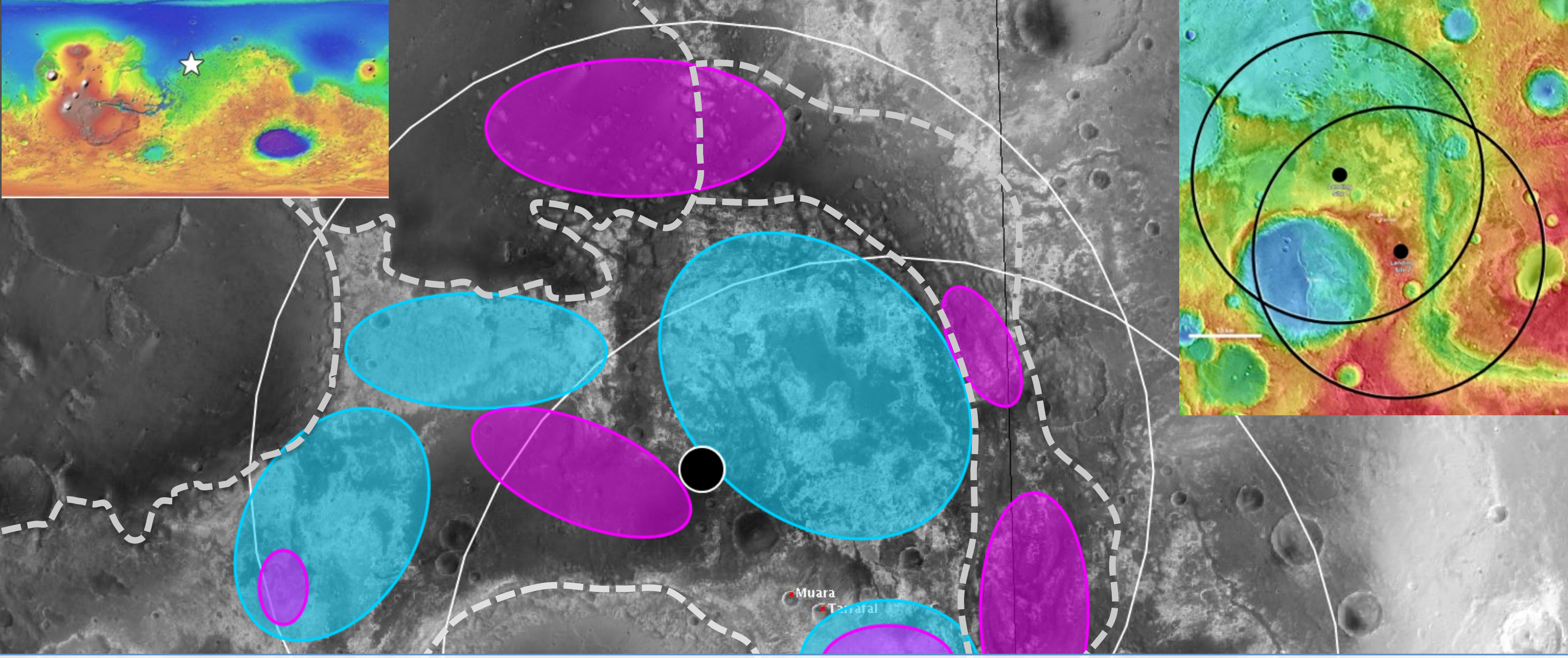

Habitable Noachian Environments and Abundant Resources in the Mawrth Vallis Exploration Zone

Abstract #1009, briony@purdue.edu

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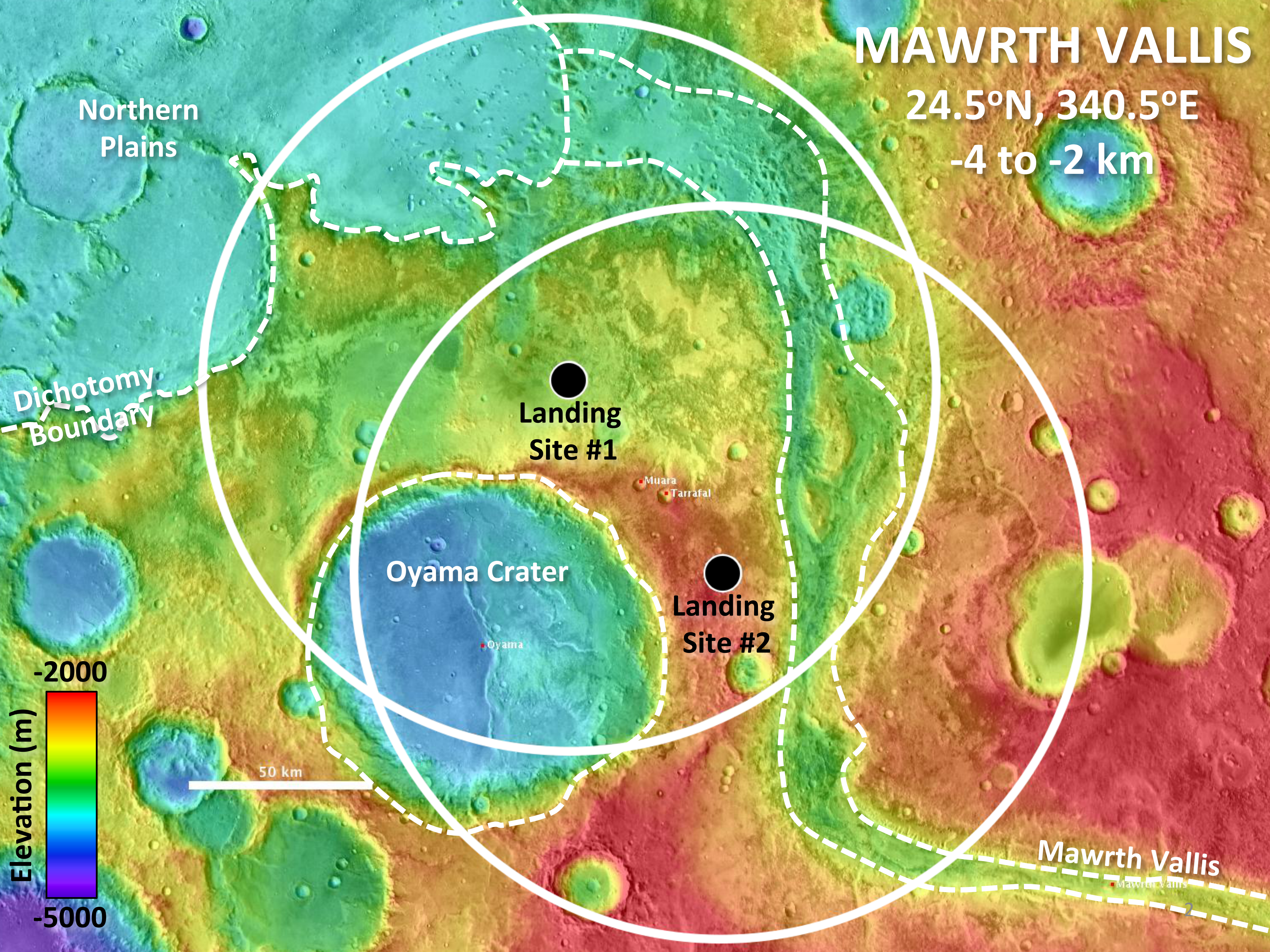
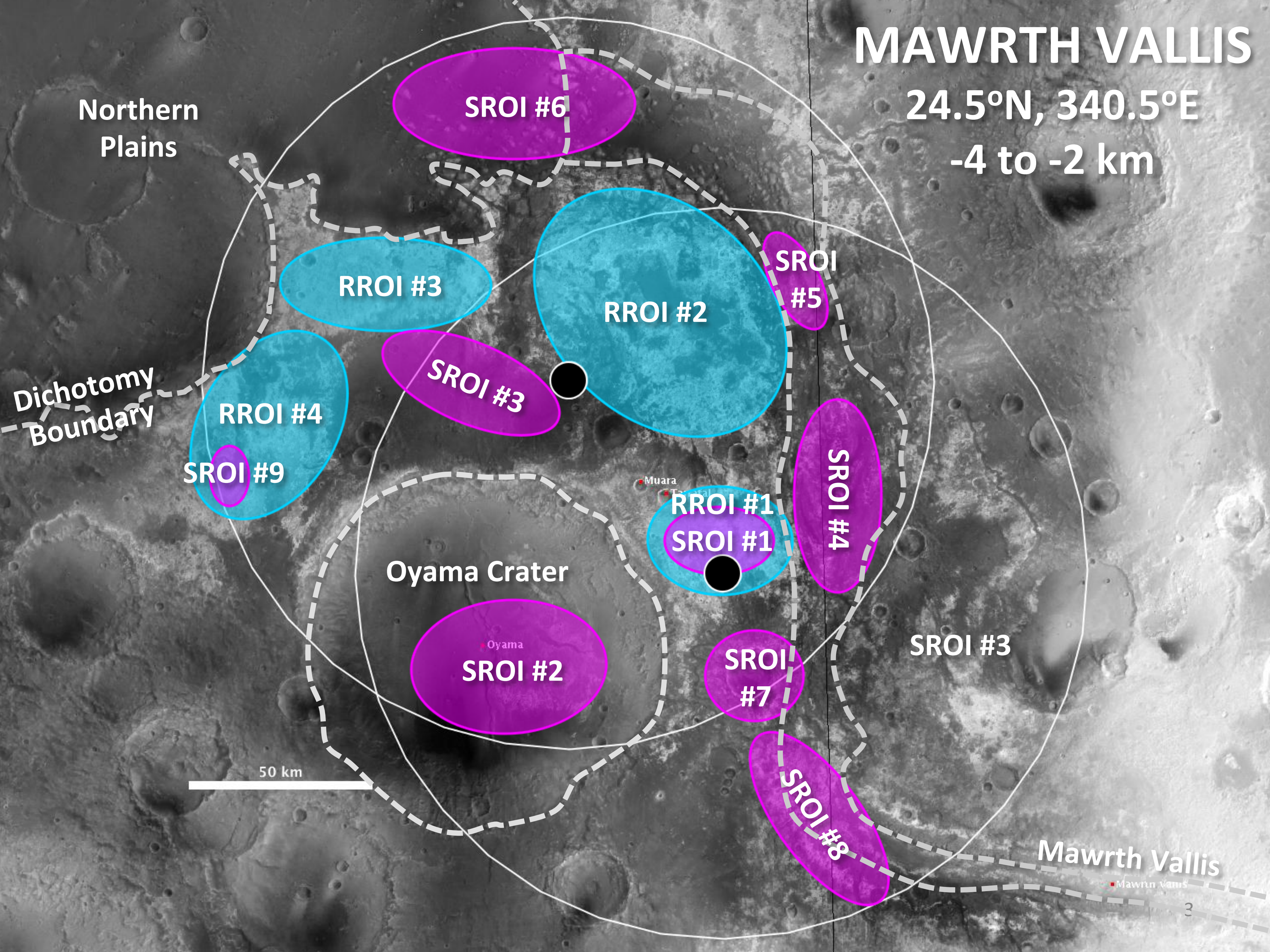

MAWRTH VALLIS
24.5ºN, 340.5ºE
-4 to -2 km
Northern Plains
Dichotomy Boundary
Landing Site #1
Muara
Tarrafal
Oyama Crater
Oyama
Landing Site #2
50 km
-2000
Elevation (m)
-5000
Mawrth Vallis
Mawrth Vallis


MAWRTH VALLIS
24.5°N, 340.5°E
-4 to -2 km
Northern Plains
SROI #6
RROI #3
RROI #2
SROI #5
SROI #3
Dichotomy Boundary
RROI #4
SROI #9
Muara
RROI #1
SROI #1
SROI #4
Oyama Crater
Oyama
SROI #2
SROI #7
SROI #3
50 km
SROI #8
Mawrth Vallis

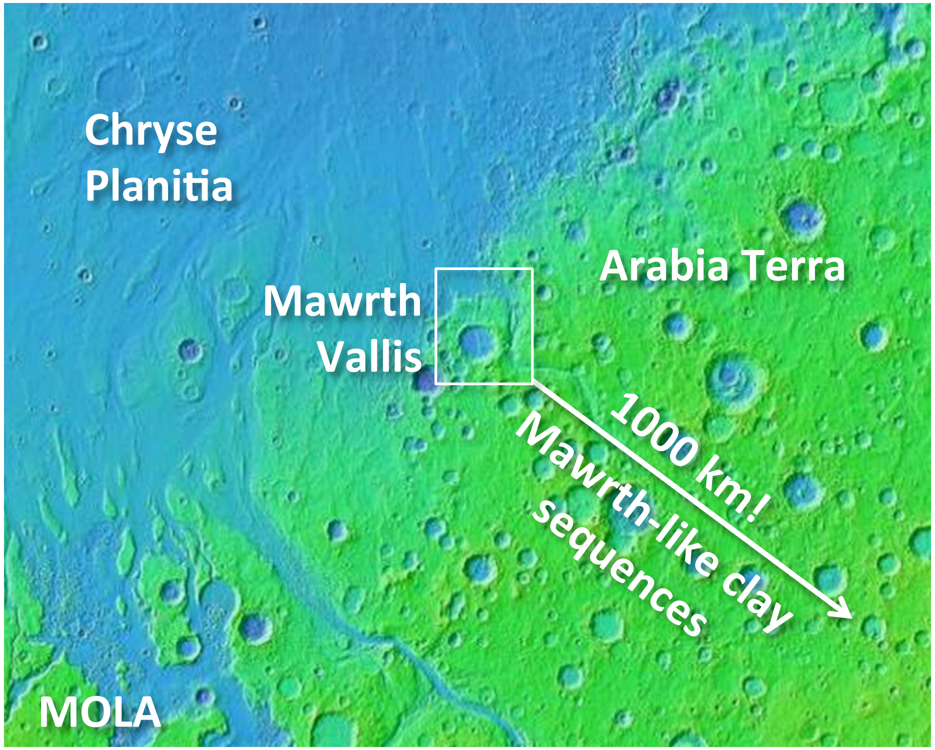
Mawrth Vallis: Value as an EZ

1. Mineralogically very diverse site recording a sequence of ancient habitable environments
2. Can sample both in place ancient altered Noachian deposits and remobilized sediments – source to sink!
3. Extremely ancient section probing an enigmatic epoch in Solar System history - sample sedimentary and volcanic rocks from the early Noachian through the late Hesperian
4. Several types of astrobiological targets, including clear locations of high preservation potential
5. Provides access to a Noachian outflow channel, the dichotomy boundary, and the northern plains
6. **Most abundant hydrated mineral resource on Mars**

Mawrth Vallis: Ancient Regional Clays

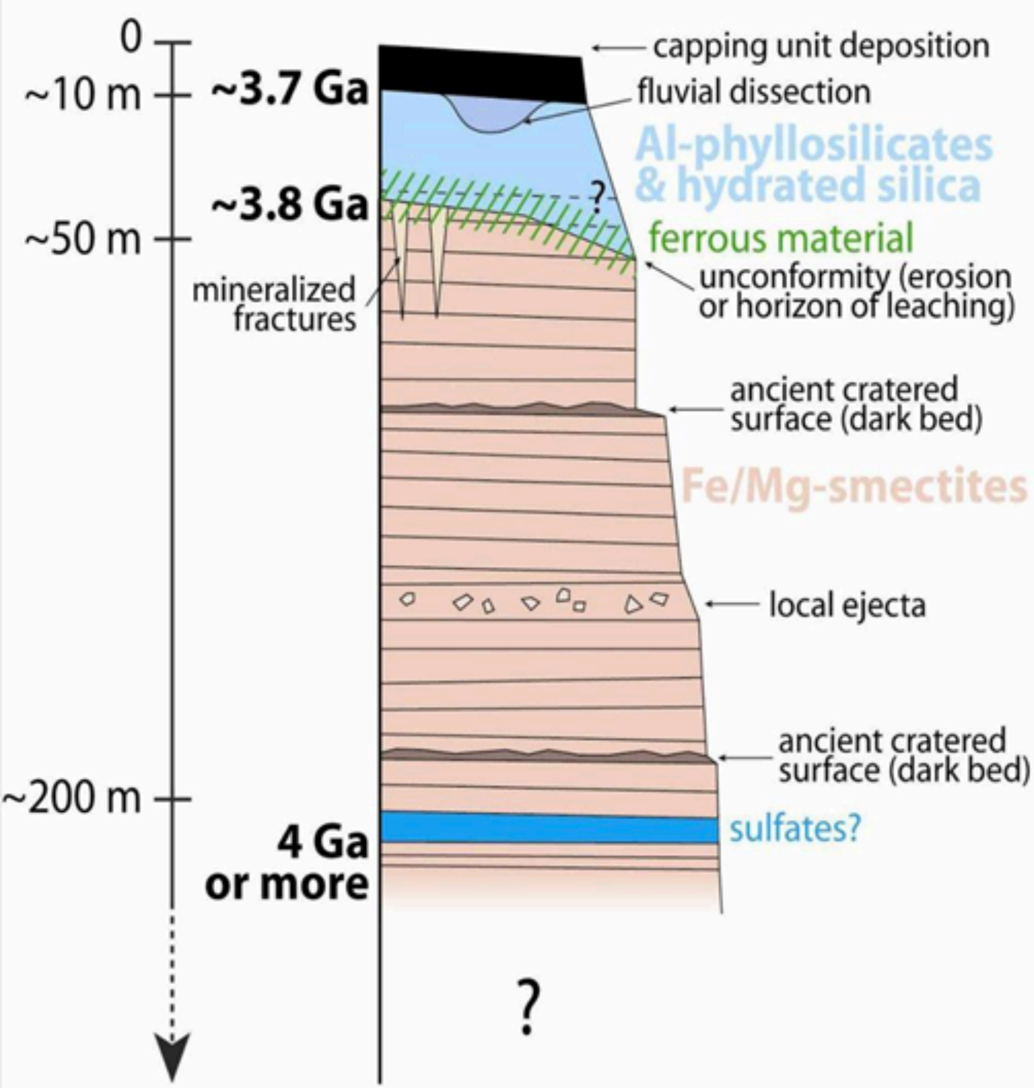
Light-toned surfaces: 200m thick clay sequence on plateau around MV

Mawrth is the best exposure of a clay-rich stratigraphy that covers a *huge* region



Noe Dobrea *et al.* (2010)

Mawrth Vallis: The Stratigraphy



- ~140 m of Fe/Mg smectites with interbedded cratered paleosurfaces, sand sheets, and sulfates
- Overlain by 20-40m of Al-clays + Al-sulfates + silica

Mawrth Vallis: The Story

- *Favored hypothesis:* Clays built up over time due to concurrent weathering and sedimentation - a paleosol sequence
- *Result:* High resolution climate record spanning the Noachian
- Each soil unit represents one surface environment, which would have included streams, ponds, etc. – highly habitable!

ANALOG: 500m thick, 10,000+ km^2 clay-rich paleosol sequence, Oregon

Science ROIs Rubric

1st EZ Workshop for Human Missions to Mars

Key	
●	Yes
○	Partial Support or Debated
	No
?	Indeterminate

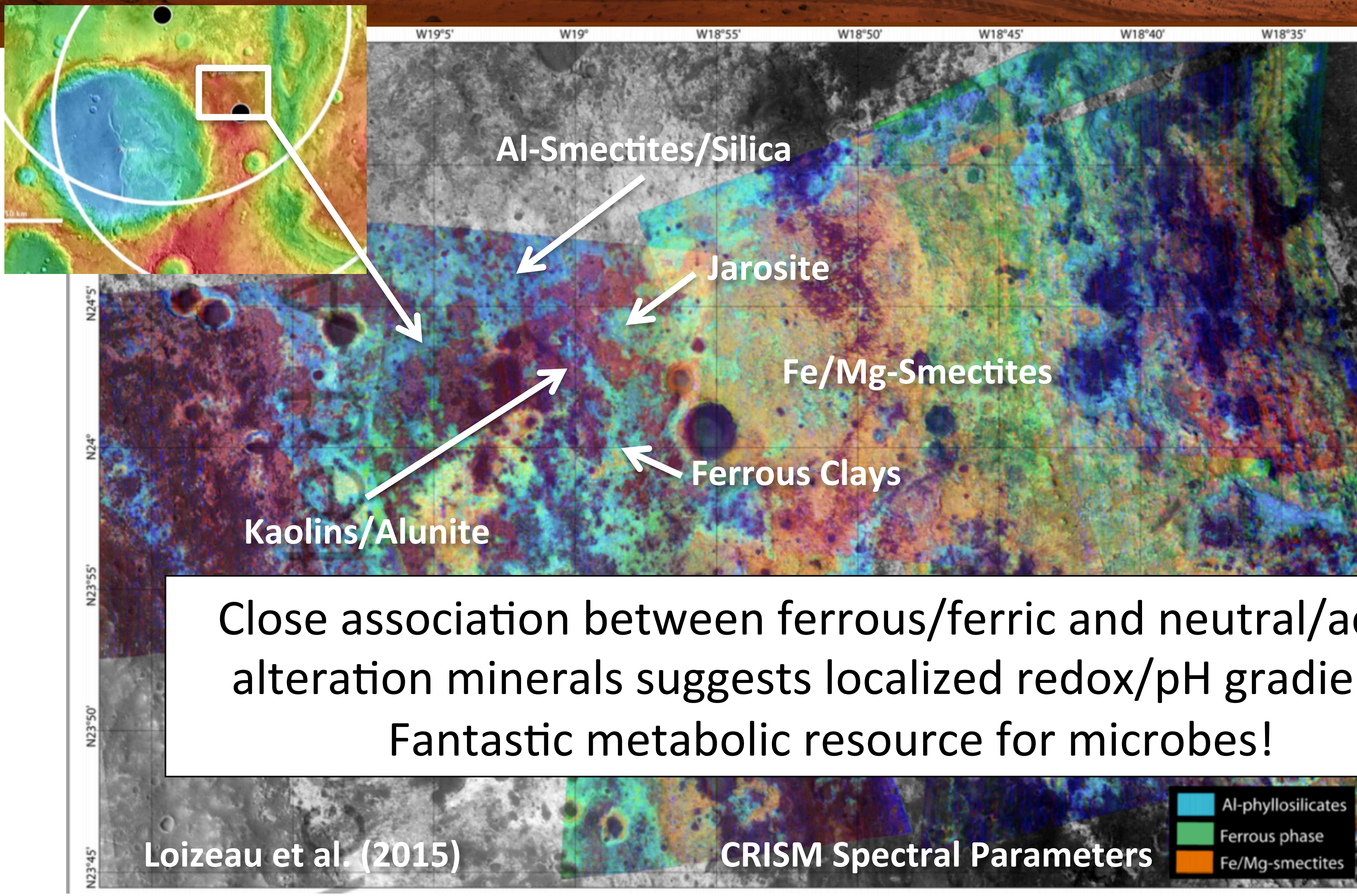
			Site Factors	SROI1/ RROI1	SROI2	SROI3	SROI4	SROI5	SROI6	SROI7	SROI8	SROI9/ RROI4	RROI2/3	EZ SUM
Science Site Criteria	Astrobio	Threshold (AND/OR)	**Potential for past habitability**	●	●		●	●	○		●	○	●	6,2
			Potential for present habitability/refugia											0,0
		Qualifying	Potential for organic matter, w/ surface exposure	●	●		○	○			○	●	●	4,3
	Atmospheric Science	Threshold	**Noachian/Hesperian rocks w/ trapped atmospheric gases**	●	●	●				●			●	5,0
		Qualifying	Meteorological diversity in space and time	●		●			●	●		●	●	6,0
			High likelihood of surface-atmosphere exchange	●		●			●	●	○	●	●	6,1
			Amazonian subsurface or high-latitude ice or sediment											0,0
			High likelihood of active trace gas sources											0,0
	Geoscience	Threshold	**Range of martian geologic time; datable surfaces**	○	●	●			○			○	○	2,4
			Evidence of aqueous processes	●	●		●	●			●	●	●	7,0
			Potential for interpreting relative ages	●	●	●			●		●	●	●	7,0
		Qualifying	Igneous Rocks tied to 1+ provinces or different times	○	●	○						○	○	1,4
			Near-surface ice, glacial or permafrost											0,0
			Noachian or pre-Noachian bedrock units	●				●		●		●	●	5,0
			Outcrops with remnant magnetization	○								○	○	0,3
			Primary, secondary, and basin-forming impact deposits	●	●	●		●	●	●	●	●	●	9.0
			Structural features with regional or global context		●		●		●					3,0
			Diversity of aeolian sediments and/or landforms	●	●	●	●	●	●			●	●	8,0

Resource ROIs Rubric

Key	
●	Yes
○	Partial Support or Debated
	No
?	Indeterminate

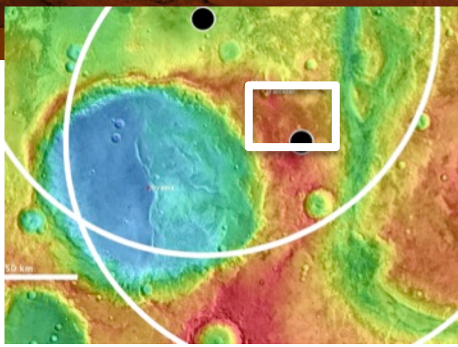
Criteria	Area	Type	Site Factors	SROI1/RROI1	SROI2	SROI3	SROI4	SROI5	SROI6	SROI7	SROI8	SROI9/RROI4	RROI2/3	EZ SUM
ISRU and Civil Engineering Criteria	Engineering		Meets First Order Criteria (Latitude, Elevation, Thermal Inertia)	●	●	●	●	●	●	●	●	●	●	10,0
	Water Resource	**Threshold**	AND/OR: **Potential for ice or ice/regolith mix**											
			AND/OR: **Potential for hydrated minerals**	●	●						●	●	●	5,0
			Quantity for substantial production	●	●						●	●	●	5,0
			Potential to be minable by highly automated systems	●	●						●	●	●	5,0
			Located less than 3 km from processing equipment site	●									●	2,0
			Located no more than 3 meters below the surface	●	●						●	●	●	5,0
			Accessible by automated systems	●	●						●	●	●	5,0
		Qualifying	Potential for multiple sources of ice, ice/regolith mix **and** hydrated minerals											0,0
			Distance to resource location can be >5 km											0,0
			Route to resource location must be (plausibly) traversable	●								●	●	3,0
	Civil Engineering	**Threshold**	**~50 sq km region of flat and stable terrain with sparse rock distribution**	●	○							○	○	1,3
			1–10 km length scale: <10°	●	○							○	○	1,3
			Located within 5 km of landing site location	●									●	2,0
		Qualifying	Located in the northern hemisphere	●	●	●	●	●	●	●	●	●	●	10,0
			Evidence of abundant cobble sized or smaller rocks and bulk, loose regolith	○	○						○	○	○	5,0
			Utilitarian terrain features											0,0
	Food Production	Qualifying	Low latitude	●	●	●	●	●	●	●	●	●	●	10,0
			No local terrain feature(s) that could shadow light collection facilities	●	●	●	●	●	●	●	●	●	●	10,0
			Access to water											0,0
			Access to dark, minimally altered basaltic sands	●	●	●			●	●	●	●	●	8,0
	Metal/Silicon Resource	**Threshold**	**Potential for metal/silicon**	●	●						●	●	●	5,0
			Potential to be minable by highly automated systems	●	●						●	●	●	5,0
			Located less than 3 km from processing equipment site	●									●	2,0
			Located no more than 3 meters below the surface	●	●						●	●	●	5,0
			Accessible by automated systems	●	●						●	●	●	5,0
		Qualifying	Potential for multiple sources of metals/silicon	●	●						●	●	●	5,0
			Distance to resource location can be >5 km											0,0
			Route to resource location must be (plausibly) traversable	●								●	●	3,0

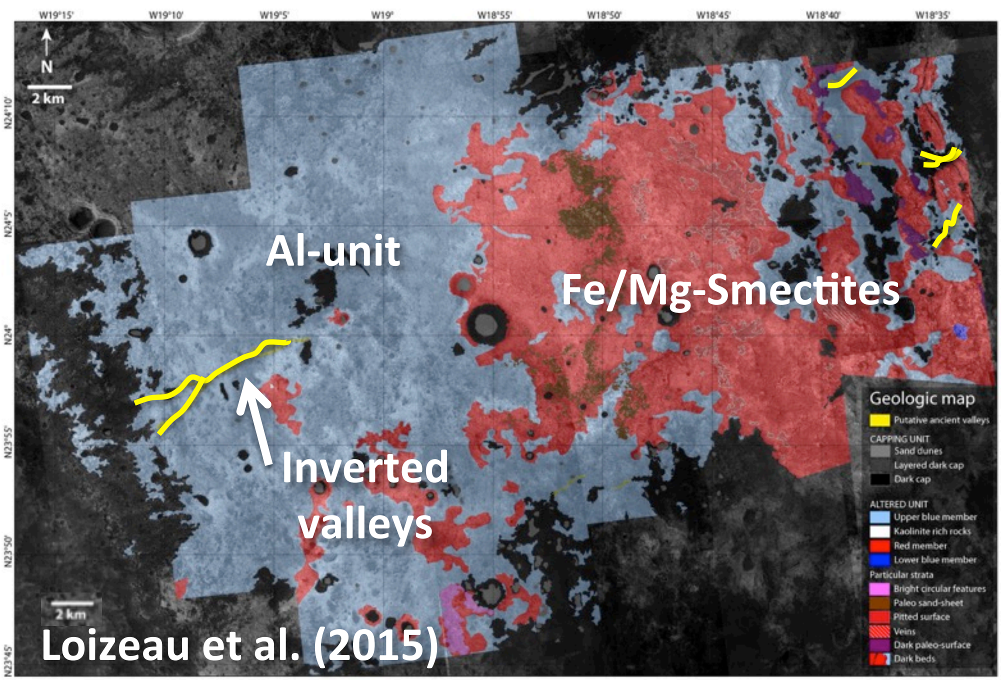
Science ROI 1: Clay Sequence



Close association between ferrous/ferric and neutral/acidic alteration minerals suggests localized redox/pH gradients. Fantastic metabolic resource for microbes!

Science ROI 1: Clay Sequence

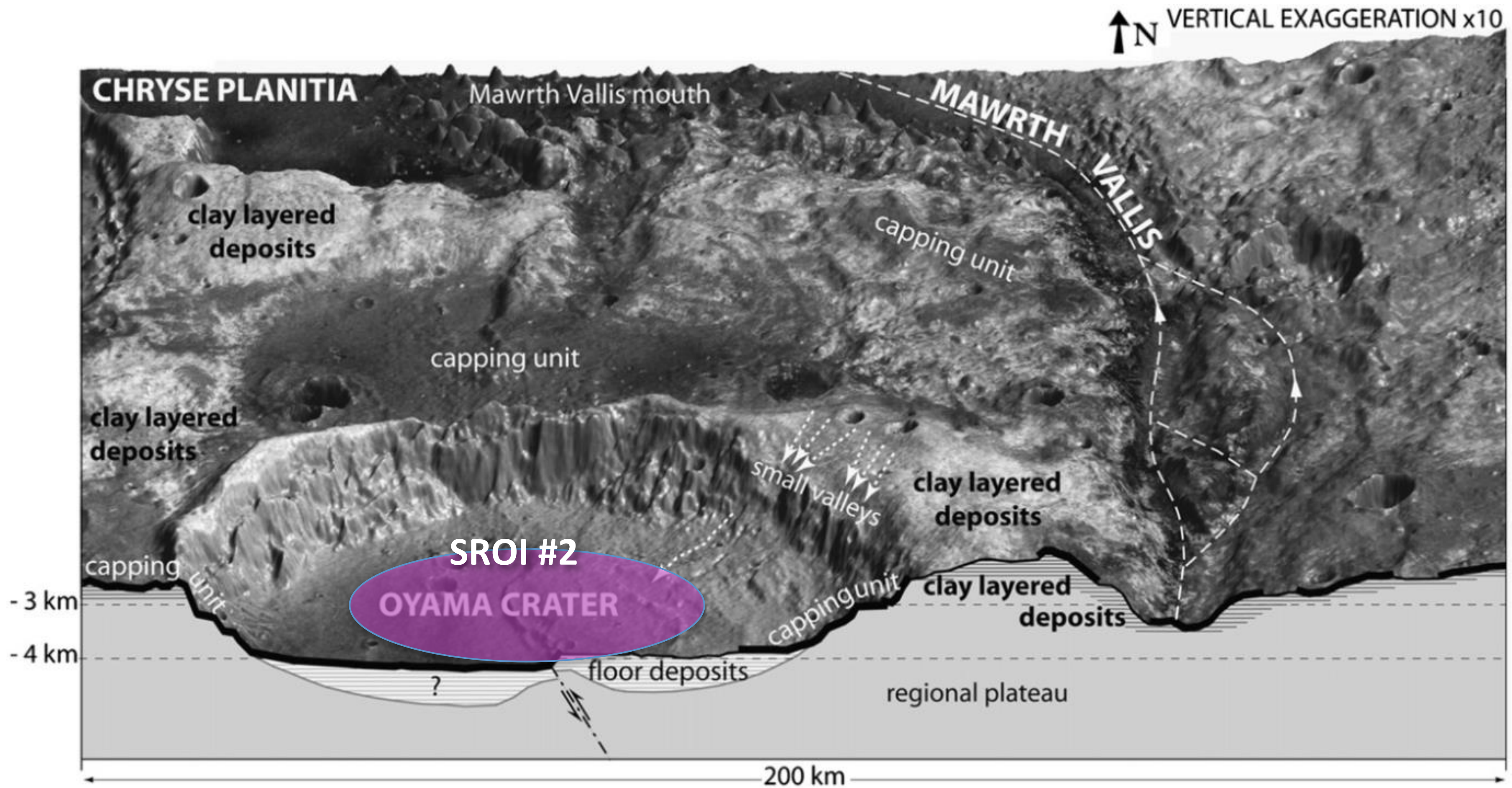




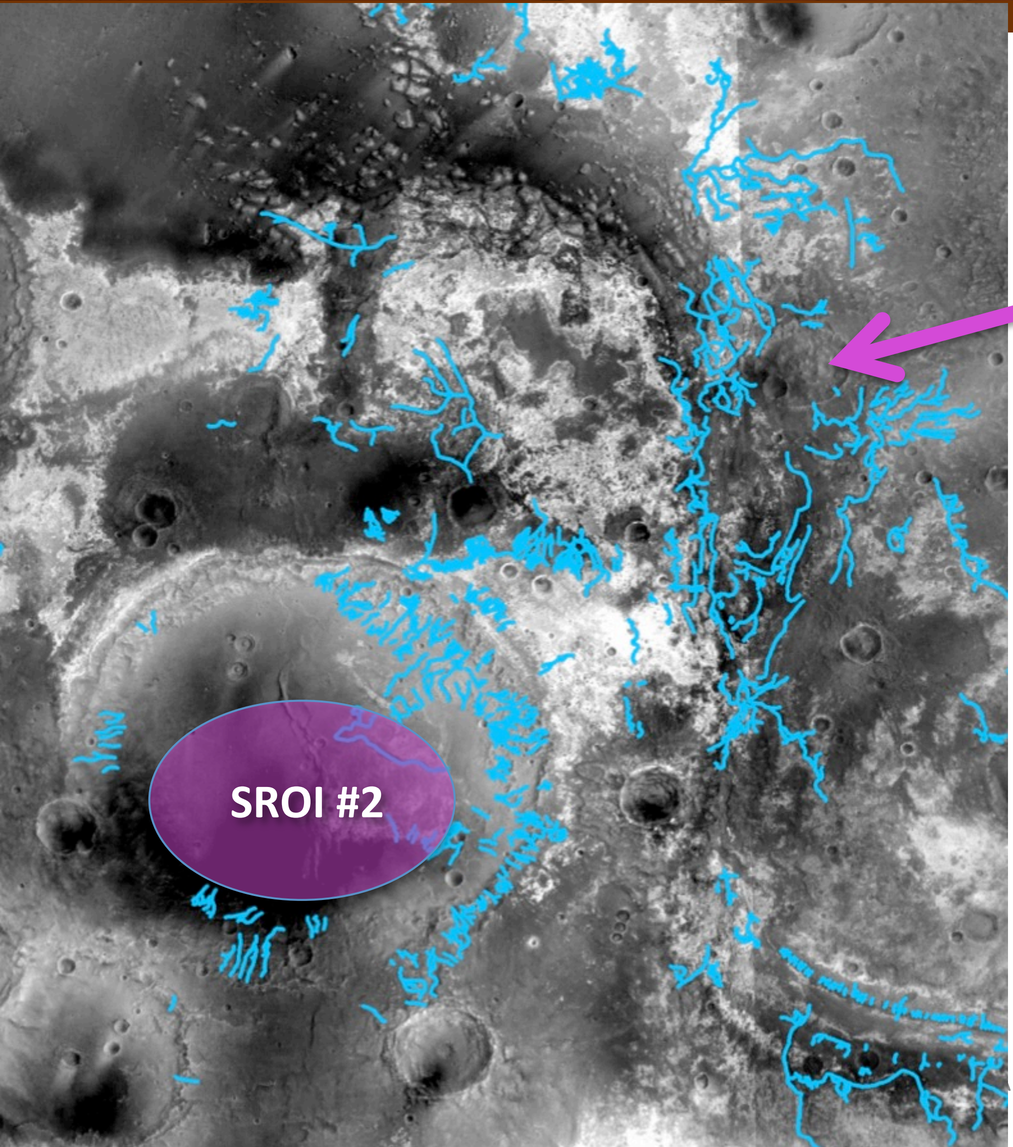
- M2020/MSL ellipse area
- Access to full clay sequence, redox gradients
- Possible paleosol climate/ environmental record spanning the Noachian
- High preservation potential for organics in reducing environments
- Other targets: inverted valleys, halo-bonded fractures, regional capping unit

Location: 341.0E, 24.1N

Science ROI 2: Oyama Crater



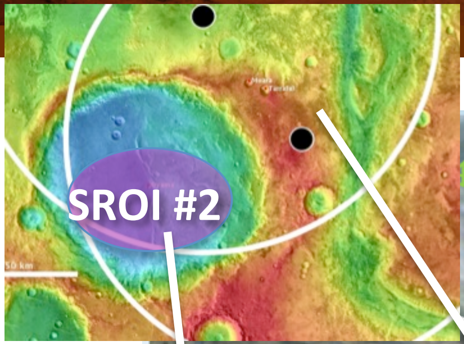
Science ROI 2: Oyama Crater

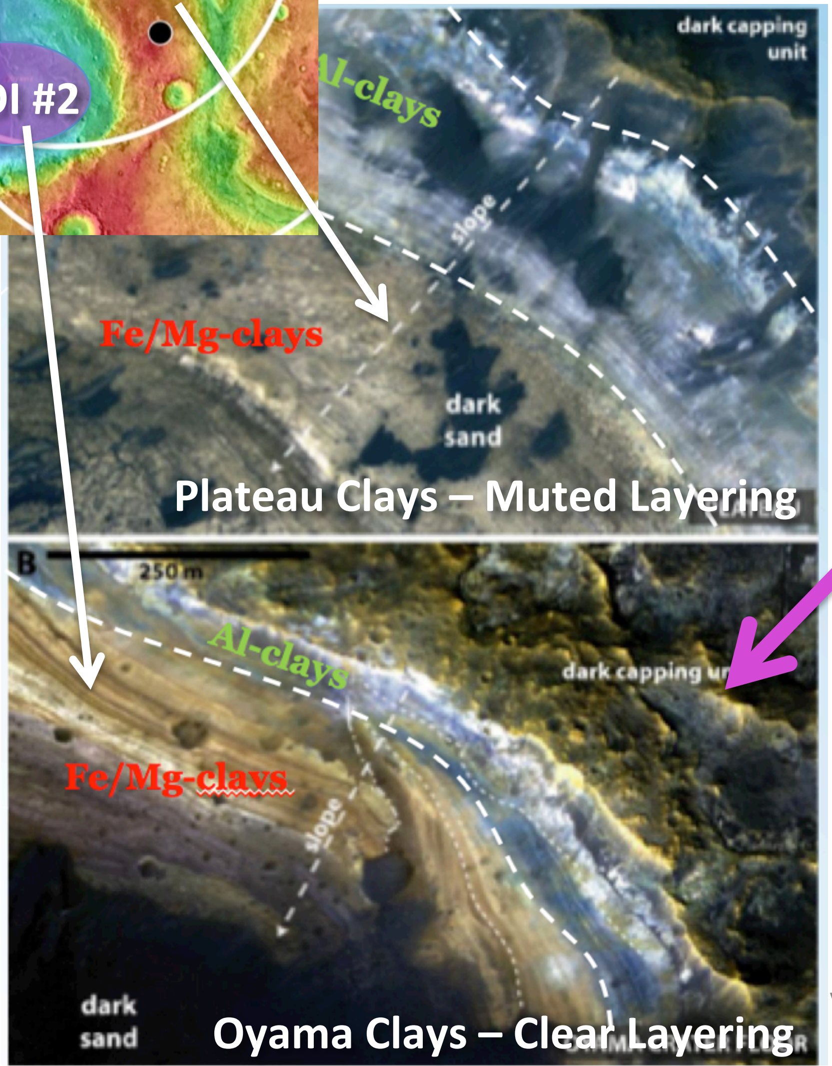


- Valleys incised into crater wall/floor are part of larger late Noachian terminal fluvial network
- Finely layered clay-rich alluvial/fluvial/ lacustrine(?) sediments
- Datable early Hesperian crater floor lavas
- Regional wrinkle ridge would provide insight into global tectonic processes

Location: 339.7E, 23.4N

Science ROI 2: Oyama Crater





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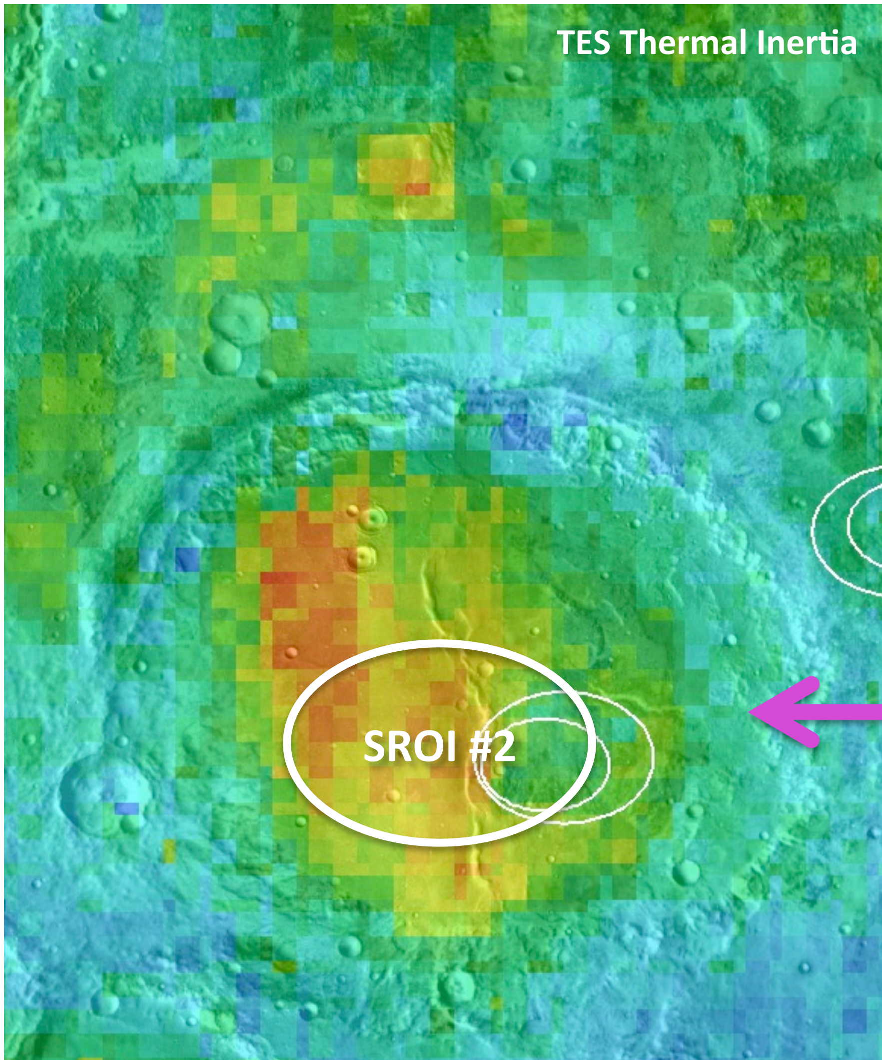
- Datable early Hesperian crater floor lavas
- Regional wrinkle ridge would provide insight into global tectonic processes

VALLIS

Location: 339.7E, 23.4N

Science ROI 2: Oyama Crater



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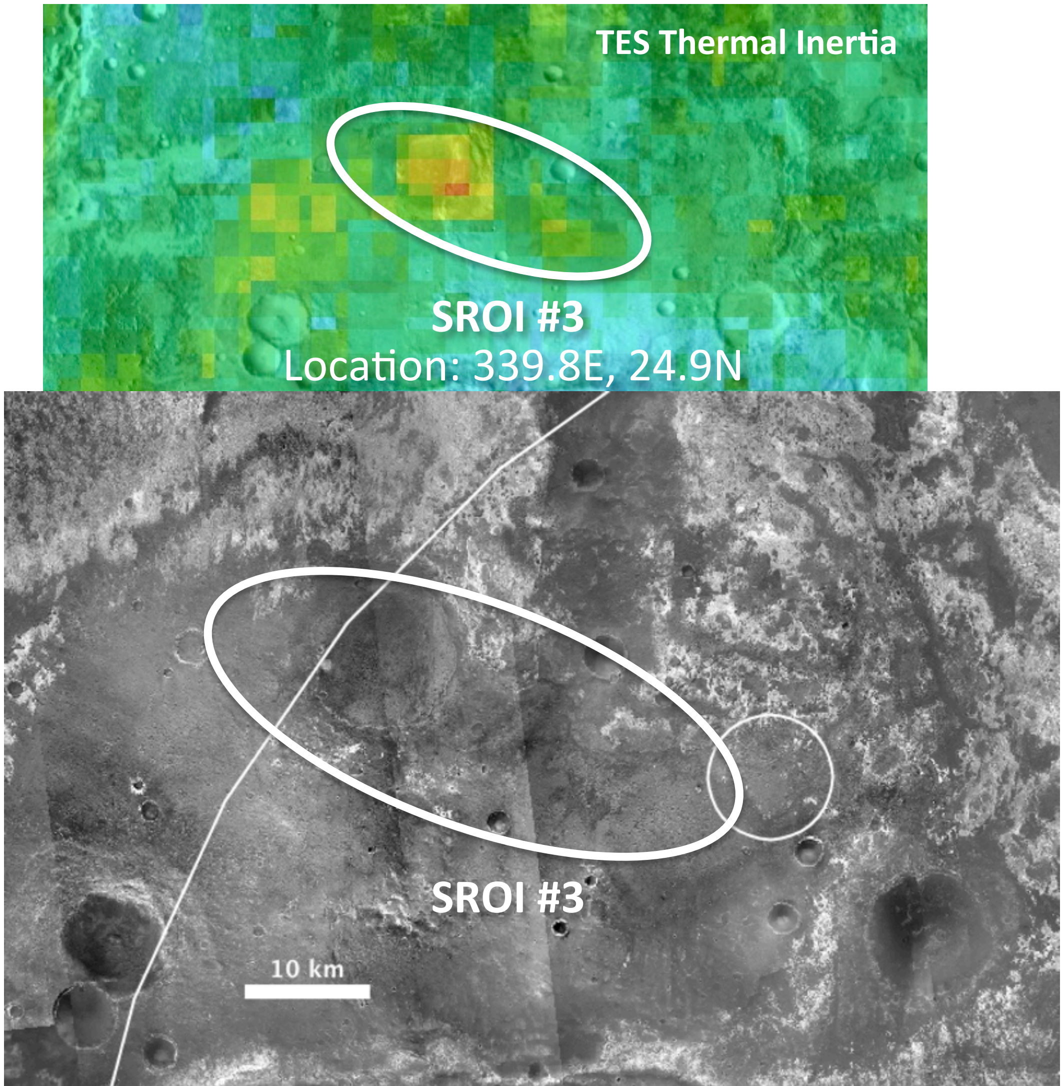
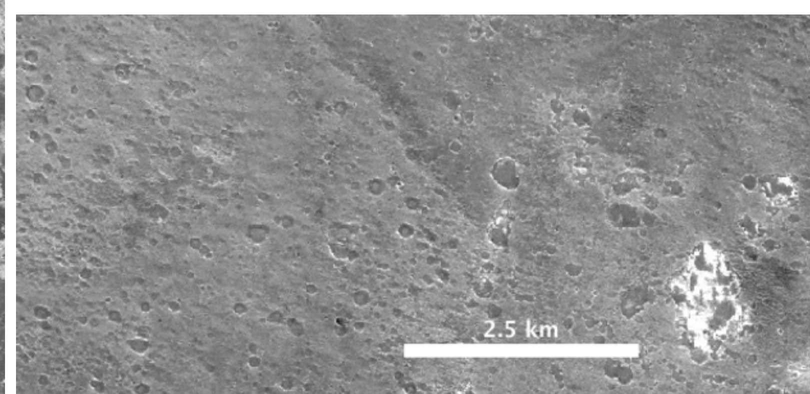
- Finely layered clay-rich alluvial/fluvial/lacustrine(?) sediments
- Datable early Hesperian crater floor lavas
- Regional wrinkle ridge would provide insight into global tectonic processes

Location: 339.7E, 23.4N

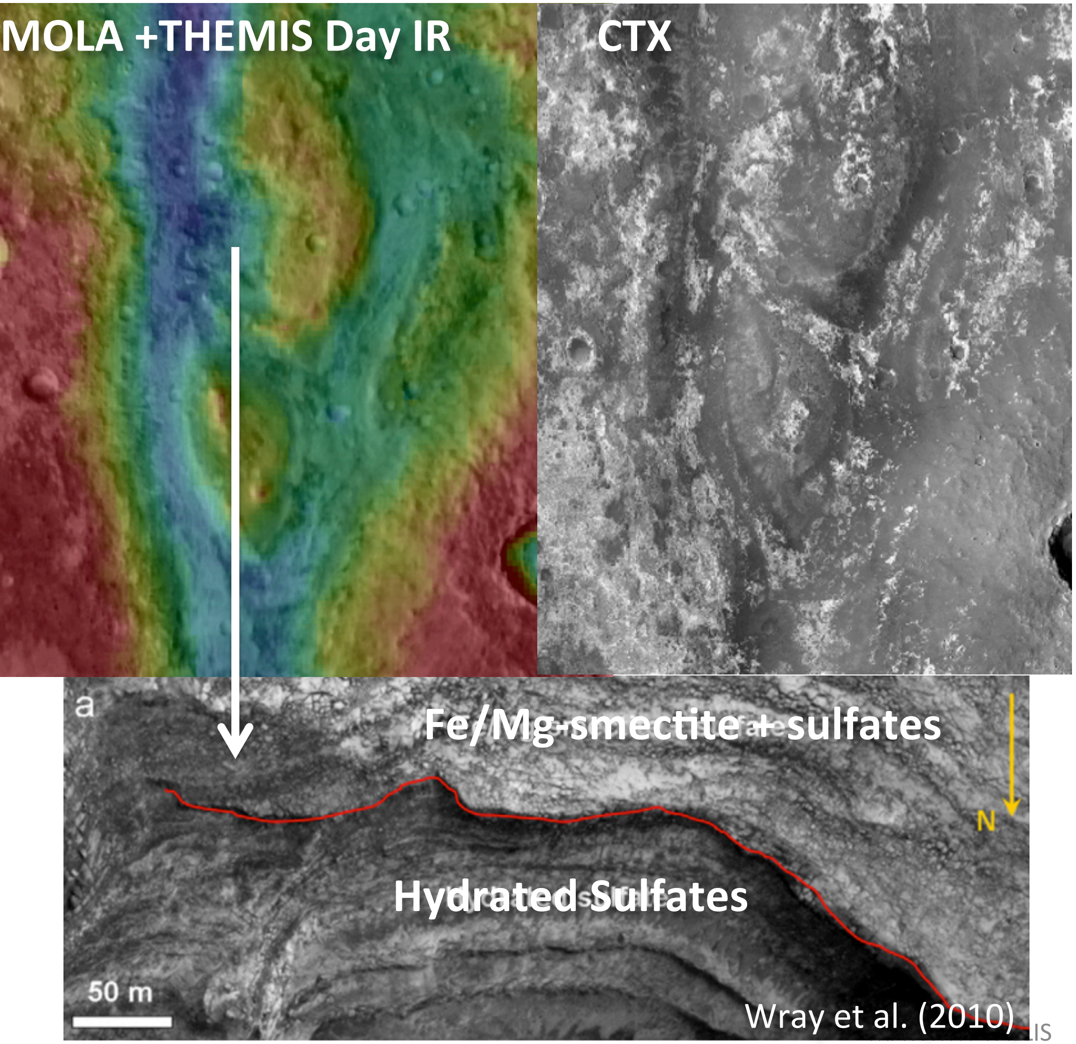
Science ROI 3: Regional capping unit



- Second datable unit
- *Regional* pyroxene-bearing capping unit, heavily cratered
- Well-dated to late Noachian
- Major sand source
- Likely pyroclastic



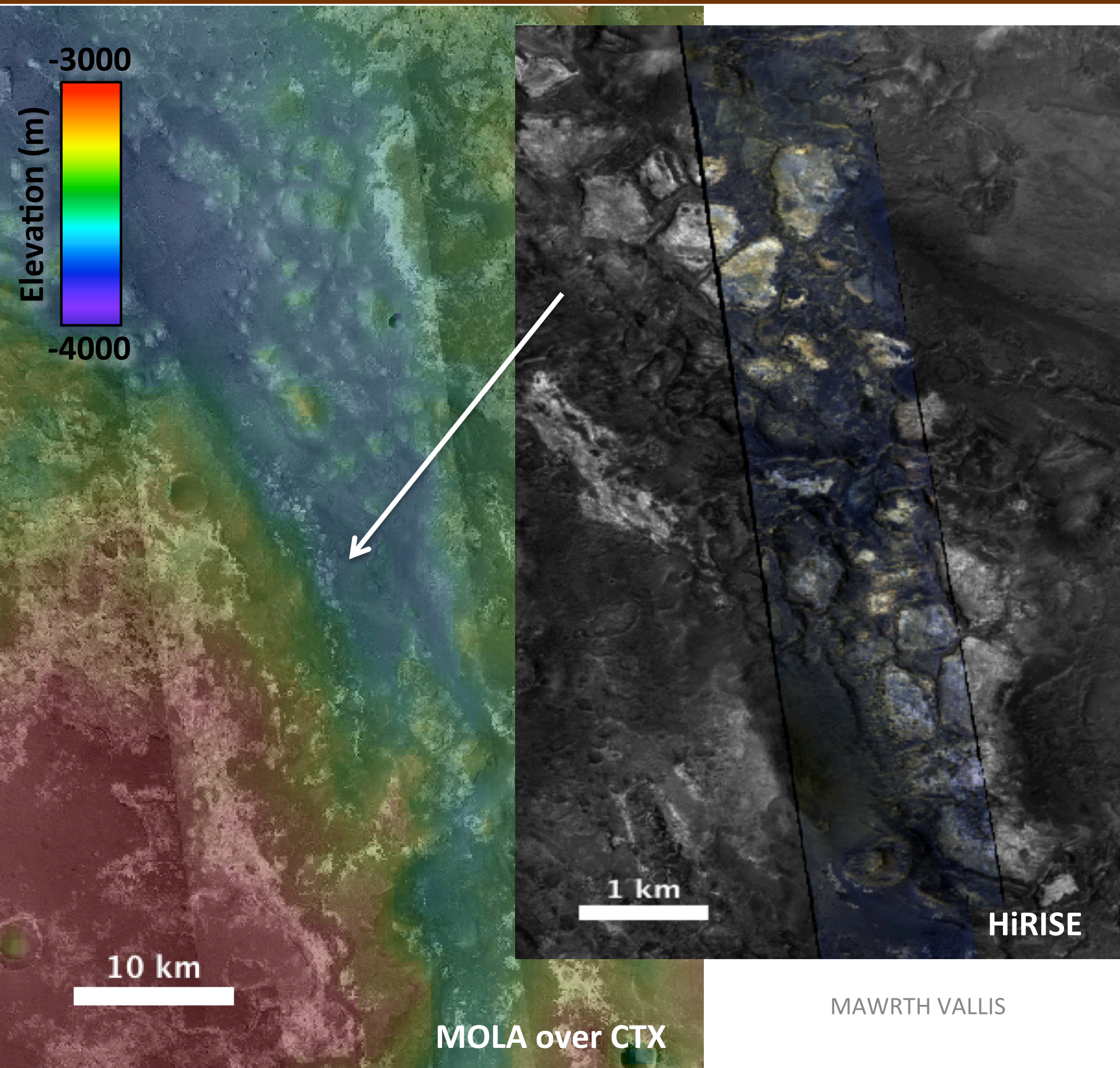
Science ROI 4: Mawrth Vallis islands



- Explore a Noachian outflow channel
- Streamlined islands may preserve flood sediments
- Determine relationship between MV incision and clay formation
- Sulfate deposits could preserve biosignatures, help understand groundwater flow on Mars

Location: 341.5E, 24.5N

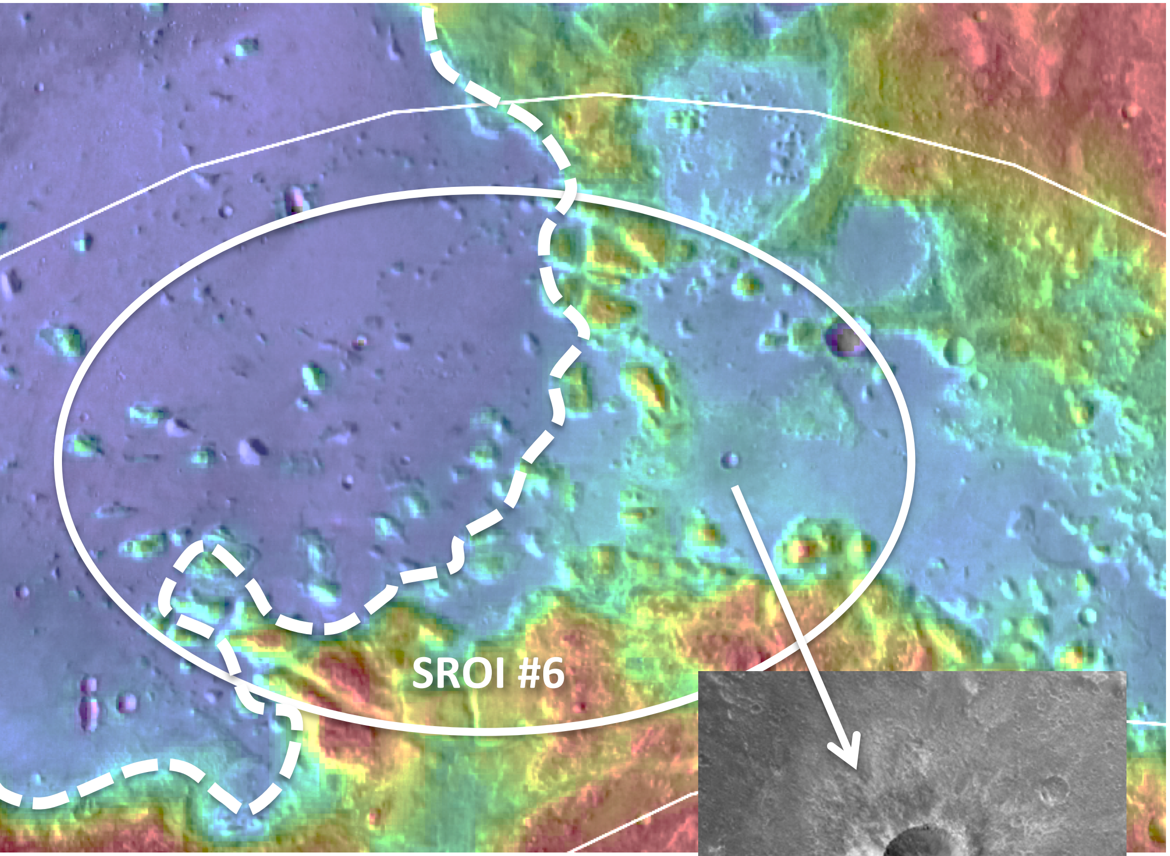
Science ROI 5: Mawrth Vallis floor

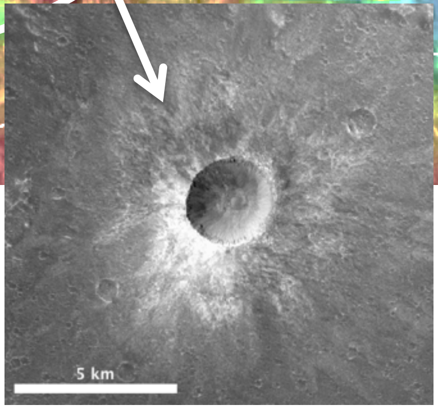


- Flood-scoured basement materials
- Megablocks with filled fractures
- Possible deep crust exposure, megabreccia, or flood deposit?
- Provide samples of different parts of crust, insight into crustal formation processes

Location: 341.3E, 25.4N

Science ROI 6: Northern Plains

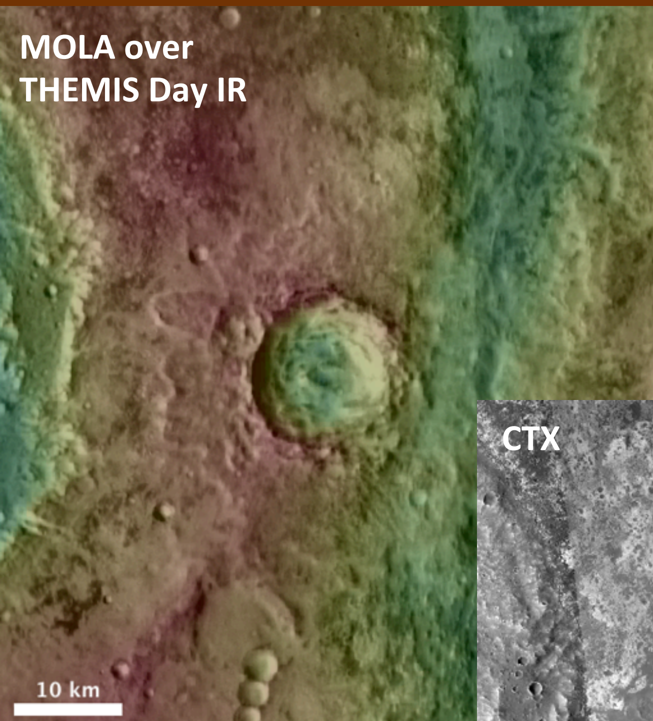


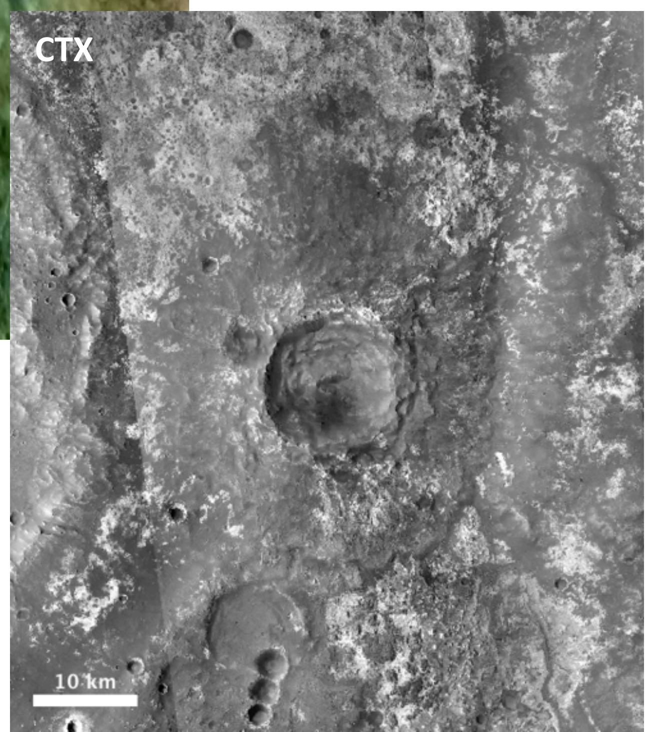


- MV provides access into N plains, can access Late Hesperian transitional unit that skirts dichotomy
- Fresh crater provides access to MV subsurface
- Origin of this unit is unclear, could provide a dateable surface

Location: 340.2E, 26.0N

Science ROI 7: Recent large crater

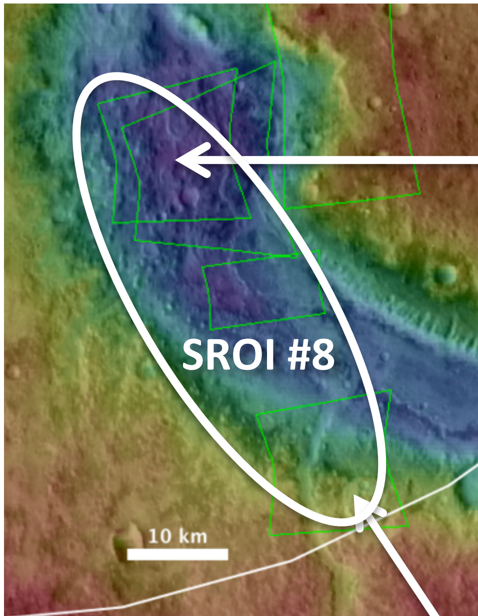


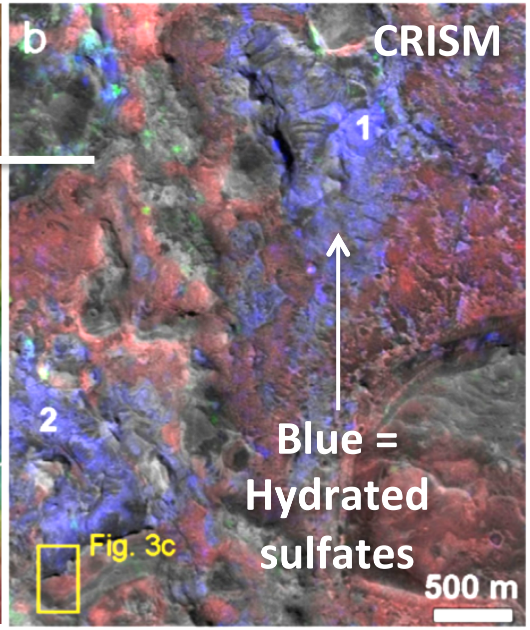


- 13 km diameter impact crater on the flank of Mawrth Vallis
- Terraces, preserved lobate ejecta blanket
- Provides access to deep plateau material
- Possible source for loose clay-rich regolith if needed for ISRU?

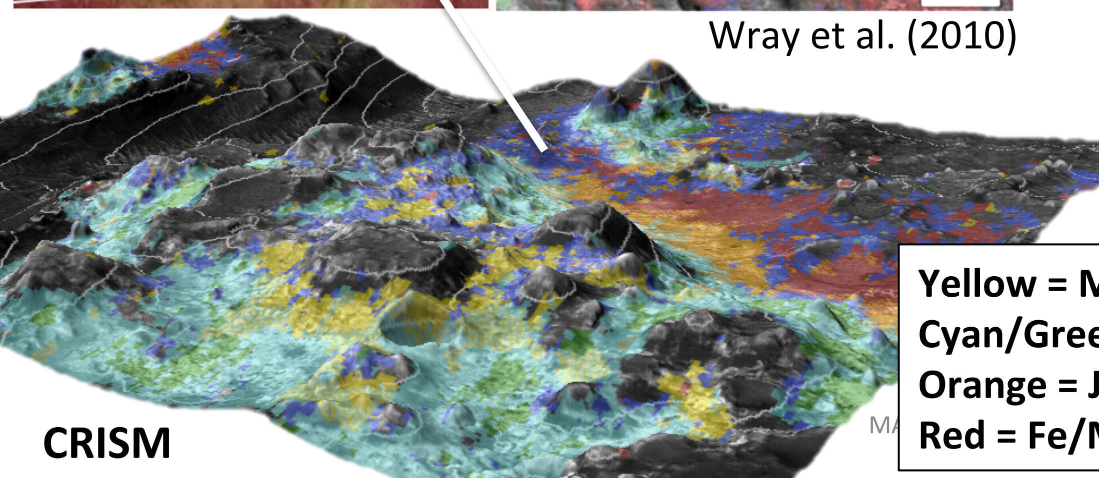
Location: 341.2E, 23.4N

Science ROI 8: Diverse Clays/Sulfates





Wray et al. (2010)

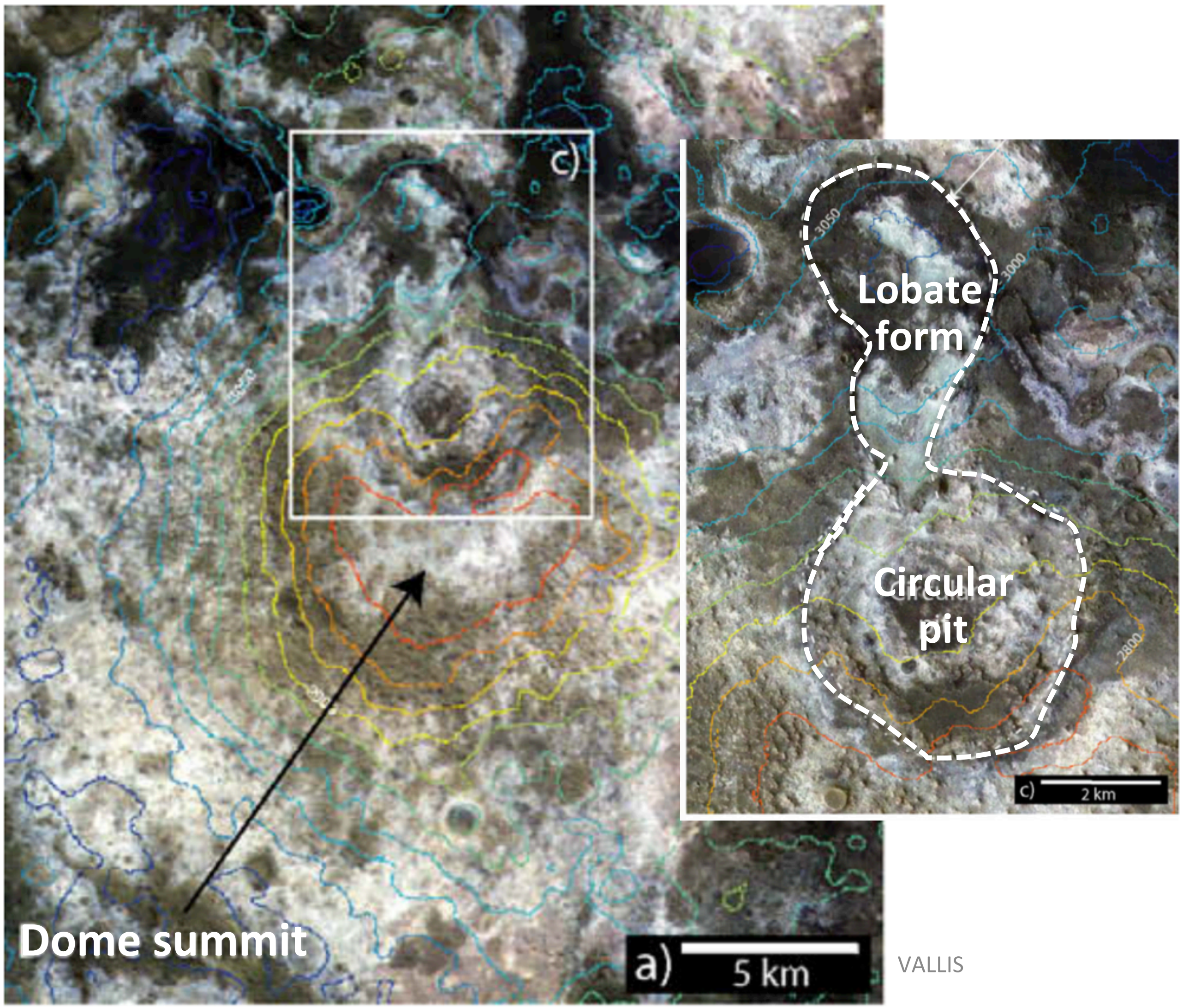


Yellow = Mg-smectites
Cyan/Green = Al-unit
Orange = Jarosite/ATS
Red = Fe/Mg-smectites

- Mg-rich smectite deposits on top of MV sequence on MV rim, could be lacustrine
- Close to large jarosite deposit, alunite detections
- Sulfate sediments on flank and within MV, perhaps due to runoff or groundwater evaporation

Location: 341.5E, 22.7N

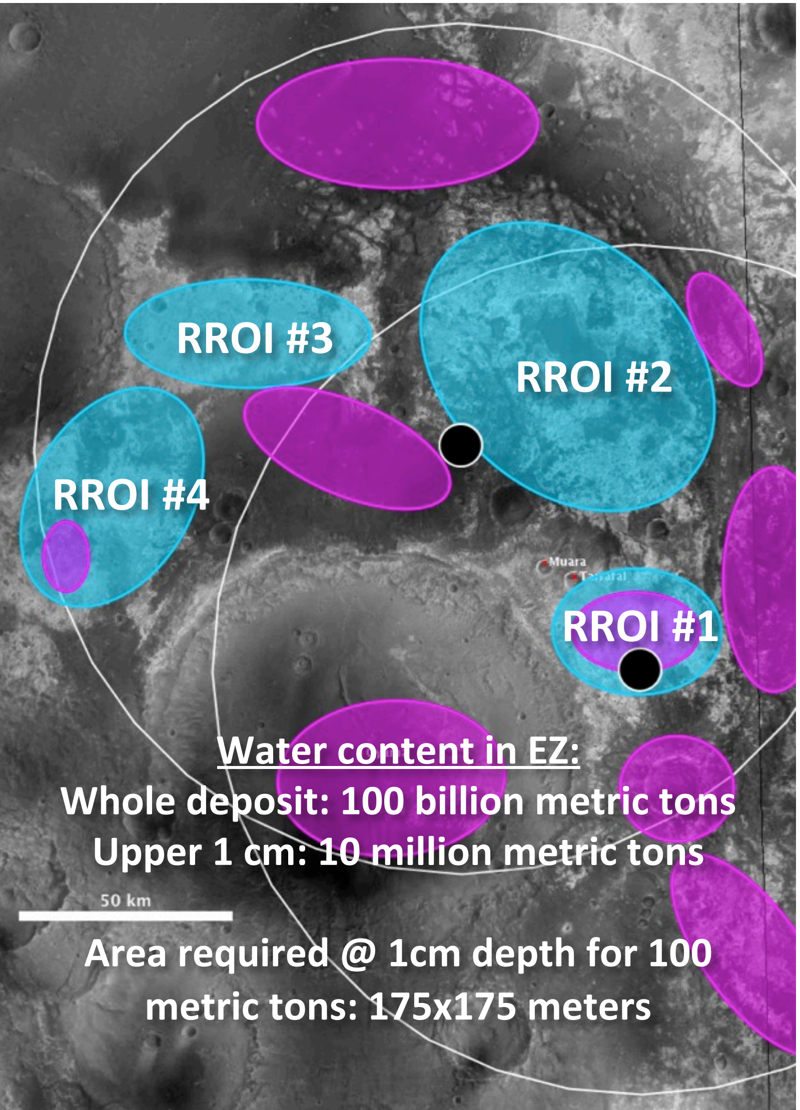
Science ROI 9: Possible mud volcano



- Odd morphology of this ~500m high edifice could be consistent with mud volcano
- Would provide access to sediments sourced from depth

Location: 338.6E, 24.2N

Resource ROIs: Unlimited Clays!



- Biggest exposed hydrated mineral deposit on Mars
- VNIR *and* mid-IR spectral models suggest clay abundances of >50 wt.%
- Add in other hydrated phases for **>75 wt.%** in lower unit!
- Likely water abundance: **7-9 wt.%** (lab + spectral modeling)
- Also excellent Fe/Al/Si feedstock – especially Al-unit

Highest Priority EZ Data Needs

- Current data coverage is very good, but some ROI's could use additional coverage:
  - **HiRISE/CRISM over Landing Site 1 to verify slopes, roughness, proximity to clays** (340.30E, 24.77N)
  - CRISM over MV floor megablocks to look for alteration (340.30E, 24.77N)
  - CRISM over Oyama clays to ID clay diversity (340.2E, 23.5N)
  - HiRISE/CRISM over SROI #6, N plains near MV mouth (location TBD)
- Logistical concerns that may require additional data:
  - Detailed traversability of MV flanks and Oyama walls
- Resources are also well characterized, but additional work is needed to characterize nature of clay surface:
  - How much *regolith* is present? General issue for all hydrated mineral resource sites globally.

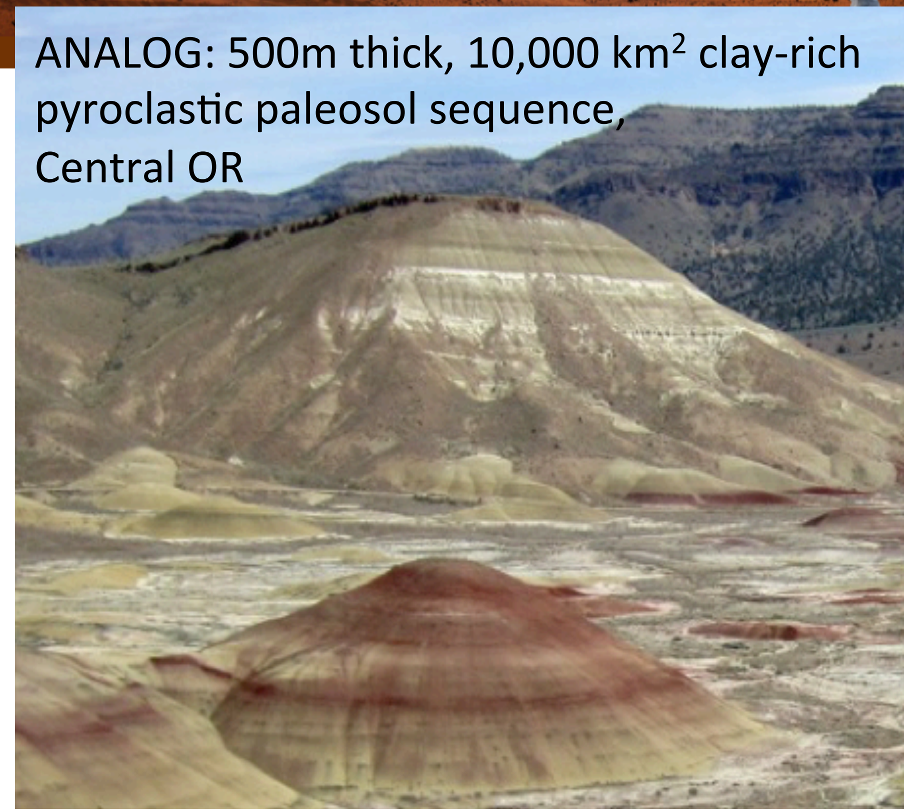
Mawrth Vallis: Value as an EZ

1. Mineralogically very diverse site recording a sequence of ancient habitable environments
2. Can sample both in place ancient altered Noachian deposits and remobilized sediments – source to sink
3. Extremely ancient section probing an enigmatic epoch in Solar System history - sample sedimentary and volcanic rocks from the early Noachian through the late Hesperian
4. Several types of astrobiological targets, including clear locations of high preservation potential
5. Provides access to a Noachian outflow channel, the dichotomy boundary, and the northern plains
6. **Most abundant hydrated mineral resource on Mars**

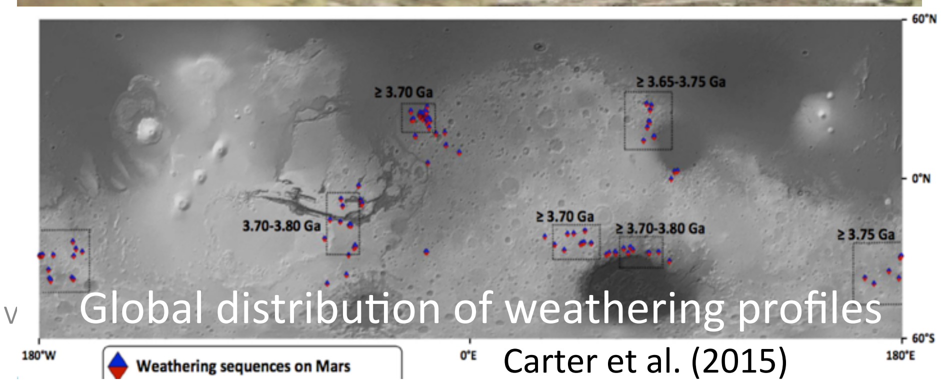
BACKUP SLIDES

Mawrth Vallis: The Story

- Major alteration at this scale implies long-term saturation by water, most likely through top-down weathering
- Too thick to be formed as a single leaching profile
- Alternative: concurrent weathering and sedimentation to form a paleosol sequence
- Potentially a high resolution climate record spanning the Noachian



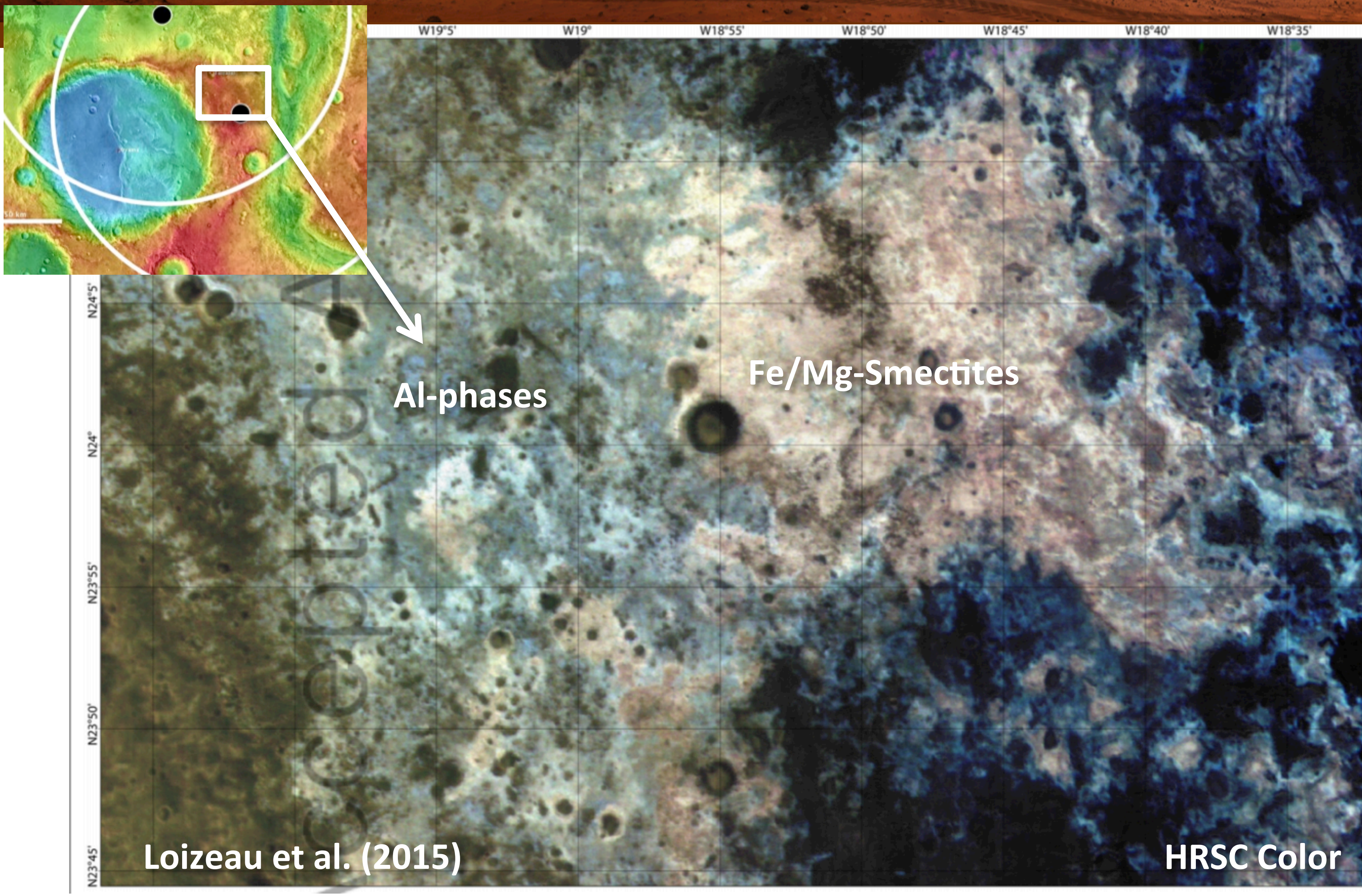
ANALOG: 500m thick, 10,000 km^2 clay-rich pyroclastic paleosol sequence, Central OR



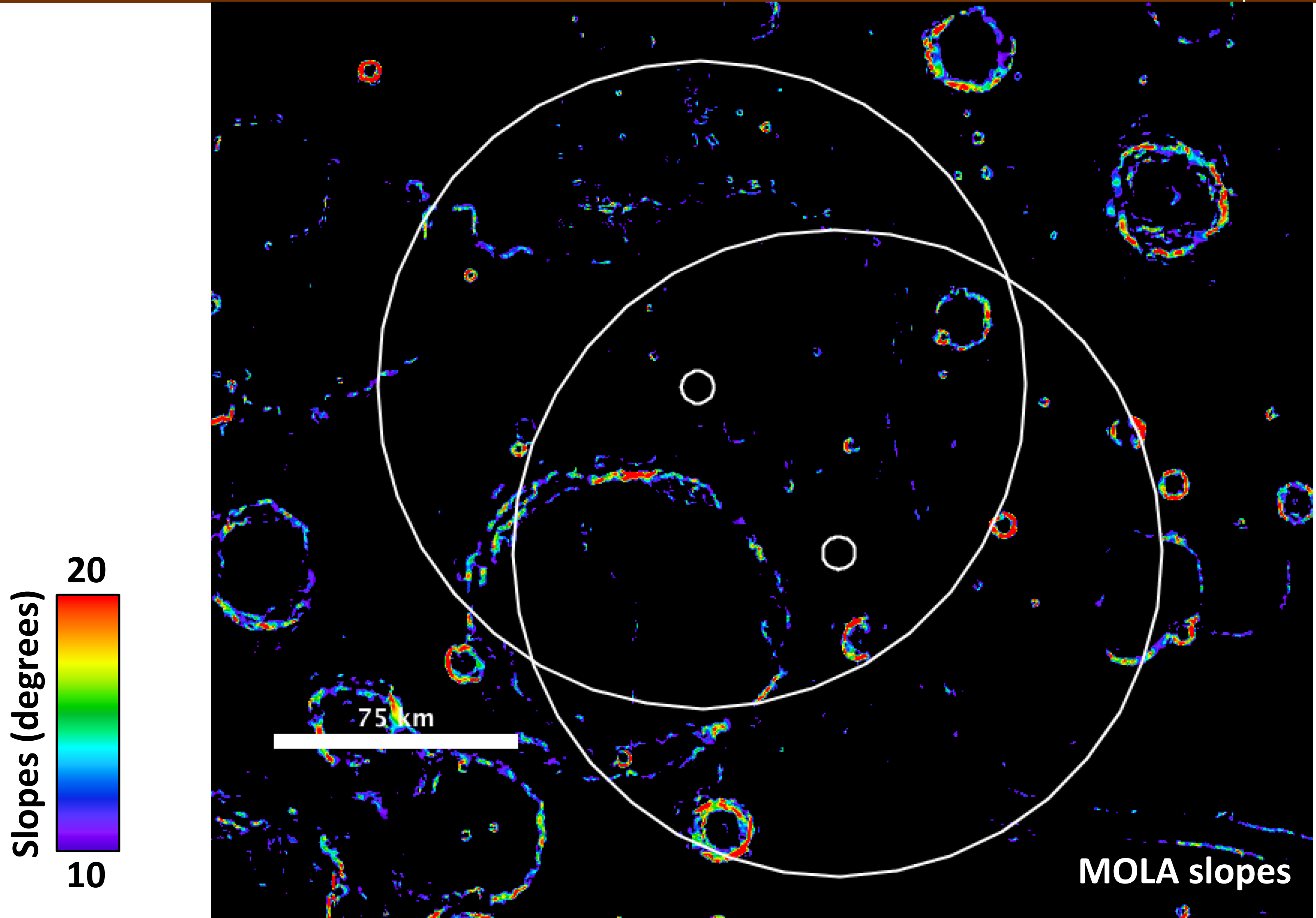
Global distribution of weathering profiles

Carter et al. (2015)

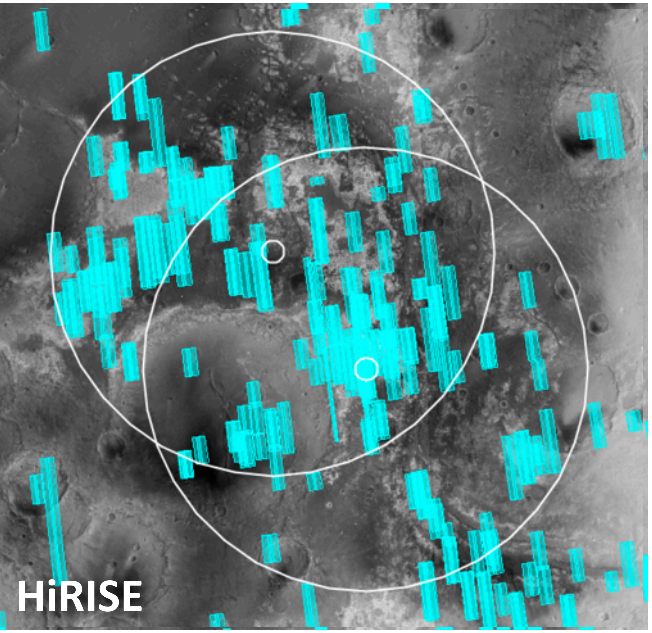
Science ROI 1: Clay Sequence

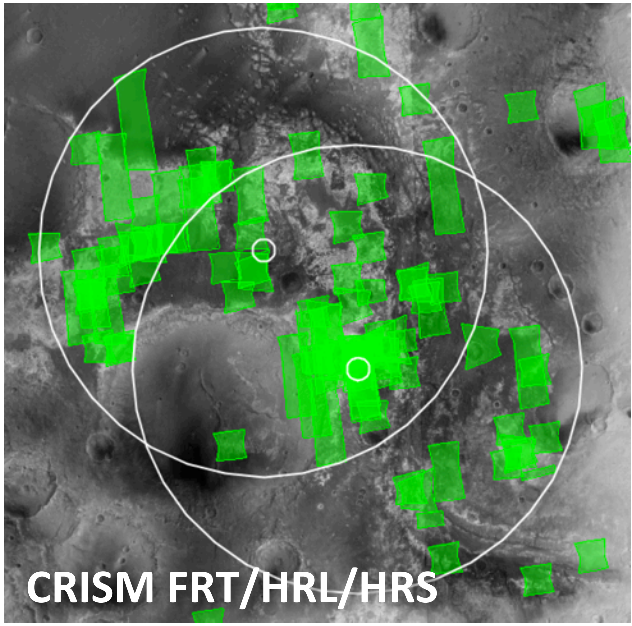


Mawrth Vallis and Oyama are accessible



Highest Priority EZ Data Needs



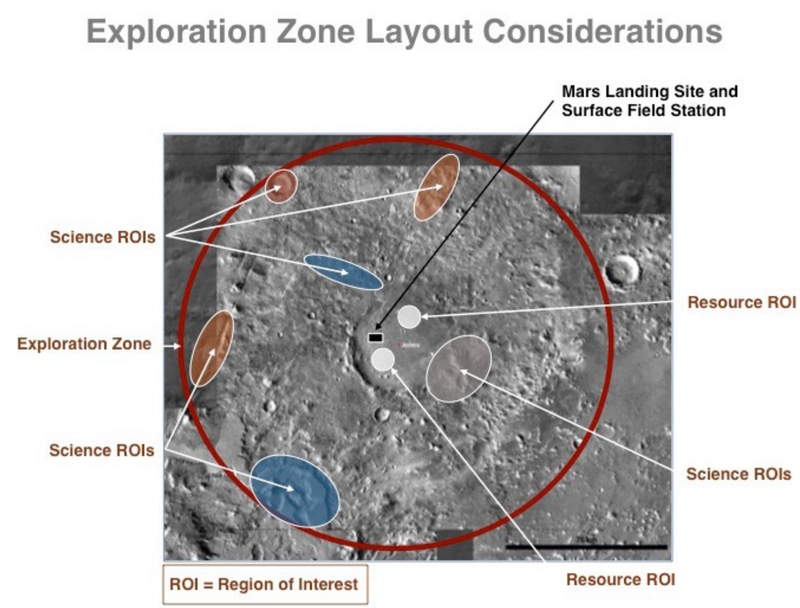


Exploration Zone Map

Full slide image of proposed Exploration Zone map graphically annotated with the following:

- Identify well-known features
- ~200 km diameter showing the EZ extent
- Science Regions of Interest - numbered SROI 1 through SROI (n)
- Resource Regions of Interest - numbered RROI 1 through RROI (n)
- Landing Site with latitude, longitude, and altitude
- Location of Surface Feld Station

FOR EXAMPLE:



Science ROI(s) Rubric

			Site Factors	SROI1	SROI2	SROI3	SROI(n)	RROI1	RROI2	RROI3	RROI(n)	EZ SUM
Science Site Criteria	Astrobio	Threshold (AND/OR)	**Potential for past habitability**									
			Potential for present habitability/refugia									
		Qualifying	Potential for organic matter, w/ surface exposure									
	Atmospheric Science	Threshold	**Noachian/Hesperian rocks w/ trapped atmospheric gases**									
		Qualifying	Meteorological diversity in space and time									
			High likelihood of surface-atmosphere exchange									
			Amazonian subsurface or high-latitude ice or sediment									
			High likelihood of active trace gas sources									
	Geoscience	Threshold	**Range of martian geologic time; datable surfaces**									
			Evidence of aqueous processes									
			Potential for interpreting relative ages									
		Qualifying	Igneous Rocks tied to 1+ provinces or different times									
			Near-surface ice, glacial or permafrost									
			Noachian or pre-Noachian bedrock units									
			Outcrops with remnant magnetization									
			Primary, secondary, and basin-forming impact deposits									
			Structural features with regional or global context									
			Diversity of aeolian sediments and/or landforms									

Complete this rubric and the one on the next slide for all ROIs (science and resource) in the proposed EZ. For each ROI, indicate whether the criteria is met fully or partially met using the key below. In the EZ SUM column, tally how many ROIs meet each criteria fully (n) and how many are met only partially (m) in the format n,m.

Key	
●	**Yes**
○	**Partial Support or Debated**
	No
?	**Indeterminate**

Science ROI 2

Image of SROI 2

- Latitude, longitude, altitude and current imaging available
- Describe characteristics of SROI 2 relevant to addressing Mars Science goals

Repeat with 1 slide summarizing each Science ROI meeting Science goals in order of priority: list threshold goals first, then qualifying goals

Resource ROI 2

Image of RROI 2

- Latitude, longitude, altitude and current imaging available
- Describe characteristics of RROI 2 relevant to addressing the potential for acquiring resources required to support human missions

**Repeat with 1 slide summarizing each Resource ROI meeting Resource goals in order of priority:
list threshold goals first, then qualifying goals**

Prioritization List of EZ Data Needs

- Provide a prioritized list of orbiter data to be collected to assess the (A) science potential and (B) resource potential of the EZ. For each request, this list should include:
  - Instrument name
  - Latitude and Longitude of center of image
  - A short justification/rationale for this request
- See following slide for detailed information about available datasets

- The HLS^2 Steering Committee will examine the requests and priorities
- All requests will be made through a central/specified POC

Available orbital datasets

Dataset	Instrument	Coverage	Spatial Res./Footprint	Where to look (in addition to PDS)
Surface images	HiRISE, *MRO*	2.4%	Res- 0.25-1 m/px; Length- 15-30 km; Width- Panchromatic: 5.4 km, Color: 1.2 km central stripe	http://hirise.lpl.arizona.edu/
	CTX, *MRO*	95%	Res- 6 m/px; Width- 30 km; Length-variable	http://global-data.mars.asu.edu/ bin/ctx.pl
	MOC (-2006), *MGS*	6%	Res- <12 m/px	http://www.msss.com/moc_gallery/
	HRSC, *MEX*	>90%	Res- 10-60 m/px; Swath width- 60 km; stereo	http://www.rssd.esa.int/PSA, http://ode.rsl.wustl.edu/mars/
NIR spectral data (e.g., composition)	CRISM, *MRO*	98% msp VIS 58% hyper VIS 83% msp NIR ~3% targeted	Res- 200 m/px, selected channels Res- 100 m/px, full spectral VIS Res- 100 m/px, selected channels Res- 18 m/px, full spectral VNIR	http://crism.jhuapl.edu/gallery/featuredImage/ index.php
	OMEGA, *MEX*	Near global	Res- <2 km/px, some areas down to 300 m/ px	http://pds-geosciences.wustl.edu/ missions/ mars_express/omega.htm
TIR spectral data (e.g, surface properties)	TES (-2006), *MGS*	Near global	Res- 3 km Footprint- 5.3 x 8.3 km	http://tes.asu.edu/data_archive.html
	THEMIS, *ODY*	Near global	Res- 100 m; Width- 20 km	https://themis.asu.edu/gallery
Digital Terrain Models/ slope maps	HiRISE, *MRO*	274	Meter-scale postings	http://www.uahirise.org/dtm/
	HRSC, *MEX*	75%	~50 m/px	http://hrscview.fu-berlin.de/
	MOLA (-2001 as altimeter), *MGS*	global	100's m spacing of points	http://mola.gsfc.nasa.gov/
Radar	SHARAD, *MRO*	40%	Fresnel width- 3 km Depth res.- 10 m and pen.- 300 m* *depending on composition	http://pds-geosciences.wustl.edu/ missions/mro/ sharad.htm
	MARSIS, *MEX*	80%	Swath width- 10 km; Depth res.- 100 m; Depth pen.- 1 km or more	http://pds-geosciences.wustl.edu/ missions/ mars_express/marsis.htm

Notes: Rows in orange are those that are generally requested from NASA. Atmospheric datasets (not listed) are also available. Global maps can be found at: http://www.mars.asu.edu/data/. A useful (free!) tool for looking at and analyzing multiple datasets: http://jmars.asu.edu/