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Moon and Mars Sample Return Analogue Deployment Validation

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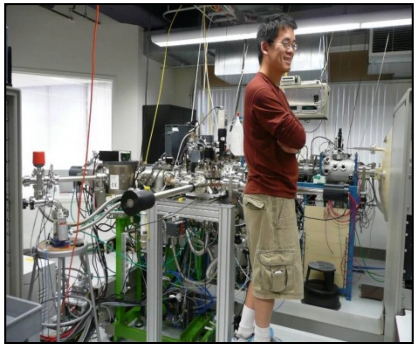
51st ESLAB Symposium

Why Sample Return missions?
And, what is need for validation?

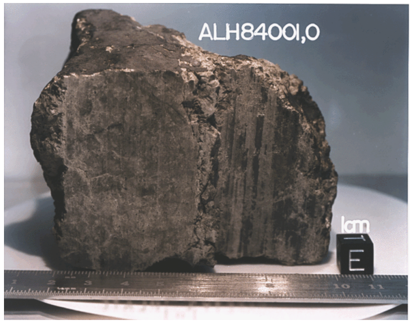
Why Sample Return?

- Why return samples to Earth?
  - Remote sensing – In situ – Sample Return
  - Laboratory instrumentation on Earth is always more sensitive than miniaturised planetary payloads
  - Samples can be curated for future new analysis methods



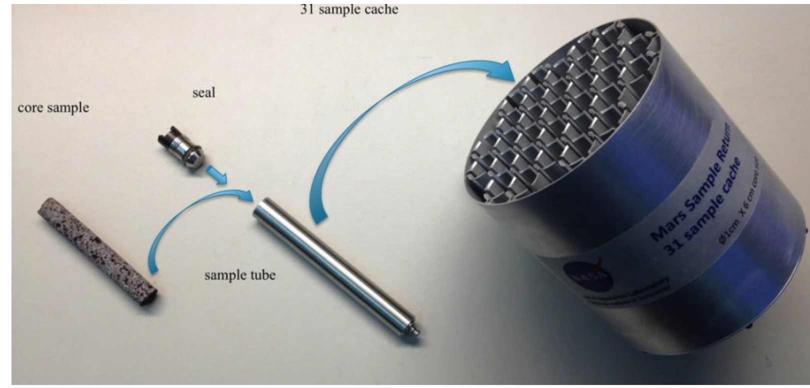
- Types of sample return
  - Robotic mission / Astronaut Extra-Vehicular Activity
  - 'Grab bag' / Targeted samples with context

- Scientific questions
  - Mars – an extreme habitable world
    - Biosignatures from early Mars
    - *Mustard et al, 2013, Mars 2020 SDT report*
  - Moon – history of the solar system
    - Older rocks not sampled by Apollo
    - *Scientific Context for Exploration of the Moon, NAS, 2007*



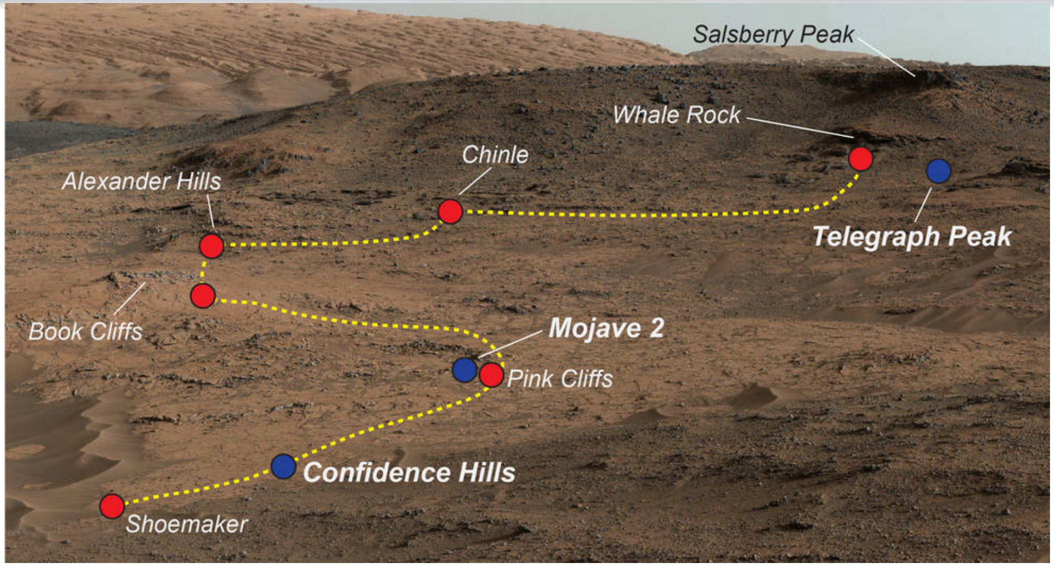
Upcoming missions:
Objective: Samples acquired with context

- Mars samples
  - Meteorites: 104 as of 2017
  - Mars Sample Return: 28 cores, 500g



- Lunar samples
  - Apollo: 6 manned space flights, 382kg of 2196 samples
  - Luna: 3 robotic flights, 300g
  - Meteorites: around 177kg
  - Human-Enhanced Robotic Architecture and Capability for Lunar Exploration and Science (HERACLES): 15kg

Sample Return:
Increased mission complexity in less time



MSL: Pahrump campaign: 1 sample for in situ analysis per 50 sols
MSR (Mars 2020): (goal) 1-2 samples for caching per 25 sols

Validation needed for Sample Return

- What are scientific approaches to selecting target for sampling?
- How do we prioritise resources for sample acquisition compared to in situ science investigations?
- What operational data and decisions are needed?
- How do we speed up the operational process?

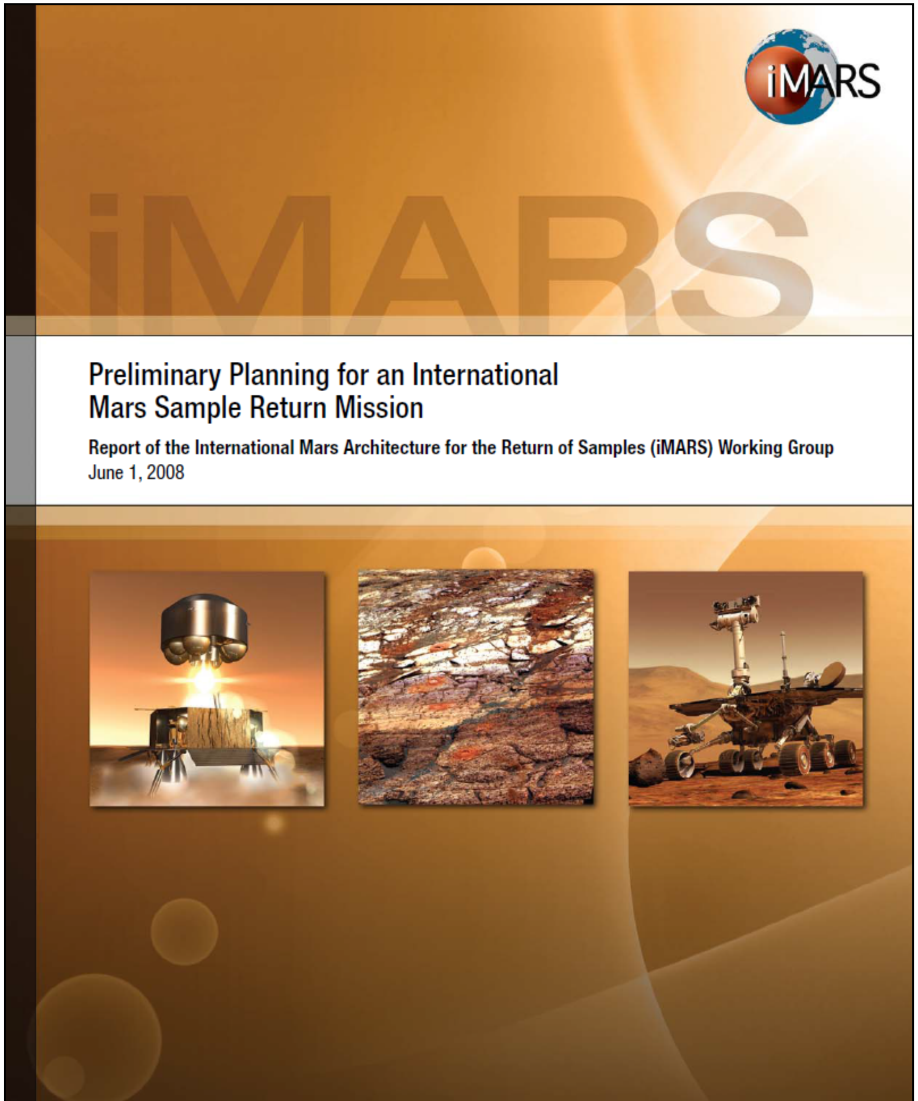
Analogue Missions to Validate Science Operations

- An analogue mission is a simulation that takes place at a site on Earth that resembles the target planetary environment.
  - The mission simulation can have value for student training, science team training, public engagement, technology demonstration and operations development.
  - The fidelity required in terms of site, mission hardware and science operations depends on the specific objectives of the simulation.

- The Mars Sample Return Analogue Deployment (MSRAD) campaign was conducted from 31st October to 19 November 2016 at a site near Hanskville, Utah, USA.
  - This was a high fidelity simulation of rover science operations using a prototype Mars rover at a scientifically relevant site, and a remote science team who communicated with the rover on a Mars-like daily command cycle.
  - Design of the test in collaboration with NASA JPL

Planning for 2016 MSRAD Campaign

CSA preparation for 2016 MSRAD campaign began in 2009..

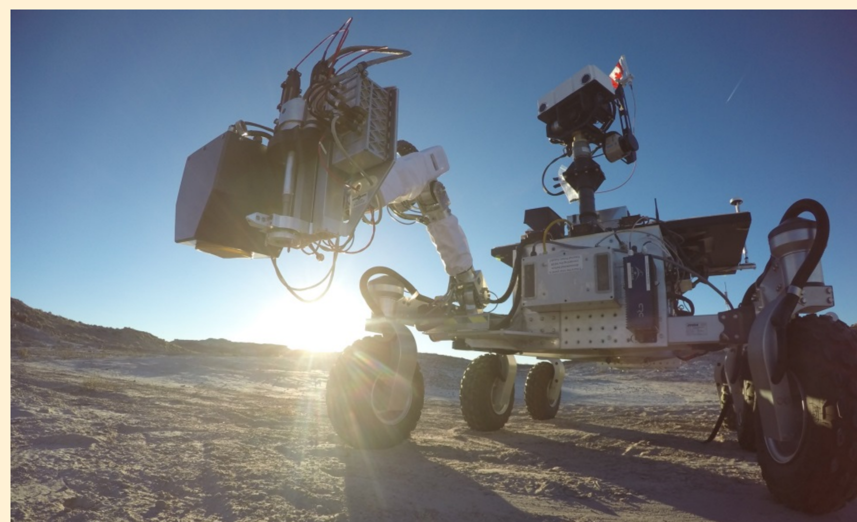


Report from the Canadian Mars Sample Return Analogue Mission Science Definition Team meeting CSA
HQ, 20-21 April 2009

V. Hipkin, R. Leveille, V. Abbasi, A. Amirfazli, E. Cloutis*, J. Crisp, R. Gellert, S. Hayati, C. Herd*, A. Koujelev, C. Lange, D. Lim*, L. May, B. Rivard , J. Rummel, , B. Sherwood Lollar*, G. Southam, A. Steele*, P. Sylvester, E. Vachon, H. Vali, S. Wagener, L. Whyte, B. Wing

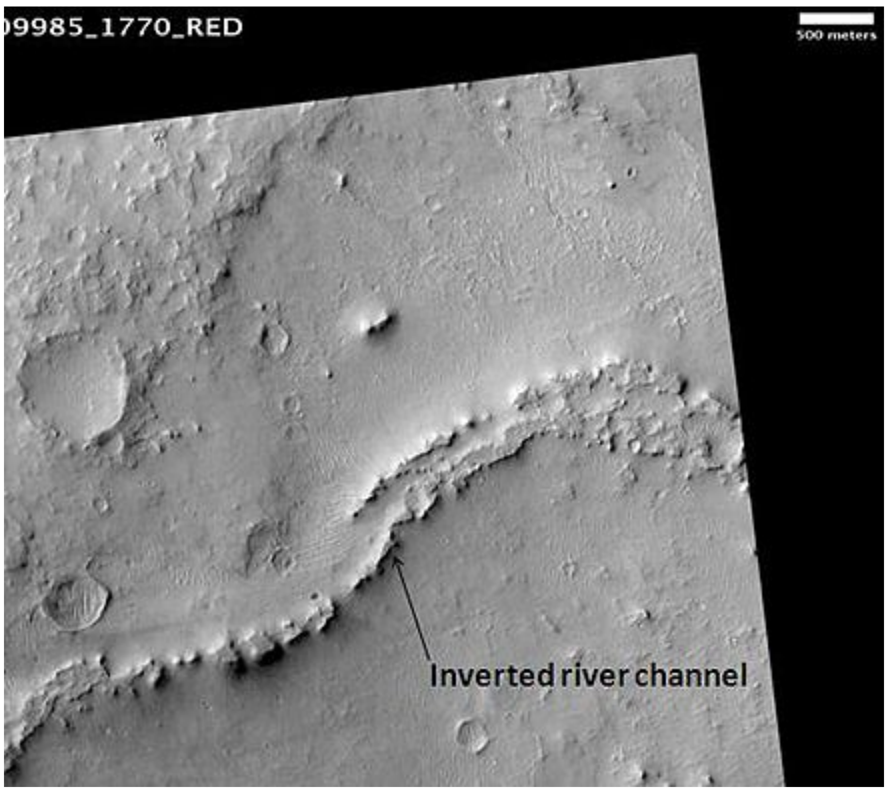
RECOMMENDATION: INSTRUMENTS: The SDT proposes the following priorities for Canadian prototyping:

- imaging/mineralogy package for regional/outcrop scale mapping
- close-up imaging/microscopy
- reduced carbon package



Mars analogue site selection: Paleochannel feature near Hanksville, Utah

Similar geological features are identified from Mars orbital remote sensing for **Jezero** under consideration as a landing site for Mars 2020, and **Aram Dorsum**, under consideration for ExoMars



2016 Analogue Mission science objectives:

- To advance understanding of the habitability potential of paleochannels: learn how to seek, identify and characterize samples containing signs of ancient life (high organic carbon)
- To advance understanding of the history of water at the site

High fidelity science operations demonstrated in 2015

See Osinski et al, 2015, LPSC

Sol 0 → Data Publication → Science Plan Preparation → Science Plan Review → Ops Sequence Preparation → Operations → Data Packaging + Ops Report Preparation → Data Publication

Western
Centre for Planetary Science and Exploration

MDA

2016 MSRAD Team

Collaborators

- Western University – CREATE Technologies & Techniques Project
- NASA Mars program office (Beaty, Parrish) & Mars 2020 Project (Williford)
- UKSA (OU, Imperial, MNH)

CSA-funded science activities

- Science Operations Centre logistics contract: PI. Osinski, Western University
- SE Science Definition Studies: PI. Osinski, Western; PI. Whyte, McGill
- Flights and Fieldwork to Advance Science & technology (FAST) : PI Cloutis, Winnipeg

2016 MSRAD
Analogue test objectives and constraints

- *To test the accuracy of selecting samples remotely using the partial context available to mission scientists using **rover-based field operations**, compared to the full context available to a **traditional human field party**.*
- *To test the efficiency of remote science operations*
- *To make a preliminary determination of the factors that affect the quality of sample selection decision-making in light of returned sample analysis*

- Simplified task given to both teams: Identify highest TOC sample as proxy for highest priority astrobiology sample
- Additional validation objective: As both teams have same task, can also get insight into strengths and weaknesses of human exploration approach compared to robotic

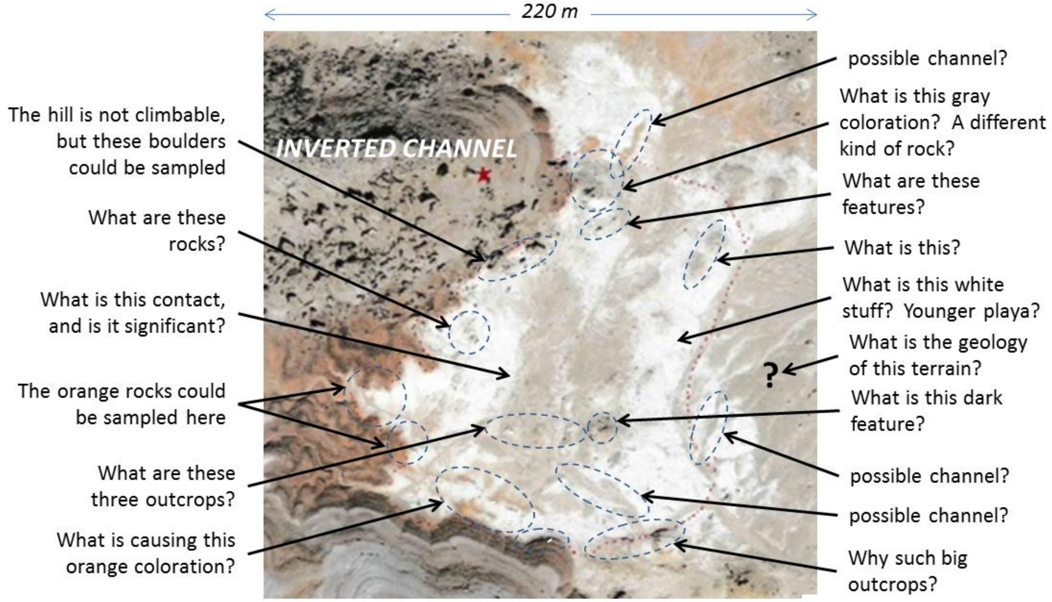
Constraints:

- Remote science team had 27 rover sols, large team, instruments resembling mars 2020 payload, pre-mission strategic plan, no knowledge of site location
- Field team had 1 day, small team, no instruments, pre-mission image of same scale as HIRISE

Documentation: Rover operations documentation
Field team voice recorder and GPS tracker
Independent additional validation

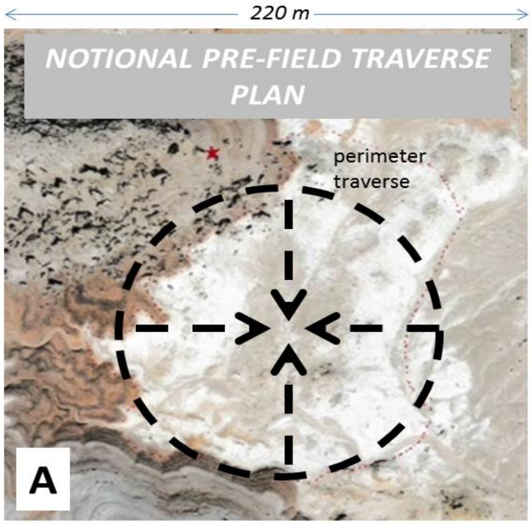
2016 MSRAD Implementation & Preliminary Results

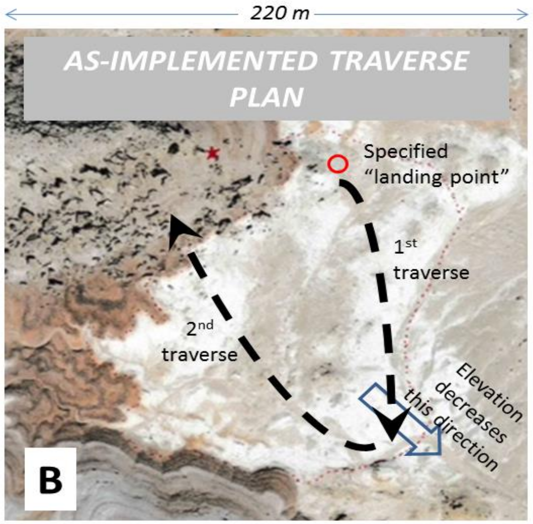
Field team breakfast meeting planning



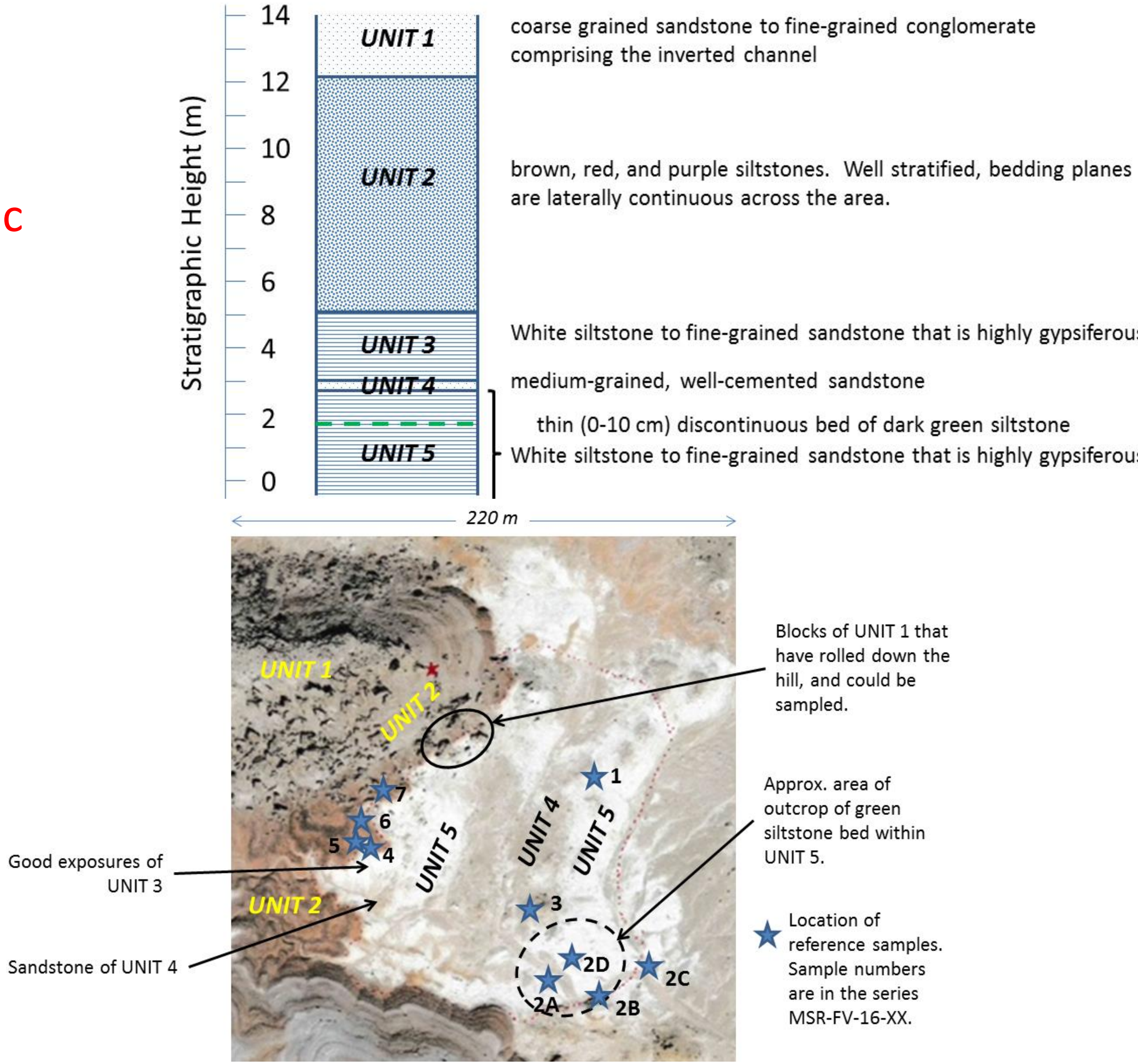
Review of HIRISE resolution site image

Traverse planned at breakfast compared with actual traverse





Field Team Results: Stratigraphic section



Field Team highest TOC sample

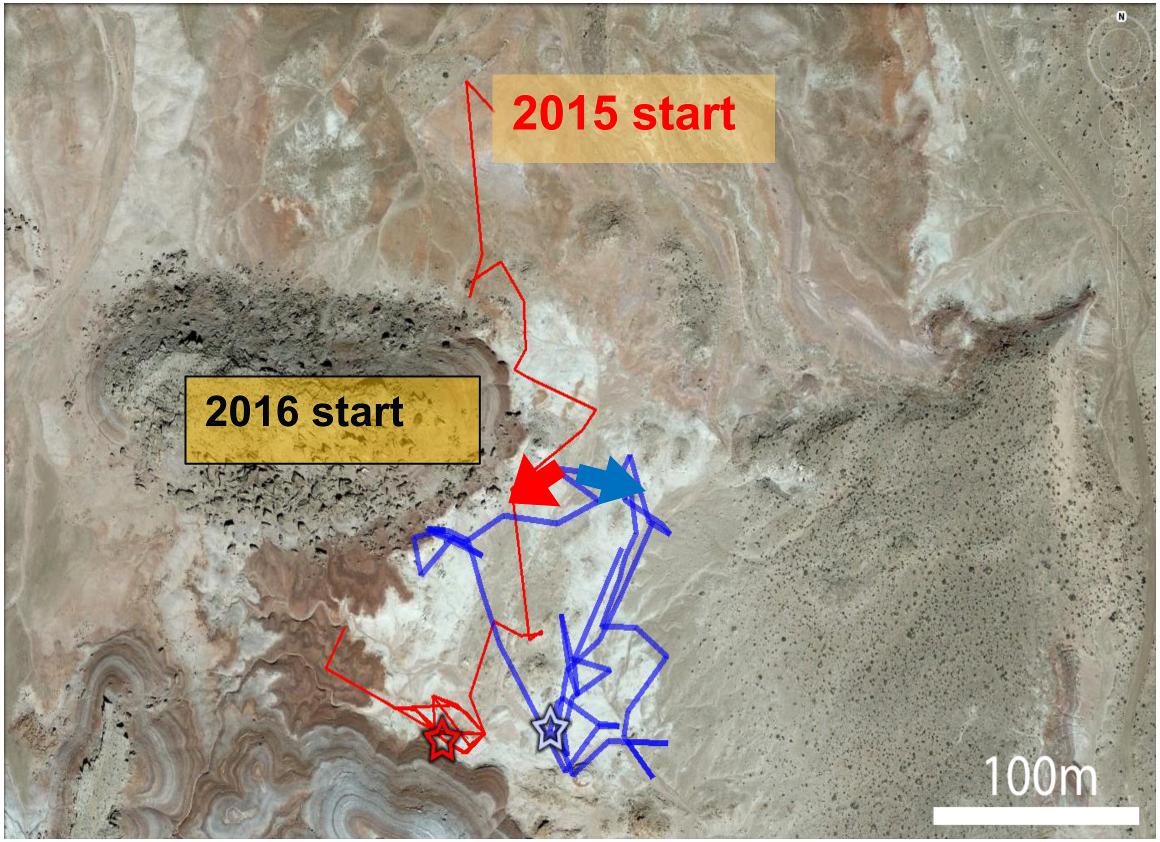
Table 1. Samples collected		
Sample Number	Stratigraphic Unit	DESCRIPTION
MSR-FV-16-1	UNIT 5	Unconsolidated gypsiferous siltstone
MSR-FV-16-2A	Green shale	Dark green to black siltstone
MSR-FV-16-2B	UNIT 5	pale green siltsone
MSR-FV-16-2C	Green shale	Dark green siltstone w. a single black lens several mm thick.
MSR-FV-16-2D	Green shale	Dark green to black siltstone, aseptic protocol used.
MSR-FV-16-3	UNIT 4	tan, well-cemented sandstone
MSR-FV-16-4	UNIT 3	gypsiferous siltstone, moderately well-cemented
MSR-FV-16-5	UNIT 2	yellow to red f. gr. ss. at boundary between Unit 2 and Unit 3
MSR-FV-16-6	UNIT 2	red fine grained sandstone
MSR-FV-16-7	UNIT 1	coarse gr. Sandstone, silica cement

Results of Sample TOC analysis		
Sample Number	Stratigraphic Unit	Total Organic Carbon (ppm)
MSR-FV-16-1	UNIT 5	84 ± 1
MSR-FV-16-2A	Green Shale	199 ± 24
MSR-FV-16-2B	UNIT 5	54 ± 1
MSR-FV-16-2C	Green Shale	463 ± 4
MSR-FV-16-2D	Green Shale	487 ± 30
MSR-FV-16-3	UNIT 4	61 ± 1
MSR-FV-16-4	UNIT 3	87 ± 7
MSR-FV-16-5	UNIT 2	146 ± 2
MSR-FV-16-6	UNIT 2	83 ± 1
MSR-FV-16-7	UNIT 1	441 ± 7

TOC results: Williford and Tuite (written comm., 2017)

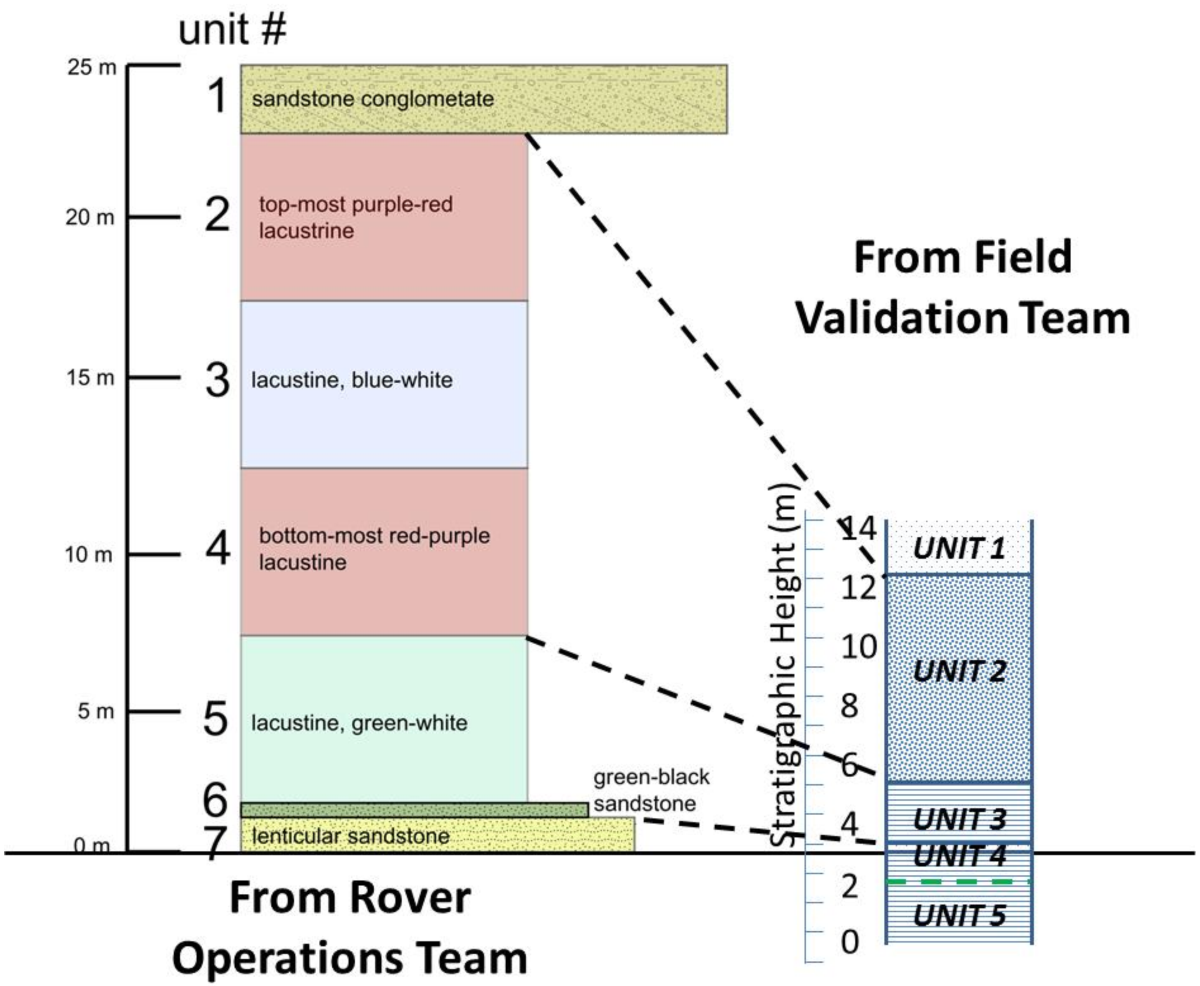
	Field Team: Data from Voice recorder & GPS used in field	
	Actions	Decisions
Start point to 15 mins	At start point, visually surveyed site. Used rock hammer to generate fresh surface for white material. Applied acid test to white material. Removed sandstone pieces with rock hammer to identify endoliths.	• Agreed direction of first traverse. • Determined white material is not a playa due to topographic form, and is a sulphate not carbonate from acid test. • Identified dark greenish rocks as potential target based on color. These are stratigraphically under sandstone layer. • Agreed sample tagging scheme to identify field targets.
00:15	First traverse continued to face of stratigraphy on southern side of site Examined desert pavement and curious 2m long log-like feature in sandstone. Observed lichens and more endoliths (modern features). Observed pale green layer near base of stratigraphy.	• Agreed strategy to target green layer for sampling, and follow it across the site and choose the darkest green material along the layer as highest TOC sample. • Agreed to complete survey of site first.
00:30	Second traverse to paleochannel base on northern side of site, avoiding remote science team active area. Investigation of colored layers by digging with a small shovel. Observation of second log like structure embedded high in paleochannel structure.	• Continued survey of site. Log-like feature not petrified wood and thought to be a sandstone lens. Team lacked expertise for its interpretation.
00:45	Continued to investigate layers exposed in base of paleochannel with colors varying from red to green to yellow.	• Continued survey. Hypothesized that color in layers suggests water is getting deeper. Layers hypothesized to be paleosols are very friable: material never consolidated and weathered in place.
01:00	Hand lens observations of sparkling gypsum crystals in weathered sol. Sit down discussion break, back near start point.	• Interim findings related to human strengths of field party: speed of investigation, immediately being able to uncover material and handle material to determine how friable, rapid acid tests. • Refined strategy: Gather as much information from field as possible then back to green layer. Collect number 1 priority sample: darkest greed material; and see how difficult it is to core. Collect other light and dark green samples. Work layer side to side across site as well as vertically. Layer is determined to be about 4' below current discussion point. A dark green material was observed in cap rock at the top of the paleochannel mound, but difficult to access.
01:15	Walked the site seeking continuity of green layer: looking for changes in color and texture.	• Agreed layer is discontinuous about 3' below sandstone. • Refined interpretation: Standing water basin with pools intermittently exposed to air.
01:30	Continued to walk the site, tagging candidates for coring.	• Refined stratigraphy of site to determine relative position of light and dark green layer(s). • Agreed eyes are being trained to spot dark green candidate material for sampling. 'Now we have decided to look for it, black layer seems to be everywhere'. • Determined rocks at site are running downhill in south-east direction.
0 1	Investigated four of the 'green layer' outcrops. Began to consider how to acquire sample	• Agreed highest priority sample using criteria: darkest, mechanically coherent, large enough to drill. Avoiding edges that appeared to be leached

Comparison with Rover team: Traverse routes and priority samples



rover track
validation team track
remote science team: primary sample
field validation team: primary sample

Comparison with Rover Team: Stratigraphic section



Remote science team	Data from Remote science team Documentarian's report, Strategic Traverse Day presentations & Operations log/uplink plan	
	Actions	Decisions
Pre-planning to Sol 12 (2016 start point)	Drove to Christian (7m), Gudfred (Li,Z), then to Margrethe (41m). For imaging: panorama then Horik (Z). Returned to Christian. • Review of imagery: dark pebbles- desert varnish? (modern feature?). Concretions? • Developed plan templates. • Using all instruments: Testing out our toolbelt to compare instruments for future work Presentations: Biogenic elements (Anna); Stratigraphy (Patrick) Need to test sedimentary model.	A strategic traverse plan was developed in advance of Sol 12 based on data from Sol 1-11 and orbital data, with testable hypotheses and identifying Features of Interest Gudfred (close outcrop), Horik (next outcrop), Valhalla Hills (east side of site), Ragnorak (far south of site), Hel (west side of site, braided channels). Agreed that the mission area is a paleochannel, now searching for signs of life. Can't rule out salt or fresh water environment. • Target Gudfred and broken shell rock (Angul) : Need for contact science on this red unit: other lithologies are documented through images, cores and scoops from Sol 1-11 (2015 deployment). • Target white eroded material (Frotho) and darker soil (Gram): Light coloured layers for organic preservation? Pigments (keratin) may determine biogenic origin of carbon.
Sols 13-15	Contact science at FOI Gudfred with white material targets Frotho, Frodi. (P/C, Sh/W, Su, V). Interesting large block identified as fall from paleochannel cap (Ivar). Drove from Christian to Beatrice (47m) to image Ivar, then to Cascade (37m) and Castle (28.5m) to image Horik(Z), Hadingus(Z). First use of autonomous geological classification. Sol 15 Strategic Traverse Day: split into 4 groups; ➢ Begin with highest res panoramic images and draw onto them any stratigraphic/ sedimentological/diagenetic features ➢ Do the same for zoom images and integrate onto panoramas where possible; otherwise, use to inform your interpretation of features on panoramas ➢ Integrate in situ geochem, spectroscopy, remote sensing to better constrain lithology and secondary mineralogy ➢ Revisit orbital imaging/remote sensing for additional insight ➢ Construct/refine composite stratigraphic section or sections ➢ Take another picture, make another measurement - iterate! Group discussion on stratigraphic column developed from different panorama views Presentations: Pixel classification lithology mapping software (Jon), Strategic planning (Scott), Identifying life in rocks (Jackie) : Sandstone endoliths can appear as bands in green (chlorophyll), orange	• Chose not to sample at Gudfred. No compelling biosignature features. Very weathered. • Considered three strategic traverse options: (1) fall rocks then Horik; (2) Horik then south to Ragnorak and circle back counter-clockwise (Valhalla Hills) or clockwise; (3) East to Valhalla Hills. Considerations include accessibility of rock for contact science/sampling as well as stratigraphy. • Informed, through LIDAR (data type unavailable to ExoMars/Mars 2020), that Horik target in Sol 12 image comprises two separate ridges, one 15m in front of another and not single ridge as it appears. • Sol 15 autonomous science drove initial strategic planning decision: Best use of autonomous science is to get images on fall rock Ivar en route to Horik. • Sol 15 strategic planning: after group discussion, agreed on same base sedimentary architecture to continue to develop. • Sandstone (endoliths) may be better than clays for preserved life. • Raman signal dominated by hydrated signal where rocks saturated. Avoid rocks that pool water. • Main decision points for next targets (no specific order): • Lithology • Lack of clay cover • Likelihood to hold environmental moisture (rain), dry targets desired • Likelihood to contain bio signatures • Sunlight orientation • Potential for contact science (rover ability, rock stability)

Preliminary results: discussion points

Documented speed of human field survey

- Completed survey and sample selection in 2 hours
- *Humans for initial stratigraphic survey, rover for systematic survey?*

Accuracy of stratigraphic relationships

- Scale and viewpoint
- *Rover mission generated detailed interpretation*

How to make sense of TOC results

- *Field team target was highest TOC of units, based on simple imaging info*.
- Low for earth (not for Mars!)
- Rover team had more sophisticated inputs from eg. Raman, targets less correlated with TOC results
- Field team sample was out of bounds for rover activity

Planetary & Space Science Special Issue in preparation:

Osinski et al, Overview

Beaty et al, Field validation results

Caudill et al, Rover science team results

Pilles et al, Rover science operations results

Cloutis et al, Sample analysis

Several additional papers..

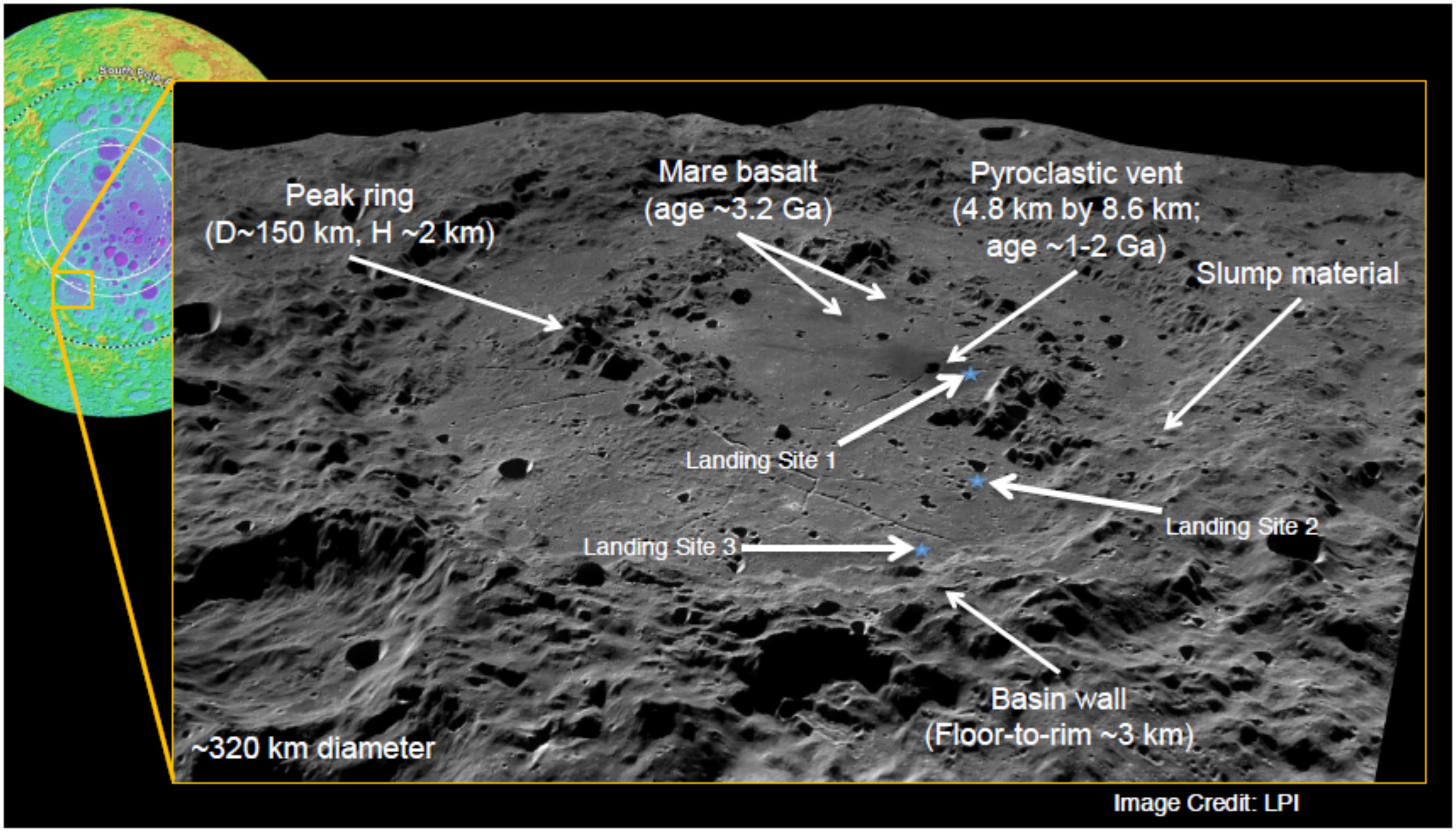
Planning for HERACLES 2019 Analogue Campaign

On behalf of HERACLES team (ESA-CSA-JAXA)

Human-Enhanced Robotic Architecture and Capability for Lunar Exploration and Science (HERACLES)

Sample Return from Schrödinger Crater

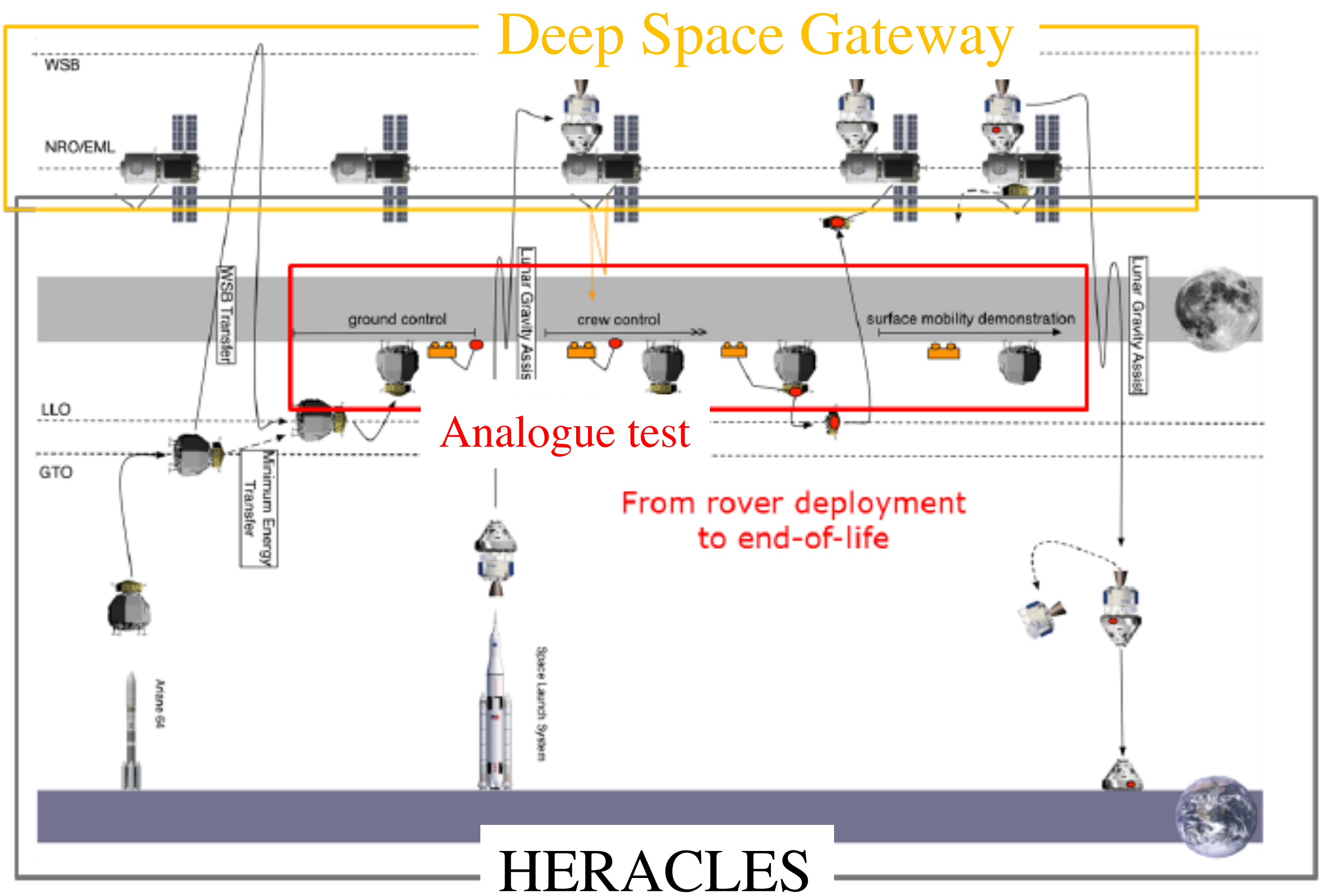
ESA-CSA-JAXA human exploration architecture demonstration



Complex mission architecture:

Even shorter robotic sampling phase

30 sols science ops of which 10 are tele-operated from Deep Space Gateway



Status of HERACLES Analogue Campaign Planning

- Campaign: Summer 2019
- Landing site:
  - Canary Islands or Craters of the Moon TBD
- Science & Sampling Objectives
  - To be refined: Canadian study (Western); International Science Definition Team
- Analogue test objectives
  - Teleoperation from ISS
  - Rover speed and navigation
  - Science operations including sample handling

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