TARGETING LIMESTONE AND BAUXITE DEPOSITS IN SOUTHERN INDIA BY SPECTRAL UNMIXING OF HYPERSPECTRAL IMAGE DATA

S. Sanjeevi

Department of Geology, Anna University, Chennai-600025. India -
ssanjeevi@annauniv.edu

ABSTRACT:

This paper presents a study about the potential of spectral unmixing of hyperspectral satellite image data for targeting and quantification of mineral content in limestone and bauxite rich areas in southern India. ASTER image (acquired in the VNIR and SWIR regions) has been used in conjunction with SRTM – DEM and field studies. A new approach of spectral unmixing of ASTER image data delineated areas rich in carbonates and alumina. Various geological and geomorphological parameters that control limestone and bauxite formation were also derived from the ASTER image. All these information, when integrated, showed that there are 16 cappings (including the existing mines) that satisfy most of the conditions favouring bauxitization in the Kolli Hills. The sub-pixel estimates of carbonate content in the limestone area of Ariyalur, south India, match well with the geochemistry of the samples collected from the study area. The study concludes that spectral unmixing of hyperspectral satellite data in the VNIR and SWIR regions may be combined with the terrain parameters to, not only target limestone and bauxite deposits accurately, but also estimate the quality of these deposits.

1. INTRODUCTION

Much information about potential areas for mineral exploration can be provided by interpretation of surface features on aerial photographs and satellite images (Lillesand et al, 2007). Due to the synoptic coverage and the varying spectral and spatial resolutions offered by satellites and airborne sensors, remote sensing has proved to be an irreplaceable tool in understanding metallogenic environments and targeting mineral habitats. From remotely sensed data, it is possible to decipher the regional lithology, tectonic fabric and also the geomorphic details of a terrain, which aid precisely in targeting of metals and minerals.

Spectral signatures, being unique to each material, can be used for differentiating various materials present in an image. Accordingly, it has been well established that the VNIR, SWIR and TIR wavelength regions provide complimentary data for geological investigations (Drury, 1987). Near-infrared reflectance spectroscopy (from 0.4 μm to 2.5μm) in particular has offered geologists an important potential source of petrological information extraction (Ramsey et al 2002). The NIR wavelength regions have been exploited extensively for mineralogical mapping by using high spectral resolution imaging systems, such as the airborne visible/infrared imaging spectrometer (AVIRIS) (Kruse et al. 1997). At the same time, various information of the land features, topography, geomorphology, and structural patterns can be deciphered from satellite derived DEM of the mineralised zone.

This paper deals with the study of spectral signatures of certain carbonate-rich and bauxite-rich areas of southern India using the VNIR and SWIR bands of ASTER image data. Bauxite and limestone abundance images were generated using the spectral unmixing approach. SRTM DEM was used for deriving topographic information relevant to the bauxite deposits. Chemical analyses of mineral samples were carried out to validate the results of spectral unmixing.

1.1 Limestone and Bauxite as resources

Limestone is an important mineral resource used in the manufacture of cement, lime, steel, glass etc. Limestone of varying grades occurs in sedimentary and crystalline rocks. While the high grade deposits are directly utilised for the manufacture of cement and lime, the other varieties are blended with the high grade deposits and made useable. With depleting limestone resources, it is of significance that we explore and exploit all the grades of limestone. The intensity of spectral reflectance/absorption of limestone or carbonate minerals recorded in remotely sensed image data is a function of their chemical composition and purity. Thus, pure limestone will reflect the visible and NIR energy, while SWIR energy in the 2.35μm region will be absorbed. The depth of absorption in the SWIR region will depend on the concentration of carbonates in the mineral. Hence, it is possible to quantify the purity of a limestone deposit by analysing the visible and carbonate absorption SWIR bands in a satellite image.

Bauxite is an ore of Aluminium and is a term for sediments rich in alumina but low in alkalis, alkaline earth and silica. The term is also extended to cover lateritic weathering products rich in gibbsite on basalt. The production of aluminium consumes over 90% of world production of bauxite, while the reminder is used for abrasives, chemicals and refractory. The term bauxite ore is applicable to bauxites, which are economically mineable containing not less than 45-50% Al_2O_3 and not more than 20% Fe_2O_3, and 3-5% combined silica. The term alumina refers to pure Al_2O_3 containing 52.9% Al and 47.1% O. Bauxite deposits originate from weathering or soil formation with enrichment of aluminum. The parent rock of bauxite may be (1) igneous and metamorphic rocks, (2) sedimentary rocks. Bauxite deposits on igneous and metamorphic rock are known to have formed throughout the Earth's history on plateaus. Examples of slope type deposits are on : basic to intermediate volcanic rocks (Hawaii; Pleistocene to sub-recent), acid metamorphic rocks (Ivory coast; Late Tertiary to sub-recent) and charnockites in

south India. Conditions which favour and the formation of bauxites are permeability, high temperature climate with continuous rainfall, location of source rock in topographically high and well drained areas, availability of pure rain water than the organic acids which will decrease the quartz dissolution, pH between 4-10, dense vegetation, bacteriological action, a mature topography permitting accumulation of the weathered products and free movement of the water table with minimum erosion. Geomorphic expression with favourable slope, which facilitate free drainage of the leachates, is very important in the formation of bauxite deposits. Raman (1976, 1978, 1981) has given an elaborate account of the bauxites and their properties.

1.2 Objectives

The objectives of this paper are:
  i. To assess the potential of the ASTER hyperspectral image data for assessing the quality of limestone deposits and to explore for new bauxite deposits.
  ii. To use spectral unmixing as an image processing approach for mineral targetting.

2. GEOLOGIC SETTING OF STUDY SITES

To determine the possibilities of using ASTER images in mapping limestone abundance and for exploration of the bauxite deposits, Ariyalur Limestone formations in Ariyalur District (Fig 1.a.) and Kolli hills (for bauxite) in the Namakkal District (Fig 1.b.) of Tamilnadu, southern India were selected.

2.1 Limestone in Ariyalur

The Adnankurichi and Periyakurichi limestone mines in Ariyalur district have an areal extent of about $3.213 km^2$ and $0.374 km^2$ approximately. The rocks of the Ariyalur area are observed as outcrops in a number of quarry sections. Madahavraju et al (2006) report that the sedimentary rocks here acted as an ancient repository for a number of flora and fauna. They further report that the Niniyur formations mainly consist of Limestone, silty shale, marl and calcareous sandstone. The total thickness of the formation is 100m. The limestone is compact, pale grey to pale brown in colour and contains rich fossil assemblage. The spectral signatures of the limestone, as recorded by the ASTER sensor, is characterized by the impurities in the form of clay and marl. Also, a pixel, in the ASTER image may not be fully occupied by the pure limestone. Thus, we have an interesting case of mixed pixels. Quantifying the actual abundance of Carbonate in the ASTER pixels can be done by spectral unmixing.

2.2 Bauxite in Kolli Hills

The maximum altitude of the Kolli hills is 1330 m. Kolli hills are considered as parts of a metamorphic province of Achaean age. The rock units are grouped under the general term 'Charnockite suite'. The charnockites consist of quartz, feldspar, hypersthene with or without garnet. On alteration, the plagioclase feldspar changes over mostly to kaolin and rarely to gibbsite. Oxides of iron replace ferro-magnesium minerals such as pyroxene and garnet. The average rainfall of the hill ranges is about 1500 mm per year. The temperature range is between 16º and 25º. Humidity varies from 68 % in the month of March to 87 % in the month of December. The climate supports a luxuriant growth of vegetation in the hill ranges. Thus, all the conditions that favour the formation of bauxite deposit exist at

(a) Map of south India

(b) Geological Map of Ariyalur area

(c) ASTER FCC image of Ariyalur area

(d) Geological Map of Kolli Hills area

(e) ASTER FCC image of Kolli Hills area

(a)

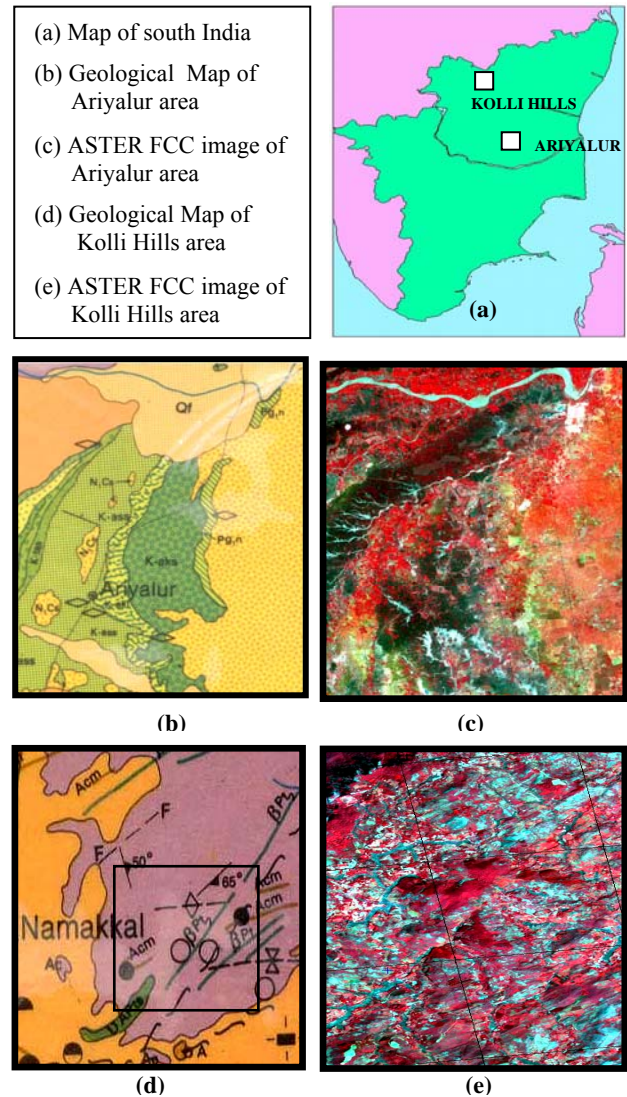**(b)**   **(c)**

(d)   **(e)**

Figure 1: Maps and images of sites selected for the study.

Kolli hills. Most of the hill cappings have proved to contain mineable deposits of bauxite and mining is presently being done in a few of these cappings (Fig 1.e). Bauxite here is of residual type with its disposition as blanket cappings on the flat-topped hill peaks. It is lateritic, yellowish brown to reddish brown in color and generally compact (Borreswara Rao and Krishna Rao, 1976). A vertical cross section of the deposits include four zones shown as below :

> Ferruginous cap
> Bauxite ore body
> Semi altered zone
> Unaltered parent rock

Jayakumar and Balamurugan (1988), Jayakumar and Govindaraju (1988) and Subrahmanian. and Mani (1979), give a detailed account of the process of bauxitisation in the Kolli Hills.

The study area starts from the north and extends upto the south with an area of 51.58 Sq Km.

3. IMAGE DATA AND METHODOLOGY

To target bauxite deposits and to quantify the carbonate concentration in limestone deposits, satellite sensors that are capable of recording the response of reflectance/absorption from these targets are to be chosen. ASTER (Advanced Spaceborne Thermal Emission and Reflectance Radiometer), a sensor system on-board TERRA-1 satellite, is dedicated to geologic mapping, and has three VNIR bands that are important sources of information about absorption in certain metals, especially iron; and for chlorophyll absorption in photosynthesizing vegetation. In the six SWIR bands, carbonate, hydrate and hydroxide mineral spectra display molecular absorption features related to overtones and combination tones (**Yamaguchi et al, 1998**). Hence, in this study, ASTER image data of the Ariyalur Cretaceous Limestone formations in south India and the Kolli Hill region and have been used extensively. Since geomorphic expression of the terrain with favourable slope is important in the formation of bauxite deposits, the topographic details were derived from SRTM DEM and integrated with the results of spectral unmixing of ASTER imgae data. The detailed methodology adopted in this study is depicted in Figure 2.
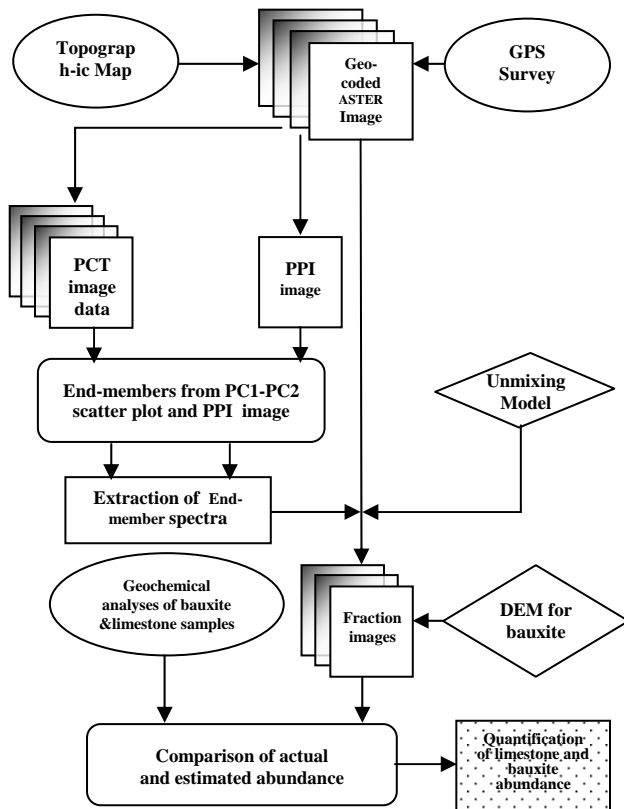

Figure 2: Flow chart of methodology adopted for this study.

Spectral Unmixing is a process that unmixes the mixed pixel, to determine the fractions of each spectral end-members, which combine to produce the mixed pixel's spectral signature. A spectral end-member is the spectral signature for a pure surface cover, we expect to find within one image domain. Linear spectral unmixing is used to determine the relative abundances of materials that are depicted in multispectral imagery based on the materials' spectral characteristics (Shimabukuro and Smith, 1991). The reflectance at each pixel of the image is assumed to

be a linear combination of the reflectance of each material/end-member present within the pixel.

The mixtures in the image are expressed as a linear combination of the responses (spectra) of each component that is assumed to be in the mixture. The model assumes that the observed pixel reflectance can be modelled as a linear mixture of the individual component reflectances multiplied by their relative proportions. It can be represented as:

$$R_i = {}^N\Sigma_{i=1} F_e R_e + E_i \qquad (1)$$

Where

R_i = Surface reflectance in band i, of the sensor,
F_e = Fraction of End Member, e
R_e = Reflectance of End Member, e in the sensor wave band, i
N = Number of Spectral End Members
E_i = Error in the sensor band i for the fit of N-End Members.

3.1 The ASTER Bands

The abundance of carbonate in Limestone and alumina in Bauxite determines the strength of absorption in the 2.35μm and 2.2μm regions of the EMR respectively. ASTER is a sensor designed especially for geological studies and is characterised by bands that correspond to the carbonate and alumina absorption regions. Bands 6 (2.185μm to 2.225μm) and 7 (2.235μm to 2.285μm) of ASTER are useful to discriminate and quantify alumina and clay minerals, while bands 7 (2.235μm to 2.285μm) and 8 (2.295μm to 2.365μm) are useful to identify and separate carbonate minerals. The two most frequently occurring forms of carbonate – calcite and dolomite – have their characteristic absorption wavelengths. Thus, calcite absorbs in band 8 of ASTER, while dolomite absorbs in bands 7 and 8. Hence, the ASTER image of the study sites were acquired and used in the study of limestone and bauxite.

4. CARBONATE AND ALUMINA ABUNDANCE MAPPING

To locate the potential areas of limestone and bauxite in the study sites, spectral unmixing of the ASTER images (Fig 1.c and 1e respectively), was done by locating the end-members (pure pixels of limestone, bauxite, vegetation and other components of the image). A scatter plot of PC1 vs PC2 and the Pixel Purity Index (PPI) images for the two scences were generated to locate the end-members.

For the Kolli Hills image, the scatter plot is triangular shaped, thereby indicating that there are three distinct end-members mixed in various proportions in the pixels of the image scene. The area contains weathered rock (as bauxite), water body and vegetation. The extreme corner points of the scatter plot helped to locate the purest end-member pixels for bauxitised soil/rock, vegetation and moisture/shade.

For the Limestone area image, the PPI image helped in locating the end-member pixels. Spectral unmixing is done with the end-member spectra (according to Eqn. 1), and the fraction images (showing carbonate and alumina abundance) are generated. For the Limestone area, as a result of unmixing, four fraction

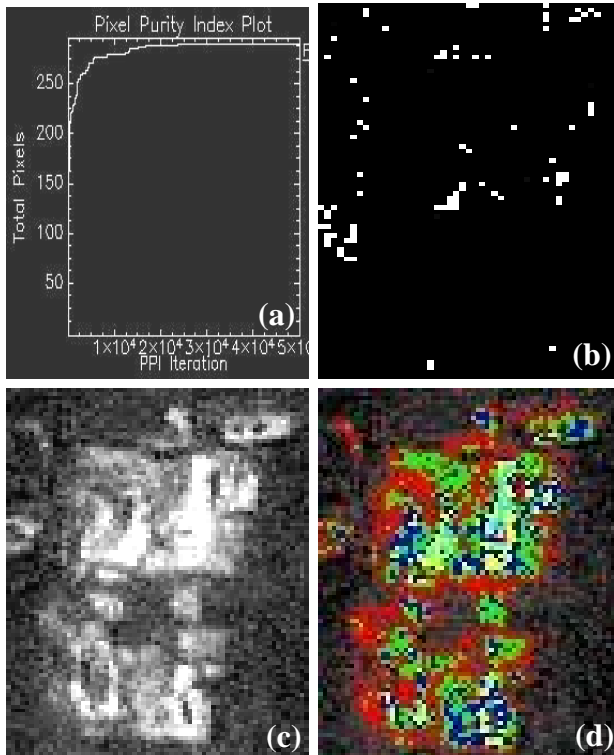Figure 3. (a) PPI plot and (b) PPI image of the Limestone mine area. (c) Carbonate fraction image and (d) density sliced fraction image; red <50%; green 50-60%; blue 60-70%; yellow 70-80%; cyan 80-90%; white >90%.

images for each classes namely Limestone, water,vegetation and sand were generated. In the fraction image, each pixel value corresponds to the fraction of Limestone ($CaCO_3$), sand, vegetation and water. The fraction image shows brighter and darker pixels. The region with higher abundance of a feature will be shown in brighter tone compared to others. The brighter pixels in the limestone fraction image contain higher $CaCO_3$. The darker pixels contain features like vegetation and sand. The Limestone abundance in then density sliced. Accordingly, 6 proportions were generated from the density sliced image and categorized as <50%, 50-60%, 60-70%, 70-80%, 80-70%, 80-90%, and <90%. This result is then validated by chemical analysis of field samples (Figure 4).

For Kolli Hills, of the three fraction images, vegetation and moisture fraction images are discarded and only the alumina fraction image is taken and density slicing is performed to demarcate bauxite rich pockets in the study area. The alumina fraction image contains pixels with values from 0 - 1. In the process of density slicing, pixels with alumina fraction value of 0.7 to 1.0 were all grouped into one density class and demarcated. These pixels (assumed be with alumina content of 70% to100%) were demarcated. (Fig 5. d)**.** All the red patches in the image are probable zones of bauxite.

Alumina rich zones identified by density slicing of the fractional image may be located outside the cappings. For locating alumina rich (bauxitised) zones that are located on cappings, it is necessary to generate Digital Elevation Model of the terrain and locate the cappings. Lineament analysis is also important to precsely locate the bauxitised areas.
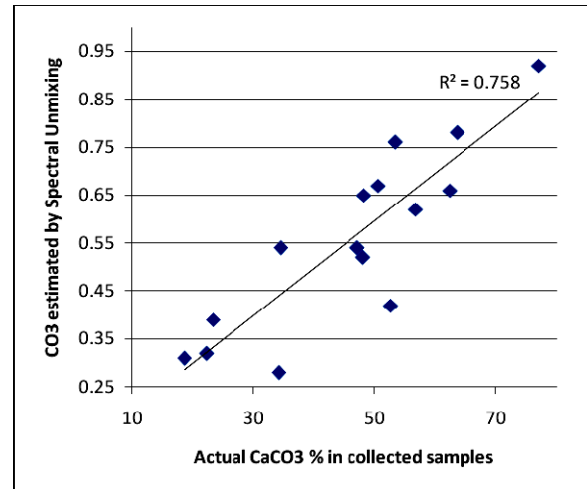

Figure 4. Correlation between carbonate in the limestone samples and carbonate abundance estimated by spectral unmixing of ASTER image data.

4.1 Generation of DEM and 3-D Image

In the SRTM – DEM, regions with height value of 1100 to 1325m are density sliced in to different classes. Such a slicing brings-out the cappings and peaks of the Kolli Hills. The density sliced DEM is then overlaid on the density sliced fractional image to locate alumina rich zones that fall on hilltops. The zone of interest is marked with identification numbers and elevation (Fig. 5d).

4.2 Preparation of lineament maps

The present bauxite mines are located in areas of high lineament density and intersection. Since lineaments regions, where weathering is prominent, are favourable areas of bauxite formation, an attempt is made to find out areas with high lineament density and intersection; and finally correlate it with the identified cappings. Lineament density map is prepared from the lineament map. The image is divided into grids of 50 x 50 pixels. Since each pixel is of 15m size, the area of one grid is equivalent to 0.5625 Sq Km in the ground. For the preparation of the lineament density map, the number of lineaments in each grid is counted. For the present study, only the grids that contain more than two lineaments are selected. By overlaying the lineament density and lineament intersection map, the common areas are demarcated. Such common areas are overlaid on the alumina fraction map.

4.3 Integrating fraction image, DEM and lineament images

It is seen that a few of the alumina rich areas identified in the density sliced fraction images and in the lineament map are located in steep slopes and low lying areas. Since this study focuses on the hilltops (cappings), an attempt is made to demarcate the alumina rich fractions that are located in the cappings. Accordingly, 26 cappings are identified using the SRTM DEM (Fig. 5d). Similarly, areas that have high incidence and intersection of lineaments are integrated with the alumina fraction image and the DEM-derived cappings image. On integrating all the above information, it is inferred that there are 16 cappings in the study area, which satisfy the conditions favourable for bauxite formation. Visit to these cappings showed that most of them were alumina rich. Five of these were

existing mines, while the remaining could be further explored for their alumina content and the viability to mine the bauxite.
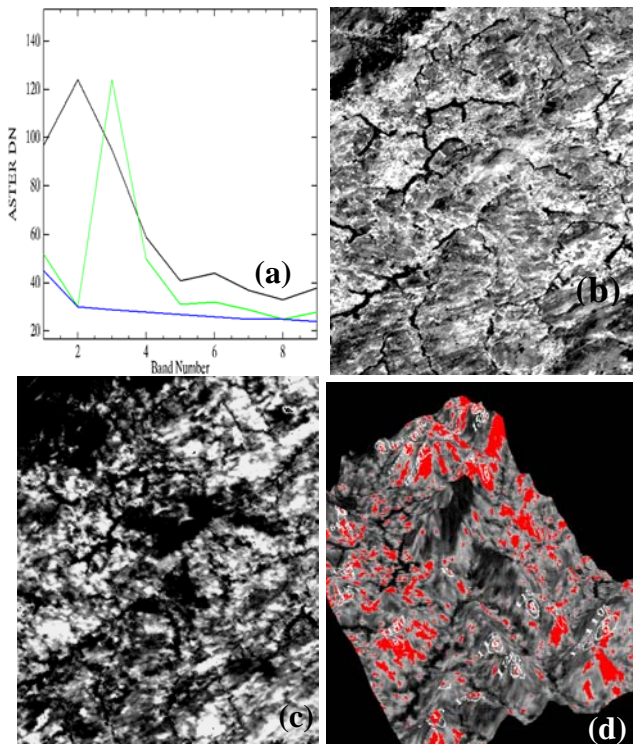

Figure 5. (a) End-member spectra (b) vegetation fraction image; (c) alumina fraction image and (d) density sliced alumina fraction image draped over DEM showing location with 70 - 100% alumina (shown in red) in the peaks.

Based on the results of spectral unmixing, lineament analysis and field visits, the study area in Kolli Hills can be characterised as in Table 1.

Al2O3	Fe2O3%	SiO2%	Site characteristics
14.3	6.35	20.7	Partly weathered charnockite
16.9	13.41	24.4	Partly weathered charnockite
7	22.23	10.2	Ferrugenous laterite
27.3	16.9	25.11	Lithomarge
15.7	12.23	22.74	Partly weathered charnockite
12.69	8.29	37.29	Partly weathered charnockite
11.04	9.93	27.57	Partly weathered charnockite
15.51	3.95	51.31	Partly weathered charnockite
45.8	6.67	3.22	Bauxite
42.1	7.3	4.3	Aluminous Laterite
42.8	10.7	5.98	Aluminous Laterite
28.2	13.1	19.7	Lithomarge
27.9	12.55	17.23	Lithomarge
35.54	25.26	2.06	Ferrugenous laterite

Table 1. Chemical composition and site characteristics of certain parts of the study area.

5. CONCLUSIONS

The paper has attempted to demonstrate the potential of using hyperspectral remote sensing in mineral exploration. The fact that remote sensing will help to acquire an idea about the field before detailed ground exploration has been proved especially in the case of limestone and bauxite exploration in south India. This study was done to understand the possibility of using ASTER SWIR imagery to be used for quantitative and qualitative analysis of mineral habitats. Linear Spectral unmixing which is a sub-pixel level classifier is attempted which gave fairly a good result. Following are the conclusions made from this study:

- Linear spectral unmixing method adopted to quantifythe CaCo3 in Limestone has given a fairly good result.
- The validation of this result with the chemical analysis has shown a coefficient of correlation of 0.758.
- The fraction images thus derived for CaCo3 (Limestone) can be used to give 75.8% predictability regarding the qaulity of limestone.
- The NIR and SWIR bands of ASTER sensor have proven to be a potential source of data for studying the bauxite deposits in the The Kolli Hills of Tamilnadu.

The specific conclusions that may be drawn as a result of this study are: (i) linear spectral unmixing has helped in generation of the alumina abundance image which was used to demarcate bauxite rich zones. (ii) DEM derived from SRTM has helped in identification of additional bauxite cappings in the study area. The validity of these findings have been done by carrying out field investigations and chemical analysis.

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ACKNOWLEDGEMENTS