



MEPAG  
E2E-iSAG

# Reference Landing Sites, Mars Sample Return Campaign

June 16, 2011

John Grant, on behalf of the E2E-iSAG team

*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

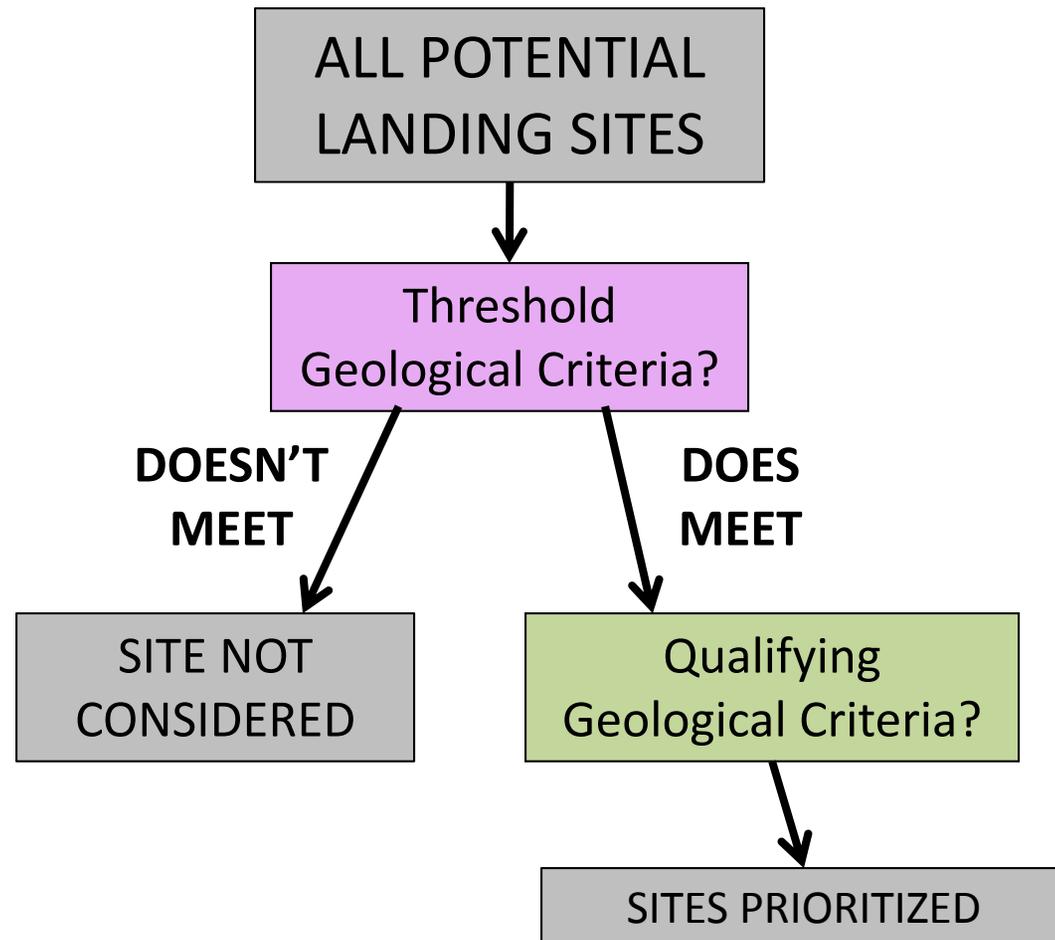


# Landing Sites: Proposed Selection Criteria

**Two types of selection criteria can be applied:**

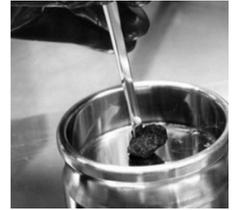
- “**Threshold**” - sites must meet these to be considered
- “**Qualifying**” – these can be used to prioritize among the remaining sites

As more is learned about the sites during the selection process, many would be dropped from consideration. In order to end up with at least one acceptable site, **it is necessary to begin the scientific selection process with a reasonable array of candidates.**





# Landing Sites: Proposed Selection Criteria



## **Threshold Geological Criteria**

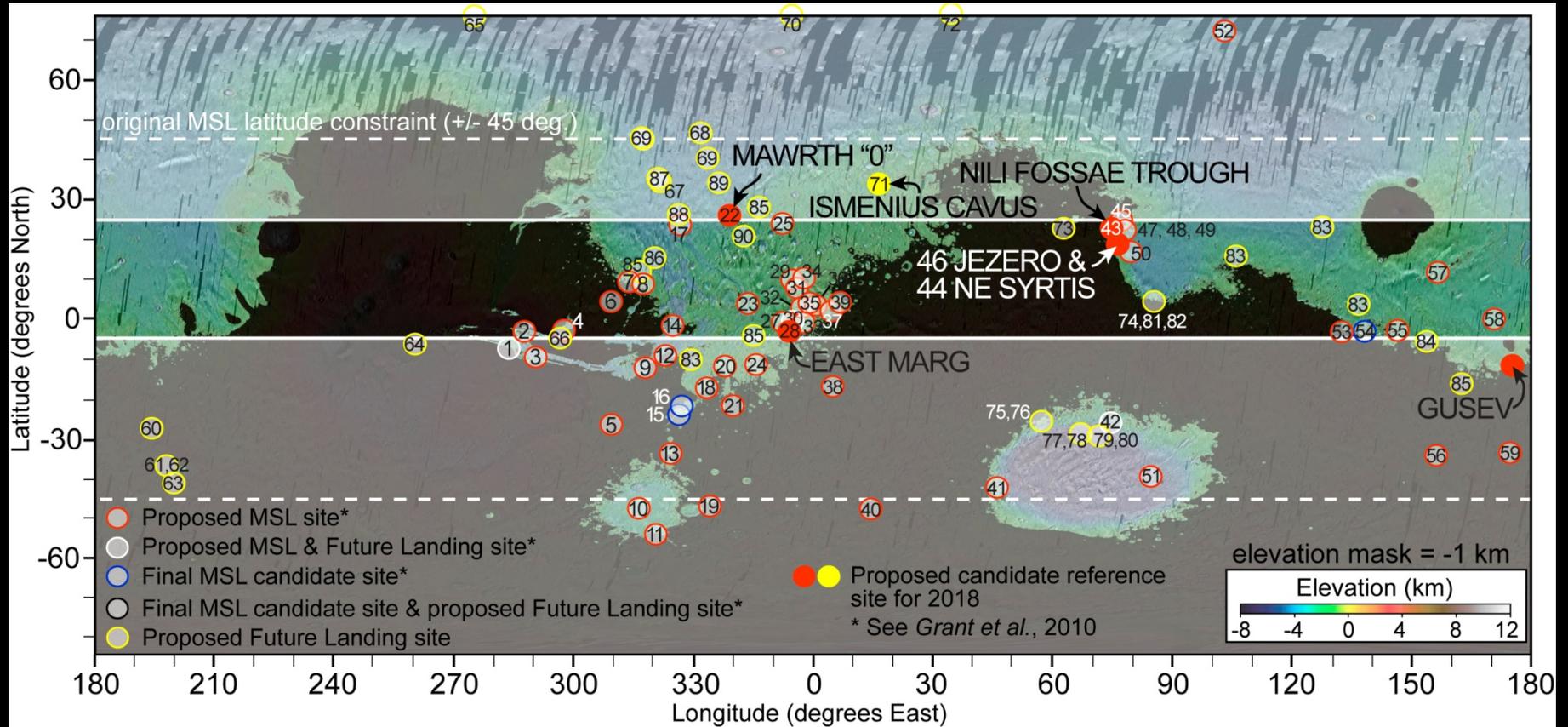
1. Presence of subaqueous sediments or hydrothermal sediments (equal 1<sup>st</sup> priority),  
OR  
hydrothermally altered rocks or Low-T fluid-altered rocks (equal 2<sup>nd</sup> priority)
2. Presence of aqueous phases (e.g., phyllosilicates, carbonates, sulfates etc.) in outcrop
3. Noachian/Early 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

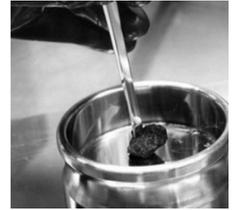
# Potential Landing Sites



- 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



**10 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 #25:** Among the ~85 candidate landing sites that have been proposed by the community to date (for all 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



Site	Center of Proposed Ellipse			Recognized Potential EDL or Mobility Issues*					Comments
	Lat (°N)	Lon (°E)	Elev. (km)	Elev.	Lat.	Terrain	"go-to"?	Other	
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

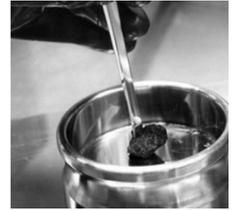
**OBJECTIVE 2 SAMPLES**  
 Unaltered Igneous rocks

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

- Lots of sites have subaqueous sediments OR hydrothermal sediments OR hydrothermally altered rocks OR Low-T fluid-altered rocks OR igneous rocks. Some have **BOTH**.
- However, at most (possibly all) of the sites that contain BOTH rock types of interest, a landing ellipse the same size as the MSL ellipse would necessarily include some terrain hazards.



## Findings related to landing sites



**DRAFT FINDING #15.** To meet the proposed science objectives, the rover mission (and the MSR-L mission) capabilities should allow consideration of a reasonable array of candidate landing sites that meet the threshold science criteria. To enable this—assuming the landing ellipse size is the same as for MSL—the landing system should allow ellipse placement over terrain that is more hazardous than permitted for MSL (alternatively, the ellipse could be reduced in size to allow placement *between* hazards). IN ADDITION, the rover would very likely need the capability to traverse to rocks outside the landing ellipse.

**Derived Finding:** Hazard avoidance capabilities and/or improved landing accuracy derive from the desire to address multiple high-priority science objectives, and should be maintained as options for consideration during the mission formulation phase. IN ADDITION, the rover would very likely need the capability to traverse to rocks outside the landing ellipse.

# Gusev Crater

Aqueous and Igneous

A Relatively Southern Site  
MER Spirit Ground Truth



Olivine basalt



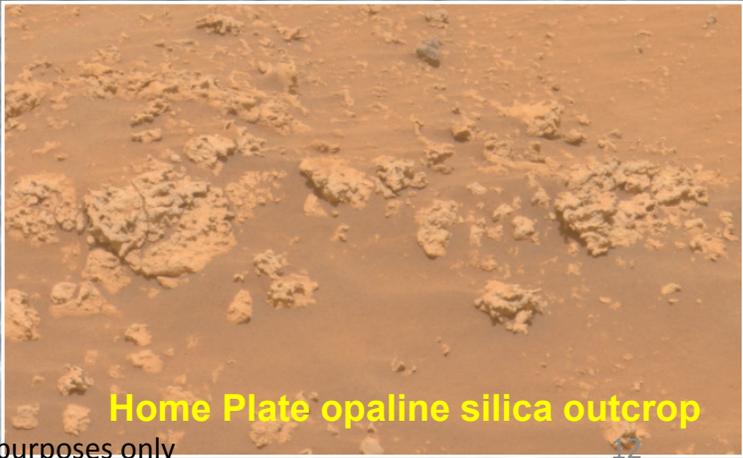
Comanche carbonate outcrop

## Volcanic Plains

- Clear evidence for hydrothermal system
- Carbonates are precipitates from solution
- Extensive Hesperian flood basalts
- Diverse, possibly Noachian igneous 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

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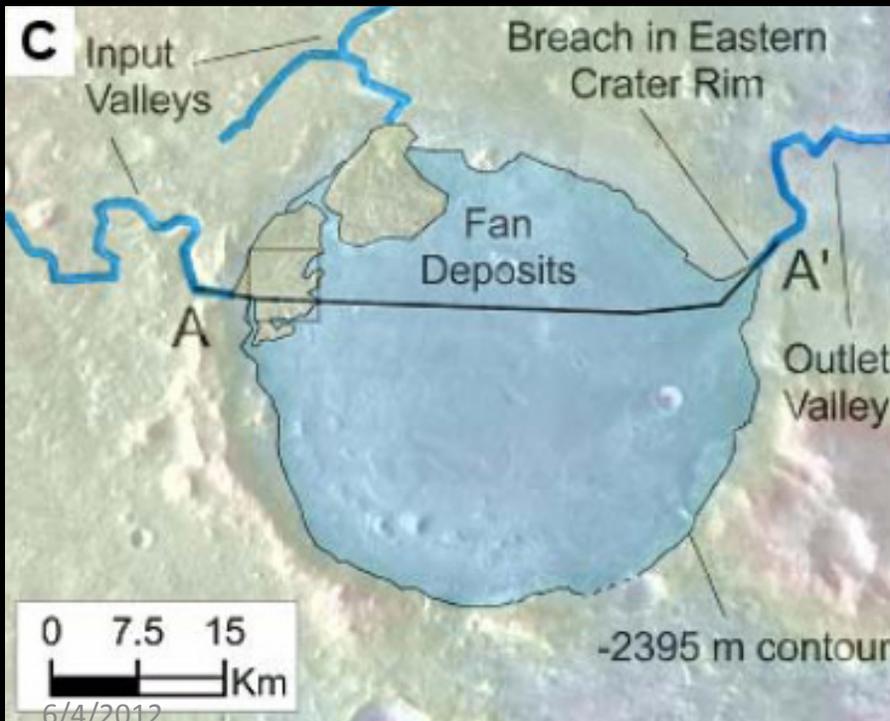
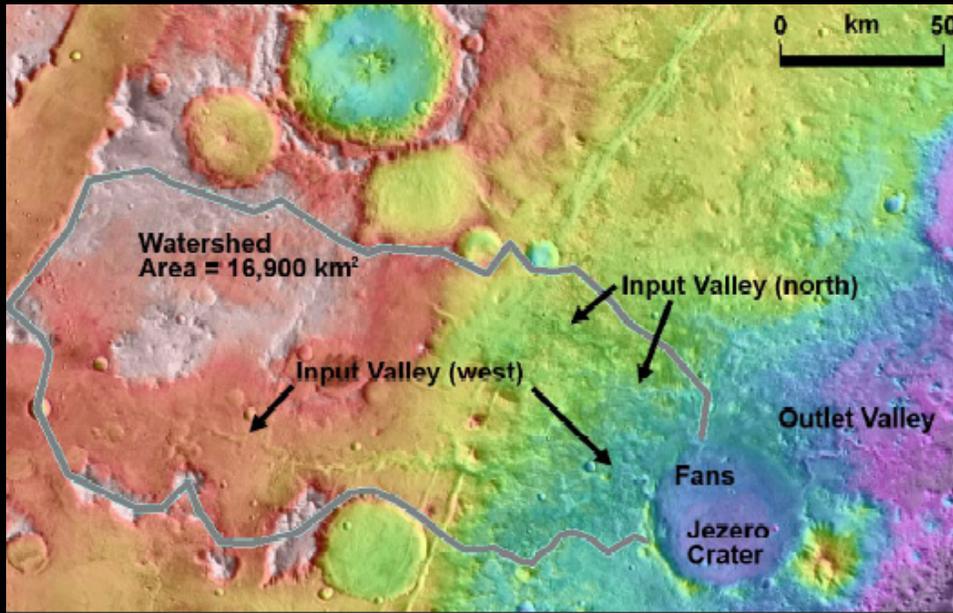
14°36'00.24" S 175°31'35.39" E elev = 6304 ft

Eye alt = 5946 ft

6/4/2012 184 ft

# Jezero Crater

Fassett, Ehlmann, Harvey and others



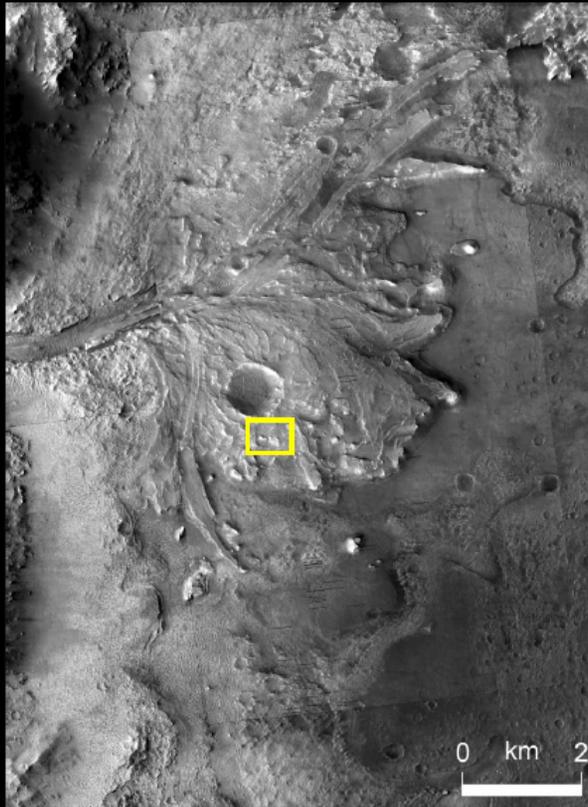
Delta system in large crater

West of Isidis Basin

Outlet at elevation implies lake

Drainage basin extends west

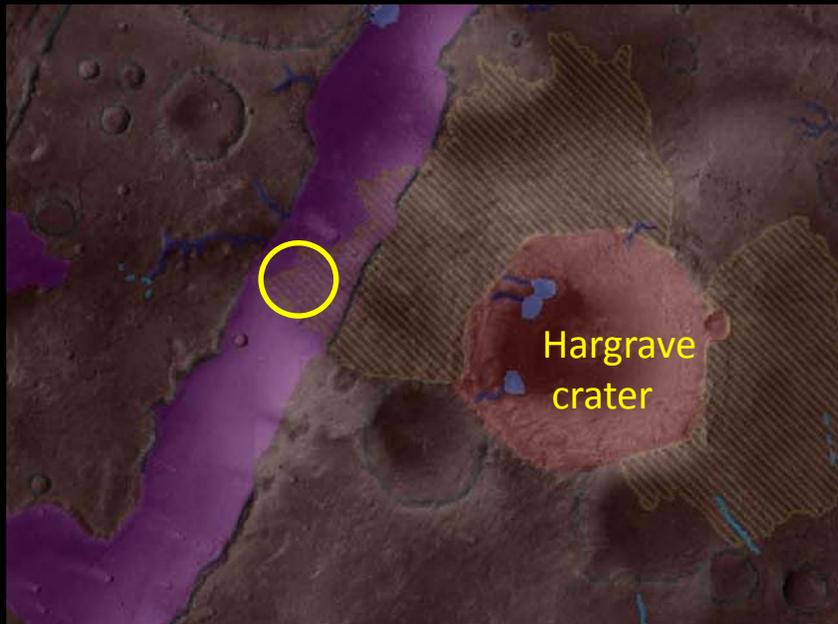
# Jezero Crater



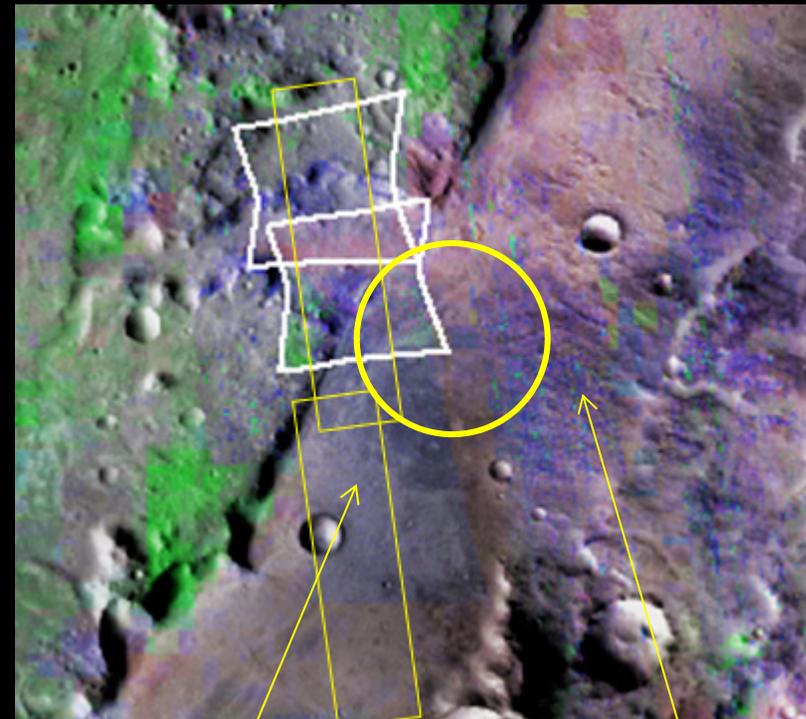
Early-Mid Noachian	Late Noachian	Hesperian to Amazonian
<ul style="list-style-type: none"> <li>Regional phyllosilicates formed</li> <li>Isidis impact: establishes regional topography and deposits extensive ejecta</li> <li>Jezero crater formed</li> </ul>	<ul style="list-style-type: none"> <li>Two valley networks breach Jezero crater rim, deposit transported phyllosilicate-rich sediment and form lake</li> </ul>	<ul style="list-style-type: none"> <li>Post-valley network activity of Nili Fossae</li> <li>'Smooth' (probable volcanic) floor unit deposited embaying fan materials</li> <li>Aeolian deflation of fan sediments and exposure of fresh surfaces</li> </ul>

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)



Hesperian lava filling      Ejecta breccia  
(crust excavation from  
Hargrave crater to the east)

## Diversity mineralogy and geology

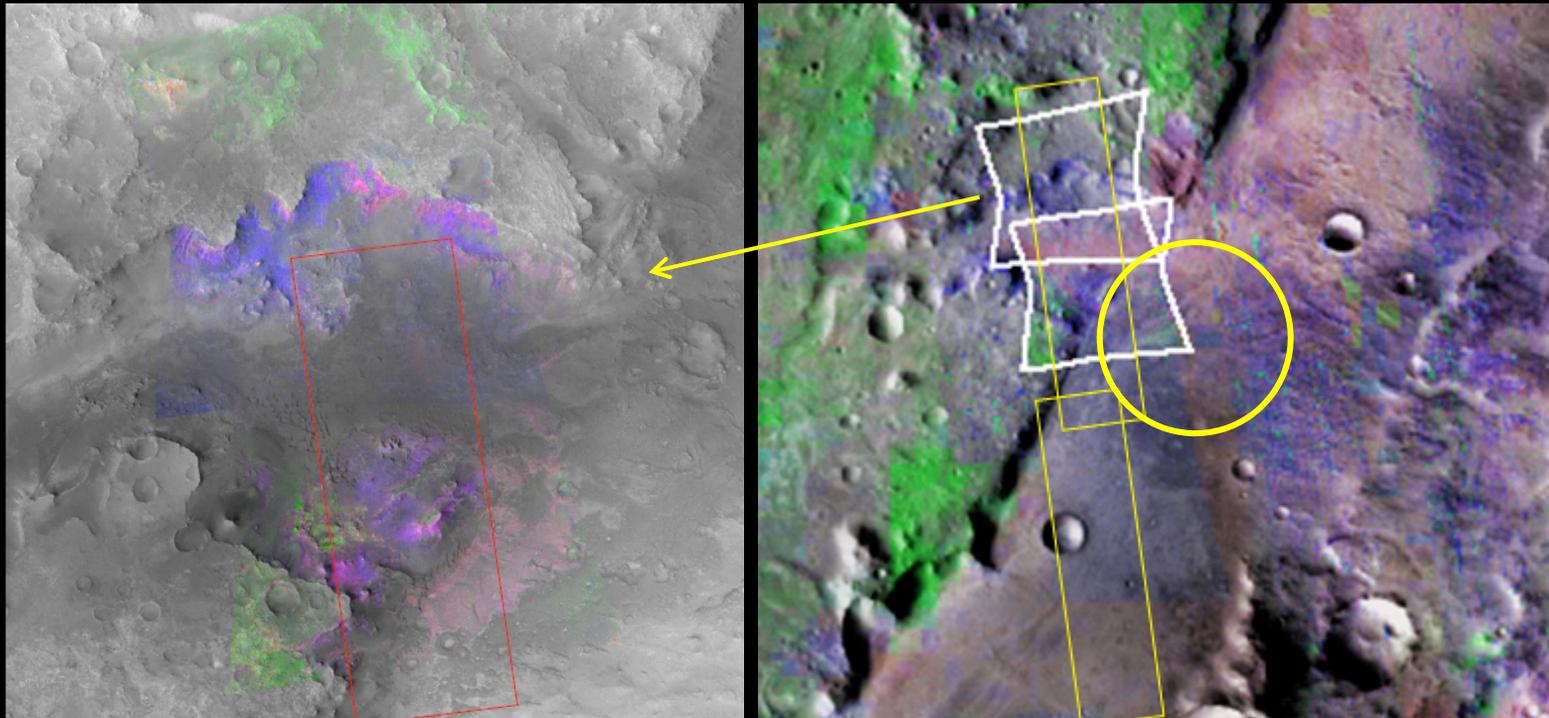
# Nili Fossae trough

## 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 limits for 2018

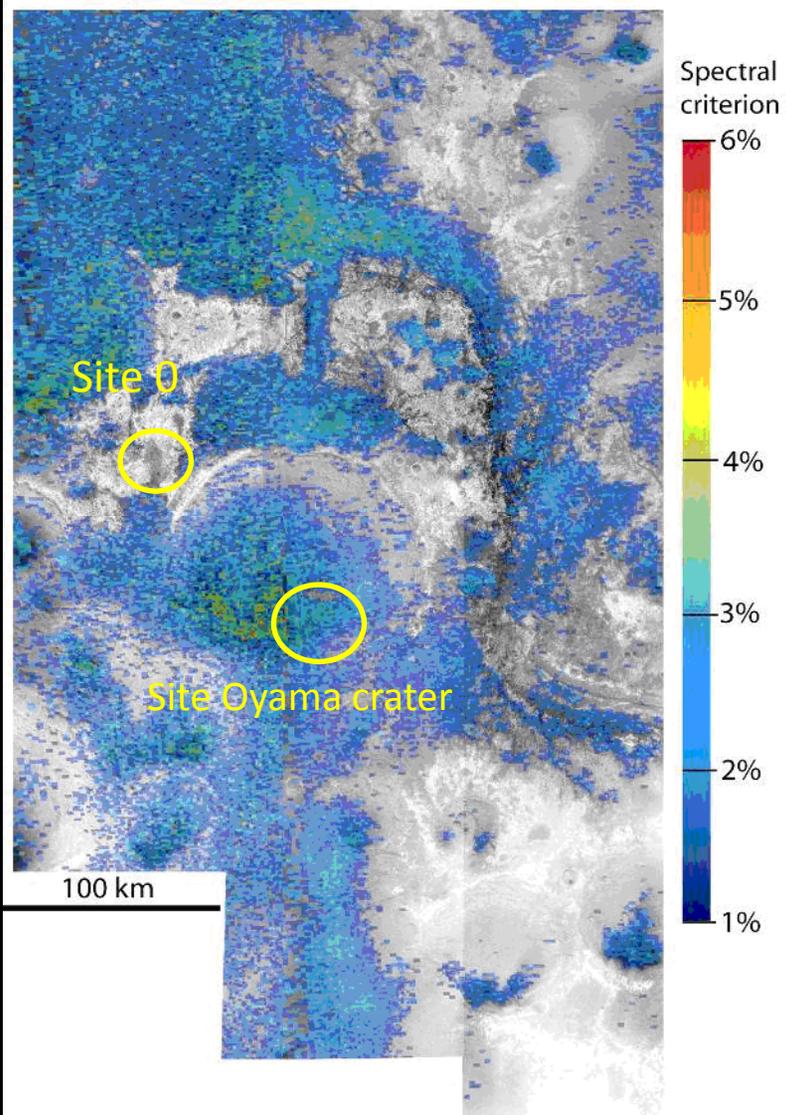
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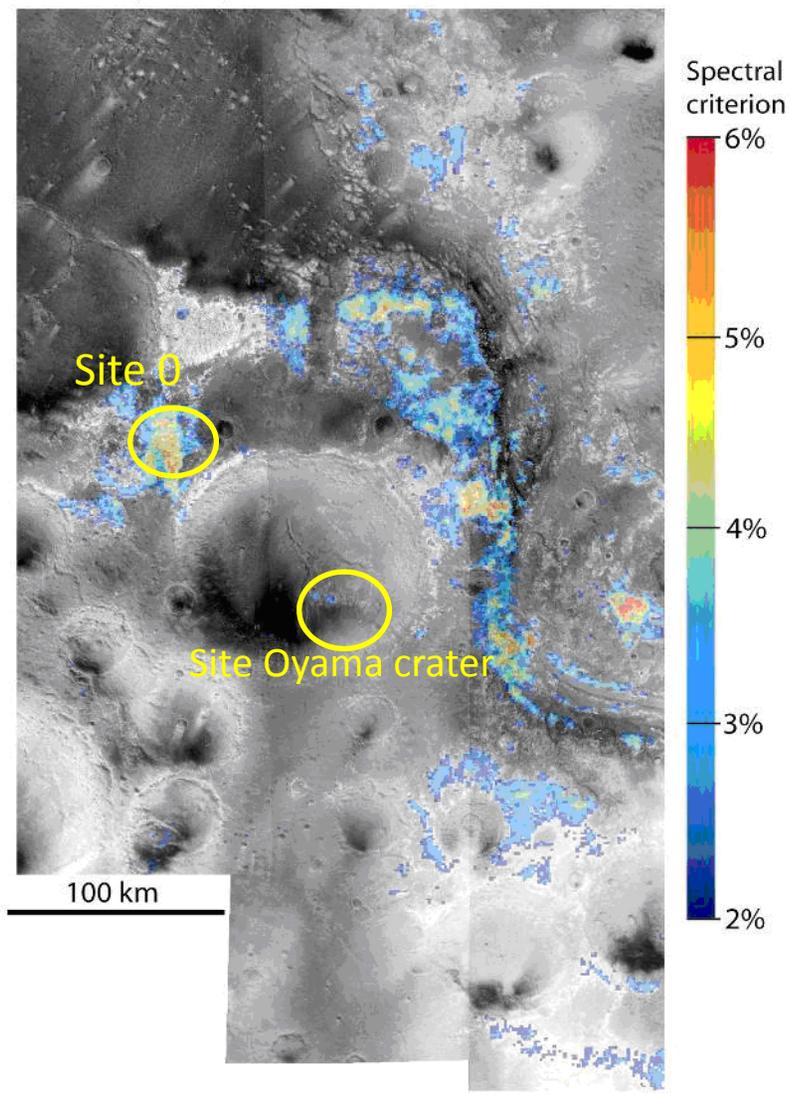
References: Mustard et al., 2007, 2009, Ehlmann, 2010

## 2 sites in Mawrth Vallis region

OMEGA detection of pyroxenes superimposed on HRSC mosaic

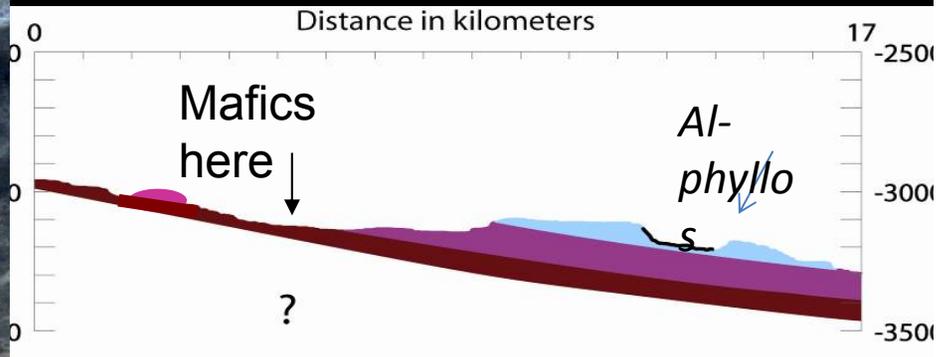
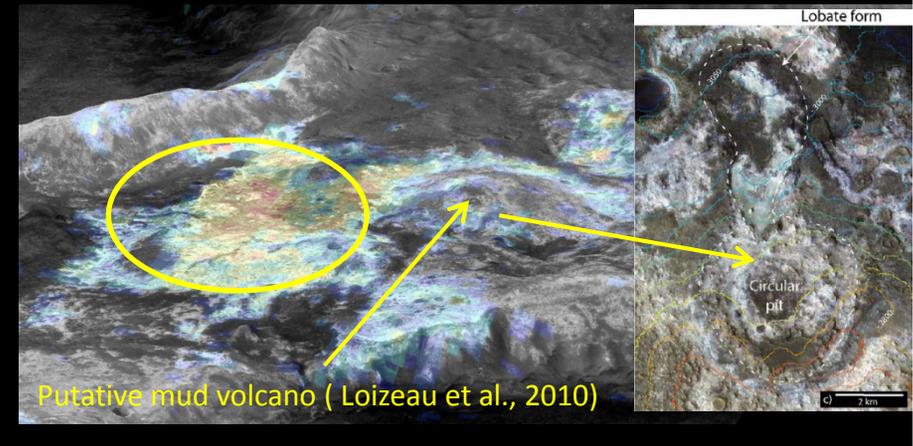
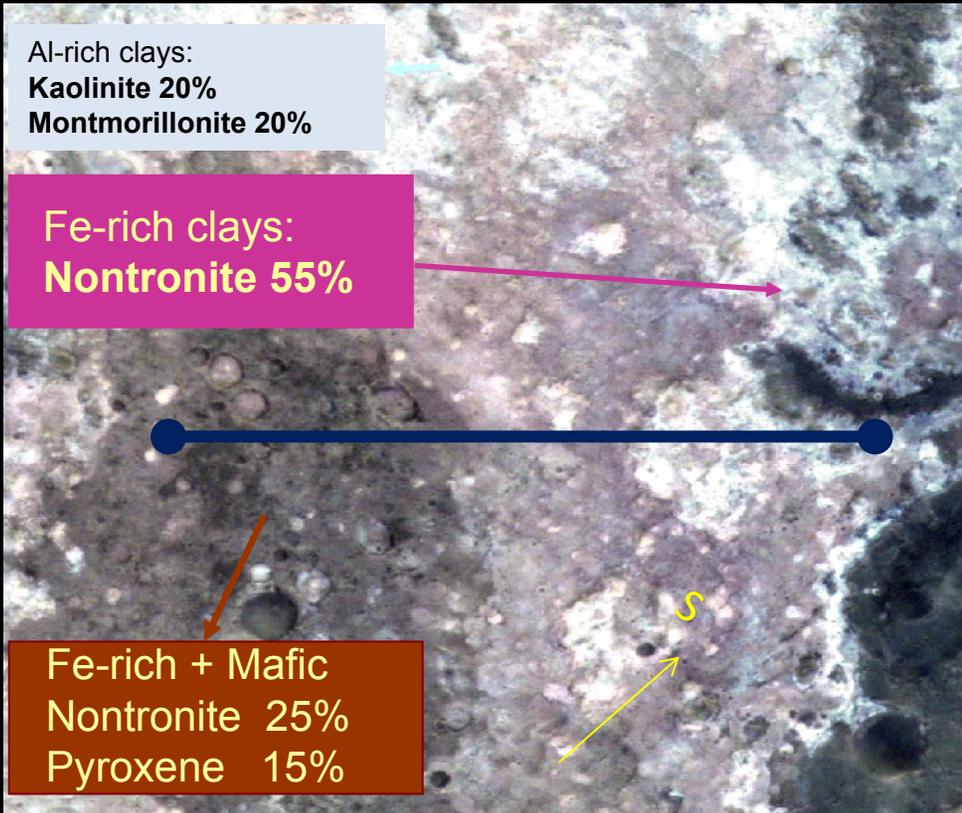


OMEGA detection of the 1.93  $\mu\text{m}$  band superimposed on HRSC mosaic



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)

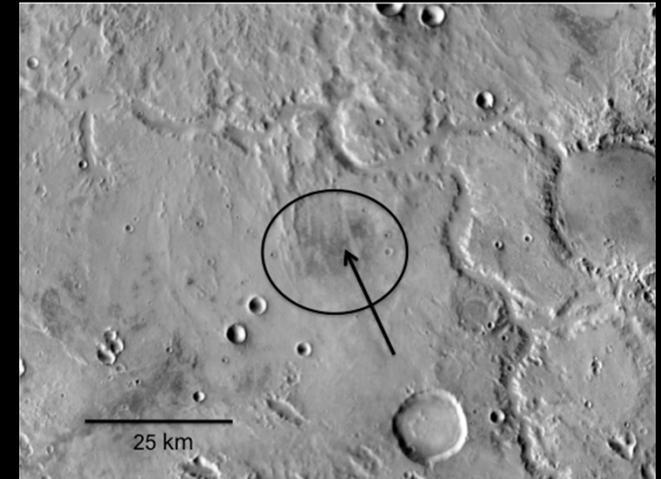
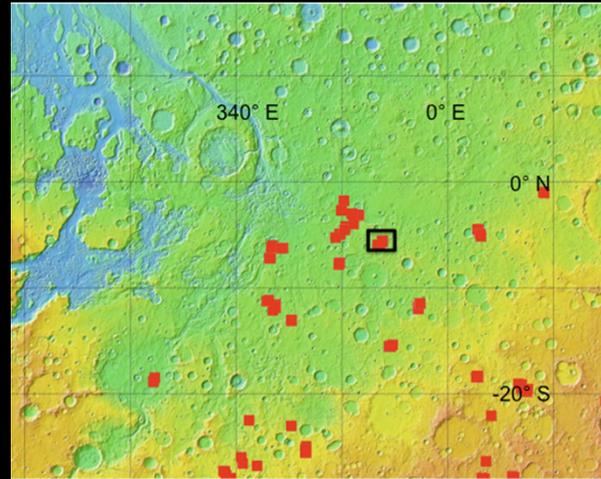
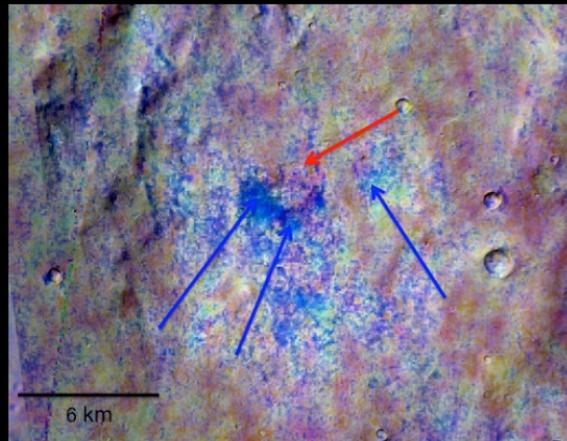
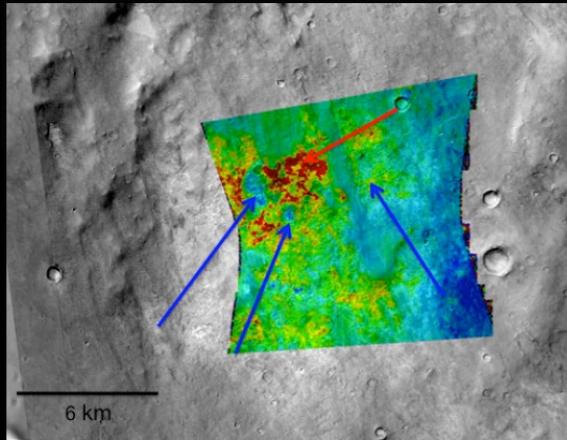
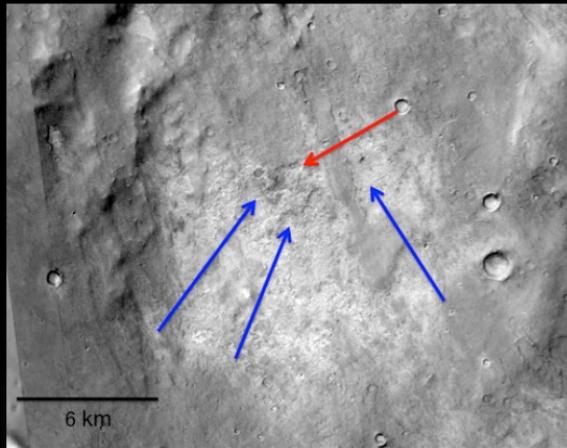
Weakness: Rough terrain relative to MSL Site to East

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

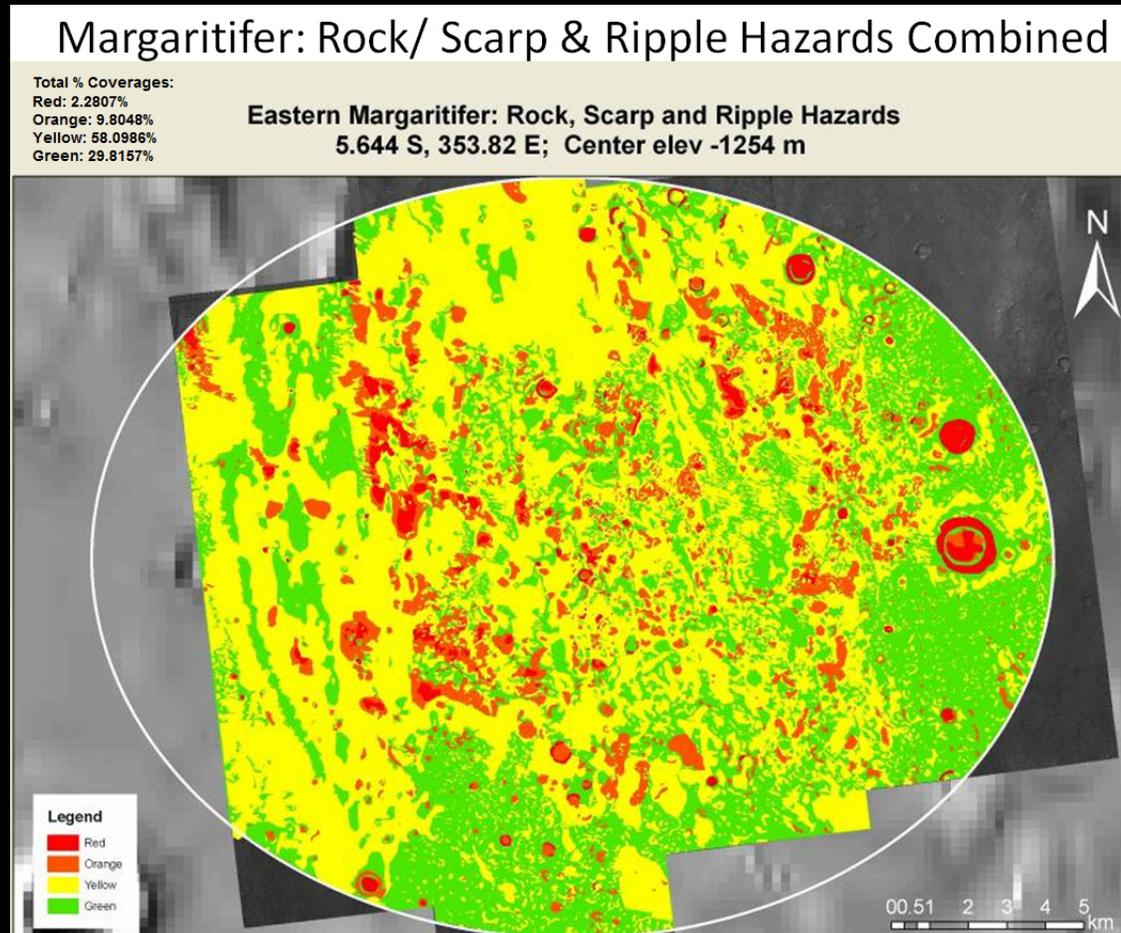


Setting in local basin, associated with valleys  
Putative Chlorides overlain by Phyllosilicates  
Chloride and Phyllos likely Noachian  
Overlain by basaltic materials  
Not clear if basaltic cap is in situ  
Relief in ellipse was issue for MSL  
See Next Slide  
Hazard Avoidance Might Resolve?

6/4/2012

# E. Marg Chloride – Preliminary Characterization

From Presentation by Golombek et al. 5/2010

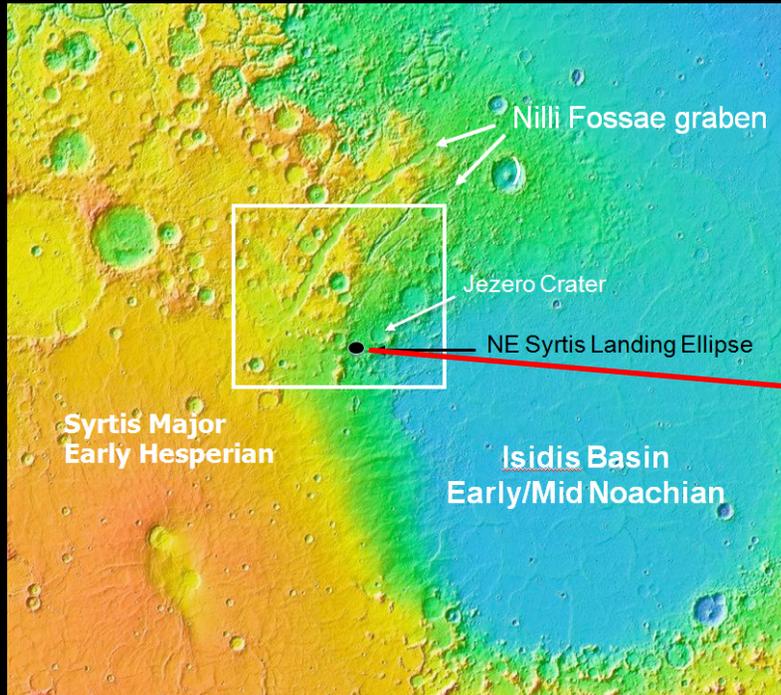


## E Margaritifer

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

# NE Syrtis Major - Science

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



## NE SYRTIS: Ellipse and Go-To Science

Cross the Noachian-Hesperian boundary and the transition from phyllosilicate/carbonate (alkaline) to sulfate (acidic)

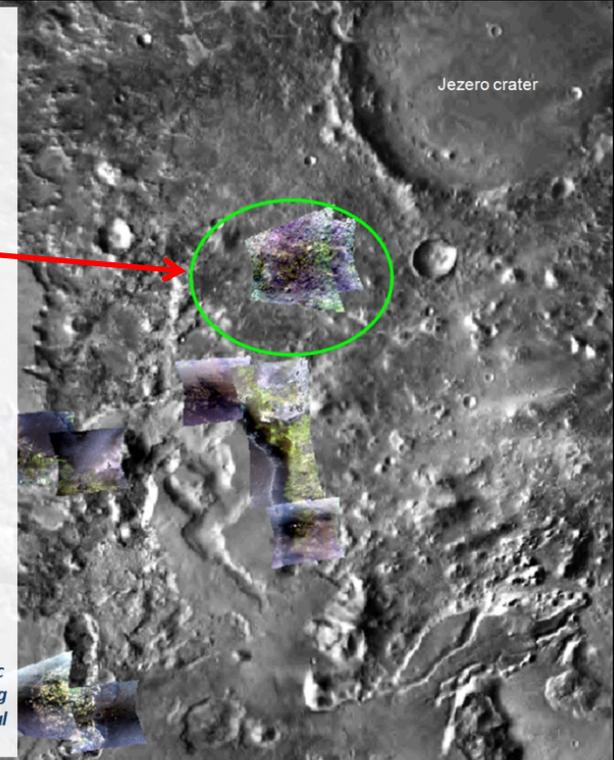
Investigate fluvial, hydrothermal, and volcano-ice interactions which present a number of diverse habitable environments on early Mars

Thick sedimentary sequence is accessible at the go-to site

In-ellipse science includes immediate investigation of Noachian alteration in breccias and of kaolinite and carbonate alteration with reactants and products in direct association; allows testing formation hypotheses, establishing aqueous geochemistry

Extended region includes four distinct aqueous environments with clear local stratigraphic relationships that fit within a regional stratigraphic and geologic framework

Fe/Mg smectite basement, kaolinite alteration, olivine-rich unit with serpentine and carbonate alteration, Hesperian volcanic flows emplaced on sediments and interacting with volatile-rich deposits with hydrothermal alteration and sulfate mineral deposition



- 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<sub>2</sub> 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 Theikian 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**

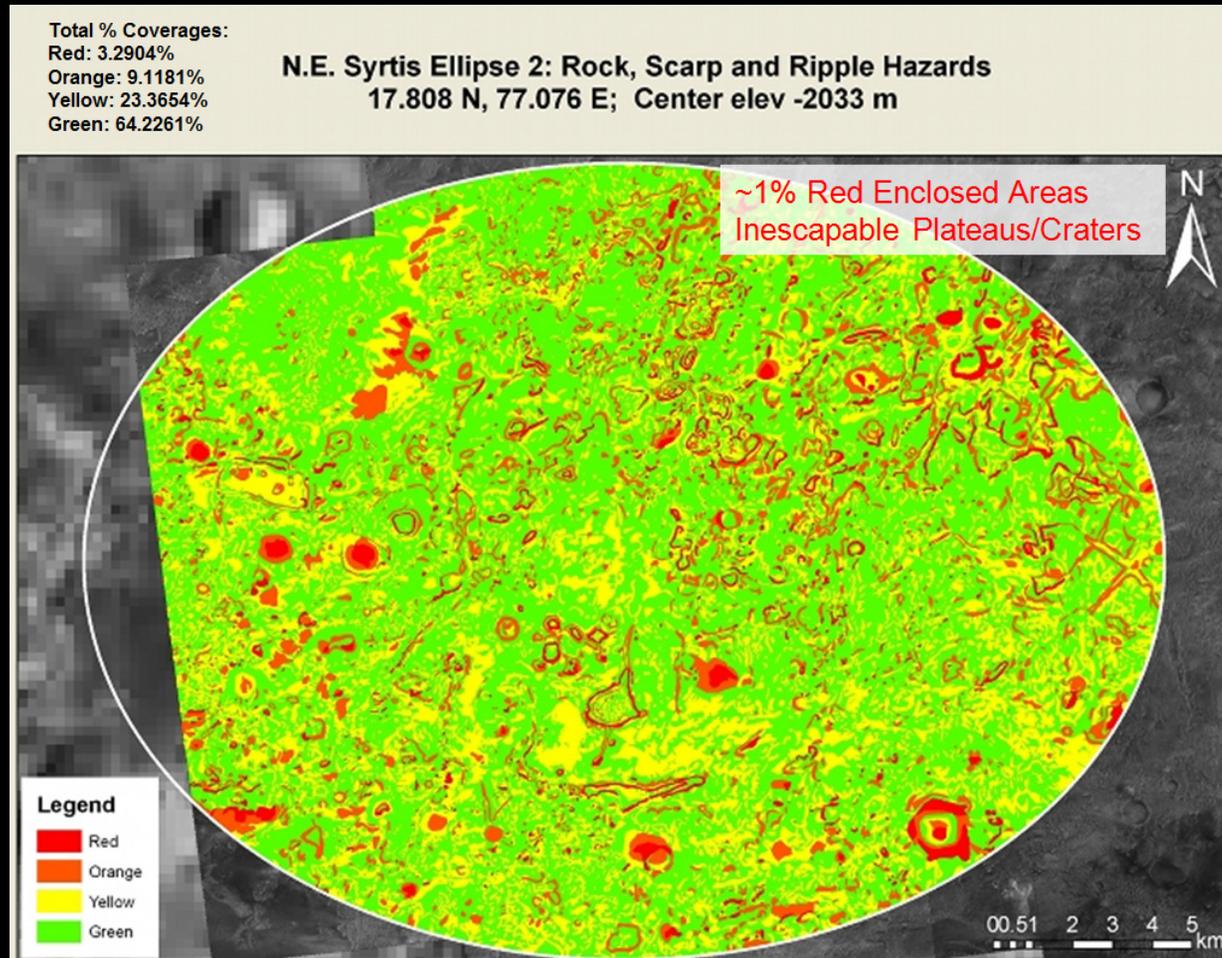
**See Next Slide from Golombek et al.**

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# NE Syrtis Major – Preliminary Characterization

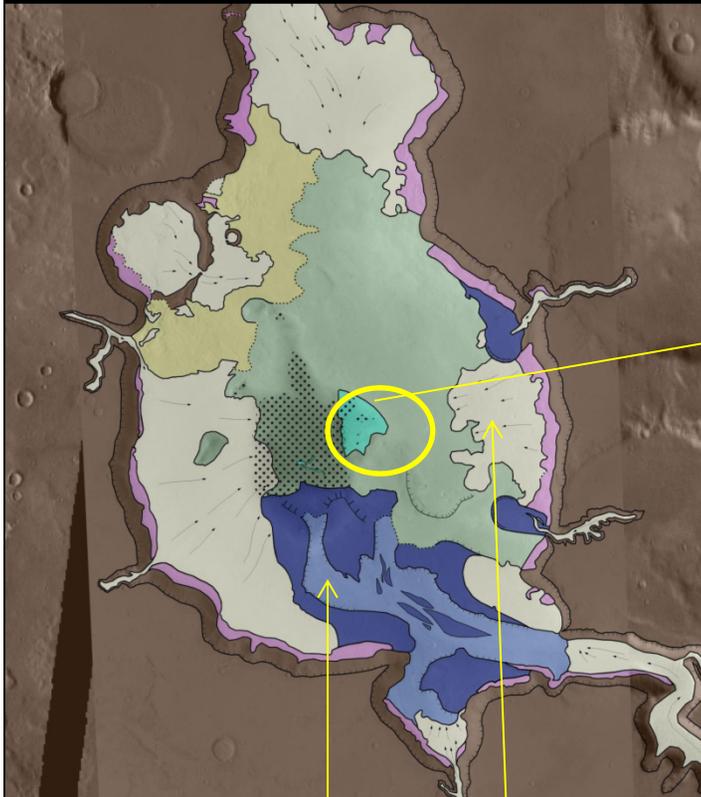
From Presentation by Golombek et al. 5/2010



## NE Syrtis

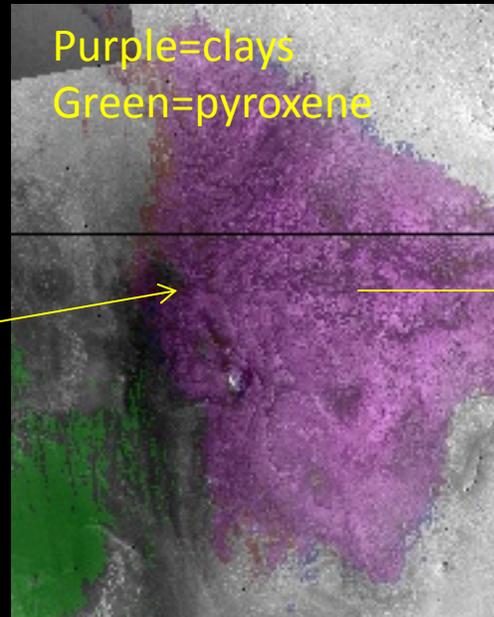
- Orange for 1 km Slopes ~4% Surface Exceeds Fuel Allocation for Terrain
- Orange for Scarps & Slopes
  - 3.3% Surface Poses Serious Landing Hazard – Engineering out Risk Highly Unlikely
  - 9.1% Surface Potential Landing Hazard- DEM's needed to Refine Hazard Assessment
  - In total: factor of 2-3+ more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

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



600 m thick  
delta deposits

Mid-latitude glacier



Purple=clays  
Green=pyroxene

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

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# Transition to Monica



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