Returned Sample Science Inputs to M-2020 Landing Site Selection

Prepared by the
Returned Sample Science Board

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Government sponsorship acknowledged for some members of the RSSB.

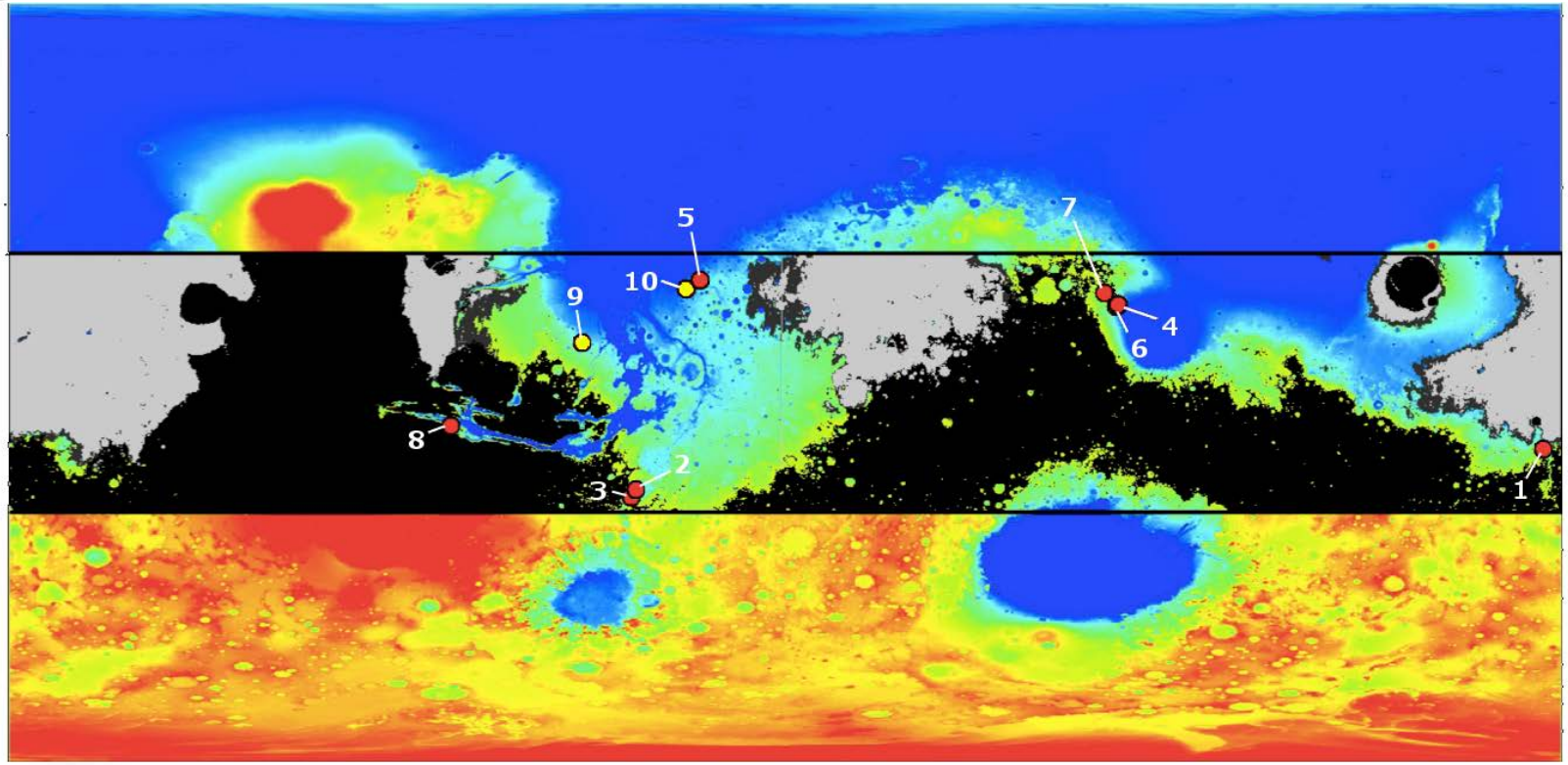
Sites Selected for Science and Engineering Evaluation (in alphabetical order)

Site	Approx Ellipse Location	Approx Elevation	Geologic Process
Columbia Hills	-14.5478N, 175.6255E	-1.9 km	Hydrothermal Crustal
Eberswalde	-23.7749N, -33.5147E	-1.4 km	Fluvial/Deltaic
Holden	-26.6200N, -34.8713E	-2.1 km	Fluvial/Deltaic
Jezero	18.4386N, 77.5031E	-2.6 km	Fluvial/Deltaic
Mawrth	23.9685N, -19.0609E	-2.3 km	Pedogenic
NE Syrtis	17.8899N, 77.1599E	-2.0 km	Hydrothermal Crustal
Nili Fossae	21.0297N, 74.3494E	-0.6 km	Hydrothermal Crustal
SW Melas	-9.8132N, -76.4679E	-1.9 km	Fluvial/Deltaic

Two sites selected for additional science investigation (approx locations):

- Hypanis (11.8N, 314.6E; -2.6 km, fluvial/deltaic)
- McLaughlin (21.9N, 337.8E; -5.0 km, fluvial/deltaic)

Selected Sites



(alphabetical order)

1- Columbia Hills (Gusev)
2- Eberswalde
3- Holden
4- Jezero
5- Mawrth
6- NE Syrtis
7- Nili Fossae
8- SW Melas

9- Hypanis
10- McLaughlin

Elevation above MOLA Geoid (m)

High: 4000 Low: -5000

Black elevation mask > 0.5 km

Thermal Inertia masks:

< 150 = Dark Gray

< 100 = Light Gray

One Input: Community Discussion of RSS Criteria (from Summer, 2015)

Shorthand	Criteria	AB	Cosmo
Age Range, Surface Water	Regional geology spanning a significant range of geologic age (wider range is better), and rocks must be present from the period of abundant surface water (TBC: LN, EH)	●	●
Water-rock Interaction	Rocks that preserve evidence of extensive water rock interaction. Prioritization: 1. Sedimentary rocks deposited in long-lived standing water (lake, ocean); 2. Sustained near-surface hydrothermal conditions (e.g. sinter); 3. Deep, subsurface high-T hydrothermal	●	
Igneous Diversity	Potential to acquire diverse igneous samples (some diversification strategies: outcrop, float, alluvial fan, conglomerate, ejecta, breccia)		●
Crater Calibration	Datable unit with a defined crater retention age (Priority: Hesperian age)		●
Deep Ejecta	Ejecta from deep crustal impacts	◎	●
Low-T Geochem	Diversity of low-T (0-200°C) geochemical environments (esp. as indicted by diversity of mineralogic detections such as clays, sulfates, carbonates)	●	●
Context	Local and/or regional context for samples can be established (some investigations require outcrop-level context, others only regional-level context).	●	◎
No Metamorphism	Absence of regional metamorphism	●	●

Prioritization: E2E-iSAG

- E2E-iSAG prioritized the scientific objectives for MSR, with the key criterion being <u>the value of the incremental knowledge to be gained by returned sample analysis</u>

Priority	Objective Reference #	Objective Description
1	A1	Critically assess any evidence for past life or its chemical precursors, and place detailed constraints on the past habitability and the potential for preservation of the signs of life
2	C1	Quantitatively constrain the age, context and processes of accretion, early differentiation and magmatic and magnetic history of Mars.
3	B1	Reconstruct the history of surface and near-surface processes involving water.
4	B2	Constrain the magnitude, nature, timing, and origin of past planet-wide climate change.
5	D1	Assess potential environmental hazards to future human exploration.
6	B3	Assess the history and significance of surface modifying processes, including, but not limited to: impact, photochemical, volcanic, and aeolian.
7	C2	Constrain the origin and evolution of the martian atmosphere, accounting for its elemental and isotopic composition with all inert species.
8	D2	Evaluate potential critical resources for future human explorers.
ADDI-TIONAL	A2	Determine if the surface and near-surface materials contain evidence of extant life

Igneous sample considerations - I

- Igneous samples are critical for elucidating the geologic evolution of Mars and establishing an absolute Mars timescale
  - While the Martian meteorites (~85) provide important insights, they lack field context and sampling is biased to < 1.5 Ga (E2E-iSAG Report, Table 2)
- **Ideal MSR igneous samples are**:
  1. In place (i.e., outcrop) **from a datable unit with a defined crater retention age, the stratigraphic relationship for which is known, with a focus on probable Hesperian age** (> 3 Ga)*
  2. Have experienced a low degree of alteration or shock
  3. Representative of a range of compositions (from ultramafic to felsic), with a priority on basalt

***This type of sample provides BOTH calibration of crater retention ages AND context, age and constraints for any life/habitability discoveries**

Igneous sample considerations - II

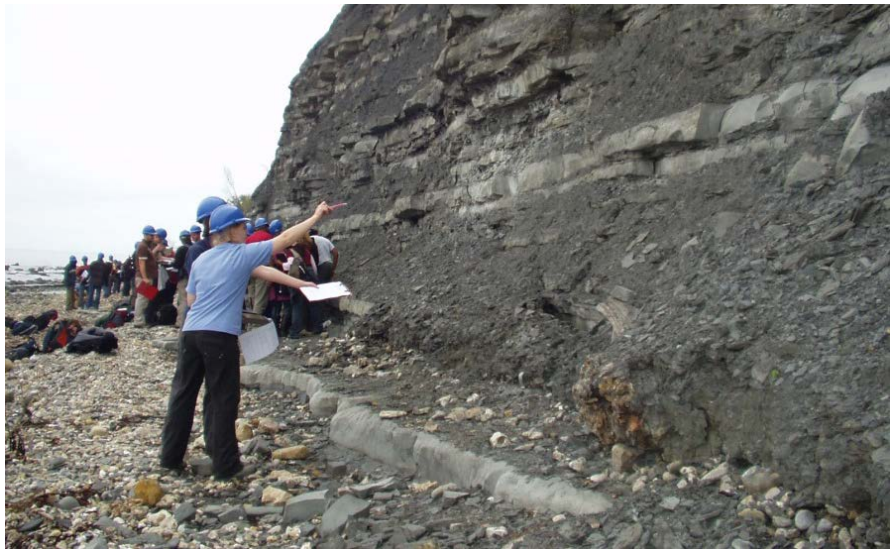
- The aspects in the selection of suitable igneous samples that may be guided by remotely sensed observations are:
  - In-place datable unit with known crater retention ages of probable ≥ Hesperian age
  - General composition and likely rock type (e.g., ultramafic/mafic/felsic)
  - General degree of alteration/weathering (e.g., low vs. high)

- ***Therefore:*** priority should be placed on basaltic igneous outcrop with known crater retention age and low degree of alteration/weathering
  - Igneous diversity would be represented by samples of opportunity, selected during the course of the mission

Sediments & organic matter

- Organic matter is intimately associated with minerals and can be preserved by coating mineral surfaces or by being entombed by mineral phases (inclusions).
- The influence of different rock types on Mars on organic preservation can be predicted from terrestrial equivalents.
- E.g. The low density of organic matter and phyllosilicates causes hydrological separation from dense minerals.
- Phyllosilicates are hydrodynamic equivalents of organic matter and are deposited together.

- Once deposited, mixtures of organic matter and fine grained minerals often produce a low porosity matrix which allows limited access to electron acceptors that induce oxidation.



Not all minerals are the same

Phyllosilicates

- Phyllosilicates are generated by the aqueous alteration of minerals
- Weathering provides opportunity for hydrodynamic separation and co-deposition with organic matter
- In situ alteration does not provide opportunity for hydrological association
- Phyllosilicate-rich rocks like mudstones and shales are potential hosts for organics
- Phyllosilicate-rich rocks like serpentinites and bentonites are more risky as organic hosts

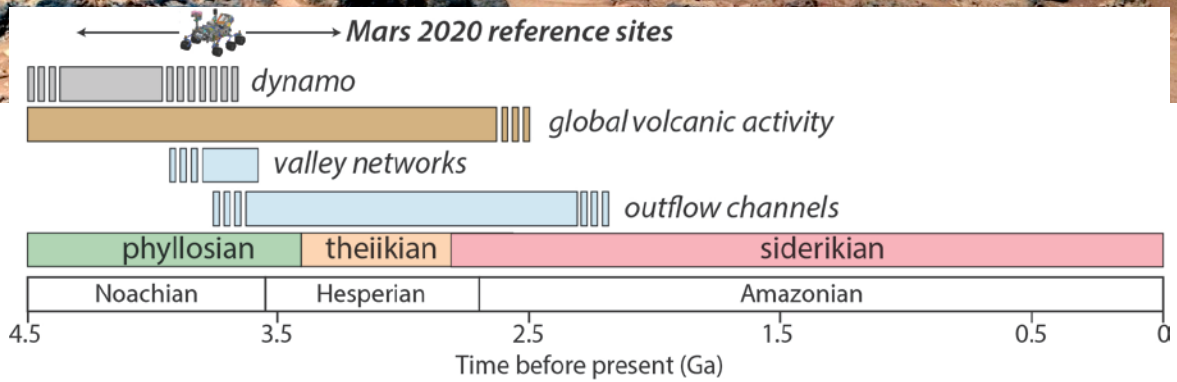
Silica

- Silica can be generated by the precipitation from hot springs or by the selective weathering of a range of minerals
- During precipitation local organic matter can be entombed making sinters desirable for seeking organics
- During transport, organic matter can be oxidised making sandstones and quartzites not desirable for seeking organics

Potential paleosols on Mars

- Paleosols can indicate long-lived water-rock interaction as well as characteristics of past climate, and on Earth can also preserve evidence of past biota
- Al-phyllosilicates overlying Fe-Mg phyllosilicates are characteristic of weathering profiles in soils on Earth, and comparable sequences on Mars have been similarly interpreted by some
- Samples of martian paleosols would likely preserve evidence of past liquid water, climate, and possible biota, similar to Earth
- Paleosols likely cannot be unambiguously identified from orbit but samples from locations with the characteristics of potential paleosols would likely be useful for other reasons as well (for example the presence of clay minerals).

Value of Ancient Samples

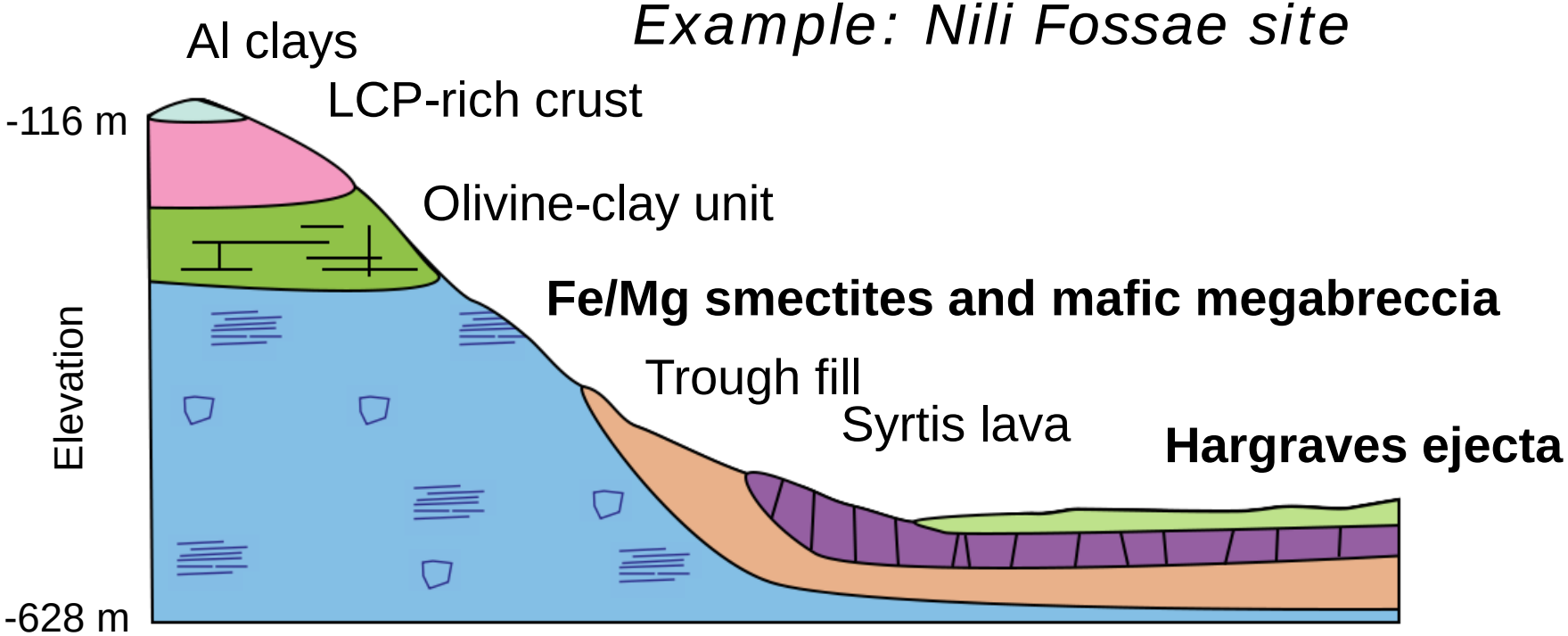


- Early Noachian samples would uniquely constrain:
  - -earliest atmosphere composition
  - -earliest surface temperatures and weathering regime
  - -the dynamo, which likely declined before 3.6 Ga and probably before 4.1 Ga
- Early Noachian samples enable test of hypothesis that decline of the dynamo led to atmospheric loss and climate change on Mars, crucial issues for habitability

Access to Noachian Crust

- Megabreccia basement
- Deep ejecta from recent craters

Example: Nili Fossae site



after Cannon et al., Ehlmann and Mustard 2012

THRESHOLD CRITERIA: SUMMARY

Ref.	Shorthand	Criteria
THRESHOLD CRITERIA		
1	Age: Period of Surface Water	Rocks must be present from the period when Mars had abundant surface water (Draft: LN-EH)
2	Water-rock Interaction	Presence of rocks that preserve evidence of extensive water rock interaction.
		Priority #1. Sedimentary rocks deposited in long-lived standing water (lake, ocean) or sedimentary rocks representing sustained near-surface hydrothermal conditions (e.g. sinter).
		Priority #2. Rocks altered by hydrothermal fluids (i.e., high-T subsurface fluids from magmatic/volcanic activity) **OR** rocks altered by meteoric fluids (i.e., low-T, near-surface fluids) **OR** geologic environments that exhibit mineralogical evidence of sustained water-rock interaction, e.g. clays in paleosols.
3	Igneous Rocks	Presence of diverse rocks that preserve igneous processes.
		Priority #1. Igneous rocks of basaltic composition from lava flows or intrusions for which the stratigraphic relationship is known or can be inferred (may be conformable or cross-cutting relative to stratigraphy)
		Priority #2. Igneous rocks, whether in outcrop, float, as clasts within an alluvial fan, conglomerate, breccia or ejecta, of diverse composition (i.e., ultramafic to felsic)
5	Impact melting or metamorphism	Absence of extensive impact melt sheets or extensive regional metamorphism that could obscure or obliterate primary igneous, sedimentary, or astrobiological features at the sampling site.

QUALIFYING CRITERIA: SUMMARY

Ref.	Shorthand	Criteria
QUALIFYING CRITERIA		
6	Age Range	Regional geology spanning a significant range of geologic age (wider range is better)
7	Igneous Calibration of Crater Chronology	Igneous samples from a datable outcrop with a defined crater retention age, the stratigraphic relationship for which is known, with a focus on probable Hesperian age (> 3 Ga)
8	Deep Ejecta	Potential to be able to sample ejecta from deep crustal impacts
9	Low-T Geochemistry	Diversity of low-T (0-200°C) geochemical **paleoenvironments to understand ancient surface condition** (esp. as indicted by diversity of mineralogic detections such as clays, sulfates, carbonates)
11	Sediments & Organic Matter	Potential to be able to collect sedimentary rocks that best entomb and preserve organic matter **(e.g., phyllosilicates and silica)**
15	Access to Ancient Samples	Potential to collect pre- or early Noachian samples that constrain the early atmosphere,near-surface temperature, dynamo, and habitability
16	sedimentary environments	Potential to be able to sample sedimentary rocks or sediments from more than one geological environment
18	Proximity	Potential to collect the most diverse suite of geological environments within the operations radius (~5 km) of the rover.
19	Temperature	Provide less post-sampling thermal alteration during their residence on the Martian surface

Backup

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