USING TERRESTRIAL MULTISPECTRAL IMAGES AS A PROXY FOR CONSTRAINING NEW THERMAL INFRARED DATA OF MARS.

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Introduction: The physical and erosional environments on Earth and Mars are clearly very different. Hyperspectral TIR data returned from the Thermal Emission Spectrometer (TES) instrument thus far has revealed only a few minerals [1,2]. However, with a thirty-fold increase in spatial resolution, the Thermal Emission Imaging System (THEMIS) instrument offers the potential of mapping very small regions. The author has shown that distinct minerals comprising only 5-10% of a spectrum (or pixel) can be identified using linear deconvolution [3]. This means that objects as small as 500 - 1000m^2 are potentially detectable, leading to possibility of identifying minerals within ejecta blocks, sand dunes, and crater walls. However, these positive mineral identifications will be hindered by the multispectral resolution of THEMIS coupled with the complicating factors of the Martian atmosphere and surface dust deposits.

Contrary to common perceptions, these factors are not enough to cause failure in extraction of mineral end-members on the surface. Much of the accuracy and confidence in such an approach relies on precursor field and laboratory investigations using terrestrial orbital instruments such as the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), which compare favorably to the THEMIS spectral and spatial resolutions (Table 1). In addition to field-based calibration/validation efforts using these data sets, a robust search algorithm will be necessary in order to winnow mineral libraries for the best-fitting end-member spectra.

Background: Multispectral TIR data sets have been the primary research tool of the author for over ten years, focusing on planetary analog sites such as dune fields, volcanic lava flows, and impact craters [4,5,6]. These studies have confirmed the need for detailed field and laboratory-based research in order to validate unit identification algorithms operating on low spectral resolution data. For the first time, a similar data set will be available for the Martian surface. The THEMIS instrument has begun to return multispectral TIR data from Mars at a relatively high spatial resolution (100m/pixel). There now exists TIR data that is both high spectral/low spatial resolution (TES) and high spatial/low spectral resolution (THEMIS). Under the appropriate conditions and with new mapping tools under development, small-scale (<2 km) and potentially very recent geomorphic features such as meteorite impact craters can be examined. An important deficit in the current TIR mapping approach at Mars is a methodology for quantitative extraction of mineralogy with scale-dependant modeling of data using proxy sites on Earth. By analyzing actual orbital data from impact craters and dune fields, combined with field mapping and new mineral identification approaches, a detailed framework for THEMIS data returned from similarly-preserved, though much older, units on Mars can be constructed.

Deconvolution Model: The fundamental goal of remote sensing measurements, whether in the laboratory or from space, is to determine the physical and chemical characteristics of the object under study. One technique employed to ascertain the surface mineralogy is spectral deconvolution, which has been used for a variety of scientific problems involving mixture analyses [2,3,4,7,9]. Deconvolution provides a relatively straightforward and computationally quick method of assessing the mineral assemblages of a surface, thereby reducing the data set to a minimum informational volume. In general, linear deconvolution has been extensively modeled and tested in the laboratory, at terrestrial analogs, and on Mars surfaces using current TES data with much success by numerous authors [2,3,8,9]. However, the limitations of such an approach are driven by the spatial and spectral resolution of the data, as well as the breadth of the available spectral library.

The over-arching principle of linear mixing is the spectral features of the end-member minerals overlap and combine to form a composite spectrum in linear proportion to their areal fractions. The residual error, expressed as a single value for the entire wavelength region, is known as the root-mean-squared (RMS) error and determines the “goodness of fit” for a particular model iteration. This value can be used as an indicator of the appropriateness of the chosen end-member suite.

This methodology is constrained by several assumptions in order to provide meaningful results. Foremost, the approach allows a maximum number of end-members equal to one plus the total number of equations or instrument wavelengths. This becomes a critical limitation in attempting to deconvolve multispectral data using large spectral end-member libraries [2,4]. What is currently lacking is a logical approach that winnows large spectral libraries into subsets in order to model the best fitting combination of minerals.

Automated Blind End-Member Analysis: Such and approach, known as blind end-member analysis, can be automated and used to refine an iterative solution to linear deconvolution of THEMIS data using hyperspectral mineral libraries [10]. A methodology such as this is critical if the multispectral THEMIS data are to be interpreted for quantitative model mineralogy of the Martian surface. Thus far, hyperspectral TES spectra have been commonly deconvolved using two or three surface end-members and two atmospheric end-members [1,2]. The use of a large suite of unknown end-members, however, provides an assurance that the unknown or mixed spectrum is being tested for all possible mineral combinations. In effect, no constraints are placed on the algorithm and its results can be assumed to be the best possible for fit of the available end-members to the unknown spectrum. For the case where the number of wavelength bands is far less than the number of available end-members, this liberal use of a large data set is impossible. In this case, a strategy must be devised to test all the end-members without violating the fundamental mathematical constraint.

One reason the concept of an automated, blind end-member algorithm is difficult to grasp is the sheer quantity of calculation involved. For example, using combinatorial mathematic algorithms, the number of possible end-member combinations of 5 or less in a library of 170 spectra is 1,115,034,284 [11]. Despite this large number of iterations, a level of analysis such as this may be required in order to accurately model the surface spectra. What remains to be assessed is the computer processing time required, the accuracy of the results, and the applicability to current terrestrial data sets.

Study Sites: Much of the initial model development and testing for this type of data analyses was carried out on Mars surface analogs such as active dune fields, recent impact craters, and ancient volcanic terrains [4,5,6]. The only study using a blind end-member approach was carried out at the Kelso Dune Field in the Mojave Desert, CA [4]. The results of this study confirmed the applicability of such an approach. The correct suite of end-members was chosen in over 94% of the pixels, and the values of the derived surface percentage compared very well with values derived from petrographic techniques. This study and recent work at Meteor Crater, AZ indicate that development of computationally-optimized, permutation-based code that iterates the deconvolution software through the entire spectral library is critical for the success of THEMIS data analyses [6].

Conclusions: Continued work on these data sets and field areas will provide insights into fundamental areas of Mars surface mineralogy and geologic processes. The overall objectives are highly relevant to the goals of both the THEMIS instrument as well as the those of the Mars 2001 project, in particular and the Mars Exploration Program in general. For example, of the four specific science objectives proposed by the THEMIS instrument, three are addressed in this study:

i. to determine the mineralogy and petrology of localized deposits ...

ii. to provide a direct link to the global hyper-spectral mineral mapping from the MGS TES ...

iii. to study small-scale geologic processes and landing site characteristics ...

In addition, several of the Mars 2001 mission science objectives are also met:

i. globally map the elemental composition of the surface ...

ii. acquire high spatial and spectral resolution images of the surface mineralogy ...

iii. provide information on the morphology of the Martian surface ...

References: [1] Bandfield, et al., *Science 287,* 1626-1630, 2000. [2] Christensen, et al., *JGR 105,* 9609-9621, 2000. [3] Ramsey and Christensen, JGR 103, 577-596, 1998. [4] Ramsey, et al., *GSA Bull. 111,* 646-662, 1999. [5] Ramsey and Fink, *Bull. Volc. 61,* 32-39, 1999. [6] Ramsey, JGR *(in press),* 2002. [7] Adams, et al., *JGR 91,* 8098-8112, 1986. [8] Thomson and Salisbury, *RSE 45,* 1-13, 1993. [9] Hamilton and Christensen, *JGR 105,* 9717-9733, 2000. [10] Christensen et al., *JGR 105,* 9735-9739, 2000. [11] Kreher and Stinson, *CRC Press,* 1999

Table 1. ASTER and THEMIS design specifications

	ASTER	**THEMIS**
Wavelength Range *(VIS-SWIR)* [µm]	0.58 - 2.43	0.45 - 0.75
Wavelength Range *(TIR)* [µm]	8.13 - 11.65	6.5 - 14.5
Spectral Resolution*(VIS-SWIR)* [bands]	9	5
Spectral Resolution *(TIR)* [bands]	5	9
Spatial Resolution*(VIS-SWIR)* [m]	15, 30	20
Spatial Resolution *(TIR)* [m]	90	100