Proposed 2018 *Mars Astrobiology Explorer-Cacher (MAX-C)* Mission

Sept. 10, 2009

Presented by Scott McLennan on behalf of the MEPAG Mid-Range Rover Science Analysis Group (MRR-SAG)

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Abstract

The MEPAG MRR-SAG has developed a concept for a Mars mission called Mars Astrobiology Explorer-Cacher (MAX-C), which would:

1.Have an *in situ* scientific exploration capability necessary to respond to discoveries by prior landers or orbital mapping missions.

2.Collect, document, and cache samples for potential return to Earth by a future mission.

3.Between its *in situ* functionality and its potential sample return-related functionality, be a key stepping stone to seeking the signs of life on Mars.

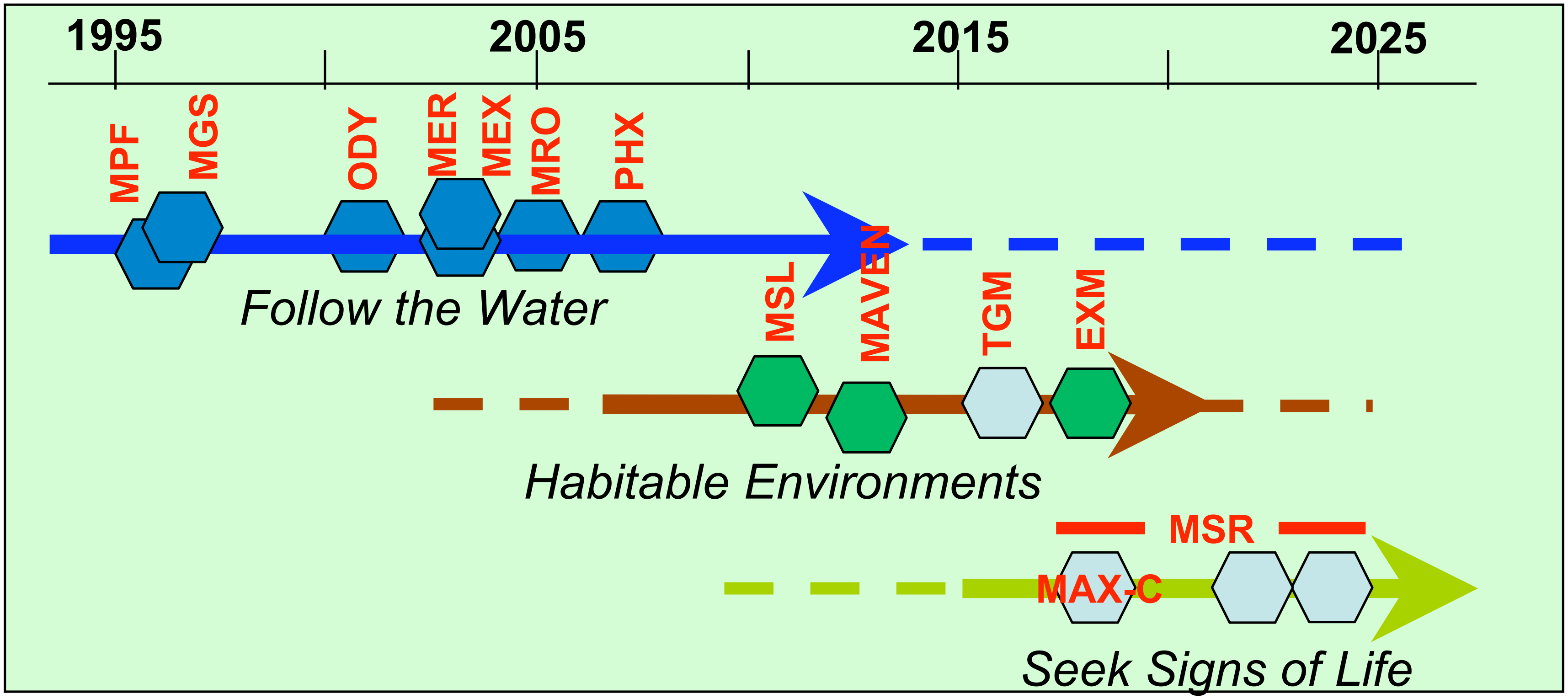
Science Priorities

Strategic Science Drivers

Strategy. Evaluate the habitability potential of various high-potential martian environments.

Results. Orbital and landed missions have revealed multiple varieties of terrane with different interpreted habitability potential.

Need. We now need a landed mission to seek possible biosignatures at a high-potential environment.



Highest Priority Science Concepts

The MRR-SAG distilled a broad range of key scientific questions into 8 general mission concepts:

Early Noachian Astrobiology
Noachian-Hesperian Stratigraphy
Astrobiology - New Terrain
Methane Emission from Subsurface
Radiometric Dating
Deep Drilling
Polar Layered Deposits
Mid-Latitude Shallow Ice

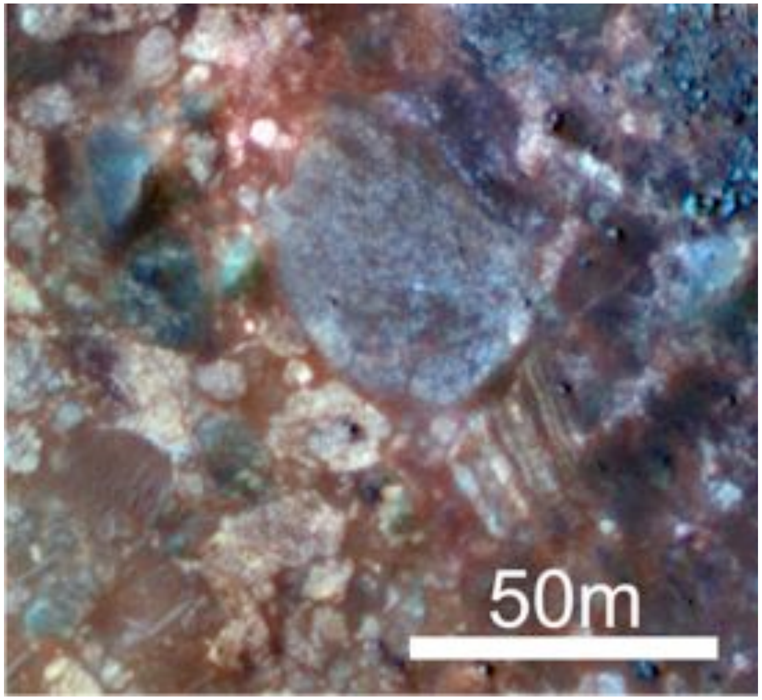
Top 3 in science priority

Concept #4

Early Noachian Astrobiology (Priority #1)

Early Noachian (> 4 Ga) terrains may tell us about:

- Early planetary evolution and the origin and composition of the crust
- Prebiotic environmental context in which life potentially arose
- Potential transition from a prebiotic world to primitive cells
- Attributes and fate of any life as conditions on Mars changed.



Megabreccia with diverse lithologies in the watershed of Jezero Crater. Portion of HiRISE color image PSP_006923_1995. Credit: NASA/JPL/University of Arizona.

Concept #2

Noachian-Hesperian Stratigraphy (Priority #2)

A Noachian-Hesperian rock sequence may tell us about:

- Surface conditions before and after the decline in erosion, aqueous weathering, fluvial activity, and magnetic field
- Whether Noachian and/or Hesperian conditions were hospitable for life
- Whether life arose and, if so, how the environmental changes affected it

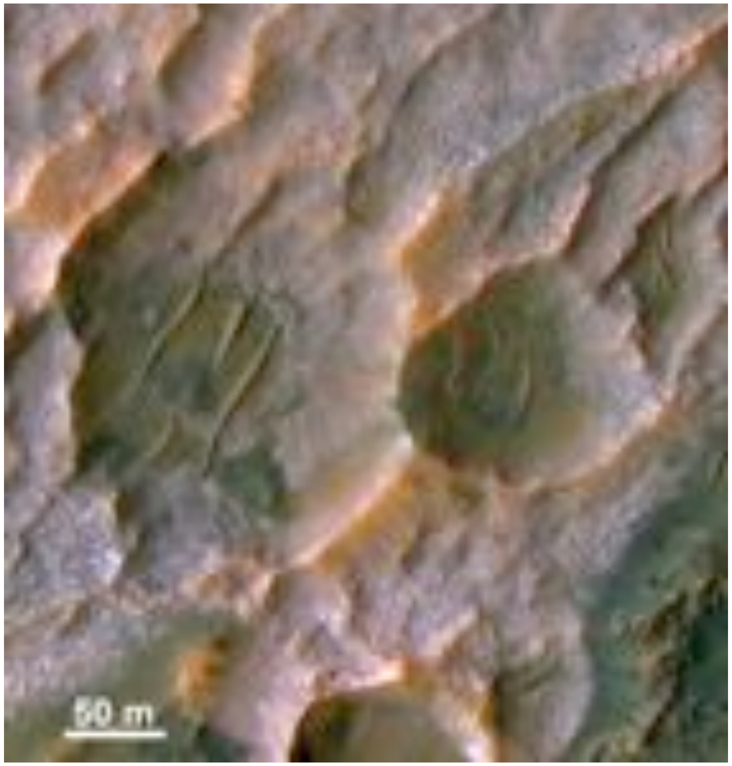
Stratigraphy of phyllosilicate-bearing strata in the Nili Fossae region, showing where CRISM detected phyllosilicates in the Noachian strata and megabreccia. HiRISE image PSP_002176_2025. Credit: NASA/JPL/University of Arizona.

Concept #5

Astrobiology – New Terrain (Priority #3)

A site in previously-unvisited ancient terrain would allow us to:

- Explore an astrobiology-relevant site that is qualitatively distinct from previously visited sites
- Characterize geologic and climatologic contexts of the composition, landscape and aqueous processes at the site
- Test life-related hypotheses in the context of another specific kind of geologic terrain.
- Determine whether habitable environments existed.

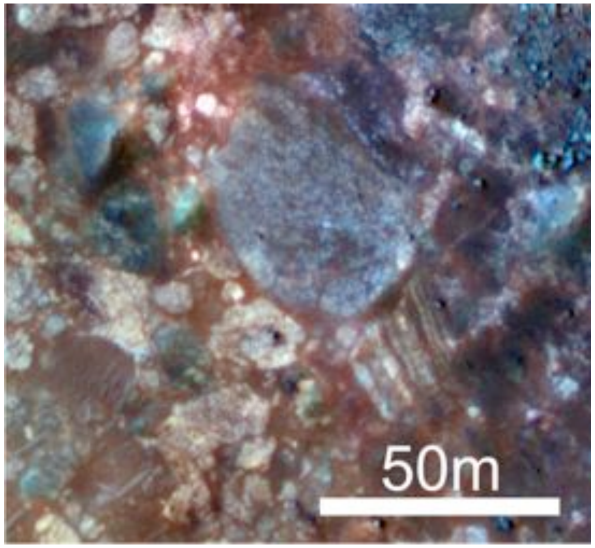


Potential chloride-bearing materials in Terra Sirenum.
HiRISE image PSP_003160_1410.
Credit: NASA/JPL/University of Arizona.

- Collect samples that could have preserved evidence of prebiotic chemistry or life

Merging of Mission Concepts

<u>FINDING</u>: A single rover with the same general capabilities and high-level scientific objectives could explore one of a wide range of landing sites relevant to our top 3 mission concepts. The differences between the concepts primarily relate to where the rover would be sent, rather than how it would be designed.



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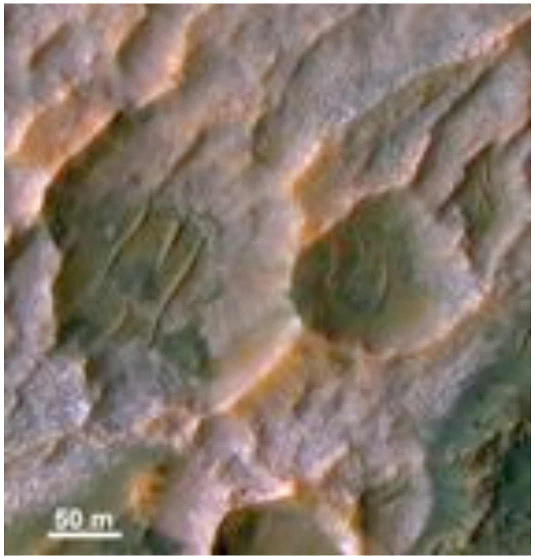

Potential chloride-bearing materials in Terra Sirenum.
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Credit: NASA/JPL/Univ. of Arizona.

Pre-decisional – for Planning and Discussion Purposes Only

Proposed *in situ* Scientific Objectives for the MAX-C Mission Concept

At a site interpreted to represent high habitability potential, and with high preservation potential for physical and chemical biosignatures:

- evaluate paleo-environmental conditions
- characterize the potential for the preservation of biosignatures
- access multiple sequences of geological units in a search for possible evidence of ancient life and/or pre-biotic chemistry

Highest-Priority Possible Secondary Scientific Objectives

Landed Atmospheric Science

Determine the relationships governing surface/atmosphere interaction through exchange of volatiles (including trace gases), sediment transport, and small-scale atmospheric flows.

Paleomagnetics

Determine the history of the early Martian magnetic field and its possible connection to climate change, global tectonics, and planetary thermal history.

#1 priority of these secondary objectives, with very low mass implications, is monitoring of atmospheric pressure.

Implementation Strategy to Achieve the Scientific Objectives

Achieving the Objectives

Functional requirements needed to achieve the scientific objectives:

- Access to outcrops
- Target selection capability
- Rock/soil interrogation
  - Chemistry
  - Mineralogy
  - Organics
  - Texture
- Documentation of sample context (at micro to macro scales)

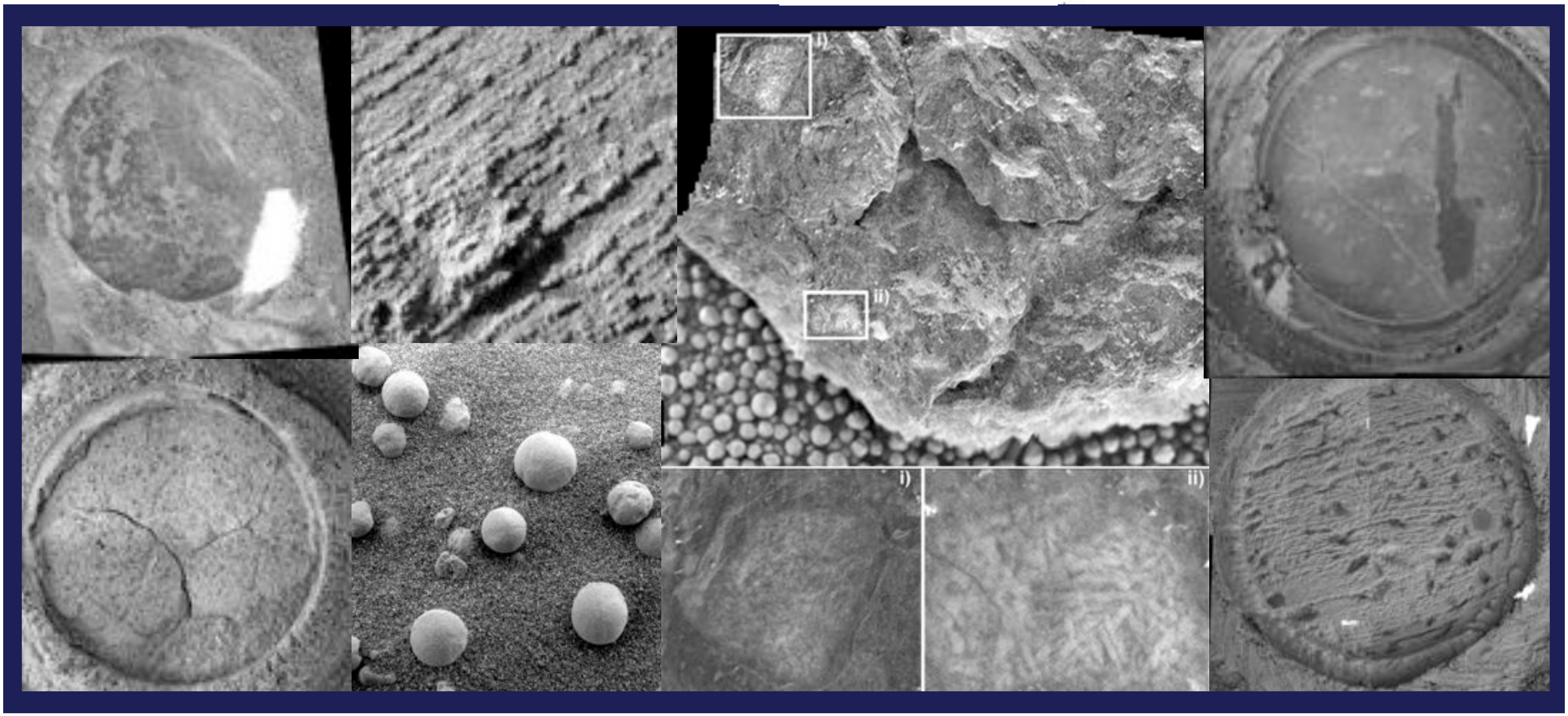
NASA/JPL-Caltech/Cornell University

Opportunity Pancam false color image of three RAT holes on the slope of Endurance Crater.

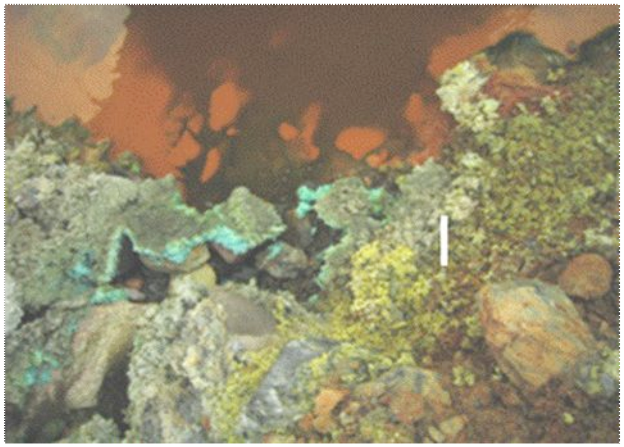
Pre-decisional – for Planning and Discussion Purposes Only

Micro-Mapping: A Powerful Tool

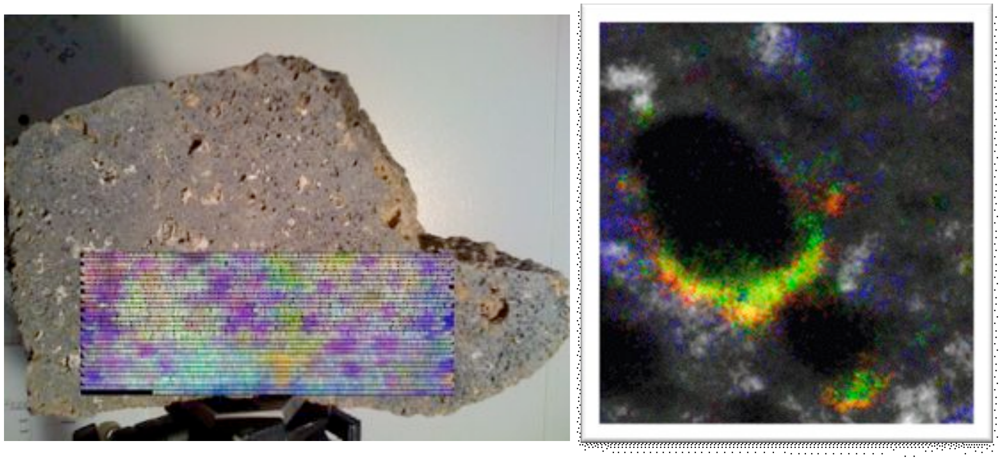
- MER close-up imaging shows interesting textures in martian rocks.
- Micro-mapping could be used to study origins of minerals, depositional / formation sequences, presence and duration of liquid water, presence and nature of organic deposits and biominerals (if present), etc.



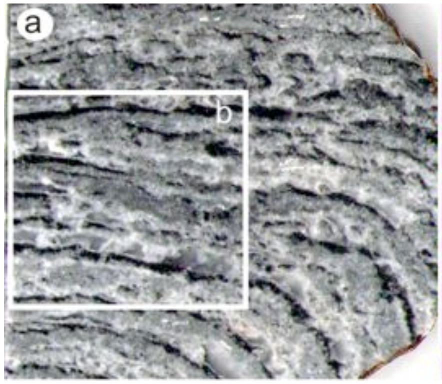
Potential Synergy from 2-D Micro-Mapping



Near-IR map of mineralogy



Deep UV Fluorescence and Raman map of sub-ppb organics, sub-ppm CHNOPS and H_2O



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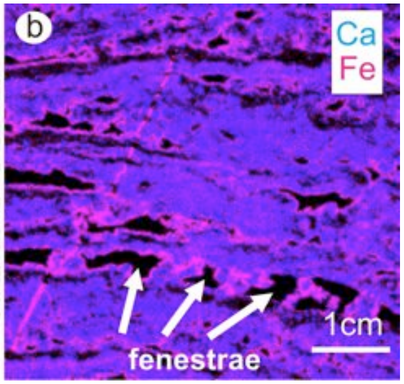
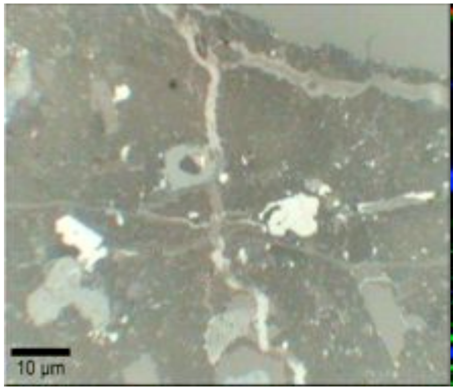


XRF map of elemental composition



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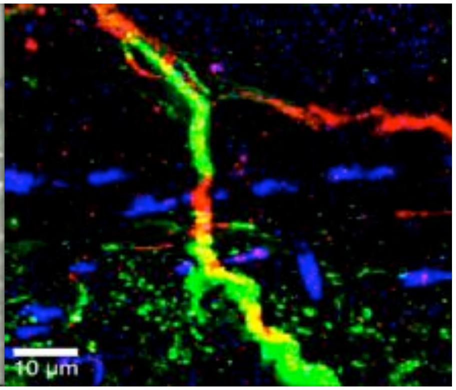
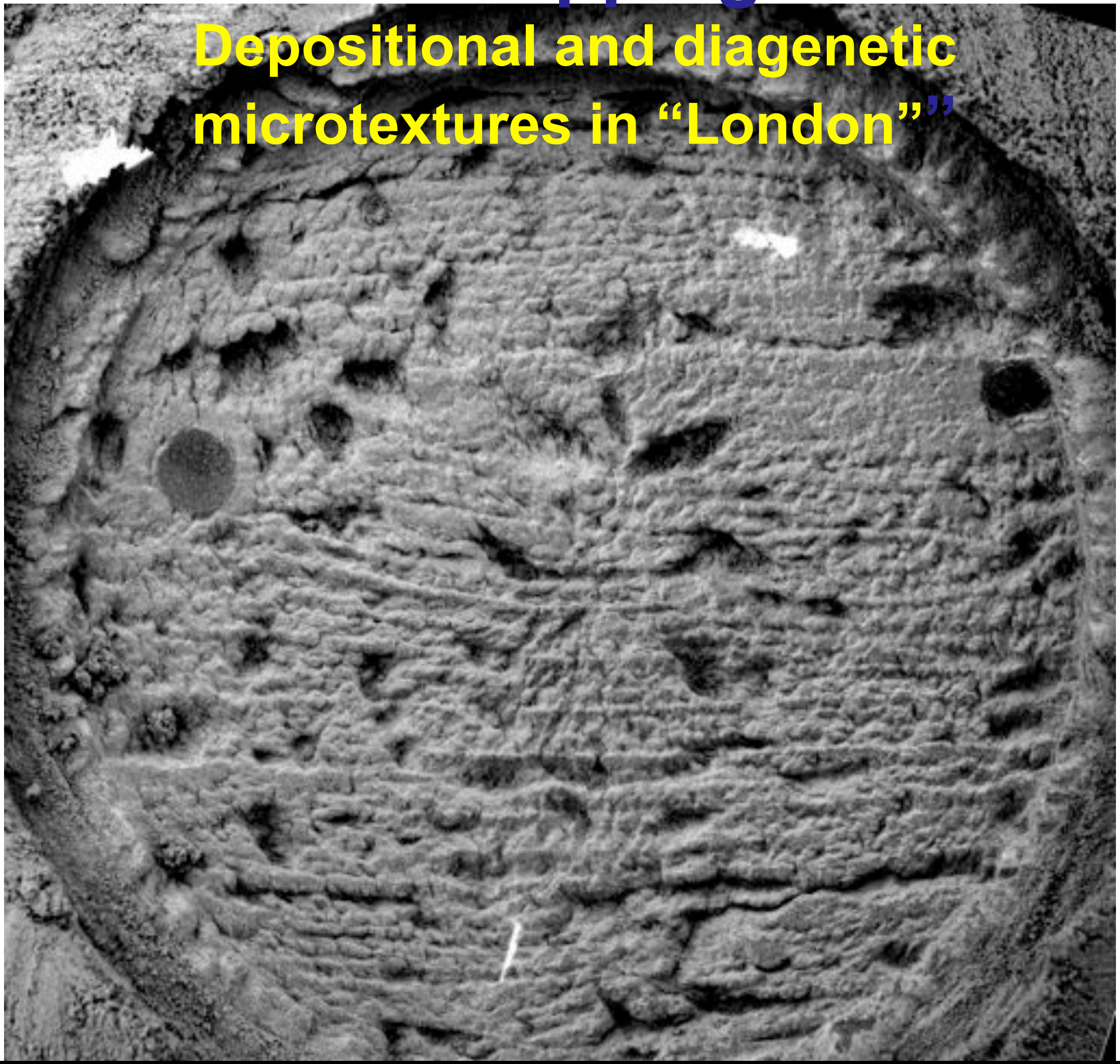


Raman map of mineralogy

Mapping instruments could be used to relate mineralogy / chemistry / elemental composition / organics to textures, fabrics, and small scale structures

Compelling Example for the Potential of 2-D Micro-Mapping on Mars



Depositional and diagenetic microtextures in “London””

Opportunity MI mosaic of a 4.5 cm diam. abraded rock surface NASA/JPL-Caltech/USGS

Implications of Investigation Strategy

Using arm-mounted tools to generate multiple, coregistered, micro-scale data sets could offer several key advantages:

- No sample delivery to instruments
- Greatly improved scale of focus—critical for recognizing candidate biosignatures on Earth
- Multiple data from same features would enable powerful interpretation capability.

Some implications:

1. High data volumes
2. Valuable in follow-up to any major MSL discoveries
3. Complementary to ExoMars
4. Avoids loss of spatial relationships when samples are powdered for analyses
5. Context documentation is critical for correct interpretations
6. Requires a flat abraded surface

Potential Contribution to Possible Future Return of Samples to Earth

Antecedent: ND-SAG Analysis

Two key findings related to the concept of sample suites

FINDING. Potential future sample return would have its greatest value if the samples are organized into suites that represent the diversity of the products of various planetary processes.

- Similarities and differences between samples in a suite could be as important as the absolute characterization of a single sample
- The minimum number for a suite: 5-8 samples.

- *Examples: Sampling several rock layers in a stratigraphic sequence, sampling along a hydrothermal alteration gradient, sampling both "ordinary" regolith and local variations in an area.*

FINDING. The collection of suites of rocks would require mobility, the capability to assess the range of variation, and the ability to select samples that span the variation.

Antecedent: ND-SAG Analysis

Science Priorities Evaluated

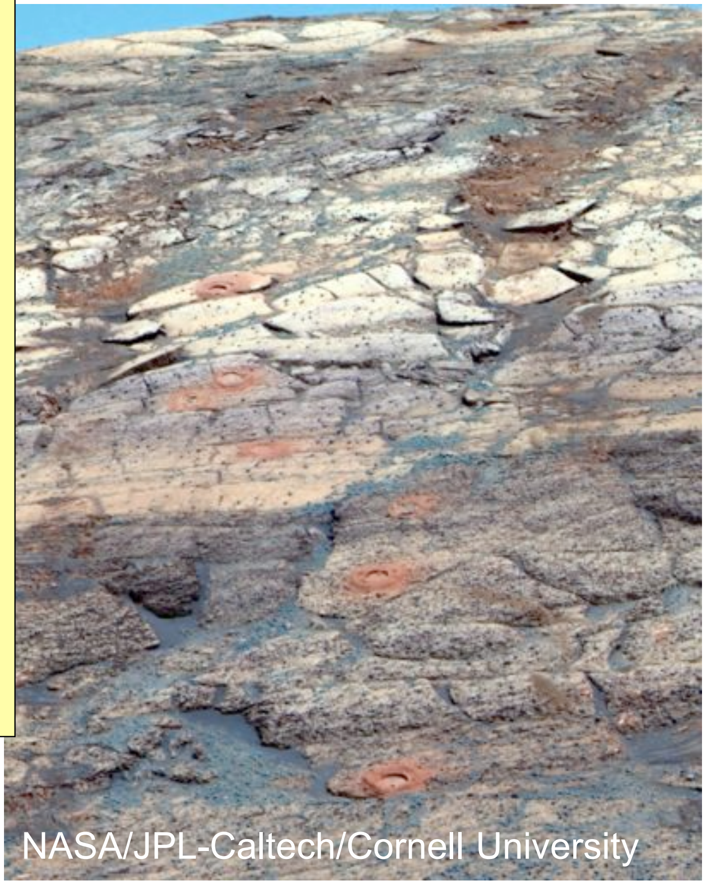
1. Sample types we are interested in collecting
2. Sample size(s)
3. Number of samples (and overall mass)
4. Sample packaging
5. Sample acquisition system
6. Sample integrity
7. Temperature
8. Sample selectivity, documentation of sample context
9. Issues associated with MSL/ExoMars cache
10. Implications regarding site selection
    a) 1 vs 2 sites
    b) Planning for surface operations
11. Planetary Protection Issues

Critical Science Planning Issues for MAX-C

Sample Return Would Need Outstanding Samples

Derived from the conclusions of ND-SAG and iMARS:

FINDING: A sample return campaign entails high cost and risk, so it must also deliver unprecedented value. To address the highest priority scientific questions, we need what we refer to as "outstanding samples." Addressing MEPAG's life-related scientific objectives would be heavily dependent on the kinds of samples that could be collected, and returned, and on our ability to understand their geological context.



NASA/JPL-Caltech/Cornell University

Opportunity Pancam false color mosaic of 7 RAT holes on the slope of Endurance Crater.

Collecting Outstanding Samples

The potential rover needed to do scientific sample selection, acquisition, and documentation for potential return to Earth is the same whether it is sent to an area that has been previously visited, or to a new unexplored site.

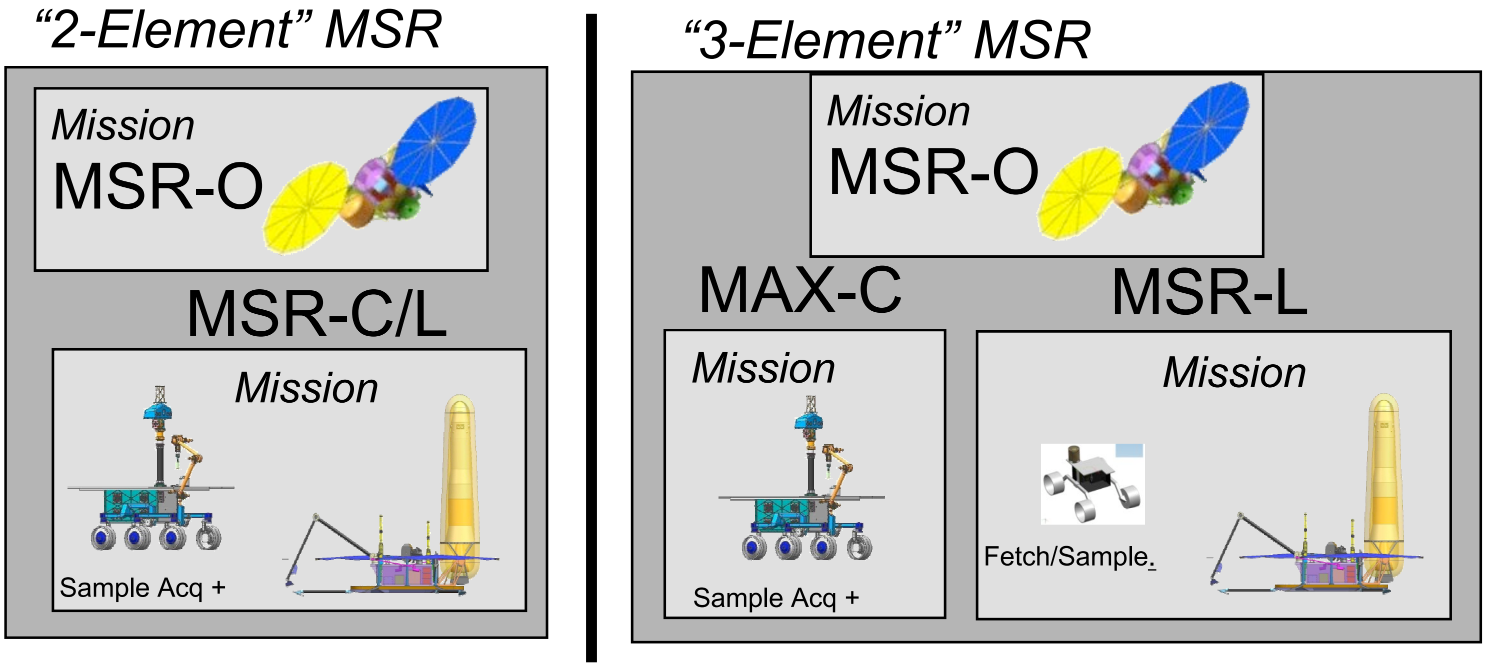
Required vs. Desired Instrumentation

- The ND-SAG noted that it is theoretically possible for a sampling rover that revisits a previously explored route at a well-characterized site to carry reduced instrumentation.
- This would mean revisiting exact positions, and possibly the same RAT holes. Since such a mission would lack capability to select or document samples, the risk of not being able to reoccupy previous sites is a potentially crucial vulnerability with extremely negative consequences to the science return.

Updated!

	ND-SAG		MRR-SAG	
Measurement	New site	Prev. site	New site	Prev. site
Color stereo imagery	YES	YES	YES	YES
Microscopic imagery	YES	YES	YES	YES
Mineralogy	YES	NO	YES	YES
Bulk Elemental abundance	YES	NO	YES	YES
Organic carbon detection	YES	NO	YES	YES
Abrasion tool	YES	NO	YES	YES

FINDING: The proposed MAX-C rover would collect, document and package samples for potential return; i.e., the first element of a potential future sample return campaign



O=orbiter
C=cacher
L=launcher

- In a potential 2-element MSR campaign, a Mars Ascent Vehicle (MAV) and capable sampling rover would be landed together. This combination might exceed acceptable EDL mass limits.
- In a potential 3-element campaign, a sampling/caching rover would land separately before a MAV. A future surface rendezvous would recover the cache and load it into the MAV.
- In both scenarios, an orbiter would be required.

The Potential Importance of Sample Caching

A potential “3-element” MSR architecture would separate the “number of miracles” needed on individual missions - a major benefit to the technology development program.

Potentially achievable with the proposed MAX-C mission:

caching

1. Develop and demonstrate the capability of **sample acquisition by coring and mechanical manipulation.**
2. **Sample encapsulation and canister loading** (assembly of a cache). This would either have direct value (if the cache were returned) or technology heritage value (if not).
3. Develop the procedures for #1 and #2 above consistent with **planetary protection and contamination control** requirements for potential sample return missions.
4. Proposed **Entry-Descent-Landing (EDL)** System
    a) Demonstrate precision landing
    b) Develop and demonstrate use of landed platform under MSL-based skycrane landing system

Relationship Between *in situ* Science and Potential Sample Return

- The kinds of rocks that would need to be interrogated to achieve the proposed *in situ* objectives are a class of samples of crucial interest for potential sample return.
- The instruments needed to achieve the proposed *in situ* objectives are the same instruments needed to select samples for potential return to Earth, and to document their context.

FINDING: Because of these compelling commonalities, it makes sense to merge these two purposes into one mission.

- Samples in addition to those described above are necessary to support other sample return-related objectives (e.g., igneous petrology/geochemistry, geochronology, etc.).

Proposed MAX-C Objectives

Primary Science Objectives: At a site interpreted to represent high habitability potential, and with high preservation potential for physical and chemical biosignatures:

- evaluate paleo-environmental conditions
- characterize the potential for the preservation of biosignatures
- access multiple sequences of geological units in a search for possible evidence of ancient life and/or pre-biotic chemistry

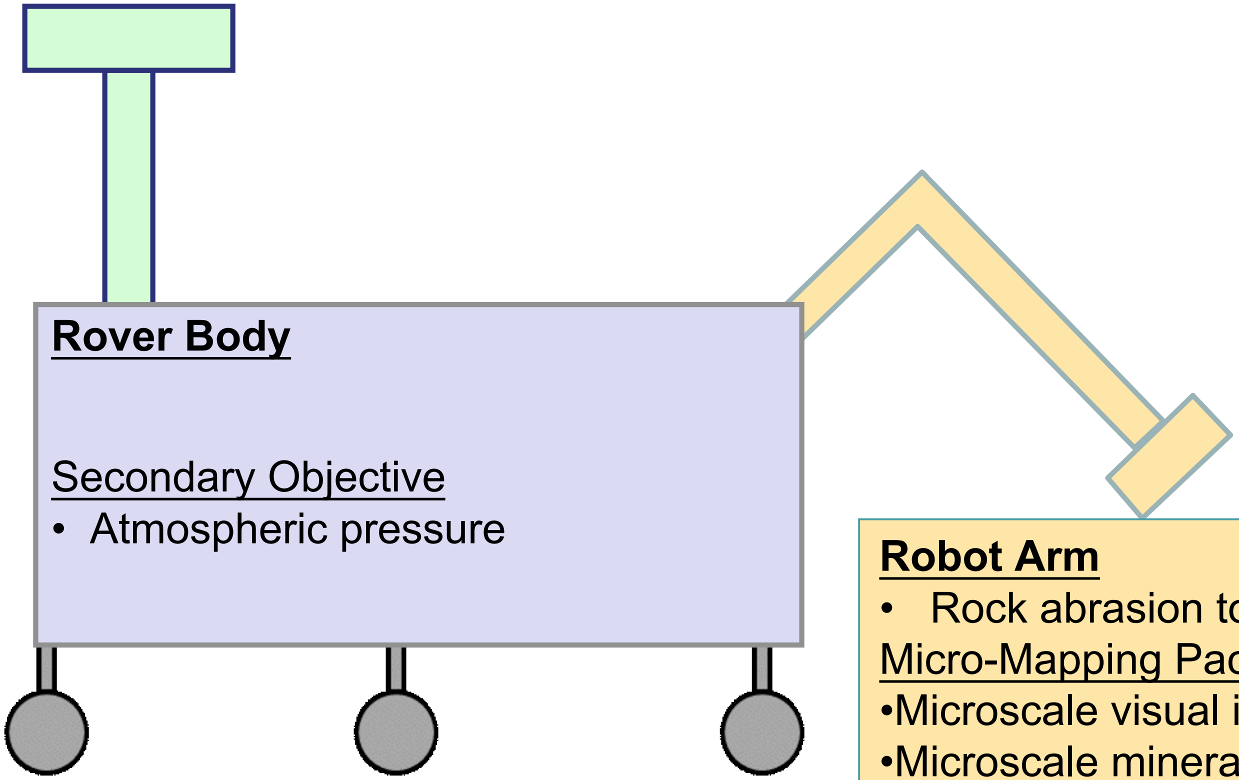
Samples necessary to achieve the scientific objectives of the proposed future sample return mission would be collected, documented, and packaged in a manner suitable for potential return to Earth.

Secondary Science Objective: Address need for long-term atmospheric pressure data from the martian surface.

MAX-C Payload Concept

Select targets and establish context

Mast
- Morphology, context
- Remote mineralogy



Rover Body

Secondary Objective
- Atmospheric pressure

Rock and Soil Interrogation

Robot Arm
- Rock abrasion tool

Micro-Mapping Package
- Microscale visual imaging
- Microscale mineralogy imaging
- Microscale organic imaging
- Microscale elemental chemistry imaging

Bulk Rock (if not achievable by above)
- Bulk elemental chemistry

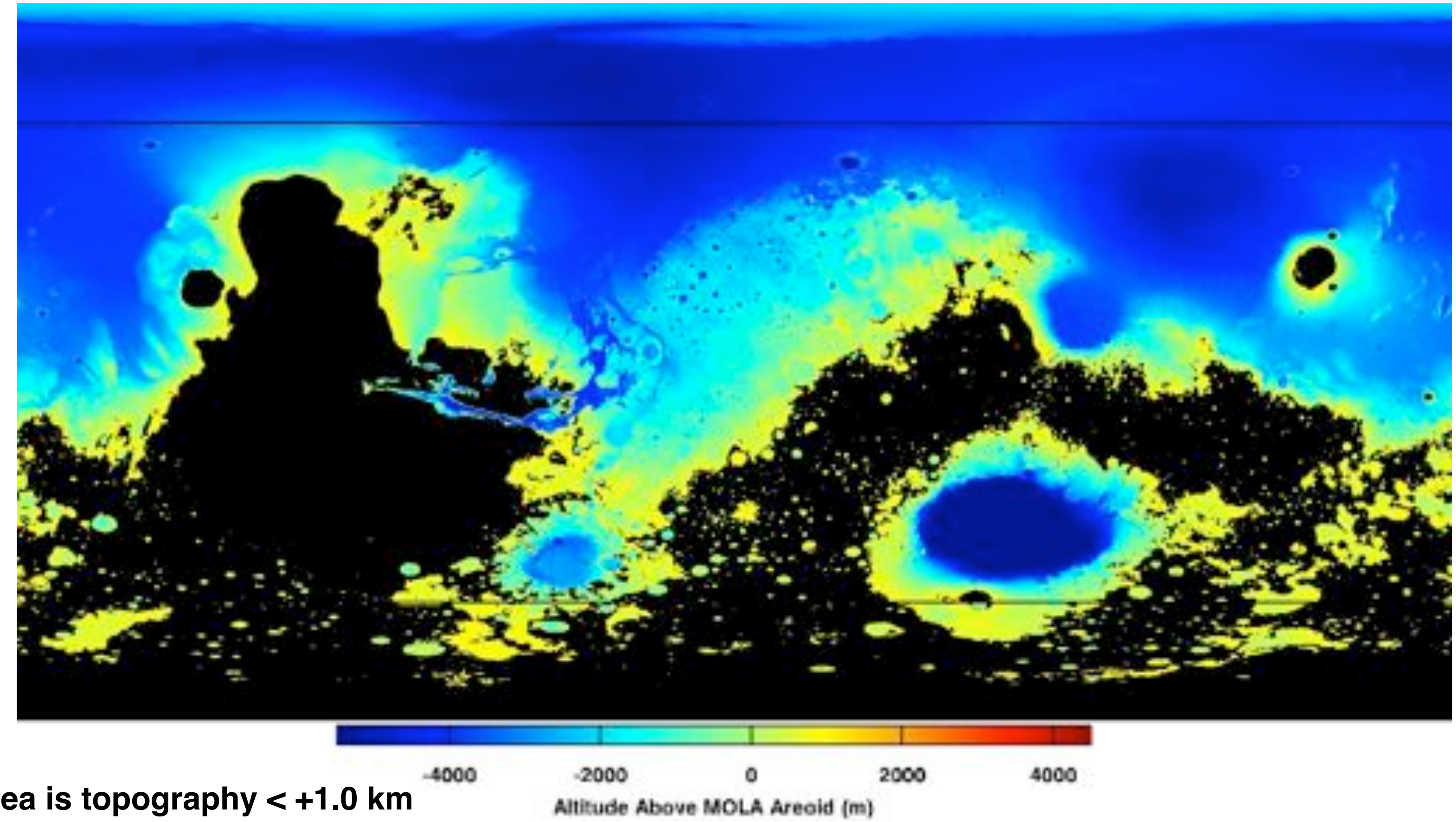
Sample Caching

Sample collection, encapsulation, and caching System (Location TBD)

MAX-C
Mission Concept:
Landing Site Issues

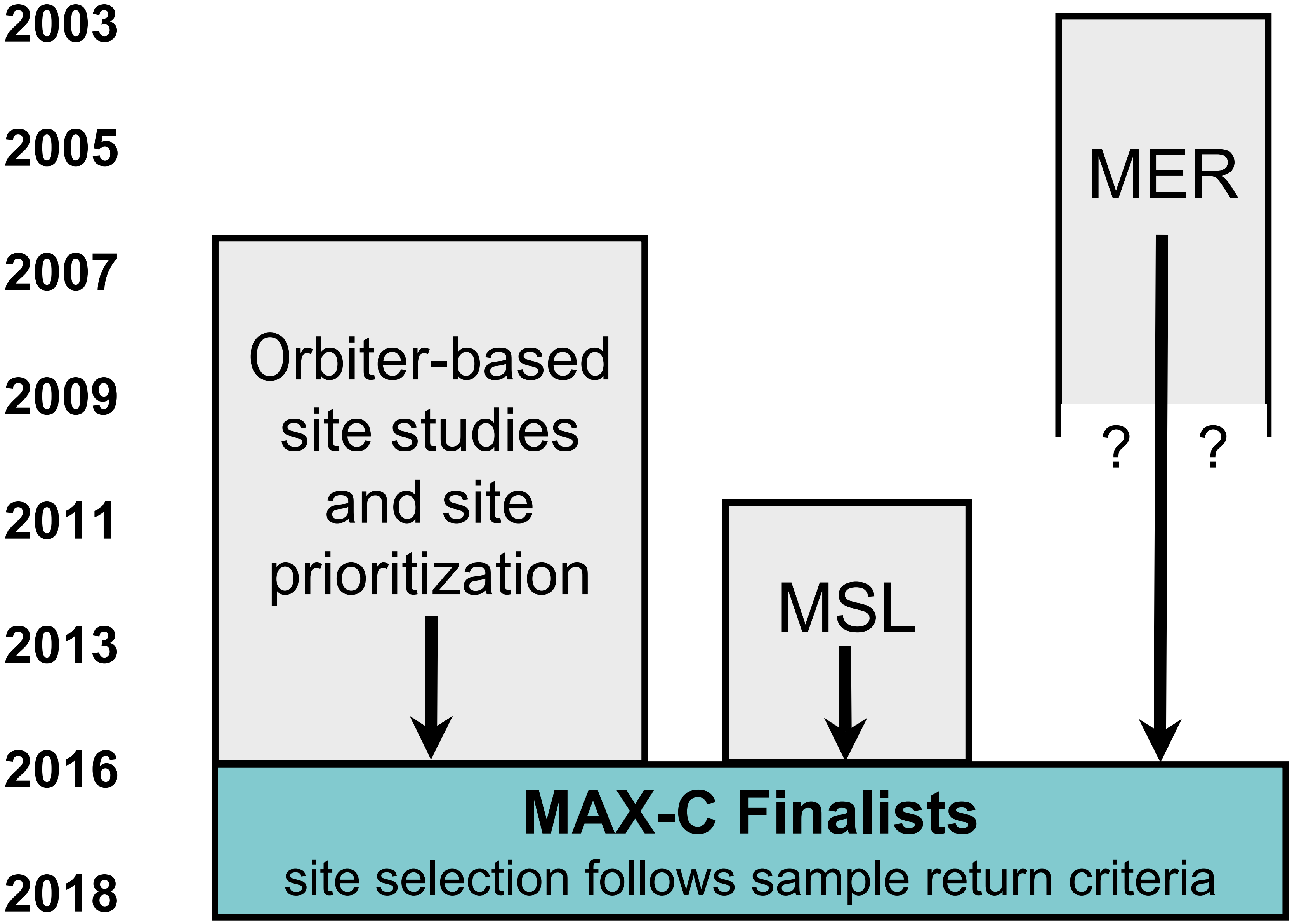
MAX-C Key Landing Site Issues

The best way to evaluate the multiple candidate sites from which to consider returning samples is via an open landing site selection competition that includes sample return selection criteria and sites as high as +1 km elevation.



Colored area is topography < +1.0 km
Horizontal lines at ±60° latitude

Identifying Candidate Sites for MAX-C



2003

2005

2007

2009

2011

2013

2016

2018

MER

? ?

Orbiter-based site studies and site prioritization

MSL

MAX-C Finalists

site selection follows sample return criteria

Pre-decisional – for Planning and Discussion Purposes Only

A “Finalist” Landing Site: Examples of Observations

Sustained habitable environment sometime in past	(1) Diverse minerals indicating extensive activity of liquid water (e.g., phyllosilicates, silica, carbonates, sulfates) (2) Evidence of a hydrothermal system (3) Other potential geochemical energy sources for life in an aqueous environment
Favors preservation of an environmental record or biosignatures	(1) Sustained sub-aqueous sedimentation (2) Rapid *in situ* mineral precipitation occurred during deposition (3) Minerals indicating reducing conditions
Possible evidence of life or prebiotic chemistry	(1) Organic molecules of uncertain origin (meteoritic or indigenous to Mars) (2) Isotopically light sulfur or carbon, etc. in minerals
Probable evidence of life or prebiotic chemistry	(1) Organic matter indigenous to Mars (2) Organic compounds resembling microbial organic matter (3) Organic deposits or rock fabrics resembling microbial mats, stromatolites or microbialites (4) Isotopic fractionation patterns together with rock fabrics or minerals that suggest a primary, possibly biological origin

MAX-C Mission Concept: Engineering Studies

(Chris Salvo)

Status of Implementation Studies

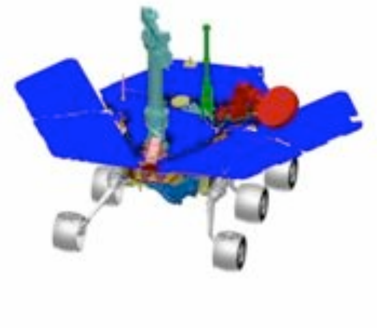
- The engineering team has begun conceptual studies (including a full Team X study) to respond to the *in situ* measurement and sample caching objectives.

- The system architecture and infrastructure hardware from Mars Science Laboratory (MSL) form the basis for the studies:
  - Cruise and EDL portions could be a direct clone of MSL (sky-crane landing system).
  - Rover design likely to be based largely on MSL components, but would entail a new system design tailored to the specific payload.
  - In the process of assessing straw-man instrument suites and supporting hardware (e.g. coring tool, robotic arm, etc.).

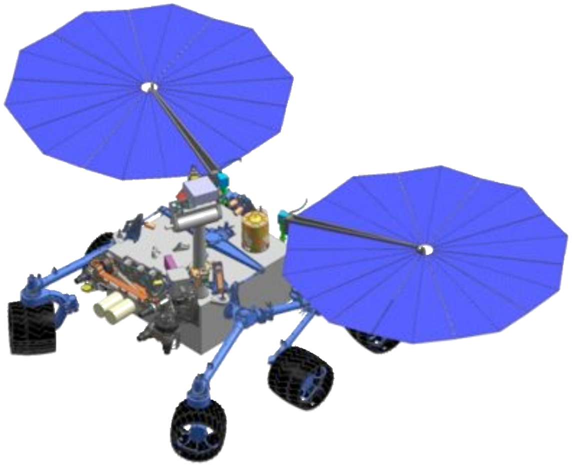
The Proposed MAX-C Rover in Context

The proposed rover could address compelling *in situ* science objectives, provide critical feed-forward to MSR, and fit program resource constraints.

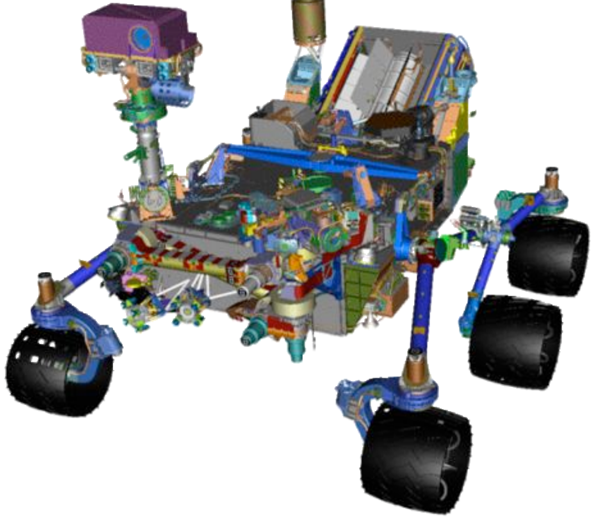
MER



MAX-C



MSL



Payload+Science Support Equipment Mass		
5+16 kg	~15+50 kg	82+155 kg

Key Engineering Attributes/Support

- Landing site access:
  - Latitude (solar-powered mission): 25N to 15S
  - Altitude: below ~0 km altitude (science team desires +1 km capability – achievable if total landed mass is contained)
  - Landing ellipse: ~7 km radius
- Traverse Performance:
  - Traverse design: ~10 km total; ~200 m/sol
  - Slope/rock access: MER-like
- Robotic Arm/Tools:
  - 5-DOF arm with rotary percussive coring/abrading tool
  - Core directly into encapsulation sleeves*
  - Bit change out provided
- Caching:
  - Extractable cache of cores, individually encapsulated/capped
  - Entire core handling/caching device enclosed and sealed with single entry port for core transfer*

** Planetary Protection/Contamination Control appropriate for subsequent sample return would be included in the design.*

Development Risk and Cost

- Cruise and EDL inheritance would minimize cost/risk:
  - Clone of MSL cruise stage, entry body, and sky-crane landing system.
  - Huge inheritance from MSL in both flight design and test hardware.

- Proposed rover system would be medium risk and medium cost:
  - New intermediate scale of rover would be a new mechanical and thermal development, based on MSL and MER.
  - High engineering component heritage from MSL.
  - Some key new instruments.
  - Technical challenges: Coring/caching system, fast rover navigation algorithms/hardware, hybrid distributed motor control.

- Planetary Protection and Contamination Control would drive an increment of cost and risk (medium).
  - Technical challenges: Bio-cleaning, cataloguing, and transport modeling.

- The MRR-SAG's cost estimate is in the range of $1.5-2.0B (RY$ for launch in 2018).

MAX-C Concept: Summary

(Scott McLennan)

MRR-SAG Conclusions

Highest priorities:

1. Respond to life-related discoveries/hypotheses by MSL, prior landed missions, orbiters, and telescopes.
2. Commence the transition from the major programmatic strategy of “Explore Habitability” to “Seek Signs of Life.”
3. For a potential future sample return campaign, reduce the risk as well as enhance the quality and value of the enabling engineering and science

The proposed MAX-C mission would extend our surface exploration of Mars, make substantial progress towards the life goal, be intended as the first element of a possible sample return campaign.

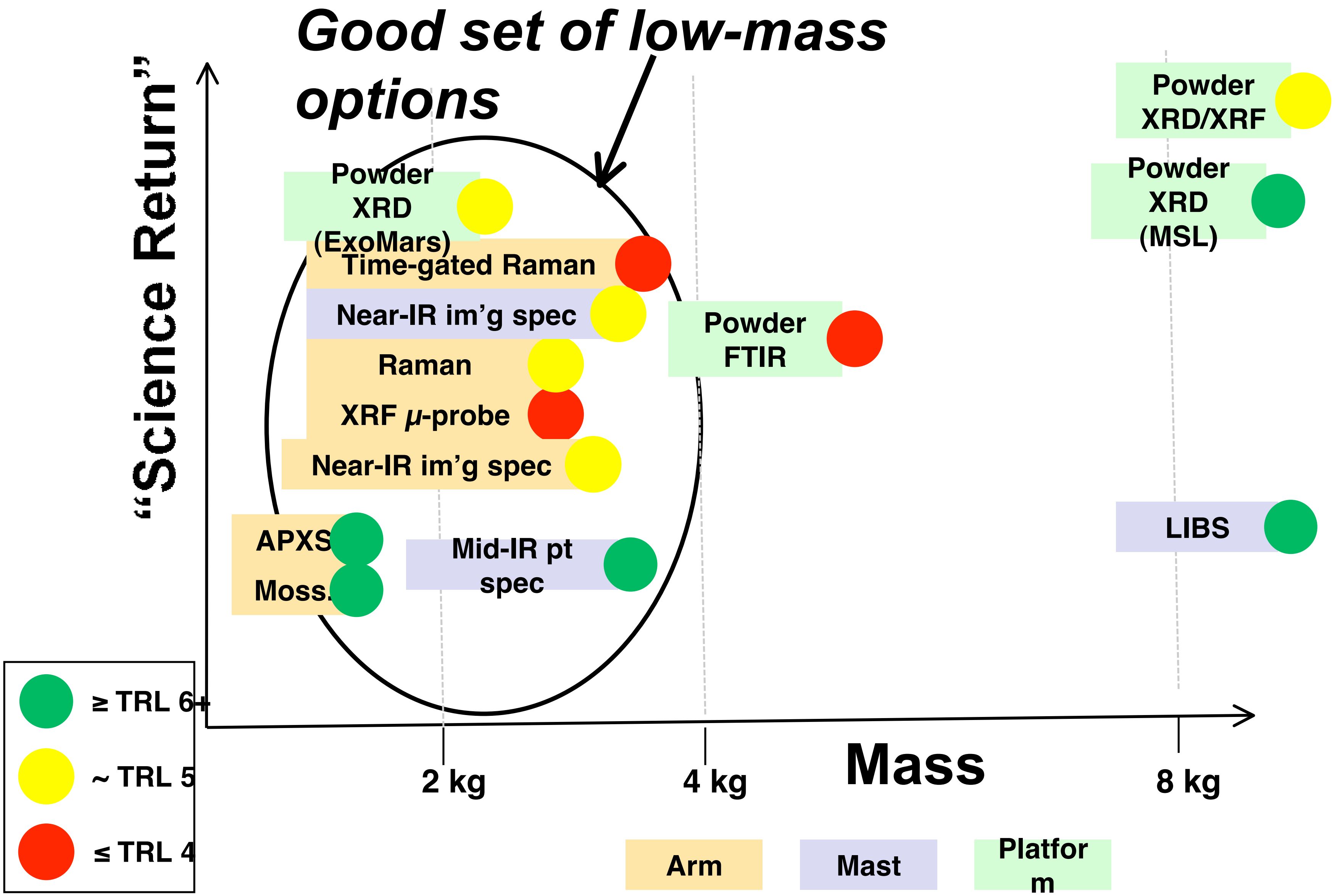
Backup Slides

Antecedent Analysis: ND-SAG

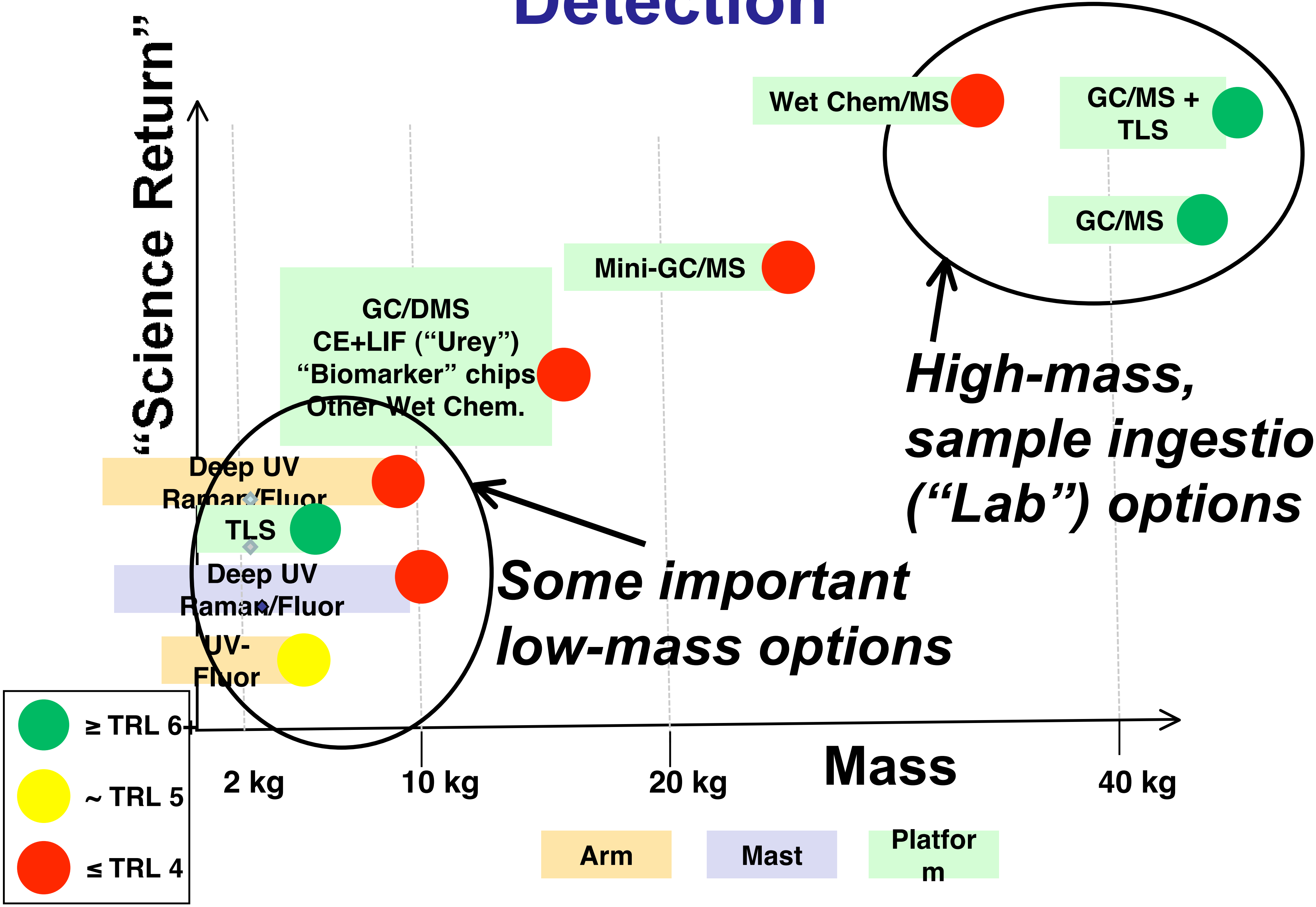
Summary of the logic of the analysis

1. Define possible scientific objectives for MSR.
   - Based on analysis of the MEPAG Goals Document.
2. What kinds of samples would be needed to achieve these objectives?
3. What are the attributes of the sample collection that would maximize its scientific value?
   - Number of samples
   - Mass/sample
   - Many other factors
4. What subset of the above would be the minimum required to define a scientifically compelling first MSR?
   - Next steps: engineering, costs, consensus

Candidate Instruments for Mineralogy


Good set of low-mass options

Candidate Instruments for Organic Detection



High-mass, sample ingestion ("Lab") options

Some important low-mass options

Requirement: Outcrop Access

FINDING: Outcrop access is fundamental to the MAX-C mission concept. Areas of extensive outcrop are typically associated with significant topography, which correlates to landing hazard.

Two different strategies would be possible:

A. “Go-to” Capability

- **Significant topography would not be allowed within the landing ellipse.**
- **Rover traverse capability must exceed the size of the landing ellipse.**

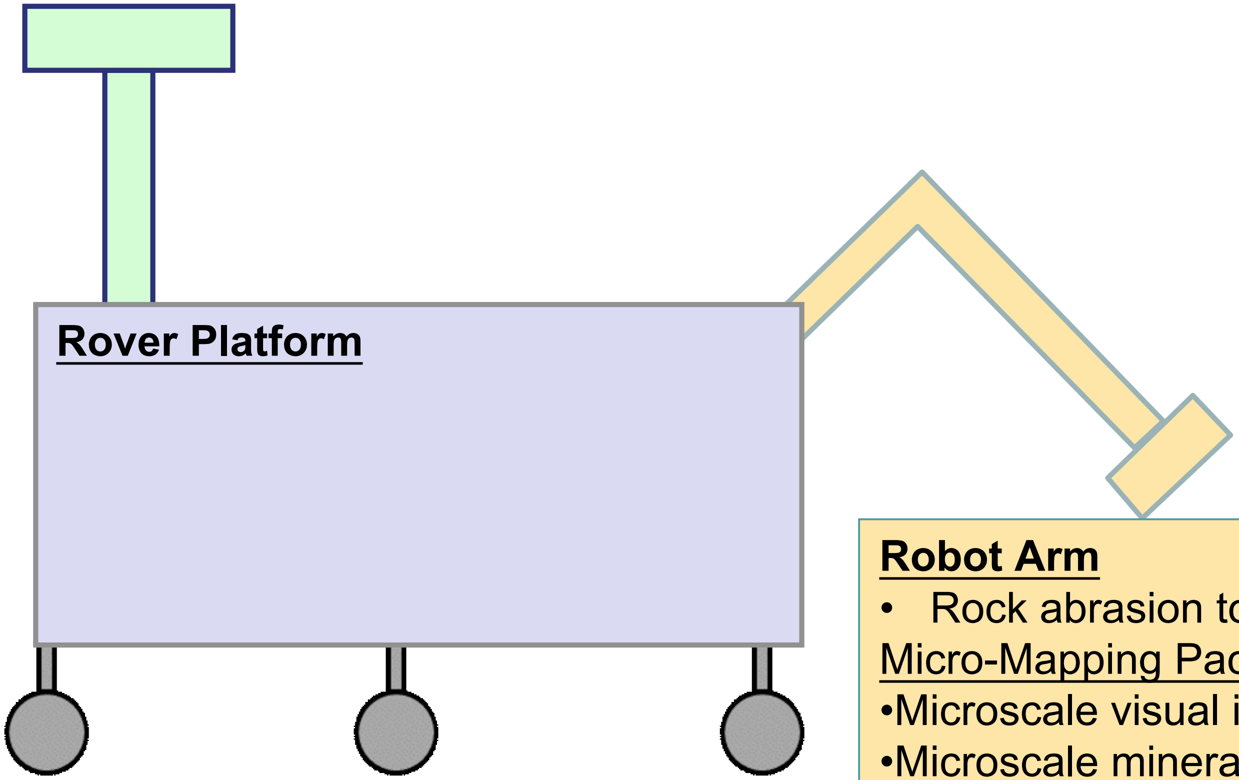
B. “Hazard Avoidance” Landing Capability

- **Significant topographic features (with outcrops) would be allowed in the landing ellipse.**
- **Rover science would be done internal to the landing ellipse.**

Proposed Science Floor Capability

Select targets and establish context

Mast
- Morphology, context
- Remote mineralogy



Rover Platform

Rock and Soil Interrogation

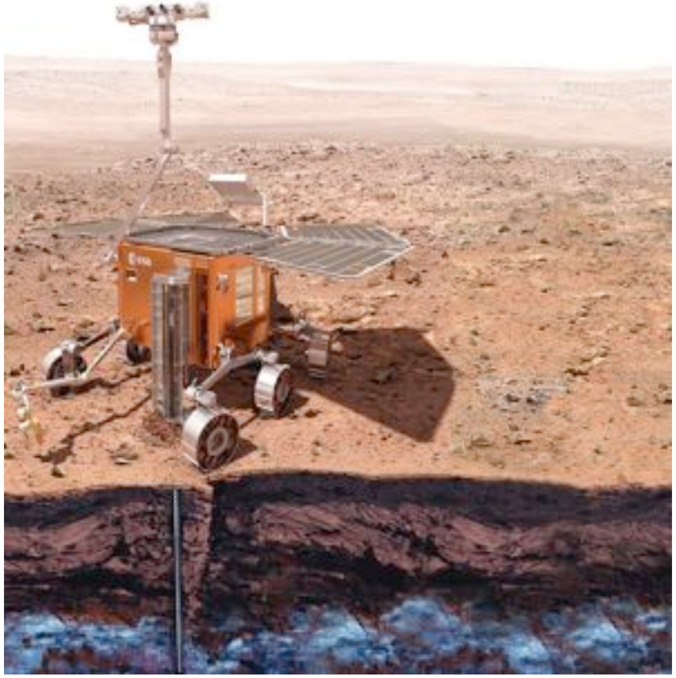
Robot Arm
- Rock abrasion tool

Micro-Mapping Package
- Microscale visual imaging
- Microscale mineralogy 2-D raster
- Microscale organic detection
- Bulk elemental chemistry

Sample Caching

Sample collection, encapsulation, and caching System (Location TBD)

Complementarity with ExoMars (EXM)



Artist's depiction of ExoMars. *Credit: ESA/AOES Medialab.*

One concept considered related to "deep" (1-2 m) drilling.

- The team assigned this a low relative priority NOT because it has low intrinsic scientific merit, but because it is presumed that this would be accomplished by EXM.
- Until EXM carries out its test, we would not know whether it would be worth doing twice!

MAX-C Mission Concepts: Science Priorities

Ref. #	Mission Concept	PRIORITY			
		Science value	Science Risk	Breakthrough Potential	OVERALL
4	Astrobiology Mission to Early Noachian Mars	2.7	2.3	2.6	2.5
2	Stratigraphic Sequence near Noachian-Hesperian Boundary	2.6	2.2	2.5	2.4
5	Astrobiology: New Terrain	2.5	2.1	2.4	2.3
7	Detection of Methane Emission from the Mars Subsurface	2.3	1.2	2.5	2.1
3	Radiometric Dating	2.3	1.5	2.1	1.9
6	'Deep' Drilling	1.9	1.6	1.9	1.8
8	Polar Layered Deposits Traverse	1.8	1.7	1.7	1.7
1	Mid-Latitude Shallow Ice	1.7	1.9	1.7	1.5

Top concept priorities, by discipline

Priority	Geologists	Astrobiologists	Atm., Geophys.
1	4	4	2
2	2	2	4
3	3	5	5
4	5	7	1

N = 23; For all categories, ratings range is 1-3, with 3 being good.

MRR-SAG Team

(27 Mars experts, including 6 international scientists)

Lisa Pratt	astrobiology
Abby Allwood	field astrobiology
Alfred McEwen	imaging, Mars geology
Ariel Anbar	isotopes, MC-ICP-MS spectroscopy
Barbara Sherwood-Lollar	astrobiology, isotopic signatures, signatures of biogenic hydrocarbons
Carl Allen	Sampling, MSR, sample curation
Daniel Glavin	astrobio, organic chemistry
Dave DesMarais	astrobio
Doug Ming	geochemistry, mineralogy, soils
Frances Westall	astrobio
Francois Poulet	Surface Science, Mineralogy
Gian Gabrielle Ori	sedimentology/stratigraphy, field geology
John Grant	rover field geology, impact craters

John Parnell	field geology, organic geochem.
Ken Herkenhoff	imaging, photometry, geol mapping
Mike Carr	water on Mars
Ralph Milliken	mineralogy, surface geology, sedimentology
Scott McLennan	sedimentology
Sushil Atreya	atmospheric chemistry
Tom McCollom	astrobiology
Vicky Hamilton	TIR spectroscopy, petrology
Vicky Hipkin	atmospheric science
ex officio	
Joy Crisp	Mars Program Office--science
Dave Beaty	Mars Program Office--science
Chris Salvo	Mars Program Office--engineering
Charles Whetsel	Mars Program Office--engineering
Mike Wilson	Mars Program Office--engineering

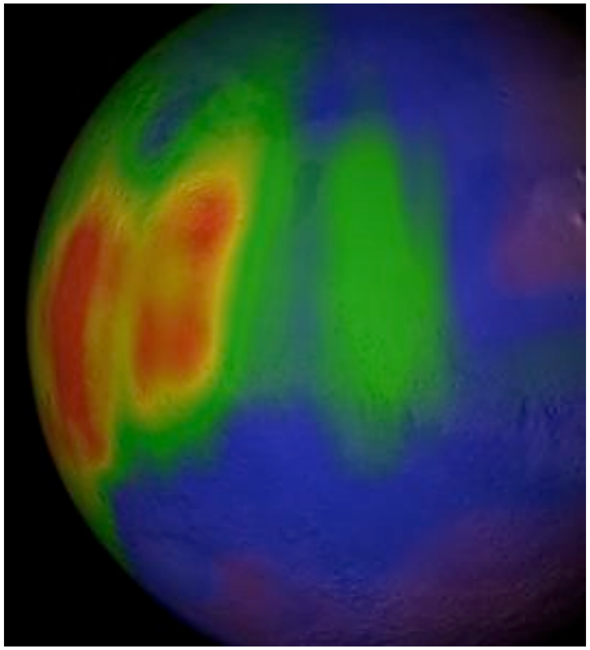
Additional experts consulted:

Fernando Abilleira, F. Scott Anderson, Paul Backes, Don Banfield, Luther Beegle, Rohit Bhartia, Jordana Blacksberg, Shane Byrne, John Eiler, Sabrina Feldman, Lori Fenton, Kathryn Fishbaugh, Mark Fries, Bob Haberle, Michael Hecht, Arthur (Lonne) Lane, Richard Mattingly, Tim Michaels, Denis Moura, Zacos Mouroulis, Mike Mumma, Scot Rafkin, Carol Raymond, Christophe Sotin, Rob Sullivan, Tim Swindle, Ken Tanaka, Peter Thomas, Ben Weiss, and Rich Zurek.

Concept #7

Methane Emission from Subsurface (Priority #4)

- Is methane being emitted from the subsurface and if so, what is the nature of the source(s)? Are methane emissions seasonal, episodic, or persistent?
- Is the source of methane abiotic or biotic (related to present or past life?)?
- Are other reduced gases (e.g., H_2S, $(CH_3)_2S$, H_2, CO, C_nH_{2n}+2) associated with methane? Are other proposed biogases present in the vicinity (N_2O, O_2, O_3)?
- What is the lifetime and destruction mechanisms of methane in the atmosphere?

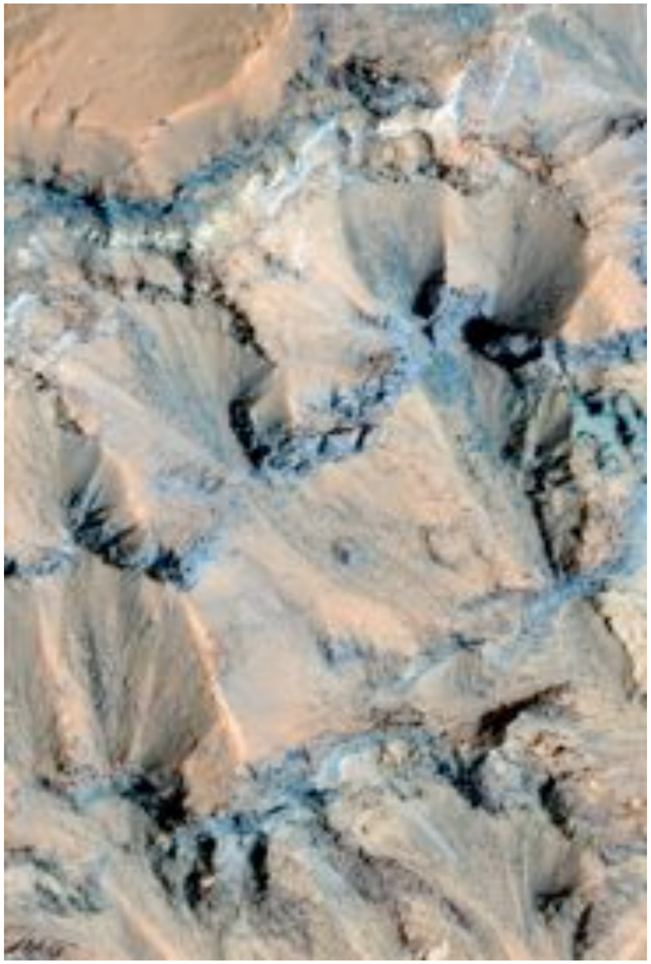


Map of methane concentrations on Mars Credit: Mike Mumma, NASA press release.

Concept #3

Radiometric Dating (Priority #5)

- Determine the absolute ages of a sequence of igneous and/or sedimentary rocks of fundamental scientific significance
- Evaluate stratigraphic models such as the concept of "mineral epochs"
- Determine absolute age of a globally significant stratigraphic boundary
- Provide calibration for crater counting chronology

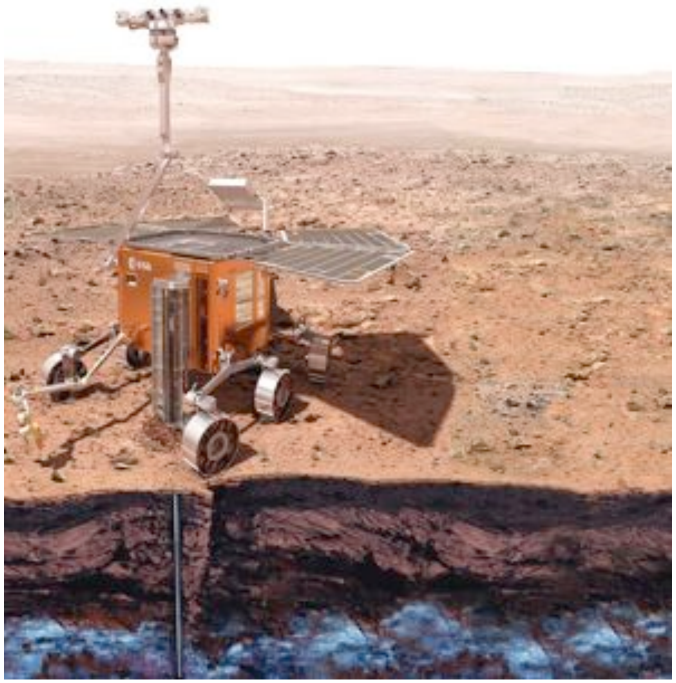


Interbedded unaltered lava (blueish enhanced colors) and deposits with hydrous alteration (light-toned units) on a steep slope in Asimov crater.

Portion of HiRISE color image PSP_004091_1325.
Credit: NASA/JPL/University of Arizona

Concept #6

Deep Drilling (1-2 m depth) (Priority #6)



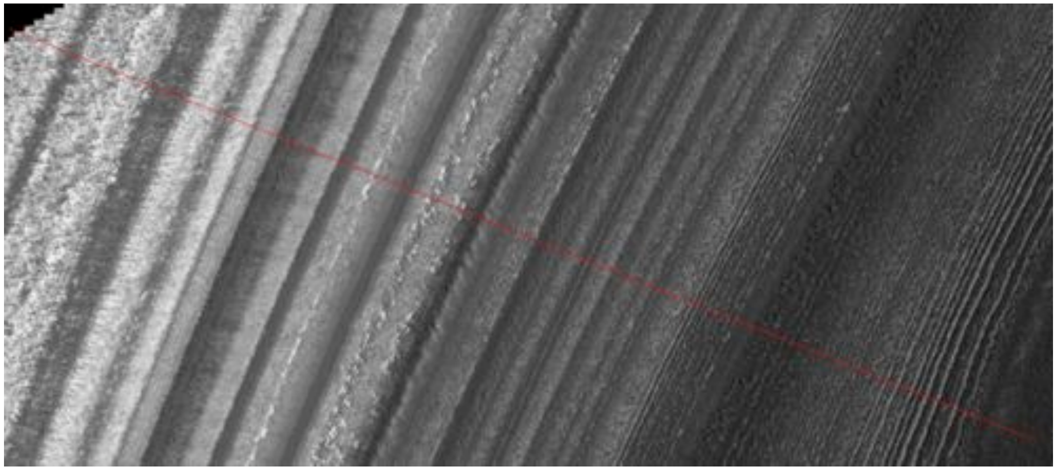
Artist's depiction of a deep drilling mission (ExoMars). *Credit: ESA/AOES Medialab.*

- What is the extension of the superficial oxidation layer and the processes acting in the near subsurface?
- How is oxidation progressing and what is causing it?
- What is the fate of the meteoritic carbon?
- What is the nature and origin of organics on Mars?
- Is there any evidence of life in the near subsurface?
- What is the paleoclimate history of Mars?
- What kinds of environments and geologic settings are/were present on Mars?

Concept #8

Polar Layered Deposits (Priority #7)

- Do the PLD contain a record of recent global climate changes and other episodic events? If so, what are the mechanisms by which climate changes are recorded?



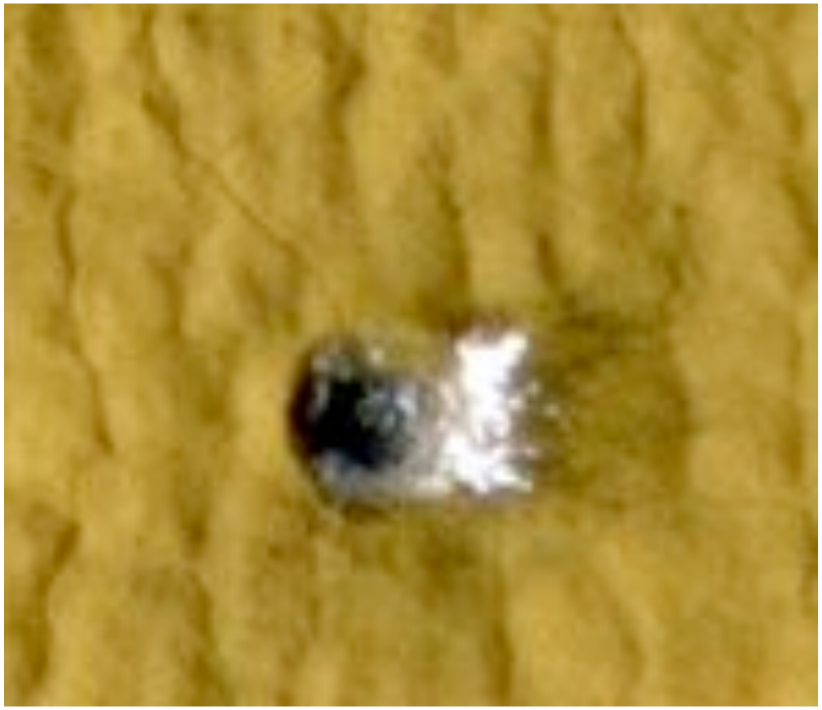
Exposure of PLD with example rover traverse. HiRISE image PSP_001738_2670. Credit: NASA/JPL/University of Arizona.

- What could be inferred about the secular evolution of water on Mars from the PLD record?
- Are recent global climate variations dominated by astronomical (orbit/axis) forcing?
- How do recent global climate changes on Mars compare with those on Earth?

Concept #1

Mid-Latitude Shallow Ice (Priority #8)

- What are the characteristics of mid-latitude periglacial sites and their relationship to obliquity cycles?
- What is the habitability of mid-latitude ice, and how does perchlorate affect the present day habitability of Mars?
- Could mid-latitude ice provide a resource for *In Situ* Resource Utilization (ISRU)?



Portion of HiRISE image of Phlegra Montes showing an impact crater formed in 2008 at 46°N latitude, which excavated a shallow layer of very pure water ice. Crater diameter is 12 m; depth is 2.5 m. HiRISE image ESP_011494_2265. Credit: NASA/JPL/University of Arizona.