Columbia Hills (Gusev Crater) Site

14.4S, 175.6E

Overarching Hypothesis: *Candidate Silica Hot Spring and detection of Olivine Carbonate-bearing Deposits*

- Columbia Hills preserves candidate opaline silica sinter and may have formed by precipitation at hot springs. Outcrops expressing digitate-nodular features may represent primary depositional forms associated with past biological activity. Local outcrops of olivine-carbonate may be representative of more widespread occurrences. Carbonate-bearing rocks may indicate weathering of mafic rocks in a denser CO_2 atmosphere.

Site Issues:

- Uncertain whether digitate-nodular features are primary depositional or erosional features
- Unclear whether stratigraphic sequence for Columbia Hills rocks can be established
- Lacks novelty

Specific Pros of Site:

Setting -

- Columbia Hills is located in the ~166 km diameter Gusev crater, and lies at the downstream terminus of Ma'adim Vallis. Water draining from Ma'adim Vallis into Gusev in the Noachian may have deposited lacustrine/deltaic sediments, subsequently largely buried by Hesperian-aged basalts. Past exploration by the MER *Spirit* showed evidence for opaline silica that could result from hot springs.

Diversity -

- Olivine Carbonate-bearing ("Comanche" outcrop) may be representative of more widespread occurrences of similar materials
- Hesperian plains volcanics provide an excellent tie point for Martian crater chronology
- Diverse igneous rocks in Columbia Hills provide insight into evolution and differentiation of Mars.
- Wide range of aqueously processed rocks and soils in Columbia Hills
- Presence of sulfates and diversity of alteration mineralogies
- Opaline silica including centimeter to decimeter-scaled nodular and digitate-nodular features may be primary depositional forms (sinter) associated with past biological activity.
- Volcanic lava and ash plains modified by impact and aeolian processes and volcaniclastic sediments
- Possible lacustrine and (or) deltaic materials south of landing ellipse add diversity of samples during the extended mission.

Preservation -

- Terrestrial hot spring silica deposits have analogous digitate features and are biologically mediated.
- Any identifiable lacustrine facies likely have predictable properties that include deposition/formation of fine-grained clays and concentration and burial of organics and biosignatures.

Exploration Targets –

- Previous exploration provides specific targets for sample acquisition
- Outcrops expressing opaline silica digitate features, olivine-carbonate-bearing rocks (Comanche). Extended mission targets include possible ash and lacustrine/deltaic deposits to south.

Remaining Uncertainties:

- Stratigraphic position (are they Noachian?) and origin of digitate features (biogenic v. erosion/leaching) and duration of setting (relatively short?)
- Is diversity of Columbia Hills representative of local or global processes and conditions?
- Whether outcrops of olivine carbonate-bearing materials are more widespread in Gusev and beyond (e.g. Jezero crater) and whether they represent habitable environments.
- Uncertain whether preservation state/potential digitate structures is consistent with gradational setting.

Jezero Crater Site

18.5N, 77.4E

Overarching Hypothesis: *A Well-Exposed Delta with Clays and Carbonates*

- Jezero crater stratigraphy, geomorphology, and mineralogy record the evolution of a open basin paleolake and formation of deltaic deposits likely in the Noachian or Early Hesperian. Distinctive stratigraphic and morphologic expressions of deltaic/lacustrine sedimentation coincide with phyllosilicate mineral enrichments in a depositional environment, including basin marginal carbonates, favorable for the preservation of organic materials and (or) other biosignatures. Carbonate-bearing rocks are also exposed beneath younger possible volcanic cover.

Site Issues:

•Age (likely Early Amazonian) and origin of mafic floor unit on the crater floor is relatively young and it may not be sufficiently extensive to constrain crater chronology

• Differing opinions related to the overall diversity of samples that may be accessed at the site.

Specific Pros of Site:

Setting -

• Jezero is a 49 km diameter crater on the western margin of Isidis basin that hosted an open basin paleolake (~250 m deep) likely in the Noachian to Early Hesperian. Jezero has excellent preservation of a fluvial-deltaic system emplaced (perhaps during multiple phases) into a standing body of water that integrates sedimentary material from a broad source region with a wide variety of mineralogies.

• Deltaic deposits are underlain by Mg-carbonate-bearing basin fill that may be detrital or part of a more regional deposit.

• A mafic floor unit that may be volcanic or volcanoclastic, and/or may or may not underlie the delta complex, covers most of the present day floor of Jezero, and was likely emplaced during the Early Amazonian

Diversity -

• Phyllosilicate-bearing deltaic deposits

• Mg-carbonate bearing basin fill that underlies the deltaic deposits

• Basin marginal carbonate-bearing materials

• Mafic floor unit

• Possible detection of hydrated silica in western delta

• Very large and diverse watershed integrated into deltaic deposit

Preservation -

• Orbital detection of phyllosilicate-bearing deltaic deposits are a well-defined target for exploration and, on Earth, they are associated with deposition/formation of fine-grained clays and the concentration and preservation of organics and biosignatures in bottomset beds, including possible hydrated silica.

• Marginal carbonates may preserve biosignatures detectable by 2020 rover

Exploration Targets –

• Well-defined fluvial-deltaic-lacustrine system coupled with mineralogical diversity within and outside the ellipse leads to definition of both a short and long term exploration strategy.

•Extended mission scenarios include possible access of northern delta or could encompass targets ~28 km away at Midway in a well characterized landing site.

Remaining Uncertainties:

• Duration of lacustrine setting remains uncertain and may have been relatively short.

• Origin and age of Mg-carbonate-bearing basin fill (regional deposit or detrital?)

• Age and origin of mafic floor unit is uncertain as is whether it embays deltaic deposits

• Whether outcrops of olivine carbonate-bearing rocks represent habitable environments and/or may be equivalent to those in Gusev and elsewhere to NW of Isidis.

Midway Site

18.3N, 77.1E

Overarching Hypothesis: *Ancient Stratigraphy of Igneous and Altered Rocks with Clays and Carbonates*

- Distinct, widespread, diverse units exposing Hesperian and Noachian-aged sequences with Isidis basin megabreccia, igneous rocks and hydrated, phyllosilicate and carbonate mineral signatures. Exposed rocks may reveal biosignatures in ancient, habitable subsurface environments, possibly related to groundwater circulation. Surface drainage, perhaps coupled with glacial activity, shaped current landscape.

Site Issues:

• Lack of high-resolution hyperspectral data makes understanding the key components of various exploration targets more difficult.
•There is a range of hypotheses for some of the diverse rocks exposed regionally at the site (e.g., olivine carbonate-bearing rocks).
•The mechanisms for concentrating or preserving organics is poorly understood and it is unlikely that the depositional setting will be further refined prior to landing and in situ evaluation.
•Some of the specific targets to be interrogated/sampled cannot be well-defined over scales of up to 10's of m scale) prior to landing and it may require a relatively long time to identify and access target rocks for interrogation. Other targets are established prior to landing

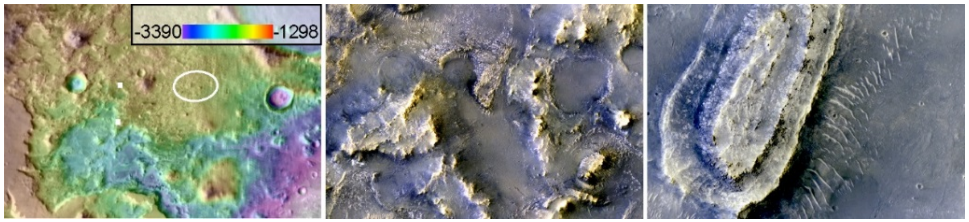
Specific Pros of Site:

Setting -
• Midway is a "land on" site located on the western margin of the Isidis basin southwest of Jezero crater. Distinct, diverse units exposing Hesperian and Noachian-aged sequences with igneous, hydrated, and phyllosilicate mineral signatures are exposed in mesas in the ellipse.
• Diversity of regional rocks at site records a transition from neutral to alkaline pH related to up to four distinct aqueous environments in the region, suggesting many of the observed mineral signatures may support evidence for the evolution of past habitable environments.
Diversity -
Megabreccia blocks occur within a more massive, iron and magnesium clay-bearing unit with local occurrences of clays in ridges, low Ca pyroxene-bearing rocks, a kaolin-group mineral, and an Al-clay weathering horizon. Possible hydrated silica in the basement and fractured units.
•Overlying, extensive olivine-bearing unit: variably fractured and altered, contains up to ~20% carbonate (possibly ancient shallow mineralization of the host rock or perhaps precipitation in mineral springs). Carbonate-bearing rocks may be representative of more widespread process.
•Mafic, crater-retaining cap may be related to Syrtis Major lavas
Preservation -
• Hydrated rock sequences may be analogous to modern lithospheric environments harboring microbial ecosystems on Earth.
Exploration Targets –
• Primary targets include the Noachian clay-bearing basement, overlying olivine carbonate-bearing unit, and basaltic cap.
Extended mission targets could include rocks on the rim of and/or inside Jezero crater 28 km away or Hesperian-aged sulfates and overlying Syrtis Major volcanic rocks and younger fluvial-lacustrine deposits ~30+ km to the south.
• Opportunities to date multiple igneous units emplaced from pre-Isidis to the Hesperian.
•Clay-bearing basement rocks can provide insight into early planetary crustal processes and habitability

Remaining Uncertainties:

• Origin of basement rocks (impact?) and circum-Isidis olivine-rich unit? Clastic? Intrusive? Volcanic?
•Origin of carbonate in the overlying olivine-bearing unit: could be ancient shallow mineralization of the host rock or perhaps precipitation in mineral springs.
•Preservation and/or abundance of organics.
•Whether outcrops of olivine carbonate-bearing rocks represent habitable environments and may be equivalent to those in Gusev and elsewhere.
•Megabreccia blocks could be from Jezero or Isidis

Northeast Syrtis Site



17.8N, 77.1E

Overarching Hypothesis: *Ancient Stratigraphy of Igneous and Altered Rocks with Clays and Carbonates*

- Distinct, widespread, diverse units exposing Hesperian and Noachian-aged sequences with Isidis basin megabreccia, igneous rocks and hydrated and phyllosilicate and carbonate mineral signatures. Exposed rocks may reveal biosignatures in ancient, subsurface habitable environments, possibly related to groundwater circulation. Surface drainage, perhaps coupled with glacial activity, shaped current landscape

Site Issues:

• There is a range of hypotheses for some of the diverse rocks exposed regionally at the site (e.g., olivine carbonate-bearing rocks).
• The mechanisms for concentrating or preserving organics is poorly understood and it is unlikely that the depositional setting will be further refined prior to landing and in situ evaluation.
• Some of the specific targets to be interrogated/sampled cannot be well-defined over scales of up to 10's of m scale) prior to landing and it may require a relatively long time to identify and access target rocks for interrogation. Other targets are established prior to landing.

Specific Pros of Site:

Setting -
• NE Syrtis is a "land on" site located on the western margin of the Isidis basin southwest of crater Jezero. Distinct, diverse units exposing Hesperian and Noachian-aged sequences with igneous, hydrated, and phyllosilicate mineral signatures are exposed in mesas in the ellipse.
• Diversity of regionally outcropping rocks at NE Syrtis site records a transition from neutral to alkaline pH related to up to four distinct aqueous environments in the region, which suggests that many of the observed mineral signatures may support evidence for the evolution of past habitable environments.

Diversity -
Megabreccia blocks (likely from Isidis) occur within a more massive, iron and magnesium clay-bearing unit with local occurrences of clays in ridges, low Ca pyroxene-bearing rocks, a kaolin-group mineral, and an Al-clay weathering horizon. Possible hydrated silica in the basement and fractured units.
•Overlying, extensive olivine-bearing unit: variably fractured and altered, contains up to ~20% carbonate (possibly ancient shallow mineralization of the host rock or perhaps precipitation in mineral springs). Carbonate-bearing rocks may be representative of more widespread unit.
•Mafic, crater-retaining cap that may be related to Syrtis Major lavas

Preservation -
• Hydrated rock sequences may be analogous to modern environments harboring microbial ecosystems on Earth

Exploration Targets –
• Primary targets include the Noachian clay-bearing basement, overlying olivine carbonate-bearing unit, and basaltic cap.
Extended mission targets could include Hesperian-aged sulfates and overlying Syrtis Major volcanic rocks and younger fluvial-lacustrine deposits ~30+ km to the south.
• Opportunities to date multiple igneous units emplaced from pre-Isidis to the Hesperian.
•Clay-bearing basement rocks can provide insight into early planetary crustal processes and habitability

Remaining Uncertainties:

• Origin of basement rocks (impact?) and circum-Isidis olivine-rich unit? Clastic? Intrusive? Volcanic?
•Origin of carbonate in the overlying olivine-bearing unit: could be ancient shallow mineralization of the host rock or perhaps precipitation in mineral springs.
•Preservation and/or abundance of organics.
•Whether outcrops of olivine carbonate-bearing rocks represent habitable environments and may be equivalent to those in Gusev and elsewhere.