MEPAG
E2E-iSAG

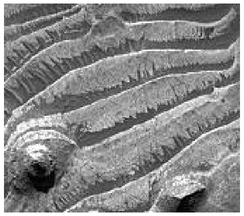
Reference Landing Sites, Mars Sample Return Campaign

June 16, 2011

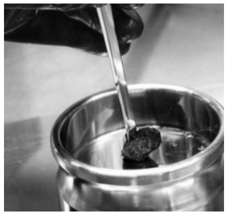
John Grant, on behalf of the E2E-iSAG team

Package 3 of 5

Pre-decisional: for discussion purposes only



Overview



Prioritized returned sample science objectives

Derived implications

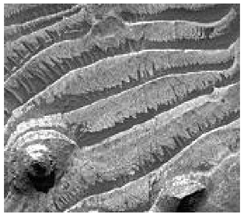
- Samples required/desired to meet objectives
- Measurements on Earth

Critical Science Planning Questions for 2018

- Variations of interest?
- # of samples?
- Types of landing sites that best support the objectives?
- Sample size?
- Measurements needed to interpret & document geology and select samples?
- On-Mars strategies?

Engineering implications

- Sampling hardware
- Instruments on sampling rover
- EDL & mobility parameters, lifetime, ops scenario
- Sample preservation

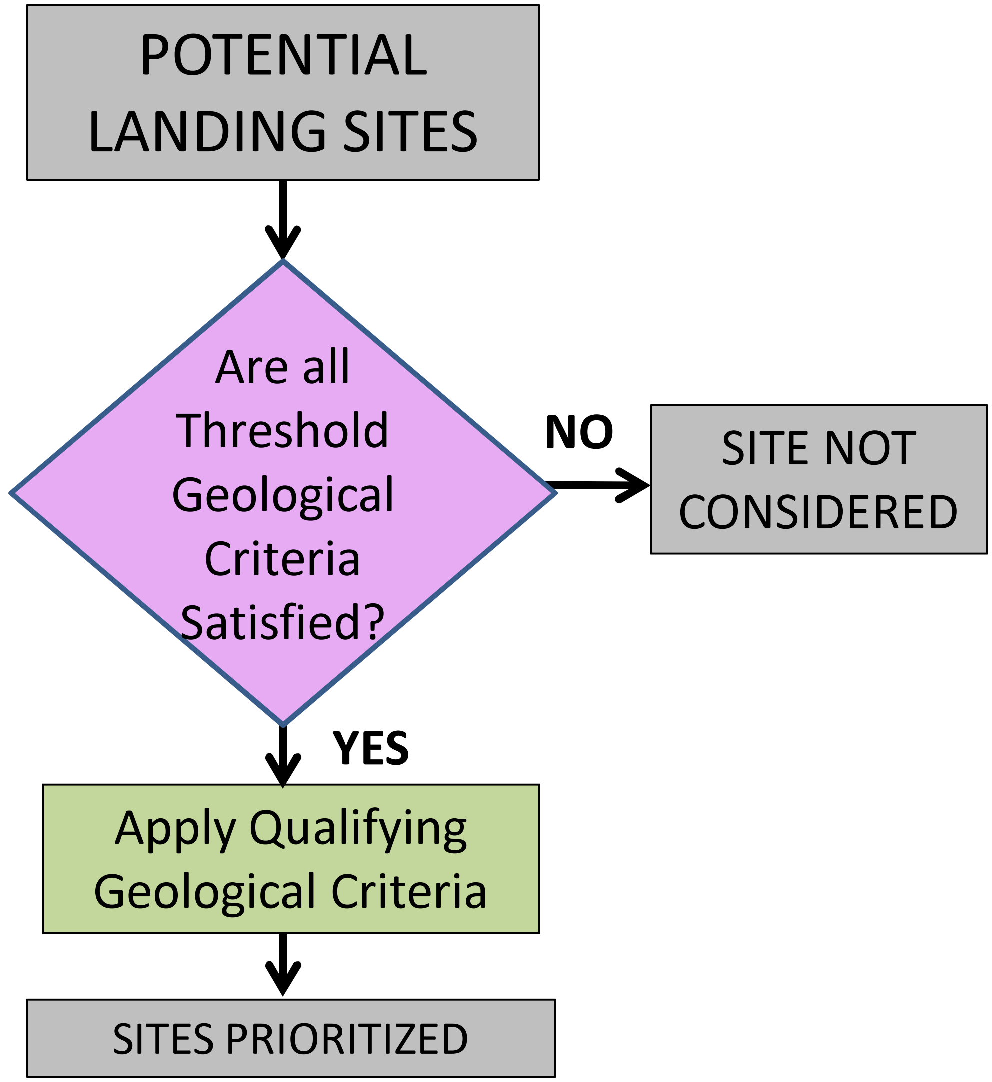


Landing Sites: Two classes of Selection Criteria

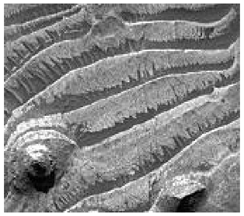
Two types of selection criteria can be applied:

- "Threshold" - sites must meet these to be considered
- "Qualifying" – these can be used to prioritize among the remaining sites

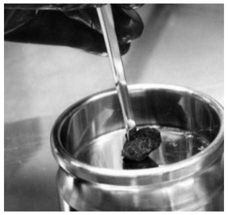
<u>DRAFT FINDING 15</u>. In order to end up with at least one acceptable site after science and engineering constraints are evaluated, it is necessary to begin the scientific selection process with a reasonable array of candidates.



Input from Matt Golombek



Landing Sites:
Proposed Selection Criteria



Threshold Geological Criteria

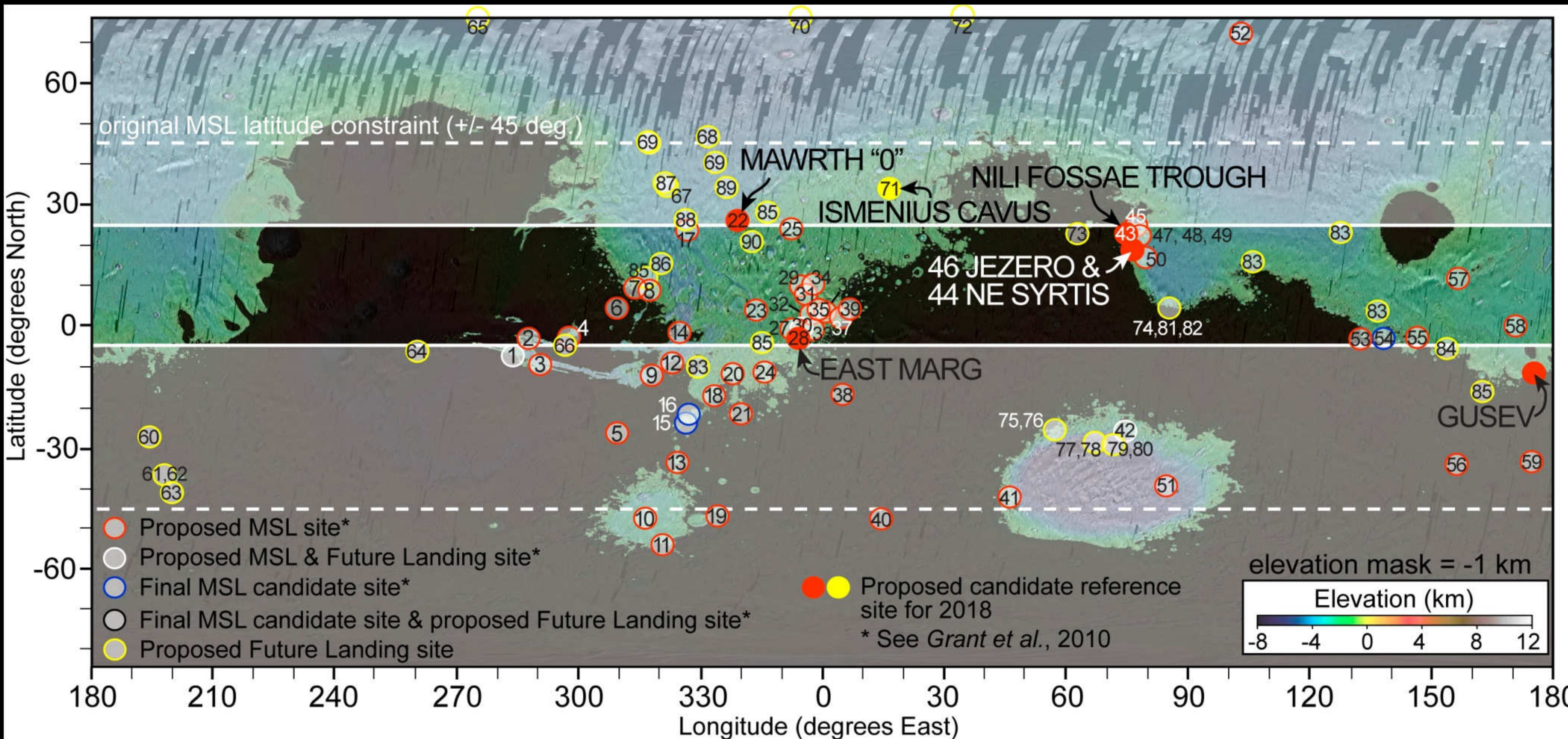
1. Presence of subaqueous sediments or hydrothermal sediments (equal 1st priority), OR
   hydrothermally altered rocks or Low-T fluid-altered rocks (equal 2nd priority)
2. Presence of aqueous phases (e.g., phyllosilicates, carbonates, sulfates etc.) in outcrop
3. Noachian/Early Hesperian age based on stratigraphic relations and/or crater counts
4. Presence of igneous rocks with known stratigraphic relations, of any age, to be identified by primary minerals.

Key question: We know there are many sites that satisfy criteria #1-3. Does the addition of criterion #4 to the threshold list over-constrain the problem?

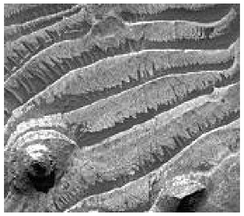
Preliminary List of **Qualifying Geological Criteria** (not used in this analysis)

1. Morphological criteria for standing bodies of water and/or fluvial activity (deltaic deposits, shorelines, etc.).
2. Assemblages of secondary minerals of any age.
3. Presence of former water ice, glacial activity or its deposits.
4. Igneous rocks of Noachian age corresponding to unaltered primitive crust, better if including exhumed megabreccia.
5. Volcanic unit of Hesperian or Amazonian age well-defined by crater counts and well-identified by morphology and/or mineralogy.
6. Probability of samples of opportunity (ejecta breccia, mantle xenoliths, etc.).
7. Potential for resources for future human mission

Potential Landing Sites



- Mask shows draft latitude and elevation constraints for the proposed MSR (as of Jan. 2011)
- All sites are community-proposed:
  - 59 sites from MSL landing site process, 26 sites from CDP future landing sites process
- Labeled sites are E2E-iSAG reference sites discussed on following slides

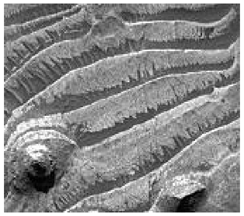


Identification of Reference Sites

11 sites of potential high interest and 5 of potential intermediate interest were identified when the threshold criteria were applied:

Terby Crater
Nili Fossae Trough
Mawrth Vallis Site 0
Oyama Crater
Gusev Crater
Nili Fossae East, with carbonates
Jezero Crater
East Margaritifer Chloride
South Meridiani
North East Syrtis Major
Ismenius Cavus
Miyamoto Crater
Eberswalde Delta
Xanthe Terra Delta
Juvantae Chasma
Melas Chasma

DRAFT FINDING #16: Among the ~85 candidate landing sites that have been proposed by the community to date (for MSR and a range of possible future missions), at least 10 potentially meet the preliminary list of MSR science criteria. However, further analysis of the sites would be needed to better evaluate their potential to meet the criteria.



Identification of Reference Sites

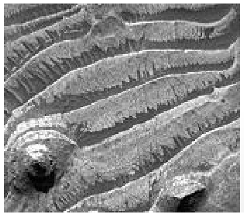
…From these, 7 were nominated for use as "reference sites“.

The reference sites:

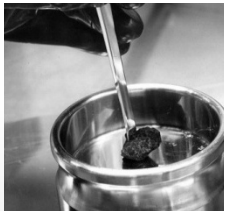
1. Were selected to provide a range of properties for both science and engineering and could therefore be used to help define landing and rover capabilities,
2. have existing image coverage that would facilitate engineering evaluations.

These candidate reference landing sites are NOT intended to serve as a short list for where sample return would occur: They are only intended to help to define reasonable science and engineering criteria as described.

It is anticipated that once these criteria are defined, a call for candidate sites would be made to the science community and would initiate a comprehensive site selection process like those employed for MER and MSL.

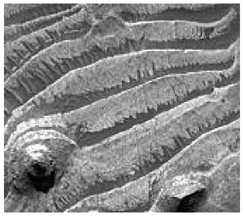


Reference Landing Sites



IT MAY BE POSSIBLE TO MEET ALL 8 PROPOSED MSR SCIENTIFIC OBJECTIVES AT ANY OF THESE SITES

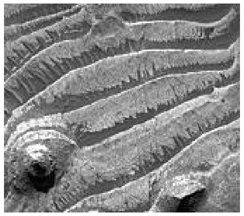
Site	Lat (°N)	Lon (°E)	Elev. (km)	The Sedimentary/hydrothermal story	The igneous story
Eastern Margaritifer Terra	-6	354	-1	In the channeled Noachian uplands south of Meridiani Planum is a small, shallow basin with an exposure of possible chlorides stratigraphically overlain by an eroding unit with very strong CRISM and even TES signatures of phyllosilicates.	The rocks appear to be capped by a basaltic unit of Noachian age.
Gusev Crater	-14	175	-2	The Noachian-aged Columbia Hills contain outcrops of opaline silica likely produced from hot springs or geysers and outcrops rich in Mg-Fe carbonates likely precipitated from carbonate-bearing solutions. Sulfate-rich soils and outcrops also are present.	Extensive unaltered Hesperian olivine-rich basalts embay the Noachian Columbia Hills. Also present are several different igneous rock types with minimal alteration.
Jezero Crater	18	78	-3	Delta with incorporated phyllosilicates and carbonates along west margin of crater. The crater formed in Noachian olivine and pyroxene-rich crust.	The crater floor has a more recent unit likely Hesperian that looks like fresh volcanic flows. Would land on volcanic and traverse to delta.
Mawrth Valles Site 0	25	339	-3	Layered Al and Fe/Mg Phyllosilicates in poorly understood setting. Possible mud volcano in the vicinity of ellipse. Land on science for exobiology.	Mafic material present in ellipse, but may be partly altered. Unaltered Hesperian volcanic at ~30 km.
NE Syrtis Major	16	77	-2	Extensive and diverse mineral assemblages within ellipse in Hesperian Syrtis Major volcanic region. Maybe water-lain deposits or in situ alteration. Likely go to required for all materials of exobiological interest.	Hesperian Syrtis Major volcanic region.
Nili Fossae Trough	21	75	-1	Widespread altered materials, as ejecta at eastern side of ellipse, in place to west of ellipse.	Land on unaltered Hesperian volcanic plain.
Ismenius Cavus	34	17	-~3	Single site to combine clay-bearing paleolake sediments and current glacial deposits. Three deltas at the same elevation confirms paleolake interpretation. Great site for both geological "field work" and sampling.	Unaltered material may be limited to dark sand, unaltered bedrock outcrops to be confirmed.



Potential engineering challenges

	Center of Proposed Ellipse			Recognized Potential EDL or Mobility Issues*					
Site	Lat (°N)	Lon (°E)	Elev. (km)	Elev.	Lat.	Terrain	"go-to"?	Other	Comments
Eastern Margaritifer Terra	-5.6	354	-1.3			X	?		Relief and eolian ripples in ellipse a concern for MSL. Land on science. Not clear if in situ volcanics are present in ellipse
Gusev Crater	-14.3	175	-1.9		X		X		Plains Landing site known to be safe (Spirit). Columbia Hills likely not land on, but are "go to". Stresses the southern latitude limit
Jezero Crater	18.4	77.6	-2.6				X	X	Rocks in ellipse on volcanic surface on floor of crater a concern for MSL, delta is "go to", volcanics are land on.
Mawrth Valles Site 0	24.5	339	-3			X	X		Relief in ellipse is greater than at candidate MSL Mawrth landing site and would be challenging to that EDL system. Volcanics are distant "go to".
NE Syrtis Major	16.2	76.6	-2.1			X	X		Relief (rock and scarp hazards) in ellipse was concern for MSL. Land on science for diverse hydrothermal minerals, "go to" for volcanics.
Nili Fossae Trough	21	74.5	-0.6	X			X		May be too high in elevation for 2018 (-0.6 km), diverse grab bag samples (including carbonate and Hesperian volcanics) in ellipse, in situ hydrothermal rocks are "go to".
Ismenius Cavus	33.5	17	-~3		X		X	X	High latitude may be incompatible with solar power; potential for ice (a PP concern), deltas likely "go to". Least imaged of sites.

* Variable coverage of the sites



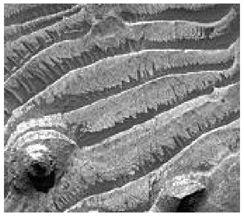
Findings related to landing sites

OBJECTIVE 1, 3, 4 SAMPLES
1A. Subaqueous or hydrothermal sediments
1B. Hydrothermally altered or Low-T fluid-altered rocks

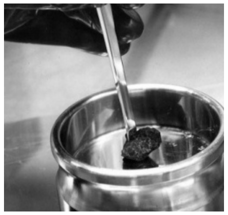
OBJECTIVE 2 SAMPLES
Unaltered Igneous rocks

ROCK TYPES PRESENT	# of currently known sites		
	Total	Go-To	Hazards?
●	>50	MOST	MANY
●	LOTS	MOST	MANY
● ●	~10	ALL?	MOST

- There are **some** sites that may contain subaqueous sediments/hydrothermal sediments OR hydrothermally altered/Low-T fluid-altered rocks **AND** igneous rocks.
- However, at most of those sites:
  - a landing ellipse the same size as the MSL ellipse would include some terrain hazards (→ need smaller ellipse or ability to avoid hazards)
  - some of the rocks of interest exist outside the ellipse (→ need capability to traverse outside the landing ellipse).



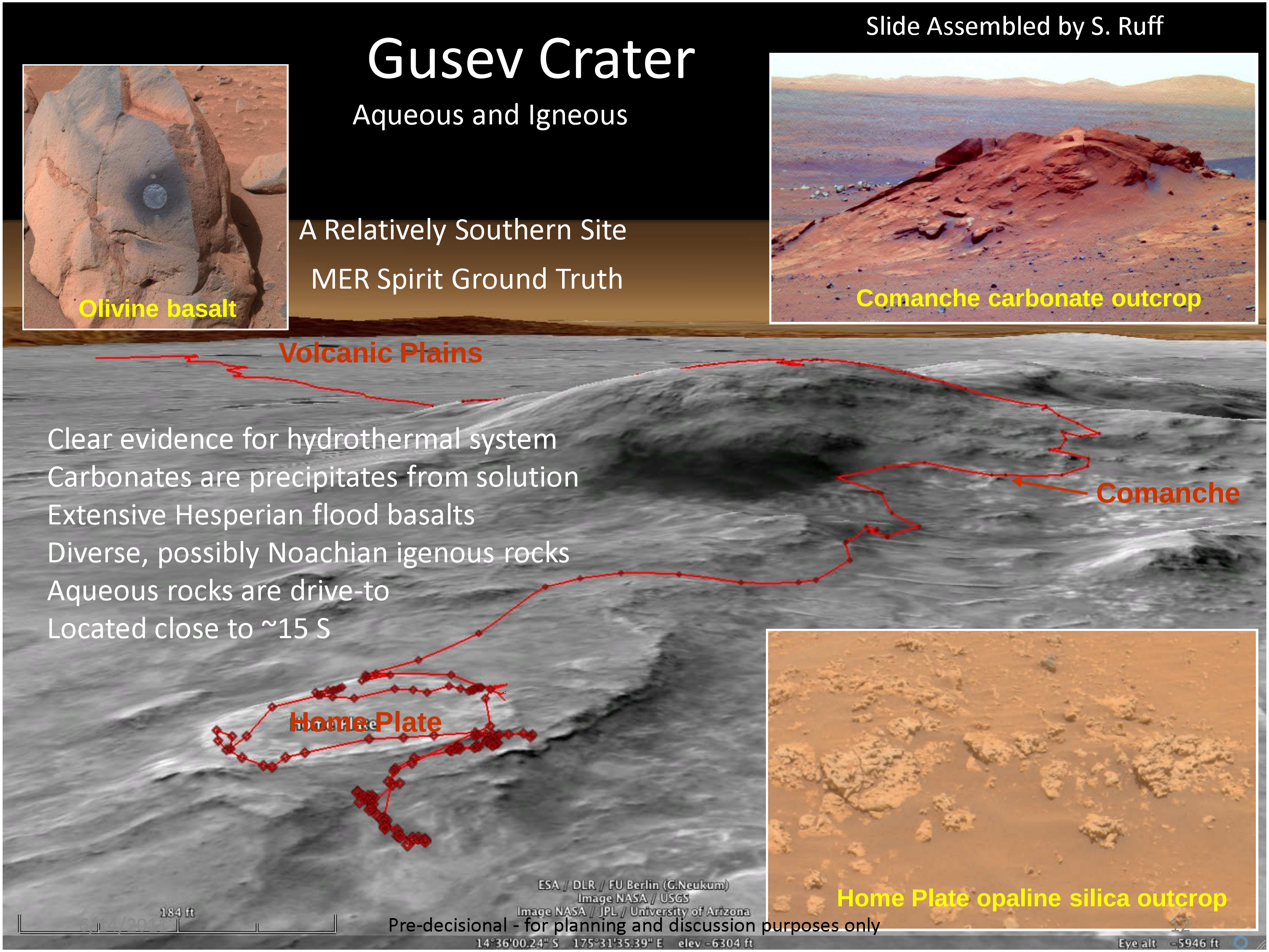
Findings related to landing sites



<u>DRAFT FINDING #17.</u> Three EDL/mobility factors will play a major role in the quality of the sample collection, and therefore in determining the ultimate scientific return of MSR:

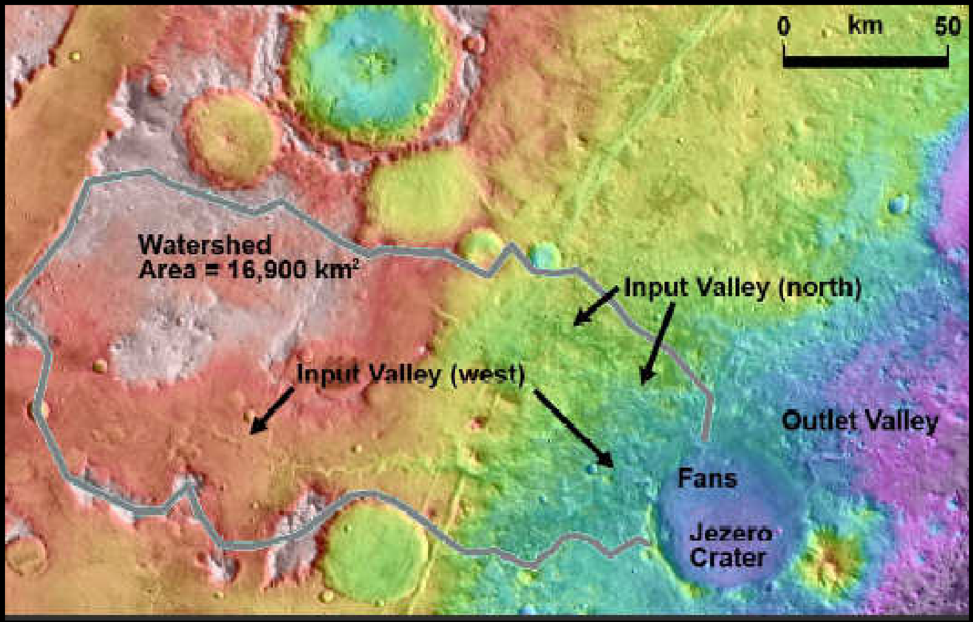
- Whether the landing system could allow ellipse placement over terrain that is more hazardous than permitted for MSL
- Whether the ellipse could be reduced in size to allow placement *between* hazards.
- Whether the rover has the capability to traverse to rocks outside the landing ellipse.

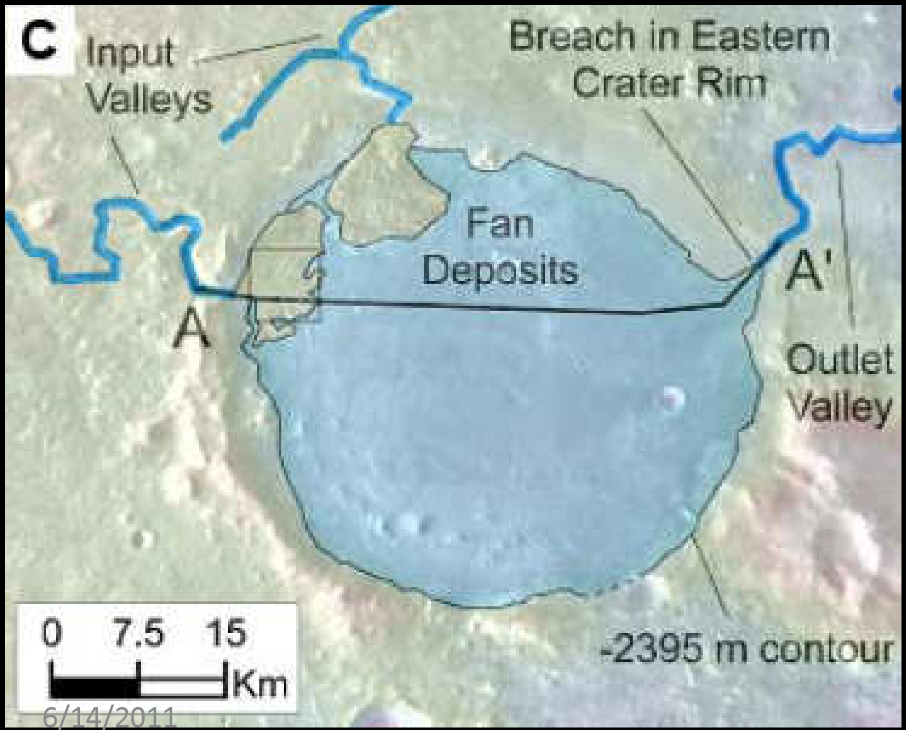
Reinforces two key findings of 2R-iSAG (2010)


Slide Assembled by S. Ruff
Gusev Crater
Aqueous and Igneous
A Relatively Southern Site
MER Spirit Ground Truth
Olivine basalt
Comanche carbonate outcrop
Volcanic Plains
Clear evidence for hydrothermal system
Carbonates are precipitates from solution
Extensive Hesperian flood basalts
Diverse, possibly Noachian igenous rocks
Aqueous rocks are drive-to
Located close to ~15 S
Comanche
Home Plate
Home Plate opaline silica outcrop
ESA / DLR / FU Berlin (G.Neukum)
Image NASA / USGS
Image NASA / JPL / University of Arizona
184 ft
14°36'00.24" S 175°31'35.39" E elev -6304 ft
Eye alt -5946 ft
Pre-decisional - for planning and discussion purposes only

Jezero Crater

Fassett, Ehlmann, Harvey and others





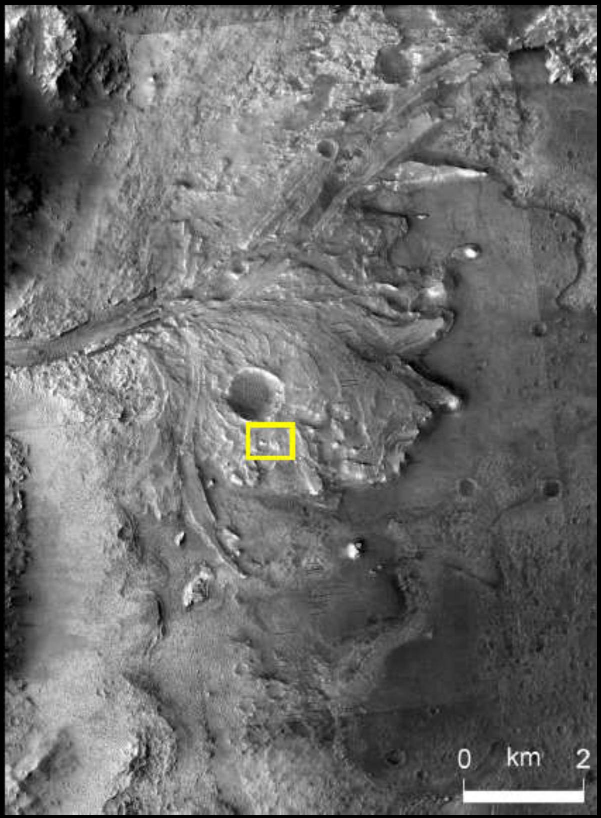
Delta system in large crater

West of Isidis Basin

Outlet at elevation implies lake

Drainage basin extends west

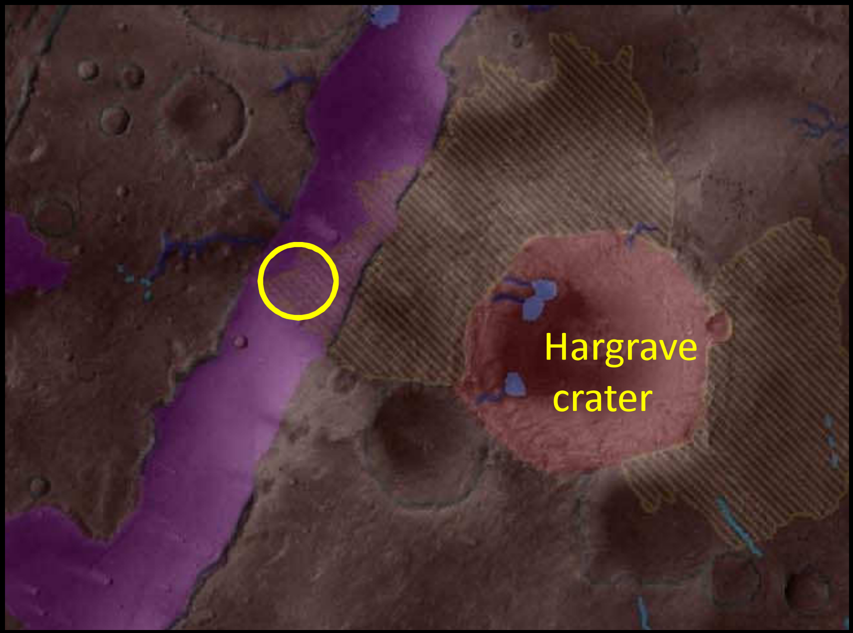
Jezero Crater



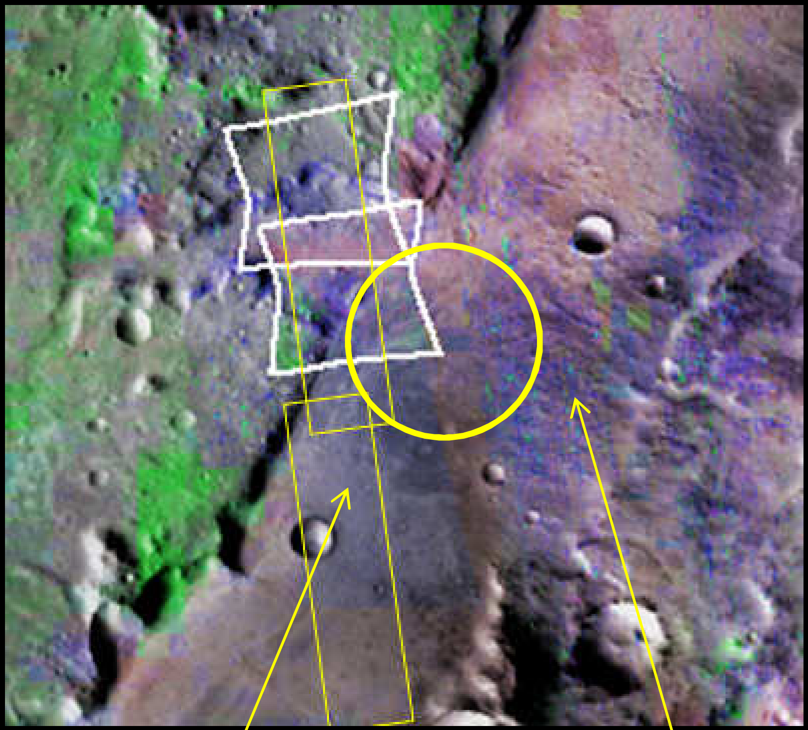
Early-Mid Noachian	Late Noachian	Hesperian to Amazonian
▪ Regional phyllosilicates formed ▪ Isidis impact: establishes regional topography and deposits extensive ejecta ▪ Jezero crater formed	▪ Two valley networks breach Jezero crater rim, deposit transported phyllosilicate-rich sediment and form lake	▪ Post-valley network activity of Nili Fossae ▪ 'Smooth' (probable volcanic) floor unit deposited embaying fan materials ▪ Aeolian deflation of fan sediments and exposure of fresh surfaces

Phyllosilicates in Delta
Volcanic sands adjacent
In place volcanics on floor
Bottomset beds buried?
Rocky surface in ellipse
an issue for MSL

Nili Fossae trough



Map of Mangold et al., JGR, 2007
Shows Hesperian lava plain (purple),
impact breccia (shaded orange)
and partially altered noachian crust (brown)



Diversity mineralogy and geology

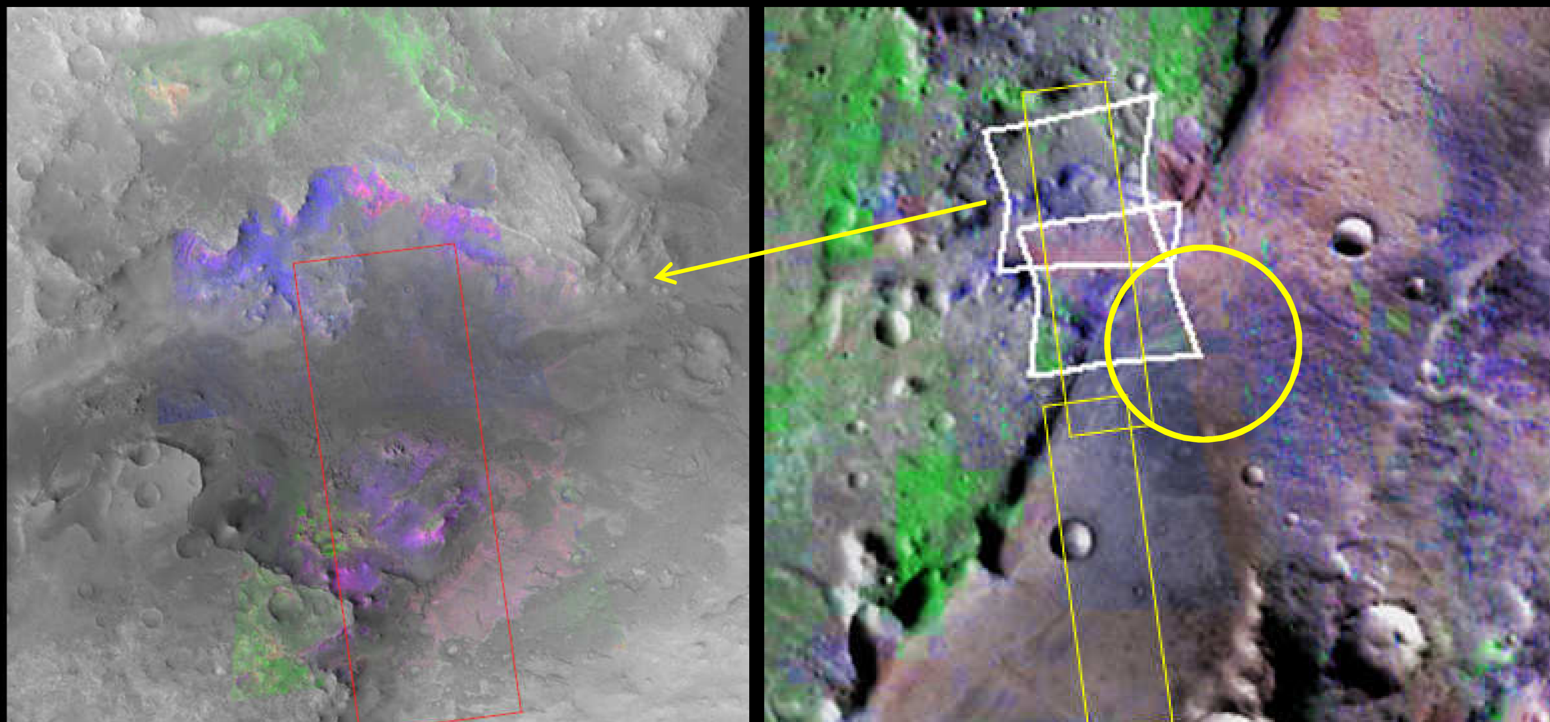
Nili Fossae trough

Phyllos and mafic crust accessible (probably Noachian)

Olivine
Low-Ca Pyroxene
Phyllosilicate
Fe-Phyllosilicate

CRISM Observations

FRT00007BC8
FRT000064D9

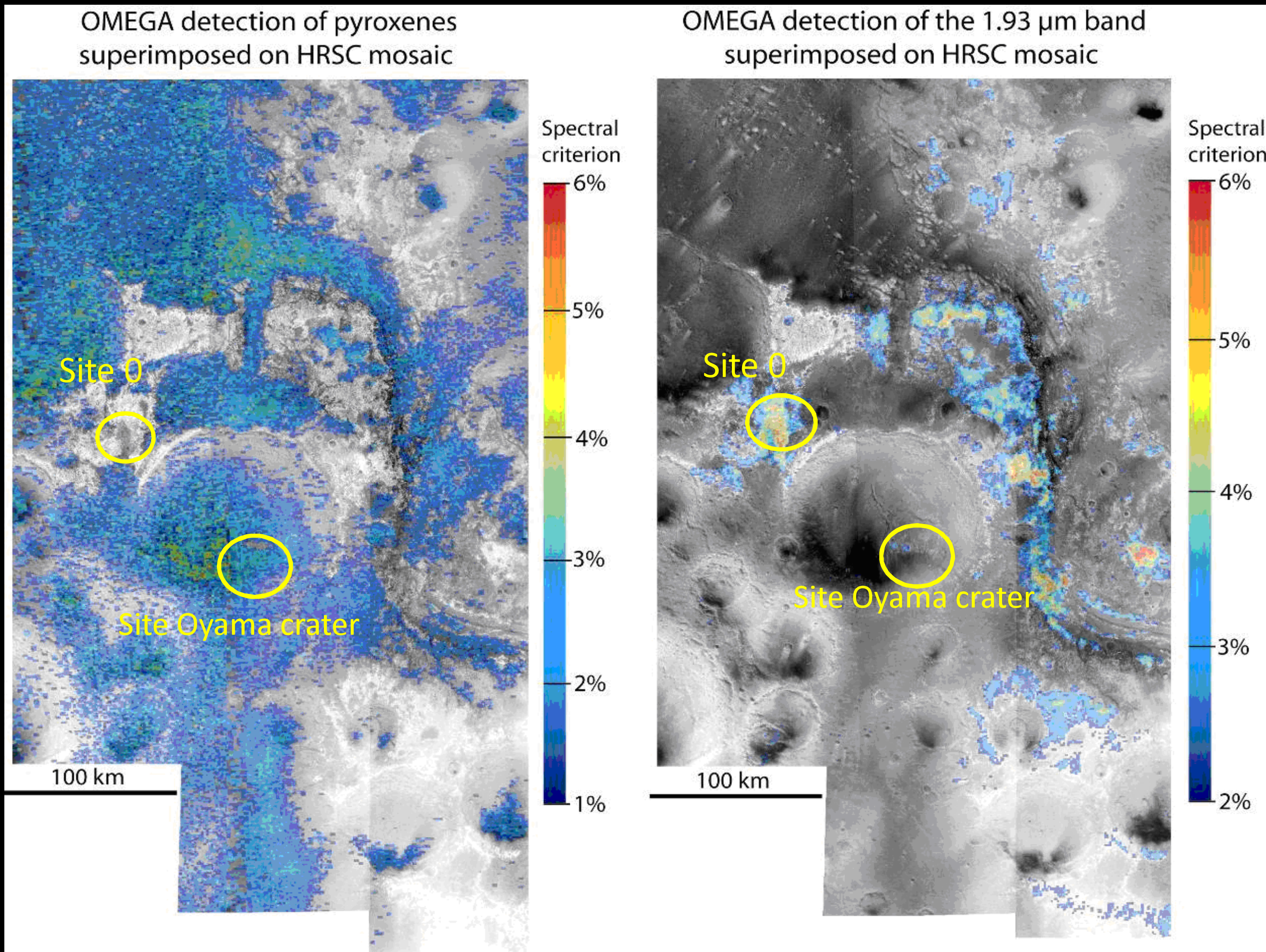


Hydrothermal alteration preferred
Possible weathering (local kaolinite)

Strength: Geologic diversity (crust, alteration, breccia, lava plain)
High mineralogical diversity (clays mainly hydrothermal, representative of Martian crust)
Weakness: High elevation (-600 m) exceeds current limite for 2018

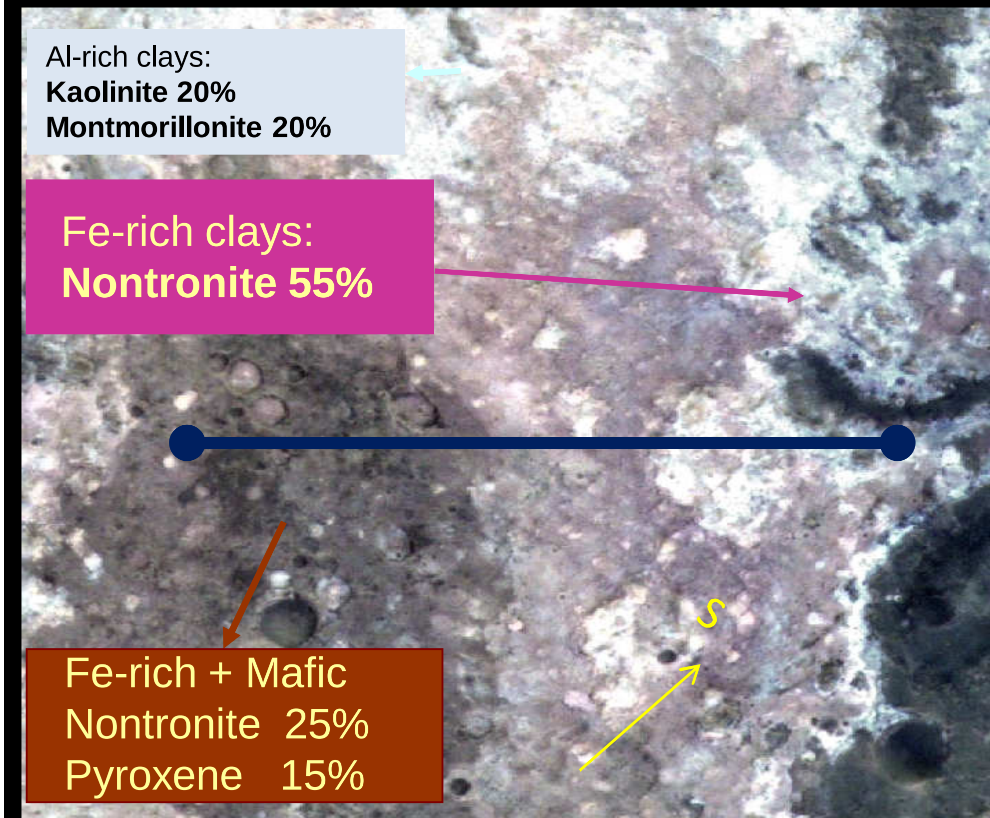
References: Mustard et al., 2007, 2009, Ehlmann, 2010

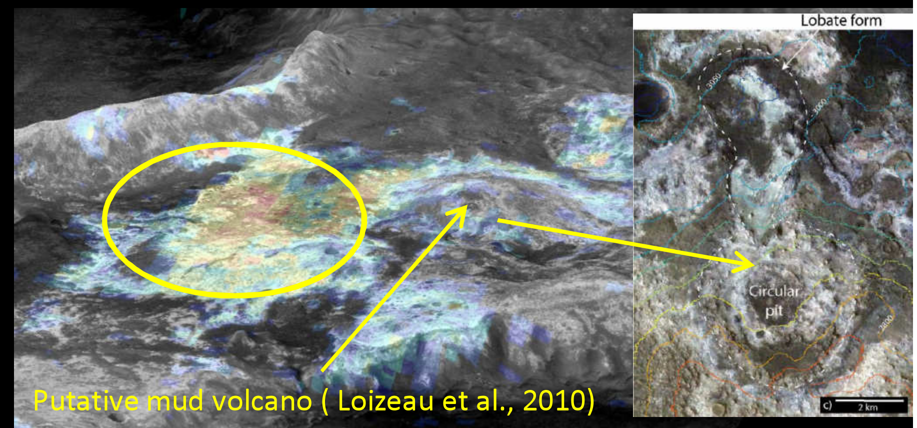
2 sites in Mawrth Vallis region

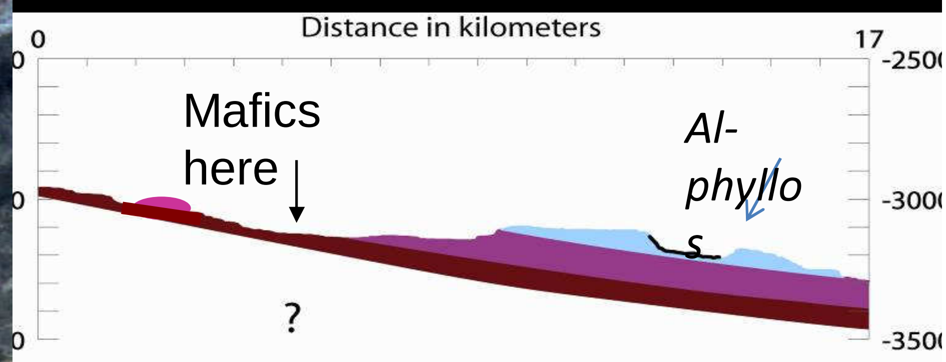


Loizeau et al, JGR, 2007

Mawrth Vallis western outcrops (site 0)







Loizeau et al., 2010

Strength: Contain clays and mafics all ancient (Noachian)
One of the highest abundance of clays on Mars, with diversity
Go to access to lava plains in Oyama crater
Possible mud volcano in the vicinity (see next slide)

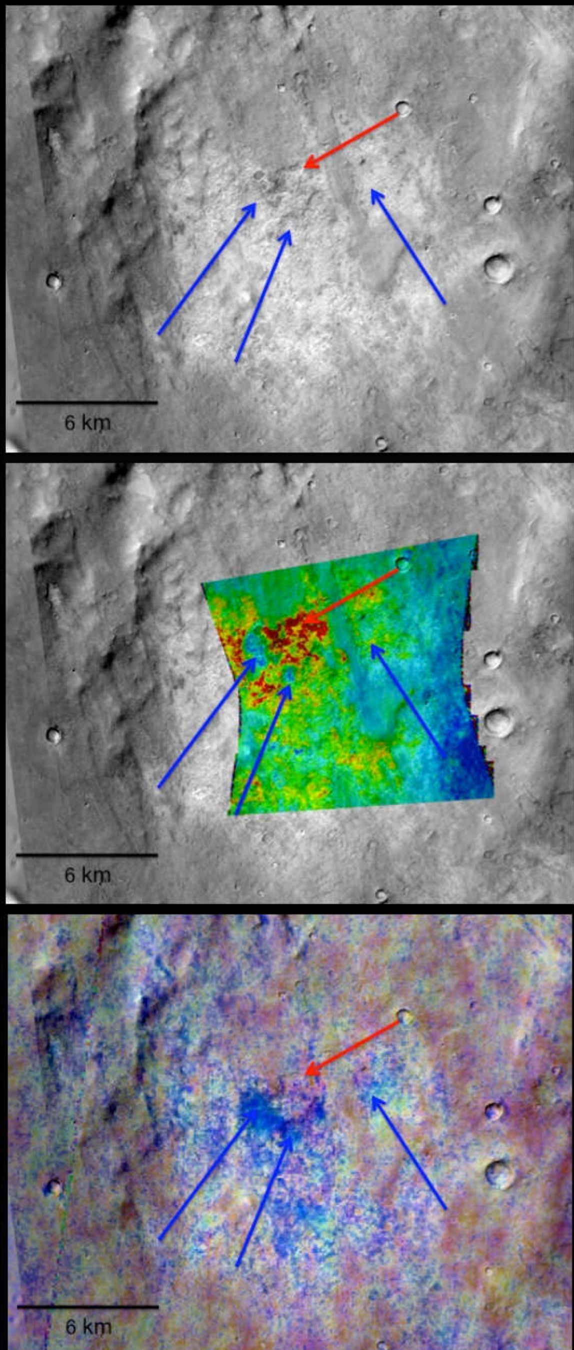
Weakness: Rough terrain relative to MSL Site to East

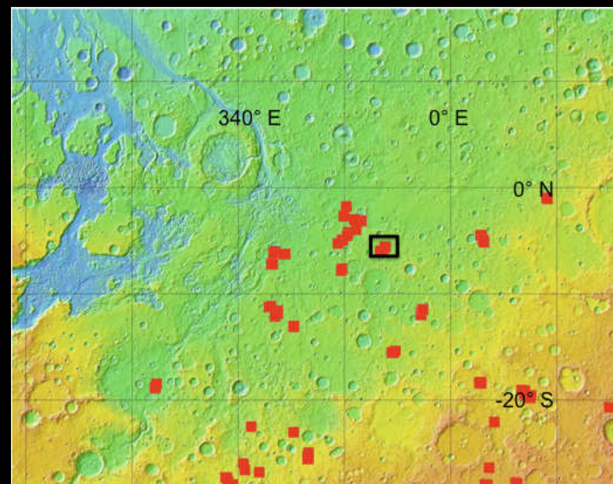
References : Loizeau et al., Icarus, 2010

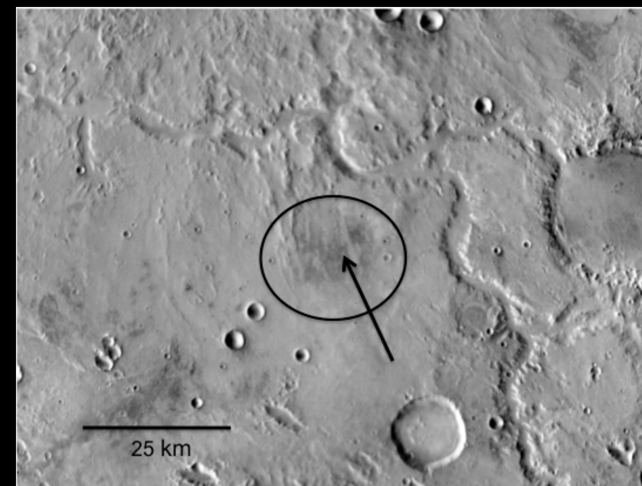
Modeling by Poulet et al, Astro & Astro, 2008

East Margaritifer Chloride

From Presentation by Christensen et al. 5/2010



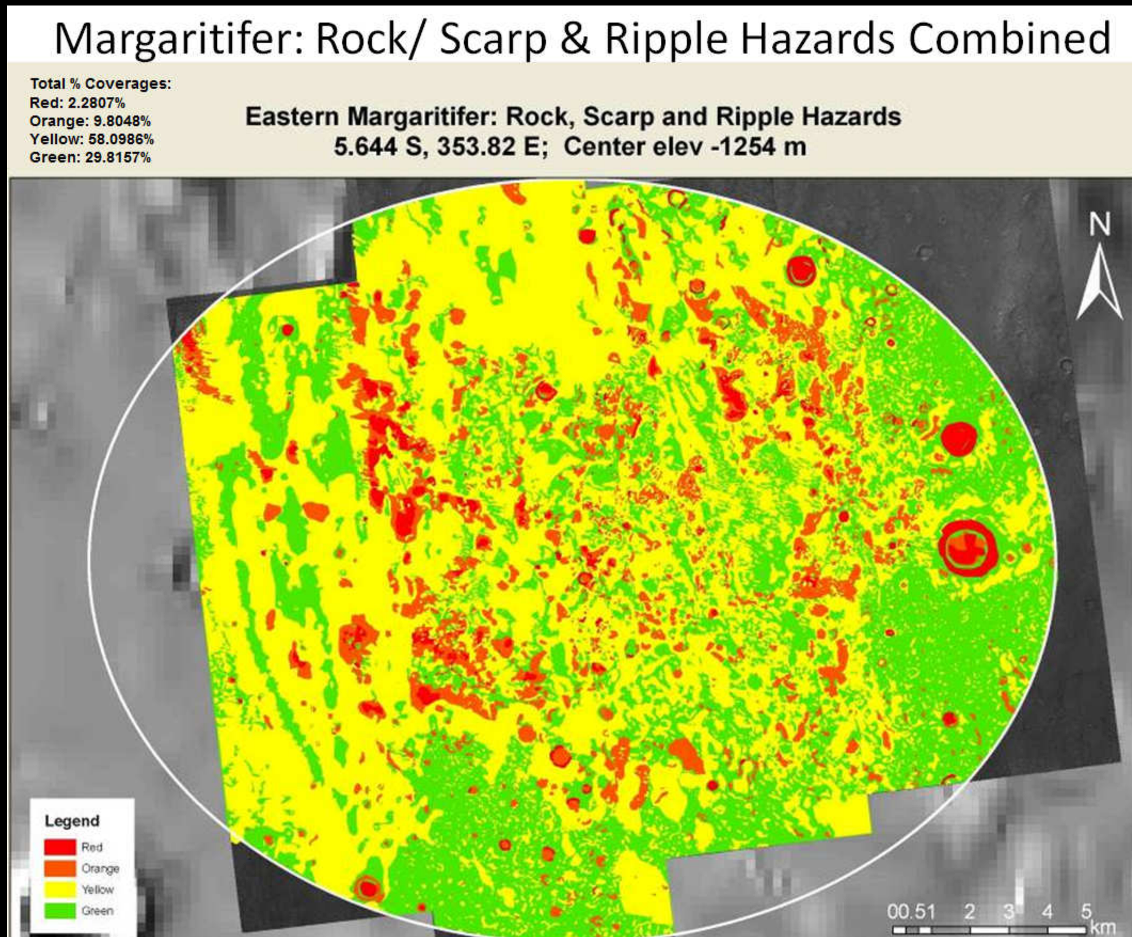




Setting in local basin, associated with valleys
Putative Chlorides overlain by Phyllosilicates
Chloride and Phyllos likely Noachian
Overlain by basaltic materials
Not clear if basaltic cap is in situ
Relief in ellipse was issue for MSL
See Next Slide
Hazard Avoidance Might Resolve?

E. Marg Chloride – Preliminary Characterization

From Presentation by Golombek et al. 5/2010

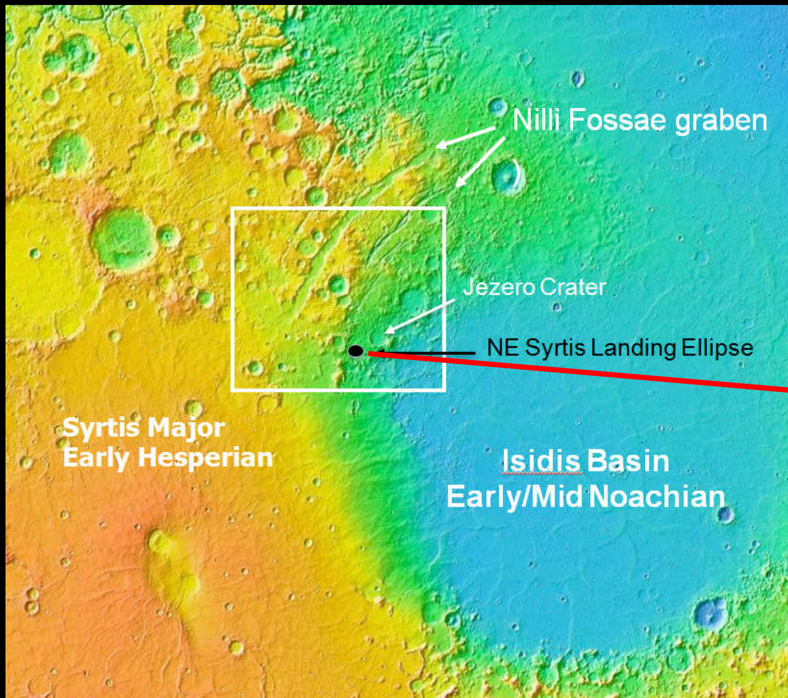


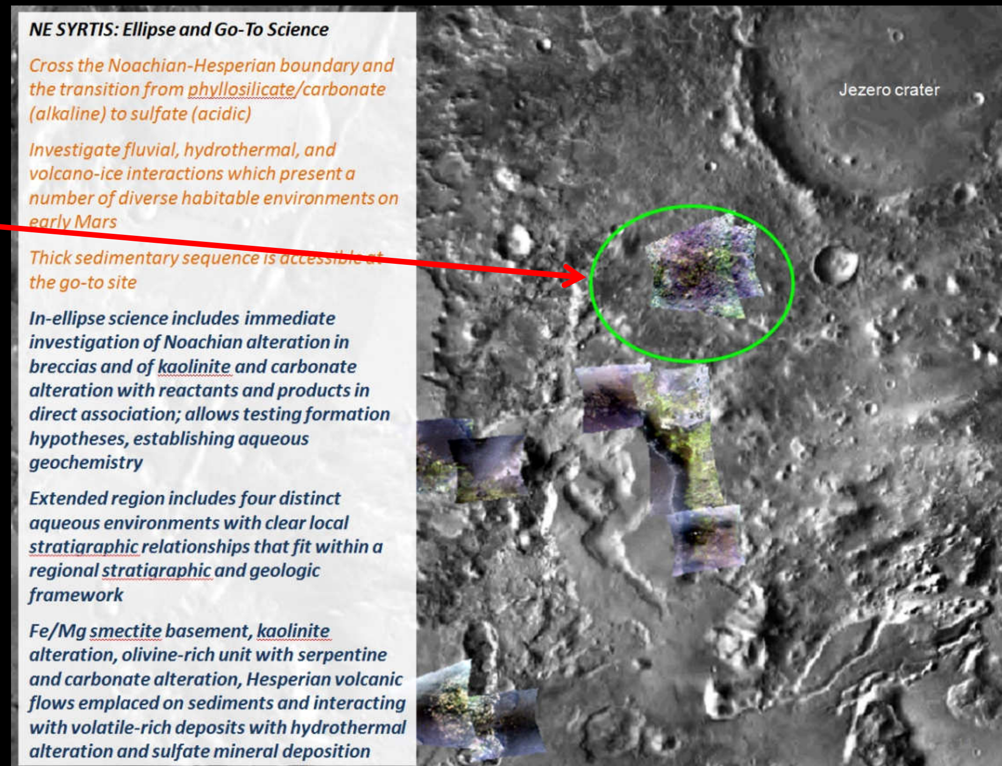
E Margaritifer

- Green for Slopes & Rocks
- Orange for Ripples – 2.3% Red; 10% Orange; Potential Landing Hazard
- Mobility Hazard Worse – Several % Surface Not Traversible;
    - Total Hazardous Area exceeds that at Eberswalde by Factor of 2

NE Syrtis Major - Science

From Presentation by Mustard, Ehlmann, and Skok 5/2010





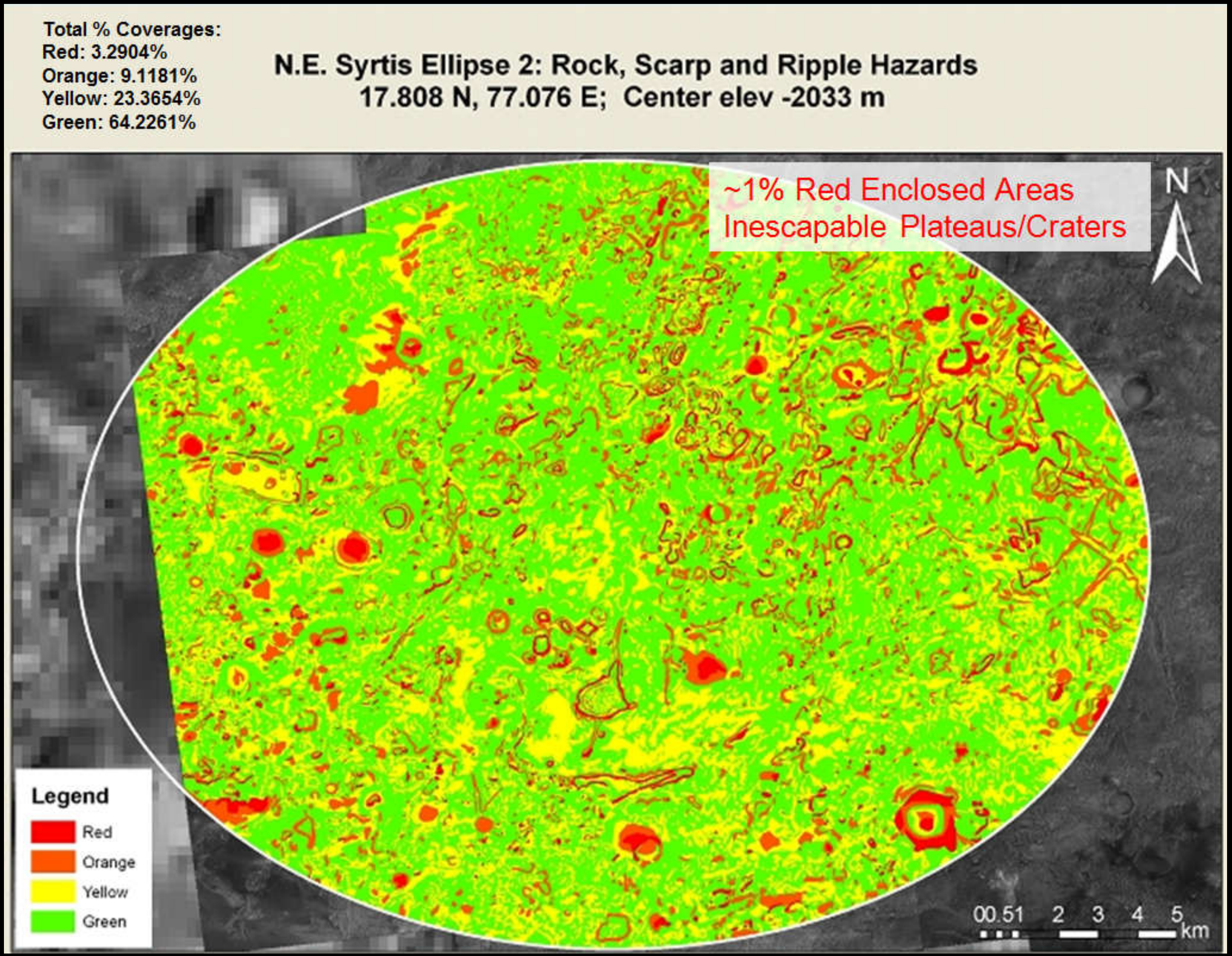
- Target-rich in-ellipse science; go-to science traverses Noachian to Hesperian
- A record of aqueous geochemistry preserved in-situ, in mineral-bearing strata, distinct in age, primary mineralogy, and geologic setting is well-suited for the MSL instrument suite
- Bedrock strata here represent 4 distinct environments of aqueous alteration where reactants and products are together. These allow addressing fundamental questions about water on early Mars:
  - **Basement Fe/Mg smectites:** Common in the S. highlands. Were phyllosilicates in the early crust mostly created by impact processes or generated by another process and simply disrupted and redistributed by them?
  - **Carbonate/serpentine/olivine**: Do these exposures represent mostly the effects of surface alteration or hydrothermal activity? How much H_2 would have been produced and methane released by the serpentinization of olivine that occurred west of Isidis?
  - **Layered phyllosilicates (Al- over Fe/Mg)**: do these represent surface formation from leaching, driven by a persistent surface hydrologic system?
  - **(Sedimentary?) acid sulfate formation**: are layered units these the result of lavas covering sulfate-bearing sediments in a paleobasin or the result of a hydrothermal system driven by volcano-ice interactions?
- Key stratigraphies from Bibring's Phyllosian and Theiikian eras: do the changes recorded here represent Mars global environmental change?

Strength: Diverse Noachian alteration+lava flows
Excellent stratigraphy
Limited fluvial deposits, no lacustrine?
Go to site for volcanics

Weakness: Relief an issue for MSL
Hazard Avoidance Might Resolve
See Next Slide from Golombek et al.

NE Syrtis Major – Preliminary Characterization

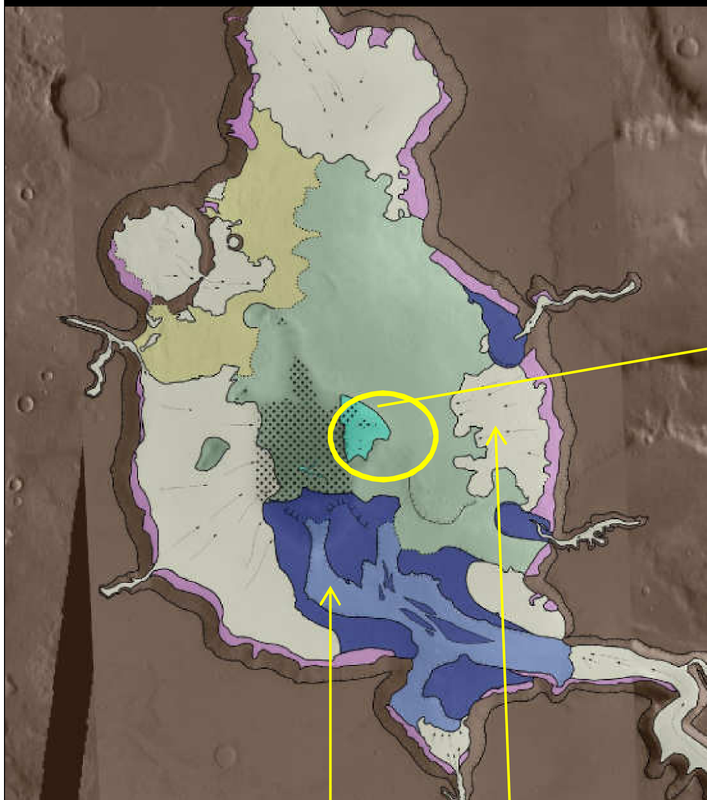
From Presentation by Golombek et al. 5/2010



NE Syrtis

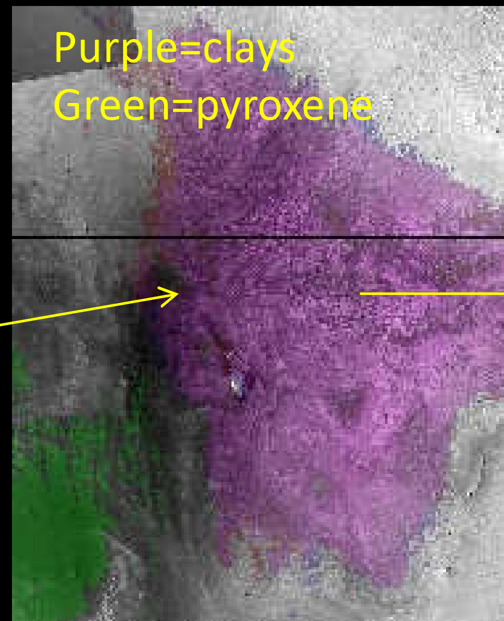
- Orange for 1 km Slopes ~4% Surface Exceeds Fuel Allocation for Terrain
- Orange for Scarps & Slopes
  - 3.3% Surface Poses Serious Landing Hazard – Engineering out Risk Highly Unlikely
  - 9.1% Surface Potential Landing Hazard- DEM's needed to Refine Hazard Assessment
  - In total: factor of 2-3⁺ more hazardous area than Eberswalde

Ismenius Cavus (South of Deuteronilus Mensae): A Northern Site

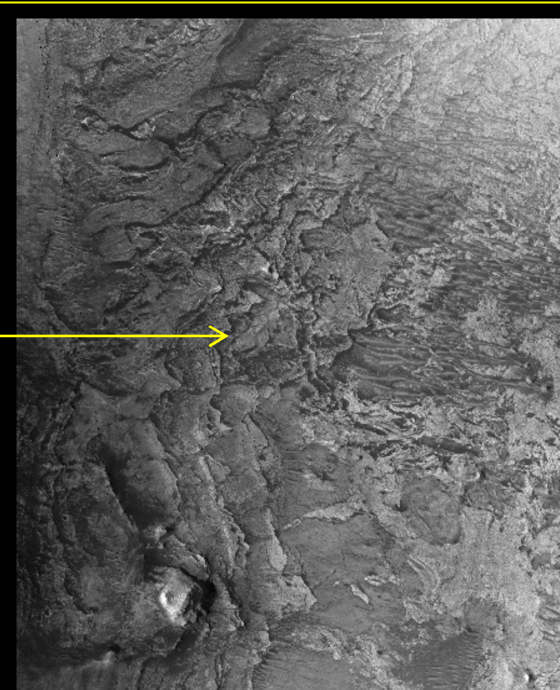


600 m thick
delta deposits

Mid-latitude glacier



Fe-Mg smectites found
by OMEGA and CRISM



Clays are in sediments
at paleolake bottom

Strength: Single site to combine clay-bearing paleolake sediments and current glacial deposits
Three deltas (in blue) at the same elevation=> Confirms paleolake

Caveat: Mafics mainly in sand, but should exist locally beneath sediments +34°North latitude

References: Dehouck et al., Planet. Space Science, 2010

Transition to Monica