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Estimation of Abundances in Two-Component Mineral Mixtures Using Mid-Infrared Laser Reflectance Ratios

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Abstract— The mid-infrared spectral region (8-14 μm wavelength) is emerging as a viable geologic remote sensing tool due to the presence of reststrahlen bands for minerals such as silicates and carbonates. An experimental study was carried out to characterize the mid-infrared laser reflectance of mineral mixtures, and to explore the potential of laser remote sensing systems to estimate mineral abundances in two-component mixtures. An empirical model was developed to establish a relationship between laser reflectance ratios at judiciously selected wavelengths and percentage of one of the minerals in the mixture. It was found that the abundances can be estimated to within2% using this technique. This method shows promise for remote estimation of mineral abundances in applications such as planetary remote sensing since the use of reflectance ratios obviates the need for absolute calibration.

INTRODUCTION

Laser reflectance sensors operating in the backscatter mode are ideally suited for remote sensing applications over conventional spectroradiometers due to their higher signal-to-noise ratios and ease of data acquisition. Although pure and uncontaminated minerals possess unique reflectance features, rocks usually occur as mixtures containing two or more constituents in their natural environment. There is a need, therefore, to develop techniques not only to identify specific minerals, but also to estimate their relative abundances in mineral mixtures. A recent study was performed using passive reflectance values of various mineral mixtures [1]. The objective of our study was to explore the potential of laser remote sensing for remote estimation of mineral abundances in mixtures, and to compare our results with the passive measurements.

In this paper, we describe the University of Nebraska's unique mid-infrared laser reflectance sensor that has been used both in the laboratory and the field for data collection from a variety of surfaces. This sensor was used to collect calibrated reflectance data in the laboratory from two-component mineral mixtures (quartz/albite, quartz/microcline, quartz/hornblende) under various relative abundances, including each mineral by itself. We also develop a simple empirical model based on the relationship between laser reflectance ratios at judiciously selected wavelengths and percentage of one of the minerals in the mixture.

EXPERIMENTAL SETUP

The laser reflectance sensor used in the experiments is described in detail in [2], and its block diagram is shown in Fig. 1. It consists of a line-tunable laser that operates in the 9-11 μm wavelength range with an output power of about 5 W. The receiver consists of a lens-detector combination, followed by a matched preamplifier and a lock-in amplifier. Both co-polarized as well as cross-polarized backscattered energy can be measured. The entire optical system is packaged in a box of approximate dimensions 104 cm x 38 cm x 22 cm.

Reflectance measurements were made at 12 wavelengths as indicated in Table I. Incidence angles used were 0 and 30 degrees. Both co-polarized and cross-polarized backscatter measurements were made. The mineral samples used were quartz, albite, hornblende, and microcline. These samples were the same as those investigated in [1]. The samples were powdered and prepared as far as possible to conform to that in [1]. The particle sizes were in the range 75-250 μm range, in order to ensure that the powder reflectance closely mimicked that of the naturally rough rock surface. Two-component mineral mixtures were formed using quartz as one constituent in all of them. Component percentages (by volume) investigated were 0/100, 25/75, 50/50, 75/25, and 100/0. The samples were placed in a 15-cm diameter Petri dish. Speckle averaging was performed by averaging 50 measurements of the reflectivity as the mineral sample was rotated during the measurement. Calibration was accomplished using a Labsphere Reflectance Standard of 94% reflectivity.

EMPIRICAL MODEL

The model assumes that the reflectance ratio, i.e., the ratio of the mineral-mixture reflectances at any two wavelengths is a volume-weighted function of its constituents. The functional form of the first-order model is given by

$$R_{12} = \frac{\rho(\lambda_1)}{\rho(\lambda_2)} = A_0 + A_1 x \qquad (1)$$

where R_{12} is the reflectance ratio, $\rho(\lambda_i)$ is the reflectance at wavelength λ_i, x is the percentage of mineral 1, and A_0 and A_1 are empirically derived constants. For the second-order model, we add a quadratic term whose coefficient is A_2. This model is

$$R_{12} = \frac{\rho(\lambda_1)}{\rho(\lambda_2)} = A_0 + A_1 x + A_2 x^2 \qquad (2)$$

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The constants $A_0 - A_2$ are obtained by best-fits to measured data. The choice of wavelengths λ_1 and λ_2 is crucial in obtaining optimal fits to data. Ideally, the wavelengths must be chosen so as to provide a large slope between the reflectance ratio and the mineral abundance.

RESULTS AND DISCUSSION

From the large data set acquired, it was determined that the relationship between mineral abundances and reflectance ratios at judiciously selected wavelengths could be fitted by both the first-order and the second-order models described above. As expected, the second-order model fit had lower RMS error. Furthermore, it was determined that ratios derived from the co-polarized reflectance values at 30 degree incidence angle gave the minimum errors.

The spectral characteristics of quartz-microcline mixtures is shown in Fig. 2. Since 100% quartz has a peak near 9.283 μm where microcline has a trough, and 100% microcline has a peak near 10.319 μm where quartz has a trough, it was conjectured that this ratio would be useful in estimating the abundance of microcline in a qaurtz-microcline mixture. Fig. 3 shows the relationship between the reflectance ratio and microcline abundance and compares the data with the model fits. As expected, the second-order fit is seen to be better. It was observed that the error between the fit and the data was 0.95% for the first-order and 0.23% for the second-order fits.

Similar results were obtained for quartz/albite and quartz/ hornblende mixtures, and these results are shown in Table II.

CONCLUSIONS

Our study indicates that laser reflectance ratios in the mid-infrared can be used as a tool for remote estimation of mineral abundances in two-component mixtures. This shows its potential in planetary remote sensing applications wherein absolute calibration is not feasible. More work is needed to characterize other mineral mixtures, and also multi-component mixtures.

ACKNOWLEDGMENT

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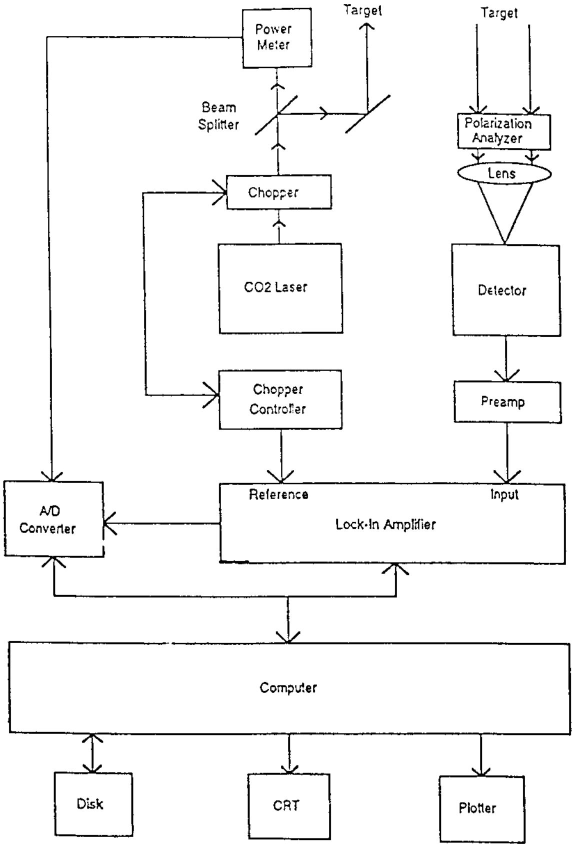

Figure 1: Block diagram of the mid-infrared laser reflectance sensor

TABLE I

WAVELENGTHS USED(μm)
9.2010
9.2500
9.2825
9.5195
9.5690
9.6395
10.1825
10.2470
10.3190
10.4945
10.5915
10.6325

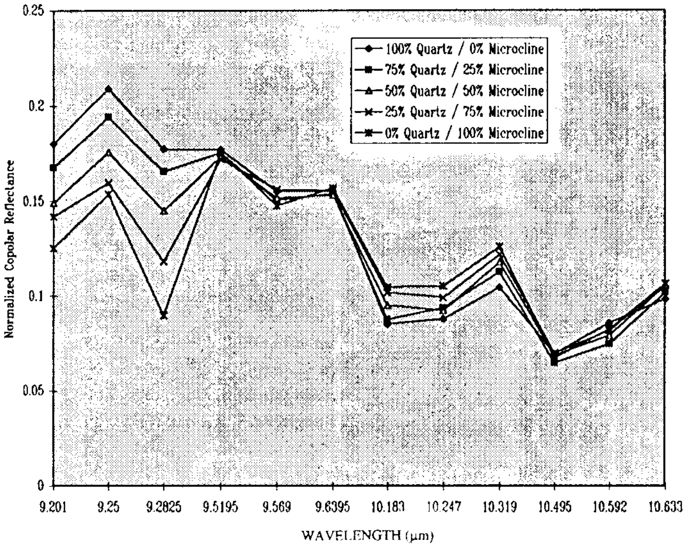

Figure 2: Laser reflectance characteristics of quartz/microcline mixture at various abundances

TABLE II

RMS ERRORS IN ABUNDANCE ESTIMATION

MIXTURE	WAVELENGTH RATIO	ORDER	RMS ERROR
QUARTZ/ MICROCLINE	9.2825/10.319	FIRST	0.95%
		SECOND	0.23%
QUARTZ/ ALBITE	9.2825/10.495	FIRST	2.58%
		SECOND	0.95%
QUARTZ/ HORNBLENDE	9.2825/10.183	FIRST	2.44%
		SECOND	1.84%

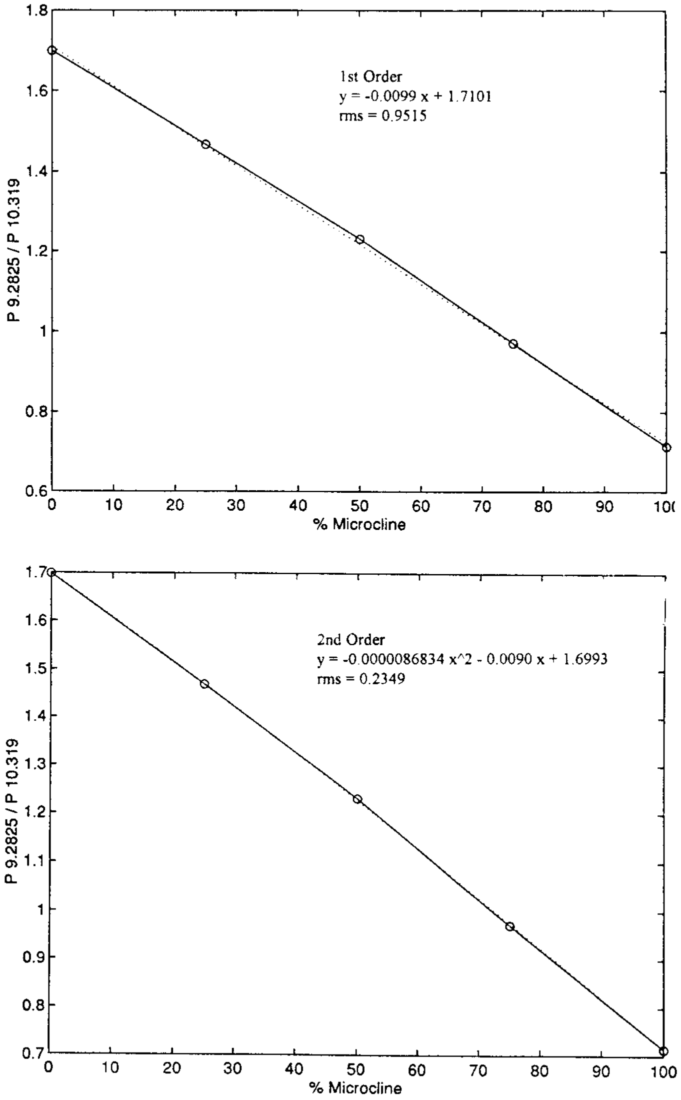

Figure 3: First and second order model fits to measured reflectance ratios for quartz/microcline mixture