SUMMARY OF THE MARS SCIENCE LABORATORY ROVER SIMULATION AT THE HAUGHTON IMPACT STRUCTURE.

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Figure 1. A panoramic view of the field site within the Haughton Impact Structure. Distance to the ~ 3m tall ridge in the center of the figure is ~ 10m (no scale cues to simulate raw imagery from Mars). Samples were taken from three areas: the periglacial polygons in the left foreground, the face of the ridge in the center of the image, and around the right side of the ridge where orange hydrothermal alteration is observed.

Introduction: A Mars Science Laboratory (MSL) rover simulation was conducted in the spring of 2011. The goals of this study were to produce a challenging simulation for MSL mission scientists using simulated reconnaissance tools available on MSL, to identify and understand the diversity of geologic materials present in a complex impact structure, and to study the role and effectiveness of analogue simulation studies as training exercises for planetary exploration.

Simulations in Planetary Science. Earth based simulations have been the foundation of training and troubleshooting in the planetary exploration field since it began. They allow evaluation of a science teams observations against existing, and often extensive, knowledge of a terrestrial site. Without them, there would be no way to circumvent potential communication issues between scientists or issues with the mission itself.

Haughton Impact Structure: The Haughton Impact Structure impact structure lies within the Canadian Arctic on Devon Island, Nunavut territory (75°22'N, 89°41'W). Devon Island consists mainly of Paleozoic carbonate-sulfate sediments overlying a gneissitic basement. The structure is approximately 23km in diameter and is the result of an impact 39 mya (Late Eocene) [1].

Haughton as an Analogue. The use of analogue sites in the planetary explorations field provides essential training and testing environments; the Haughton site is ideal for analogue studies of Martian exploration. With both limited precipitation and a lack of vegetation, the geologic record of the impact and its associated deposits are relatively well preserved by the polar desert environment. SETI and the Mars Institute host a joint initiative at the impact structure called the Haughton-Mars Project. The goals of this project are to understand the geology of the structure and also to use the environment as testing grounds for future planetary explorations [2].

Site Selection and Geologic Setting: This study focuses on an area (**Figure 1**) of the crater at a site near Trinity Lake. It is a geologically complex area displaying evidence for hypervelocity impact (shatter cones), hydrothermal activity (Fe oxidation and carbonate/sulfate mineral re-precipitation), periglacial processes (polygons), and limited biologic features (epilithic lichen, fossilized stromatolites, and a friendly bird). Needless to say, this is an interesting area with complex geochemistry and mineralogy [3].

Simulating MSL's Science Payload: MSL is an unprecedented mission in every way, the camera and instrument suites are no exception. Two of the imagers and three of the analytical instruments aboard the rover were simulated in this study.

Imagers:
The MastCam and Remote Micro-imager (RMI) were approximated using a Nikon D-80, 10.2 megapixels camera with AF-S Nikkor 18-135 mm 1:3.5-5.6G ED and AF-S Nikkor 70-300mm 1:4.5-5.6 G ED lenses respectively.

Analytical Instruments:
The ChemCam laser-induced breakdown spectroscopy (LIBS) device was simulated using a laboratory setup at Los Alamos National Labs with parameters virtually identical to the ChemCam instrument. The laser was a Spectra-Physics Indi Nd:YAG laser operating at 1064 nm and a repetition rate of 10 Hz at an energy of ~17 mJ/pulse. Three Ocean Optics HR2500+ (UV, VIS, VNIR) spectrometers were used as well as a demultiplexer. Each sample had five shot locations with 50 shot accumulations. All analyses were conducted under Martian atmospheric conditions, ~ 7 Torr of CO^2.

The CheMin X-ray diffraction (XRD) instrument was simulated using a Terra Portable XRD, cobalt K-alpha, filtered, 250 frames per analysis. At the time of analysis detections were believed to be relatively good. Abundances were obtained using JADE fill-pattern fitting that is RIR sensitive, however, the results were believed to be reasonable with one possible exception being the smectite-bearing sample (Sample 5). Smectites do not have CIF files so it was fit as amorphous.

The alpha particle X-ray spectrometer (APXS) was simulated using a laboratory APXS at the University of Guelph. It is known as the flight equivalent unit because it is essentially a twin of the APXS deployed on the Curiosity rover. The APXS detects both X-ray fluorescence (XRF) and alpha-particle induced X-ray emission (PIXE) energy from the sample that is produced from six 244Cm sources located in a ring around a shielded central silicon drift detector. To derive element concentrations for elements with atomic numbers (Z) of $11 \leq Z \leq 39$, a non-linear least-squares code GUAPX was used to fit each spectrum. The GUAPX code includes calibration factors that were determined using geochemical reference materials and simple chemical compounds. Each of the rocks contain a large portion of elements with X-ray energies that are too low to be detected by APXS (e.g., C and O), therefore the analyses were calculated without those 'X-ray invisible' components and normalized to 100%.

Summary

- A simulation designed using samples and imagery collected from the arctic.
- Training exercise for MSL mission scientists in three countries (US, Canada, & France).
- Laboratory analysis of samples by ChemCam, APXS, and CheMin simulators for realistic data.
- Participants gained valuable mission operations experience.
- Simulation foreshadowed issues seen in the actual MSL mission.

Simulation: Science team members participated in three different countries: the U.S., France, and Canada. Participants were provided with sets of documents for each of the three simulated sols. These included panoramic views of the simulation area (**Figure 1**), image packages showing close-ups of the sample areas, image packages showing macro images of the selected samples to simulate the RMI, and chemical and mineralogical data for selected samples. LIBS spectra were given for all fourteen samples, XRD data for nine samples (**Figure 2**), and APXS data for three samples. The simulation was performed via telecom, without the use of video.

Digital simulation during the Tuesday evening poster session, LPSC 2013

Available at:
http://s1292.photobucket.com/user/HaughtonMSLsimulation/profile/
Password: marssciencelab

Sample	split	smectite	mica	quartz	calcite	dolomite	aragonite	gypsum	goethite
Sample 1	bulk sample					100			
Sample 3	gray clast			91	9				
Sample 5	white vein				98	2			
Sample 5	gray matrix	7	1	3	23	66			
Sample 7	bulk sample					100			
Sample 8	mamillary surface plus base				52	27	21		
Sample 8	mamillary surface				36	29	35		
Sample 8	interior matrix				71	29			
Sample 10	brown surface coating			8	85				7
Sample 10	gray matrix								
Sample 11	white late xls							100	
Sample 11	dark/light brown matrix							83	17
Sample 12	white late xls							100	
Sample 12	dark/light brown matrix							32	68
Sample 13	weathered surface			1.5	98.5				
Sample 13	interior matrix			1.5	98.5				

Estimated abundances in wt%

Figure 2. X-ray diffraction data for nine of the simulation samples.

Results: Each simulated sol equated to about four hours of discussion on the local geology, individual samples, and plans for the following sol. For the purpose of this abstract, the observations made during the simulation are grouped into two categories:

Simulation observations and lessons learned

- Video conferencing instead of the telecom format would have facilitated more interaction between participants. The higher degree of anonymity within the study, related to the lack of face to face contact, allowed some of the participants to keep quiet unless asked to give their input. Another issue was self identification before speaking; most participants had to be reminded to say their name to avoid confusion and mix-ups. Face to face interactions would have also cut down on unproductive silences. One in particular was nearly a minute and a half.
- Separating communications and science staff, having one orator per team, eliminates the issue of speaker identification and decreases other misunderstandings (audibility, language barriers, etc.).
- Themed groups might have made the simulation run more efficiently. Instead of each separate group of participants focusing on the same issues, one group might be asked to address a certain area of a site or the division may be based on science goals.
- A need was expressed for a grid format on the images to quickly point out areas of interest. When a specific rock or LIBS point needs to be addressed in an image, it will be necessary to have quick and accurate identification so that no one is looking in the wrong area.
- A need was expressed for ChemCam spectra peak identification software.

Science team observations and lessons learned

- Participants accurately interpreted the entire simulation area in terms of the geology and other processes present.
- Participants needed familiarization with MSL's major mission goals. Having a list of the overall mission goals and their priorities may have helped participants better allocate time spent analyzing specific areas and samples.
- Participants needed additional familiarization with MSL's analytical capabilities (e.g. using the scoop for CheMin instead of drilling).
- Participants were slow to relate observations from previous sols. Each day was almost treated like an entire new mission until everyone was reminded of the science discoveries made the day before. A recap of the major issues at the beginning of each sol would be beneficial to the mission for both science and time saving purposes.
- Participants focused on the interesting samples more than the geology and processes of the site as a whole.
- Participants were uncertain about the question of thin coatings vs. solid rock in some samples.
- Participants did not request soil analyses.
- Judgments on the scale of the MastCam images varied. Scale bars were not included in the original images.

Conclusions: The simulation was successful and this study has produced intriguing insights into planetary simulations that require more investigation.

Simulation participants. The simulation provided participants valuable experience in dealing with a mission scenario, and for some their first experience with mission operations. One of the participants commented saying that the simulation, "demystified the job". Another noted it as "too difficult of a site to decode"; however, challenging simulations are necessary when one cannot be certain about the complexity of sites explorers will encounter.

Geology. Through this simulation, much was learned about the geochemistry, mineralogy, and the processes at work within the study area. Each analysis, whether quantitative or qualitative, yielded valuable information about the area's past and present. The samples and their associated data used in this simulation can be available upon request for future research purposes.

Planetary simulations. Simulations utilizing analogue sites are an important tool for planetary explorers. They provide authentic training experience as well as allow us to refine and reassess the methods employed to explore other planets, increasing science return [4]. This simulation gave participating scientists a chance to practice communicating amongst each other while both solving geologic puzzles and minor mission issues before they were encountered on Mars. Future exploration, including manned missions to other bodies, will benefit greatly from analog training exercises. Extensive landing site studies have been conducted for missions to the Moon [5], now we have the charge of training our explorers with simulations.

Future Work: This simulation has inspired a publication that relates the findings of this study to MSL's first 90 sols on Mars. Observations regarding the instruments (such as the image scale issues seen at the Point Lake outcrop) and the communication between scientists (such as the issue of relaying information from day to day) will be addressed. This simulation was designed to prepare participants for mission operations, but it also serves as an educational tool for future explorers. All the information in this simulation study (images, samples, data, etc.) can be available for subsequent simulations and experiments.

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