The Importance of Land-on Science for Answering Key Questions about Early Mars with the Mars2020 mission

"Exploration for life on Mars **requires a broad understanding of integrated planetary processes**…Therefore, this endeavor must also investigate the geological and geophysical evolution of Mars; the history of its volatiles and climate; the nature of the surface and subsurface environments, now and in the past; the temporal and geographic distribution of liquid water; and the availability of other resources (e.g., energy) necessary for life.
[Decadal Survery, Appendix: Caching Rover concept, 2010].

Bethany Ehlmann

Caltech, JPL

1st Mars 2020 Landing Site Workshop

May 14, 2014

Mars2020 Science Objectives

Objective A: Exploring an astrobiologically relevant ancient environment on Mars to decipher its geological processes and history, including the assessment of past habitability
Objective B: Support the search for biosignatures (preservation potential, characterization) via 1) context imaging, 2) context mineralogy, 3) fine-scale imaging, 4) fine-scale mineralogy, 5) fine-scale elemental chemistry, and 6) organic meatter detection
Objective C: Assemble a cache of scientifically selected, well-documented samples packaged in such a way that they could be returned to Earth

- To make Mars2020 the first step in the multi-decadal goal of sample return, we need to collect a cache *compelling* enough to initiate the return mission

Mars: The Decadal-Level Questions

- **Think big, think decadal-level questions, embrace Mars' biggest mysteries, think diversity**
- Mars 2020 will explore a site that is astrobiologically relevant and habitable
- This is most of the candidate sites… how to discriminate?
  - Taphonomy (organic preservation)
  - Mission efficiency
  - Diversity
  - Number of "Decadal Level" contributions to broad questions in planetary science

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Taphonomy

- Organics preservation on Earth from <3.5 Ga is well-understood
  - Follow the sedimentary basins
  - Find lacustrine deposits of non-diagenetically altered fine-grained materials
- Organics preservation on Earth from >3.5Ga is less well-documented
- Mars, >3.5Ga, preserves diverse aqueous environments
  - Open- and closed-basin lakes
  - Silica deposits around volcanic vents
  - Carbonate deposits
  - Chloride and sulfate evaporites
  - Sedimentary aquifers (repeated groundwater fluctations)
  - Hydrothermal systems with mineralized veins
  - Igneous rocks

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These too (Gale); but inherited from igneous rocks? Meteorite infall? [Freissnet et al; Eigenbrode et al., in review]

Confirmed this has organic matter (lab analysis of meteorites) [Steele et al., 2012]

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→ Not clear we know enough that taphonomy is the decider

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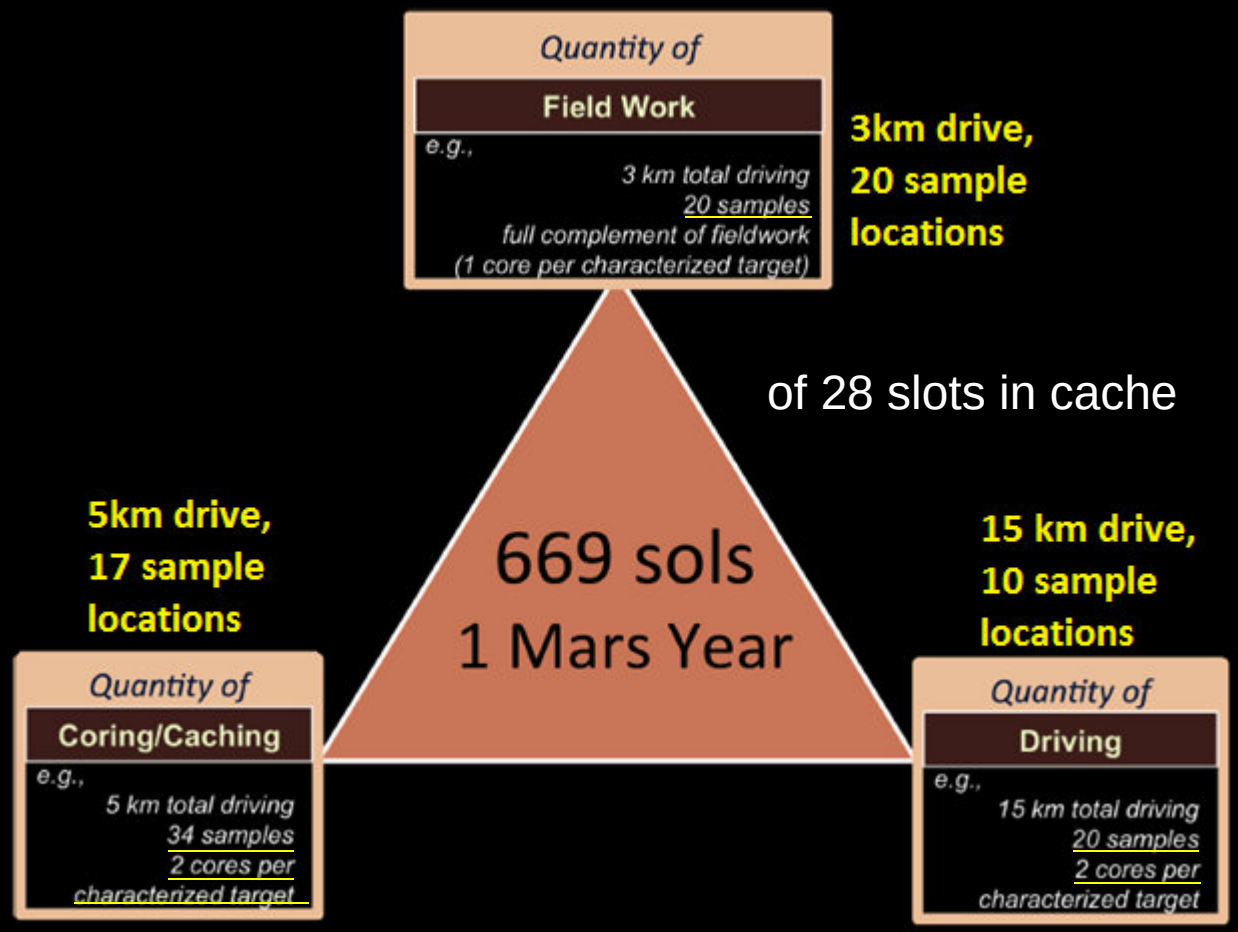
Challenging Primary Mission: Drive Distance vs. # Samples

Mars2020 SDT



- These scenarios all assume several factors faster than MSL

4 levers on science return/time

driving sols = distance / speed

1 EDL System Capability + 3 Landing Site Selection

4 Mobility System Capability

2 Payload Choices: Req'd Time for Measurement

modifed from Mars2020 SDT

- Suggest we deploy all of these levers to our advantage, approximately in this priority order (more later)

Mars: The Decadal-Level Questions

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Intimately related

Decadal Survey Questions

Accretion, volatile supply, planetary differentiation, atmosphere evolution, role of large impacts

Organic matter priomordial sources

Ancient habitats/life

Planetary climate change and systems science

TABLE 3.1 The Key Questions and Planetary Destinations to Address Them

Crosscutting Theme	Priority Questions	Key Bodies to Study
Building new worlds	1. What were the initial stages, conditions, and processes of solar system formation and the nature of the interstellar matter that was incorporated?	Comets, Asteroids, Trojans, Kuiper belt objects (see Chapter 4)
	2. How did the giant planets and their satellite systems accrete, and is there evidence that they migrated to new orbital positions?	Enceladus, Europa, Io, Ganymede, Jupiter, Saturn, Uranus, Neptune, Kuiper belt objects, Titan, rings (see Chapters 4, 7, and 8)
	3. What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres, and what roles did bombardment by large projectiles play?	Mars, the Moon, Trojans, Venus, asteroids, comets (see Chapters 4, 5, and 6)
Planetary habitats	4. What were the primordial sources of organic matter, and where does organic synthesis continue today?	Comets, asteroids, Trojans, Kuiper belt objects, uraniaun satellites, Enceladus, Europa, Mars, Titan (see Chapters 4, 5, 6, and 8)
	5. Did Mars or Venus host ancient aqueous environments conducive to early life, and is there evidence that life emerged?	Mars and Venus (see Chapters 5 and 6)
	6. Beyond Earth, are there modern habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now?	Enceladus, Europa, Mars, Titan (see Chapters 6 and 8)
Workings of solar system	7. How do the giant planets serve as laboratories to understand Earth, the solar system, and extrasolar planetary systems?	Jupiter, Neptune, Saturn, Uranus (see Chapter 7)
	8. What solar system bodies endanger Earth's biosphere, and what mechanisms shield it?	Near-Earth objects, the Moon, Comets, Jupiter (see Chapters 4, 5, and 7)
	9. Can understanding the roles of physics, chemistry, geology, and dynamics in driving planetary atmospheres and climates lead to a better understanding of climate change on Earth?	Mars, Jupiter, Neptune, Saturn, Titan, Uranus, Venus (see Chapters 5, 6, and 8)
	10. How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?	All solar system destinations. (see Chapters 4, 5, 6, 7, and 8)

What are specific, Decadal-level questions for Mars?

Mars' Biggest Mysteries/Decadal-level questions

1) What is the nature of the Noachian crust?

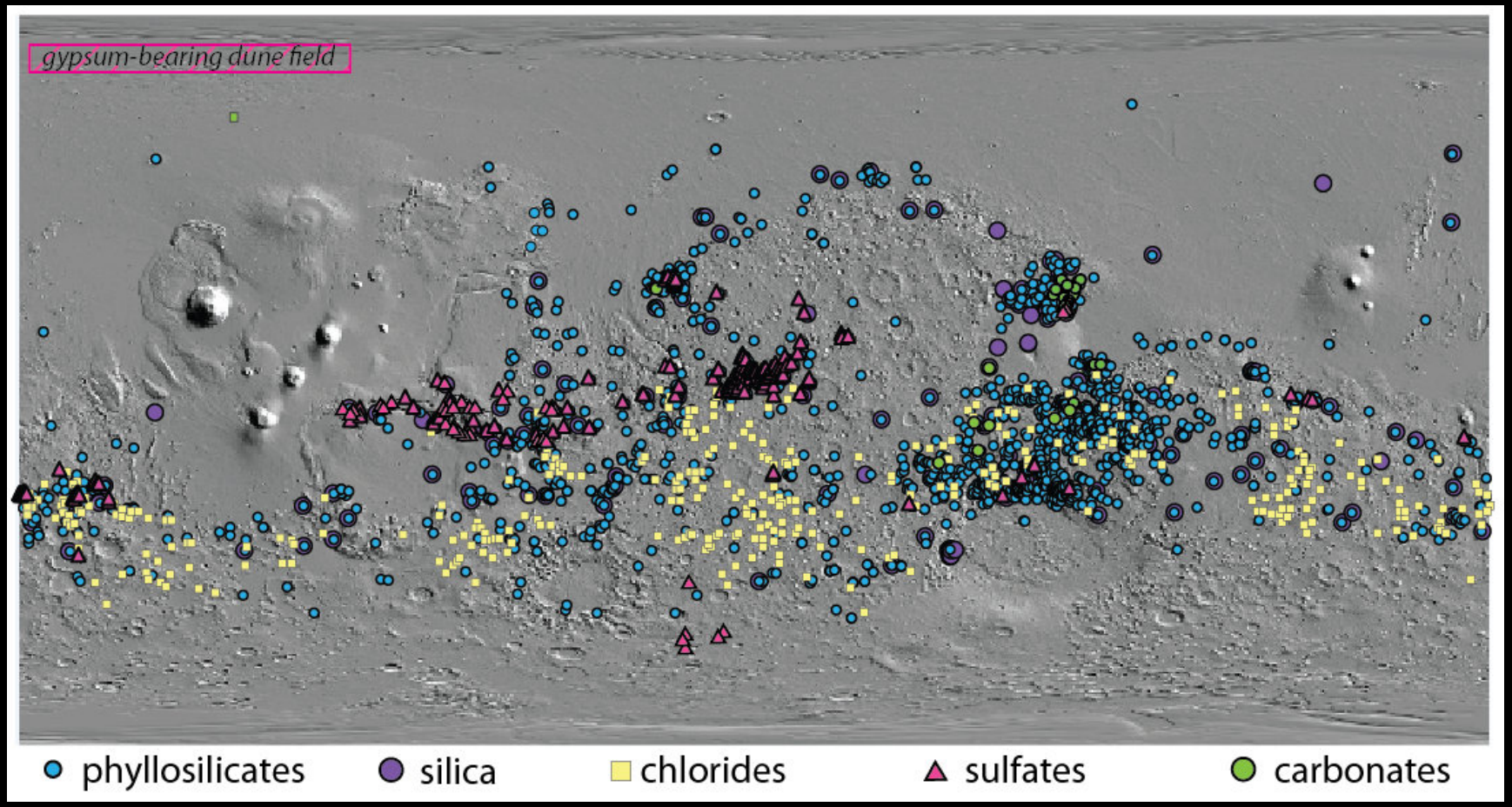
2) Where is the carbon/water? (Mars' geochemical cycles?)

3) How heterogenous is the Mars mantle?

4) When did the dynamo cease?

5) How old is the Martian surface?

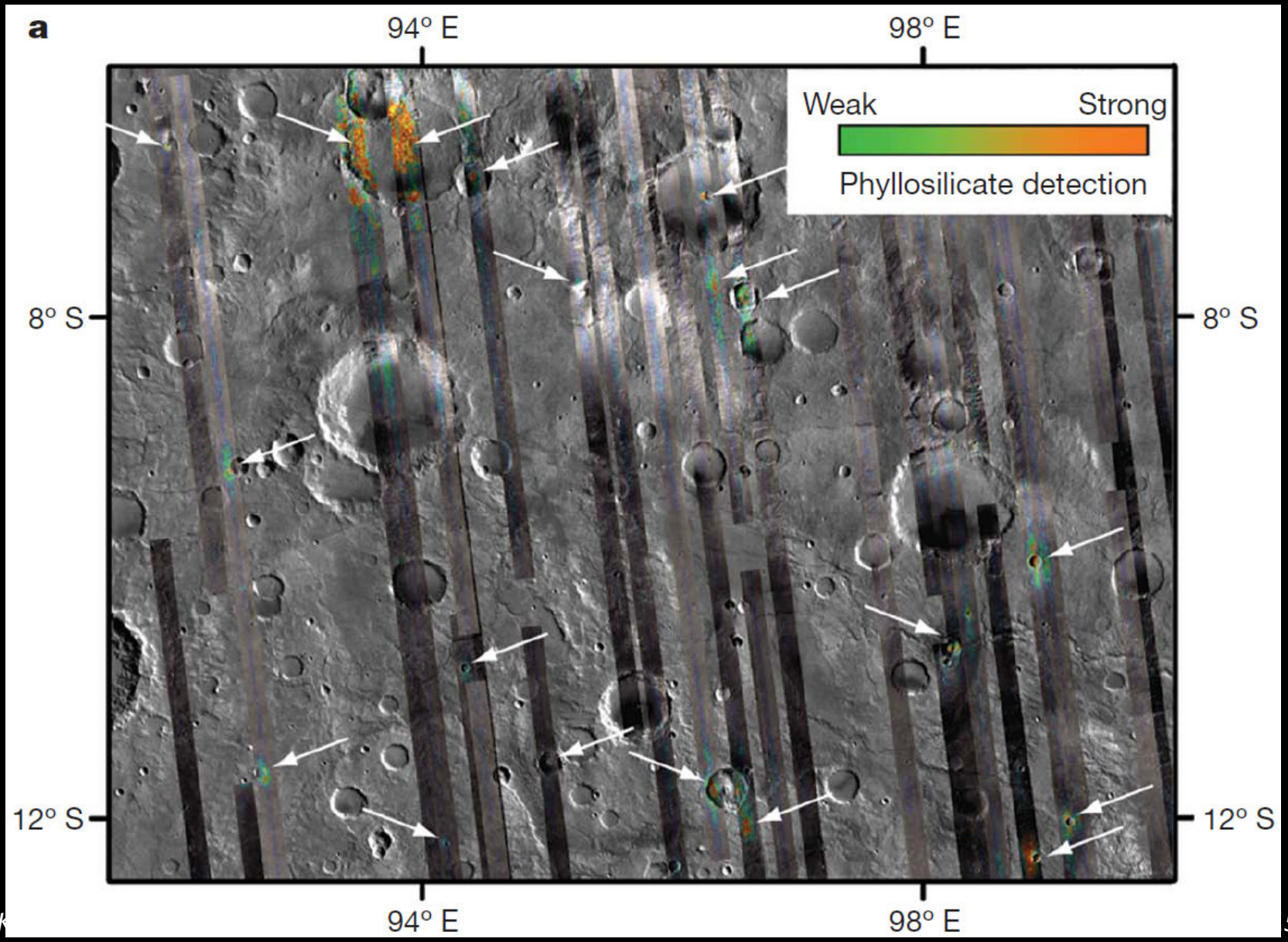
Global View of Aqueous Minerals: I. Widespread (pre?) Noachian clay minerals



[Ehlmann & Edwards, in press, Ann. Rev. Earth Plan. Sci.]

Distribution of the major classes of aqueous minerals on Mars. Phyllosilicate detections from compilations by Ehlmann et al. (2011), Carter et al. (2013), and Pan & Ehlmann (2014). Silica detections compiled by Carter et al. (2013). Chlorides compiled by Osterloo et al. (2010). Carbonate-bearing rock detections reported by Ehlmann et al. (2008) or reviewed in Niles et al. (2012) (square indicates Phoenix lander soil carbonate). Sulfate detections from Murchie et al. (2009), Milliken et al., (2010), Ackiss et al. (2012), and Carter et al., (2013), edited to remove locations with ambiguity with hydrated silicates.

Crustal Clays: 1000s of clay minerals exposed in craters



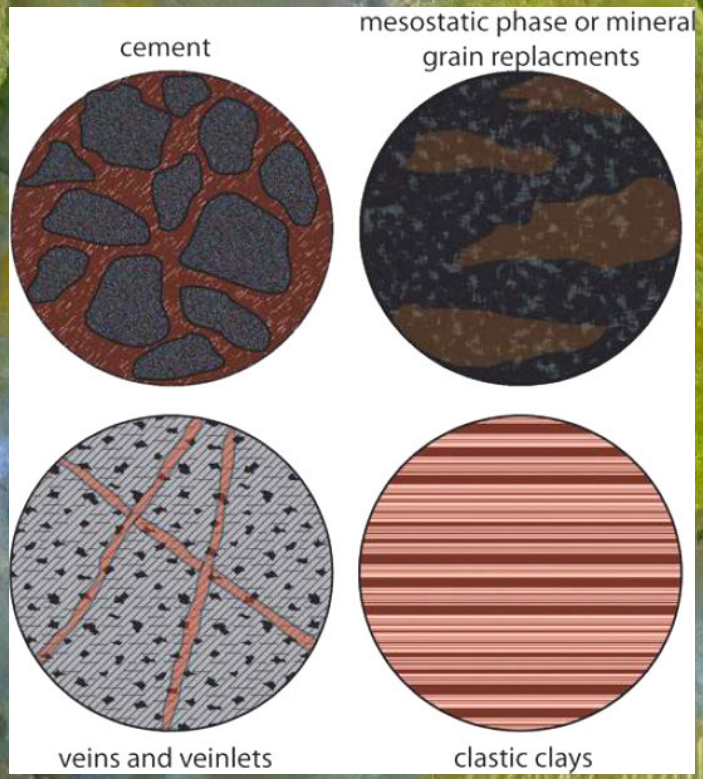
[Mustard et al., Nature, 2008]

Crustal Clays: No large Noachian terrain without aqueous alteration; but large contiguous exposures are special spots for exploration

What do these clays tell us about Mars

- Deuteric?
- Hydrothermal?
- Metamorphic?
- Diagenetic?
- Weathering?
- Precipitate?

- Not discernible from orbit – requires petrology



[Michalski et al., 2010]

carb./ olv

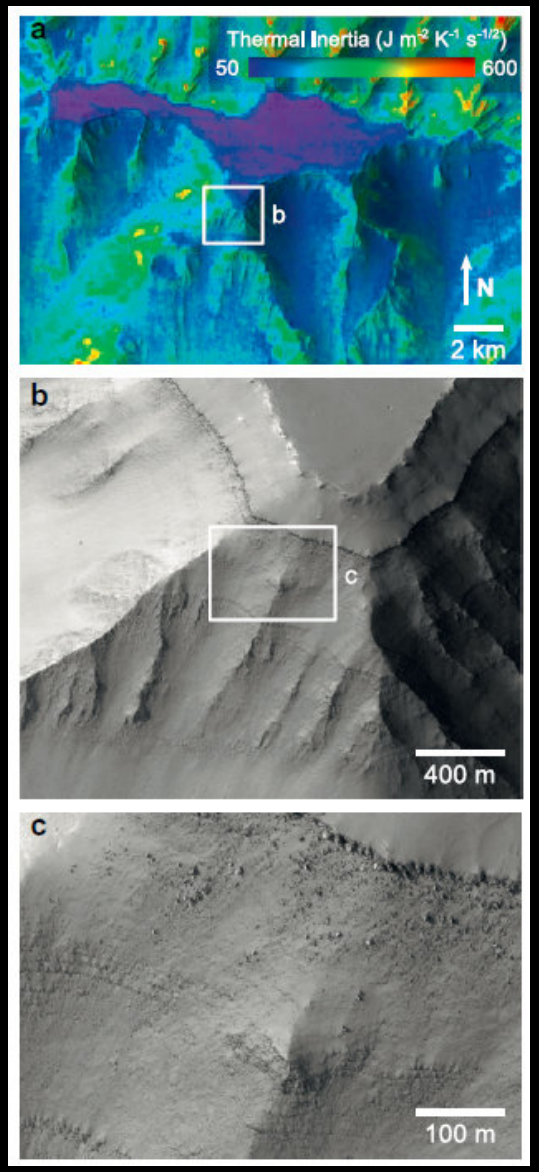
mafic cap

Ehlmann et al., 2009, JGR; Mustard et al., 2009, JGR

Mystery #1: Ancient Crust: What is it — Lavas, Volcaniclastics, Sediments?

- Is the altered ancient crust mainly
  - Lavas, sometimes altered by subsurface groundwater [McEwen et al., 1999; Ehlmann et al., 2011]
  - Sediments with precipitated/transported minerals [Grotzinger and Milliken, 2013]
  - Loosely consolidated volcaniclastics [Bandfield et all., 2013]
- A lunar-like megabreccia regolith, once predicted, has not been seen for Mars
- The "nature of the ancient crust" has substantial bearing on dominance of surfacial/climate vs. igneous processes in dictating Mars' early evolution

➢ Interrogate the crustal clays
➢ Seek multiple types of clays
➢ Visit the "rocky" ancient Noachian strata



Bandfield et al., 2013, Icarus

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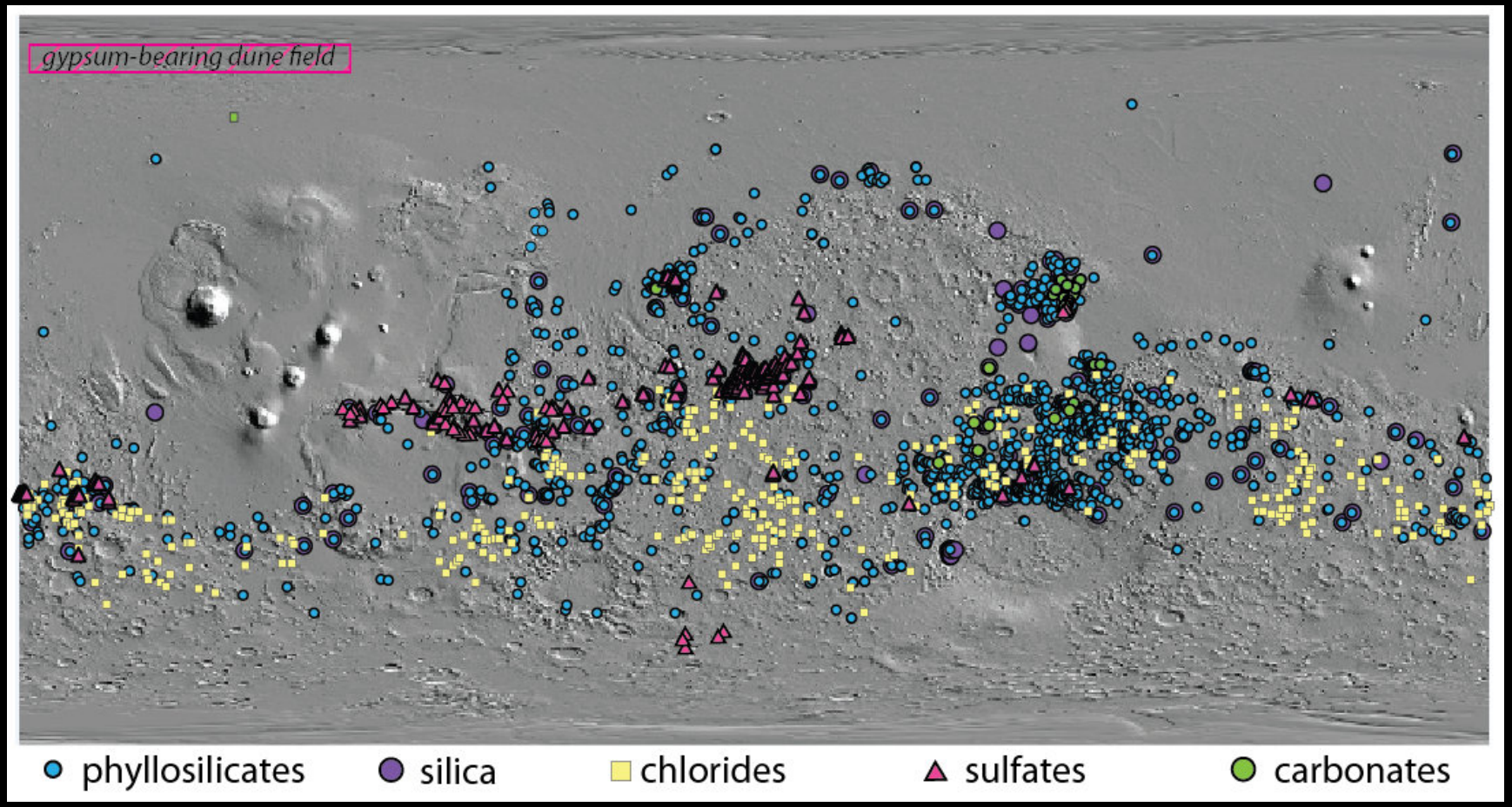
Global View of Aqueous Minerals: II. Why do salts vary in space and time?



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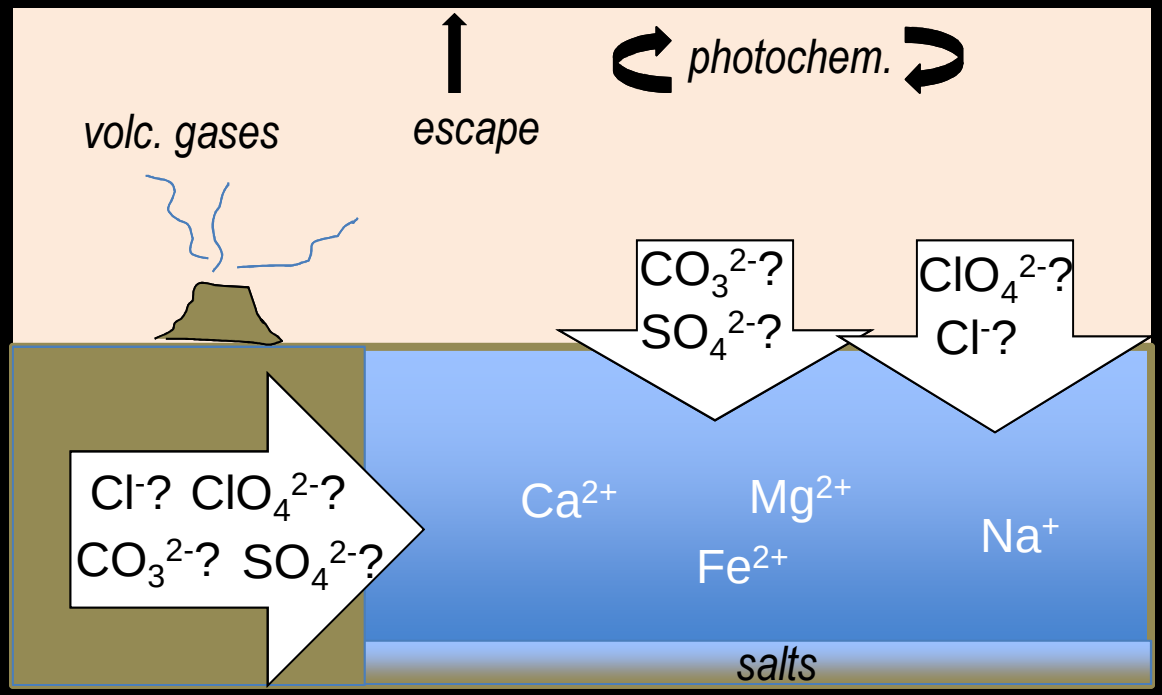
Mystery #2: Fundamental Controls on Mars Geochemical Cycles



- We do not understand the composition of the early atmosphere and its relationship to climate and the geologic record
- Need to understand igneous processes; relationship to volatiles, rock mineralogy
- ➢ Seek more than one type of salt indicating changes in geochemistry, especially including those important compositions we have never visited

Mars' Biggest Mysteries/Decadal-level questions

1) What is the nature of the Noachian crust?

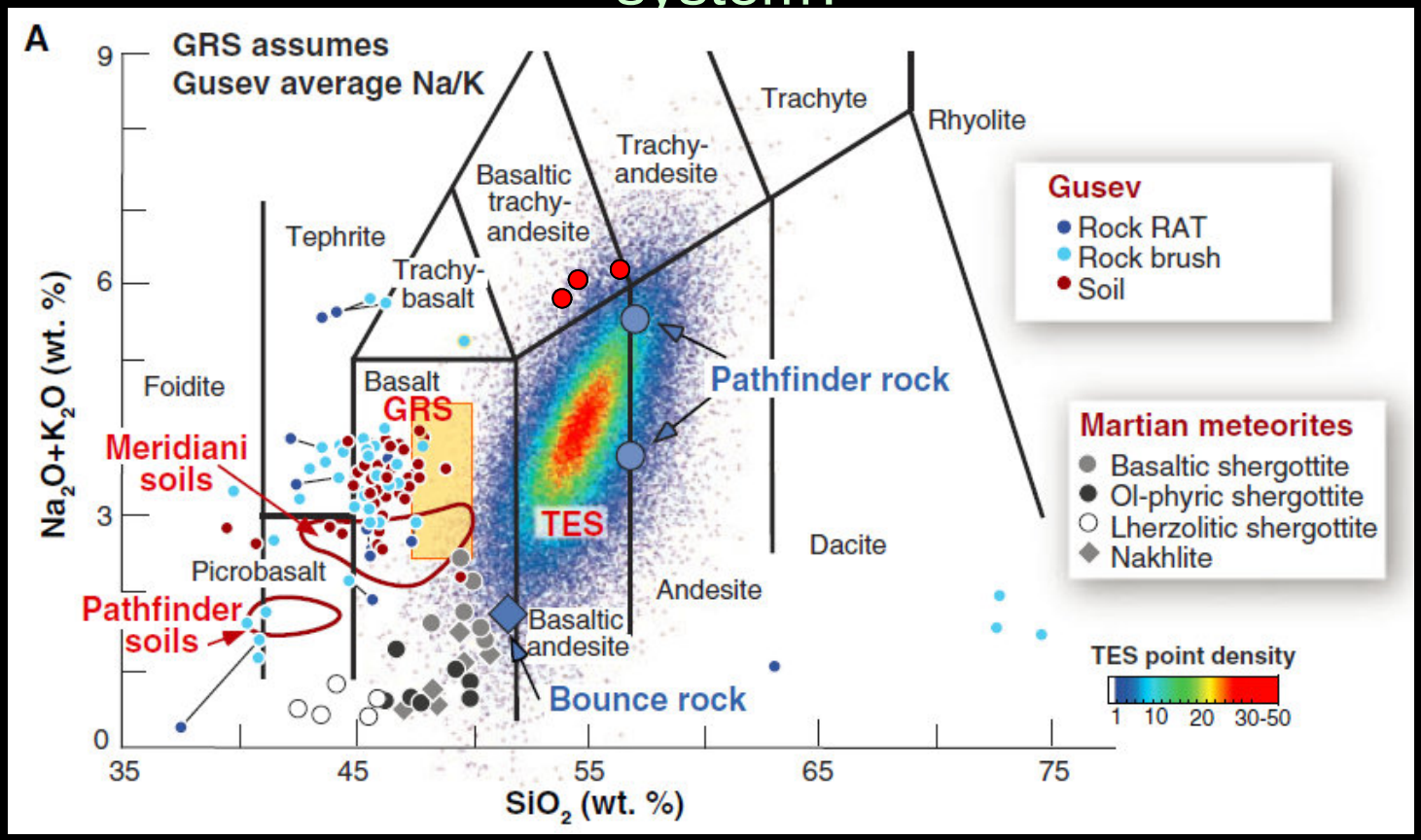
2) Where is the carbon/water? (Mars' geochemical cycles?)

3) How heterogenous is the Mars mantle/igneous history?

4) When did the dynamo cease?

5) How old is the Martian surface?

Mystery #3: What controls the diversity of igneous rocks? How do igneous processes influence the Mars climate system?



[McSween et al., 2009, Science + Stolper et al., 2013 + Schmidt et al., 2014]

- Enormous igneous diversity discovered in last few years (McSween et al., 2006; Stolper et al., 2013; Agee et al., 2013, Schmidt et al., 2014)
- Volatile content? Reasons for changes through time? Influence on surface climate?
- Timing of differentiation? Amount of crustal recycling?
- → Seek 1 (and preferably more) in place, unaltered igneous units to understand temporal context

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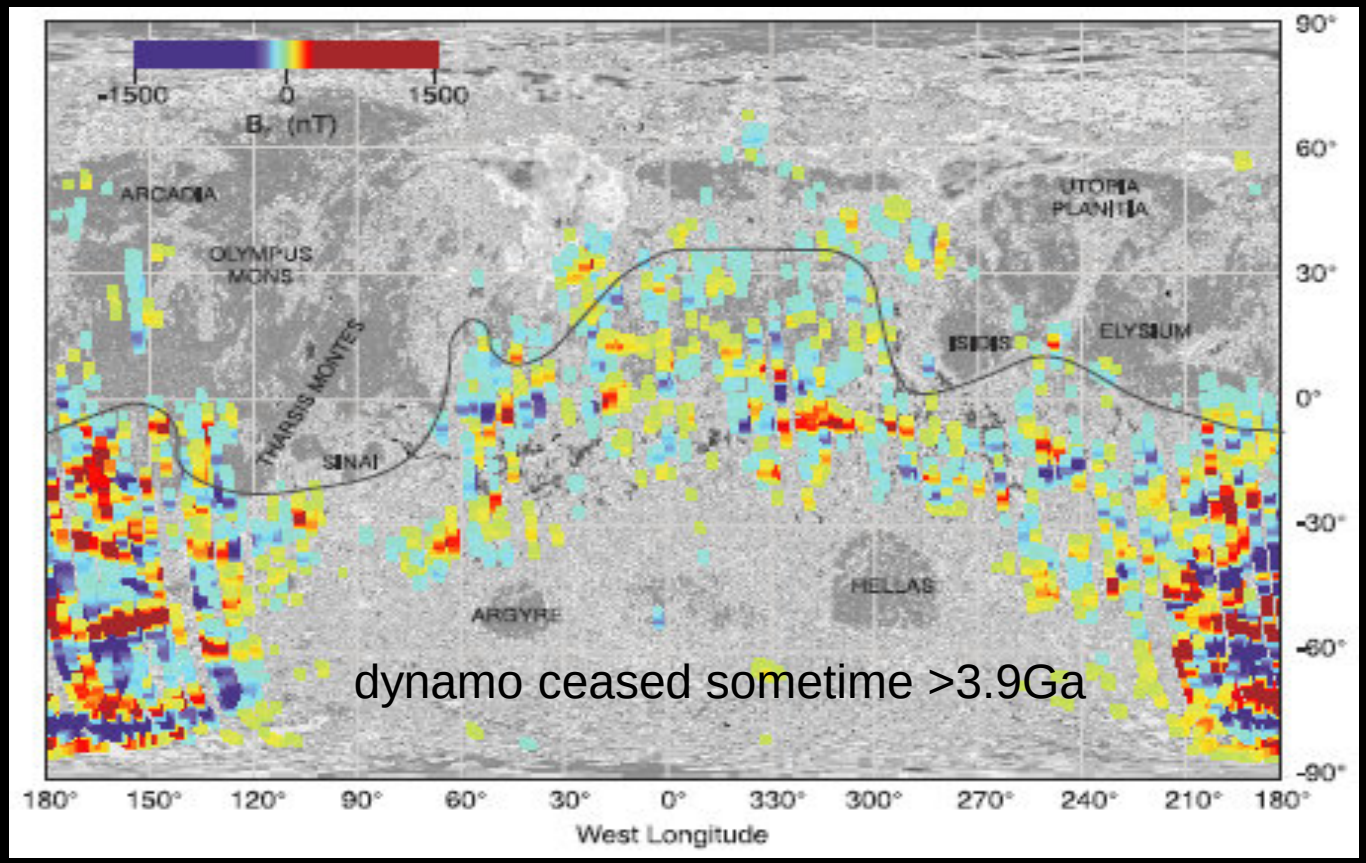
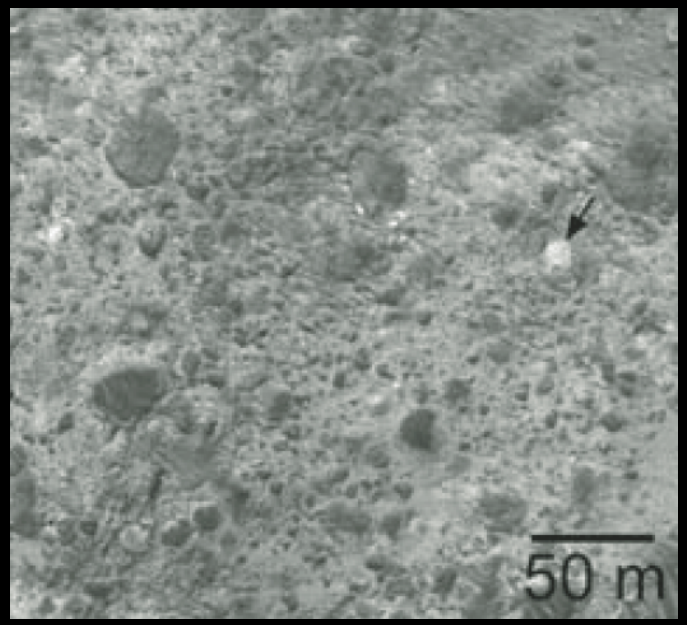
Mystery #4: When did the dynamo cease?



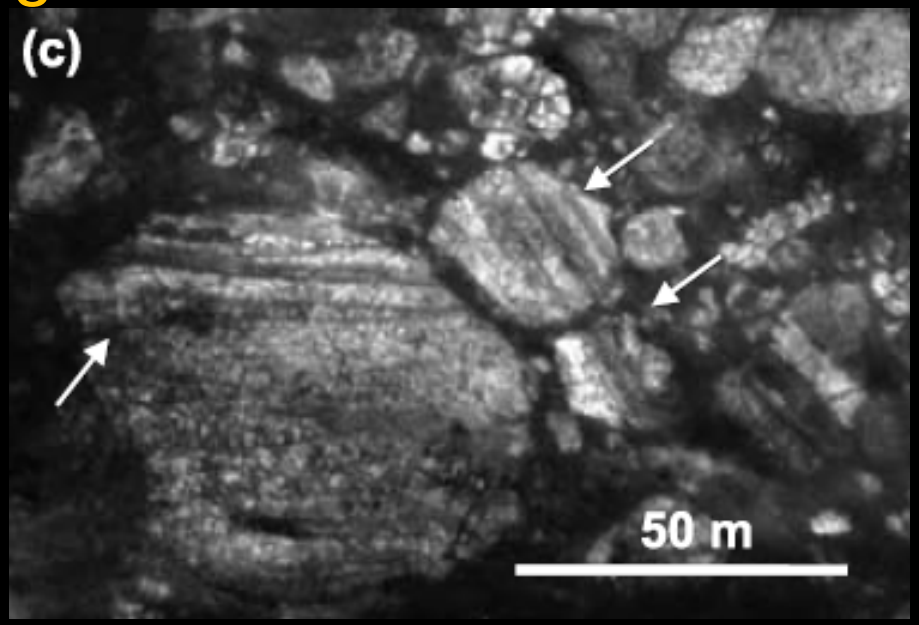
[Acuna et al., 1999, Science]

- Activity and state of the core
- An influence on climate and atmospheric loss?

Mystery #4, Answerable? → Seek the megabreccia

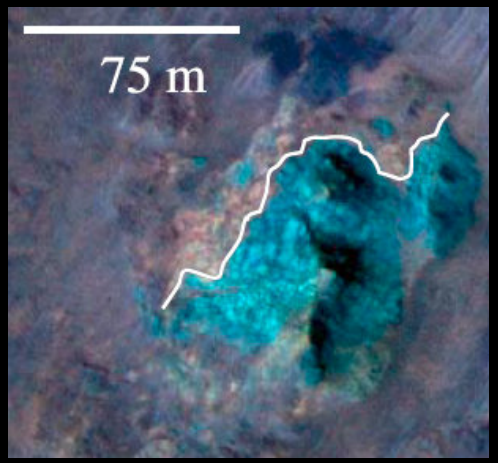


Holden crater [Grant et al., 2008, Geology]



NE Syrtis/Nili Fossae [Mustard et al., 2009]

- Crust even earlier than the surface age exists to be interrogated and sampled
  - Dynamo timing
  - Early magmatism
  - Early aqueous environments



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Mystery #5: How old is the Martian surface?

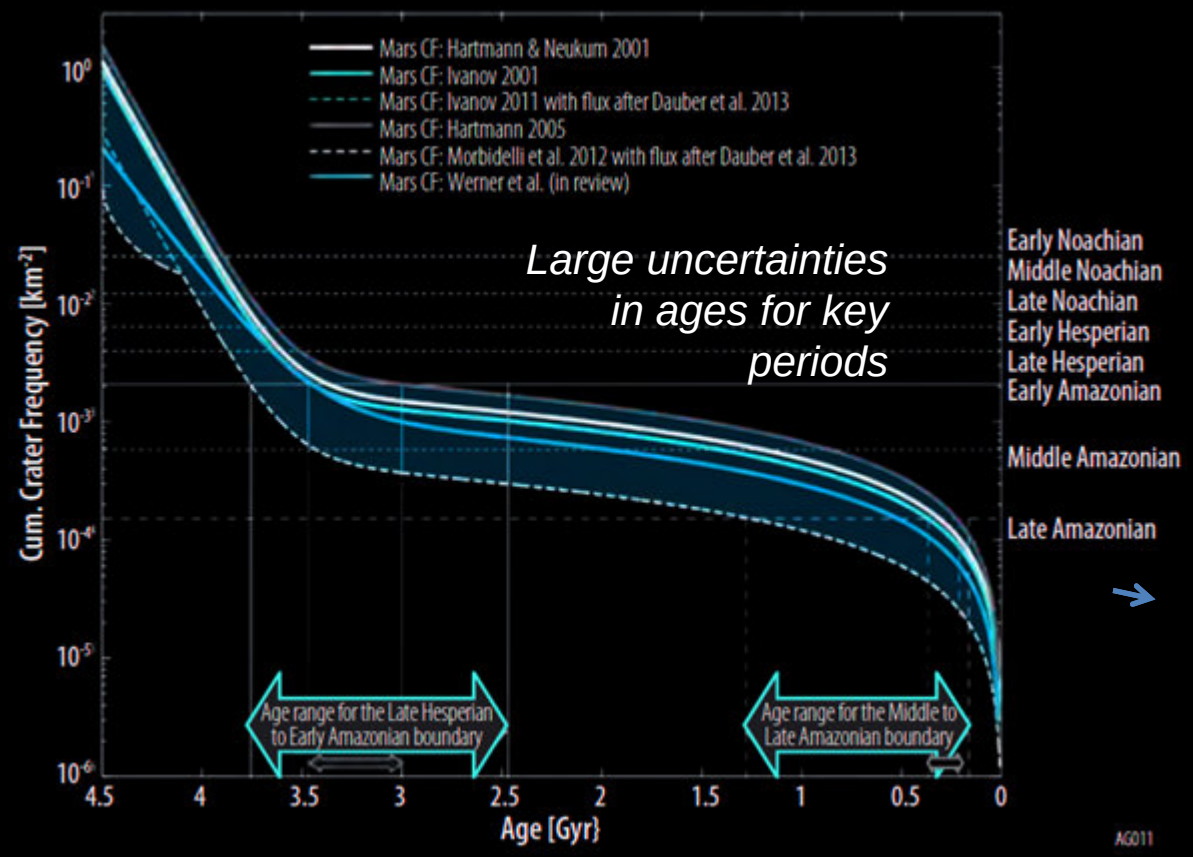
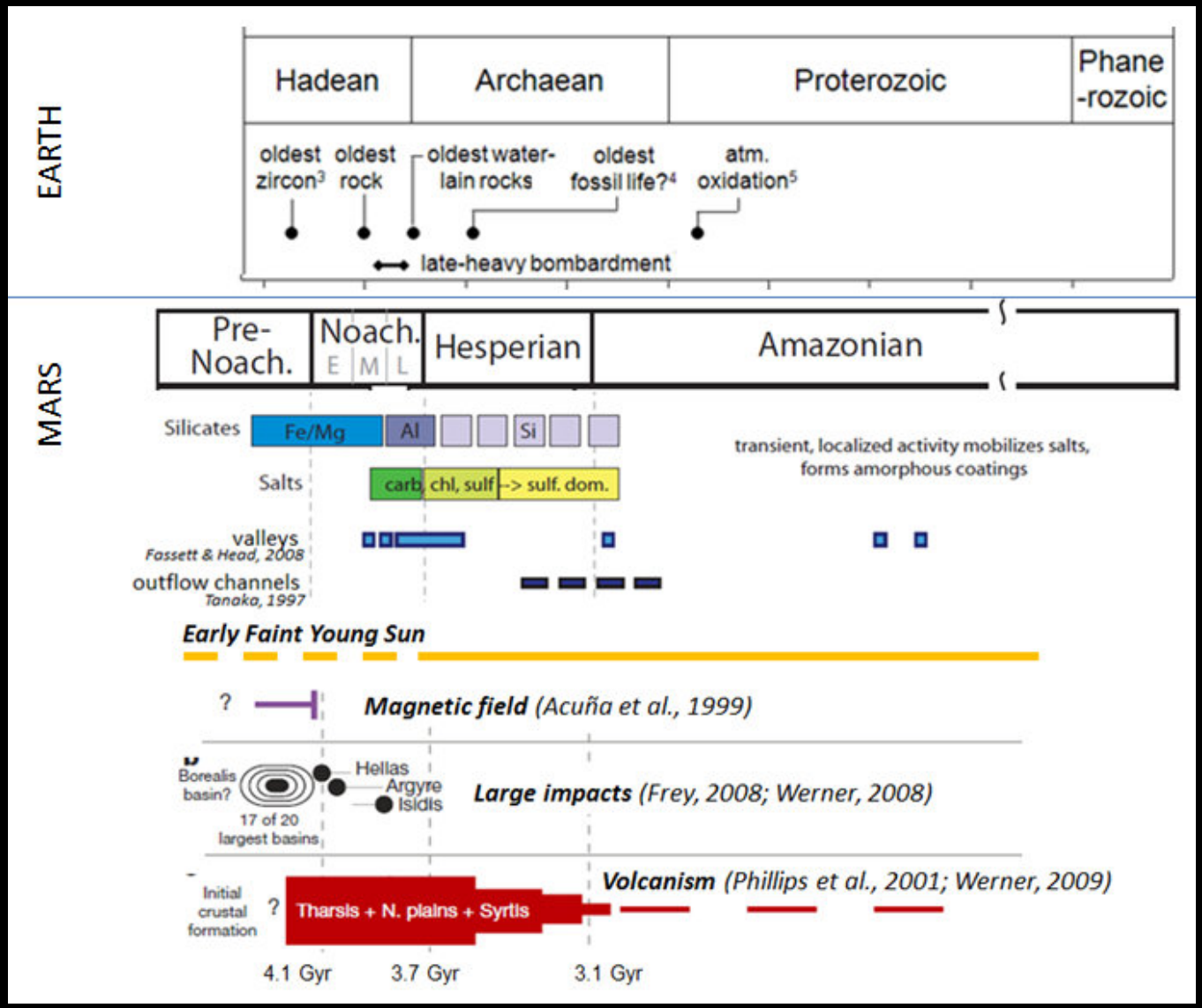


figure courtesy S. Werner

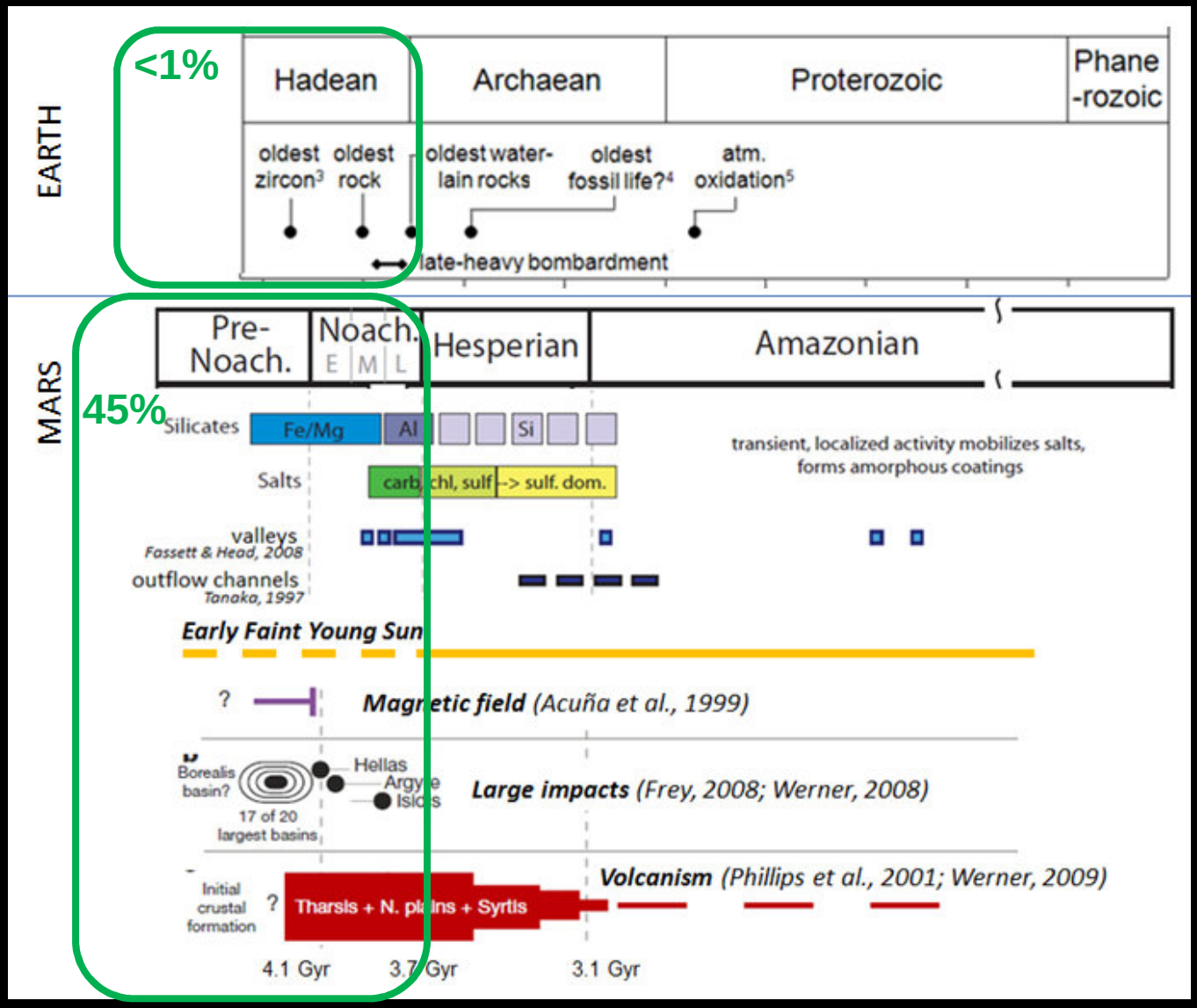
- Timing of Late Heavy Bombardment?
- Similarity of cratering choronology (and our ability to extrapolate) in the inner solar system
- → Seek large units with firmly established ages based on crater frequency
- → Examine stratigraphies with globally correlatable upper and lower bracketing units, age well-established
- → Igneous rocks, in place, to bracket the age of sedimentary units

A Unique Opportunity, Early Solar System Processes

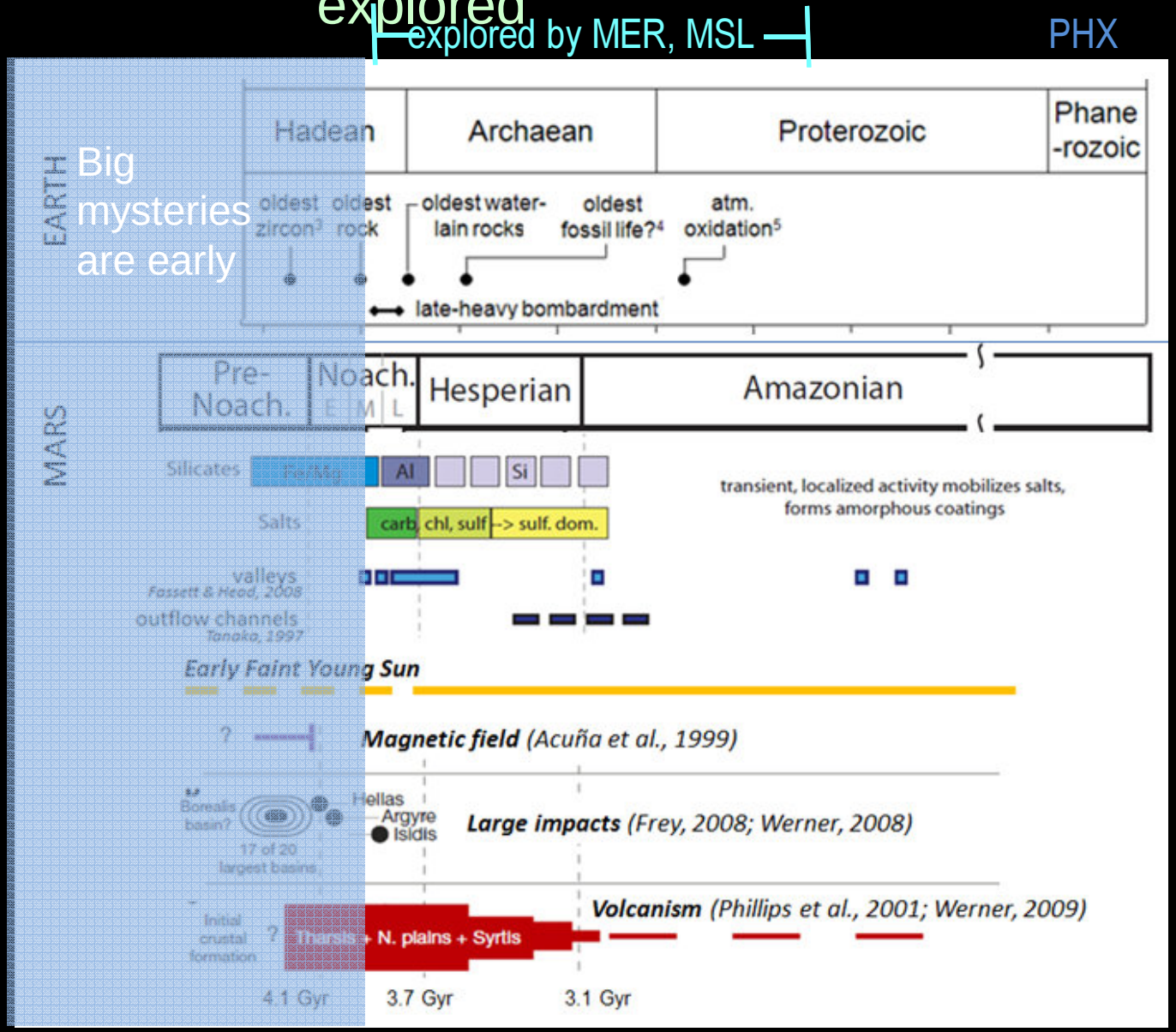


A Unique Opportunity, Early Solar System Processes

Total % rocks accessible



Go Noachian/phyllosian – Mars' earliest history less explored



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Meeting Mars 2020 Science Criteria

Top Tier

Scientific Objectives in Priority Order

1	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 signs of life.
2	Quantitatively constrain the age, context, and processes of accretion, early differentiation, and magmatic and magnetic history of Mars.
3	Reconstruct the history of surface and near-surface processes involving water.
4	Constrain the magnitude, nature, timing, and origin of past planet-wide climate change.
5	Assess potential environmental hazards to future human exploration.
6	Assess the history and significance of surface modifying processes, including, but not limited to: impact, photochemical, volcanic, and aeolian.
7	Constrain the origin and evolution of the martian atmosphere, accounting for its elemental and isotopic composition with all inert species.
8	Evaluate potential critical resources for future human explorers.

Mandatory: Determine if the surface and near-surface materials contain evidence of extant life.

Sample Types in Priority Order

- 1A Subaqueous or hydrothermal sediments (EQUAL PRIORITY)
- 1B Hydrothermally altered rocks or low-T fluid-altered rocks
- 2 Unaltered Igneous Rocks
- 3 Regolith
- 4 Atmosphere, rocks with trapped atmosphere

May include in trapped vesicles

Key: MEPAG Goals

I. Life	II. Climate	III. Geology
IV. Prepare for Humans		

Decadal Goals vs. Landing Site Science Available

- This is very understandable, right now: We have a wealth of information from MSL landing site vetting, MRO data

- The top 10 sites (science+safety) include
  - Chloride evaporites and Clay Highlands (e.g. E. Margarifter)
  - Clay(+/-Carbonate)-bearing Deltaic/Fan Sediments (e.g. Eberswalde, Jezero, Holden)
  - Groundwaters and Acid Sulfate Precipitation (e.g. Meridiani)
  - Layered sulfate/clay sediments (e.g. Gale)
  - Lavas and Ancient Crater Peak Hills (e.g. Gusev)
  - Noachian/Hesperian type stratigraphy: Clay/Megabreccia - Carbonate/Olivine-Sulfate-Lava (e.g. NE Syrtis)
  - Surface-weathered Layered Clays (e.g. Mawrth)

Decadal-level Diversity?

DRAFT	Aqueous minerals							Setting			Plan. Evol.			Strat Age		
Site	Crustal clays	Other Fe/Mg clay	Al Clay in strat.	Carbonates	Chlorides	Sulfates	Silica	Sediments	Weathering	In-Situ Hydroth. Groundwater	Megabreccia	Ign. Cap/Lava	2nd Igneous Unit	Lower Bracket	Upper Bracket	Land-On "Primary" Science w/ MSL sys.
Eberswalde		✓						✓						✓	~	×
Jezero		✓		✓				✓				✓	~	✓	~	×
Holden Crater	✓	✓					✓	✓			✓		~			×
Meridiani	~	✓				✓				✓				✓	✓	✓
Gale		✓				✓		✓						✓		×
E. Margarifter	✓				✓			✓		✓		~		?	?	×
Gusev			?	✓		✓	✓			✓		✓			✓	?
NE Syrtis	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	×
Mawrth		✓	✓			~	✓	✓	✓			✓			✓	✓
your site here																

Decadal-level Diversity?

Relatively few sites support "better-than meteorite" work for answering Decadal questions. But they exist!

DRAFT	Aqueous minerals							Setting				Plan. Evol.					
Site	Crustal clays	Other Fe/Mg clay	Al Clay in strat.	Carbonates	Chlorides	Sulfates	Silica	Sediments	Weathering	In-Situ Hydroth.	Groundwater	Megabreccia	Ign. Cap/Lava	2nd Igneous Unit	Older Bracket	Younger Br	Land-On "I Science w/
Eberswalde		✓						✓							✓	~	✗
Jezero		✓		✓				✓					✓	~	✓	~	✗
Holden Crater	✓	✓					✓	✓				✓		~			✗
Meridiani	~	✓				✓				✓					✓	✓	✓
Gale		✓				✓		✓							✓		✗
E. Margarifter	✓				✓			✓		✓			~		?	?	✗
Gusev			?	✓		✓	✓			✓			✓			✓	?
NE Syrtis	✓	✓	✓	✓		✓		~	✓	✓	✓	✓	✓	✓	✓	✓	✗
Mawrth		✓	✓			~	✓	✓	✓				✓			✓	✓
your site here																	

Reaching Decadal Science

only need a few… in fact 1, plus 1-2 backups

For site selection, one would ideally have many choices of sites where sedimentary, hydrothermal, and unaltered igneous outcrops were present (as in E2E-iSAG, 2012). Of the ~65 proposed MSL landing sites evaluated by E2E-iSAG (2012), only 10 included outcrops of unaltered igneous rock, and only a few of those sites would be accessible using the proposed EDL system for Mars 2020. This may be too few sites to ensure that a suitable final site could be found (based on results of past landing site selection processes). Combining the MSL EDL capabilities and E2E-iSAG site constraints does not ensure that an adequate landing site would be found. There are two options to relieve this impasse: improve the EDL capabilities of Mars 2020 over those of MSL; and/or relax the E2E-iSAG (2012) requirement that the landing site have access to unaltered igneous rocks in outcrop.

latter diminishes compellingness of cache science

Finding 8-7: Access to unaltered igneous rocks as float is considered a threshold-level field site requirement, but requiring that they be collected from known stratigraphic context would add significant science risk to the mission – it may be impossible to access a suitable field site using 'as applied' MSL capabilities.

1) Improve Mars2020 EDL
2) Improve drive capabilities and pick instruments for speediest fieldwork
3) Restrict site list early to best Decadal Science to design EDL to, with 1-2 backups with no igneous rocks IDed for contingency
4) Choose to ignore E2E-iSAG requirement of igneous rocks in outcrop now

best option

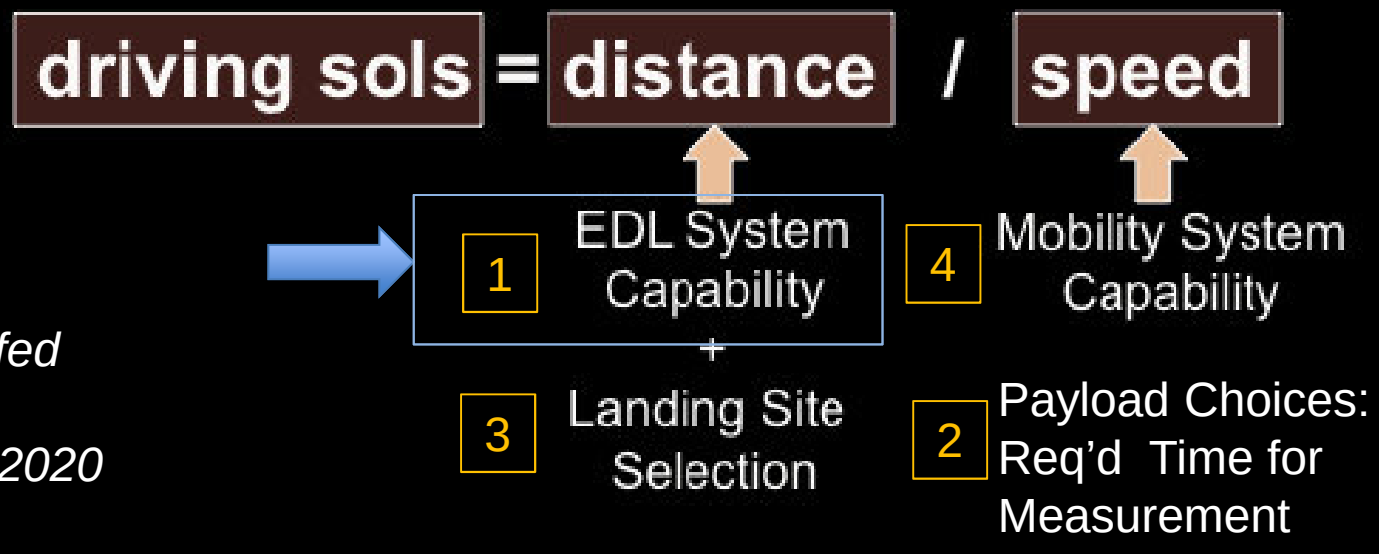
worst option

Decadal-level Diversity?

DRAFT Site	Aqueous minerals							Setting			Plan. Evol.			Strat Age		Land-On "Primary" Science w/ MSL sys.
	Crustal clays	Other Fe/Mg clay	Al Clay in strat.	Carbonates	Chlorides	Sulfates	Silica	Sediments	Weathering	In-Situ Hydroth. Groundwater	Megabreccia	Ign. Cap/Lava	2nd Igneous Unit	Lower Bracket	Upper Bracket	
Eberswalde		✓						✓						✓	~	✗
Jezero		✓		✓				✓				✓		✓		✗
Holden Crater	✓	✓					✓	✓								✗
Meridiani	~	✓				✓									✓	✓
Gale		✓				✓		✓								✗
E. Margarifter	✓				✓			✓							?	✗
Gusev			?	✓		✓	✓								✓	?
NE Syrtis	✓	✓	✓	✓		✓		✓	✓						✓	✗
Mawrth		✓	✓			~	✓	✓	✓			✓			✓	✓
your site here																

Few sites permit immediate, "Land-on Science"→ causes challenge to collect Decadal-quality samples during primary mission

4 levers on science return/time



modifed from Mars2020 SDT

- [1] allows (a) collection of a more scientifically compelling catch; (b) land-on Decadal-quality science, from day 1, (c) early development of technique needed for fetch rover that collects cache canister

The cache: Mars 2020+

- We are in the atypical position of needing to think long-term, inclusive of, but also beyond single mission success. Mars2020 is an investment.

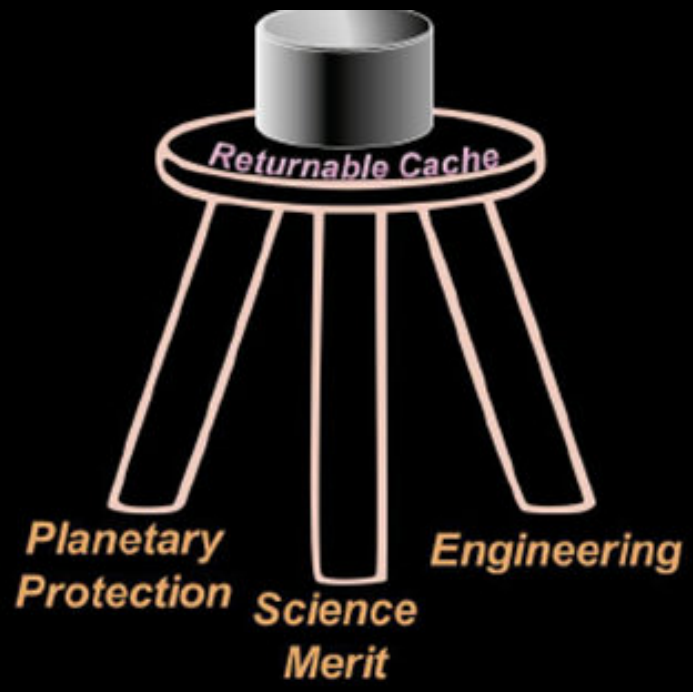
Three attributes are essential to making a cache returnable.

This is a Mars-2020 responsibility

1. The cache has enough scientific value to merit returning.
2. The cache complies with planetary protection requirements.
3. The cache is returnable in an engineering sense.

we will do this

Under most (all?) scenarios for missions 1 and 2 of an MSR campaign, this requires more precise landing than MSL-like capabilities



Mars2020 SDT

Take home points

- **Embrace the opportunity to tackle Mars' biggest mysteries, think diversity when selecting sites**

- Doing Decadal Science: would examine/collect
  - "typical" crustal clays: enigmatic, ubiquitous Noachian process
  - ≥2 of ~12 additional Martian aqueous environments (1 in primary mission)
  - ≥1 unaltered igneous unit(s) (preferably 2, including megabreccia or different age/composition lava or impact melt)
    - If not in place, we are stuck in similar situation to meteorites (provenance uncertain)

- This requires Land-On Science to enable selection and caching of the most diverse sites with Decadal-level questions
  - capability needed anyway for fetch rover
  - Backup sites already IDed in case of delays in development
  - Invest now, to (a) ease pressure on surface operations and (b) create a Decadal-level cache worthy of return

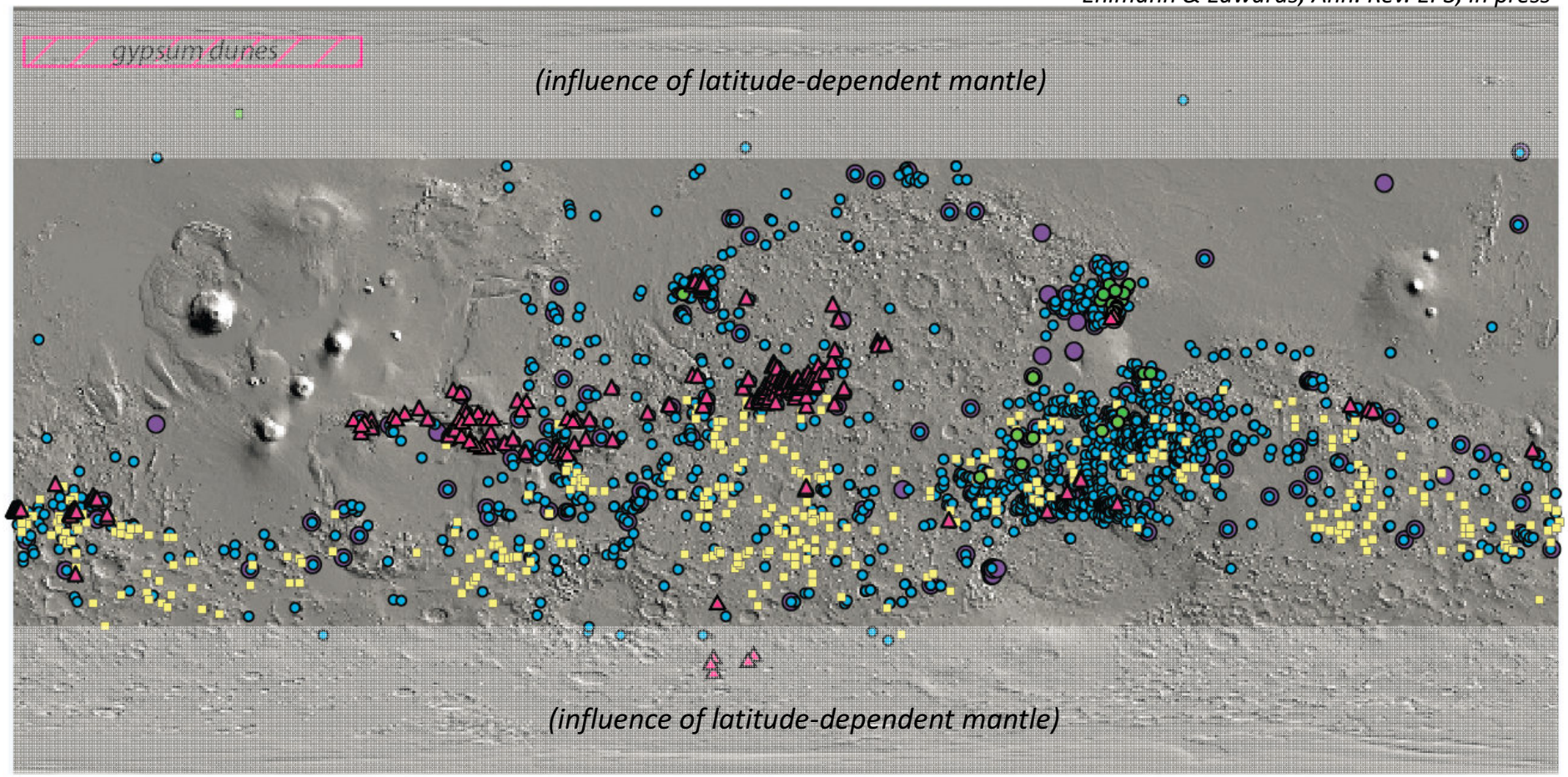
Extras

Mars' Biggest Mysteries/Decadal-level questions

1) What is the nature of the Noachian crust?
   - Which process(es) were responsible for globally widespread aqueous alteration to clay minerals in "crustal clays"?
   - What is the nature of the early Martian crust: sediments, ashes, lavas?
2) Where is the carbon/water? (More broadly, what were/are Mars' ature of geochemical cycles?)
   - Controls on surface precipiation of salts, quantities precipitated
   - Mantle gas content → atmospheric composition
3) How heterogenous is the Mars mantle?
   - Nature and timing of differentiation, mixing (e.g. magma ocean), plumes, crustal recycling
   - Controls on the atmosphere (redox, quantity)
4) When did the dynamo cease?
5) How old is the Martian surface?
   - LHB timing and crater choronology scalability across planets
   - Age of formation of rocks vs. crater retention age vs. timing of alteration?

Distribution of Aqueous Minerals on Mars (circa 2014)

Ehlmann & Edwards, Ann. Rev. EPS, in press



phyllosilicates — *Ehlmann et al., 2011, Nature; Carter et al., 2013, JGR*

silica

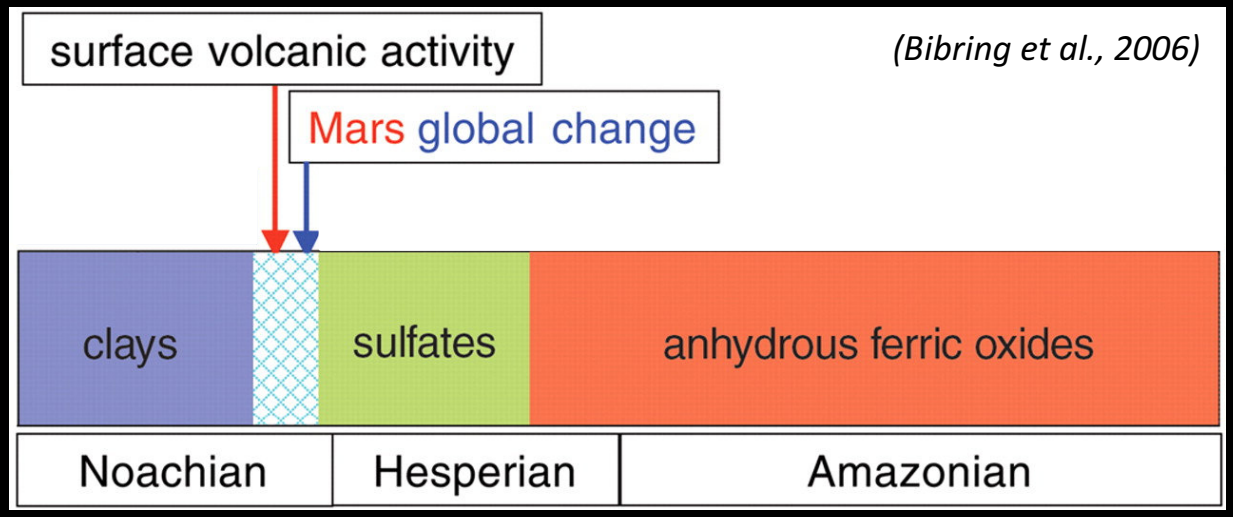
chlorides — *Osterloo et al., 2010, JGR*

sulfates

carbonates — *Niles et al., 2013, Space Sci Rev*

→ Alteration minerals are in the most ancient terrains

→ Ancient environmental diversity (varying with space and time)



Gale Crater:
Sedimentary Environments

Meridiani:
Sedimentary Environments

Gusev Crater?:
Altered volcanic hills, timing uncertain