THE PRIMARY UNCERTAINTIES IN INFRARED SPECTRAL STUDIES OF MARS. L.E. Kirkland[1,2], K.C. Herr[2], and P.M. Adams[2], [1]Lunar and Planetary Institute, contact information at www.lpi.usra.edu/science/kirkland; [2]The Aerospace Corporation.

Introduction: A key goal for infrared remote sensing studies of Mars is to determine which minerals are present and absent. Visible/infrared spectroscopy is the primary method for remote mineral identification. In order to understand the resulting interpretations, it is necessary to understand the sources of uncertainty. Here we detail the primary uncertainties in the method.

Interpretations of remote sensing data sets of Mars currently differ widely. For example, different researchers interpret non-detection of a mineral differently. Some interpret non-detection as absence of the mineral, while others note that minerals in the field commonly exhibit weak or absent spectral bands [1]. The wide ranging compositional interpretations cause changing or contradictory geologic interpretations. Thus the same remote sensing data sets are interpreted as pointing to a "cold/dry Mars" and a "watery past."

The resulting confusion leads researchers to ask, what are the uncertainties in these data sets? Here we illustrate three of the four primary uncertainties. We also explain work needed to address the current contradictions and confusion.

The four primary uncertainties are: (1) Limited ability to detect unknown minerals, i.e., when we have no reference spectrum (no sample). (2) Variations in surface texture that cause huge uncertainties in mineral abundance calculations. (3) Misunderstandings of how much mineral is required for detection. This uncertainty impacts interpretations of what non-detection means. (4) Coatings cause significant uncertainties, but due to space, we do not cover them here.

Mars analog data: One of our Mars analog sites is Coso Hot Springs, California. In June 2005, we acquired hyperspectral imagery over the full terrestrial optical range. SpecTIR measured airborne hyperspectral images covering 0.4-2.5 µm. SEBASS measured mid- and thermal infrared (2.5-5 and 7.5-12.5 µm) hyperspectral imagery. RamVan measured ground based, MiniTES analog hyperspectral imagery (7.5-12.5 µm).

Uncertainty #1: Unknowns: Minerals are detected by searching for a match to a signature measured of a sample. However, when we lack a matching library signature, i.e., lack a sample (Fig.1), then detection has poorer sensitivity. For Mars, we do not know what samples are missing from the library, and thus what unknown minerals may be present and undetected.

Uncertainty #2: Abundance determination: In order to calculate abundance, the spectral contrast of the target is compared to the spectral contrast of a reference spectrum. However, increasing surface roughness and decreasing particle size can decrease the target spectral contrast. Thus we need a reference spectrum that has the same spectral contrast as the target, e.g., that was measured of a material with the same surface roughness and particle size.

Fig.2 illustrates how an incorrect reference spectrum leads to an incorrect abundance estimate [2]. The black trace shows a reference laboratory spectrum, measured of 100% gypsum. Current abundance calculations assume that a field deposit composed of 100% gypsum will exhibit the same spectral contrast as the laboratory spectrum. The red and blue traces show field (MiniTES analog) spectra measured of gypsum outcrops, of a rough-surfaced gypsum (red trace), and a smooth-surfaced gypsum (blue trace).

Table 1 shows that the calculated abundances are incorrect. That occurs because the reference spectrum did not have the same spectral contrast as the targets, because the materials have different surface textures.

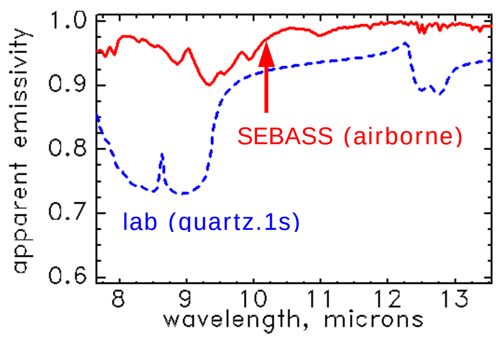

Fig.1: This plot illustrates why a search for the unknown found by SEBASS at Coso would fail if using an incorrect reference spectrum (here, quartz).

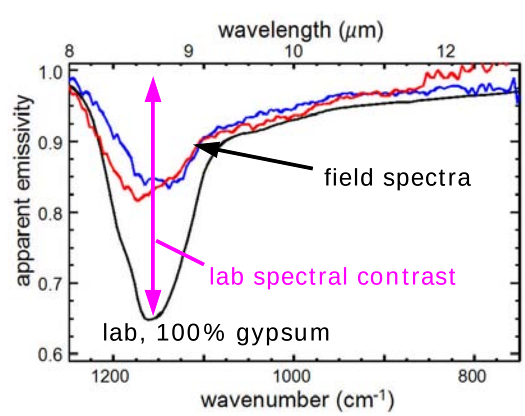

Fig.2: Abundance is estimated by comparison to a laboratory spectrum.

Table 1: Abundance using spectra from Fig. 2

Abundance	*smooth* gypsum in outcrop	*rough* gypsum in outcrop
inferred	36%	39%
actual	~15%	~70-90%

Note the large difference between the inferred and actual abundances, based on methodology, instrumentation, and data as currently used for Mars.

Uncertainty #3, Undetected minerals: Mineral deposits do not always exhibit detectable spectral signatures. A classic example of that result is White Rock on Mars. No clear spectral features have been reported in observations of White Rock. Yet most researchers agree that White Rock is made of something. The result indicates the hazard in deciding that lack of a spectral feature necessarily means lack of a given mineral.

Terrestrial observations show that surface roughness in particular decreases the spectral contrast, making the minerals undetectable [1]. The minerals are present, but unknown. Such deposits (e.g., White Rock) require higher sensitivity for identification than instruments at Mars currently have.

Terrestrial vs. Mars studies: A greater recognition of the primary uncertainties requires terrestrial analog studies that better mimic the remote sensing pathway for Mars. Fig.3 illustrates the typical terrestrial pathway. The path usually starts with information about the site, including from general geologic knowledge of terrestrial processes. Remote sensing results are then checked for consistency with on-site studies and/or general terrestrial geologic knowledge.

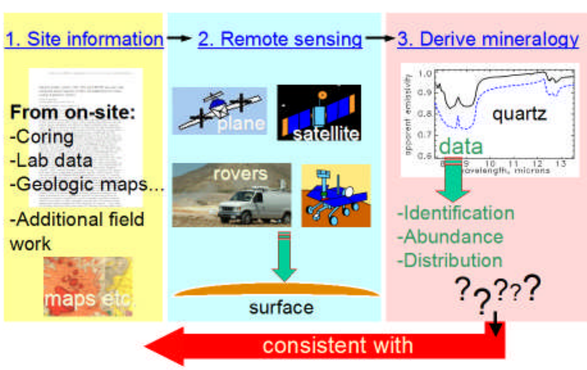

Fig.3: Typical terrestrial remote sensing pathway. Questions from Step 3 are iterated against knowledge from Step 1. (Geologic map from [3]).

In contrast, Fig.4 illustrates the path for Mars. For Mars, we lack intensive on-site information, e.g., onsite geologic surveys, laboratory analysis of samples, and cores. We also lack the kind of general geologic knowledge that exists for terrestrial work, e.g., typical weathering products and formation pathways.

Terrestrial analog studies need to mimic the approach as implemented for Mars. A "blind study" (where the analysts do not know the terrestrial location studied) is not sufficient. The data sets must include the four primary sources of uncertainty for Mars: (1) unexpected mineralogy (Fig.1); (2) variations in texture to bring out difficulties in abundance calculations (Table 1); (3) infrared stealthy surfaces (like White Rock); and (4) coatings. Until the community faces those issues first hand using high quality Mars analog data, topics on Mars like White Rock and abundance analysis will continue to confuse many researchers and thereby degrade interpretation accuracy and quality.

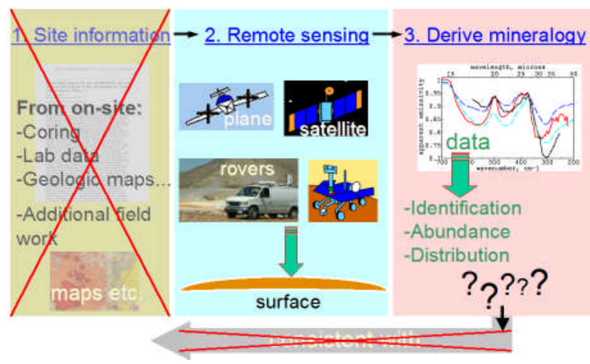

Fig.4: Mars remote sensing differs from terrestrial (Fig.3).

Summary: We have illustrated three primary uncertainties: (1) When a spectral search does not include a library signature of a given mineral, the search has poorer sensitivity. The issue is most acute for weakly exhibited spectral features. For Mars, the difficulty is increased by the unknown mineralogy and relatively poor sensitivity of current instruments [4].

(2) Abundance estimates as used for Mars have huge uncertainties (up to 100%). The high uncertainty is generally unrecognized by researchers who lack field hyperspectral imagery, because lack of such data causes unfamiliarity with the spectral impact of textual variety that occurs outside the lab.

(3) Surface roughness can cause minerals to remain undetected even at high abundance. High sensitivity is critical to identify such targets (e.g., White Rock).

Awareness of those topics requires exposure to field analog studies that parallel Mars work. Exposure would require analysis of adequate TES and MiniTES analog data by the Mars research community.

References: [1] Kirkland L. E. et al (2003) Infrared stealthy surfaces: Why TES and THEMIS may miss some substantial mineral deposits on Mars, JGR 108(E12), 5137. [2] Greenhagen B.T. et al. (2005) *LPSC XXXVI*, Abstract #2117. [3] Duffield and Brown (1981) *USGS Map I-1200*. [4] Kirkland L.E. et al. (2001) Thermal infrared spectral band detection limits for unidentified surface materials, *Appl. Optics 40*, 4852.