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October 23rd, 2018

Dr. Michael Meyer,
Lead Scientist, Mars Exploration Program
Planetary Science Division,
Science Mission Directorate
NASA Headquarters
300 E Street SW
Washington, DC 20546

Dear Michael:

This letter summarizes the outcomes and findings of the fourth Mars 2020 Landing Site Workshop held in Glendale, CA, from October 16-18, 2018. The meeting was very well attended, with more than 150 to over 200 people present on each of the three days of the workshop. Participants included members of science community and the Mars 2020 project and instrument science teams on all three days of the workshop. The workshop was broadcast using Adobe Connect and attracted an additional ~80 participants daily, though remote attendees did not participate in assessment of the candidate landing sites.

The workshop included oral presentations and discussion related to the science potential of the four remaining candidate landing sites (Table 1): Columbia Hills, Jezero Crater, and NE Syrtis, including an additional landing ellipse within the NE Syrtis region dubbed "Midway." Midway is located closer to Jezero crater than the original NE Syrtis ellipse and was proposed as a site by the Mars 2020 Science Team that might enable achieving the science objectives of the mission by accessing exploration targets relevant to both Jezero crater and NE Syrtis.

Table 1. Remaining Candidate Landing Sites for Mars 2020 Mission. Ellipse center point, elevation and ellipse size with the long axis oriented east-west.

Location	Lat (degN)	Long (degE)	Approx MOLA Elevation (km)	Approx Buffered Ellipse Axes (km)
Columbia Hills	-14.5711	175.4374	-1.9	9 x 8
Jezero	18.4463	77.4565	-2.6	9 x 8
Midway	18.2747	77.0480	-2.0	9 x 8
NE Syrtis	17.8899	77.1599	-2.0	9 x 8

Presentations emphasized new science content, increasing confidence in the interpretations of site science potential, and (or) potential extended mission targets for the sites. In addition,

the Mars 2020 Project provided mission scenarios for each site that included discussion of potential exploration targets, observations, and sampling strategies relative to mission goals and important Mars science described in the 2013-2022 Planetary Science Decadal Survey.

Workshop presentations were grouped into introductory sessions related to mission status and strategies that were followed by sessions focused on each of the candidate sites. The website marsnext.jpl.nasa.gov serves as an archive for the workshop program, scientific selection criteria used for assessment, and workshop presentations. The final sessions on the third day were geared towards compilation of summary quad charts for each site and community assessment relative to the scientific selection criteria (Table 2). Additional time was provided for discussion at the end of each session and all discussion sessions were lively and involved. We recognize and sincerely appreciate the considerable time and effort made by participants in preparing what were uniformly excellent presentations for the workshop.

The quad charts summarizing the science pros, issues, and remaining uncertainties are provided in Figures 1-4 and as a separate attachment to this letter. The assessment relative to the scientific selection criteria (Table 2) that followed was made using an online "ballot" submitted to Google Forms and subsequently tabulated in near real-time. Workshop participants were instructed to assess each site relative to each criterion using values of one (low) to five (high). We want to recognize Jacob Adler at ASU for his continued work in creating the assessment tool. Summary results were presented as color plots (red low, yellow intermediate, green high) portraying the average and standard deviation of each site relative to individual criteria (Figure 5) and in tabular form (Figure 6) for the average score for all six criteria for each site.

Table 2. Criteria Used to Assess Candidate Sites at 4th 2020 Landing Site Workshop

Prime Mission Assessment

Criterion 1 (In-Situ Science):

The landing site includes an astrobiologically-relevant ancient environment and has geologic diversity with the potential to yield fundamental scientific discoveries when it is a) characterized for the processes that formed and modified the geologic record; and b) subjected to astrobiologically-relevant investigations (e.g., assessment of habitability and biosignature preservation potential). (scoring: 1=low potential, 5=high potential)

Criterion 2 (Returnable Cache Science):

A rigorously documented and returnable cache of rock and regolith samples assembled at this site has the potential to yield fundamental scientific discoveries if returned to Earth in the future. (scoring: 1=low potential, 5=high potential)

Criterion 3:

There is confidence in the assumptions, evidence, and any interpretive models that support the assessments for Criteria 1 and 2 for this site (or proposed traverse). (scoring: 1=low confidence, 5=high confidence).

Extended Mission Scenario Assessment

Criterion 1 (In-Situ Science):

The extended mission scenario has the potential to yield fundamental additional scientific discoveries using the rover payload. (scoring: 1=low potential, 5=high potential)

Criterion 2 (Returnable Cache Science):
Rock and regolith samples assembled in the extended mission have the potential to yield fundamental additional scientific discoveries if returned to Earth in the future. (scoring: 1=low potential, 5=high potential)
Criterion 3:
There is confidence in the assumptions, evidence, and any interpretive models that support the assessments for Criteria 1 and 2 for the extended mission. (scoring: 1=low confidence, 5=high confidence).

The quad charts (Figures 1-4) reveal that all four candidate sites represent diverse and potentially high value exploration targets for the Mars 2020 rover. The Columbia Hills site within Gusev crater includes putative hot spring deposits of opaline silica sinter with small (cm's scale) finger-like features that, on Earth, form in association with biological activity. Moreover, the nearby carbonate rocks may record past weathering in a thicker atmosphere. Landing on cratered volcanic plains would enable sampling that could eventually constrain the age of cratered surfaces across Mars. Targets for extended mission exploration include possible lake and delta deposits to the south of the landing site and within Gusev crater. Nevertheless, it is uncertain whether the finger-like features were formed by deposition or erosion, how old they are, or whether they may relate to past biological activity. Moreover, it is unclear whether the rocks forming the Columbia Hills can be confidently placed in a broader context.

The Jezero crater site includes a river delta that extends into the crater and occurs at the same elevation as an outlet on the far side of the crater, thereby indicating the presence of a lake once filling the crater in Noachian to Early Hesperian times on Mars. The delta and nearby outcrops expose clays and other materials whose properties make them favorable for preserving organics and (or) other biogenic signatures. In addition, there are carbonate-bearing rocks whose origin may relate to past weathering and overlying cratered and possibly volcanic rocks on the crater floor that could be used to help constrain Martian chronology. Candidate extended mission targets include access to the rocks in and around the Midway site (below). Remaining uncertainties relate to the duration of the lake and the age, the origin of the carbonate-bearing rocks, and whether the crater floor rocks are of the correct type and extent to be useful in constraining the broader chronology of the planet.

The Midway and NE Syrtis Sites include access to ancient rocks that include clays and carbonate-bearing rocks with evidence for past alteration by water. These rocks form a widespread and diverse sequence spanning from the Noachian to Hesperian in age and may be accessible at either of the two sites. Importantly, both sites expose large blocks of ancient and sometimes layered materials dubbed "megabreccia" that were likely excavated and emplaced during formation of the nearby Isidis (NE Syrtis) and (or) Jezero craters (Midway). As such, these rocks, and others in and around the sites may provide insight into the changing conditions on Mars, ranging from those recorded in ancient subsurface groundwater environments to younger sequences possibly shaped by surface drainage. Possible extended mission scenarios include a trek to the south from the NE

Syrtis site to interrogate younger sulfate and volcanic rocks to a journey from the Midway site to Jezero crater to access the materials exposed near the delta there (above). Both sites have remaining uncertainties: there are multiple hypotheses for the origin of rocks exposed at the sites and it is unclear how organics might be concentrated and preserved. Moreover, high-resolution spectral data at Midway is sparse and makes understanding key aspects of the exploration targets more difficult and it is not clear whether the megabreccia blocks at Midway are derived from Isidis basin or Jezero crater.

The summary assessment plots (Figures 5 and 6) reveal the Jezero crater site is assessed the highest or nearly the highest for all criteria relative to both the prime and extended mission. The Midway and NE Syrtis sites were also assessed highly for all criteria for the prime and extended mission, but slightly below the Jezero crater site. By contrast, the Columbia Hills site was consistently assessed lower than the other three sites for almost all criteria related to both the prime mission and extended mission objectives (except it was assessed slightly higher than the Midway site relative to the confidence in interpretations for the prime mission). Interestingly, the Midway and Jezero crater sites were assessed the highest (and received the most votes for high potential) with respect to extended mission criteria, perhaps reflecting the interest in possible extended mission opportunities between the two sites.

We continue to appreciate the opportunity for the science community to contribute to the Mars 2020 landing site selection process. It is clear that the workshops bring broad expertise into assessment of the candidate landing sites and result in energetic discussion of the relative merits of candidate landing sites.

Sincerely,

John Grant

Matt Golombek
Co-Chairs, Mars 2020 Landing Site Steering Committee

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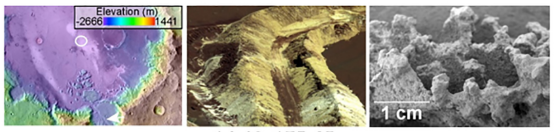
Columbia Hills (Gusev Crater) Site



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.

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.

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

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.

Figure 1. Columbia Hills summary quad chart

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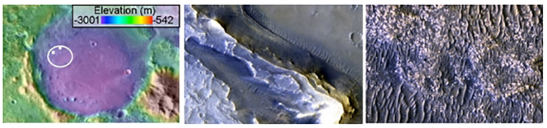
Jezero Crater Site



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.

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.

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.

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.

Figure 2. Jezero crater summary quad chart

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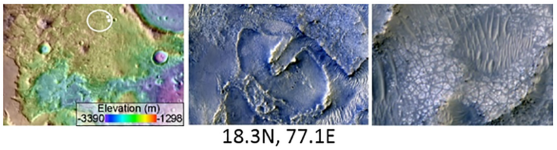
Midway Site



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

Figure 3. Midway summary quad chart

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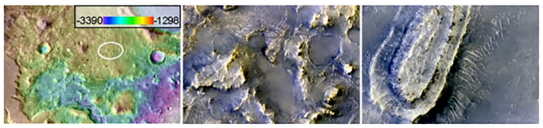
Northeast Syrtis Site



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.

Figure 4. NE Syrtis summary quad chart

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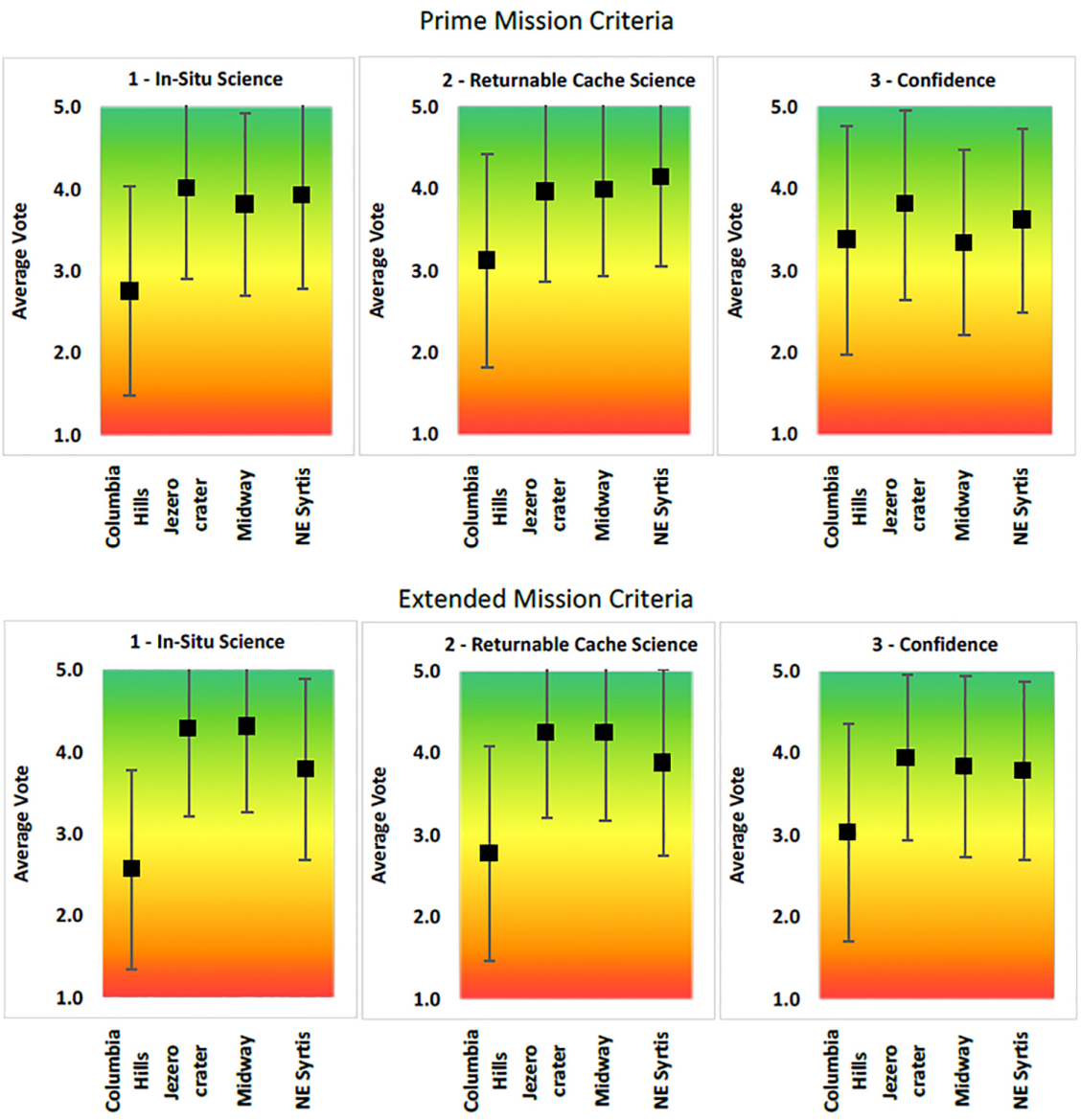

Figure 5. Summary assessment of the final four candidate sites (average and standard deviation) relative to each of the five criteria. Red/1 is the low, Yellow/3 is intermediate, and Green/5 is high.

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Average Vote	Columbia Hills	Jezero crater	Midway	NE Syrtis
Prime Mission				
Criterion 1	2.8	4.0	3.8	3.9
Criterion 2	3.1	4.0	4.0	4.1
Criterion 3	3.4	3.8	3.3	3.6
Extended Mission				
Criterion 1	2.6	4.3	4.3	3.8
Criterion 2	2.8	4.2	4.2	3.9
Criterion 3	3.0	3.9	3.8	3.8

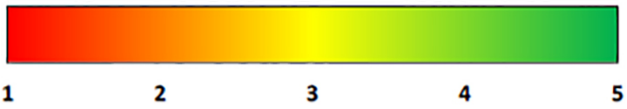

Figure 6. Summary of the average score for all six criteria for each of the final four candidate sites. Red/1 is low, Yellow/3 is intermediate, and Green/5 is high.