A Laboratory Study of Weathered Carbonates, with Implications for the Infrared Remote Sensing of Carbonates on Mars.  L. E. Kirkland, K. C. Herr, P. M. Adams, J. W. Salisbury, and A. Treiman; 1 Lunar and Planetary Institute, Houston, TX  <kirkland@lpi.usra.edu>; 2 The Aerospace Corporation, El Segundo CA, <kenneth.c.herr@aero.org>; and 3 Johns Hopkins University, retired, <salisburys@worldnet.att.net>.

Introduction.  Planetary spectroscopists have diligently searched the infrared spectral data sets for evidence of carbonates in order to validate the existence of a past warm and wet climate on the planet Mars.  Currently, there is no strong spectral evidence of the presence of carbonates on Mars.  Carbonate exhibits strong bands in the thermal infrared at 6.5, 11.25, and 35 µm.

Airborne remote sensing measurements (SEBASS) of the Mormon Mesa, near Mesquite, Nevada, show that the indurated, massive carbonate material present (calcrete) exhibits unexpectedly weak bands at 6.5 and 11.25 µm [1, this issue].  Since these bands are typically used to search for the presence of carbonate, we undertook a laboratory study of samples from the Mesa to understand why the bands are weak, and what this indicates for the potential to detect carbonates on Mars using currently available and planned spectral measurements, including TES and the proposed spectral instrument for the 2001 flight, THEMIS.

Surface texture.  Figure 2 shows a Secondary Electron (SEM) image of a weathered surface of the calcrete.  The large, rounded grains are quartz, and the fine, very rough material is the cemented calcite (calcrete).  These images show that the calcrete, while massive, has a very rough surface on a scale of less than ~10 µm.  In addition, the calcrete has a pitted surface, while the limestone is relatively smooth.

Discussion.  We propose that the unexpectedly weak 6.5 and 11.25 µm bands exhibited by the calcrete result from its very rough surface at scales smaller than millimeters.  Two effects may contribute to this result: a cavity (hohlraum) effect, and volume scattering.

Cavity effect.  The cavity effect occurs when energy emitted from a cavity undergoes multiple scattering from internal cavity surfaces, which reduces spectral contrast of reststrahlen bands and increases emissivity [4].  In general, the greater the ratio of the cavity depth to entrance width, the greater the increase in emissivity, and the lower the observed spectral band contrast.  Thus lower spectral band contrast will result from the presence of pits or vesicules.

Volume scattering.  Volume scattering also reduces the spectral band contrast, either as a result of fine
particle size or very fine scale surface roughness [5]. When a mineral is ground up, it loses spectral contrast for large particles compared to a polished surface due to the cavity effect. As the particles become even smaller, they also become optically thin, and then volume scattering also subtracts from the spectral contrast of the reststrahlen bands. When the scale of the surface roughness is fine enough, many optically thin, rough edges are created, and multiple scattering becomes in part volume scattering. This can be discerned when the shape of the reststrahlen band is changed by self-absorption.

For example, note the shift of the 6.6 µm band peak in Fig. 1 to shorter wavelength for the calcrete and soil compared to the limestone cobbles, as a result of progressively increasing volume scattering.

**Conclusions.** Roughness on a scale of microns, and/or a pitted or vesicular surface will cause a material to behave more like a blackbody. Our laboratory examination of the calcrete indicates these effects cause the observed reduction in spectral contrast at 6.5 and 11.25 µm. We have no hemispherical reflectance measurements of the 35 µm band, but its spectral contrast should be similarly reduced.

It has generally been accepted that a massive carbonate would be detectable by thermal infrared instruments that have been flown to Mars, including TES. However, our results indicate this may not be the case. Although the limestone conglomerate (arroyo) would be detectable, the calcrete would only be detectable at SNR >1000 at 11.25 µm, which is higher than the SNR of TES (~345). For spectral remote sensing to contribute to the exploration of Mars, it is important to determine the instrument parameters needed to detect these weathered materials. Future studies should include examinations of weathered materials in order to determine under what conditions TES and the proposed 2001 THEMIS may or may not detect them.


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

**Figure 2:** SEM image of calcrete. Image recorded of the upper, weathered surface of a typical calcrete from Mormon Mesa. The large, rounded grains are quartz, and the small, very rough material surrounding the quartz is calcite, cemented as calcrete. Additional details are at: [http://www.lpi.usra.edu/science/kirkland/](http://www.lpi.usra.edu/science/kirkland/).