Nili Fossae Carbonate Plains: Solving the Carbonate Puzzle and Examining Olivine from Primitive Melts or Mantle

Land-on science to understand early aqueous environments, reservoirs of carbon, and planetary igneous evolution

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1st Mars 2020 Landing Site Workshop
May 15, 2014
Isidis Basin
Early/Mid Noachian
(~3.96 Ga, Werner, 2005)

Syrtis Major
Early Hesperian
(~3.5 Ga, Werner, 2011)

Nilli Fossae graben

Carbonate Plains

Jezero crater

Libya Montes

Largest Exposure of Carbonate-Bearing Rocks on Mars

NE Syrtis
Meeting Mars 2020 Science Criteria

Nili Fossae Carbonate Plains geology addresses key science topics in the M2020 SDT report, E2E-iSAG sample criteria:

1. **Aqueous, habitable environments:**
   Largest exposure of carbonate-bearing rock on Mars, formed by precipitation from liquid water
   *Ehlmann et al., 2008, Science; Niles et al., 2013, SSR*

2. **Understanding Sources and Sinks of the Martian Atmosphere**

3. **Planetary Evolution & Igneous Processes:**
   Capping later mafics overly the largest olvine-rich (ultramafic?) rock unit on Mars, comprised of komatiitic lavas or impact-excavated mantle cumulates
   *Hoefen et al., 1997, Science; Hamilton & Christensen, 2005, Geology; Mustard et al.,*
In Search of the “Missing” Martian Carbonate?

- Carbonate: a minor phase in Martian dust (<5 wt. %) [Lellouch et al., 2000; Bandfield et al., 2003] and in Martian meteorites [e.g. Bridges, 2001]
- As of 2008, not IDed in rock though expected common, weathering product with water and CO$_2$-atmosphere
- Implications of carbonate paucity:
  - Acidic conditions precluded carbonate formation and preservation? [Fairen et al., 2004; Bullock & Moore, 2007; Mukhin, 1996]
  - Low pCO$_2$ when liquid water was present at the surface? [Chevrier et al., 2007; Halevy et al., 2007]
  - Waters driving aqueous alteration on Noachian Mars were not in contact with the atmosphere? [Ehlmann et al., 2011]
  - After ~4Gyr, always low atmospheric pressure [Hu, Kass, Ehlmann, Yung, in prep]
Carbonate is rare among alteration minerals...

Global View of Water-formed Minerals

Carbonate is rare among alteration minerals...
Where there is carbonate, it is special

- Some aqueous crustal environments were neutral to high pH and never experienced an overprinting acidic period
- Carbonate likely formed in conjunction with olivine weathering/serpentinization
- Aqueous activity in Nili Fossae extended well into the Hesperian (Mangold et al., 2007, JGR)
- Carbonate persists to the present and was not removed by acid weathering
- Heart of figuring out the "case of the missing atmosphere"
Global Olivine Abundance
High-Mg olivine from primitive melts or mantle

Highest Fo#, circumferential to basins

Fo75-100  Fo58-74  Fo42-57

Koeppen & Hamilton, 2008, JGR
Is this site at all typical of Mars or just “weird”?

- Special because high-Mg olivine taps primitive lavas or mantle cumulates
- Other olivine/carbonate-bearing rocks like this may exist on Mars but merely be less exposed
- Mars2020 Primary mission: Special opportunity to investigate a key habitable environment, a key process for geochemical cycling, and a unit that may tap Mars’ mantle
- Mars 2020: Extended mission: access to regionally-extensive type stratigraphy with typical alteration assemblages

**GUSEV CRATER:**
(Morris et al., 2010, Science)
- 40% olivine
- 35% amorphous silicate
- 25% carbonate

\[
(Mg_{0.62}Fe_{0.25}Ca_{0.11}Mn_{0.02})CO_3
\]
Key Martian Stratigraphies

Ehlmann, et al., 2011, Nature
Part of a Regionally Extensive, Time-Bracketed and Well-Understood Section

(from NE Syrtis area)

- Age Brackets:
  - Lower (oldest): Age of the Isidis impact disrupted the Fe/Mg smectite/pyroxene unit (parts are brecciated)
  - Upper (youngest): Overlying mafics, Hesperian Syrtis Major volcanic province

Ehlmann & Mustard, GRL, 2012
A Schematic History of Water

- Syrtis lavas: ~3.7 Gy
- Nili olivine: ~3.9 Gy
- Nili basement: >3.9 Gy

Fluvial activity

- No alteration
- Partial/local alteration
- Basement alteration

Mangold et al., 2007, JGR
Largest Exposure of Carbonate-Bearing Rocks on Mars

- Isidis Basin
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  (~3.96 Ga, Werner, 2005)

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- Nili Fossae graben
- Carbonate Plains

- Jezero crater
- NE Syrtis

- Isidis Basin
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  (~3.96 Ga, Werner, 2005)

- Libya Montes
stratigraphy

cap
olivine carb
Fe/Mg
smectite
Mineralogy & Exposure

Fe/Mg smectite beneath cap unit

Mafic cap unit

Olivine, in dunes and in-situ (partially altered)

Carbonate in bright, polygonally fractured terrain

5 km

\[ \text{H}_2\text{O}, \text{Mg,Fe-OH} \]

\[ \text{H}_2\text{O}, (\text{Mg})\text{CO}_3 \]

\[ \text{Mg,Fe-OH} \]
Banded carbonate beneath olivine-bearing dune

stratigraphy

- cap
- olivine carb
- Fe/Mg smectite
Relationships between key units


Hypothesis: Physical erosion and aeolian transport “clean” eroded, coarse olivine grains to form dunes.
Magnesite formation mechanisms (terrestrial)

(Möller, 1989)

- Hydrothermal fluids
- Serpentinization
- Diagenesis of marine beds
- Weathering of olivine and serpentine rich bodies
- Precipitate in playas fed by ultramafic catchments

For carbonates on Mars,

(1) Olivine-rich rock and
(2) its interaction with water seem to be essential

Observed elsewhere in the region. Ehlmann et al., 2010, GRL; Ehlmann & Mustard, 2012, GRL
A possible analog

Oman
Tracing the Serpenitinization Process through Carbonate Chemistry

Mg(Fe,Ca)-rich Ultramafic rocks (olivine, pyroxene)

<zone of ongoing serpenitinization>

\[ (\text{Fe,Mg})_3\text{Si}_2\text{O}_5(\text{OH})_2 + \text{Mg(OH)}_2 + \text{H}_2 \]

Mg-carbonate precipitation

Mg\(^{+2}\)-HCO\(_3\)\(^{-1}\)-Type Waters

Ca\(^{+2}\)-OH\(^{-1}\)-Type Waters
Land-On Carbonate

Carbonate plains/knobs

Mafic cap unit

Nili Fossae Carbonate Plains -- Ehlmann, Edwards, Wiseman, Mustard -- 1st Mars2020 Landing Site Workshop - 31
### Preliminary Landing Site Safety

**Slope map at 1000 m baseline from MOLA**

25km x 20km  18km x 14km

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Requirement</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation</td>
<td>&lt; +0.5 km</td>
<td>-1.5 km</td>
</tr>
<tr>
<td>Latitude</td>
<td>±30°</td>
<td>21.7°</td>
</tr>
<tr>
<td>Relief</td>
<td>&lt;100 m on 1km-1,000 m baselines</td>
<td></td>
</tr>
<tr>
<td>Slopes</td>
<td>&lt;25°-30° on 2-5 m baselines</td>
<td>needs investigation</td>
</tr>
<tr>
<td>Rocks</td>
<td>~7% rock abundance</td>
<td>appears clear; needs further investigation.</td>
</tr>
<tr>
<td>Radar Reflectivity</td>
<td>-20 to +15 dB at Ka band</td>
<td></td>
</tr>
<tr>
<td>Thermal Inertia/Albedo</td>
<td>&gt;100 J m⁻² s⁻⁰.⁵ K⁻¹ &lt;0.25</td>
<td>&gt;230 m⁻² s⁻⁰.⁵ K⁻¹ &lt;0.19</td>
</tr>
</tbody>
</table>
Landing Site Safety: Dunes

Testing the MSL mobility system
Durmont Dunes, CA, Summer ‘12
Landing Site Safety: Dunes

- Large-ellipse (25 km x 20 km at time of downselect) meant MSL landing in the dunes was an unacceptable risk.
- Reduced ellipse size, range-trigger, or terrain-relative navigation (TRN) would remove this risk.

See Golombek presentation yesterday.
Nili Fossae Carbonate Plains: A Summary

• Immediate Access to Land-On Primary Science
  – Extensive aqueous alteration to form carbonate
    • Testing the relative importance of sedimentation, weathering, and hydrothermal processes for early aqueous environments
    • No later overprinting by an “acid bath”
    • How much carbonate? Stored by what process? Important questions for understanding the global reservoir
  – High-Mg mafic/ultramafic rocks
    • preserves a record of early igneous processes (komatiitic-type melts) or a record of impact processes and mantle-derived cumulates
    • mafic/ultramafic rocks Materials for answering important questions about the nature of the Mars mantle and history of volcanism
• Diverse, fundamental questions about ancient Mars are accessible here, providing decades of work on returned samples