Geologic Exploration Enabled by Optimized Science Operations on the Lunar Surface

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And the NASA FINESSE and BASALT Teams
Conducting Science and Exploration in the Realm of the Moon & Beyond

Can address these aspects via **ANALOG MISSIONS** to establish operational and engineering design to support science and exploration missions.

- **FINESSE = SSERVI** (PI Heldmann)
- **BASALT = PSTAR** (P Lim)

Program leveraging for maximum benefit to NASA (e.g., personnel, travel, post-docs, comms, software, instruments, etc).

Slides adapted from FINESSE NPP Alex Sehlke Invited Keynote Lecture at Sensors Expo, San Jose, CA (June 2017)
PARTNERS

- **Scientists** – Geologists (volcanology and impact cratering), Planetary Scientists, Professors and K-12 Teachers
- **Engineers** – Experts in communications, instrumentation, imagery, robotics, digital terrain modeling, etc.
- **Post-doctoral Research Fellows** – Mostly volcanology and planetary science
- **Students** – High School, University Undergraduates & Graduates at ALL levels
- **Educators and Media Personnel** – Specialists in E/PO activities, programmatics, and promotional articles; Teachers and Museum experts at all levels
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**Participating Institutions:**


Astronauts!

Current (Active), Former (Retired), and New (Class of 2017!) Astronauts are active participants in FINESSE – BASALT Programs from both NASA and CSA.

PARTNERS

David Saint-Jacques, CSA (FINESSE Clearwater)
Jeff Hoffman, MIT AeroAstro (FINESSE Idaho)
Steve Swanson, Boise State Univ.
Moon, Deep Space and Mars present new operational paradigms for Human Space Flight

- Decision-making at a different cadence than is currently experienced during space exploration.

- With science and discovery as key drivers, what operational concepts, EVA types and support tools will prove successful within this working paradigm?
The Anatomy of a Research Analog

Places on Earth that allow us to approximate operational and/or physical conditions on other planetary bodies and within deep space
West Clearwater Impact Structure (WCIS)

WCIS possesses one of the best records of impact melt rocks and breccias among terrestrial impact structures.

WCIS Field Research Lead: Gordon Osinski (Western University, Canada)

WCIS Geochronology Lead: Kip Hodges (Arizona State University)
West Clearwater Impact Structure (WCIS)

Geochemical and Petrographic Study of Melt Veins at the West Clearwater Lake Impact Structure, Canada

Rebecca Wilks, The University of Western Ontario

Degree
Master of Science

Program
Geology

Abstract
The formation of central uplifts in complex impact craters is poorly understood. It is generally accepted that a weakening mechanism is a necessary precursor to accommodate such a large movement of rock. It has been hypothesized that impact-generated melt may have a significant role in weakening the rock of a crater floor to allow for uplift, but it is uncertain if this melt rock is a product of in situ melting or injected melt. In this study, melt veins within surface and drill core samples of target rocks from the West Clearwater Impact Structure were analysed using optical microscopy, electron microprobe analysis, and bulk chemistry analysis to determine their formation process. Mixing model results suggest that melt vein structures within the very centre of the crater, collected from the surface and at depth exhibit in situ melting, whereas veins around the periphery of the central uplift are formed by the injection of impact melt.

Recommended Citation
http://hdl.handle.net/10214/4195
West Clearwater Impact Structure (WCIS)

Geochemical and PeVeins at the West Clearwater Structure, Canada

Rebecca Wilks, The University of Western Ontario

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Recommended Citation
Wilks, Rebecca, "Geochemical and PeVeins at the West Clearwater Lake Impact Structure, Can Repository: 4195.
http://hdl.handle.net/10.1016j.epsl.2016.07.053

Highlights
- We dated the Clearwater Lake impact craters (Canada) via the (U-Th)/He zircon method.
- Results presented here indicate that the adjacent twin craters formed ~170 Ma apart.
- Suggesting Clearwater East and West impact craters do not comprise an impact doublet.

Abstract
The (U-Th)/He method has been applied to constrain the formation ages of the Clearwater West and East impact structures of Quebec, Canada. Zircons were separated from impact melt samples from a surface exposure at Clearwater West (~32 km diameter), and from a drill core at Clearwater East (~26 km diameter). The (U-Th)/He results indicate ages of 280 ± 27 Ma (2σ, n = 7) for Clearwater West, and 450 ± 56 Ma (2σ, n = 8) for Clearwater East. Our (U-Th)/He date for Clearwater West supports the findings of previous Rb-Sr (266 ± 15 Ma, 2σ) and 40Ar/39Ar (280 ± 4 Ma and 238 ± 2 Ma, 2σ) impact melt studies. Our (U-Th)/He date for Clearwater East also overlaps with previously published 40Ar/39Ar dating results, which yielded U-shaped spectra, with 'maximum' and 'best-estimate' dates of ~450-470 Ma. Our results support the contention, previously based solely on 40Ar/39Ar data, that the Clearwater West and East impact structures do not comprise an impact doublet that formed coevally from a binary asteroid pair.
West Clearwater Impact Structure (WCIS)

Diachrony of the Clearwater West impact structures indicated by the ($^{207}$Pb/$^{206}$Pb) of Clearwater West, $^{87}$Sr/$^{86}$Sr, and $^{142}$Nd ratios and $^{108}$Ag/Ag$^{+}$ dates from the Clearwater Lake breccia, Clearwater West, British Columbia, and Clearwater East, British Columbia, Canada

Abstract

Large impact structures have complex morphologies, with zones of structural uplift that can be expressed topographically as central peaks and/or peak rings internal to the crater rim. The formation of these structures requires transient strength reduction in the target material and one of the proposed mechanisms to explain this behavior is acoustic fluidization. Here, samples of shock-metamorphosed quartz-bearing lithologies at the West Clearwater Lake impact structure, Canada, are used to estimate the maximum recorded shock pressures in three dimensions across the crater. These measurements demonstrate that the currently observed distribution of shock metamorphism is strongly controlled by the formation of the structural uplift. The distribution of peak shock pressures, together with apparent crater morphology and geological observations, is compared with numerical impact simulations to constrain parameters used in the block model implementation of acoustic fluidization. The numerical simulations produce craters that are consistent with morphological and geological observations. The results show that the regeneration of acoustic energy must be an important feature of acoustic fluidization in crater collapse, and should be included in future implementations. Based on the comparison between observational data and impact simulations, we conclude that the West Clearwater Lake structure had an original rim (final crater) diameter of 35-40 km and has since experienced up to -2 km of differential erosion.
West Clearwater Impact Structure (WCIS)
The ESRP, which includes **Craters of the Moon National Monument and Preserve (COTM)** has geologically young basaltic terrain (eight eruptive episodes between ~15,000-2000 YBP) that provide targets to observe myriad alteration states of basalt and volcanic constructs.

**COTM Science Leads:**
- **Scott Hughes** (Idaho State University)
- **Shannon Kobs** (Idaho State University)
- **Brent Garry** (NASA Goddard)
Basaltic terrains in Hawai‘i provide a range of volcanic features that complement those found on the ESRP. These terrains are dominantly primary basalt, with a wide variety of derived tholeitic (silica saturated/over-saturated) and alkalic (silica undersaturated) compositions with an associated variety of surficial features.

The historically active volcanoes such as Kilauea enable the investigation of relatively sterile, recently-erupted lava as well as basaltic substrates and hydrothermal steam vent environments (fumaroles).
SCIENCE

Science investigations focus on Volcanic Construct Evolution and Magma Source Evolution (cinder cones, lava flows, lava tubes) as SSERVI Target Body analogs.

TECHNOLOGY

Incorporate and evaluate technologies directly relevant to conducting the science, including mobile science platforms, extravehicular informatics, display technologies, communication and navigation packages, remote sensing, advanced science mission planning tools, and scientifically relevant instrument packages.

SCIENCE OPERATIONS

Conduct the science within simulated exploration conditions. Identify which human-robotic concepts of operations (ConOps) and supporting capabilities enable scientific return and discovery.
Operational Concepts

**EVA: Extra-Vehicular Activity;**
Exploration and Sampling

**IVA: Intra-Vehicular Activity;**
Management and Support of EVA, Link to Earth (Landing Module, Habitat)

**Mission Support:** Science Team on Earth
Bi-directional communications under time-delayed conditions to simulate data transmission latencies.
Incorporating New Technologies

- Handheld/portable science instruments
- Taking laboratory into the field
- Collecting data on the go
- Sample evaluation
- Sample prioritization
- Able to scan a larger area
- Possibly capturing a larger variety of samples
- Assessment of objective completion
Visible near-infrared (NIR) spectrometer

ASD Halo Mineral Identifier
- Built in spectral library helpful for evaluation

Spectral resolution 3-9 nm
X-Ray Fluorescence (XRF) spectrometer

Bruker Tracer IV-SD

• Elemental abundances
**InField: A field-portable version of the Resource Prospector NIRVSS instrument**

T. Colaprete, PI

Why “InField” in the field (e.g., Hawaii):

- Learn more about “decisional data” in support of RP instrument, analysis and operations
- Separate our spectra & images to see what kind of value they provide. Value determined by several factors:
  - Science/discovery value
  - Ease/speed of analysis
  - “Decisional” nature of data

**DOC Context multi-color imagery**

**Identification chart**

- Consistent with Lichen
Field Portable Instrument Testing and Evaluations

Objective:
Identify ‘road tested’ instrument capabilities that enable and enhance scientific return during human exploration.

Methods:
Field and lab based evaluation of relevant COTS instruments as they perform within our science and mission architecture requirements

- Comparison of lab vs field results
- Ergonomics and instrument use considerations
- Utility of instrument data in science decision-making pathways (esp. for sample high-grading; “collect the best, leave the rest”)

Output:
Identification of capability requirements for future instrument development leading to hardware development

Sehlke et al. (in prep)
Time and Atmosphere as Parameters

Only limited time during EVAs (~4 to 6 hours) for a limited number of mission days, also limited sample return.

A. Sehlke,
Quality loss due to poor contact

- Avoid analyzing parts if samples with vesicles and/or cracks deeper than ~5 mm.
- Analyses with depths of 10 or more mm are essentially worthless.

Results:
- Reflectivity (measured) decreases about 50% within the first ~8 mm
- Minor absorption features (e.g. 550 and 1150 nm) preserved within first ~8 mm
- Major absorption features preserved (OH and H₂O bands), even up to 20 mm
- Auto mineral ID reproduced between 2-10 mm, afterwards minerals “get lost”
We find that integrating scientific instruments into online data bases (e.g., data streaming) greatly enhances sciences in analog exploration missions.

- Our NIR spectrometer cannot be integrated, so other time-consuming solutions necessary
- Manual read out
- Taking images of built-in screen

Integration into online data base, less time is needed to get information from other planet to Earth, eliminates ambiguity (unclear audio and visual)
Every ounce costs energy: Weight

- VNIR = ~ 6.0 lbs
- XRF = ~ 4.5 lbs
- FTIR = ~ 6.5 lbs
- LIBS = ~ 4.0 lbs

Full suite of instruments adds substantial weight (a total of 21.0 lbs /~10 kg in this case).

- Extra load carried by support team
Ergonomic Perspective

Size
Critical to reach rocks exposed in small holes, cracks and overhang
Bringing students and teachers into the field to conduct science and exploration research alongside FINESSE personnel.

Partnered with Idaho State Space Grant, also have teachers from Massachusetts & Maryland.

Post-deployment analysis of school and community impacts & activities based on Spaceward Bound experience.
Training in Advanced Technology and Exploration Research to Optimize Teamwork in Space

Develop & test a high altitude, multi-spectral imaging system and a low altitude, visible spectrum imaging system of Craters of the Moon National Monument and Preserve.

Funded through NASA USIP (Undergraduate Student Instrument Project) Award to Univ. of Idaho in collaboration with NASA FINESSE.
THANK YOU!

Happy to discuss continued and new collaborations!

@ FINESSE_NASA

Jennifer.Heldmann@NASA.gov
### Science Operations Research Questions & Assessment Methodology

1A. Do the baseline ConOps, systems, & communication protocols developed and tested during previous NASA analogs work acceptably during real scientific exploration? What improvements are desired, warranted, or required?

1B. Do the baseline ConOps, systems, & communication protocols remain acceptable across Mars mission communication latencies & bandwidth considerations? What improvements are desired, warranted, or required?

2A. Which capabilities are enabling and enhancing for scientific exploration?

2B. Does the degree of enabling and enhancing vary as communication latency and bandwidth availability varies?

<table>
<thead>
<tr>
<th>Operational Acceptability: Able to reliably conduct operations with accurate exchange of all pertinent information and without excessive workload or (in-sim) avoidable inefficiencies or delay.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific Acceptability: Able to reliably complete and record scientific observations, measurements, and/or sampling with sufficient quantity, distribution, resolution, accuracy, and/or integrity to test the scientific hypothesis/hypotheses.</td>
</tr>
<tr>
<td>Capability Assessment should reflect the extent to which a capability or potential capability could be useful specifically during a human exploration mission.</td>
</tr>
<tr>
<td>Simulation Quality should reflect the extent to which the simulation combined with other relevant experience and reasonable assumptions allowed meaningful evaluation of the question being asked (e.g., unplanned communications drop-outs or unresolved hardware failures).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scale Rating</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Simulation quality (e.g. hardware, software, procedures, comm., environment) presented either zero problems or only minor ones that had no impact to the validity of test data.</td>
</tr>
<tr>
<td>2</td>
<td>Some simulation limitations or anomalies encountered, but minimal impact to the validity of test data.</td>
</tr>
<tr>
<td>3</td>
<td>Simulation limitations or anomalies made test data marginally adequate to provide meaningful evaluation of test objectives (please describe).</td>
</tr>
<tr>
<td>4</td>
<td>Significant simulation limitations or anomalies precluded meaningful evaluation of major test objectives (please describe).</td>
</tr>
<tr>
<td>5</td>
<td>Major simulation limitations or anomalies precluded meaningful evaluation of all test objectives (please describe).</td>
</tr>
</tbody>
</table>
Scientific & Operational Acceptability

We identified 45 capabilities that were rated at least marginally enhancing for scientific exploration traverses executed under this ConOp.

20/45 were rated essential/enabling (impossible or highly inadvisable to perform mission without capability).

- Traverse precursor imagery
- Station precursor imagery
- Comm coverage maps*
- Voice comm EV ↔ IV
- Text comm IV ↔ ground
- Still imagery
- EV helmet/chest video
- +/- 1m position tracking
- EVA feature pointer (e.g., meter stick to point at features for photos)
- EVA feature marker (e.g., candidate sample location marker)
- EV navigational aids*
- EV text-based display*
- Mapped field notes
- Automatic/manual bandwidth prioritization tool*
- Dynamic leaderboard
- Spatial/temporal synchronization of data
- Tactical EVA management tool
- Handheld minerological instrument**
- Handheld multispec instrument**
- Handheld temperature instrument**

15/45 were rated significantly enhancing (likely to significantly enhance one or more aspects of the mission).

- Virtual training for EV*
- Traverse path planning
- Automated transcription of EV/IV voice
- EV graphical display
- EV timeline management aids*
- +/- 1cm position tracking and marking*
- EV-controlled enhanced still imagery and video*
- Event button*
- Photo leaderboard
- Mobile SA camera with position and orientation tracking
- High-resolution 360º imagery from on/near surface*
- Mobile automated LIDAR**
- Mobile automated multispectral imagery**
- Real-time 3D terrain model*
- Augmented reality*

red = not implemented at high enough fidelity/resolution
red* = not implemented
red** = science-objective dependent