IMPORTANCE OF REMOTE SENSING IN MINERAL EXPLORATION AND LIMESTONE IN THE MODERN AGE

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Abstract: Dams, state and national highways, bridges, heavy industries, thermal and nuclear power plants, housing etc. These activities are bound to increase in the future owing to the increased economic independence and growth in India. Such an exponential growth has lead to an increase in the demand of iron ore (steel), limestone (cement) in the country. Further, the spurt in automobile industries and housing sectors has increased the demand for aluminium. Increased environmental awareness has resulted in reduced use of forest wood for housing and increased use of aluminium panels.

All the above facts demand the need for exploring new and additional deposits of iron ore, limestone and bauxite. Given the vast territory of the Indian state, and the difficult terrains in terms of forest cover and ruggedness, conventional mapping and exploration technique may not befitting and adequate. Hence, there is a need to use modern technique such as remote sensing to overcome this limitation and identify new/additional deposits of iron ore, limestone and bauxite.

This research is concerned with development and application of certain recent remote sensing based approaches to locate and characterize iron ore, limestone and bauxite in the state of Tamilnadu, south India.

Keywords: Remote Sensing, Mineralexploration, Lime Stone, Moderan Age.

Introduction: India has been witnessing tremendous growth in infrastructure projects over the past decades, which includes construction of major power projects,

As a mineral exploration tool. As regards iron ore, only hematite exhibits typical NIR absorption, while magnetite lacks the characteristic spectra dams, state and national highways, bridges, heavy industries, thermaland nuclear power plants, housing etc. These activities are bound to increase in the future owing to the increased economic independence and growth in India. Such an exponential growth has lead to an increase in the demand of iron ore (steel), limestone (cement) in the country. Further, the spurt in automobile industries and housing sectors has increased the demand for aluminium. Increased environmental awareness has resulted in reduced use of forest wood for housing and increased use of aluminium panels.

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This research is concerned with development and application of certain recent remote sensing based approaches to locate and characterize iron ore, limestone and bauxite in the state of Tamilnadu, south India.

In remote sensing studies, we rely on the spectral response of objects to recognise and map them. The unique spectral characteristic of carbonate (limestone) and alumina (bauxite) (Figure 1.1) and the existence of dedicated remote sensing sensors such as ASTER (Yamaguhi 1998) andHyperion (USGS 2012) to map these minerals have encouraged me to use remote sensing. However, studies of magnetite deposits have also been attempted in this thesis. Accordingly, the aim and objectives of this research are listed in the next section.

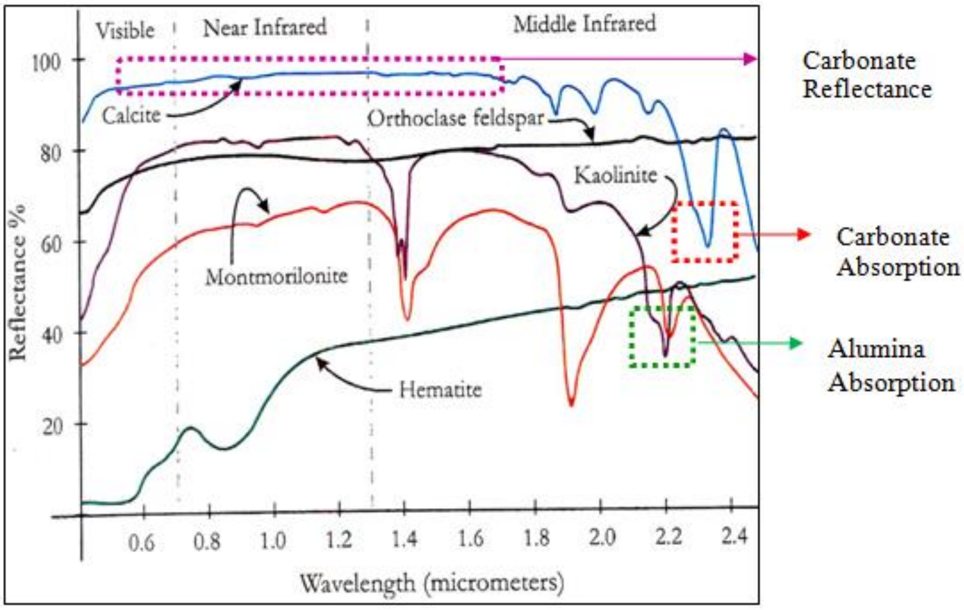

Figure 1.1: Reflectance Curves of Some Common Rock Forming Minerals. Note The Typical Absorption Spectra of Limestone AndAlumina

Aim and Objectives: The aim of the study is to demonstrate the applicability of digital analysis of hyperspectral and multispectral imagery for locating and characterizing bauxite, iron ore and limestone deposits in the state of Tamilnadu, south India.

The objectives of the study are:

- To understand the spectral response of bauxite, iron ore and limestone in the Very near Infrared (VNIR) and Short wave infrared (SWIR) regions.
  To carry out spectra based image analysis such as ratioing, classification spectral unmixing and fusion to extract information about the extent and quality of the mineral deposits.
- To validate the accuracy of extracted information by field visits and Geochemical analysis.

To evaluate the applicability of remote sensing in exploring these three minerals, three test sites have been identified. These are the Kolli hills near Namakkal district, Tamilnadu for bauxite studies, Kanjamalai hills near Salem district, Tamilnadu for iron ore studies and Talaiyuthu area of Tirunelveli district, Tamilnadu for limestone studies.

Though the existence of magnetite as a ore of iron has been reportedand established in Kanjamalai hills, the ruggedness of the terrain and presence of vegetal cover has made it a challenging task to decipher the spatial distribution of the grades of the ores in the hills. Thus this thesis does not attempt to discover or explore magnetite in the Kanjamalai hills, but to map the additional ridges of magnetite quartzite and to prepare a map showing the spatial distribution of the various grades of magnetite.

In a similar fashion, though bauxite and limestone have been reported from the Kollimalai hills and Tirunelveli districts respectively, this thesis attempts to explore for additional capping of bauxite in Kollimalai hills and additional bands of limestone-kanker in Tirunelveli districts. Apart from this, quantification of the grades of limestone in the hitherto reported deposits, using satellite images and image processing technique has also been attempted.

Demand for Bauxite, Iron and Limestone in the Modern Age:

Bauxite Demand in India: India has large resources of bauxite, occupying the sixth place in theworld total resources. The resources of metallurgical grade bauxite are quite adequate while those of the chemical and refractory grade bauxite are relatively limited considering the future requirement. With the abundance of bauxite resources, Eastern Ghat regions of Odisha state and Andhra Pradesh state are likely to be the hubs for bauxite mining activities in future. The production of bauxite was at 13,952 thousand tonnes in 2009 – 2015. There were 200 operating mines in 2009 -15 as against 198 in the previous year. In all, 93 producers reported production of bauxite in 2009 -15. Ten principal producers having 68 mines contributed 78% of the total production. 44 major mines, each producing more than 50 thousand tonnes per annum, together accounted for about 89% of all-India production. Production of bauxite during2000 - 2009 (IBM 2010) is shown in Figure 1.2, indicates an increasing overall demand. the pilot study has conducted in 2015 data has taken 2011 to 2015.

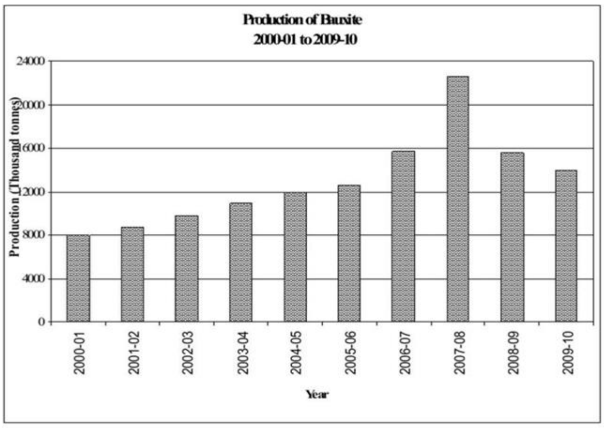

Figure 1.2 Production of Bauxite (IBM 2010)

Iron Ore Demand in India: India has rich potential of iron ore, both in terms of quantity and quality. It can easily meet both the domestic demand and the export market. India is among the leading exporters of iron ore in the world. There is a tremendous scope for using the mined ore within the country for augmenting steel production and export steel in lieu of iron ore on a large scale. The iron ore production constituting 218.6 million tonnes in the year 2009 -10, showed an increase of about 2.7% from that of the preceding year which could be attributed to better utilization of resources and increased demand. There were 319 reporting mines in 2009 -10. Among them, 34 mines were in the public sector and 285 in private sector. Besides, production of iron ore was reported as an associated mineral by 16 mines in the current year as compared to 14 in the previous year. The contribution of public sector to the total production was about 27.1%. The remaining 72.9% of the total production in 2009 -10 was from the private sector (IBM 2010).

The all-India resources of iron ore can be placed at 28.5 billion tonnes. Further, in view of the drilling technology constraints in the past, the drilling in iron ore leasing areas was confined to 60-80 m. Recent experience has shown that in many of the iron ore leasing areas, the depth continuity is beyond 80 m. This will also result in augmentation of resources. Further, BIF which was hitherto consider as waste is now important sources of iron ore with adoption of suitable processing technology. Apart from this, many of the iron ore bearing areas have not been explored in detail. Detailed exploration in such areas will further augment the resources. In view of this, it is felt that iron ore resources which are presently at 28.5 billion tonnes, is expected to increase after detailed exploration and there will be no problem in meeting thefuture demand of iron ore. Production of iron ore during 2000-2009 is shown in Figure 1.3 (IBM 2010).

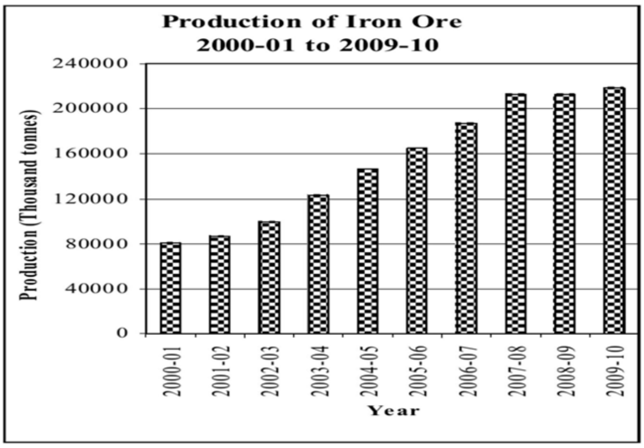

Figure 1.3: Production of Iron ore (IBM 2010)

Limestone Demand in India: India has huge resources of limestone distributed over different parts of the country. India is comfortably placed in the world in annual capacity and production of cement. Cement-grade limestone occurs in all the limestone-bearing areas, while chemical-grade limestones occur in selective areas. Increase in construction and steel production in the country has escalated the demand for chemical grade limestone. As per the Indian Bureau of Mines report (2010) the production of limestone in 2009 -10 (Figure 1.4) at about 228.9 million tonnes increased by 3% from that of the previous year. Increase in demand in the market, led some principal producers of limestoneto increase production during the year. There were 557 reporting mines in 2009 -10. Fifteen mines, each producing more than 3 million tonnes perannum contributed about 33% of the total production of limestone in 2009 -10. The share of 13 mines, each in the production range of 2 to 3 million tonnes was 14% of the total production. About 30% of the total production was contributed by 47 mines, each producing 1 to 2 million tonnes annually. The remaining 23% of the total production was reported by 482 mines during the year. Twenty-two principal producers contributed about 78% of the total production. About 8% of the production was reported by public sector mines as against 6% in the previous year (IBM 2010).

To ensure rational utilization of limestone reserves of various grades available in the mining lease area and to assess the shortfall, if any, for new plants including expansion of existing cement plants in view of infrastructure development and housing boom, it is imperative that periodic re-assessment of captive limestone reserves be made. Utilization of marginal-grade limestone would need to be explored further.

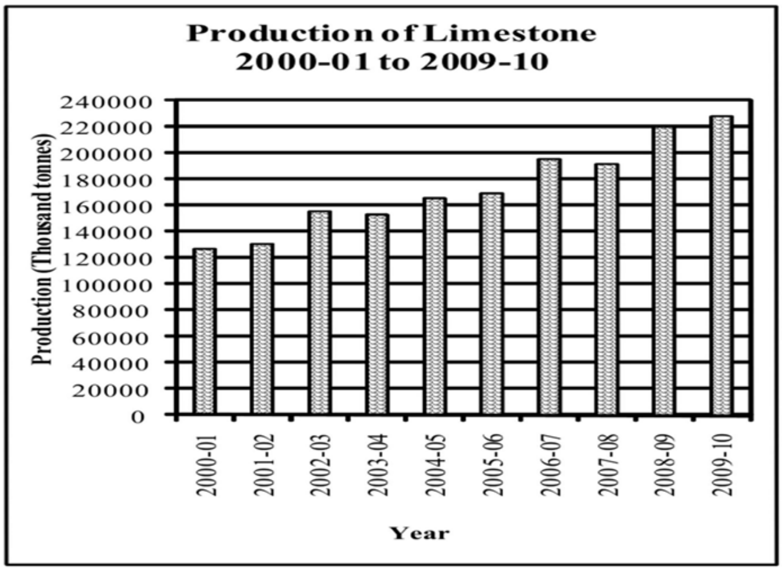

Figure 1.4: Production of Limestone (IBM 2010)

Mineral Exploration: The lack of detailed exploration programmes in the past, coupled with the abundance of recent discoveries using modern techniques, demonstrates the high possibility of discovering new deposits, as well as expanding the reserves of existing mines. As population increases and more nations industrialize, the demand for natural resources continues to increase. Growing pressure for environmental sustainability and the spread of population centres has driven the search for economically viable mineral deposits into more remote and desolate regions, Moon et al (2006).

According to Kruse (1998), classical geologic mapping and mineral exploration utilize physical characteristics of rocks and soils such as mineralogy, weathering characteristics, geochemical signatures, and landforms to determine the nature and distribution of geologic units and to determine exploration targets for metals and industrial minerals. Subtle mineralogical differences, often important for making distinctions between rock formations, or for defining barren ground versus potential economic ore, are often difficult to map in the field.

Mineral exploration is ever expanding science and as civilization progresses; it has become more challenging to incorporate advanced method to delineate hidden deposit. The demand of ore in the field of mineral exploration is to use new technology to discover mineral deposit in cost effective manner, Moon et al (2006). Today, there are a variety of remote sensing tools available to the exploration geologist. The synthesis of the various forms of imagery, digital image processing, spectral analysis, remote mapping and field work has come together with the help of GIS technology (www.angelfire.com).

Importance of Remote Sensing in Mineral Exploration: As metals and minerals form an indispensable part of any nation's economy, more and more modern technologies are invented and employed for the search of new deposits. As a tool, remote sensing helps a geologist to narrow down his study area and search for mineral wealth. Aerial photographs form an irreplaceable tool in bringing out the total architecture of the metallogenic environments, whereas the remotely sensed data being collected by the satellites with the varying spectral, spatial and temporal resolutions give unique information with new rank and style about the metallogenic environments, Singh and Dowerah (2010). From such remotely sensed data, it is possible to bring out the regional lithology, tectonic fabric and also the geomorphic details of a terrain, which aids precisely in targeting of metals and minerals.

Use of remote sensing in mineral exploration began some 60 years ago with hand-held cameras being pointed out of aircraft windows and has since evolved through stereoscopic aerial photography to sophisticated space age technology, with satellite and airborne multispectral and hyperspectral digital imaging systems (www.agarss.com).

Commenting on the role of geological mapping and exploration Marjoribanks (2010) states that geological maps and section are essential tools to visualize spatial, 3-dimentional and geological relationships. These maps allow theories on ore deposits controls to be applied and lead to prediction being made on the location, size, shape and grade of potential ore bodies. The author lists few mapping technique and compares their characteristics (Table 1.1). Finally the author summarises and comments that for small scale maps (1:50,000 to 1:1,00,000), remotely sensed imageries are vertically the only really suitable mapping base, although of good topographicmaps are available at the scales, they can be used as a sanded – choice substitution. He adds that where there is no aerial photography available on any suitable scale, satellite imagery can provide a suitable base for regional geologic mapping.

The art of remote sensing aids faster identification of mineralized zones and metallogenic belts either directly or indirectly. Their direct manifestation is in the form of contrasting tonal grades in the rocks. The digitally enhanced colour coded satellite data also show different metals and minerals with varying signatures as the spectral signatures are greatly modified by metal and mineral content. Bakliwal et al (1985), have demonstrated that the exposed soils and vegetation masked metalliferous horizons can be picked up by special processing of satellite data where as in the case of concealed deposit remote sensing greatly helps in bringing out the lithological architecture, folded rhythmicities, lineament network and also the geomorphic panorama through which metals and minerals can be preciselytargeted.

Table 1.1: Comparison of mapping techniques (Marjoribanks 2010)

Mapping technique	Ideal scales	Indications	Advantages	Disadvantages
Pace and compass	1:100–1:1,000	Rough prospectMap. Infill between survey points	Quick. No assistance andminimal equipmentNeeded	Poor survey accuracy, especially on uneven ground
Tape and compass	1:100–1:1,000	Detailed prospect Maps. Linear Traverse maps.Mine mapping	Quick. Goodaccuracy. Nopreparation needed	May need assistance. Slow for large equidimentional areas

Pegged grid	1:500– 1:2,500	Detailed maps of established prospects	Fair survey Accuracy. Relatively quick. Same grid controls/correlates all exploration stages	Expensive. Requires Advance preparation. Poor survey control in dense scrub or hilly terrain
Plane table	1:50– 1:1,000	Detailed prospect Mapping in areas of complex geology. Open cuts	High survey Accuracy. Noground preparation required	Slow. Requires assistance. Geological mapping and surveying are separate steps
GPS and DGPS	1:5,000– 1:25,000	Regional and semi-regional Mapping. Firstpass prospect mapping	Quick, easy downloadabledigital surveyData. Good backup for other techniques atsimilar scales	Encourages geological mapping as collection of point data
Topographic map sheet	1:2,500– 1:100,000	Regional mapping and reconnaissance. Areas of steep Topography. Mine Mapping. Base for plotting GPS observations	Accurate georeferenced map base. Height contours	Difficulty in exact location. Irrelevant map detail obscures Geology. Not generally available inlarge scales
Remote sensed reflectance imagery	1:500– 1:100,000	Preferred choice. Ideal geological mapping base at all scales	Geological Interpretation directly from Image. Stereo viewing. Easy feature location	Scale distortion (air Photos). Expensive if new survey needs to be acquired

Hyperspectral sensors operative from spaceborne and airborne platform can contribute to locate the zone of significance to carry out detail geophysical and geochemical study to prove a mineralisation is economic or not within a short period with better accuracy and thereby can reduce the cost of exploration and also can contribute in locating the “target” within shorter period of time. This would definitely better the exploration performance and reduce the cost of “deposit realization” (Guha 2011).

Spectra of Minerals and Rocks: The basis for remote sensing for mineral exploration is a proper understanding of the spectra of minerals and rocks. It has been proved that field spectroscopy has a role to play in at least three areas of remote sensing, namely calibration, prediction and modelling. Milton (1987), explains that field and laboratory based spectro-radiometric techniques have been successfully used to predict certain properties of water bodies, grasslands, minerals and rocks, forests, crops and several other surface features from their reflectance spectra.

The three fundamental types of absorption features in the 0.4 to 2.5μm region should be understood to realise the need for hyperspectralsensing for mineral exploration.

Charge Transfer Absorptions: These absorptions occur mostly in the visible region of the spectrum, and are caused by light at certain wavelengths causing electrons to be transferred between atoms. A good example of this is Fe^{3+} and Fe^{2+}. Light at the proper wavelength causes an electron to be transferred from a Fe^{2+} atom to a Fe^{3+} atom. This is what causes rusty objects to appear red. In general, this type of absorption is quite broad, so it would be possible to detect them with conventional multispectral sensors such as Landsat. However, there is overlap among the absorptions caused by different atoms, so ahyperspectral sensor is needed to tell them apart.

Electron Transition Absorptions: In atoms with an incomplete electron shell, light at the proper wavelength can bump electrons into different positions in the shell. These absorptions tend to be narrower than the charge transfer absorptions and the type of atom and the position and variety of its neighbours controls the wavelengths of the absorptions. This feature is especially useful in geology, where the arrangement of atoms in a mineral is very well defined. Since subtle variations in the position of the band centre are important, it is necessary to have many narrowly spaced bands to take advantage of this feature.

Vibrational absorptions: When light at the same wavelength as a molecule (or part of a molecule) strikes the molecule, it causes the molecule (or part of the molecule) to vibrate. This leads to light absorption. In general these absorptions are very narrow, although their widths and depths vary. Many of the absorptions seen in the 0.4 to 2.5μm region actually originate at longer wavelengths, and what we are seeing are combinations and overtones of the original wavelength. Most of these absorptions can be detected with a multispectral sensor.

Actual detection of minerals is dependent on the spectral coverage, spectral resolution, and signal-to-noise ratio of the spectrometer, theabundance of the mineral and the strength of absorption features for that mineral in the wavelength region measured.

As regards specific minerals and their spectra, many authors have attempted several studies. Gaffey (1986), explains that carbonate minerals are important and their spectra exhibit a number of diagnostic absorption bands in the 0.3-2.5μm region. As regards the spectroradiometric studies, it has been observed that in the 0.4 to 2.5 μm reflectance spectra of serpentinized dunite, serpentinization is responsible for decrease in contrast of olivine – pyroxene iron absorption feature and an appearance of OH^- absorption features near

1.4 – 2.3 µm associated with serpentine minerals, Van der Meer et al (2008). The absorption trough for magnesite is high in the SWIR (2-2.35 nm) region. This is mainly due to vibrational transitions and overtones in carbonate minerals caused by stretching and bending of the C-O bond in the CO^{2-} ion

Strong absorption is also perhaps due to overtones formed bending transition to produce absorption features in 2.3 µm. Similarly, it has been observed by Govindan (2009), that magnesite has a definite absorption in the 2.35 µm region while dunite does not exhibit such absorption.

Mineral Exploration with Multispectral Images: As satellite image collection and data management improved, a new kind of remote sensing application began to be used by exploration geologists. Multispectral imaging and thematic mapping allowed surface mapping to be performed remotely in ways only dreamed about during the era of early photo interpretation. Different scanning spectrums enabled researchers to begin cataloguing various reflection and absorption properties of soils, rock, and vegetation. These spectra could be utilized to interpret actual surface lithologies from remote images (Evans 1995).

Remote sensing has opened up new steps in mineral exploration, asit pictorially exhibits the various litho units with due contrast, the folded and faulted structures in their true perspective and different geomorphic phases with their natural architecture. The most significant experiments in sensing the earth resources were initiated with the launching of the first earth recourses Technology Satellite or LANDSAT-1 in July 1972 followed by other satellites in the Landsat series (LANDSAT 2, 3, 4, & 5 SPOT, IRS). In India in order to provide continued space based services to user community Indian Remote Sensing satellite IRS-1A was launched on March 17th 1988 followed by IRS-1B, IC, ID, P3, P4, P5, P6 etc and recently RISAT 1 on April 26th 2012 (ISRO 2012).

In the past 10 years, new spaceborne multispectral and hyperspectral remote sensing instruments have been launched and have provided higher spectral resolution data that can be used for mineral exploration. These recent developments have enabled remote sensing technology to become an increasingly important tool for mineral exploration, particularly for remote areas with little or no access, or areas that lack detailed topographic or geologic base maps, Zhang et al (2007).

When the Landsat multispectral scanner (MSS) began operations in the early 1970's, remote sensing geology took an enormous leap forward but still functioned largely by way of photo geological interpretation of hard copy. Since then, the Landsat Thematic Mapper (TM) instruments have provided the geological user with information relating to specific groups of minerals, specifically the iron oxides and clays (www.agarss.com). However, the data remains coarse and of general purpose only with low spectral and spatial resolution, requiring sophisticated statistical processing techniques not readily understood by the average geological user.

Spaceborne multispectral systems such as Landsat MSS, TM have four to seven spectral channels. Landsat MSS data have mainly been utilized for structural and geomorphic interpretation at regional scales Goetz et al (1983); Abrams et al (1983); Sultan et al (1987) and Perry (2004). Landsat TM imagery has been used more routinely for mineral exploration becausethe two SWIR channels may be used to detect associated alteration mineral assemblages. ASTER channels are more spectrally contiguous than other multispectral sensors such as the Landsat 5 Thematic Mapper and the Landsat 7 Enhanced Thematic Mapper, especially in shortwave and thermal infrared wavelength ranges. Thus, the ASTER sensor can achieve a higher degree of accuracy in the spectral identification of rocks and minerals, Crosta and Filho (2003).

Mineral Exploration Using Hyperspectral Images: The term "hyperspectral imaging" was first coined in a paper discussing the early results of the technique of imaging spectrometry by Goetz et al (1985). The invention and development of aerial photography and sensor technology have played an important role in remote sensing for observing and classifying a distant object or image on the earth surface. However, the technology has certain limitations to obtain specific information related to a particular earth mineral due to broad spectral band or low spectral resolution, Zaini (2009). The recent advances in remote sensing technology like hyperspectral remote sensing has allowed acquiring a precise earth surface mineralogy image due to high spectral resolution, so it can be used for identifying and mapping of a specific mineral Goetz (1991); Campbell (1996); Mustard and Sunshine (1999); Van der Meer et al (2006) and Sabins (2007). Absorption peaks of various cations and anions in different regions of electromagnetic spectrum are shown in Table 1.2.

Table 1.2: Absorption Peaks of Various Cations and Anions in Different Regions of Electromagnetic Spectrum (Gupta 2003)

Cations/Anions	**Absorption peaks (μm)**
Normal - Visible and near Infrared (VNIR) Region	
Ferric ion *	0.40, 0.50, 0.70 and 0.87
Ferrous ion*	0.43, 0.45, 0.57, 0.55, 1.00 and 1.80 – 2.00
Manganese	0.34, 0.37, 0.41, 0.45 and 0.55
Copper	0.80
Nickel	0.40, 0.74 and 1.25
Chromium	0.35, 0.45 and 0.55
Normal - Short Wavelength Infrared (SWIR) Region	
Hydroxyl ions	1.44 and 2.74 – 2.77
AI – OH	2.20
Mg – OH	2.30
Water molecules	1.40 and 1.90
Carbonates	1.90, 2.00, 2.16, 2.35 and 2.55
Thermal Infrared (TIR) Region	
Silicates	9.00 – 11.50 (depending upon the crystal structure)
Carbonates	7 (not used in remote sensing) and 11.30
Sulphates	9 and 16
Phosphates	9.25 and 10.30
Nitrates	7.20
Nitrites	8 and 11.8
Hydroxides	11

Hyperspectral sensors look at objects using a vast portion of the electromagnetic spectrum. Certain objects leave unique 'fingerprints' across the electromagnetic spectrum. These 'fingerprints' are known as spectral signatures which enables identification of the materials. Hyperspectral imaging is part of a class of techniques, it also alternatively referred as spectral imaging or spectral analysis. Hyperspectral deals with imaging narrow spectral bands over a contiguous spectral range, and produce thespectra of all pixels in the scene. So a sensor with only 20 bands can also be hyperspectral when it covers the range from 500 to 700 nm with 20 to 10 nm wide bands. While a sensor with 20 discrete bands covering the VIS, NIR, SWIR, MWIR, and LWIR would be considered multispectral. Therefore the concept of "contiguity" is important.

Airborne hyperspectral remote sensing imagery with narrow and contiguous spectral bands, have been widely used for geological explorations, especially for identifying and mapping earth surface minerals in many areas all around the world. Carbonate minerals have diagnostic absorption features of reflectance spectra in the SWIR and TIR band due to electronic and vibrational processes, so that the spectra can be used to discriminate carbonate minerals from other minerals and identify calcite and dolomite Hunt and Salisbury (1971), Gaffey (1985, 1986), Crowley (1986), Van der Meer (1994, 1995, 2004, 2006), Clark (1999) and Gupta (2003).

Hyperspectral remote sensing also would be useful to understand the mineral distribution of any area reported as geologically virgin (i.e. no geoexploration activities are taken up yet to understand the mineral potential of the area, Guha (2011). Hyperspectral remote sensing has a definitive role in the following segment of mineral exploration: (a). In delineation of host rock known for containing economic minerals (e.g. Kimberlite; Bauxite etc.) (b) In delineation of alteration zone often associated with hydrothermal and supergene enrichment and volcanic exhalative deposits (Porphyry Cu deposit; Pb-Zn deposit). (c). In delineation of geobotanical stress associated with mineral enrichment (Kruse 1998).

A wide variety of hyperspectral data are now available, along with operational methods for quantitatively analyzing the data and producing mineral maps. Hence, it illustrates the potential of these data and how theycan be used as a tool to aid detailed geologic mapping and mineral exploration.

Conclusions: From the above descriptions and discussions, it is inferred that bauxite, iron ore and limestone are important components in the industrial world including India and is in great demand. Further, multispectral and hyperspectral remote sensing can aid in identification of these deposits and the characterisation of the grade of certain ore deposits.

The following chapters provide details about the use of multispectral and hyperspectral remote sensing, and the results obtained from the experiments carried out in the central and southern tracts of Tamil Nadu, South India to map bauxite, iron ore and limestone.

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