Journal of Human Performance in Extreme Environments

Volume 12 | Issue 1 Article 7

Published online: 12-24-2015

Pre-Mission Input Requirements to Enable Successful Sample Collection by a Remote Field/EVA Team

Barbara A. Cohen
NASA Marshall Space Flight Center, barbara.a.cohen@nasa.gov

Darlene S. S. Lim
BAER Institute, darlene.lim@nasa.gov

Kelsey E. Young
CRESST/University of Maryland, College Park, kelsey.e.young@nasa.gov

Anna Brunner
Arizona State University, Anna.Brunner@asu.edu

Richard C. Elphic
NASA Ames Research Center, richard.c.elphic@nasa.gov

See next page for additional authors

Recommended Citation

Cohen, Barbara A.; Lim, Darlene S. S.; Young, Kelsey E.; Brunner, Anna; Elphic, Richard C.; Horne, Audrey; Kerrigan, Mary C.; Osinski, Gordon O.; Skok, John R.; Squyres, Steven W.; Saint-Jacques, David; and Heldmann, Jennifer L. (2015) "Pre-Mission Input Requirements to Enable Successful Sample Collection by a Remote Field/EVA Team," *Journal of Human Performance in Extreme Environments*: Vol. 12 : Iss. 1 , Article 7.
DOI: 10.7771/2327-2937.1071
Available at: http://docs.lib.purdue.edu/jhpee/vol12/iss1/7

Pre-Mission Input Requirements to Enable Successful Sample Collection by a Remote Field/EVA Team

Authors
Barbara A. Cohen, Darlene S. S. Lim, Kelsey E. Young, Anna Brunner, Richard C. Elphic, Audrey Horne, Mary C. Kerrigan, Gordon O. Osinski, John R. Skok, Steven W. Squyres, David Saint-Jacques, and Jennifer L. Heldmann

Pre-Mission Input Requirements to Enable Successful Sample Collection by a Remote Field/EVA Team

Barbara A. Cohen,[1] Darlene S. S. Lim,[2] Kelsey E. Young,[3] Anna Brunner,[4] Richard C. Elphic,[5] Audrey Horne,[4] Mary C. Kerrigan,[6] Gordon O. Osinski,[6] John R. Skok,[7] Steven W. Squyres,[8] David Saint-Jacques,[9] and Jennifer L. Heldmann[5]

[1]*NASA Marshall Space Flight Center*
[2]*BAER Institute*
[3]*CRESST/University of Maryland,* College Park
[4]*Arizona State University*
[5]*NASA Ames Research Center*
[6]*University of Western Ontario*
[7]*SETI Institute*
[8]*Cornell University*
[9]*Canadian Space Agency*

Abstract

We used a field excursion to the West Clearwater Lake Impact structure as an opportunity to test factors that contribute to the decisions a remote field team (for example, astronauts conducting extravehicular activities (EVA) on planetary surfaces) makes while collecting samples for return to Earth. We found that detailed background on the analytical purpose of the samples, provided to the field team, enables them to identify and collect samples that meet specific analytical objectives. However, such samples are not always identifiable during field reconnaissance activities, and may only be recognized after outcrop characterization and interpretation by crew and/or science team members. We therefore recommend that specific time be allocated in astronaut timeline planning to collect specialized samples, that this time follow human or robotic reconnaissance of the geologic setting, and that crew member training should include exposure to the laboratory techniques and analyses that will be used on the samples upon their return to terrestrial laboratories.

Keywords: Exploration, analogs, field studies, sampling strategy

Introduction

The science community has had success with two distinctly different modes of human-in-the-loop remote field experience. One model is based on the Apollo Science Support team (or science backroom) structure, where the science team helped to train the crews, designed geologic traverses, and supported the crews during surface operations (Lofgren, Horz, & Eppler, 2011). These teams helped astronauts make real-time sampling and traverse decisions, but because of the complexity of the mission, traverses and extra-vehicular activities (EVAs) were pre-planned and carefully orchestrated so real-time deviations were minimal. Additionally, these science teams had the benefit of knowing that tens to hundreds of kilograms of rock samples were to be returned to round out the in situ observations.

In contrast to Apollo, the Mars Exploration Rovers, Phoenix, and Curiosity missions are conducted entirely robotically, with significant time delays between science-driven decisions and remote field activities. Distinctive operations methods and field methodologies have been developed for robotic missions because of their reliance on the "backroom" science team (rather than astronaut crew members) to understand the surroundings (e.g., Yingst, Cohen, Ming, & Eppler, 2011). Data are uplinked and downlinked once a day, giving the team many hours or even days to assimilate the data and decide on a subsequent plan of action. Furthermore, the duration of these missions is a function of the sustainability of the hardware and continued budgetary support. As a result, in most cases, these missions have continued well past their nominal

FINESSE is funded by a grant from NASA's Solar System Exploration Research Virtual Institute (SSERVI), J Heldmann, PI. We would also like to extend our thanks to the Nunavik Parks system. This research has made use of NASA's Astrophysics Data System (ADS). This is SSERVI publication SSERVI-2015-094.

Correspondence concerning this article should be sent to Barbara.A.Cohen@nasa.gov.

http://dx.doi.org/10.7771/2327-2937.1071

operational ranges. This has allowed the scientific investigation of Mars to progress with more operational flexibility per mission than what is expected for human missions where crew safety and Earth return opportunities will constrain mission lengths and operations at both strategic and tactical levels.

Long-duration, deep space or outpost-type human missions will necessitate the need for greater crew autonomy than has been previously experienced during Apollo or current activities on the International Space Station. As well, in deep space, inevitable time-delayed communications between the astronauts and the ground will likely require the development of new uplink and downlink strategies, associated operations concepts, and vetted technical capabilities. These missions are expected to include not only classic flight support elements, but also a supporting team of scientific experts (Science Backroom Team or SBT) tasked with enabling the astronauts to efficiently conduct science and make discoveries. The frequency of communication between the astronaut team and the SBT will likely vary with the mission location, and any associated orbital characteristics that would affect the rate of data transmission. Despite these operational complexities, based on terrestrial analog experience (e.g. Lim, Brady, & The Pavilion Lake Research Project, 2011) it is expected that drawing on the expertise of a broader SBT will provide valuable intellectual support to the astronauts. However, a strong and practiced SBT-astronaut relationship will be key to maximizing scientific return.

The selection, curation and return of samples to Earth will be key tasks for future astronauts. Returned sample mass will be limited – even potentially more limited than was the case during the Apollo era – so insightful and discerning sample selection will become a crucial component of future missions. A key component of this decision-making process will involve interactions between the astronauts and the SBT. However, as discussed earlier, this may be limited in scope and frequency by the underlying communication constraints of a mission. NASA conducts several analog tests each year in preparation for future human exploration (NASA 2015). Missions such as the Desert Research and Technology Studies, the NASA Extreme Environment Mission Operations and the Pavilion Lake Research Project have been investigating the effects of time-delayed communications on EVA activities. In all cases, mission activities are performed under simulated deep-space communication parameters ranging from 50 seconds one-way light time delays, akin to operating on a near-earth asteroid, to 10 minute one-way light time, akin to operating on Mars (Abercromby, Chappell, & Gernhardt, 2013; Chappell, Abercromby, & Gernhardt, 2013). In the Pavilion Lake Research Project, these investigations take place within the context of a real (non-simulated and non-supplemented) science program, that includes mapping, in situ data collection, and sample selection and collection activities (Brady et al., 2010; Forrest et al., 2010; Lim et al., 2011). Typically, the crew members and scientists involved in these tests have had very focused objectives and time-constrained agendas. As such, conducting focused research into the factors contributing to crew decision-making for sample return has not, to date, been a feasible inclusion in these tests.

Our study was conducted with the intent to address this knowledge gap by specifically evaluating the selection and collection process by human explorers for samples that are to be returned to Earth. We conducted our research during a science-driven field deployment to a remote impact crater in Northern Quebec, Canada – the West Clearwater Impact Structure (WCIS). Specifically, our work was part of the NASA Solar System Exploration Virtual Institute funded FINESSE (Field Investigations to Enable Solar System Science and Exploration) research program (Heldmann et al., 2013). The FINESSE WCIS mission was focused on understanding the cratering mechanics and geochronology of the field site, and as such sample characterization, selection and sampling were intrinsic and required elements of our field activities. We examined the *in situ* sample characterization and real-time decision-making process of the astronauts, with a guiding hypothesis that pre-mission training that included detailed background information on the analytical fate of a sample would better enable future astronauts to select samples that would best meet science requirements.

We conducted three tests of this hypothesis over several days in the field. Our investigation was designed to document processes, tools, and procedures for crew sampling of planetary targets. This was not meant to be a blind, controlled test of crew efficacy, but rather an effort to explicitly recognize the relevant variables that enter into sampling protocol and to be able to develop recommendations for crew and backroom training in future endeavors. We did not consider a communication delay to be germane to the sampling objectives being tested because communications were merely for information, not for instruction.

Site Description

The West Clearwater Lake Impact Structure (Figure 1) is a complex impact crater 32 km in diameter formed in the Precambrian Canadian Shield. Target lithologies comprise predominantly granitic gneiss, granodiorite, and quartz monzodiorite with cross-cutting diabase dykes. Though currently filled with a freshwater lake, WCIS is relatively well preserved, with a large ring of islands providing good exposures of impact melt rocks and other impactites (Phinney, Simonds, Cochran, & McGee, 1978; Simonds, Phinney, McGee, & Cochran, 1978).

WCIS appears to possess one of the best records of impact melt rocks and breccias among terrestrial impact structures, with a general stratigraphy of impact melt-bearing fragmental breccia overlain by various impact melt rocks. However, it has not been visited by impact cratering

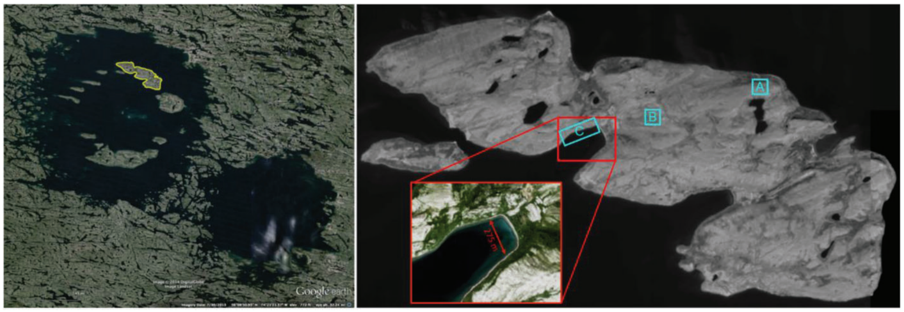

Figure 1. (left) Google Earth Landsat image of the West and East Clearwater Lakes impact features. FINESSE field activities took place on Ile LePage, highlighted in yellow; (right) Ile LePage camp site and scale (red) and test sites (A, B, C) described in this paper (cyan).

researchers since 1977, and studies of the various impactites at WCIS have not been conducted with modern-day analytical techniques. One of the primary FINESSE field deployment objectives was to collect impact melt rocks and impact melt-bearing breccias from a number of locations around the WCIS structure to enable high-precision geochronologic analysis of the crater (Osinski et al., 2015). We completed this study in concert with FINESSE geologists who were mapping the lithological, structural, paleomagnetic, and hydrothermally altered characteristics of the WCIS.

Method

We conducted three tests during a week-long deployment of FINESSE team members to Ile Lepage, one of the inner ring islands of the WCIS (Figure 1). We conducted our tests at three field sites on Ile Lepage after two full days of team participation in field site activities, including using remote sensing data and previously compiled geologic maps, hiking overland to become familiar with the terrain, and examining previously collected samples from other locations within the crater. In addition, each team member shared information about their projects and laboratory techniques with the entire team. We chose our “crew members” as volunteers from the team, all of whom had had moderate training in geologic fieldwork and had become familiar with the general field setting, but who were not experts on impact cratering or geochronology.

The first two exercises (Tests A and B) were short, focused tests of our hypothesis using one Test Director, one backroom scientist, and one crew member. These had similar constructs and used a real team objective to drive the exercise. Test A was to sample hydrothermal vugs; Test B was to sample impact melt-bearing lithic breccia and diabase along a contact to investigate their age relationship and examine contact metamorphism. In each case, a Test Director oversaw the exercise and worked with the backroom scientist to identify a site, a sampling objective, and information on the sample analysis to guide the crew member. Prior to the field deployment, the test director briefed the crew member on the sampling objective and the laboratory techniques that would be used on the samples. At the field sites (Figure 2), the crew member had 30 minutes to survey a small section of outcrop (10–15 m) and acquire a suite of three samples. The crew member talked through his process to the backroom scientist and the test director kept track of the timeline using verbal cues to the crew member. At the conclusion, the backroom scientist appraised the samples and train of thought that led to collection.

Test C was a longer duration, 90-minute exercise involving more detailed sampling objectives. The goal was to test our hypothesis in a mission scenario that more closely resembled a real-world mission. This test had two Test Directors, two

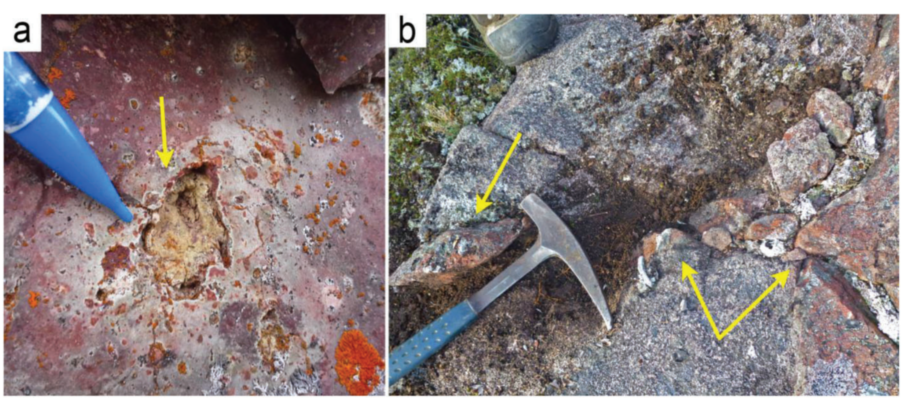

Figure 2. Test A and Test B sites characterized by the Test Director and backroom scientist prior to crew member arrival: a) yellow arrow points to hydrothermally deposited minerals filling vugs in the outcrop (pen for scale); b) yellow arrows point to a contact between diabase (gray) and impact melt-bearing lithic breccia (red).

crew members, and ten team members on the SBT. The site was an extensive, wave-cut cliff that had not been previously examined by any of the FINESSE team members except the Test Directors. During the pre-EVA period, the SBT and crew members worked in camp where they could not view the outcrop. The SBT used a Gigapan image of the outcrop (Figure 3), which is analogous to planetary remote sensing imagery (Yingst et al., 2014), to formulate hypotheses for the origin and nature of the outcrop units, and then to define prioritized characterization and sampling objectives, with the primary goal being to collect samples for geochronologic analysis and the examination of shock-related features. Secondary sampling objectives included identifying and collecting samples of a hydrothermal nature. The SBT turned these objectives into a science plan, which they communicated to the crew members in camp prior to crew deployment. As part of the science plan, the SBT also discussed their sampling needs in depth with the crew members, including laboratory methods, objectives, and samples sizes needed. During the deployment, the outcrop and crew members were out of sight of the SBT; the crew relayed real-time information to the SBT by two-way communications with no time delay. Both the crew and SBT re-evaluated their hypotheses and science plans in real-time. The 90-minute time limit for the EVA imposed moderate time pressure on both the crew and the science team.

Discussion

The focused tests (A and B) were successful in meeting the scientific and sampling objectives. The crew members applied their knowledge of how the samples were to be used in further study (technique, sample size, and scientific need) to focus on the sampling task. The crew member was comfortable spending minimal time describing and mapping the outcrop, because we set up the task with mapping and context already established. However, the sampling task was not shortened because of this prior knowledge. In both test cases, the crew member used all available time to obtain samples that met the science objectives.

The larger test (Test C) was not successful in meeting the sampling objectives. As the crew members began describing the lithologies, it was quickly apparent that the lithologies were not as the SBT had expected. As such, the SBT's pre-mission science briefing was largely unusable by the EVA field team. When the outcrop was not as expected, the crew members instinctively switched to field characterization mode, taking significant time to characterize and map the outcrop. One crew member admitted that he "kind of lost track" of the originally proposed sampling strategy as he focused on basic outcrop characterization. Although it is logical that a significant amount of time must be spent by the crew and supporting SBT to understand outcrops and their significance, and also that outcrop characterization is necessary in order to obtain appropriate samples, this type of characterization was not the initial objective for this EVA.

Instead, during Test C, the EVA crew independently altered the sampling strategy and became focused on acquiring "representative" samples of the newly characterized lithologies, rather than acquiring samples that specifically met the analytical objectives of the science team. Furthermore,

Figure 3. Science team backroom for Test C.

Table 1
Science plan for Test C. Units and waypoints are shown in Figure 4.

Part 1: Initial walkthrough (45 mins)	
Start at unit E (i)	
Description of Unit E	5 min
Move toward Unit D, describe differences and their nature (abrupt vs diffuse contact), after point ii spend extra time looking for possible sampling locations in Unit D	15 min
Move to Unit C via point iii, describe, take up to two samples	15 min
Move to Unit B, describe	5 min
Move to Rock 1, call in	5 min
Halt movement; Sample in Unit A while science team confers and modifies plan if needed	Up to 30 min
Part 2: Focused Sampling (40 mins)	
Walk to Unit B	5 min
Sample Unit B (very low priority)	10 min
Walk to Unit D	5 min
Sample Unit D, important to get fresh face and context	15 min
Sample Unit E (optional, only if different from Unit C)	5 min

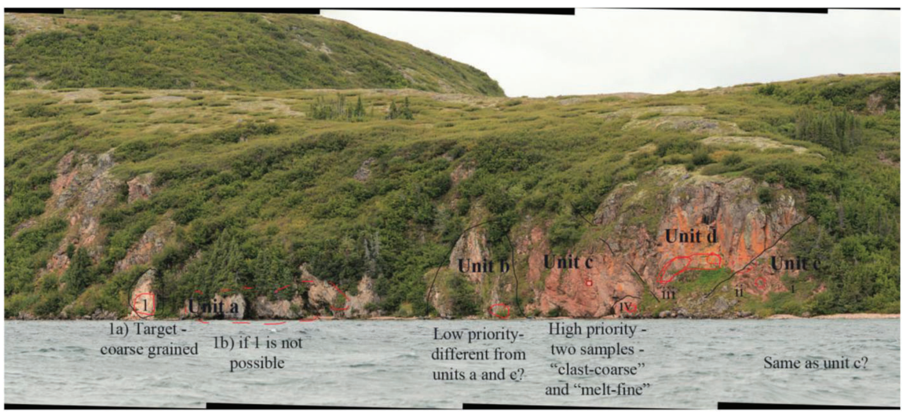

Figure 4. Science Team annotated Gigapan for Test C, used to create science plan (Table 1).

guidance from the SBT became largely ineffectual during the EVA, since their knowledge of the worksite rapidly became less refined than that of the astronauts in the field.

As a consequence of the deviation away from the initial sampling strategy, the EVA team also ran short on time to gather potentially important secondary samples, such as those along a contact or those with hydrothermal inclusions. This effect was not seen in the two more focused studies, where the working environments were well-understood prior to their EVA and the crew member kept to their instructions to concentrate on retrieving samples for specific studies and post-mission analysis. Many science objectives require sample selection decisions to be made with a more focused understanding of how they will be analyzed once they are returned to the science team for processing. However, even after a detailed discussion of the studies and techniques, the crew in Test C deviated from this guidance when faced with an outcrop that was not well characterized prior to the EVA.

Conclusions

1. Sampling activities should be given a significant amount of specifically allocated time in EVA timelines; ideally, sampling should be done as a follow-up to a previously studied outcrop (either by humans or robotically) where both the EVA crew and SBT have become comfortable with its context and characteristics. Field characterization of an outcrop is a focused activity that takes significant time and training (Lim et al., 2010, 2011; Bleacher, Eppler, Tewsbury, & Helper, 2014). Sampling of representational lithologies can be added to this activity for little cost (Hurtado Jr, Young, Bleacher, Garry, & Rice, 2013). However, we have shown that the identification of samples for specific laboratory study and analysis requires further thought, preparation, and integration with science operations planning. We suggest that sampling of this type be considered a separate activity from field characterization, and that crew members be trained in sampling needs for different types of analytics (representative lithologies vs. specialized samples).

2. Crew training should include exposure to the laboratory techniques and analyses that will be used on the samples. Our hypothesis posited that crew member knowledge of how the samples would be used upon return would aid them in choosing and acquiring relevant samples. Our testing bore this hypothesis out, where crew

members in Tests A and B efficiently focused on sampling for specifically-defined laboratory activities, though they also had previous contextual information about the outcrop. Nevertheless, exposing the crew members to the laboratory analysis techniques that will be used gives the crew first-hand knowledge of sample size, state, and selection criteria before getting into the field, potentially increasing both efficiency and science return.

3. Though not explicitly tested in these scenarios, the use of field-portable geochemical technologies (e.g., Young, Bleacher, and Evans, 2014) may have potential for increasing crew member contextual knowledge of the outcrop to support sample collection strategies. For example, a field portable X-ray Fluorescence unit may have enabled the crew members to interrogate the samples for K abundance in real-time, ensuring they their ability to collect samples suitable for K/Ar or $^{40}Ar/^{39}Ar$ dating. If the crew members were able to high-grade sample locations using a combination of field mapping and real-time chemical analysis, the likelihood of collecting valuable geochronologic samples may increase, which may be worth the additional time they would have to spend sampling to deploy these technologies. This recommendation merits further consideration in future test scenarios.

4. Collecting and using samples from analog field studies is an important part of test fidelity. Though simulations such as these can teach us a fair bit about decision-making processes and timeline building, one EVA participant noted that when he wasn't collecting "real" samples, he wasn't at his best. For example, on a previous study at Pavilion Lake (Lim, Brady, and the Pavilion Lake Research Project Team, 2011), the underwater nature of sample collection ensured that only one person (the crew member) was able to collect any samples at all, and a graduate student thesis was riding on the outcome. Conversely, at WCIS, all participants could re-walk the test outcrops, and collect their own samples if needed. This effect suggests that higher-fidelity studies involving truly remote science team participants conducting actual scientific studies, such as the FINESSE studies, merit further attention to capture lessons for application to future crew situations.

References

Abercromby, A. F. J., Chappell, S. P., & Gernhardt, M. P. (2013). Desert RATS 2011: Human and robotic exploration of near-Earth asteroids. *Acta Astronautica*, *91*, 34–48, doi:10.1016/j.actaastro.2013.05.002.

Bleacher, J. E., Eppler, D. B., Tewksbury, B. J., & Helper, M. A. (2014). Astronaut geology training. Paper presented at *Annual Meeting of the Lunar Exploration and Analysis Group*. Laurel, MD: Lunar and Planetary Institute, #3033.

Brady, A. L., Slater, G. F., Omelon, C. R., Southam, G., Druschel, G., Andersen, D. T., Lim, D. S. S. (2010). Photosynthetic isotope biosignatures in laminated micro-stromatolitic and non-laminated nodules associated with modern, freshwater microbialites in Pavilion Lake, B. C. *Chemical Geology*, *274*, 56–67.

Chappell, S. P., Abercromby, A. F., & Gernhardt, M. L. (2013). NEEMO 15: Evaluation of human exploration systems for near-Earth asteroids. *Acta Astronautica*, *89*, 166–178, doi:10.1016/j.actaastro.2013.03.002.

Forrest, A. L., Laval, B. E., Lim, D. S. S., Williams, D. R., Trembanis, A. C., Marinova, M. M., . . . McKay, C. P. (2010). Performance evaluation of underwater platforms in the context of space exploration. *Planetary and Space Science*, *58*, 710–716, doi:10.1016/j.pss.2009.08.007.

Heldmann, J. L., Colaprete, A., Cohen, B., Elphic, R., Garry, W., Hodges, K., . . . Tornabene, L. (2013). Terrestrial analog field investigations to enable science and exploration studies of impacts and volcanism on the Moon, NEAs, and moons of Mars. Paper presented at *American Geophysical Union*. San Francisco, CA, #P54B-01.

Hurtado Jr, J. M., Young, K., Bleacher, J. E., Garry, W. B., & Rice, Jr, J. W. (2013). Field geologic observation and sample collection strategies for planetary surface exploration: Insights from the 2010 Desert RATS geologist crewmembers. *Acta Astronautica*, *90*, 344–355, doi:10.1016/j.actaastro.2011.10.015.

Lim, D. S. S., Brady, A. L., & The Pavilion Lake Research Project (PLRP) Team (2011). A historical overview of the Pavilion Lake Research Project – Analog science and exploration in an underwater environment. *Geological Society of America, Special Paper*, *483*, 85–116.

Lim, D. S. S., Warman, G. L., Gernhardt, M. L., McKay, C. P., Fong, T., Marinova, M. M., . . . Williams, D. (2010). Scientific field training for human planetary exploration. *Planetary and Space Science*, *58*, 920–930.

Lofgren, G. E., Horz, F., & Eppler, D. (2011). Geological field training of the Apollo astronauts and implications for future manned exploration. *GSA Special Papers*, *483*, 33–48, doi:10.1130/2011.2483(03).

NASA (2015). *Analog missions and field testing*. Retrieved from https://www.nasa.gov/exploration/analogs/.

Osinski, G. R., Brunner, A., Collins, G. S., Cohen, B. A., Coulter, A., Elphic, R., . . . Young, K. (2015). Revisiting the West Clearwater Lake Impact Structure, Canada. Paper presented at *Lunar and Planetary Conference, 46*. Houston: Lunar and Planetary Institute, #1621.

Phinney, W. C., Simonds, C. H., Cochran, A., & McGee, P. E. (1978). West Clearwater, Quebec Impact Structure, Part II: Petrology. *Proceedings of Lunar and Planetary Science Conference*, *9* (pp. 2659–2694).

Simonds, C. H., Phinney, W. C., McGee, P. E., & Cochran, A. (1978). West Clearwater, Quebec impact structure. I – Field geology, structure and bulk chemistry. II – Petrology. *Proceedings of Lunar and Planetary Science Conference*, *9* (pp. 2633–2693).

Yingst, R. A., Cohen, B. A., Ming, D. W., & Eppler, D. B. (2011). Comparing Apollo and Mars Exploration Rover (MER)/Phoenix operations paradigms for human exploration during NASA Desert-RATS science Operations. *Acta Astronautica*, doi:10.1016/j.actaastro.2011.10.001.

Yingst, R. A., Cohen, B. A., Hynek, B., Schmidt, M. E., Schrader, C., & Rodriguez, A, (2014). Testing Mars Exploration Rover-inspired operational strategies for semi-autonomous rovers on the moon II: The GeoHeuristic operational Strategies Test in Alaska. *Acta Astronautica*, *99*, 24–36, doi:10.1016/j.actaastro.2014.01.019.

Young, K. E., Bleacher, J. E., Evans, C. A., Arzoumanian, Z., Gendreau, K. & Hodges, K. V. (2014). The integration of handheld technologies into planetary surface exploration. Paper presented at *Lunar and Planetary Science Conference, 45*. Houston: Lunar and Planetary Institute, #3043.