Challenges for Establishing the Chronology Function of Mars using Volcanic Terrains (or other Units) at Mars 2020 Landing Sites

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Mars 2020 mission goals related to chronology

- Threshold Geologic Criteria:
  - "**Noachian/Early Hesperian age based on stratigraphic relations and/or crater counts**"

  And two Potential Qualifying Geological Criteria:

  "4) **Igneous rocks of Noachian age, of known stratigraphic context,** 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."
- Golombek et al. (2016) scientific criterion:

"5) The landing site offers an adequate abundance, diversity, and quality of samples **suitable for addressing key planetary evolution questions** if and when they are returned to Earth."

Challenges in Determining a Chronology

There remains inconsistent methodologies to establish a model chronology using terrain units that occur within the landing site ellipses.

"Landing site agnostic" issues

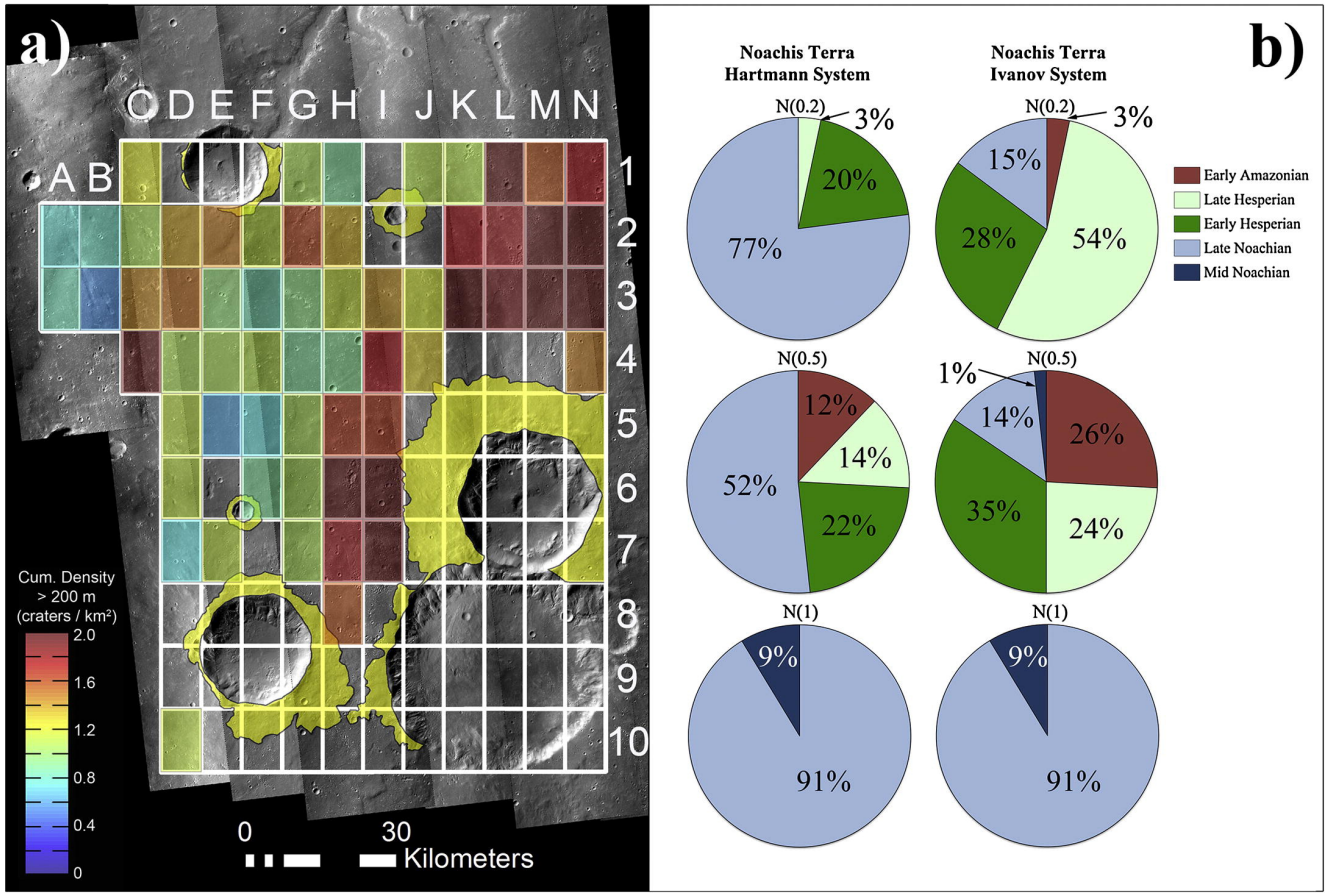
1. Chronology & production functions (Ivanov, Neukum, Hartmann)
2. Epoch boundaries (Werner and Tanaka, 2011; Michael, 2013)
3. Plotting methods & fits (cumulative, incremental, differential)

Ones that we will discuss here:

1. Scales of crater mapping
    1. Data used for mapping (THEMIS, HRSC, CTX, HiRISE)
    2. Minimum diameters – N(1), N(2), N(5), N(n)?
    3. Randomness in the cratering pattern
2. Uncertainties in geologic mapping ("what's volcanic?", "what's the stratigraphic position?")
3. Interpretations of model ages as formation vs. retention

Noachis Terra: Area vs. Age

- Challenges of small area counts <u>at the scale of terrains in the landing ellipses</u> (~100 km^2).
  - Number of craters (limited statistics).
  - Lack of km-sized craters (most <km-sized craters resurfaced since Noachian).
  - 100-m-scale craters represent post-resurfacing population (Hesp. or Amaz. ages common).
  - Clusters and dispersed patterns in the crater distribution (see age variations below).

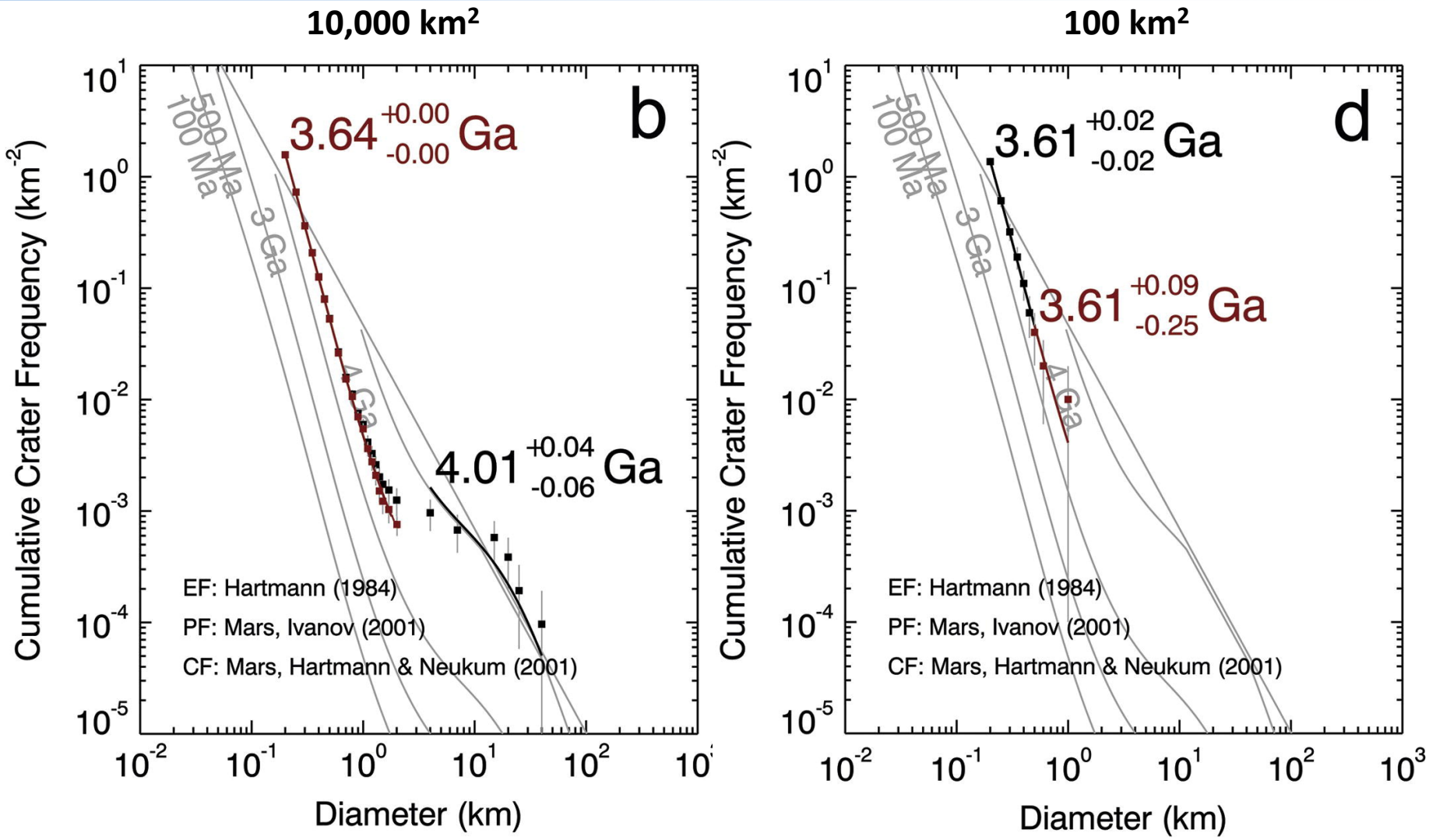


- Also note variation between chosen chronology systems and epoch boundary definitions.

- Using N(0.2) (the best count statistics) is Noachis Terra Noachian, Hesperian, or Amazonian?

Warner et al., "Minimum Effective Area for High Resolution Crater Counting of Martian Terrains" Icarus, V245, p198-240, 2015

Noachis Terra: Area vs. D



Warner et al., "Minimum Effective Area for High Resolution Crater Counting of Martian Terrains" Icarus, V245, p198-240, 2015

Effects of Erosion and Unit Area Size on Crater Retention Age

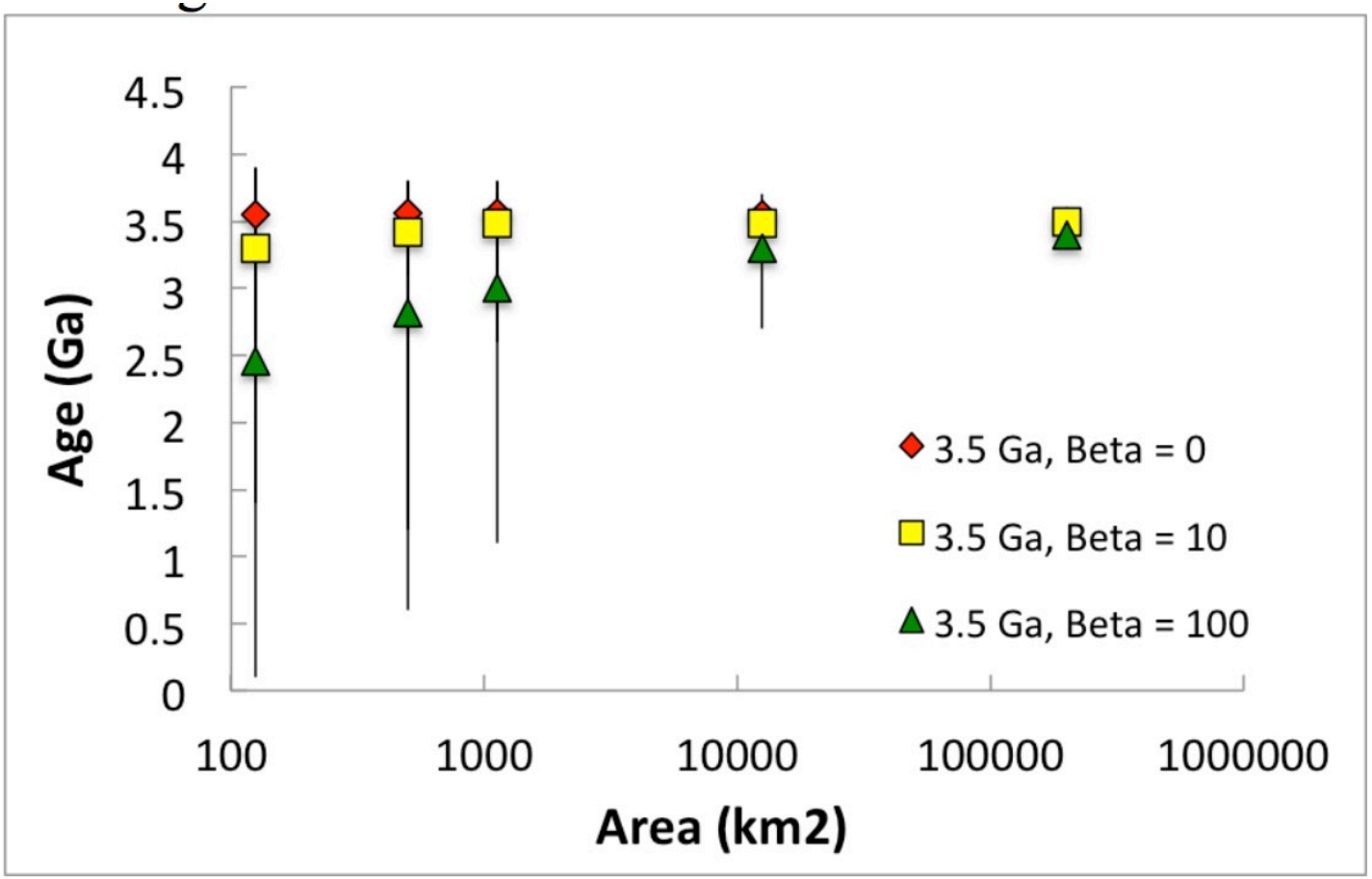
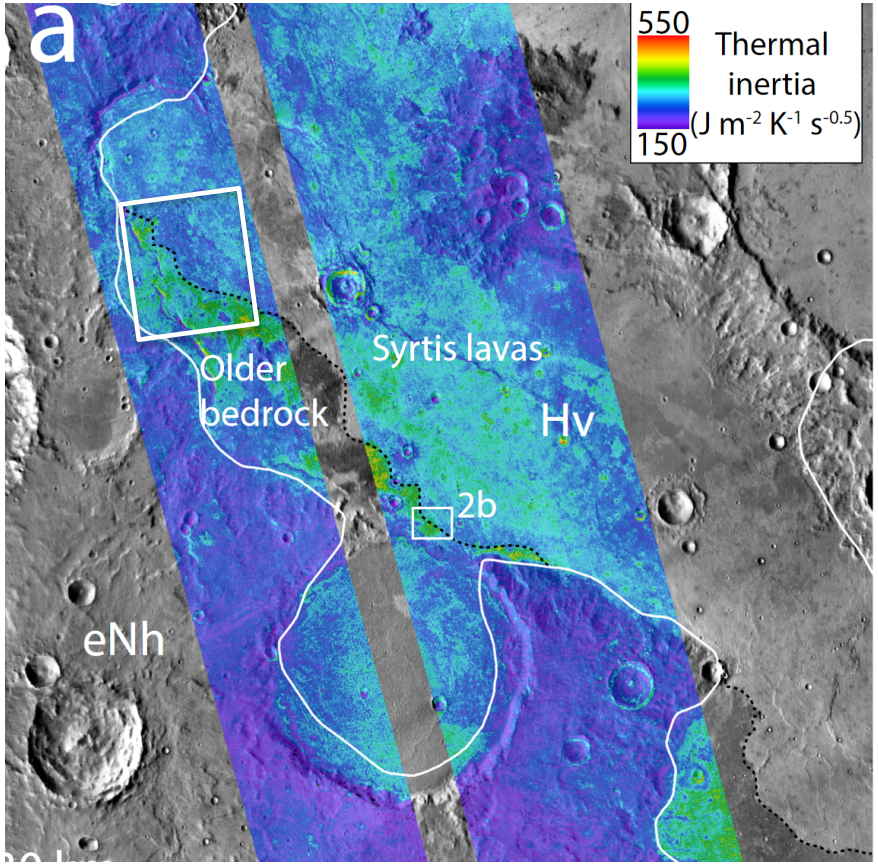


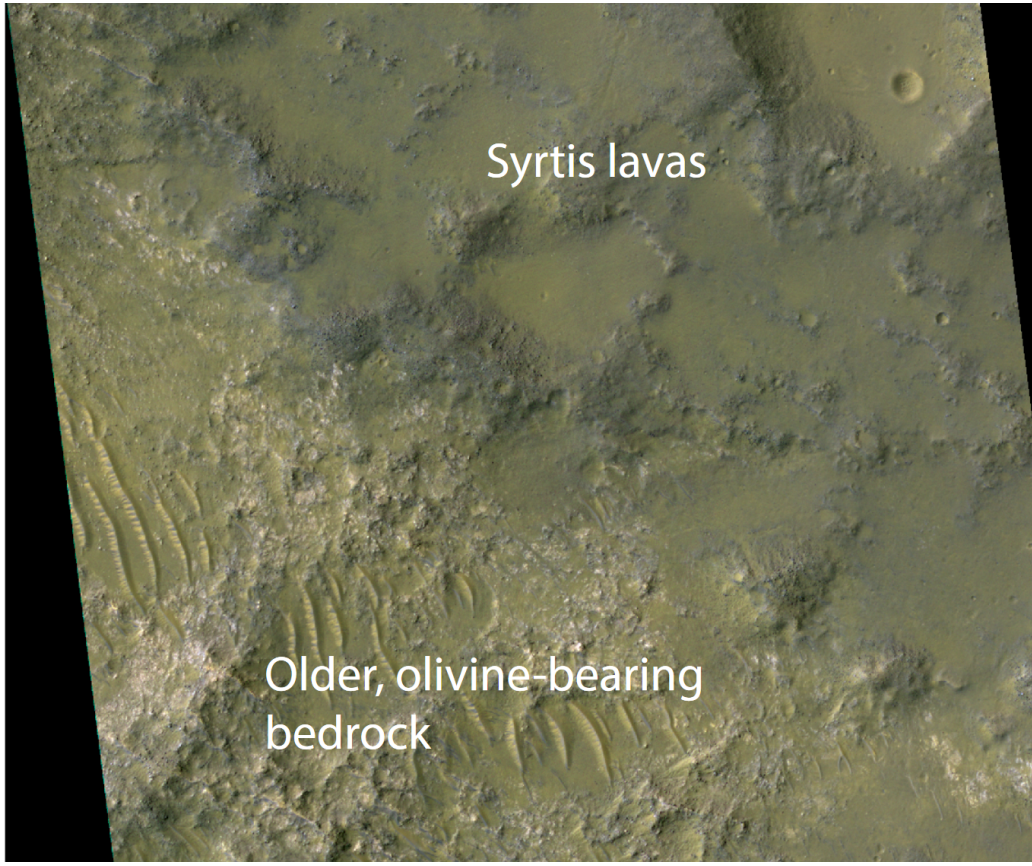
Figure 2. Mean surface age as a function of sampled area (n=1600) for beta = 0 (no erosion), beta = 10 nm/yr (low erosion) and beta = 100 nm/yr (moderate erosion) for an ideal 3.5 Ga surface (per Hartmann 2004 iteration).

Palucis and Dietrich, "How Small is Too Small? A Simple Model for Assessing Uncertainties of Individual Crater Age Measurements for Martian Surfaces" #2353 LPSC 2014

Are all mafic, high thermal inertia units volcanic?

- High TI units in highlands previously mapped as lava plains.
- Multiple high TI units in the Noachian highland crust.
- Many light-toned, olivine bearing units w/poor crater preservation.



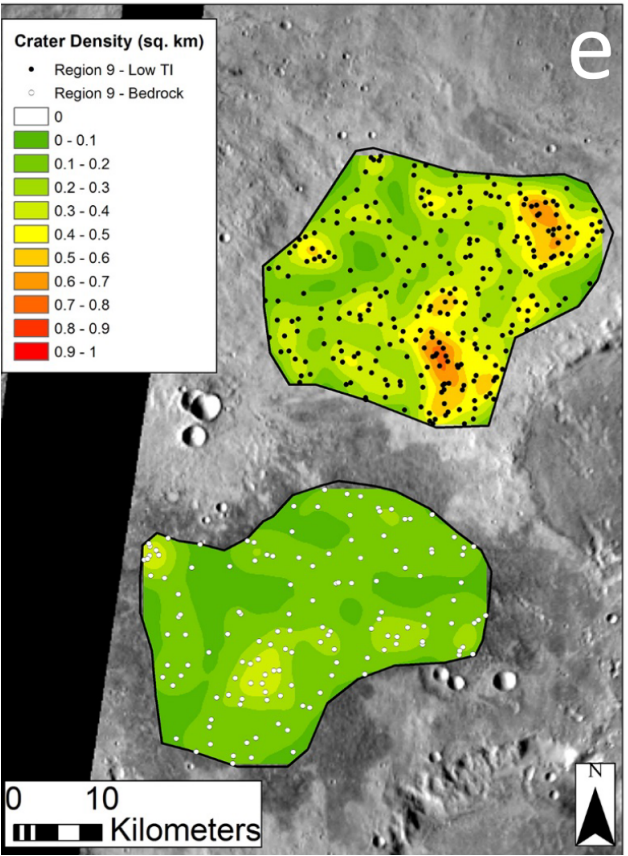


Rogers et al. (2018)

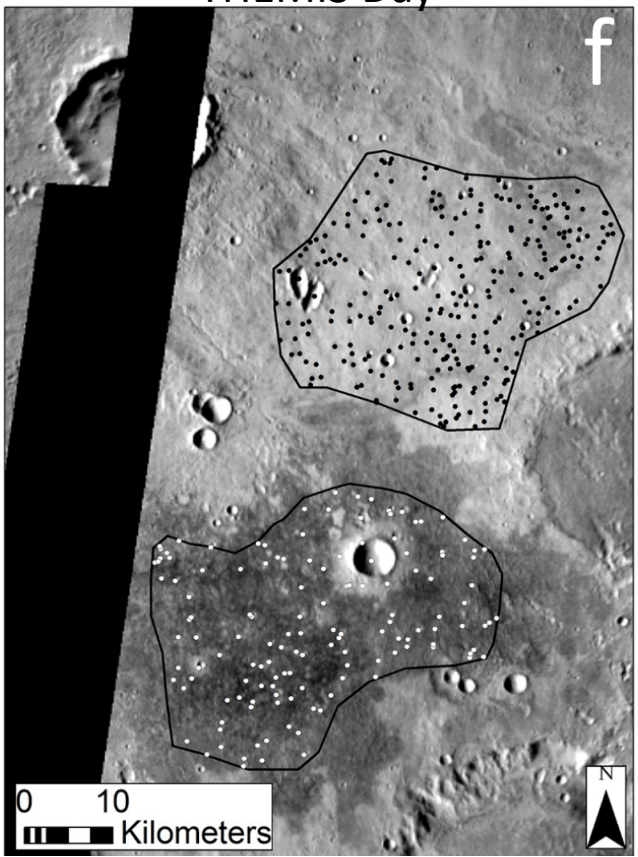
Crater Density Negatively Correlates with High Thermal Inertia

- High TI units may be clastic rocks.
- Hypothesis: regolith development on clastic rocks results in production of mobile sand-sized fines that are stripped by eolian processes (constant resurfacing).
- Hypothesis: regolith development on volcanic units produces a fragmentation rock-size distribution (fine sand to boulders) that is relatively immobile (e.g. Gusev regolith).

Rogers et al. 2018



THEMIS Day



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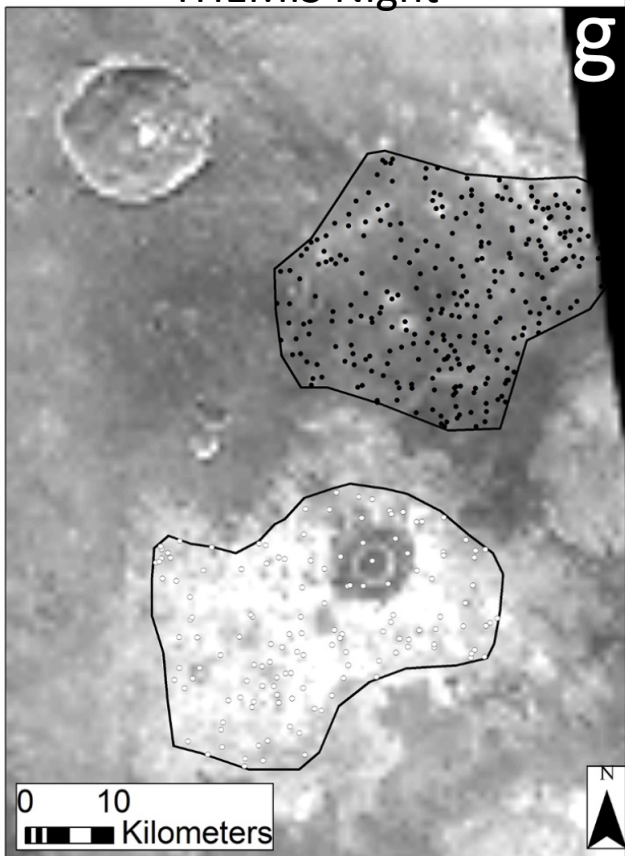
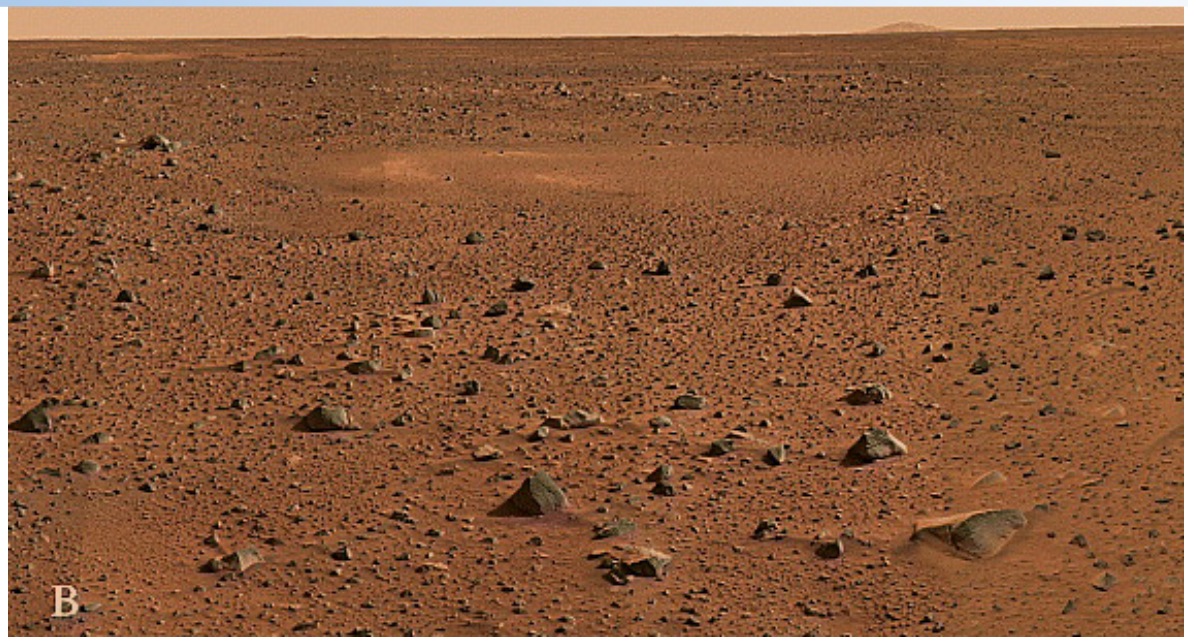


Regolith at Gusev vs. Meridiani



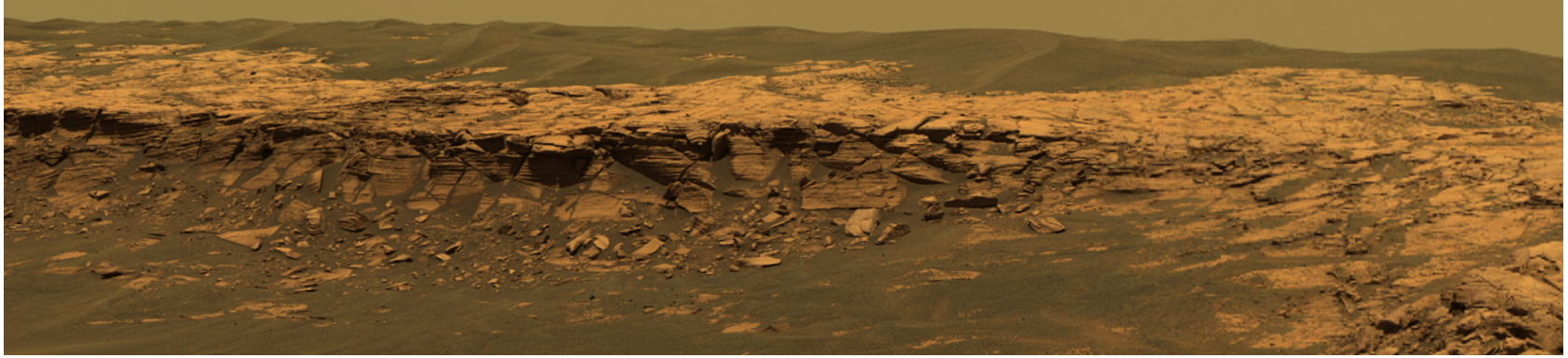
Gusev crater

- ~10 m thick regolith
- Dust coating, fine sand to cobbles.
- Moderate TI

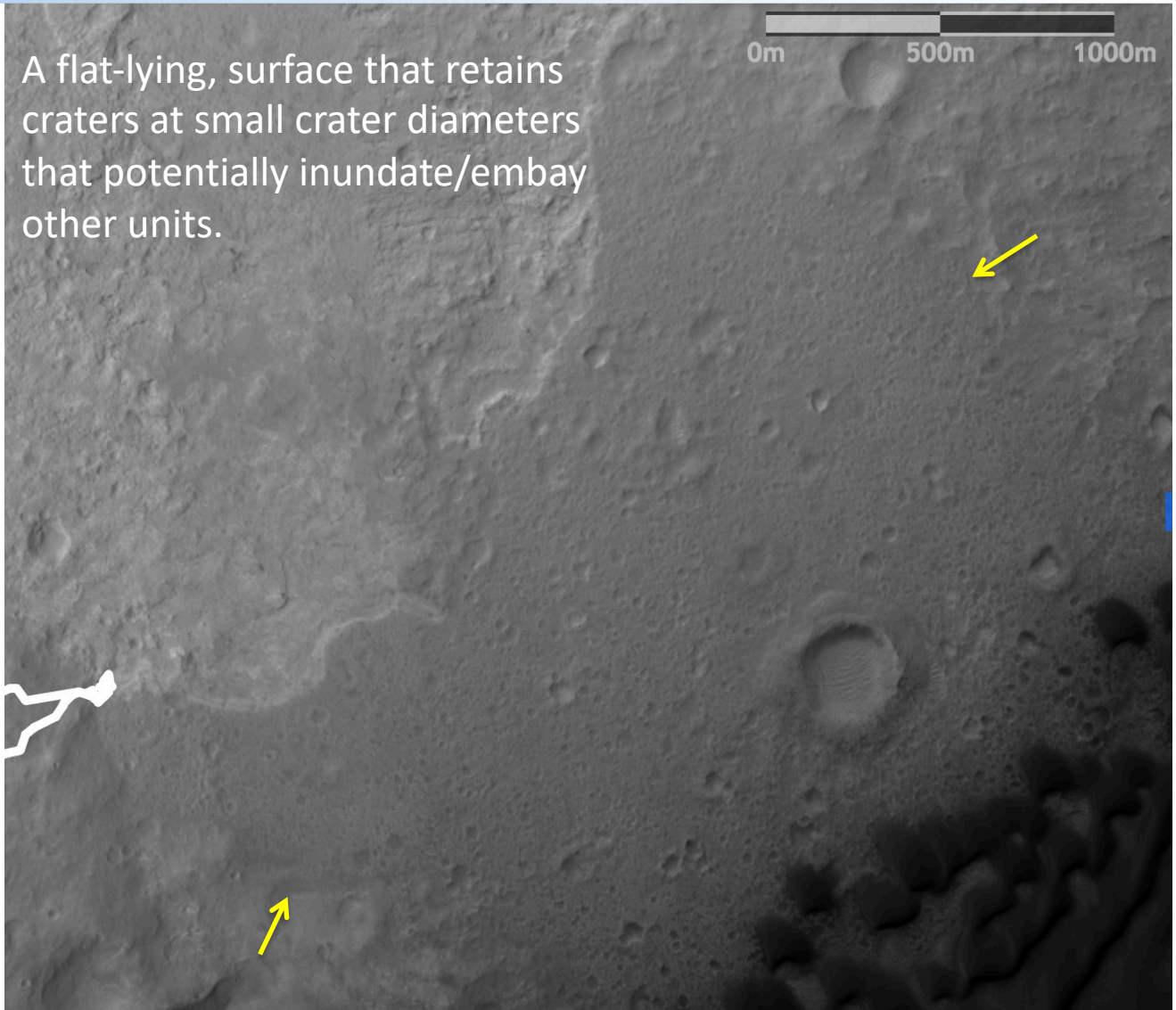
Geology of the Gusev cratered plains from the Spirit rover transverse, Volume: 111, Issue: E2, First published: 12 January 2006, DOI: (10.1029/2005JE002503)

Meridiani Planum

- No regolith
- High TI sandstone overlain by sand ripples & dunes



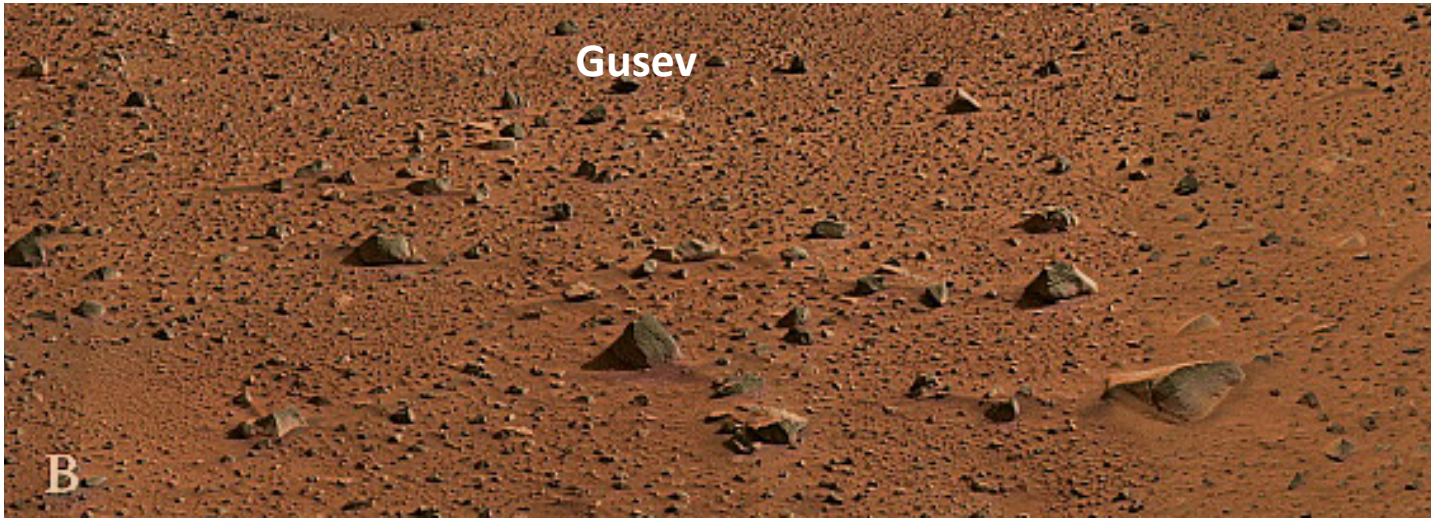
Are all units with high crater retention volcanic? Gale Crater "cratered surface unit"

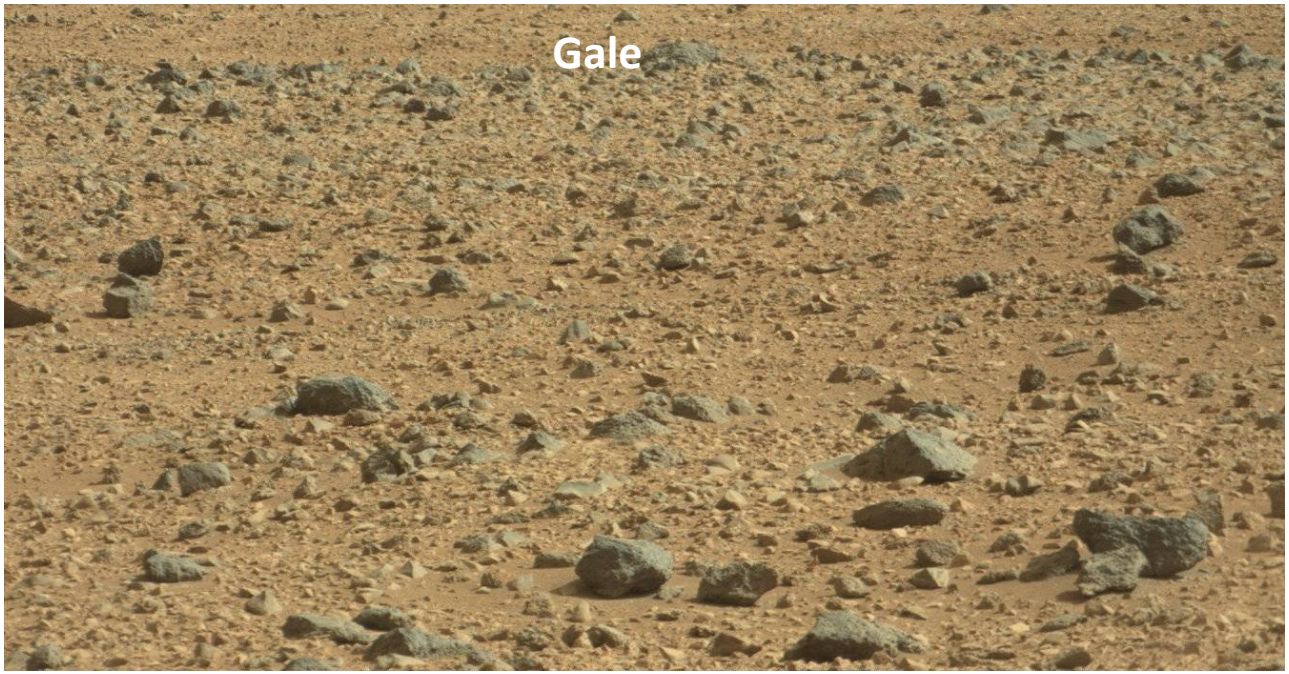


A flat-lying, surface that retains craters at small crater diameters that potentially inundate/embay other units.

Gale Crater compared to Gusev Plains

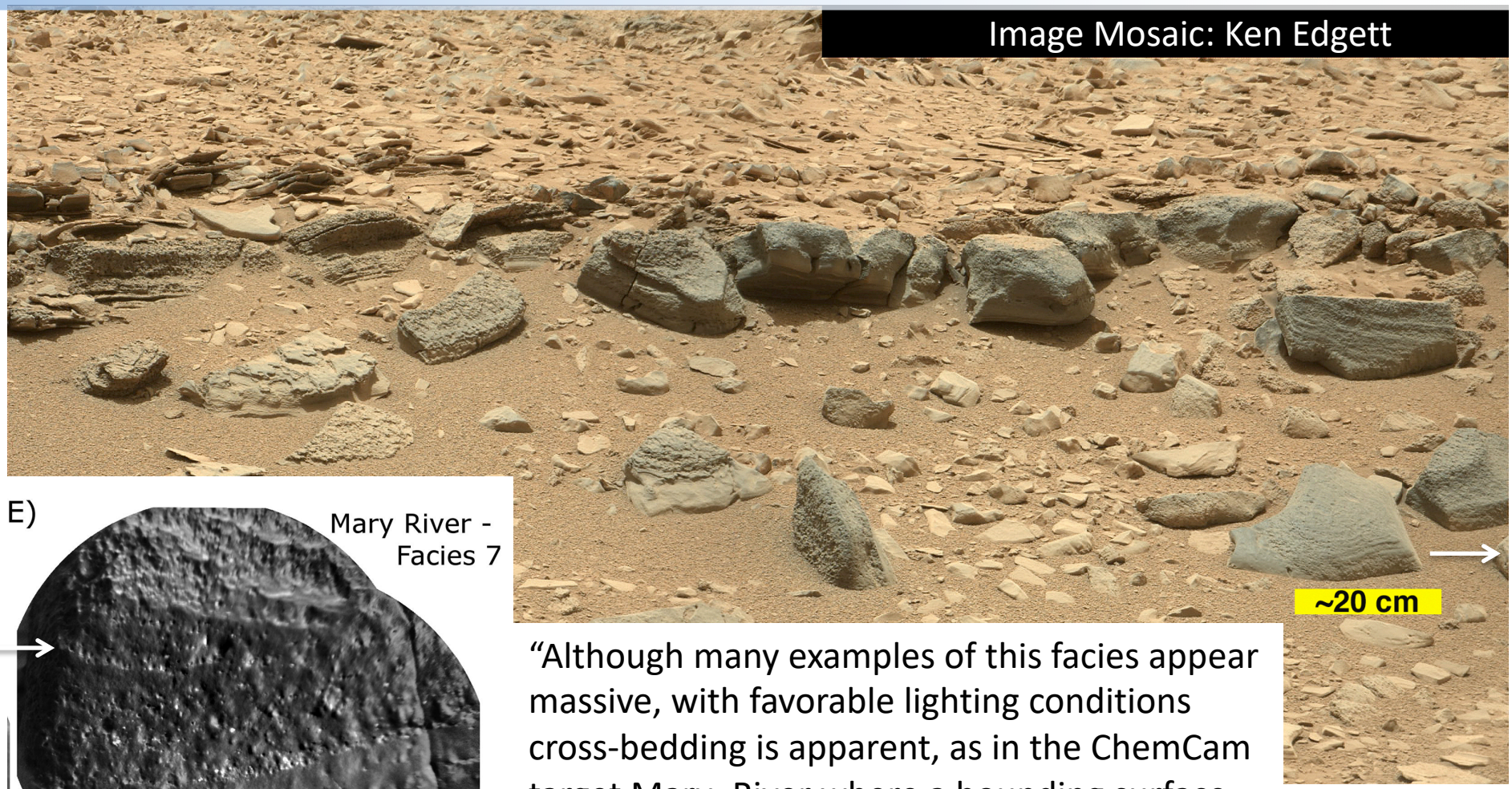
Geology of the Gusev cratered plains from the Spirit rover transverse, Volume: 111, Issue: E2, First published: 12 January 2006, DOI: (10.1029/2005JE002503)

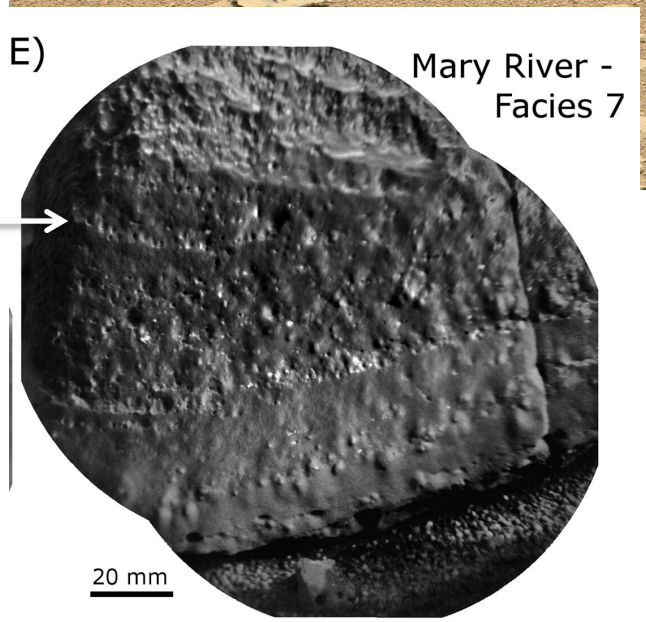




Cratered surface unit in Gale Crater overlooking Shaler outcrop. M100, NASA-JPL/MSSS.

Gale Crater “cratered unit” – sedimentary structures



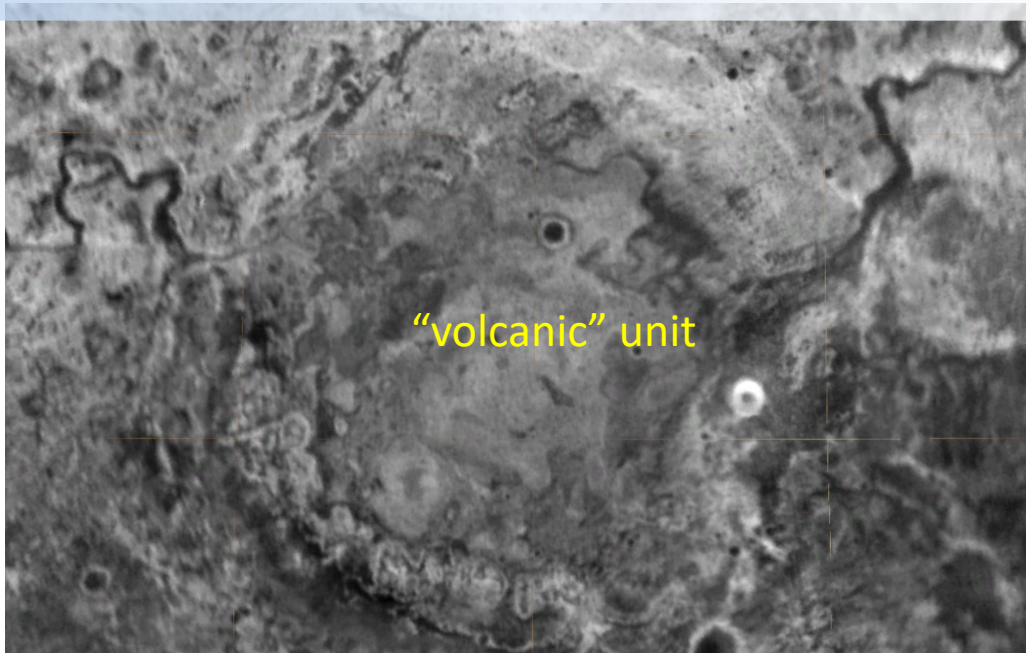


“Although many examples of this facies appear massive, with favorable lighting conditions cross-bedding is apparent, as in the ChemCam target Mary_River where a bounding surface between two bed sets is preserved.” – Anderson et al. 2015

Cratered surface unit in Gale Crater overlooking Shaler outcrop. M100, Sol 309. NASA-JPL/MSSS/Ken Edgett.

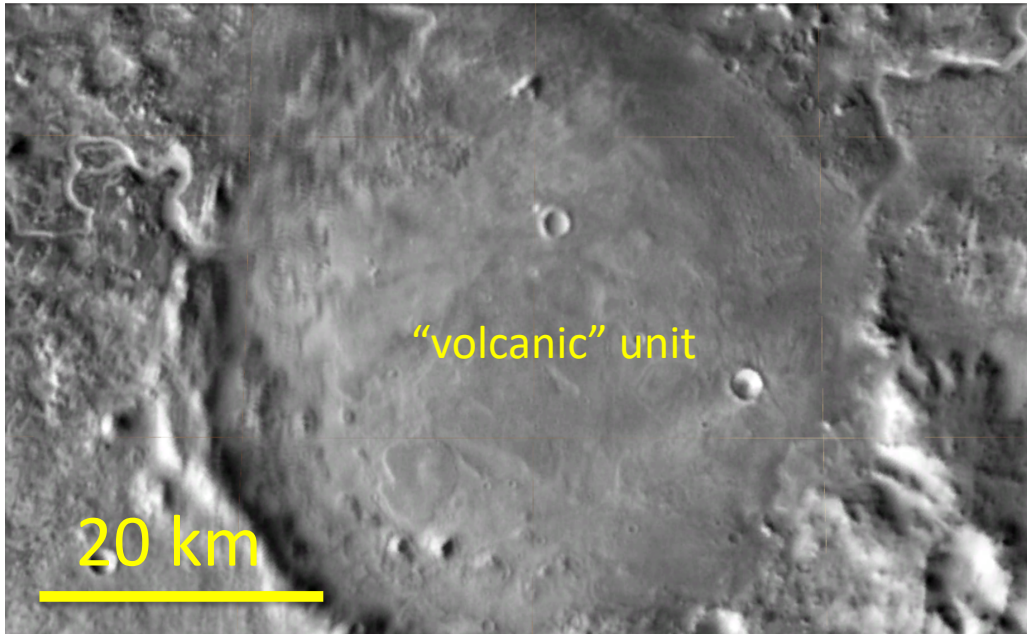
Moderate to High TI units in Jezero

THEMIS Night

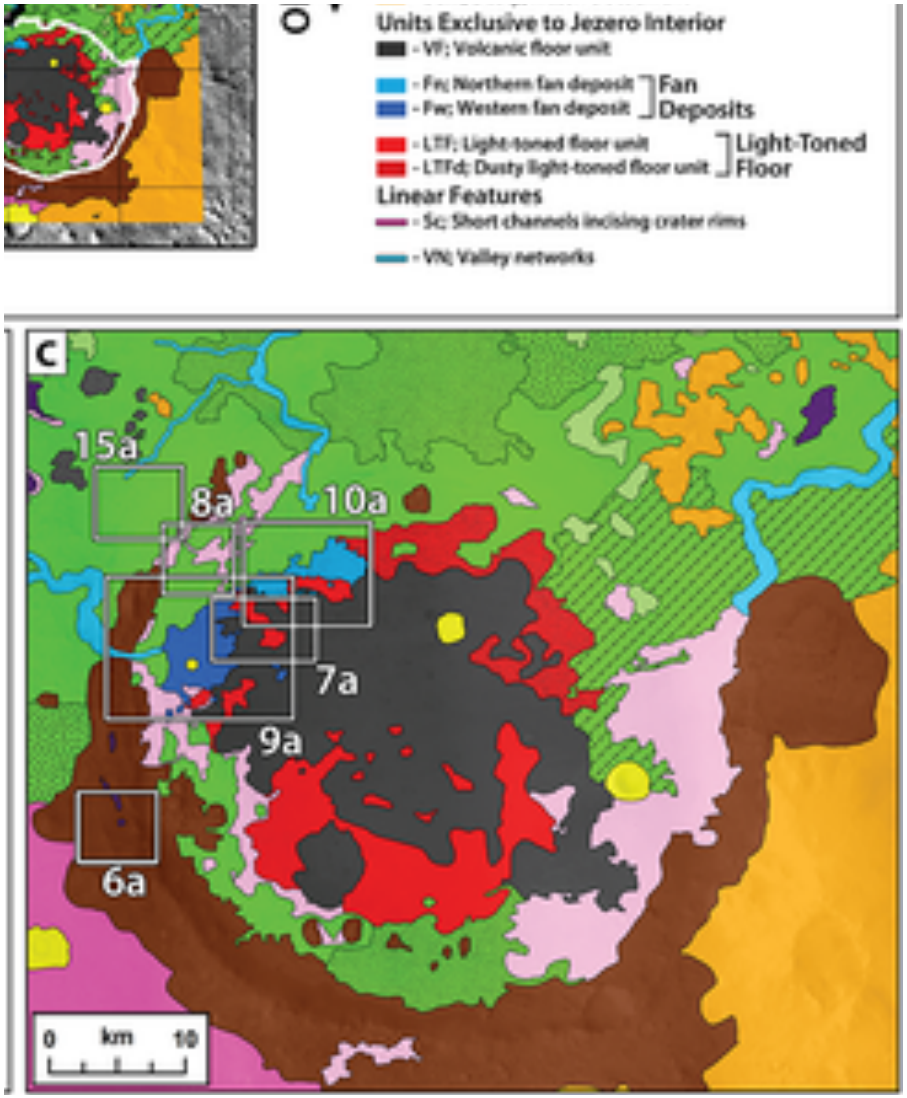


Volcanic, clastic, or volcaniclastic?

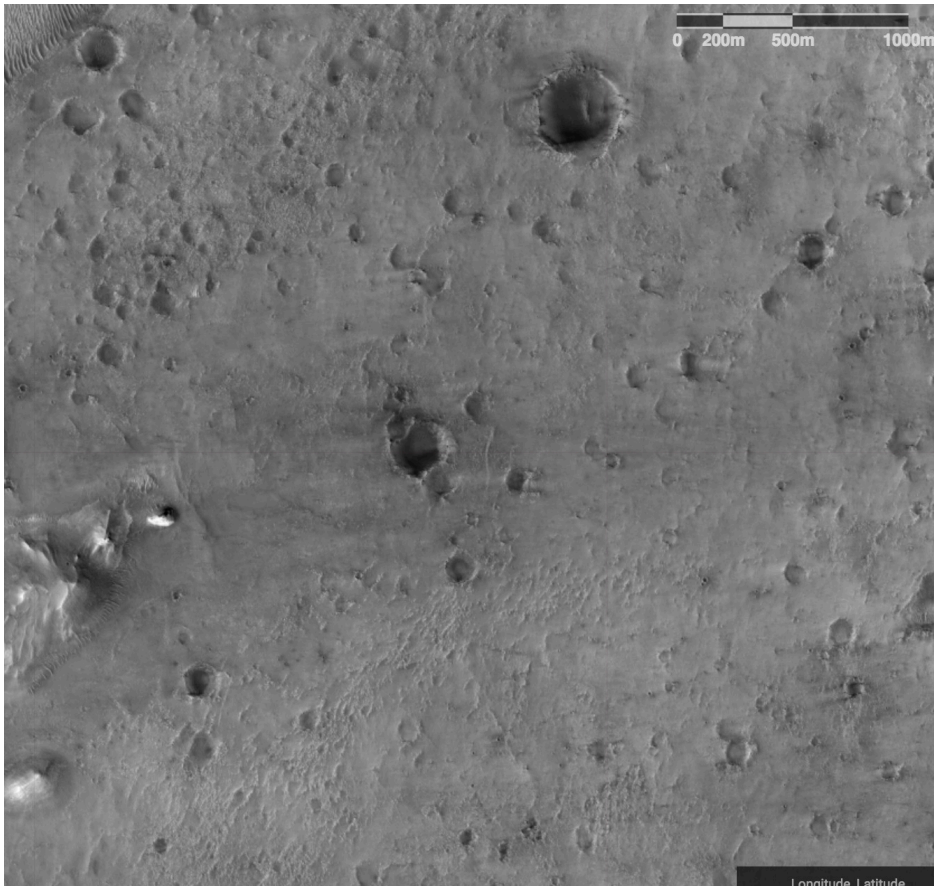
THEMIS Day



Jezero Crater – Volcanic Unit



"Volcanic unit" covers a limited area with few km-scale craters.
Craters are somewhat degraded, shallow, D < 1 km



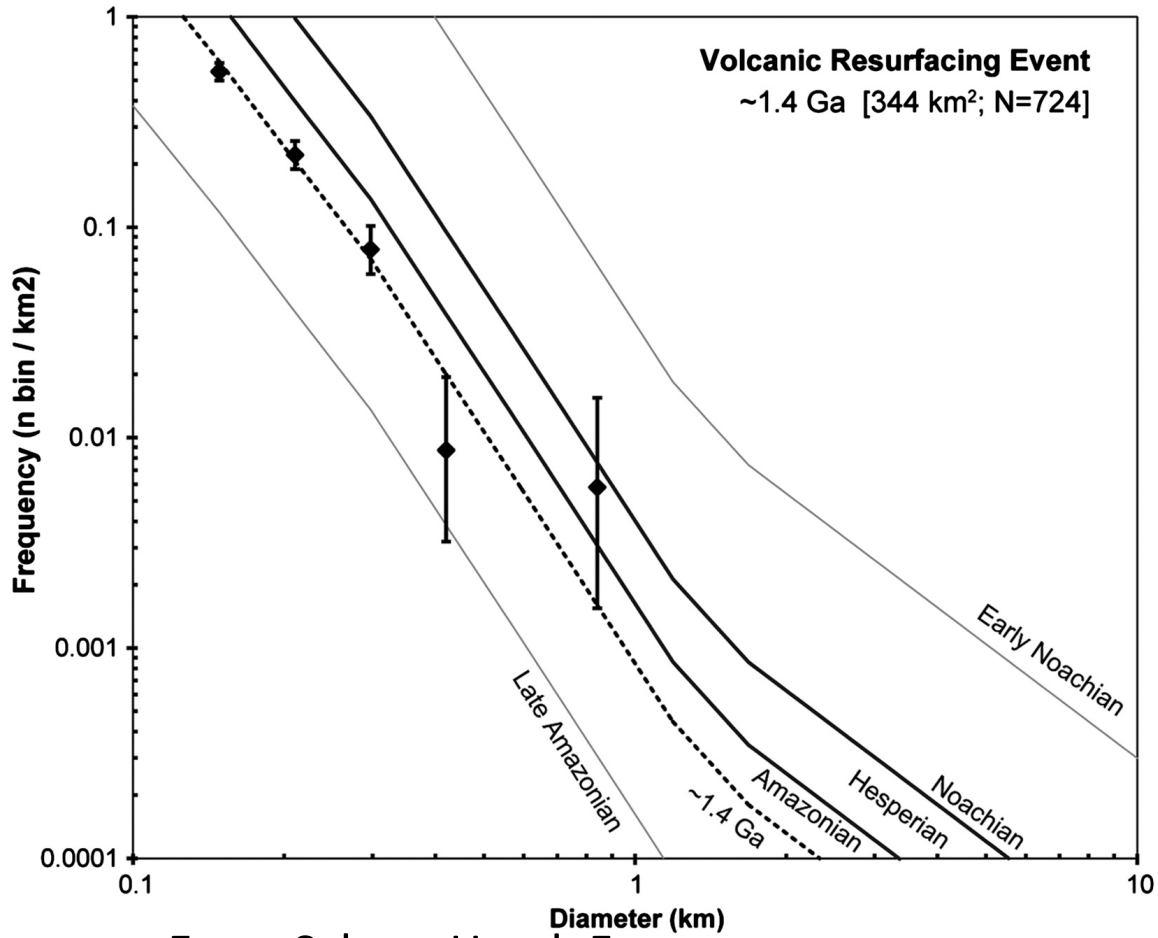
Example: Jezero Volcanic Unit

- There is a fundamental issue if we use spatially restricted volcanic terrains in the landing sites to establish the chronology function of Mars.

- Is the size frequency distribution that we see representative of the crystallization age of that unit?

- Example: Jezero crater volcanic unit at 344 km^2 = 1.4 Ga.

- Small area and statistics = lack of km-sized craters and potential for non-representative clustered or dispersed crater patterns.

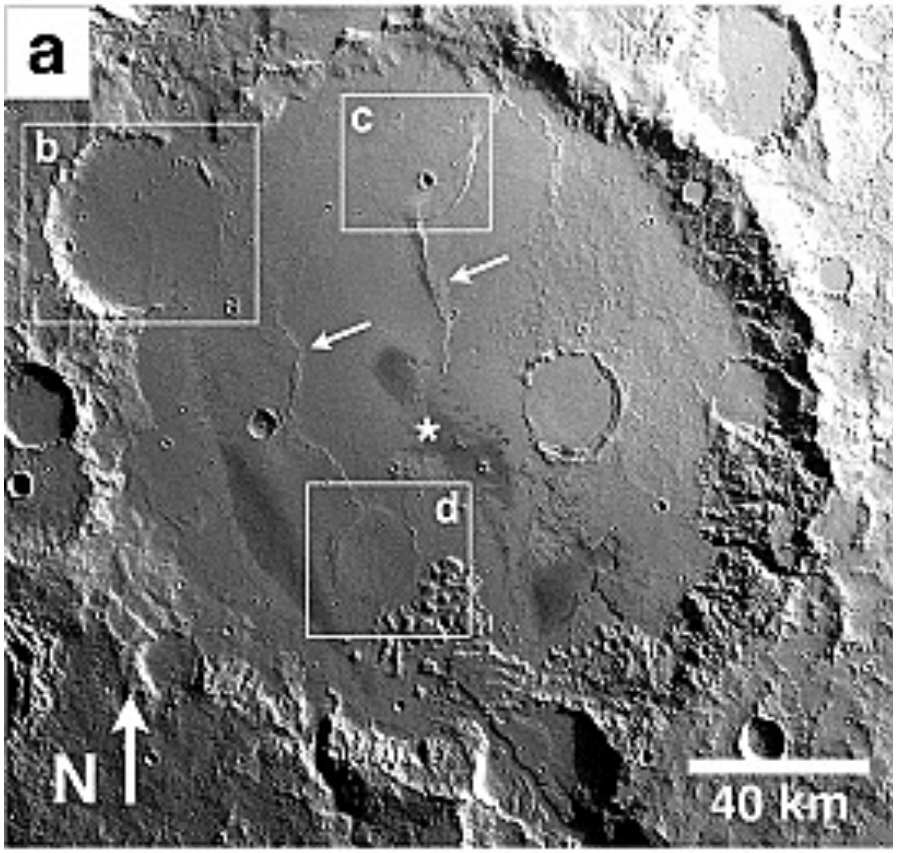


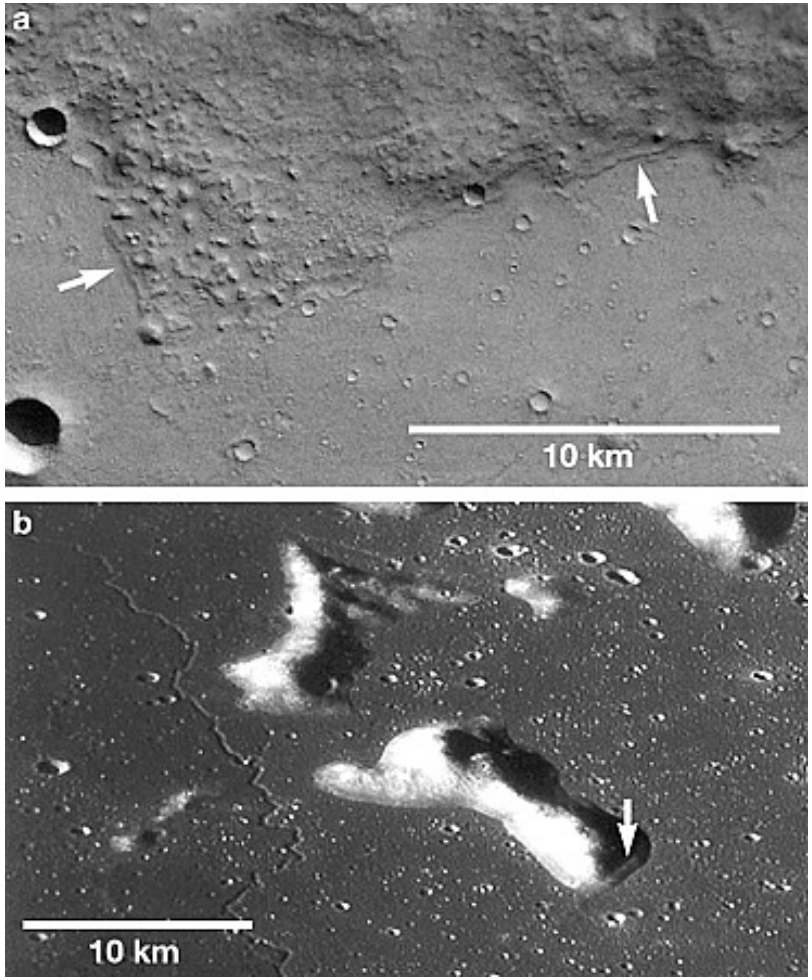
From Schon, Head, Fassett

https://doi.org/10.1016/j.pss.2012.02.003

" An overfilled lacustrine system and progradational delta in Jezero crater, Mars: Implications for Noachian climate"

Columbia Hills Offers a Well-Defined Volcanic Unit over > 1,000 km^2

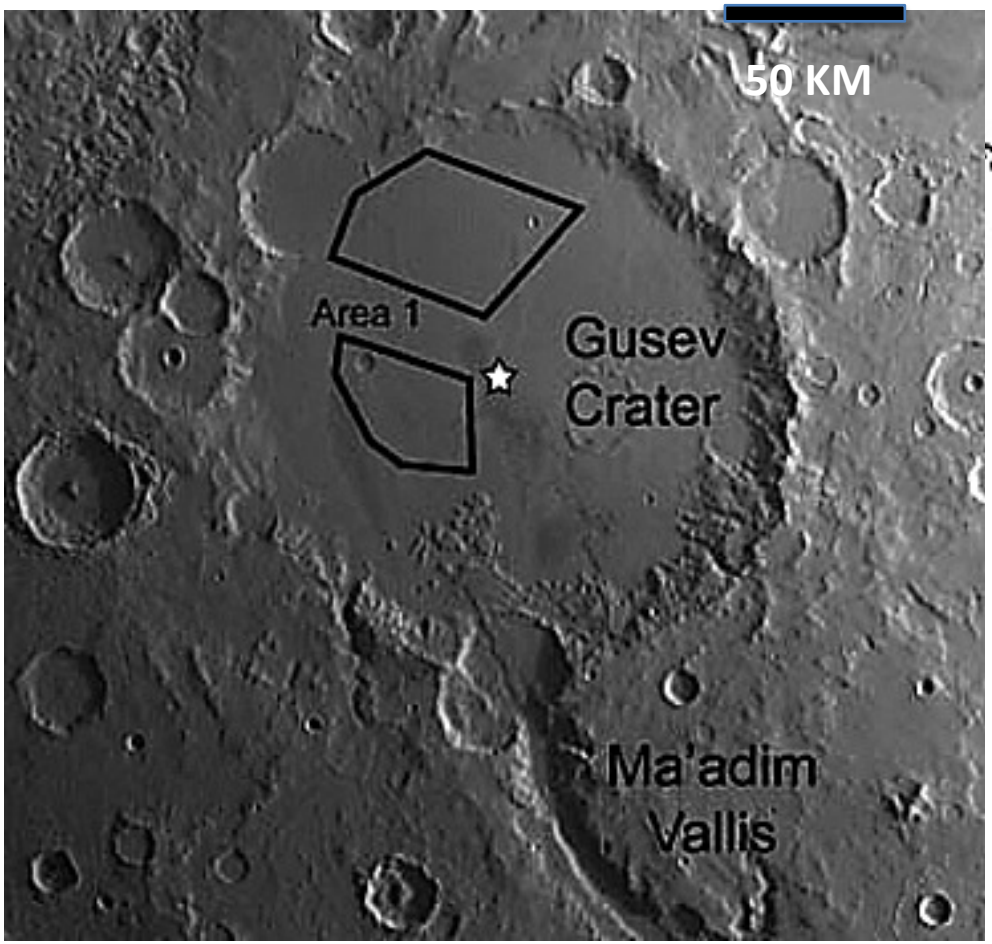


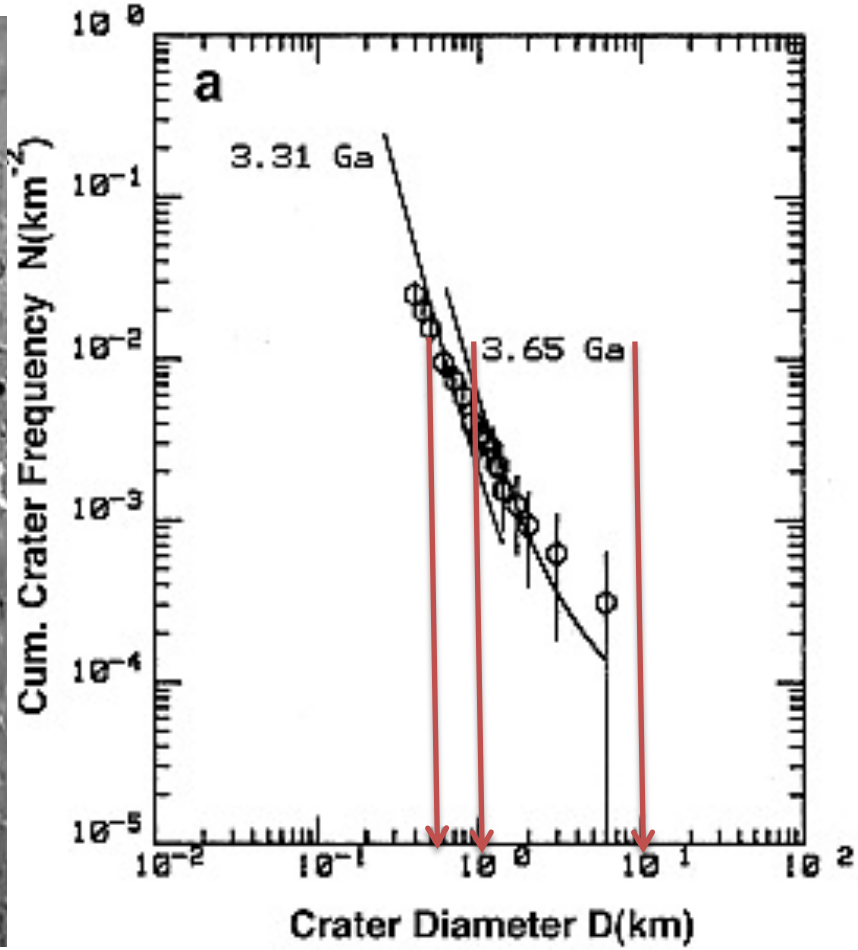


From Greeley et al.

Fluid lava flows in Gusev crater, Mars, Volume: 110, Issue: E5, First published: 21 May 2005, DOI: (10.1029/2005JE002401)

However, which N(D) do you choose?
Are these unique chronostratigraphic units?





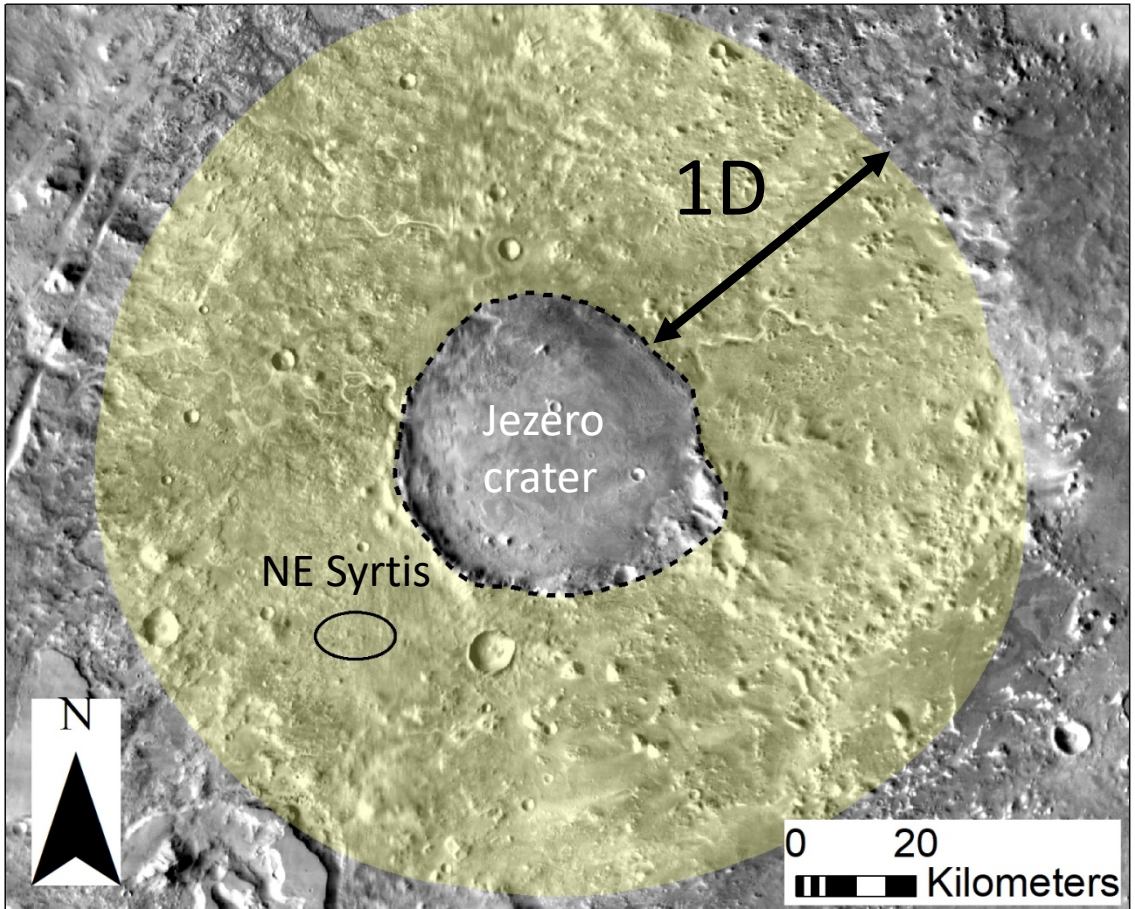
Greeley et al., **Fluid lava flows in Gusev crater, Mars, Volume: 110, Issue: E5, First published: 21 May 2005, DOI: (10.1029/2005JE002401)**

Stratigraphic Relationships of Ejecta

- NE Syrtis & Midway offer a unique opportunity to sample Noachian-age impact breccias and possibly impact melts
- Dates from Isidis could define the base of the Noachian.
- Scale of Isidis basin is ideal for establishing regional stratigraphic relationships (although ejecta not preserved).
- Similar methods used for establishing the lunar chronology function (e.g. Nectaris, Imbrium, Eratosthenes, Coperincus).
- What are the challenges?

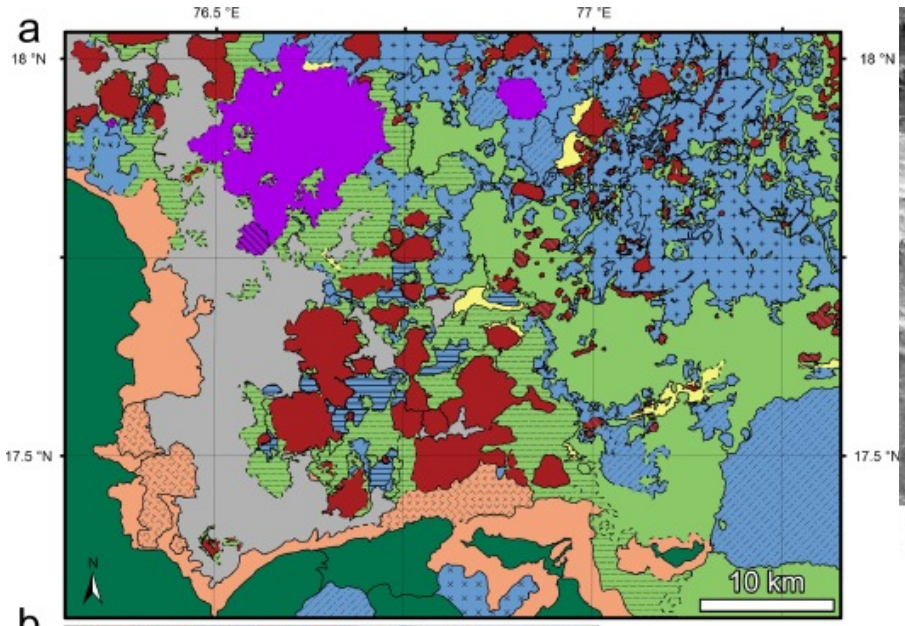
Stratigraphic Challenge

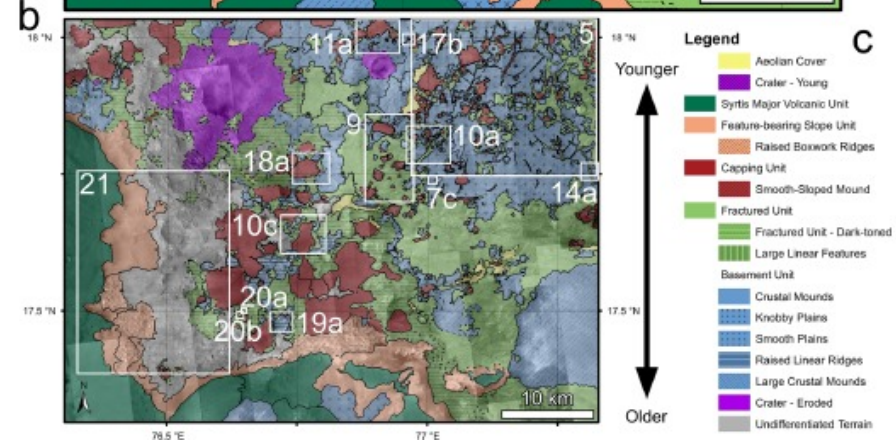
- By nature of it's age (Early Noachian, Werner, 2007) the Isidis basin is superposed by multiple 10 km-scale craters with overlapping ejecta, challenging orbital and in-situ stratigraphic interpretations.
- For example, NE-Syrtis and Midway landing sites are within 1D range (continuous ejecta) of Jezero crater.

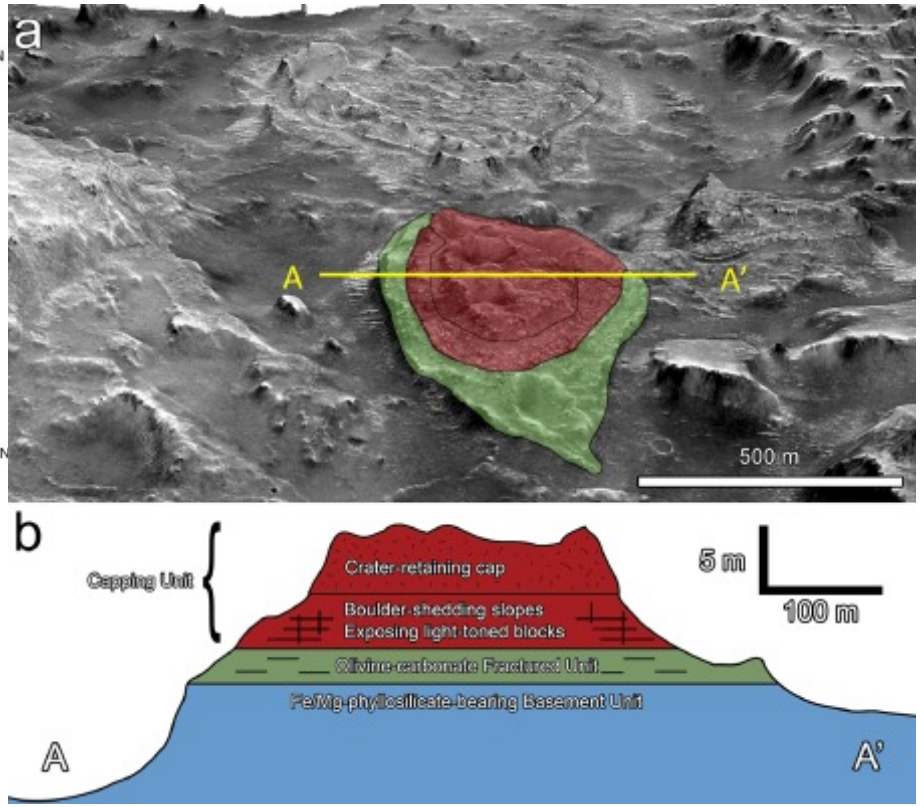


NE Syrtis/Midway Geology

Geologic unit areas are small and dissected. Few (any?) D >= 1km craters covering purported volcanic/impact units.







Do we see these units elsewhere with more craters to count?
Are they volcanic or just more indurated than what's below them?

Bramble et al. 2017

Sampling Breccias

14051 (6) Impact melt breccia

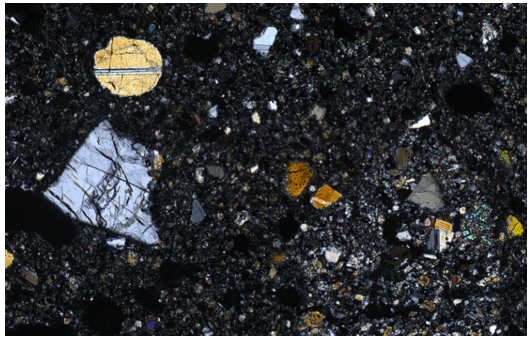
Images: NASA/LPI

VIEW MICROSCOPE

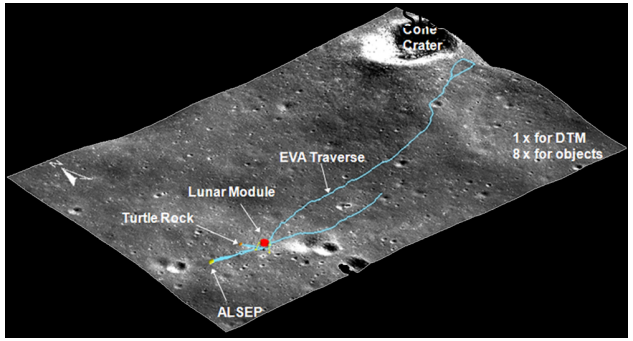
Fact sheet

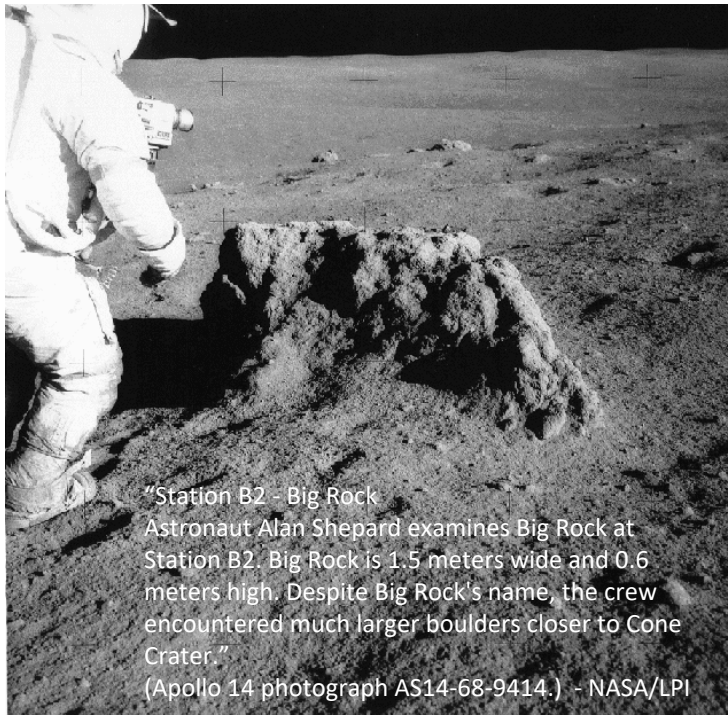
The sample weighed 191.3 grams before analysis and is 3.71±0.05 Ga old (Ar/Ar).

"The Apollo 14 landing site was in a region formed by impact-basin debris. Most of the 42 kilograms of rocks and soil collected on Apollo 14 are breccias. In some cases, the rock fragments that form a breccia are themselves breccias. Such rocks obviously have experienced complex histories with multiple generations of impact events. "
https://www.virtualmicroscope.org/content/14311-86-impact-melt-breccia



Credit: NASA/Goddard/Arizona State University/The Ohio





"Station B2 - Big Rock
Astronaut Alan Shepard examines Big Rock at Station B2. Big Rock is 1.5 meters wide and 0.6 meters high. Despite Big Rock's name, the crew encountered much larger boulders closer to Cone Crater."
(Apollo 14 photograph AS14-68-9414.) - NASA/LPI

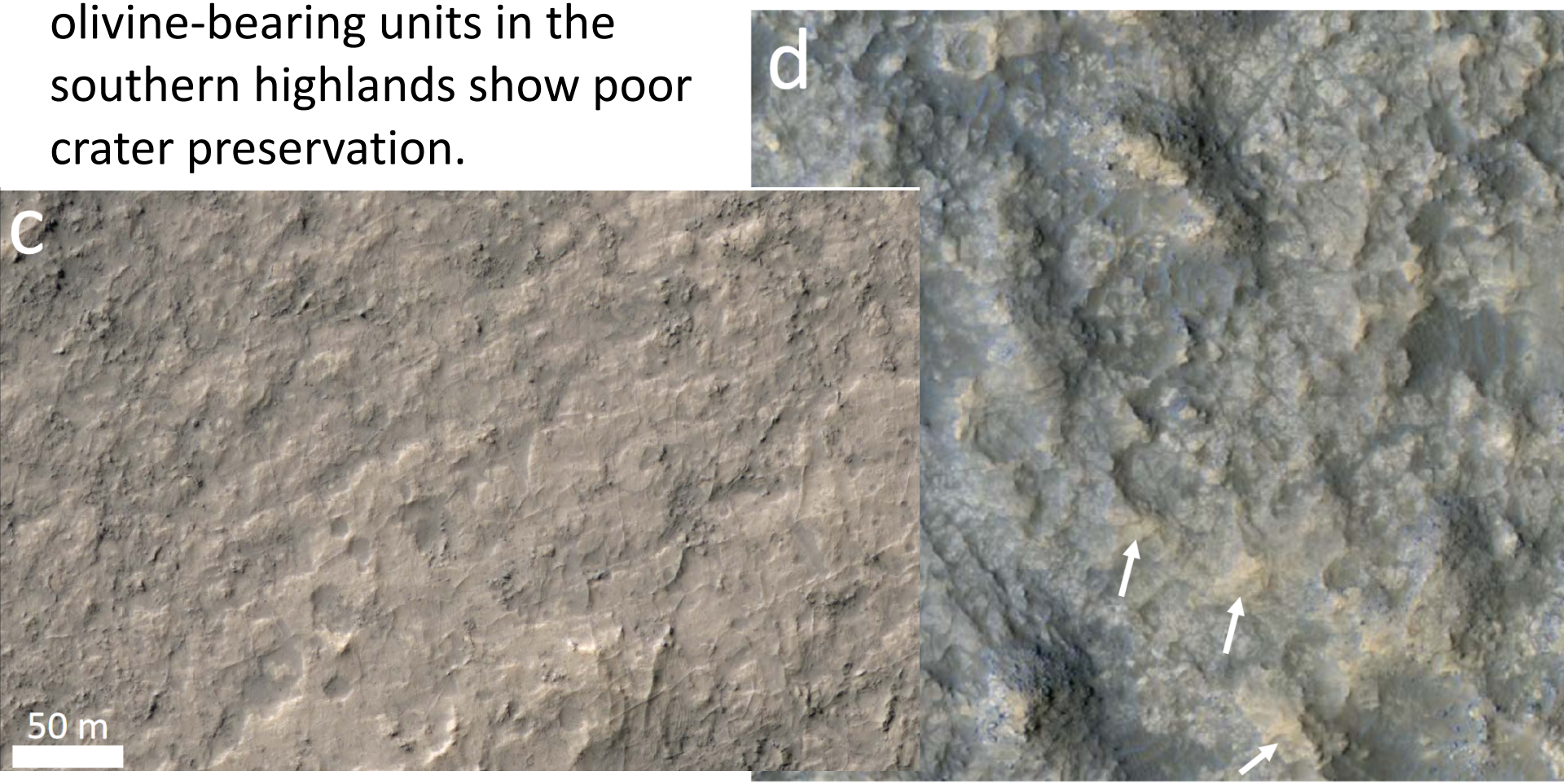
Discussion/Conclusion

- Finding a large (>=1000 km^2) contiguous geologic unit that retains craters and is well bounded by regional stratigraphy can be challenging.
- Columbia Hills contains a volcanic unit identified from orbit and verified on the ground. No mega breccias identified by the Spirit rover in Columbia Hills. Is there impact melt there? What does dating Columbia Hills mean?
- Jezero Crater has a mapped 'volcanic unit' with some consistent geomorphic expression (embayment, deflation levees). However, areal coverage is small (~3-400 km^2) and may only have a younger crater population. Mega breccias have been identified, but what is there origin?
- NE Syrtis (or MDW) have highly dissected "volcanic units" with few preserved craters, especially at km-scale D. No obvious volcanic morphology, other than being more resistant/boulder-shedding.
- Mega breccias identified at NE Syrtis and Jezero may be from the Isidis impact or several nearby impact structures as noted in Bramble et al. 2017. May prove difficult to disentangle breccia origin from multiple potential crater sources.
- Oldest dated breccias on Earth are ~2 Ga and altered. Will impact melt devitrify after 3-4 Ga?

Backup Slides

High TI, Olivine-Bearing Units?

- Many of the Noachian high TI olivine-bearing units in the southern highlands show poor crater preservation.

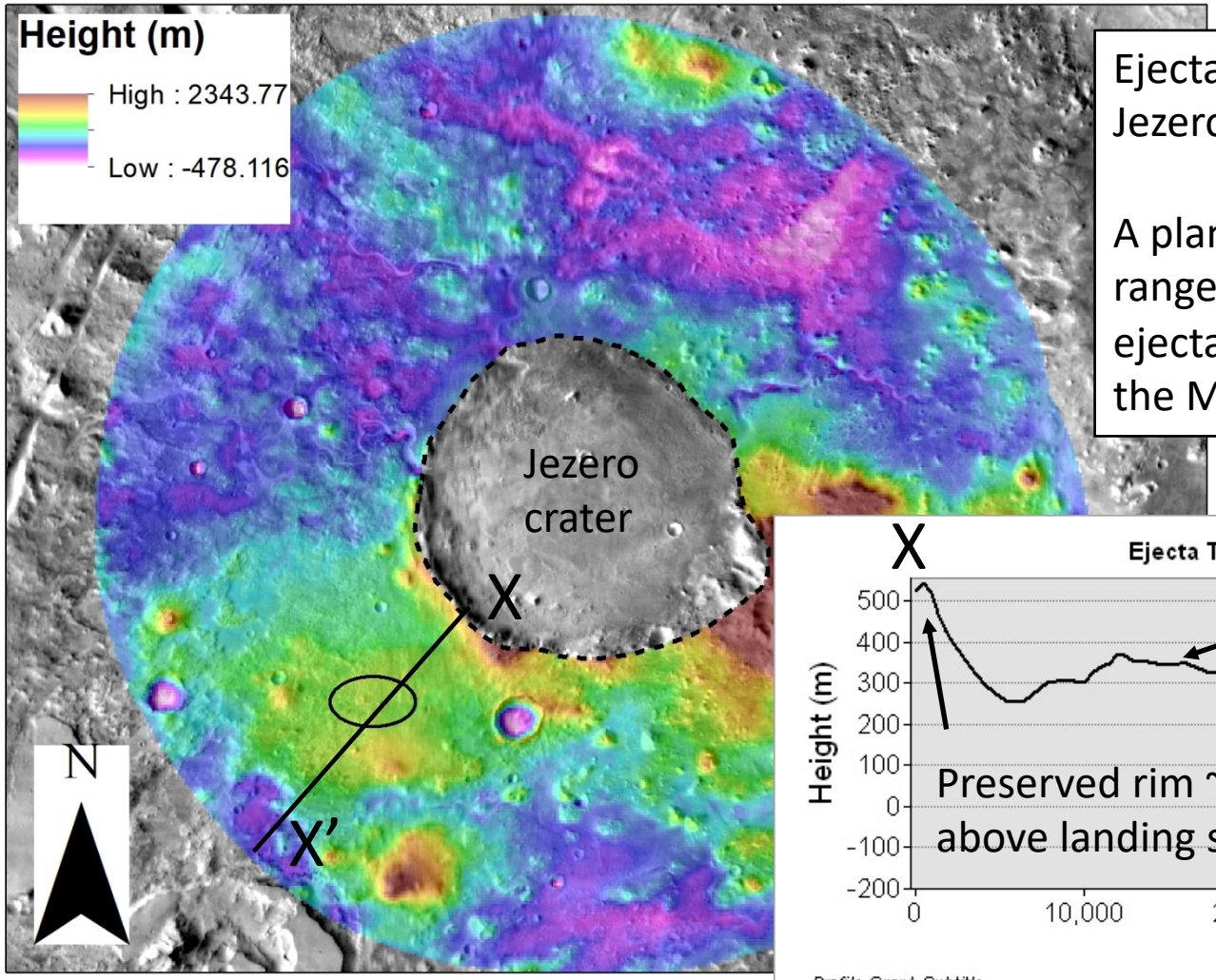


Rogers et al. 2018

Ejecta Denudation

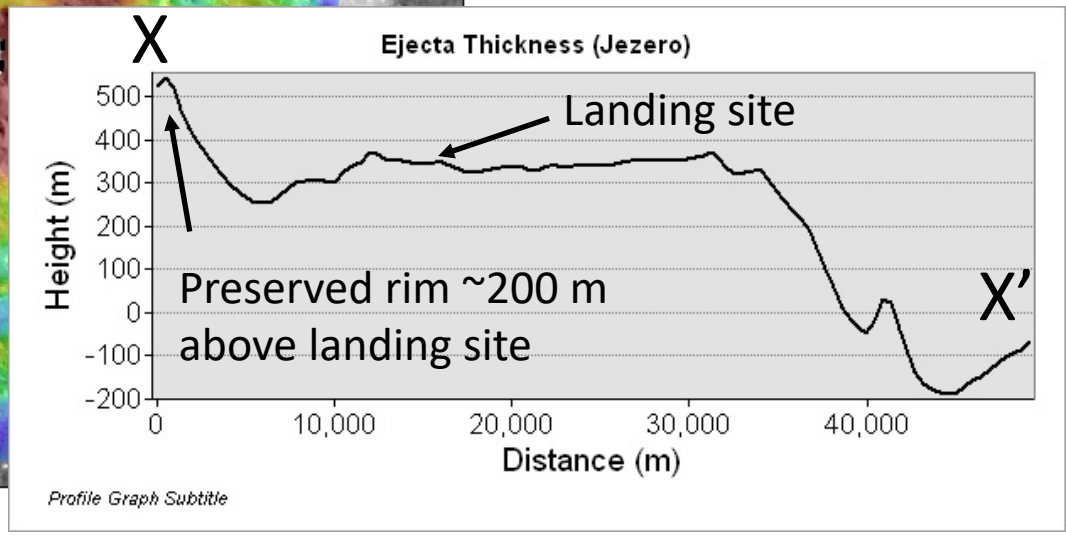
- Potential Jezero ejecta, if present, is significantly degraded (particularly to north), but remnants may be preserved (southern rim/ejecta may be preserved).

Work by N. Warner



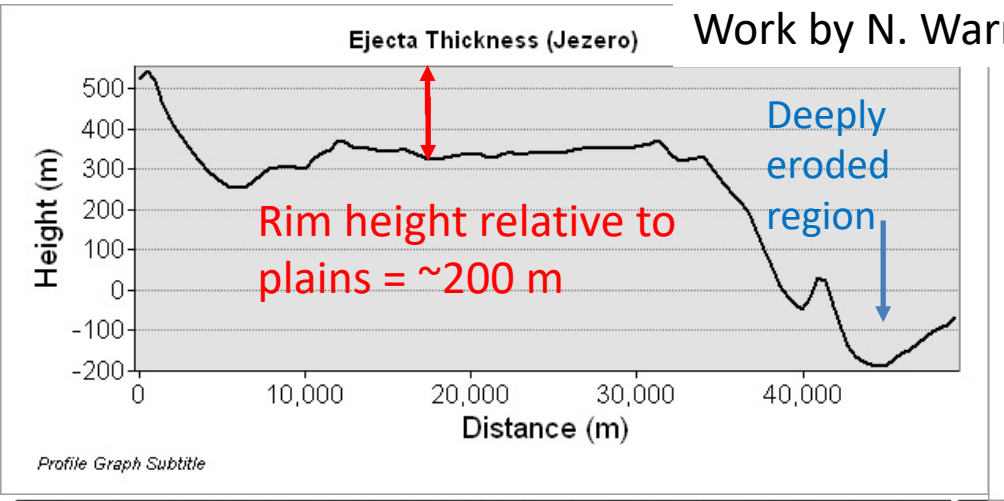
Ejecta thickness map for Jezero crater.

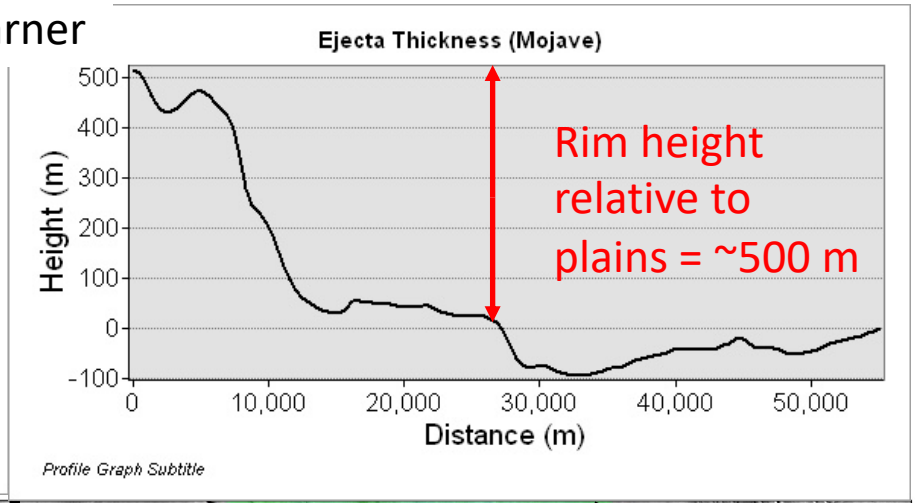
A plane was fit to the 1D range of the continuous ejecta and subtracted from the MOLA gridded DEM.

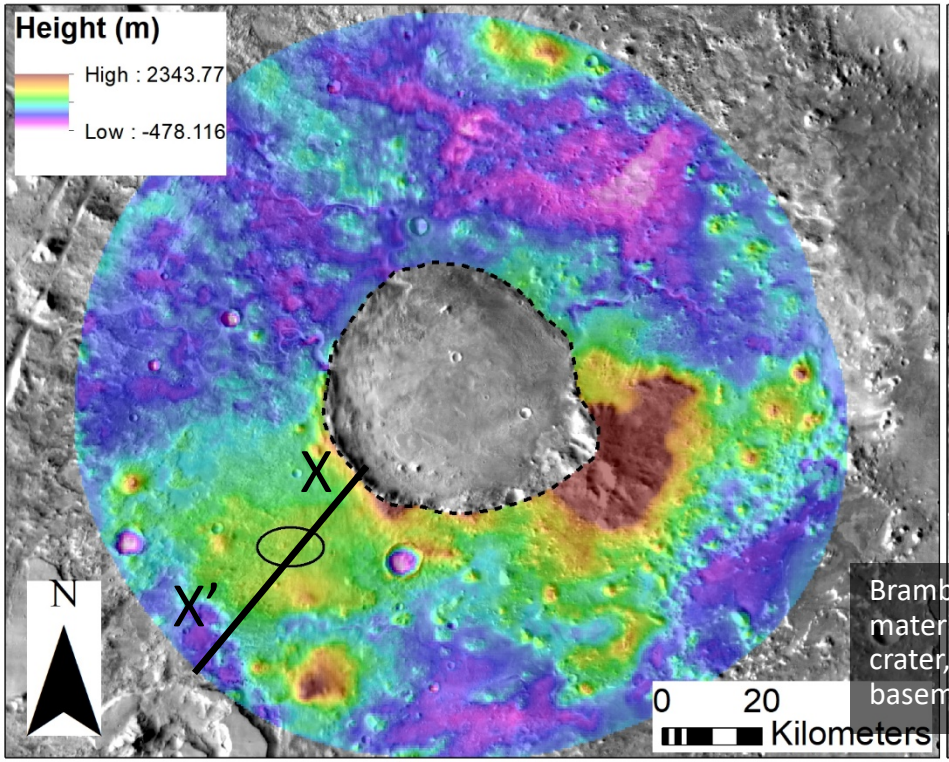


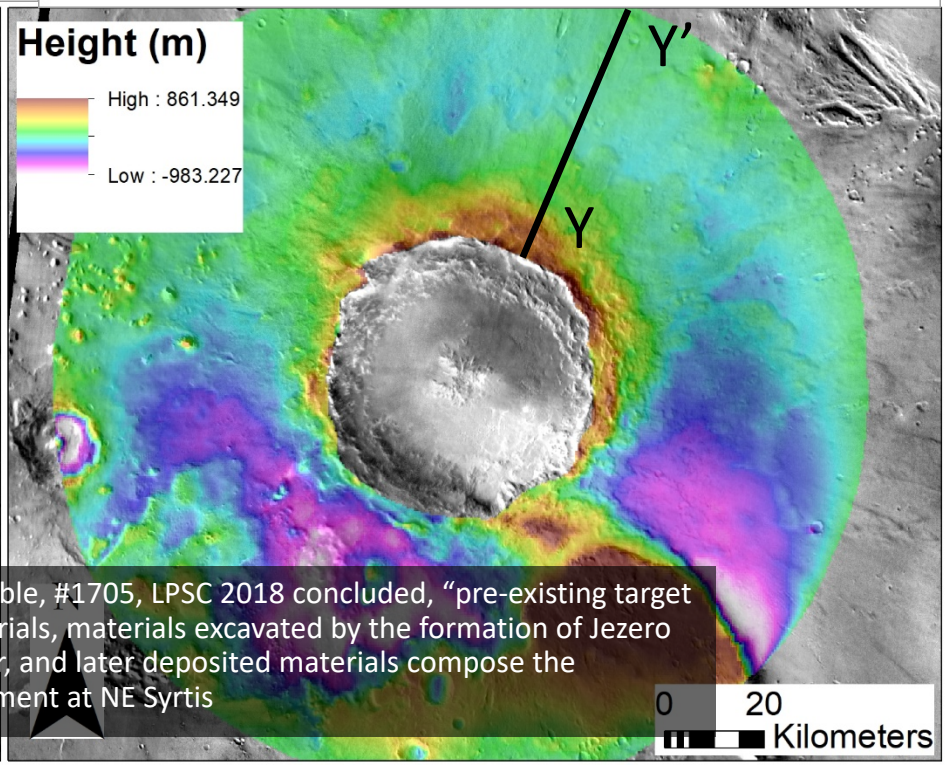
Crater Preservation Comparison

Work by N. Warner









Bramble, #1705, LPSC 2018 concluded, "pre-existing target materials, materials excavated by the formation of Jezero crater, and later deposited materials compose the basement at NE Syrtis