Inside ellipse
1A: inverted channels at ellipse center
1B-D: craters with layered outcrops on fan surface
1E: knob of underlying material (megabreccia)
1F: upper LTL outcrops
1G: coarse material (distal Uzboi, poss. megabreccia)
1H: fan toe (exposed contact between alluvium and underlying material)
1I: LTL outcrop

[Other outcrops of each material type are available]

Outside ellipse
2: many LTL outcrops
3: bedded coarse deposits (proximal Uzboi)
4: LTL outcrops, higher phyllosilicate abundance

Extended mission
5: topographically higher LTL section
6: knob of underlying material (megabreccia)
Holden Crater Overview

- 26°S, 34°W
- 155 km diam.
- ~2 km floor
- Phyllosilicate-rich LTL rocks
- Alluvial fans and bajada from deeply dissected wall alcoves
- Coarse flood deposit from Uzboi Vallis rim breach
- Underlying bedrock outcrops
Diversified Habitability Investigation

**Alluvial fans**
- Paleoclimate and atmospheric evolution: Paleohydrology and runoff requirements for observed sediment load from a well-defined watershed
- Mineralogy, weathering, and diagenetic alteration: Alluvial gravel/cobbles sample top 1-2 km of highland crust, up to 800 Myr of the Noachian Period

**Light-toned, layered materials with Fe,Mg phyllosilicates**
- Stratigraphy, sedimentology, and geochemistry of 100-m-thick medium to fine-grained section reflects depositional environment and change over time
- Ideal site to search for organics and effects of biological processes

**Flood deposits**
- Paleoflood hydrology, rocks from rim breach & Uzboi, late-stage weathering

**Bedrock outcrops**
- Ancient bedrock uplifted during impact, possible hydrothermal system
Holden target 1A: Inverted channels on alluvial bajada

-26.38 North, 325.15 East
Km from ellipse center: 0

Rationale:
Alluvial deposits derived from crater wall, fluvial hydrology, sample reworked upper highland crust

Morphology and Mineralogy:
Inverted paleochannels: basaltic, possibly altered

What will the rover specifically do here?
Determine diversity of materials in upper >1 km of highland crust, determine emplacement mechanism for fans, examine stratigraphy within inverted channels for temporal change in environment
Targets of interest: select 1-2 after landing based on landing site and optimal traverse. Similar outcrops located elsewhere in ellipse.

Ellipse center
PSP_002154_1530
Left: 397 m across
Below: 1.59 km across
Holden target 1B: Layered outcrop in crater wall on bajada

-26.35 North, 325.15 East km from ellipse center: 1.9 (Use if MSL lands nearby)

Rationale:
Alluvial deposits derived from crater wall, alluvial fan stratigraphy, samples of upper highland crust

Morphology and Mineralogy:
Inverted paleochannels: basaltic, possibly altered

What will the rover specifically do here?
Determine diversity of materials in upper >1 km of highland crust, determine emplacement mechanism for fans, examine stratigraphy in crater wall for temporal change in environment
Target of interest

PSP_015999_1535
Top: 397 m across
Right: 793 m across
Crater diameter: 510 m
Holden target 1C: Layered outcrop in crater wall on bajada

-26.33 North, 325.22 East
km from ellipse center: 5.2

Rationale:
Alluvial deposits derived from crater wall, alluvial fan stratigraphy, samples of upper highland crust

Morphology and Mineralogy:
Inverted paleochannels: basaltic, possibly altered

What will the rover specifically do here?
Determine diversity of materials in upper >1 km of highland crust, determine emplacement mechanism for fans, examine stratigraphy in crater wall for temporal change in environment
PSP_015999_1535
Right: 1.59 km across
Below: 397 m across
Crater diameter: 740 m
Holden target 1E: Knob of underlying rocks (megabreccia)

-26.39 North, 325.28 East km from ellipse center: 7.0

Rationale: Megabreccia on Holden floor, light-toned veins in rock, possible former hydrothermal environment

Morphology and Mineralogy: Knob of coarse rocks with tone/color contrasts and veins

What will the rover specifically do here? Examine rocks and veins for possible hydrothermal deposits, chemical energy sources, organics, and alteration; determine diversity of materials exposed on crater floor
ESP_019678_1535
Right: 1.59 km across
Below: 793 m across

Targets of interest
Holden target 1H: Alluvial fan toe

-26.50 North, 325.19 East km from ellipse center: 7.5

Rationale:
Exposed contact between alluvial fan deposits and underlying lighter-toned material

Morphology and Mineralogy:
Inverted paleochannels: basaltic, possibly altered; light-toned material: finer-grained, likely phyllosilicate-bearing, fractured

What will the rover specifically do here?
Sample light-toned, layered material, compositional and stratigraphic analyses, search for organics, determine if alluvial and LTL materials are interbedded
Layered alluvial deposits overlie fractured, lighter-toned material at the fan toe.

Target 3 location

Target 4 location

PSP_001468_1535
Each 793 m across

100 m
Holden target 1I: Light-toned, layered materials

-26.52 North, 325.23 East
Km from ellipse center: 9.5

Rationale:
Section of light-toned, layered strata, suggestive of a quiescent depositional environment

Morphology and Mineralogy:
Thinly bedded, laterally continuous, fine-grained strata

What will the rover specifically do here?
Stratigraphic and compositional analyses, identify depositional environment, suggest consistent sediment source and weathering history, search for organics
33 m section
8° slope
>40 light/dark pairs

ESP_016276_1535
397 m across
<table>
<thead>
<tr>
<th><strong>Oxidized iron minerals</strong></th>
<th><strong>Mafic mineralogy</strong></th>
<th><strong>Hydroxylated silicates</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>red = BD530 (ferric minerals)</td>
<td>red = OLINDEX (olivine or iron phyllosilicates)</td>
<td>red = BD2300 (Fe/Mg phyllosilicate)</td>
</tr>
<tr>
<td>green = SH600 nm (coatings)</td>
<td>green = LCPINDEX (low-Ca pyroxene)</td>
<td>green = BD2210 (Al phyllosilicate or hydrated glass)</td>
</tr>
<tr>
<td>blue = BDI1000nm (variety of iron minerals)</td>
<td>blue = HCPINDEX (high-Ca pyroxene)</td>
<td>blue = BD1900 (hydrated sulfates, clays, glass, or water ice)</td>
</tr>
</tbody>
</table>

**Bound water**
- red = SINDEX (water-containing minerals or water ice)
- green = BD2100 (monohydrated sulfates or water ice)
- blue = BD1900nm. (hydrated sulfates, clays, glass, or water ice)

**CRISM FRT0000C1D1, derived products**
Credit: NASA/Johns Hopkins University Applied Physics Laboratory
Holden target 2: Light-toned, layered materials

-26.55 North, 325.22 East
Km from ellipse center: 10.5

Rationale:
Section of light-toned, layered strata, suggestive of a quiescent depositional environment

Morphology and Mineralogy:
Thinly bedded, laterally continuous, fine-grained strata

What will the rover specifically do here?
Stratigraphic and compositional analyses, identify depositional environment, suggest consistent sediment source and weathering history, search for organics
Targets of interest. Many other LTL outcrops are available along the notional traverse.

ESP_015999_1535
783 m across

Target 3 location

100 m
Holden Crater LTL Materials

100 m
Holden target 3: Coarse deposits (proximal Uzboi Vallis)

-26.59 North, 325.25 East km from ellipse center: 13.6

Rationale:
Rocks likely derived from Uzboi Vallis, late-stage flooding of Holden crater floor

Morphology and Mineralogy:
Coarse-grained, cross-bedded deposits, likely basaltic, possibly altered

What will the rover specifically do here?
Examine deposits from late-stage lake, weathering environment, chemical energy sources, organics; determine diversity of materials exposed on floor
Targets of interest

ESP_002088_1530
Above: 793 m across
Right: 199 m across
Holden target 4:
Best phyllosilicate signature, light-toned, layered outcrop
-26.64 North, 325.21 East km from ellipse center: 17.2

Rationale:
Section of light-toned, layered strata, suggestive of a quiescent depositional environment

Morphology and Mineralogy:
Thinly bedded, laterally continuous, fine-grained strata

What will the rover specifically do here?
Stratigraphic and compositional analyses, identify depositional environment, suggest consistent sediment source and weathering history, search for organics
Targets of interest

ESP_002088_1530
Left: 793 m across
Below: 793 m across
Relative phyllosilicate signature, Credit: R. Milliken
Holden target 5:
Topographically higher light-toned, layered outcrop

-26.70 North, 325.18 East km from ellipse center: 19.8

Rationale:
Section of light-toned, layered strata, suggestive of a quiescent depositional environment

Morphology and Mineralogy:
Thinly bedded, laterally continuous, fine-grained strata

What will the rover specifically do here?
Stratigraphic and compositional analyses, identify depositional environment, examine LTL spatial variability, search for organics
ESP_019322_1530
Right: 433 m across
Below: 5.5 km across

Target of interest
Holden target 6: Knob of underlying rocks (megabreccia)

-26.71 North, 325.18 East km from ellipse center: 20.2
[Extended mission]

Rationale:
Megabreccia on Holden floor, light-toned veins in rock, possible former hydrothermal environment

Morphology and Mineralogy:
Knob of coarse rocks with tone/color contrasts and veins

What will the rover specifically do here?
Examine rocks and veins for possible hydrothermal deposits, chemical energy sources, organics, and alteration; determine diversity of materials exposed on crater floor
Targets of interest

ESP_019322_1530
Right: 793 m across
Below: 5.5 km across
Veins in positive relief
800 m
Holden Crater Site

26S, 325E

Overarching Hypothesis:
- Holden crater preserves evidence of a closed fluvial-lacustrine system that provides the opportunity to apply a geomorphic systems approach to evaluating and preserving evidence for a sustained, habitable environment.

Specific Cons of Site:
- Origin of stratified light-toned materials as lacustrine versus alternate depositional processes remains uncertain, but in situ evaluation of bedding character and chemistry is likely to distinguish origin.
- Relatively limited variety of phyllosilicate minerals known to preserve organics detected from orbit.

Specific Pros of Site:
Setting -
- The bajada in the ellipse and light-toned layered materials comprise one of the largest and best preserved alluvial systems on Mars. The diverse and potentially weathered sediments likely record the environmental conditions responsible for their formation during the Hesperian, perhaps into the Early Amazonian. This sequence is underlain by the light-toned layered deposits and overlying Uzboi flood deposits and enable the age of the target deposits to be related to global stratigraphy.
- Collectively, additional diverse and widespread megabreccias in and outside the ellipse and alluvial materials in the ellipse suggest sampling of rocks ranging in age from early crustal Noachian to perhaps into the Hesperian or even Early Amazonian.

Diversity -
- Diversity is represented by fan sediments, phyllosilicate-bearing light-toned layered deposits, Uzboi flood deposits, and mega-breccias in the crater walls/floor.
- The mineralogical diversity in the light-toned layered deposits and crater walls/floor include both altered and primary compositions.

Preservation -
- Strata comprising the light-toned layered materials may be the equivalent of bottom set beds emplaced in a lacustrine setting, which might preserve organics for interrogation by the MSL.

Exploration Targets -
- Well-defined exploration targets exist within and outside the landing ellipse. Targets within the ellipse offer access to all major units for interrogation, though thicker sections of the light-toned layered materials and megabreccias occur farther to the south. Putative bottomset beds provide a target for evaluating any preserved organics.

Remaining Uncertainties:
- There are no shorelines or stratigraphic geometries and limited evidence for other properties associated with the light-toned layered deposits and fans that can be used to more confidently define their origin and genetic relationships.
- Diverse megabreccia occurrences within the ellipse, walls, and rims may include evidence that they supported an impact-induced hydrothermal system.
- Light-toned layers high on the west wall of Holden may relate to older beds excavated from the pre-existing Holden basin.
- Age of light-toned layered deposits and adjacent alluvial fan surfaces are no older than Early Hesperian and fans may be as young as Early Amazonian, though there is no consensus whether this is an issue for habitability and evaluating conditions for life.
Conclusions

- Good outcrops of all four target materials are available within the MSL ellipse
- More outcrops and lower strata of all four are accessible to the south
- One of the most deeply eroded crater rims on Mars: abundant water
- Diversified habitability investigation minimizes risk
- Sampling and chronology opportunities
- Safe landing site, trafficable route, low elevation