Hydrothermal alteration and fluvial sites in the northwest Hellas region

Eldar Noe Dobrea¹, Scott Mest¹, Frank Chuang¹, Jack Mustard², David Crown¹ and Gregg Swayze³

¹Planetary Science Institute, Tucson, AZ
²Brown University, Providence, RI
³USGS Denver Spectroscopy Lab, Denver, CO
Mars 2020 science Objectives

A. Explore an astrobiologically relevant ancient environment on Mars;
B. Assess the biosignature preservation potential within the selected geological environment and search for potential biosignatures;
C. …progress towards the future return of … samples to Earth;
D. Provide an opportunity for contributed Human Exploration & Operations Mission Directorate or Space Technology Program participation.

We can (partially) address objective A from orbit:

• Geological evidence for raw materials, energy, water, and favorable conditions

However, “Assessing the biosignature preservation potential within a formerly habitable environment and searching for potential biosignatures as called for in Objective B begins with the in situ measurements necessary to identify and characterize promising outcrops.”
Hellas

• ~2300-km-diameter basin formed in Early Noachian by impact of ~250 km object (e.g., Leonard and Tanaka, 2001)

• Energy deposited by impact should have produced elevated temperatures for a prolonged period (how long? how hot?)

• Subsequent modification by aeolian, fluvial, glacial/periglacial, volcanic processes gave rise to a diversity of geological environments and landforms inside Hellas and in the circum-Hellas region.

• Of particular interest to the question of habitability is the possibility that a variety of aqueous systems may have developed in the region after the Hellas impact.
  • Hydrothermal systems (e.g., Newsom, 1980).
  • Marine/lacustrine (e.g., Wilson et al., 2007; Condit et al., 2010 and references therein)

• Impact also thought to have triggered vent volcanism (e.g., Williams et al., 2009)

• Evidence for aqueous activity in the region during that time period:
  • Mineralogical: phyllosilicates in Tyrrhena Terra (Pelkey et al., 2007; Loizeau et al., 2009) and around Hellas (e.g., Ansan et al., 2011; Crown et al., LPSC 2011).
  • Morphological: heavy dissection of the region, layered intercrater deposits
NW Hellas Region preserves record of diverse geological processes.
Preserves record of diverse geological processes
Fluvial Dissection

Dissected Plains

Schaaberle

breach

Dissected Plains

Prehnite

Pitted Plains

Pitted Plains (PPL3)
Plains Deposits and Pits

Occur at elevations < -500 m
Pits 100-250 meters deep
Erosion of plains reflects buried structures, wind dir.
Plains Deposits and Pits: west pit

Layered – thin
Forms yardangs
Eroded material redistributed on pit floors
Plains Deposits and Pits: east pit
Plains Deposits and Pits: south pit
~3.7 Ga
<table>
<thead>
<tr>
<th>Primary mineral or rock</th>
<th>Reported alteration minerals</th>
<th>Hydrothermal Alteration environment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basalt</td>
<td>Kaolinite, smectite, jarosite, alunite</td>
<td>Acidic pH</td>
<td>Morris et al., 2001; Morris et al., 2003</td>
</tr>
<tr>
<td>Pyroxene-amphibole andesite</td>
<td>Cristobalite, alunite, pyrite, kaolinite, goethite, hematite</td>
<td>Acidic pH</td>
<td>Isobe and Korenaga, 2010</td>
</tr>
<tr>
<td>Basalt</td>
<td>Mg-carbonate, talc</td>
<td>Neutral to basic pH</td>
<td>Brown et al., 2010</td>
</tr>
<tr>
<td>Wollastonite</td>
<td>Mg-montmorillonite, talc, mixed layer stevensite/chlorite</td>
<td>Neutral to basic pH groundwater</td>
<td>DeRudder and Beck, 1963; Whitney and Eberl, 1982</td>
</tr>
<tr>
<td>Granite, K-feldspar</td>
<td>Kaolinite, muscovite, biotite, halloysite</td>
<td>-</td>
<td>Thomas and Walter, 2004;</td>
</tr>
<tr>
<td>Impact melt rock</td>
<td>Fe-chlorite, Fe smectite, silica, K feldspar, zeolite</td>
<td>-</td>
<td>Newsom, 1980; Allen et al., 1982</td>
</tr>
<tr>
<td>Olivine</td>
<td><strong>serpentine</strong></td>
<td>-</td>
<td>Normand et al., 2002</td>
</tr>
<tr>
<td>Basalt, grabbro</td>
<td><strong>Prehnite</strong>, quartz, calcite, epidote</td>
<td>Also in low-grade metamorphism</td>
<td>Freedman et al., 2009</td>
</tr>
</tbody>
</table>
Potential Hydrothermal/low grade metamorphic alteration products on Mars

- Prehnite: Nili Fossae (Ehlman et al., 2009), Argyre rim (Buczkowski et al., 2010), NW Hellas (Crown et al., LPSC 2011)
- Serpentine: Nili Fossae (Ehlman et al., 2009)
- Chlorite: Nili Fossae (e.g., Ehlman et al., 2009; Poulet et al., 2005); NW Hellas (Crown et al., LPSC 2011)
- Hydrated silica: Nili Fossae (Skok et al., this session)

- Of particular interest is Prehnite ($\text{Ca}_2\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_2$)
  - Metamorphic grade transitional between zeolite and greenschist facies
  - Forms under specific conditions: 2-7 kbar, 200 – 350°C, and XCO2 < 0.004 (Blatt and Tracy, 1995)
  - Typically associated with chlorite and pumpellyite (e.g., Frey and Robinson, 1999).
• Prehnite: absorptions at 2.35-2.36, 1.48, 2.23, 2.28, 2.57 μm
• Chlorite: absorptions at 1.40, shoulder at 2.25-2.26, 2.33-2.35
• Serpentine: absorptions at 1.40, 2.32-2.33, 2.50-2.51
• “Vermiculite” – mixed layer vermiculite/biotite. Can also be other mixed layer smectite/chlorite: absorption at 1.92, steep drop-off at 2.30-2.31
• Illite/muscovite - absorptions at 2.2, 2.35
Results

Spectral library hydothermal alteration products
- Vermiculite
- Serpentine
- Chlorite
- Prehnite
- Illite

Examples of alteration products in NW Hellas observed in CRISM data
- FRT969C
- FRT1214D
- FRT1384C
- FRT1214D
- FRT124B3

Reflectance

Relative Reflectance

Wavelength (µm)
Prehnite in unit Nh – Hilly Unit – Forms rugged, high-relief, densely cratered terrain with numerous isolated massifs. Channels and ridges common; faults along west rim.

*Interpretation: Uplifted crustal material and ejecta from Hellas impact and post-impact structural and erosional modification* (Leonard and Tanaka, 2001)
Prehnite (ripple-forming unit)

Prehnite + Chlorite
(units contains ripple-forming material and indurated rough unit)

"Prehnite pit"
Prehnite (ripple-forming unit with outcrops)

Prehnite + Chlorite (Rough rocky unit)

Illite/muscovite (rocky unit)

"Prehnite hill"
Prehnite (smooth and ripple-forming unit)

“Prehnite hill” (adjacent to west)
Pitted Plains Deposits: FRT0001366A

Fe/Mg phyllos
Geological inferences

- We observe a variety of alteration products including prehnite, chlorite, illite/muscovite, mixed-layer S/C or B/V, saponite.
- Prehnite+chlorite+illite/muscovite in close spatial association strongly suggestive of hydrothermal activity.
  - observed in Hilly Unit - interpreted to be uplifted crustal material and ejecta from Hellas impact and post-impact structural and erosional modifications.
- Subsequent erosion of Noachian plains material resulted in dissection and redeposition to form smooth embaying plains and intracrater units 200-400 m in thickness.
- Fe/Mg phyllosilicates identified within pit walls in plains units.
Scientific framework at NW Hellas

- Astrobiology
  - Hydrothermal system provides all components needed for life. Whereas temperatures may be too high at prehnite-forming location, surrounding areas will be lower in temperature (this is true for hydrothermal systems on Earth – e.g. ocean vents).
  - Fluvial deposits contain material derived from highlands crust.
  - Fe/Mg phyllosilicates in fluvial materials → good for sequestration of organics
  - Hydrothermal system and fluvial deposits both present low-energy environments, → good for preservation
Scientific framework at NW Hellas

- Style, timing, and temporal extent of alteration and depositional processes on ancient Mars
  - Bedding, thickness, periodicity of layers
  - Mineralogy and extent of aqueous alteration
  - Aqueous chemistry
- Habitability
  - Soil chemistry
  - Water abundance
  - Redox potential
- Style and timing of erosional processes
  - Exposure ages
  - Small-scale textures (e.g., aeolian pitting, glacial scouring, etc)
1000-m slopes and access to science objectives

25x20 km ellipse

26°14′ S, 56°26′ E

Landing on Fluvial deposits
10 km to hydrothermal units

Pitted units

Prehnite (in unit Nh)

Mixed-layer

-700 m elev

Slopes (deg)

- 0 - 2.5
- 2.5 - 5
- 5.0 - 15
- 15 - 20
- 20 - 38
Access to science objectives

- Plains units have very gentle (<2.5°) slopes throughout, and are easily accessible to landing system.
- Scarcity of boulders in this unit makes landing and traverse straightforward.
- Fluvial deposits occur within landing ellipse.
- Hydrothermal units 10 km from center of 25x20 km ellipse.
- Pitted units also 10 km from center of ellipse.
Pitted Crater Floors

Polygonally-fractured unit

Scooped unit

Layers

Layered Morphologic stratigraphy ~300-500 m thick
• **Unit above 500 m – Npl2 – Subdued cratered unit** – Forms widespread moderate to heavily cratered, relatively smooth plains marked by subdued crater rims, small channels, ridges, and uneven terrain. Crater floors partly to completely infilled with smooth material; ejecta blankets rare. Some heavily eroded craters dissected by small channels. Faults rare. Material gradational with most adjacent units. *Interpretation* – Ancient veneer of aeolian, fluvial, and perhaps volcanic materials that partly resurface underlying cratered and dissected units (units Npl1 and Npld).

• **Prehnite in unit Nh – Hilly Unit** – Forms rugged, high-relief, densely cratered terrain with numerous isolated massifs. Channels and ridges common; faults along west rim. *Interpretation*: Uplifted crustal material and ejecta from Hellas impact and post-impact structural and erosional modifications.

• **Smooth pitted plains in unit Hpl3 – Smooth unit** – Forms moderately cratered, smooth, flat to undulating, relatively featureless plains and patches around the rim and within highlands surrounding Hellas basin. Channel common; faults and flow fronts rare. Embays all other materials of plateau sequence and fills man impact craters. *Interpretation*: Thick fluvial, aeolian, and volcanic deposits burying most underlying rocks

• (Leonard and Tanaka, 2001)