Detection of minerals using spectrometric measurements

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Abstract

Spectrometric measurements as a part of remote sensing are used for different practical investigations. The objective of the present paper is to check the possibility of the spectrometric measurements for detection of minerals. In the present investigations laboratory spectral reflectance measurements of the iron-containing minerals in the visible and near infrared (VNIR) range of the electromagnetic spectrum are performed. For the interpretation of the obtained spectrometric data and establishing of the dependence between the content of the iron in the minerals and the reflectance value spectral transformations are used. In brief, spectrometric measurements when properly used are a helpful technique for detection of the minerals.

Спектрометрични измервания за определяне на минерали

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Резюме

Спектрометричните измервания, като част от дистанционните изследвания, се използват за различни проучвания с практическо приложение. Целта на настоящата работа е да се провери възможността на спектрометричните измервания за разпознаване на минерали, респективно полезни изкопаеми. В рамките на настоящото изследване са проведени лабораторни спектрометрични измервания на минералите, съдържащи желязо, във видимата и близката инфрачервена (VNIR) област от електромагнитния спектър. За тълкуването на получените спектрометрични данни и за установяването на зависимостите между съдържанието на желязо в изучаваните минерали и отражателната способност се използват спектрални преобразувания. Обобщено, спектрометричните измервания, когато се използват правилно, са полезен начин за разпознаване на минерали.

Introduction

In the 1960's laboratory study conducted mainly by Graham Hunt and John Salisbury (Hunt and Salisbury, 1970) made the pioneering laboratory reflectance measurements of reflectance variations from mineral and rocks. Their research at the Air Force Cambridge Laboratory demonstrated the potential for remote detection of important rock elements and specific minerals. They published their laboratory spectral measurements in Modern Geology. Most of their laboratory spectra were measured under controlled conditions using dry, powdered samples of relatively pure mineral substances from a wide variety of localities which are described. Their work is in the basis of the development of spectral libraries by the U. S. Geological Survey (USGS) and the Jet Propulsion Laboratory (JPL) of the California Institute of technology (CIT).

In the 1960's and 1970's study with laboratory spectrometers determined that minerals associated with mineral deposits have discrete spectral signatures that should allow their detection and mapping in the field. Research in the 1970's found that clays and iron oxides, associated with mineralized systems, could be detected in multiband image data and mapped using their broad spectral signatures. Beginning in the 1980's, study with prototype airborne imaging spectrometer data and ground-based spectrometers recognized groups

of alteration minerals that are main indicators of mineralized systems. Recent airborne and satellite systems have confirmed that detailed mineral mapping is possible from aerospace measurements, as verified by ground-based spectrometric measurements. These spectral measurements provide evidence for the mineral assemblages. Iron oxide and iron sulfate minerals (hematite, goethite and jarosite respectively) were found associated with alteration zones. There are now several reference spectral libraries and airborne/spaceborne case histories available that illustrate the unique spectral character of these unique mineral spectra and our ability to recognize and map them from imagery. The developed technology and methods are used in a variety of related areas such as mineral exploration, detection of minerals, and the assessment of the effectiveness of mined-land reclamation.

The physics of visible/near-infrared /VNIR/ spectrometric measurements are well known (Мишев, 1981; Мишев и др., 1987; Clark et al., 1999). Main spectral features in these regions allow detection of a variety of materials using laboratory and field spectrometric measurements, including minerals, vegetation, man-made materials, snow and ice, and water (Clark et al., 1999, 2003, 2007). In geology, electronic processes at wavelengths less ~1.0 micrometers allow identification of minerals containing Fe^{+3}, while molecular vibrational features at wavelengths between ~1.0 and 2.5 micrometers are diagnostic of minerals containing anion groups such as Al-OH, Mg-OH, Fe-OH, Si-OH, CO_3, NH_4, and SO_4. Small differences in absorption band position and shape can be correlated with mineral compositional differences and variability (Clark et al., 1999).

Field and laboratory spectrometric measurements have a critical role in the calibration, analysis, and validation of imaging spectrometer data. Imaging spectrometer datasets have been acquired around the world using airborne platforms and recent satellite systems provide spectral measurements for selected areas. A lot of examples demonstrate the relationship between laboratory, field, and imaging spectrometer data.

Materials and methods

Field and laboratory spectrometric measurements supply several purposes in the context of spectrometric data acquisition and analysis: 1) providing critical information for calibration of data and atmospheric removal, 2) acting as a source of library spectra for comparison to analysis results and identification of materials, and 3) assisting with validation of mapping results.

Atmospheric correction is a requirement for most non-imaging and imaging spectrometer analysis applications. Early efforts at removal of atmospheric effects were empirical in nature, limited by the availability of adequate atmospheric models and correction software. More recently, well-calibrated spectrometric data and the availability of software have produced excellent reflectance data without specifically requiring the use of ground spectral measurements (Kruse, 2004). These use water-vapor features near 0.9 and 1.1 micrometers to estimate water vapor on a pixel-by-pixel basis. The water vapor estimates are used along with data characteristics (band centers, full-width-half-max /FWHM/ response) and acquisition parameters (ground elevation, flight altitude, site latitude/longitude, date and time) with an atmospheric model to produce a per-pixel reflectance corrected dataset. Field spectra measured for targets occurring in the data still result in improvements, however, when used to refine the atmospheric correction.

Spectral libraries provide the reference against which imaging spectrometer data are compared to determine surface composition. There are a variety of spectral libraries available for earth-surface materials (Salisbury et al. 1991; Grove et al., 1992; Clark et al., 2003, 2007; Baldridge et al., 2009). These are principally used for identification of mineralogy, but also include some spectra of man-made materials, vegetation, snow-ice, and water. There is still great need for development of more detailed spectral libraries that include these materials and specifically spectral variability.

Field and laboratory spectra are most usually used to confirm imager mapping results. A main factor is that the field instrumentation must have at least the same spectral resolution or better than the airborne/satellite data. Confirmation of imaging spectrometer results is very difficult to characterize a surface in terms of the remote sensing picture element or pixel. Field spectrometers typically measure very small areas, therefore, field

measurements are made of all of the land surface components and these are compared to what usually amounts to a mixed spectral data from the imager. It isn't possible to validate every pixel in an image dataset – in-situ measurements are usually made of key materials in key locations and specific methods for data analysis are applied.

In the presented work we focused our attention on iron-containing minerals because the iron-containing minerals are a special case for remote sensing and they are widespread. Ground-based laboratory spectrometric reflectance measurements in the $(0.55-1.1)\mu m$ range of the electromagnetic spectrum are performed over minerals hematite, goethite and siderite. In these experiments it was used spectrometric system for remote sensing SPS-1 designed and constructed in the Remote Sensing Systems Department at Space Research and Technology Institute – Bulgarian Academy of Sciences (Илиев, 2000).

Methods for the comparative analysis and for the quantitative interpretation of the spectral data are applied. For the comparative analysis reflectance spectra from laboratory spectrometric measurements are compared to libraries' ones in one and the same range. The obtained in experiments spectral reflectance data are compared to reflectance spectra data from Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). For the quantitative data interpretation spectral indices are selected (Jackson, 1983; Elvidge and Lyon, 1985).

AVIRIS became operational in 1987. This system was flown in an Earth Resources U-2 high altitude aircraft, permitting coverage of large areas throughout the United States and, later around the World. AVIRIS measures near-laboratory-quality spectra in 224 9.2 nm-wide channels in the spectral range $(0.41-2.45)\mu m$, with 10 to 20 meter ground instantaneous field of views, over about a 10 to 20-kilometer ground swath (Porter and Enmark, 1987). Later in the 1990's AVIRIS was alternatively mounted in a Twin Otter aircraft to acquire higher spatial resolution data. Development and flight of this spectral system was paralleled by the development of portable ground-based spectrometers for verification of the spectral signatures of cover types. The Spectral Image Processing System (SIPS) (Kruse et al., 1993b) was used to preview the AVIRIS radiance images and to extract image radiance spectra for calibration. The data were calibrated to apparent reflectance using ground targets and the empirical line method (Roberts et al, 1985; Kruse et al., 1993a). Once the data were calibrated to reflectance, interactive analysis using SIPS was used to determine the principal minerals at the surface. Extraction of average spectra from areas with spectral character allowed comparison to library spectra of specific minerals for detection. Laboratory spectra for calcite, dolomite, illite (sericite), hematite, and goethite were used as references for the classification. The $(2.0-2.4)\mu m$ region was selectively used for the carbonates and sericite, while the $(0.4-1.0)\mu m$ range was used for the iron oxide minerals. These regions were chosen for encoding because of observed diagnostic spectral characteristics limited to these wavelength ranges of the spectrum. Selected examples comparing Fe Oxide spectra from the AVIRIS data to those in the spectral library are shown in Figure 1. Analysis results for these data have been published in Kruse et al., 1993a.
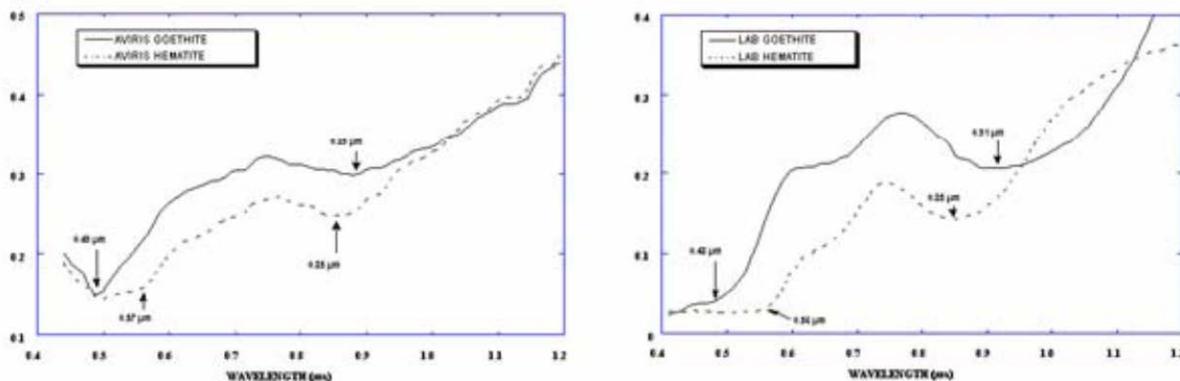

Figure 1 AVIRIS spectra for hematite and goethite compared to laboratory spectra

Different spectral indices from multispectral remotely sensed data have been proposed and widely used in various applications. The most basic assumption is that some algebraic combination of remotely sensed spectral bands can tell us something useful about composition and quantitative chemical elements' content of the minerals. Other factors, such as solar irradiance, atmospheric conditions, and sensor viewing geometry also affect the spectral

reflectance. A good index should be very sensitive to these different factors. Therefore, to find the ideal spectral index, one must determine those factors that affect indices on the basis of a physical understanding of the interactions between electromagnetic radiation, the atmosphere, and the studied surface (Чимитдоржиев и Ефременко, 1998).

Results and discussion

In Figures 2 spectral reflectance graphics of the iron-containing minerals goethite, hematite and siderite are presented and compared to AVIRIS spectra. The iron absorption at $(0.8-1.0)\mu m$ range is reduced in depth according to it content in the different minerals. The $0.9\mu m$-absorption line shifts position with elements substituted for the iron.
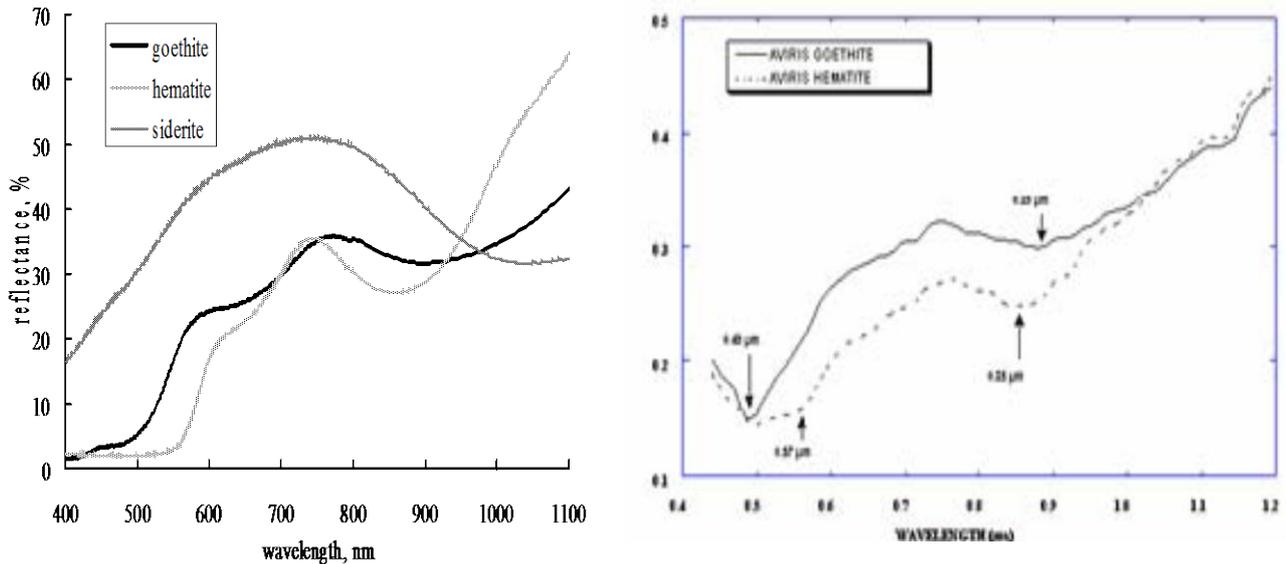

Figure 2 SPS-1 laboratory spectra for goethite, hematite and siderite and compared to AVIRIS spectra

In Table 1 relationships between the content of the iron (Fe) and the spectral contrast indices (SCI) are presented. The indices values decrease as the content of the iron increases and this demonstrate correlation between the absorption depth in the $(0.8-1.0)\mu m$ range and the iron content. Therefore, this dependence could be used for detection of different iron-containing minerals.

Table 1 Relationships between content of the iron (Fe) and spectral contrast indices (SCI)

Fe, %	$SCI1 = r(\lambda = 750nm)/r(\lambda = 800nm)$	$SCI2 = r(\lambda = 750nm)/r(\lambda = 900nm)$
Hematite – 70%	1,11535	1,07576
Goethite – 90%	1,10929	0,98763

As discussed above there are many iron-containing minerals with similar but distinct absorption bands. How many different iron-containing minerals could be detected using spectrometric measurements is the question which requires a lot of data as a result of the combined experiments.

Conclusions

The determining process of detecting the iron concentration was based on the remote sensing spectral analytical techniques discussed in the sub-sections. Iron shows typical absorption and reflection features in the VNIR bands. Based on the contrasting characteristic in different band passes spectral analysis had been performed to capture the best possible signature that would show similar characteristics respective of hematite and goethite. Detailed spectral analysis including other methods such as continuum removal to isolate absorption features can certainly improve the success of distinguishing the iron-containing minerals.

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