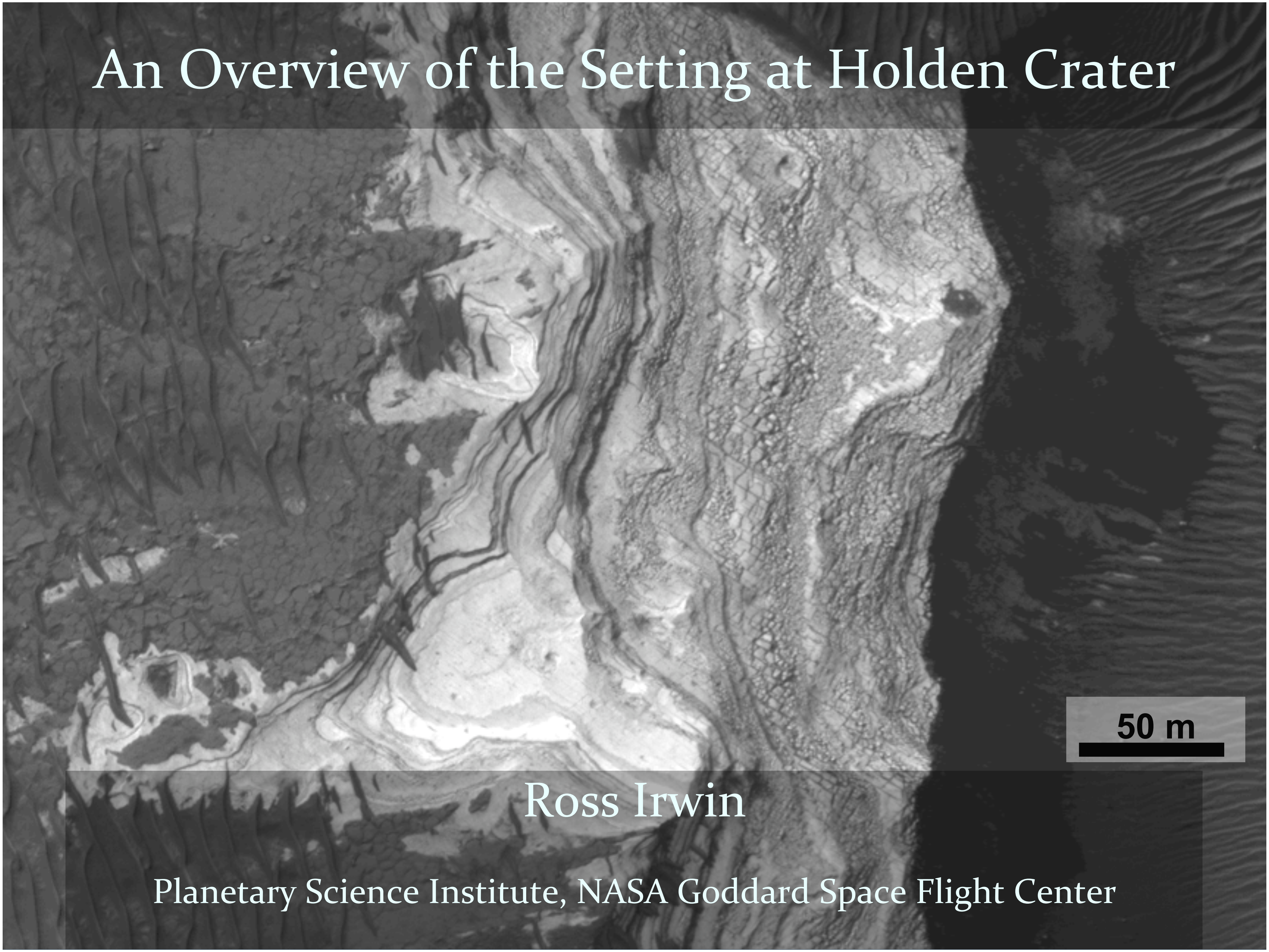
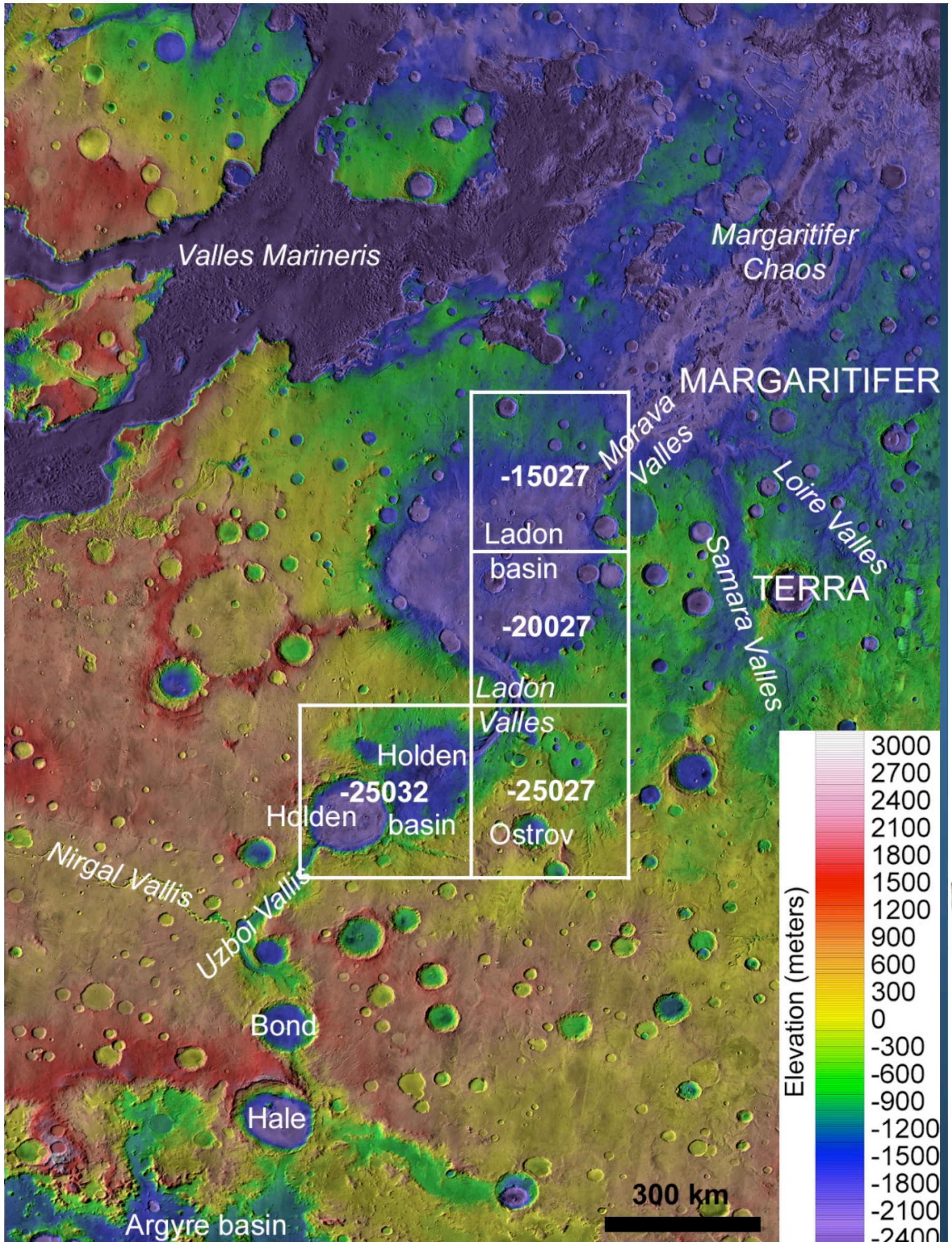
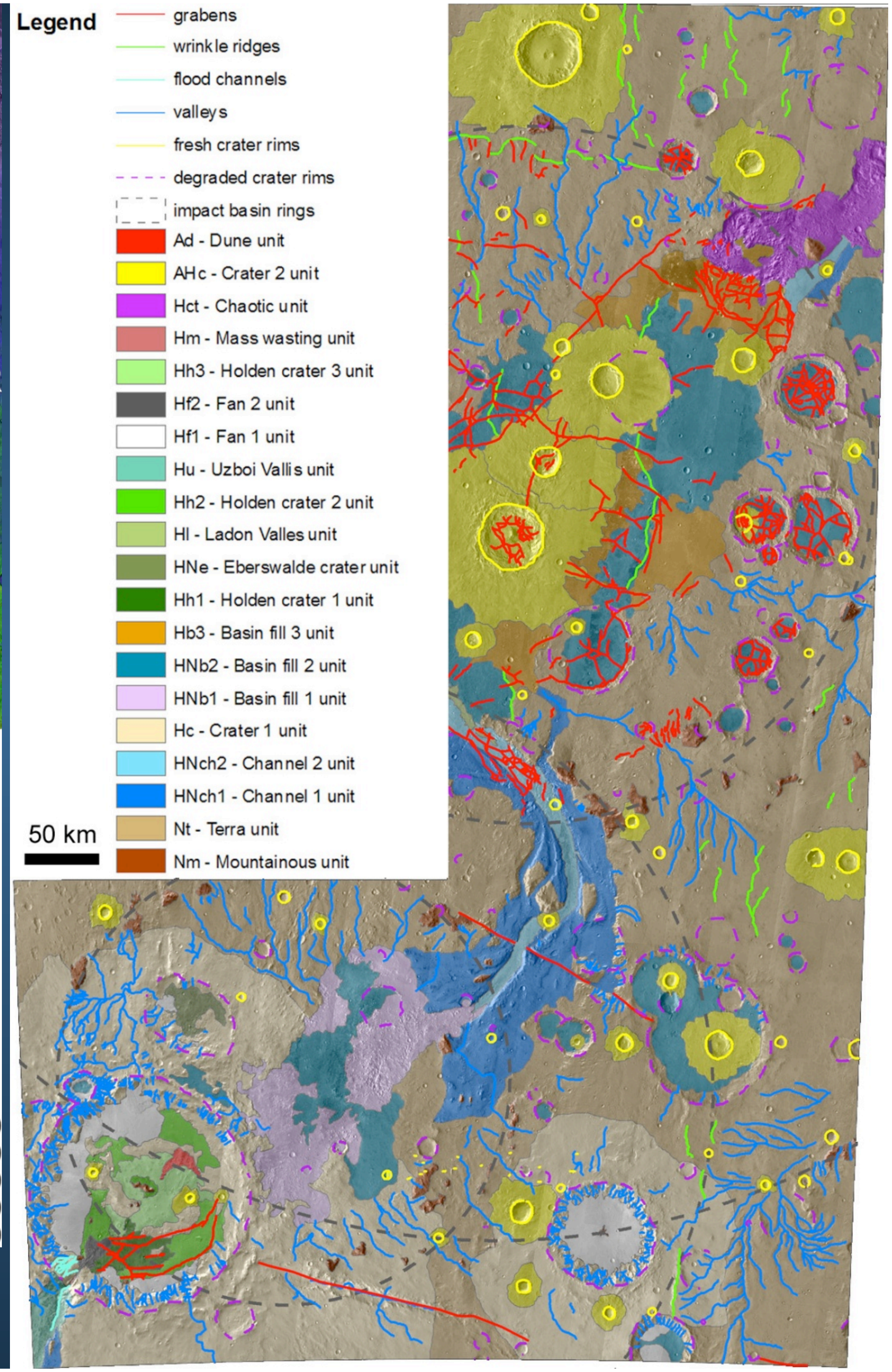
An Overview of the Setting at Holden Crater



Ross Irwin

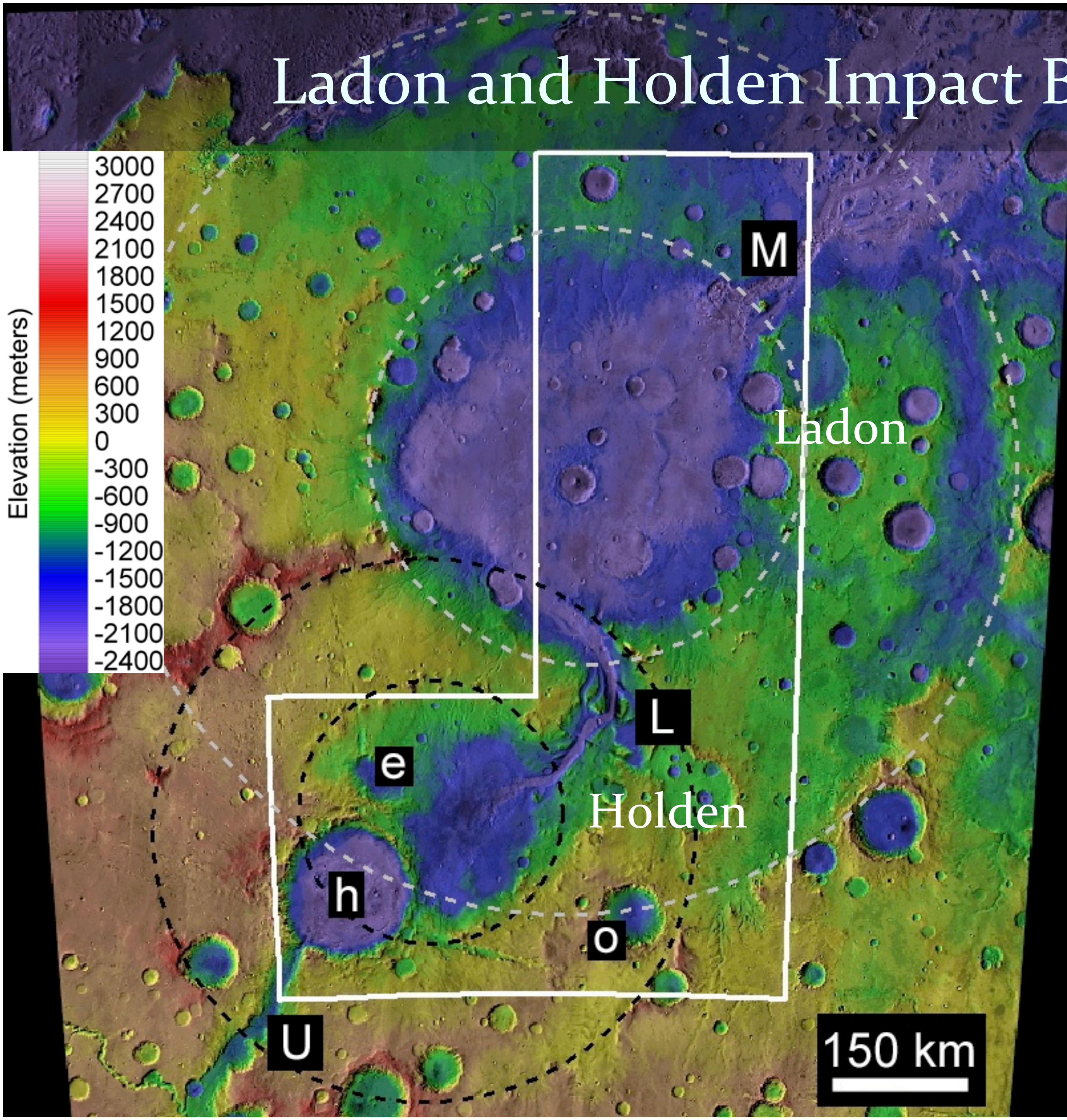
Planetary Science Institute, NASA Goddard Space Flight Center





Irwin and Grant, submitted 1:500k map

Ladon and Holden Impact Basins



M: Morava Valles

L: Ladon Valles

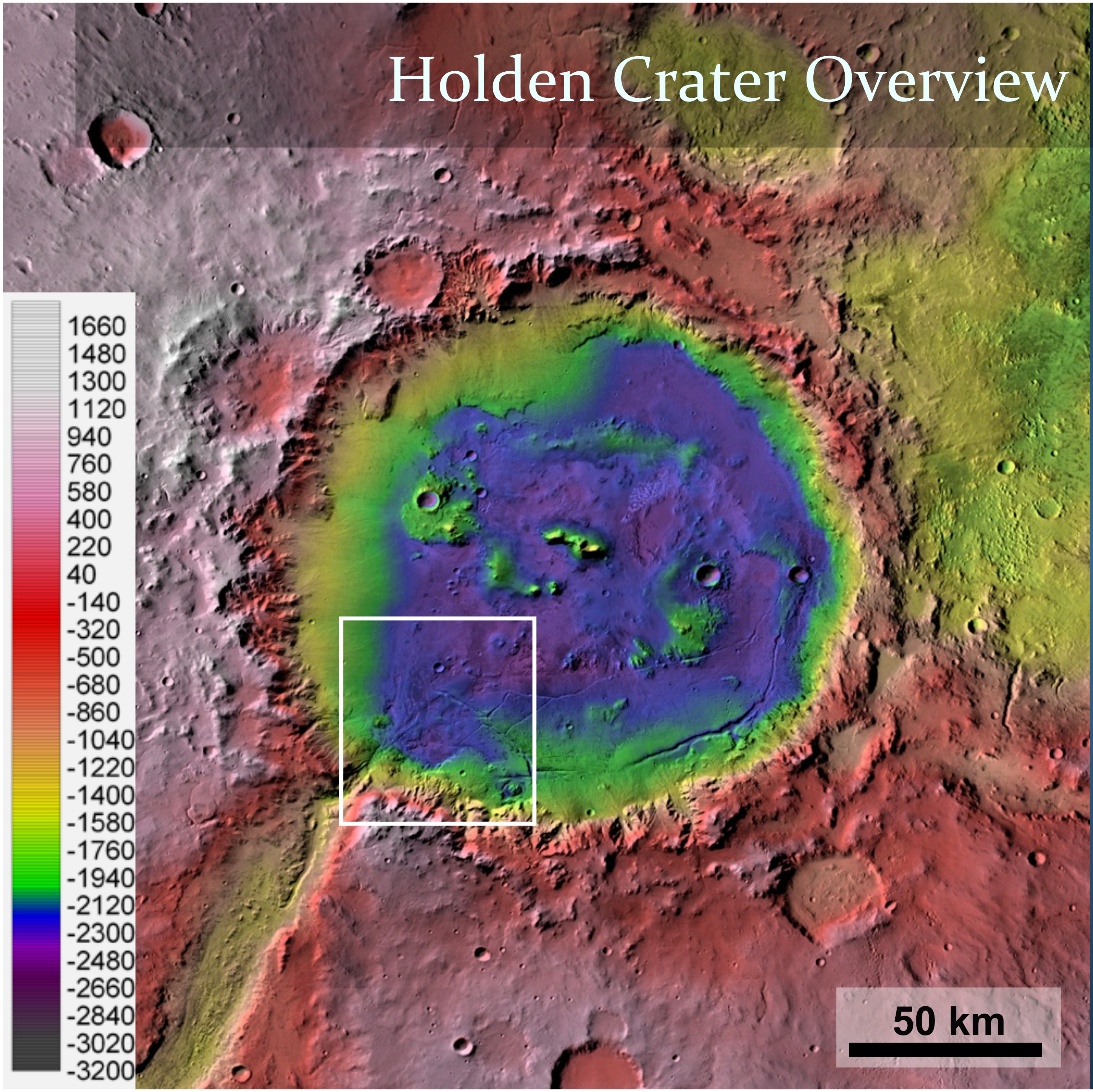
U: Uzboi Vallis

h: Holden crater

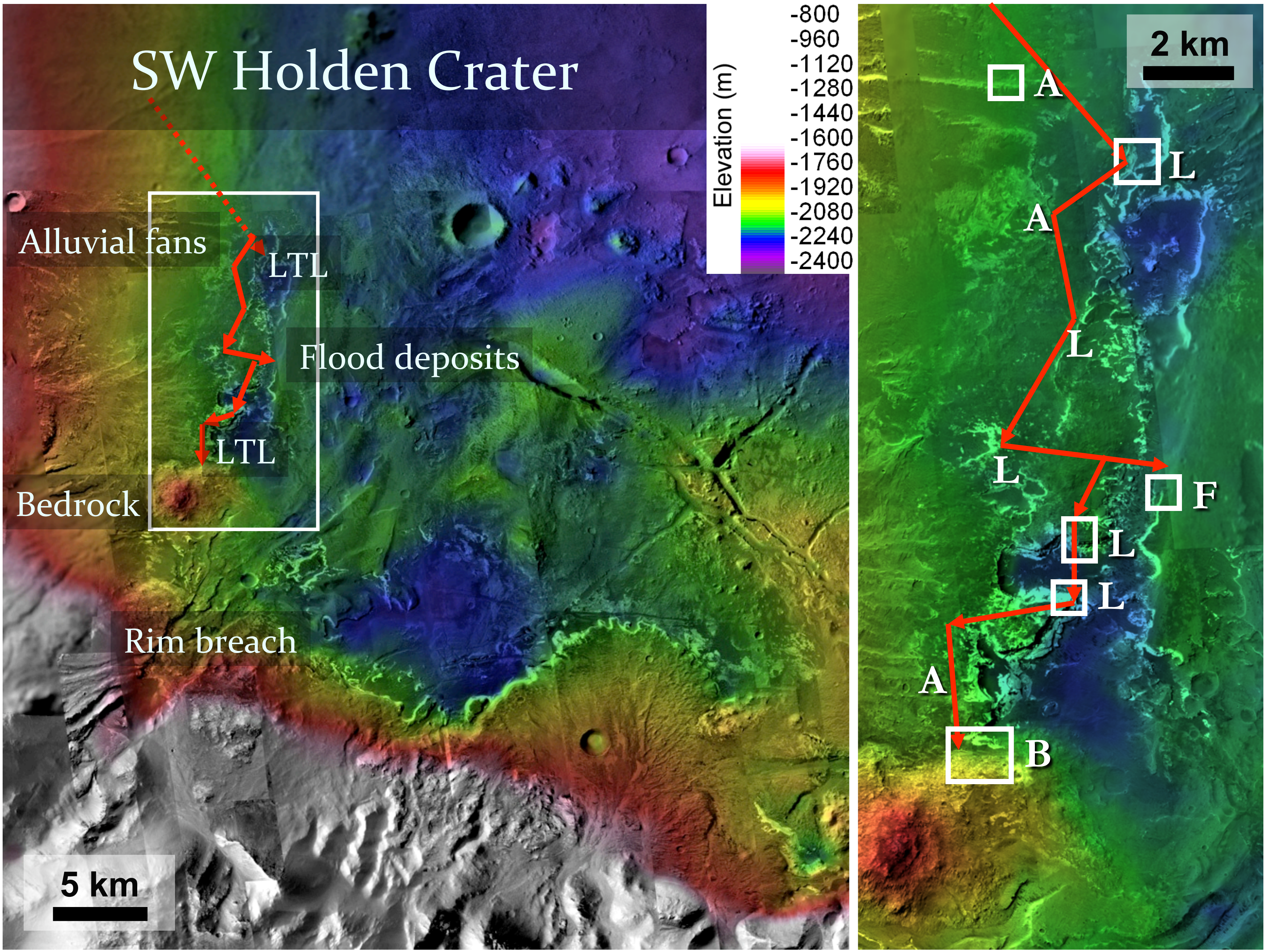
e: Eberswalde crater

o: Ostrov crater

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


SW Holden Crater
Alluvial fans
LTL
Flood deposits
LTL
Bedrock
Rim breach
5 km
Elevation (m)
-800
-960
-1120
-1280
-1440
-1600
-1760
-1920
-2080
-2240
-2400
2 km
A
L
A
L
L
F
L
L
A
B

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 outcrop

- Ancient bedrock uplifted during impact, possible hydrothermal system

MSL Science Objectives

I. Assess the biological potential of at least one target environment.

1. Determine the nature and inventory of organic carbon compounds.
2. Inventory the chemical building blocks of life (C, H, N, O, P, S).
3. Identify features that may represent the effects of biological processes.

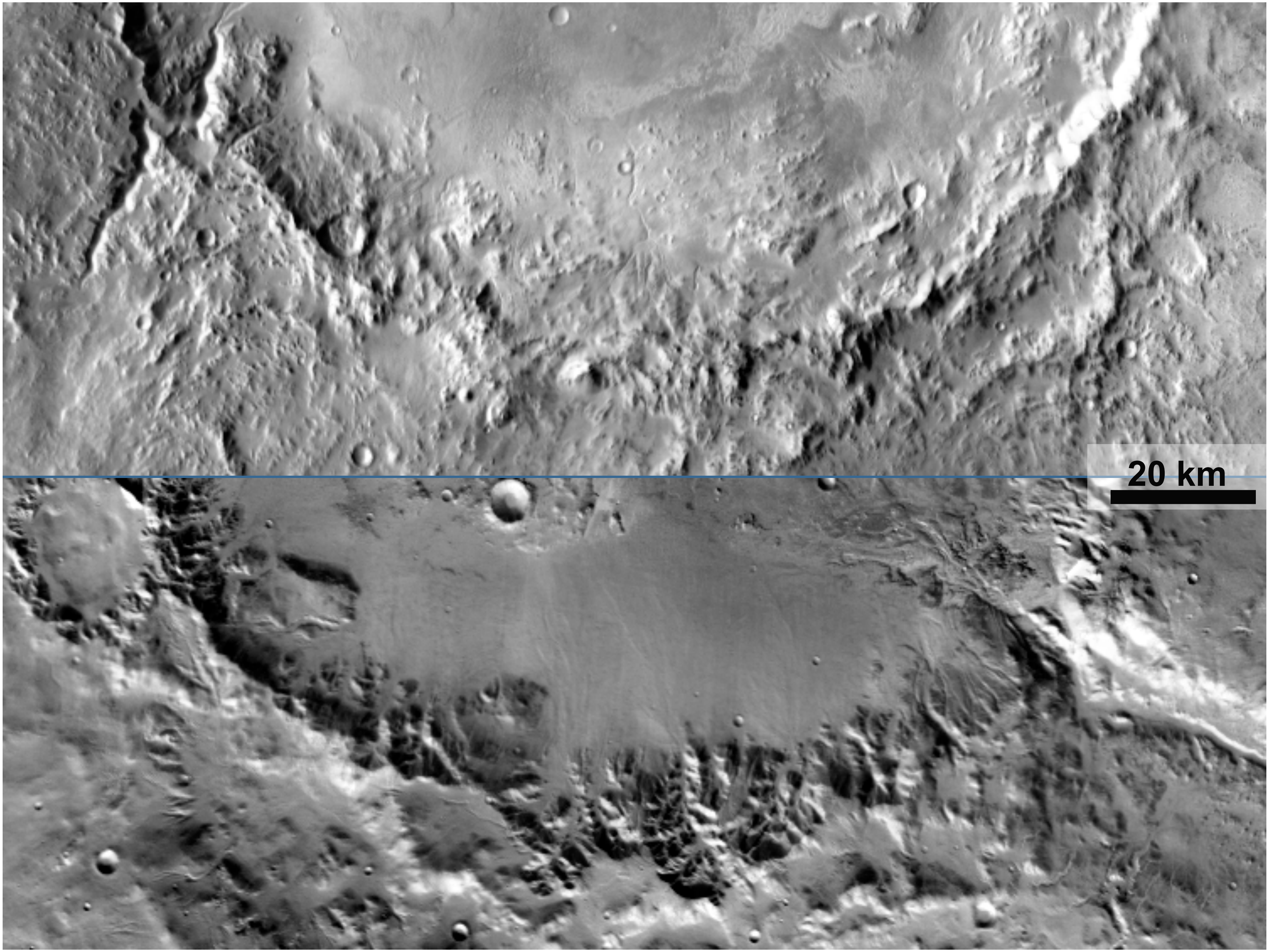
II. Characterize the geology and geochemistry of the landing region at all appropriate spatial scales.

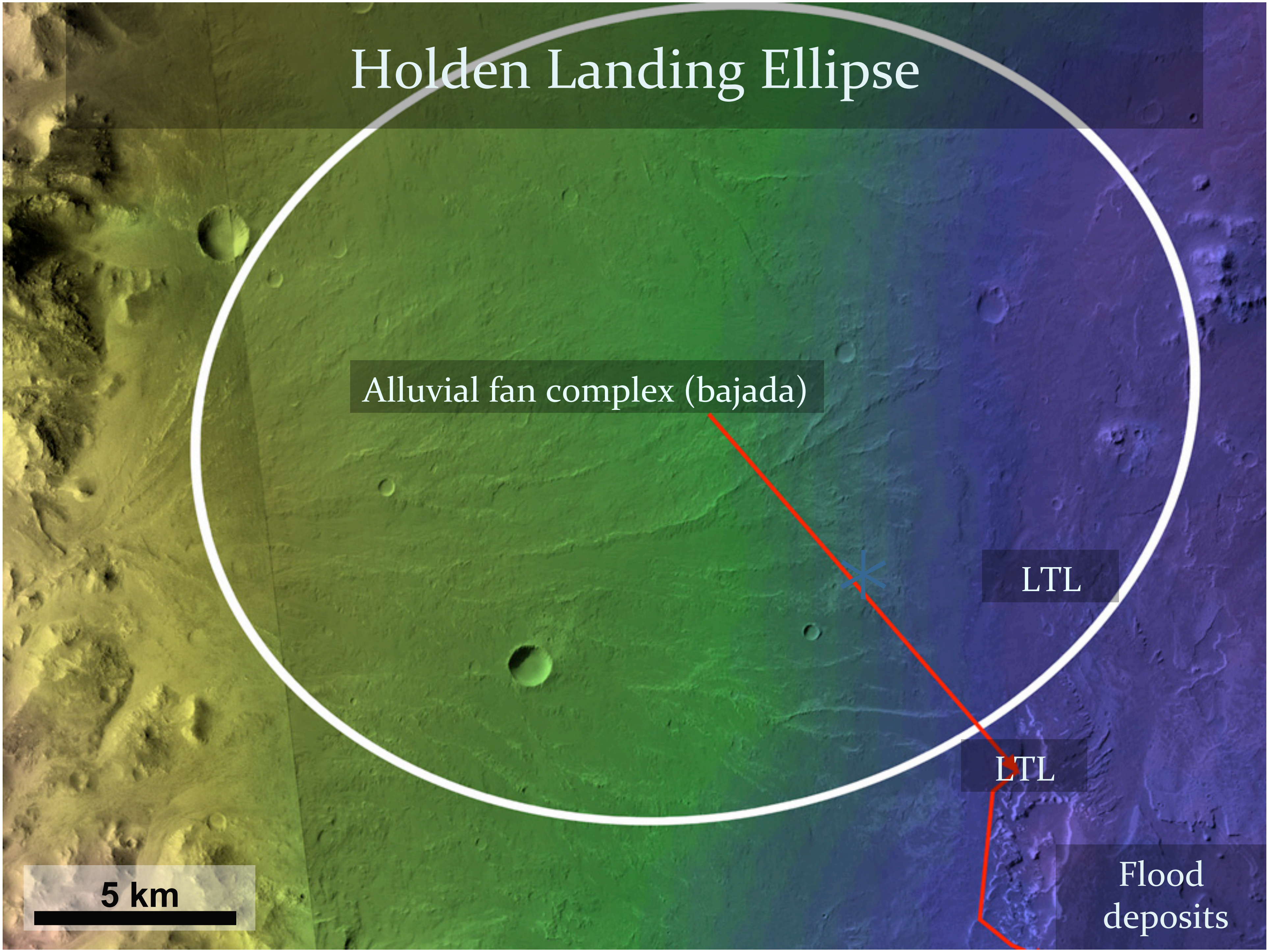
1. Investigate the chemical, isotopic, and mineralogical composition of the Martian surface and near-surface geological materials.
2. Interpret the processes that have formed and modified rocks and regolith.

III. Investigate planetary processes of relevance to past habitability, including the role of water.

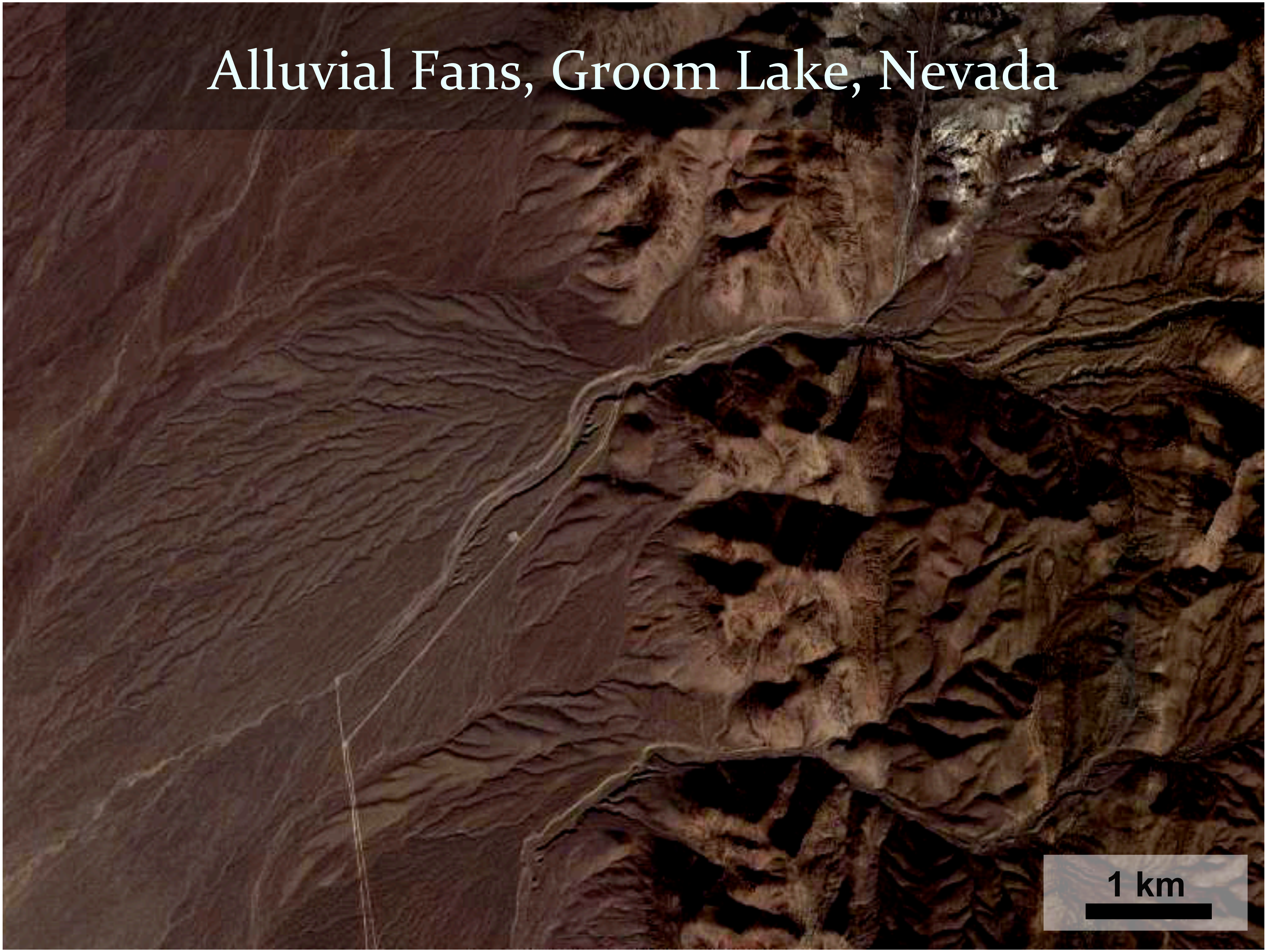
1. Assess long-timescale (i.e., 4-billion-year) atmospheric evolution processes.
2. Determine present state, distribution, and cycling of water and CO_2.

IV. Characterize the broad spectrum of surface radiation, including galactic cosmic radiation, solar proton events, and secondary neutrons.


20 km


Holden Landing Ellipse
Alluvial fan complex (bajada)
LTL
LTL
Flood deposits
5 km

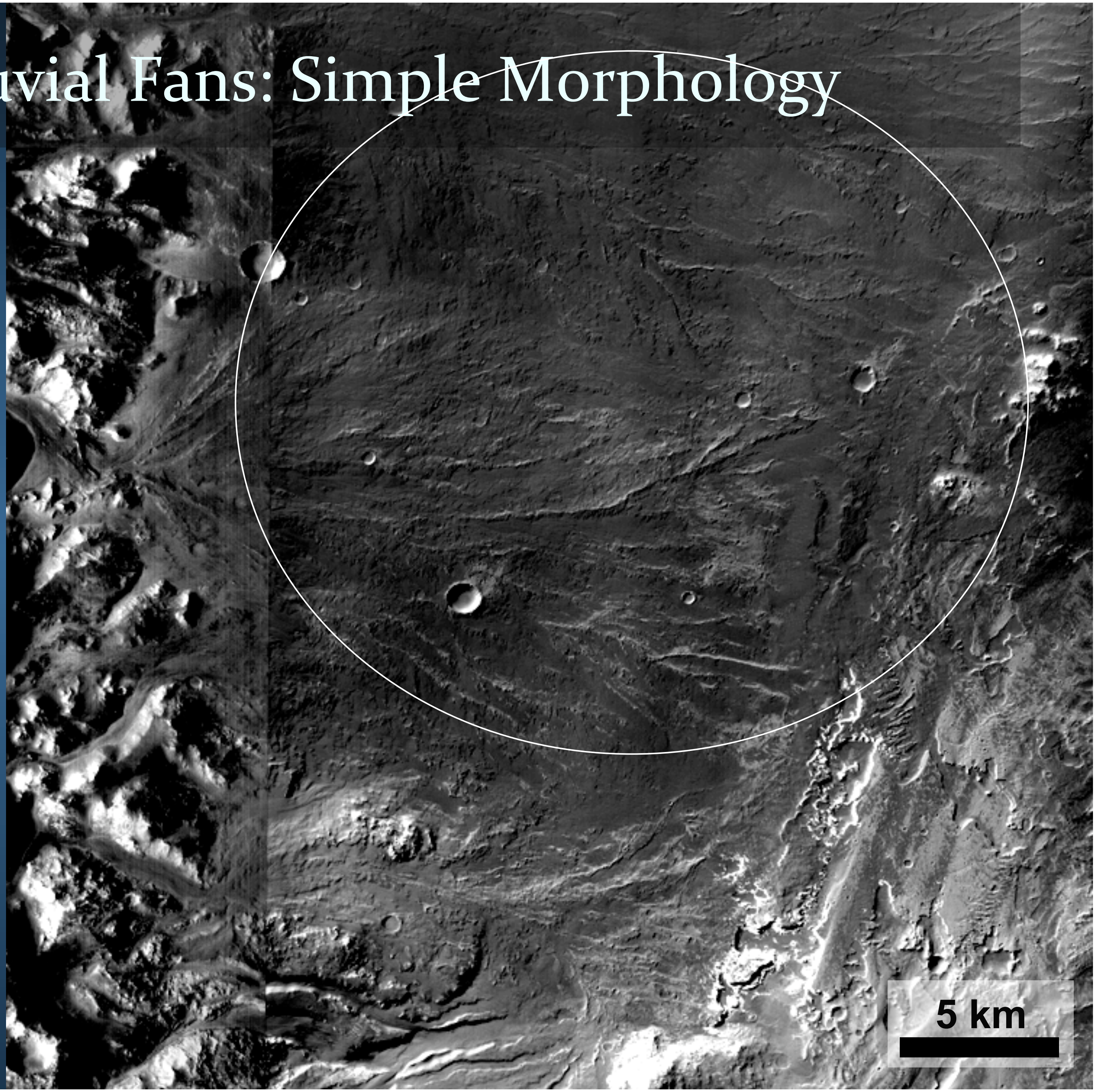
Alluvial Fans, Groom Lake, Nevada



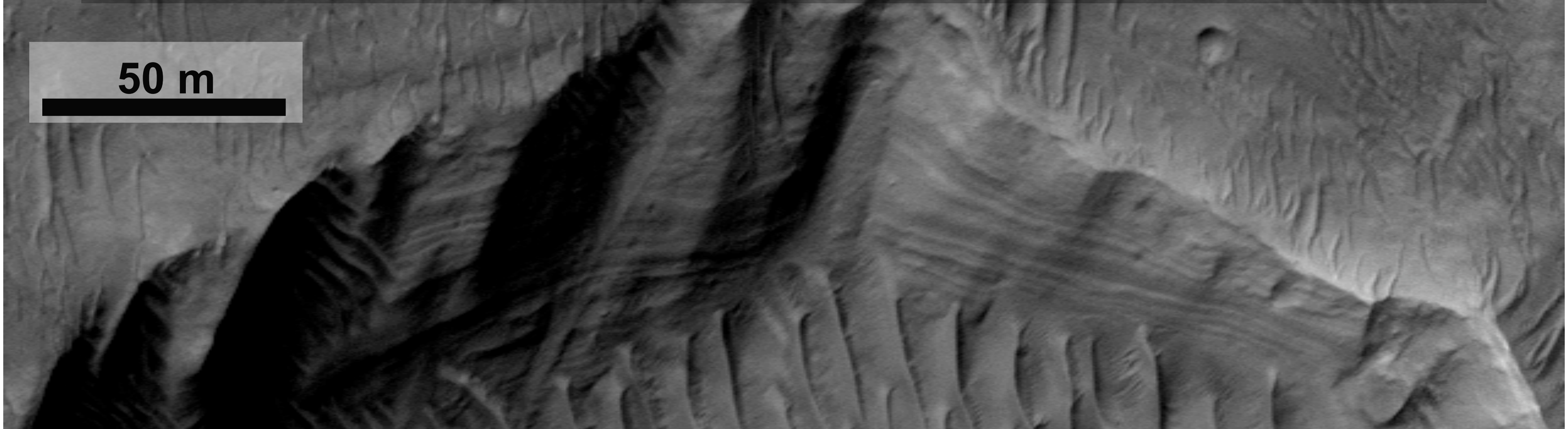
Alluvial Fans: Simple Morphology

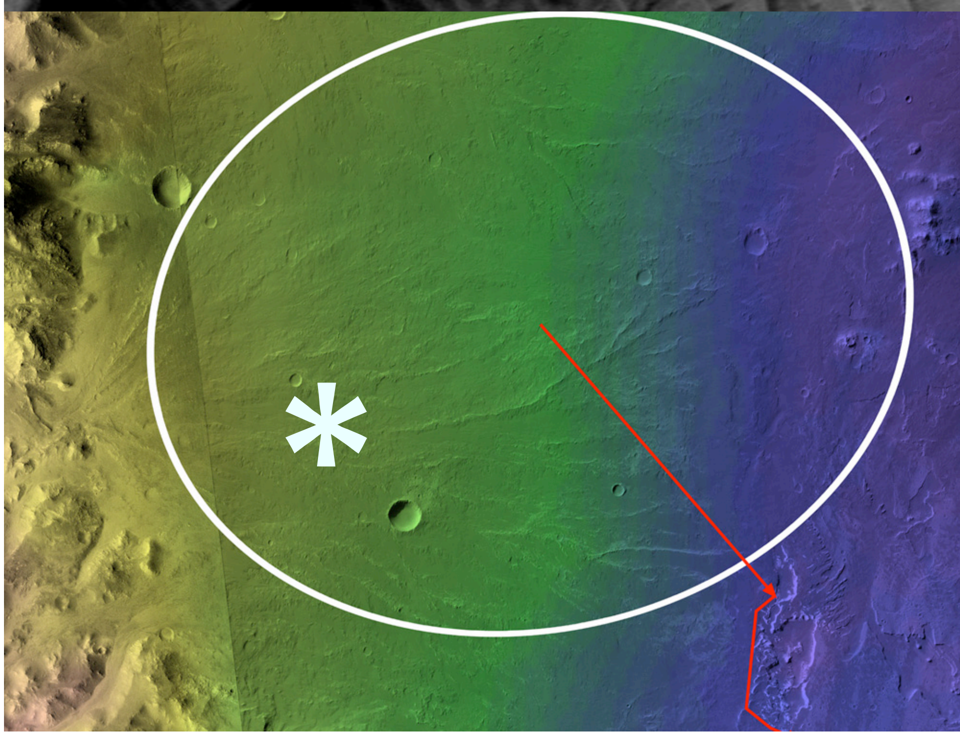
Moore and Howard (2005)

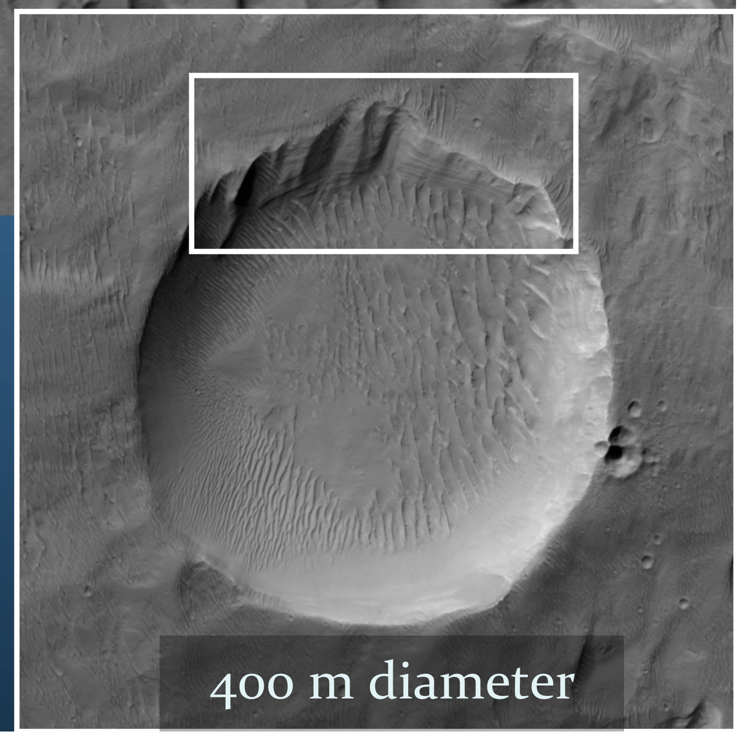
- Little to no fan segmentation
- Little to no dissection of fan surfaces
- Abrupt climate change
- Gradients and channels resemble fluvial deposits rather than debris flows



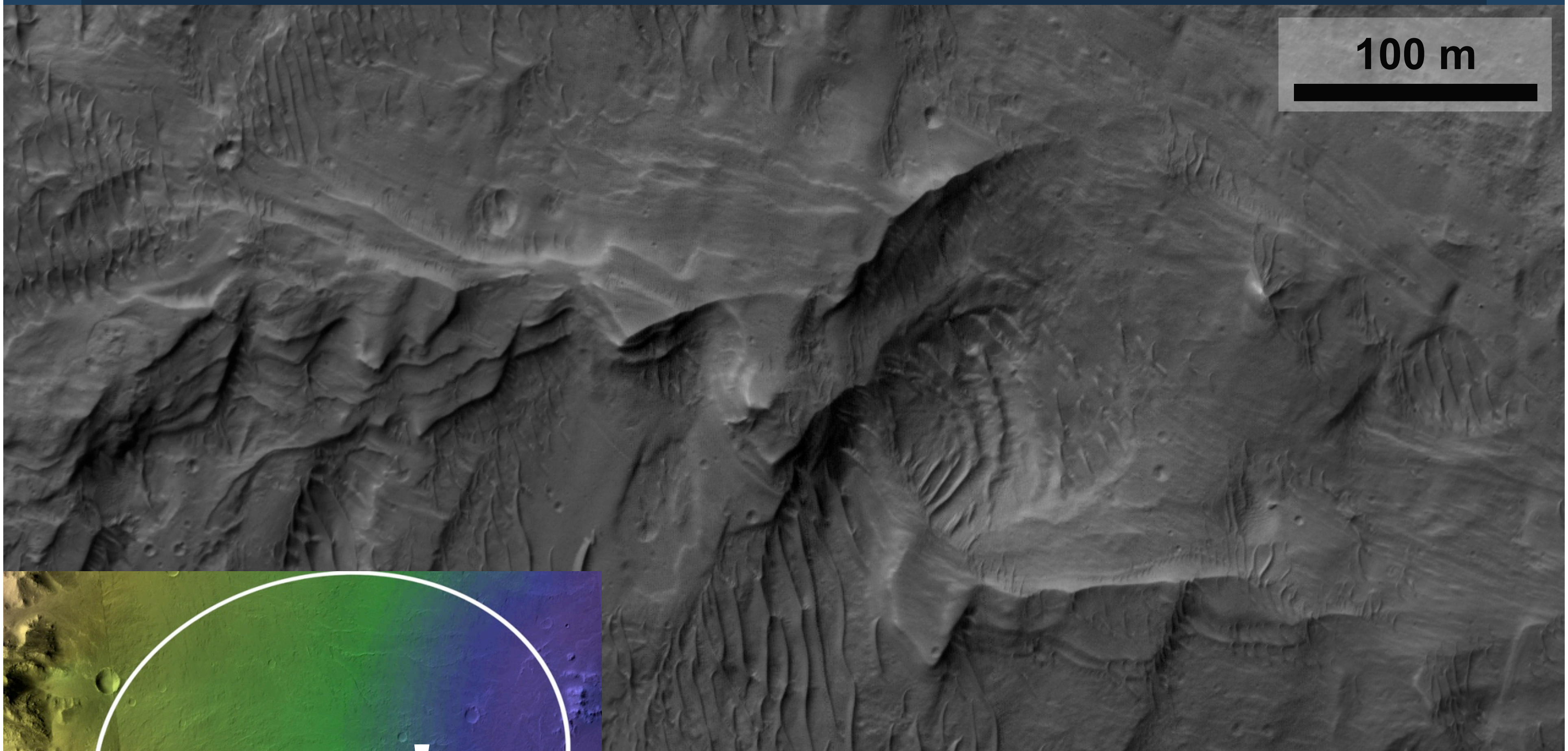
Science Traverse: Alluvial Fans

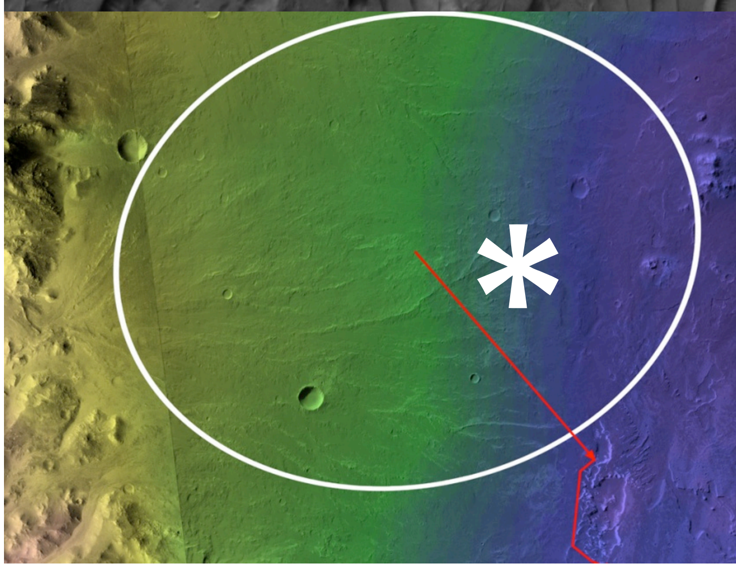




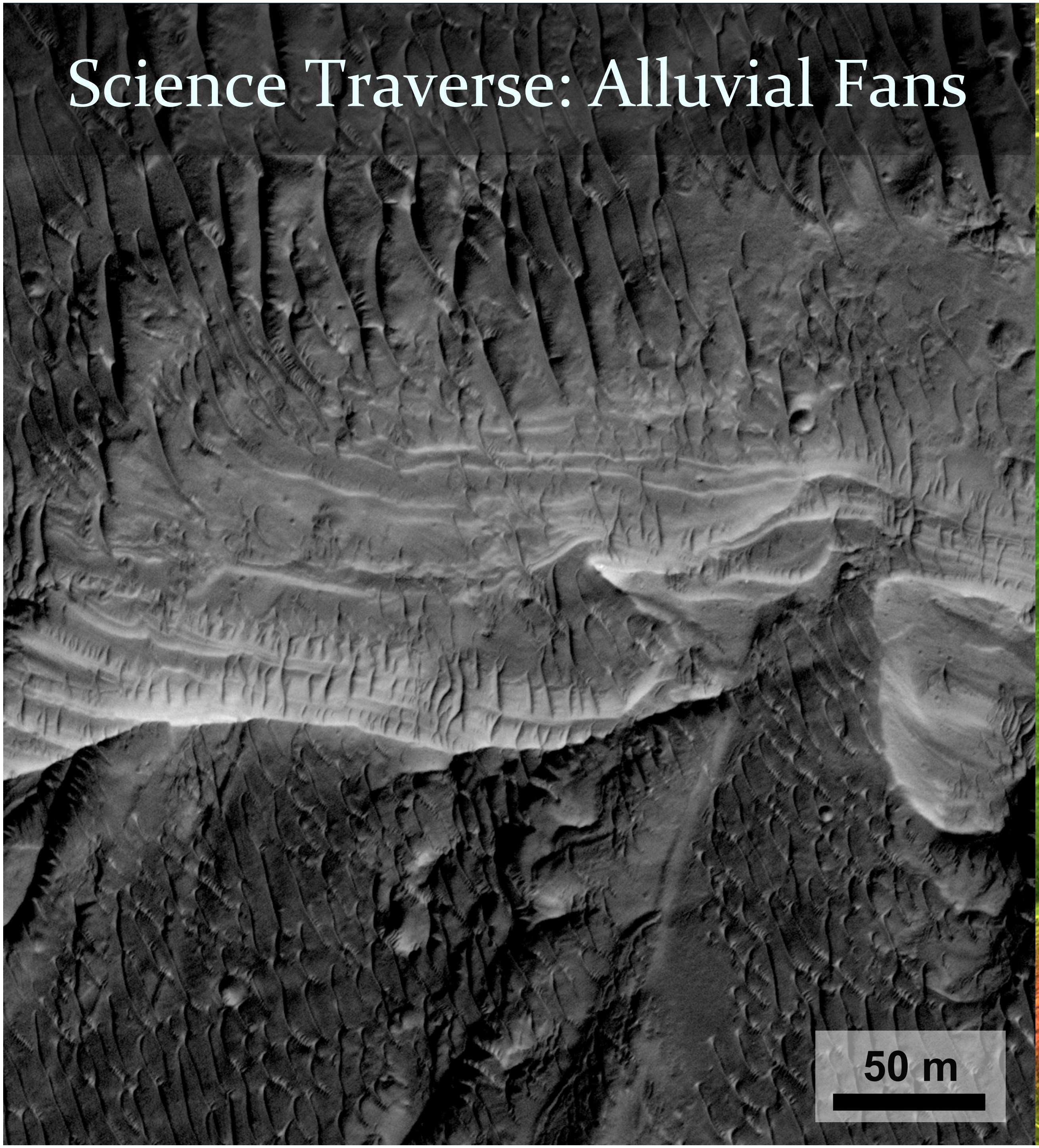


Science Traverse: Alluvial Fans





Science Traverse: Alluvial Fans



MSL Investigation of Alluvial Fans

I. Lithology of alluvial sand, gravel, and cobbles

1. Diversity of transported highland material from 2 km sequence of the crater wall, all within the ellipse at or near the landing site

II. Pre-erosional and post-depositional weathering environment

1. Exposure to groundwater in highland crust, chemical energy sources
2. Diagenetic change in highland bedrock before the Holden crater impact
3. Origin of phyllosilicates before or after Holden crater impact
4. Physical and/or chemical weathering of wall rock to produce transportable particles
5. Post-depositional weathering processes on alluvial sediment, contrast with Gusev crater
6. Composition and origin of finer-grained matrix in fan deposits, similar to LTLD?
7. Composition of intermediate-sized component, reworked in aeolian ripples?

MSL Investigation of Alluvial Fans

III. Fluvial transport processes and environmental implications

1. Matrix- or clast-supported deposits (debris flow or fluvial transport)
2. Grain size, rounding and down-fan changes (flow intensity and transport)
3. Bedding and sorting (more sustained or short, high-intensity flows)
4. Paleosols or duricrusts between beds? (intervals of activity)
5. Post-depositional cementation or loose lag (preservation mechanism)
6. Paleodischarge and runoff estimate from slope, grain size, width
7. If observed, lenticular gravelly deposits at the fan toe could help determine channel width

IV. Sedimentary sequence and relative timing of major stratigraphic units

1. Incision of fluvial flows into LTLD? (change in base level)
2. Interfingering of coarse and fine deposits (test contemporary age of fans and LTLDs)

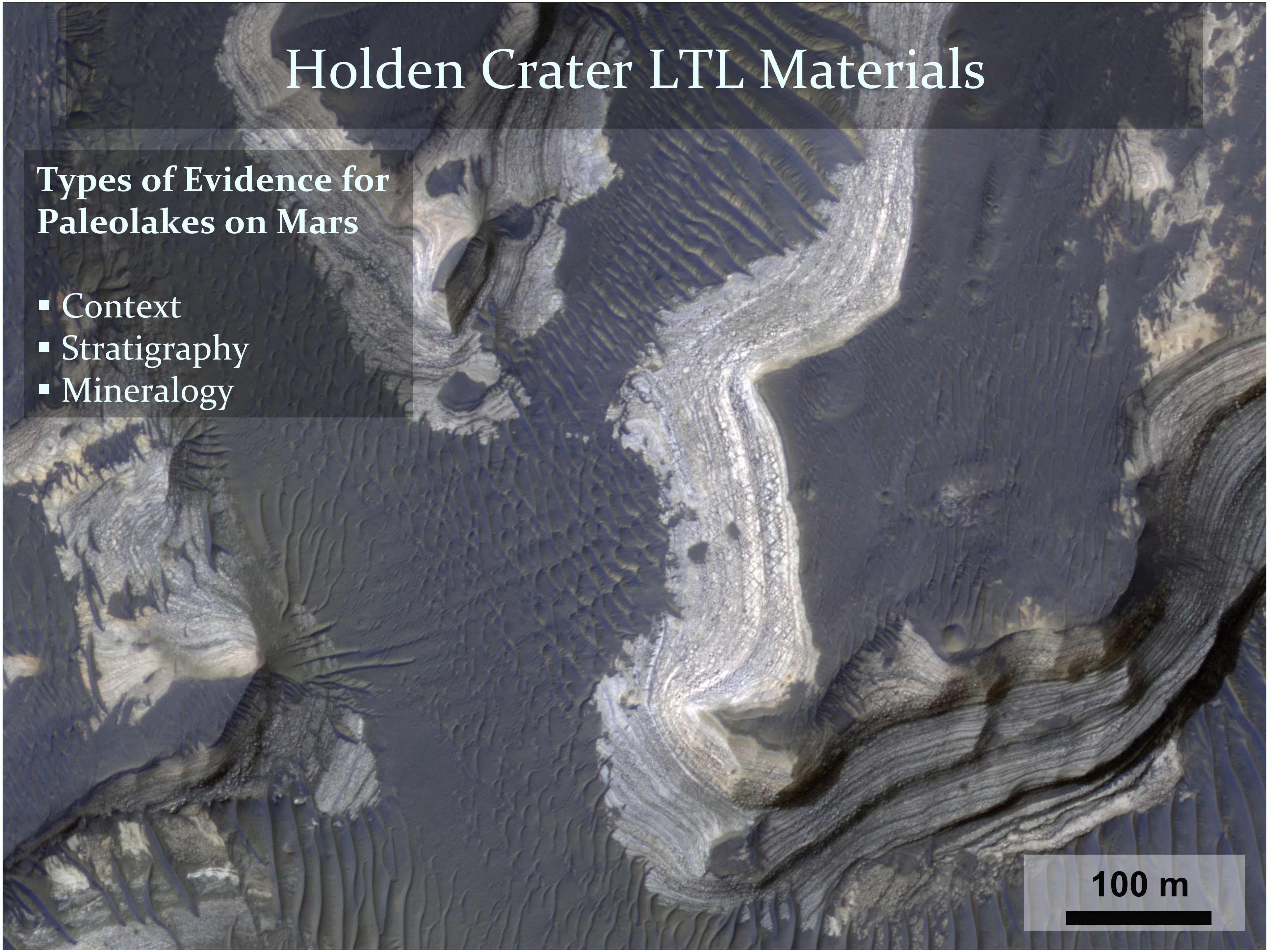
V. Implications of the above observations for paleoenvironment and habitability

1. Paleoclimate required to yield observed fluvial deposits
2. Atmospheric water supply and changes over time

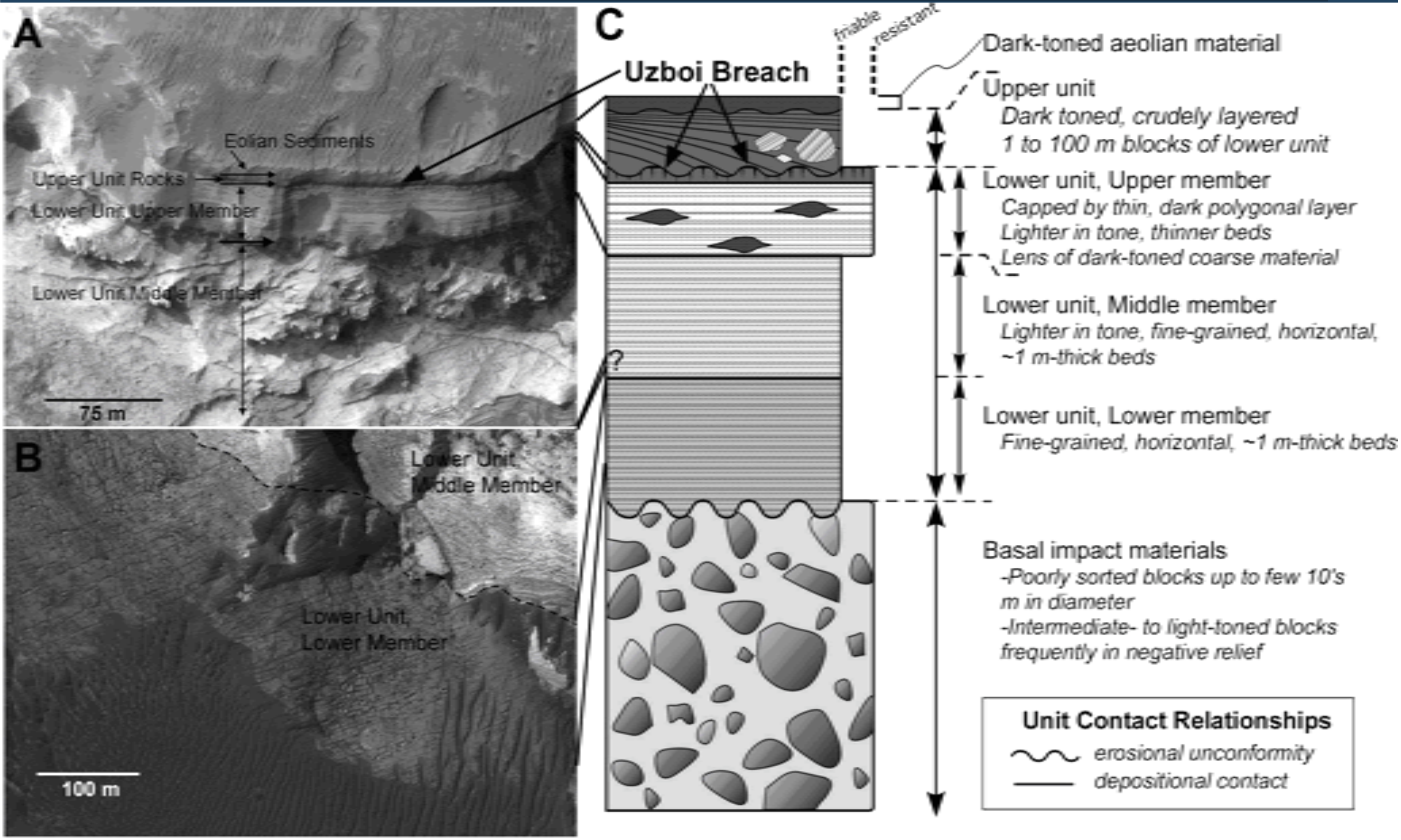
Holden Crater LTL Materials

Types of Evidence for Paleolakes on Mars

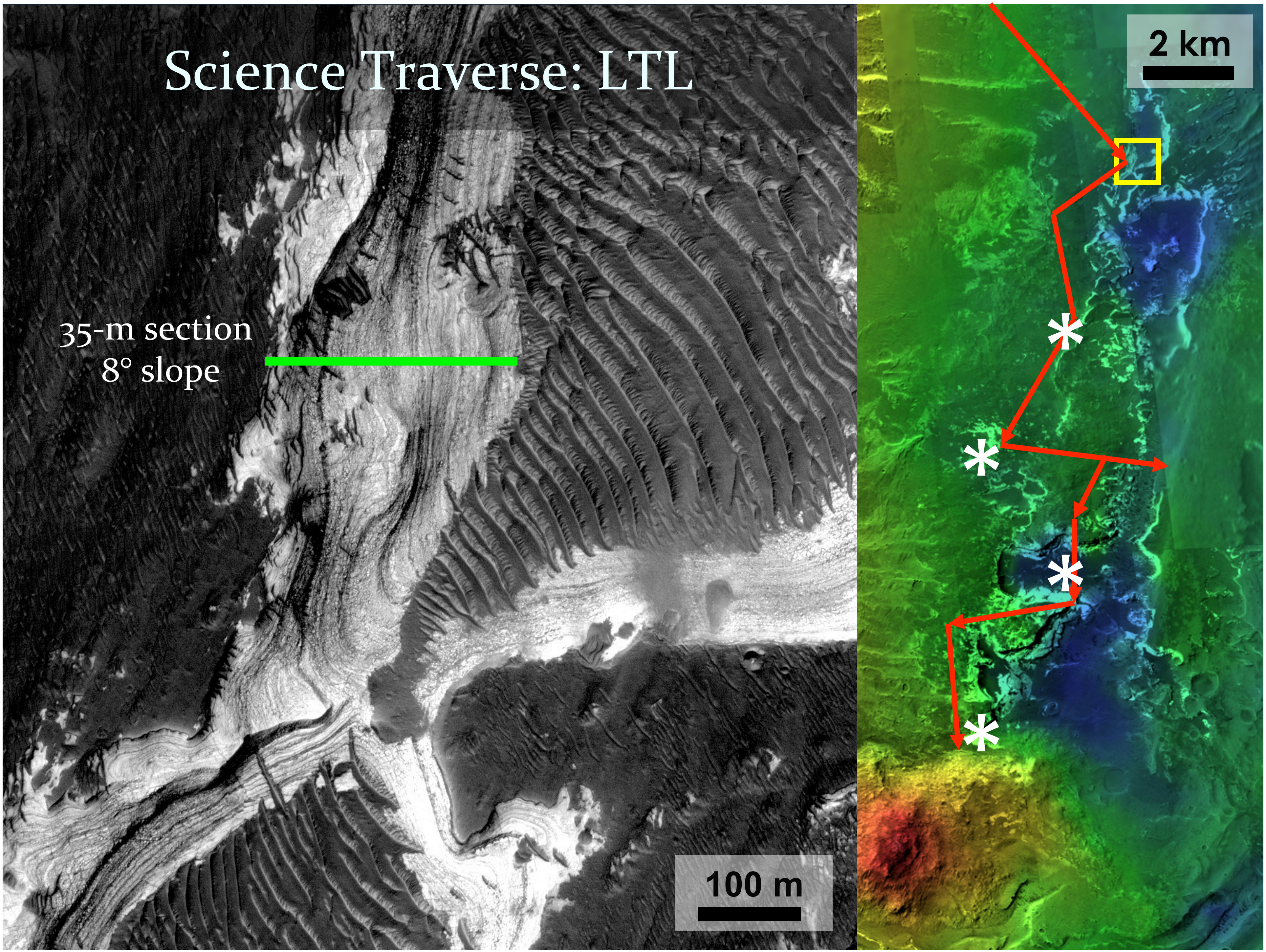
- Context
- Stratigraphy
- Mineralogy



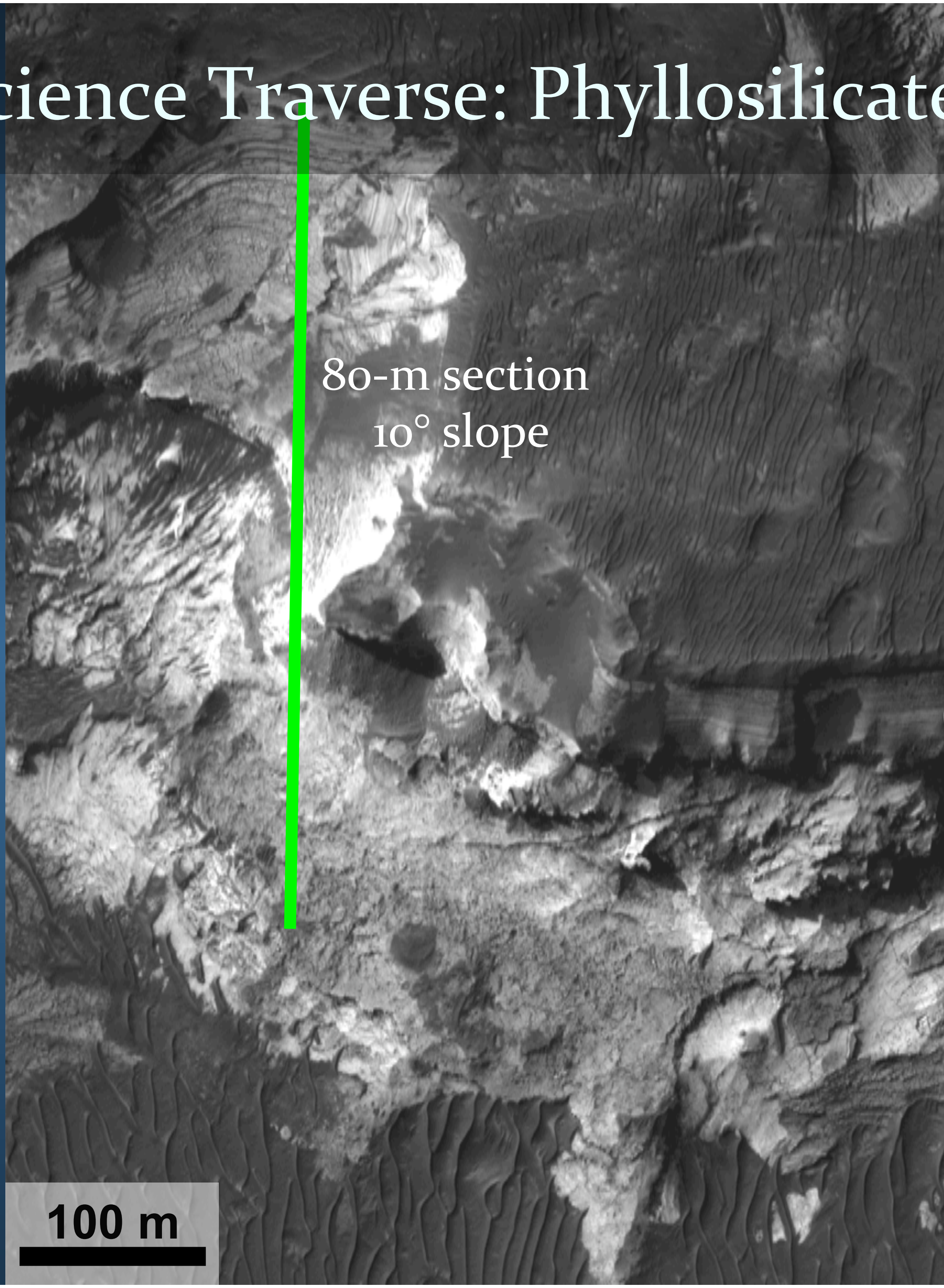
Holden Crater Fill Stratigraphy

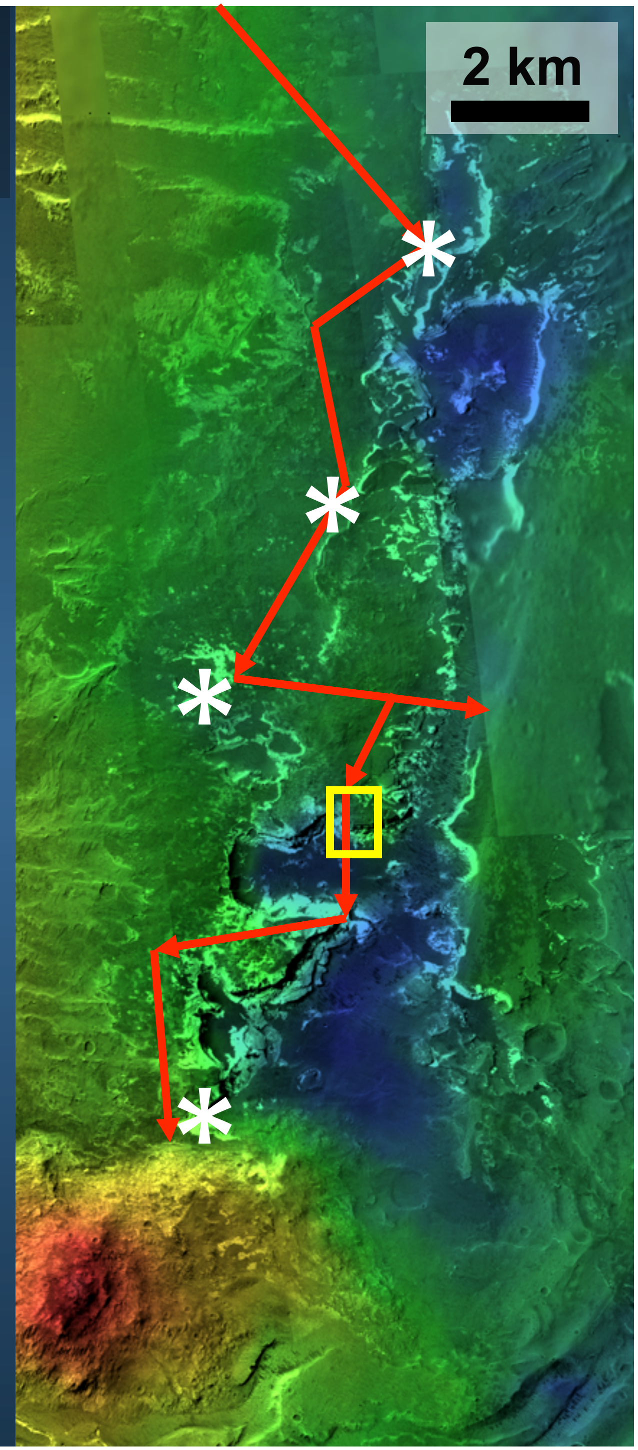


Grant et al., 2008

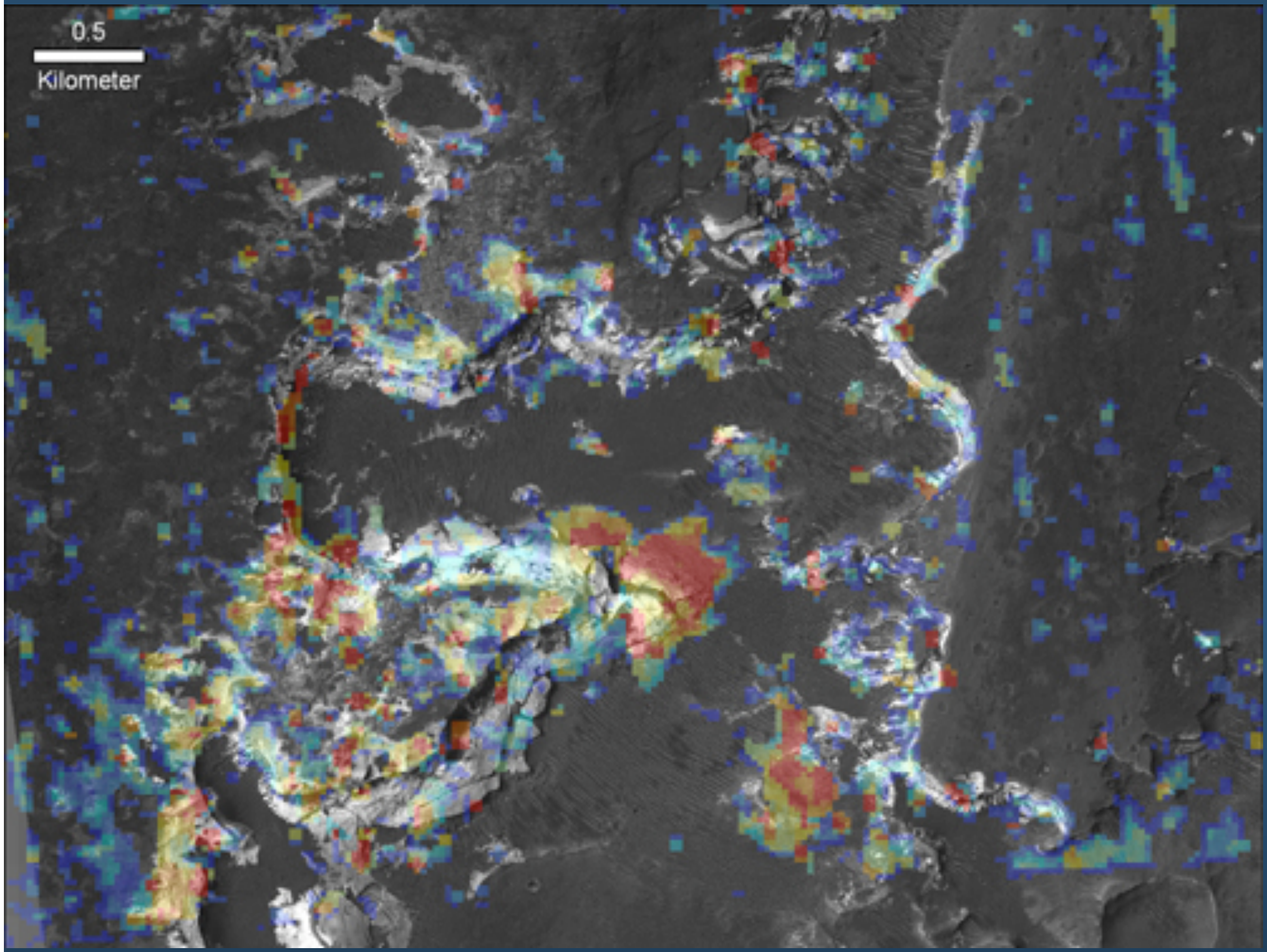

Science Traverse: LTL
35-m section
8° slope
100 m
2 km

Science Traverse: Phyllosilicates

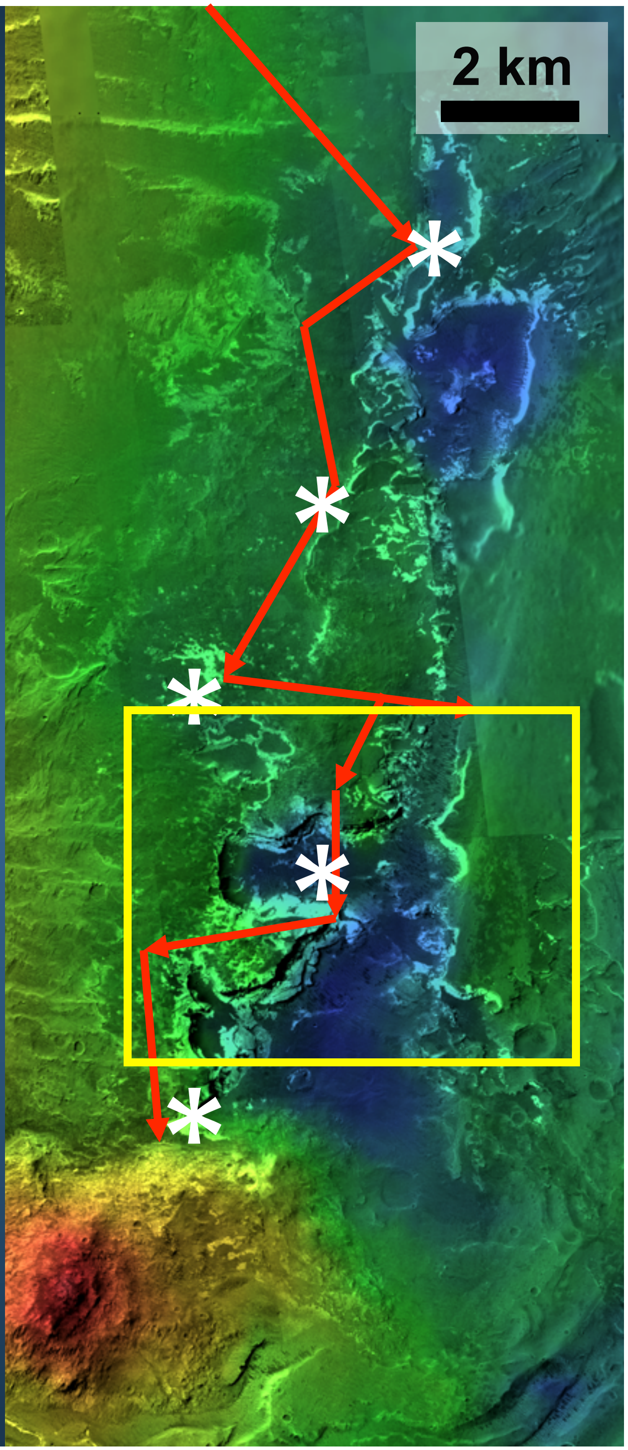




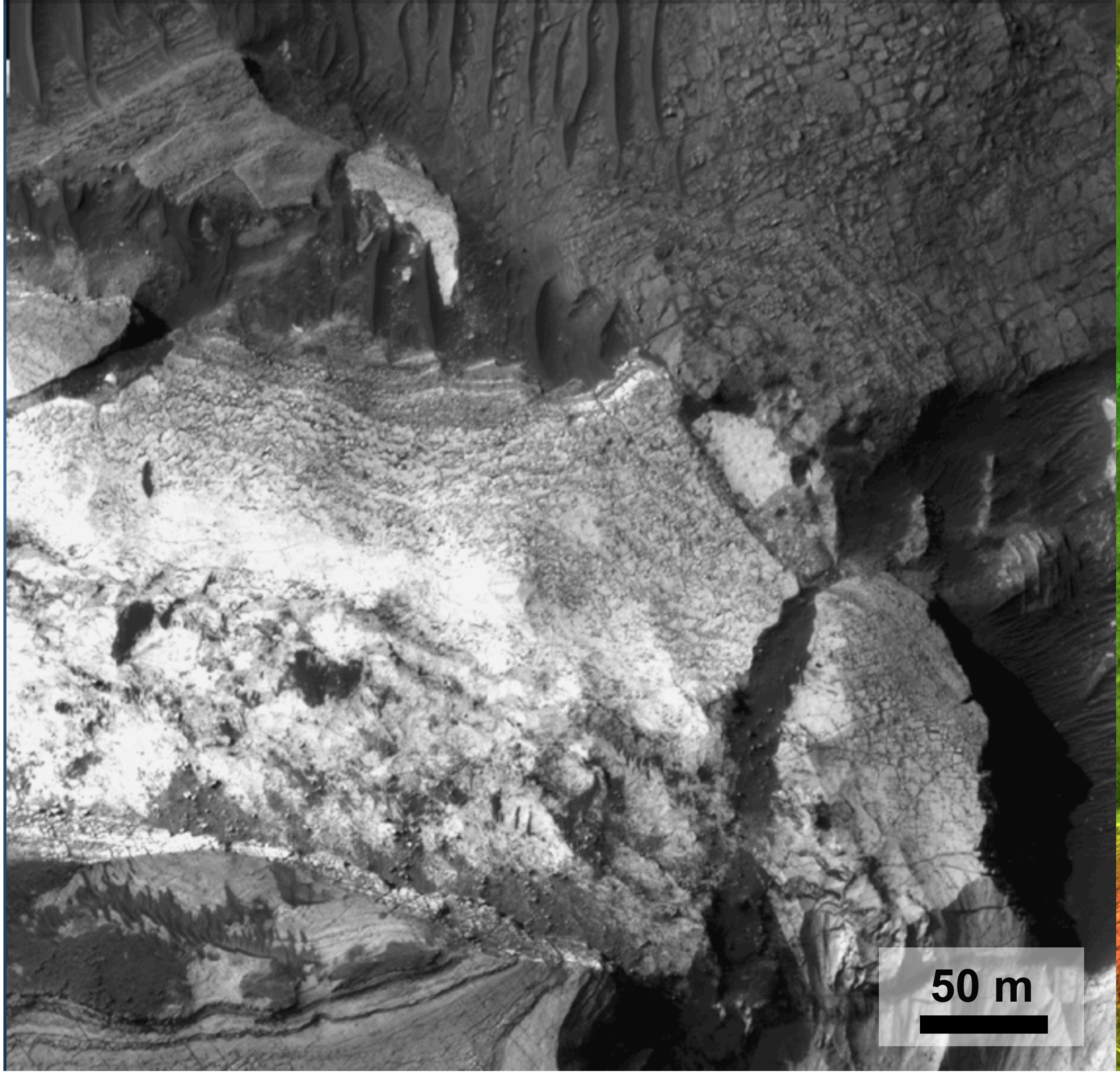
Science Traverse: Phyllosilicates

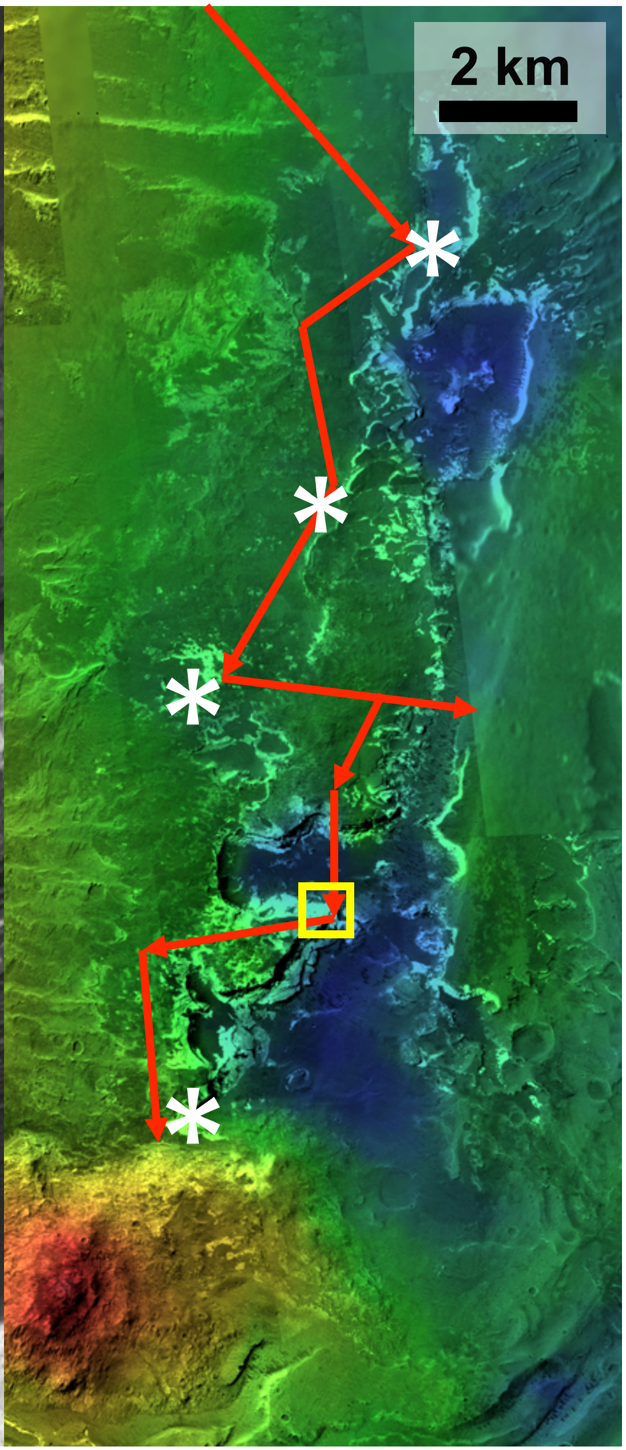


Credit: R. Milliken

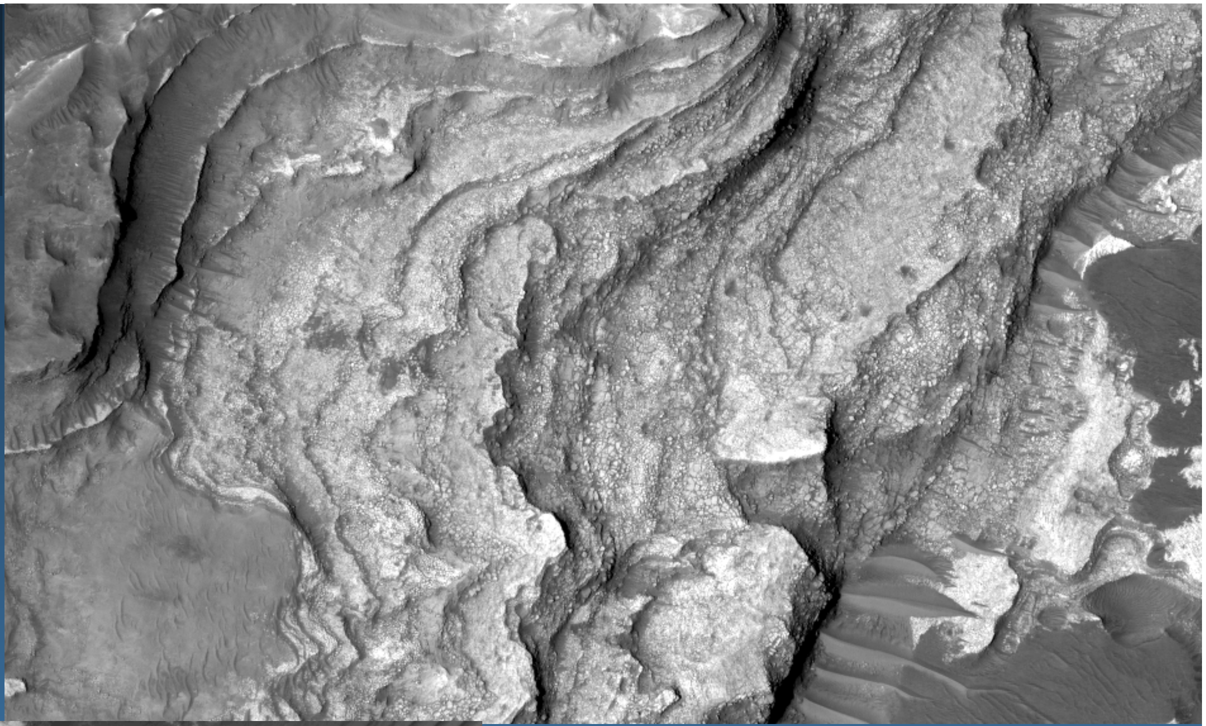


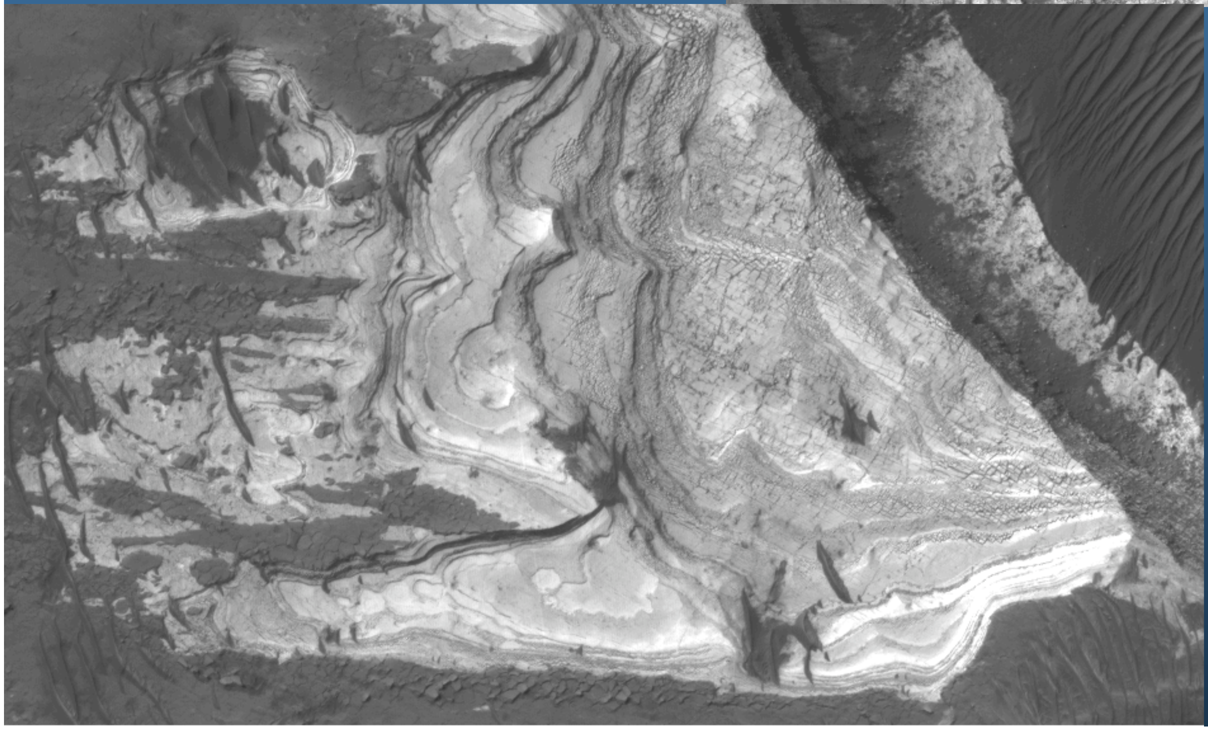
Science Traverse: Phyllosilicates



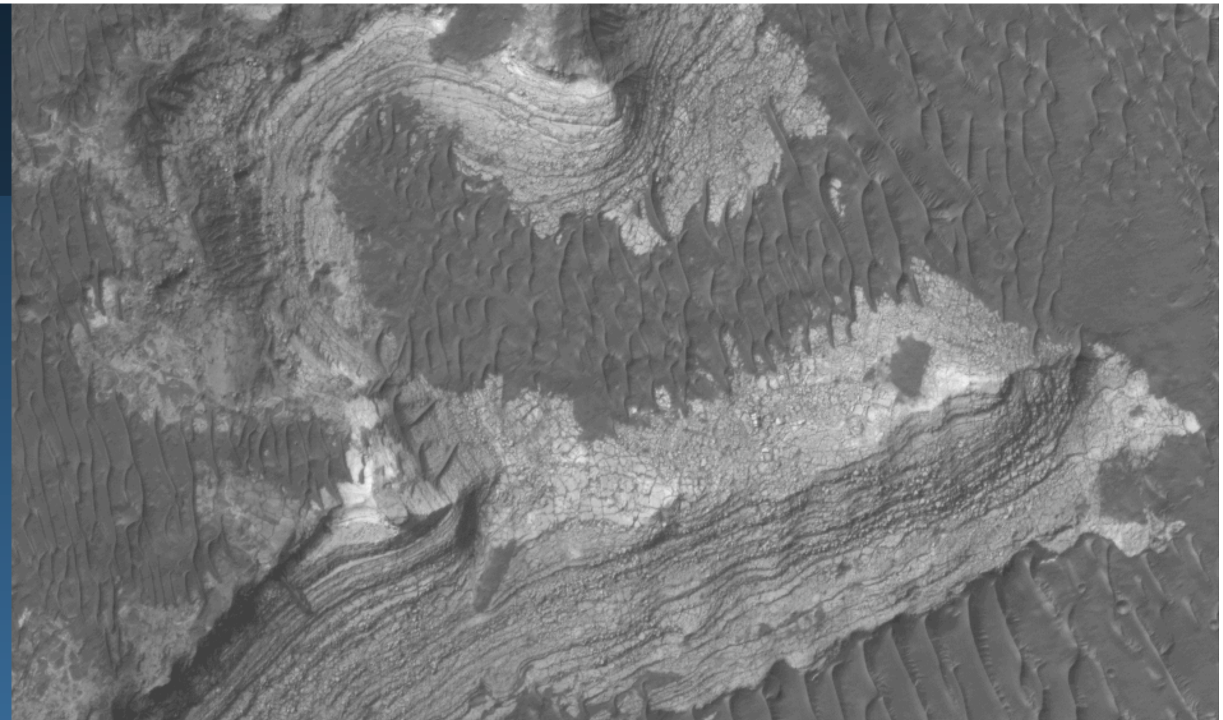


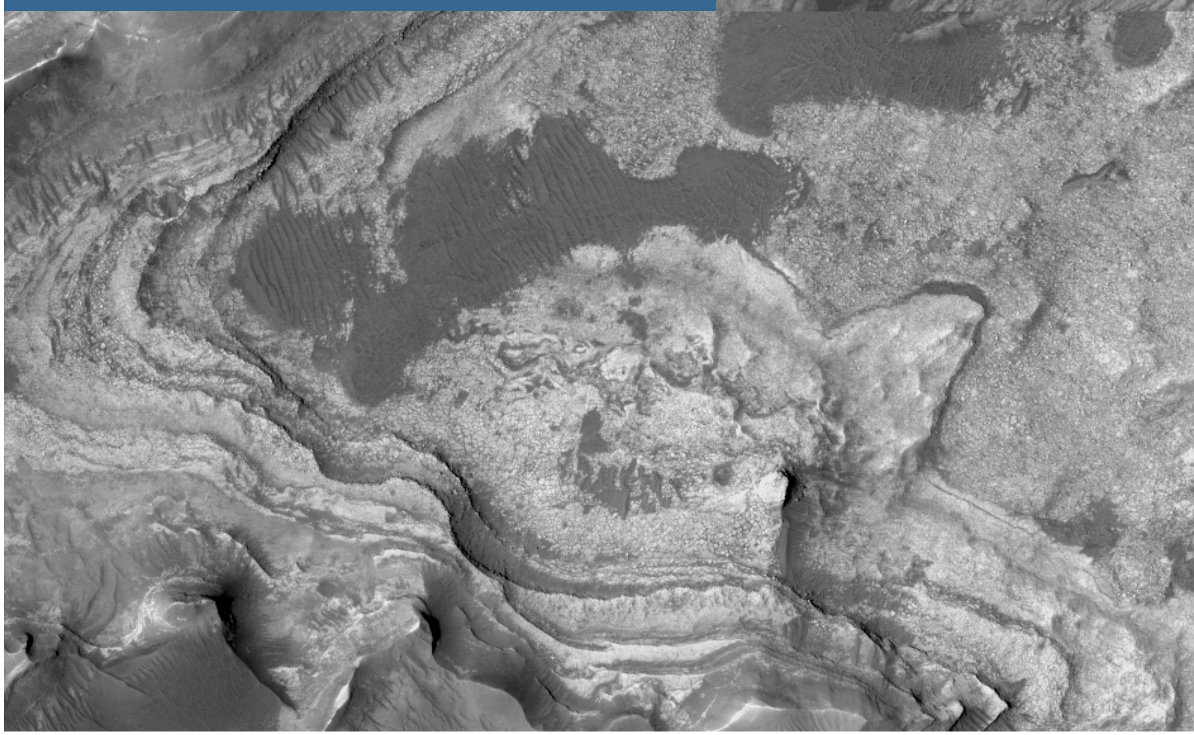
LTL Outcrops



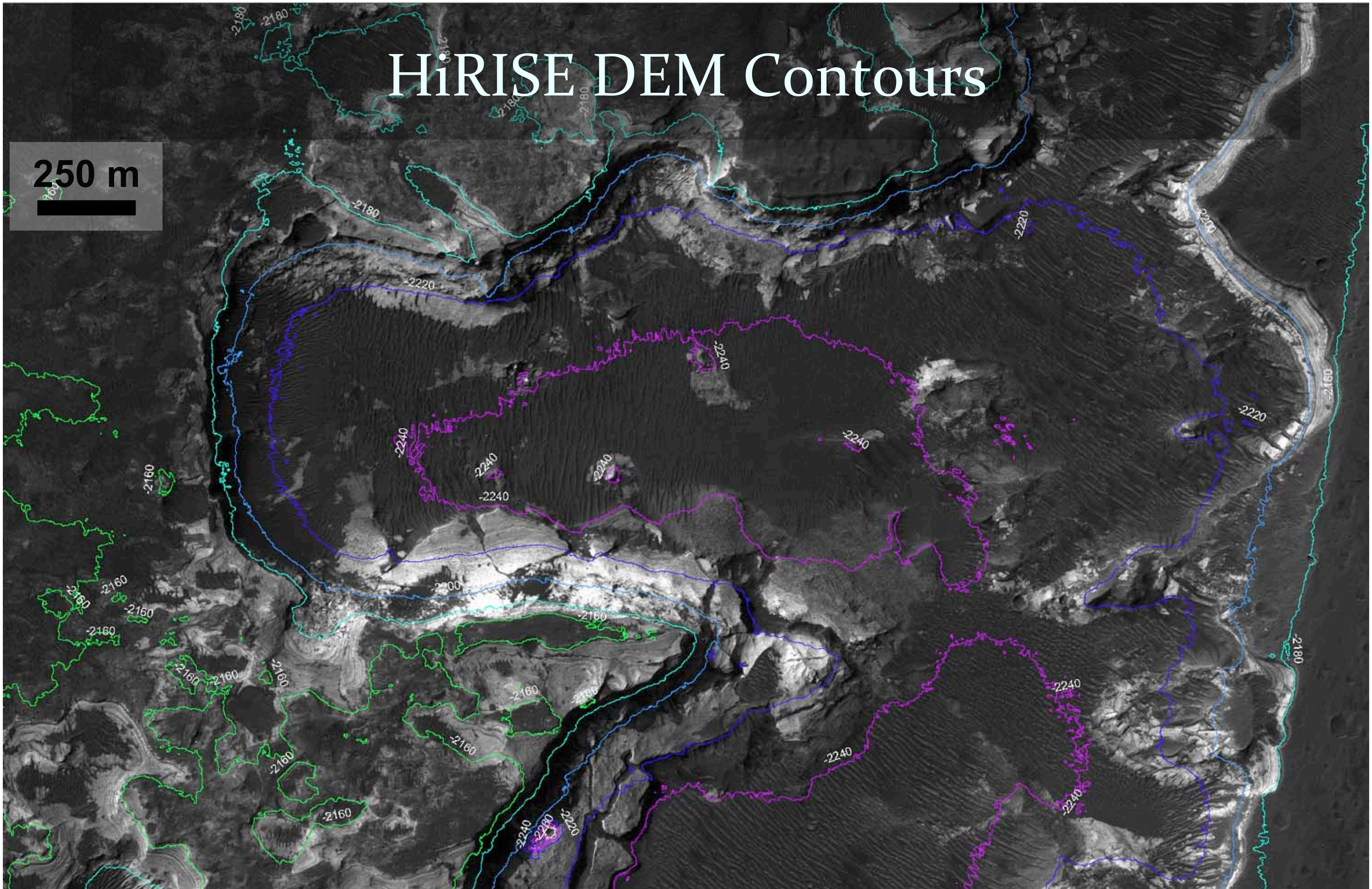


LTL Outcrops





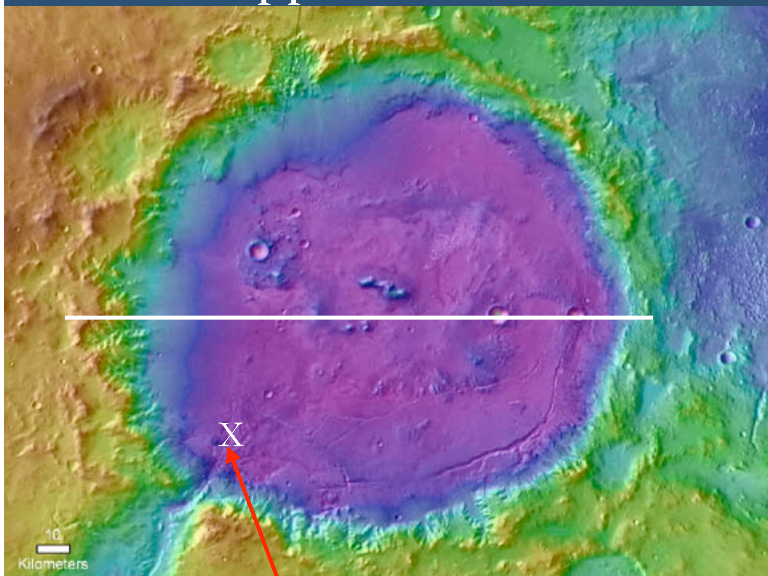
HiRISE DEM Contours

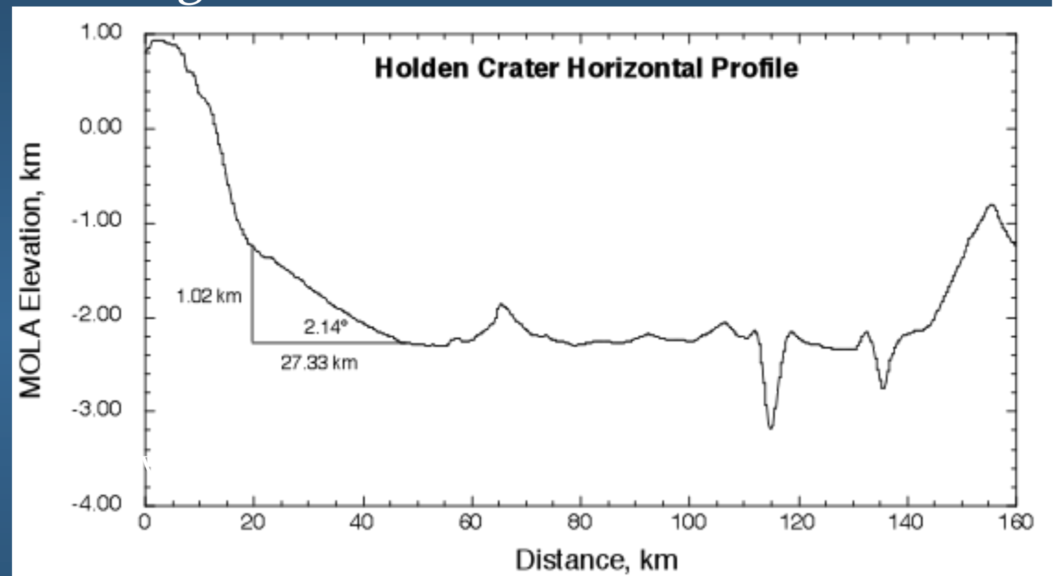


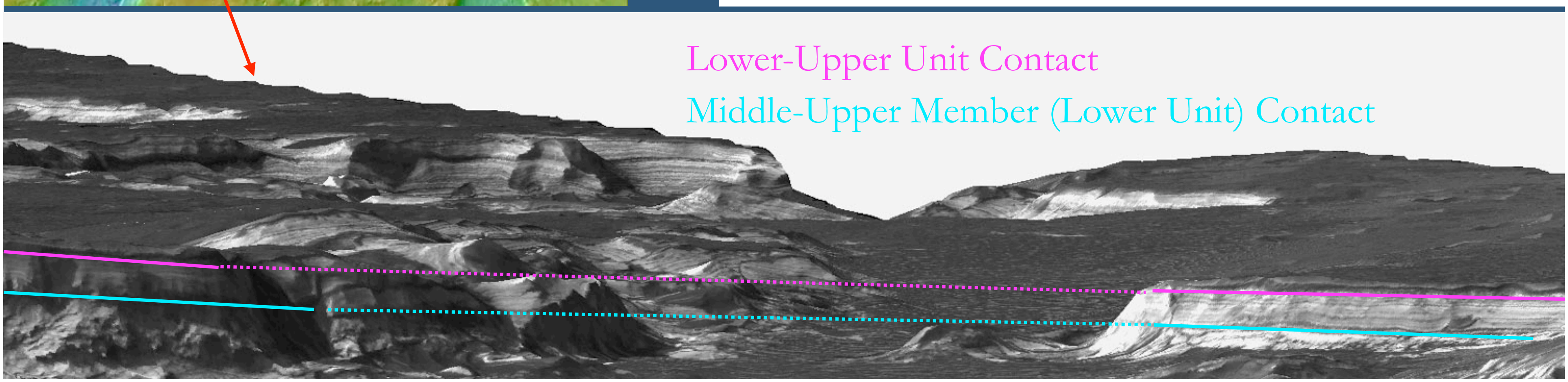
HiRISE DEM (1 m) shows LTLD bedding planes and contacts follow contours locally (100 m), but not over long scales (1-10 km). DEM: Lewis/Aharonson

Alluvial fans slope <2.5° (1° in places), extend tens of km into the crater and cover the LTL materials. LTL outcrops are rare except in the SW portion of the crater, where they are exposed by erosion.

The contacts between units also exhibit shallow dips, and the majority of beds do not appear to be truncated on short length scales.

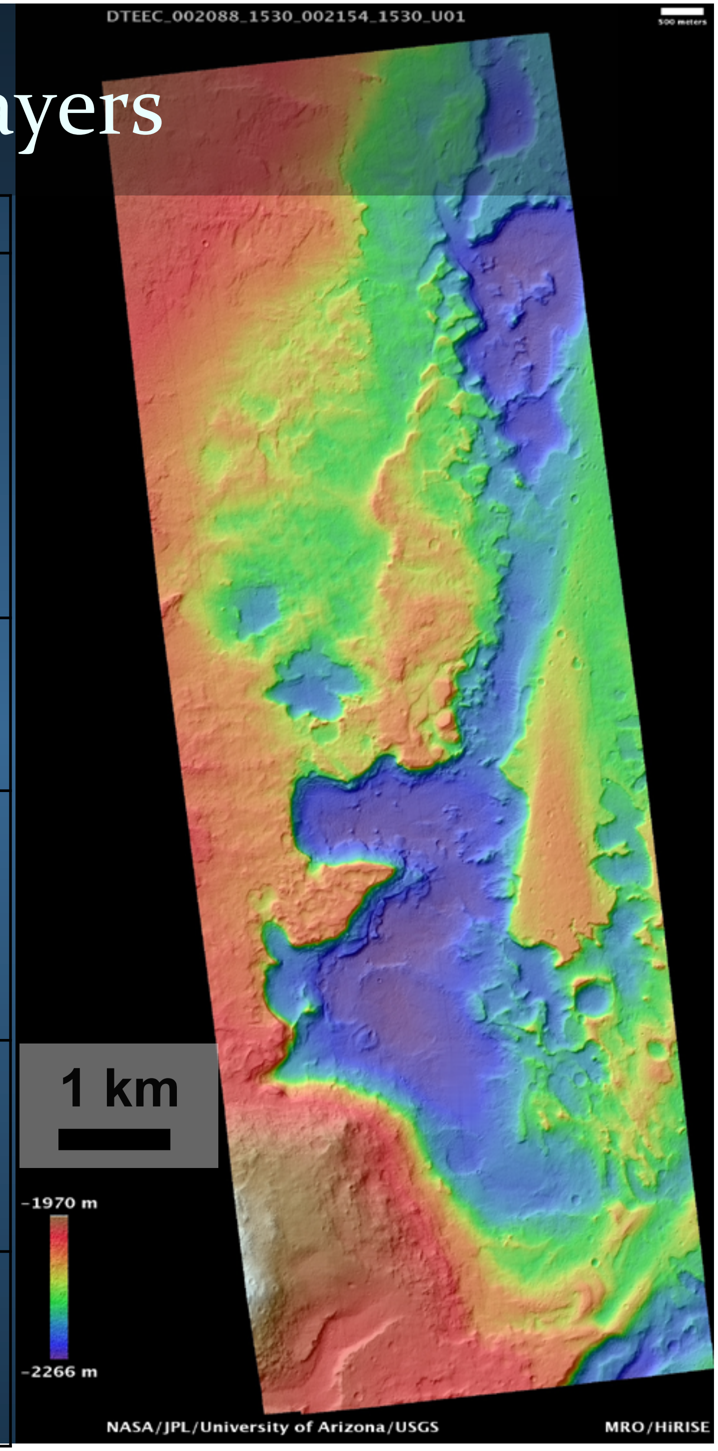






Hypotheses for Layers

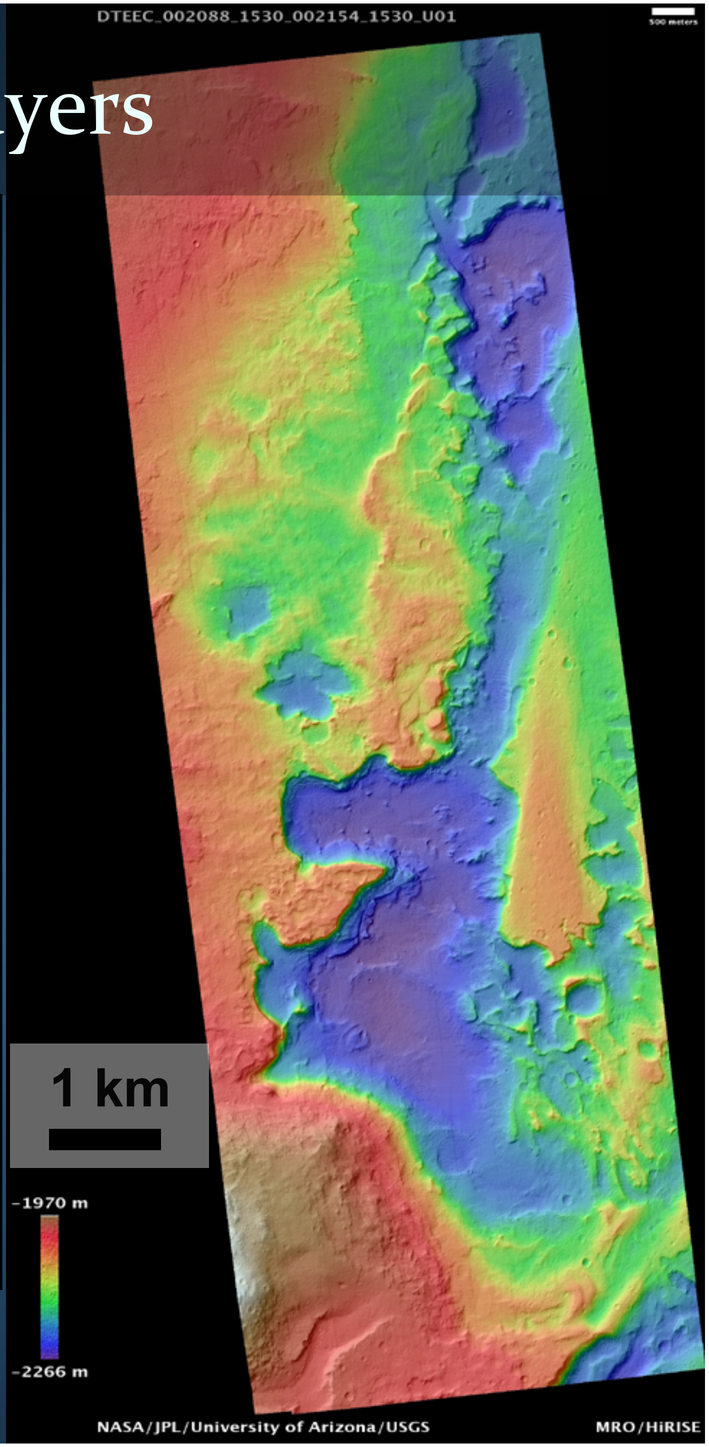
Lithology	Supporting features	Contrary features	Confidence
Lava flows	1. Erosional resistance, craters preserved 2. Equipotential or lobate flows 3. Mafic mineralogy 4. Low albedo 5. Raised margins 6. Wrinkle ridges	A. Deeply etched or deflated surface B. Drapes basin rim and exterior surface C. Secondary minerals D. High albedo E. Graded with channels F. Distributary network	High if 1–6 observed, A–F not observed
Tephra	1. Drapes topography 2. Mafic mineralogy 3. Near volcanic source	A. Confined to basin B. Secondary minerals C. No volcanic source	Moderate to low if 1–3 observed, A–C not observed
Impact ejecta (proximal)	1. Nearby fresh crater 2. Erosional resistance 3. Ballistic or fluidized 4. Low albedo for most target materials	A. No obvious source B. No greater resistance C. Thin, horizontal layers D. High albedo	High if 1–4 observed, A–D not observed
Airfall deposit (suspended particles)	1. Etched surface 2. Drapes topography 3. Weak spectral signal 4. Massive fine-grained layers	A. Erosional resistance B. Confined to basin C. Strong mafics or salts D. Contains boulders	High to moderate if 1–4 observed, A–D not observed
Aeolian dune deposit/sand sheet (saltated)	1. Breaks down to wind-transportable sizes 2. Mafic mineralogy 3. Low albedo	A. Breaks down to resistant boulders B. Phyllosilicate or salt C. High albedo	Moderate if 1–3 observed, A–C not observed



Hypotheses for Layers

Lithology	Supporting features	Contrary features	Confidence
Alluvial or deltaic deposit	1. (Inverted) channels 2. Discontinuous beds over <km scales 3. Dips into basin 4. Etched surface 5. Confined to basin 6. Sourced by valley(s)	A. No paleochannels B. Continuous beds over >km scales C. Flat-lying strata D. No deflation E. Drapes rim crest F. No source dissection	High if 1–6 observed, A–F not observed
Evaporite deposit	1. Salt signatures 2. Med/high albedo 3. Confined to basin 4. Flat-lying in center 5. Polygonal fractures	A. Mafic signature B. Low albedo C. Drapes topography D. Steeply dipping beds E. Inverted channels	High if 1–5 observed, A–E not observed
Pelagic deposit	1. Etched surface 2. Massive or laterally continuous bedding 3. Flat-lying beds 4. Secondary minerals 5. Confined to basin	• Erosionally resistant • Discontinuous beds over <km scales • Steeply dipping beds • Mafic mineralogy • Drapes exterior	Moderate if 1–5 observed, A–E not observed

These features are non-unique individually and collectively, but they are a starting point for interpretation of exposed stratigraphy.



MSL Investigation of LTL Materials

I. Composition of sedimentary deposits freshly exposed by wind

1. Mineralogy and diversity (advanced weathering products, other sediments)
2. Grain size (energy of depositional setting)
3. Vertical changes in mineralogy and sedimentology (temporal change)
4. Evaporites in or throughout the section? (deep lake or playa?)
5. Cementation, diagenesis, concretions, crystal growth (aqueous activity)

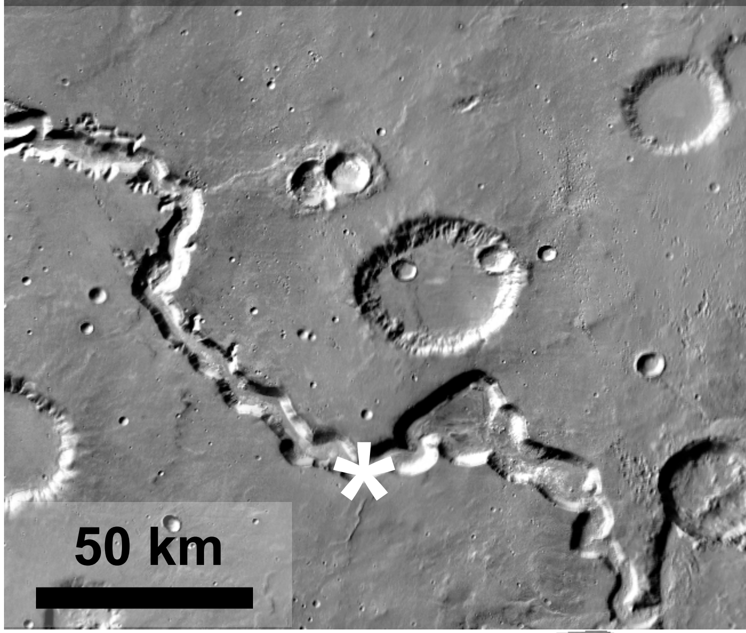
II. Sedimentary structures

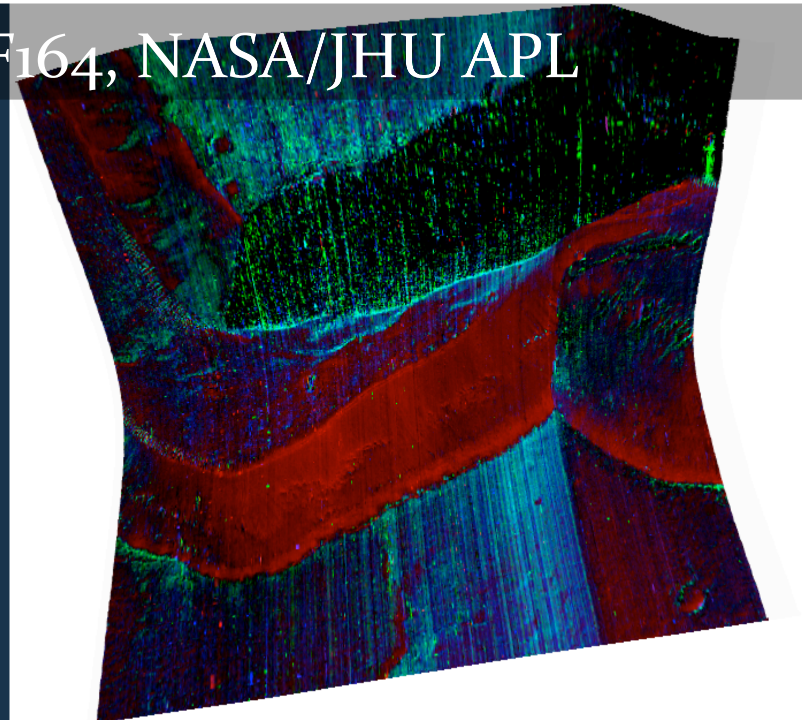
1. Bed thickness and sorting, variability thereof (sustained or pulsed supply)
2. Ripples or cross-bedding? (surface or shallow lacustrine flows vs. pelagic)
3. Mudcracks, deflated surfaces, paleosols, duricrusts between beds? (subaerial exposure)
4. Unconformities within the LTL? (major intervals of non-deposition)
5. Other materials in lenses? (contemporary geological activity)

III. Habitability

1. Geochemical environment (inferred pH, dissolved solids and concentration, change or continuity through time: favorability for or effects of biological processes)
2. Preservation, nature, and inventory of organic compounds
3. Inventory the chemical building blocks of life (C, H, N, O, P, S).

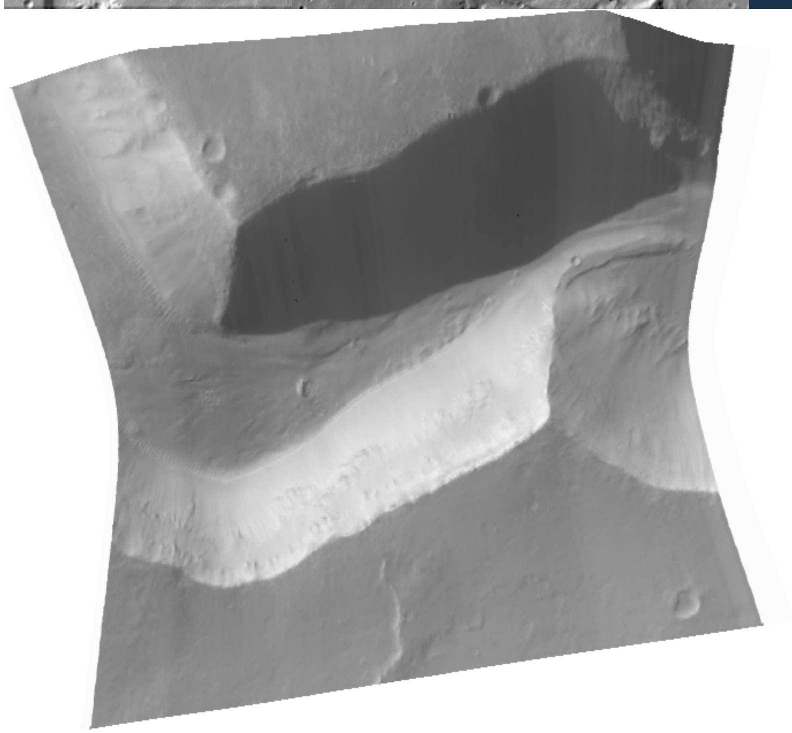
CRISM FRT FRT0000C1D1_07_IF164, NASA/JHU APL



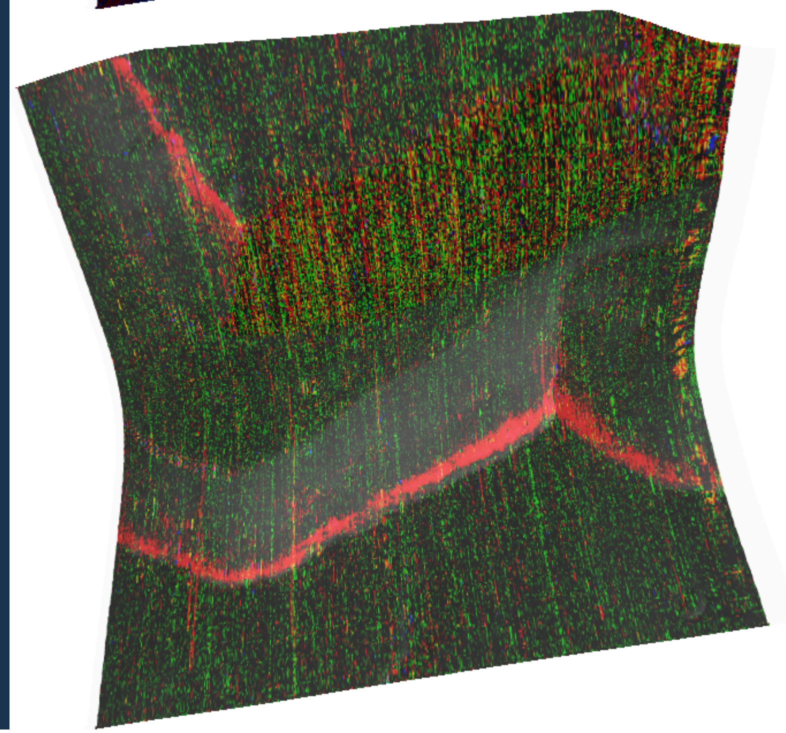


OLINDEX
LCPINDEX
HCPINDEX

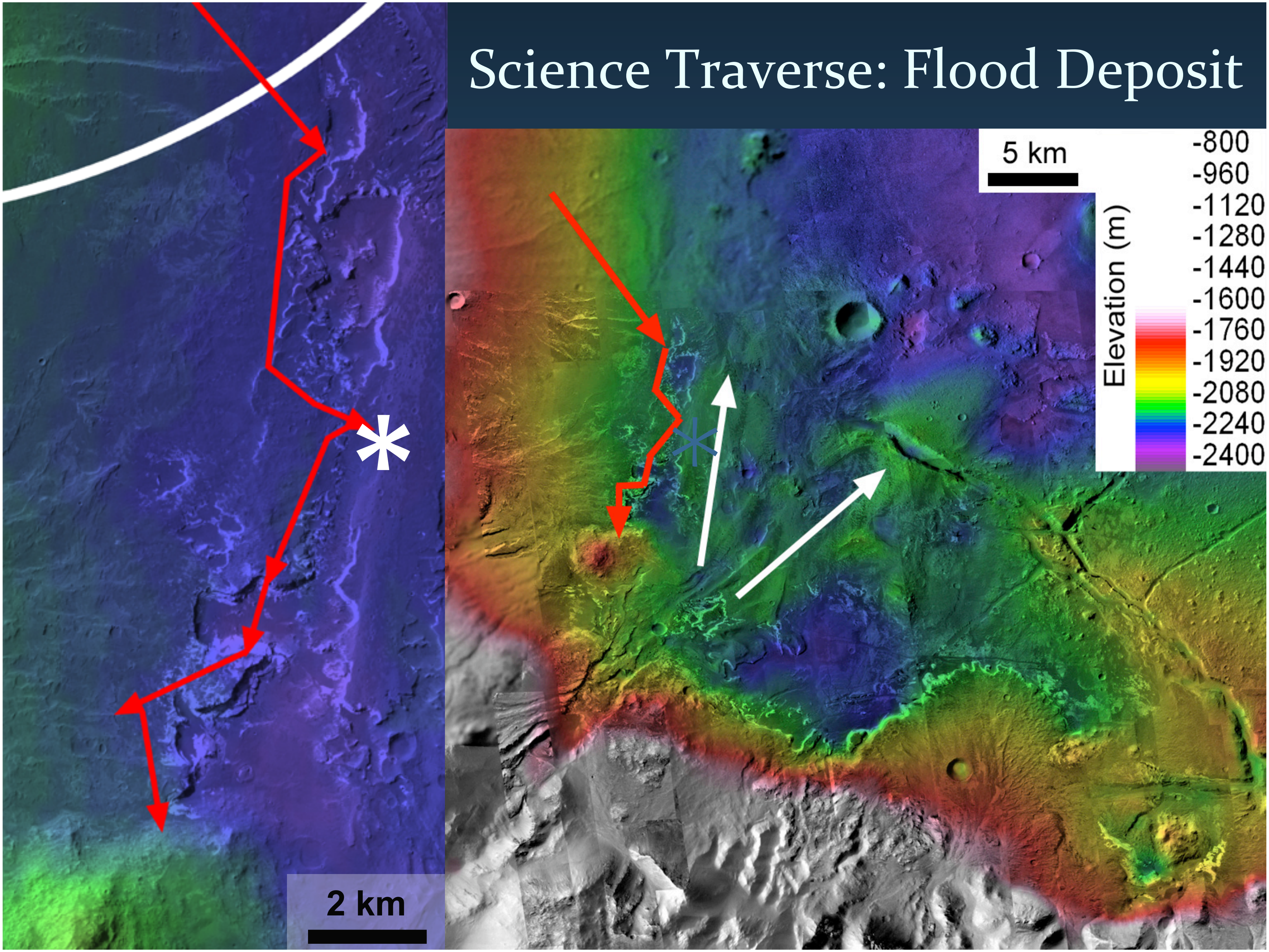
Buczkowski et al. (2010), LPSC



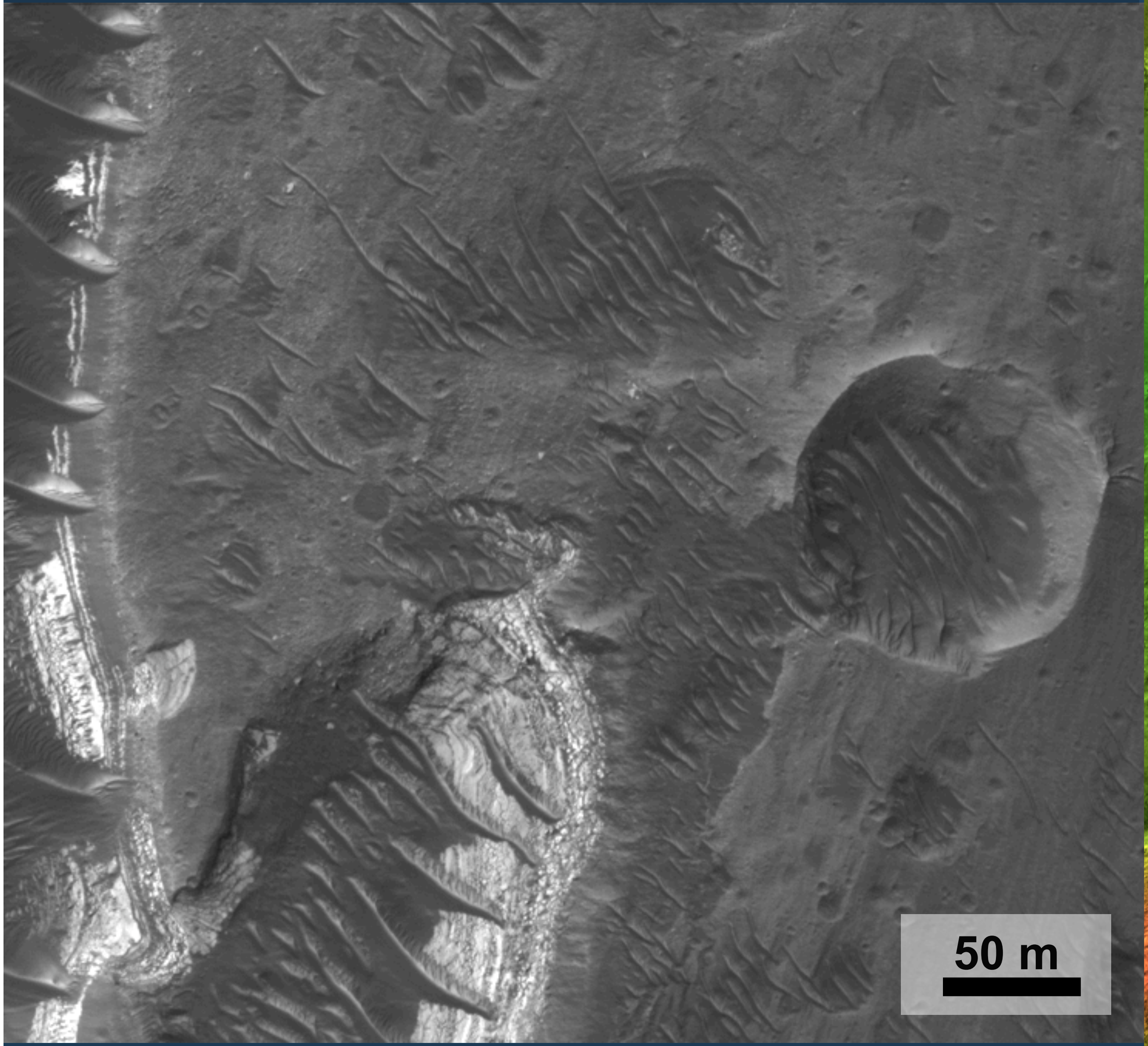
Fe/Mg phyllo.
Al phyllo. hydrated glass
Hydrated sulfate, clay, glass, ice

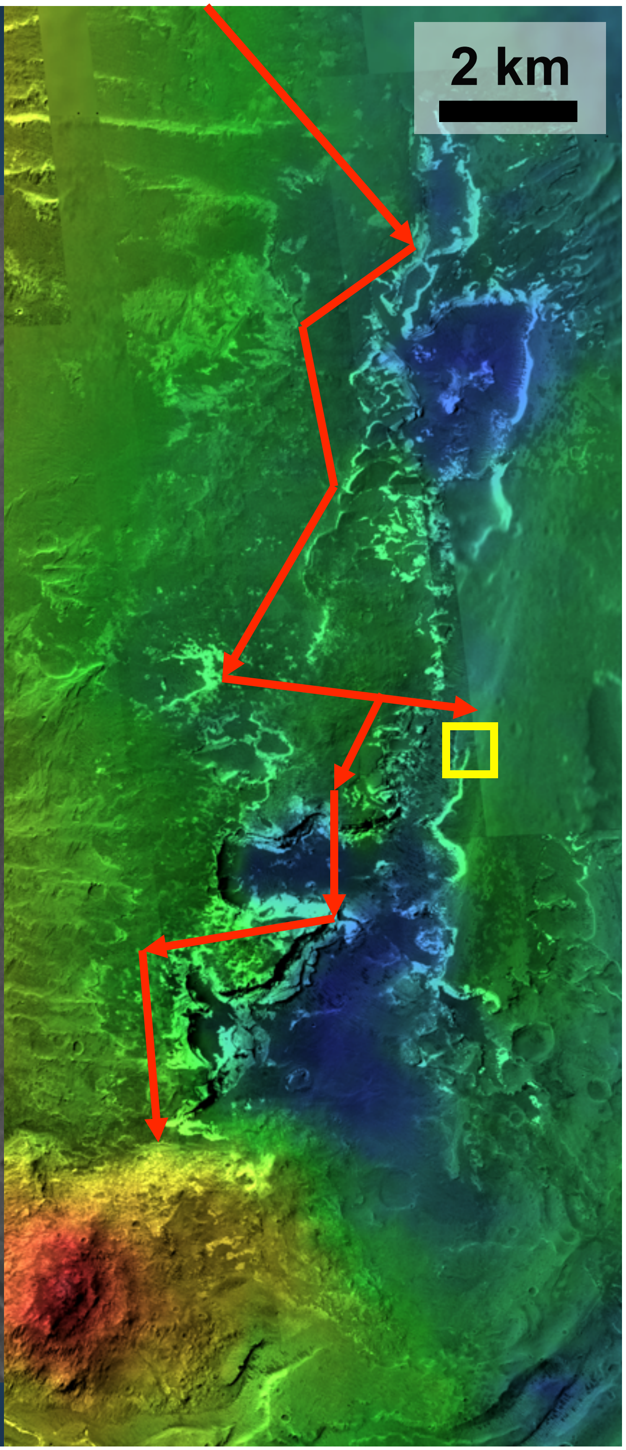


Science Traverse: Flood Deposit

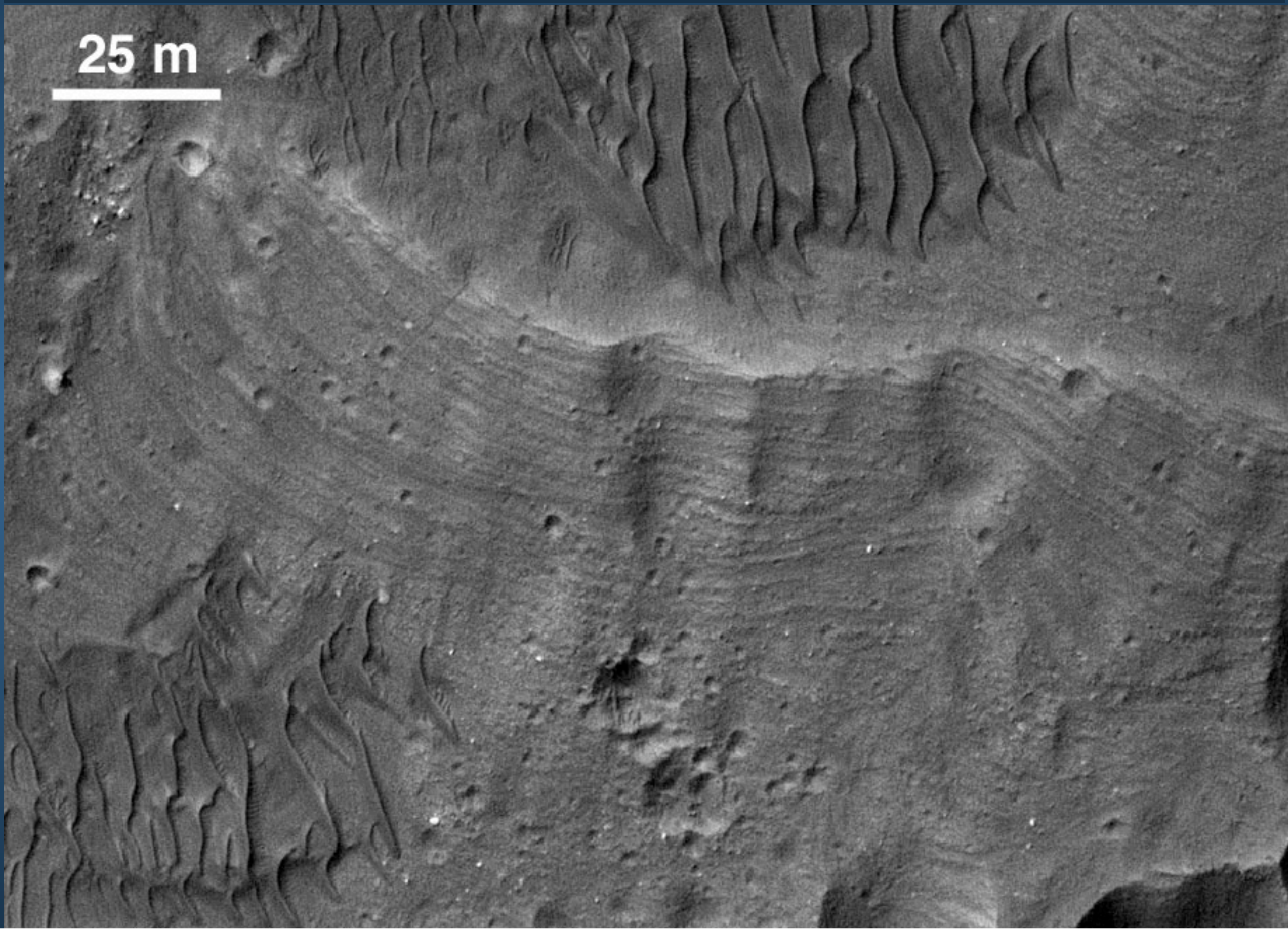


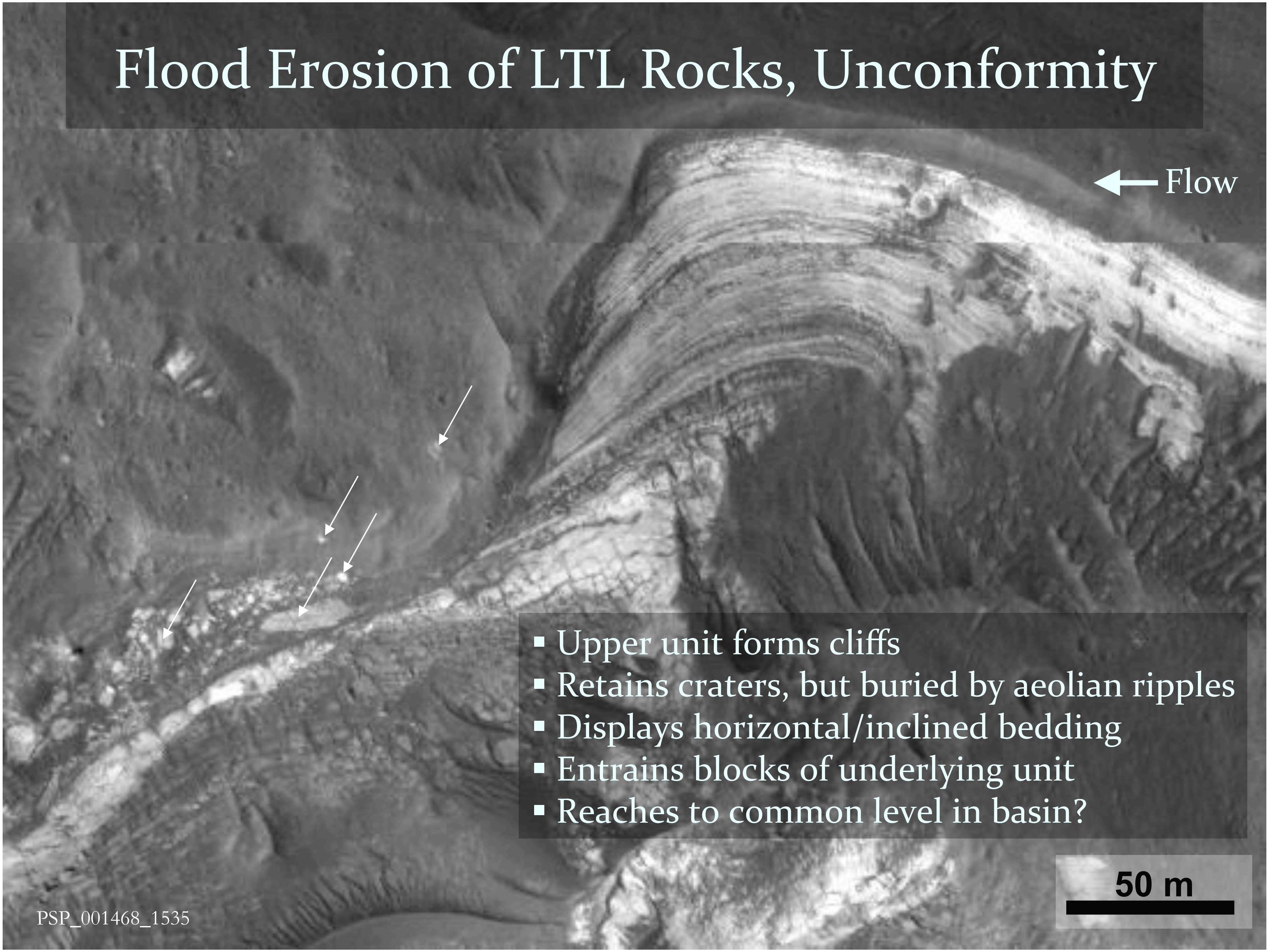
Science Traverse: Flood Deposits





Meter-Scale Features of Flood Deposit




Flood Erosion of LTL Rocks, Unconformity
Flow
▪ Upper unit forms cliffs
▪ Retains craters, but buried by aeolian ripples
▪ Displays horizontal/inclined bedding
▪ Entrains blocks of underlying unit
▪ Reaches to common level in basin?
50 m
PSP_001468_1535

MSL Investigation of Flood Deposit

I. Lithology of gravel and boulders derived from 2 km of the crater rim

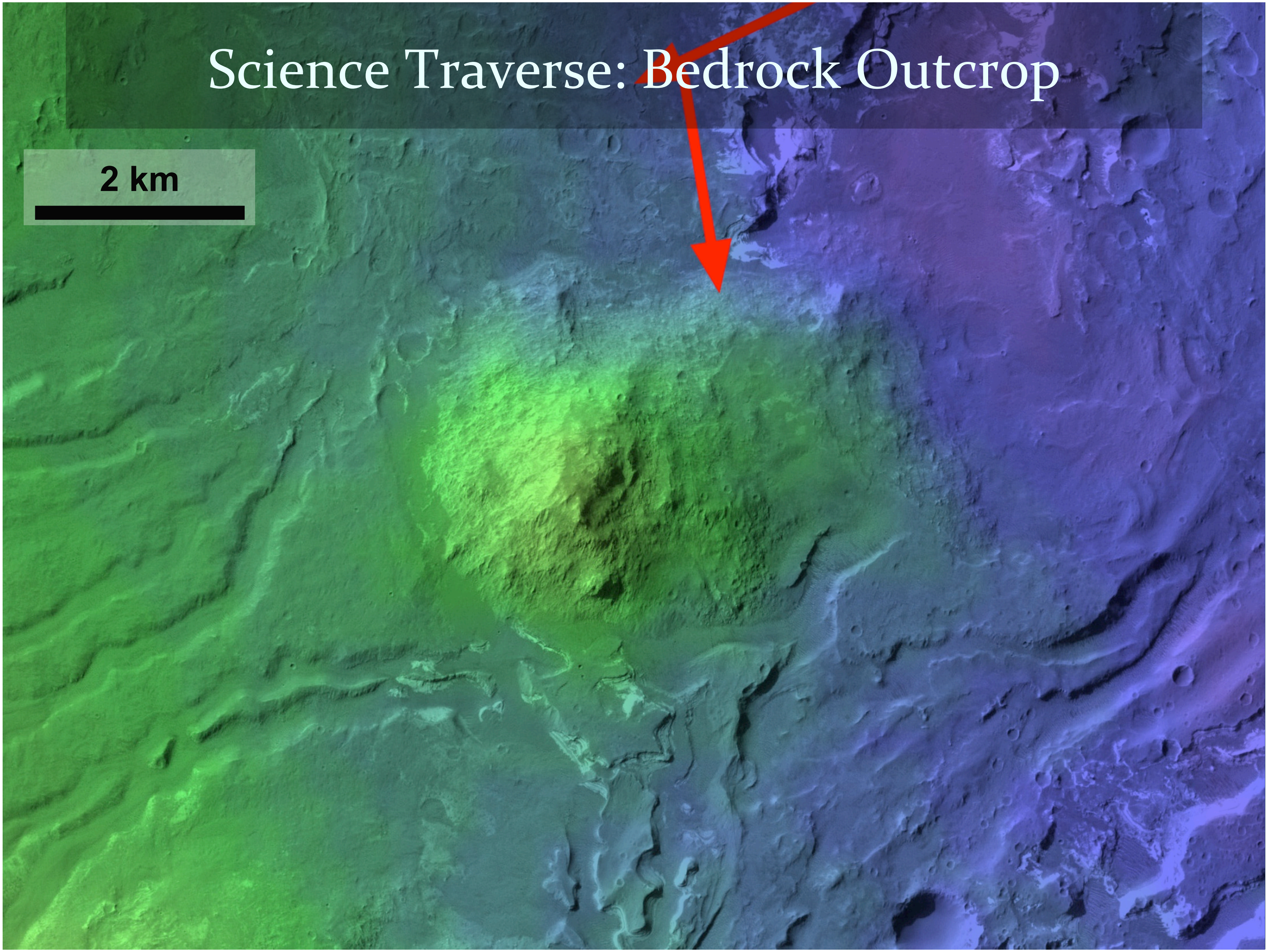
II. Grain size and sorting (pulsed discharge, slowly declining, or sustained inflow)

III. Post-depositional environment for flood deposits

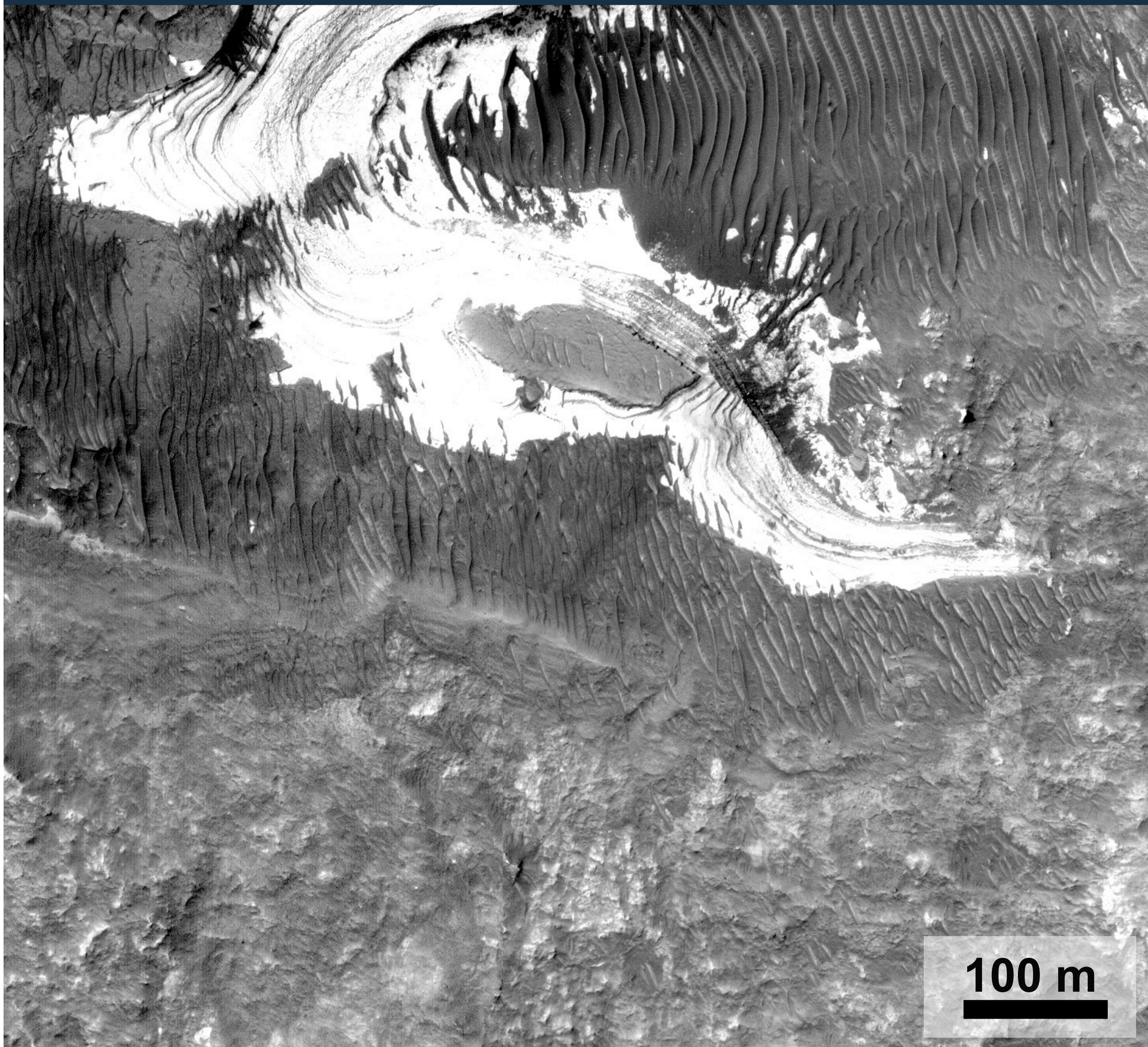
1. Remnants of fine-grained sediment from settling? (similar to LTLD or not?)
2. Post-depositional cementation?
3. Post-depositional weathering rinds on flood deposits, contrast with Gusev

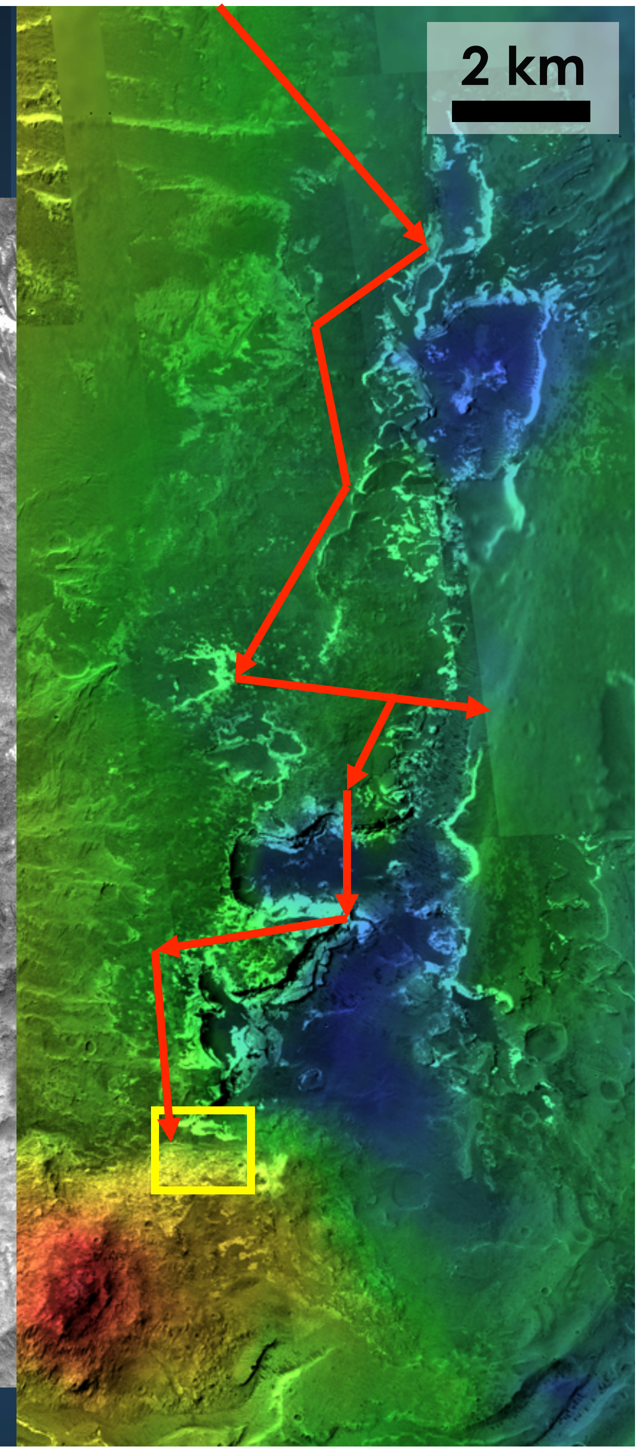
IV. Implications for paleoenvironment and habitability

1. Geochemical environment (inferred pH, dissolved solids, change or continuity through time: duration and characteristics of the second epoch of flooding in the crater)
2. Preservation, nature, and inventory of organic compounds; effects of biological processes
3. Inventory the chemical building blocks of life (C, H, N, O, P, S).


Science Traverse: Bedrock Outcrop
2 km

Science Traverse: Bedrock





MSL Investigation of Bedrock Outcrop

I. Mineralogy/petrology, compared to materials in alluvial fans

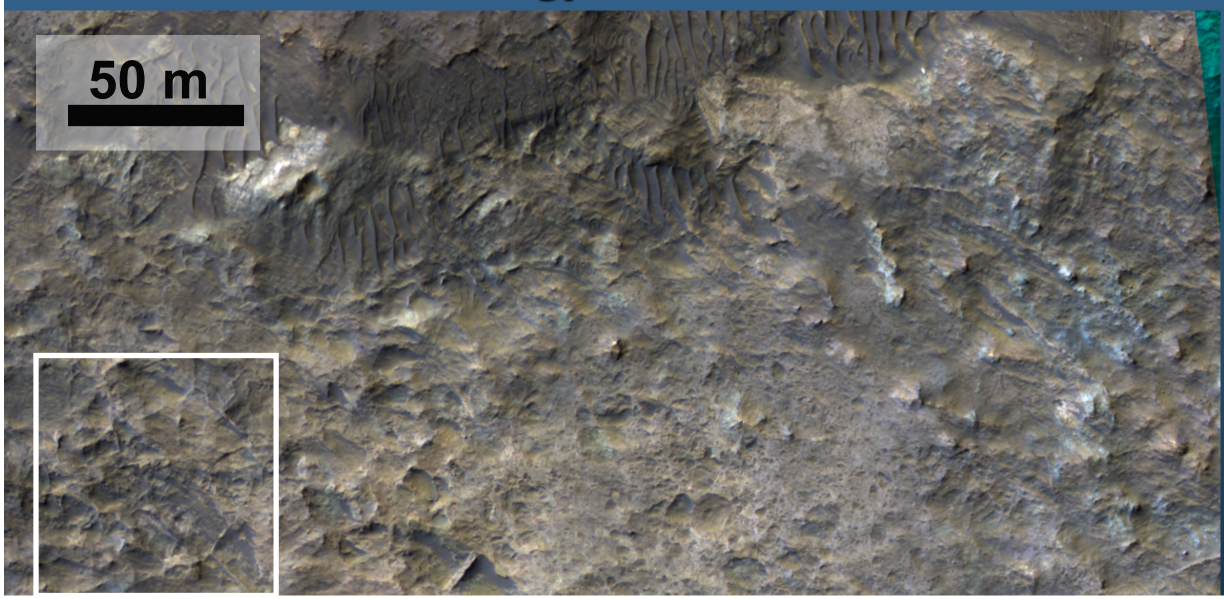
1. Changes in mineralogy/petrology with depth in the Martian crust
2. Diagenetic modification before, shortly after, long after the impact (low/high-T)
3. Characteristics of impact melt, if present

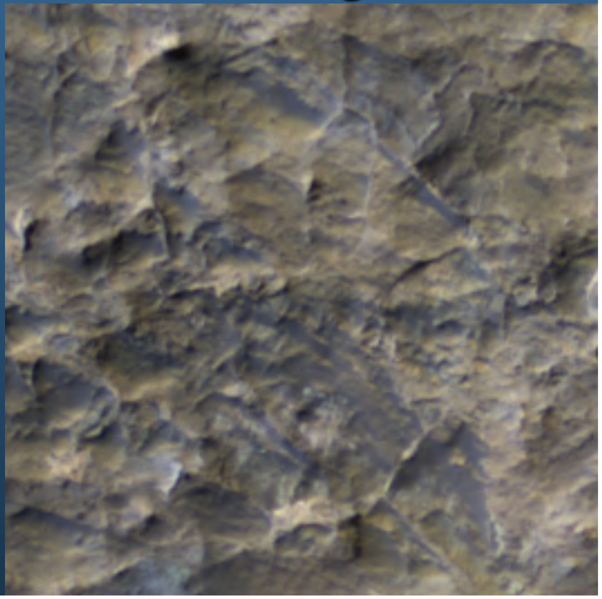
II. Ancient surface weathering of in-place bedrock

1. Compare exposure to weathering with transported sediment

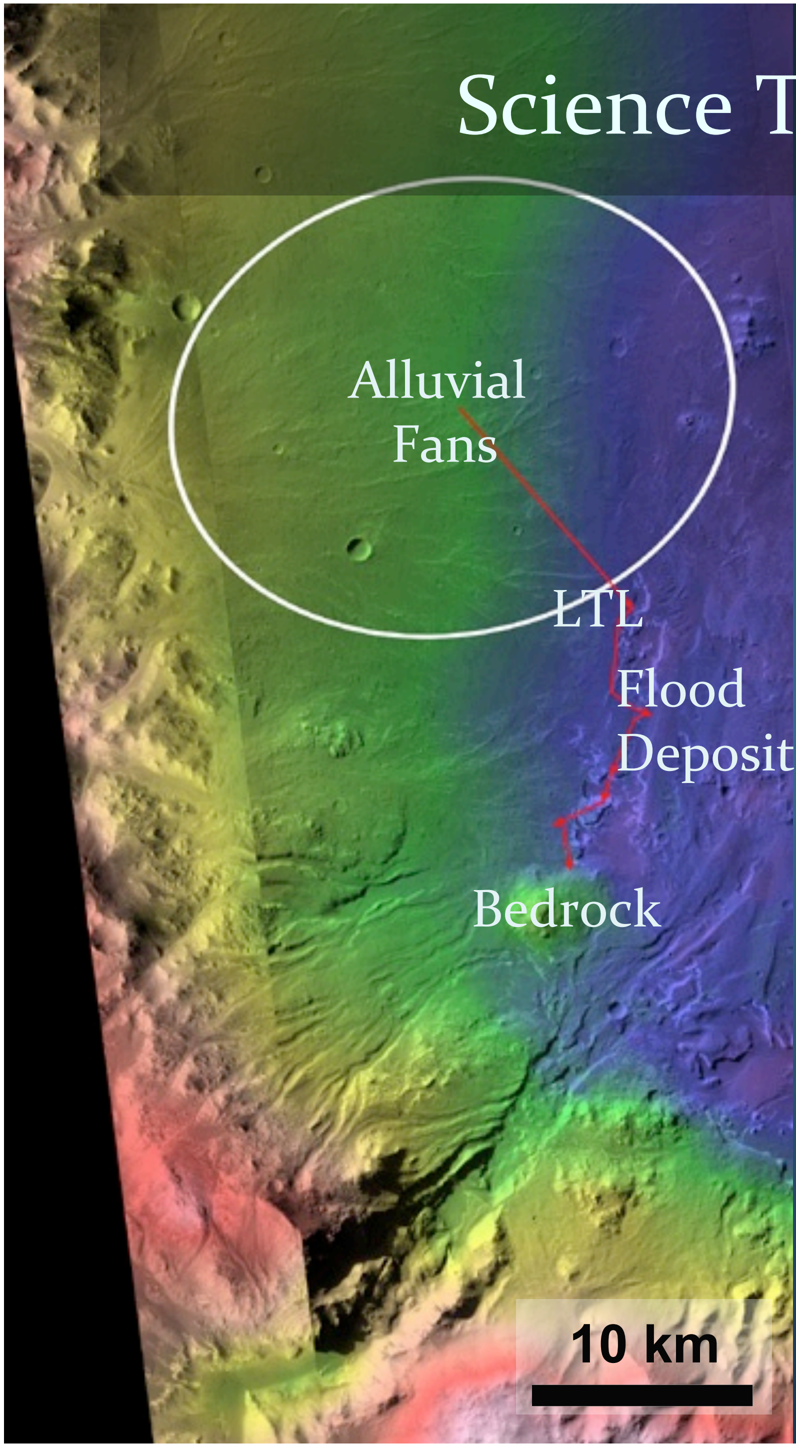
III. Habitability

1. Geochemistry of Noachian subsurface materials and fluids
2. Chemical energy sources for life (craters as hydrothermal settings)

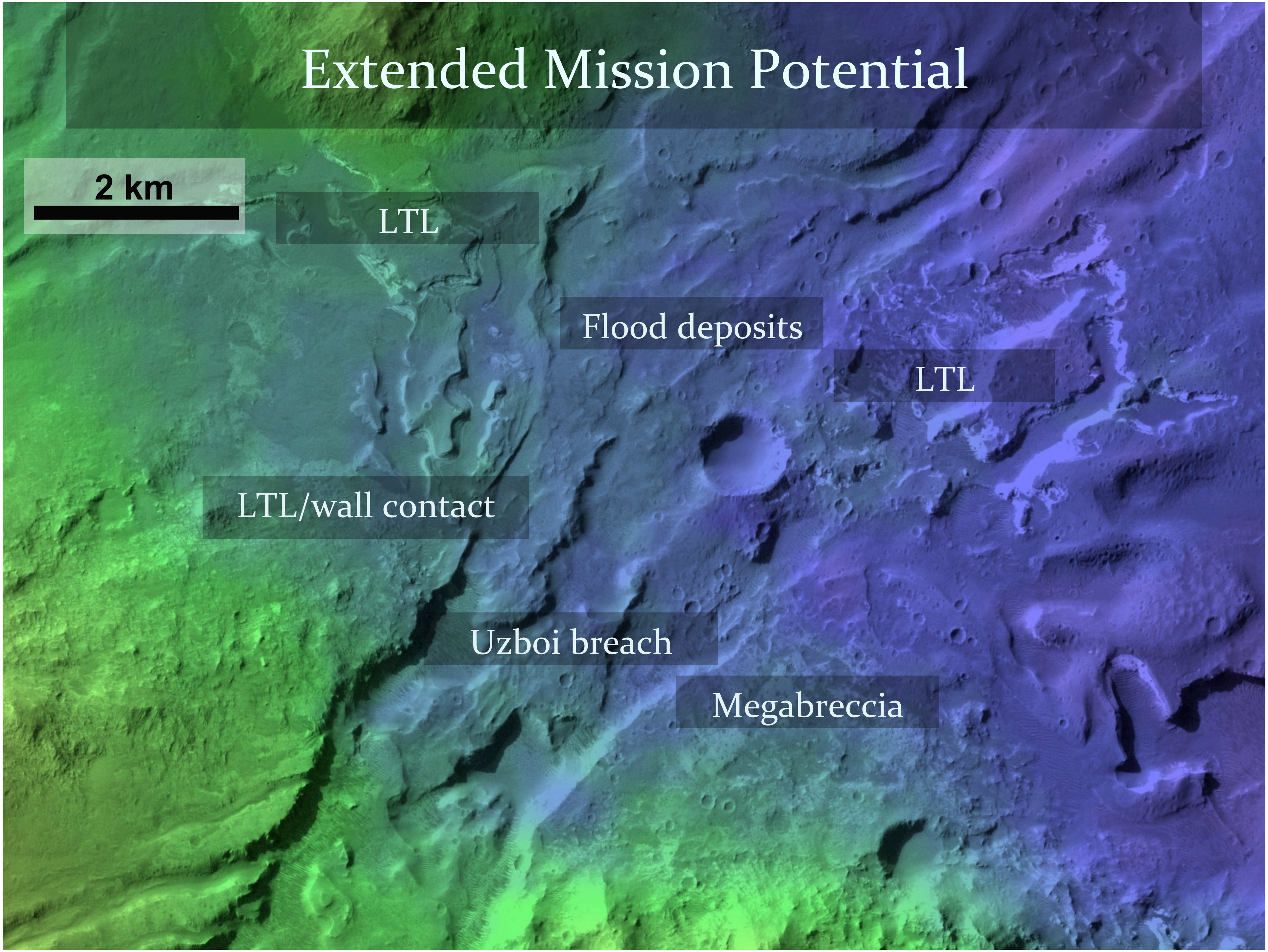




Science Traverse: Distances



Target	Distance from ellipse center
Alluvial fans	<0.5 km
LTL materials	11.5 km
Uzboi flood deposits	18 km
Bedrock outcrop	26 km


Extended Mission Potential
2 km
LTL
Flood deposits
LTL
LTL/wall contact
Uzboi breach
Megabreccia

Summary

Holden crater offers a diversified habitability investigation with:

- 100-m stratigraphic section of phyllosilicate-bearing, fine-grained LTL rocks with clear stratigraphic context beneath fluvial deposits
- Alluvial fans with discrete source area (implications for runoff) sampling 2 km of Noachian crust
- Late-stage flood deposits
- Accessible outcrops for possible impact hydrothermal system
- Safe landing ellipse containing one key objective (alluvial fans)
- Trafficable route