**A Field Study of Thermal Infrared Spectra of Carbonates, with Implications for Studies of Mars.** L. E. Kirkland[1], K. C. Herr[2], E. R. Keim[2], J. W. Salisbury[3], 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; [3]Johns Hopkins University, <salisburys@worldnet.att.net>.

**Summary.** Data recorded of the Mormon Mesa 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 carbonates are present on Mars, this type of reduced spectral contrast in massive carbonates could explain why they have not been detected using remotely sensed thermal infrared spectra, including data returned by the Global Surveyor Thermal Emission Spectrometer (TES).

A goal of this study is to examine spectra recorded of weathered carbonates in the field, and to appraise what the results indicate for the search for carbonates on Mars. We conclude that the observed reduction in band contrast may be sufficient to preclude TES from detecting massive, well exposed carbonate deposits such as those at the Mormon Mesa. However, SEBASS data demonstrates that these deposits can be detected if the spectra are recorded with sufficient signal to noise ratio (SNR).

**Introduction.** If Mars had a denser $CO_2$ atmosphere in its past and if liquid water had been present on its surface, then large deposits of carbonate materials likely formed [1]. Critical to the validation of this warm and wet climate model is the determination of whether carbonates are present on Mars. In addition, carbonates typically mark regions of hydrothermal activity, and provide a suitable environment for the preservation of biomarkers. Identifying carbonate deposits on Mars would thus provide valuable input for landing site selection [2]. Currently, there is no strong spectral evidence for the presence of carbonates on Mars.

Three spectrometers have returned thermal infrared spectra from Mars: the 1969 Mariner 7 Infrared Spectrometer (IRS, 1.9 - 14.4 µm); the 1971 Mariner 9 Infrared Interferometer Spectrometer (IRIS, 5-50 µm); and the 1996 Thermal Emission Spectrometer (TES, 6 - 50 µm). These spectral data sets are available to the planetary community and can be used to search for the presence of carbonates on Mars.

Calcite has strong infrared bands centered near 6.5, 11.25, and 35 µm. However, weathering and surface roughness dramatically reduce the band contrast of most materials, including the carbonate bands listed above. To better understand the real-world signatures of carbonates deposits, and how they might be detected remotely using thermal infrared spectroscopy, we studied the spectral signature of weathered carbonates at the Mormon Mesa, Nevada.

**Field site and data.** 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 [3] (Figs. 1 and 2). In addition, there are localized regions that contain limestone in a conglomerate (Fig. 3)

**Figure 1: Mormon Mesa.** Shown with The Aerospace Corporation's field spectrometer van, containing two spectrometers to measure the 3-5 and 7-13 µm regions. The indurated 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.

**Figure 2: Calcrete and soil.** Typical mesa material, with calcrete fragments and a reddish calcite and quartz soil. Ruler is 17 cm (6.7") long. Lab measurements show the massive calcrete has very weak bands at 6.5 and 11.25 µm, while the carbonate rich soil produces almost none.

Our study utilizes a combination of data from the airborne SEBASS hyperspectral imaging spectrometer; field spectral data (3-5 and 7-13 µm); and laboratory spectra (2.5 - 25 µm) [4, *this issue*]. Here, we present results of the airborne and field work for the 7-13 µm region. Additional information is available through http://www.lpi.usra.edu/science/kirkland/.

The Aerospace Corporation's Spatially Enhanced Broadband Array Spectrograph System (SEBASS) recorded very high quality spectra of Mormon Mesa in May, 1999, covering the wavelength ranges from ~2-5 and 7-13 µm, with a SNR ~1900 at 11 µm and 270K (Table 1). High quality field spectra covering the same spectral wavelengths were also acquired in December 1999, using two van-mounted spectrometers from The Aerospace Corporation (Figs. 1 and 4).

**Table 1: Instrument parameters.**

| instrument | 4µm SNR | 11µm SNR | 4µm Δλ ($cm^{-1}$) | 11µm Δλ ($cm^{-1}$) |
|---|---|---|---|---|
| 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; Δλ=spectral resolution; n/a=not applicable

**Observations.** SEBASS recorded spectra of areas that had a range of percent coverage by calcrete vs. soil, with typical coverage of ~50% calcrete, up to 100% calcrete coverage near spoils from past road work. However, none of the regions that consisted predominantly of calcrete or soil 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. Only the asphalt road, (which contained limestone in the aggregate), and the arroyo, (which contained limestone, Fig. 3), showed a distinct signature at 11.25 µm.

Results of laboratory work undertaken in conjunction with this study indicate that surface roughness most likely causes the surprisingly weak bands in the calcrete at 6.5 and 11.25 µm [4].

**Conclusions.** Most spectral studies to determine detection limits have relied predominantly on laboratory measurements of well-crystalline, pure end-members. However, our results show the importance of extending thermal infrared spectral studies to the field. The unexpectedly low spectral contrast of the 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 proposed 2001 THEMIS were flown over Mormon Mesa, none would detect the carbonate-rich soil or massive calcrete present.

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

**Figure 3: Arroyo conglomerate.** Material at arroyo horizontal surfaces consists predominantly of a calcrete matrix, with cobbles of brown and dark gray limestone, and some sandstone. The limestone produces clear, strong bands at 6.5 and 11.25 µm. Scale is ruled in cm.

**Figure 4: Field spectrometer.** The silver column (mid-right) contains the optical train that allows the spectrometer to view outside the van, and incorporates a mirror that can raster scan in two dimensions. A spectrum is visible on the green screen in mid-left. The joy stick in front of the screen allows the user (here, Ken Herr) to "drive" the spectrometer field of view, viewable on the small, gray screen.