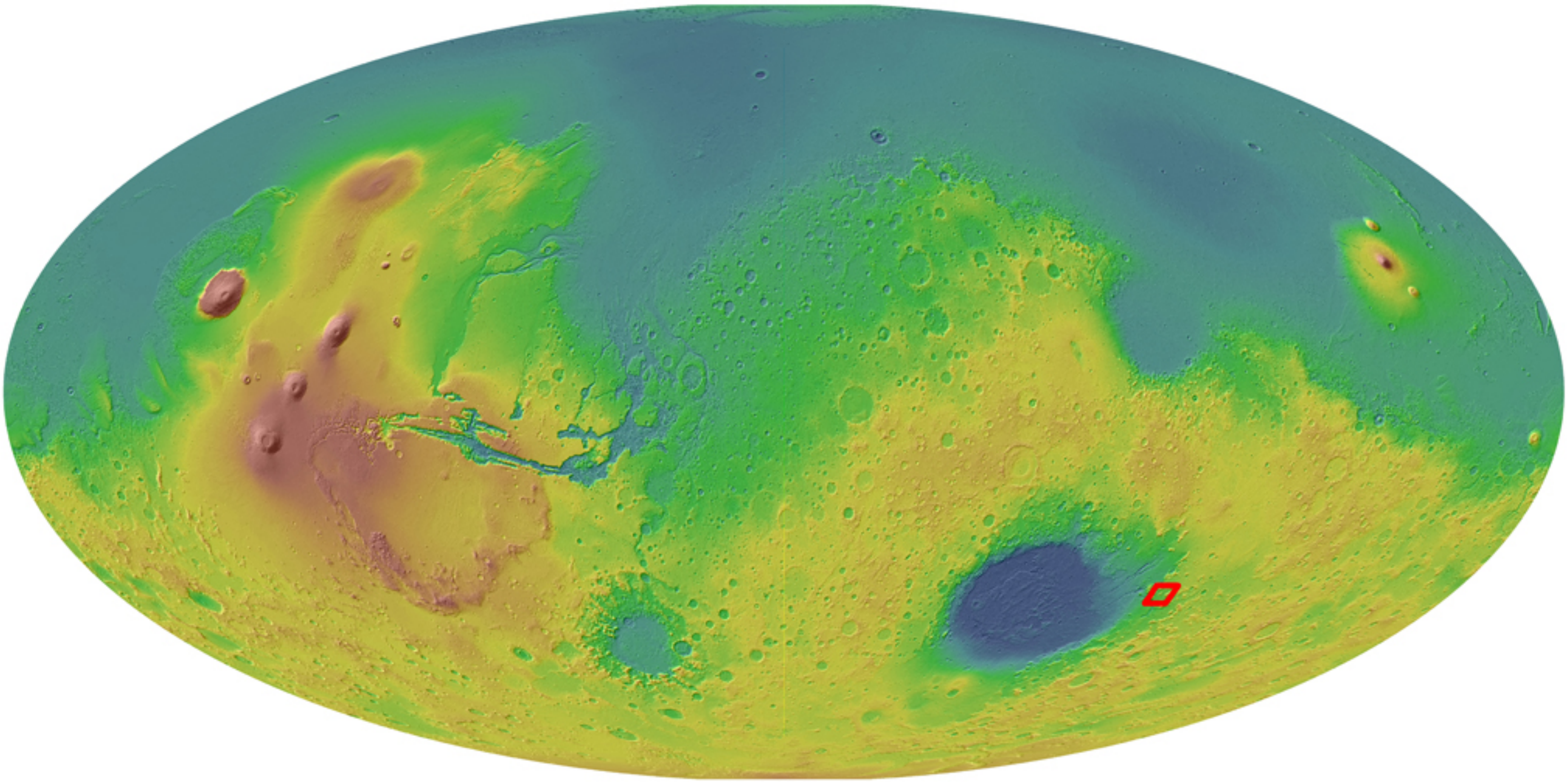
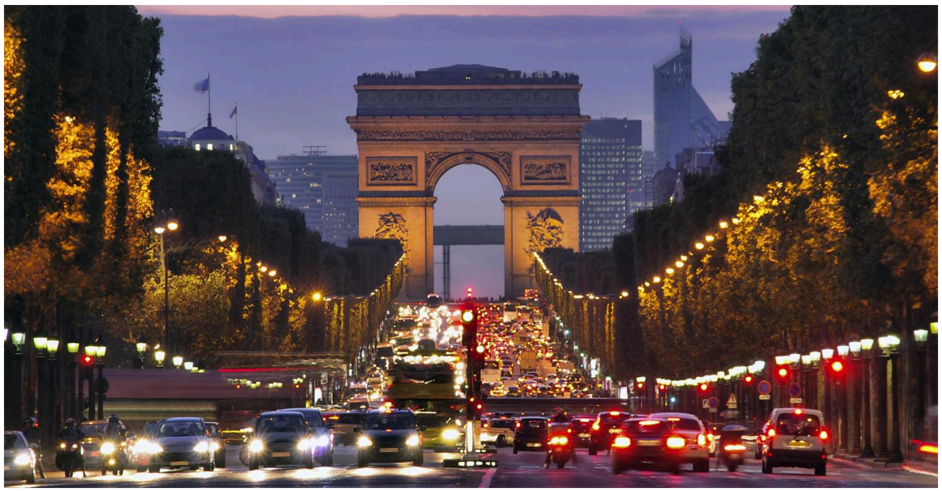
# The Hellas Rim: Ancient Craters, Flowing Water, & Abundant Ice

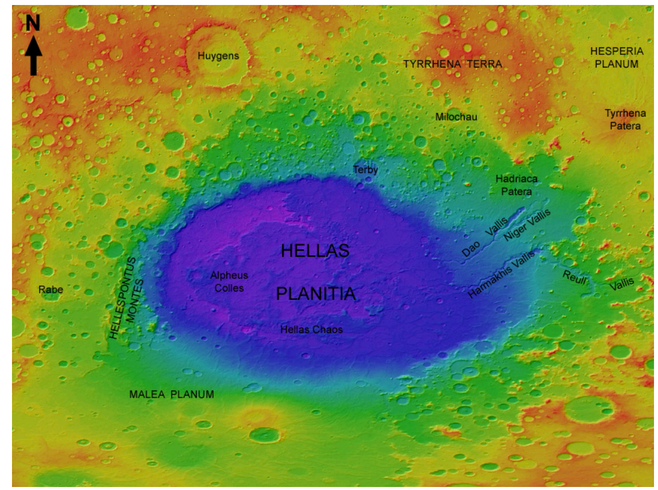


Abstract #1037 – Joe Levy & Jack Holt – UTIG

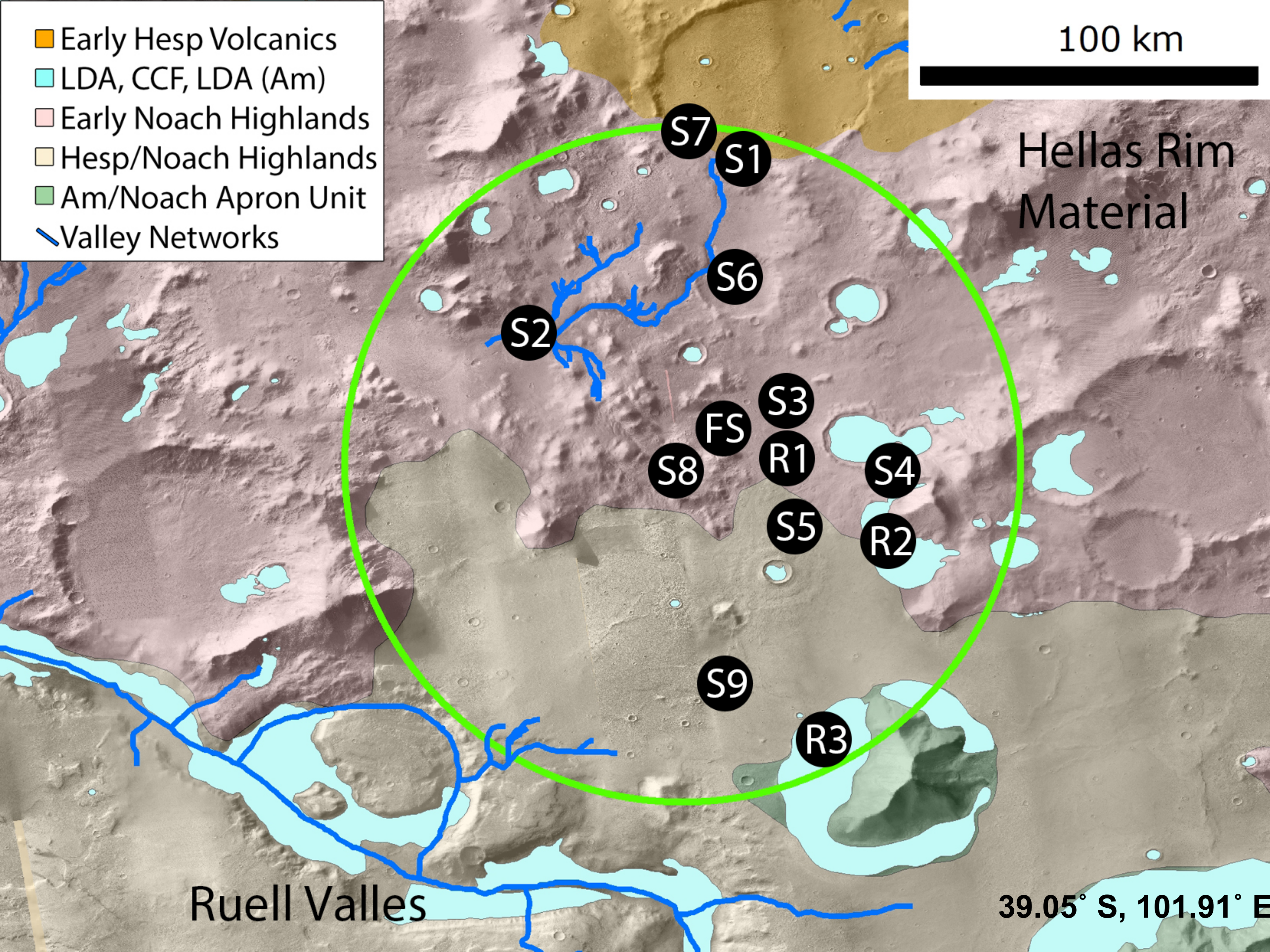
# Hellas: The Champs-Élysées of Mars







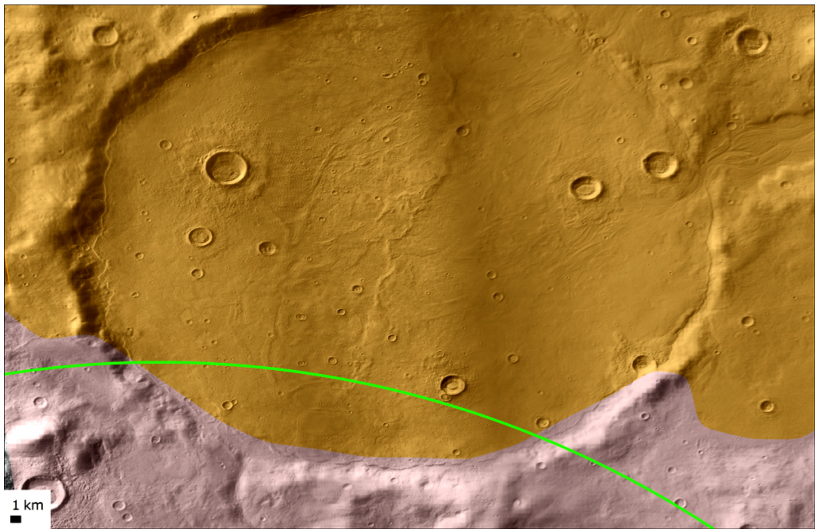

Monumental attractions
A long history, not just a time slice
A thoroughfare for major events
Excellent café culture

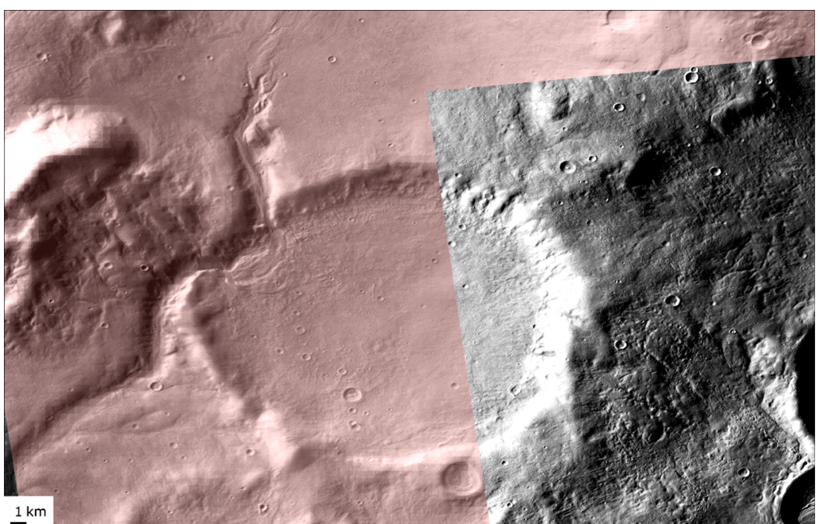


Early Hesp Volcanics
LDA, CCF, LDA (Am)
Early Noach Highlands
Hesp/Noach Highlands
Am/Noach Apron Unit
Valley Networks
100 km
Hellas Rim Material
S7
S1
S6
S2
S3
FS
R1
S8
S4
S5
R2
S9
R3
Ruell Valles
39.05° S, 101.91° E

# Open Basin Lakes

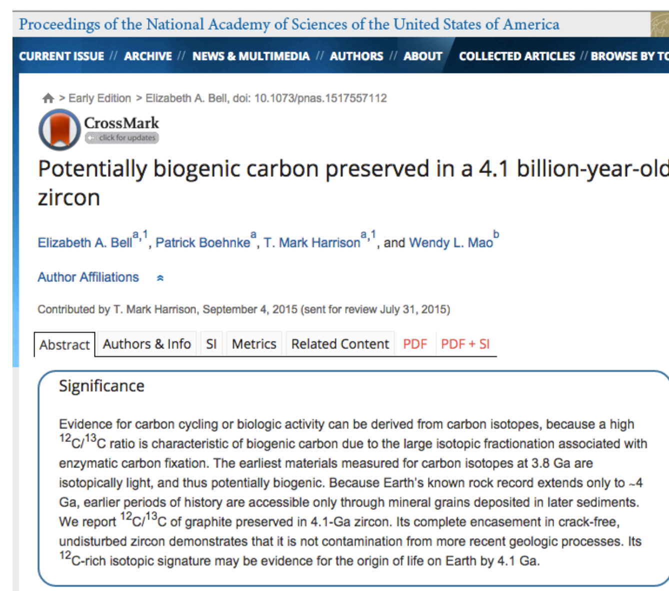





Key Factor: Past habitability (S1, S7, S6)

- Post-Hesperian volcanism fluvial incision
- Linked fluvial systems
- Exposure of basin cross section in breach
- Cap as feature not bug?


Proceedings of the National Academy of Sciences of the United States of America

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> Early Edition > Elizabeth A. Bell, doi: 10.1073/pnas.1517557112

CrossMark

Potentially biogenic carbon preserved in a 4.1 billion-year-old zircon

Elizabeth A. Bell[a,1], Patrick Boehnke[a], T. Mark Harrison[a,1], and Wendy L. Mao[b]

Author Affiliations

Contributed by T. Mark Harrison, September 4, 2015 (sent for review July 31, 2015)

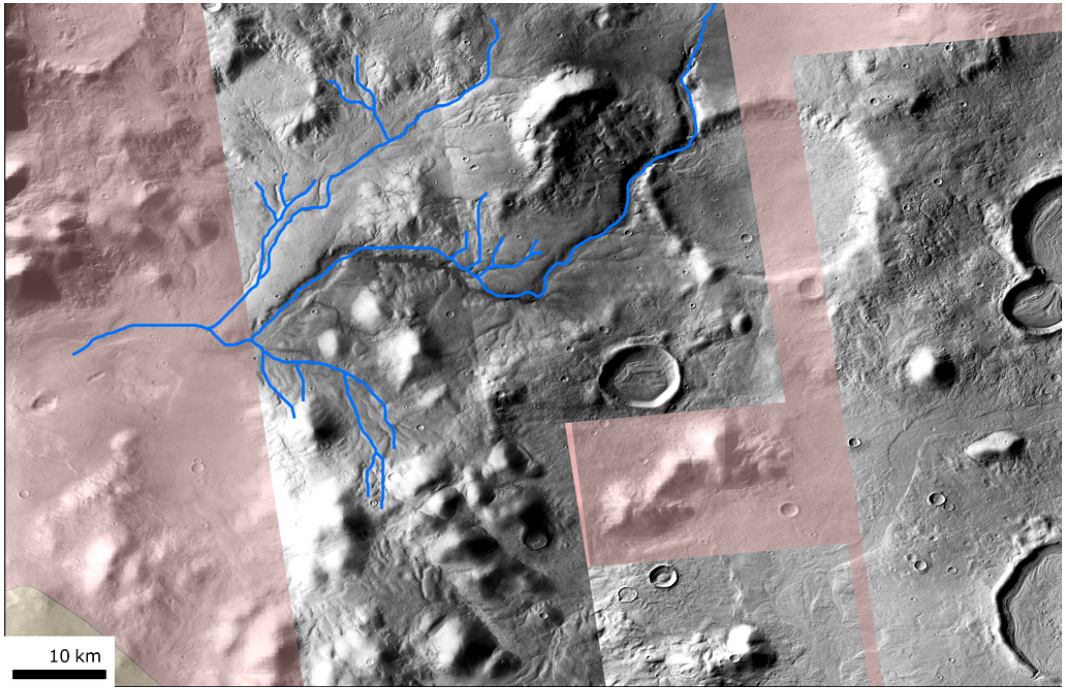
Abstract | Authors & Info | SI | Metrics | Related Content | PDF | PDF + SI

Significance

Evidence for carbon cycling or biologic activity can be derived from carbon isotopes, because a high $^{12}C/^{13}C$ ratio is characteristic of biogenic carbon due to the large isotopic fractionation associated with enzymatic carbon fixation. The earliest materials measured for carbon isotopes at 3.8 Ga are isotopically light, and thus potentially biogenic. Because Earth's known rock record extends only to ~4 Ga, earlier periods of history are accessible only through mineral grains deposited in later sediments. We report $^{12}C/^{13}C$ of graphite preserved in 4.1-Ga zircon. Its complete encasement in crack-free, undisturbed zircon demonstrates that it is not contamination from more recent geologic processes. Its $^{12}C$-rich isotopic signature may be evidence for the origin of life on Earth by 4.1 Ga.

# Valley Networks of All Sizes



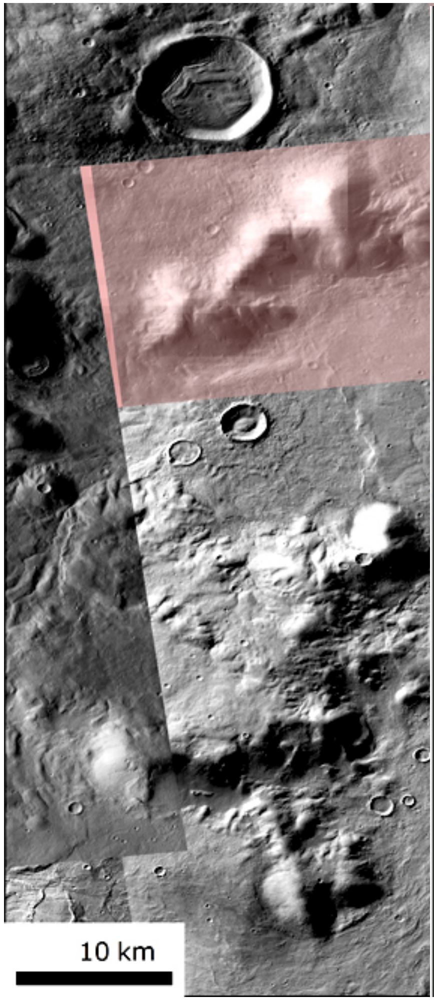


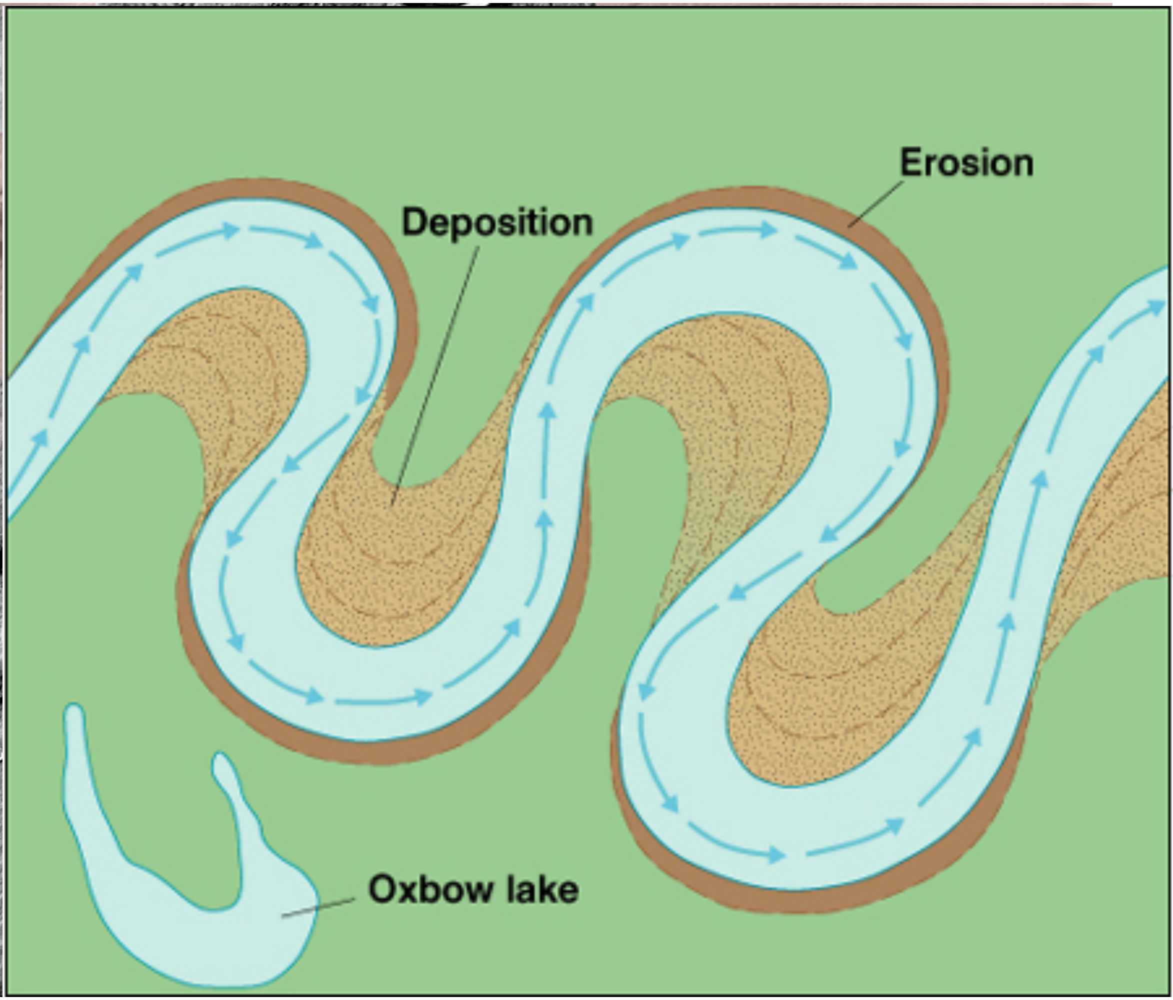

Hynek et al. 2010

# Valley Networks of All Sizes



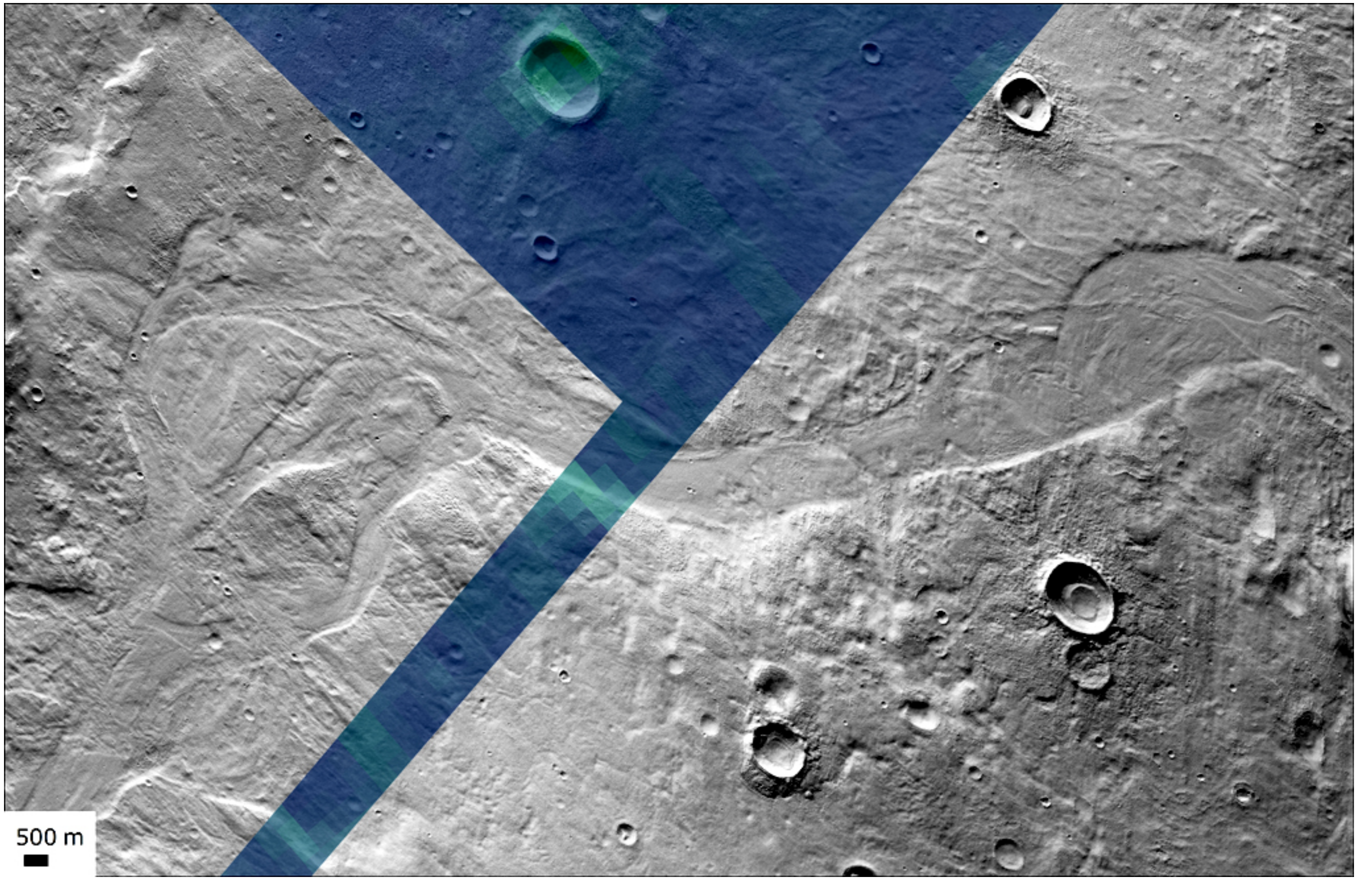
Meandering valley plus channel plus distributary fan



# Resource 1A: Fluvially-Sorted Sediments





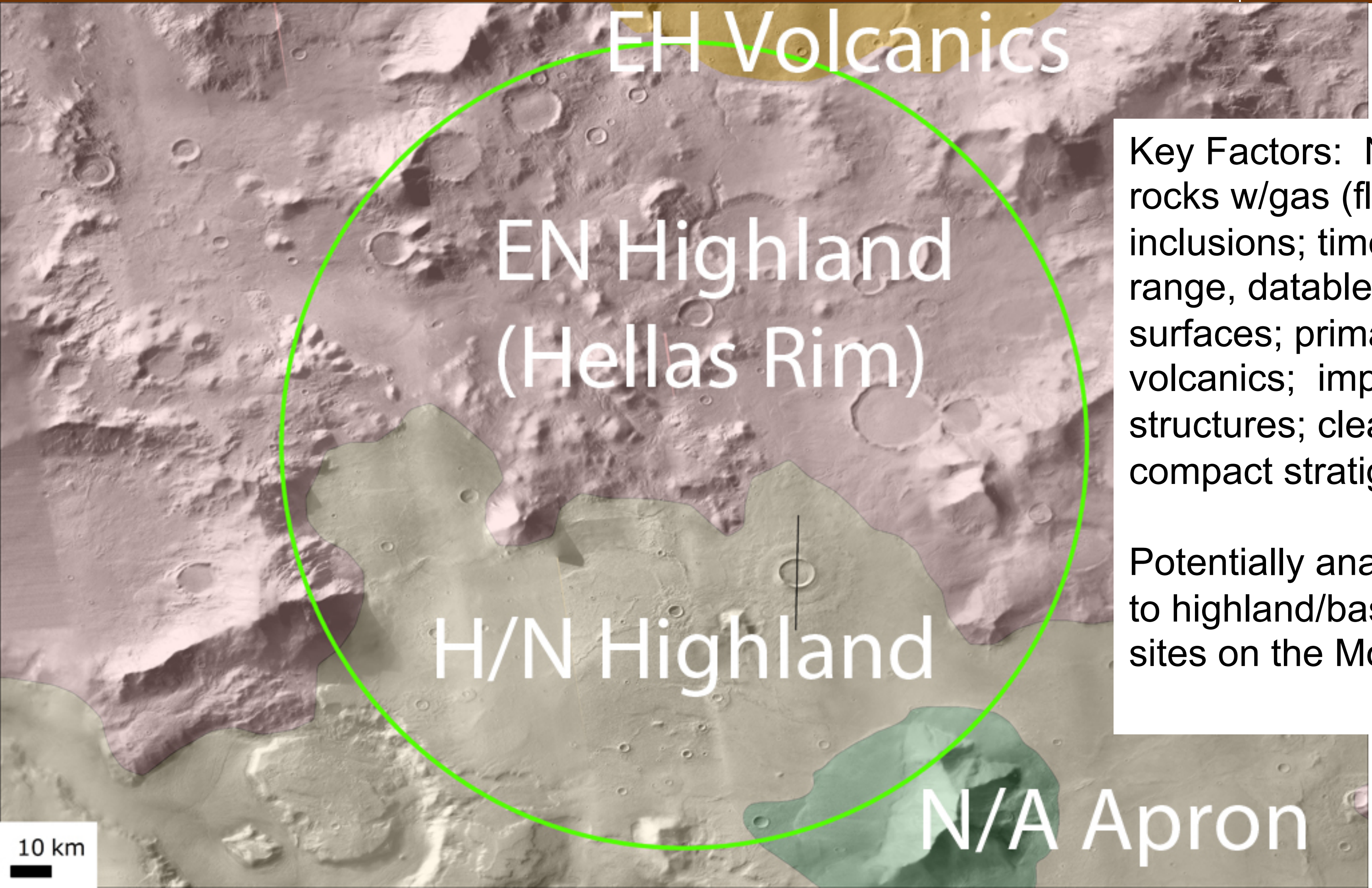

Meandering channels.

Lateral sorting of sediments likely (silt/ sand to coarse)

Let nature do the sorting for you.

# Noachian/Hesperian Volcanic and Datable Units



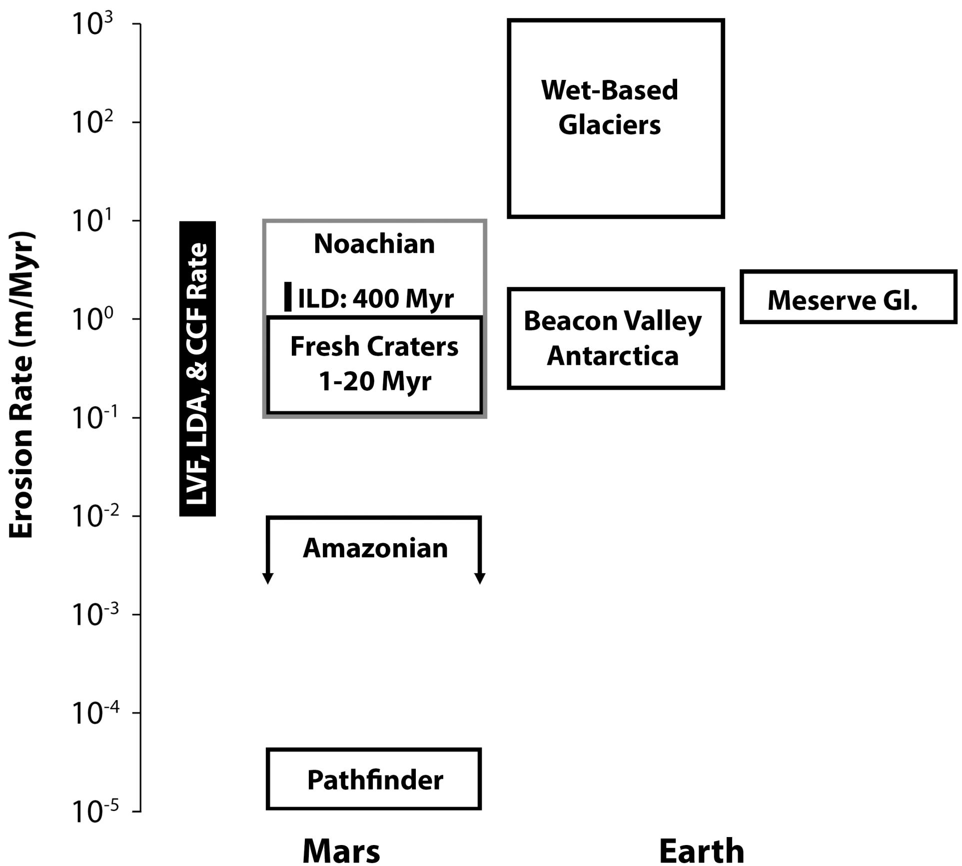



Key Factors: N/H rocks w/gas (fluid?) inclusions; time range, datable surfaces; primary volcanics; impact structures; clear, compact stratigraphy.

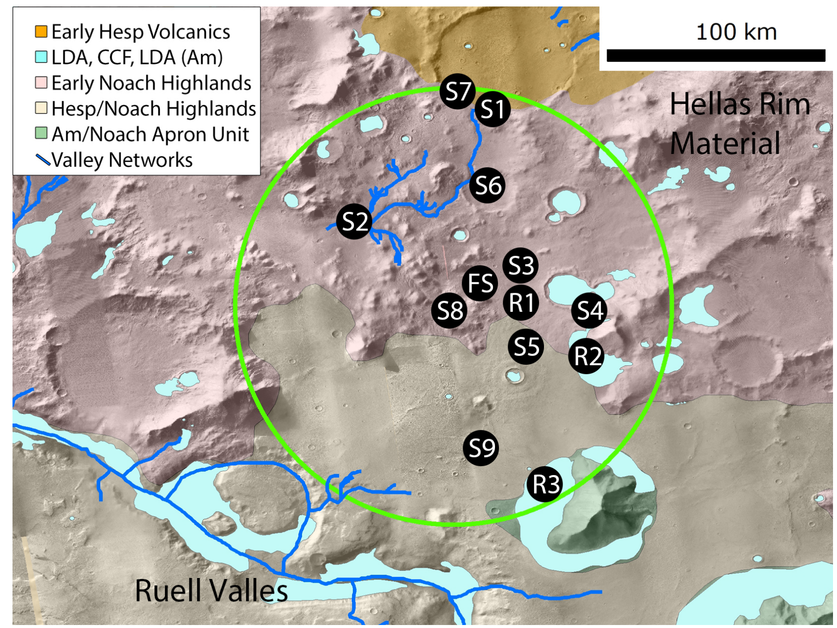
Potentially analogous to highland/basin-rim sites on the Moon.

# Surface Exposure: Glacial Buzzsaw






Levy et al., 2015

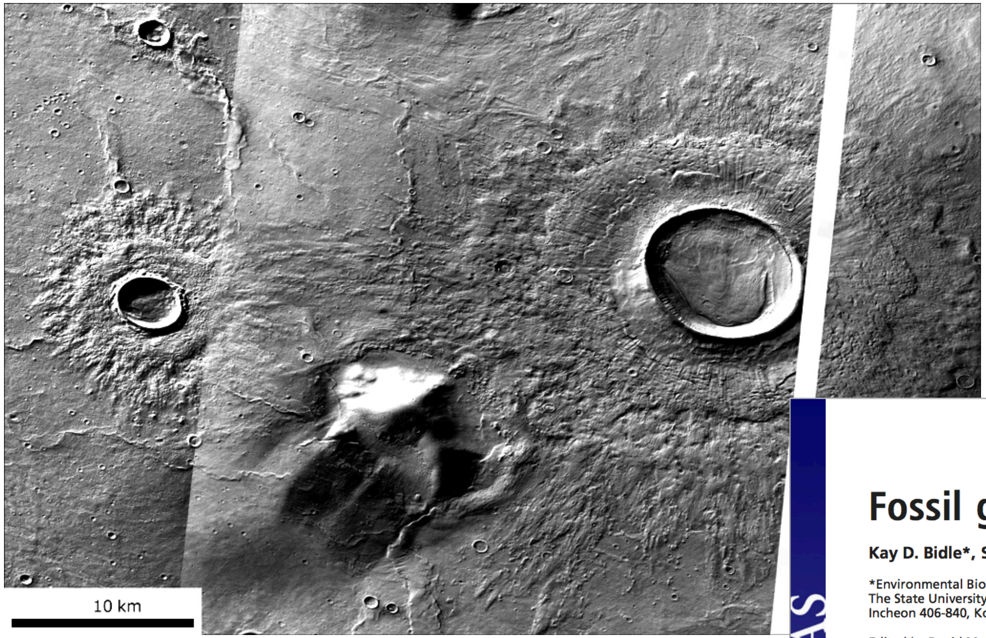



Key Factor: Surface organic matter.

Glaciated terrains on Mars have erosion rates 4-7 orders of magnitude faster than flat-lying plains areas. **The freshest exposures of old rocks on Mars are likely in glacially-modified areas.**

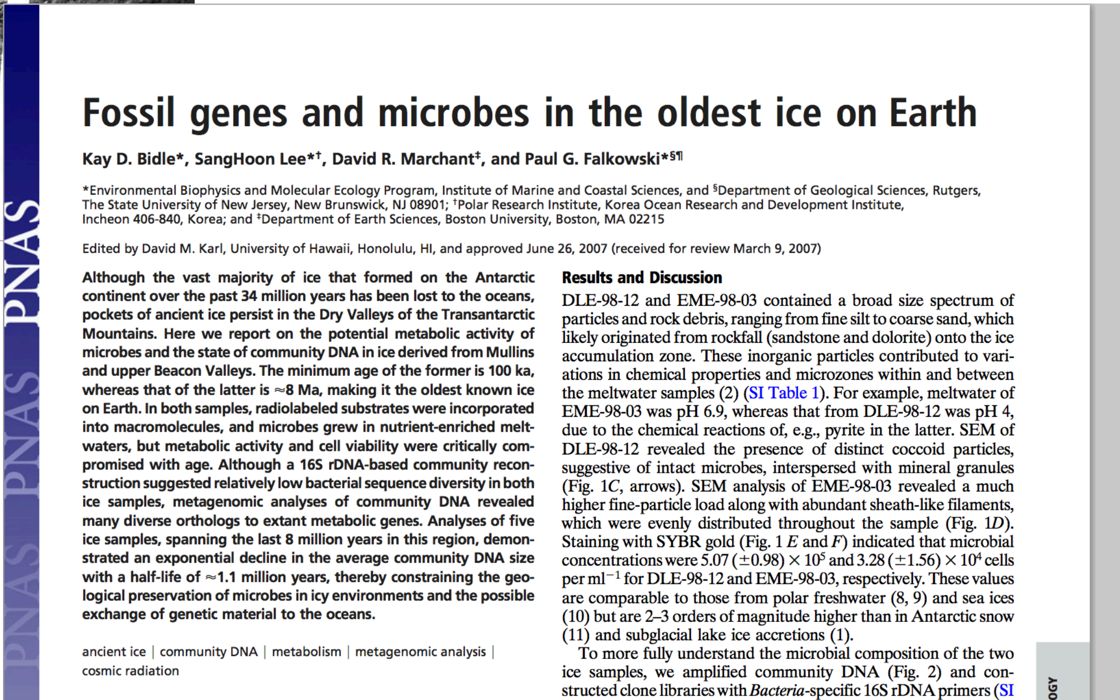
# Persistent Ice






Key Factor: Habitability/Refugia, Amazonian ice.

MLE craters with glacial deposits in them suggest persistent ground and surface ice.



PNAS PNAS PNAS PNAS

## Fossil genes and microbes in the oldest ice on Earth

Kay D. Bidle*, SangHoon Lee*†, David R. Marchant‡, and Paul G. Falkowski*§¶

*Environmental Biophysics and Molecular Ecology Program, Institute of Marine and Coastal Sciences, and §Department of Geological Sciences, Rutgers, The State University of New Jersey, New Brunswick, NJ 08901; †Polar Research Institute, Korea Ocean Research and Development Institute, Incheon 406-840, Korea; and ‡Department of Earth Sciences, Boston University, Boston, MA 02215

Edited by David M. Karl, University of Hawaii, Honolulu, HI, and approved June 26, 2007 (received for review March 9, 2007)

**Although the vast majority of ice that formed on the Antarctic continent over the past 34 million years has been lost to the oceans, pockets of ancient ice persist in the Dry Valleys of the Transantarctic Mountains. Here we report on the potential metabolic activity of microbes and the state of community DNA in ice derived from Mullins and upper Beacon Valleys. The minimum age of the former is 100 ka, whereas that of the latter is ≈8 Ma, making it the oldest known ice on Earth. In both samples, radiolabeled substrates were incorporated into macromolecules, and microbes grew in nutrient-enriched meltwaters, but metabolic activity and cell viability were critically compromised with age. Although a 16S rDNA-based community reconstruction suggested relatively low bacterial sequence diversity in both ice samples, metagenomic analyses of community DNA revealed many diverse orthologs to extant metabolic genes. Analyses of five ice samples, spanning the last 8 million years in this region, demonstrated an exponential decline in the average community DNA size with a half-life of ≈1.1 million years, thereby constraining the geological preservation of microbes in icy environments and the possible exchange of genetic material to the oceans.**

ancient ice | community DNA | metabolism | metagenomic analysis | cosmic radiation

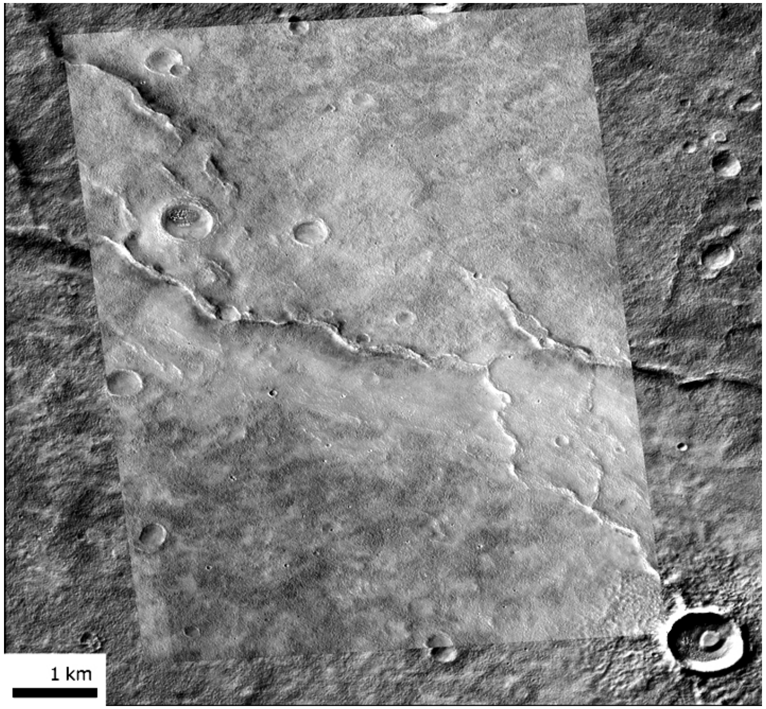
### Results and Discussion

DLE-98-12 and EME-98-03 contained a broad size spectrum of particles and rock debris, ranging from fine silt to coarse sand, which likely originated from rockfall (sandstone and dolorite) onto the ice accumulation zone. These inorganic particles contributed to variations in chemical properties and microzones within and between the meltwater samples (2) (SI Table 1). For example, meltwater of EME-98-03 was pH 6.9, whereas that from DLE-98-12 was pH 4, due to the chemical reactions of, e.g., pyrite in the latter. SEM of DLE-98-12 revealed the presence of distinct coccoid particles, suggestive of intact microbes, interspersed with mineral granules (Fig. 1*C*, arrows). SEM analysis of EME-98-03 revealed a much higher fine-particle load along with abundant sheath-like filaments, which were evenly distributed throughout the sample (Fig. 1*D*). Staining with SYBR gold (Fig. 1 *E* and *F*) indicated that microbial concentrations were 5.07 ($\pm$0.98) $\times 10^5$ and 3.28 ($\pm$1.56) $\times 10^4$ cells per ml$^{-1}$ for DLE-98-12 and EME-98-03, respectively. These values are comparable to those from polar freshwater (8, 9) and sea ices (10) but are 2–3 orders of magnitude higher than in Antarctic snow (11) and subglacial lake ice accretions (1).

To more fully understand the microbial composition of the two ice samples, we amplified community DNA (Fig. 2) and constructed clone libraries with *Bacteria*-specific 16S rDNA primers (SI

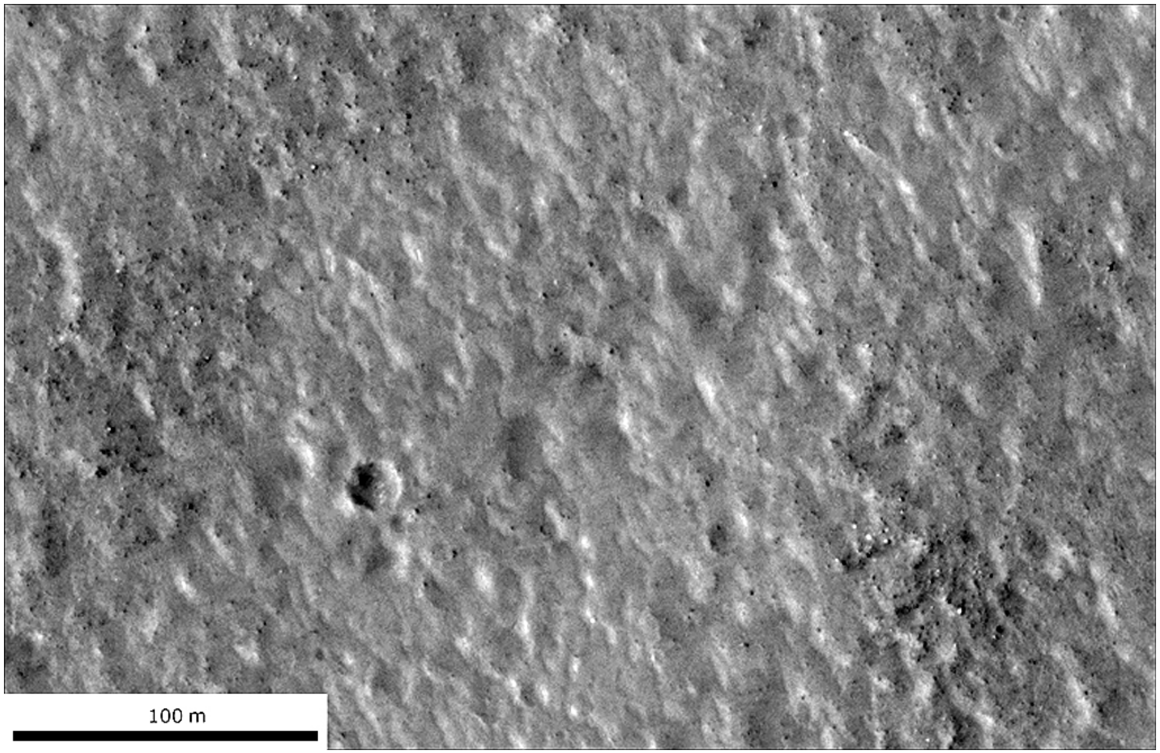
# Persistent Ice…Melting



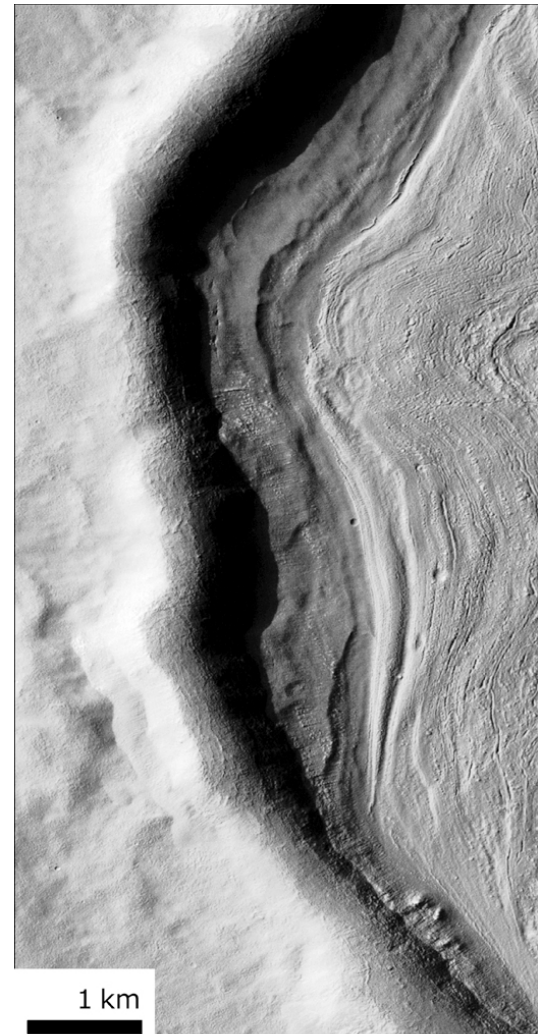



# Resource 1: Ubiquitous & Concentrated Ground Ice






- Seasonal ice (Vincendon et al., 2010)
- Dissected LDM (PPG)
- Likely ice-cemented within upper few annual skin depths



# Resource 1: Ubiquitous & Concentrated  Ground Ice



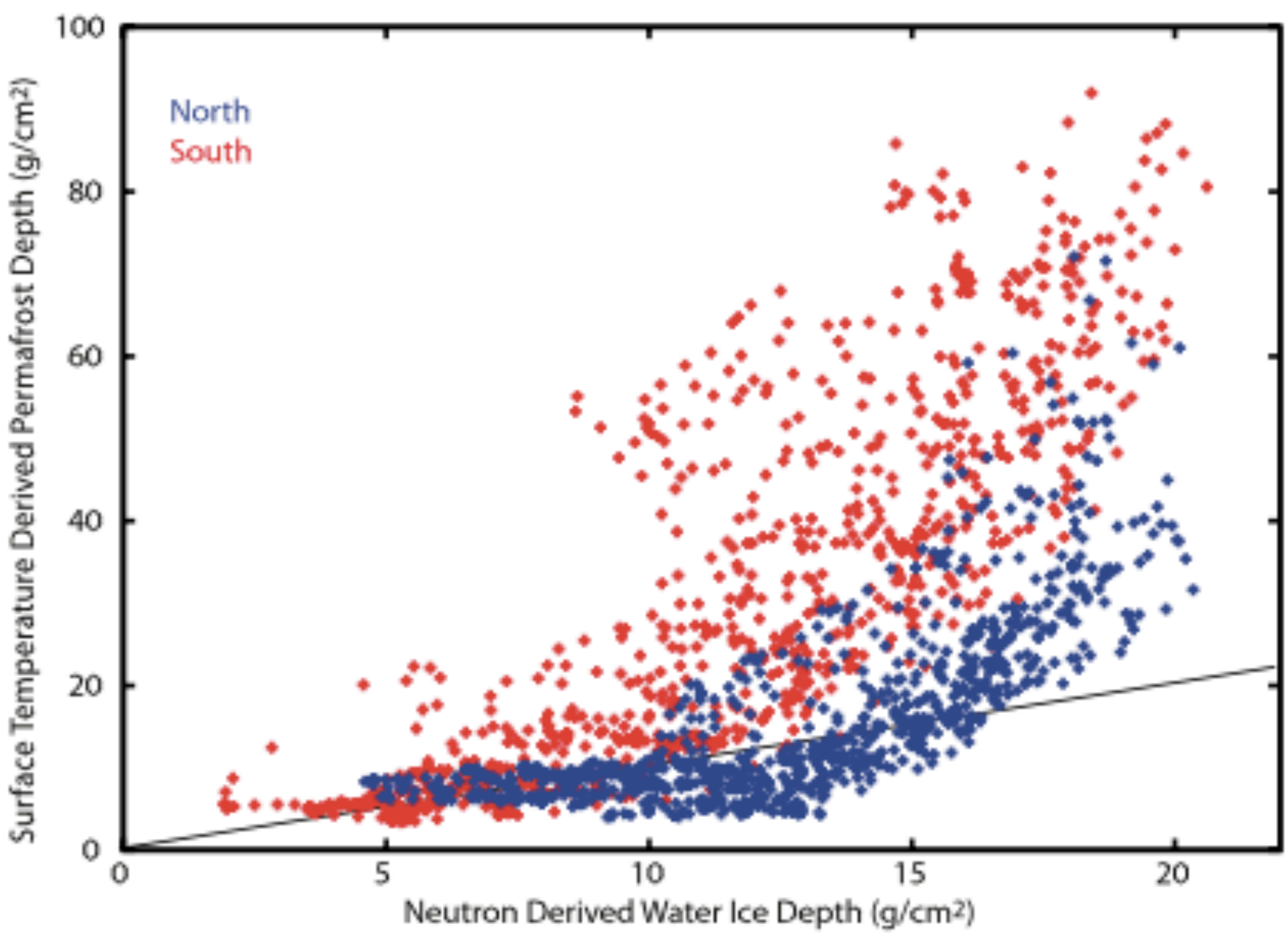
Bandfield & Feldman, 2008

50-80˚ lat

Ice at

3-50 cm

@ 2 g/cc

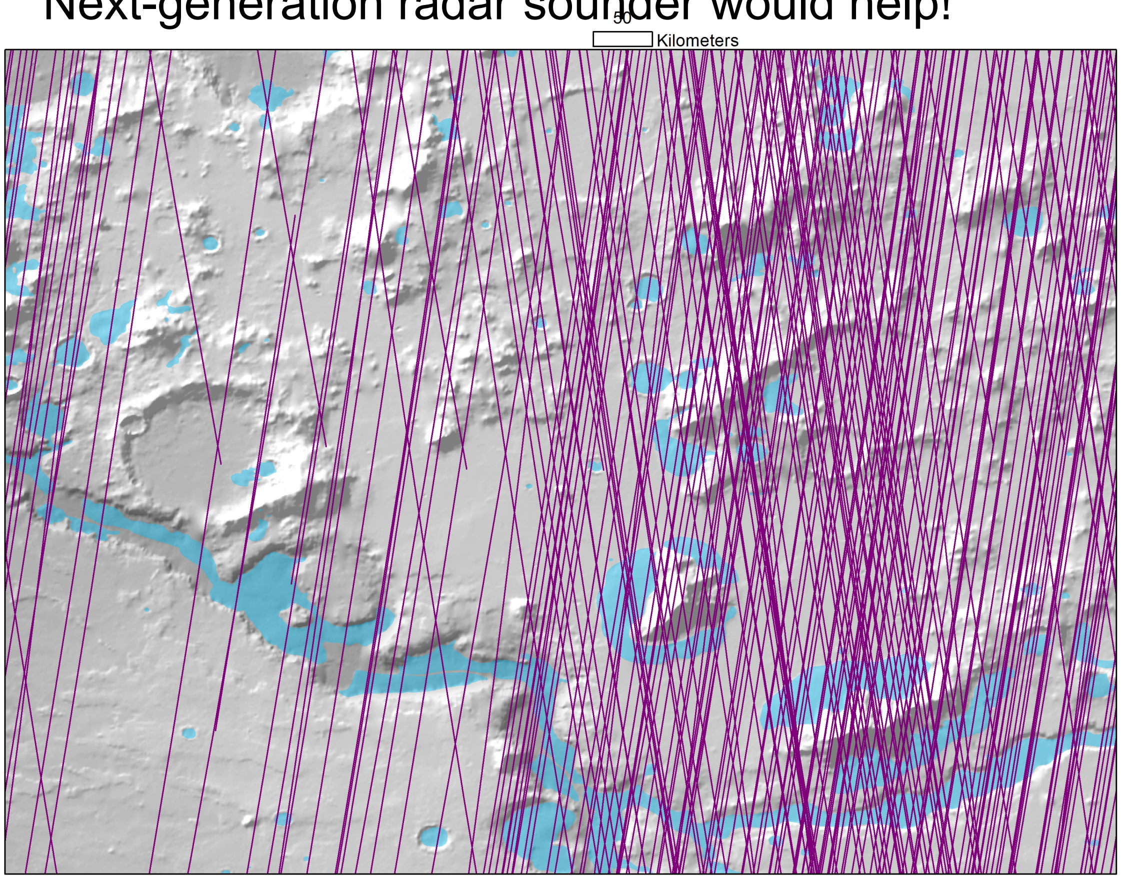


# Resource 2: Debris-Covered Glaciers

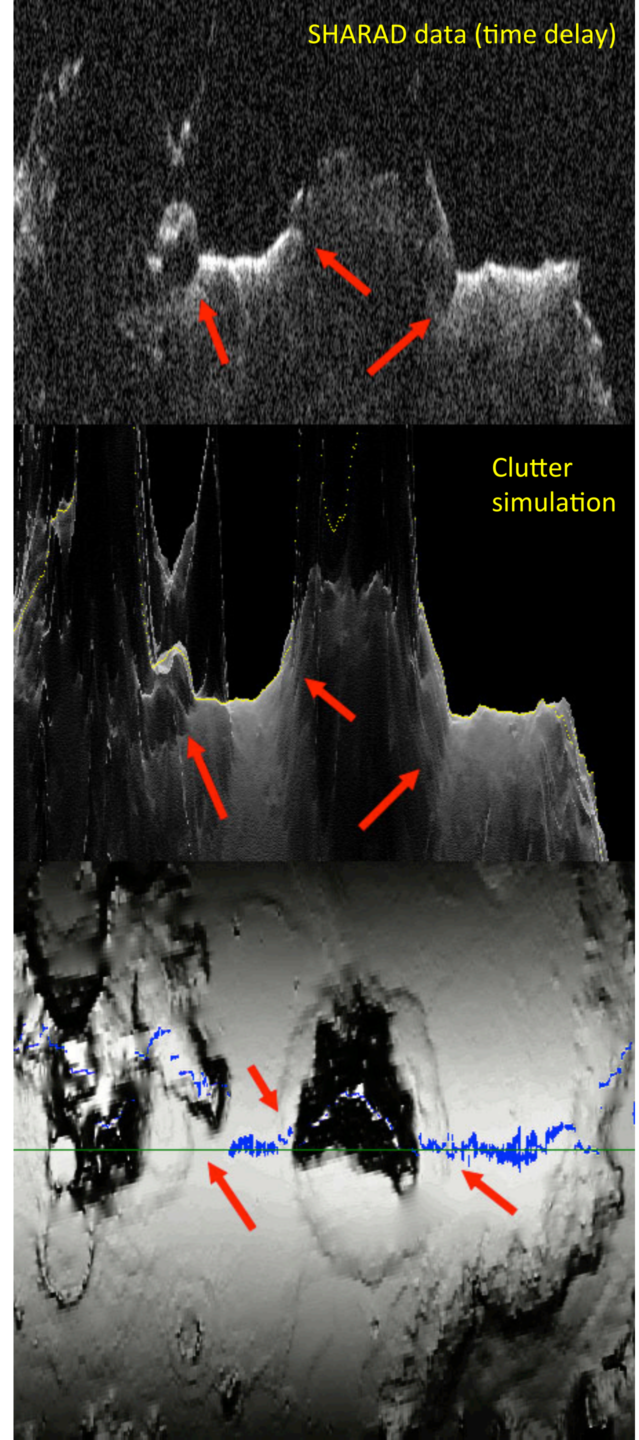


Many SHARAD tracks are not favorable orientation, (too much clutter) or features are too small. 3D migration with dense coverage could help.

Next-generation radar sounder would help!

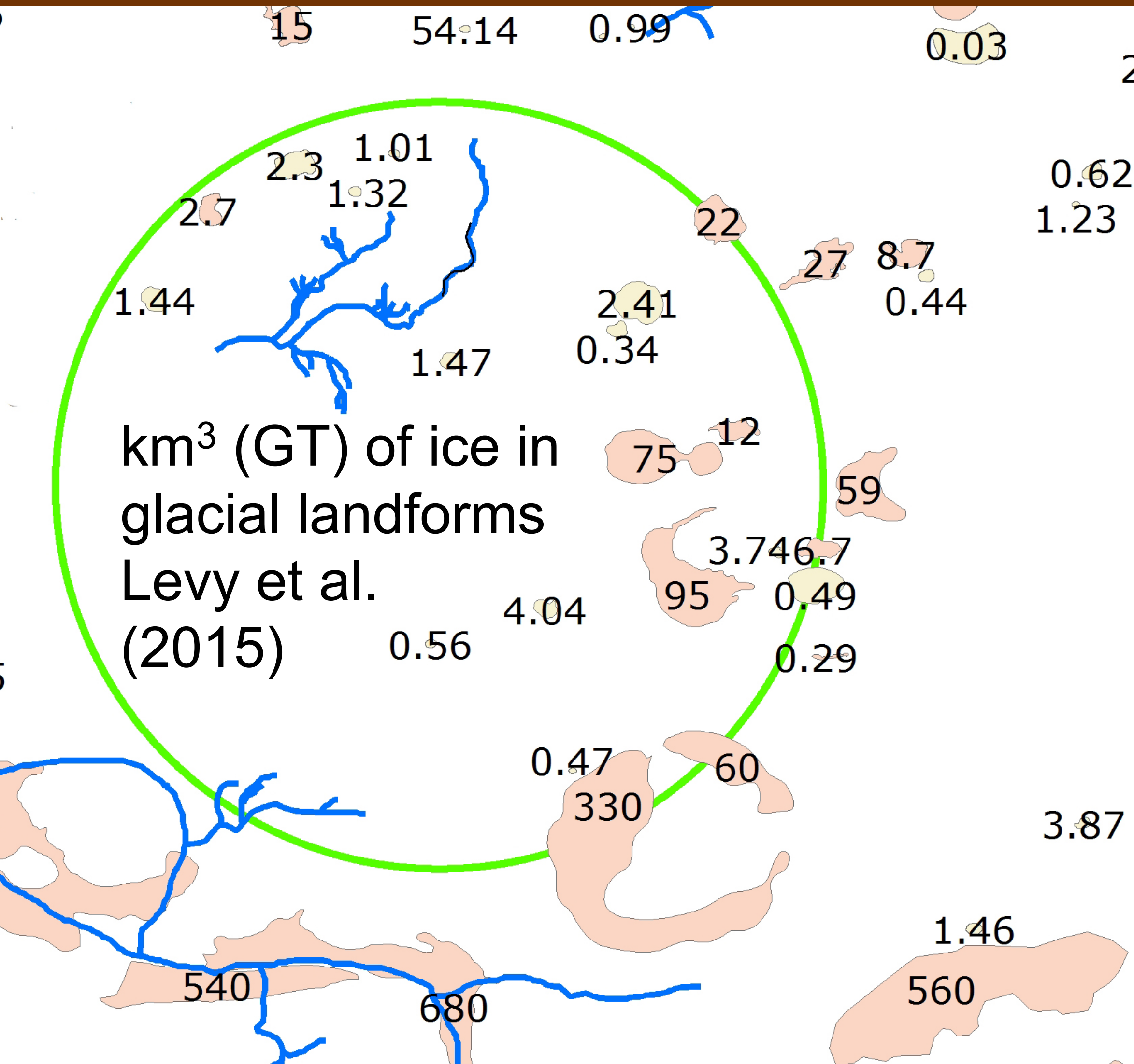


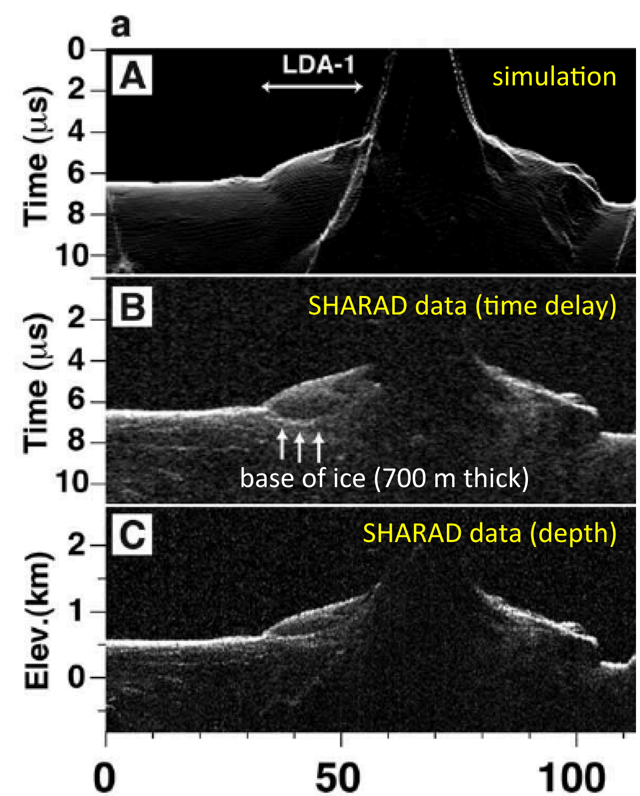

Current SHARAD coverage



# Resource 2: Debris-Covered Glaciers






Holt et al. (2008)

# Resource 2: Debris-Covered Glaciers



If you've got to melt it to drink it an explore it, you might as well live in it:

Ice as shielding.

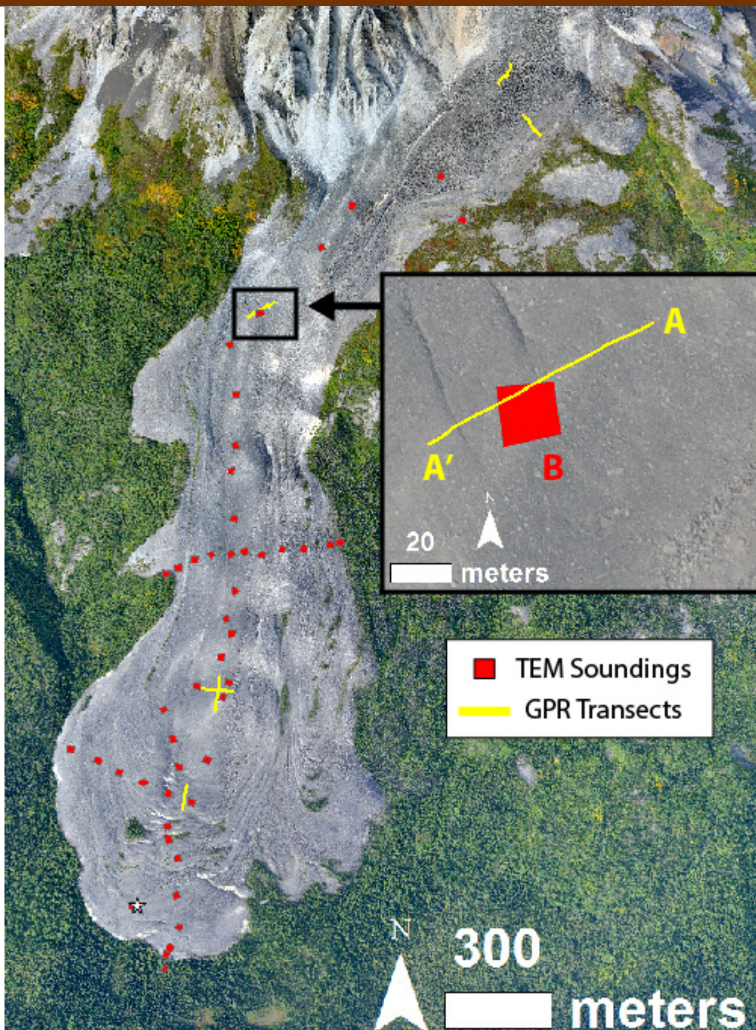
# Resource 2: Debris-Covered Glaciers

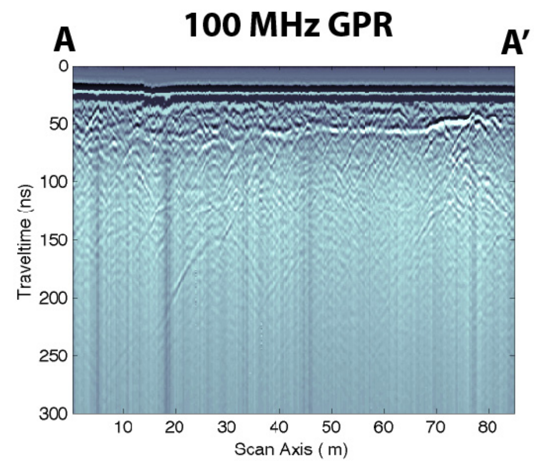


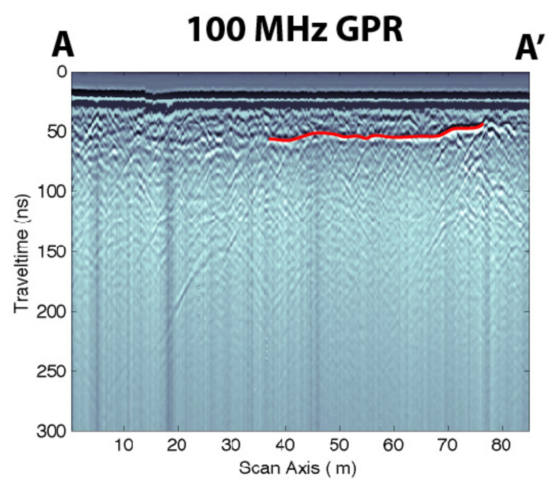
Advanced imaging helps characterize the debris layer over the ice.

# Resource 2: Debris-Covered Glaciers

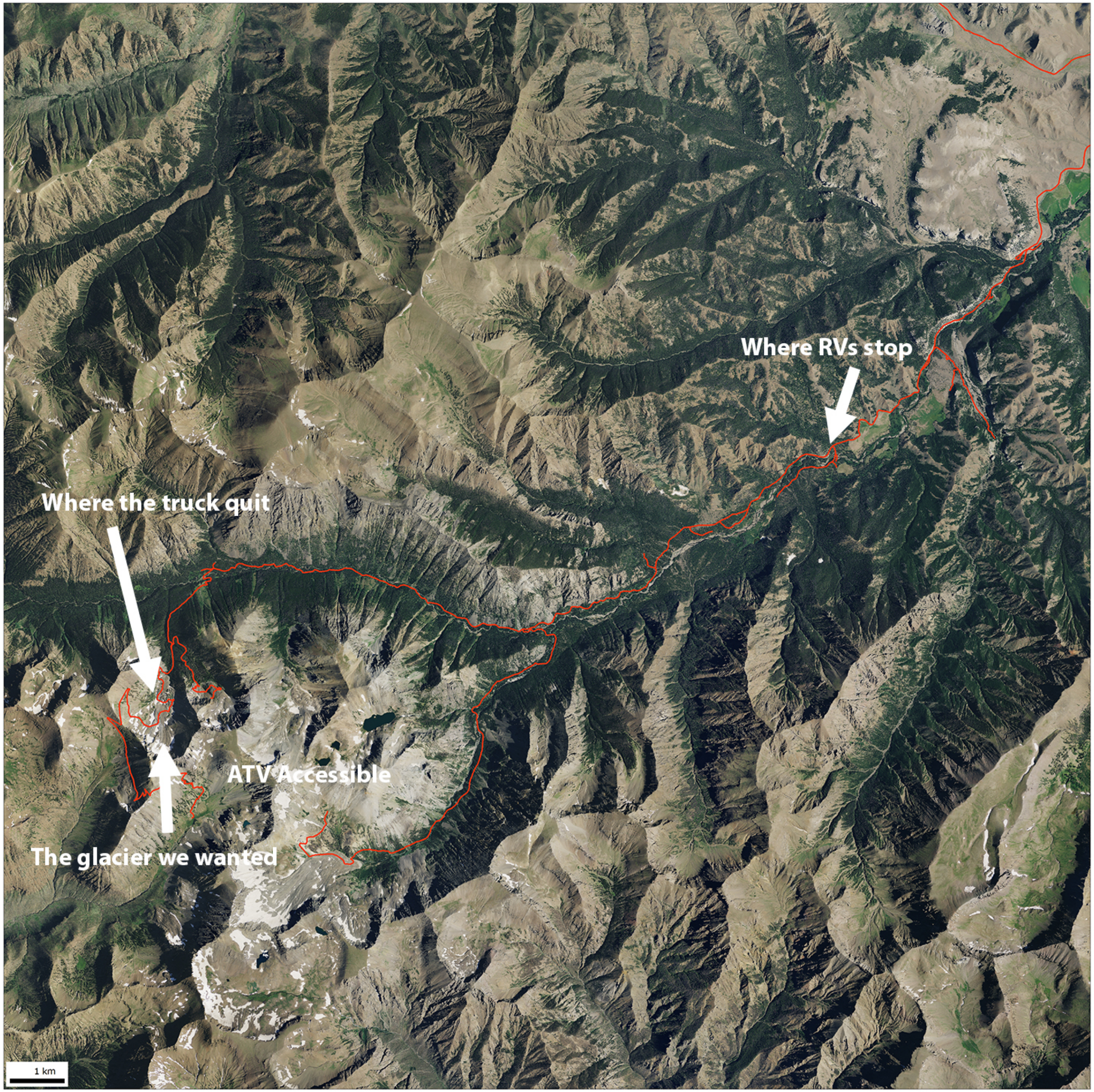





Advanced radar sounding is key to confirm the thickness and depth of glacial and mantle ice deposits.


Where RVs stop
Where the truck quit
ATV Accessible
The glacier we wanted
1 km


MCM:
800 keep the lights on
100 scientists

Crew of 4: ½ scientist
(Hopefully the top half)

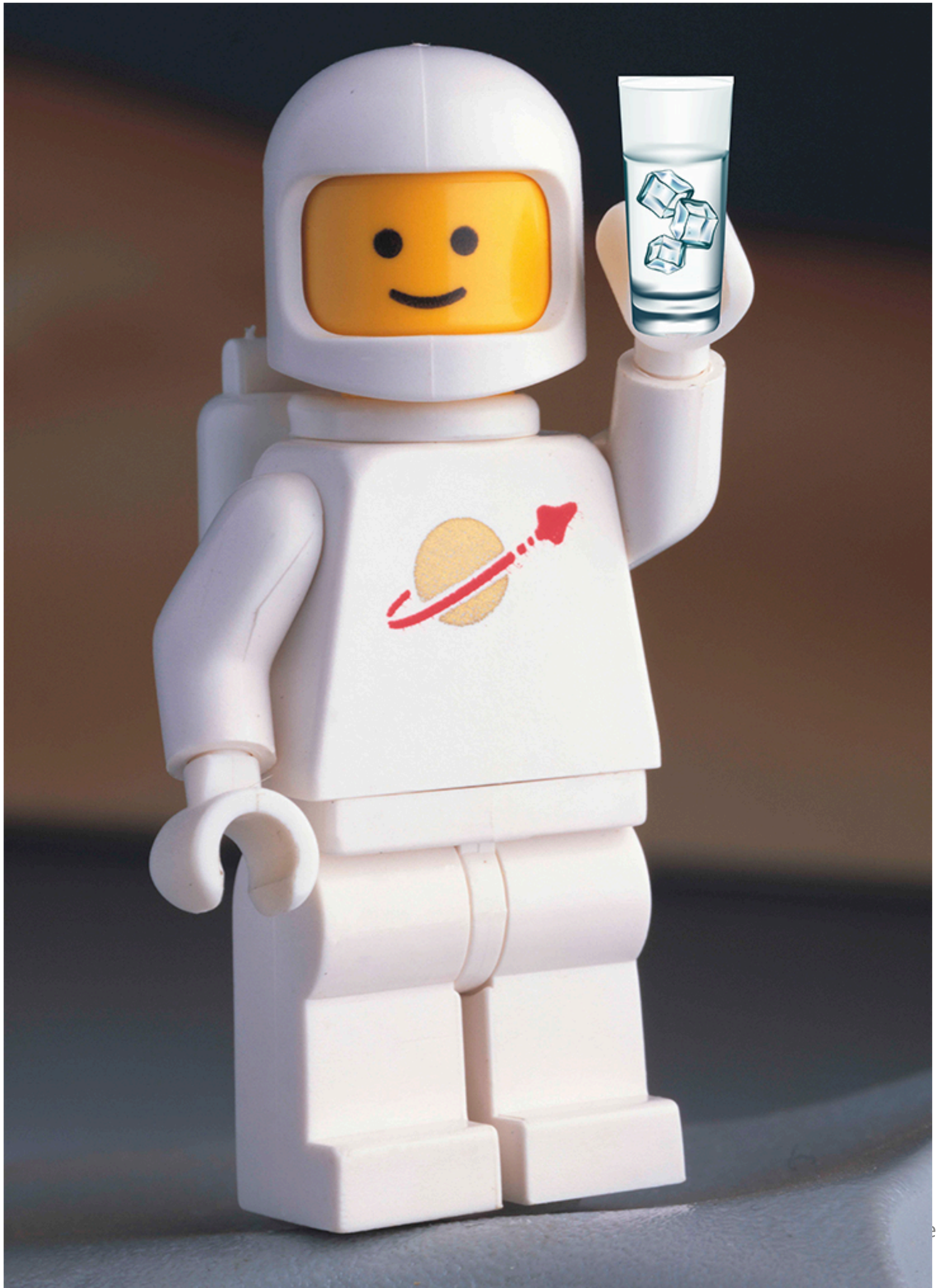
## Access matters

# Highest Priority EZ Data Needs



- Next generation **orbital radar sounder** and **high resolution imagers** for accurately determining ice-protective layer characteristics and thicknesses (all mid-lat sites), as well as mapping thin near-surface ice (e.g., LDM deposits).

*We know glacial ice and ice-rich permafrost are present in many sites on Mars. Developing engineering tools to use that ice is currently data-limited.*



If lives depend on it, go to the ice.

# RUBRICS


A hole in CRISM coverage: focus on morphology and geology

# Science ROI(s) Rubric



| Site Factors | | | | SRO I1 | SRO I2 | SRO I3 | SRO I4 | SRO I5 | SRO I6 | SRO I7 | SRO I8 | SRO I9 | RRO I1 | RRO I2 | RRO I3 | EZ SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | | | | | | | | | | | | | |

| Key | |
|---|---|
| ● | Yes |
| ○ | Partial Support or Debated |
| | No |
| ? | Indeterminate |

# Resource ROI(s) Rubric

1st EZ Workshop for Human Missions to Mars

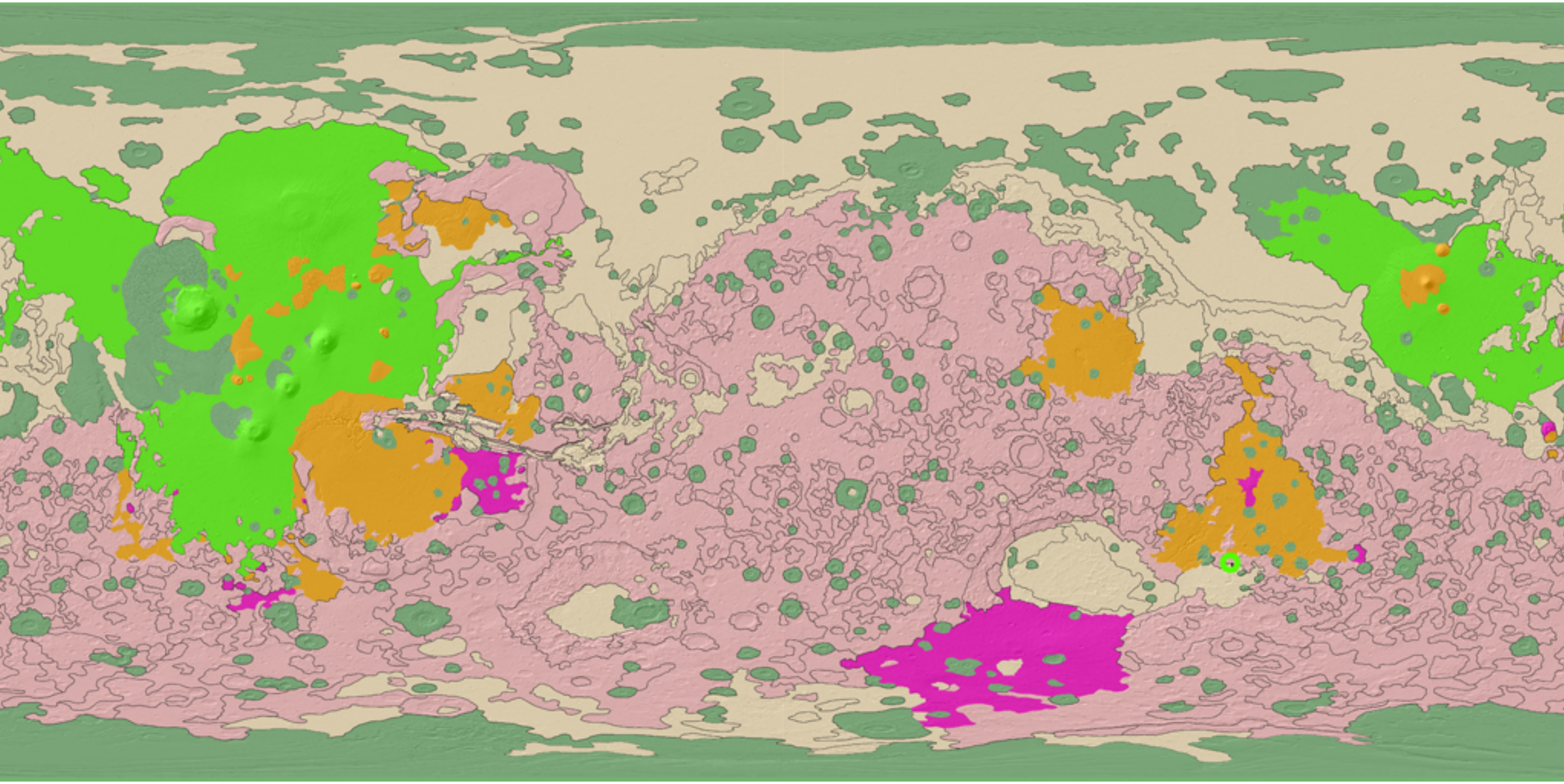
| | | | Site Factors | SROI1 | SROI2 | SROI3 | SROI(n) | RROI1 | RROI2 | RROI3 | RROI(n) | EZ SUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ISRU and Civil Engineering Criteria | Engineering | | Meets First Order Criteria (Latitude, Elevation, Thermal Inertia) | | | | | | | | | |
| | Water Resource | Threshold | AND/OR: **Potential for ice or ice/regolith mix** | | | | | | | | | |
| | | | AND/OR: **Potential for hydrated minerals** | | | | | | | | | |
| | | | **Quantity for substantial production** | | | | | | | | | |
| | | | **Potential to be minable by highly automated systems** | | | | | | | | | |
| | | | **Located less than 3 km from processing equipment site** | | | | | | | | | |
| | | | **Located no more than 3 meters below the surface** | | | | | | | | | |
| | | | **Accessible by automated systems** | | | | | | | | | |
| | | Qualifying | Potential for multiple sources of ice, ice/regolith mix **and** hydrated minerals | | | | | | | | | |
| | | | Distance to resource location can be >5 km | | | | | | | | | |
| | | | Route to resource location must be (plausibly) traversable | | | | | | | | | |
| | Civil Engineering | Threshold | **~50 sq km region of flat and stable terrain with sparse rock distribution** | | | | | | | | | |
| | | | **1–10 km length scale: <10°** | | | | | | | | | |
| | | | **Located within 5 km of landing site location** | | | | | | | | | |
| | | Qualifying | Located in the northern hemisphere | | | | | | | | | |
| | | | Evidence of abundant cobble sized or smaller rocks and bulk, loose regolith | | | | | | | | | |
| | | | Utilitarian terrain features | | | | | | | | | |
| | Food Production | Qualifying | Low latitude | | | | | | | | | |
| | | | No local terrain feature(s) that could shadow light collection facilities | | | | | | | | | |
| | | | Access to water | | | | | | | | | |
| | | | Access to dark, minimally altered basaltic sands | | | | | | | | | |
| | Metal/Silicon Resource | Threshold | **Potential for metal/silicon** | | | | | | | | | |
| | | | **Potential to be minable by highly automated systems** | | | | | | | | | |
| | | | **Located less than 3 km from processing equipment site** | | | | | | | | | |
| | | | **Located no more than 3 meters below the surface** | | | | | | | | | |
| | | | **Accessible by automated systems** | | | | | | | | | |
| | | Qualifying | Potential for multiple sources of metals/silicon | | | | | | | | | |
| | | | Distance to resource location can be >5 km | | | | | | | | | |
| | | | Route to resource location must be (plausibly) traversable | | | | | | | | | |

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

# BACKUP SLIDES

# Noachian/Hesperian Volcanic and Datable Units





Access to N (pink) and H (orange) global volcanics is a non-trivial challenge

# Ice stability depths





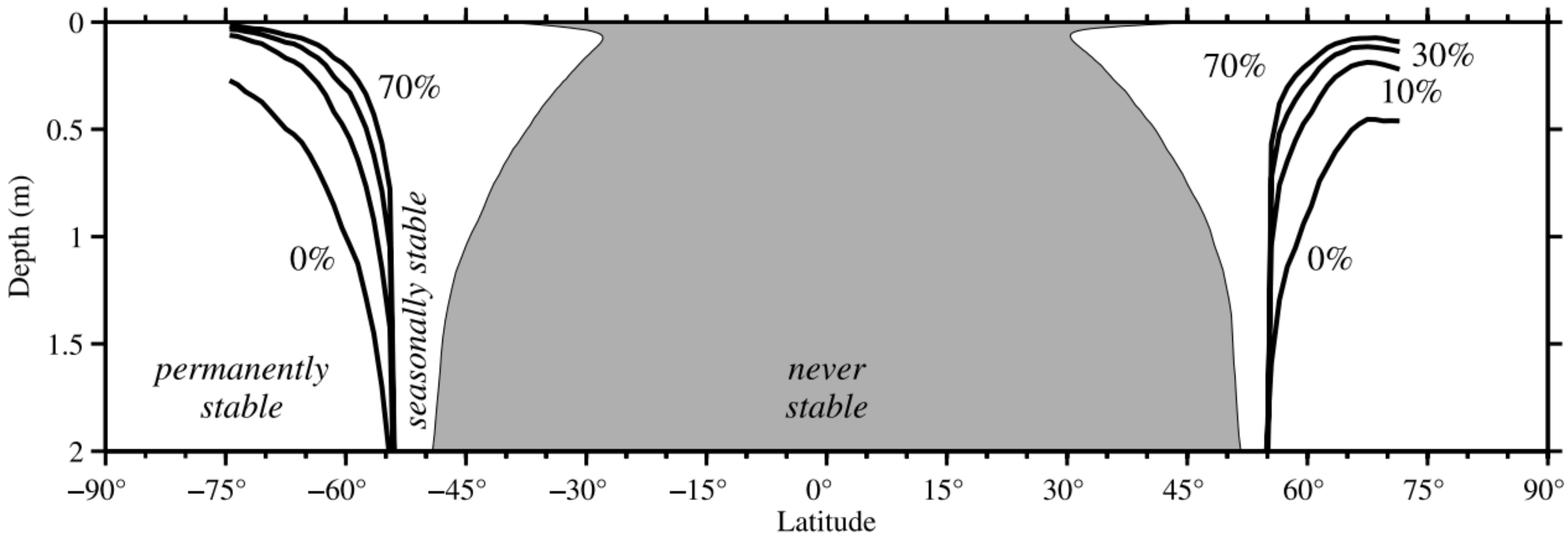



**Figure 7.** Permanent and seasonal stability for zonally averaged regolith parameters and humidities. The solid lines labeled "0%" indicate depths to permanent stability when no ice is present. When pore spaces are filled with ice at depths where it is stable, the burial depths become shallower than for dry regolith. Burial depths for 0%, 10%, 30%, and 70% volume fraction of ice are shown. No burial depths are plotted at the high latitudes where thermal inertias or humidities from TES are least reliable. In the presence of adsorption, free $H_2O$ frost is not expected within the lightly shaded area at any day of the Mars year

More stable on slopes, areas with low D, etc.

# 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

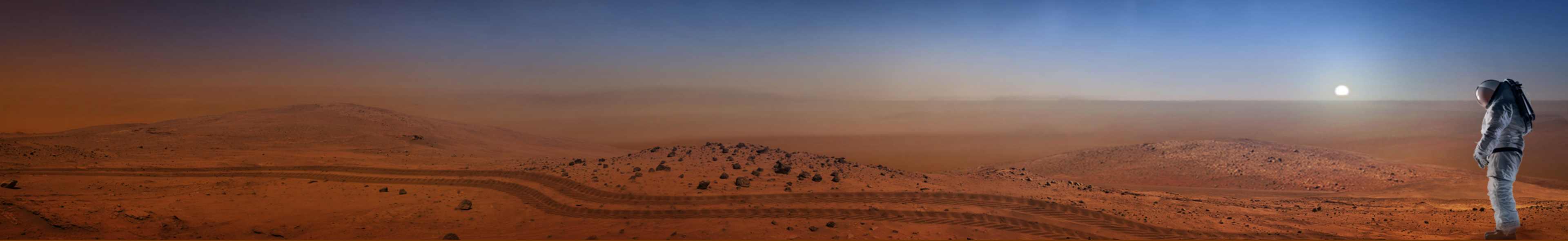
# Available orbital datasets

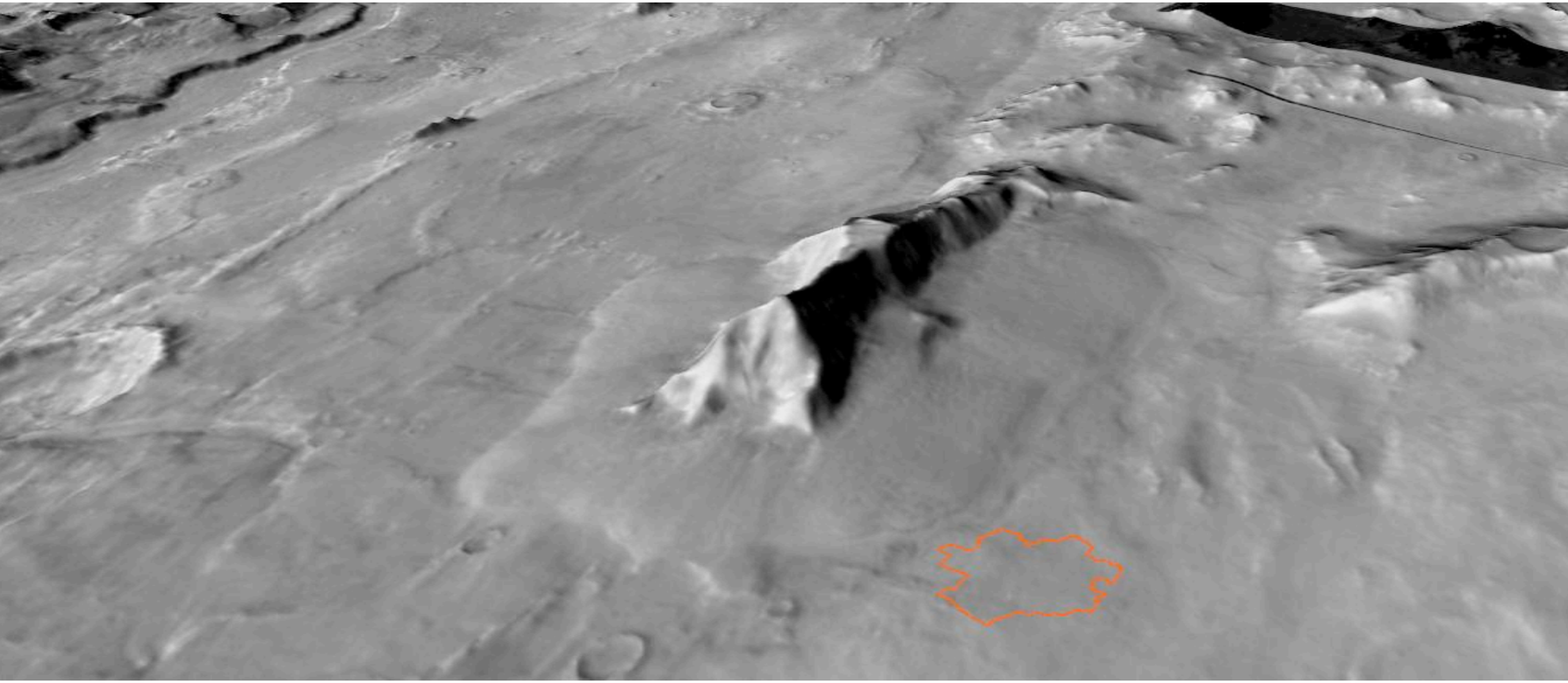
| Dataset | Instrument | Coverage | Spatial Res./Footprint | Where to look at |
|---|---|---|---|---|
| Surface images | HiRISE | 2.4% | Res- 0.25-1 m/px<br>Width- Red: 6km wide, Color: 1.2 km wide, Nominal length- 35km; | http://hirise.lpl.arizona.edu/ |
| | CTX | 95% | Res- 5 m/px<br>Width- 30 km | http://global-data.mars.asu.edu/ bin/ctx.pl |
| | MOC (-2006) | 6% | Res- <12 m/px | http://www.msss.com/moc_gallery/ |
| | HRSC | >90% | Res- 10-60 m/px<br>Swath width- 60 km | http://www.rssd.esa.int/PSA, http://ode.rsl.wustl.edu/mars/ |
| NIR spectral data (e.g., composition) | CRISM | 97% msp VNIR, to 36% hsp IR | Res- 20-200 (msp) m/px<br>msp Footprint: 10 km x 45-540 km | http://crism.jhuapl.edu/gallery/featuredImage/index.php |
| TIR spectral data (e.g, thermal inertia for rock counting, surface texture/ type, subsurface cavities) | TES (-2006) | Near global | Res- 3 km<br>Width- 5.3,<br>Length- 8.3 km | http://tes.asu.edu/data_archive.html |
| | THEMIS | Near global | Res- 100 m<br>Width- 20 km | https://themis.asu.edu/gallery |
| Digital Terrain Models/slope maps | HiRISE | 274 (there are more stereo images) | Meter-scale | http://www.uahirise.org/dtm/ |
| | HRSC | 75% | ~50 m/px | http://hrscview.fu-berlin.de/ |
| | MOLA (-2001 as altimeter) | global | 100s m spacing of points | http://mola.gsfc.nasa.gov/ |
| Radar | SHARAD | 40% | Swath width- 3km, Depth res.- 10m, Depth pen.- 300m | http://pds-geosciences.wustl.edu/missions/mro/sharad.htm |
| | MARSIS | 80% | Swath width- 10km, Depth res.- 100m, Depth pen.- 1km | http://pds-geosciences.wustl.edu/missions/mars_express/marsis.htm |

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

# Ice galore





City of Austin, TX for scale at Euripus Mons