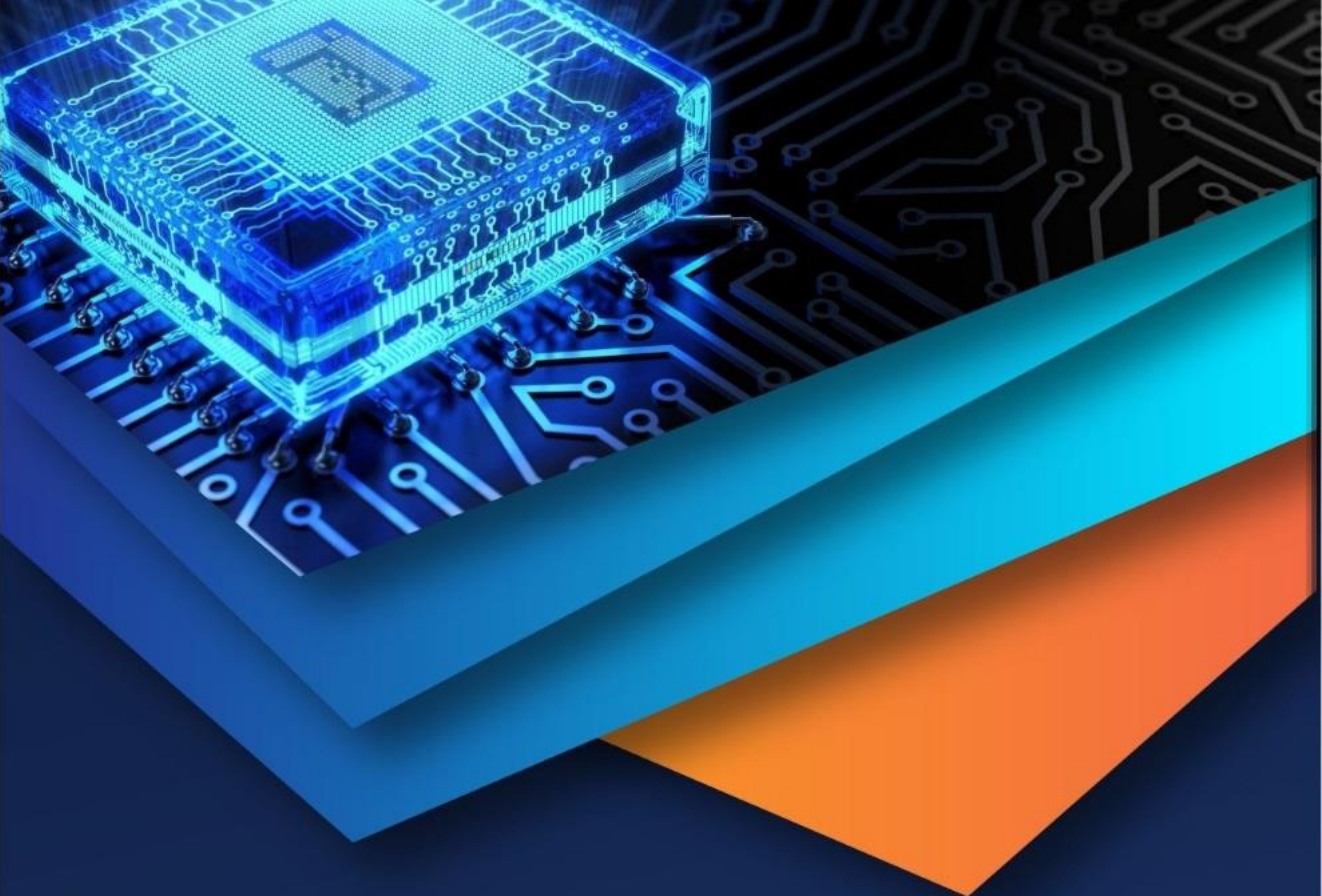

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