In-situ age dating at the Mars 2020 site: The importance of establishing Martian chronology

Mars 2020 rover, artist's conception. NASA / JPL / Caltech

Bradley Thomson
Center for Remote Sensing
Boston University
bjt@bu.edu

BOSTON UNIVERSITY

Nathan Bridges (APL),
Harald Hiesinger (U. Münster),
Caleb Fassett (Mt. Holyoke)

Chronology and astrobiology

- Conditions on past Mars dissimilar from present
  - Morphological and mineralogical evidence for greater aqueous activity in past
- Mars 2020 sent to address ***what*** the former environment was like (at a given locale)
  - What were P, T conditions? eH/pH levels?
  - Availability of liquid water?
- Of equal importance is the question of ***when***
  - Understanding the timing of events provides insights into reaction rates, not just processes
  - Provides insights into kinetics, not just mechanics
  - Kinetics critical to assess astrobiological potential
- Igneous rocks provide key to *when*

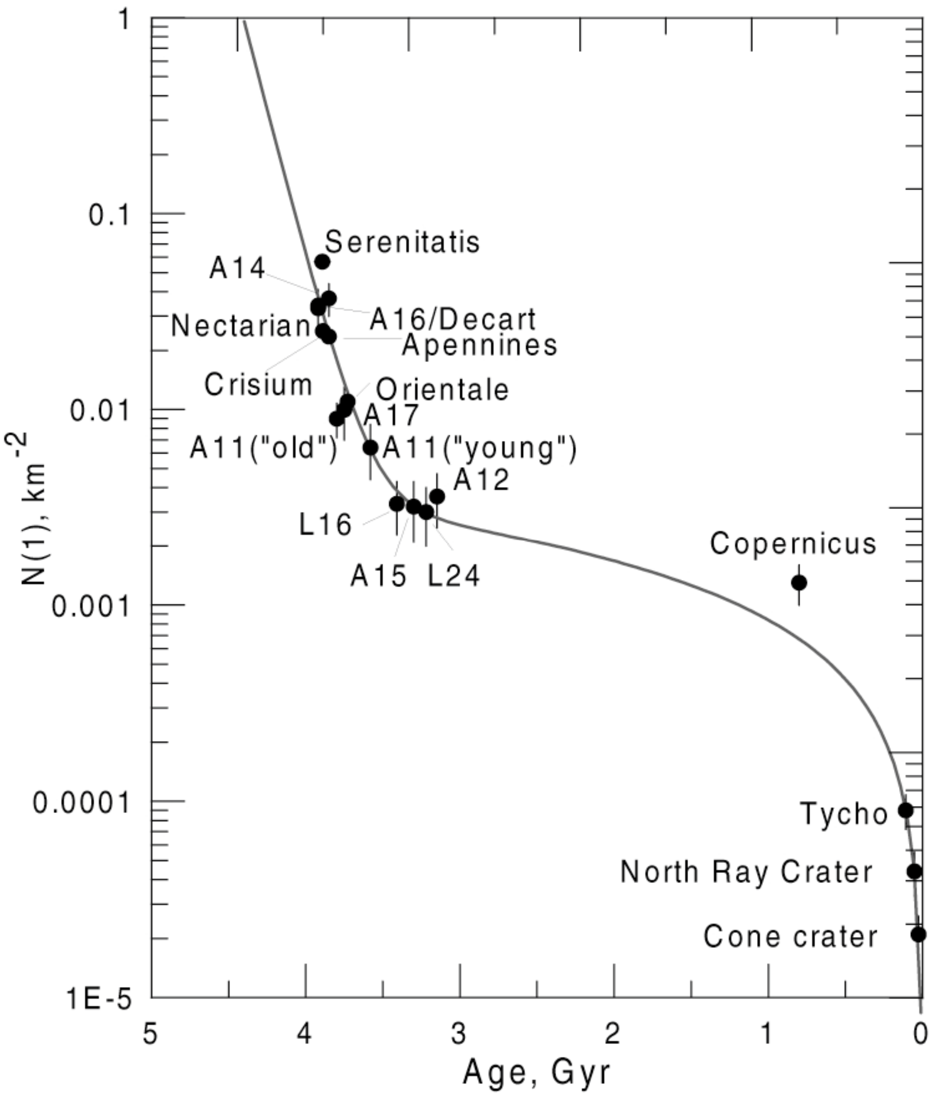
Why igneous rocks?

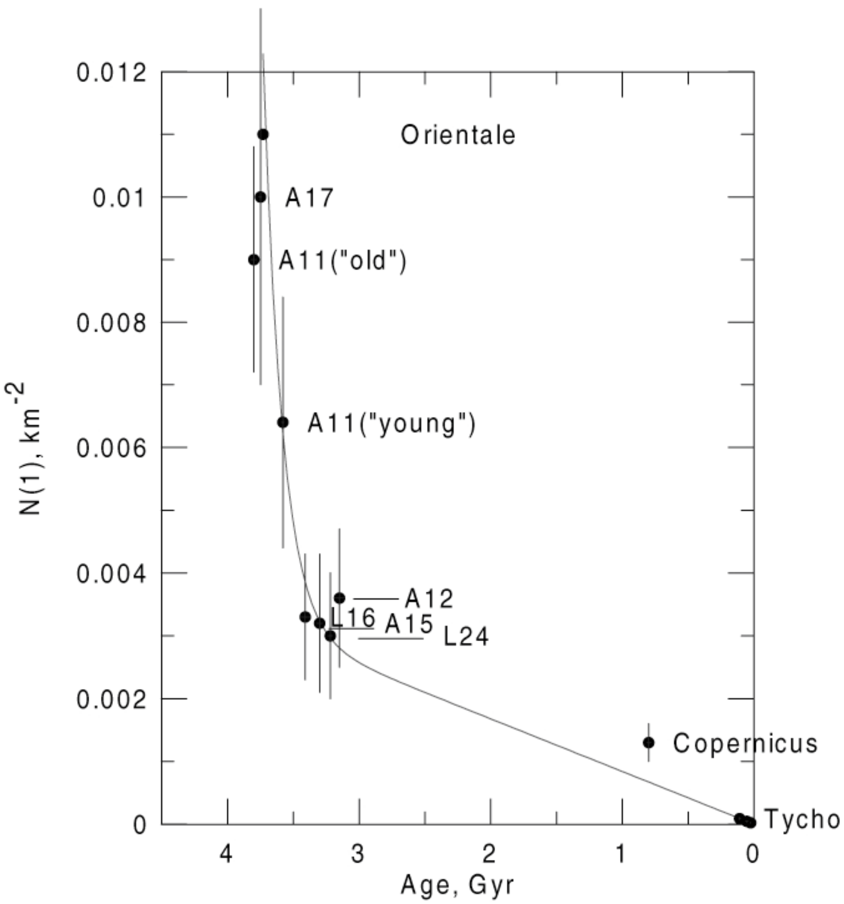
- Derived radiometric ages of igenous rocks provide formation age
- Sedimentary rocks provide combination of component ages, not formation age
- On Earth, sedimentary facies are dated by bounding igneous rocks (dikes, ash layers, lava flows, etc.)

Outline

1) Introduction
2) Lunar Chronology
3) Age constraints from meteorites
4) Age constraints from MSL
5) Ideal tie point characteristics
6) Past heritage
7) Conclusions

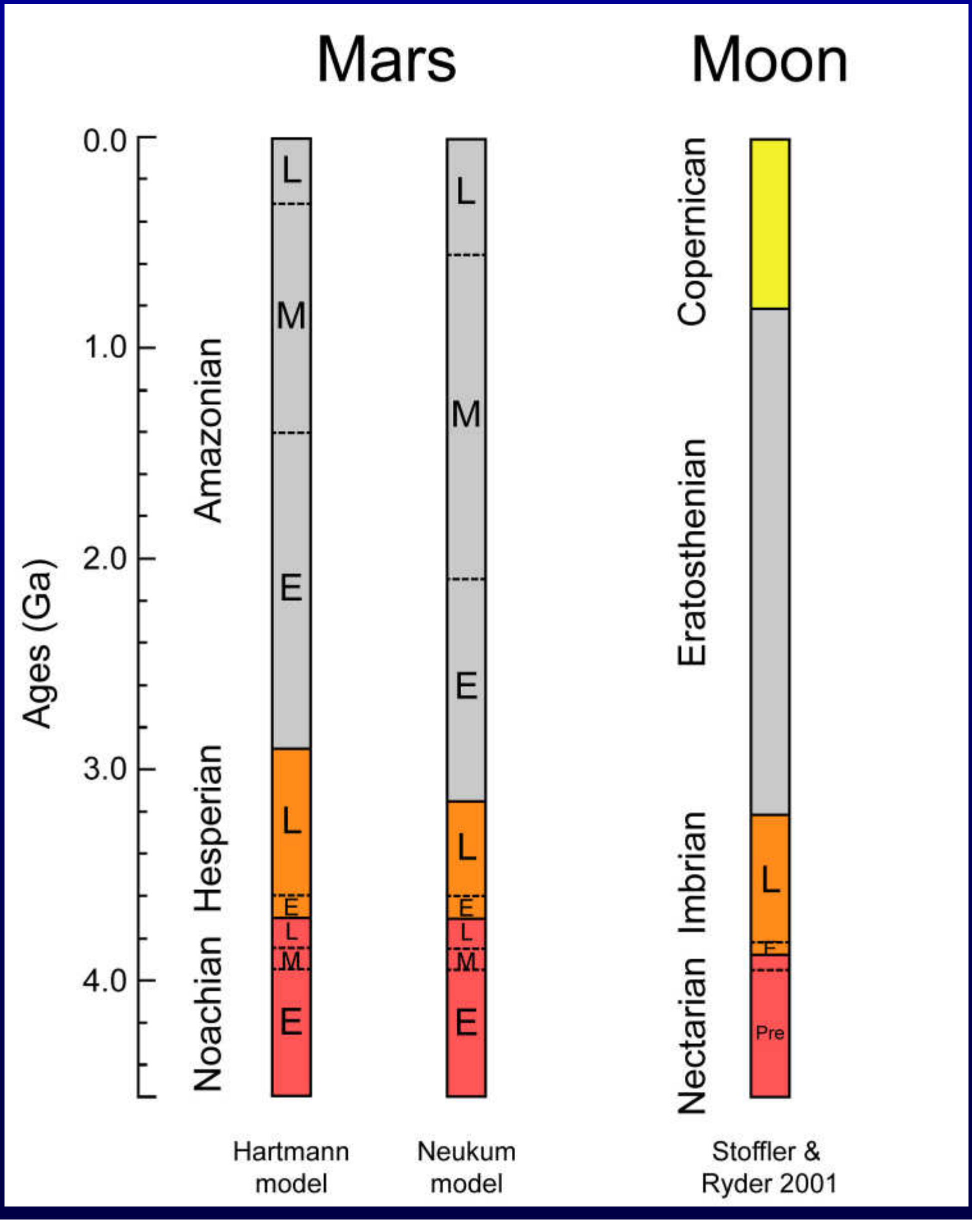
Lunar igneous chronology





Neukum et al., 2001

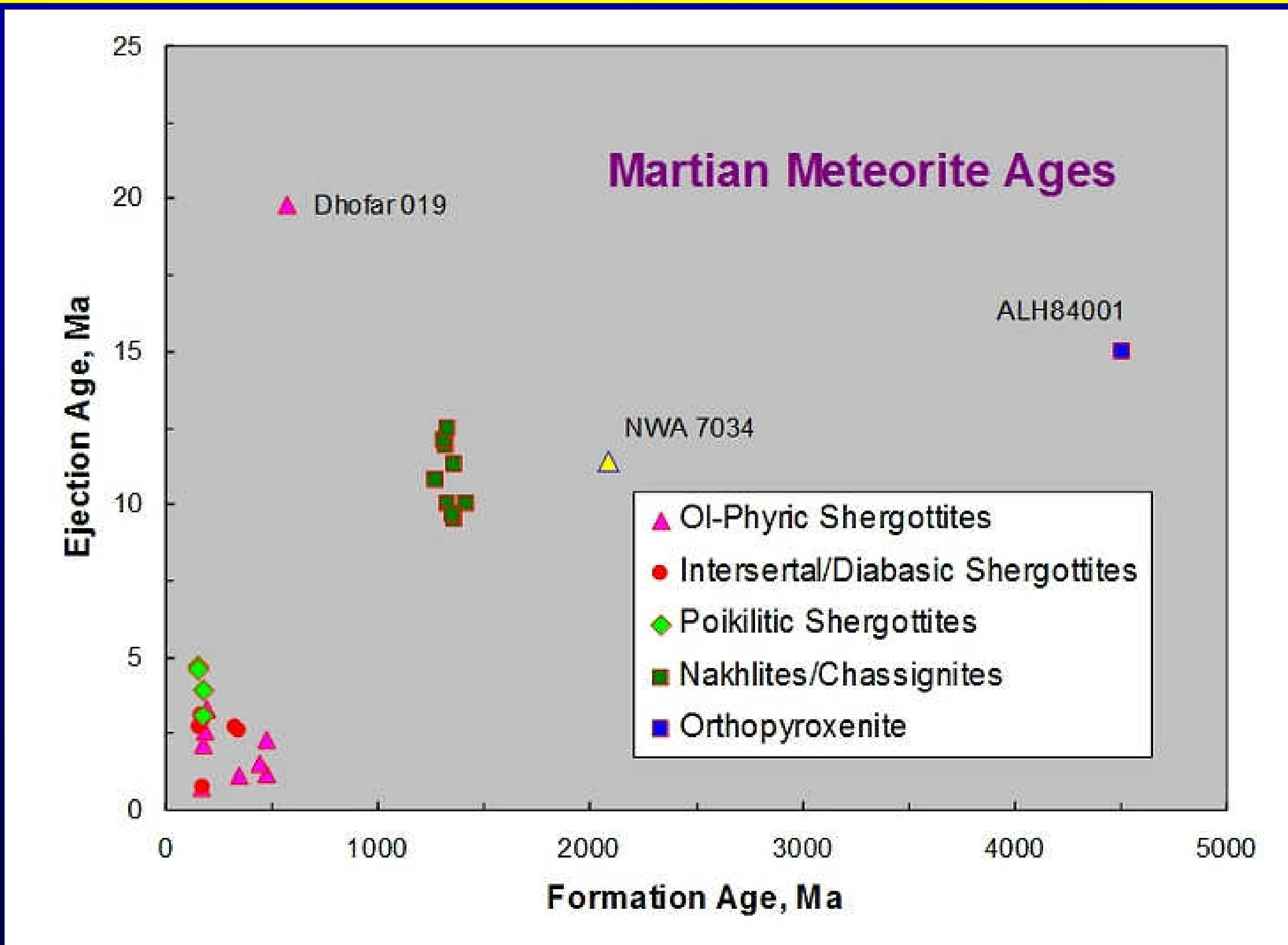
Moon is our ‘standard candle’



Outline

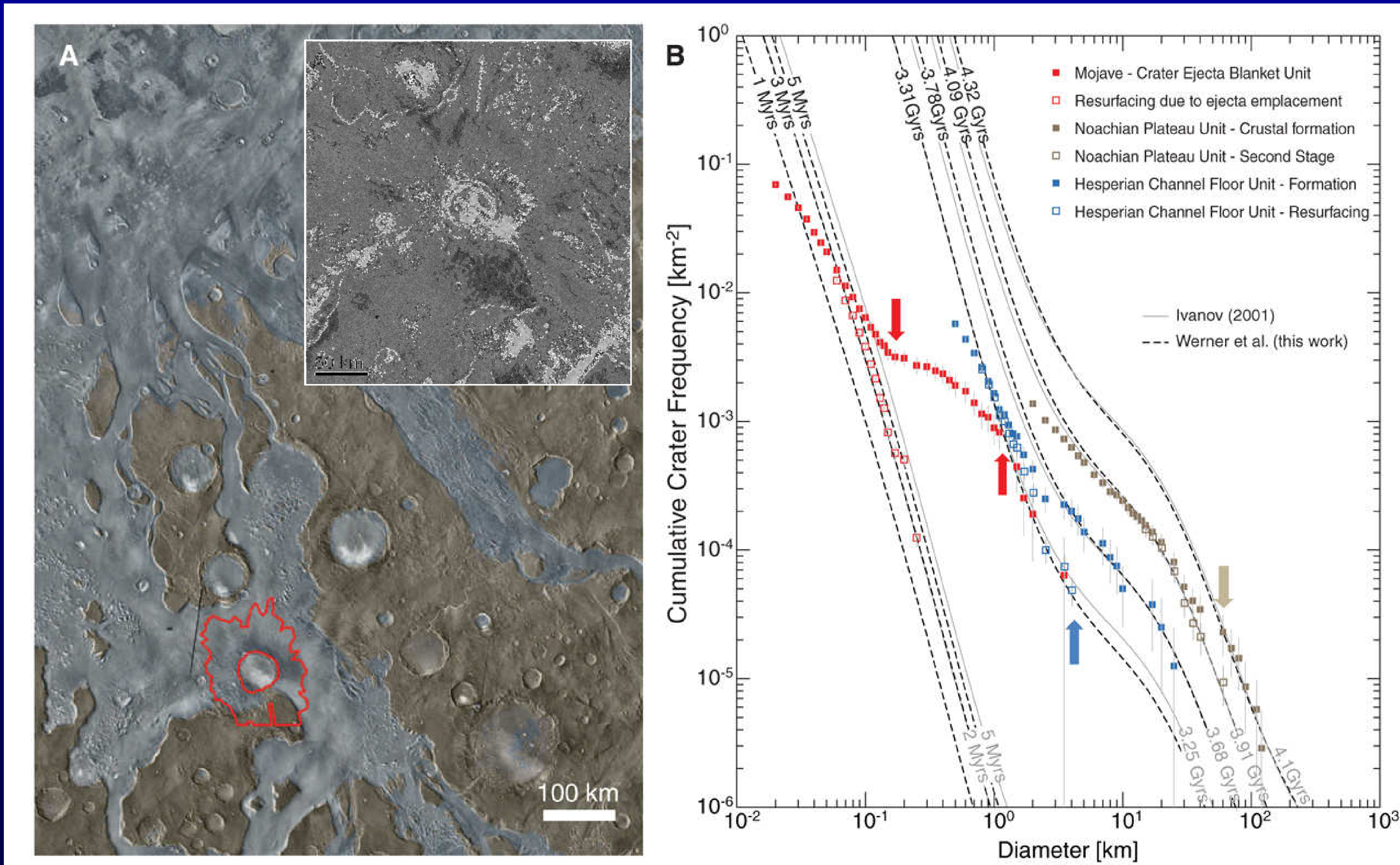
1) Introduction
2) Lunar Chronology
3) Age constraints from meteorites
4) Age constraints from MSL
5) Ideal tie point characteristics
6) Past heritage
7) Conclusions

Meteorites from Mars



T. Irving (U. Wash; www.imca.cc)

Mojave crater: Shergottite source?



Werner et al., 2014

Outline

1) Introduction
2) Lunar Chronology
3) Age constraints from meteorites
4) Age constraints from MSL
5) Ideal tie point characteristics
6) Past heritage
7) Conclusions

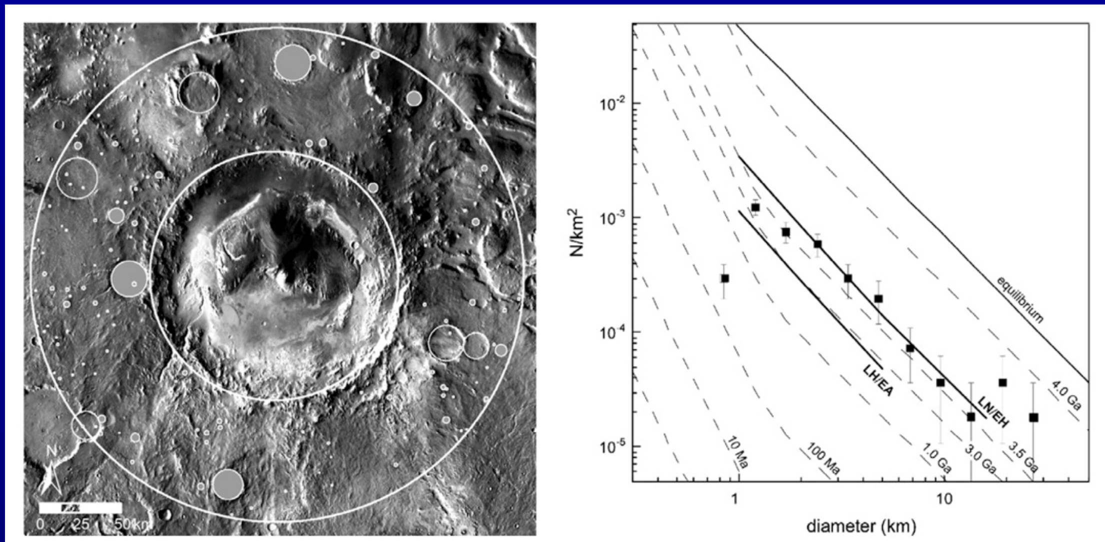
MSL *in situ* age dates

- K-Ar age of Sheepbed mudstone is 4.13±0.42 Ga [*Farley et al.*, 2014]
- Two component model:

$$T_B=(1-F_D)T_A+F_DT_D$$

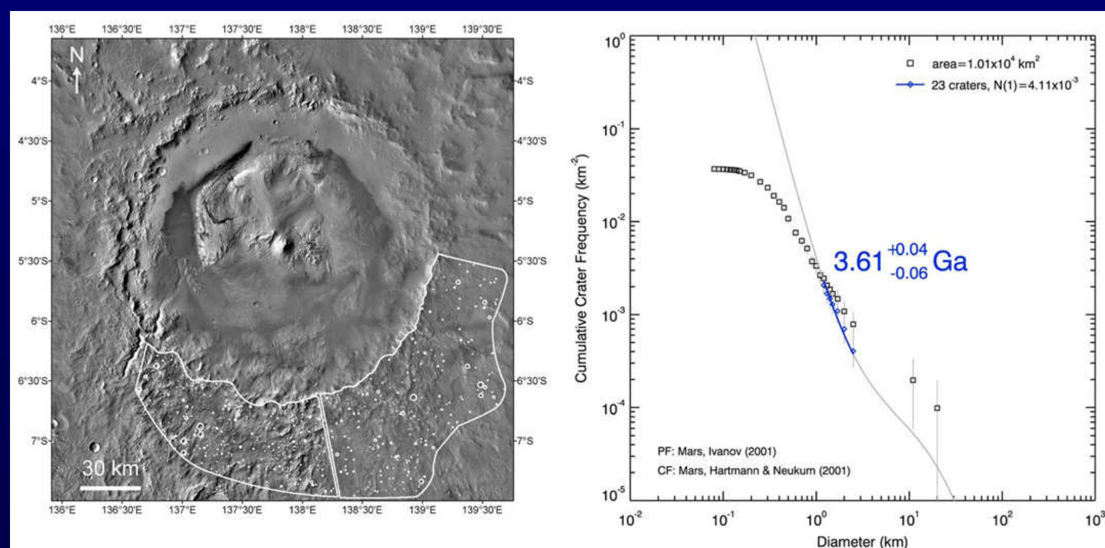
  where T_B is bulk age, T_A is age of authigenesis, and F_D is the detrital fraction
- Host of K unknown. Five potential sources:
  1. Pre-impact target lithology (detrital grains)
  2. Gale impact ejecta and shocked/brecciated in place material (detrital)
  3. Eolian dust added via settling from atmospheric suspension (detrital)
  4. Phyllosilicates (authigenic component)
  5. Diagenetic fracture fill (authigenic component)

Crater retention ages



~3.6-3.8 Ga

Thomson et al., 2011



~3.6 Ga

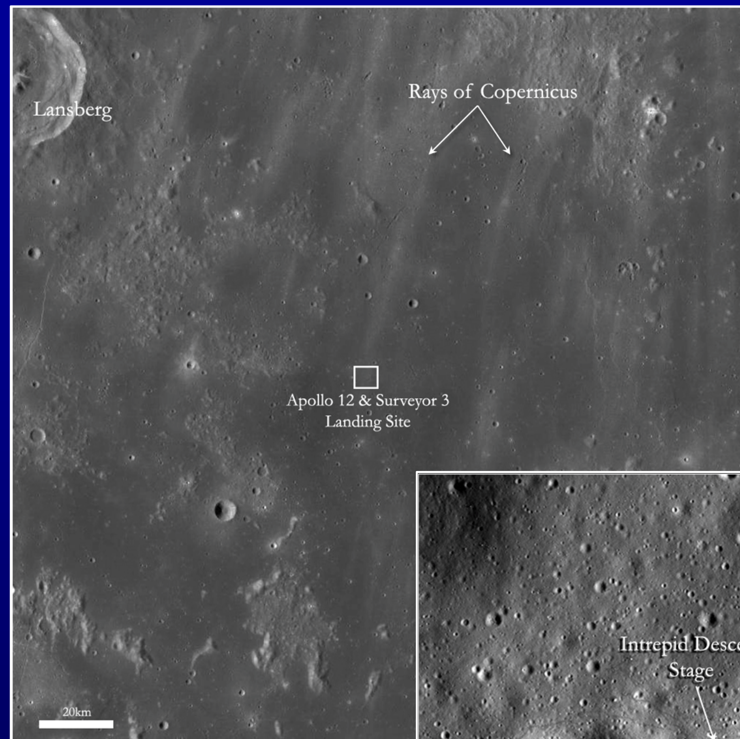
Le Deit et al., 2013

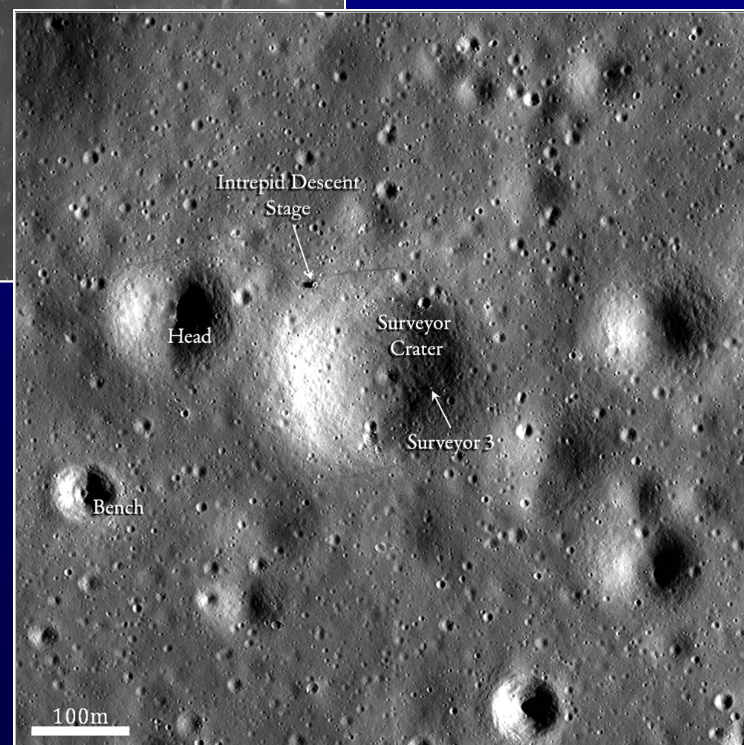
Selecting a tie point

Q: What is an ideal site to serve as a tie point for chronology?

A: Broad, low relief area of uniform formation age (with minimal modification since emplacement)

→ Likely igneous





Apollo 12 example
LROC WAC and NAC images
NASA / GSFC / ASU

Outline

1) Introduction
2) Lunar Chronology
3) Age constraints from meteorites
4) Age constraints from MSL
5) Ideal tie point characteristics
6) Past heritage
7) Conclusions

Heritage of igneous rationale

- MSR discussed in the literature for >30 years (e.g., NRC, 1978, 1990a,b 1994, 1996, 2003, 2006, 2007)
- Well-articulated in MEPAG E2E-iSAG (2012) *Astrobiology*, *12*, 175–230
  - McLennan, S.M., M.A. Sephton, C. Allen, A.C. Allwood, R. Barbieri, D.W. Beaty, P. Boston, M. Carr, M. Grady, J. Grant, V.S. Heber, C.D.K. Herd, B. Hofmann, P. King, N. Mangold, G.G. Ori, A.P. Rossi, F. Raulin, S.W. Ruff, B. Sherwood Lollar, S. Symes and M. G. Wilson
- Objective C1: Quantitatively constrain the age, context, and processes of accretion, early differentiation, and magmatic and magnetic history of Mars
- Sample types of interest: Igneous rocks for age determination by radiogenic isotopes and for constraining the martian interior

MEPAG E2E-iSAG Reference sites

Site	The sedimentary/hydrothermal story	The igneous story
Eastern Margaritifer Terra	Shallow basin with possible chlorides stratigraphically overlain by eroding phyllosilicates	Rocks appear to be capped by a basaltic unit of Noachian age
Gusev Crater	Columbia Hills contain outcrops of opaline silica and outcrops rich in Mg-Fe carbonates, sulfates also present.	Extensive Hesperian olivine-rich basalts embay the Noachian Columbia Hills
Jezero Crater	Delta with phyllosilicates and carbonates along west margin of crater	Floor may have Hesperian volcanic flows
Mawrth Valles Site 0	Layered Al and Fe-Mg phyllosilicates in poorly understood setting	Mafic material present but may be partly altered; unaltered Hesperian volcanics at ~30 km
NE Syrtis Major	Extensive and diverse mineral assemblages likely due to *in situ* alteration	Hesperian Syrtis Major volcanic region
Nili Fossae Trough	Widespread altered materials	Land on unaltered Hesperian volcanic plain
Ismenius Cavus	Site with clay-bearing paleolake sediments and current glacial deposits	Unaltered material may be limited to dark sand

Mars 2020 Science Definition Team

- Differed with E2E-iSAG (2012) on accessibility of igneous rocks:

  "This SDT agrees that these samples are highly desirable, but is concerned how this would limit, early in the mission development, the number of candidate sites."

  - Authors: Mustard, J.F., M. Adler, A. Allwood, D.S. Bass, D.W. Beaty, J.F. Bell III, W.B. Brinckerhoff, M. Carr, D.J. Des Marais, B. Drake, K.S. Edgett, J. Eigenbrode, L.T. Elkins-Tanton, J.A. Grant, S. M. Milkovich, D. Ming, C. Moore, S. Murchie, T.C. Onstott, S.W. Ruff, M.A. Sephton, A. Steele, and A. Treiman.
  - Independent assessment team: Johnson, J., B. Cohen, B. Ehlmann, P. Ehrenfreund, M. Hecht, B. Jakosky, A. McEwen, G. Retallack, R. Quinn.

- Only 10 of ~65 MSL sites included igneous outcrops

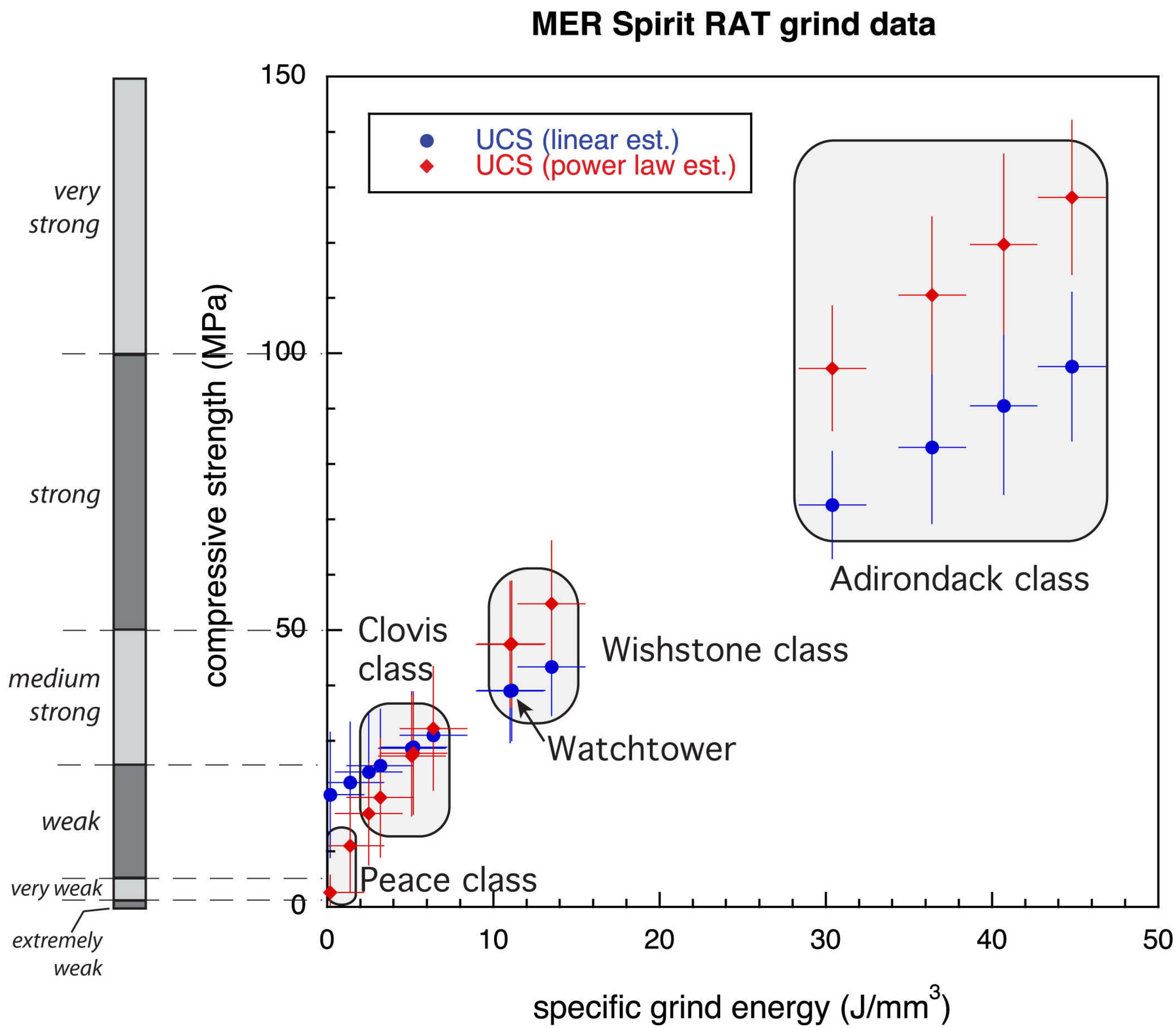
SDT on igneous relevance to biosignatures

- Relatively unaltered igneous rocks can host:
  - Abiotic organic matter [*Steele et al.*, 2012a,b]
  - Such terrains represent habitable environments on Earth, i.e., deep biosphere [*Stevens and McKinley*, 1995; *Chapelle et al.*, 2002]
  - Hypothesized remains of ancient martian microbial communities [*McKay et al.*, 1996]

Conclusions

- Igneous rocks necessary to establish chronology
- Understanding ***when*** is a vital aspect of astrobiological exploration
- What would a single tie point provide?
  - Would help constrain R_{bolide}, the Mars/Moon impact flux ratio (largest uncertainty)
  - Would improve age dating planet-wide

Additional



Thomson et al., 2013