

DEVELOPMENT OF A MICROSCOPIC THERMAL EMISSION SPECTROMETER: ANALYSIS OF PRIMARY IGNEOUS MATERIALS FOR PLANETARY ANALOGS. C. S. Edwards¹ and P. R. Christensen¹,
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Motivation:

Conventional spectroscopic techniques for geologic materials commonly rely on measurements that have a larger spatial resolution than the mineral phases present in the sample. Vibrational spectroscopy is commonly utilized to determine mineralogical properties of observed materials in the laboratory and on planetary bodies. Vibrational spectroscopy is based on the principle that energy is emitted at specific frequencies related to the vibrational motions of the material's crystal lattice, which is directly related to the structure and elemental composition of the material [e.g. 1, 2].

A key strength of thermal infrared spectroscopy is the fact that the spectra of mixtures of geologic materials are a linear combination of the individual components [e.g. 3, 4-6] because little of the emitted energy is subsequently transmitted through other mineral grains due to very high absorption coefficients. The modeled mineral abundances for bulk measurements [e.g. 4, 5] have been shown to be approximately accurate (5-10%) to the areal abundances of the major individual mineral phases in the sample.

Spectral unmixing techniques have also been applied to planetary datasets including Thermal Emission Spectrometer (TES) and the Miniature Thermal Emission Spectrometer (Mini-TES) in a variety of studies, where the bulk mineralogy of Mars has been quantitatively characterized [e.g. 7] and the compositions of unique locations on the planet have been assessed in detail [e.g. 8-11]. These hundreds of meters to kilometer scale planetary data are then related to well characterized laboratory minerals and analog samples to interpret geologic processes on the surface of Mars. However, several difficulties exist when using these large-scale data to characterize mineralogy quantitatively, including the presence of many accessory minerals below individual detection limits, grain size effects, porosity, cements (e.g. salts and carbonates), coatings (e.g. silica [e.g. 12], clay minerals), and the weathering style of the grains (e.g. resistant or friable).

Instrument Description:

In order to assess these issues, it is necessary to examine a variety of natural planetary analog samples at the scales of individual grains where the petrology of the observed material can be directly assessed. In pursuit of this, we have developed a micro-emission thermal infrared Fourier transform spectrometer (μ FTS) with a DLATGS pyroelectric detector, a $\sim 85\text{-}90\mu\text{m}$ analysis spot size, and spectral range of $2000\text{-}200\text{cm}^{-1}$

at $2\text{-}16\text{cm}^{-1}$ sampling. This instrument uses a sample cup for natural rock and mineral samples that requires little to no preparation other than sizing the material for analysis with a set of black body calibration targets attached to automated XYZ stages (Fig 1).

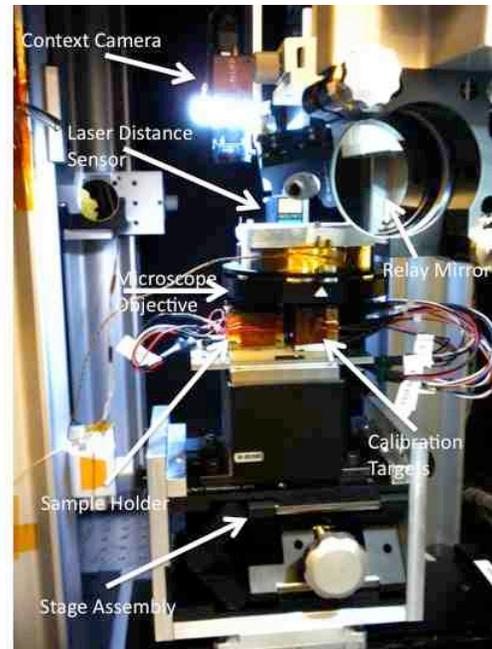


Fig 1. A side view of the assembled and aligned micro-emission spectrometer with specific components labeled. This view shows the sample cup, blackbody calibration targets, microscope objective, and relay optics.

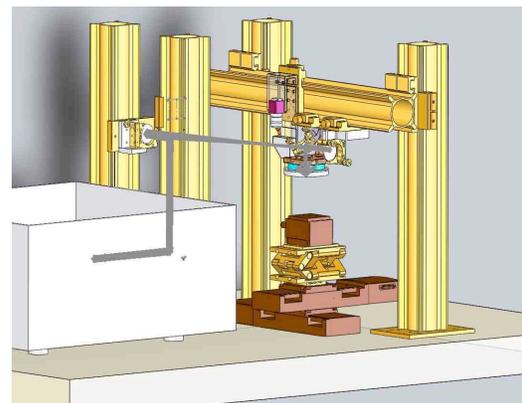


Fig 2. An isometric model view of the laboratory setup with the environmental chamber removed. A set of XYZ stages controls the position of the sample under the microscope, context camera, and laser-focusing sensor to $<1\mu\text{m}$. The optical path is shown as grey lines, though with a custom built miniaturized spectrometer matched to the optical system, the experiment can be greatly simplified.

This assembly moves under the microscope to raster over a sample, collecting data at user specified locations over the regions of interest. The experimental setup (Figs 1 and 2) is quite similar to that originally constructed by Ruff et al. [13] and follows much of the same calibration and instrument response principles put forth in that work. One major difference is complexity of the optical system required to achieve a $\sim 90\mu\text{m}$ spot, the $\sim 7\mu\text{m}/\text{pixel}$ co-aligned context camera, and the mechanization required to automatically acquire tens to hundreds of spectra over the sample.

This technique provides several advantages over traditional bulk spectral analysis where the spot size is small enough to measure individual grains, weathering rinds, alteration coatings, cements, accessory phases, and laboratory samples that are only available in small quantities (e.g. synthetic pigeonite), reducing the need for and complexity of spectral unmixing. The μFTS provides additional constraints on spectral unmixing, as we can essentially point count minerals, use them as endmembers to compare to bulk analysis and average the μFTS grid data together to compare with bulk analysis techniques. These types of experimental procedures are extremely useful in calibrating the data from the μFTS and can illustrate fundamental assumptions and problems with current bulk analysis methods.

Analysis of Primary Igneous Materials:

In this study we present the analysis of a medium-grained quartz-monzonite with individual primary minerals ranging from 1 to 5mm in size (Fig. 3). The primary mineralogy of this sample has been determined to be plagioclase ($\sim 44\%$), K-feldspar ($\sim 36\%$), and quartz ($\sim 20\%$) by bulk emission spectroscopy. When an average spectrum is computed from the 18×18 grid acquired from μFTS , significantly different abundances are modeled with K-feldspar (64%) and quartz (31%) dominating the unmixing results and plagioclase modeled at only 5%. Several reasons may exist for this mismatch, including a slope in the μFTS emissivity spectra that was not fully removed in calibration, or in the systematic sampling we are not collecting representative fractions of the areal abundance as observed by the bulk emission spectra. Additionally, the μFTS also measures accessory minerals (Fig 3c) that are then likely over estimated in the average spectrum, as their areal abundances are low ($<1\text{-}2\%$).

If we run the same unmixing procedure on the μFTS spectra, K-feldspar, plagioclase and quartz are nearly always the primary endmembers (except where accessory phases are directly measured) with pure spectra and mixing the three endmembers observed. If we use a representative sampling of μFTS components as endmembers to unmix the bulk and average μFTS spectra, we model the average μFTS spectrum and the

bulk spectra relatively well, indicating that all the phases observed by the μFTS are present in the bulk spectrum.

Future Work:

While we only present a single analysis of this technique on a medium-grained quartz-monzonite sample, this technique has been applied to basaltic materials and a variety of other igneous materials more commonly associated with planetary surfaces other than Earth. Additionally, work is underway to examine olivine-basalts with mantle xenoliths through a variety of weathering horizons in an effort to constrain the nature of the weathering occurring in arid environments on Earth as an analog for the weathering of olivine-rich basalt bedrock on Mars [e.g. 14, 15].

References:

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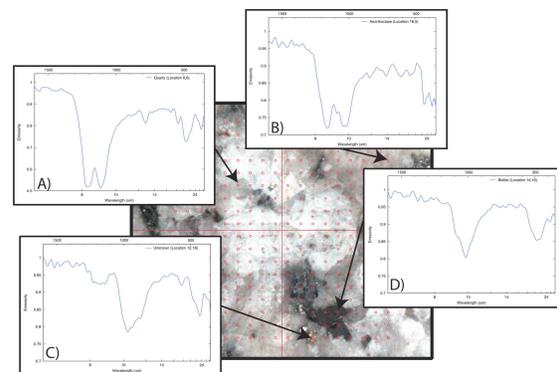


Fig 3. This figure illustrates a typical acquisition grid for the micro-emission spectrometer. In this case we selected an 18×18 grid to with $500\mu\text{m}$ spacing between acquiring points. In this mode the spectrometer operates as a reconnaissance tool evaluating the variety of mineralogy present and characterizing unique materials. This sample is a quartz-monzonite and is primarily composed of quartz (A), anorthoclase (B), and biotite (D), with trace amounts of an accessory mineral (C), which based on the position of the Si-O stretching features is likely a variety of sphene/titanite. The light toned areas in the context image are visible reflection off of mineral faces and have a composition primarily consistent with anorthoclase and some quartz.