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

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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 igneous 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’
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Mojave crater: Shergottite source?

Werner et al., 2014
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MSL *in situ* age dates

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

- Two component model:
  
  \[
  T_B = (1-F_D)T_A + F_D T_D
  \]

  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
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Heritage of igneous rationale

- MSR discussed in the literature for >30 years (e.g., NRC, 1978, 1990a,b 1994, 1996, 2003, 2006, 2007)

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


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 $R_{\text{bolide}}$, the Mars/Moon impact flux ratio (largest uncertainty)
  - Would improve age dating planet-wide
MER Spirit RAT grind data

Compressive strength (MPa)

Specific grind energy (J/mm³)

Thomson et al., 2013