Field Investigations to Enable Solar System Science & Exploration

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SSERVI

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SOLAR SYSTEM EXPLORATION RESEARCH

VIRTUAL INSTITUTE

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Overview

Science and exploration field-based research program aimed at generating strategic knowledge in preparation for the human and robotic exploration of the Moon, near-Earth asteroids (NEAs) and Phobos & Deimos.

We infuse our science program with leading edge exploration concepts:
"**science enables exploration and exploration enables science**."

Overview

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We infuse our science program with leading edge exploration concepts: "**science enables exploration and exploration enables science**."

The primary research objectives of our Science and Exploration programs are as follows:

1) **FINESSE Science**: Understand the effects of volcanism and impacts as dominant planetary processes on the Moon, NEAs, and Phobos & Deimos.
2) **FINESSE Exploration**: Understand which exploration concepts of operations (ConOps) and capabilities enable and enhance scientific return.

Terrestrial Fieldwork

The volcanic and impact records on Earth remain invaluable for our understanding of these processes throughout our Solar System, for it is our primary source of first hand knowledge on volcanic landform formation and modification as well as the three-dimensional structural and lithological character of impact craters.

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Robotic and human terrestrial field investigations will
1) help decipher impact and volcanic science questions
2) address new questions improve the overall architecture of SSERVI Target Body exploration.

Science enables exploration and exploration enables science.

Field Site Selection

1) Science – The study site should be scientifically relevant to the established scientific goals of the investigation. Rationale: science-driven field activities require bona fide scientific investigations that must be enabled by the unique natural laboratory offered by the analog field site with high relevance to the associated science on the Solar System Target Bodies.

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3) Accessibility – The site should not be in a country with an official Department of Foreign Affairs Travel Warning, or in a country where logistics are either very difficult and/or expensive and/or hazardous; this includes sites with severe permitting restrictions. Rationale: if a site is not accessible, then is not sensible or safe to consider it for this analog mission.

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4) Preservation and availability of science targets – The site should be relatively well preserved, such that the features of scientific value are observable in the field. Rationale: In order to address our scientific objectives, we require the presence of particular scientific features. Quite simply, if virtually all the relevant materials have been eroded then there is little scientific value in visiting a site and the analog mission will not achieve its science goals.

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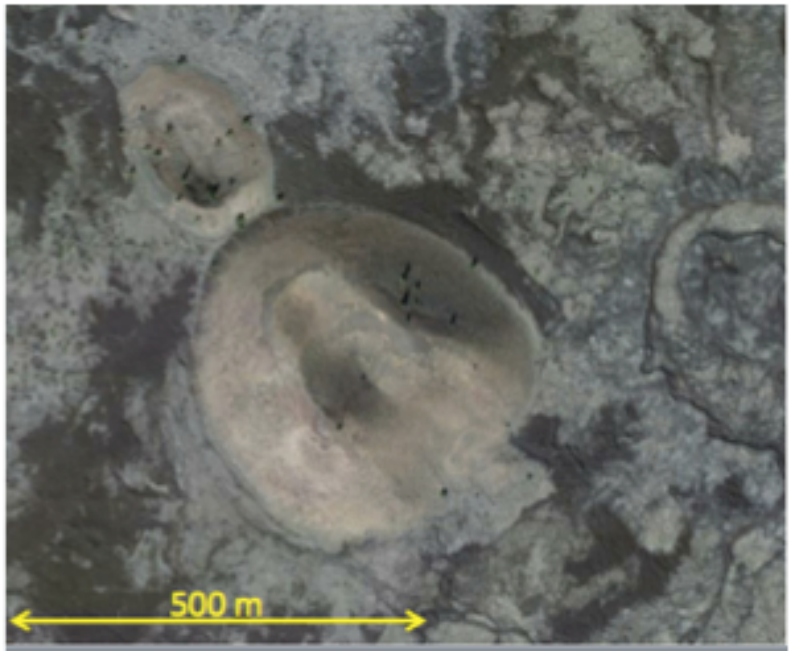
5) Previous work done – These analog missions are science-driven, therefore, in order for high fidelity mission operations, we require sites that are under-explored and investigated, particularly in modern times. Rationale: In order to carry out a science-driven process, our driving paradigm is that the astronauts and mission control team must not have visited a site and further that relatively little recent work has been conducted on these sites.

Craters of the Moon (COTM)

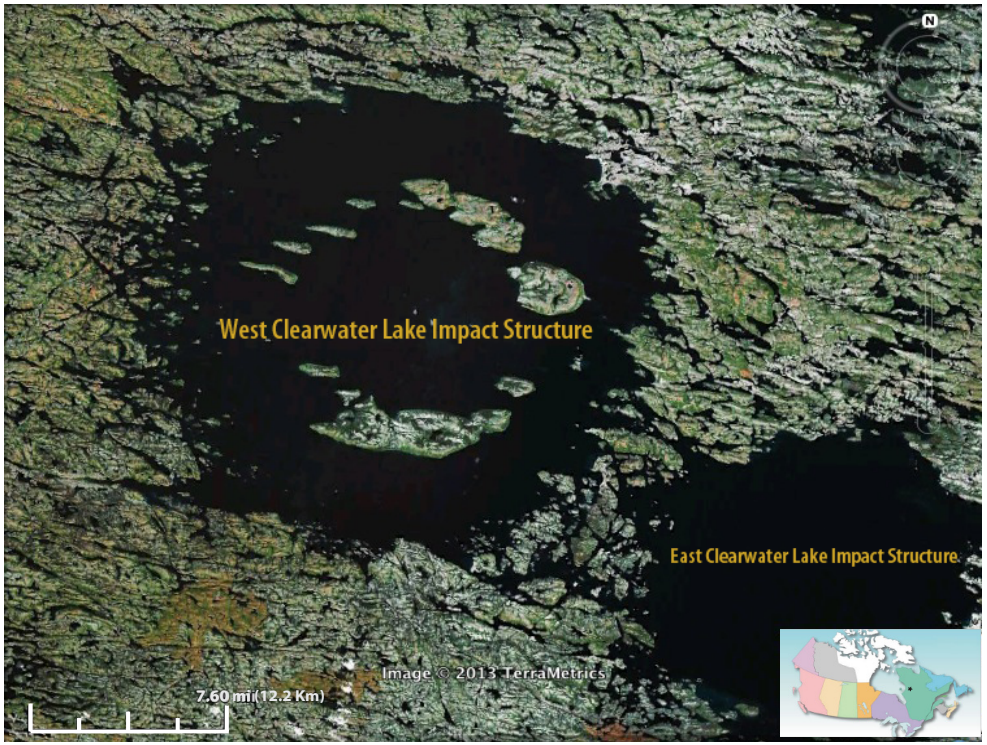
COTM and the surrounding East Snake River Plane (ESRP), a relatively young (~2-15 ka) dominantly basaltic polygenetic volcanic system, hosts a variety of well-exposed undisturbed analogs to volcanic formations on the Moon and other planetary bodies.

Nearly every type of lunar volcanic feature is represented at COTM and immediate surroundings.



West Clearwater Impact Structure (WCIS)

Located in northern Quebec, Canada, Clearwater is the site of an unusual binary impact ~290 Myr ± 20 Ma. WCIS comprises a large ~25 km diameter lake with a discontinuous ring of islands towards its interior.



WCIS appears to possess one of the best records of impact melt rocks and breccias among terrestrial impact structures.

Studies of the various impactites at Clearwater have not been conducted with modern-day analytical techniques and the most accurate map available of the WCIS is 1:50,000 in scale.

Volcanic Science

Volcanism is a fundamental geologic process in the Solar System with evidence for volcanic activity on the terrestrial planets, moon, and asteroids.

FINESSE will focus on two topics related to volcanism:

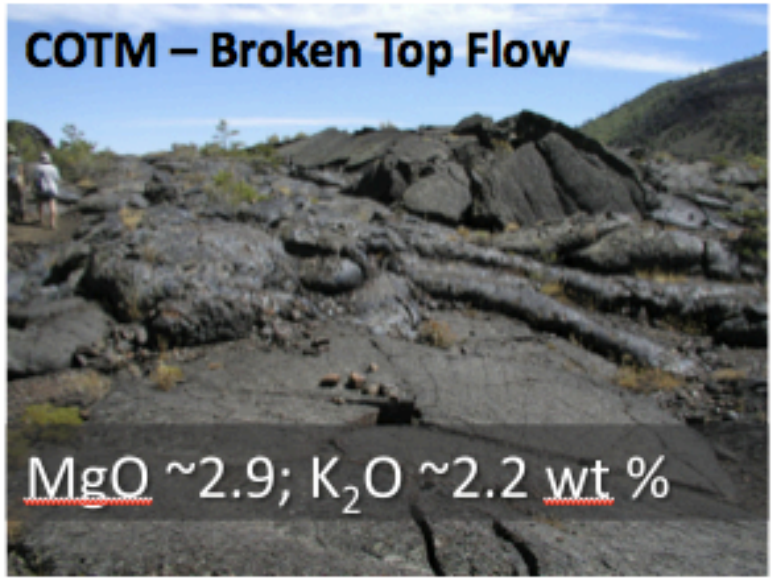
I. Volcanic Construct Evolution

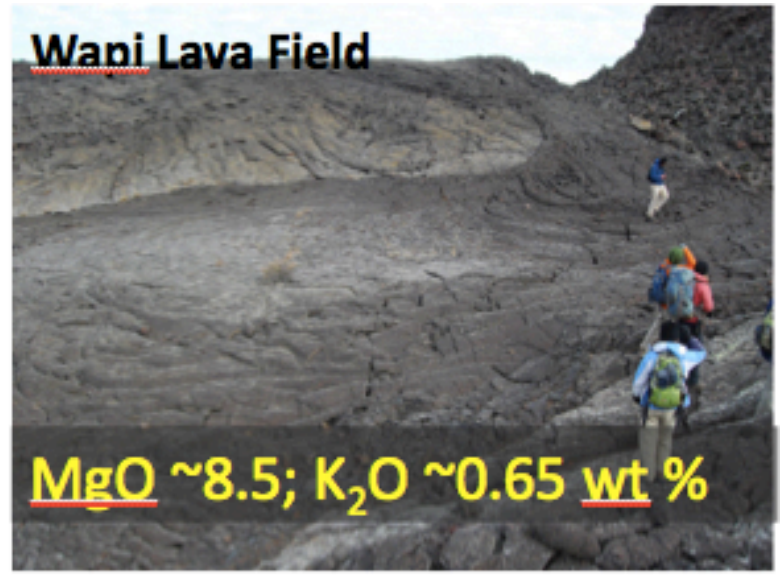
II. Magma Source Evolution

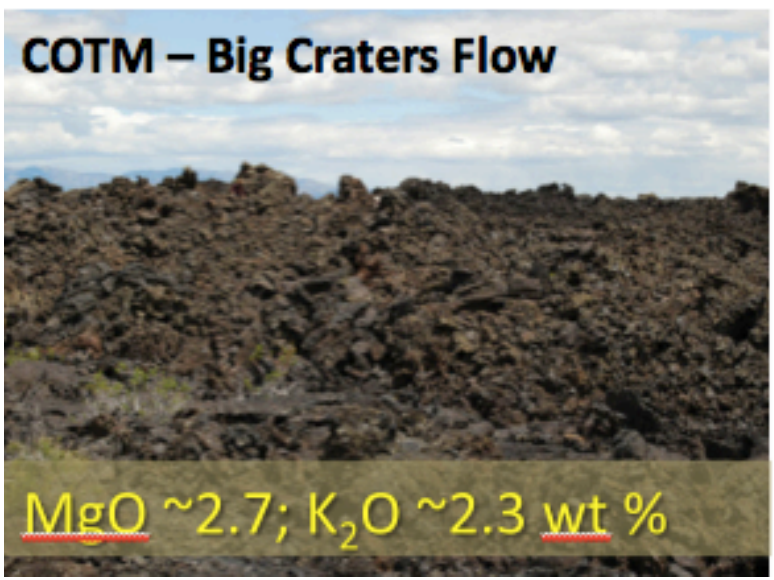
We will investigate **cinder cones**, **lava flows**, and **lava tubes** at COTM and compare them to analogous geologic features on the Moon in Marius Hills and the Hortensius Domes.

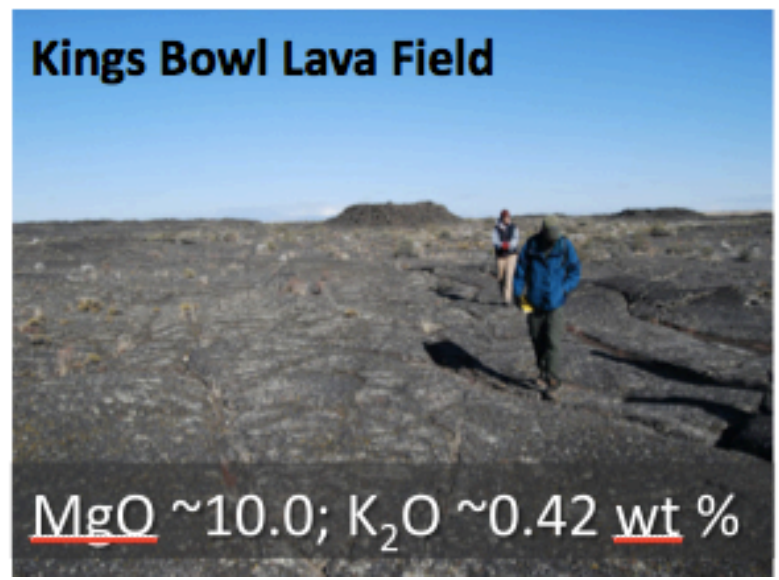
Diverse Lava Flow Types

Variable scales of surface roughness



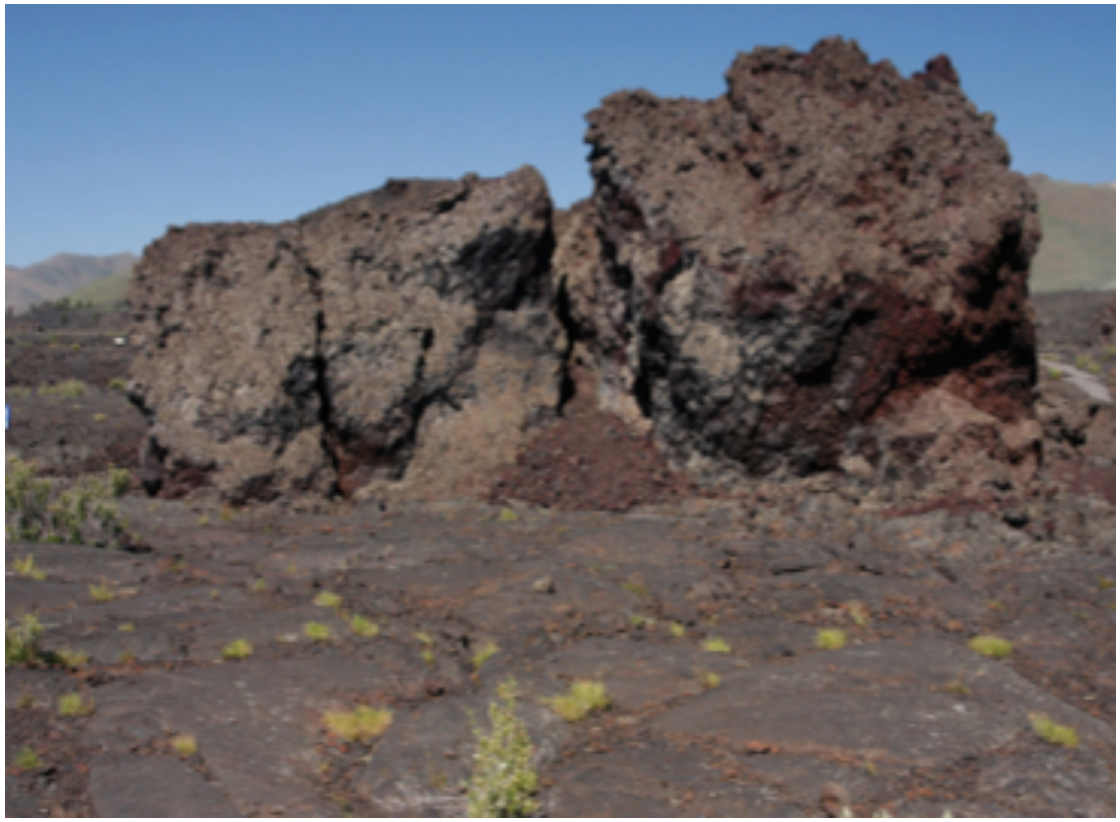






North Crater Lava Flows & Rafted Blocks

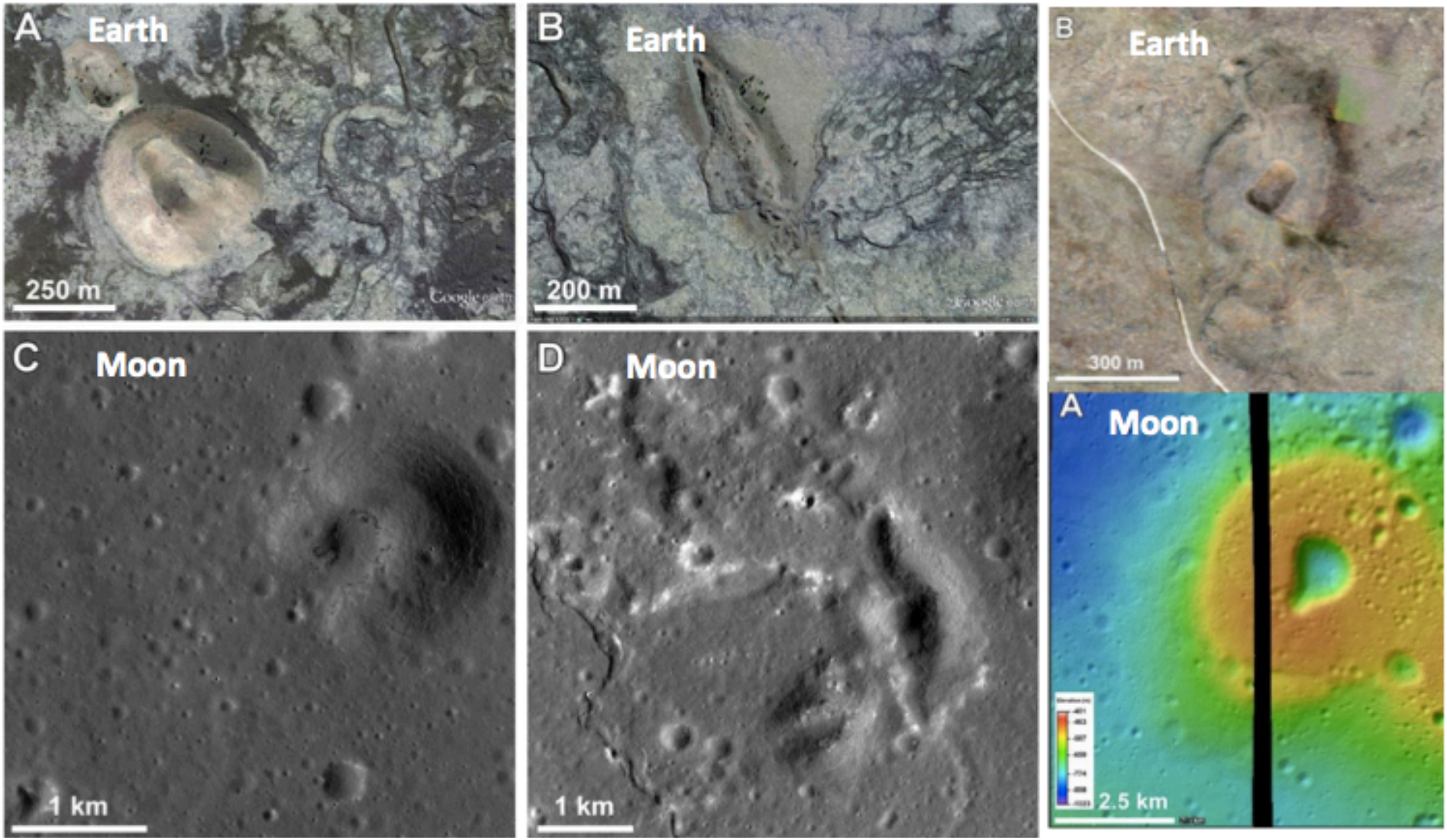
- Potential analog for impact melt flows
- Extreme variation in surface roughness and topography
- Blocks simulate chunks of intact un-melted target



At Craters of the Moon, large chunks of agglutinated spatter from the cone were ripped out and carried several km from vent. Block shown is ~8 m high.

Comparative Planetology

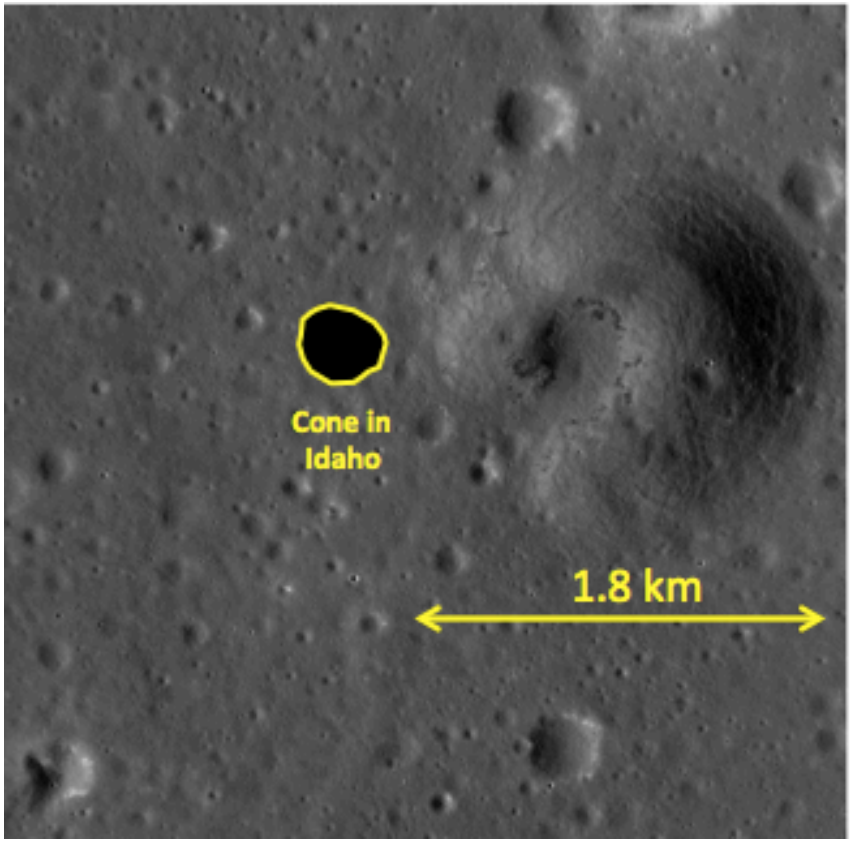
We will investigate cinder cones, lava flows, & lava tubes at COTM and compare them to analogous geologic features on the Moon in Marius Hills & the Hortensius Domes.



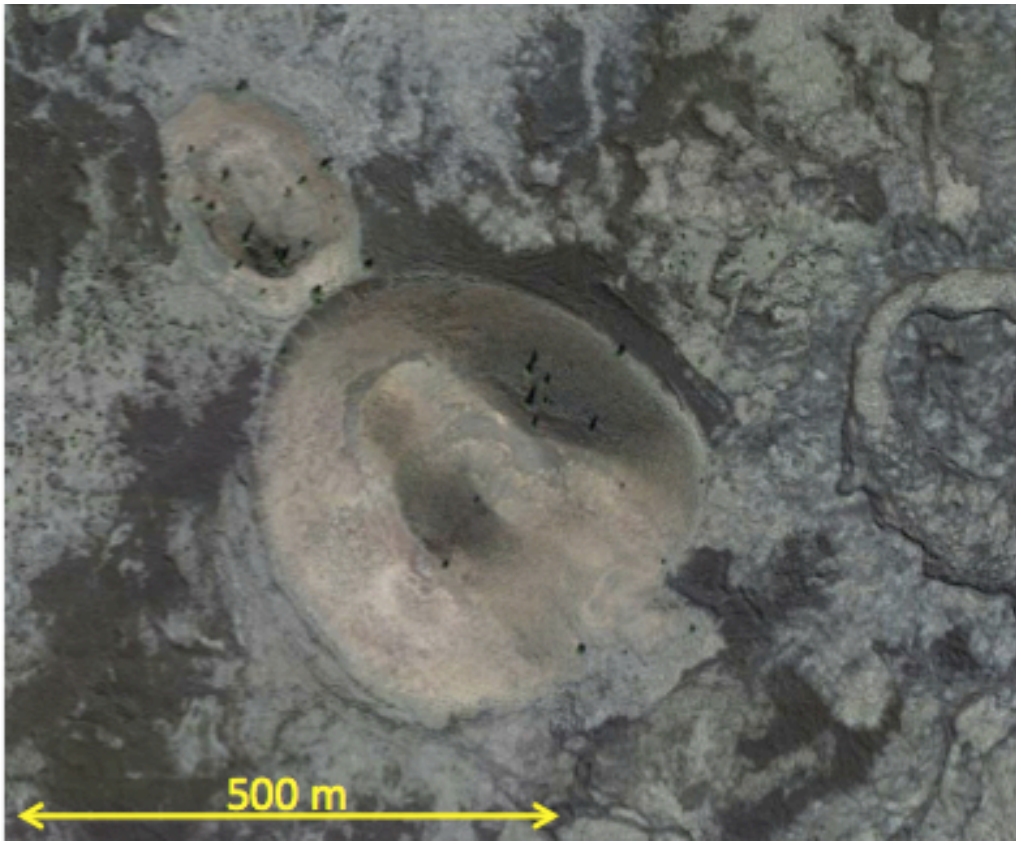
Cone Analog

- Moderately different scales
- Horseshoe morphology
- Embayed by other flows

Cone in Marius Hills

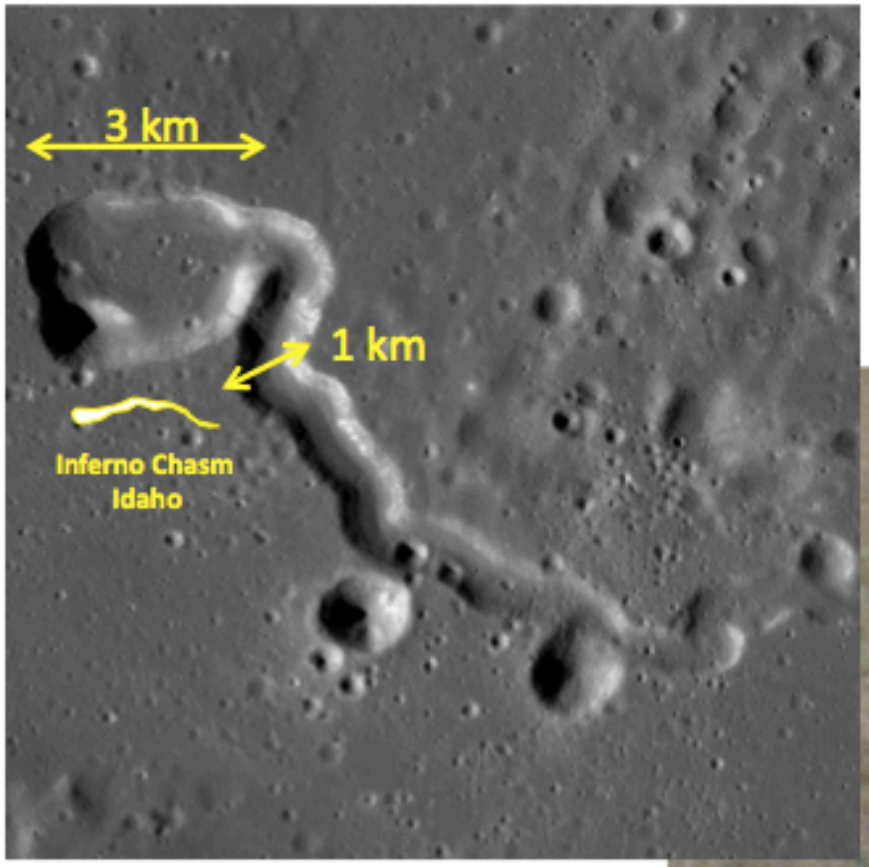


Cone in Idaho



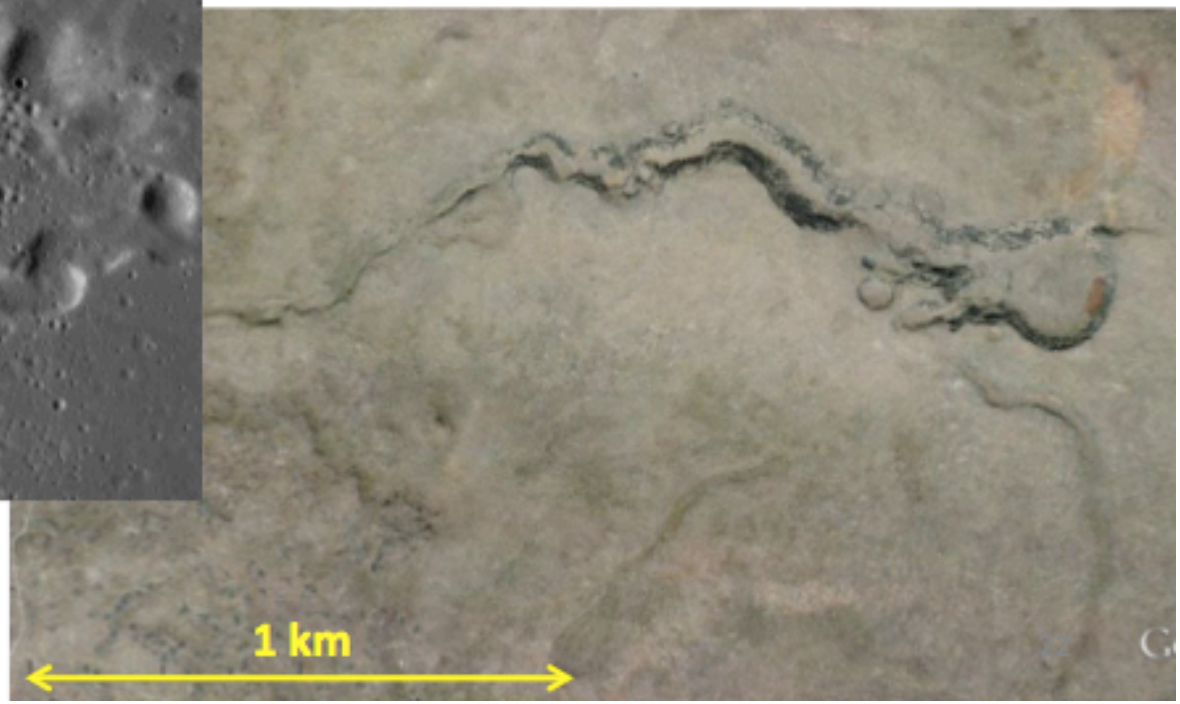
Rille Vent / Chasm Analog

Marius Hills, vent for a rille



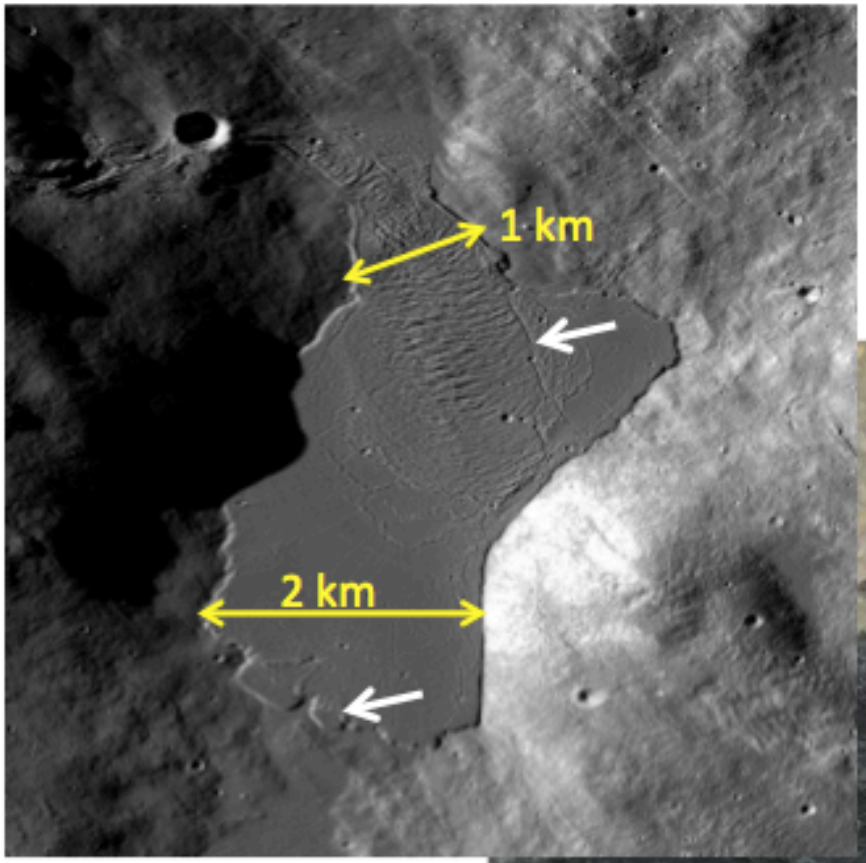
- Very different scales
- Similar morphology
- Circular, rimless vent area
- Meandering channel

Inferno Chasm, COTM (near Kings Bowl)



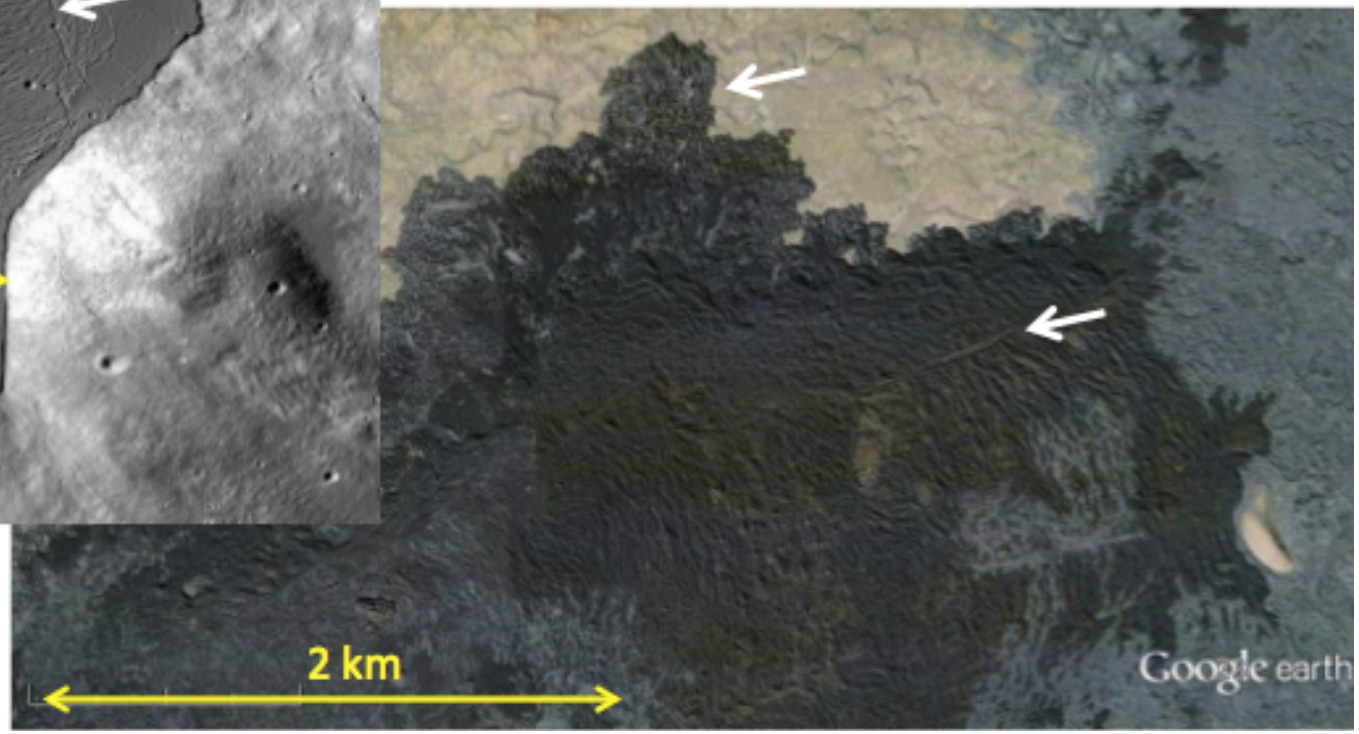
Impact Melt Analog

Impact melt, Tycho crater

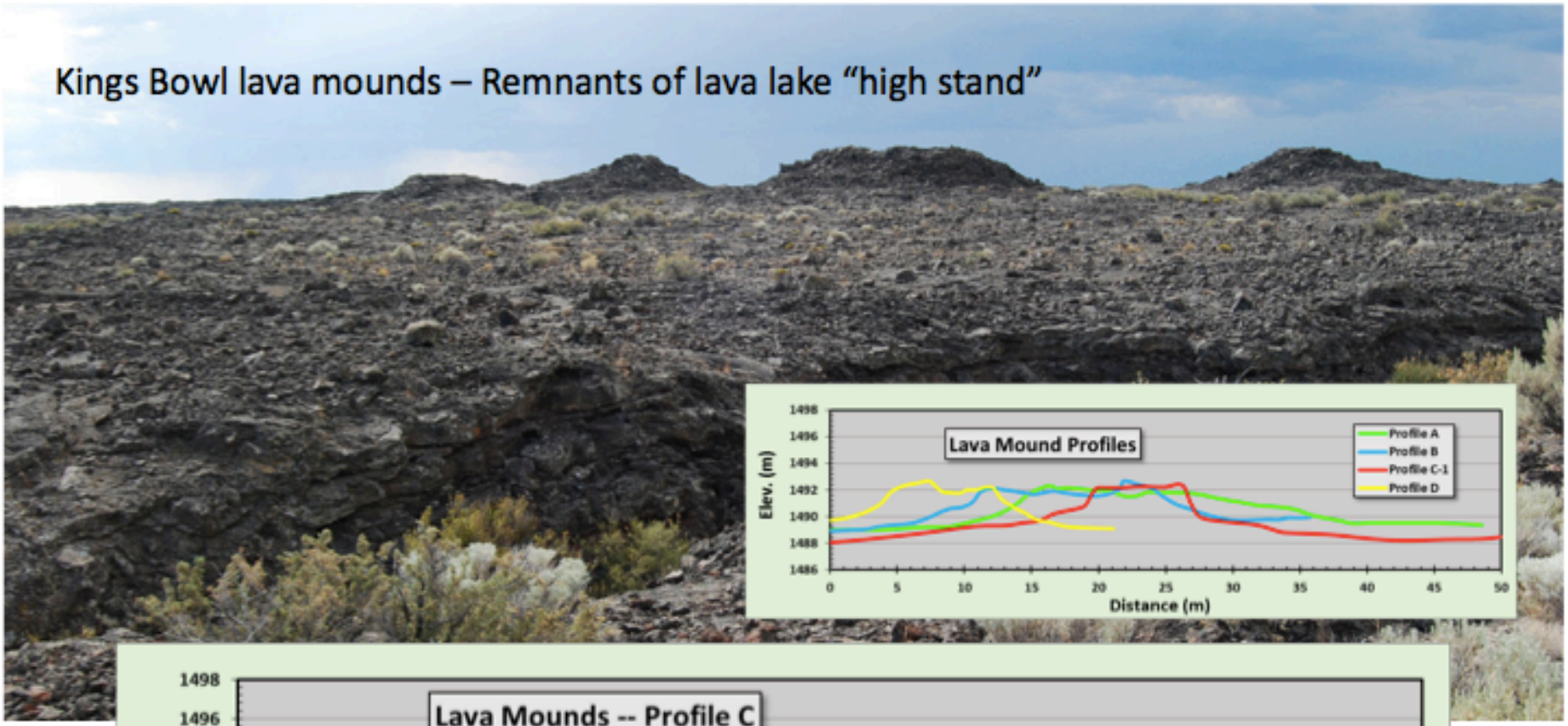


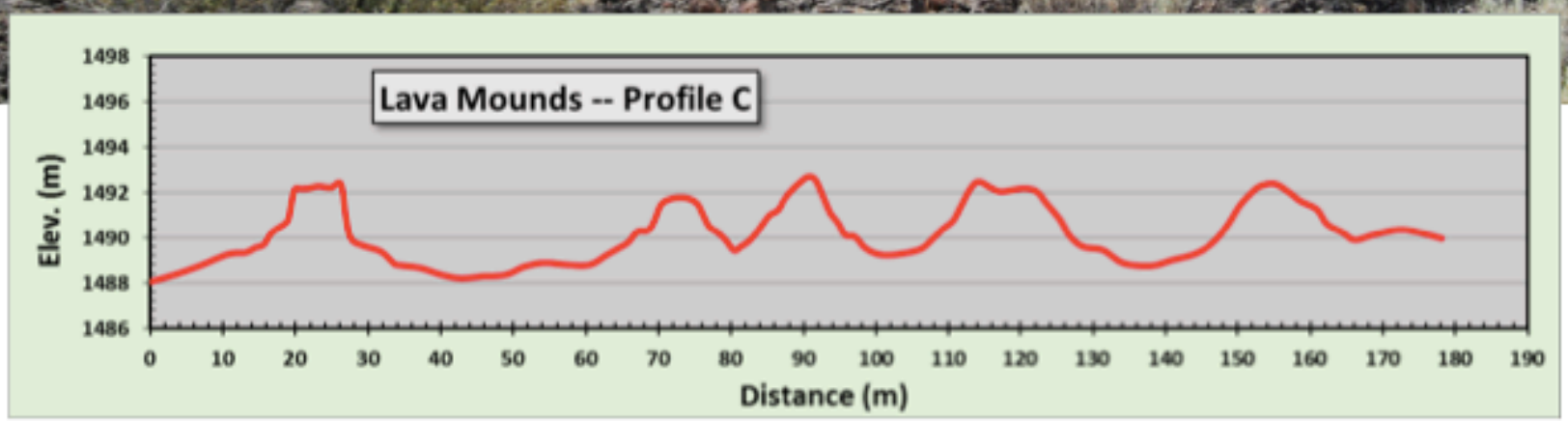
- Scale of flows are similar
- Rippled texture
- Linear scars
- Lobes along margins

North Flow, Idaho (near visitor center)



Idaho Fieldwork 2014





Idaho Fieldwork 2014

FINESSE team measuring boulder dimensions, Craters of the Moon, Idaho.

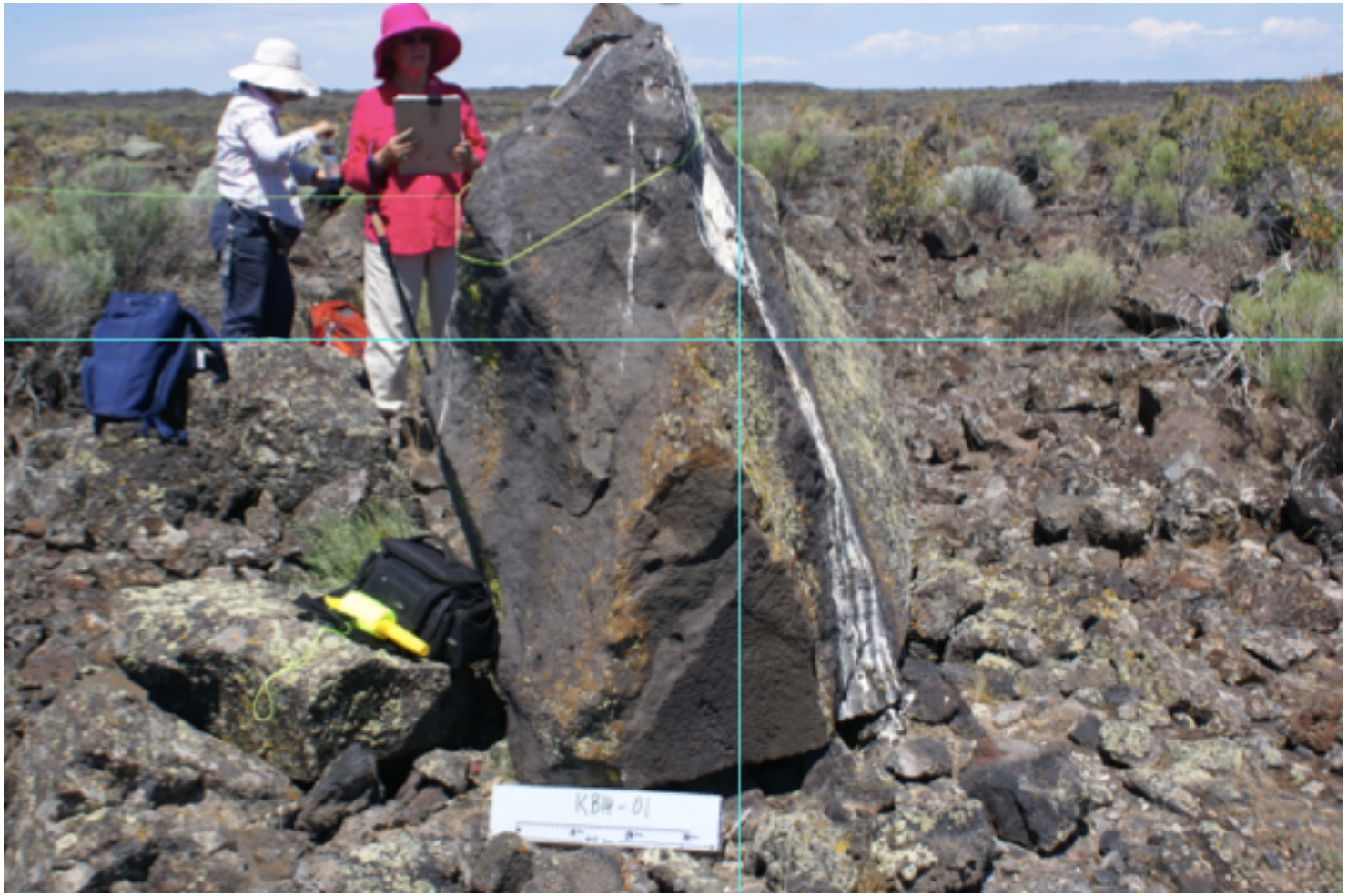


Photo credit: Derek Sears

Idaho Fieldwork 2014

Snakes on a lava plain! (Craters of the Moon, Idaho)

Photo credit: Derek Sears

Idaho Fieldwork 2014

FINESSE Fieldwork 2014

Let's go fly a kite: testing a new platform for science data acquisition.

Photo credit: Derek Sears

Impact Science

Impact cratering is generally acknowledged to be a ubiquitous geological process that affects all planetary objects with a solid surface.

FINESSE will focus on three topics related to impacts:

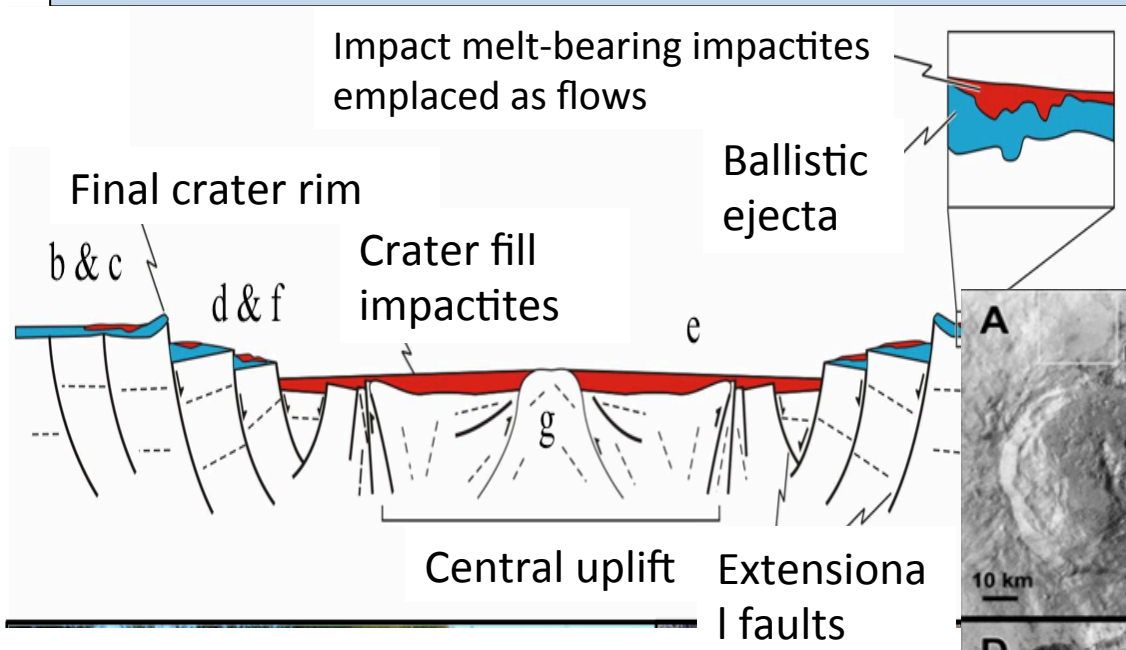
I. Impact Rock Modification

II. Cratering Mechanics

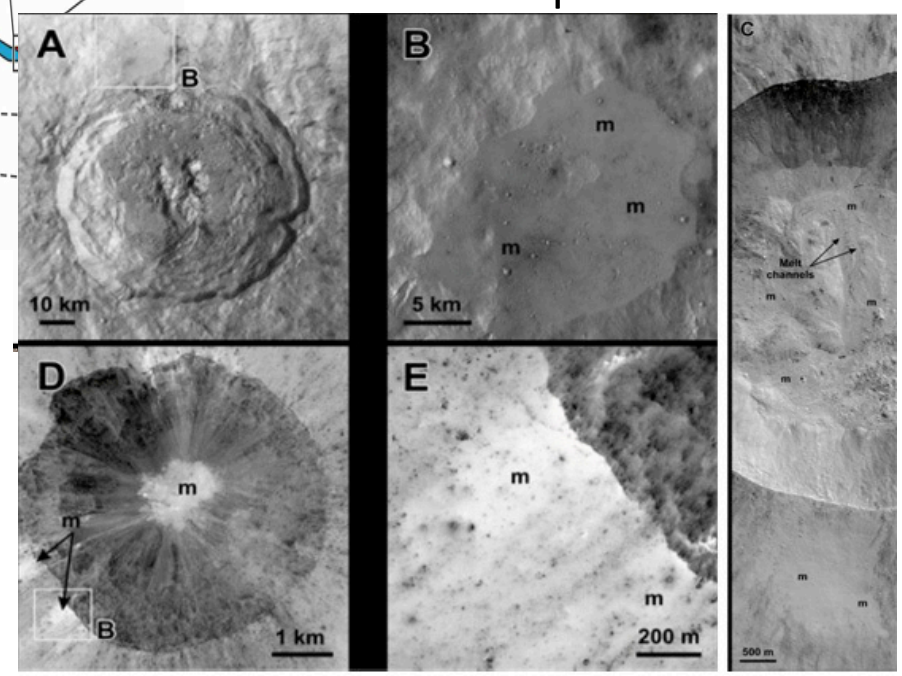
III. Chronologic Record

Impact Rock Modification

The goal of the Impact Rock Modification research is to understand the nature and formation of impact melts, breccias, and the effects of volatiles.



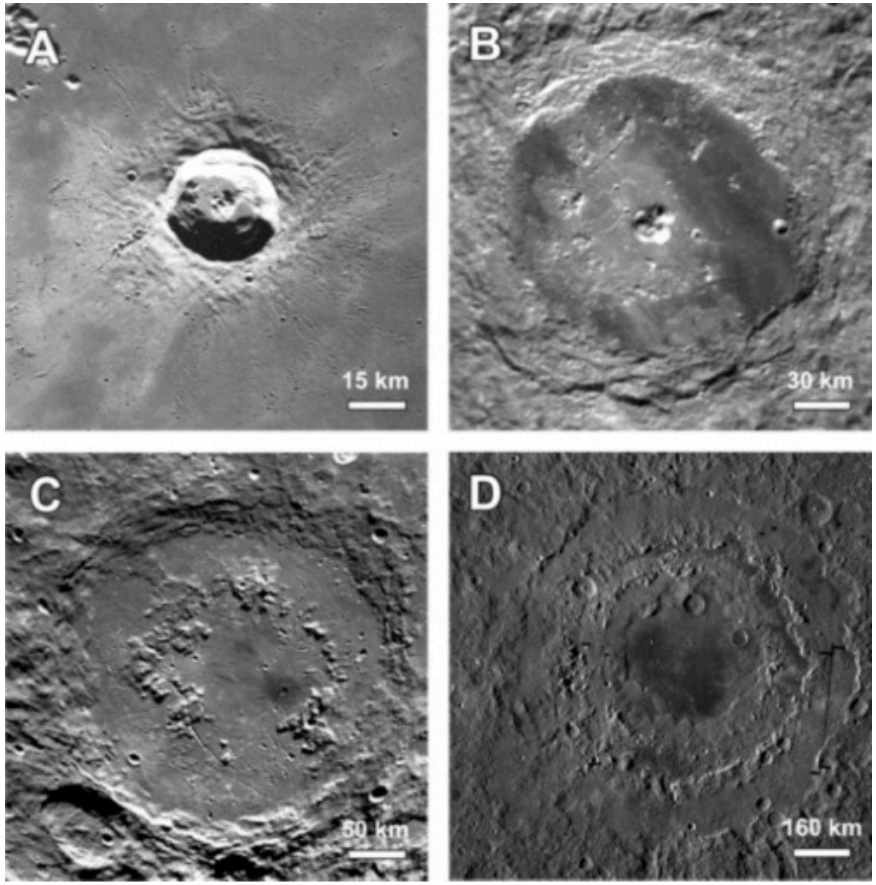
Lunar impact melts



Cratering Mechanics

The goal of the Cratering Mechanics research is to understand the mechanisms of crater formation and influence of target materials.

A) The 27 km Euler Crater with well developed **central peak**.
B) The 165 km diameter Compton Crater, a rare class of **central-peak basin** craters on the Moon.
C) Well developed **peak ring basin** morphology in the 320 km diameter Schrödinger impact crater
D) The ~950 km diameter Orientale Basin **multi-ring basin**.



Chronologic Record

The goal of the Chronologic Record research is to optimize sampling and geochronology protocols and understand the nature of impactors.

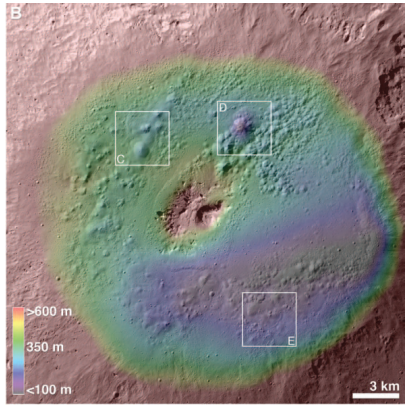
➔We will explore the relative value of three isotopic systems for dating an impact event in a systematic way (U-Pb zircon, $^{40}Ar/^{39}Ar$, ^{4}He from the decay of U, Th, and Sm radioactive isotopes in zircon and apatite).

➔We will use a variety of sampling strategies of distinctive impactite materials, and laboratory analysis of returned samples will permit an assessment of the relative success (as measured by the quality of geochronologic data obtained) of each.

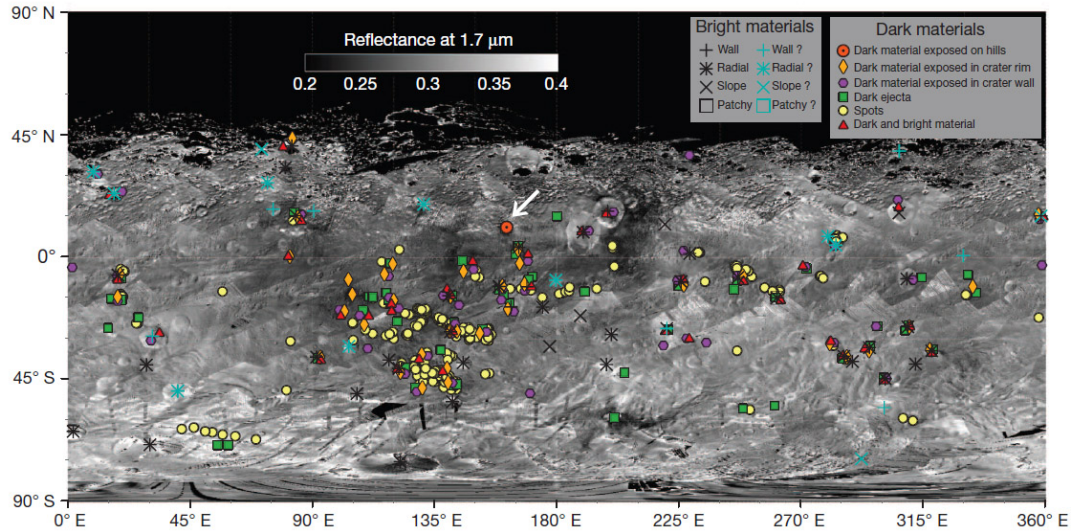
Sample techniques range in sophistication from unconstrained grab sampling of impact materials based on simple imaging or rudimentary field observation to detailed instrumental chemical and textural analysis.

Asteroid Connections

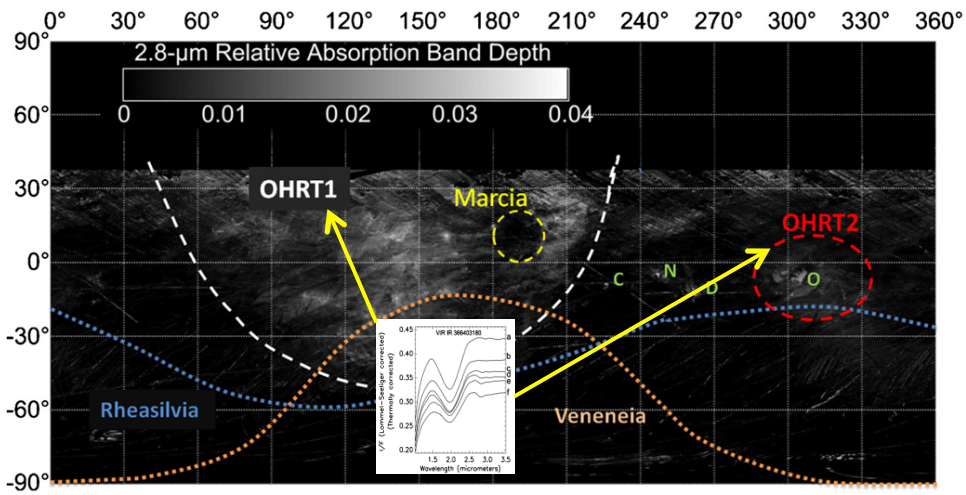
Surprising discoveries of the Dawn mission during its observations of Vesta.



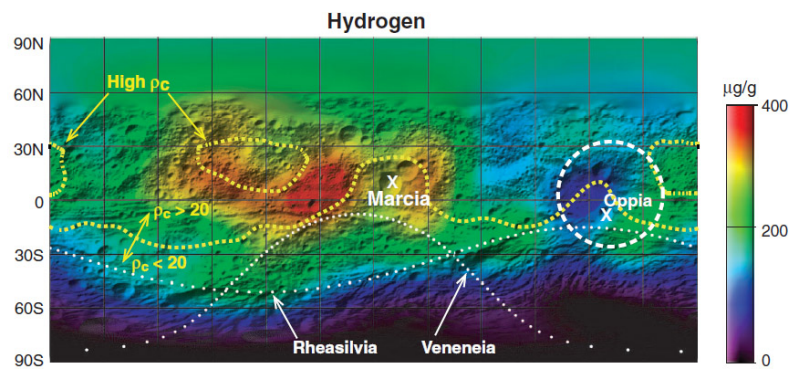
Pits in crater bottom of Marcia (Denevi et al., 2012)



Dark materials on Vesta (McCord et al., 2012)

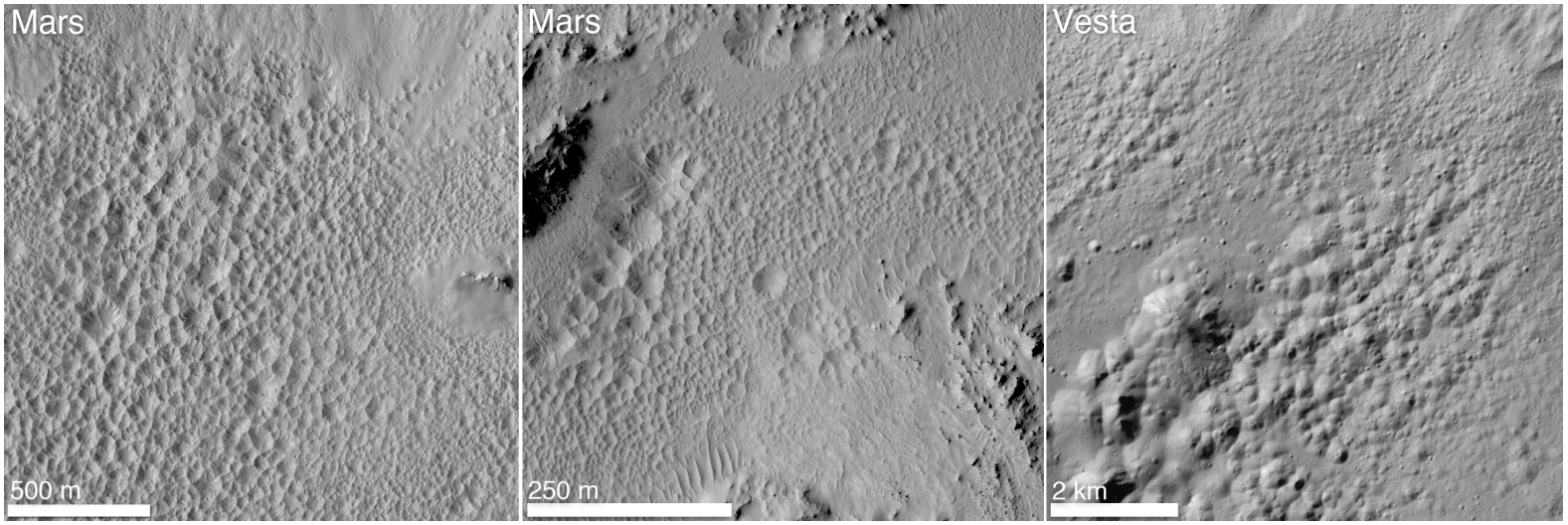


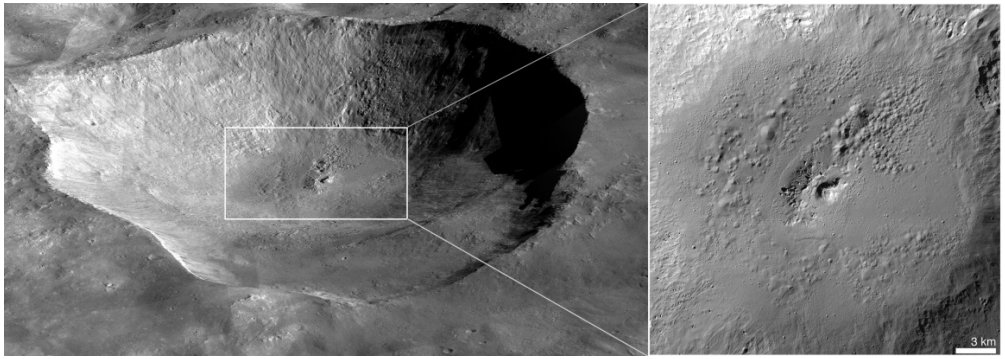
OH abundance by IR spectroscopy (DeSanctis et al., 2012)



H abundances by N spectroscopy (Prettyman et al., 2012)

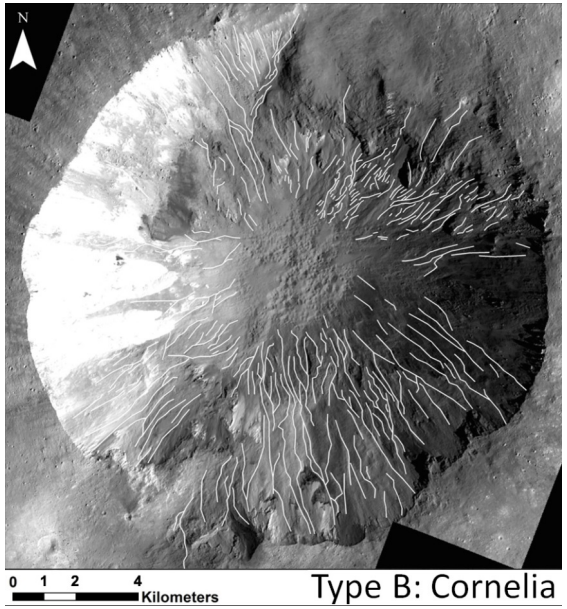
Asteroid Connections





Pits and on Vesta and Mars (Tornabene et al,. 2012)

Gullies surrounding pits in Vesta crater Cornelia. (Scully et al., 2012; 2013)

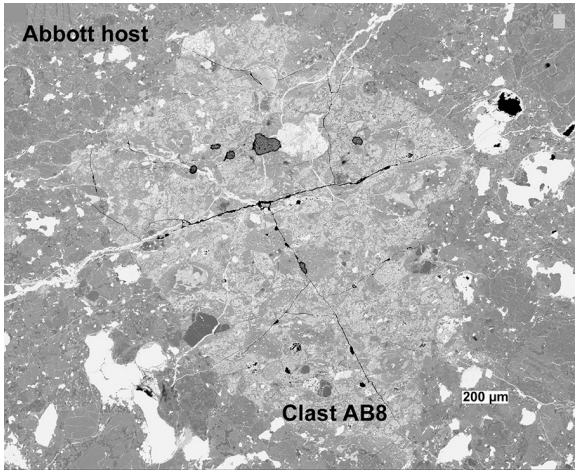


Asteroid Connections

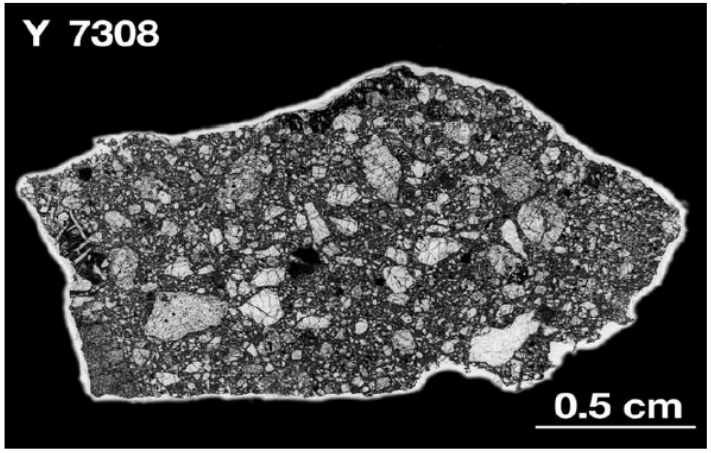
Presence of water has been ascribed to the presence of infall material resembling CM chondrites

Meteorite	Class	H_2O+	H_2O-	C
Orgueil	* CI1	10.80	6.10	2.80
ALH83100	* CM2	12.05	1.33	1.46
ALH83102	* CM2	11.01	1.93	1.39
Banten	* CM2	8.51	2.19	1.78
Murchison	* CM2	8.95	1.14	1.85
Murchison, ma1	* CM2	10.08	2.37	2.03
Murchison, ma2	* CM2	11.61	2.61	2.69
Y-791824	* CM2	10.28	2.22	1.22
Y-793321	* CM2	6.54	2.69	1.35

Analysis of CM meteorites for H_2O and C (wt%) by Jarosewich (1990)



CM clast in the Abbott H5 chondrites (Rubin and Bottke, 2009, BSE image)



CM-like (and other) clasts in a howardite (Bischoff et al., 2006)

West Clearwater Fieldwork 2014

Making plans during the morning briefing for a productive day at West Clearwater Impact Structure.

Photo credit: David Saint-Jacques

West Clearwater Fieldwork 2014

Bugshirt Brigade! FINESSE team members at West Clearwater Impact Structure, fighting bugs and doing science.

Photo credit: Steve Squyres

West Clearwater Fieldwork 2014

Shattercones as evidence of impact origin at West Clearwater.

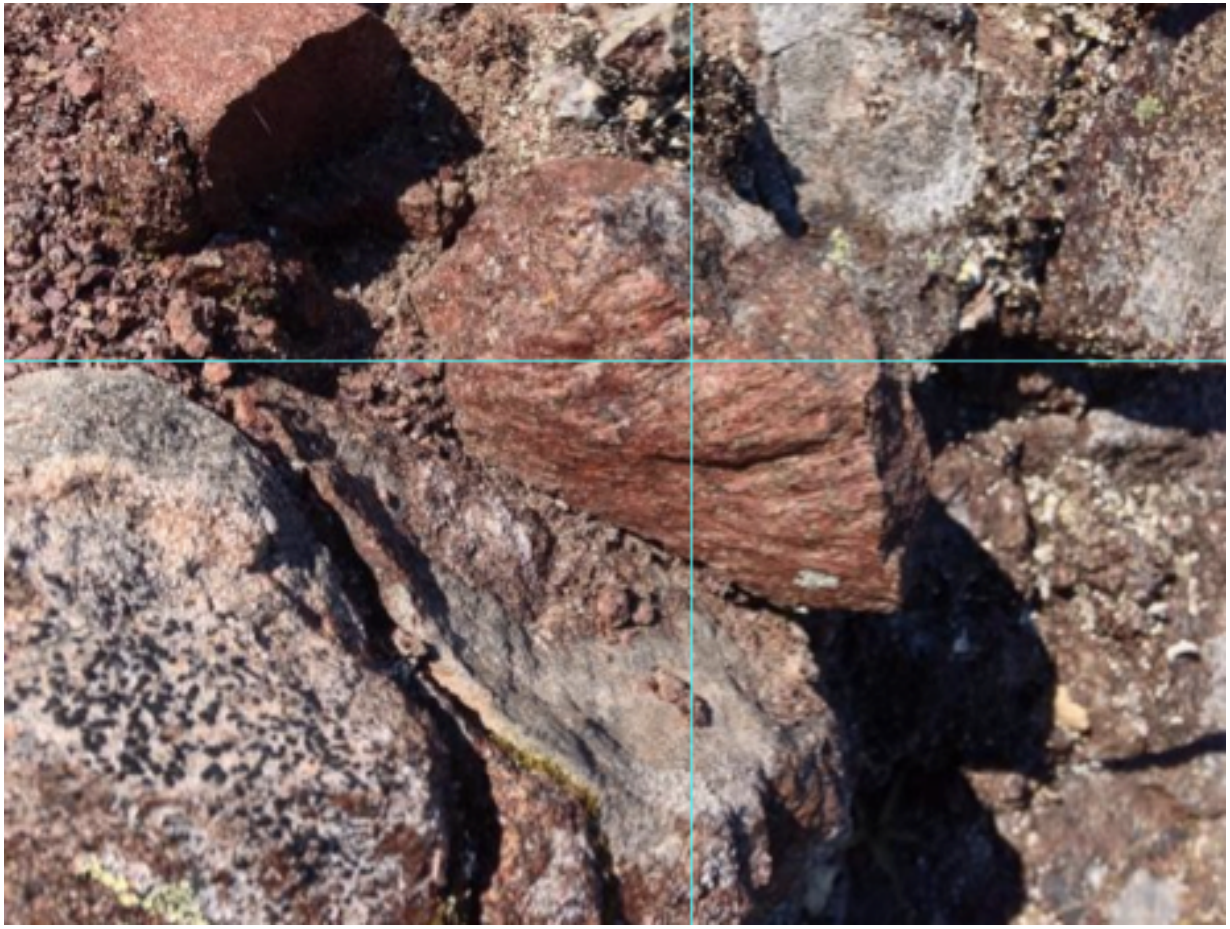
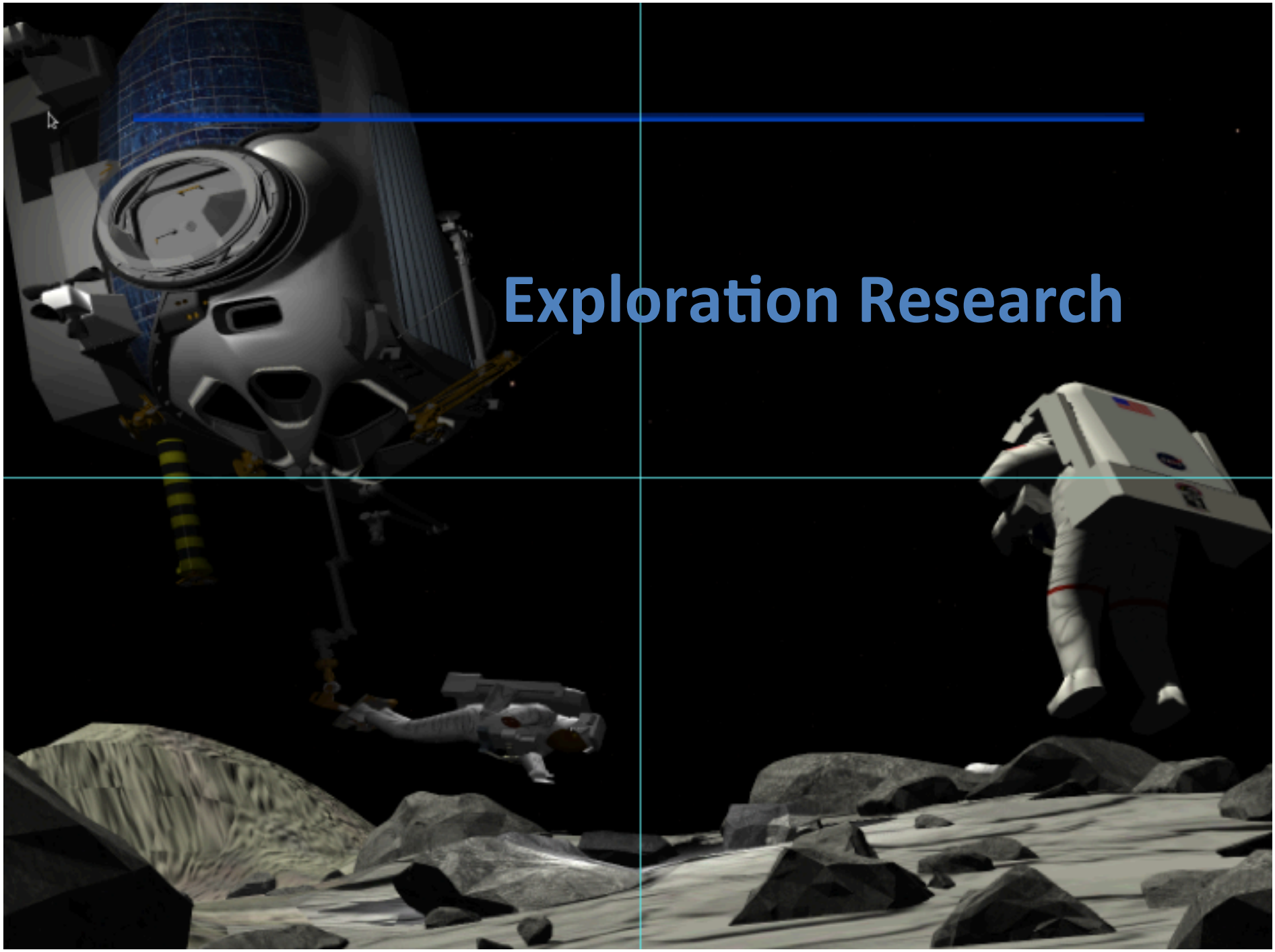


Photo credit: David Saint-Jacques

Exploration Research



Just so we're all on the same page…

"Concepts of Operations" (ConOps) are defined as operational design elements that guide the organization and flow of hardware, personnel, communications, and data products through the course of a mission implementation.

The term "Capabilities" is defined as specific functional mission aspects that can take the form of hardware or software. Additionally, capabilities may be high-level ("architecture level") such as high-bandwidth communications or can be lower-level such as pan-tilt-zoom capability on a camera.

By learning which ConOps and Capabilities are enabling or enhancing (and which are not) early on in the development process, NASA's limited resources are better managed towards value-add systems and support technologies.

Humans conducting science in hostile environments

<u>Human Needs:</u>
Stay Alive
Protect the Environment
Productively conduct your science
Explore to make discoveries

Which Concepts of Operations (ConOps) and Capabilities enable and enhance science return?

Exploration Program

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The primary research objectives of our Science and Exploration programs are as follows:

1) **FINESSE Science**: Understand the effects of volcanism and impacts as dominant planetary processes on the Moon, NEAs, and Phobos & Deimos.
2) **FINESSE Exploration**: Understand which exploration concepts of operations (ConOps) and capabilities enable and enhance scientific return.

FINESSE Exploration Research Areas

1. Robotic ConOps
2. Science ConOps and Mission Capabilities
3. Communications
4. Hardware Capabilities.

Robotic ConOps

Human-robotic partnerships should not be limited to side-by-side activities.

Robotic Roles:
-- *Reconnaissance*
-- *Support*
-- *Follow-up*

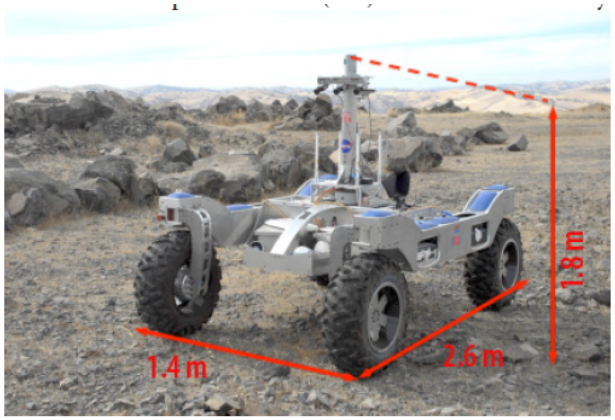


Figure 3.2.3-9. KRex is a four-wheel planetary rover.

Figure 3.2.3-10. UAV-S800 hexacopter with stabilized camera gimbal.

Science ConOps and Mission Capabilities

ConOps designs should be based on operational best practices and required capabilities that enhance and enable scientific data return, discovery, and innovation.

The FINESSE Exploration Program will build on human exploration ops concepts that have been developed and tested at previous NASA analogs and apply and evaluate them within real, non-simulated scientific exploration scenarios involving a mix of human and robotic assets.

COTM Communications and Network Implementation Overview

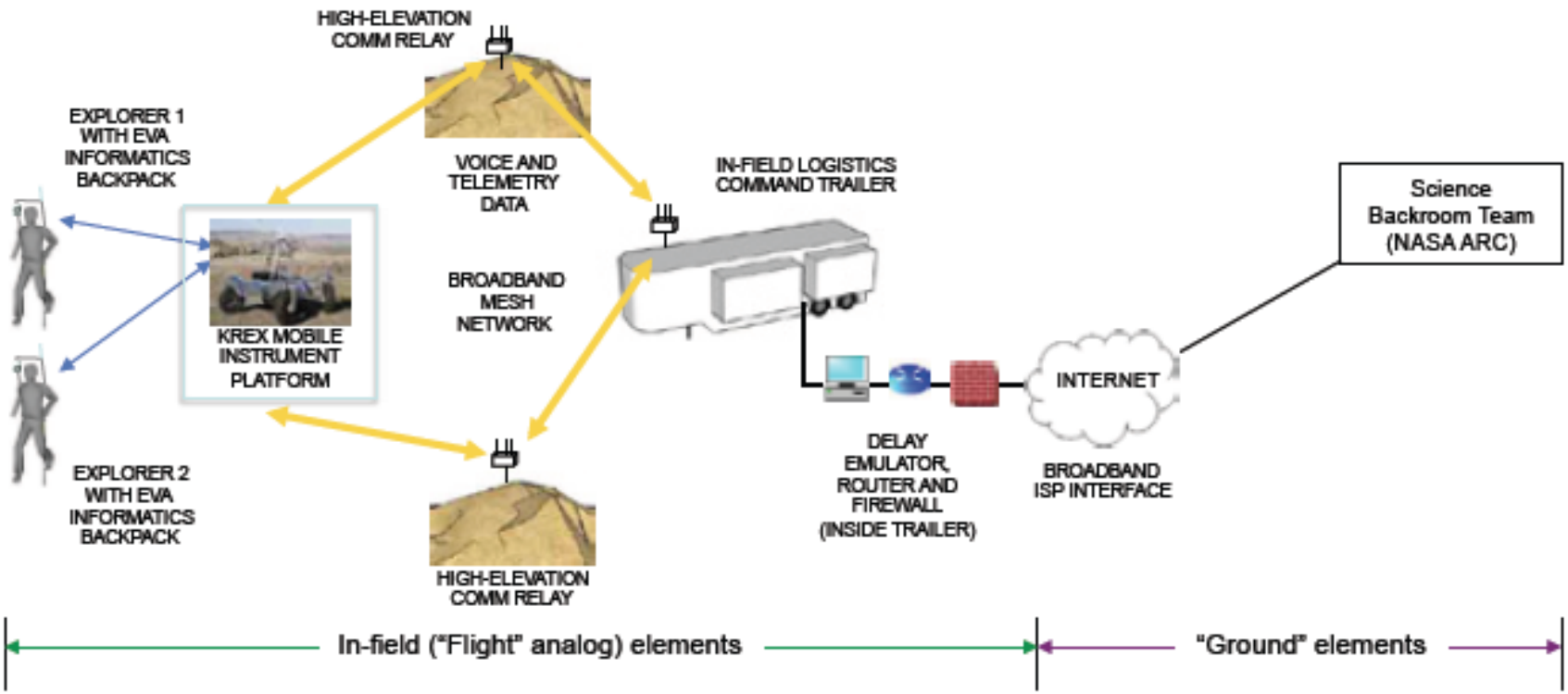


Figure 3.2.3-1. Overview of COTM communications and network implementation plan. Human explorers and robotic assistants will work jointly to meet our science return objectives. In-field "Flight analog" elements will be on space time (i.e., lunar, NEA or Phobos & Deimos delay), while the Ground Elements will be on Earth time.

Science Ops Capabilities

- **Habitat Intravehicular (IV) Workstation**

Science Ops Capabilities

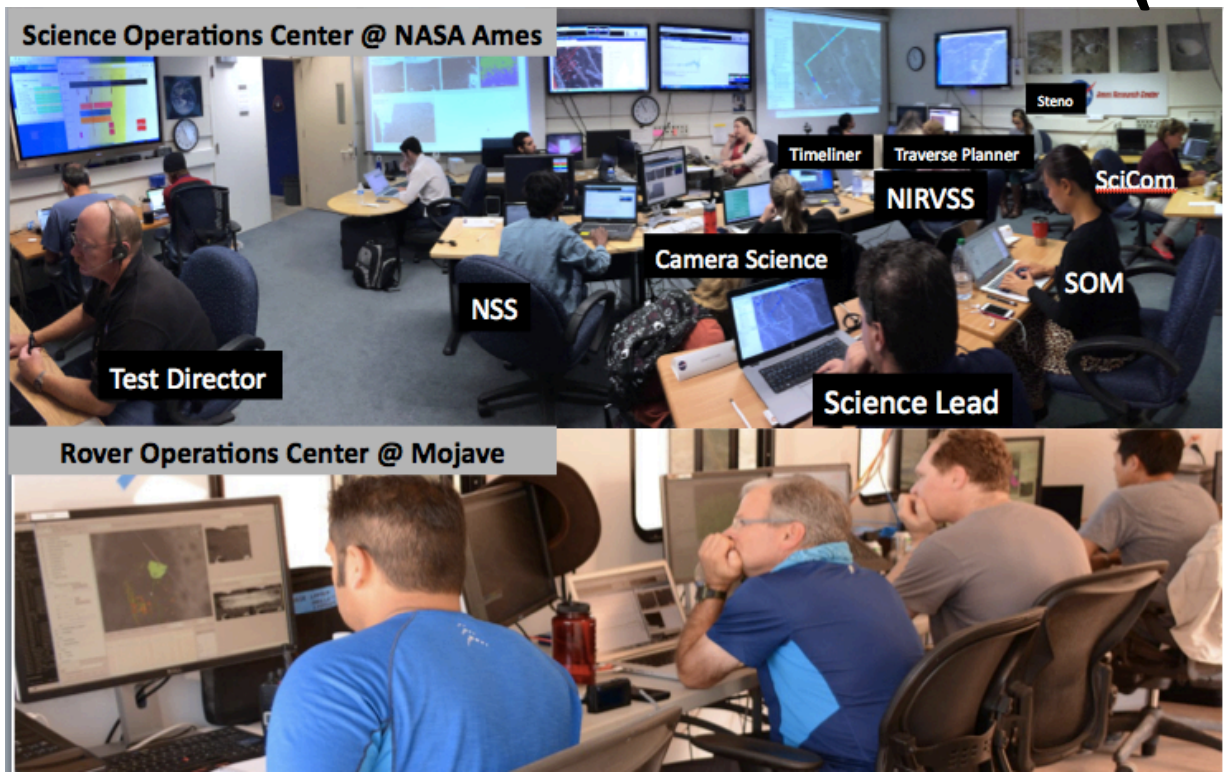
- Habitat Intravehicular (IV) Workstation
- Mobile Instrument Platform (MIP)

Science Ops Capabilities

- Habitat Intravehicular (IV) Workstation
- Mobile Instrument Platform (MIP)
- EVA Shirtsleeve Backpacks

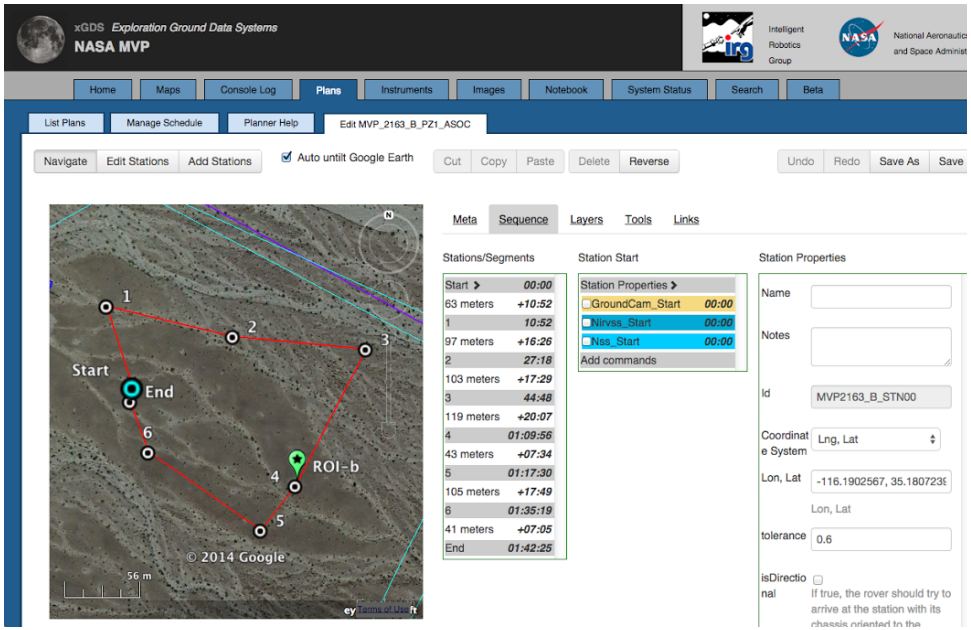
Science Ops Capabilities

- Habitat Intravehicular (IV) Workstation
- Mobile Instrument Platform (MIP)
- EVA Shirtsleeve Backpacks
- distributed Science Backroom Team (dSBT)



Science Ops Capabilities

- Habitat Intravehicular (IV) Workstation
- Mobile Instrument Platform (MIP)
- EVA Shirtsleeve Backpacks
- distributed Science Backroom Team (dSBT)
- Exploration Ground Data Systems (xGDS)



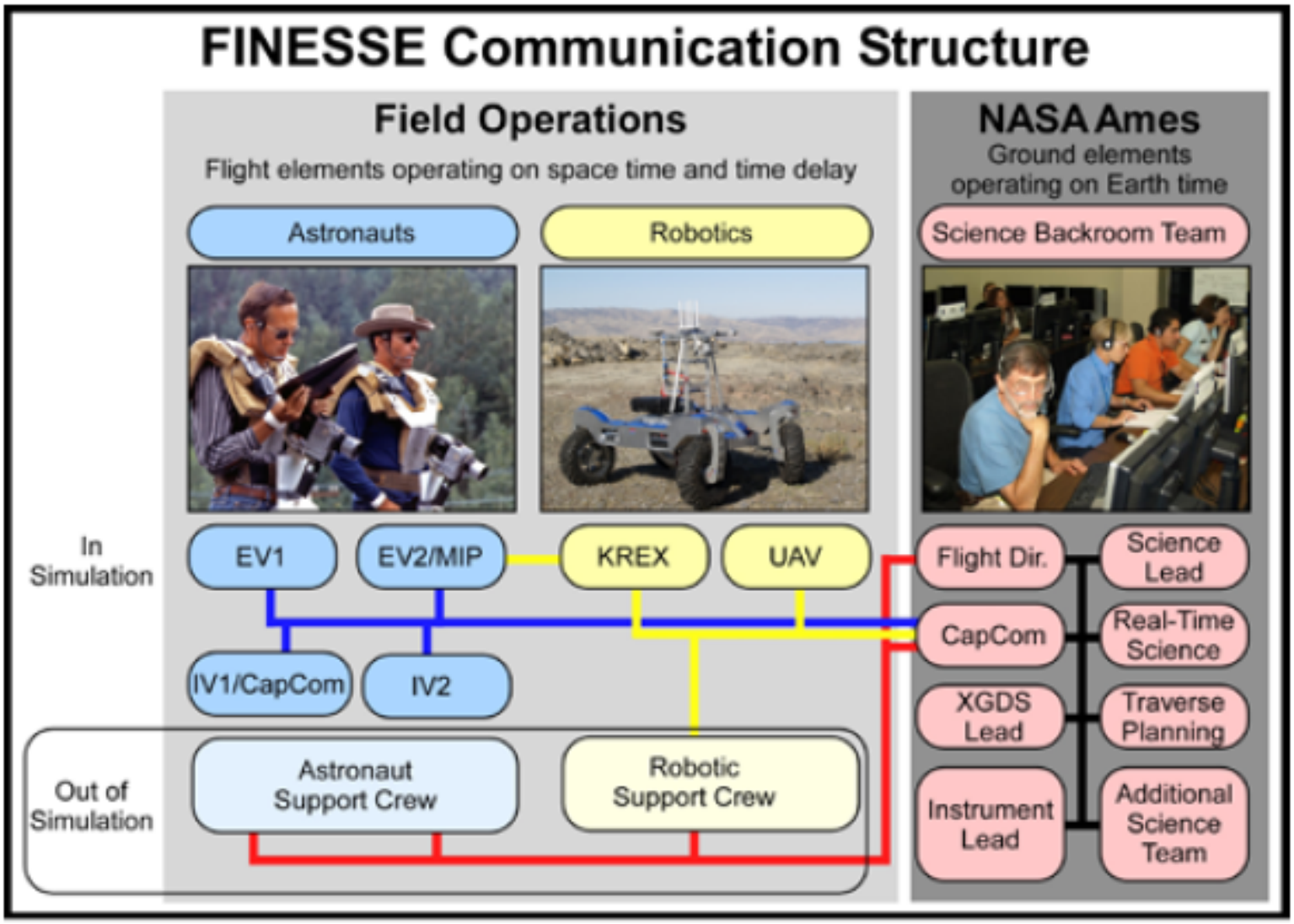


Figure 3.2.3-5. FINESSE Communications structure. Communications delays (lunar, NEA and Phobos & Deimos OWLT) will be implemented. A core team of "out of simulation" support crew will assist with all in-field activities as needed.

Communications

Latencies:

Communications, and specifically the design principles and operational methodologies required to manage unavoidable time-delayed communications during human scientific exploration, will be critical to our future successes in human and robotic spaceflight beyond low Earth orbit.

Simulated Communications Latencies

Table 3.2.3-3. Communication delays between Earth and human destinations[1]. Delay shown for each direction (x2 for round-trip).

	Closest	Furthest
ISS (Direct Uplink)	0.0011 s	0.0012 s
Earth Geosynchronous	0.12 s[2]	
ISS via TDRS Relay	0.25 s	0.28 s
Earth-Moon L1	1.01 s	1.15 s
Lunar Surface[3]	1.21 s	1.35 s
Earth-Moon 2 (aka "Waypoint")	1.30 s	1.45 s
Earth-Sun L1	4.91 s	5.04 s
Near-Earth Asteroids[4]	50 s[5]	648.71 s[6]
Phobos/Deimos (Mars)	~186 s	~1340 s

[1] Infrastructure System delays not shown. Will add 1-2 seconds.
[2] Assumes an average geosynchronous orbit of 35,000 km (21,748 miles)
[3] Assumes near-side Lunar surface, far-side adds orbiting relay
[4] NEAs of interest
5 This represents the closest NEA considered for a human mission (0.1 AU NASA/HEFT)
[6] For asteroids located as far from Earth as 1.3 AU

Communications

Bandwidth:

As the quantity of data generated during space missions increases, so does the demand for increased communications bandwidth. The budgetary, technical, and, in some cases, operational costs of increased bandwidth requirements make it important to understand the minimum necessary bandwidth to achieve mission success and optimal scientific productivity.FINESSE will compare the acceptability of scientific exploration activities when operating under two different communications bandwidths.

Evaluation Program Strategy

From Field to DRM – evaluating ConOps and exploration capabilities to shape future human-robotic exploration architectures

Our field program will be highly integrated across multiple assets, multiple field teams, and varying instrument and exploration platforms. As well, our focus will be on obtaining high quality planetary science data and sample return priorities.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary		Minor improvements desired		Improvements warranted		Improvements required		Major improvements required	
1	2	3	4	5	6	7	8	9	10

No Rating
Unable to assess capability
NR

Acceptability Rating Scale

Education and Public Outreach

Flagship Project → Spaceward Bound

Bringing students and teachers into the field to conduct science and exploration research alongside FINESSE personnel.

Education and Public Outreach

Brent Garry explains to Jeff Karlin (teacher field participant via the FINESSE Spaceward Bound program) the intricacies of running the new LiDAR system at the Highway Flow. Craters of the Moon.

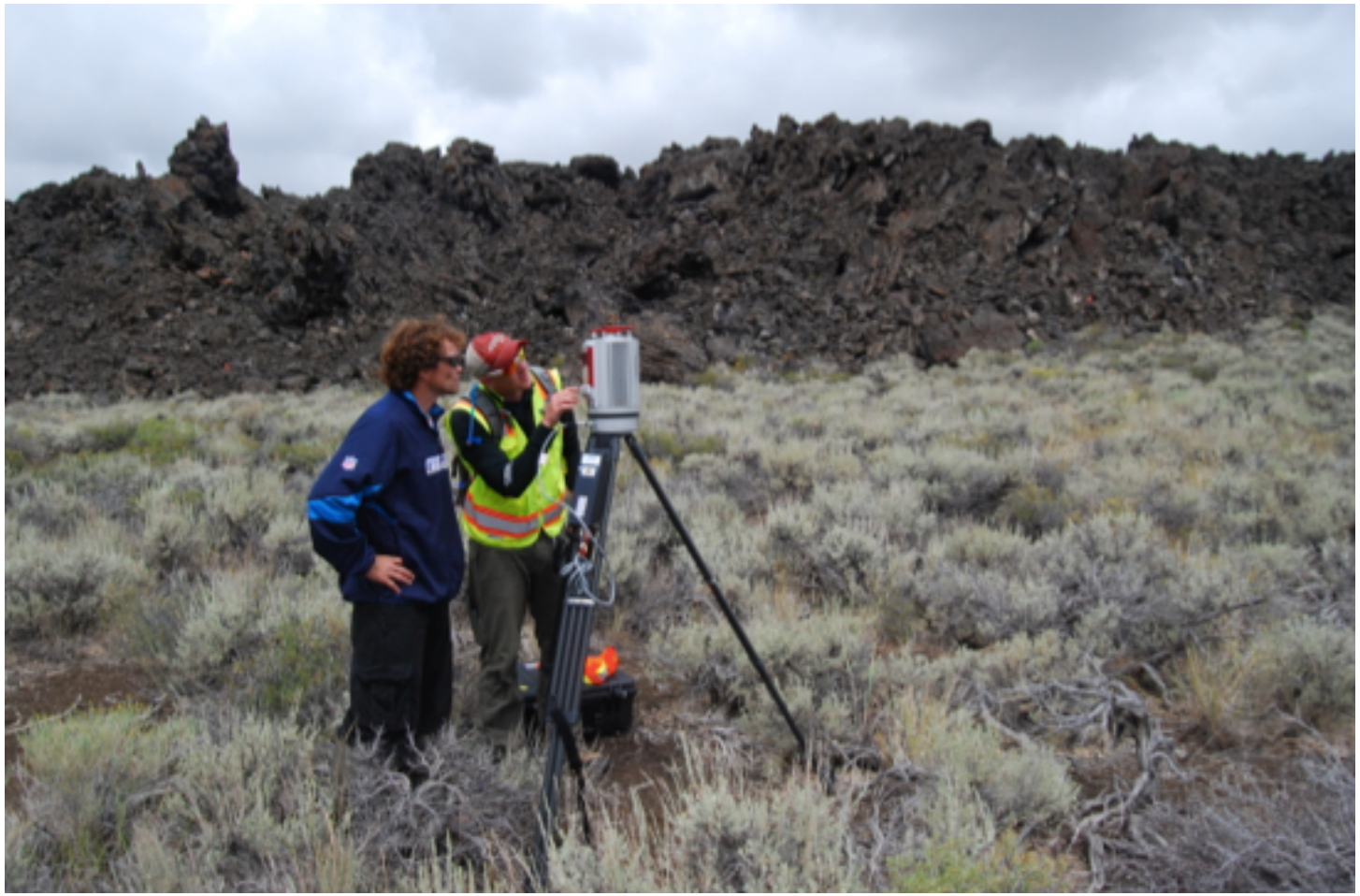


Photo credit: Scott Hughes

Education and Public Outreach

Spaceward Bound participation can result in scientific publications for the teachers!

Kobs-Nawatniak, S., Sears, D.W.G., Hughes, S.S., Borg, C., Sears, H., Skok, J.R., Elphic, R., Lim, D., Heldmann, J.L., Haberle, C.W., Guy*, H., Kobayashi, L, Garry, W.B., Neish, C., and K. Kim. Reconstruction of a Phreatic Explosion from Block Dispersion Modeling at King's Bowl, Idaho. AGU annual meeting, San Francisco CA. December 2014.

* Spaceward Bound teacher participant

Education and Public Outreach

http://www.idahospacegrant.org/#!programs/cbvo

Education and Public Outreach

Haven House Shelter Series
Menlo Park, CA

InnVision Shelter Network

FINESSE team members giving seminar series to introduce students and families to careers and opportunities in STEM fields.

Education and Public Outreach

International Observe the Moon Night

http://sservi.nasa.gov/articles/international-observe-the-moon-night-2014/

Thank you!