THE SEARCH FOR UNDERGROUND HYDROTHERMAL ACTIVITY USING SMALL CRATERS: AN EXAMPLE FROM THE NEVADA TEST SITE.

L. E. Kirkland[1,2], K. C. Herr[2], P. M. Adams[2], L. B. Prothro[3], and B. M. Allen[3]. [1]Lunar&Planetary Institute, 3600 Bay Area Blvd., Houston, 77058; [2]The Aerospace Corporation, laurel.e.kirkland@aero.org, kenneth.c.herr@aero.org, paul.m.adams@aero.org, [3]Bechtel Nevada, prothrlb@nv.doe.gov, allenbm@nv.doe.gov.

Summary: Craters can create windows into subsurface geology. Hydrothermal alteration products that correlate with ejecta from small craters (<100 m deep) can flag possible near-surface hydrothermal activity. A region with such activity is a highly prized target for Mars exploration. Here we describe an airborne (satellite analog) study that identified mineral indicators of hydrothermal activity exposed by manmade explosion craters in a basalt flow. Abstract [1] presents the related ground-based study. This field development work draws mainly on operational expertise from outside NASA. One goal is to develop an operational foundation for routes to discovery for Mars.

Introduction: Near-surface explosive tests at the Nevada Test Site (NTS) in the Mojave desert created numerous small craters (~25–400 m diameter) that are unique Mars analog sites. The NTS is a restricted access test facility, ~65 miles northwest of Las Vegas. The U.S. Department of Energy manages the NTS. The NTS sites are particularly valuable because controlled access preserved the craters relatively undisturbed.

Infrared spectroscopy is the primary method used to explore the mineralogy of Mars remotely. The MarsLab project is the first thermal infrared, hyperspectral study of the mineralogy exposed by small, fresh terrestrial craters. The overarching project goals are: (1) define the types of materials that infrared airborne (satellite analog) and ground-based spectrometers identify and miss, and explain why; and (2) define implications for the exploration of Mars.

Here we describe exploration of manmade craters on a basalt flow. The techniques used mimic those that are, or can be, used for Mars.

Craters: We selected craters in Buckboard Mesa, a lava flow described as an olivine basalt, with a silica content of ~53% [2], and ~2.8 million years old [3]. The flow is ~70 m thick at the two crater sites discussed here [4]. Most of the basalt is gray to black, but local regions are oxidized to a reddish color. The flow overlays tuffaceous sandstone. The water table is ~240 m below the upper mesa [2]. Approximately 0.5–4 m of aeolian silt and sand cover much of the flow [2]. Thus in most regions, aeolian deposits dominate the airborne observations.

Thin carbonate [2] and opalline coatings occur on the ejecta basalt, especially at joints (Fig. 1). The coatings were formed by water that flowed along the joints [2,5]. During upheaval from the explosion (spalling), the rocks separated along the joints, preferentially exposing the coatings in the ejecta. Thus the ejecta can have notable coverage by the coatings, even though the volume of the hydrothermal alteration material may be small. The preferential exposure aids remote detection.

Here we discuss studies of the craters Buckboard 12 and Danny Boy (Table 1). Other craters in basalt where we have airborne data include Buckboard 10, Pre-Schooner Bravo, Charlie, and Delta.

Fig. 1: Buckboard 12 ejecta. This whitish coating does not effervesce. Infrared spectra and X-ray diffraction measurements indicate the coating is opal. Ruler is 15 cm.

Instrumentation: The thermal-infrared spectrometer SEBASS (~7.5–12.5 µm, 128 bands) is the only airborne instrument in use that is similar to the Mars orbited TES (~6–50 µm) [6]. RamVan (~7.5–12.5 µm, 181 bands) is the only field spectrometer that raster-scans images like the 2003 Mars rover MiniTES (~6–25 µm) [6,7].

Results: SEBASS detected signatures that (1) are indicators of hydrologic activity and (2) correlate with crater ejecta. That combination is a flag for potential near-surface hydrothermal alteration.

Fig. 2 shows an aerial photo and part of a SEBASS scene. Primary spectral results are: (1) *Opal*. Spectral signatures consistent with opal occur mainly in regions with Buckboard-12 ejecta, with a few isolated hits in the Danny Boy ejecta; (2) *Calcite*. Spectral signatures that match calcite occur mainly in regions with Danny Boy ejecta, with a few isolated hits in the Buckboard-12 ejecta. Fig. 3 shows example airborne spectra.

For Mars, the route to discovery would involve (1) identification of small, fresh craters using visible imagery; (2) targeting selected sites using high spatial resolution spectroscopy (<10-20 m pixels); (3) identification of ejecta mineralogy. Although opal and calcite are identified in this study, other minerals (e.g., zeolites) may be indicators elsewhere or on Mars. Our airborne trials demonstrate the effectiveness of the small-crater method, and indicate that the spectrometer will require higher sensitivity than the current orbited instruments at Mars.

References: [1] Kirkland L. E. et al. (2005) *LPSC XXXVI*. [2] Lutton R. J. (1968) *Project Dugout*, PNE-602F. [3] Fleck R. J. et al. (1996) *JGR, 101*, 8205. [4] Nordyke M. D. and W. Wray (1963) *Results from a Nuclear Cratering Detonation in Basalt*, UCRL-6999. [5] Hill C. A. and Schluter C. M. (1993), *Petrographic description of calcite/opal samples*, DOE/NV Report 10461-T61. [6] Kirkland L. E. et al. (2003), Infrared stealthy surfaces: Why TES and THEMIS may miss substantial mineral deposits on Mars, *JGR, 10.1029/2003 JE002105, 108(E12)*, www.lpi.usra.edu/science/kirkland. [7] Kirkland L. E. et al. (2002), *Rem. Sens. Env. 80*, 447. [8] Moore H. J. (1977) *J. Res. USGS, 5*, 719. [9] NTS Orthophoto Site Atlas (1998) *DOE/NV/11718-604*, N13. [10] SEBASS scene date Dec. 2003; B-12 is spectrum x1527/y62; varnished is x456/y90; Danny Boy is x1295/y95.

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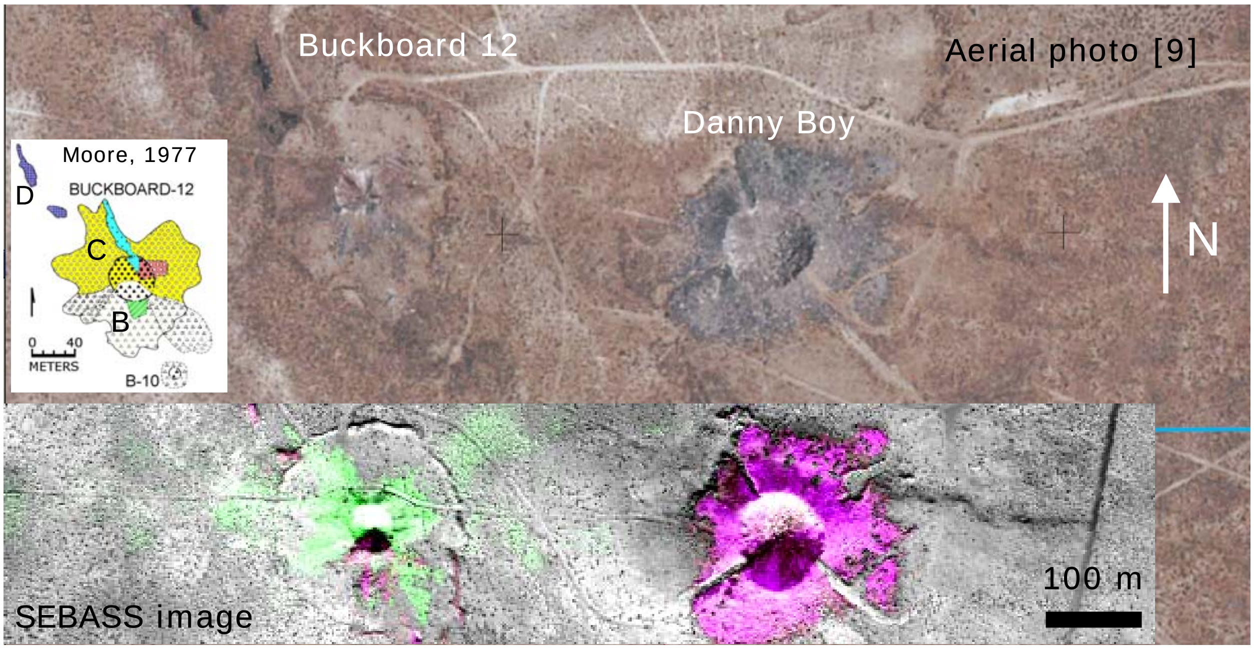

Fig. 2: An aerial photo and part of a SEBASS image (offset for clarity). The ejecta makes a window into sub-surface material. SEBASS image color coding: gray=8.6 µm (1163 cm^{-1}) brightness temperature; purple=linear unmixing of basalt signature from Danny Boy; green=linear unmixing of lab signature measured of a Buckboard-12 opal sample. Geologic map is from [8], and labels are: C=cinder-rich region; B=blocky basalt; D=dike; LPSC Abstract [1] has additional labeling.

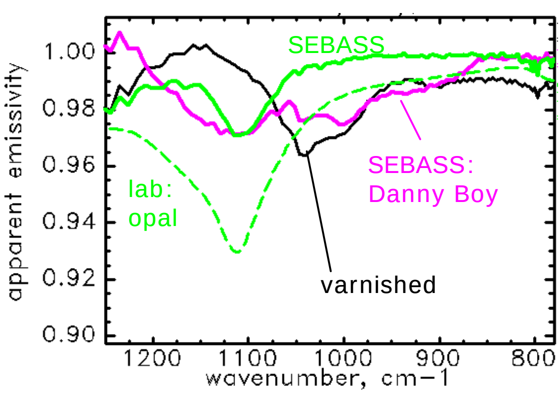

Fig. 3: SEBASS data. The green SEBASS spectrum is of the cinder-rich ejecta region, north of Buckboard 12. The lab sample was also collected there. “Varnished” was shiny, black rocks from the mesa cliff. “Danny Boy” is from the Danny Boy ejecta. [10] gives spectral indices.

Table 1: MarsLab crater details

	Watusi	Scooter	Sedan	B-12	Danny
size (m)	24	94	390	35	66
depth (m)		23	98	11	20
DOB (m)		38	194	13	34
date made	Sep 2002	Oct 1960	Jul 1962	Sep 1960	Mar 1962
charge	18	500	104,000	20	430
SDOB		48	42	48	45
substrate	A	A	A	B	B
type	chem	chem	nuclear	chem	nuclear

size=diameter at rim; *depth*=apparent depth; *DOB*=depth of burst (depth of charge placement); *charge*=tons TNT equivalent; *SDOB*= scaled depth of burst ($m/kt^{1/3}$); *substrate*: A=alluvium, B=basalt; *type*: chemical or nuclear explosive; *B-12*= Buckboard 12; *Danny* = Danny Boy.