A Second Field Season on Mars*:
The Merits of Returning to Gusev Crater for a Sample Caching Mission

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A Second Field Season on Mars: The Merits of Returning to Gusev Crater for a Sample Caching Mission

DISCLAIMER

I would not promote Gusev for Mars 2020 if it were not a caching mission.
**Scientifically, Why Gusev Crater?**

**Threshold Geological Criteria:**
1. Presence of subaqueous sediments or hydrothermal sediments (equal 1st priority), OR
   hydrothermally altered rocks or low-T fluid-altered rocks (equal 2nd priority)
2. Presence of minerals indicative of aqueous processes (e.g., phyllosilicates, carbonates, sulfates, etc.) in outcrop
3. Noachian/Early Hesperian age based on stratigraphic relations and/or crater counts
4. Access to unaltered igneous rocks as float
5. Not a Special Region

**Potential Qualifying Geological Criteria:**
1. Morphological criteria for standing bodies of water and/or fluvial activity (deltaic deposits, shorelines, etc.).
3. Presence of former water ice, glacial activity or its deposits.
4. Igneous rocks of Noachian age, of known stratigraphic relation, better if including exhumed megabreccia.
5. Volcanic unit of Hesperian or Amazonian age well-defined by crater counts and well-identified by morphology and/or mineralogy.
6. Probability of samples of opportunity (ejecta breccia, mantle xenoliths, etc.).
7. Potential for resources for future human mission
Global Context

Gusev Crater
Gusev crater was chosen for the Mars Exploration Rover Spirit because of geomorphic features indicative of an ancient lake, i.e., a potentially habitable environment.

Potential Qualifying Geological Criteria:

1. Morphological criteria for standing bodies of water and/or fluvial activity (deltaic deposits, shorelines, etc.).

Eroded delta?
Key Water-related Discoveries in Gusev

- Outcrops and soil composed of nearly pure opaline silica (Squyres et al., 2008)
- Comanche carbonate-rich outcrops (Morris et al., 2010)
- Home Plate
- Husband Hill
Silica Outcrops at Home Plate

- APXS: SiO$_2$ 72% (Background subtraction)
- APXS: SiO$_2$ 85%

Squyres et al. [2008]  
Ruff et al. [2011]

~5 cm across

HiRISE

Pancam ATC

Elizabeth Mahon

Spirit

10 cm
Silica Soil at Home Plate

Gertrude Weise soil
APXS:
SiO$_2$ > 90%
Squyres et al., 2008

Pancam ATC

Abraded outcrop
Ruff et al. [2011]

MI

~5 cm across
Opaline Silica at Home Plate

Squyres et al. [2008]

Mini-TES vs. Lab spectra
Candidate Origins

Hot spring sinter: opaline silica outcrops are primary precipitates from silica-rich liquid producing *stratiform* deposits.

Fumarolic silica residue: opaline silica outcrops are country rock altered by acid-sulfate steam condensates producing *non-stratal* alteration.

Yellowstone National Park

Sulphur Banks, Hawai‘i
Eroded *stratiform* outcrops of opaline silica suggest sinter deposits

Ruff, Farmer et al. [2011]

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**Threshold Geological Criteria:**

1. Presence of subaqueous sediments or hydrothermal sediments (equal 1st priority)

Pancam false color
Hydrothermal Systems and Life

Hydrothermal environments exhibit high rates of biological productivity that often coexist with pervasive mineral precipitation.

Such conditions favor microbial fossilization.

The deposits of hydrothermal systems preserve a wide variety of fossil biosignatures.
Borcher’s Spring, Yellowstone

Life at High Temperatures

Fossilized cyanobacteria

Living cyanobacteria
Filament sheaths & molds

Amorphous opal + clays

Primary pore space

Geopetal infill

J. D. Farmer
Key Water-related Discoveries in Gusev

Outcrops and soil composed of nearly pure opaline silica (Squyres et al., 2008)

Comanche carbonate-rich outcrops (Morris et al., 2010)

Husband Hill

Home Plate
Comanche Outcrops

- Comanche is 16-34 wt% Mg-Fe carbonate, ~40 wt% Mg-rich olivine (Fo\textsubscript{72}), and the remainder as an amorphous silicate (Morris et al., 2010)

Mini-TES (bulk mineralogy)  Mössbauer (Fe mineralogy)

Model Results
- Mg-Fe carbonate 34%
- Mg-rich olivine 33%
- Amorphous silicate 33%
# Comanche Outcrops

**APXS (elemental chemistry)**

## Table 1. Chemical composition of Comanche Spur Palomino whole rock, with light elements as CO$_2$ and calculated components olivine, carbonate, and residue.

<table>
<thead>
<tr>
<th></th>
<th>Whole rock* (wt %)</th>
<th>Component†</th>
<th></th>
<th>Component§ (wt %)</th>
<th>Residue (wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Olivine‡</td>
<td>Carbonate§</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>36.1 ± 0.4</td>
<td>37.8</td>
<td>—</td>
<td>62.1</td>
<td></td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.22 ± 0.06</td>
<td>—</td>
<td>—</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>2.56 ± 0.08</td>
<td>—</td>
<td>—</td>
<td>7.68</td>
<td></td>
</tr>
<tr>
<td>Cr$_2$O$_3$</td>
<td>0.63 ± 0.03</td>
<td>—</td>
<td>—</td>
<td>1.88</td>
<td></td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>4.84 ± 0.03</td>
<td>—</td>
<td>—</td>
<td>14.5</td>
<td></td>
</tr>
<tr>
<td>FeO</td>
<td>15.4 ± 0.1</td>
<td>25.6</td>
<td>19.2</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>0.37 ± 0.01</td>
<td>—</td>
<td>1.43</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>21.6 ± 0.2</td>
<td>36.4</td>
<td>26.2</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>1.69 ± 0.02</td>
<td>—</td>
<td>6.55</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>1.0 ± 0.2</td>
<td>—</td>
<td>—</td>
<td>3.0</td>
<td></td>
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<tr>
<td>K$_2$O</td>
<td>0.03 ± 0.05</td>
<td>—</td>
<td>—</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>0.39 ± 0.07</td>
<td>—</td>
<td>—</td>
<td>1.16</td>
<td></td>
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<tr>
<td>SO$_3$</td>
<td>2.36 ± 0.04</td>
<td>—</td>
<td>—</td>
<td>7.08</td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>0.53 ± 0.01</td>
<td>—</td>
<td>—</td>
<td>1.61</td>
<td></td>
</tr>
<tr>
<td>CO$_2$</td>
<td>12 ± 5</td>
<td>—</td>
<td>46.4</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Chemistry total</td>
<td>99.8</td>
<td>99.8</td>
<td>99.8</td>
<td>99.8</td>
<td></td>
</tr>
<tr>
<td>Component total</td>
<td>99.8</td>
<td>40.9</td>
<td>25.7</td>
<td>33.2</td>
<td></td>
</tr>
</tbody>
</table>

*APXS data from (21) recalculated to 12 wt % CO$_2$. †All Ca and all Mn calculated as carbonate. ‡Equivalent to (Mg$_{0.72}$Fe$_{0.28}$)SiO$_4$. §Equivalent to (Mg$_{0.62}$Fe$_{0.25}$Ca$_{0.11}$Mn$_{0.02}$)CO$_3$.  

Morris et al. (2010)
Hypothesis 1: Carbonate enrichment inferred to result from volcanic hydrothermal activity via dissolution of pre-existing carbonate rocks followed by transport and precipitation into the Comanche outcrops (Morris et al., [2010])

Hypothesis 2: Carbonate enrichment resulted from water-limited leaching of formerly widespread Algonquin-like tephra deposits by surface ephemeral waters, followed by transport and evaporative precipitation of the fluids into Comanche outcrops (Ruff, Niles, Alfano, and Clarke [2014], Geology)
Relationship to Olivine-rich Algonquin Outcrops

These are clastic, olivine-rich rocks that make up an apparent olivine fractionation sequence, increasing in MgO and decreasing CaO and Al₂O₃ (Mittlefehldt et al., 2006)

Potential Qualifying Geological Criteria:
4. Igneous rocks of Noachian age, of known stratigraphic relation
Spectral and chemical models indicate Comanche alteration was an addition to Algonquin-like host rock rather than depletion or isochemical replacement of primary phases.

Ruff et al., 2014, *Geology*
Relationship to Olivine-rich Algonquin Outcrops (3)

- A key result is that the chemistry of the added phases strongly resembles that of fluids in equilibrium with Algonquin-like rocks; could explain minimal Ca-carbonate
- Low temperature fluids are required to generate abundant Fe$^{2+}$ under modeled conditions; weakens case for hydrothermal fluids

![Fluid Composition in Equil. w/ Algonquin](image)
Comanche/Algonquin outcrops display distinctive knob and ridge morphology and higher thermal inertia than surrounding terrain.
Morphologic And Thermal Expression

- Additional examples of Comanche/Algonquin-like terrain

- Interpreted as remnants of formerly more extensive Algonquins-like tephra deposits that mantled the region and were eroded prior to flood basalts at 3.65 Ga
**Hypothesis:** Given the likelihood of water flows from Ma’adim Vallis, we suggest a scenario in which flooding led to water-limited leaching of formerly widespread Algonquin-like tephra deposits followed by transport and evaporative precipitation of the fluids into the Comanche rock. (Ruff et al., 2014)

**Threshold Geological Criteria:**

- Presence of subaqueous sediments or hydrothermal sediments (equal 1st priority),
  - OR
- Hydrothermally altered rocks or low-T fluid-altered rocks (equal 2nd priority)
- Presence of minerals indicative of aqueous processes (e.g., phyllosilicates, carbonates, sulfates, etc.) in outcrop
Re-analysis of the Columbia Hills using CRISM: results

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

Carter and Poulet, 2012 J. Carter new results
Re-analysis of the Columbia Hills using CRISM: results

**Kaolinite (RELAB)**

Potential Qualifying Geological Criteria:

3.65 Ga Wrinkle-ridged Plains of Gusev

= Hesperian Ridged Plains

Greeley et al. (2005)
Hesperian Ridged Plains = Adirondack Class

Columbia Hills

Adirondack rock
Wide Distribution of Adirondack Basalt on the Plains

Potential Qualifying Geological Criteria:
5. Volcanic unit of Hesperian or Amazonian age well-defined by crater counts and well-identified by morphology and/or mineralogy.

Hamilton and Ruff [2012]
Sulfur-rich Soils

Husband Hill

Paso Robles soil
APXS:
SO₃  32%
SiO₂  23%

Home Plate

Pancam ATC

HiRISE
Sulfur-rich Soils

Arad soil
APXS:
SO₃ 34%
SiO₂ 32%

Pancam ATC
Sulfur-rich Soils

Tyrone soil
APXS:
SO₃  28%
SiO₂  33%

Pancam ATC

Home Plate

Husband Hill
Sulfur-rich Soils

Troy soil
APXS:
SO$_3$ 36%
SiO$_2$ 28%

Potential Qualifying Geological Criteria:

- Assemblages of secondary minerals of any age.
  (Probably recent in these examples.)
Conclusions

• Gusev crater displays a rich history of aqueous, hydrothermal, volcanic, and erosional processes
• It checks all the boxes for Threshold Geological Criteria and most of the Qualifying Criteria, already validated in situ
• Testable hypotheses and new questions can be investigated in conjunction with sampling across a compact and accessible landing site
• Which samples to cache can be debated years in advance
Back Up
Columbia Hills

CTX/THEMIS nighttime IR

Carter and Poulet, 2012

Kuzmin et al., 2000