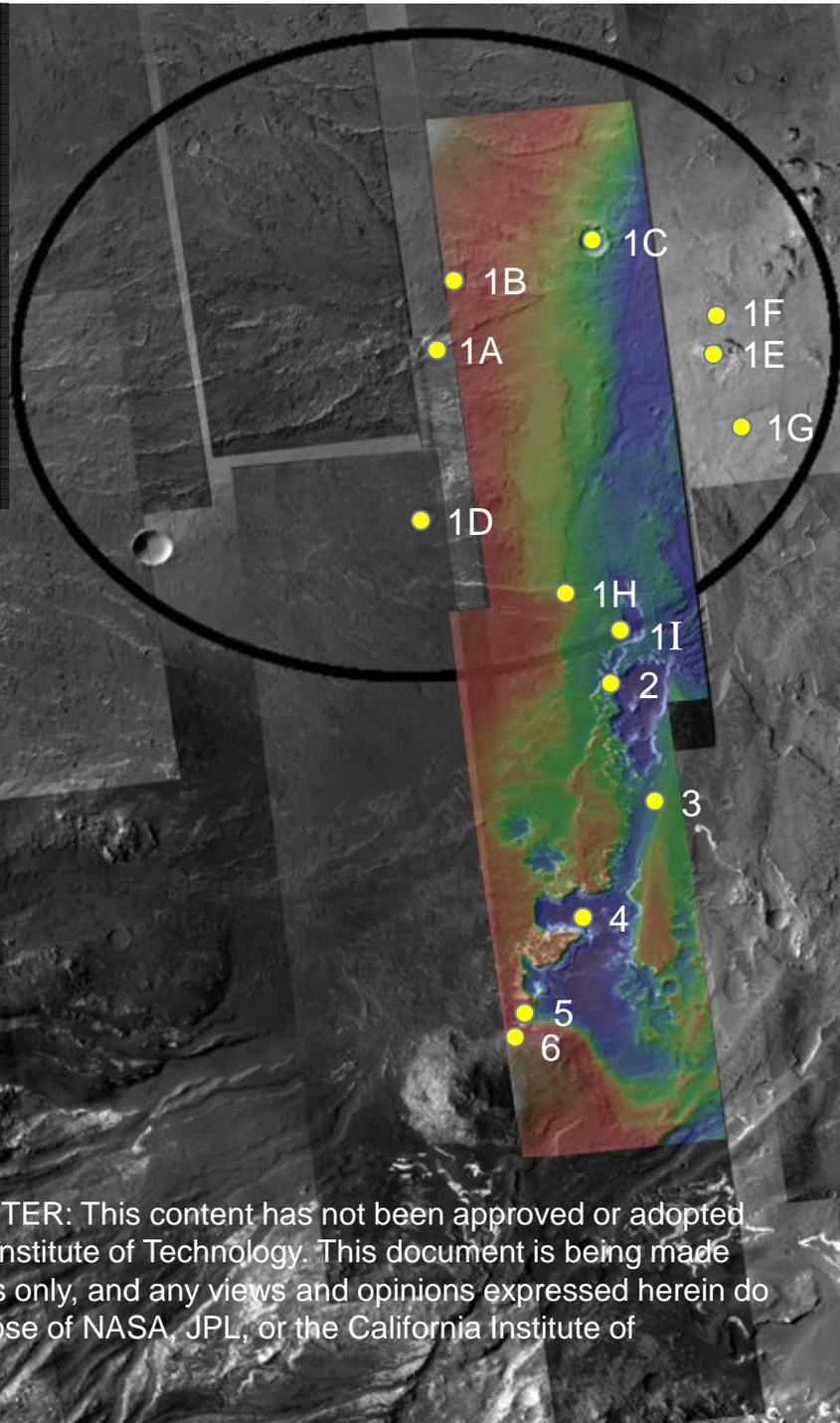


# Holden Crater Rover Targets

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Smithsonian Institution  
1<sup>st</sup> Mars 2020 Workshop  
May 16, 2014



## *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*

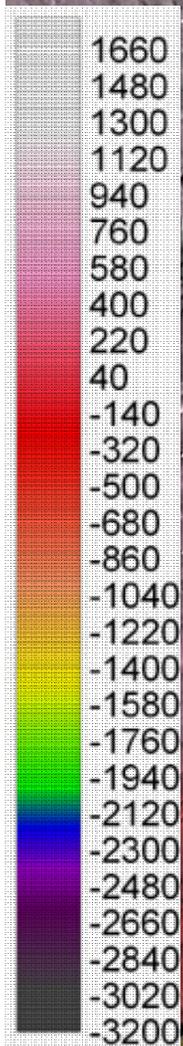
- 2: many LTL outcrops
- 3: bedded coarse deposits (proximal Uzboi)
- 4: LTL outcrops, higher phyllosilicate abundance

## *Extended mission*

- 5: topographically higher LTL section
- 6: knob of underlying material (megabreccia)

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# Holden Crater Overview



50 km

- 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

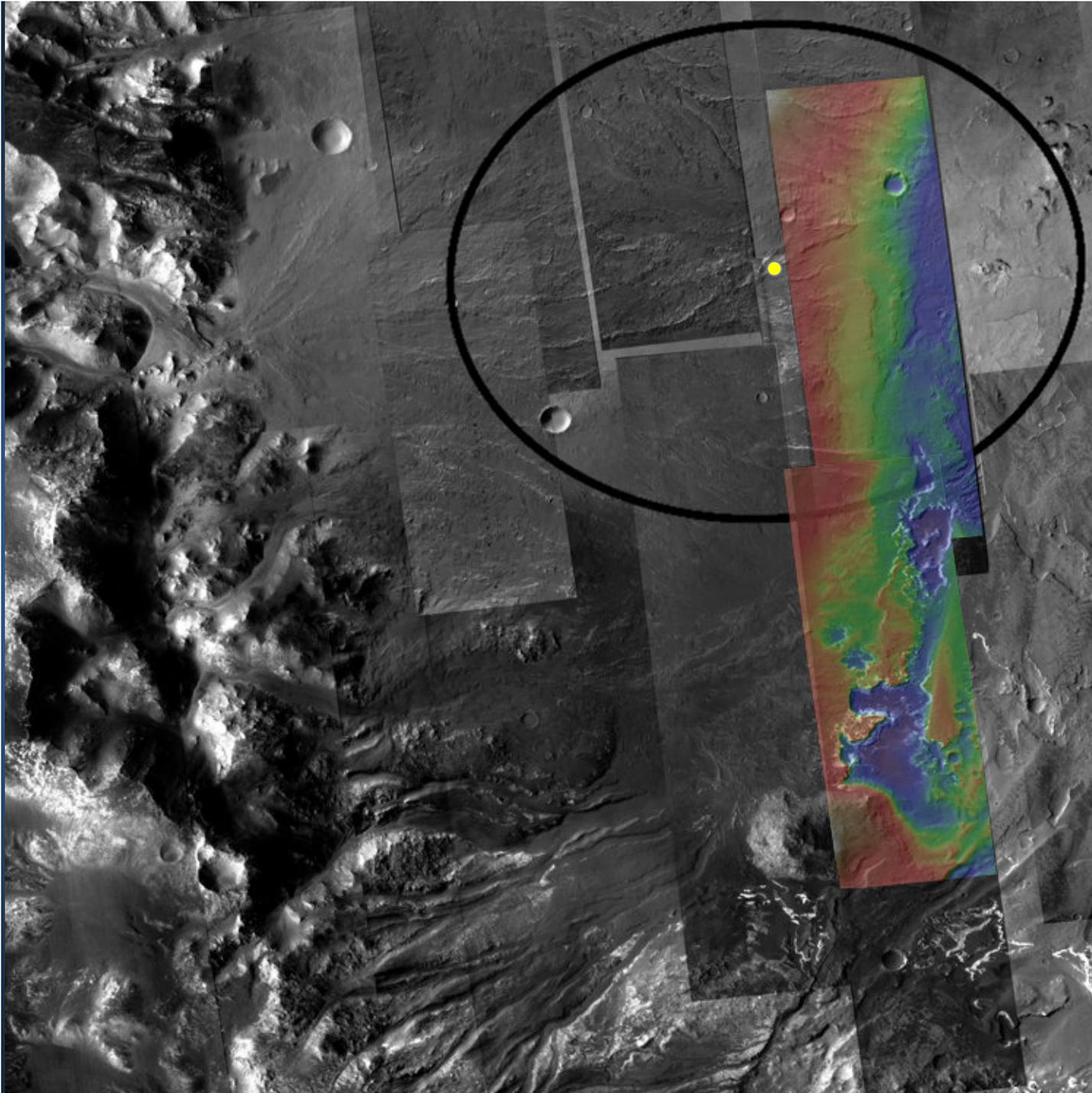
- Stratigraphy, sedimentology, and geochemistry of 100-m-thick medium to fine-grained section reflects depositional environment and change over time
- Ideal site to search for organics and effects of biological processes

## 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*

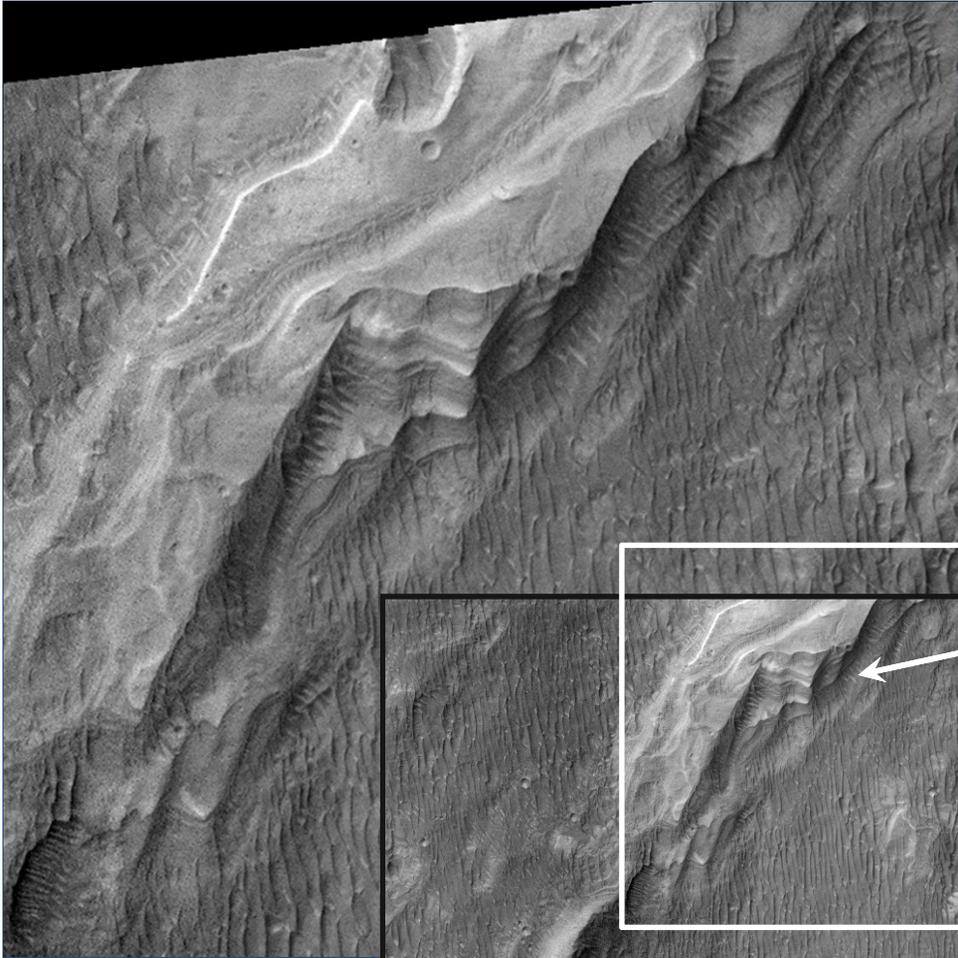
Morphology and

Mineralogy:

*Inverted paleochannels:  
basaltic, possibly altered*

What will the rover  
specifically do here?

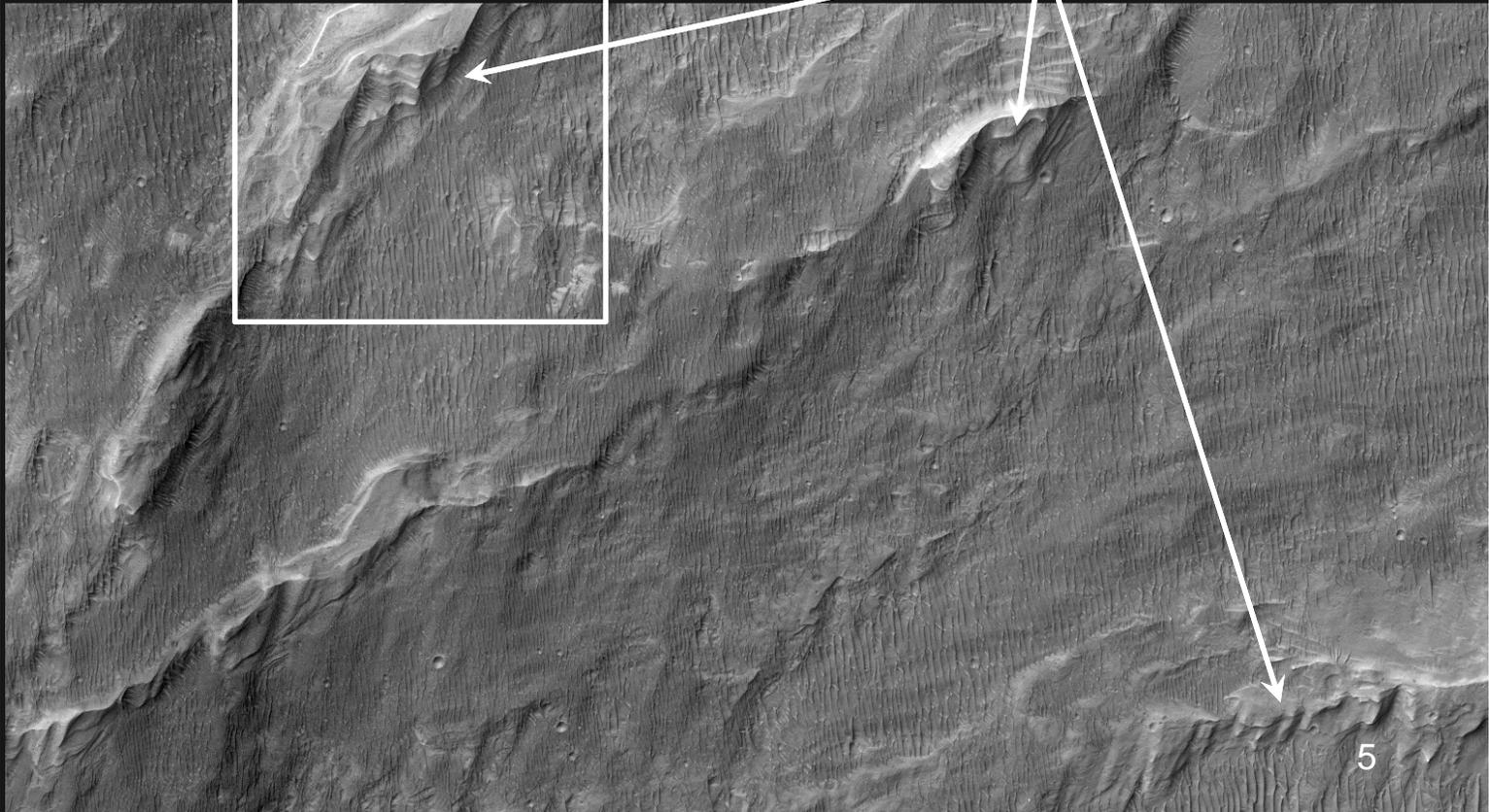
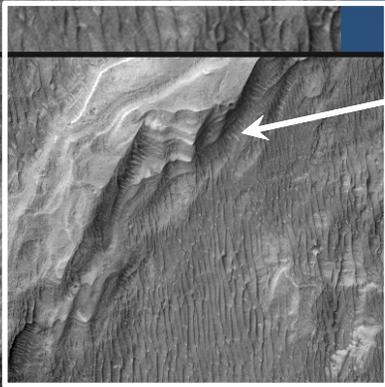
*Determine diversity of  
materials in upper >1 km of  
highland crust, determine  
emplacement mechanism  
for fans, examine  
stratigraphy within inverted  
channels for temporal  
change in environment*



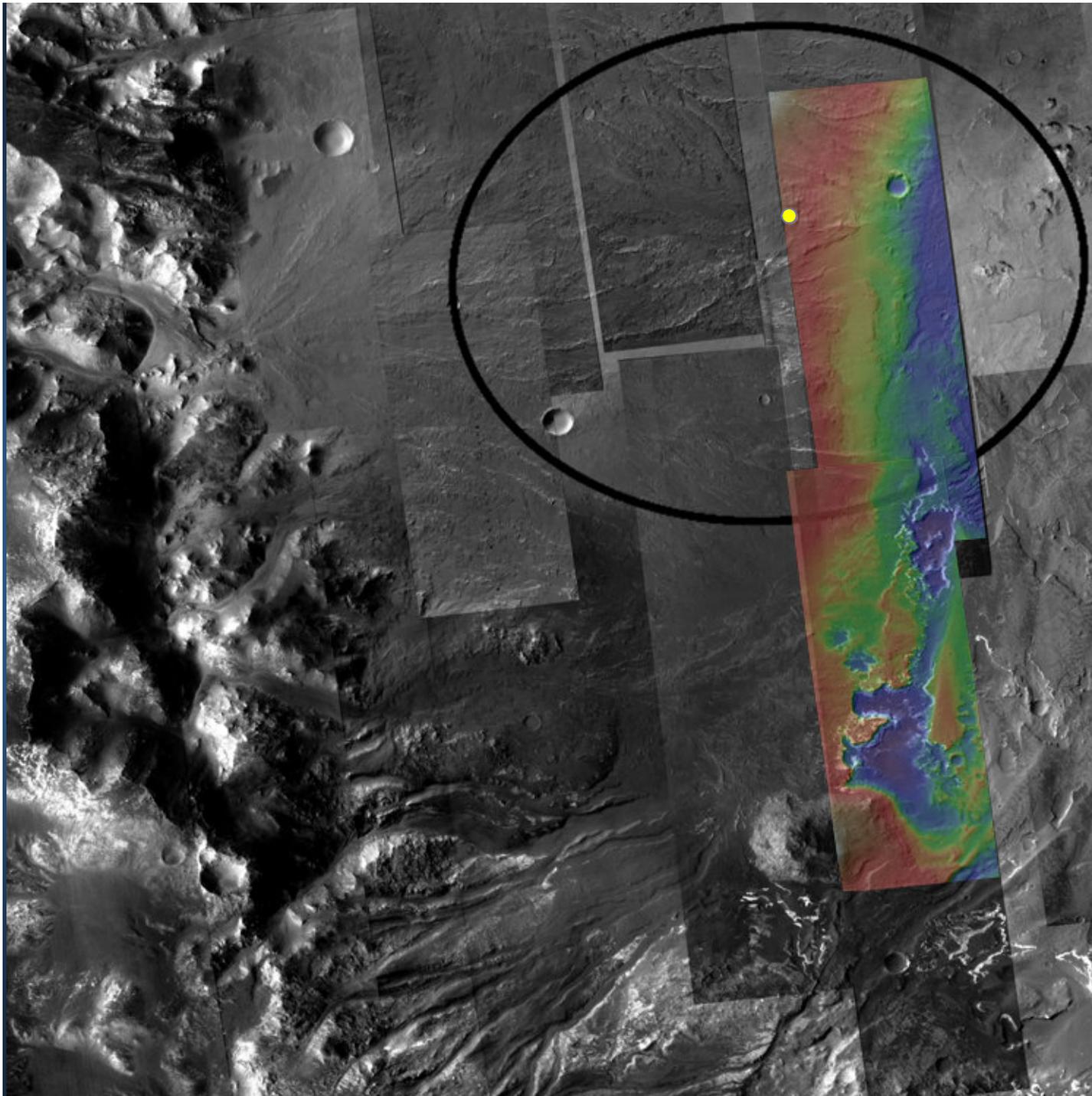
100 m

Ellipse center  
PSP\_002154\_1530  
Left: 397 m across  
Below: 1.59 km across

Targets of interest: select 1-2 after landing based on landing site and optimal traverse. Similar outcrops located elsewhere in ellipse.



200 m



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:

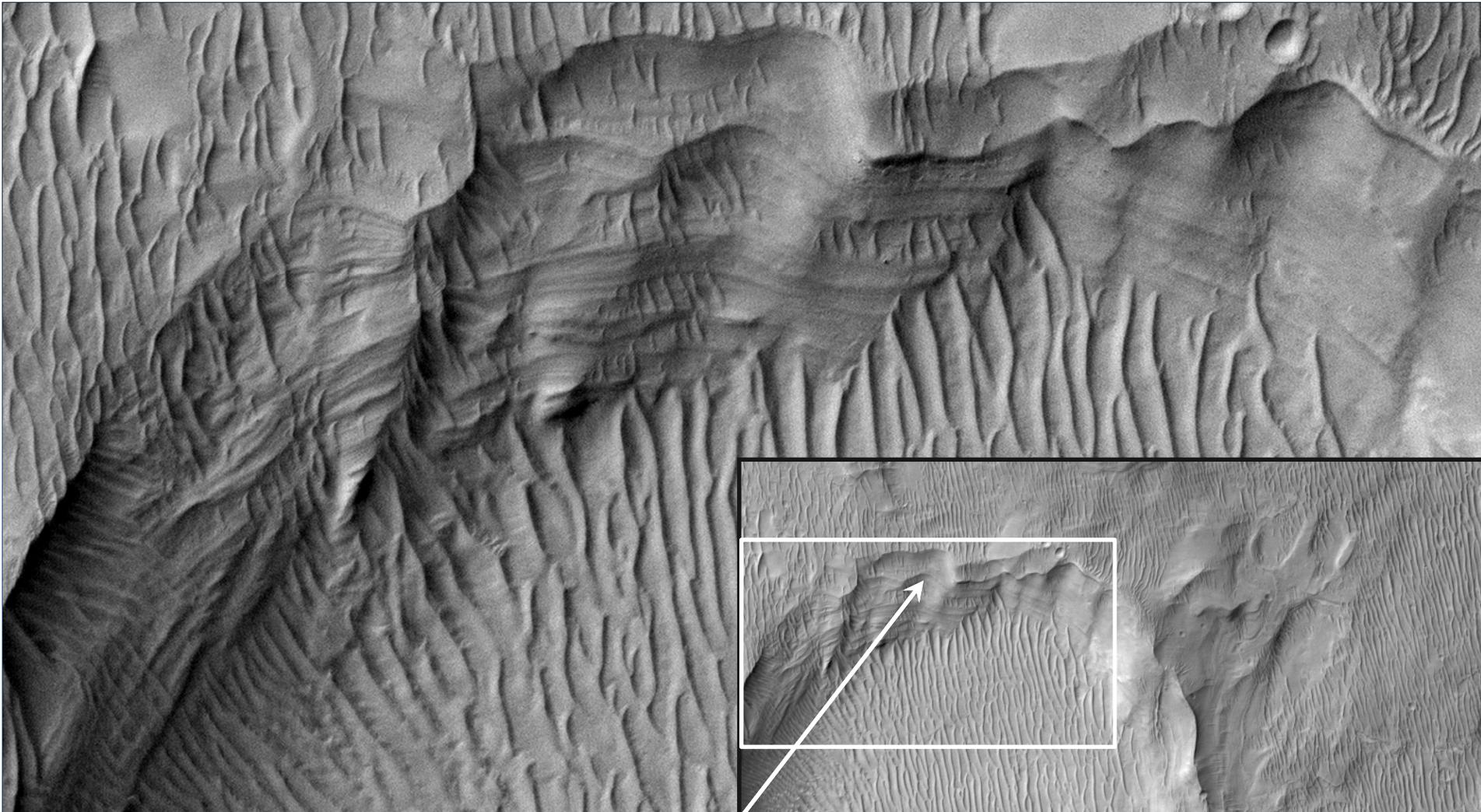
*Alluvial deposits derived  
from crater wall, alluvial fan  
stratigraphy, samples of  
upper highland crust*

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*



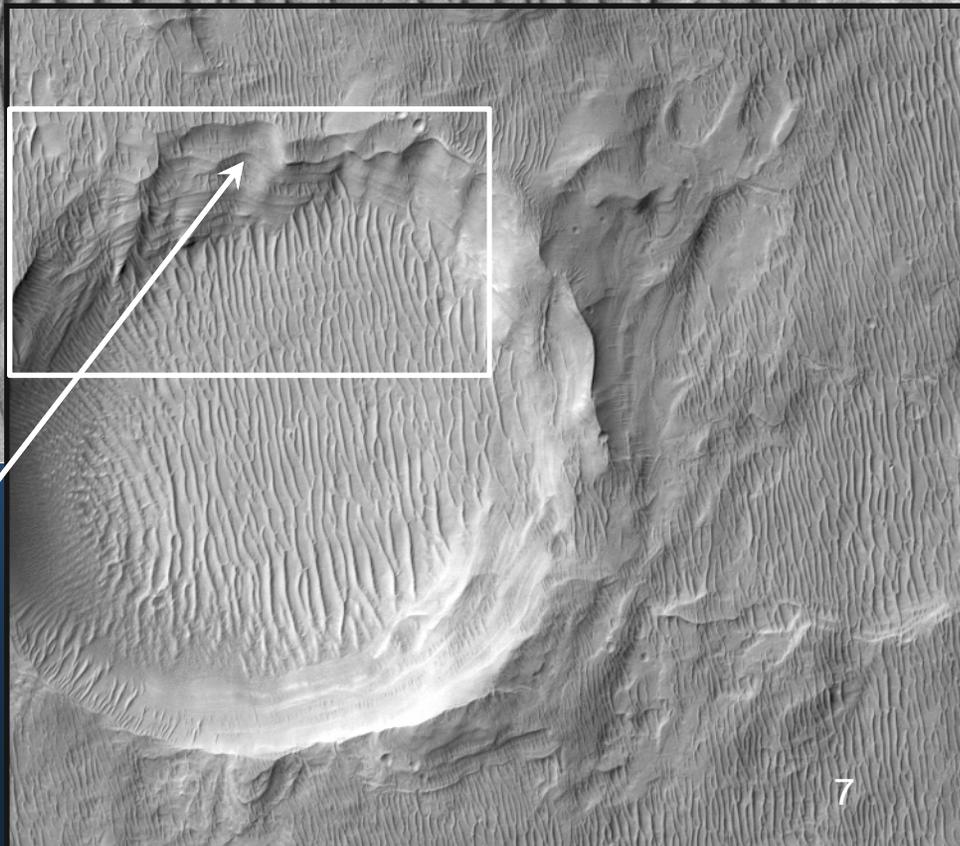
50 m

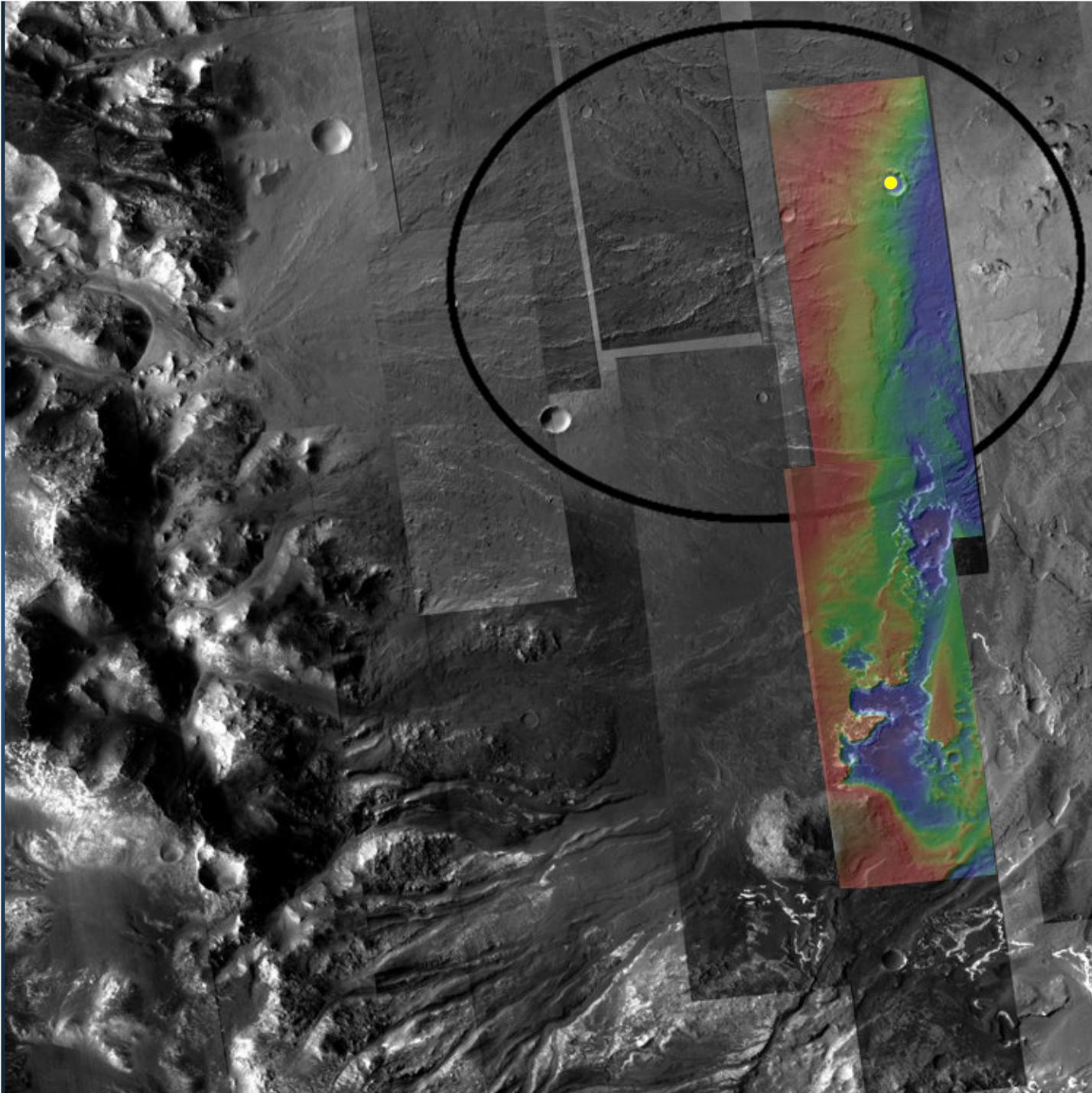


Target of interest

PSP\_015999\_1535  
Top: 397 m across  
Right: 793 m across  
Crater diameter: 510 m

200 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?

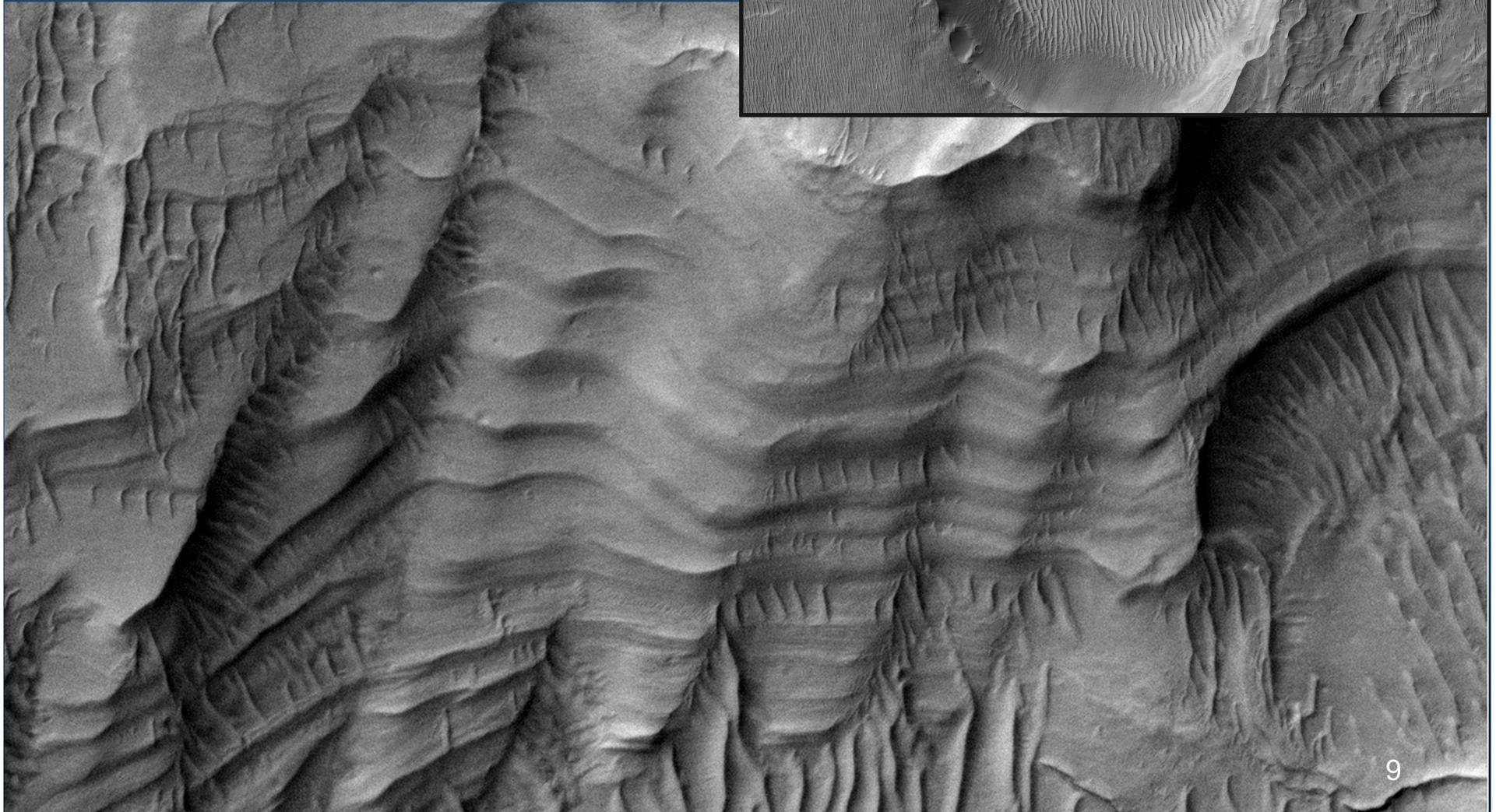
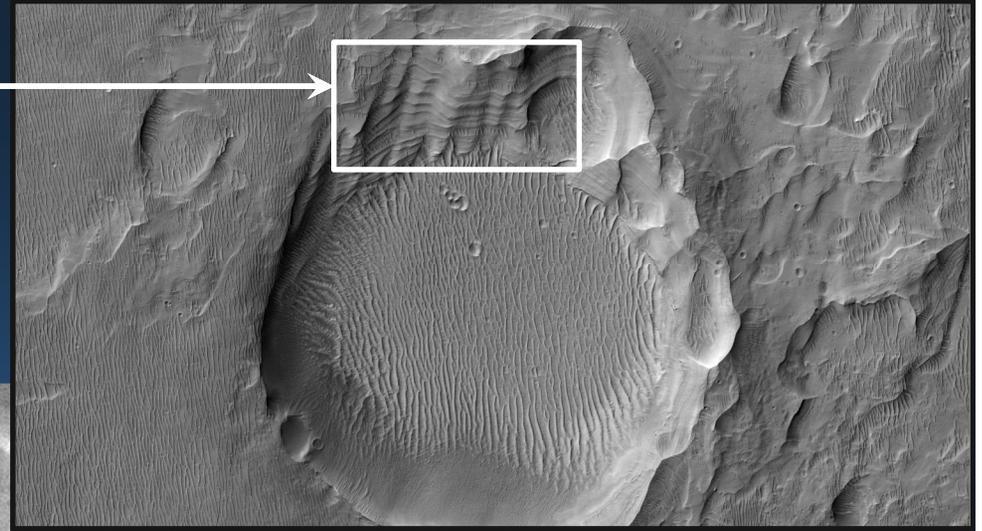
*Determine diversity of  
materials in upper >1 km of  
highland crust, determine  
emplacement mechanism  
for fans, examine  
stratigraphy in crater wall  
for temporal change in  
environment*

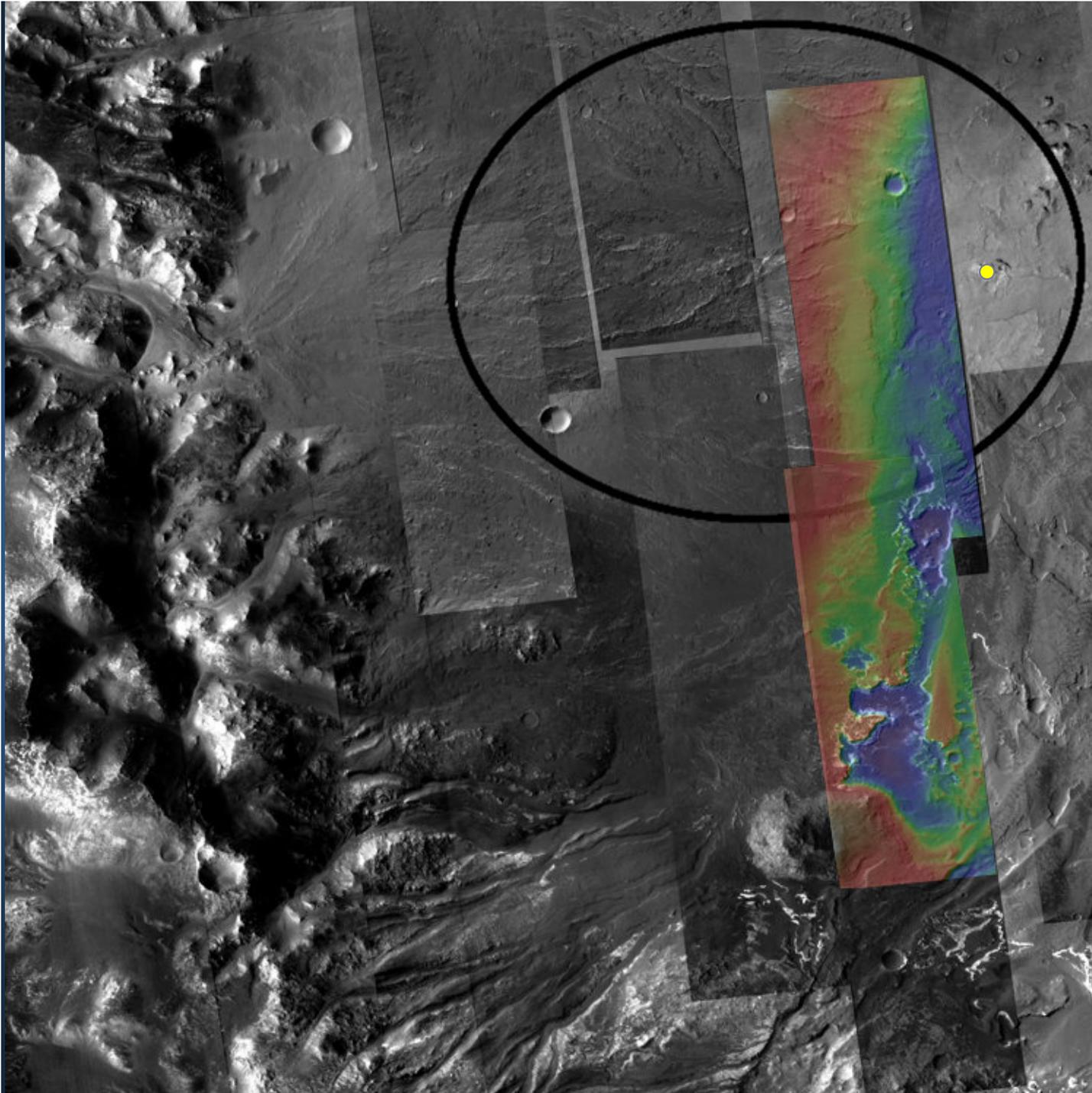
PSP\_015999\_1535  
Right: 1.59 km across  
Below: 397 m across  
Crater diameter: 740 m

50 m

Target of interest

300 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?

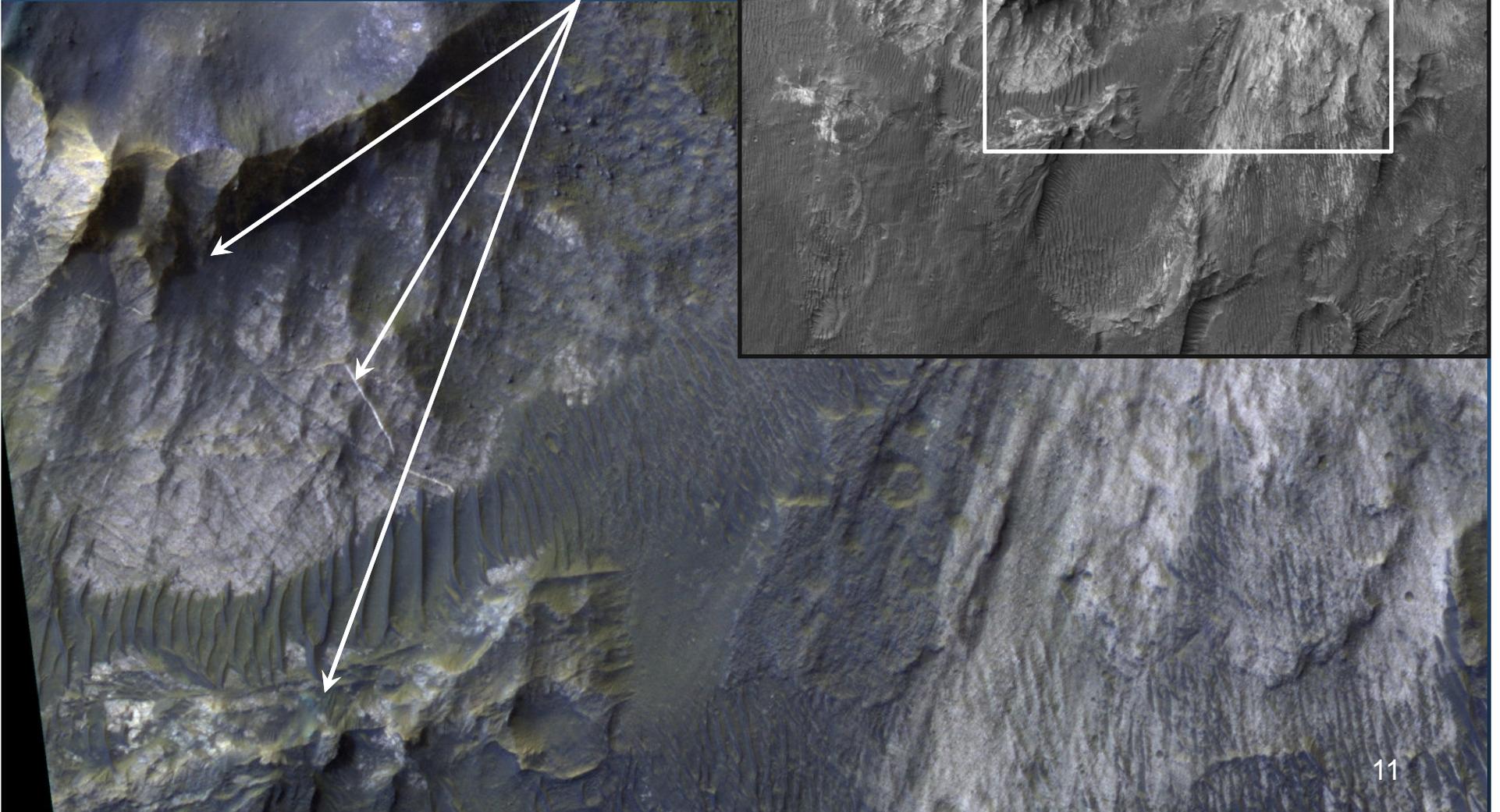
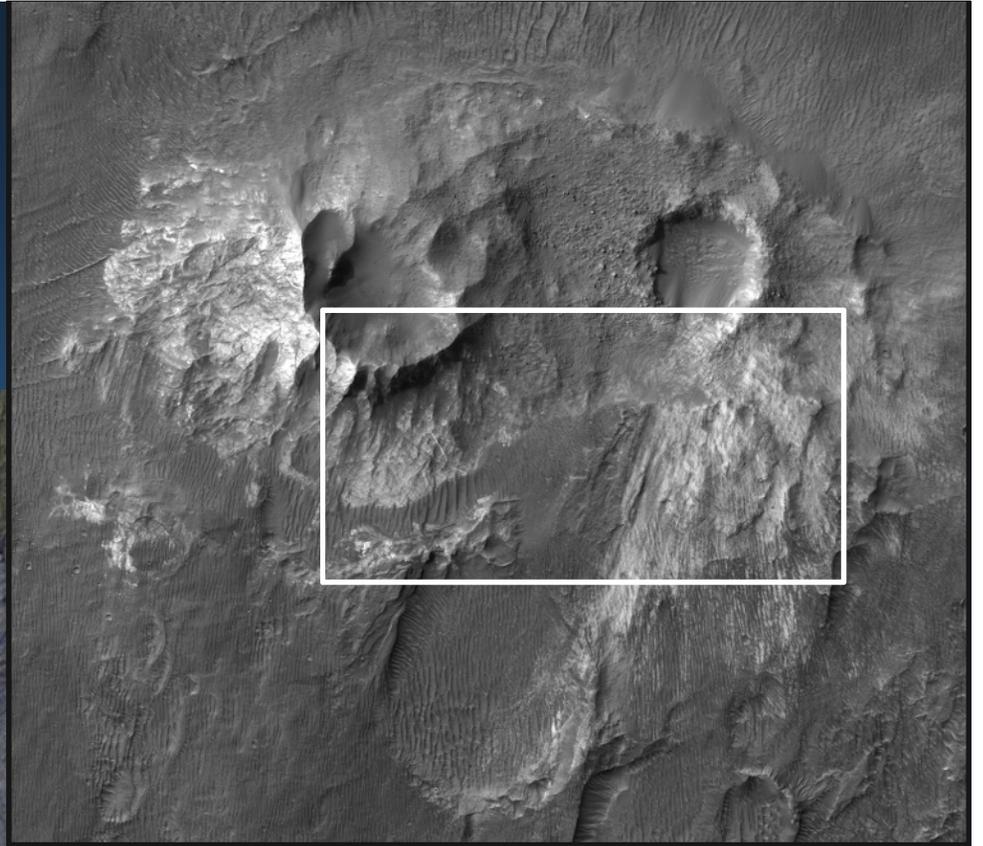
*Examine rocks and veins for  
possible hydrothermal  
deposits, chemical energy  
sources, organics, and  
alteration; determine  
diversity of materials  
exposed on crater floor*

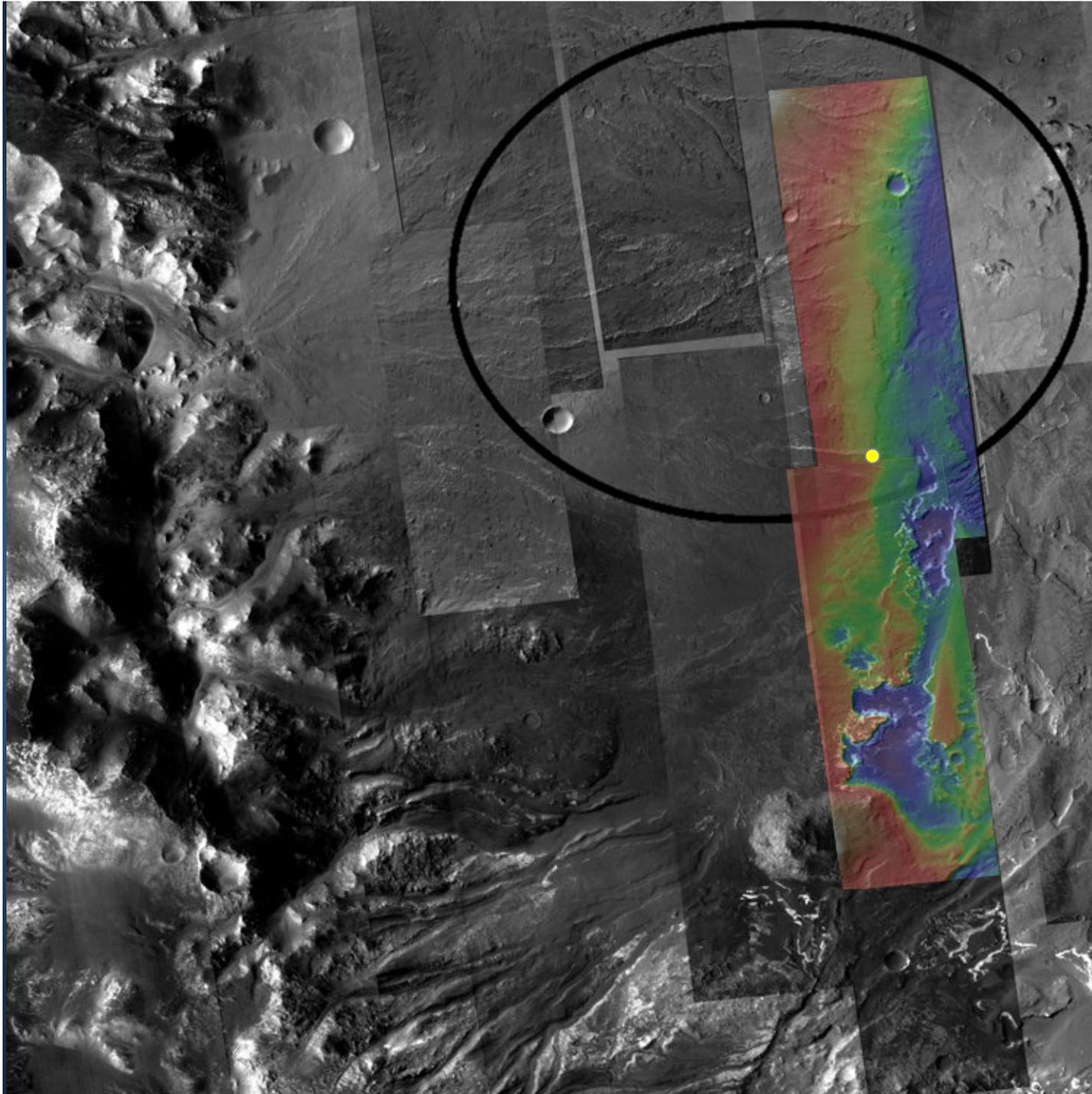
ESP\_019678\_1535  
Right: 1.59 km across  
Below: 793 m across

300 m

100 m

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*

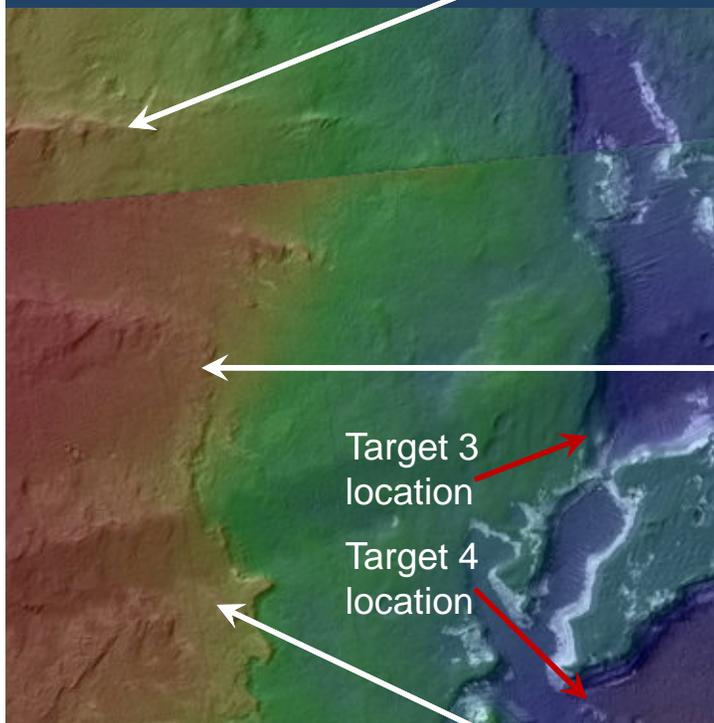
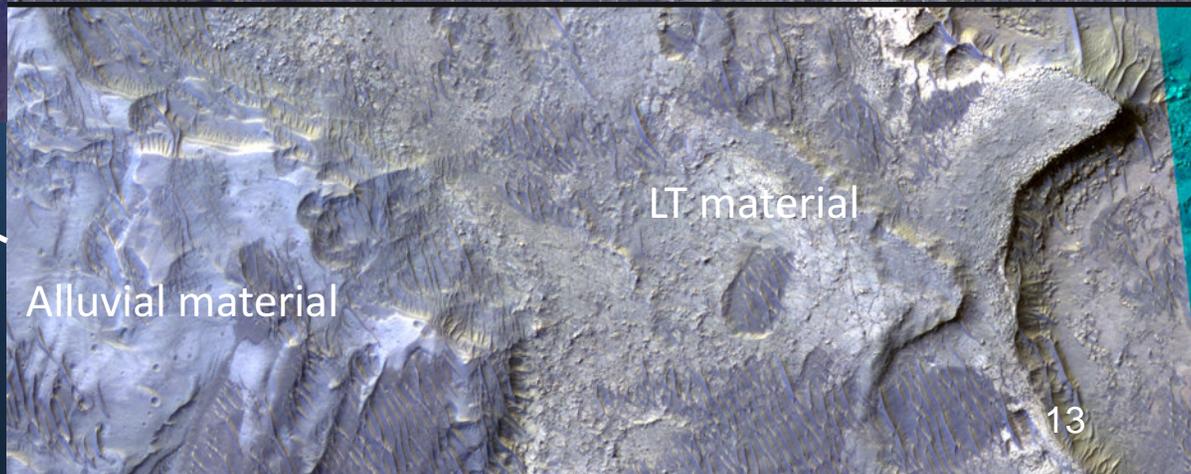
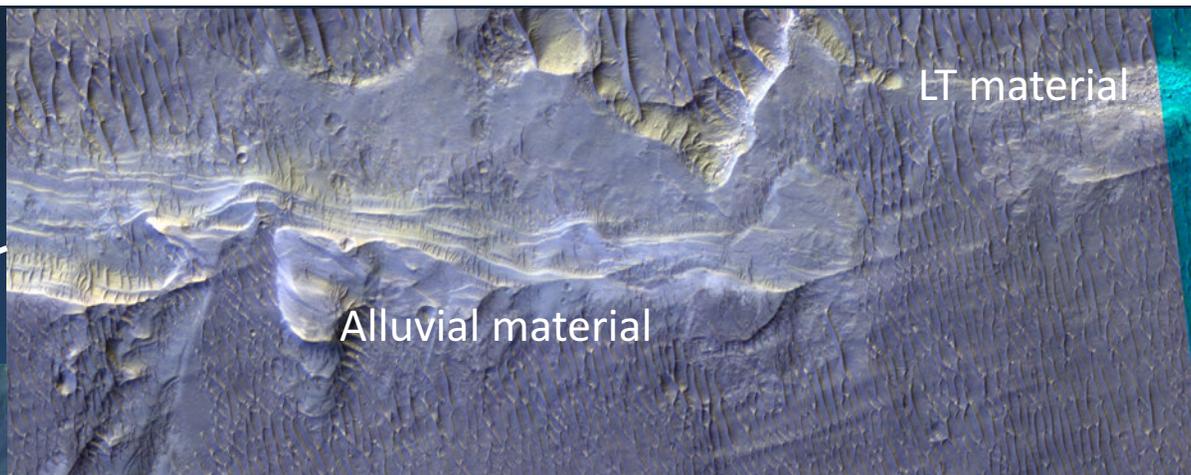
### Morphology and Mineralogy:

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

### What will the rover specifically do here?

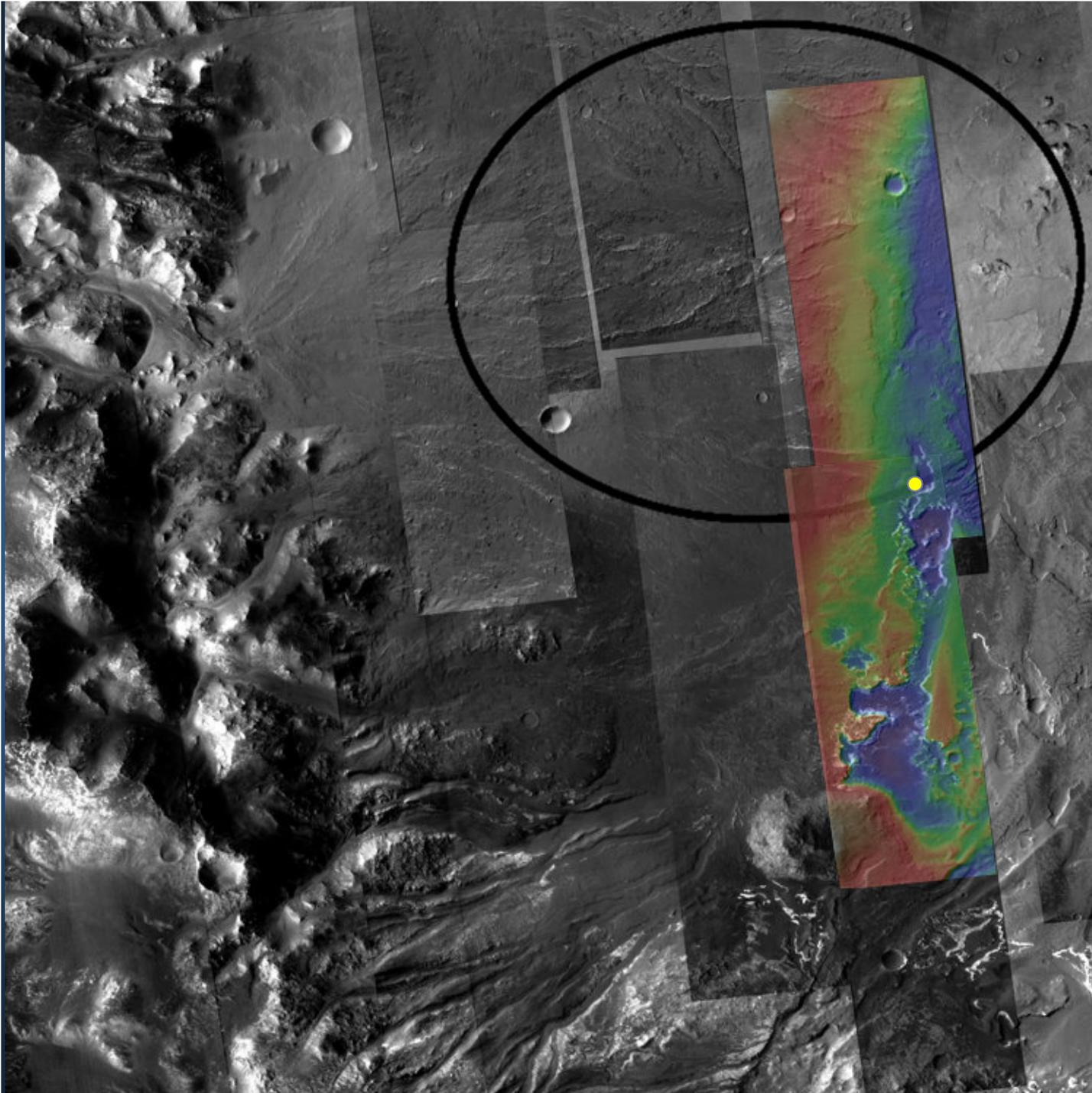
*Sample light-toned, layered  
material, compositional  
and stratigraphic analyses,  
search for organics,  
determine if alluvial and LTL  
materials are interbedded*

Layered alluvial deposits overlie fractured, lighter-toned material at the fan toe.



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?

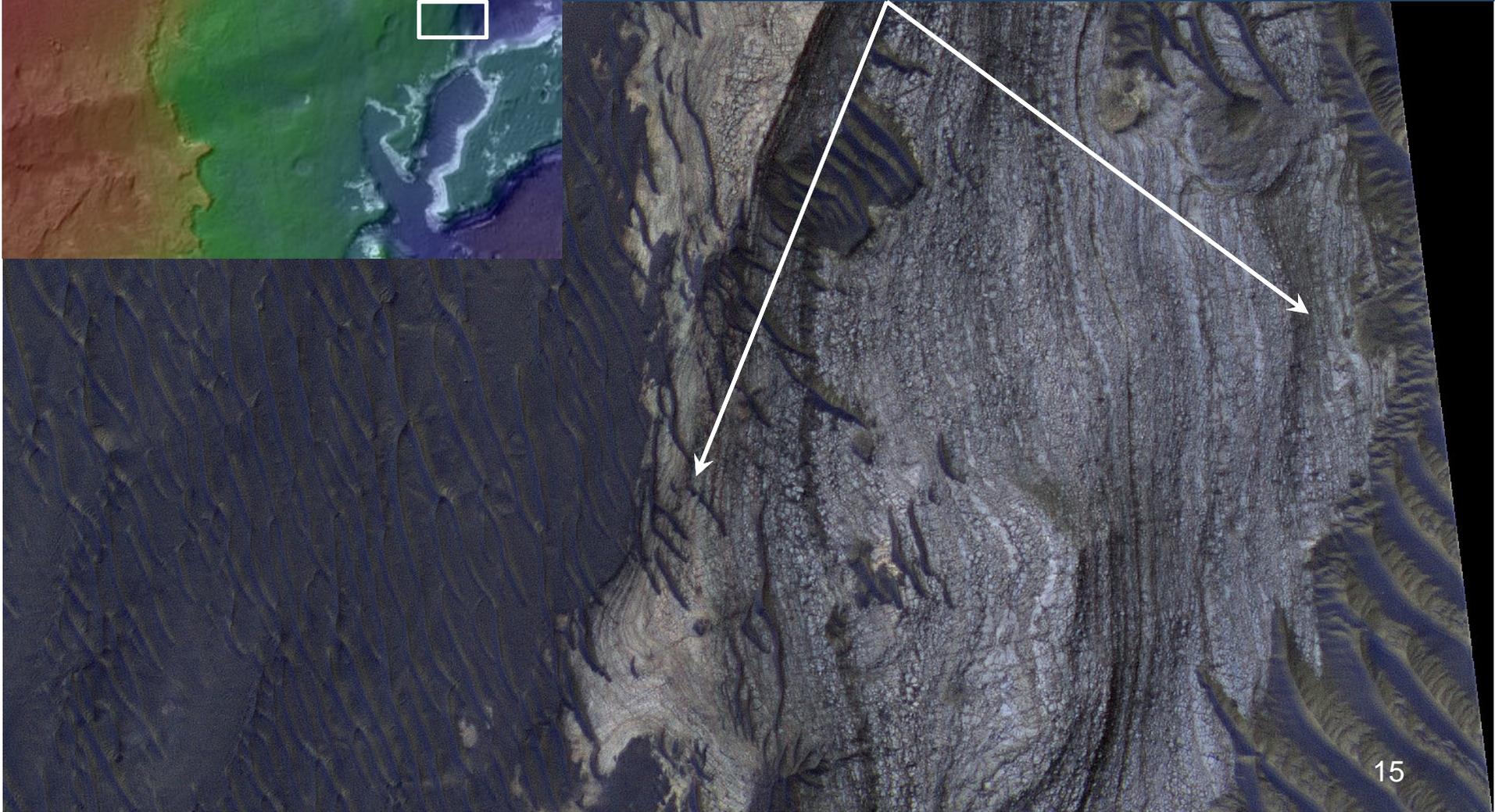
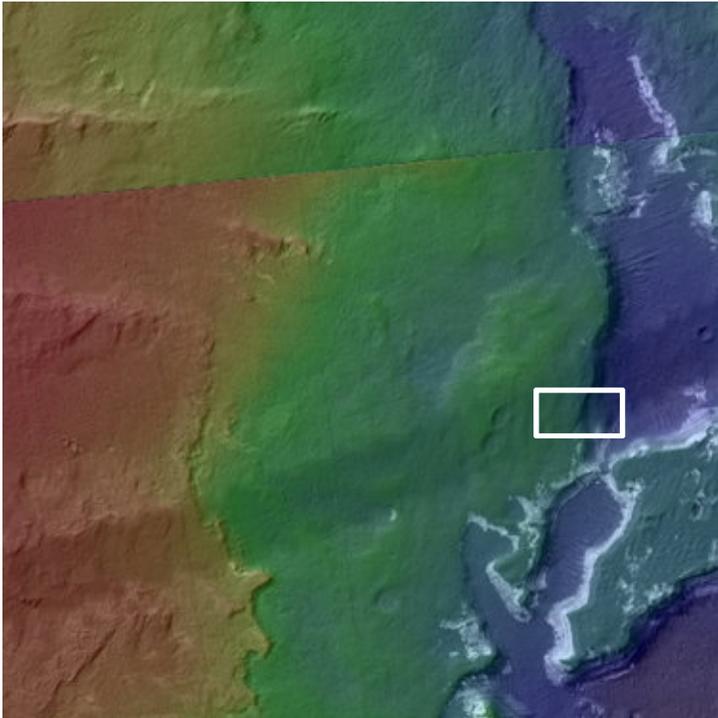
*Stratigraphic and  
compositional analyses,  
identify depositional  
environment, suggest  
consistent sediment source  
and weathering history,  
search for organics*

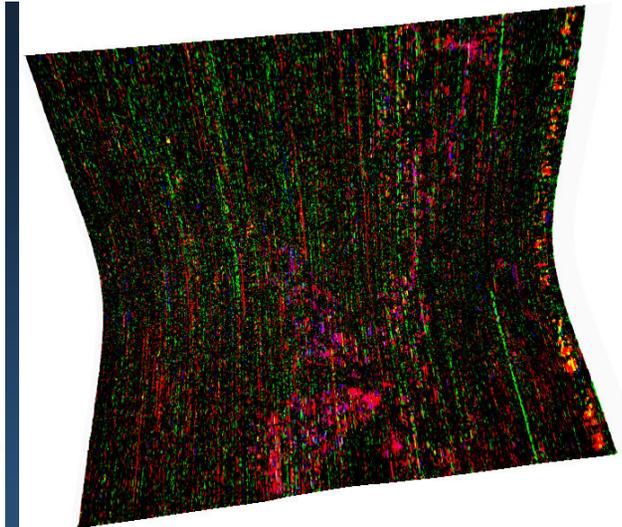
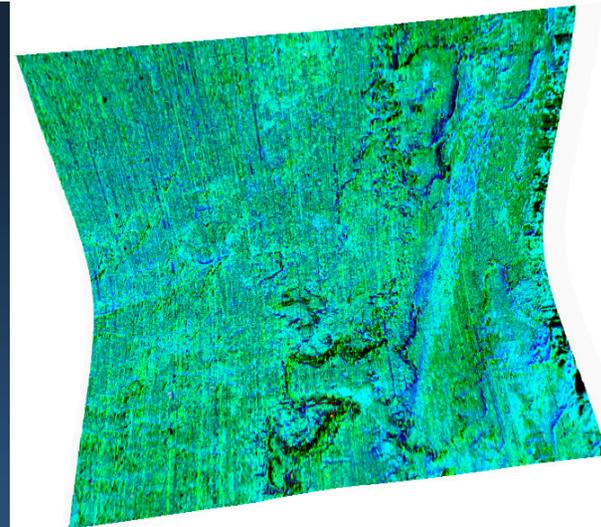
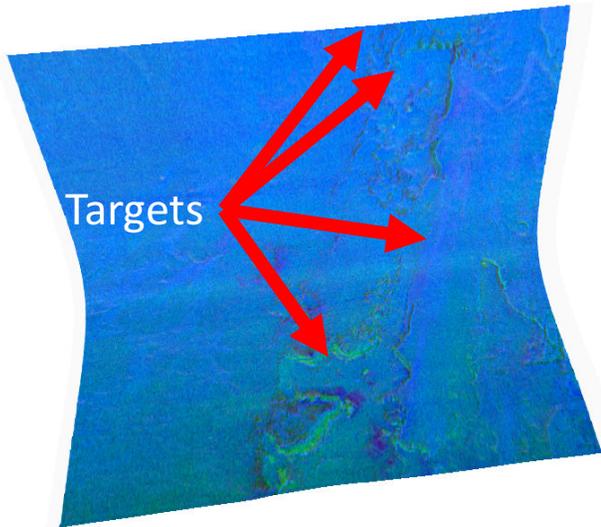
33 m section  
8° slope  
>40 light/dark pairs

ESP\_016276\_1535  
397 m across

50 m

Target of interest.

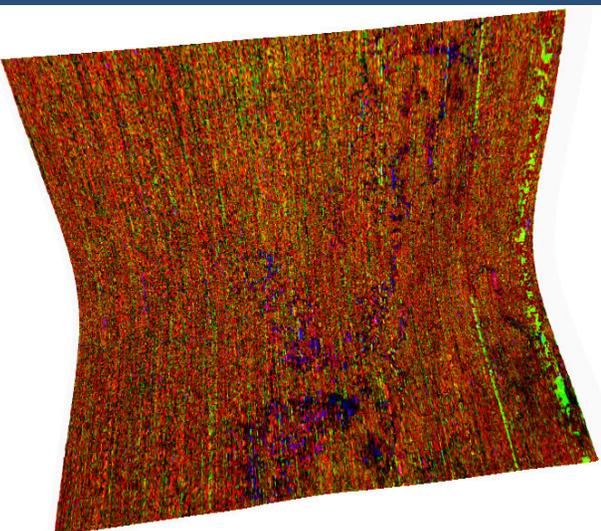




**Oxidized iron minerals**  
 red = BD530 (ferric minerals)  
 green = SH600 nm (coatings)  
 blue = BDI1000nm (variety of iron minerals)

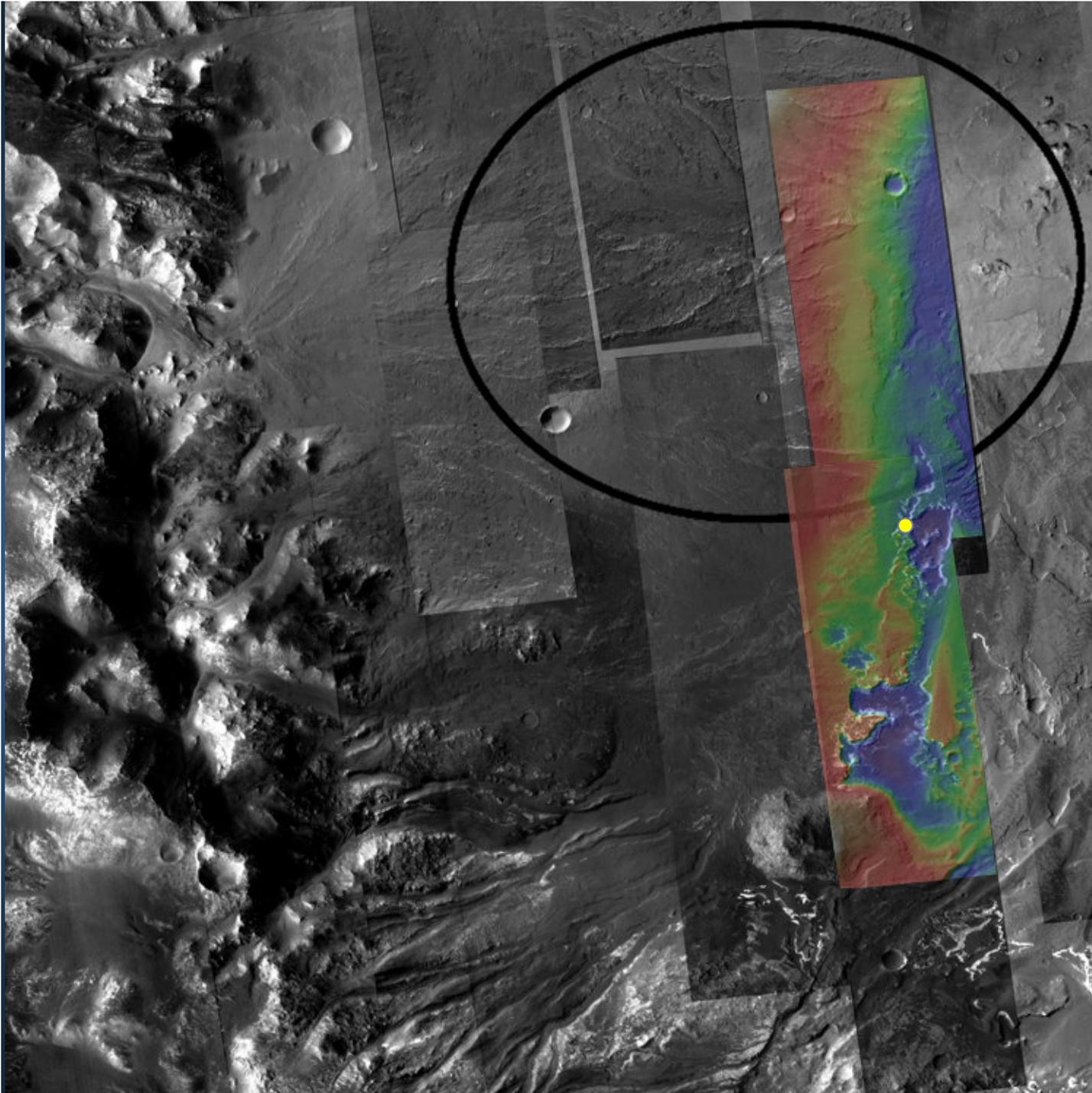
**Mafic mineralogy**  
 red = OLINDEX (olivine or iron phyllosilicates)  
 green = LCPINDEX (low-Ca pyroxene)  
 blue = HCPINDEX (high-Ca pyroxene)

**Hydroxylated silicates**  
 red = BD2300 (Fe/Mg phyllosilicate)  
 green = BD2210 (Al phyllosilicate or hydrated glass)  
 blue = BD1900 (hydrated sulfates, clays, glass, or water ice)



**Bound water**  
 red = SINDEXT (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*

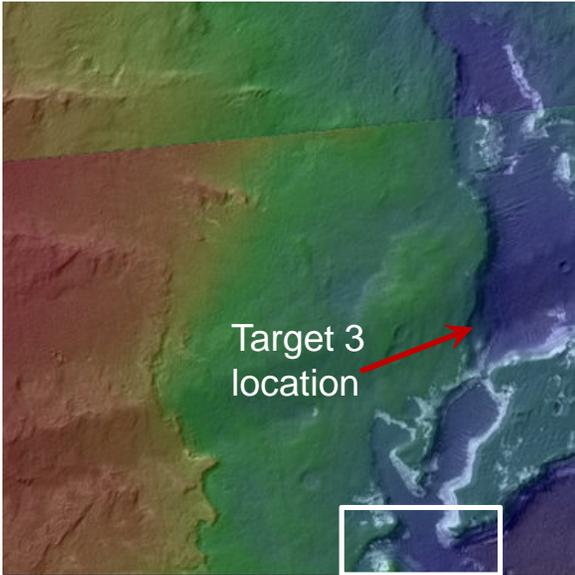
### Morphology and

### 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*



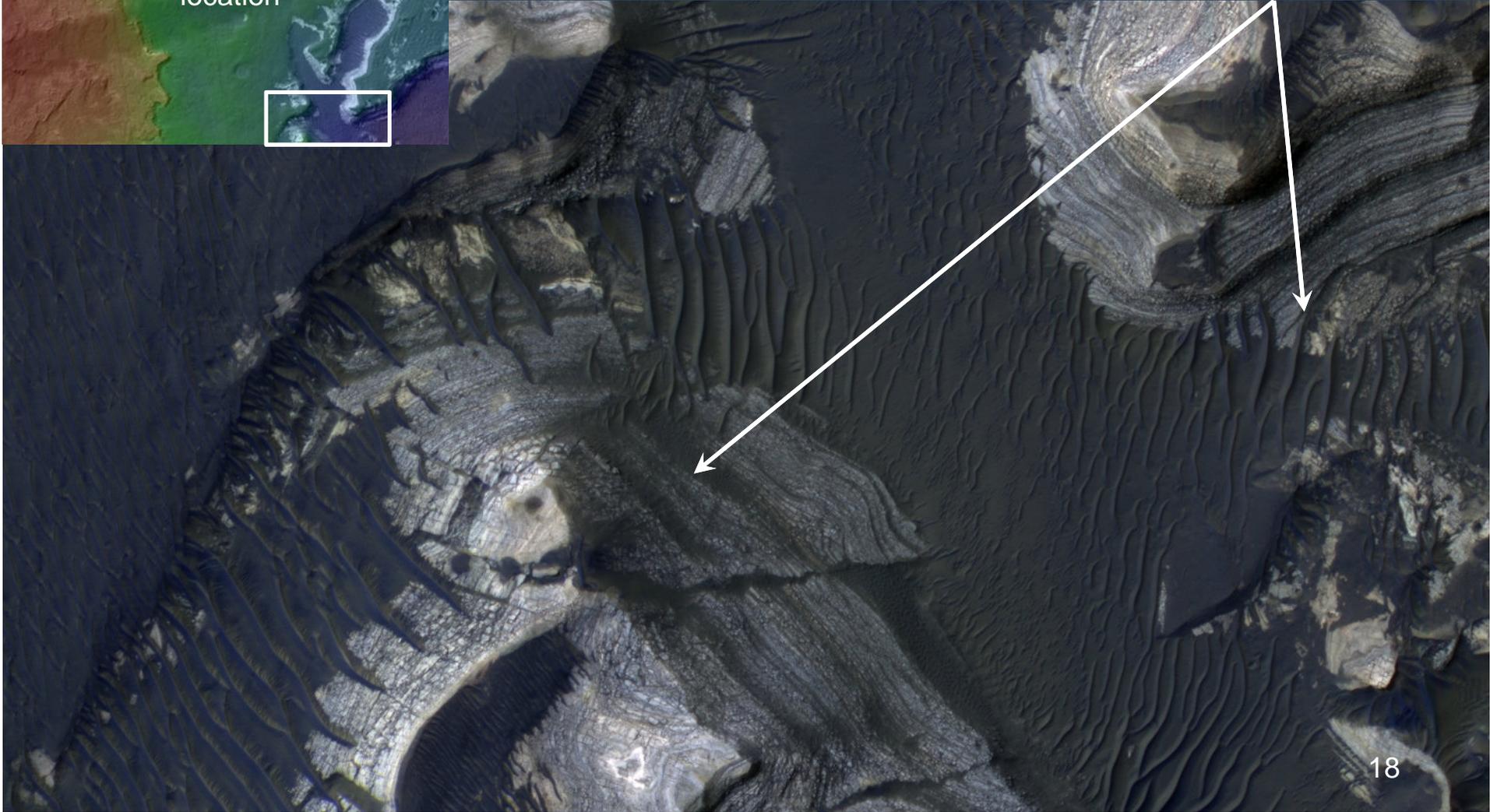
Target 3  
location

100 m



ESP\_015999\_1535  
783 m across

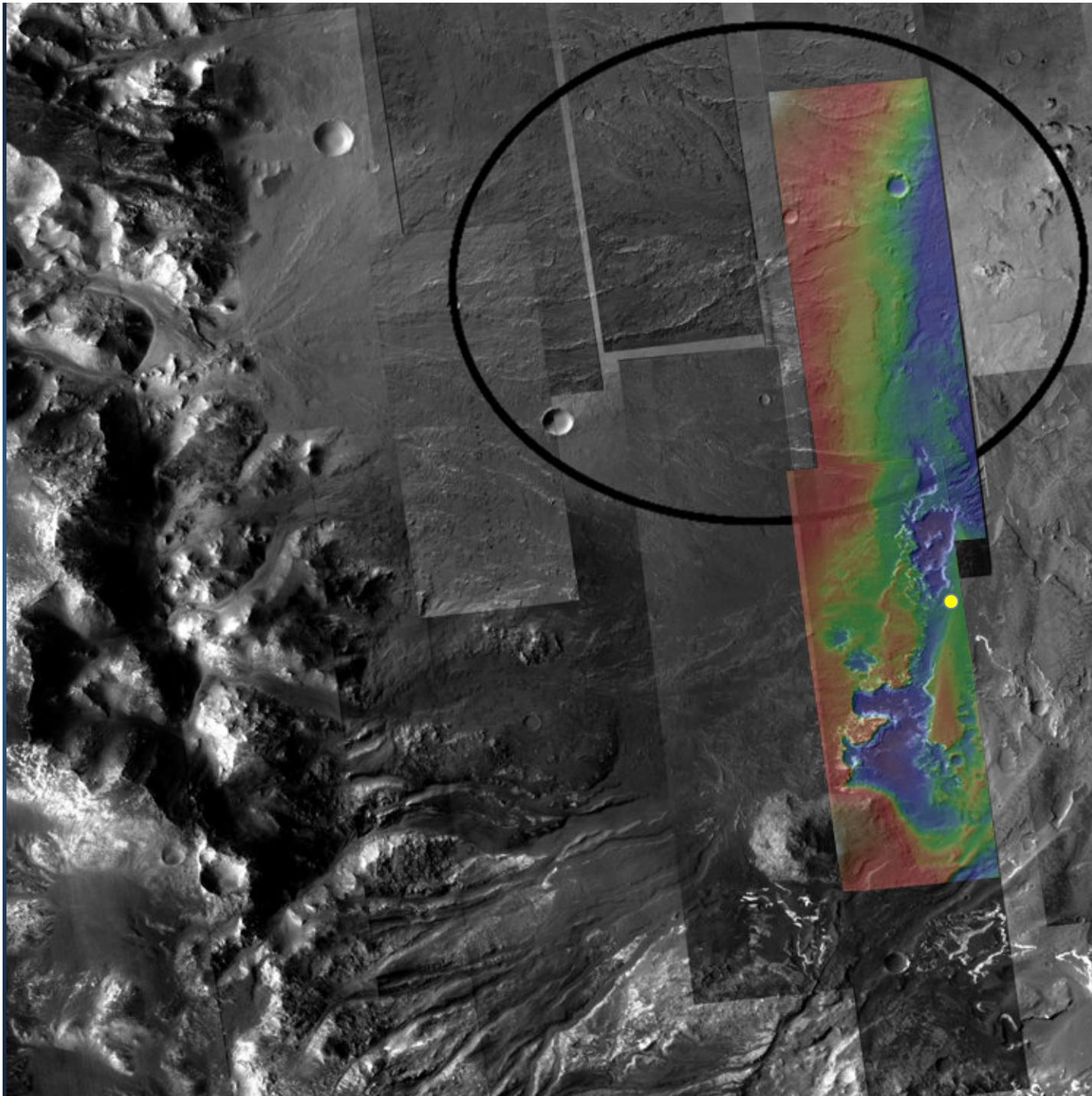
Targets of interest.  
Many other LTL outcrops  
are available along the  
notional traverse



# 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:

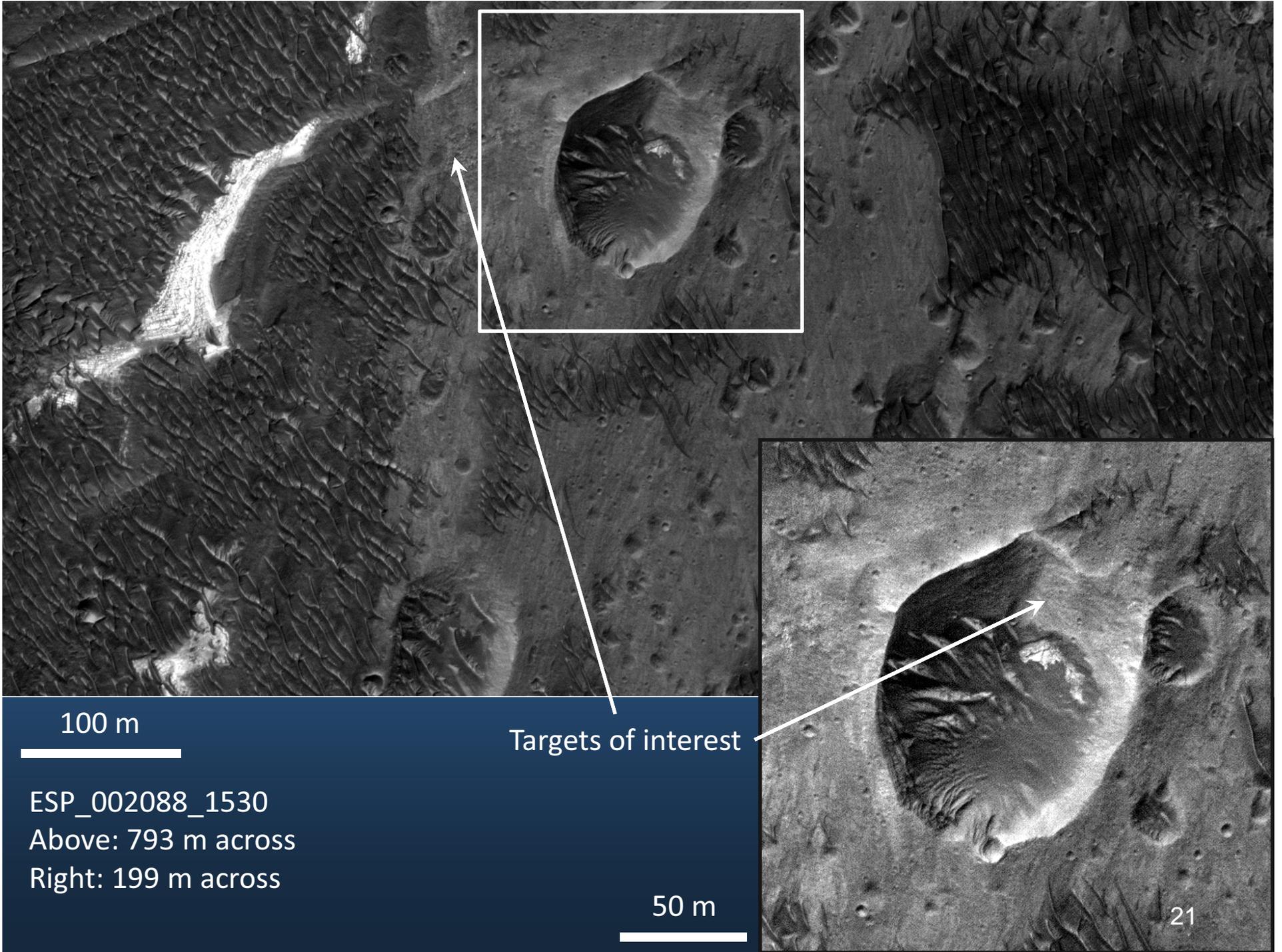
*Rocks likely derived from  
Uzboi Vallis, late-stage  
flooding of Holden crater  
floor*

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*

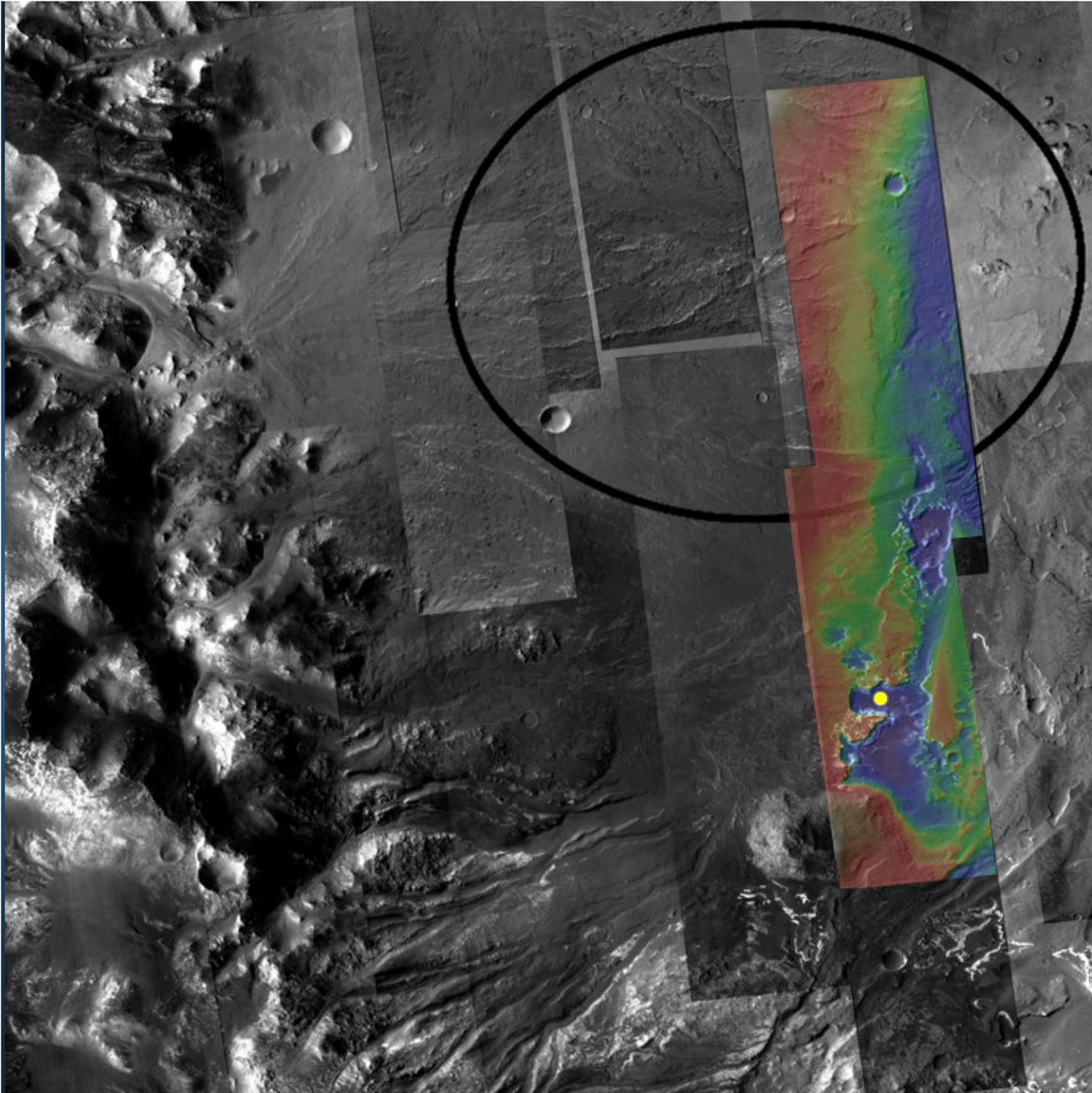


100 m

Targets of interest

ESP\_002088\_1530  
Above: 793 m across  
Right: 199 m across

50 m



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 22*



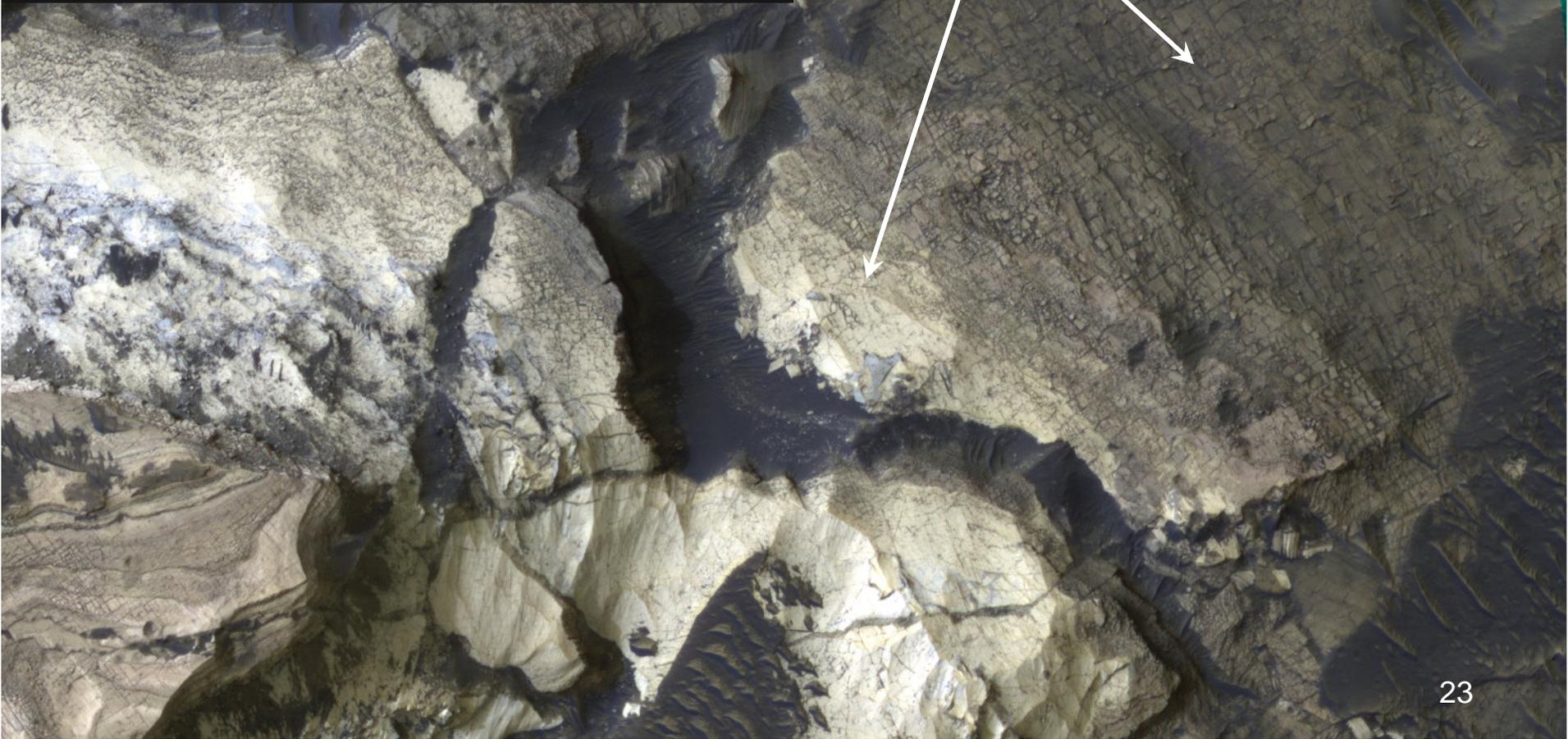
200 m

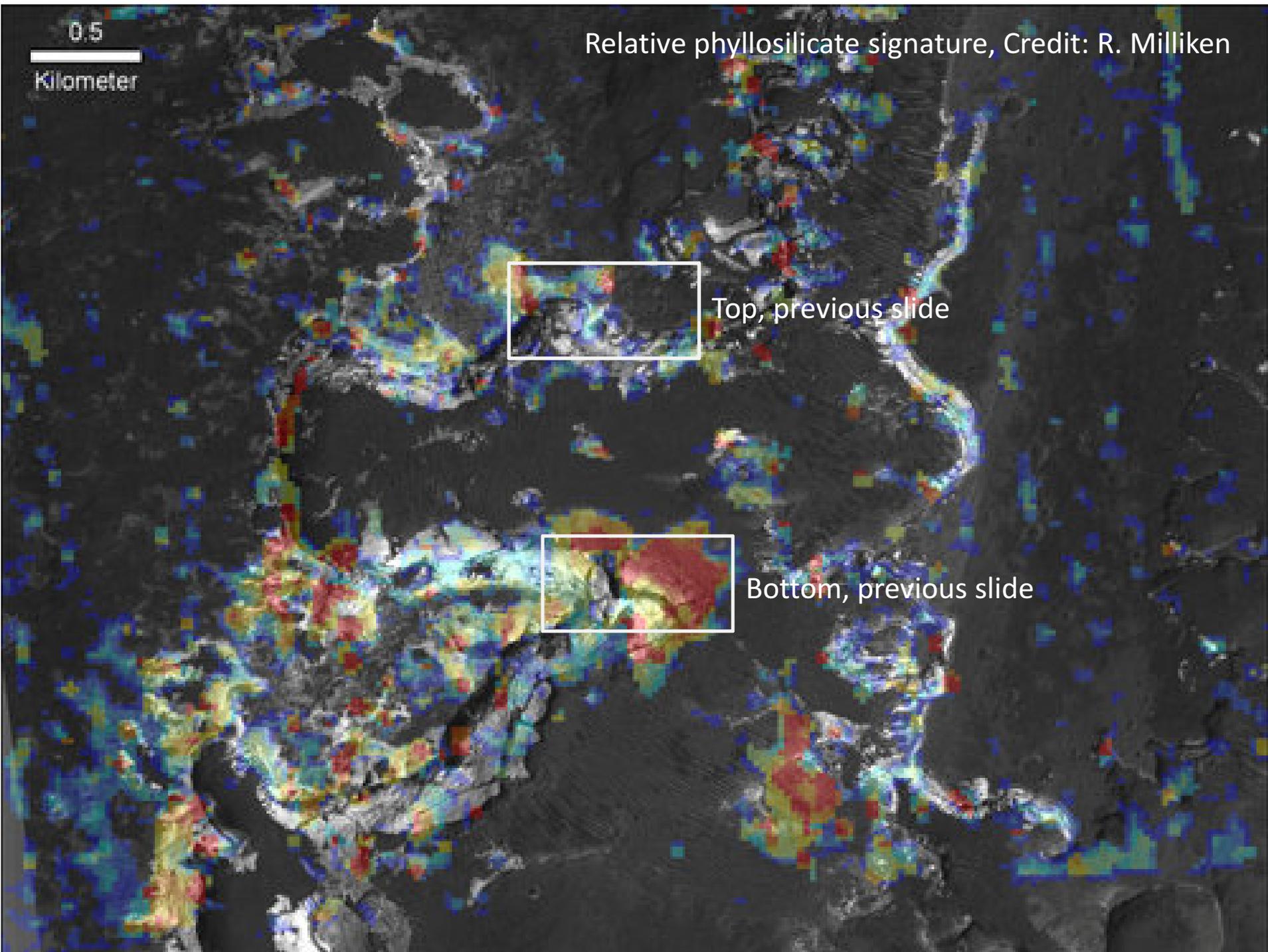


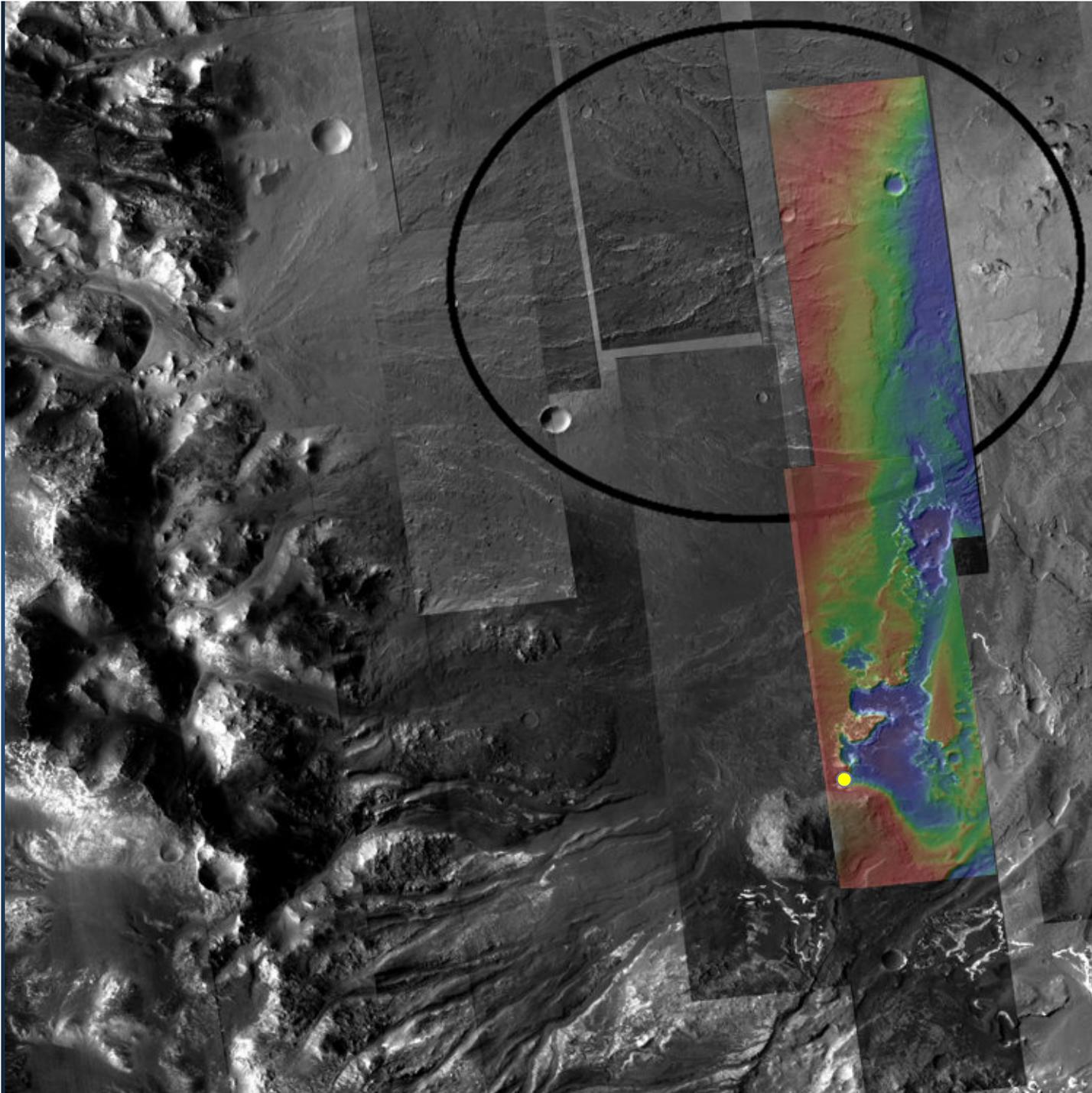
ESP\_002088\_1530  
Left: 793 m across  
Below: 793 m across

Targets of interest

100 m







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*

100 m

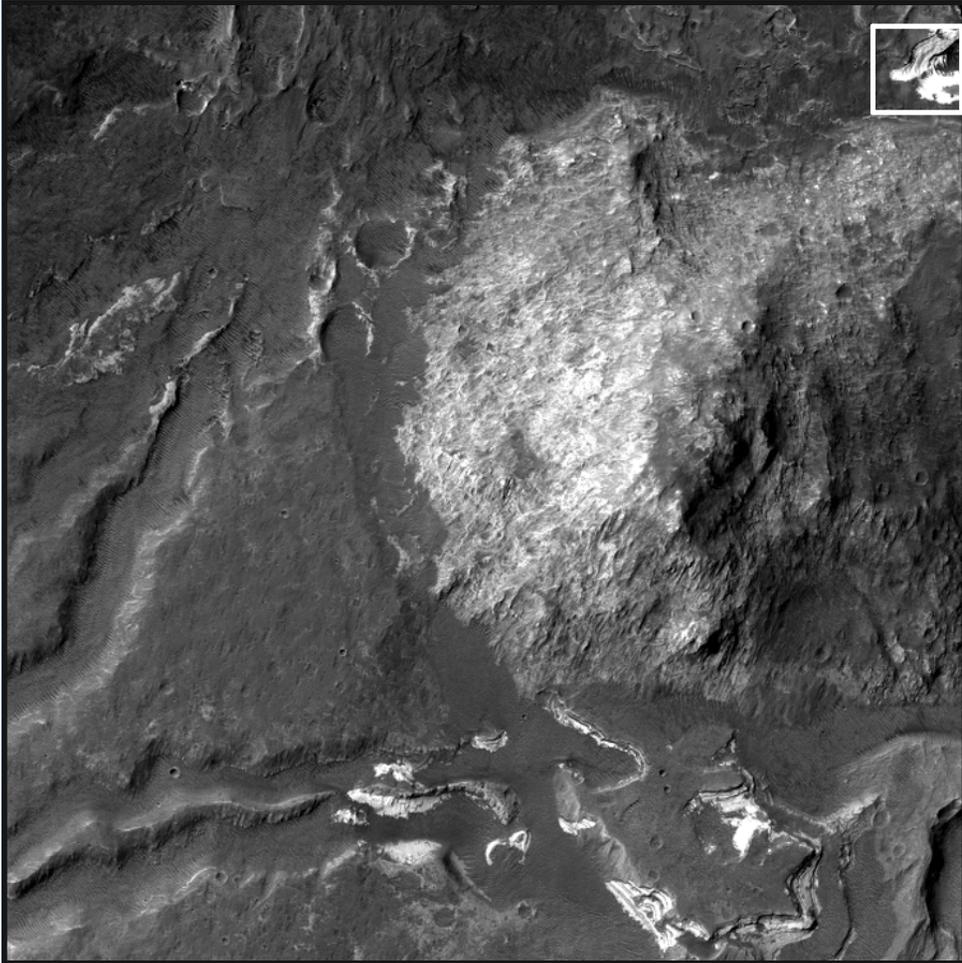
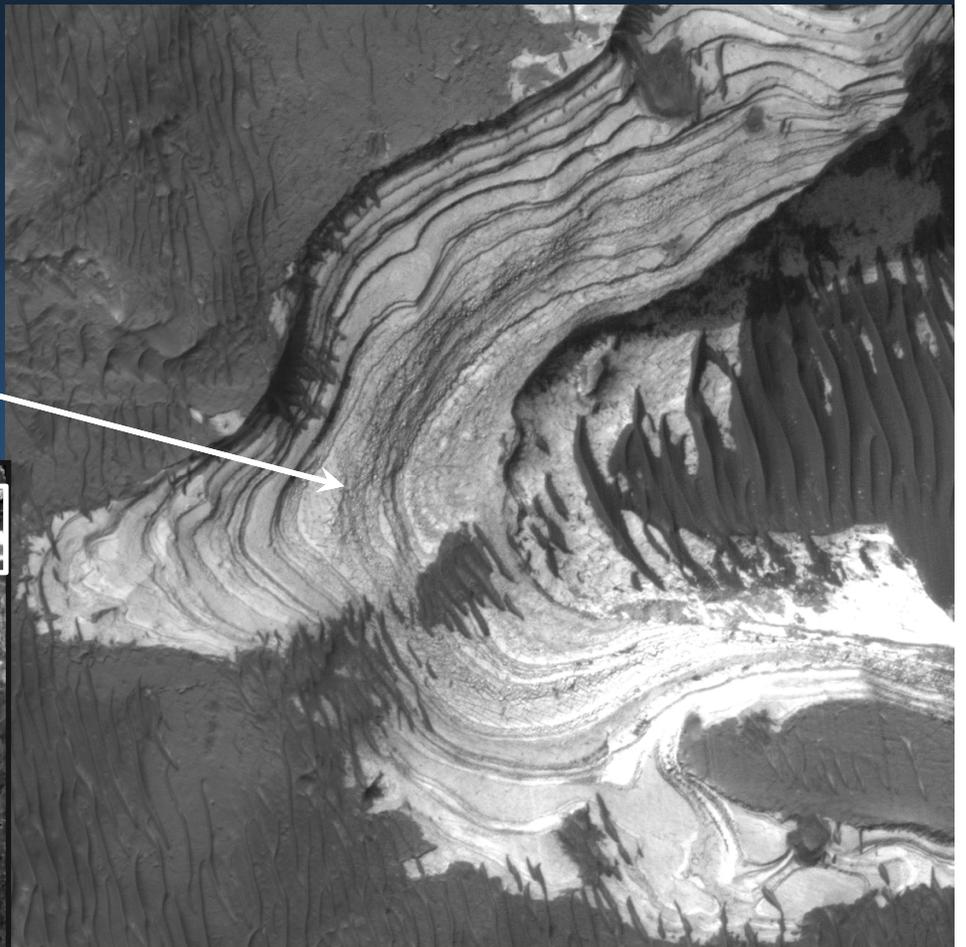
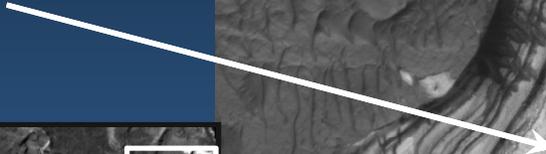


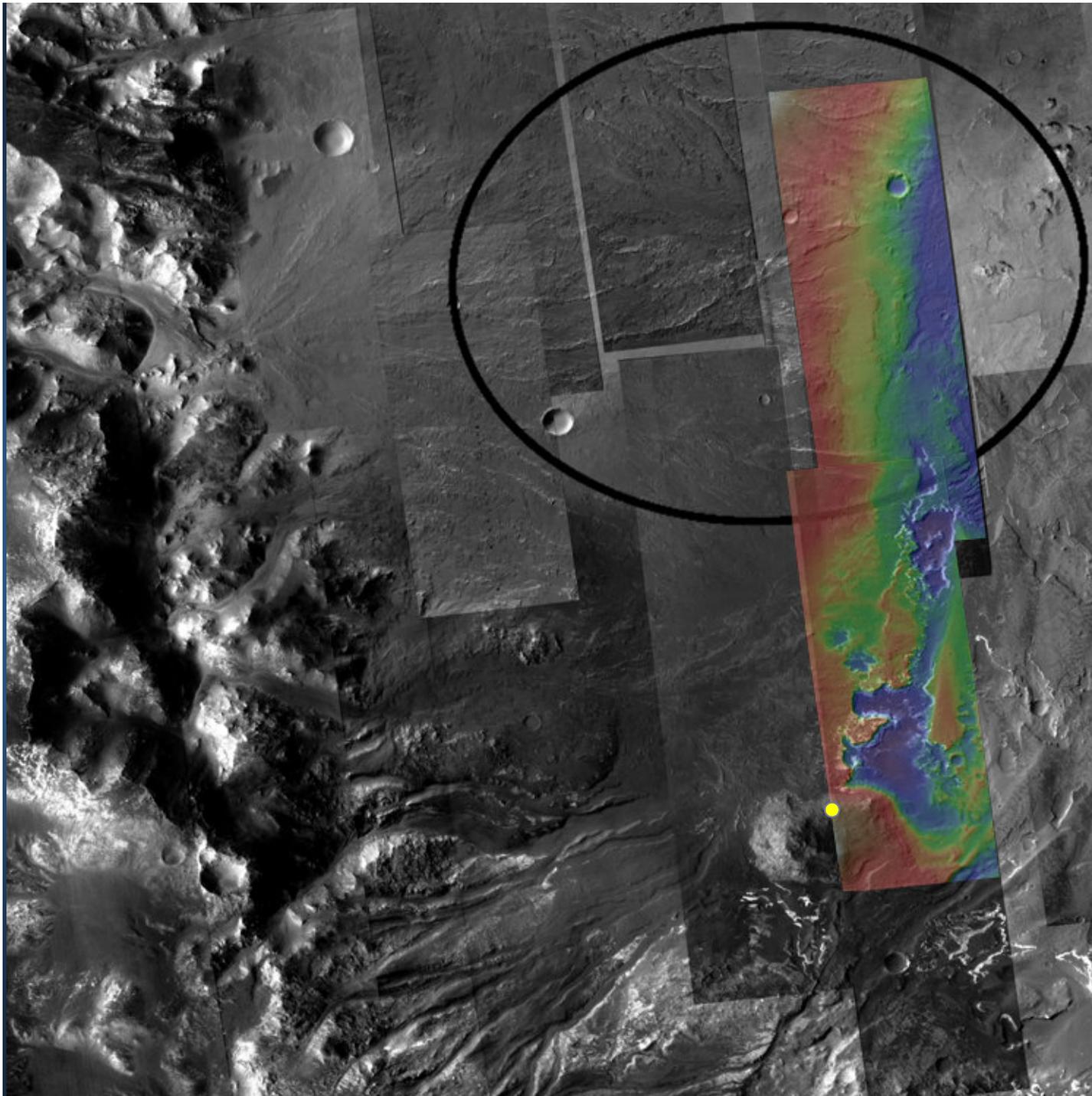
ESP\_019322\_1530  
Right: 433 m across  
Below: 5.5 km across

800 m



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*

100 m

Targets of interest

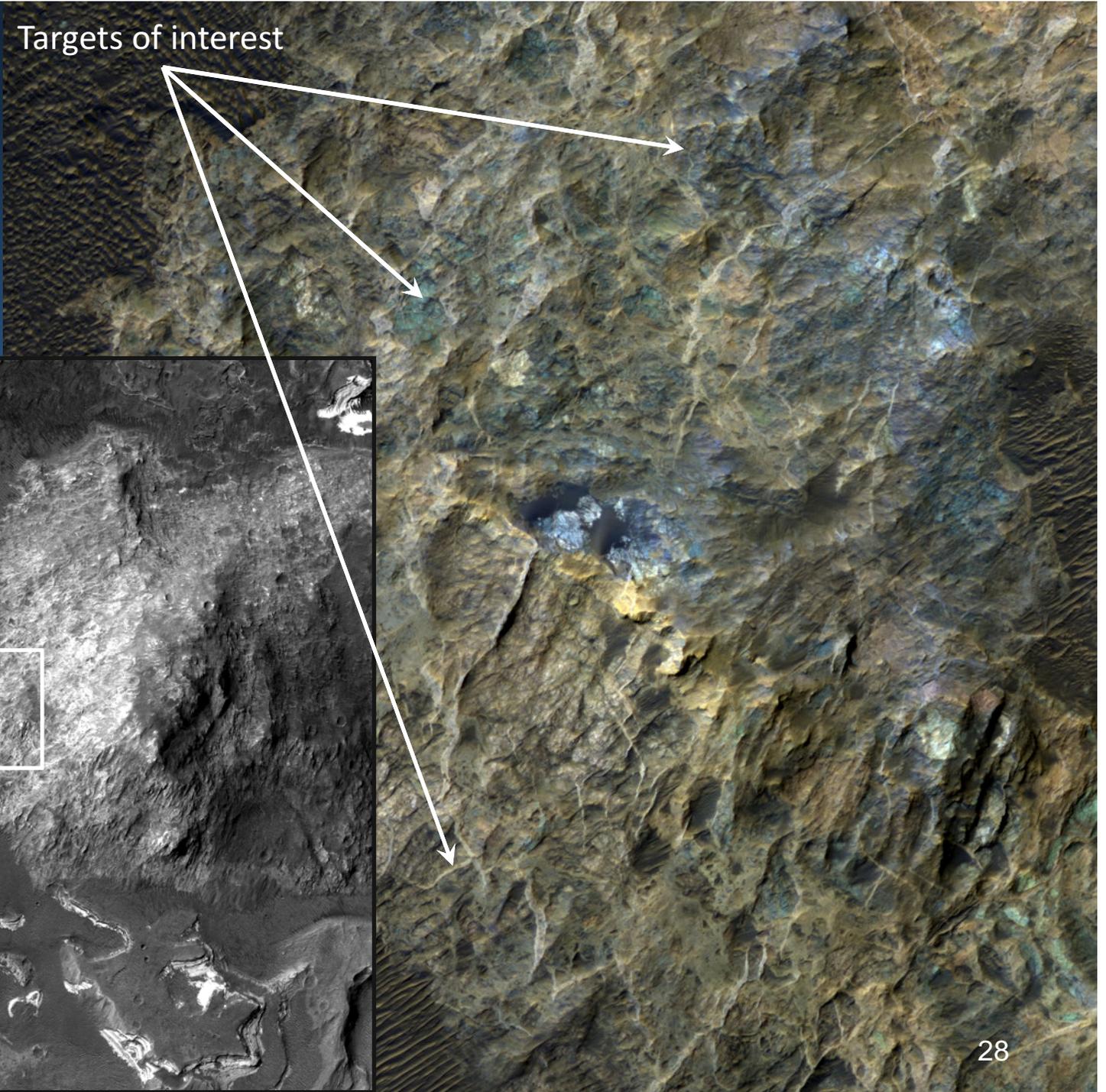
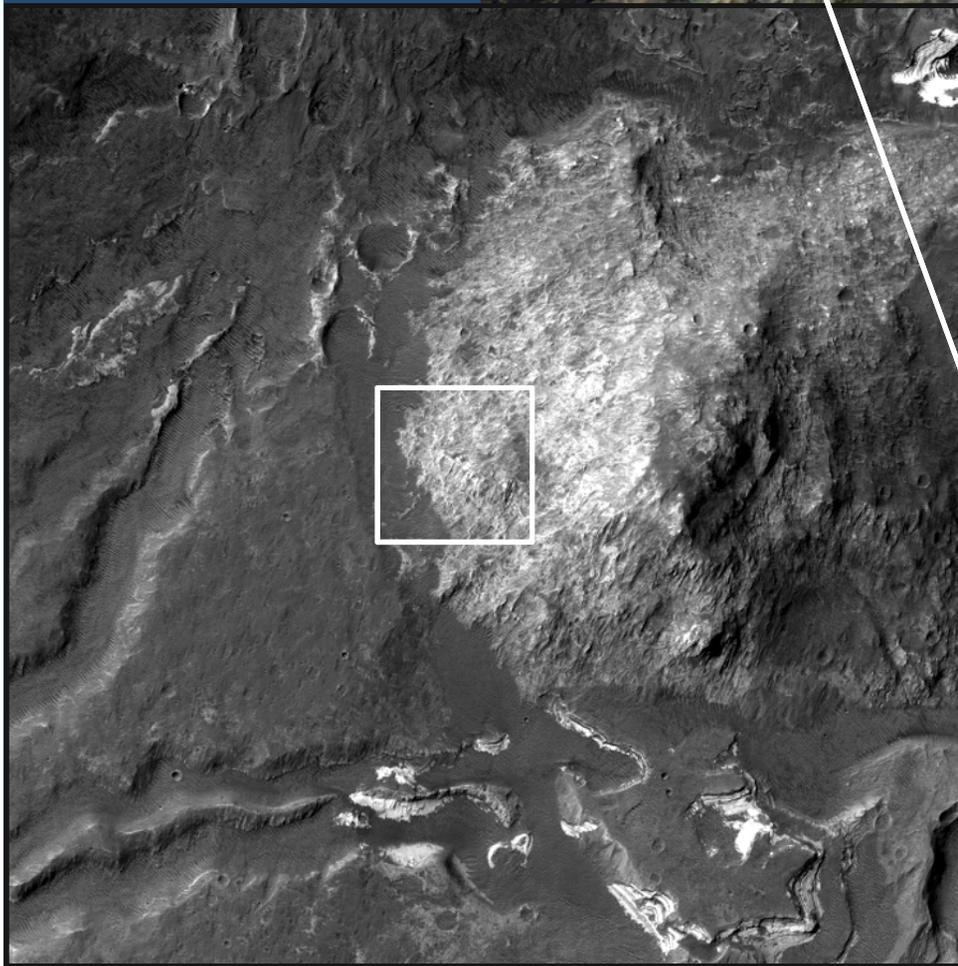
ESP\_019322\_1530

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 suggests 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 stratal 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

20 km

