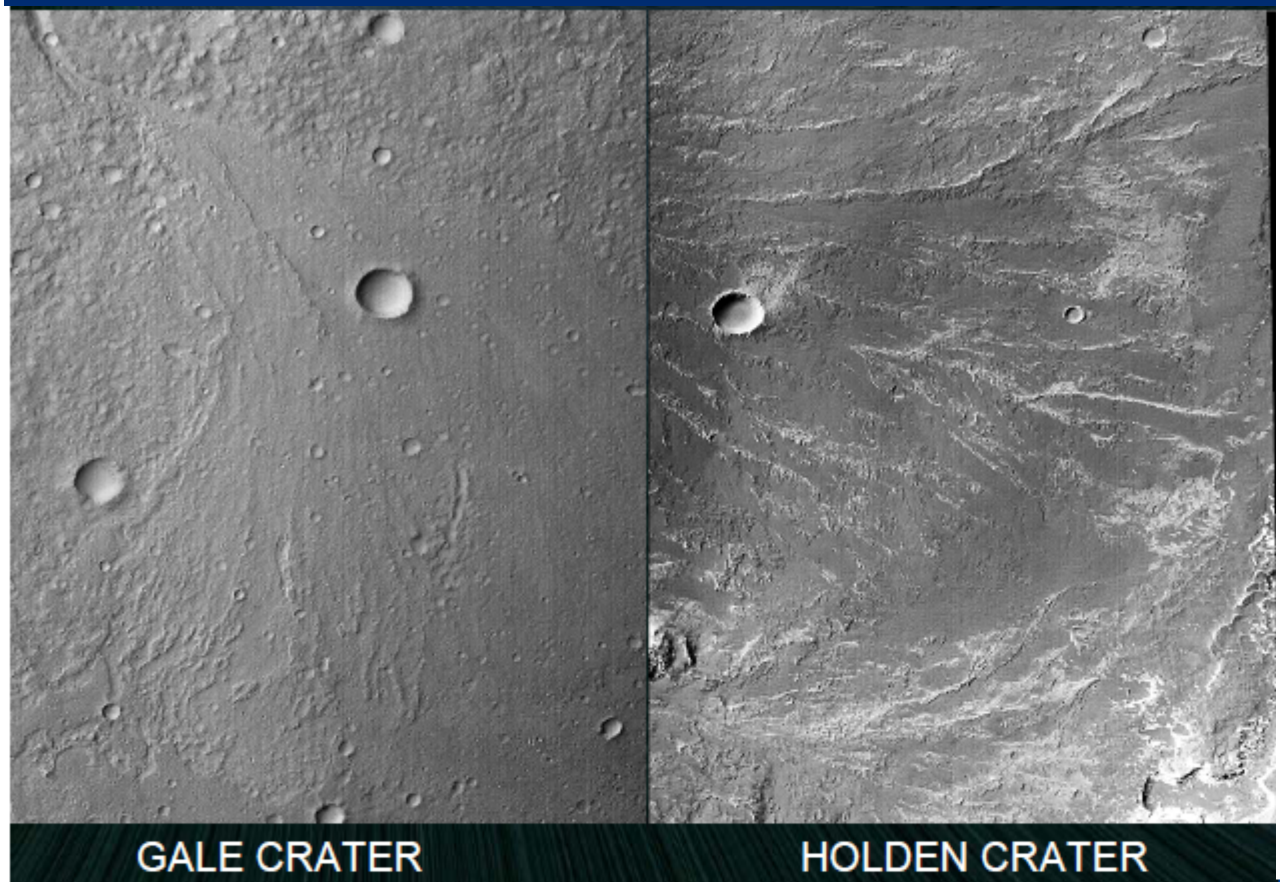
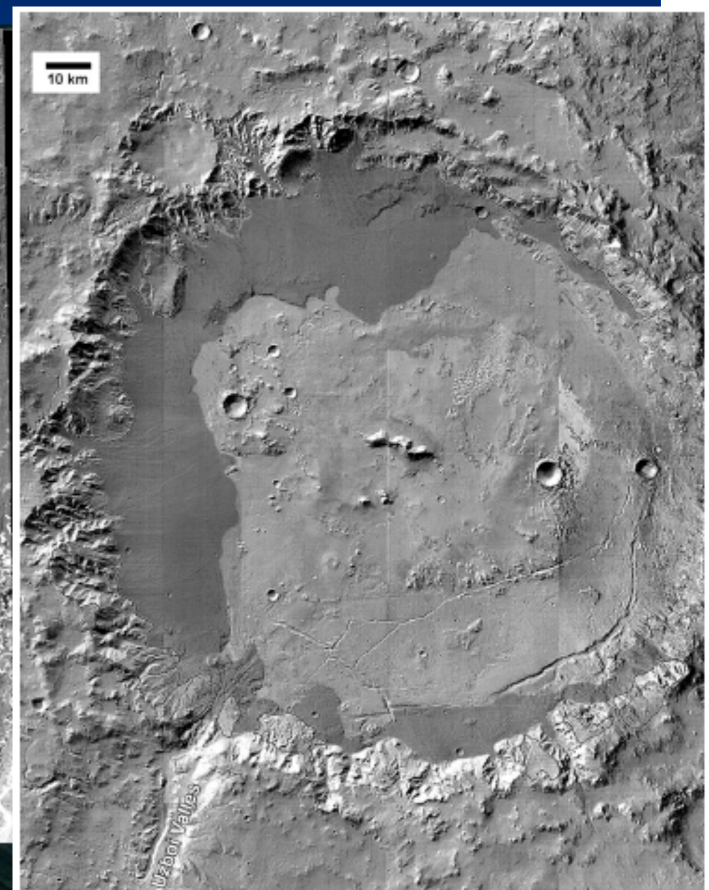
Alluvial Fan Science Potential





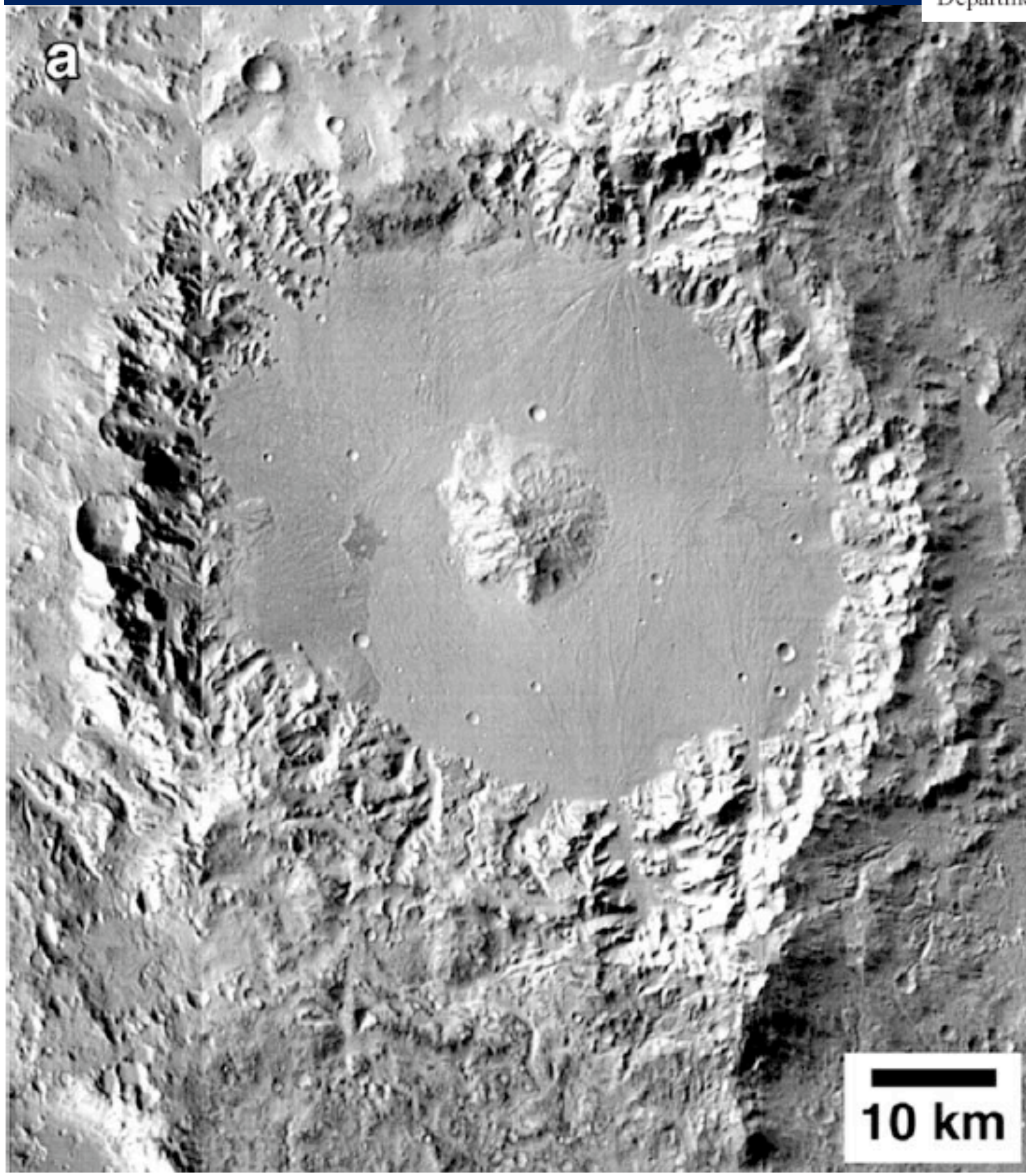
Kelin X. Whipple, SESE, ASU

Large alluvial fans on Mars

Jeffrey M. Moore
Space Sciences Division, NASA Ames Research Center, Moffett Field, California, USA

Alan D. Howard
Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia, USA

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 110,
E04005, doi:10.1029/2004JE002352, 2005



Fans Common in Craters

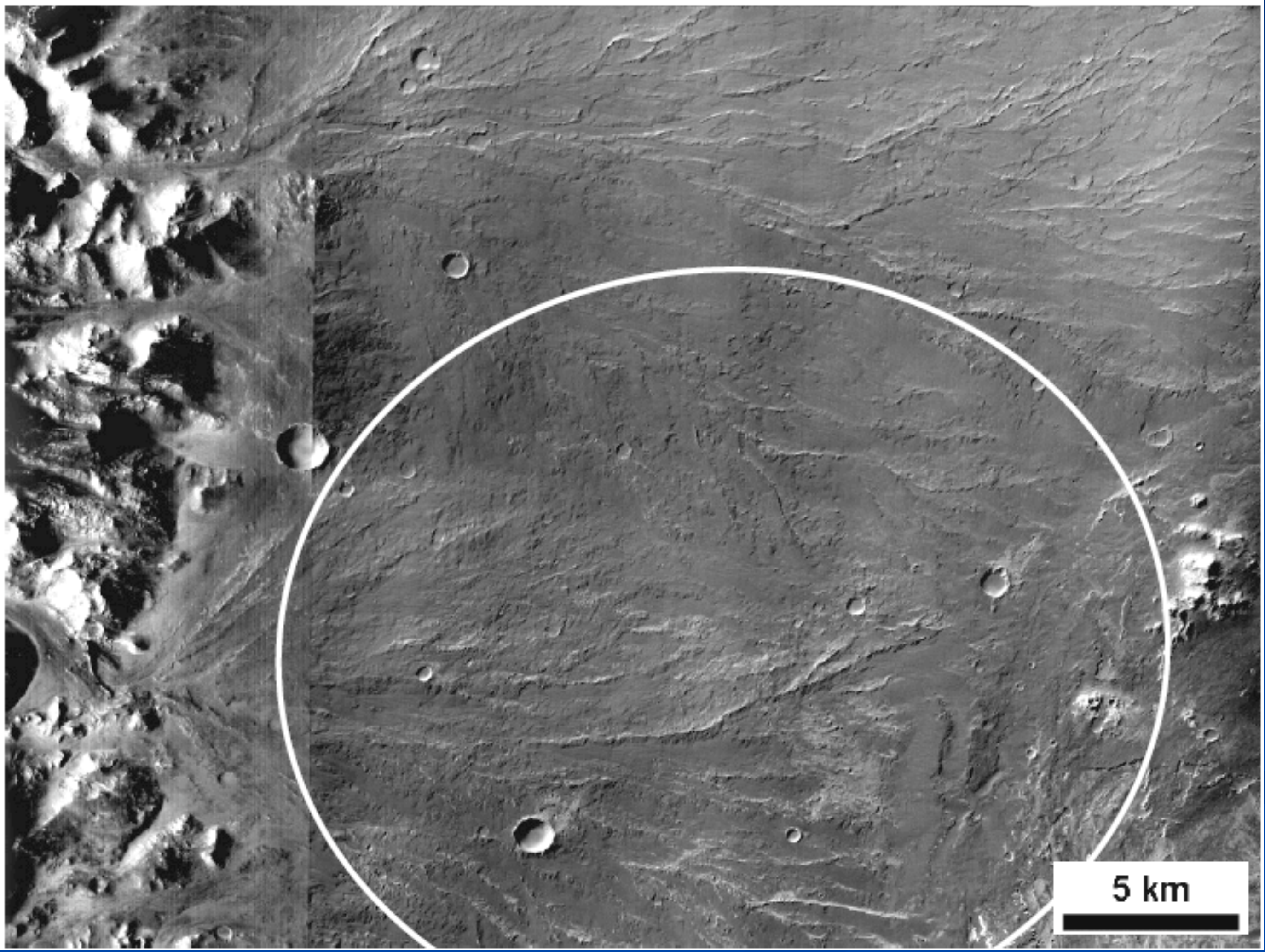
Late Noachian, Widespread within Latitudinal Band

Excellent Context:

Understand LTLD in Relation to Environmental Conditions in General

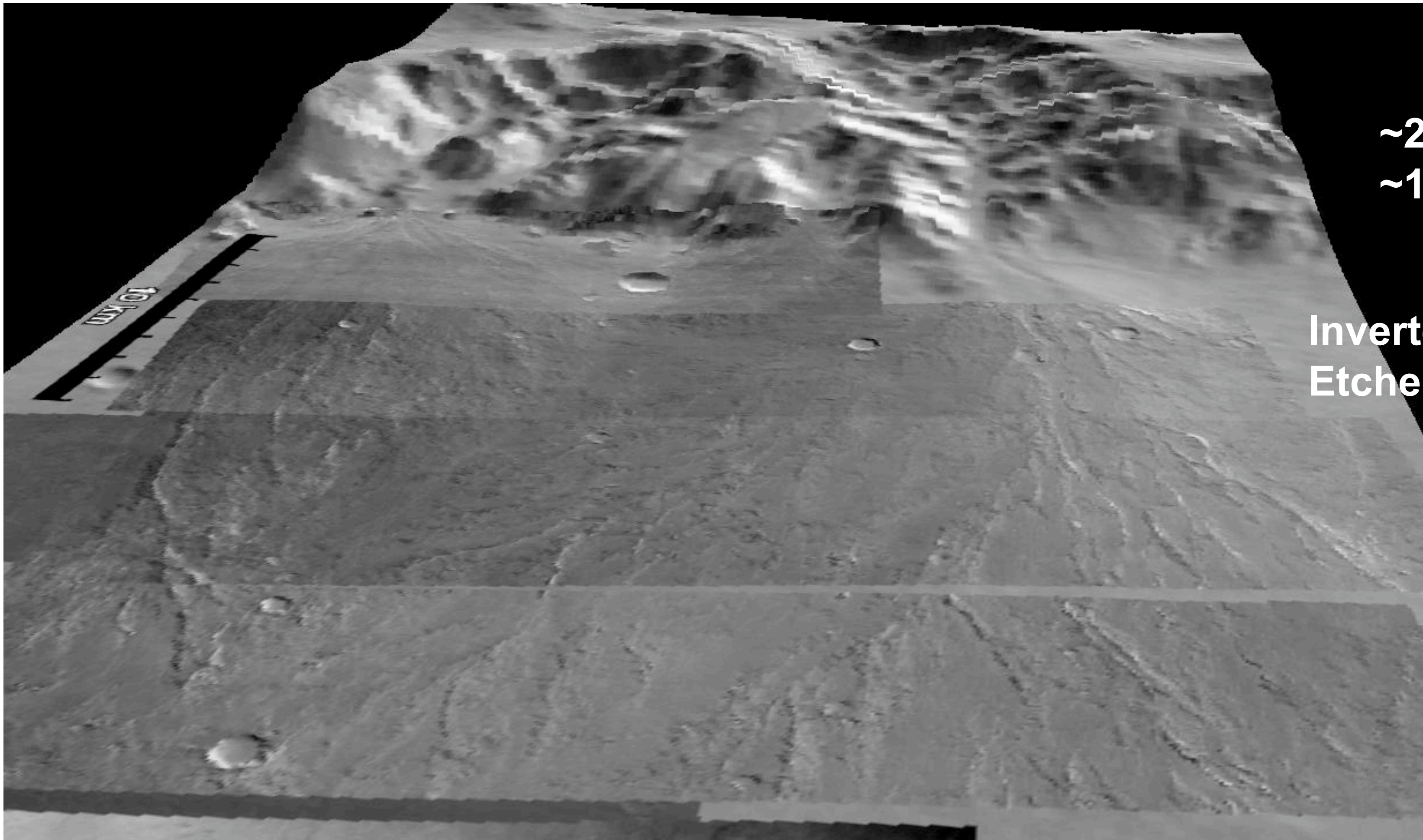
Bajada Traverse: Scientific Bonus

Context, Clay Source?, Depositional Process, Weathering?, Paleohydrology/climate, Sample ~2km crust in Rim



Science Value: Bajada Traverse

- Source-Area (Crater Wall) Materials
    - Lithology, Mineralogy (clast/matrix), Weathering
- Context for LTLD
    - Depositional Environment (relation to LTLD)
    - Paleoclimatic Conditions (hydraulics, weathering)
    - Plausible Water Source(s)
    - Duration of Active Sediment Transport
- Depositional Process
    - Fluvial (gravel – boulder) – flow depth, grain size
    - Fluvial (sand – granule) – ditto
    - Intermittency?
    - Mudflow / Debris Flow – composition (water content)
    - Other Mass Flow?

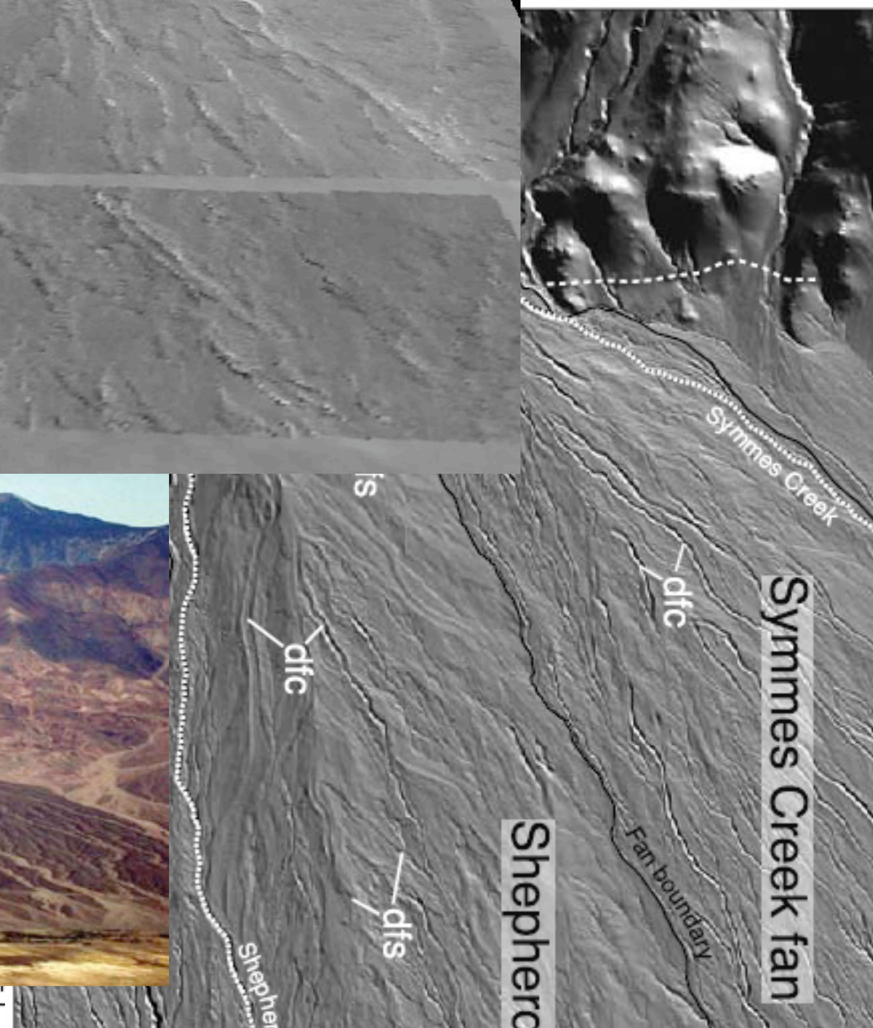


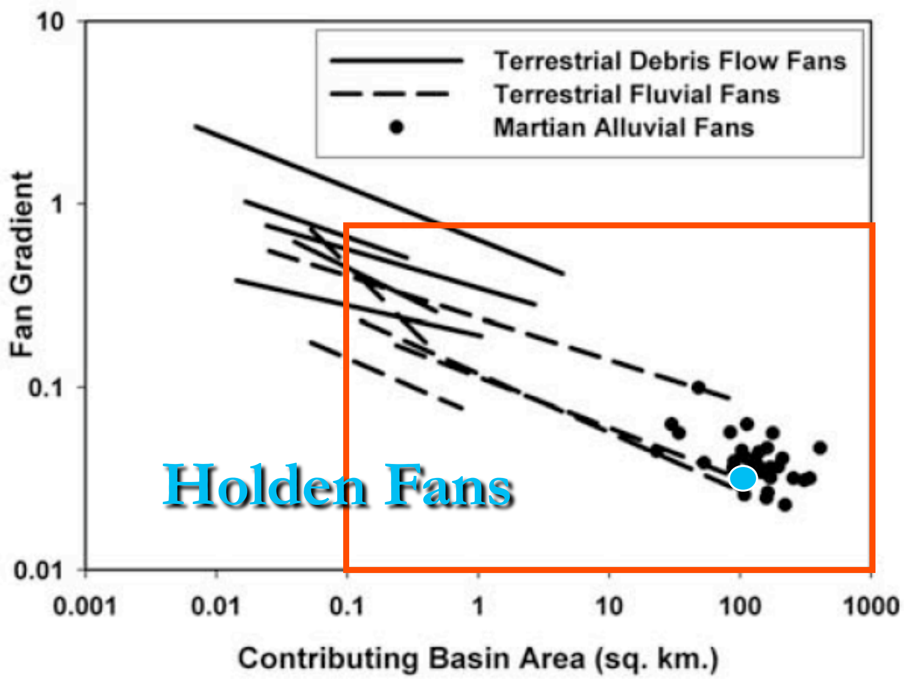
~2km relief
~100 km^2

Inverted Chns
Etched surface

S = 2.5 degrees (0.043)

10-20x steeper than Eberswalde





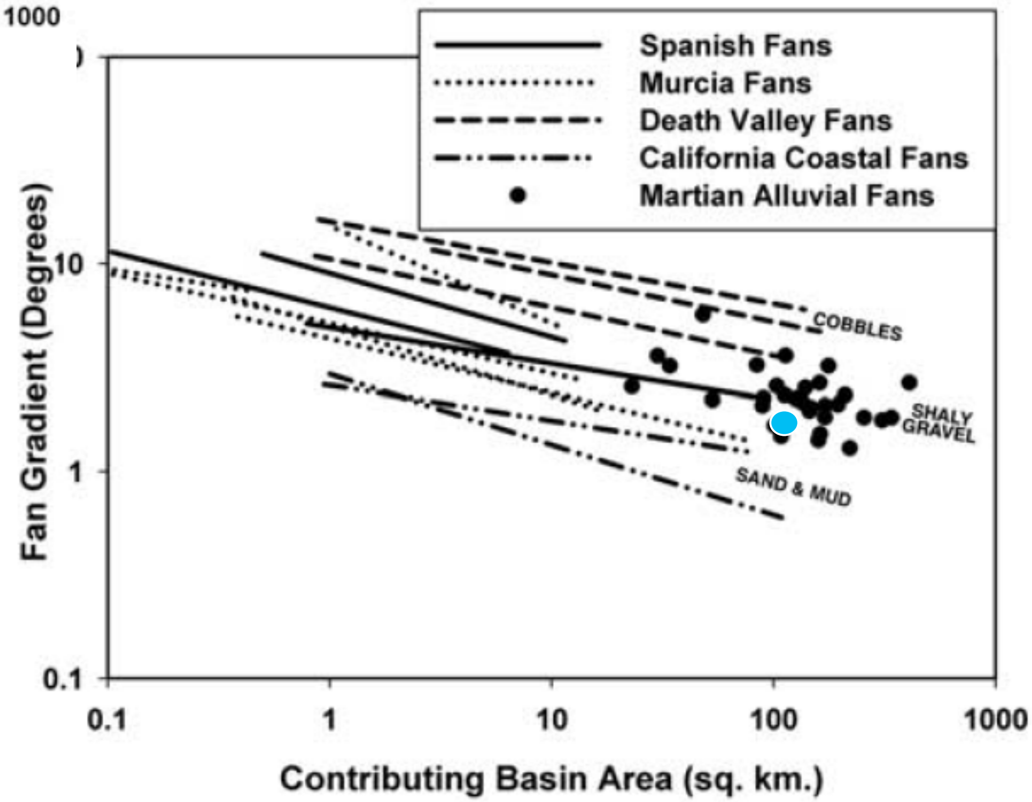
Large alluvial fans on Mars

Jeffrey M. Moore
Space Sciences Division, NASA Ames Research Center, Moffett Field, California, USA

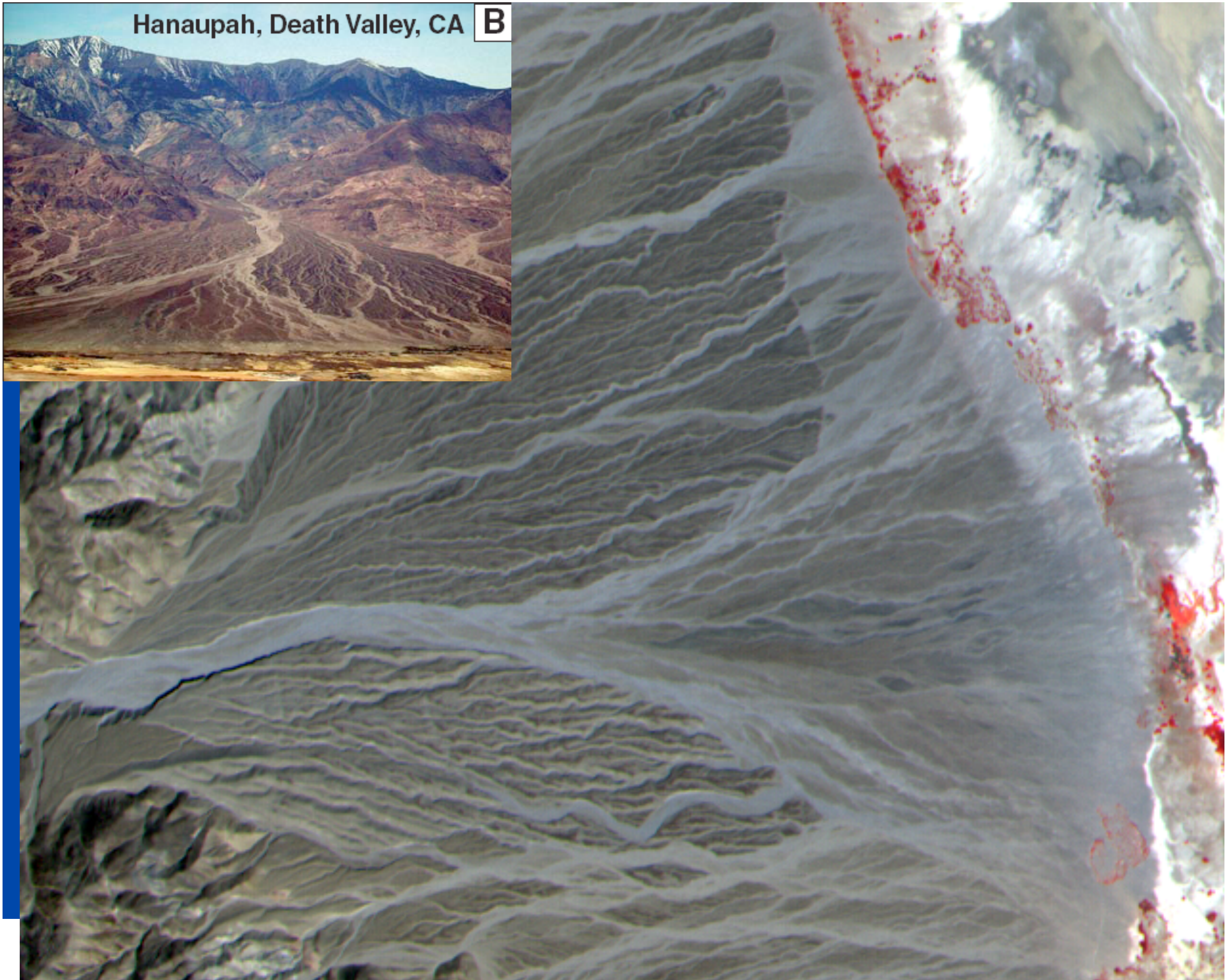
Alan D. Howard
Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia, USA

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 110,
E04005, doi:10.1029/2004JE002352, 2005

Fluvial Fans Best Analog



Comparison suggests Sand/Fine Gravels, But Some Mudflow Fans Can be Just as Gentle (Jiang Jia Gully, China Owens Valley, CA)


Hanaupah, Death Valley, CA
B

Alluvial Fan-Related Testable Hypotheses (in situ observations required)

H1. Fans are alluvial as suggested by Moore and Howard (2005). Sediment was transported in suspension or as traction load in floods of water analogous to terrestrial alluvial fans.

- Test 1: sediment texture: grain support, sorted/stratified bedding, bed and bar forms, flood couplets.
- Test2: downstream fining and facies changes.
- Test3: channel sands/gravels preserved in eroded remnants of inverted channel, evidence of lobate gravel sheets, bar and swale topography.
- Null hypothesis: mudflow fans. Matrix supported deposits, layered by lacking internal sorting or stratification. Lobate mudflow fronts, coarser/thicker mudflows support the inverted channel forms, limited downstream fining


A

Alluvial Fan-Related Testable Hypotheses (in situ observations required)

H2. Fan formation took place over a protracted time interval – an extended period of conditions producing runoff of liquid water.

- Test1: Clear evidence of in-situ weathering/soil formation (authigenic clays, soil profile development, buried paleosols.
- Test2: Unconformities in sedimentary sequence at lobe/segment scale . Segmentation and terrace formation evident.
- Test3: Calculation of minimum duration from estimates of bankful flow velocity (need grainsize distribution) indicates long minimum durations and large minimum volumes of water.
- Null hypothesis: Fan formation was very brief, potentially a single episode of hydrologic activity. No in-situ weathering or buried paleosols, no significant unconformities, flow reconstructions indicate short formation times, or mudflow composition suggests a minimal source of water.

Alluvial Fan-Related Testable Hypotheses (in situ observations required)

H3. Holden Crater flanks experienced significant rainfall and/or significant runoff.

- Test1: Fans are alluvial, see H1a above.
- Test2: Flow hydraulic conditions require significant runoff, see H2c above. Also same calculations will constrain minimum duration of required environmental conditions.
- Null hypothesis: Very limited water/runoff required – fans are mudflow dominated with limited indications of channelized mudflows.

Alluvial Fan Slope: Simple Theory

Bedload - Unchanneled

$$\frac{Q_{so}}{Q_w} \approx \frac{2}{3}\overline{S}$$

Suspended Load

$$\frac{Q_{so}}{Q_w} \approx 3\left(\frac{2}{3}\overline{S}\right)$$

Slope Set by Q_s/Q_w ratio

But proportionality Factor ~15 Range!

Need data !

Bedload - Channeled

$$\frac{1}{5}\left(\frac{2}{3}\overline{S}\right) \leq \frac{Q_{so}}{Q_w} \leq \frac{1}{3}\left(\frac{2}{3}\overline{S}\right)$$

Eberswalde: $Q_s/Q_w \sim 1\%$

Holden: $Q_s/Q_w \sim 3\%$ (if fluvial)

Required Water Volume (Fluvial)

$$\frac{Q_{so}}{Q_w} = \frac{V_f}{V_w} \qquad V_w = V_f \left(\frac{Q_{so}}{Q_w} \right)^{-1}$$

$$\frac{1}{7}\overline{S} \le \frac{Q_{so}}{Q_w} \le 2\overline{S} \qquad \frac{Q_{so}}{Q_w} \approx \frac{2}{3}\overline{S}$$

15-250(50) V_f

Essence : $S \rightarrow Q_s/Q_w$

$V_f \rightarrow V_w$ **(assume all sed in fan)**

Need Estimate Q_w **to Get at Runoff and** *Min* **Duration of Runoff Generating Conditions**

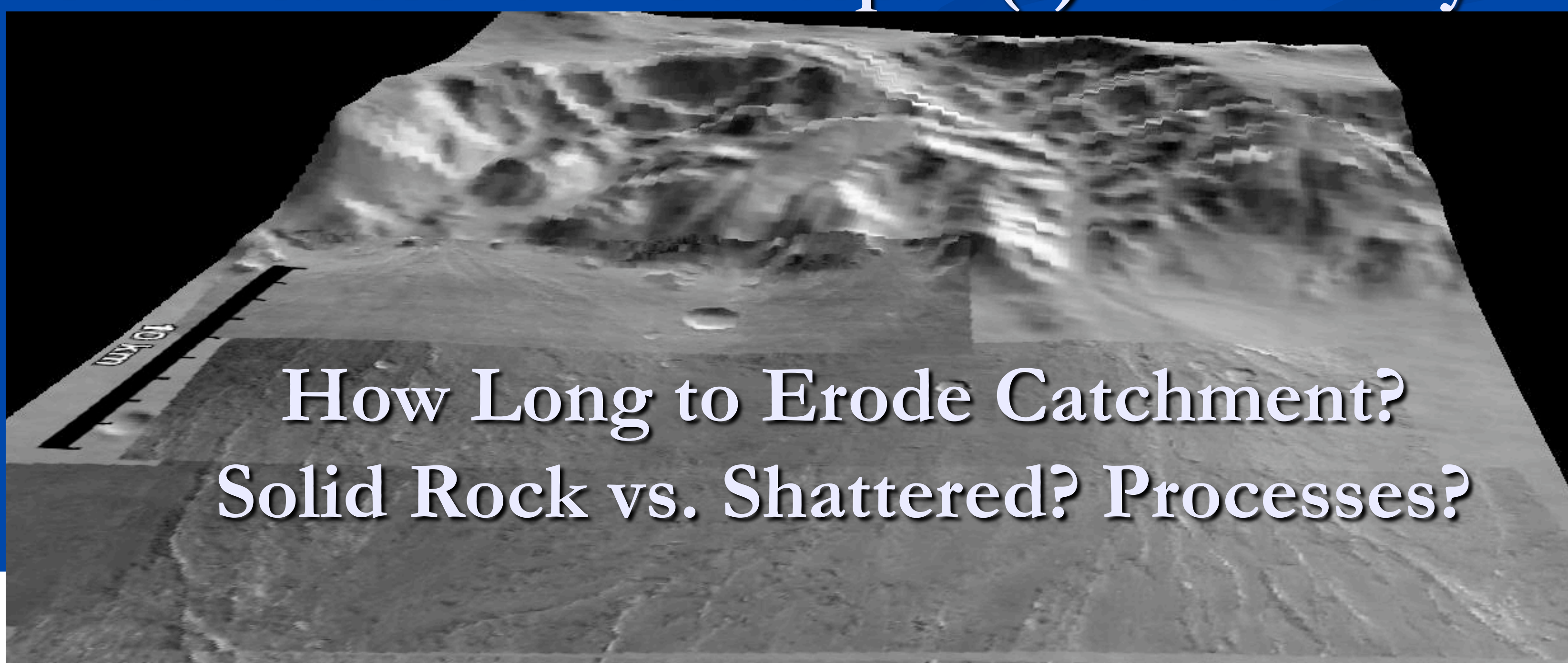
Water Volume & Q_w -> Formation Time

$$u = \sqrt{\frac{ghS}{C_f}}$$

$$Q_w = uhw$$

Grainsize → roughness (C_f) and Shear Stress

Shear Stress → Flow depth (h) → Velocity



Required Water Volume (Fluvial)

$$\frac{Q_{so}}{Q_w} = \frac{V_f}{V_w}$$

$$V_w = V_f \left(\frac{Q_{so}}{Q_w} \right)^{-1}$$

$$\frac{1}{7}\overline{S} \le \frac{Q_{so}}{Q_w} \le 2\overline{S}$$

$$\frac{Q_{so}}{Q_w} \approx \frac{2}{3}\overline{S}$$

15-250(50) V_f

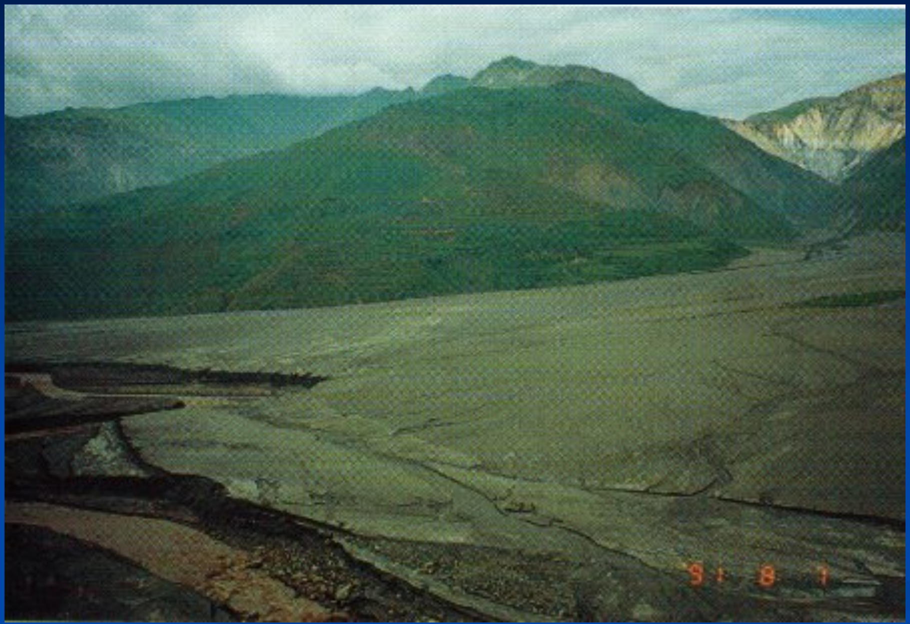
Required Water Volume (Mudflow)

$$V_w = V_f \frac{Q_w}{Q_{so}}$$

$$\frac{Q_{so}}{Q_w} = 1.5 - 4$$

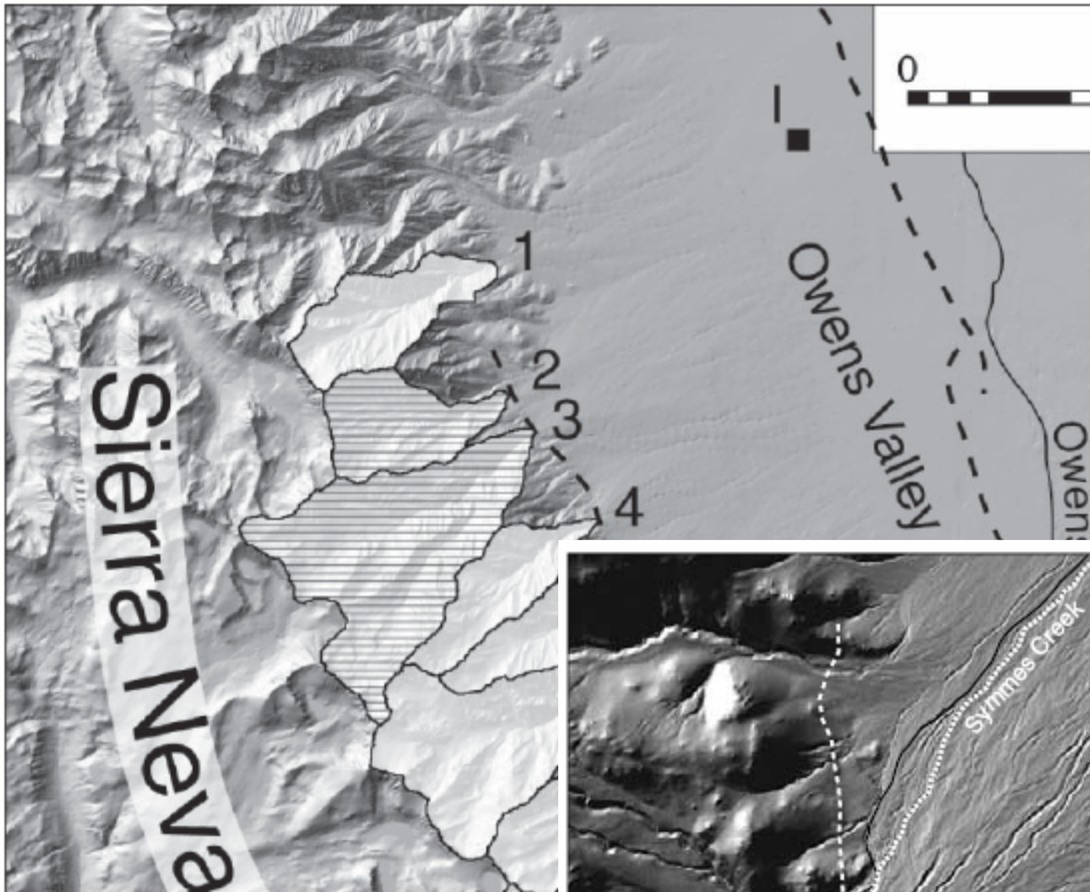
~40x Less!

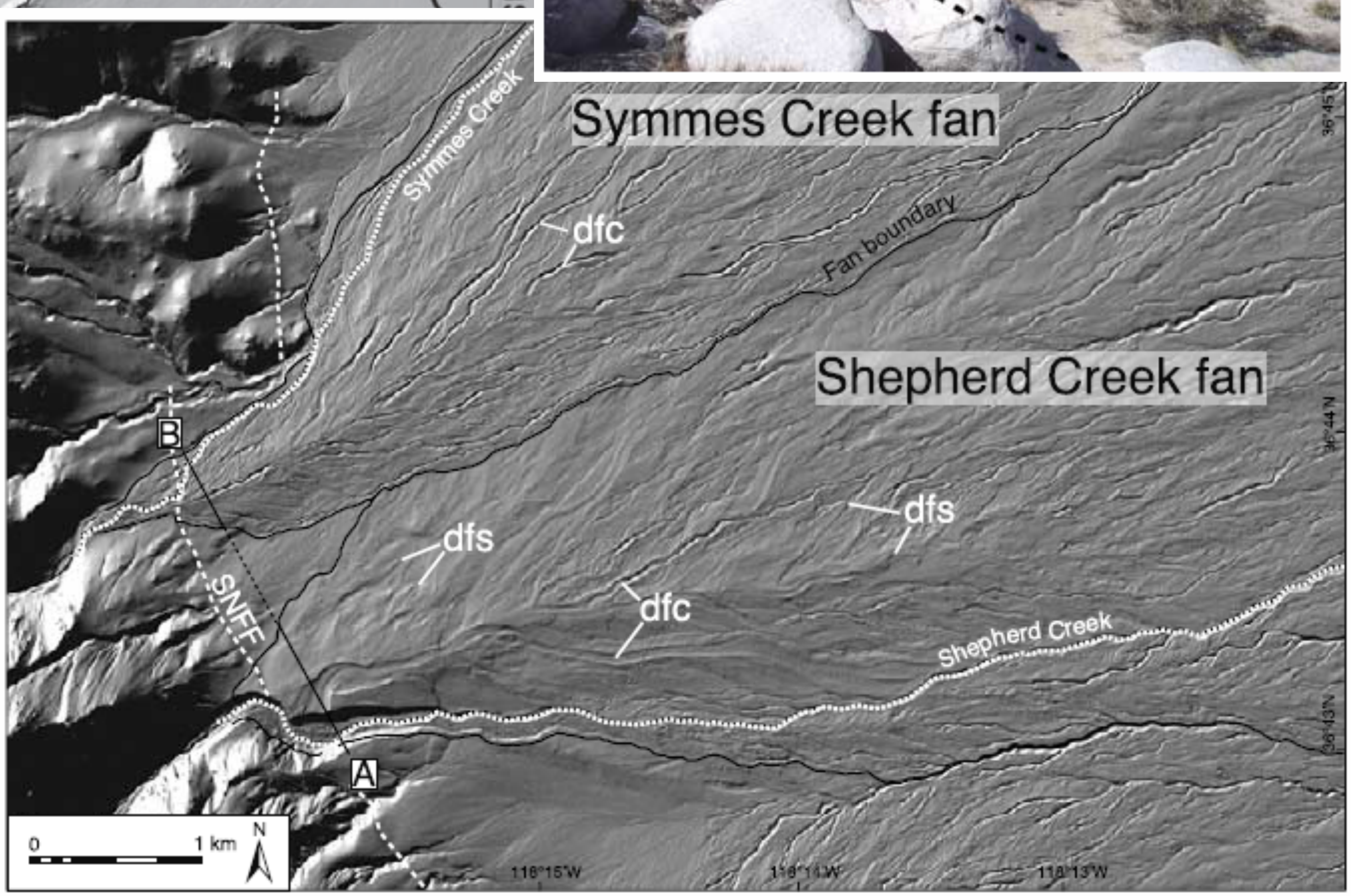
Jiang-Jia Gully, China



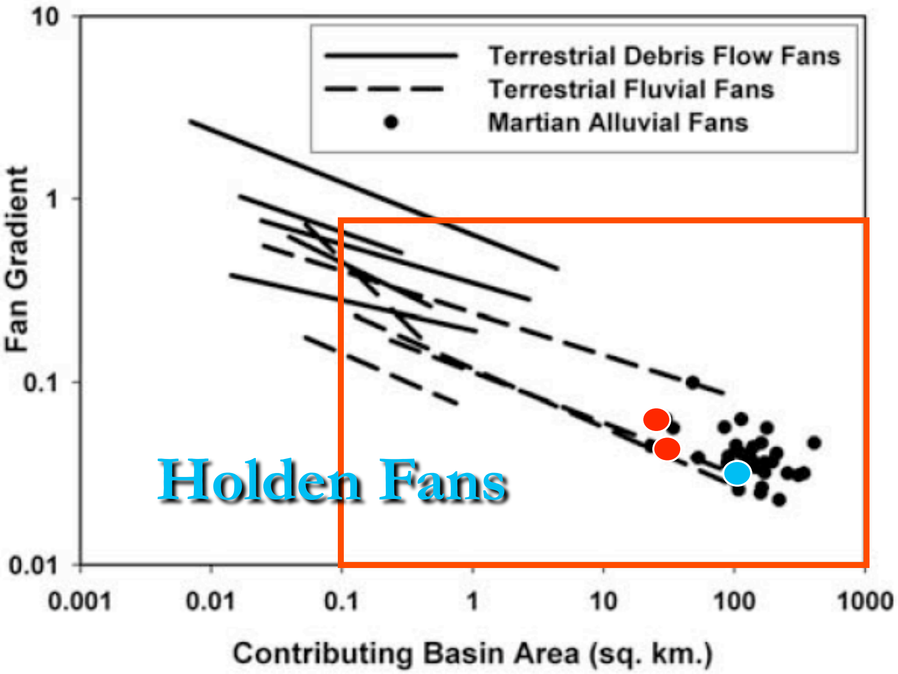
Basin Area = 48 km^2
Fan Slope = 3 degrees
{A = ~100km^2; S = 2.5}

Plausible Analog that must be Entertained – Crater Fans in General





***A*: 40km²**
***S*: ~4 degrees**



Large alluvial fans on Mars

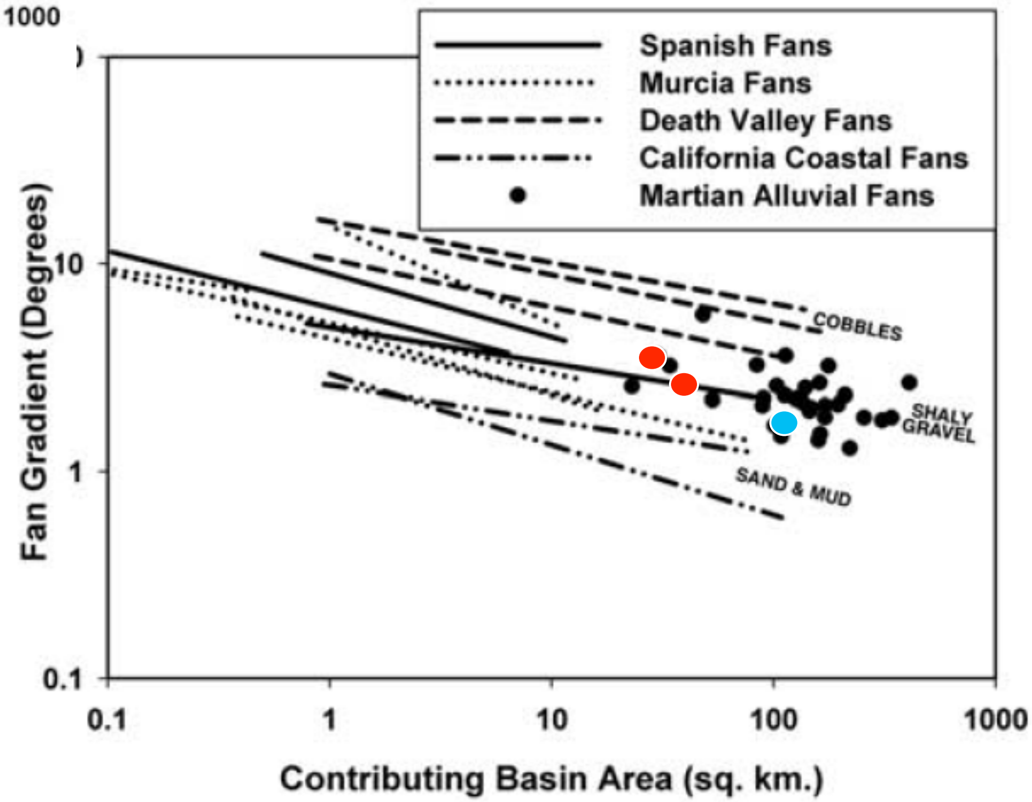
Jeffrey M. Moore
Space Sciences Division, NASA Ames Research Center, Moffett Field, California, USA

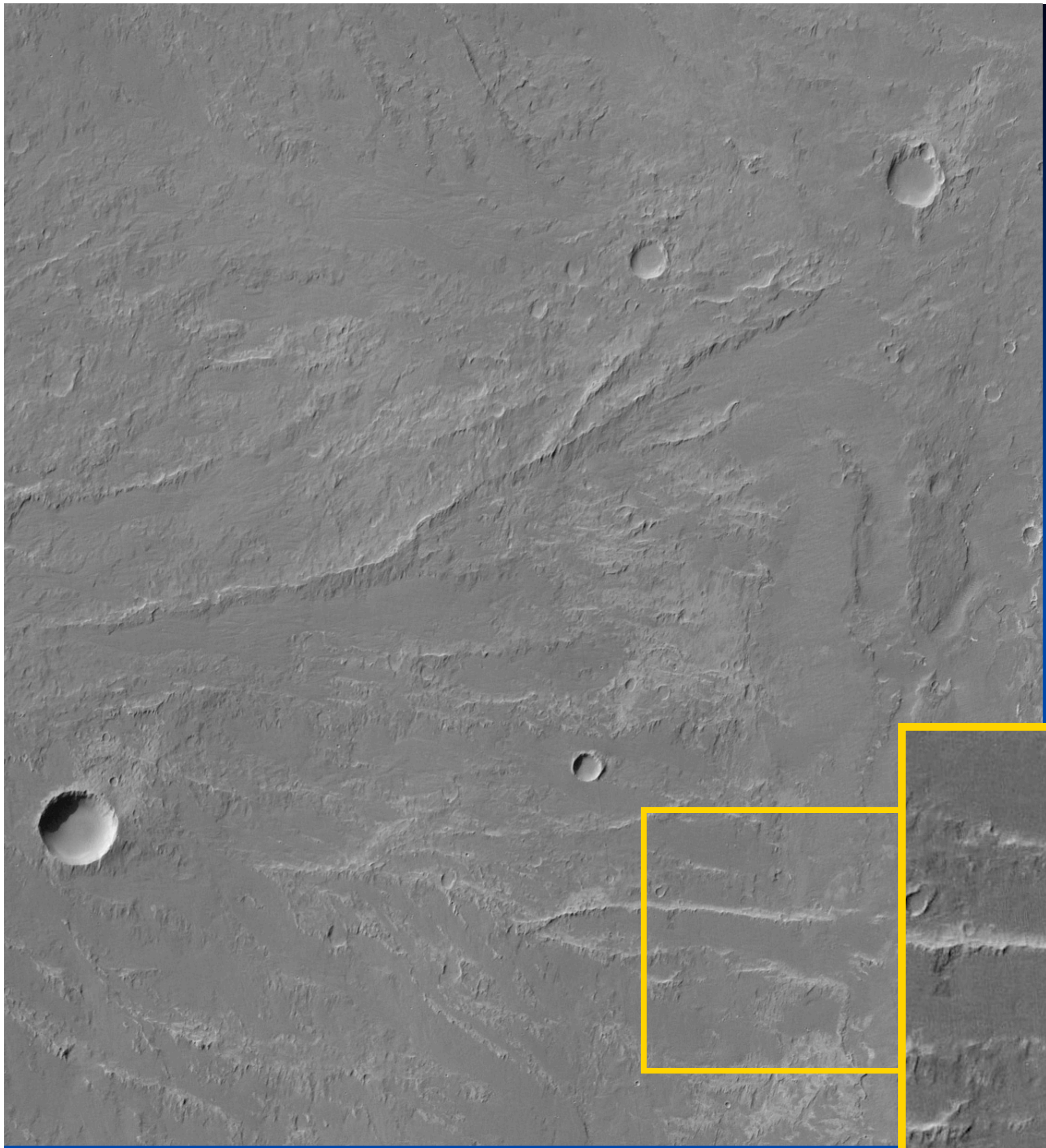
Alan D. Howard
Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia, USA

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 110,
E04005, doi:10.1029/2004JE002352, 2005

Fluvial Fans Best Analog

Comparison suggests Sand/Fine Gravels, But Some Mudflow Fans Can be Just as Gentle (Jiang Jia Gully, China Owens Valley, CA)



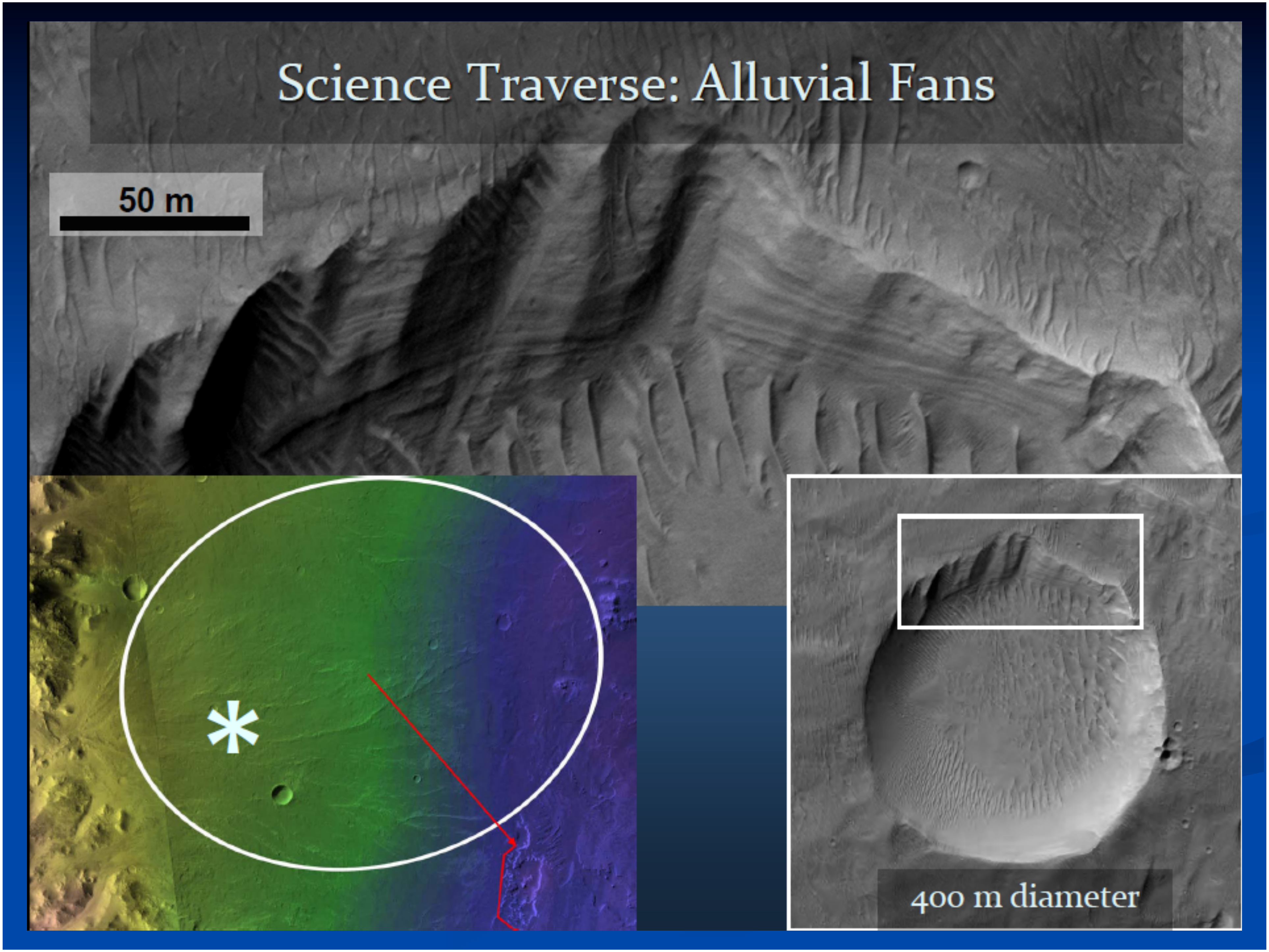


Relation to LTLD

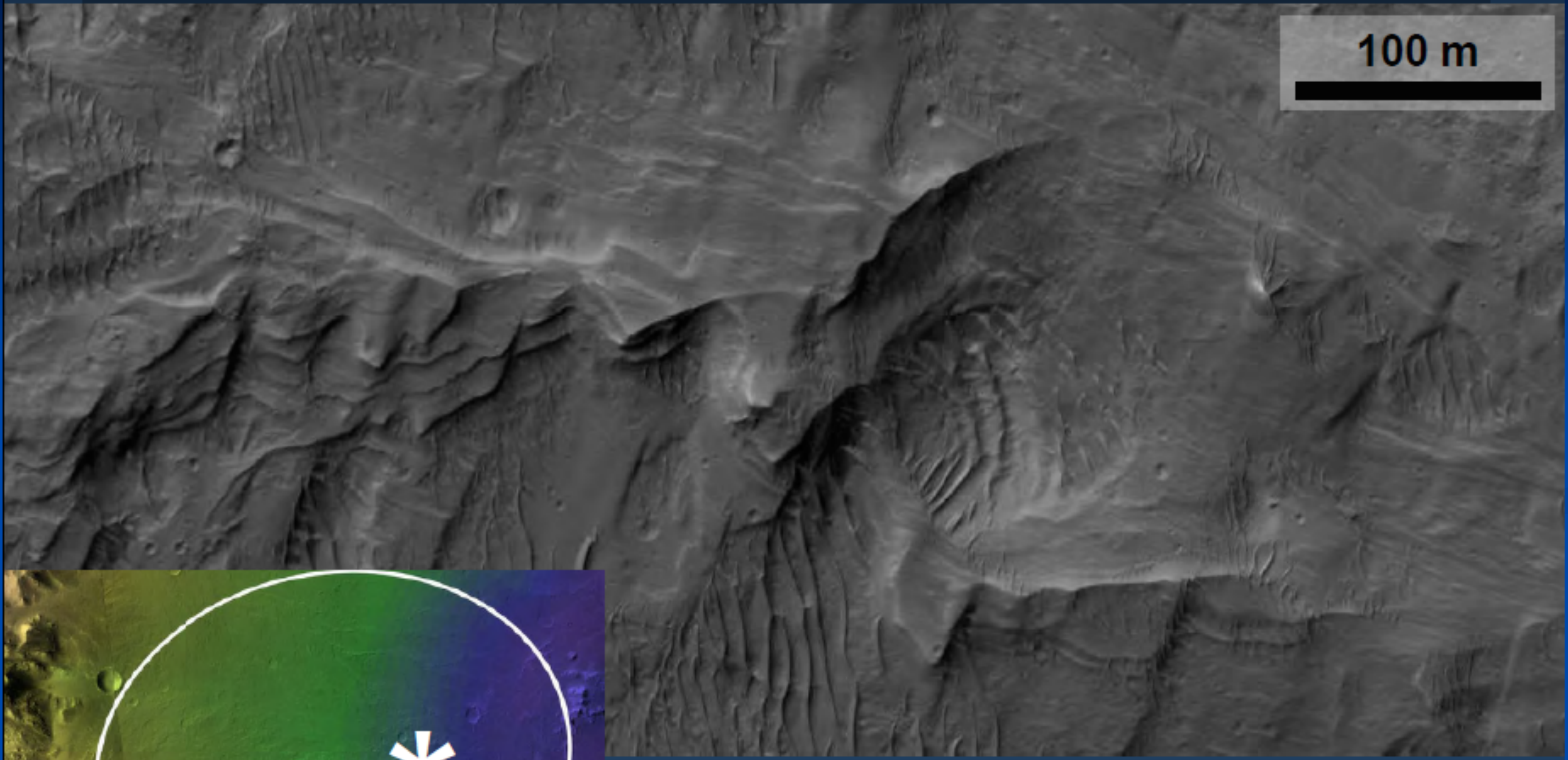
Layers exposed in every fresh crater

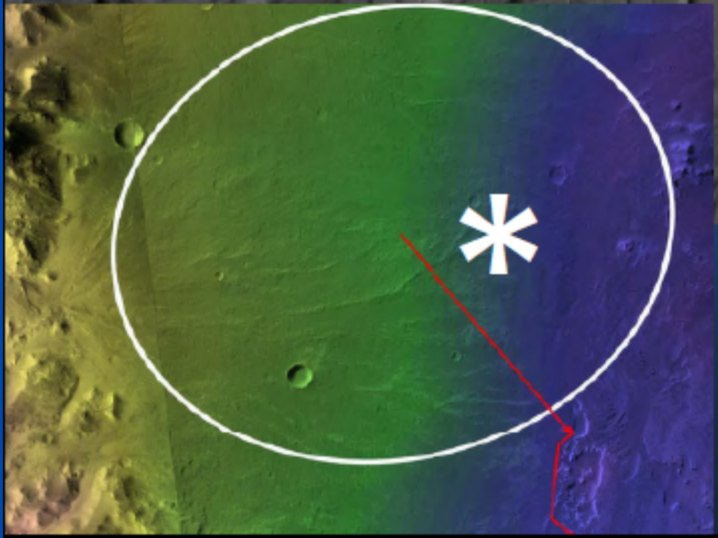
Layers exposed in every channel ridge

Contact/transition potentially exposed in cliffs where LTLD can be studied

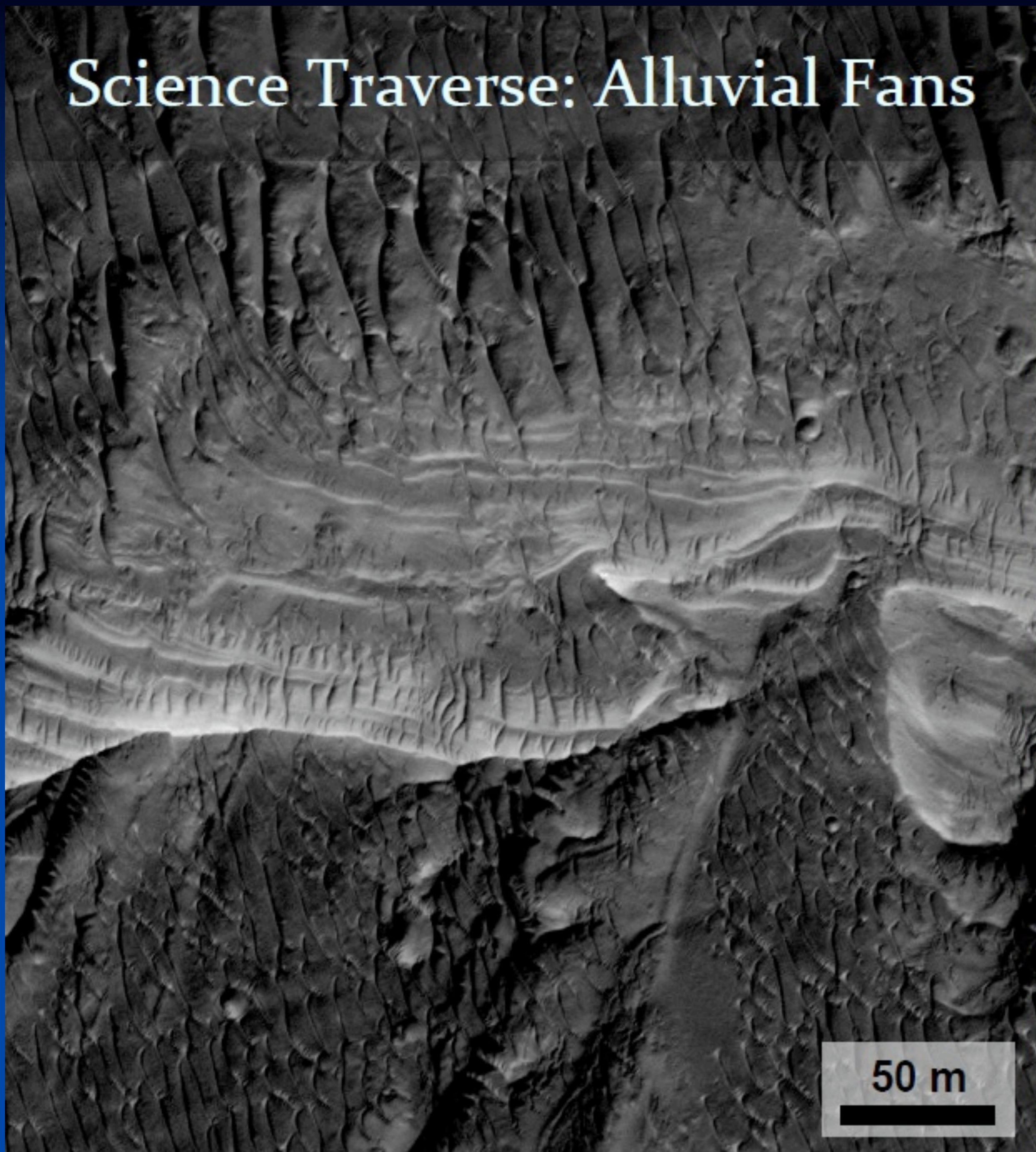

Science Traverse: Alluvial Fans
50 m
*
400 m diameter

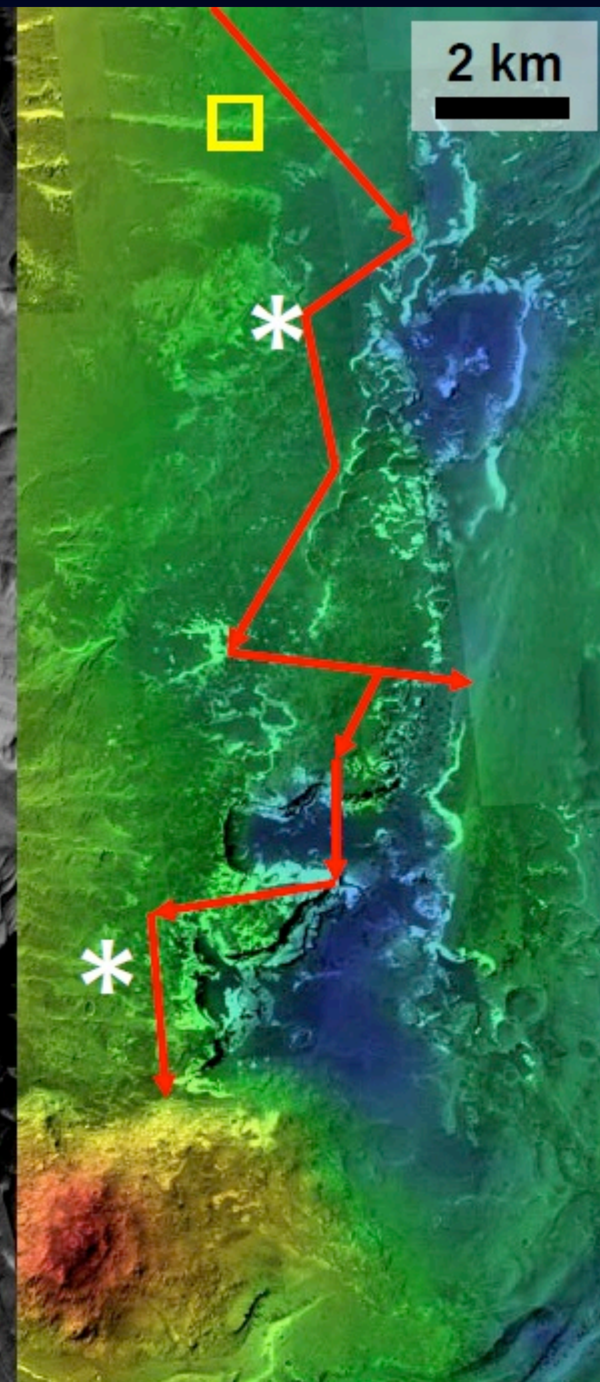
Science Traverse: Alluvial Fans





Science Traverse: Alluvial Fans





Alluvial Fan-Related Testable Hypotheses (in situ observations required)

H4. Substrate in the crater rim source area was weathered in place before erosion and transport to the fan surface.

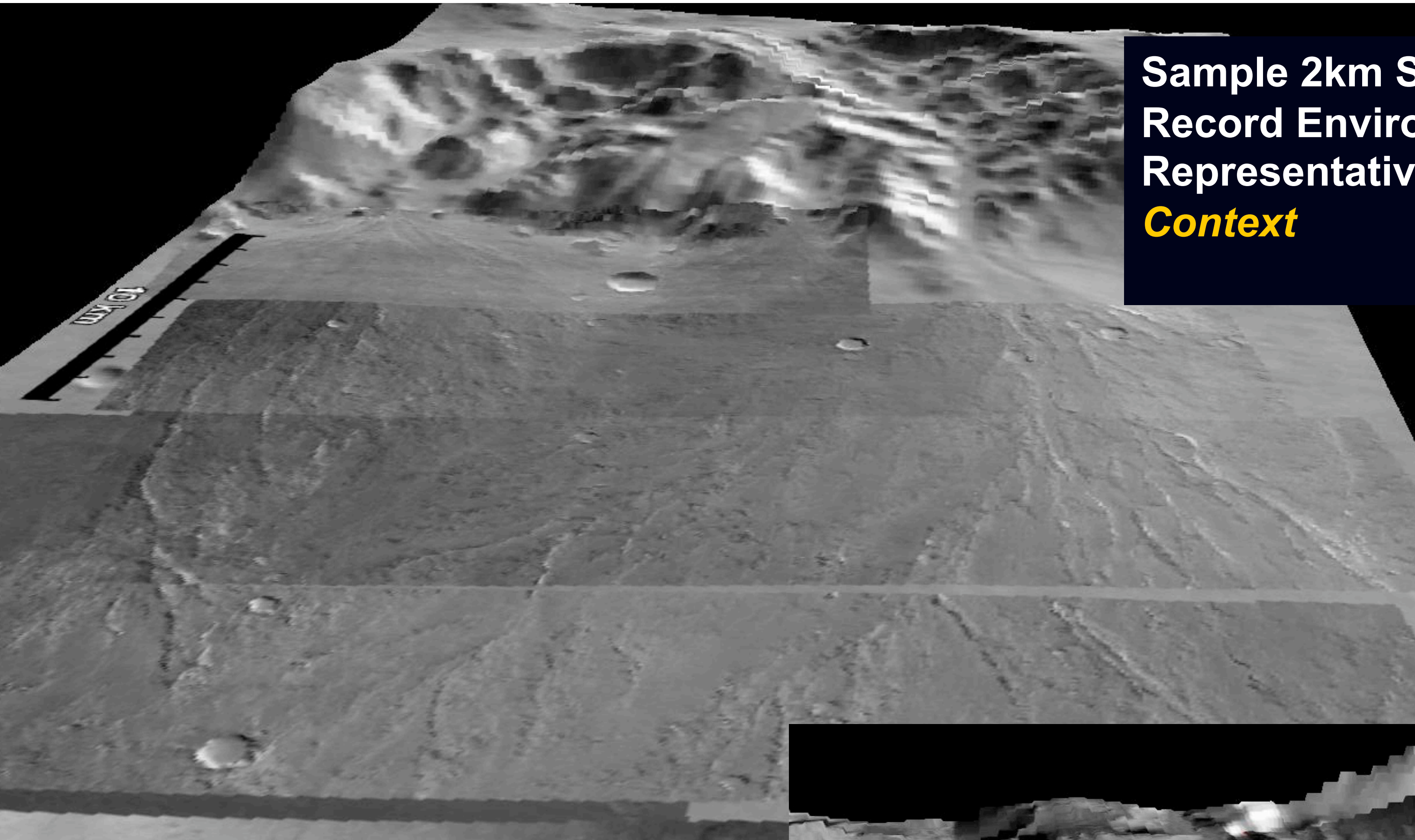
- Test: Detrital clays present in matrix of deposits. Clays present but not clearly authigenic. No soil horizonation.
- Null hypothesis: No weathering evident in the source material.

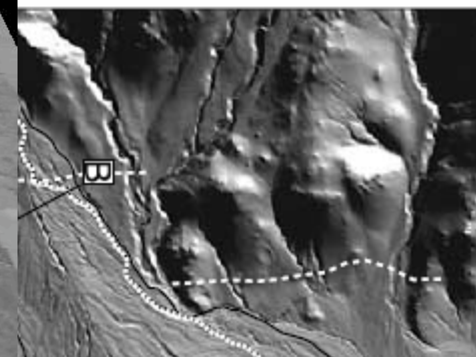
Alluvial Fan-Related Testable Hypotheses (in situ observations required)

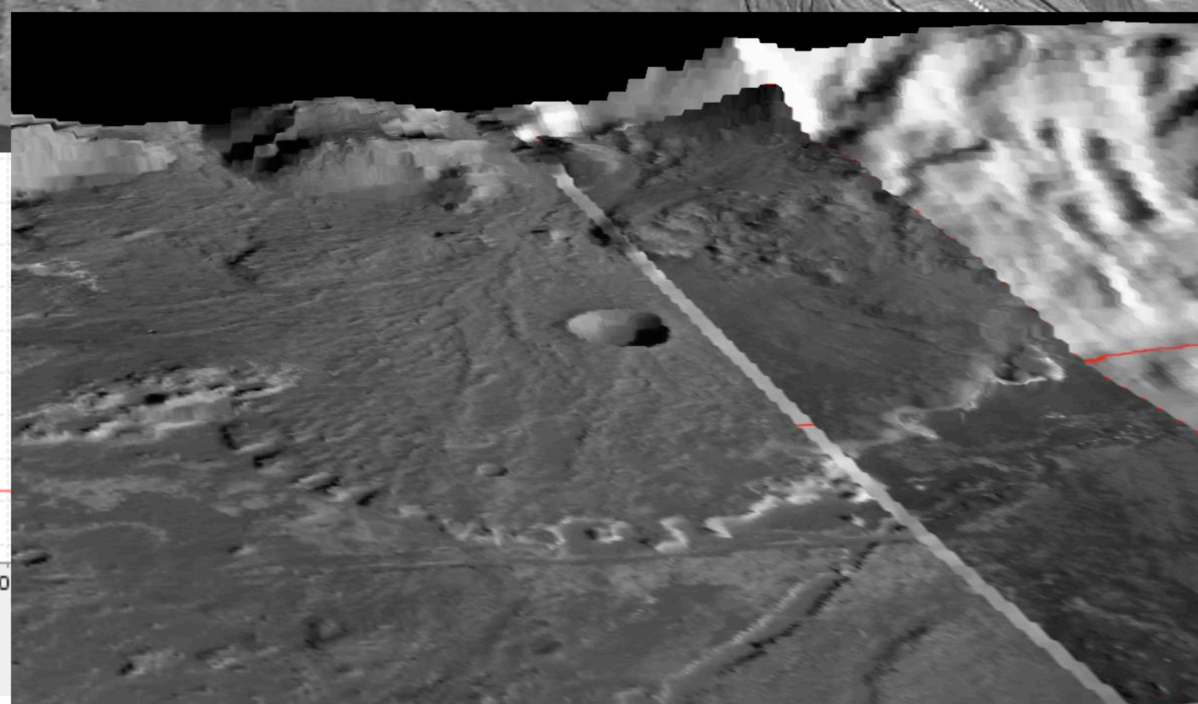
H5. Fan formation was contemporaneous with accumulation of light-toned layers and thus provide environmental conditions relevant to them.

- Test1: Interfingering between fan facies and facies of light-toned layers identified in exposures near base/toe of fans.
- Alternate: Fan sediments clearly onlap over light-toned units and thus post-date them. Nature of contact can indicate time lag.

Sample 2km Section;
Record Environmental Conditions
Representative of Time Period
Context

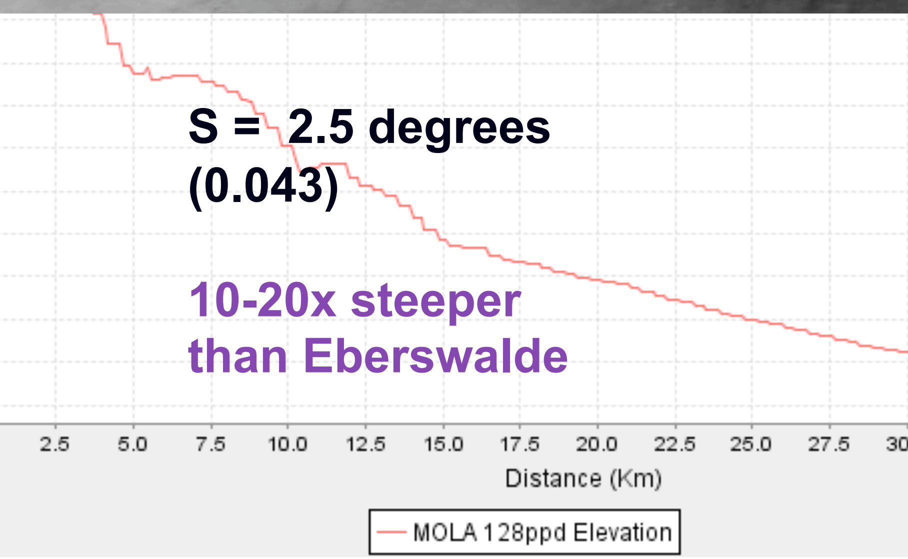


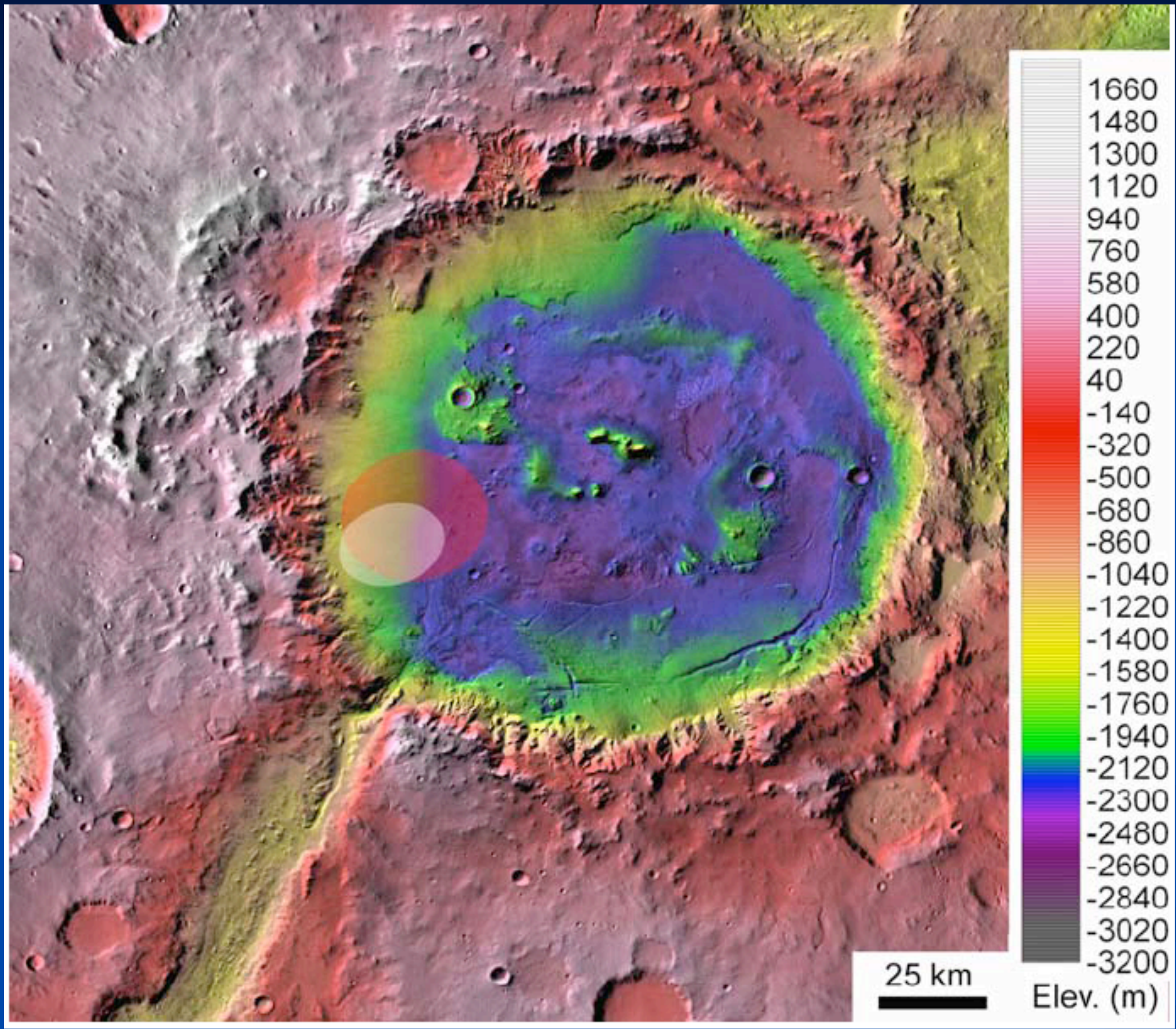




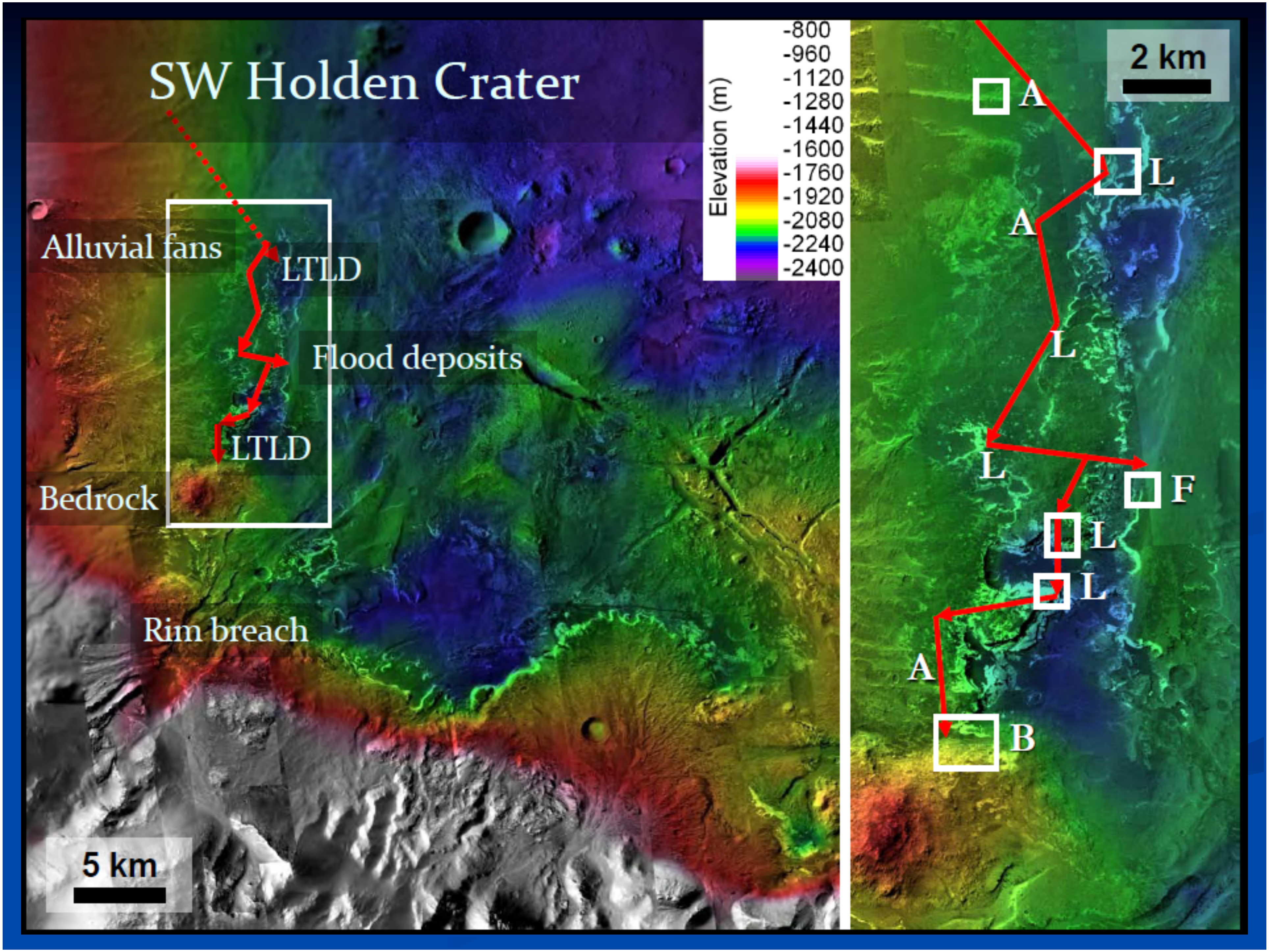
S = 2.5 degrees
(0.043)

10-20x steeper
than Eberswalde

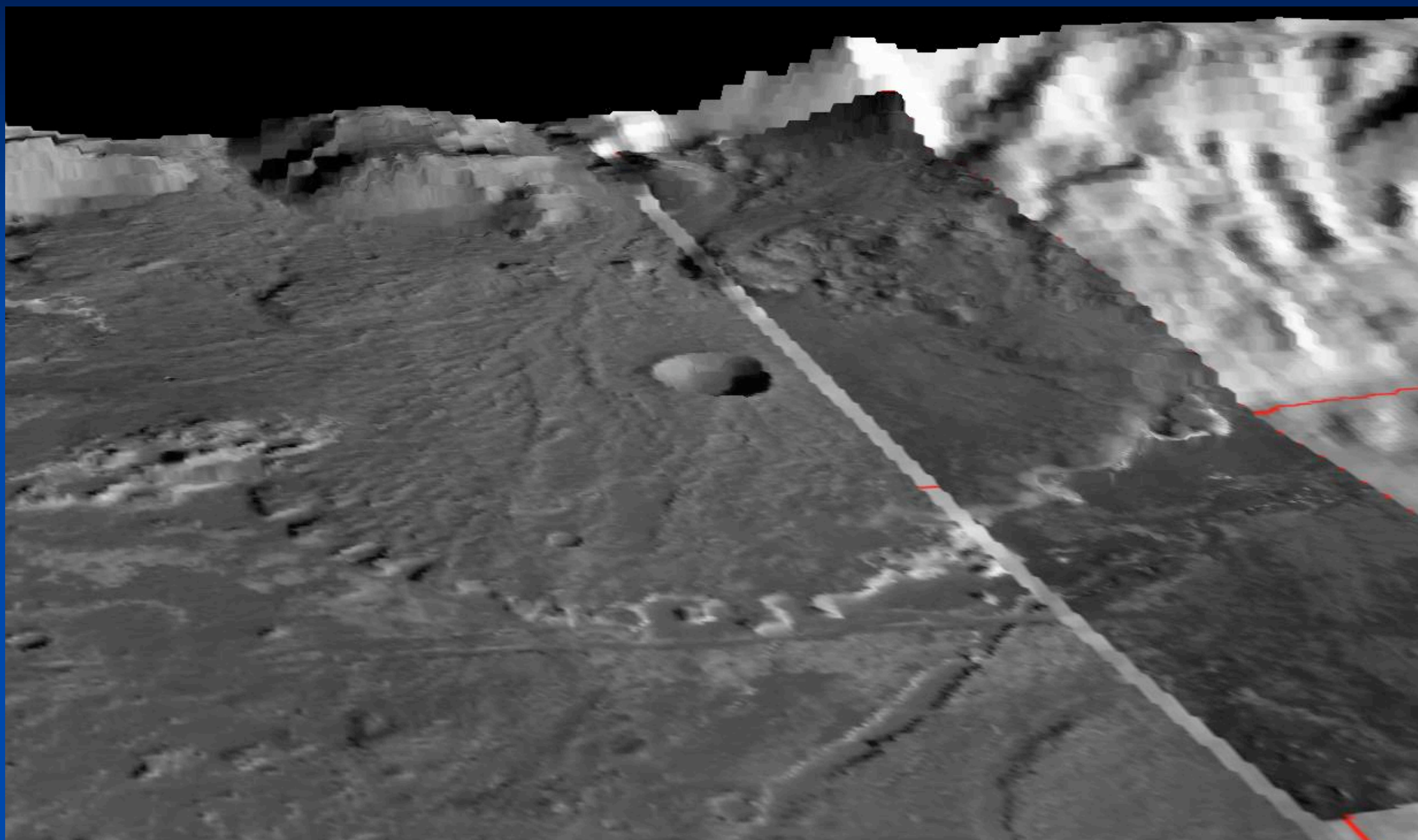


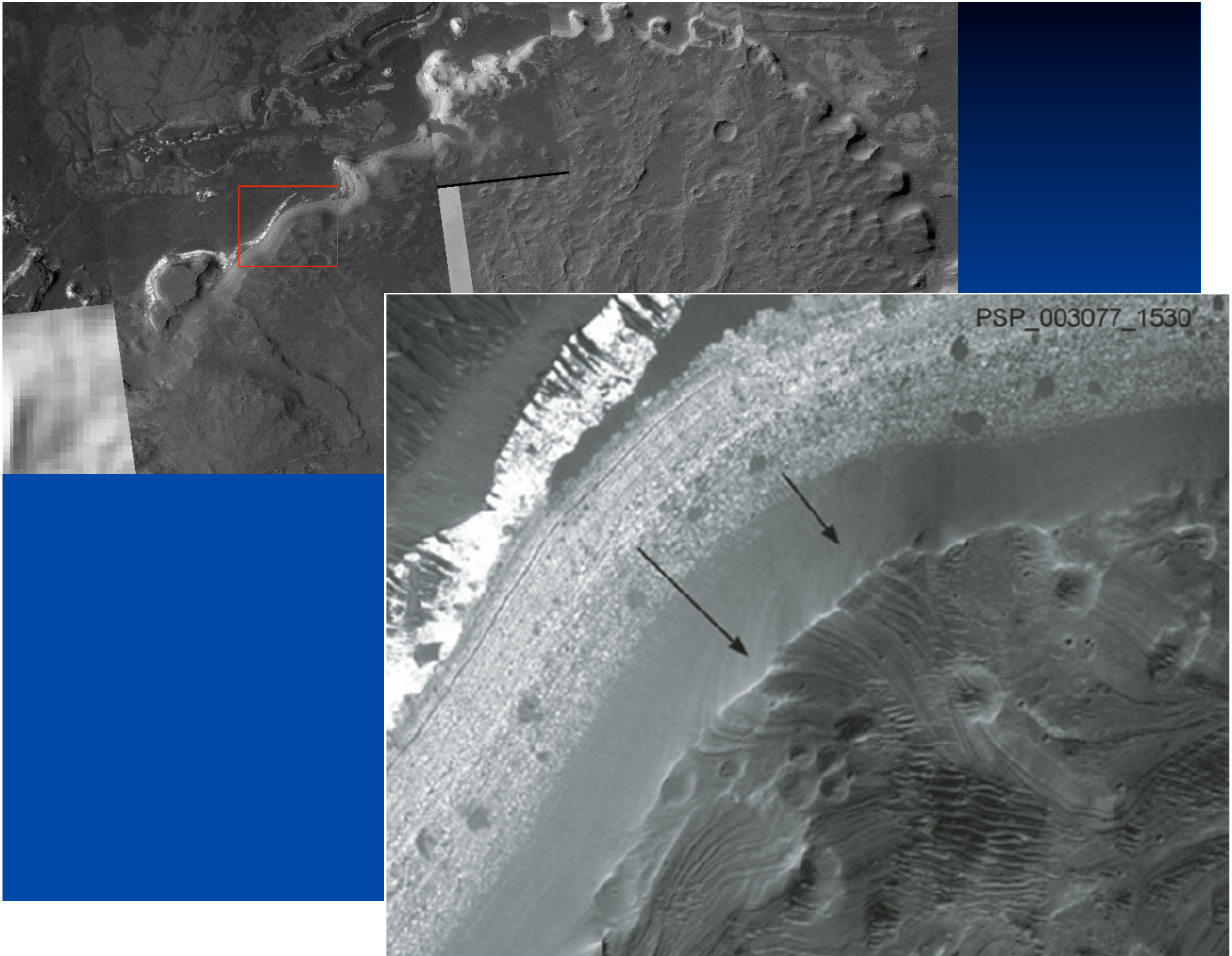


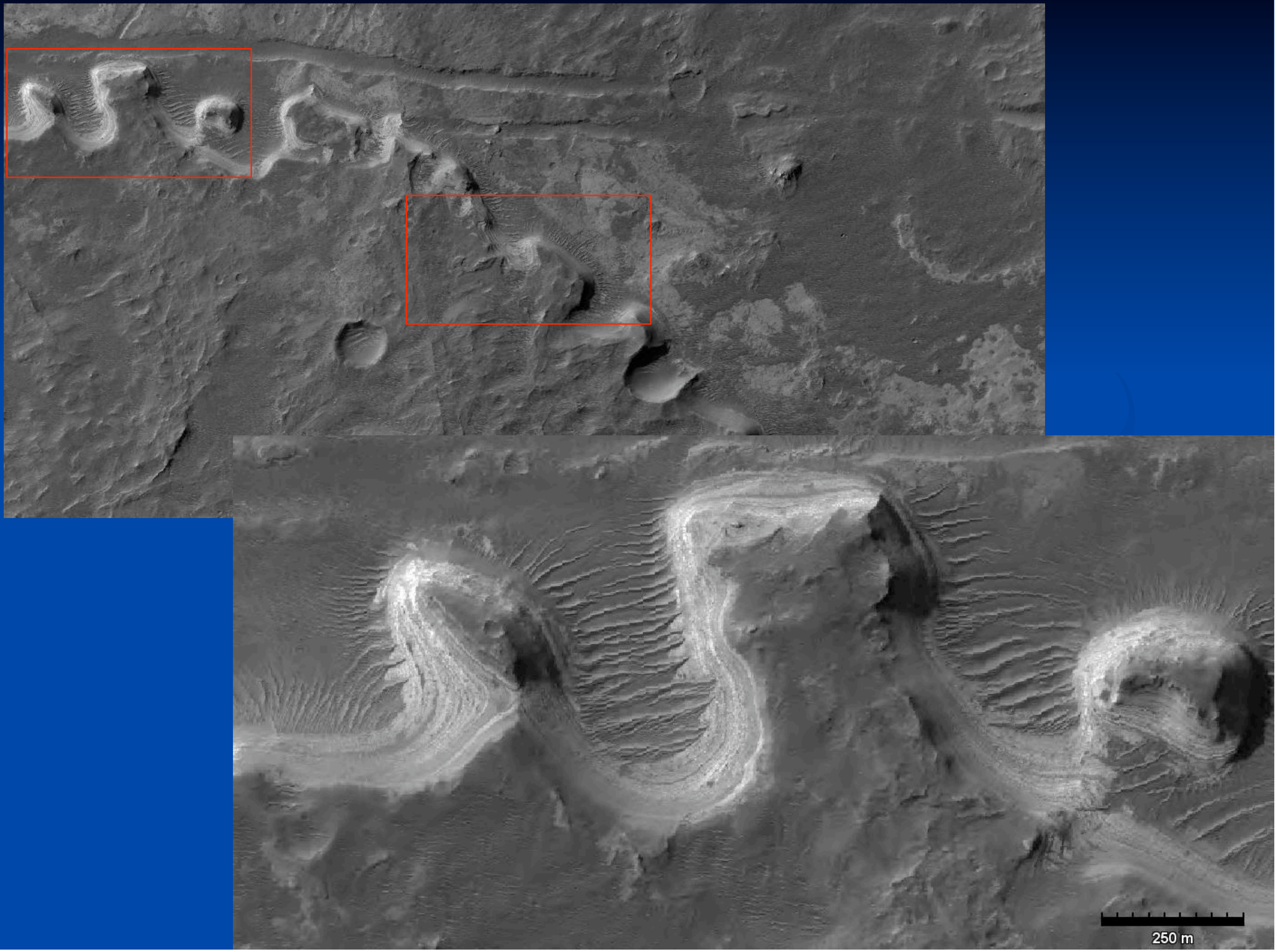
Common Elevation Alluvial Fan Margins (~2000m): Top LTLD


SW Holden Crater
Alluvial fans
LTLD
Flood deposits
LTLD
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

Fan-Delta?   Truncated Fan?




PSP_003077_1530


250 m

Constraining Environmental Conditions (Fluvial Fans)

Flow and Sediment Transport Relations

$$\tau_b = \rho C_f u^2$$

$$C_f^{-1/2} = \alpha_r$$

$$\tau_b = \rho g h S$$

$$q_s^* = \alpha_s (\tau^* - \tau_c^*)^n$$

$$q_s^* = \frac{q_s}{\sqrt{\mathbf{R} g D} D}$$

$$\tau^* = \frac{\tau_b}{\rho \mathbf{R} g D}$$

$$\mathbf{R} = \frac{\rho_s - \rho}{\rho}$$

Expanding Flow Model (bedload)
Parker et al. (1998)

$$S = \{R[(\frac{1}{\alpha_s}\frac{Q_{so}\left(1-\hat{r}^2\right)}{\sqrt{RgD}D\chi\theta r})^{1/n} + \tau_c^*]\}^{3/2}\alpha_r(\frac{Q_w}{\sqrt{gD}D\chi\theta r})^{-1}$$

Reduce: n = 3/2 (bedload); $\tau^* >> \tau_c^*$

Terrestrial Fans (Stock et al., 2008), Experimental Fans

$$\overline{S} = \frac{2}{3}R\frac{\alpha_r}{\alpha_s}\frac{Q_{so}}{Q_w}$$

$$\frac{Q_{so}}{Q_w} \approx \frac{2}{3}\overline{S}$$

No Dependence on g, D, or Flow Width!

Equilibrium Channel Model (bedload)

$$S = R^{-1/2}\alpha_c^{-1}\alpha_s^{-1}\alpha_b^{3/2}\alpha_r\left(\frac{\alpha_b}{R}-\tau_c^*\right)^{-n}\left(\frac{Q_{so}\left(1-\hat{r}^2\right)}{Q_w}\right)$$

Reduce: n = 3/2 (bedload); Critical Stress Dominant

$$\overline{S} = \frac{2}{3}R\frac{\alpha_r}{\alpha_c\alpha_s}\frac{1}{c_w}\frac{Q_{so}}{Q_w}$$

$$\alpha_c \approx 2-4$$

$$c_w \approx 0.1$$

$$\frac{1}{5}\left(\frac{2}{3}\overline{S}\right) \leq \frac{Q_{so}}{Q_w} \leq \frac{1}{3}\left(\frac{2}{3}\overline{S}\right)$$

Equilibrium Channel Model (suspended load, n = 5/2)

$$\overline{S} = \frac{2}{3} R \frac{\alpha_r}{\alpha_c \alpha_s} \frac{1}{\tau^*} \frac{Q_{so}}{Q_w}$$

$$\tau^* = 2$$

$$\alpha_c \approx 1.5$$

$$\frac{Q_{so}}{Q_w} \approx 3\left(\frac{2}{3}\overline{S}\right)$$

Water Volume -> Formation Time

$$u = \sqrt{\frac{ghS}{C_f}}$$

$$Q_w = uhw$$

Weakest link w/o Data

$$T = \frac{V_w}{Q_w}$$

$$T = \frac{V_f}{Q_{so}}$$

$$Q_{so} = \frac{Q_{so}}{Q_w} Q_w$$

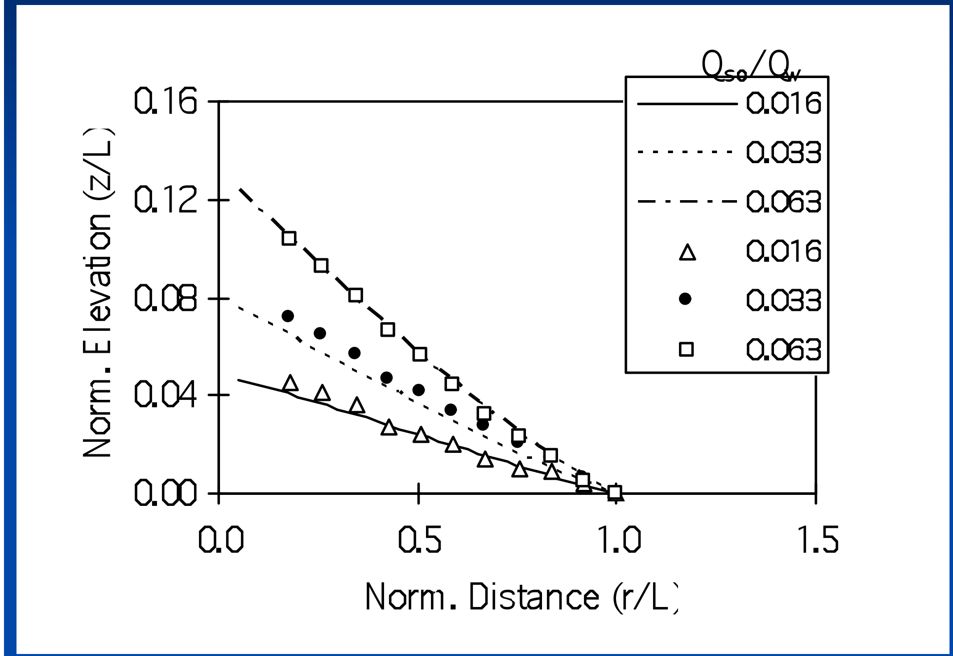
$$\frac{1}{2}\frac{V_f}{\bar{S}Q_w} \leq T \leq 7\frac{V_f}{\bar{S}Q_w}$$

~10's – 1000 years minimum

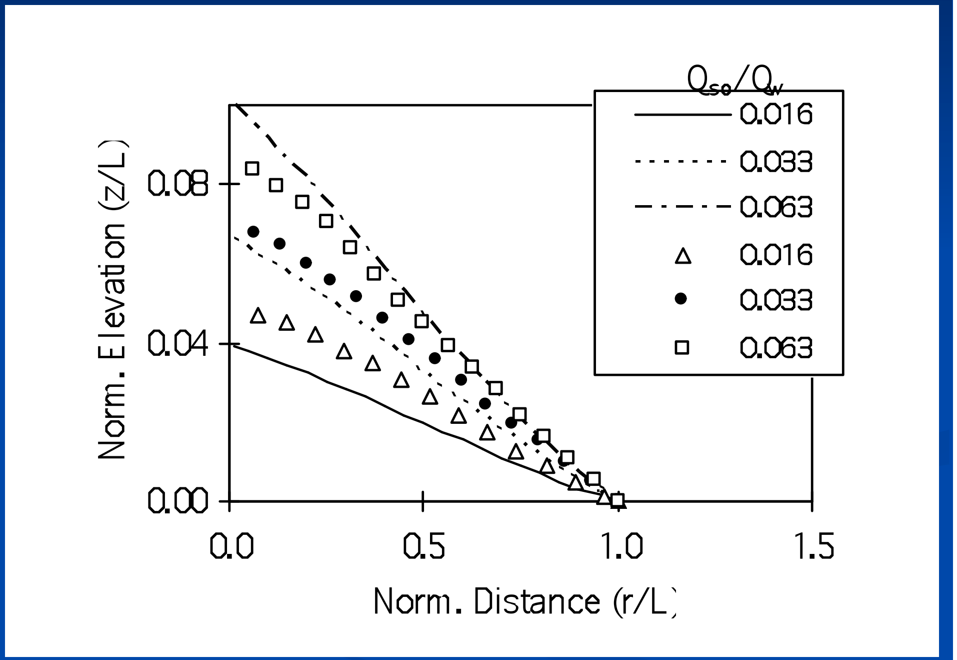
(200 – 20000) [5% intermittency]

Alluvial Fan Slope: Simple Theory

Bedload-Dominated Sand



Suspension-Dominated Sand

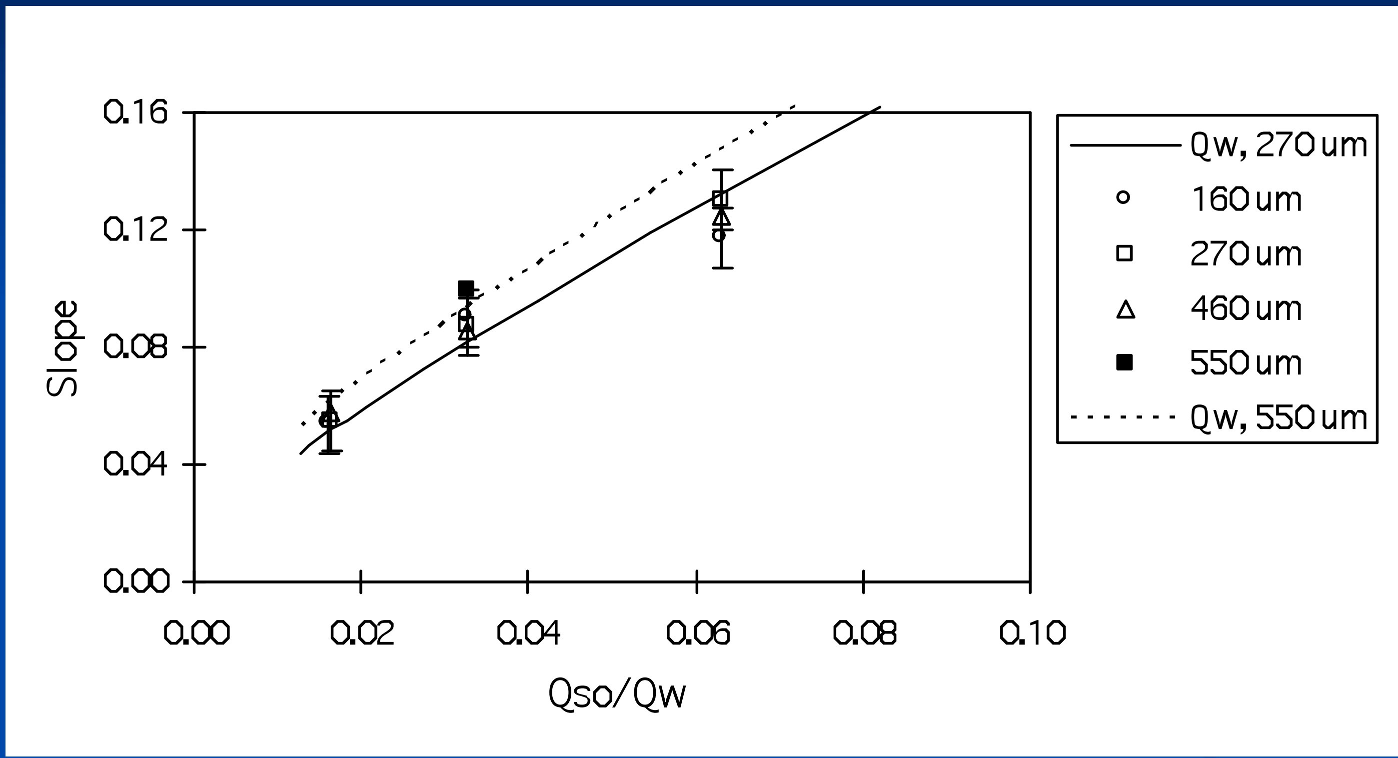


Straight to Concave Profiles

Convexo-Concave Profiles

Lines are Theoretical Prediction (no tuning of parameters)

Bedload-Dominated Sand Experiments



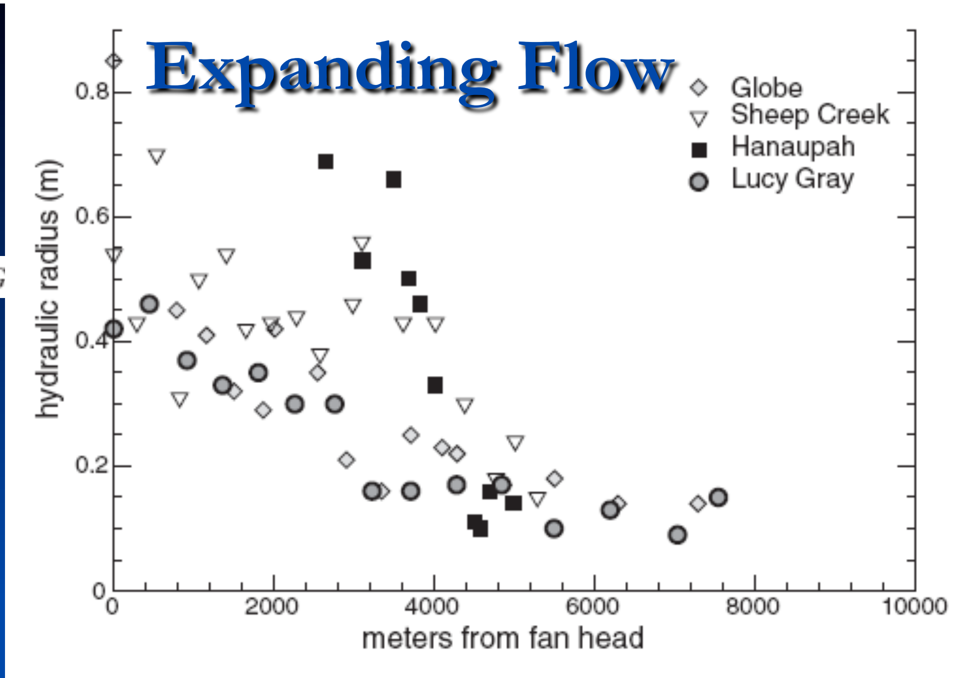
Vary Qw

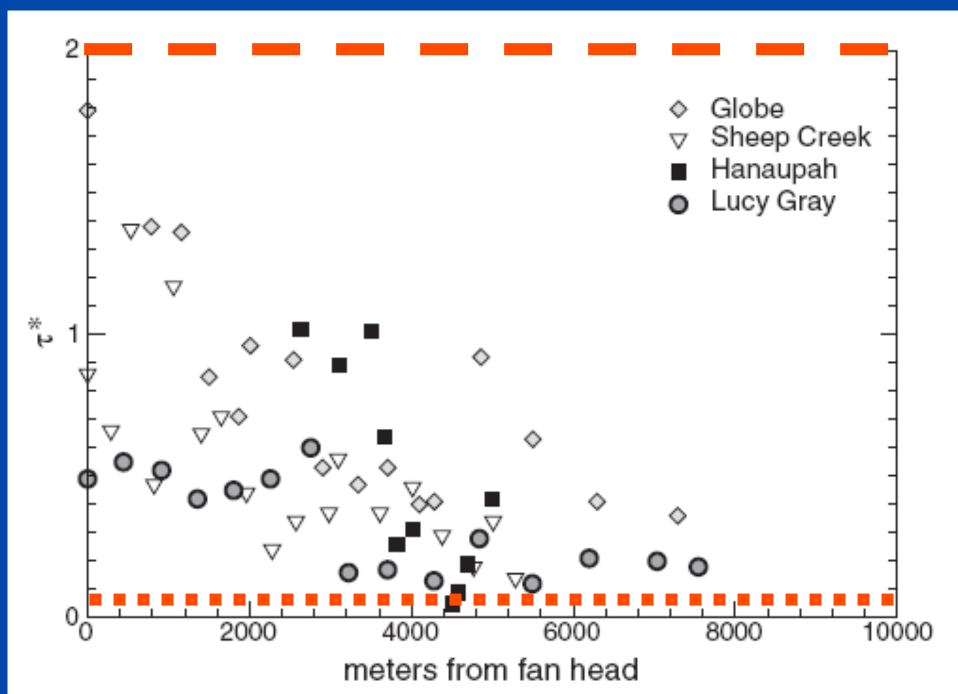
Lines are Theoretical Prediction (no tuning of parameters)

Calculation of Q_w

- Empirical method by Irwin et al. (2005)
  - $Q_2 = 1.9w^{1.22}$
  - Correction for Mars: multiply by factor of 0.76 ($1.25^{-1.22}$) to account for lower velocity on Mars for same discharge

Expanding Flow



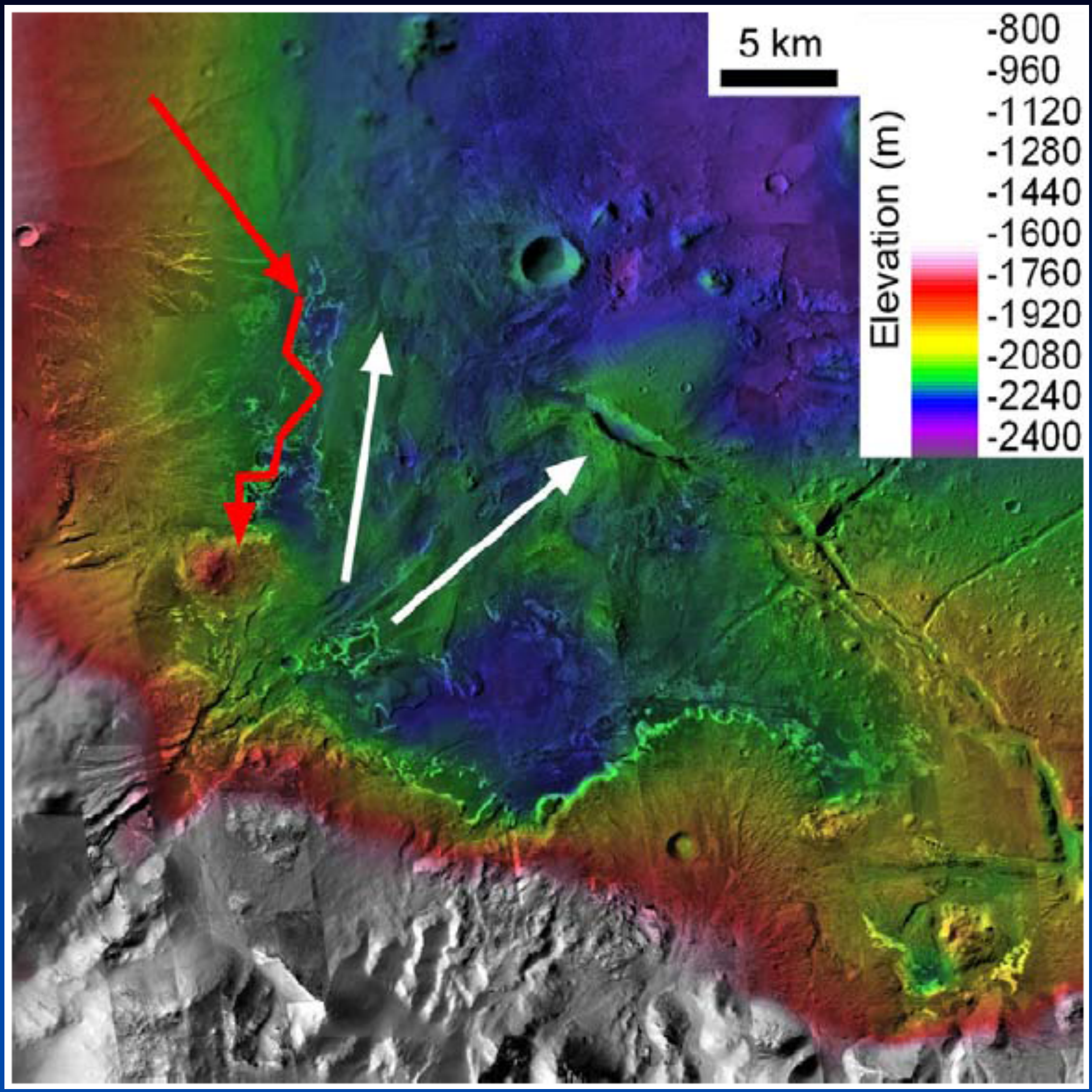


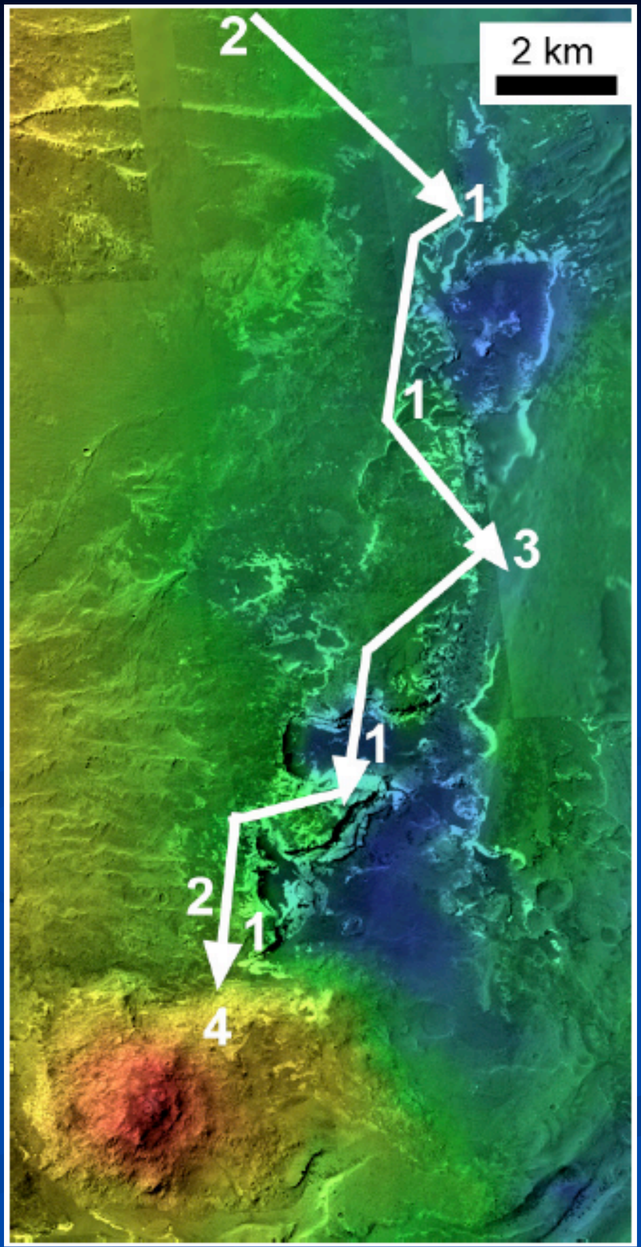
Sandy channels

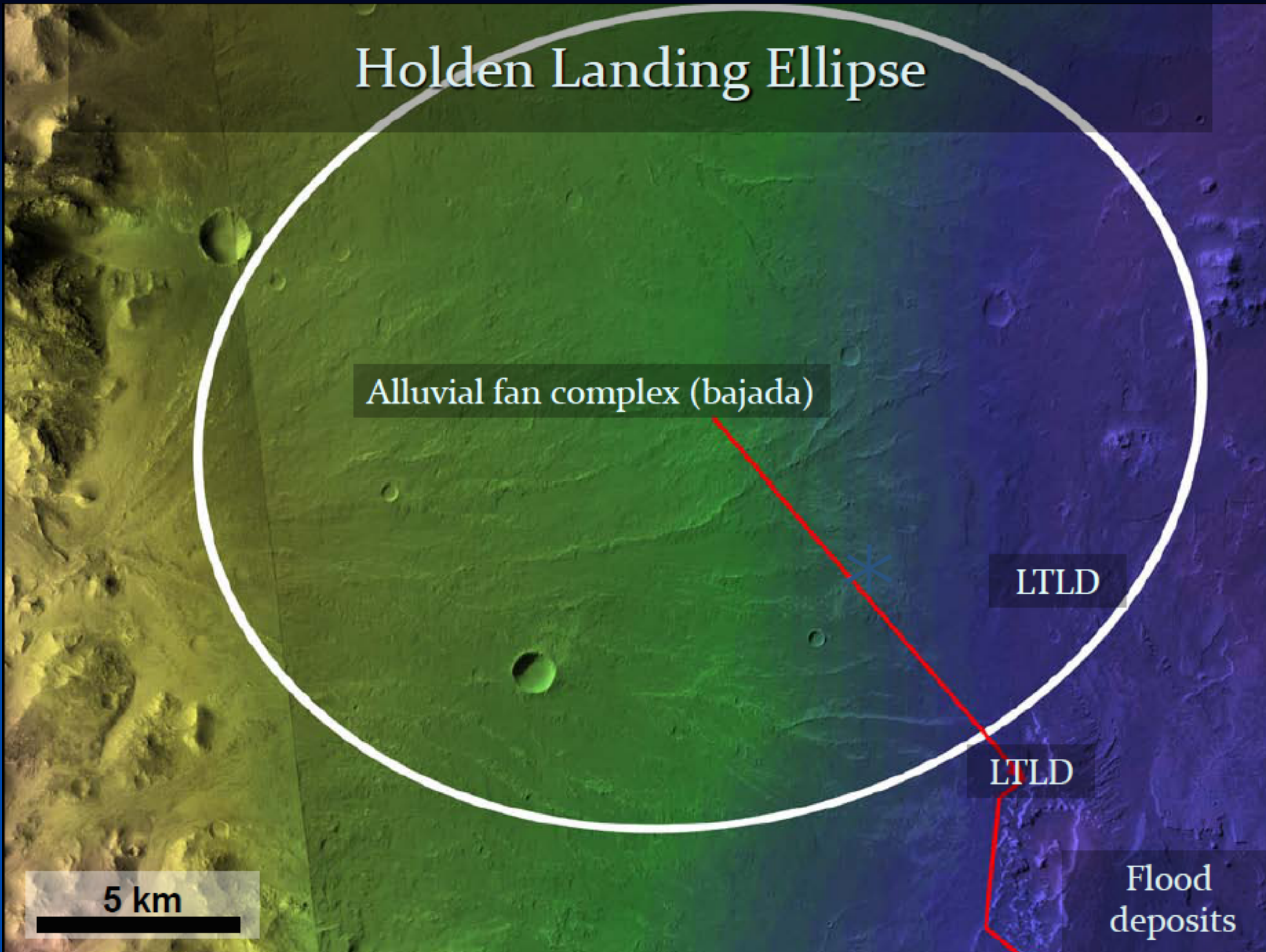
$$\tau^* >> \tau_c^*$$

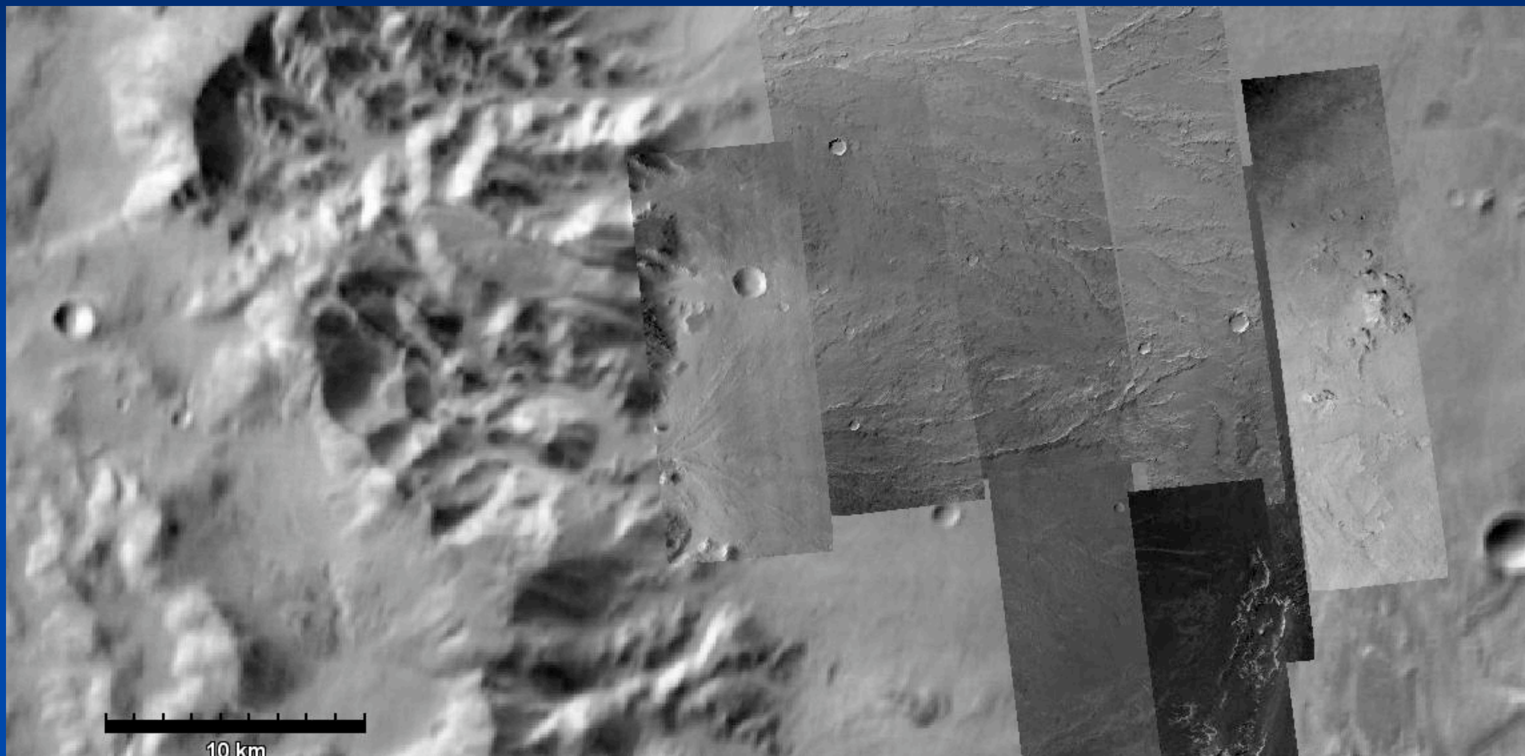
Gravel channels

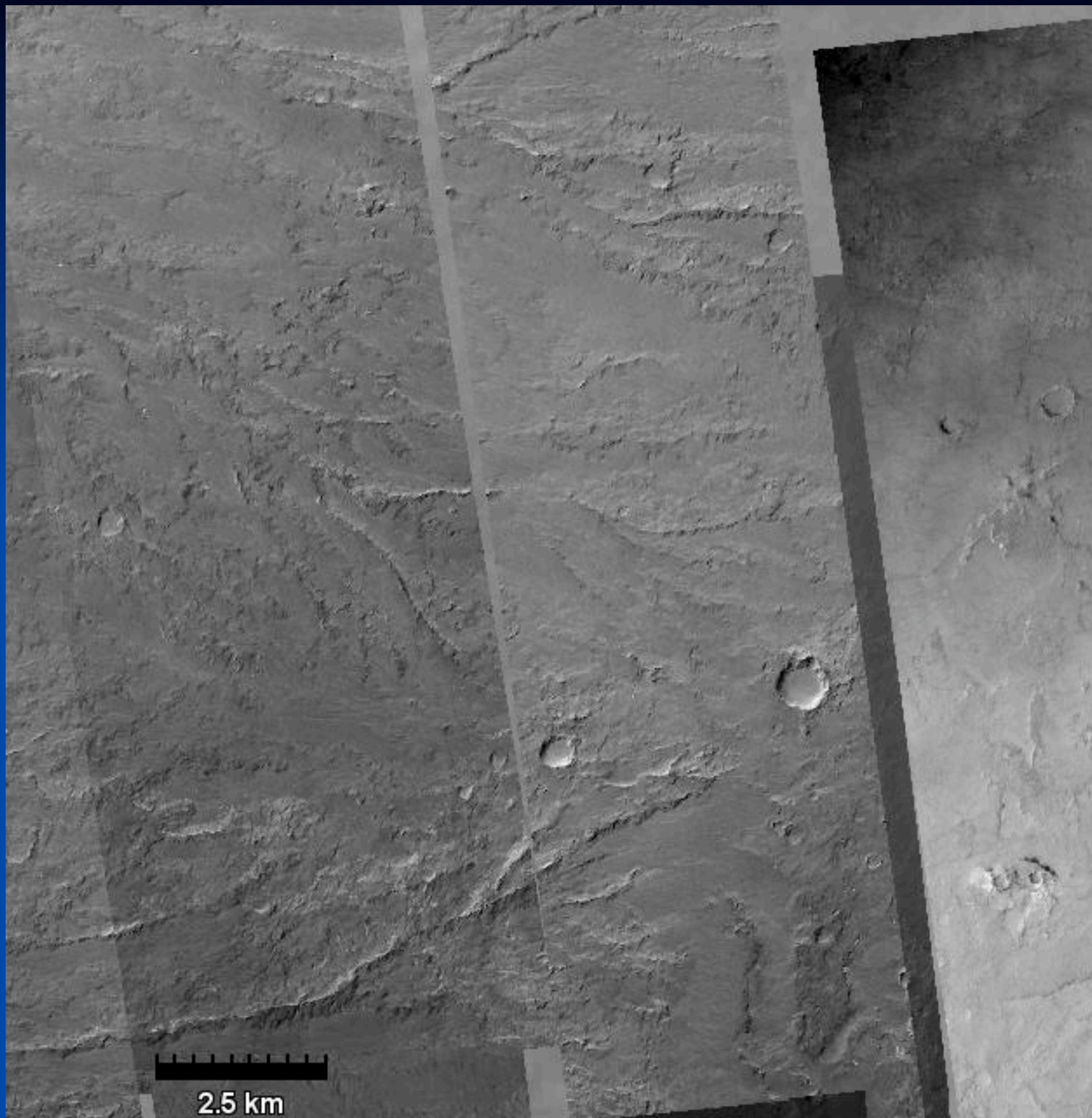
$$\tau^* = 1.3\tau_c^*$$


5 km
Elevation (m)
-800
-960
-1120
-1280
-1440
-1600
-1760
-1920
-2080
-2240
-2400


2 km
2
1
1
3
1
2
1
4


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


10 km


2.5 km