REMOTE SENSING OF GEOLOGIC MATERIALS AT MAN-MADE CRATERS.

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Introduction: Craters made by nuclear detonations at the Nevada Test Site (NTS) provide unique test beds for cratering processes and remote detection of the geologic materials present [1,2,3,4]. Here we present results of a remote sensing study that detected an unusual infrared spectral signature at Schooner crater. The signature matches an unusually fine tectosilicate. The deposits are present as large beds. Laboratory analysis shows a composition of feldspar and unexpectedly, tridymite and cristobalite.

The finding is significant because: (1) Most remote sensing searches of Mars use laboratory spectra measured of coarse silicates (greater than ~75 µm). This study shows that interesting material at a cratering site may remain undetected in searches that do not include spectra of fine silicates. (2) The detection illustrates that it is important to detect a material even when the material is not included in the database used for the search. However, a typical "linear unmixing" approach does not accomplish that type of search well.

Schooner Crater: Schooner has been long recognized as a good analog to craters on the moon and Mars [2,3]. Schooner is part of a series of large craters made at the NTS to study excavation effects [5]. The craters are particularly valuable because the controlled site access preserved them relatively undisturbed, and for the extensive geologic and drilling studies.

Schooner was made in 1968 using a 31 kt nuclear detonation with a charge depth of 108 m [3,6]. The resulting crater has an apparent depth of 63 m [6].

Schooner is an interesting potential analog to craters in layered terrain on Mars. The Schooner site was selected to combine strong and weak layering with a water table [6]. The detonation was at approximately the boundary between underlying densely welded tuff, and overlying non-welded or weakly welded tuff (Table 1). The perched water table at this boundary caused a significant gas acceleration phase [2].

Airborne Data: In June 2005, "SEBASS" imaged Schooner, covering the 3–5 and 7.5–12.5 µm ranges in 256 bands, at 2 m/pixel spatial resolution. SEBASS is the only airborne imager used for thermal-infrared, hyperspectral Mars and lunar analog studies [7].

Ground Data: In Feb 2006 we imaged Schooner using RamVan, which is a ground-based imaging spectrometer. RamVan covers the 7–13 µm range in 181 bands. The Mars 2003 rover MiniTES is similar to the RamVan instrument. Both are raster-scanning, thermal infrared spectrometers [8]. RamVan has scanned several other craters at the NTS [9,10].

Spectral behavior of fine silicates: Coarse silicates typically have a broad emissivity trough centered in the ~9–10 µm spectral range, called a reststrahlen band [11]. However, as the particles become small enough to become translucent, radiance begins to survive passage through the grains, and that alters the spectral shape. That effect is called "volume scattering" [12,14,16,17]. For fine silicates, volume scattering begins to invert the ~9–10 µm emissivity trough, and for tectosilicates causes a broad spectral trough centered at ~11.5 µm [12, 13]. The trough occurs in the ~11 µm range for these silicates because that is where their transmission is high. Salisbury and Wald [14] refer to this broad emissivity trough in very fine silicates as a "transparency" feature [12,14]. They also note that the transparency feature can provide compositional information.

Fig. 1 illustrates this spectral behavior for an example rhyolite from the ASTER spectral library [15].

Table 1. Schooner layered terrain. (Data: [6], p.301)

layer	depth (m)	density (g/cm^3)	bulk modulus (GPa)	water weight %
densely welded tuff	0-39	2.3	6.3	0.3
weakly welded tuff	39-61	1.6	2.8	8.5
nonwelded tuff	61-103	1.5	1.5	12.0
----approximate depth of explosion (108 m)----				
densely welded tuff	103-148	2.2	7.9	5.3

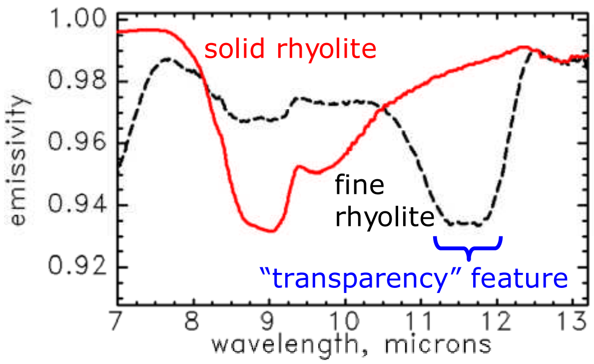

Fig. 1 Particle size alters the spectral shape. The solid rhyolite has a ~9 µm band, while the fine rhyolite shows a strong emissivity trough centered near 11.5 µm. Red=solid and black=fine (<75 µm sieve size) "rhyolite H1," ASTER library [15]. Solid rhyolite spectrum is scaled to 1/2 band strength for clarity.

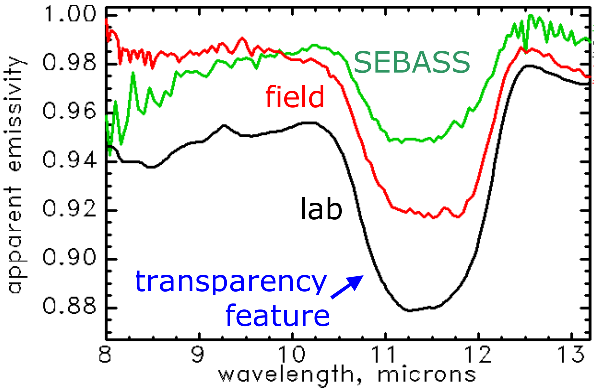

Fig.2 Airborne, field, and laboratory spectra from Schooner. The locations of the material were identified using the airborne imagery, then imaged on-site with RamVan and samples collected [18]. SEBASS detected the material only in the thick ejecta and the crater itself.

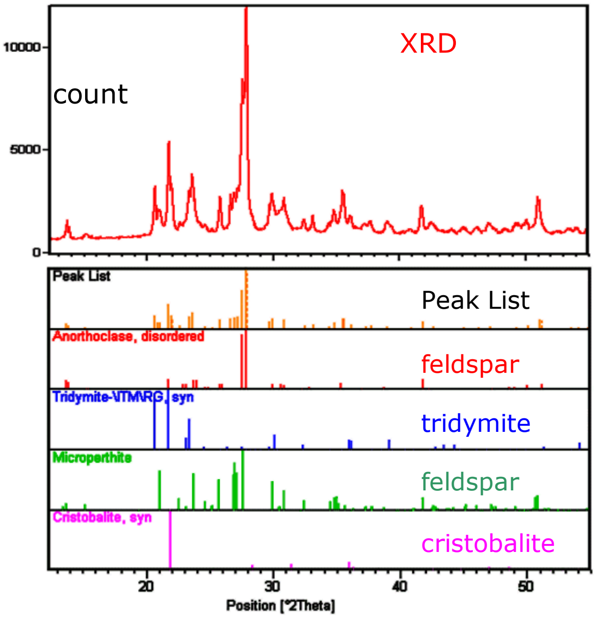

Fig.3 XRD of the material. This identifies a K-Na feldspar; tridymite, and cristobalite.

Particle sizes: In the sample, the larger particles are mainly feldspar (or volcanic glass) and are ~10–65 µm size. The silica is mainly <6–7 µm in size [19].

Conclusions: A remote sensing study of the Mars analog crater Schooner detected substantial deposits of an unusually fine silicate that included an unexpected composition. The most important point this study shows is that we need the capability to detect unexpected materials in order to provide reliable geologic interpretations. The results illustrate the importance of conducting field analog studies in order to develop a solid foundation for exploration, and to test and develop reliable algorithms to explore the unknown.

References: [1] Nordyke M. D. (1961) *JGR*, 66, 3439–3459. [2] Nordyke M. D. (1977), in *Impact and Explosion Cratering*, ed. D.J. Roddy et al., 103–124. [3] Moore, H. J. (1977) *J. Res. U.S.G.S.*, 5, 719–733. [4] Kirkland L. E. et al. (2004) *LPSC XXXV, abs. 1846*. [5] DOE/NV-209-Rev.15 (2000) *United States Nuclear Tests*. [6] Henny R.W. (1981) AFWL-TR-81-36. [7] Kirkland L.E. et al (2003), JGR 108(E12), 5137. [8] Kirkland L.E. et al. (2002) *SPIE 4495*, 158 169. [9] Kirkland L.E. et al. (2005) *LPSC XXXVI* Abs. #2199. [10] Kirkland L.E. et al. (2005) *LPSC XXXVI* Abstract #2185. [11] Salisbury J. W. et al. (1991) Infrared (2.1–25 µm) Spectra of Minerals. [12] Salisbury J. W. and Walter L. S. (1989) *JGR 94*, 9192–9202. [13] Maturilli A. et al. (2006) *Planet. Space Sci.*, *54*, 1057–1064. [14] Salisbury J. W. et al. (1994) *JGR 99*, 11897–11911. [15] Baldridge A. M. et al. (2008) In press *Rem. Sens. Env.* [16] Vincent R. K. and Hunt G. R. (1968) *Appl. Opt. 7*, 53–58. [17] Logan L. M. et al. (1973) *JGR 78*, 4983–5003. [18] SEBASS shot 2 x1241/y119; RamVan 1337, x29/y26; lab "schooner anomaly <105 µm," measured at The Aerospace Corporation. [19] In order to measure the particle sizes, a small amount was dispersed in methanol and sonicated. It was then diluted by ~20x and filtered to retain particles >0.5 µm. The result was imaged in an SEM using backscattered electron images with Z contrast and secondary electron images (topographic contrast). We then used a software package that detects particles and measures their size and composition.

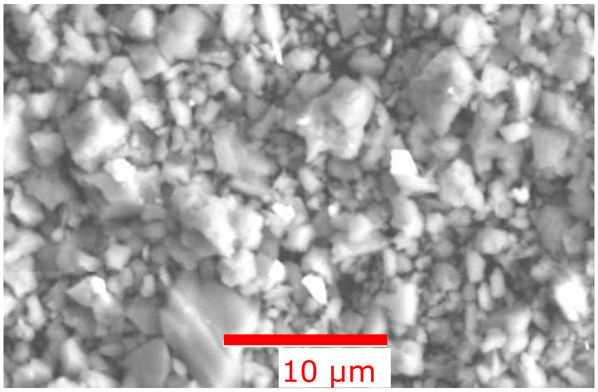

Fig.4 SEM image. Note the unusual "broken glass" texture. This texture is inconsistent with typical weathered aeolian deposits and playa material.

Fig.5: Picture of a sample. Note the pen tip for scale.