A Field Study of Thermal Infrared Spectral Signatures, with Implications for Studies of Mars. L. E. Kirkland[1], K. C. Herr[2], E. R. Keim[2], P. B. Forney[3], J. W. Salisbury[4], J. A. Hackwell[2]; [1]Lunar and Planetary Institute, Houston, <kirkland@lpi.usra.edu>, [2]The Aerospace Corporation, <kenneth.c.herr@aero.org>; <eric.r.keim@aero.org>; <john.a.hackwell@aero.org; Lockheed Martin Missiles and Space, <paul.forney@lmco.com>; [4]Johns Hopkins University, <salisburys@worldnet.att.net>.

Summary. Data recorded of indurated, weathered carbonates by the airborne hyperspectral imaging spectrometer SEBASS show that some massive carbonates exhibit dramatically reduced spectral contrast for the strong carbonate bands at 6.5 and 11.25 µm. If massive carbonates are present on Mars, this type of reduced spectral contrast could explain why they have not been detected using thermal infrared data sets, including the Global Surveyor Thermal Emission Spectrometer (TES). It could also cause similarly rough carbonates to be missed by the planned 2001 nine-band radiometer THEMIS. On the other hand, SEBASS data demonstrate that these deposits can be detected by spectra recorded with sufficient signal-to-noise ratio (SNR).

The observed reduction in band contrast is significant, and we conclude it is cause by surface roughness effects [1]. The nature of carbonate and other formations on Mars is uncertain, as well as the amount and kind of subsequent weathering, but a rough surface is certainly a possibility that must be taken into account. These results should be considered in planning for future instruments, and when utilizing thermal infrared spectra for landing site selection.

This effect was found by drawing on expertise and unique technology most commonly used for the Department of Defense (DoD). The significance of the lessons learned illustrate the importance both of extending spectral studies to the field, and of drawing on data sets and expertise from non-traditional groups, in order to best define what is needed to detect and identify interesting materials and desirable landing sites on Mars using infrared spectroscopy.

Background. If Mars had a denser CO_2 atmosphere in its past and surface water, then large deposits of carbonate likely formed [2]. Critical to the validation of this model is the determination of whether carbonates are present. In addition, carbonate deposits would provide important input for landing site selection [3]. Currently, there is no strong spectral evidence for carbonates on Mars, which has long been a puzzle in spectral studies.

Three spacecraft spectrometers have returned thermal infrared spectra from Mars, and these spectral data sets are available to the planetary community. Table 1 gives instrument details.

In the thermal infrared, calcite has clear bands centered near 6.5, 11.2, and 35 µm. However, weathering and surface roughness dramatically reduce the band contrast of most materials.

Field site. Mormon Mesa is near Mesquite, Nevada. It has a cap rock of massive, strongly indurated calcite (calcrete), overlain by loamy soil rich in carbonate and quartz, and significant coverage by fragments of calcrete [4] (Figs. 1 and 2); and localized regions contain limestone in a conglomerate [1,4].

Figure 1: Mormon Mesa. The indurated calcite (calcrete) cap rock is visible along the cliff edge (left), and extensive coverage of calcrete fragments are visible on the mesa top, over a reddish calcite and quartz soil. Shown with The Aerospace Corporation's field spectrometer van, operated by The Surveillance Technologies Department, with two spectrometers to measure the 3-5 and 7-13 µm regions.

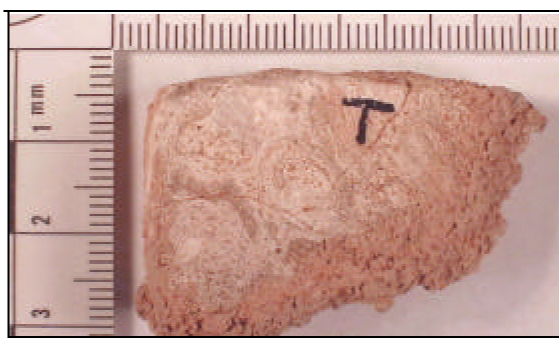

Figure 2: Typical calcrete sample, collected with the *in situ* top surface marked for reference, to allow the lab characterization to be performed on the weathered surface that is measured by the field spectrometers and SEBASS.

Data. The Aerospace Corporation's Spatially Enhanced Broadband Array Spectrograph System (SEBASS) recorded unique, high quality spectra of

Mormon Mesa in May, 1999. SEBASS is an airborne, hyperspectral imaging spectrometer (Table 1). High quality field spectra covering the same spectral wavelengths were acquired in December 1999, using two van-mounted spectrometers from The Aerospace Corporation [1]. Additional information is at http://www.lpi.usra.edu/science/kirkland/.

The Aerospace Corporation is a non-profit research arm of the Department of Defense, and specializes in the development and assessment of advanced technology. SEBASS is operated by the Spectral Applications Department, and the field spectrometers by the Surveillance Technologies Department. These collaborators represent groups, expertise, technology, and data sets that are not generally incorporated into planetary studies, but that proved critical to this work.

SEBASS measures with the highest combined spectral resolution and SNR of any terrestrial airborne thermal infrared spectrometer, and so is uniquely capable to detect and examine the signature of spectrally subtle materials. In addition, as a result of the inherent nature of DoD-related studies, members of these groups have decades of experience with applied field spectral studies.

An airborne spectrometer can measure hundreds of thousands of spectra of extended spatial regions, providing the means to study more extended areas and spectral variations than is possible in the laboratory alone. The combined ability of SEBASS to measure relatively large regions, and to detect and identify spectrally subtle materials allowed us to discover that the massive carbonate at Mormon Mesa exhibits an unexpectedly weak spectral signature.

We then investigated in more detail the signature of field type regions found by SEBASS, using a combination of *in situ* field spectrometer measurements and laboratory spectra, and laboratory compositional and textural characterization of field samples [1].

Table 1: Instrument parameters.

instrument	4µm SNR	11µm SNR	4µm $\Delta\lambda$ (cm^{-1})	11µm $\Delta\lambda$ (cm^{-1})
SEBASS		1900	13.7	3.7
M21	n/a	1000	n/a	2
M100		n/a	3.3	n/a
1969 IRS		710	24.7	10
1971 IRIS	n/a	100	n/a	2.4
1996 TES	n/a	345	n/a	20

M21=Brunswick Model 21; M100=Block Engineering Model 100; SEBASS=Spatially Enhanced Broadband Array Spectrograph System; SNR=rms signal to noise ratio, 270K; $\Delta\lambda$=spectral resolution; n/a=not applicable

Observations. SEBASS spectra show that none of the regions covered predominantly by calcrete exhibited a strong 11.25 µm carbonate band. This observation is significant, because it has generally been assumed that a massive carbonate will exhibit a strong 11.25 µm band, and detection limits of carbonates on Mars have been based on this assumption [1]. Our laboratory work indicates that surface roughness causes a cavity effect and volume scattering, which causes the surprisingly weak bands in the calcrete at 6.5, 11.25, and 35 µm (Fig. 3) [1].

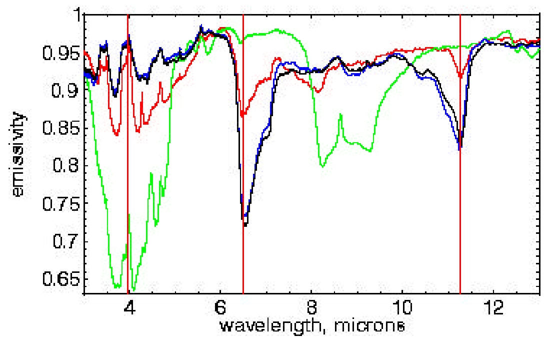

Figure 3: Hemispherical reflectance measurements by P. Adams at The Aerospace Corporation, converted to emissivity using 1-reflectance. Red = typical calcrete from the Mesa top; green = typical soil; blue = black limestone from the arroyo conglomerate; **black = limestone pebble** from asphalt road aggregate. Reference lines at 3.95, 6.5, and 11.25 µm. Note the weakened or absent 6.5 and 11.25 µm troughs in the calcrete and soil, and the clearly evident 3.9 µm peak.

Conclusions. Most spectral studies to determine detection limits have relied predominantly on laboratory measurements of well-crystalline, pure end-members. Desirable instrument parameters and detection limits for remote sensing of Mars are based on those results. However, our results show the importance of extending thermal infrared spectral studies to the field, and the relevance to spectral studies of Mars. The low spectral contrast carbonate deposits at the Mormon Mesa would require a SNR of greater than ~1000 at 11.25 µm to detect, and this exceeds the SNR of any instrument flown to Mars. SEBASS was able to detect the massive calcrete, which validates the use of thermal infrared field spectra to detect these deposits. However the spectra it recorded indicate that if the 1971 IRIS, 1996 TES, or the planned 2001 THEMIS were flown over Mormon Mesa, none would detect the carbonate-rich soil or massive calcrete present.

References. [1] Kirkland L. et al. (2000) *LPSC abs.1876 and LPSC abs.1915*. [2] Pollack J. B. et al. (1987) *Icarus 71*, 203. [3] Farmer J. D. and Des Marais D. J., (1999) *JGR 104*, 26,977. [4] Gardner L. R. (1972) *GSA Bull. 83*, 143.