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Potentials of Spectrometry in Economic Rocks Mapping -A Brief Analysis for Three Economic Rocks of Three Different Geological Provinces of India

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Abstract

In this research article, we have demonstrated how spectrometric properties of diagnostic absorption features of rocks imprinted in their reflectance spectra can be used to delineate economic rocks (limestone, bauxite and gossans) from the adjacent country rocks. Spectral features or absorption features of rocks, discussed in this paper, are identified based on the comparative analysis of spectral feature of diagnostic constituent minerals of these rocks. It has also been observed that the each economic rock can be separated from their respective "background" country rock(s) based on the combination of certain spectrometric properties (wavelength of absorption feature and asymmetry) of their respective diagnostic absorption features imprinted in their reflectance spectra. The study also revealed that the separability of these economic rocks from their respective host rock will be affected if spectral profiles of mixed set up (where economic rocks are linearly mixed with the associated country rocks within the field of view of spectroradiometer) are collected instead of pure rocks. This observation justifies the fact that size of minimum distinguishable unit (i.e., pixel in case of spectral data presented as a image) of spectral measurement should be less than the size of the exposure/target, for effectively separating one pure target i.e., an economic rock from the associated country rocks.

Keywords: Absorption feature; Bauxite; Gossans; Limestone; Reflectance spectra; Spectrometric properties

Introduction

Spectroscopy is the study of light and its interaction with different terrain elements. Reflectance spectroscopy has been successfully used to characterize / identify several pure mineral species based on the diagnostic absorption features imprinted in their respective reflectance spectra [1-5]. Spectroscopy has been used to identify mineralogical composition for serpentine, carbonate, olivine, clay etc. mineral groups [1-4,6]. On the other hand, spectroscopy has been conservatively used to delineate mixture like rocks. This is due to the fact that the spectral features of mixtures are not only guided by the mineralogical composition but also influenced by the optical coupling of different spectral features of its constituent minerals. This is a common phenomenon for mixtures like natural rocks. In mineral exploration, an important step is to spatially map the surface exposures of economic rocks to narrow down the area for detailed geochemical, petrographical studies of the rock. In these respect, reflectance spectroscopy can play significant role and economic rocks can be delineated within the associated country rocks based on their absorption features imprinted in their respective reflectance profiles [7]. Most importantly, reflectance profiles can be collected from any distance from the target as the absorption features are essentially governed by the atomic processes rather than the measurement set-up [6,8]. Therefore, absorption features of reflectance spectra collected from remote / space borne sensors can be used as an important tool for spatial mapping of these rocks. Rock spectroscopy has been used in

recent past for characterizing rocks based on their spectral features [8-14]. In some of these cases, this has been achieved by comparing reflectance profile of a rock with the reflectance profiles of its dominant and characteristic constituent minerals to ascertain the diagnostic spectral features of rock. Quantitative analysis of spectral features has been attempted to delineate different clay minerals [15,16]. In this regard, waveform characterization of spectral profiles are attempted wherein the shape of a spectral feature is described with quantitative parameters [16]. Methods are also available to calculate these quantitative parameters both for laboratory derived and hyperspectral data (collected from the remote platform) derived spectra [15,16]. This has also laid the foundation for further research, in analyzing the spectral profiles of different economic rocks and respective country rocks for delineating these economic rocks from the country rocks based on their respective diagnostic spectral features. Once the diagnostic spectral features of these rocks are ascertained, derivation of spectrometric parameters of diagnostic absorption features for these economic rocks and associated country rocks can be made and these spectrometric parameters can be used for delineating the above mentioned rocks from others.

In present study, attempt has been made to characterize three different economic rocks based on spectrometric properties of absorption features. These economic rocks are limestone, bauxite and gossans. Limestone is predominantly made of up of carbonate minerals whereas bauxite and gossans are composed of aluminum hydroxides and iron oxides/hydroxides respectively. Importantly, minerals like calcite, gibbsite and goethite; which are well characterized by their respective diagnostic absorption features imprinted in their respective reflectance spectra of visible-near infrared-shortwave infrared (VNIR-

SWIR) domain. Therefore, spectral profiles of these rocks are analyzed with reference to the spectral profiles of these dominant/characteristic constituent minerals of the respective rocks to derive their diagnostic spectrometric parameters. Once the spectrometric parameters are derived, these parameters are further used for delineating these economic rocks from the associated country rocks. In addition to above, the study has also attempted to understand the role of relative size of the ground sampling diameter (pixel size) with respect to the size of the pure target in contributing the variability in the spectral separation of different rocks from the adjacent rocks.

Study Area and Geology

There different study areas are chosen for limestone, bauxite and gossans. All these areas are associated with under-production mines. Bauxite deposits of state of Jharkhand, India occur above a height of 900 m and these deposits are intimately associated with deposits like laterites [17]. Bauxite deposits in these areas are the result of chemical weathering process driven extreme residual enrichment [18]. Samples are collected from several places of the study area; which has open cast mines for bauxites. The study area is bounded with latitude 23 0 18' to 230 20' and longitude from 840 15' to 84021'. Bauxites / laterites are formed as the capping over granite-granodiorite/trondhjemite gneiss known as Chotonagpur granite–gneiss [18] (Figure 1a).
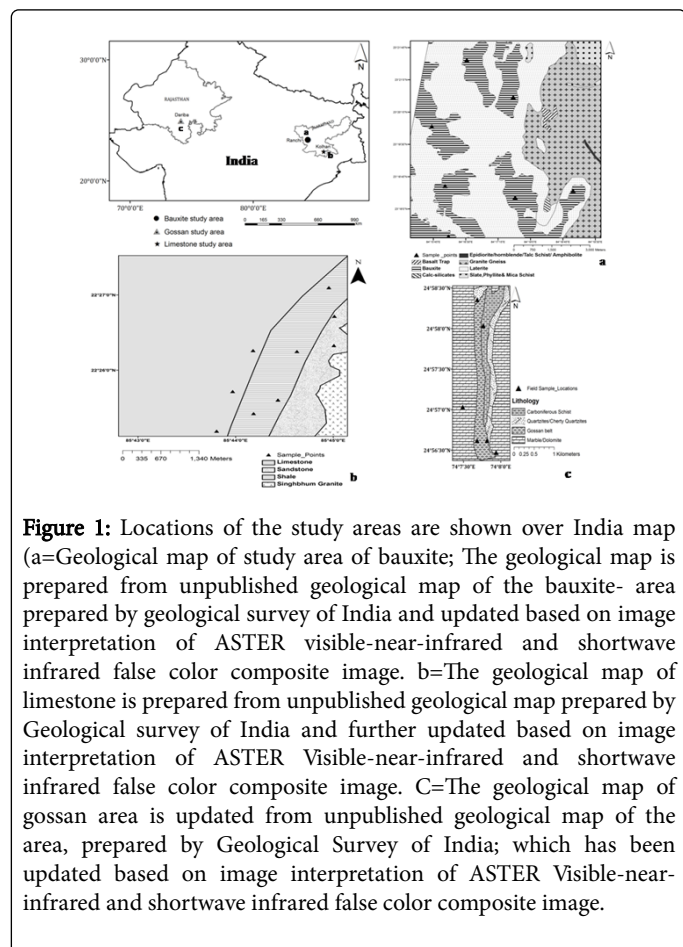

Figure 1: Locations of the study areas are shown over India map (a=Geological map of study area of bauxite; The geological map is prepared from unpublished geological map of the bauxite- area prepared by geological survey of India and updated based on image interpretation of ASTER visible-near-infrared and shortwave infrared false color composite image. b=The geological map of limestone is prepared from unpublished geological map prepared by Geological survey of India and further updated based on image interpretation of ASTER Visible-near-infrared and shortwave infrared false color composite image. C=The geological map of gossan area is updated from unpublished geological map of the area, prepared by Geological Survey of India; which has been updated based on image interpretation of ASTER Visible-near-infrared and shortwave infrared false color composite image.

Gossan rocks are the results of precipitated oxide and hydroxides where surface leaching of sulphides have resulted in removal and consequent segregation of these sulphides underneath the surface,

where redox interface is changed (oxidation zone to reduced Zone). The study area chosen for collecting gossans samples is associated with Pb-Zn deposits and associated with mining lease area of famous Dariba mines and bounded by latitude from 24°56'22" to 24°58'31" and longitude 74°07'21" to 74°08'07". In Dariba, well developed gossans showing different types of box-works containing limonite, goethite, jarosite, jasper, turquoise malachite, azurite, Mn-oxides etc. are exposed [19,20]. Limestone deposits of the study area occur at the eastern part of India and it is part of Jharkhand state. These limestone deposits are being presently mined at different places of study area and bounded by latitude from 22°25' to 22°28' and longitude 85°43' to 85°46'. Limestones are part of Kolhan group of sediment. Kolhan group of sediments are characterized by elliptical outcrop of middle to late proterozoic in age [21]. The limestone deposits of Kolhan sediments occur at S-W part of state of Jharkhand and associated with sandstone, shale, which are the integral part of Kohan sedimentary sequence. The geological map with sample locations for each economic rock is illustrated in Figure 1b.

Methodology

We have collected few samples for each economic rock (10-15 no's) from their respective study areas along with the samples of associated country rocks. Samples are cut into rectangular chips (3" × 5" and 5" × 7") for the purpose of spectral profile collection using spectroradiometer operative within 350-2500 nm wavelength domain. This wavelength range is also known as visible-near infrared-shortwave-infrared (VNIR-SWIR) region. Most of these economic rocks have their diagnostic spectral features within the visible near infrared and short wave infrared (VNIR-SWIR) domain. Details of their absorption features imprinted in their respective reflectance spectra are discussed in results section.

Spectral profiles are collected with a stable set up with phase angle of 250. Phase angle is the angle between fore/measurement optics of spectroradiometer and the illuminator. Argon lamp is used to illuminate the rock. For deriving the reflectance profiles of the rocks, a white lambertian surface is used and this surface is generally known as" white reference" in spectroscopy [22]. The methodology for collecting spectral profiles of rocks is well discussed [8-11]. The same methodology has been followed for collecting spectral profiles. Broadly, measurement optics of the spectroradiometer is fixed with tripod and measurement optics are placed approximately 450 angle with respect to illuminator for collecting the spectral radiance of the rock samples and the reference panel. Spectralon is used as white reference in the present study as it is known for its stable reflectance equals to one across the entire VNIR-SWIR electromagnetic domain. The ratio of spectral radiance of the rock sample to the spectral radiance of the white lambertian surface is used to derive the reflectance [22] and these reflectance values are plotted across wavelength of electromagnetic radiation to record the variability of reflectance across the entire VNIR-SWIR wavelength-region. Spectral profiles thus collected for multiple spots for each sample are averaged to get representative spectra of each sample of each rock type. These spectral profiles have several insignificant kinks imprinted over the reflectance spectra resulted due to poor SNR (signal to noise ratio) of the spectroradiometer specifically at the 2000-2400 nm wavelength region. This is due to the poor albedo of natural surfaces like rocks within this wavelength range. These kinks are removed by using suitable averaging filters. The details of spectral data collection for these rocks are already discussed [8,9]. Spectrometric parameters of

the diagnostic absorption features of rocks are collected using DISPEC 3.2(c) tool developed by ITC (Faculty of Geoinformation science and earth observation, University of Twente, The Netherlands). The mathematical basis for deriving the spectrometric parameters of each diagnostic feature is also well discussed [23-25]. Spectrometric parameters are derived to characterize the geometry (depth, width, symmetry) and wavelength of absorption of diagnostic absorption feature. The schematic diagram of spectrometric parameters of an absorption feature is given in Figure 2. In the figure, W is width of absorption feature, d is the depth of the absorption feature, λ is the wavelength of absorption. Asymmetry (A) is another important spectrometric parameter; which is calculated based on the area of the absorption feature on either side of the wavelength of maximum depth in the absorption feature. If the feature has the larger area at the left side of absorption minima then it is negatively skewed and therefore would have the negative value for asymmetry. The asymmetry or symmetry factor of the spectral feature ranges from –1.0 to 1.0, and asymmetry would be 0 for a symmetric absorption feature. The mathematical expression for calculating aforesaid spectrometric parameters are well discussed in literature [24]. In the present study, diagnostic spectral features of each economic rocks are derived based on the comparison of the spectral profiles of these rocks with spectral profiles of the characteristic constituent minerals of these rocks. Once the diagnostic spectral features of these rocks are identified, the spectrometric parameters of two prominent diagnostic features are derived. The selections of the prominent diagnostic features are based on the width, depth of the absorption features, provided these features also indicative of diagnostic absorption feature of the characteristic minerals in the rock. For e.g., diagnostic spectral feature of the bauxite is characterized by the absorption feature of gibbsite and it also has appreciable depth and width; which can be easily identified in the reflectance spectra.

Figure 2: Schematic diagram showing different spectrometric parameters of a spectral feature. λ is the wavelength of a absorption of a spectral/absorption feature, w is the width of the absorption feature, S is the shoulder of the absorption feature, Aleft and Aright are the areas to the left and the right of the wavelength of maximum absorption of spectral feature generally used for calculating the symmetry factor or asymmetry(A).

Results

In the present study, we have collected spectral profiles of gossan, limestone and bauxite samples. Representative spectral profiles of these rocks are illustrated in Figure 3 with the spectral profiles of associated

country rocks. It has been observed that a particular rock type has same/similar spectral profiles; characterized by same/similar diagnostic spectral features of its characteristic constituent minerals. Therefore, representative spectral profiles of each economic rocks are illustrated with its characteristic constituent minerals. Spectral profiles of bauxite, gossans and limestones are plotted and compared with the USGS mineral spectra of gibbsite, goethite and calcite; which respectively are the main constituent minerals of these rocks (Figure 4).
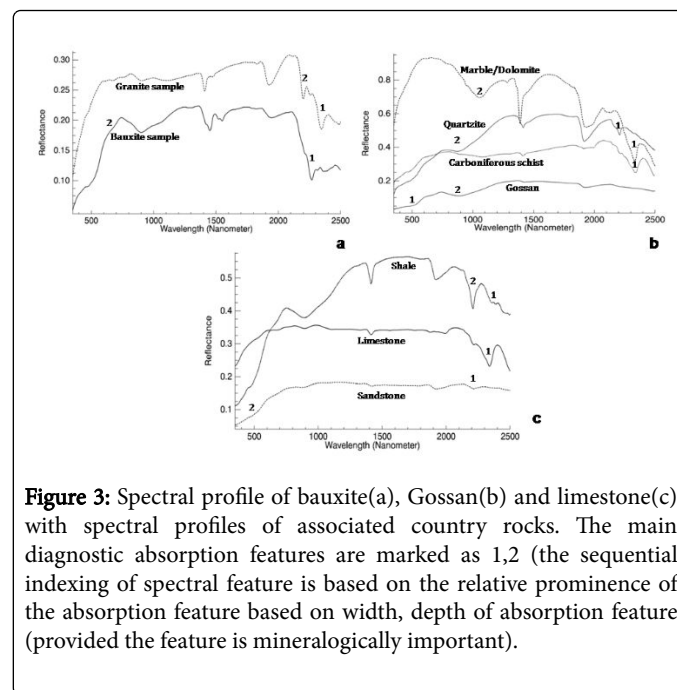

Figure 3: Spectral profile of bauxite(a), Gossan(b) and limestone(c) with spectral profiles of associated country rocks. The main diagnostic absorption features are marked as 1,2 (the sequential indexing of spectral feature is based on the relative prominence of the absorption feature based on width, depth of absorption feature (provided the feature is mineralogically important).
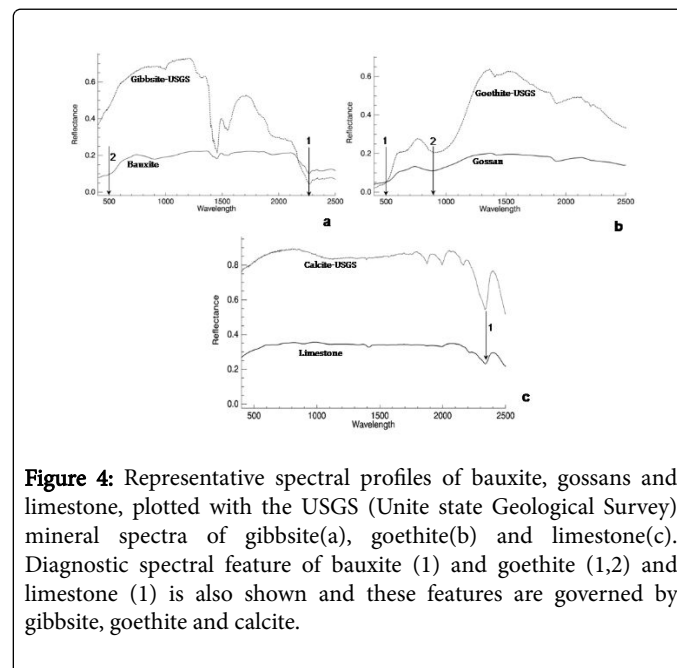

Figure 4: Representative spectral profiles of bauxite, gossans and limestone, plotted with the USGS (Unite state Geological Survey) mineral spectra of gibbsite(a), goethite(b) and limestone(c). Diagnostic spectral feature of bauxite (1) and goethite (1,2) and limestone (1) is also shown and these features are governed by gibbsite, goethite and calcite.
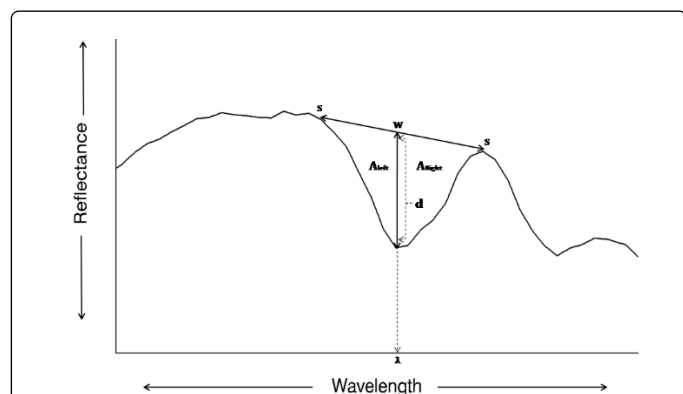
It has been observed that limestone has diagnostic spectral features in conformity main constituent mineral (for limestone it is calcite) and same is the case for bauxite and gibbsite. Specifically, the diagnostic
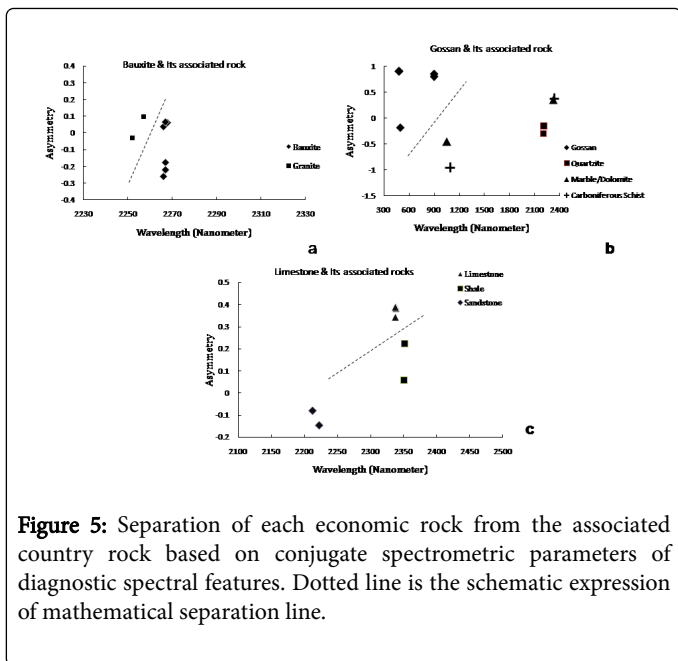
spectral feature of bauxite (marked as feature -1) matches well with the spectral feature of gibbsite in terms of wavelength of absorption. This feature (2268 nm) is resulted due to vibration of Al-OH bond of gibbsite. On the other hand, Gossan has two absorption features one is at around 484 nm and other one is around 899 nm. The spectral absorption at 484 nm is due to electronic transition in iron mineral whereas absorption feature at 899 nm is due to crystal field effects resulted from the movement of electron from one orbital to other [6] (Figure 4 and Table 1). Calcite has several vibrational bonds (overtones, combination) in shortwave infrared domain and diagnostic spectral feature of limestone (2338 nm) is resulted due to vibrational feature of calcite [3]. Limestone preserves the diagnostic spectral feature of limestone. The details of the spectrometric properties of the diagnostic feature of these rocks are illustrated in Table 1.

These spectrometric parameters of the absorption features of limestone, gossans and bauxites are plotted in asymmetry v/s wavelength data space, to understand the separability of these rocks from their respective associated country rocks based on spectrometric parameters of diagno-absorption features. It has been observed that each rock can be delineated from associated country rocks based on conjugate use of two spectrometric parameters (wavelength of absorption and asymmetry of absorption; Figure 5). In these cases, spectrometric parameters of the diagnostic absorption features of each respective economic rock-country rock(s) pair are compared. The diagnostic absorption feat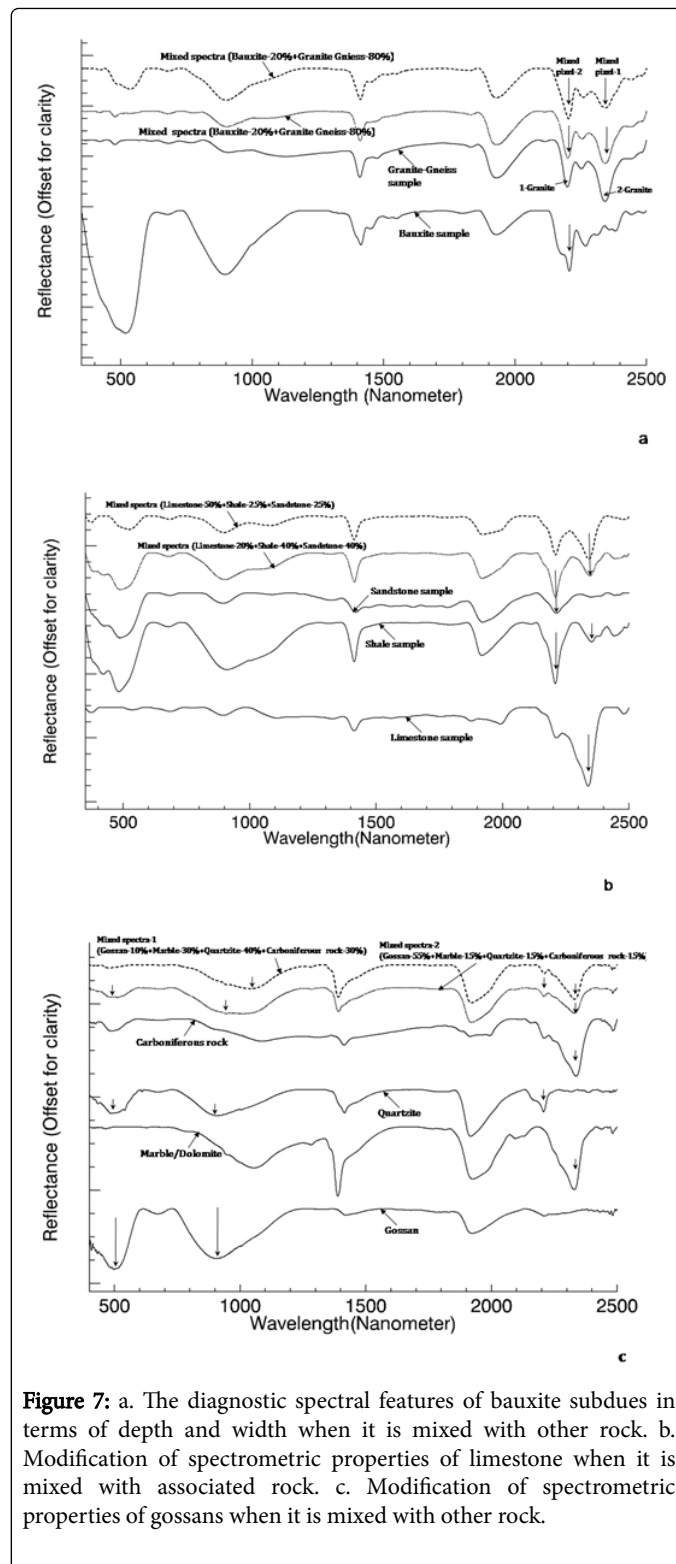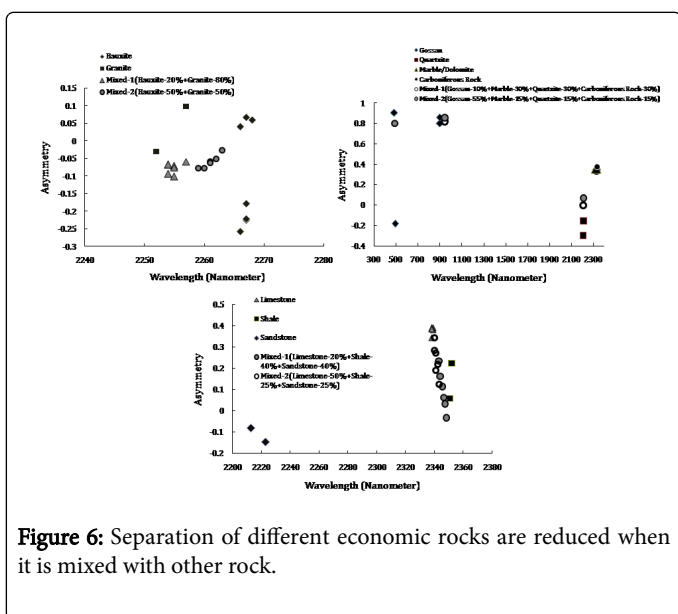ure-pair; which is close to each other in terms wavelength of absorption are only plotted in spectrometric data space for comparison. The granite-granodiorite-tronjhemite gneiss [19] associated with bauxite is characterized with the spectral feature at 2198 nm and 2346 nm. Amongst these parameters, 2198 nm absorption feature is closer in terms of wavelength of absorption of diagnostic spectral feature of bauxite; which is at 2268 nm (Figure 3 and Table 1). Therefore, spectrometric parameters of these absorption features are used for delineating bauxite from its associated country rock. Similarly, for limestone and its associated country rocks; sandstone associated with limestone has an absorption feature closer at 2213 nm; which is proximal to the diagnostic absorption feature of limestone and shale has two absorption features; out of which absorption feature at 2352 nm is closest to diagnostic spectral feature of limestone. These features are used to clarify whether limestone can be delineated from associated country rocks based on spectrometric parameters of diagnostic absorption feature (Figure 3 and Table 1). Gossan has spectral feature quite distinct from the diagnostic spectral features of its associated rock types. However, secondary absorption features of quartzite (at 923 nm), marble/dolomite (at 1053 nm) and carbonaceous schist (1097 nm) are closer in terms of wavelength to the diagnostic spectral feature of gossans at 899 nm (Table 1). Therefore, spectrometric parameters of these spectral features are derived for separating gossans from its country rocks. However; most prominent absorption feature of gossans is well separable from the associated country rocks based on wavelength of absorption.

Ranchi bauxite and its associated rock (Jharkhand, India)

Rock types	Bauxite		Granite	
Spectral Parameters	Feature-1	Feature-2	Feature-1	Feature-2
Wavelength	2268	896	2346	2198
Width	67	205	53	42
Depth	0.13988289	0.25333046	0.088957306	0.19807918

Dariba Gossan and its associated rock (Rajastan, India)

Rock types	Gossan		Quartzite		Marble/Dolomite		Carboniferous rock	
Spectral Parameters	Feature-1	Feature-2	Feature-1	Feature-2	Feature-1	Feature-2	Feature-1	Feature-2
Wavelength	899	484	2214	923	2328	1053	2336	1097
Width	105	49	52	102	91	186	91	133
Depth	0.26693	0.3143	0.2046	0.0952	0.336	0.2204502	0.30661	0.11805

Kolhan Limestone and its associated rock (Jharkhand, India)

Rock types	Limestone		Sandstone		Shale	
Spectral Parameters	Feature-1	Feature-2	Feature-1	Feature-2	Feature-1	Feature-2
Wavelength	2338	--	2213	--	2352	2208
Width	121	--	74	--	53	44
Depth	0.44831198	--	0.06334444	--	0.059226085	0.18987409

Table 1: Spectral Parameters for major economic rocks and their associated country rocks of Indian craton.

Figure 5: Separation of each economic rock from the associated country rock based on conjugate spectrometric parameters of diagnostic spectral features. Dotted line is the schematic expression of mathematical separation line.

In addition to above, an attempt is made to study the spectrometric properties of mixed rock (when target rocks are mixed with the associated country rock; within the foot print of spectroradiometer). Ground sampling diameter or foot print of spectroradiometer is often quite larger than the usual size of the exposures of rocks like bauxite, limestone and gossans; which have usually small exposures as these rocks are easily weathered under tropical weathering set up like India. Therefore, understanding of spectral response of mixed rock is important; as the spectral data collected from remote platform of satellite or helicopter, often provide good volume of spectral data. As the ground sampling diameter or unit of spectral data collection of remote spectral sensors is often larger than the size of exposures of each pure rock, therefore; the spectral profiles of mixed target or rock rather than the pure units are collected from remote observation.

Figure 6: Separation of different economic rocks are reduced when it is mixed with other rock.

Figure 7: a. The diagnostic spectral features of bauxite subdues in terms of depth and width when it is mixed with other rock. b. Modification of spectrometric properties of limestone when it is mixed with associated rock. c. Modification of spectrometric properties of gossans when it is mixed with other rock.

In the effort to understand the implication of mixing in influencing spectral separation of one economic rock from the associated country rock, we have mixed spectral profiles of economic rocks with the spectral profiles of associated rocks. It has been observed that the mixed rock (target+back ground rock) are not separable distinctly from the associated country rocks based on spectrometric parameters

of diagnostic spectral features of each economic rock as it was the case for pure rocks (Figure 6). It is also observed that wavelengths of absorption of pure rock are laterally shifted. Also, the wavelength axis and depth, width of diagnostic absorption features are modified when we derive spectral feature of mixed rock by using linear equation. These linear equations are derived based on the spectral profile of each economic rock with spectral profile of the associated country rock with different relative weights as input (Figure 7a-7c). It is interesting to note that such mixed spectra of bauxite, limestone or gossans inherite the spectral characteristics of the country rocks. This sensitivity increases as we increase the relative weight or the fraction of the target rock spectra in the linear equation to simulate the response of mixed spectra as the footprint of the radiometer becomes larger than the size of the target rock (Figure 7a-7c).

Discussion and Conclusion

A means for separating these rocks from the associated rocks. Therefore, the spatial mappings of these rocks are possible if spectral data is collected along two dimensions for the part of the earth surface. Remote earth observation sensors collect spectral data with high spectral resolution and this data can be presented and processed as an image. Derivations of spectrometric parameters are also possible from these data and therefore space borne spectral or hyperspectral data can also be used for separating one rock from the other. However, the separability of economic rock would be difficult based on spectral features (i.e., Derivation of spectrometric parameters of diagnostic absorption features of economic rocks provide conjugate use of spectrometric parameters of absorption feature) if size of the minimum area of spectral measurement or pixel size of spectral measurement is larger than the exposure size of the economic rock. Therefore, either we require spectral measurement with high spatial resolution for mapping as many as pure target is possible we may have to utilize sub pixel mapping algorithm to map an economic rock from the mixed target or.

To conclude, it can be said that collection of reflectance spectral data of appreciable resolution via remote sensing sensors, will enable targeting economic rocks deposits by the virtue of their spectrometric parameters. As remote hyperspectral sensor collect reflectance spectra of different rocks in spatial domain and display spectral information in terms of image; hence, these spectral images can be processed to derive wavelength of absorption and asymmetry for each pixel of the image. These parameters therefore can be conjugately used to isolate economic target from background.

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