Gusev Crater: A Geologically Diverse, Engineering Safe Site with Evidence for Past Habitable Environments and Potential Biosignatures

A potential biosignature is an object, substance and/or pattern that might have a biological origin and thus compels investigators to gather more data before reaching a conclusion as to the presence or absence of life.

Steve Ruff, Jim Rice, and Alex Longo with Jack Farmer

Opaline silica outcrops in Gusev crater
Pancam approximate true color image

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Gusev Crater

ROI ~3x5 km
Eroded delta?
Comanche Carbonate-rich Outcrops

Mg-Fe carbonates up to ~30 wt% are hydrothermal in origin [Morris et al., 2010]

or are lacustrine evaporites [Ruff et al., 2014]
Comanche Carbonate-rich Outcrops Preexisting terrain, including Columbia Hills

Mantle of Algonquin-like tephra Pre-existing terrain, including Columbia Hills

Floodwaters from Ma’adim Vallis, perhaps repeated Evaporative precipitates

Erosion followed by flood basalts Comanche outcrops

Readily testable in situ or are lacustrine evaporites [Ruff et al., 2014]
Outcrops and soil composed of nearly pure opaline silica of surface hydrothermal origin!

(Squyres et al., 2008; Ruff et al., 2011)

Fumarolic acid-sulfate leaching or hot spring/geyser silica precipitation (sinter)?
Outcrops and soil composed of nearly pure opaline silica of surface hydrothermal origin (Squyres et al., 2008; Ruff et al., 2011)
Candidate Terrestrial Analog:
El Tatio, Chile (Atacama)
Hot Spring/Geyser system

- 4300 m elevation
- Hyper-arid environment
- Diurnal freeze-thaw (Nicolau et al., 2014)
- Silica precipitation dominated by evaporation
- Fluids evaporate to dryness; halite precipitation is final product
- Extreme UV radiation (Cabrol et al., 2014)
Home Plate “Silica-rich Nodular Outcrops”
Squyres et al. (2008); Ruff et al. (2011)

Found exclusively in stratiform occurrences typically over a light-toned platy unit; consistent with a sedimentary origin (Ruff et al., 2011)
Sol 778 Pancam approximate true color
El Tatio, Chile hot spring discharge apron
Sol 778 Pancam approximate true color

"Digitate protrusions"
Ruff et al. (2011)
“Digitate protrusions”
Ruff et al. (2011)

Sol 778 Pancam approximate true color

El Tatio, Chile hot spring discharge apron
Digitate protrusions
El Tatio, Chile hot spring discharge channel

Diatoms

Filamentous bacteria

Digitate protrusions
Erosional or primary feature?

Erosional or primary feature?

Primary feature Microbially mediated?

Diatoms

Filamentous bacteria

Digitate protrusions

El Tatio, Chile hot spring discharge channel
Siliceous Algal and Bacterial Stromatolites in Hot Spring and Geyser Effluents of Yellowstone National Park, Malcolm Walter et al., Science, 1972

Vertical Zonation of Biota in Microstromatolites Associated with Hot Springs, North Island, New Zealand, Jones et al., Palaios, 1997

Microbial-silica interactions in Icelandic hot spring sinter: possible analogues for some Precambrian siliceous stromatolites, Konhauser et al., Sedimentology, 2001
El Tatio, Chile hot spring discharge channel sample
El Tatio, Chile hot spring discharge channel sample
Thermal Emission Spectroscopy

Sol 1174 Pancam approximate true color

Clara Zaph4
Mini-TES target

After Ruff et al. [2011]
Viewing Angle Effects
Or Something Else?

El Tatio Sinter
at 0 degree viewing angle
No Diagenesis
Does This Constitute a Recent Exposure?

Opaline silica exposed in wheel scuff
Pancam approximate true color mosaic
### Environmental Setting for Biosignature Preservation and Taphonomy of Organics

<table>
<thead>
<tr>
<th>Setting</th>
<th>Description</th>
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<tbody>
<tr>
<td>Deltaic or Lacustrine</td>
<td>Perennial</td>
</tr>
<tr>
<td>Lacustrine (evaporitic)</td>
<td>Surface (&lt;100°C)</td>
</tr>
<tr>
<td>Hydrothermal (surface)</td>
<td>Surface (&lt;100°C)</td>
</tr>
<tr>
<td>Hydrothermal (subsurface)</td>
<td>Pedogenic</td>
</tr>
<tr>
<td>Pedogenic</td>
<td>Fluvial/Alluvial</td>
</tr>
<tr>
<td>No diagenetic overprinting</td>
<td>Recent exposure</td>
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</table>

### Columbia Hills

- Fluvial-lacustrine sediments

#### Type 1A & 1B Samples: Aqueous Geochemical Environments indicated by Mineral Assemblages

- Crustal phyllosilicates
- Sedimentary clays
- Al clays in stratigraphy
- Carbonate units
- Chloride sediments
- Sulfate sediments
- Acid sulfate units
- Silica deposits
- Ferric Ox./Ferrous clays

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Carter and Poulet, 2012

Kuzmin et al., 2000

10 km
Re-TEST of the Columbia Hills using CRISM: results

Fe/Mg phyllosilicates mixed with olivine (carbonates and/or serpentines in some cases)

Kaolinite

Fe-rich phyllosilicate

Type 1A & 1B Samples: Aqueous Geochemical Environments indicated by Mineral Assemblages

Carter and Poulet, 2012

J. Carter new results
### Halley Subclass Unit

- **SO₃**: >10 wt%
- **Fe**: >50% in hematite

#### Type 1A & 1B Samples: Aqueous Geochemical Environments indicated by Mineral Assemblages

<table>
<thead>
<tr>
<th>Mineral Assemblages</th>
<th>Color</th>
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<tbody>
<tr>
<td>Crystalline phyllosilicates</td>
<td>Green</td>
</tr>
<tr>
<td>Sedimentary clays</td>
<td>Yellow</td>
</tr>
<tr>
<td>Al clays in stratigraphy</td>
<td>Blue</td>
</tr>
<tr>
<td>Carbonate units</td>
<td>Orange</td>
</tr>
<tr>
<td>Chloride sediments</td>
<td>Light Green</td>
</tr>
<tr>
<td>Sulfate sediments</td>
<td>Red</td>
</tr>
<tr>
<td>Acid sulfate units</td>
<td>Brown</td>
</tr>
<tr>
<td>Silica deposits</td>
<td>Pink</td>
</tr>
<tr>
<td>Ferric Ox./Ferrous clays</td>
<td>White</td>
</tr>
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</table>

Diagram showing arrows pointing to various locations on the surface, indicating the presence of specific mineral assemblages.
3.65 Ga Wrinkle-ridged Plains of Gusev

= Hesperian Ridged Plains

= Adirondack Class basalt

Greeley et al. (2005)
### Type 2 Samples: Igneous

<table>
<thead>
<tr>
<th>Igneous unit (e.g., lava flow, pyroclastic, intrusive)</th>
<th>2nd Igneous unit</th>
<th>Pre- or Early-Noachian Megabreccia</th>
<th>Oldest stratigraphic constraint</th>
<th>Youngest stratigraphic constraint</th>
<th>Stratigraphy of units well-defined</th>
<th>Dateable surface, volcanic (unmodified crater SFD)</th>
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#### Context: Martian History Sampled, Timing Constraints

- **Greeley et al. (2005)**

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**Wrinkle-ridged Plains of Gusev**

- **= Hesperian Ridged Plains**

**Spirit landing site**

- **= Adirondack Class basalt**

**THEMIS VIS**
Algonquin Class Tephra

Ruff et al. (2014)

Columbia Hills

HiRISE: All scenes 250 m across

THEMIS colorized night IR over CTX

3 km
Algonquin Class Tephra

Columbia Hills

Ruff et al. (2014)

3 km

THEMIS colorized night IR over CTX

Type 2 Samples: Igneous

Context: Martian History Sampled, Timing Constraints

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2nd Igneous unit

Pre- or Early-Noachian Megabreccia

Oldest stratigraphic constraint

Youngest stratigraphic constraint

Stratigraphy of units well-defined

Dateable surface, volcanic (unmodified crater SFD)

3 km
<table>
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<tr>
<th>Landing Site Factor</th>
<th>Mars 2020 Mission and Decadal Priority Science Factors</th>
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<td></td>
<td>Environmental Setting for Biosignature Preservation and Taphonomy of Organics</td>
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<tr>
<td></td>
<td>Deutal of Lacustrine ( perennial )</td>
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<tr>
<td>Gusev</td>
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**Landing Site Scientific Selection Criteria:**

1. The geologic setting and history of the landing site can be characterized and understood through a combination of orbital and in-situ observations. **YES**

**Objective B**

2a. The landing site offers an ancient habitable environment. **YES**

2b. Rocks with high biosignature preservation potential are available and are accessible to investigation for astrobiological purposes with instruments on board the rover. **YES**

**Objective C**

3a. The landing site offers an adequate abundance, diversity, and quality of samples suitable for addressing key astrobiological questions if and when they are returned to Earth. **YES**

3b. 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. **YES**