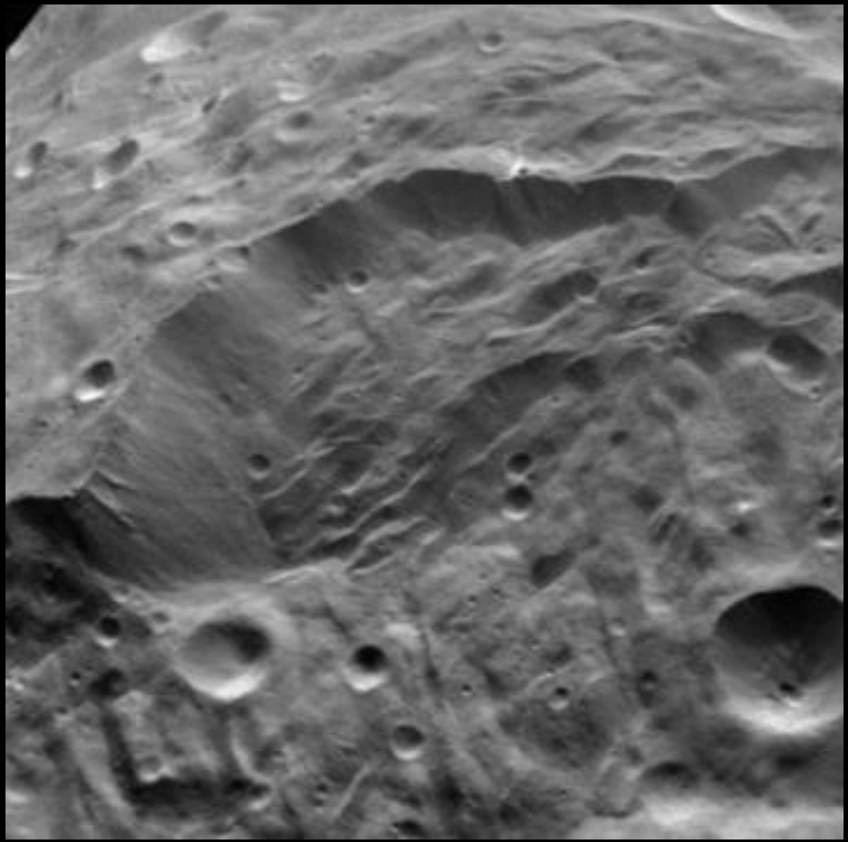
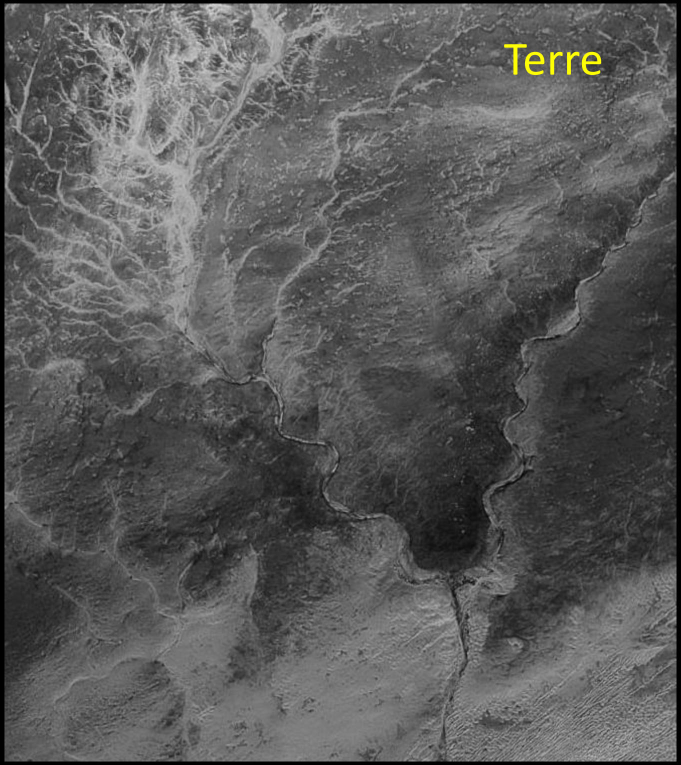
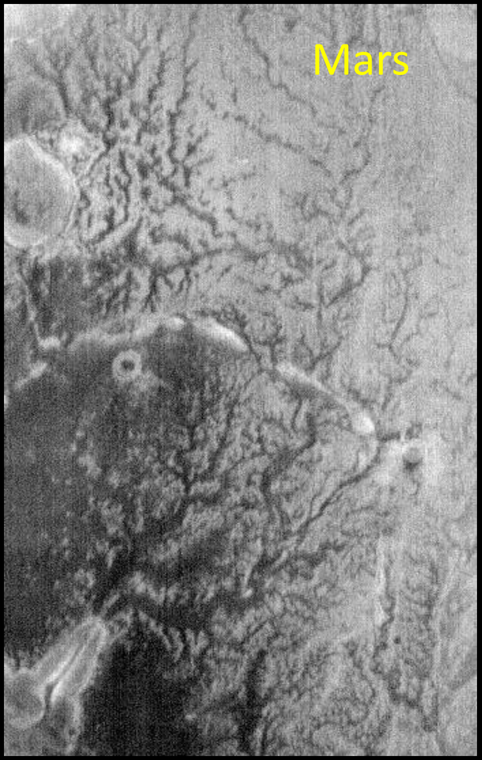
Gravity driven flows on planets: process diversity and formation conditions

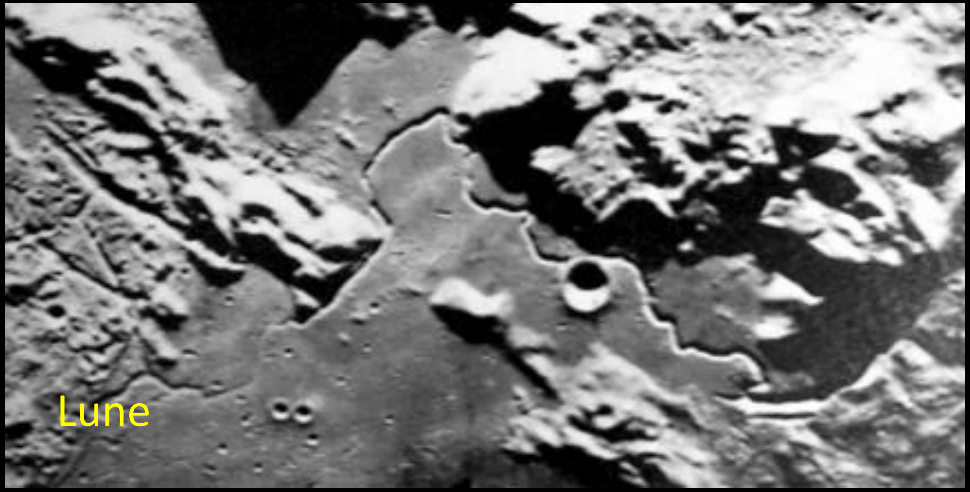


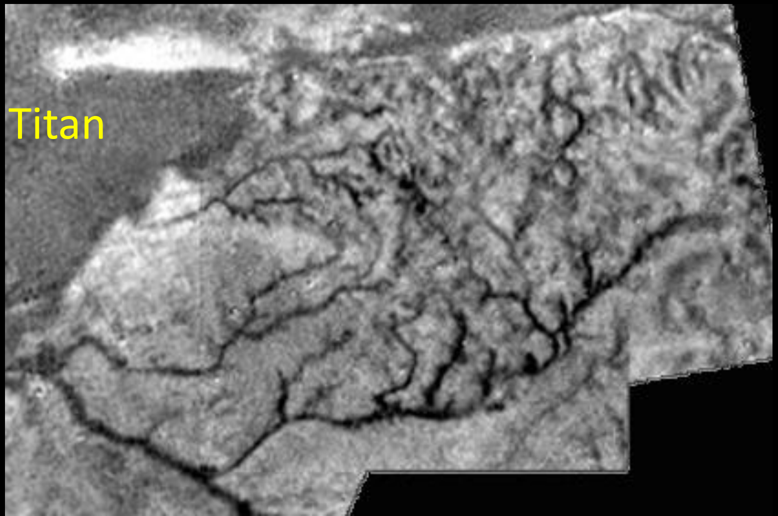
Effect of gravity?

A variety of fluids?



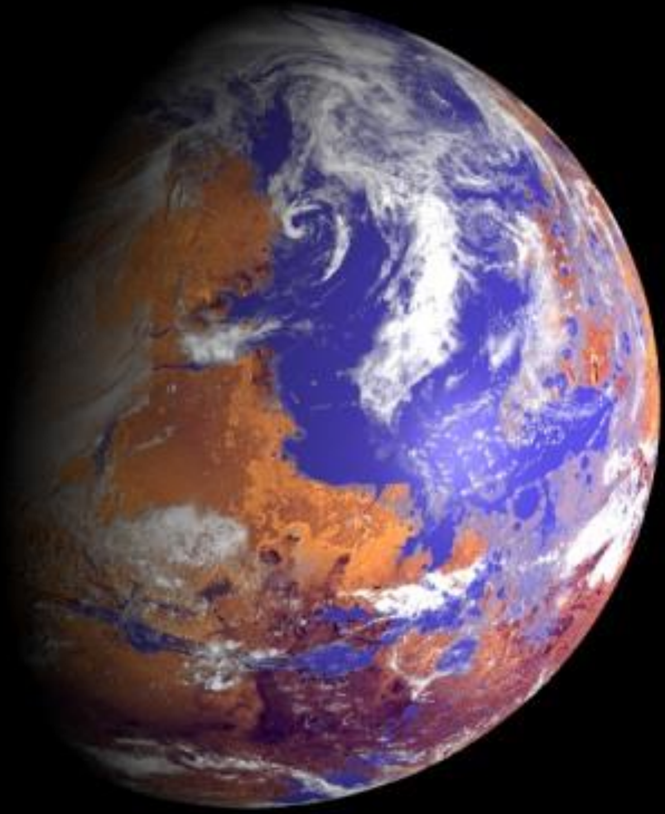






The special interest of Mars

4 Gy ago?

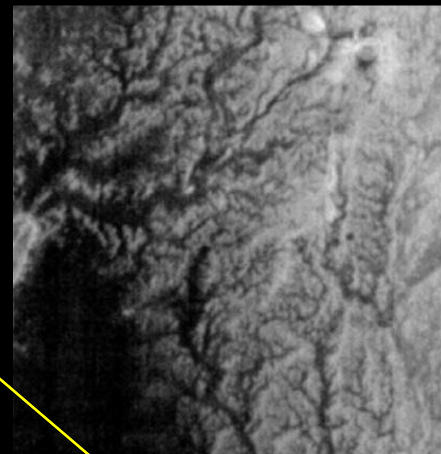


?

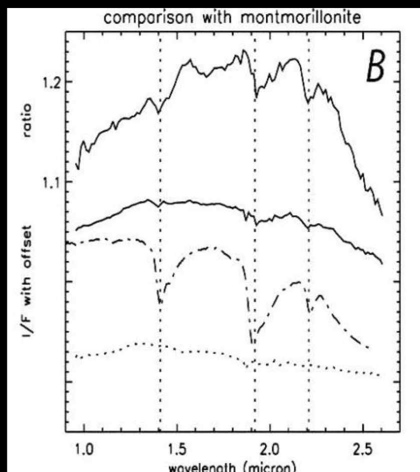
Today
6 hPa
From -130°C to +10°C

Approche

Morphologie – Conditions physiques

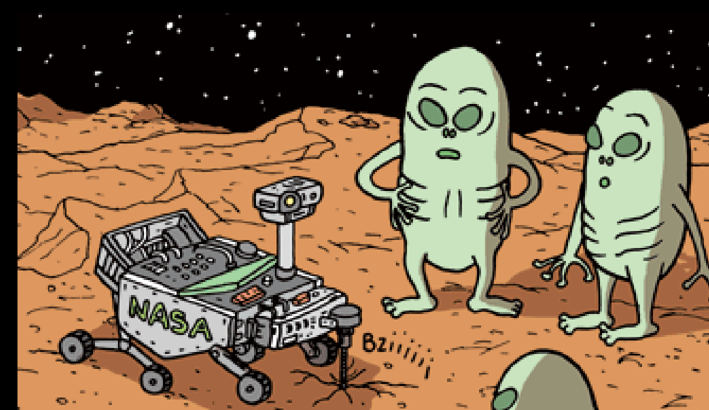


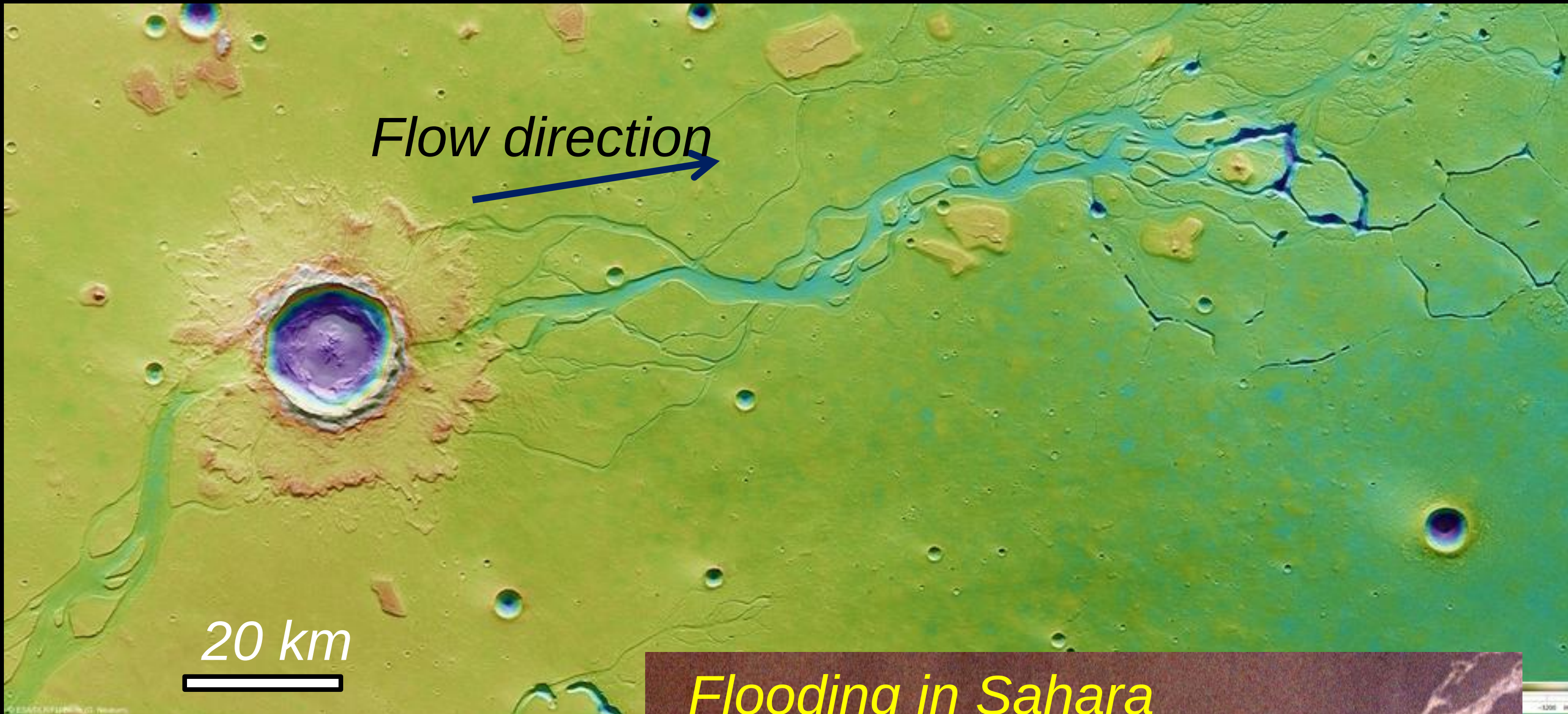
Minéralogie
–
Conditions chimiques



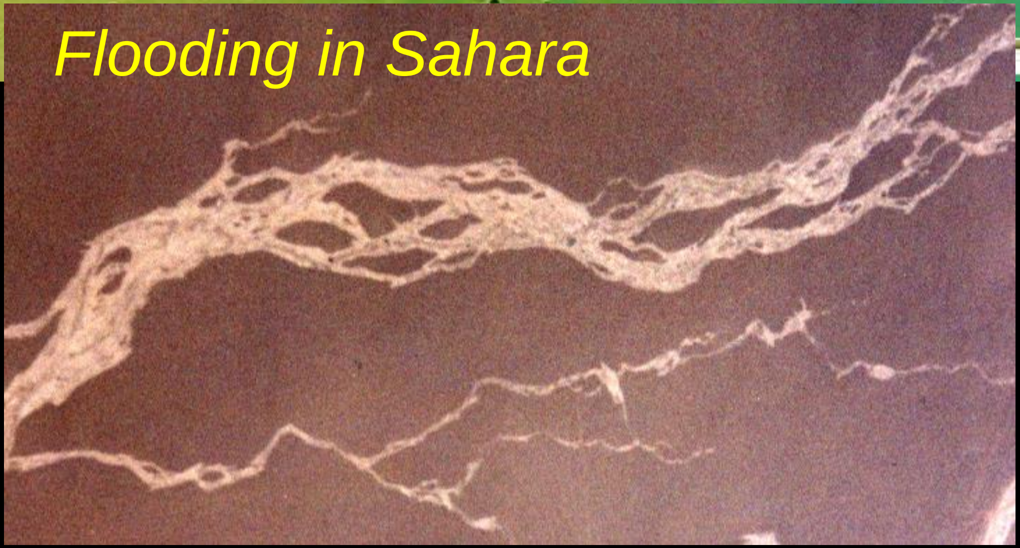
Couplage:
Conditions environmentales

?

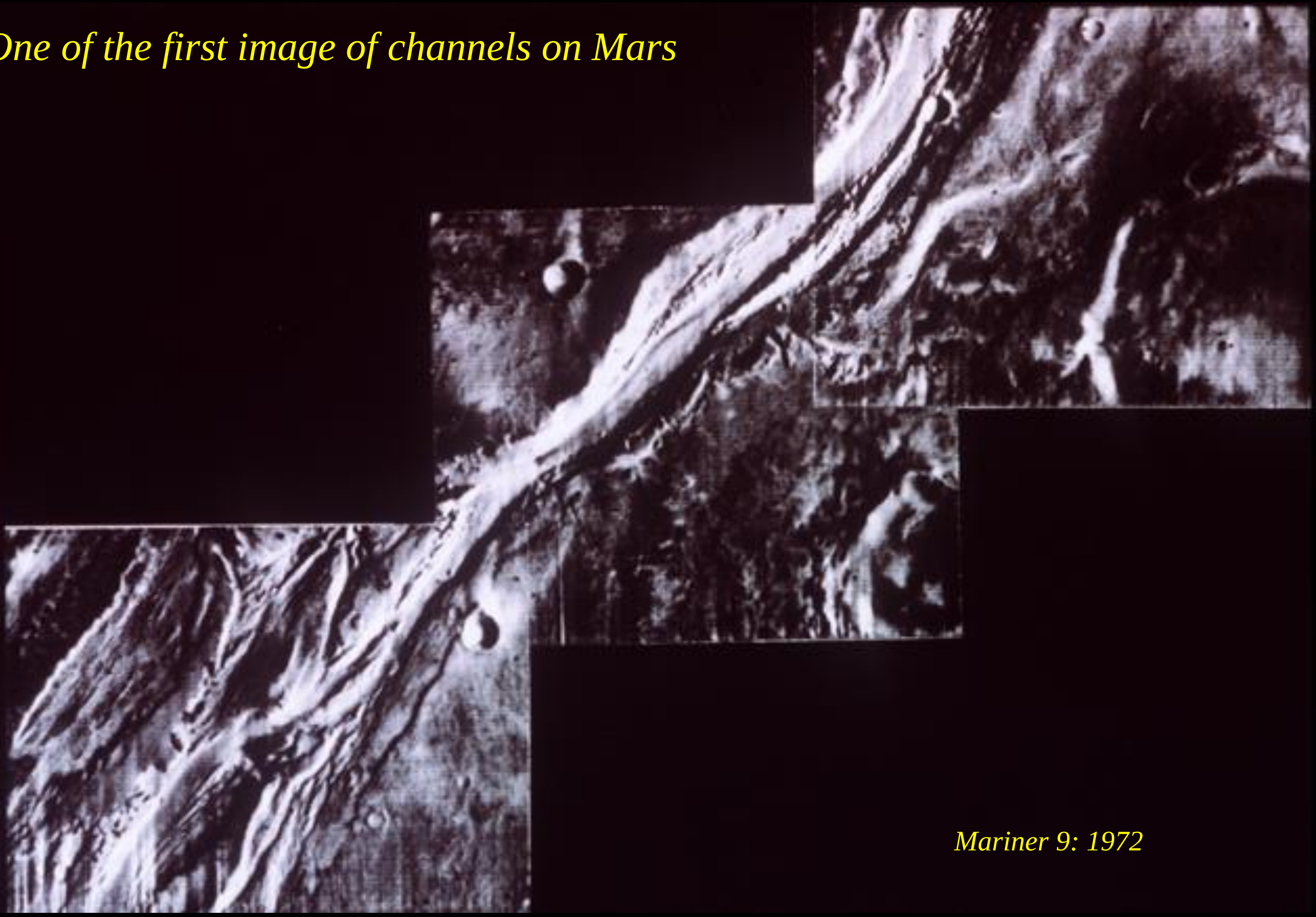




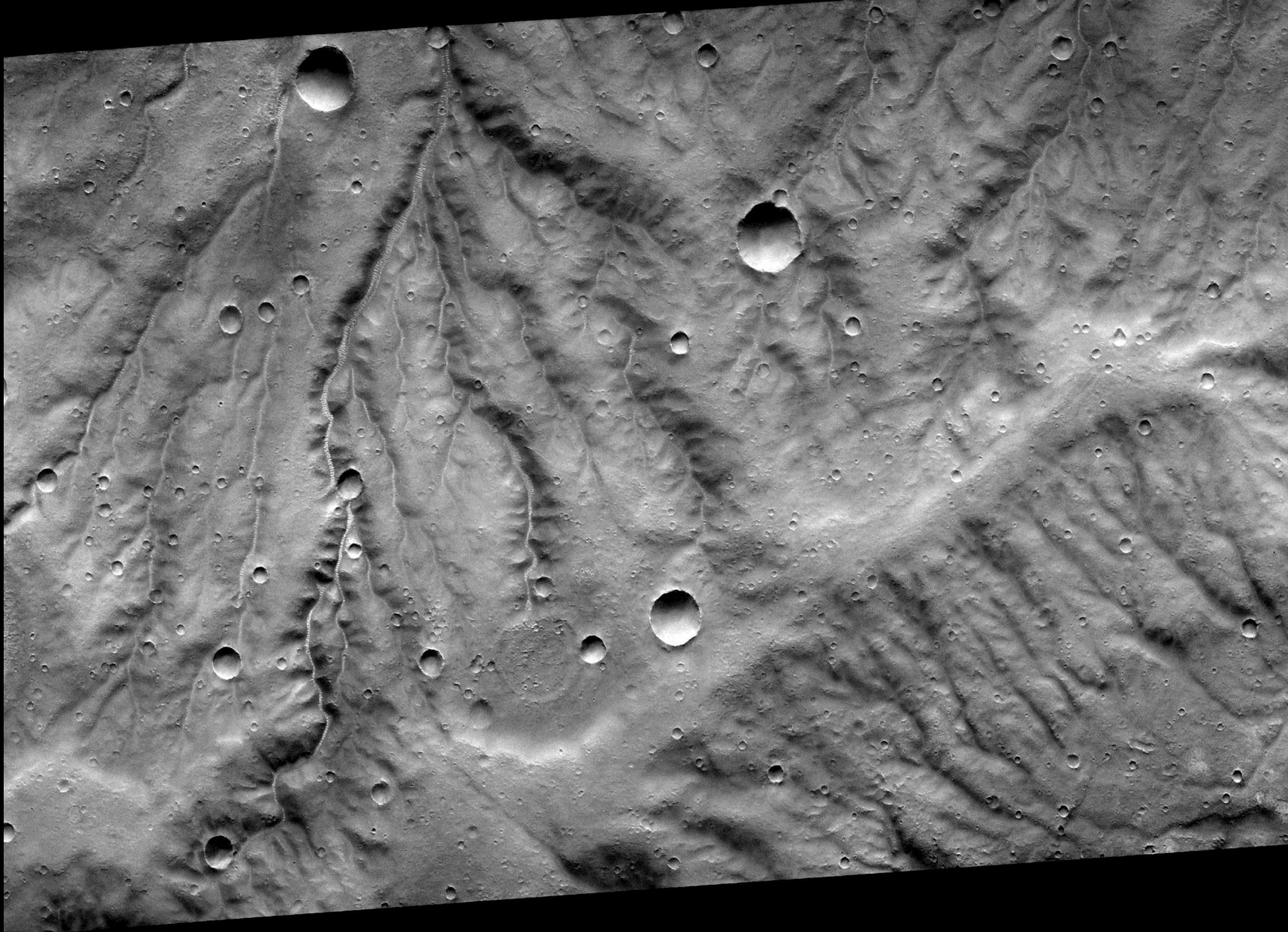
HRSC view of Hrad Vallis

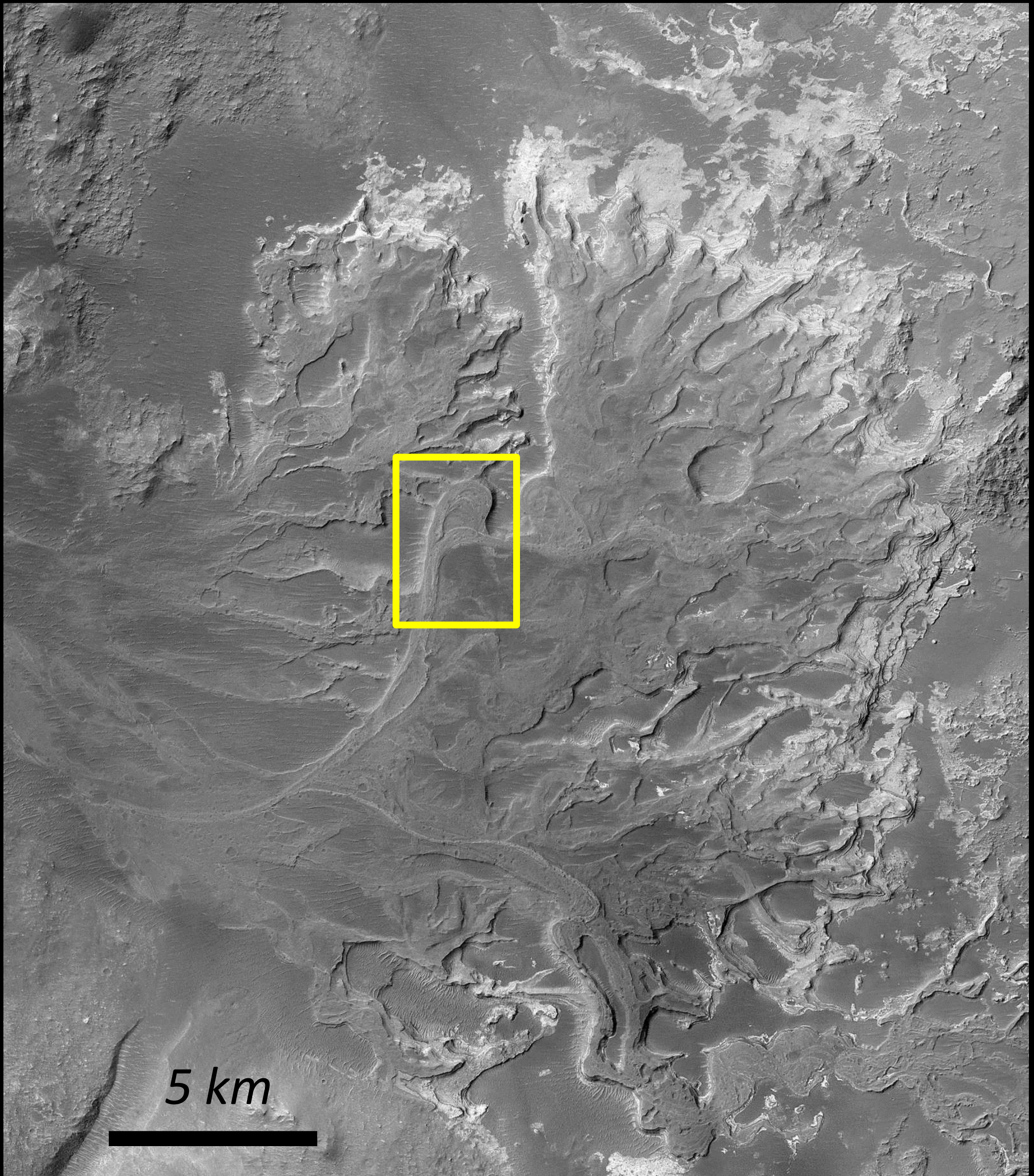


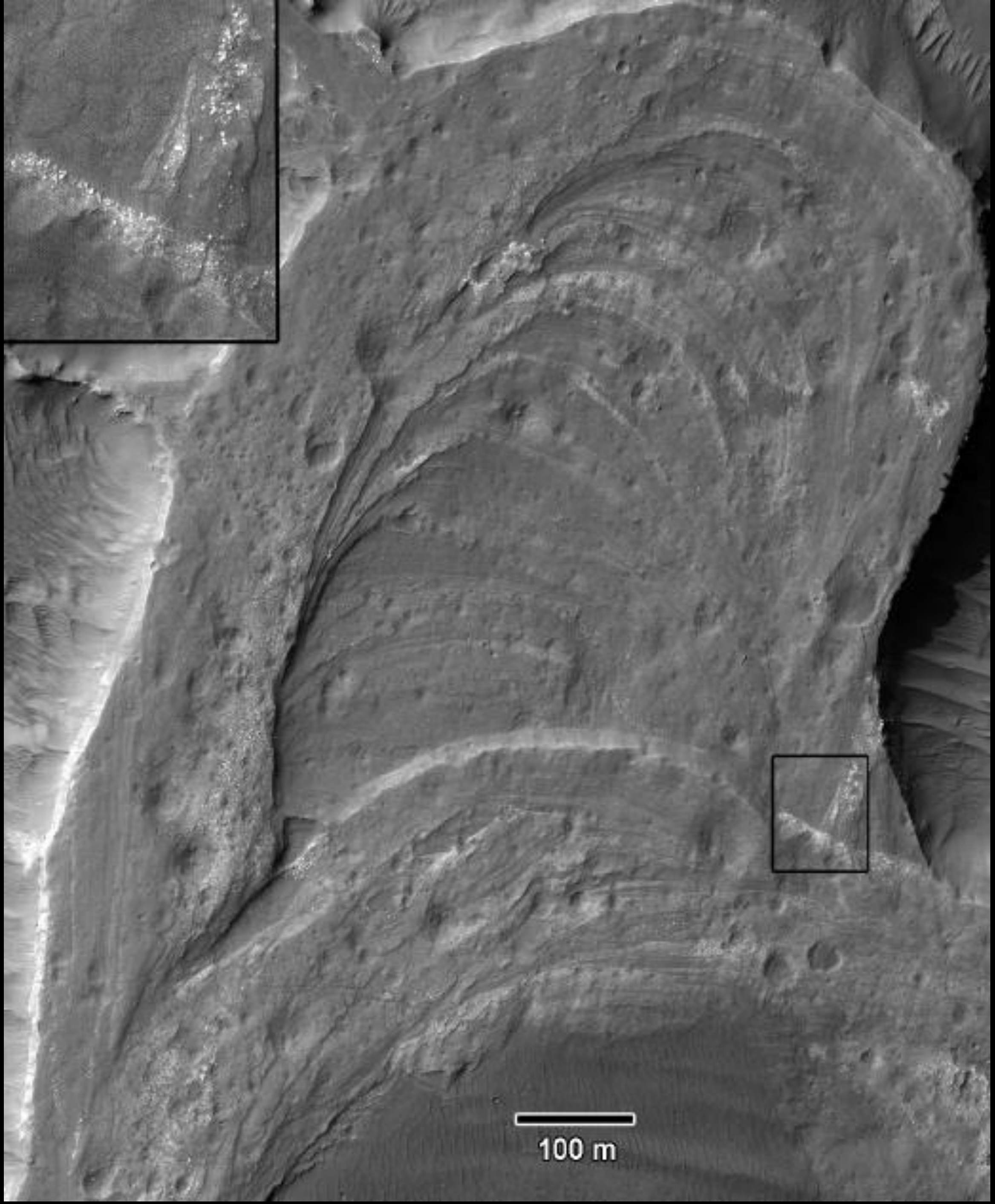
One of the first image of channels on Mars



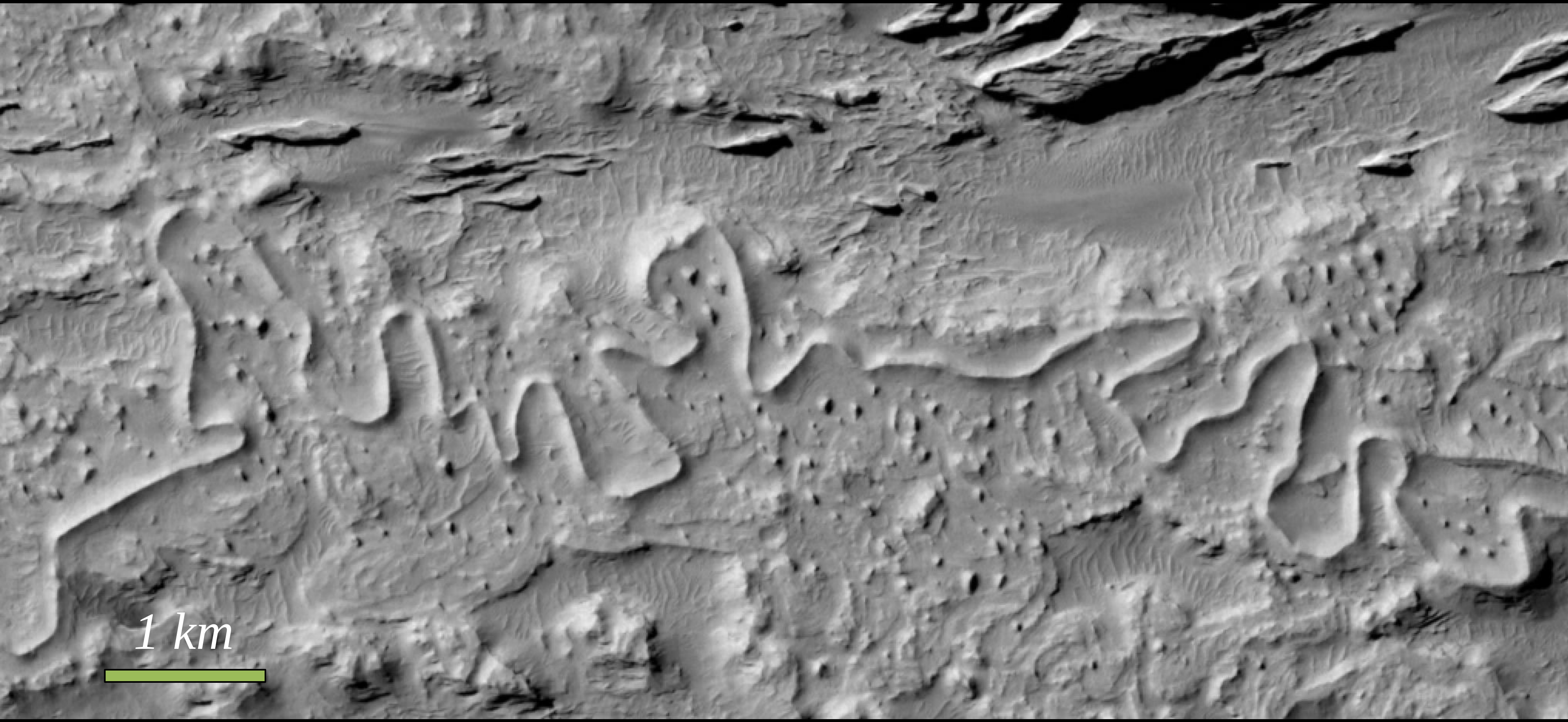
Mariner 9: 1972



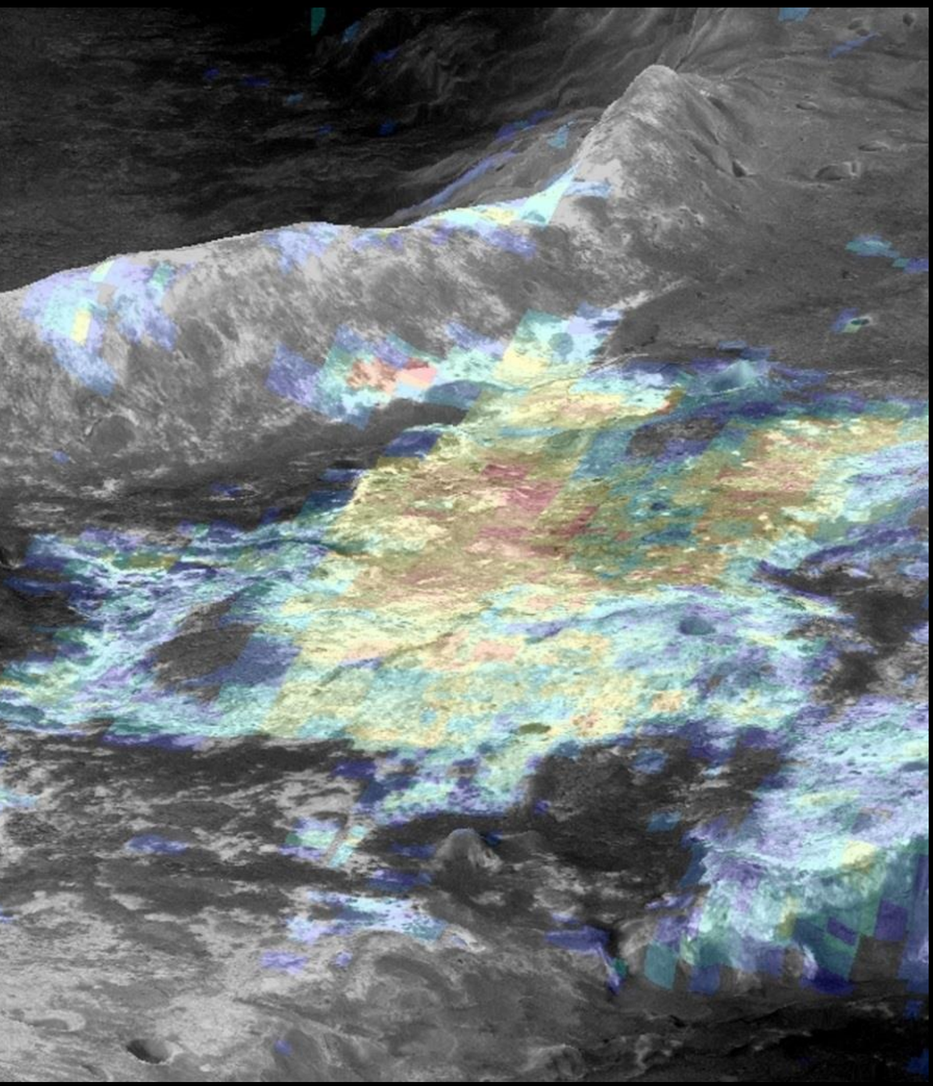

5 km

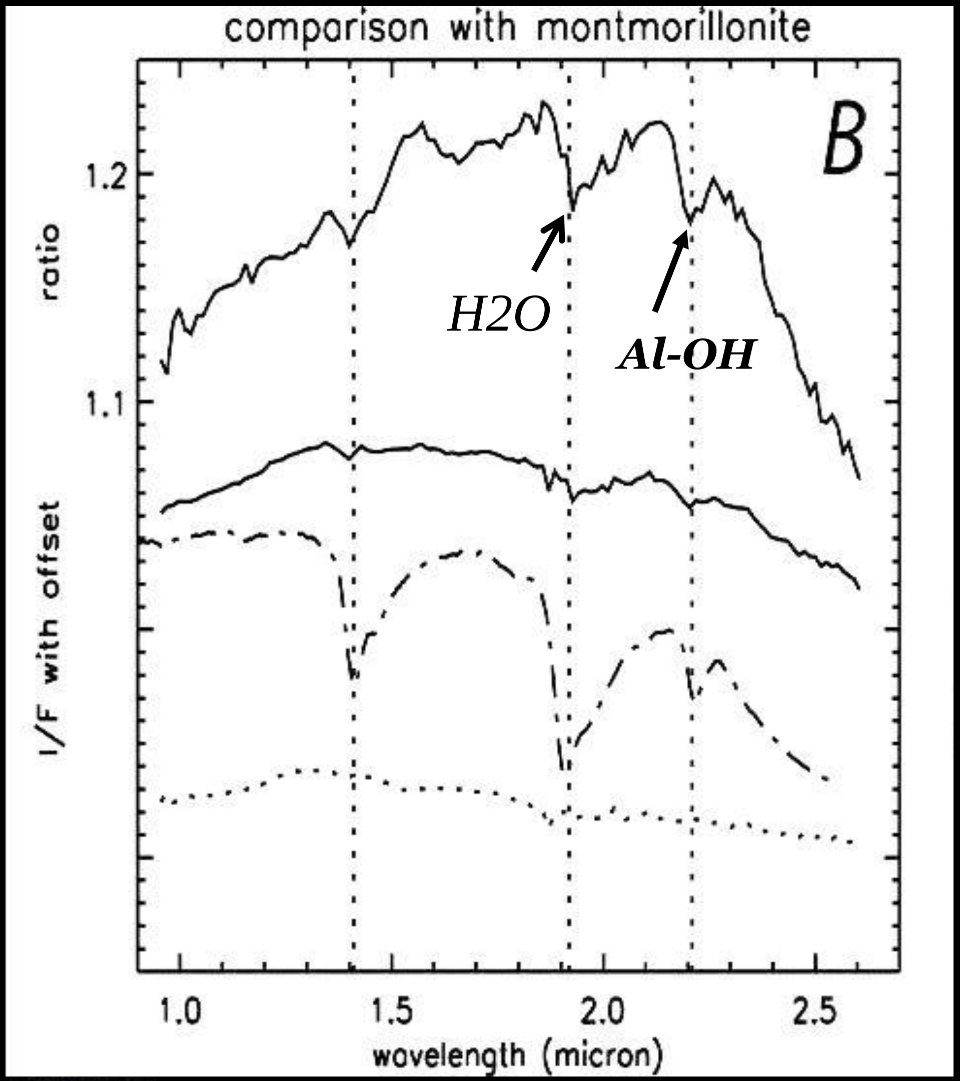

100 m

Meandering inverted channels



Detection of phyllosilicates





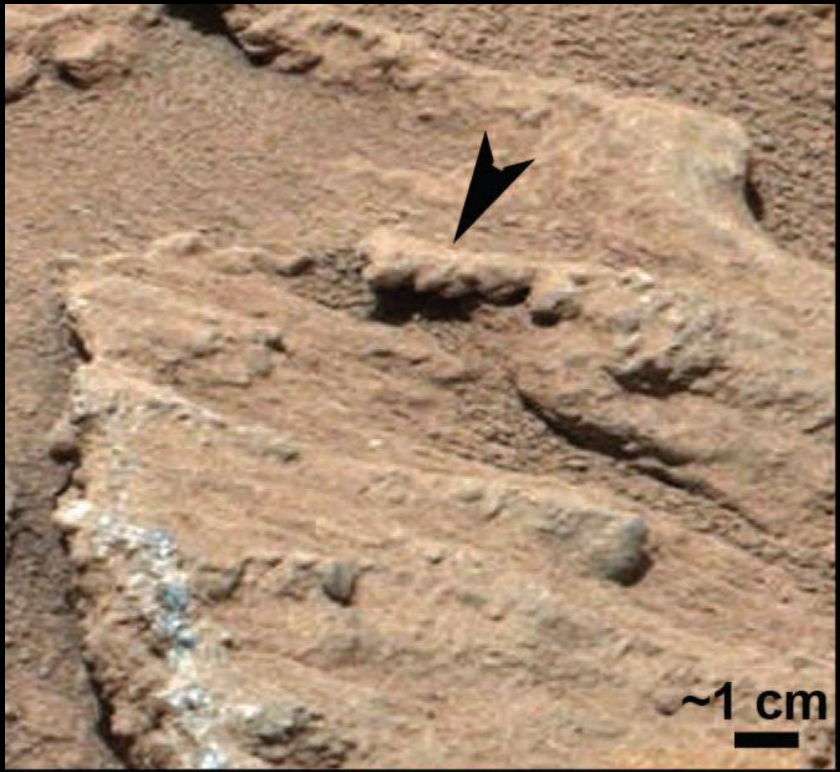
Mars Express OMEGA

NASA/JPL-Caltech/MSSS

Hottah, sol 34

Williams et al., Science, 2013

Earth

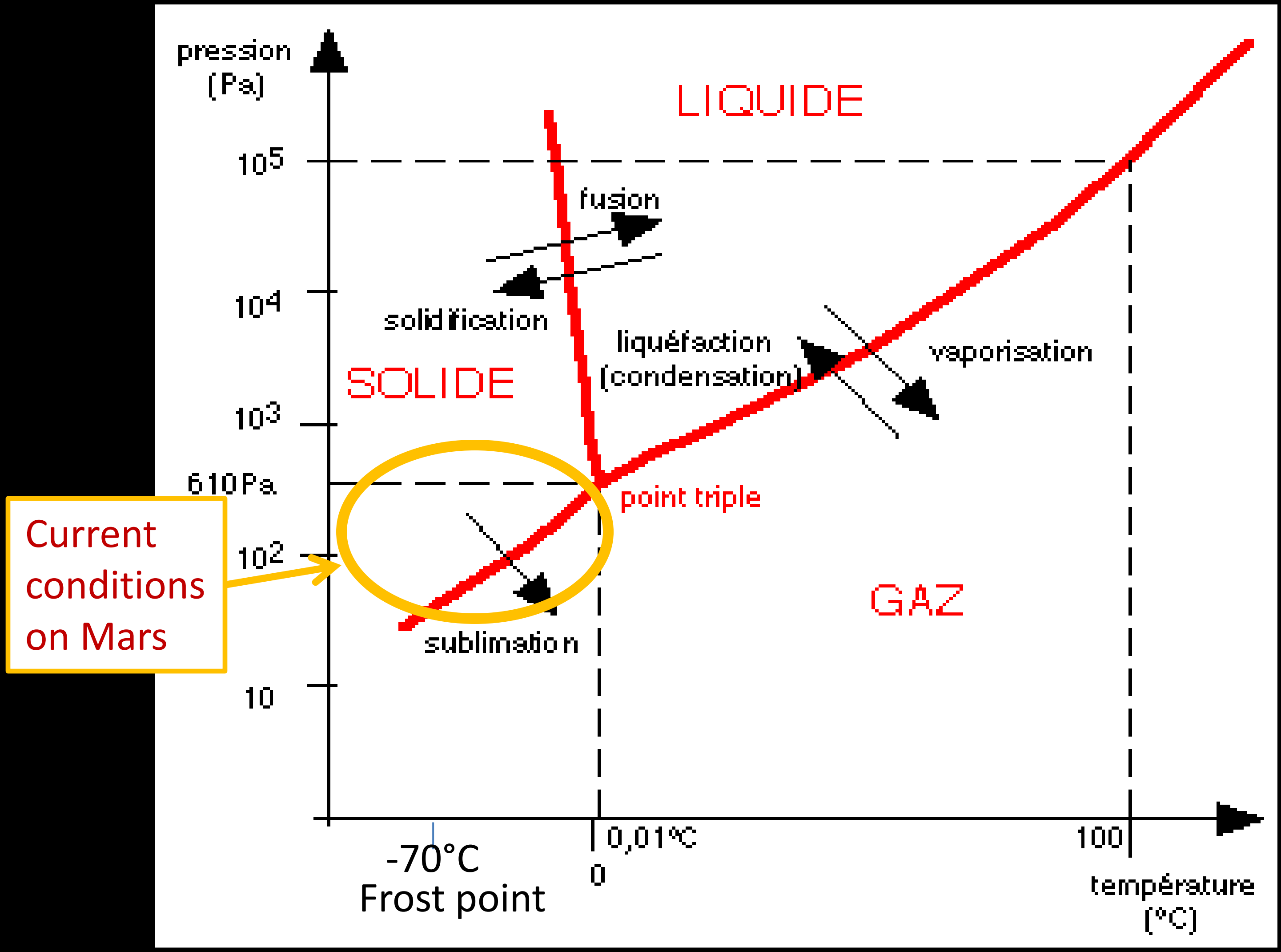


Layering and imbrication of pebbles

Williams et al., Science, 2013

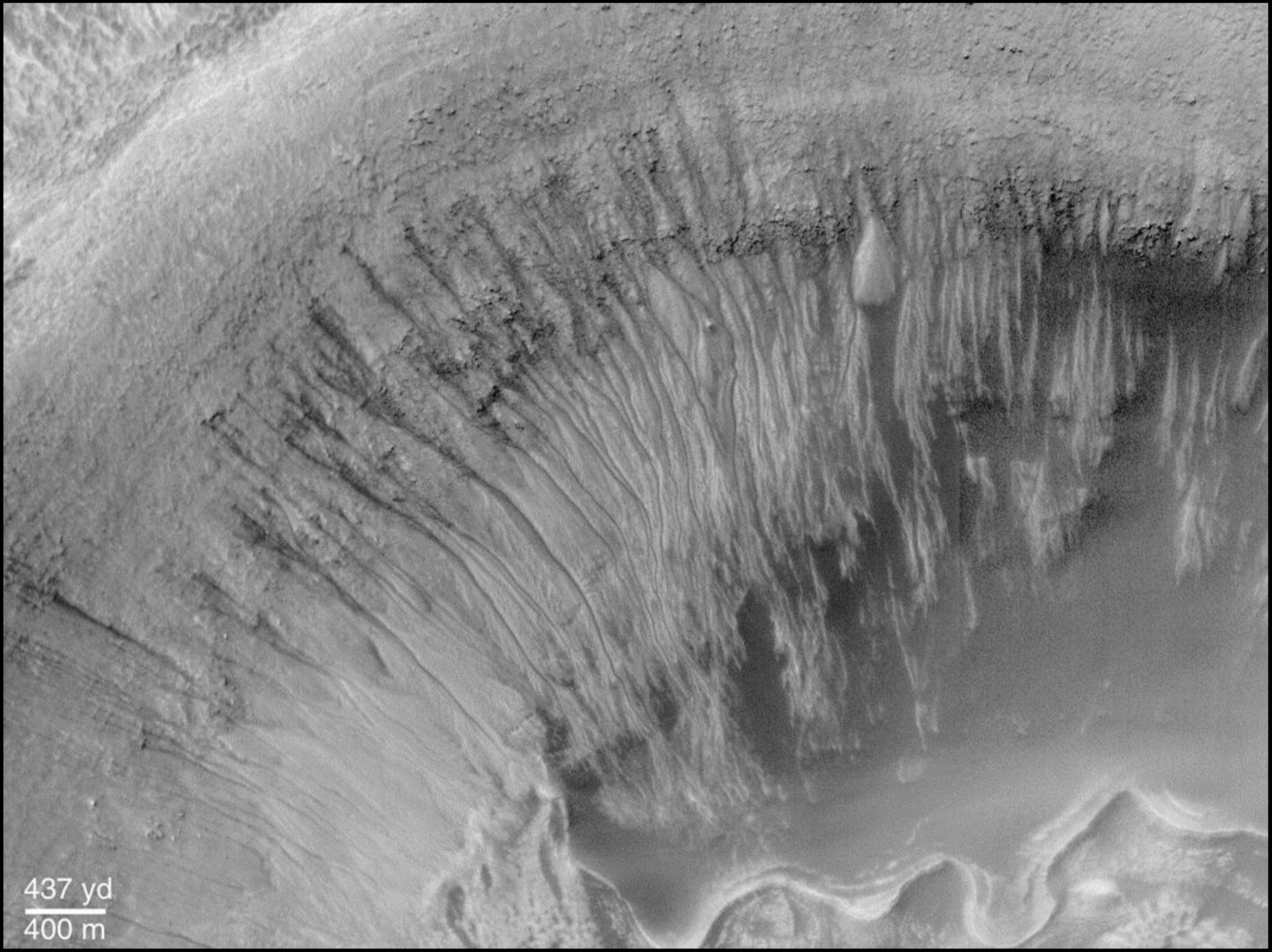
Conditions on current Mars

Liquid water is currently poorly stable

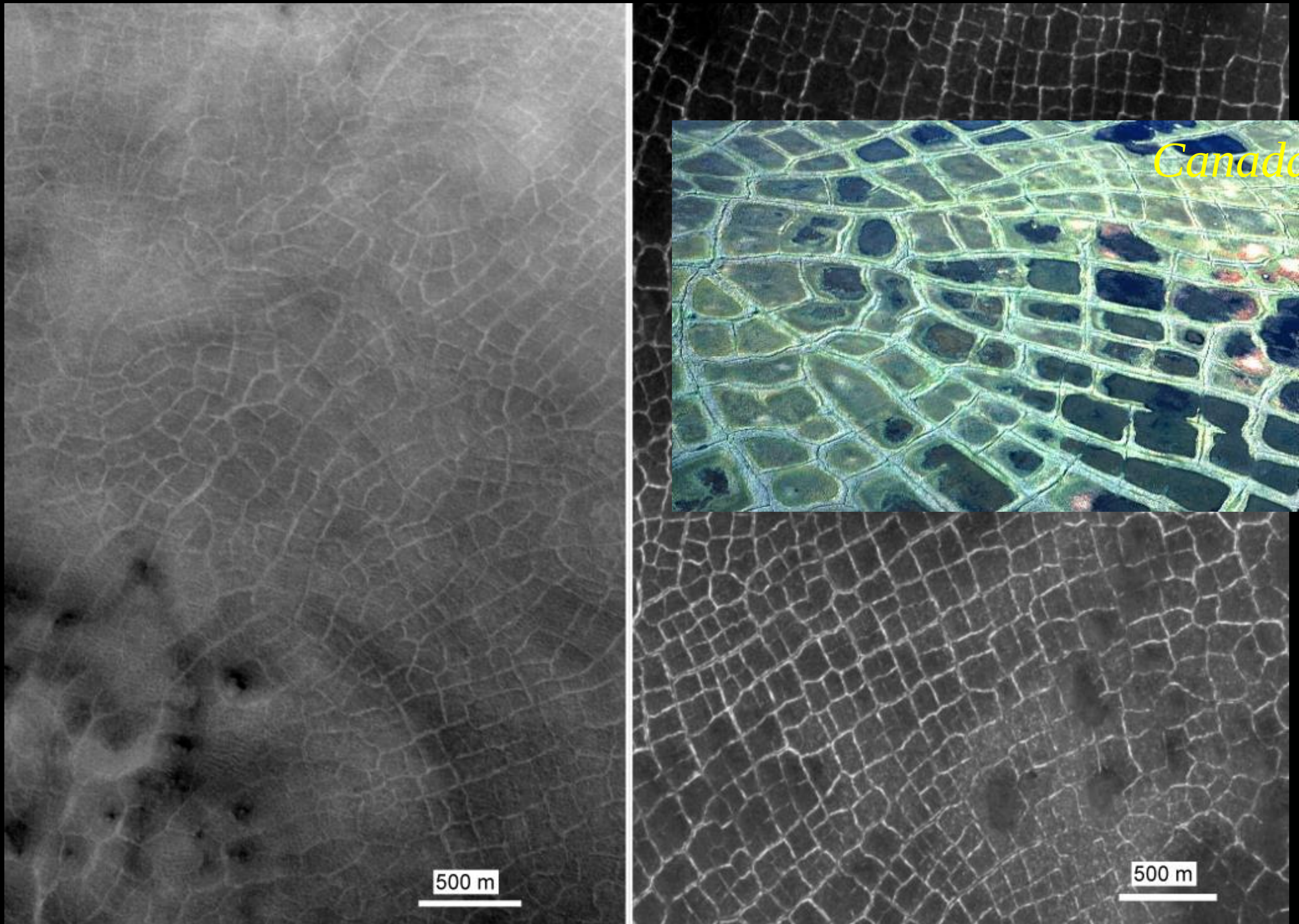


Recent gullies on Mars

Recent gullies discovered by the MOC camera of MGS

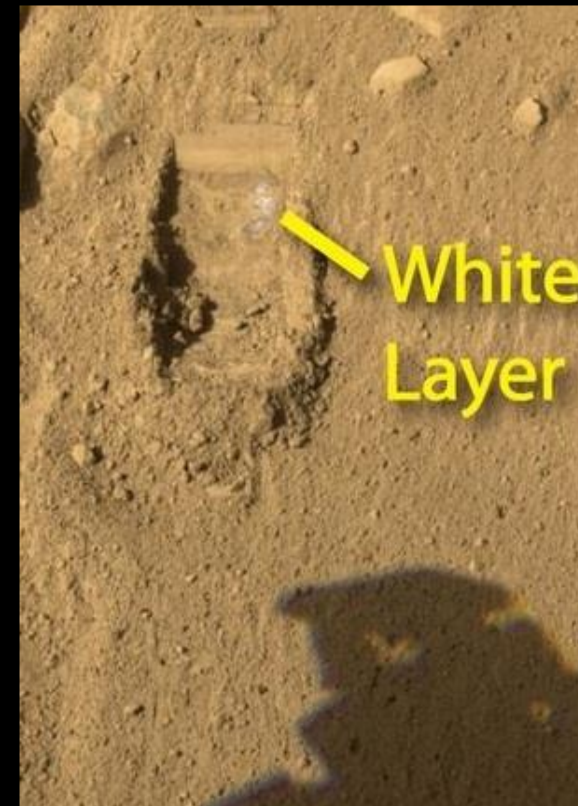


Periglacial polygons

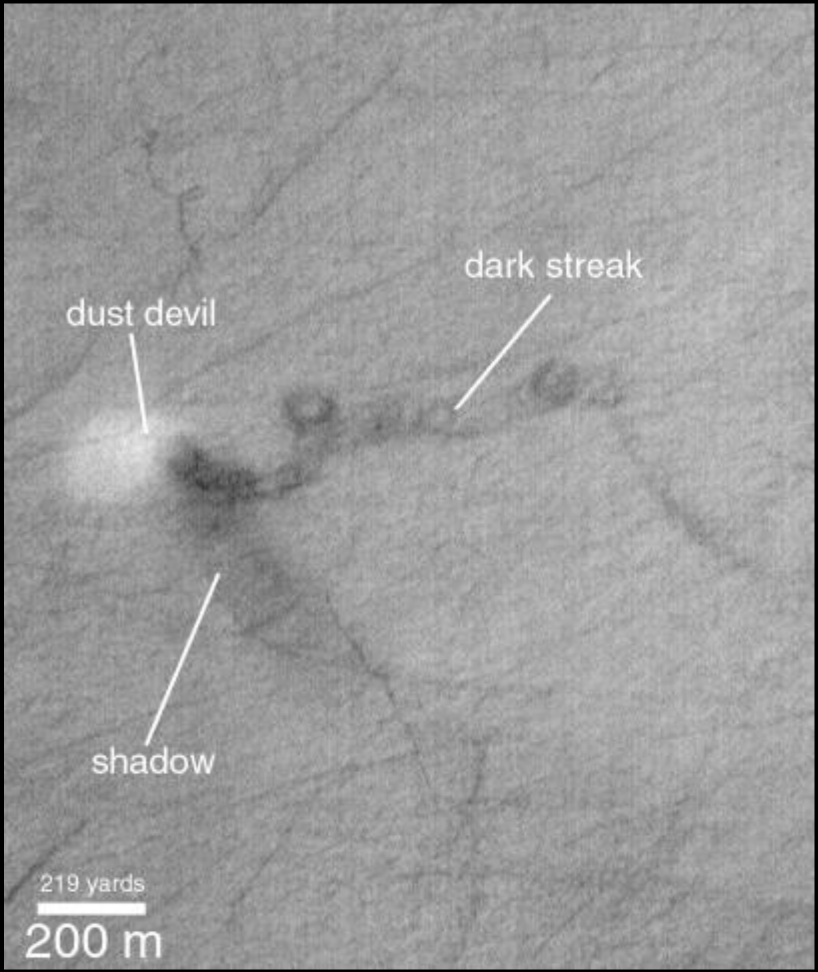


MOC images

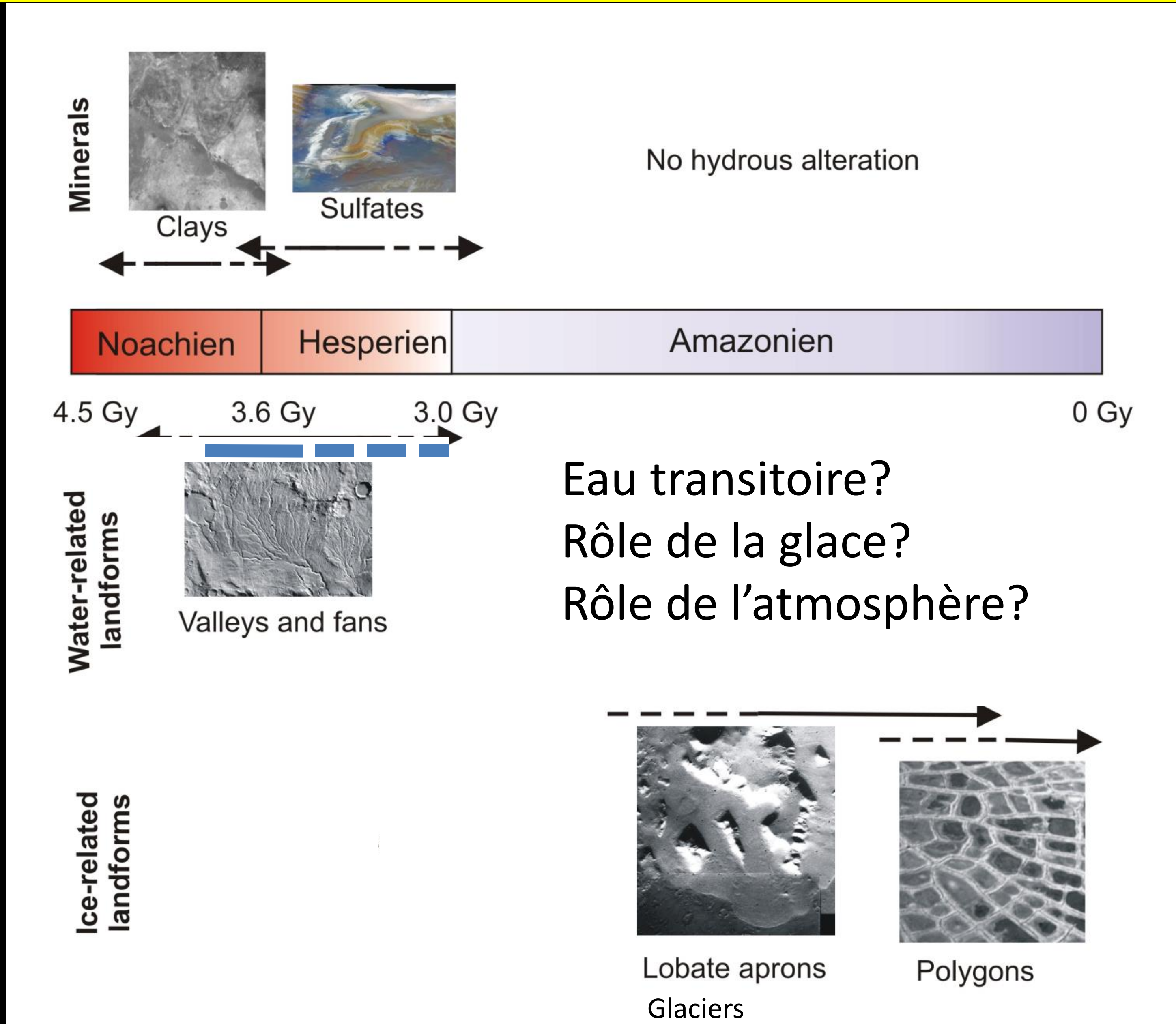

Mars Phoenix, 2008


White
Layer

- Patterns of dark or bright lines are the result of dust devil activity
- They usually remove dust from darker surface



Chronology of water-related landforms and sediments



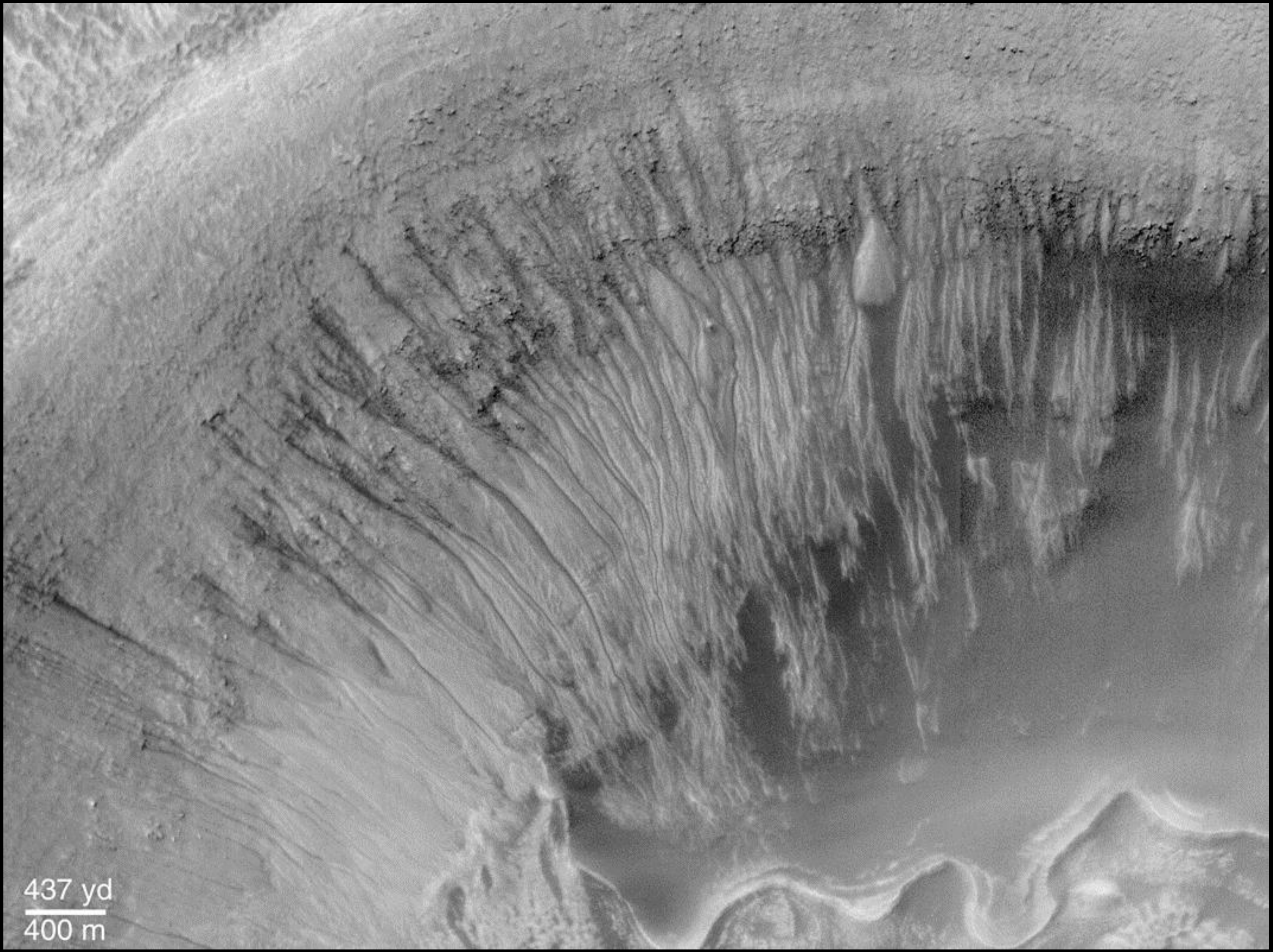
Flows on Mars:
Are they wet or not?

All landforms have been interpreted to be wet once….

Usuaully it is more popular to propose wet processes…

Recent gullies on Mars

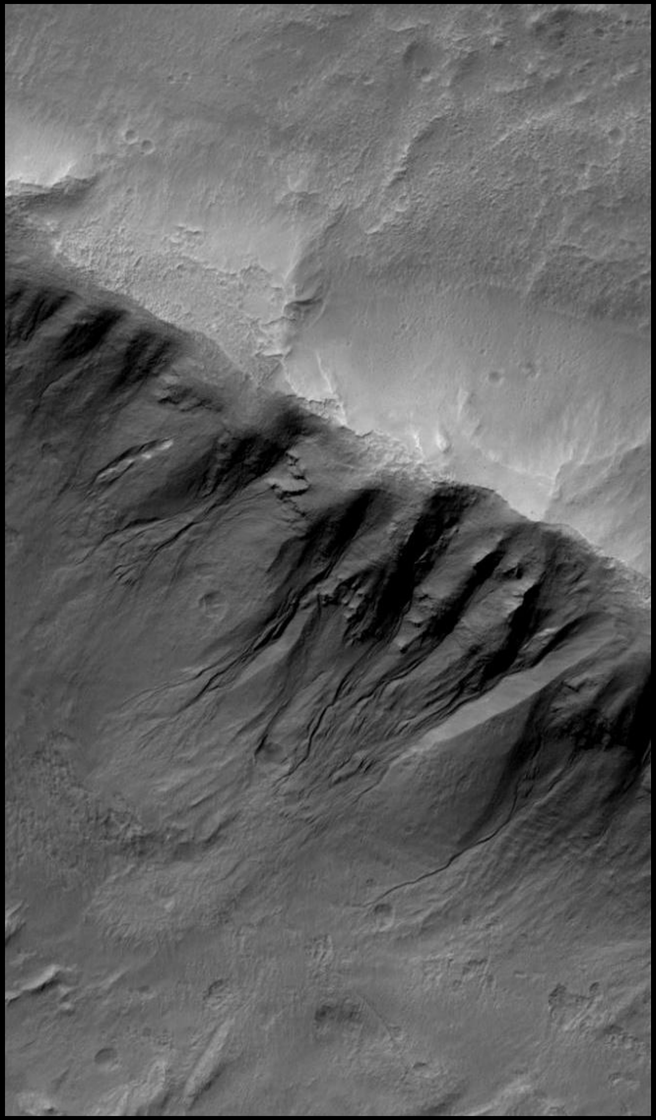
Recent gullies discovered by the MOC camera of MGS



Recent gullies

Malin and Edgett (Science, 2000):
Seepage of water from aquifers

More recent consensus:
Gullies formed by surface processes
(near surface ice/snowmelt due to insolation)
(Costard et al, 2002, Christensen, 2003, etc.)



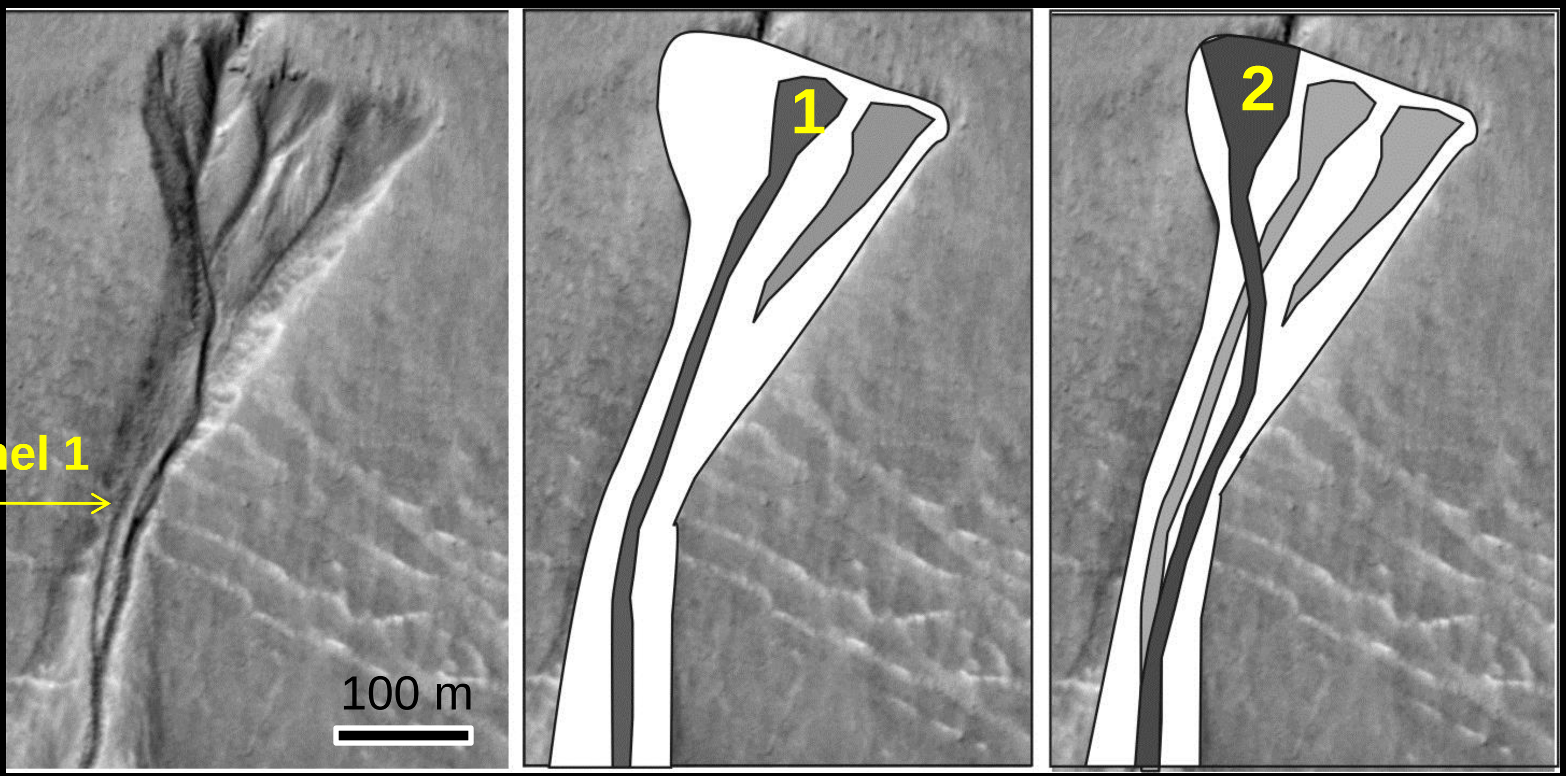
Gullies on isolated hills

Recent gullies: Observations

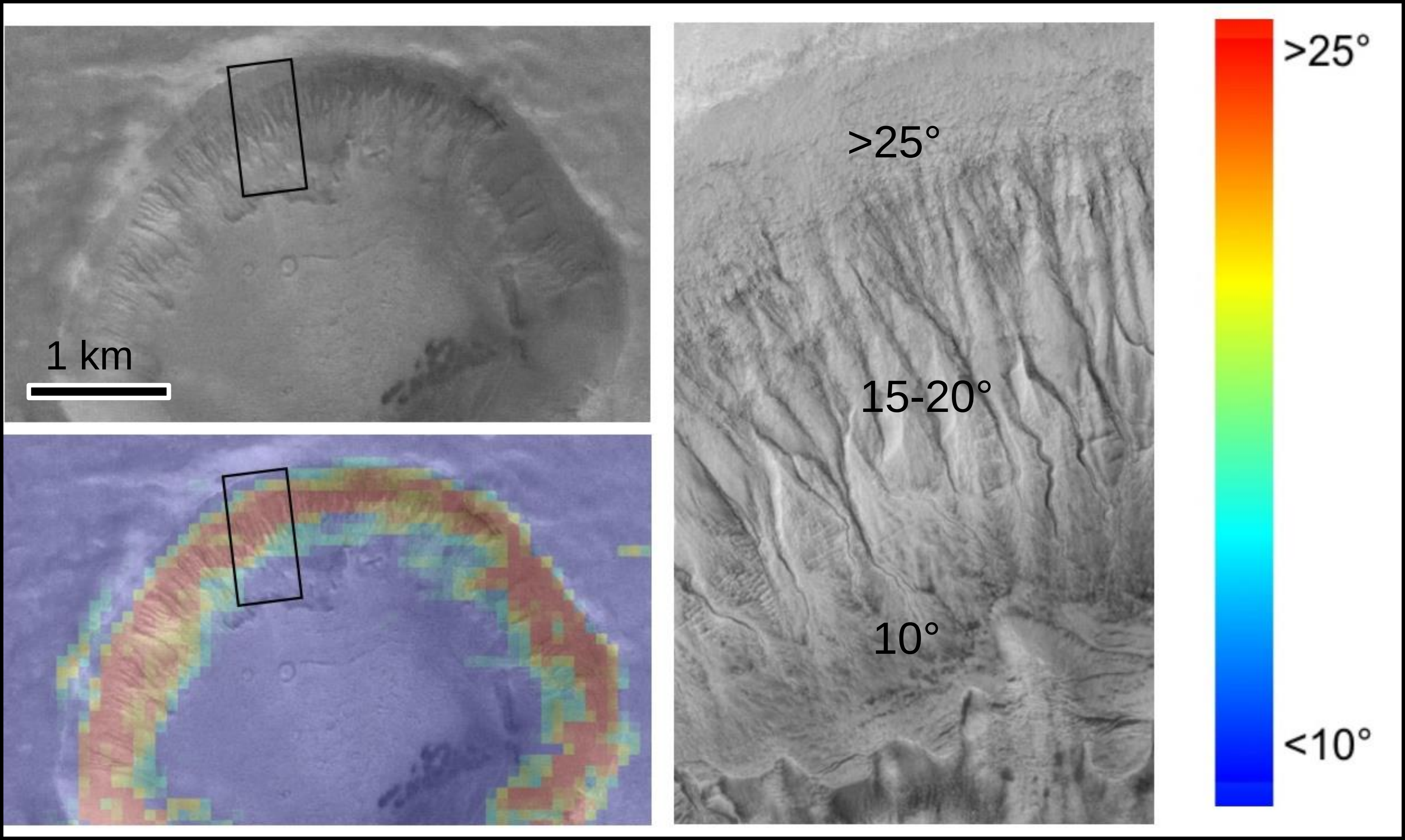
Gullies are episodic : They do not form in simultaneously

The second event crosses the first channel without connecting to it

Channel 1



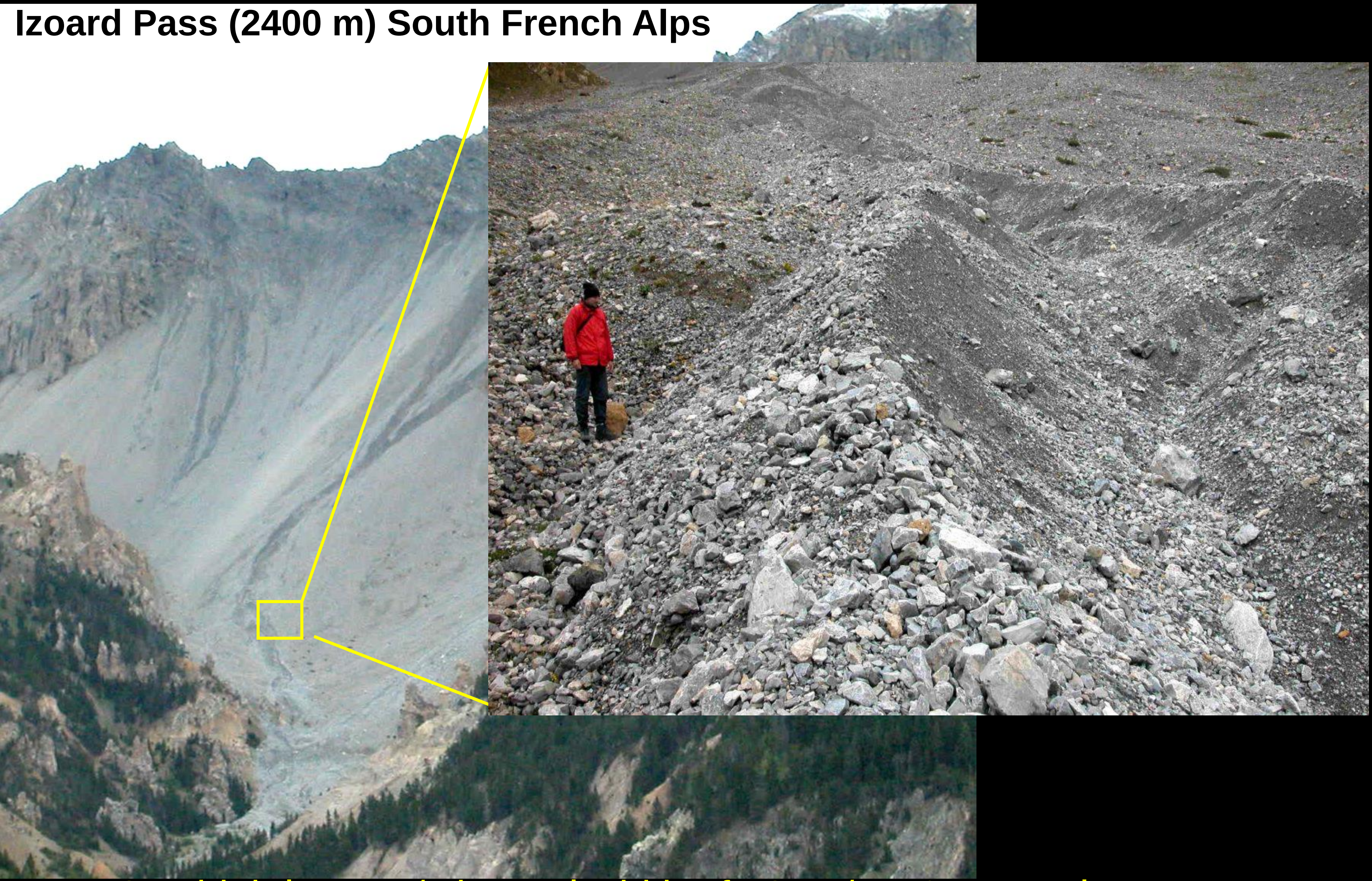
Recent gullies: Slopes



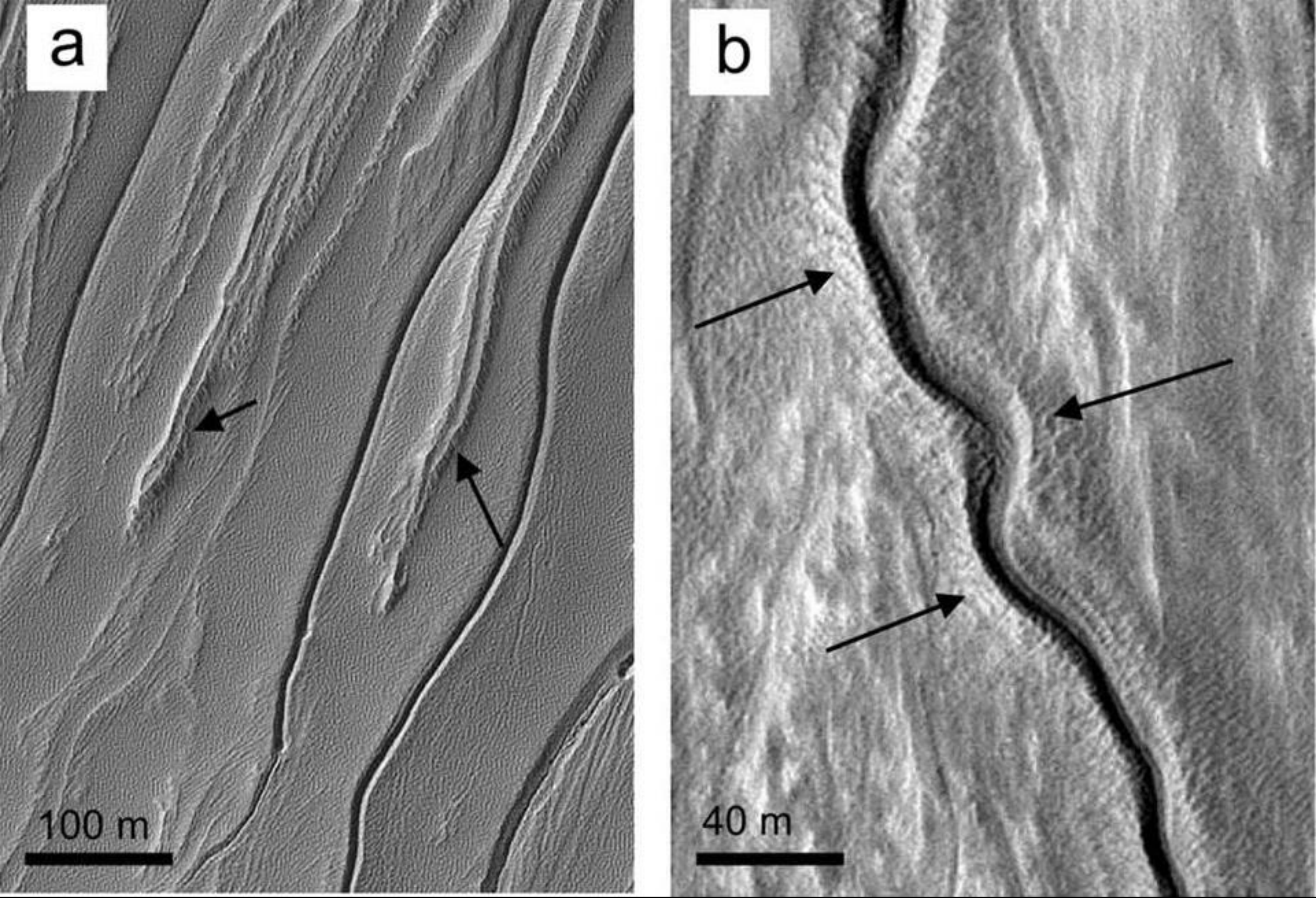
Most of sinuous gullies occur on slope 10 to 25° steep (Kreslavsky, 2008, Reiss et al., 2009, Mangold et al., 2010)

Recent gullies: Terrestrial analogues

Izoard Pass (2400 m) South French Alps

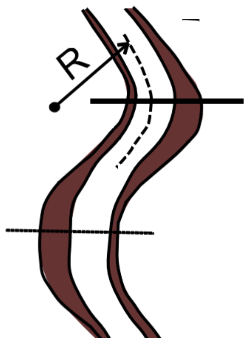


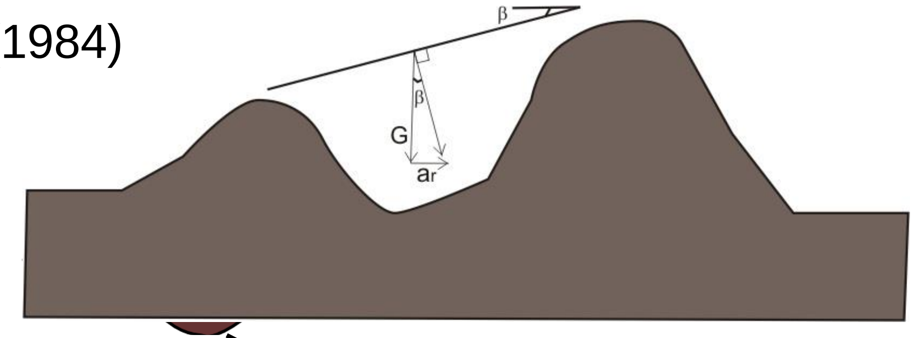
2 m high levees / channel width of 12 m / 15° steep slope


a
100 m
b
40 m

Recent gullies: Velocities

Johnson and Rodine (1984)





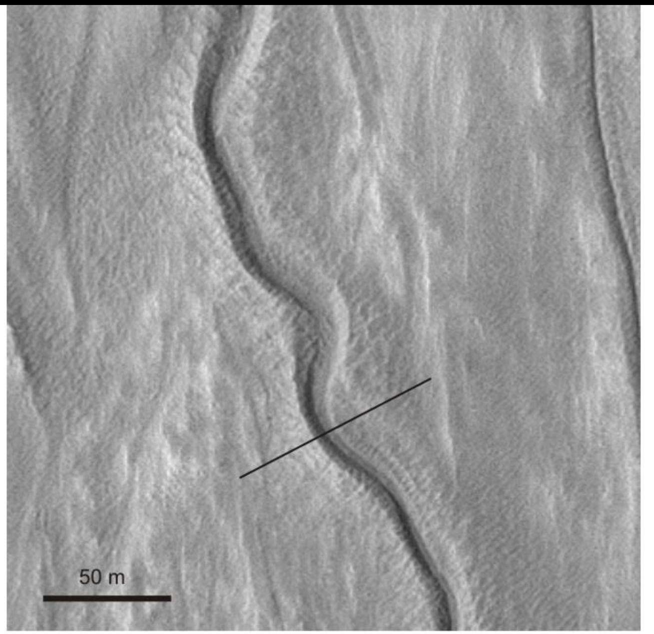
$ar = U^2/R$ → $\tan\beta = ar/G = U^2/(R.g.\cos\alpha)$

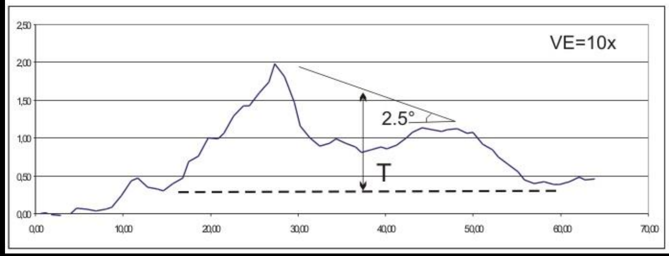
$G = g.\cos\alpha$ → $U = (g.R.\cos\alpha.\tan\beta)^{1/2}$

Mean velocity — Radius of curvature — Slope — Tilt

Tilt β=2.5°
R=25 m
Tflow=1.2 m
Slope α=10° **=>** **V= 2.0 m.s^{-1} μ= 460 Pa.s**

Low velocity, high viscosity



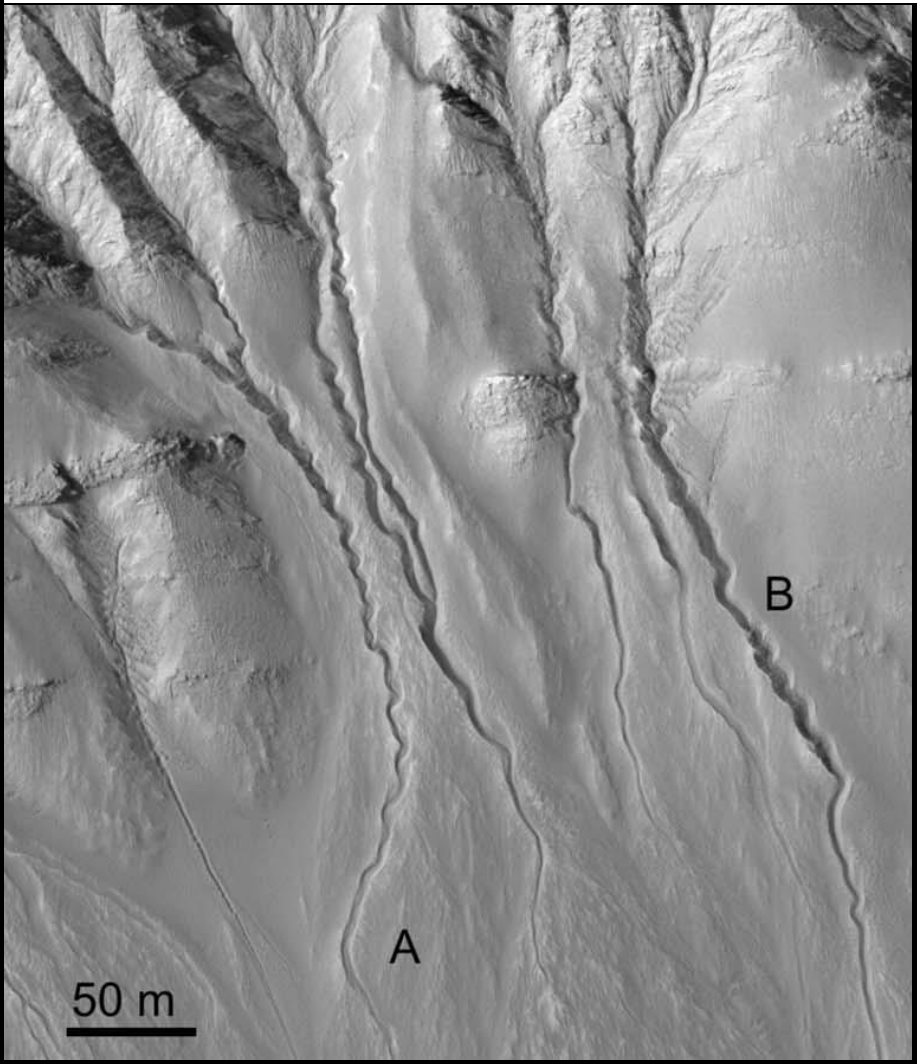


Photoclinometry profile

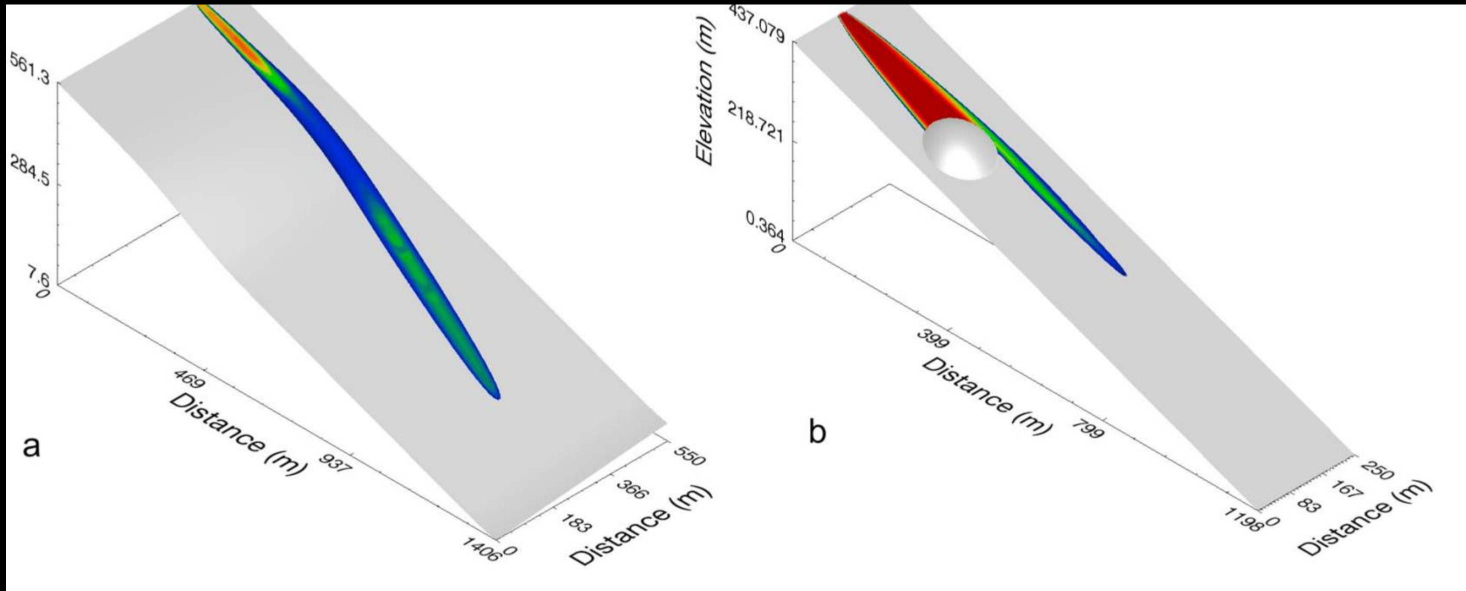
Mangold et al., 2003

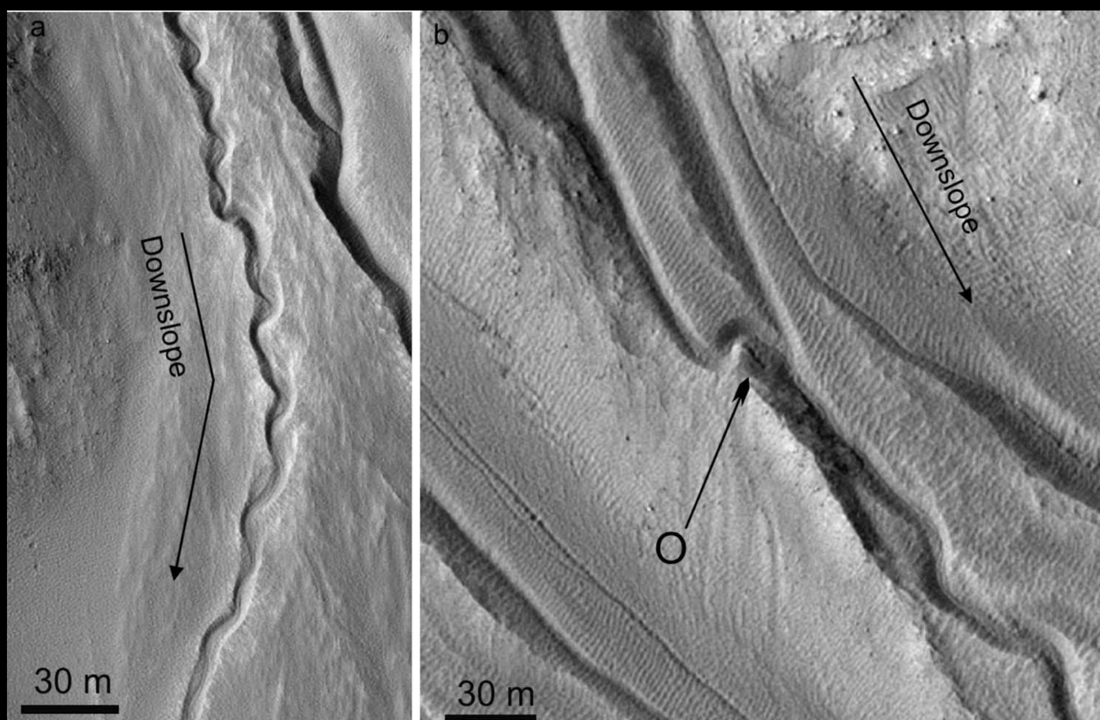
Sinuous gullies on Mars: Frequency, distribution, and implications for flow properties

N. Mangold,[1] A. Mangeney,[2] V. Migeon,[1] V. Ansan,[1] A. Lucas,[2] D. Baratoux,[3] and F. Bouchut[4]



Sinuous channel: Usually not observed for granular flows

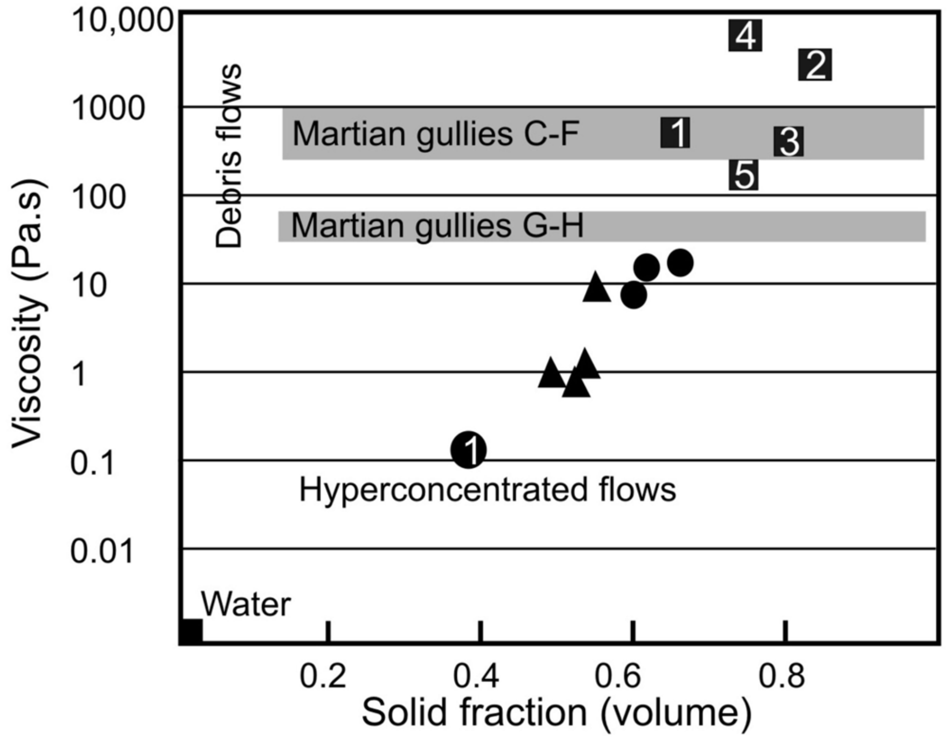




Mangold et al., 2010

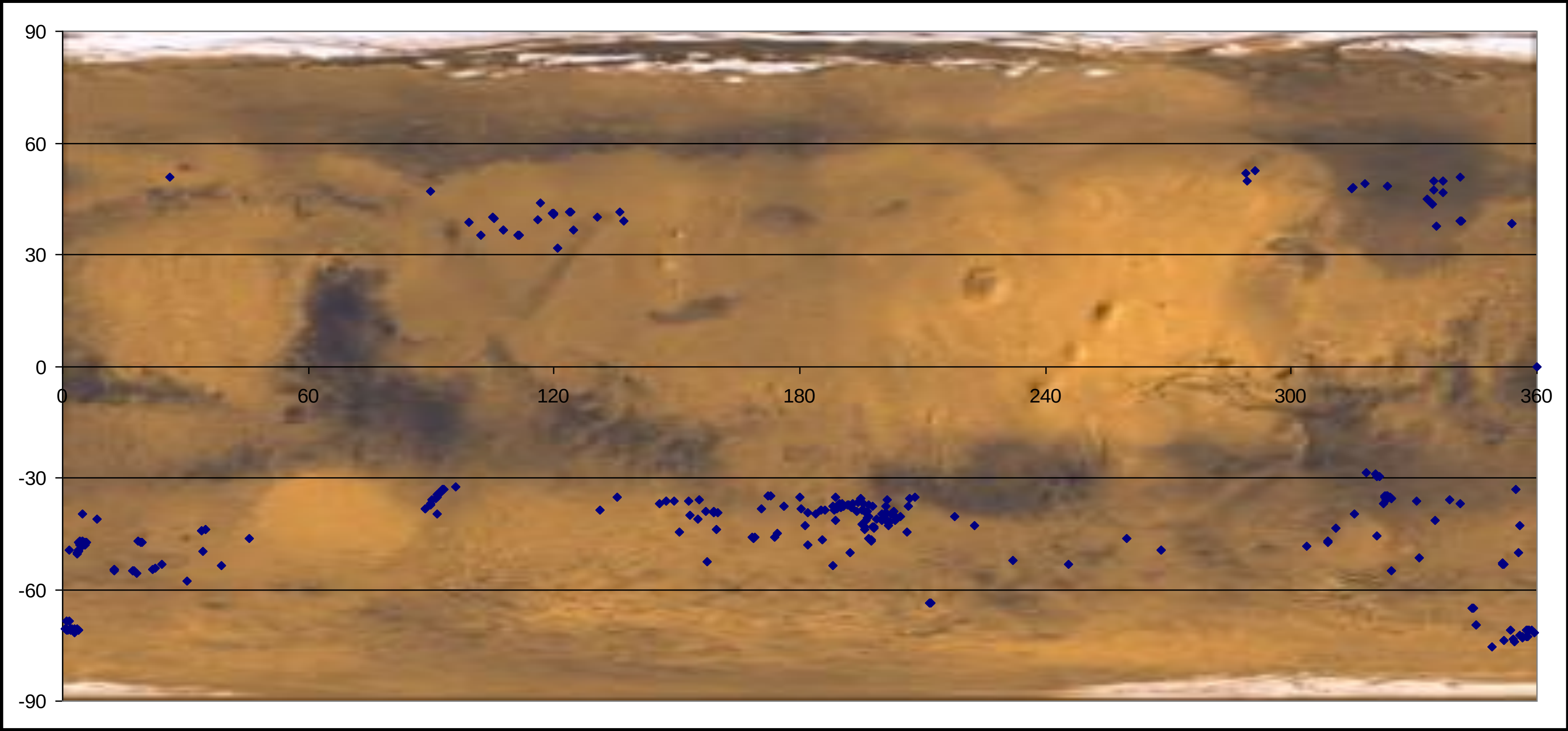
Table 1. Physical Properties of Gullies Using Profiles in Figure 13

Profile	Yield Strength, K (Pa)	Velocity, V (m s^{-1})	Viscosity, μ (Pa s)
A	2200	–	–
B	<120	–	–
C	1800	2.0	460
D	840	1.9	1040
E	1900	1.1	290
F	1100	1.7	450
G	840	3.3	95
H	380	2.6	40

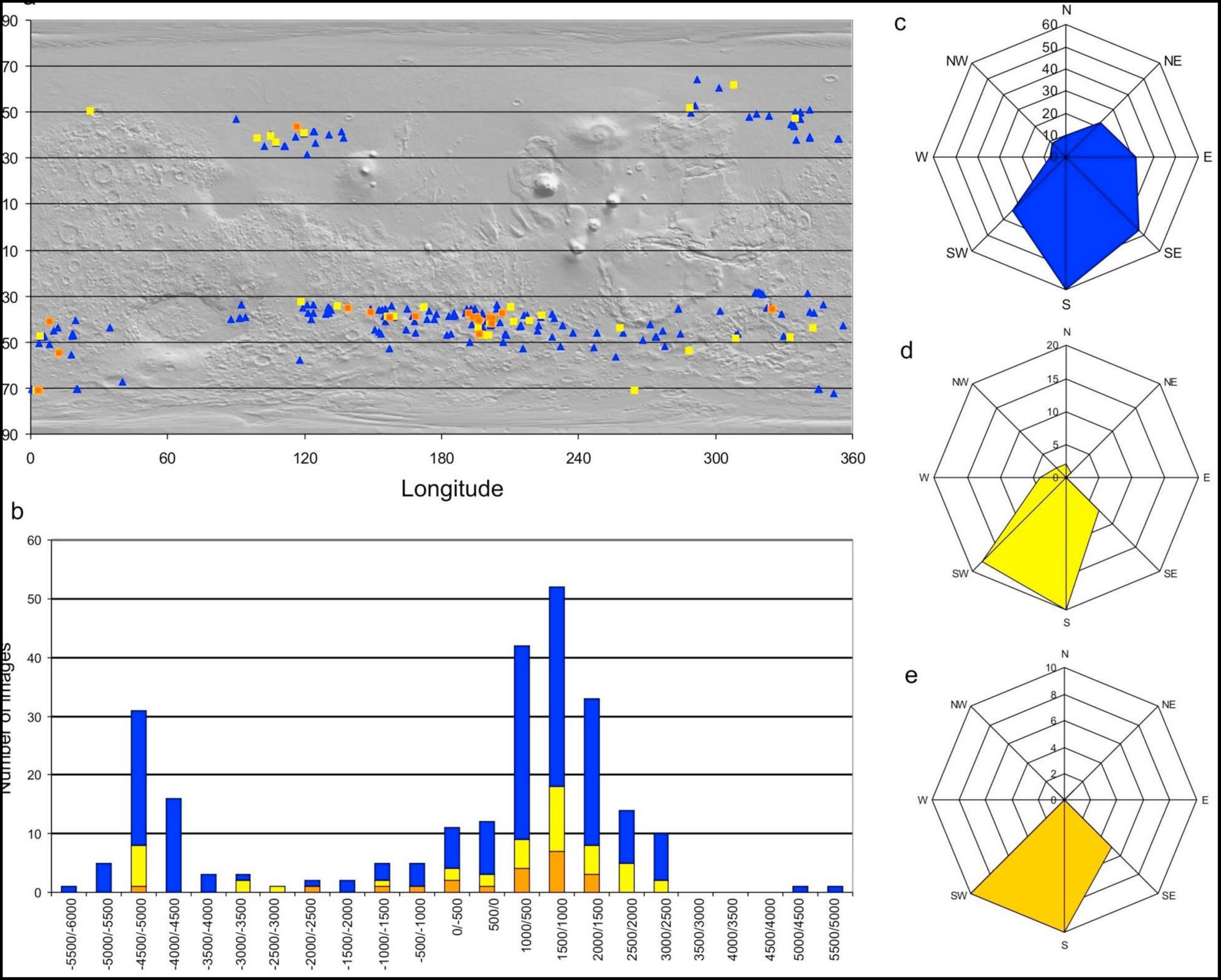


Recent gullies: Geographic distribution

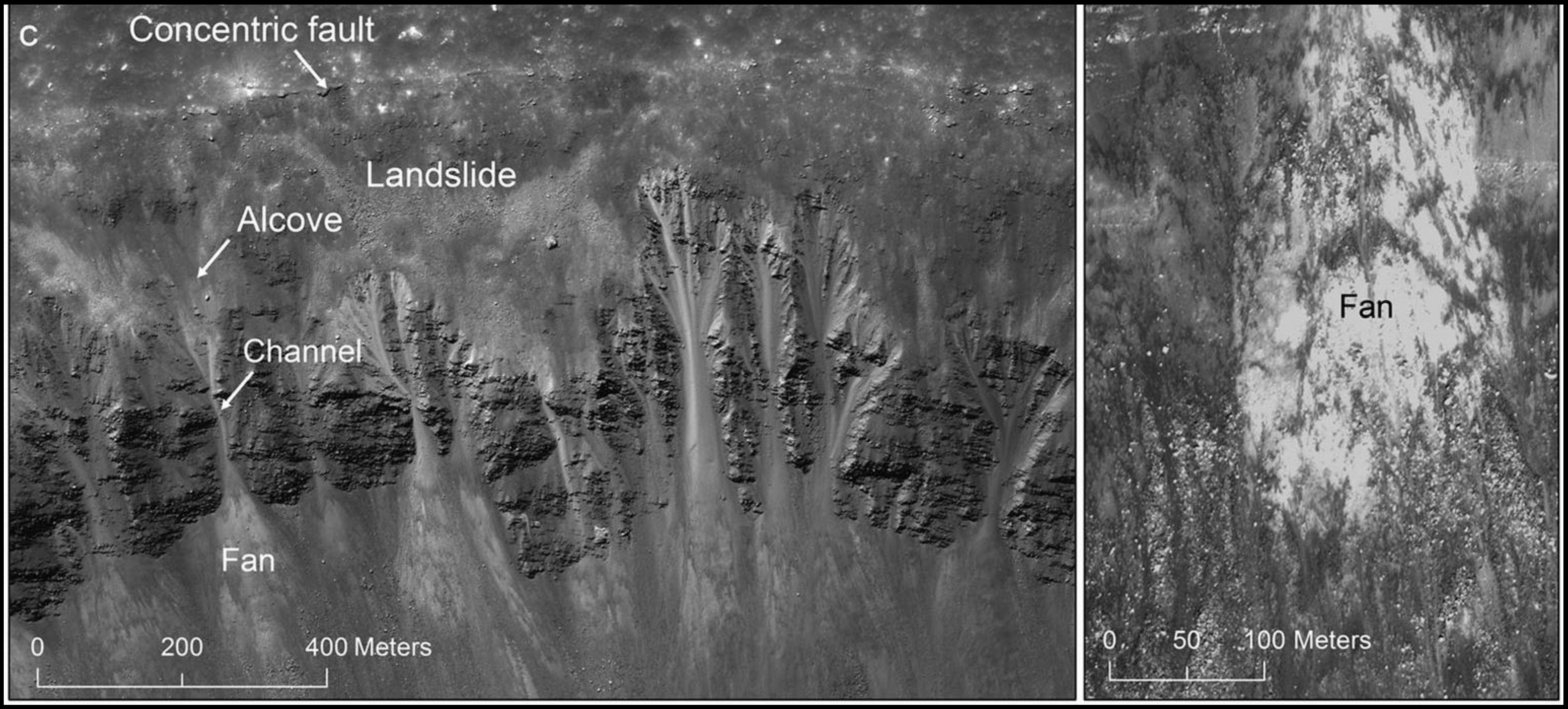
Distribution latitude > 30 N and 30 S
No equatorial flows



Presence in latitude range where many ice related features exist



a
90
70
50
30
10
10
30
50
70
90
0
60
120
180
240
300
360
Longitude
b
Number of images
60
50
40
30
20
10
0
-5500/-6000
-5000/-5500
-4500/-5000
-4000/-4500
-3500/-4000
-3000/-3500
-2500/-3000
-2000/-2500
-1500/-2000
-1000/-1500
-500/-1000
0/-500
500/0
1000/500
1500/1000
2000/1500
2500/2000
3000/2500
3500/3000
4000/3500
4500/4000
5000/4500
5500/5000
c
N
NE
E
SE
S
SW
W
NW
60
50
40
30
20
10
0
d
N
NE
E
SE
S
SW
W
NW
20
15
10
5
0
e
N
NE
E
SE
S
SW
W
NW
10
8
6
4
2
0



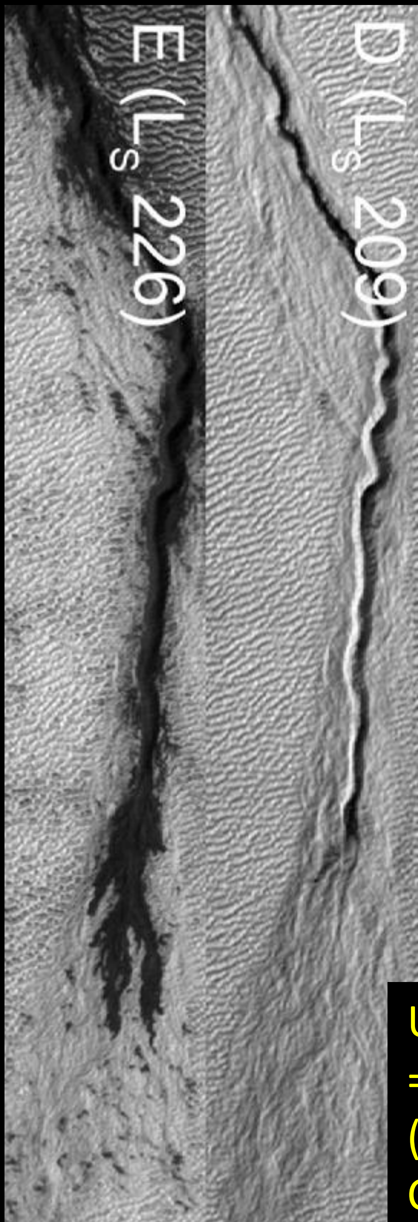
Examples on the moon:

Dry granular flows can explain these flows

Very different from the Martian gullies

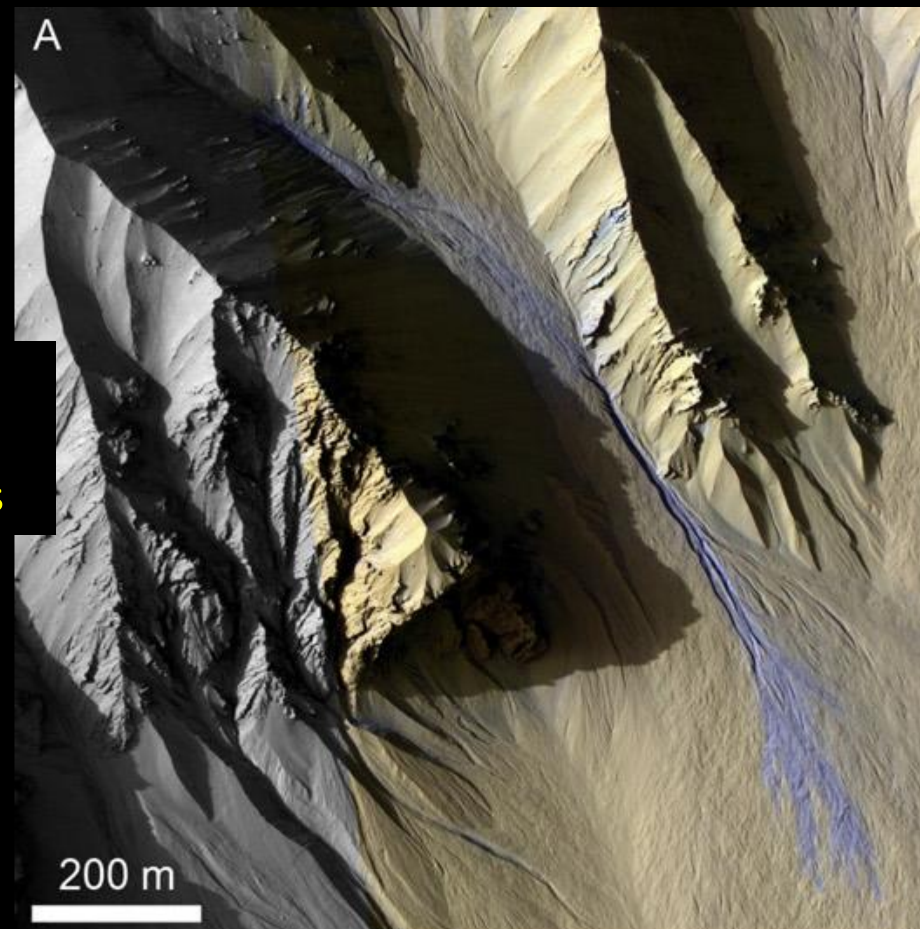
No large levees, no deep channels, no sinuosities

Recent and current landforms: Gullies



<= Currenlty forming gullies on dunes (Dundas et al., 2012)

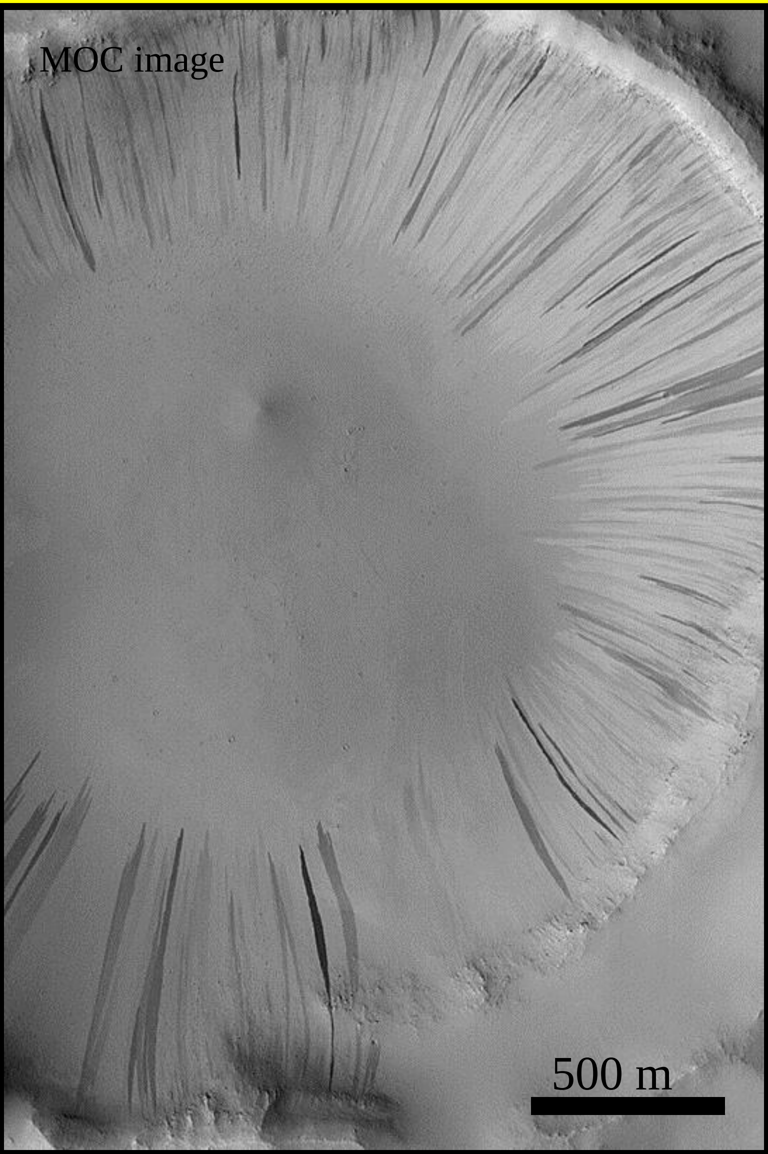
Activity in gullies over bedrock
(Dundas et al., 2012)

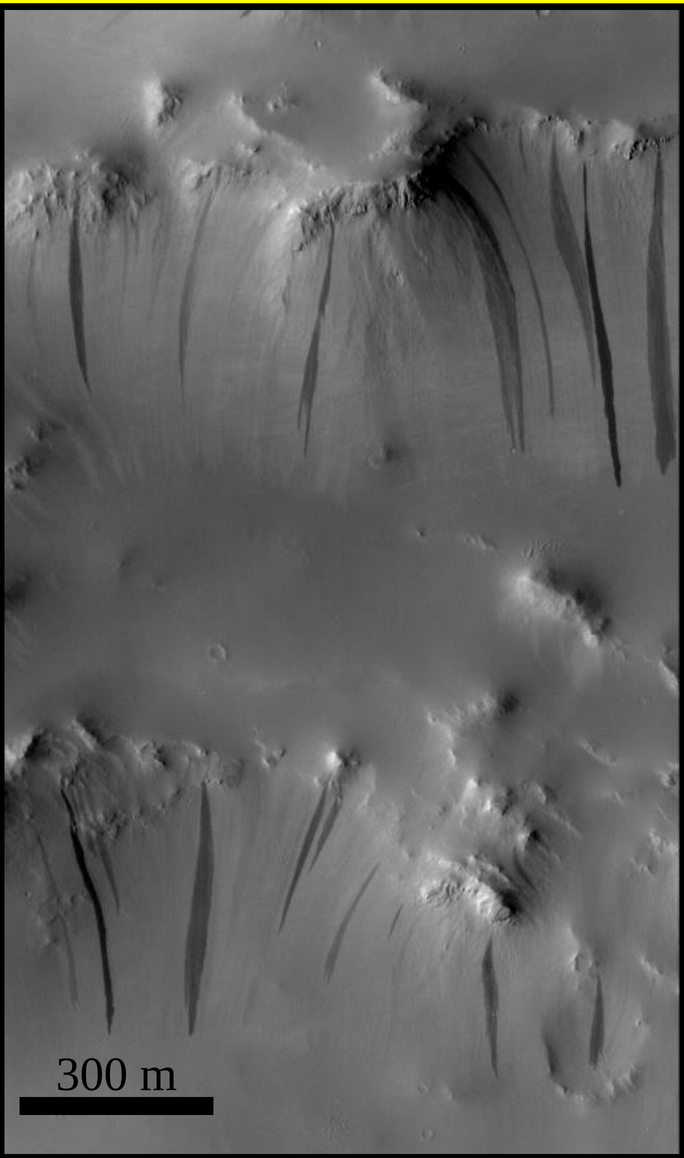


May not explain
all the erosion
not channeled flows

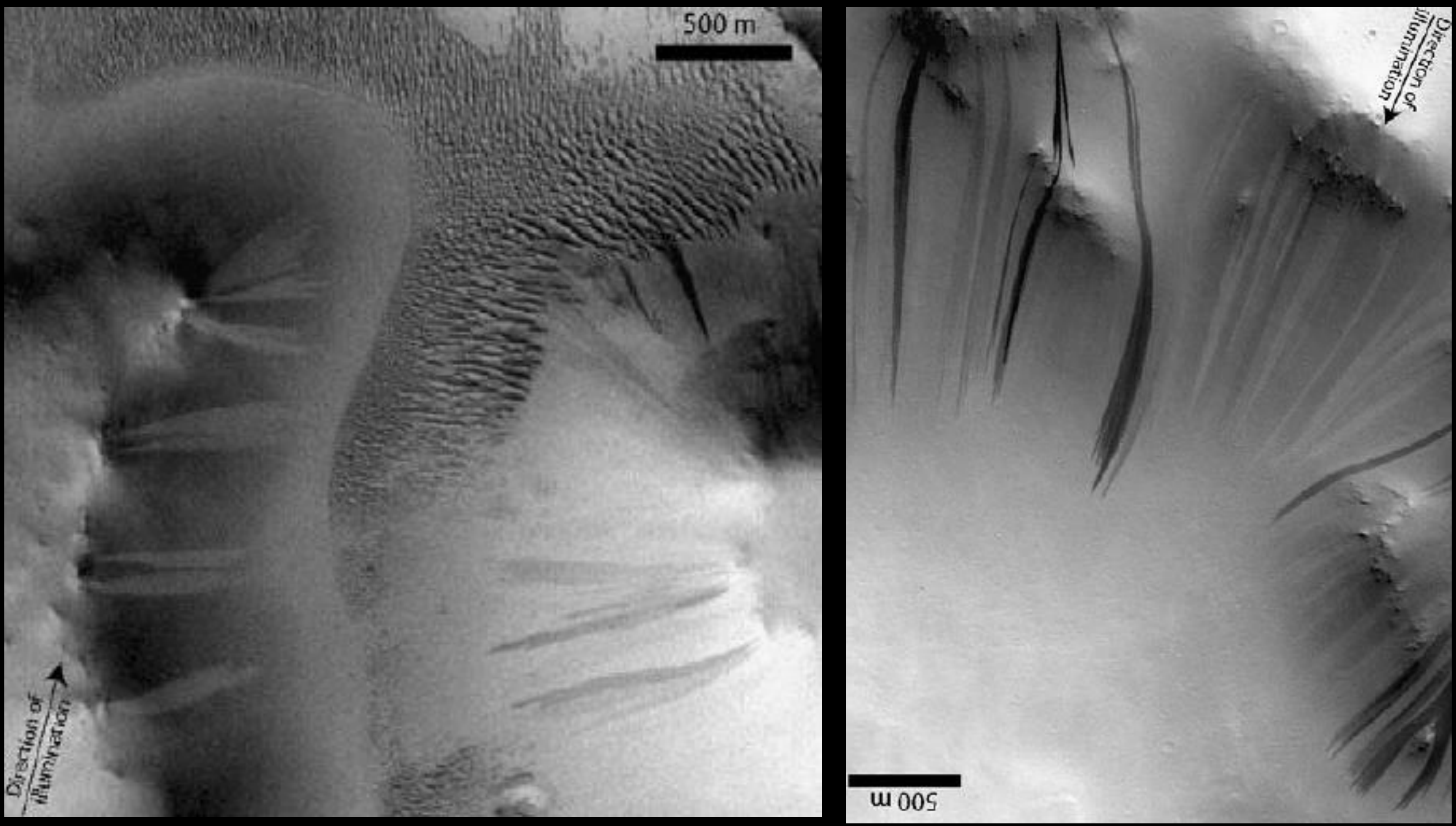
Usually seen at defrosting
=> Related to CO2 ice
(does not mean these are
CO2 ice flows)

Slope streaks: Dark or bright streaks associated to hillslopes





Slope streaks in Arabia Terra



500 m
Direction of illumination
500 m
Direction of illumination

- Slope streaks: Dark or bright streaks associated to hillslopes

Slope streaks are correlated with low thermal inertia regions (means dust rich regions)

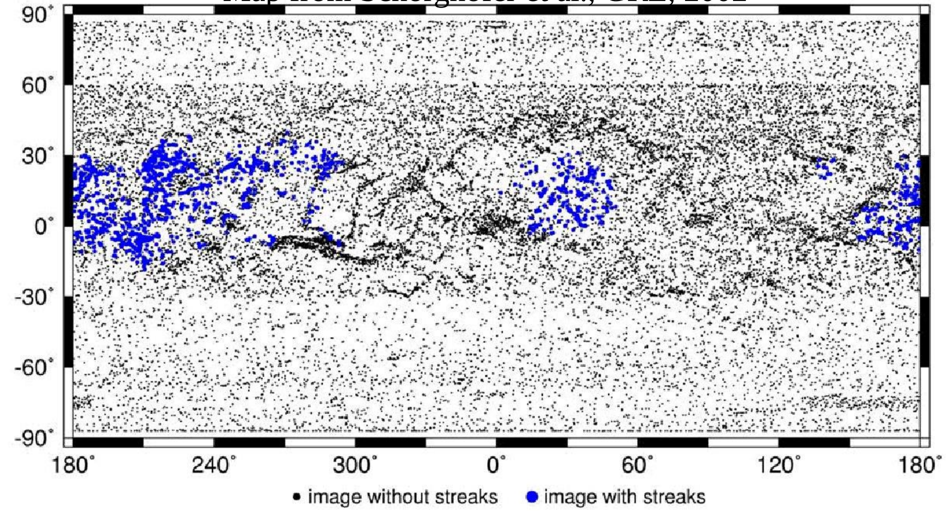
The origin of these features is debated:

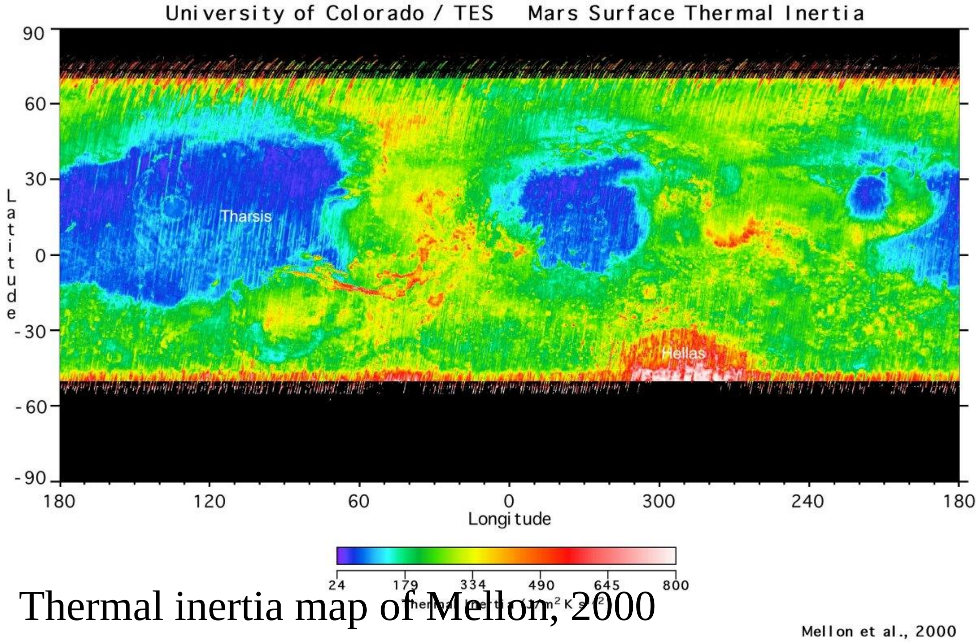
* Pure dry mass wasting hypotheses
(Sullivan, JGR, 2001)
Analogue to snow avalanches

* Downslope water flow
(Motazedian, LPSC, 2003, Miyamoto et al., 2004)

But equatorial features occur where liquid water is strongly instable

Map from Schorghofer et al., GRL, 2002

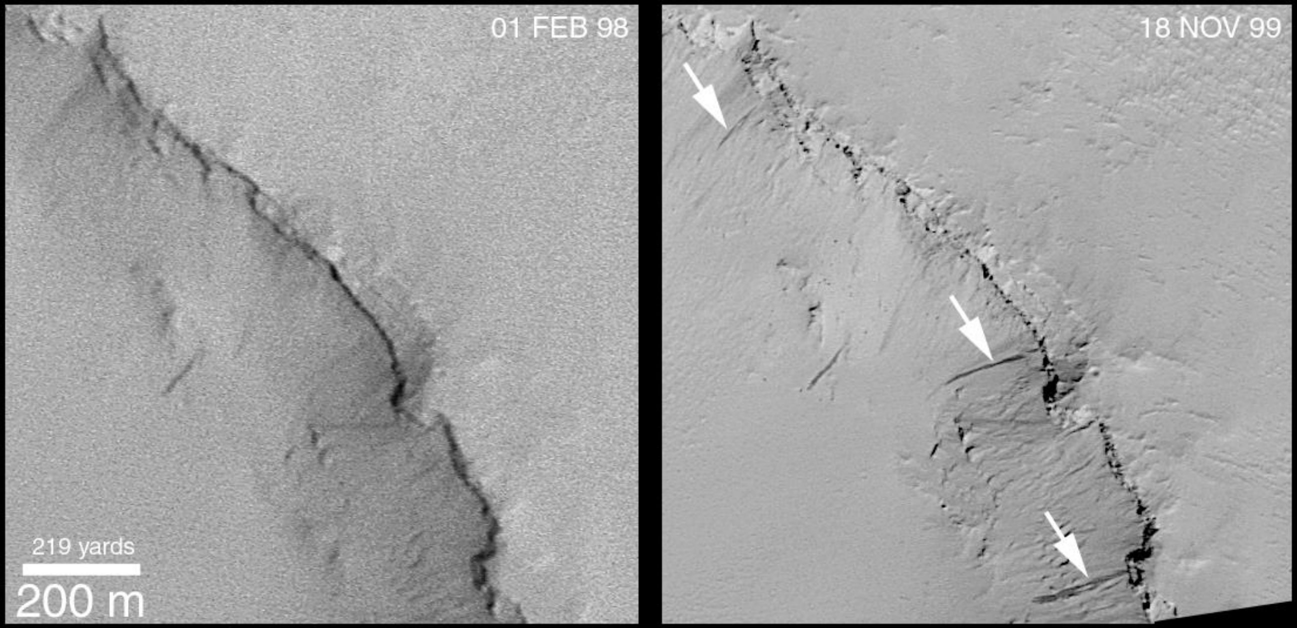




Thermal inertia map of Mellon, 2000

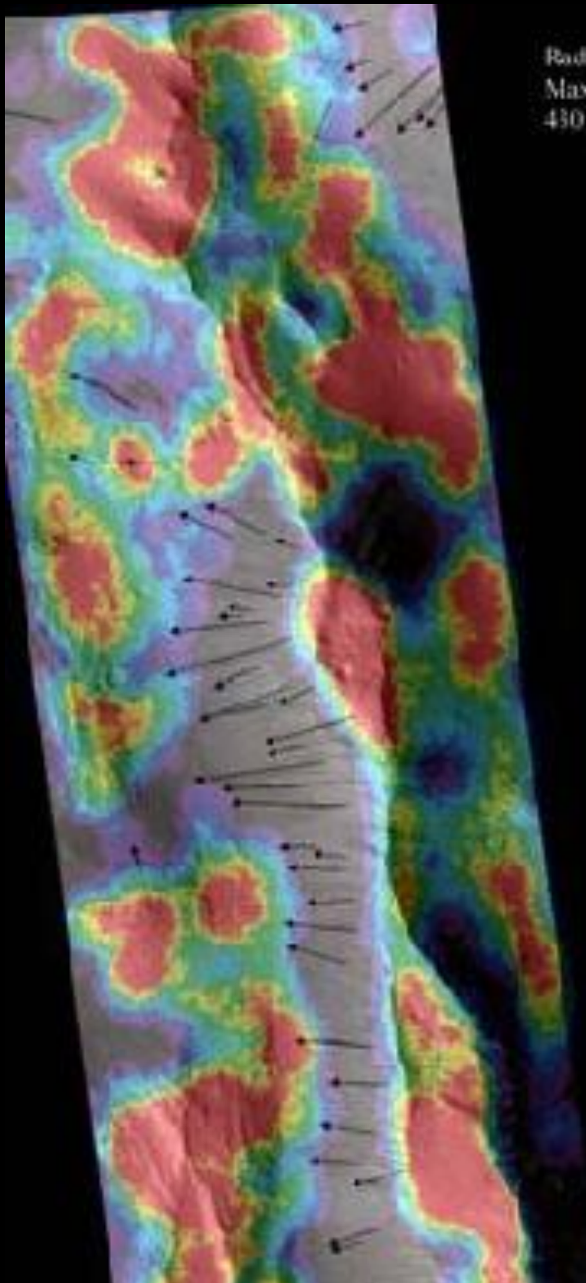
- Slope streaks: Dark or bright streaks associated to hillslopes

What is certain: They are active currently at surface



New ones have been discovered on MOC (Malin and Edgett, JGR, 2000)

Current formation rate: 7% new streaks/per Martian year/per existing streaks (Aharonson, JGR, 2003)

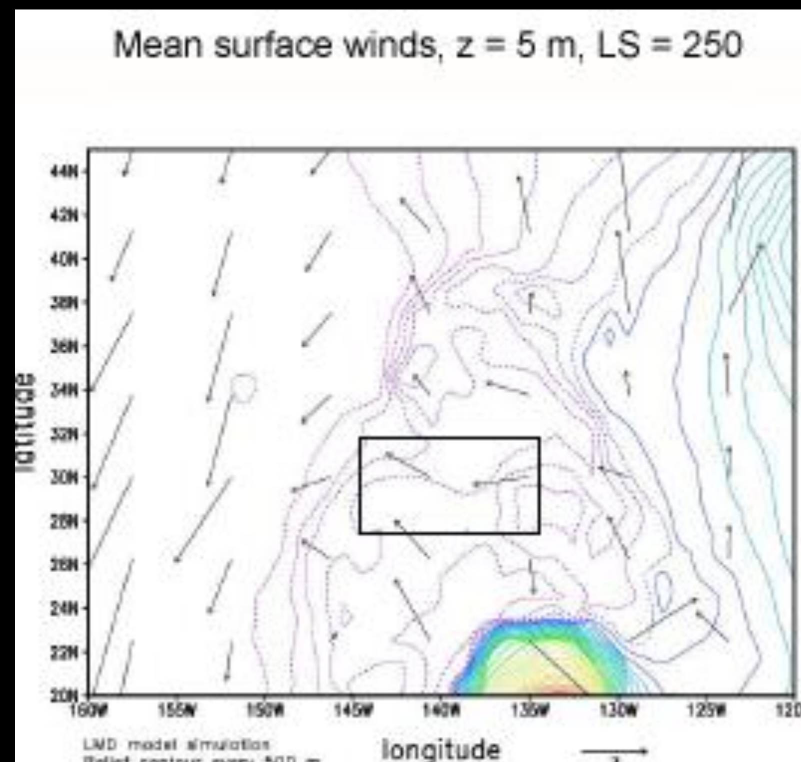


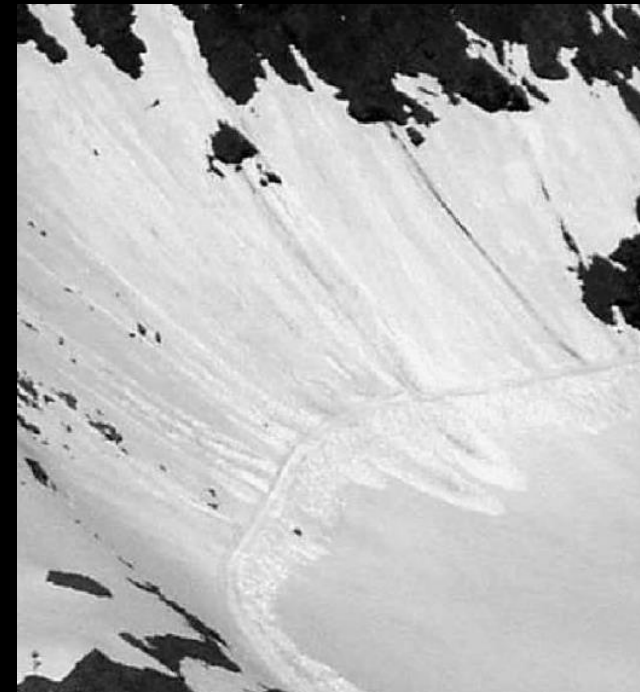
Baratoux et al., 2006

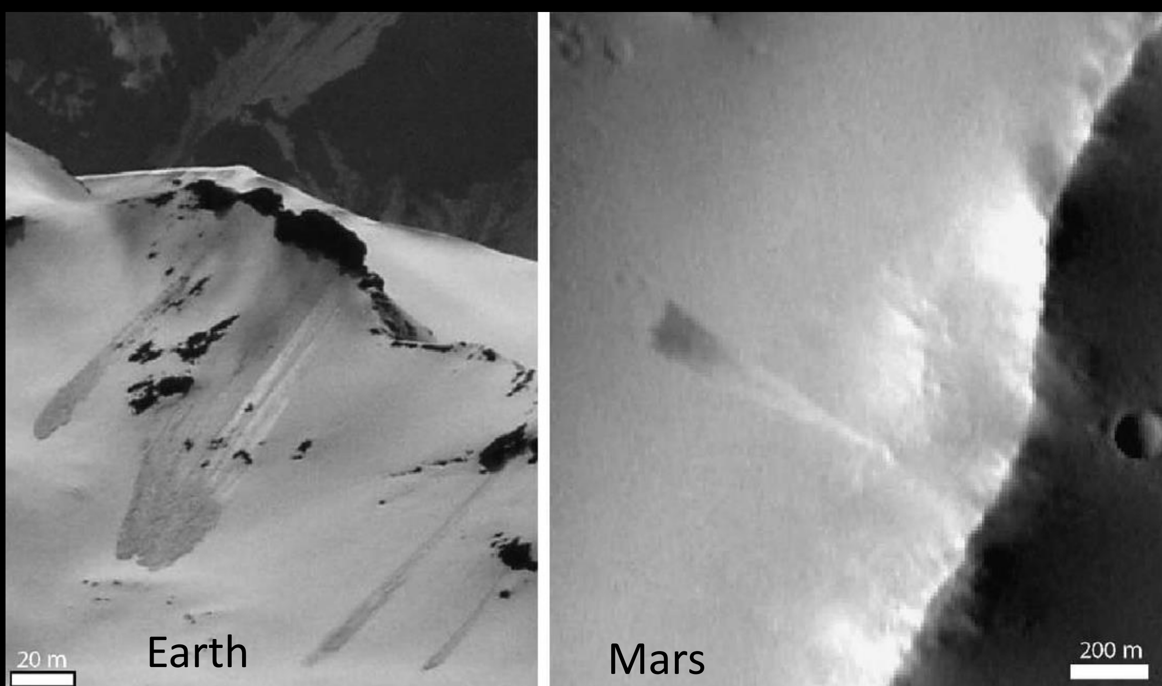
Red=small craters
Without craters means dust covered terrain

=>Streaks are related to dust blankets

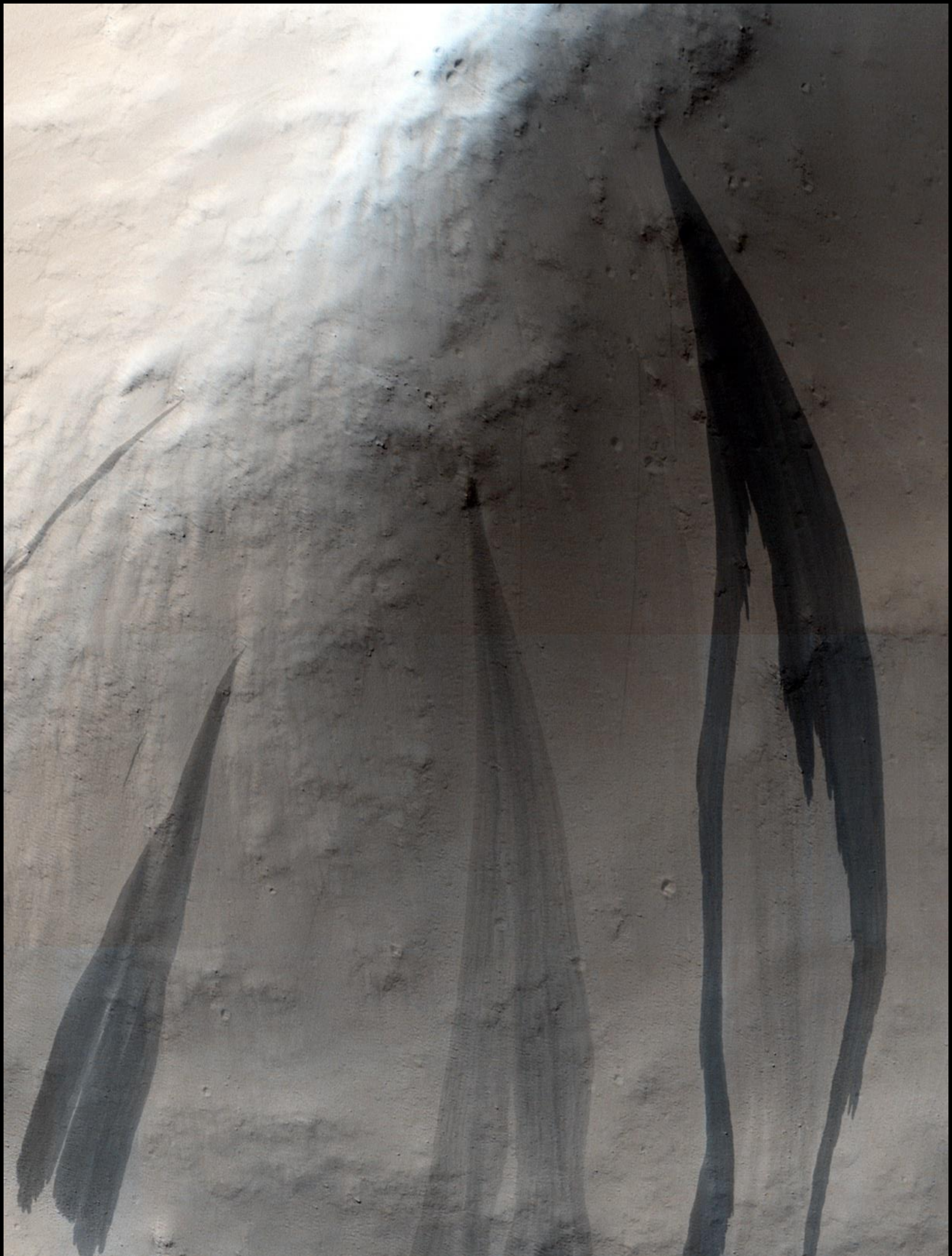
Related to wind directions
Because accumulation in the lee of wind
+triggering when unstability is created





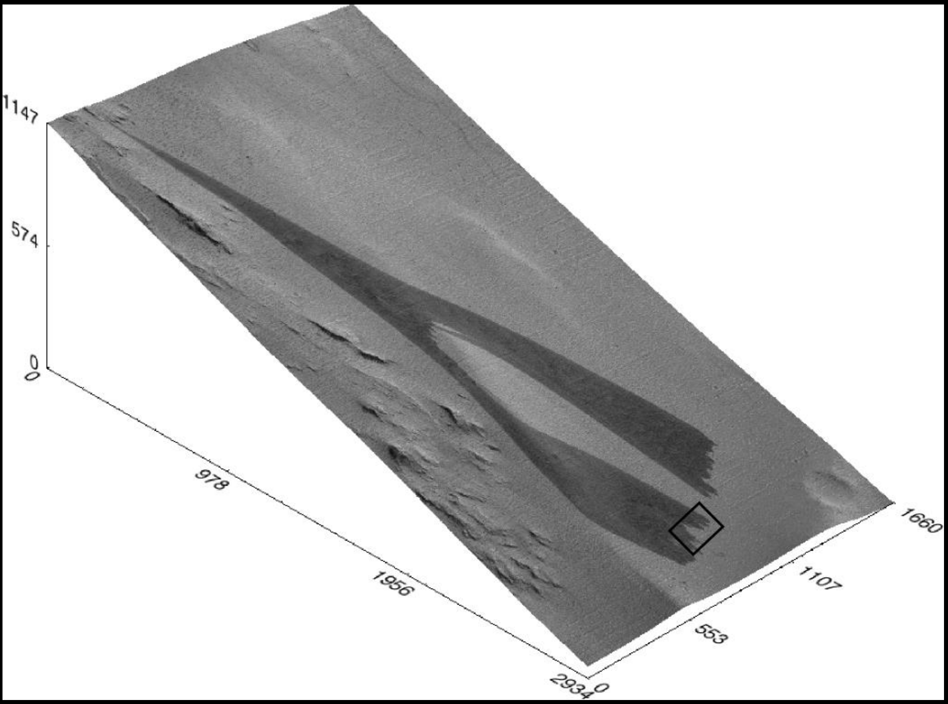


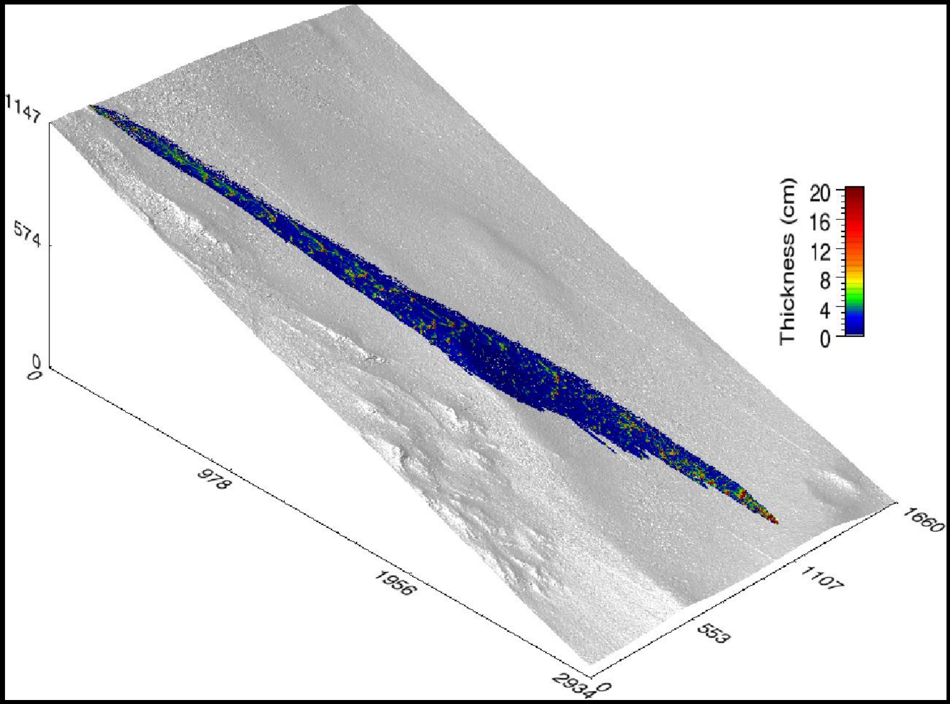
Snow avalanches on Eartyh…



All slopes are < 20°!

Often < 10°!!





Pente environ 15°

Tentative de simulation (Thèse A. Lucas)

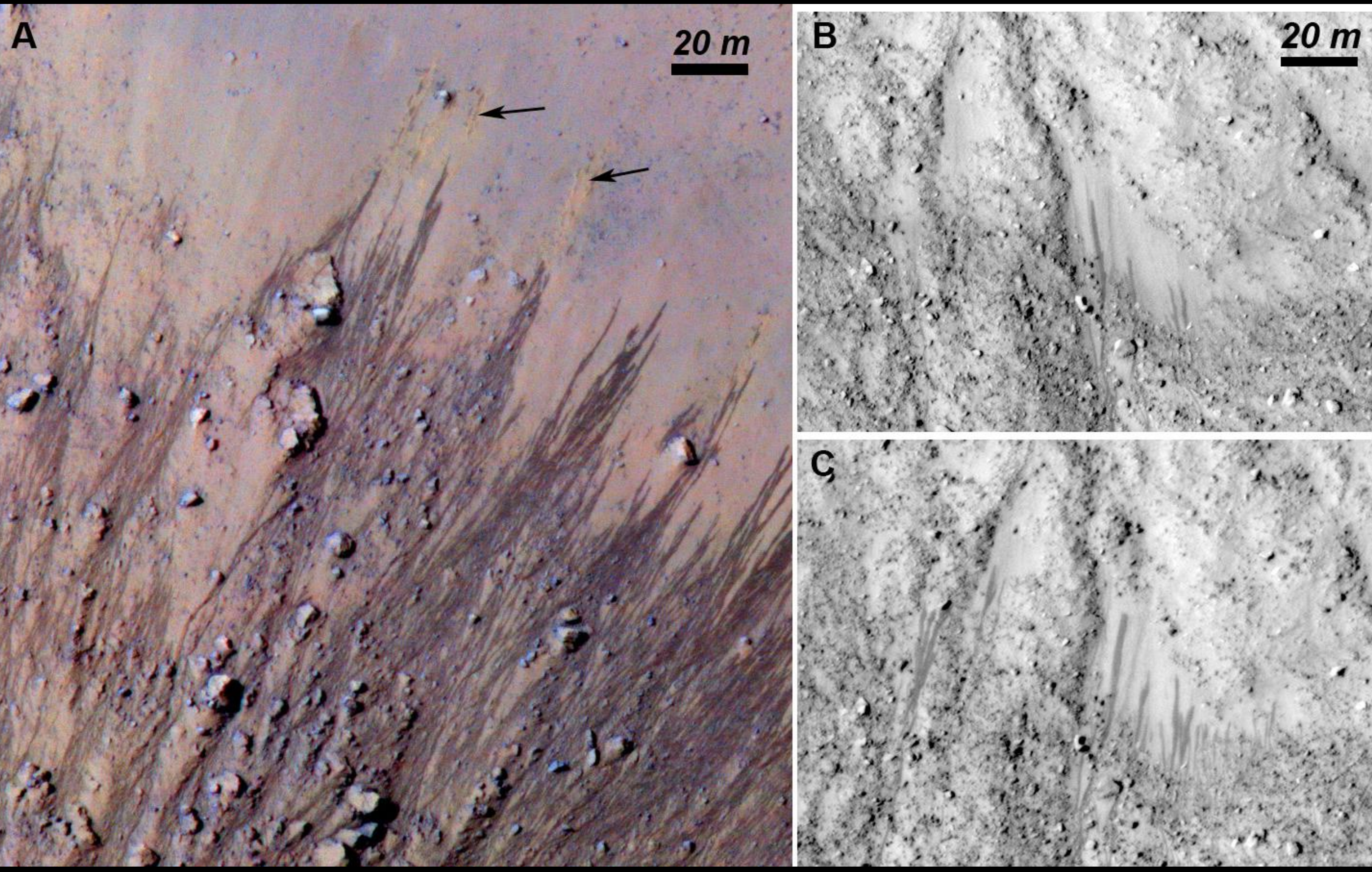
Epaisseur < 5 cm OK

Mais pas de divisions en deux parties.

Et surtout coefficients de frictions artificiellement faibles: 10-12°

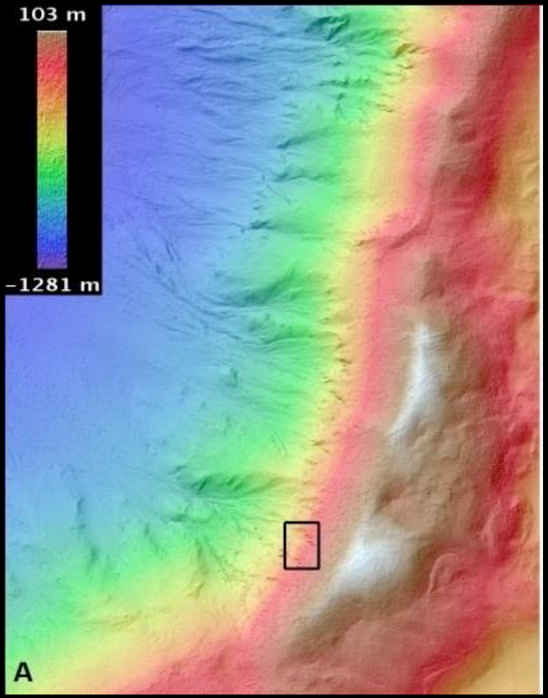
Pas d’explication physique à ces très faibles frictions

Recurrent Slope Linae (RSL)



Recent and current landforms: Recurrent Slope Linae (RSL)

Mc Ewen et al., Science, 2011: Possible volatile rich flows



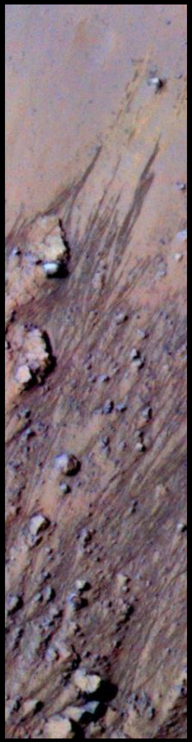
Slope is 40°, suggest dry granular flows
But the flows form seasonally

Mc Ewen et al., Science, 2011:
Possible volatile rich flows

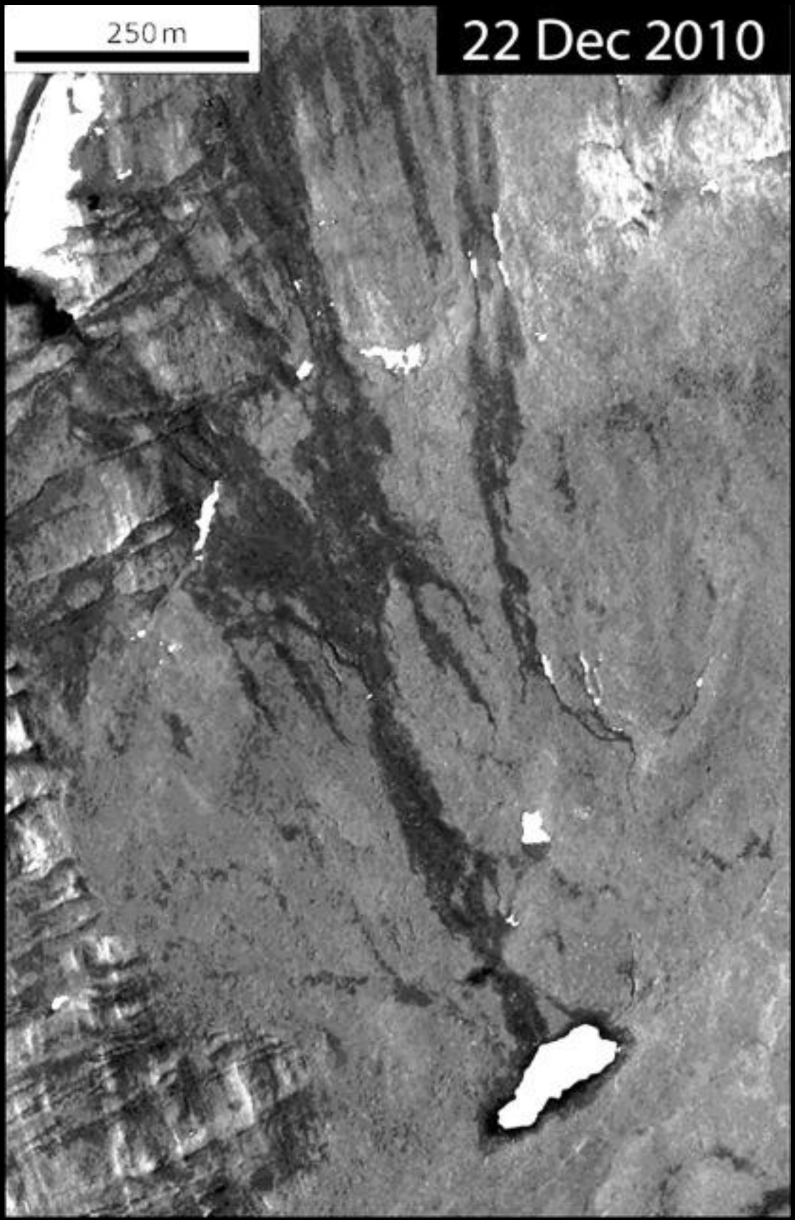
Table 1. Slope Streaks vs. TSL

Attribute	Slope streaks	TSL
Slope albedo	High (>0.25)	Low (<0.2)
Contrast	~10% darker	~40% darker
Dust index*	High (e<0.95)	Low (e>0.96)
Thermal inertia	Low (<100)	180-340 *(12)*
Width	Up to 200 m	Up to 5 m
Slope aspect preferences	Varies with regional wind flow *(14)*	Equator-facing in middle latitudes
Latitudes; Longitudes	Corresponds to dust distribution	10°S to 48°S; all longitudes
Formation L_s	All seasons *(31)*	L_s 260-20
Fading timescale	Years to decades	Months
Associated with rocks	No	Yes
Associated with channels	No	Yes
Abundance on a slope	Up to tens	Up to hundreds
Regional mineralogy	Mars dust	Variable
Formation events	1 event per streak or streaks	Incremental growth

* 1350-1400 cm^{-1} emissivity (see SOM)



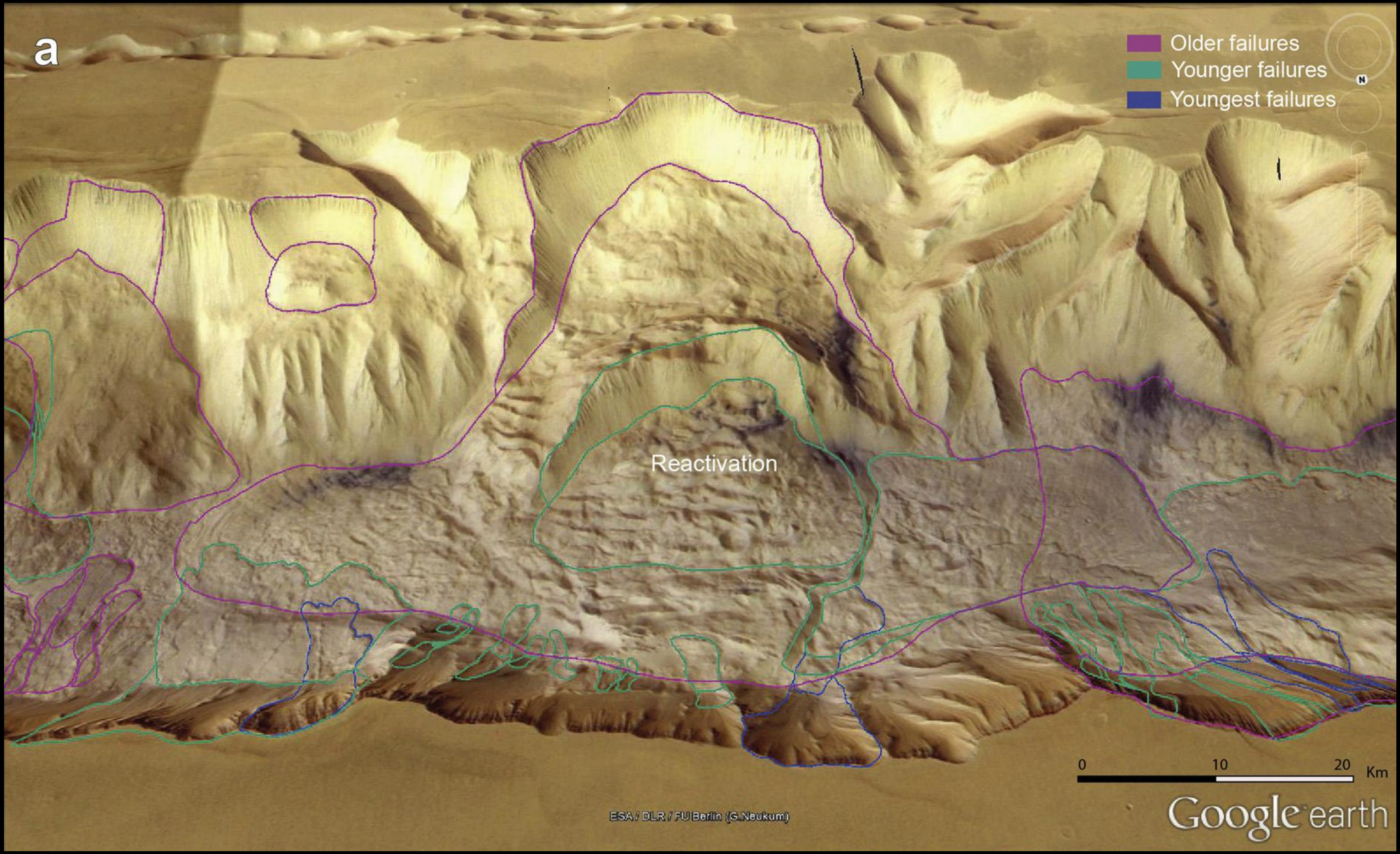
Metastable ice melting?



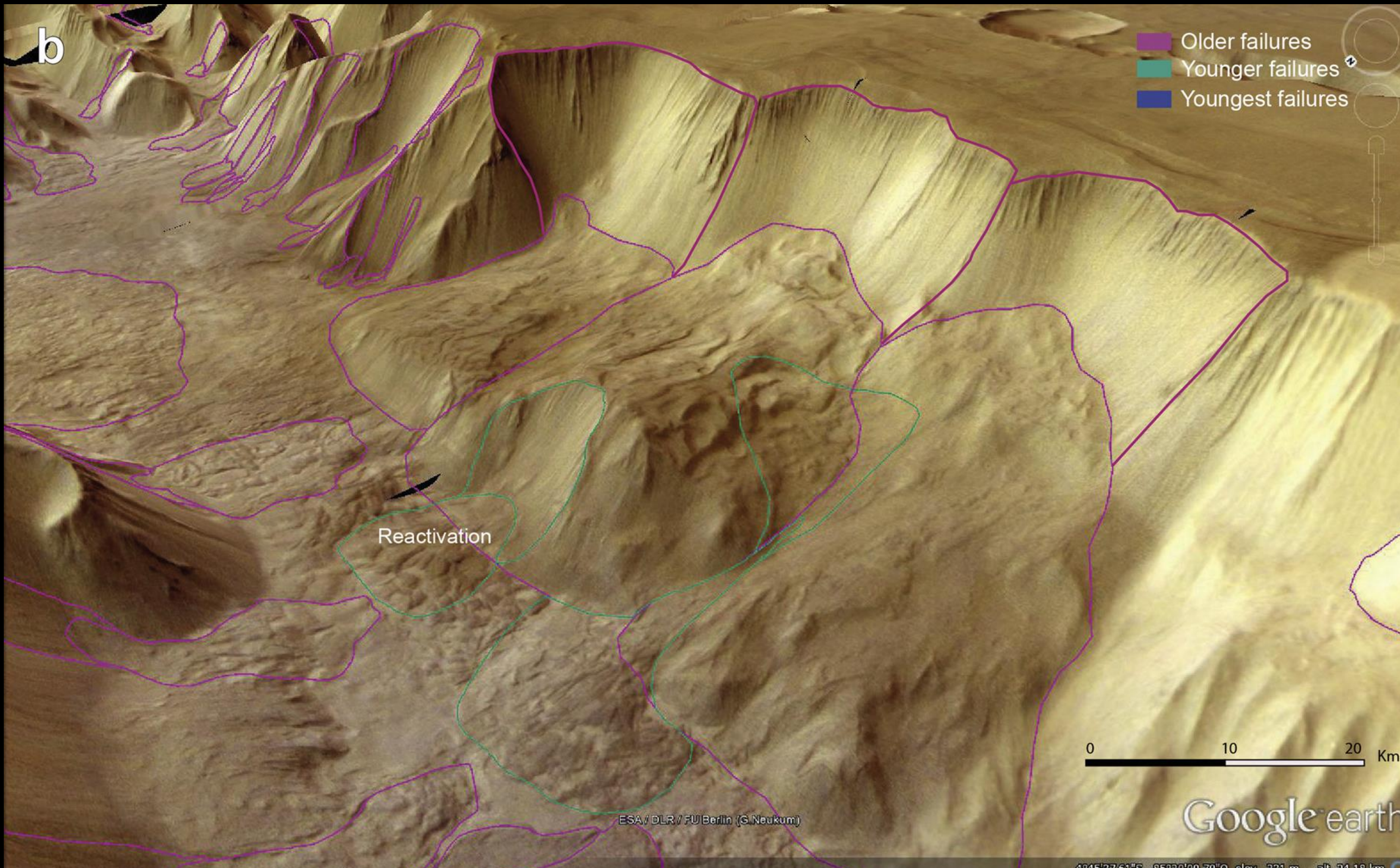
Avalanche granular, ice?,

The giant landslides in Valles Marineris

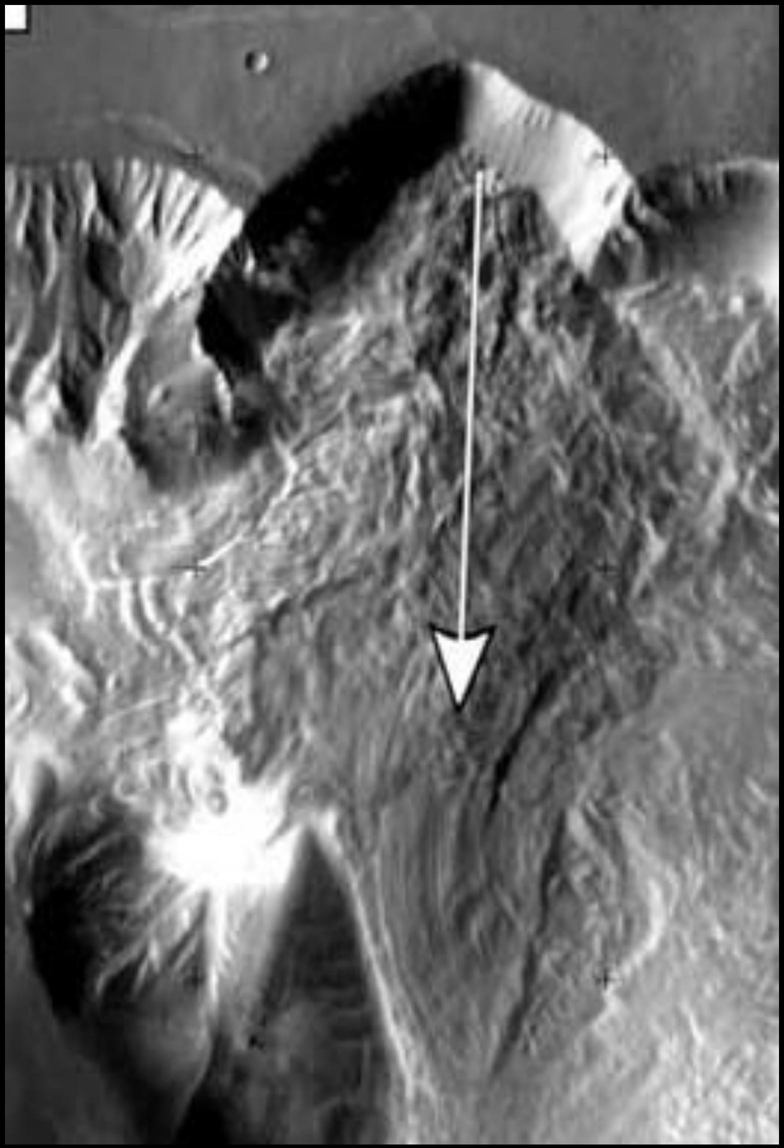
Brunetti et al., 2014



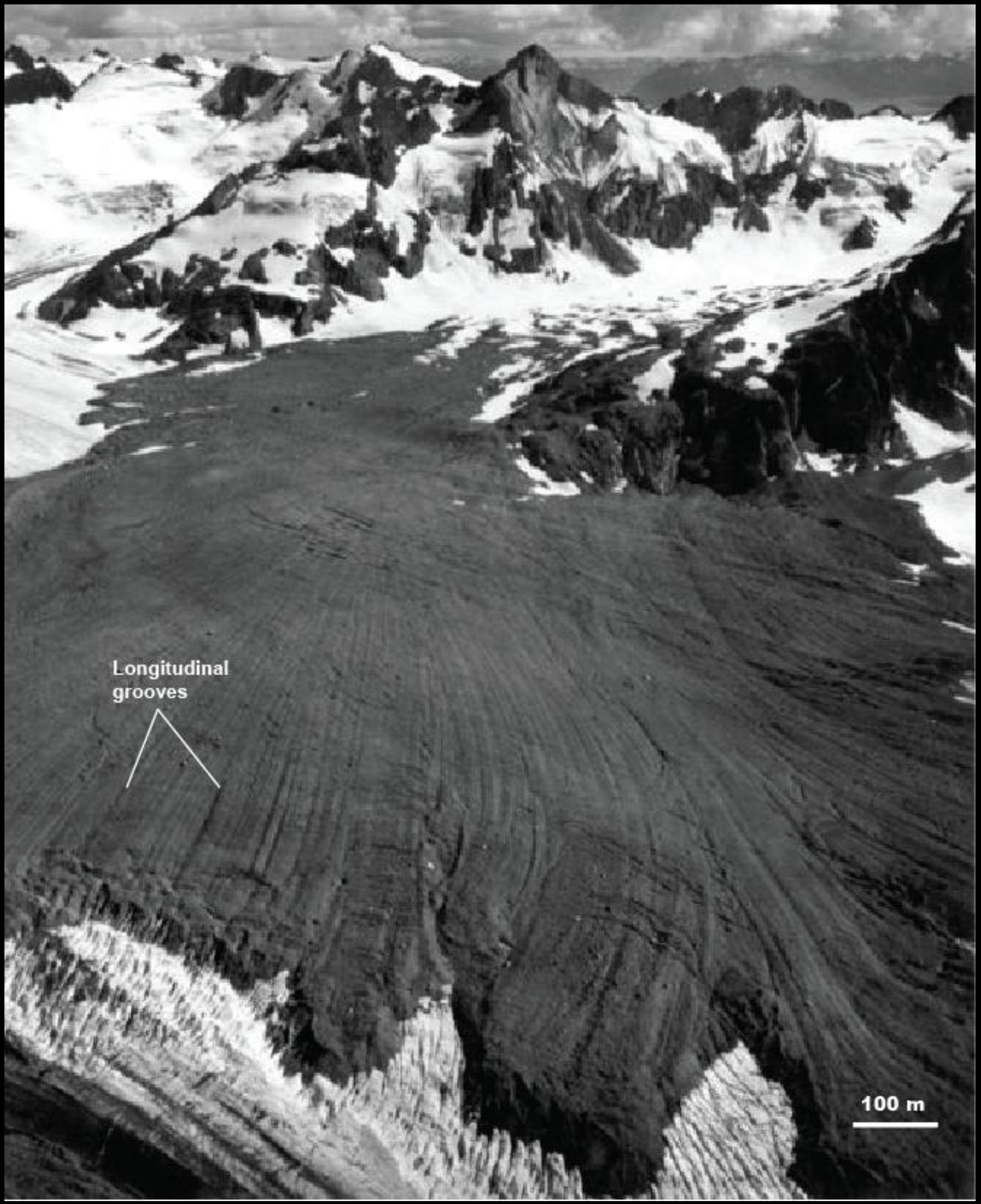
Brunetti et al., 2014



Mars

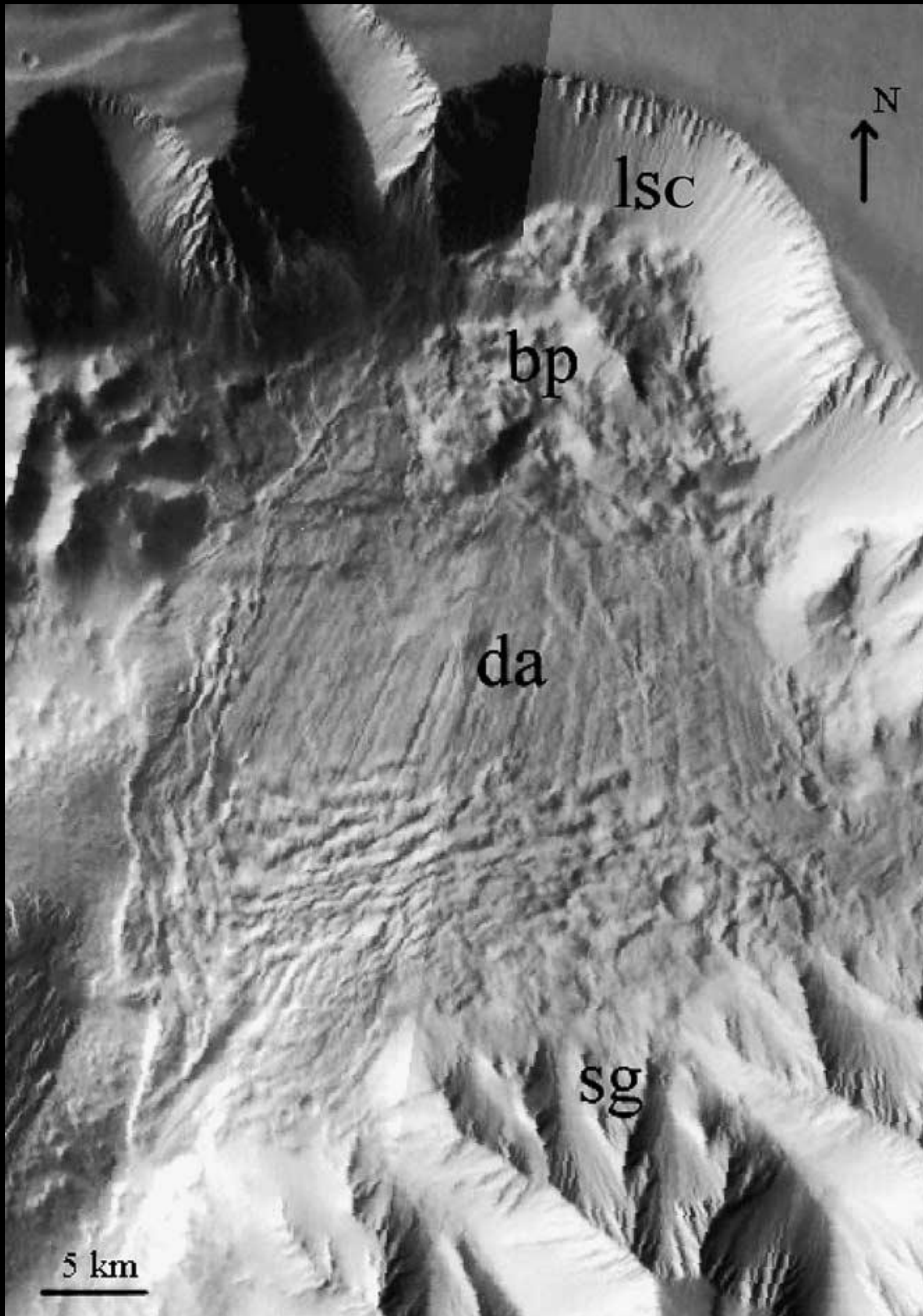


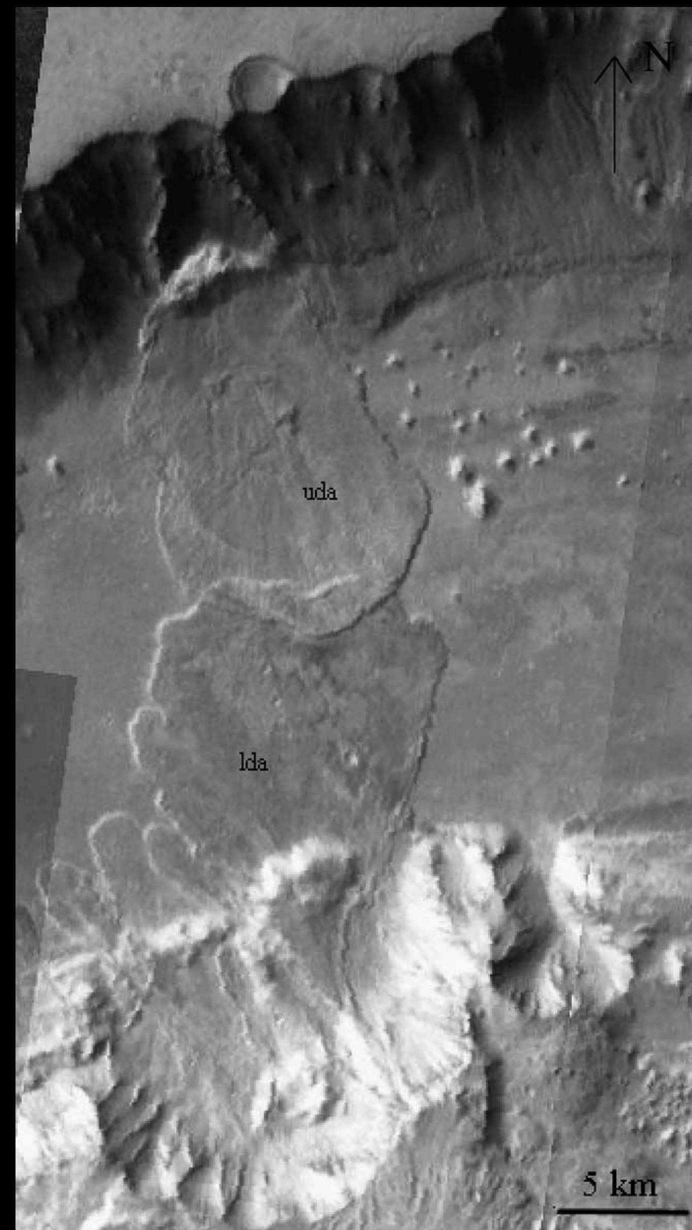
Earth. Alaska

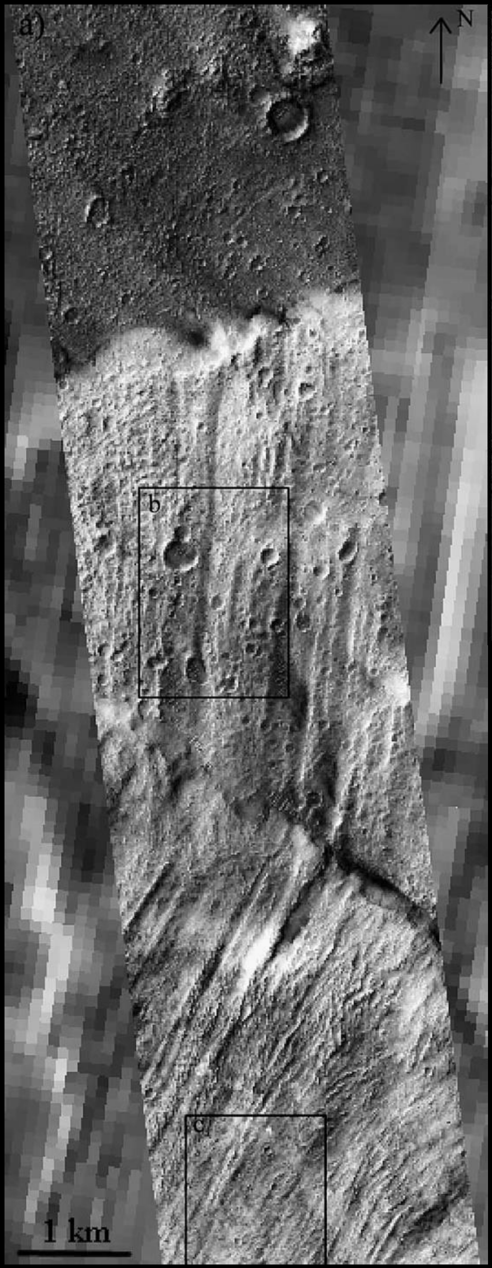


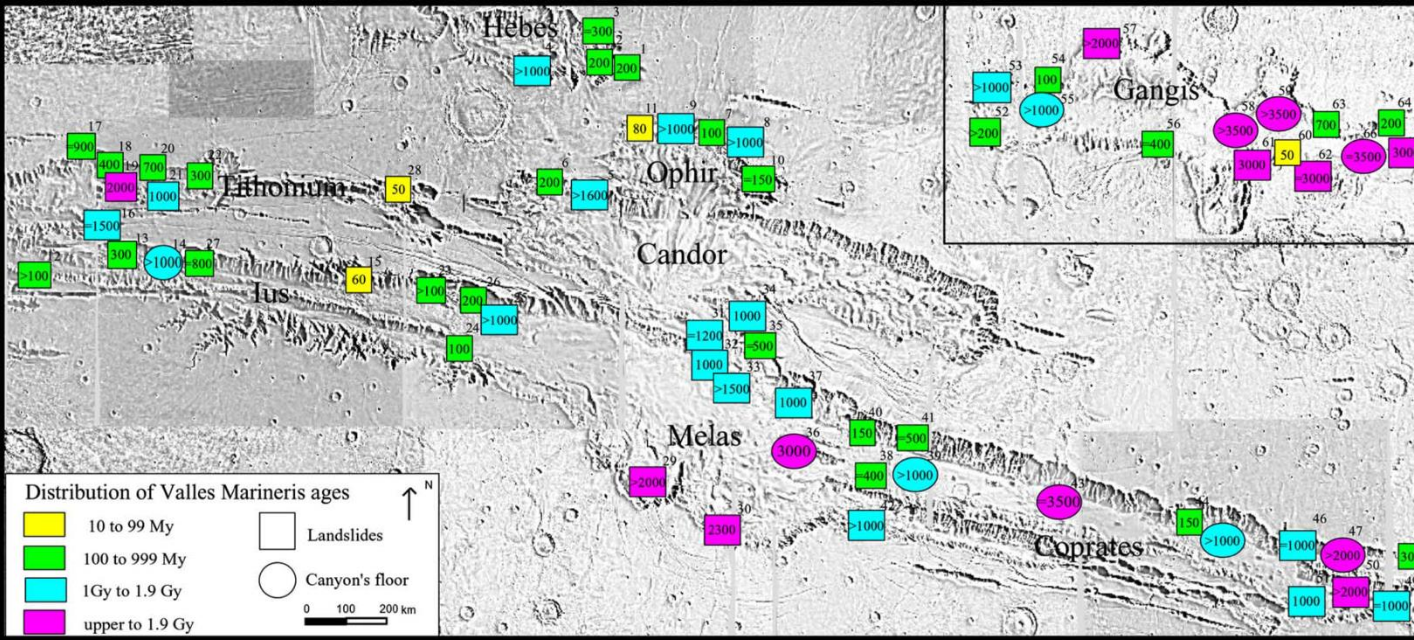
Thèse A. Lucas

Velocities can reach 200 km/h









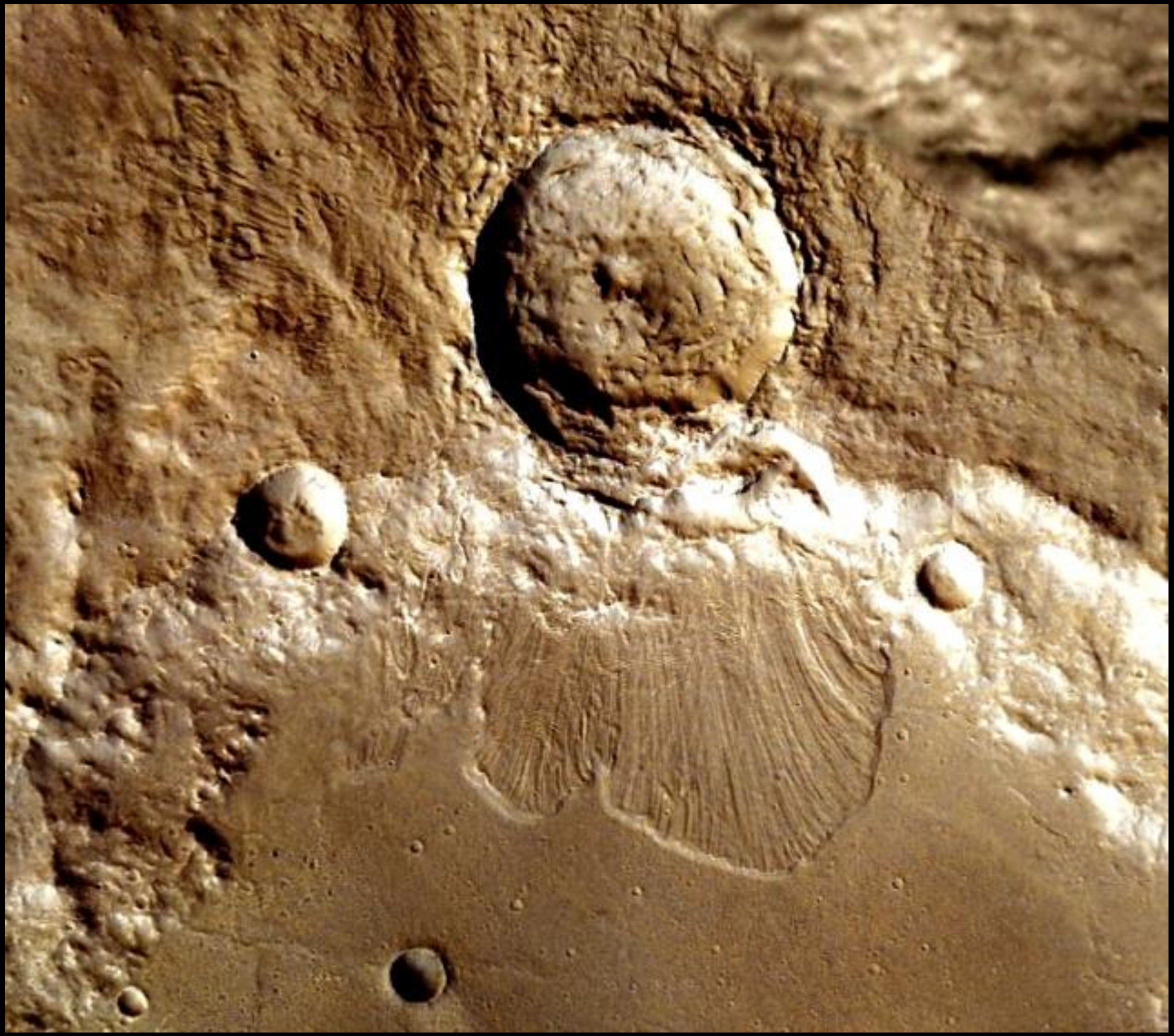
Quantin et al., 2004:
Ages of landslides are variable
From 3 Gy to less than 100 Ma

No obvious link with climatic variations

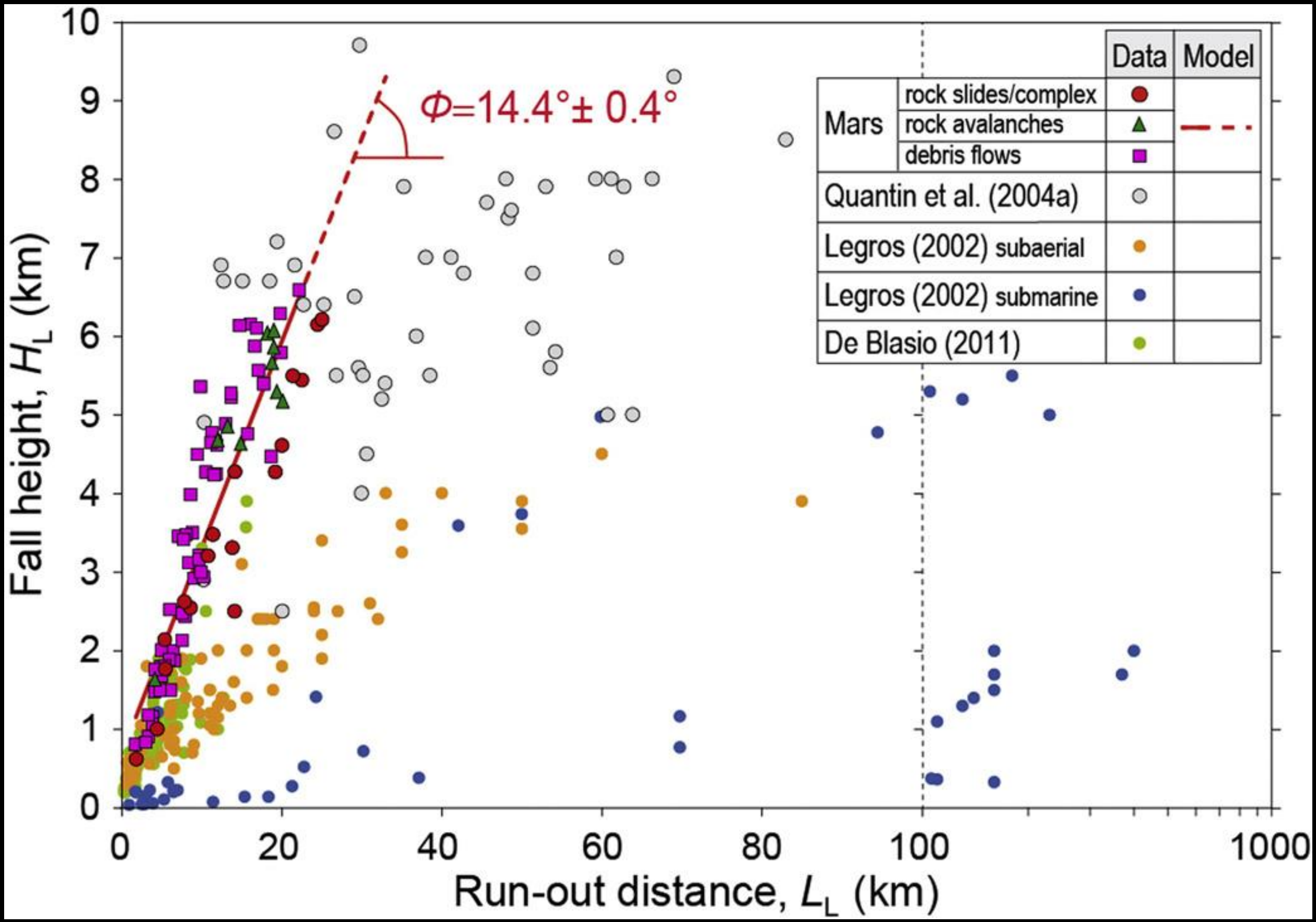
Triggering mechanisms

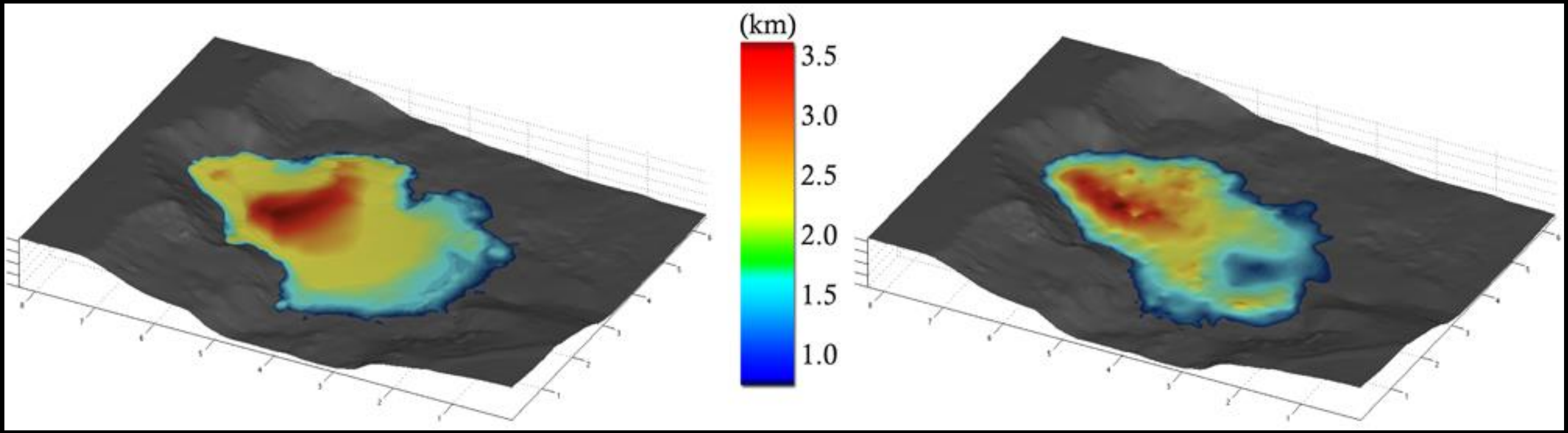
Likely impact ejecta

Possibly tectonism



Brunetti et al., 2014





Simulation DEM

Lucas et al., 2010

Long run out.

Possible simulation works only with apparent friction angles at 9.8°.

No physical explanation to the low friction,
but not a usual process compared to Earth (very large landslides).

Water is possible but not necessary.

ARTICLE

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Frictional velocity-weakening in landslides on Earth and on other planetary bodies

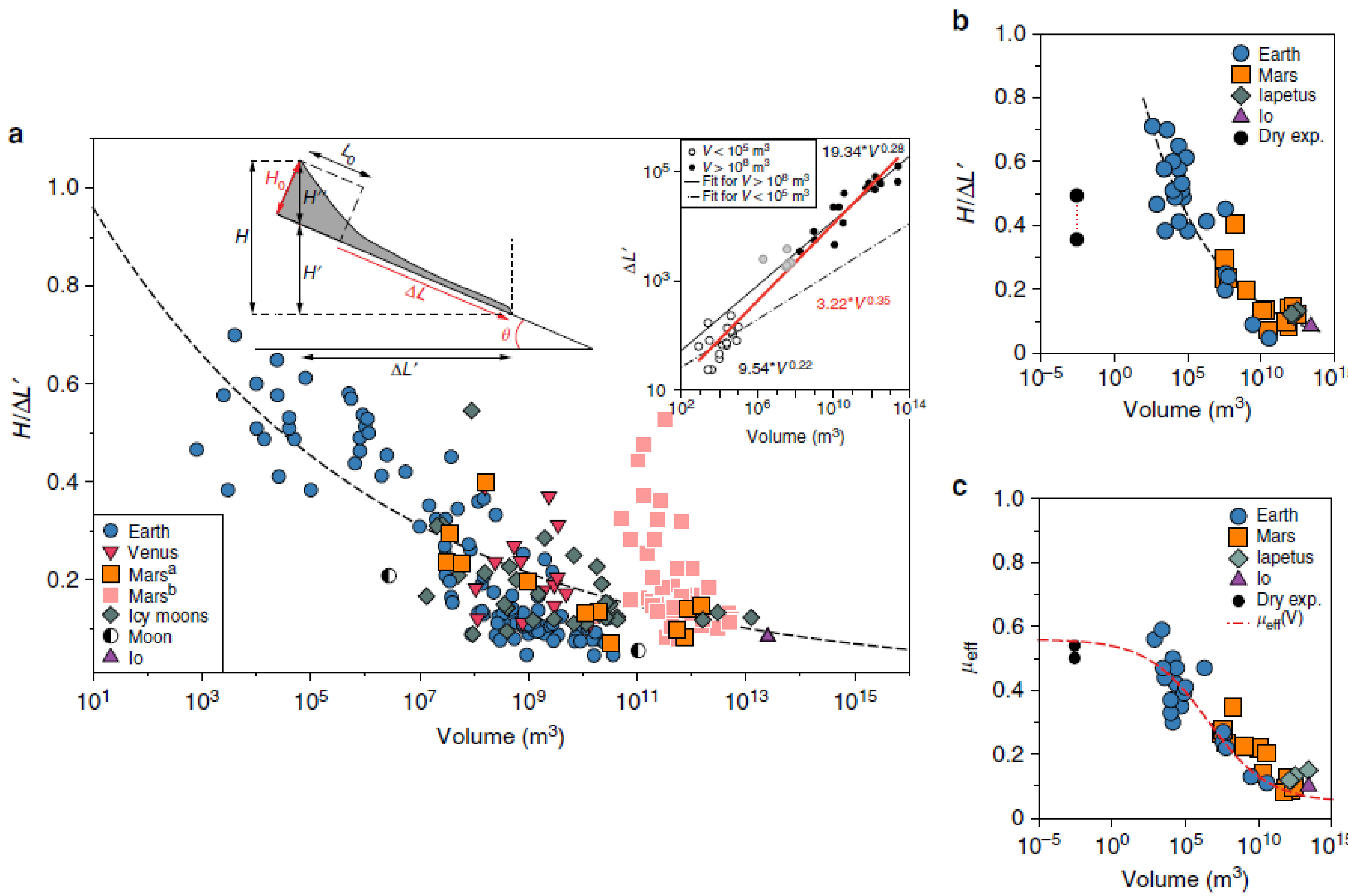
Antoine Lucas[1,2,†], Anne Mangeney[1,3] & Jean Paul Ampuero[2]

$$\mu_{\mathrm{eff}} = \tan\delta = \tan\theta + \frac{H_0}{\Delta L}. \quad (1)$$

The analytical solution also shows that the Heim's ratio is

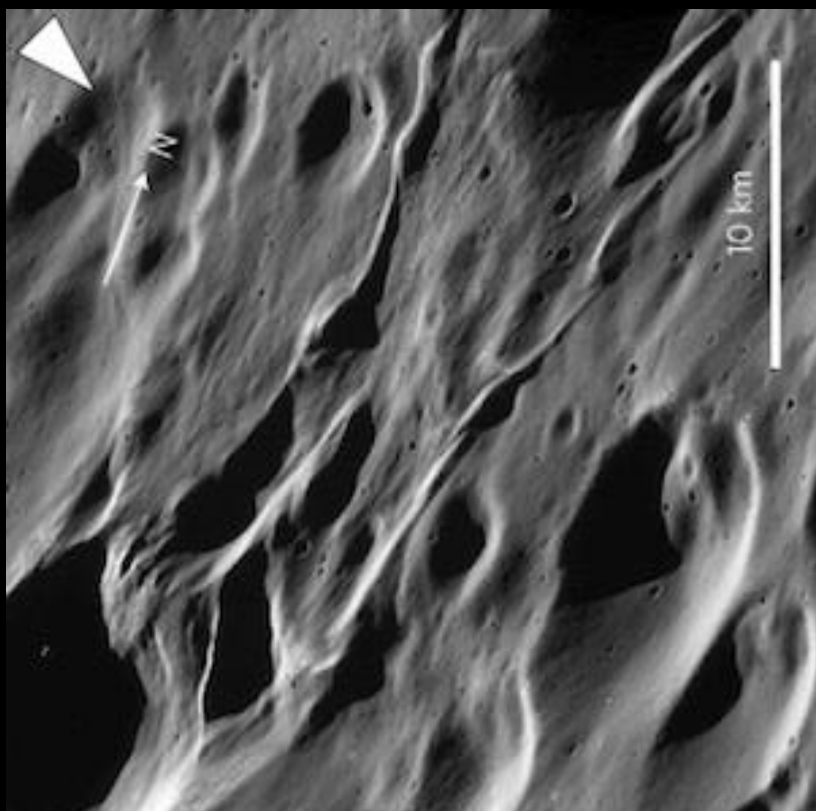
$$\frac{H}{\Delta L'} = \tan\theta + \frac{1}{\cos^2\theta\left(\frac{2k}{\tan\delta - \tan\theta} + \frac{L_0}{H_0} - \tan\theta\right)}, \quad (2)$$

where L_0/H_0 is the inverse of the initial aspect ratio and k an empirical coefficient (for example, with $k=0.5$, the results of granular collapse experiments are quantitatively reproduced[4,20]).



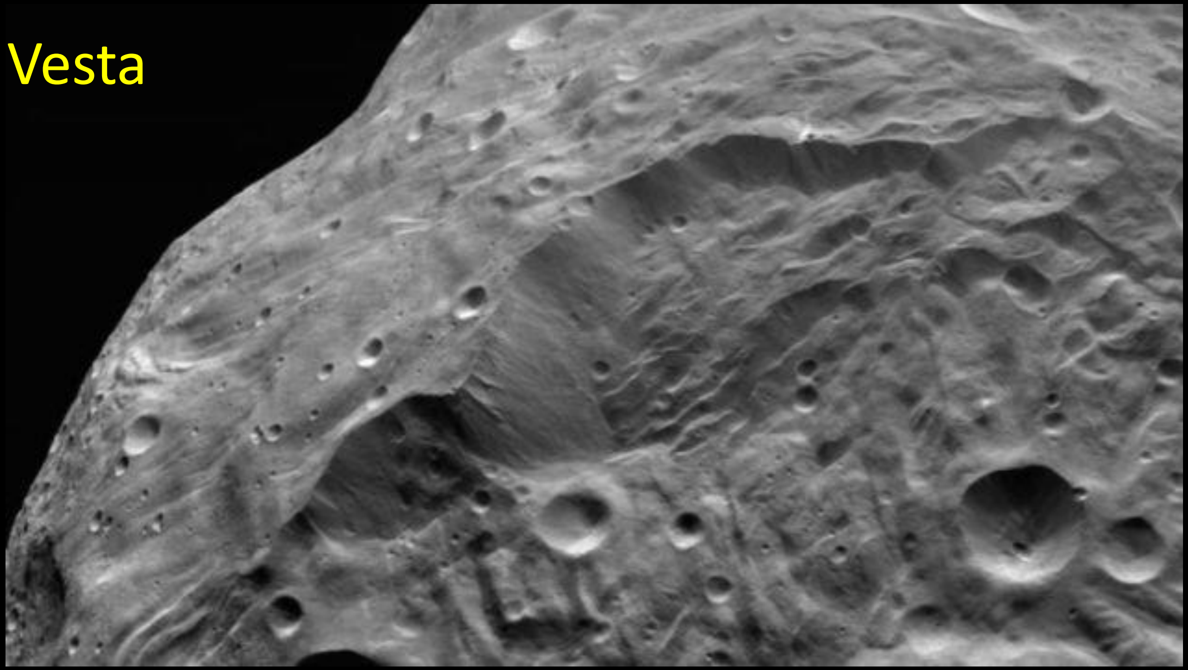
Effect of gravity on granular flows?

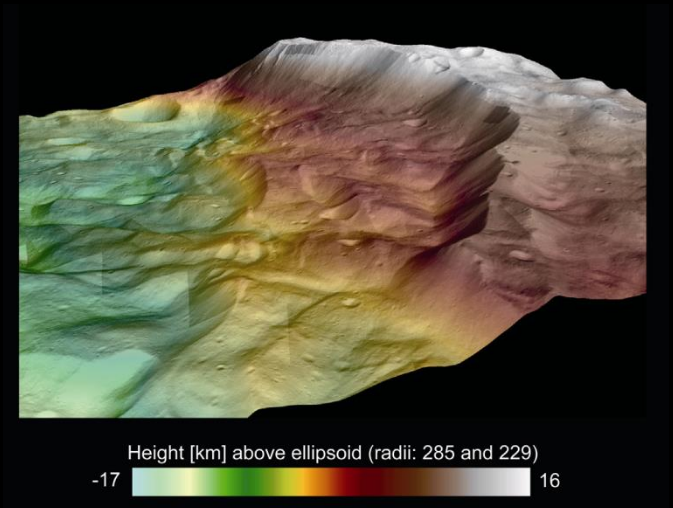
Iapeteus

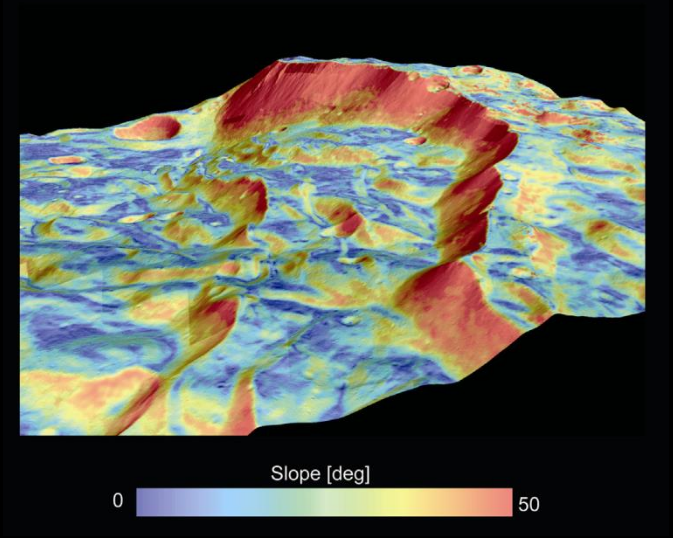


Callisto

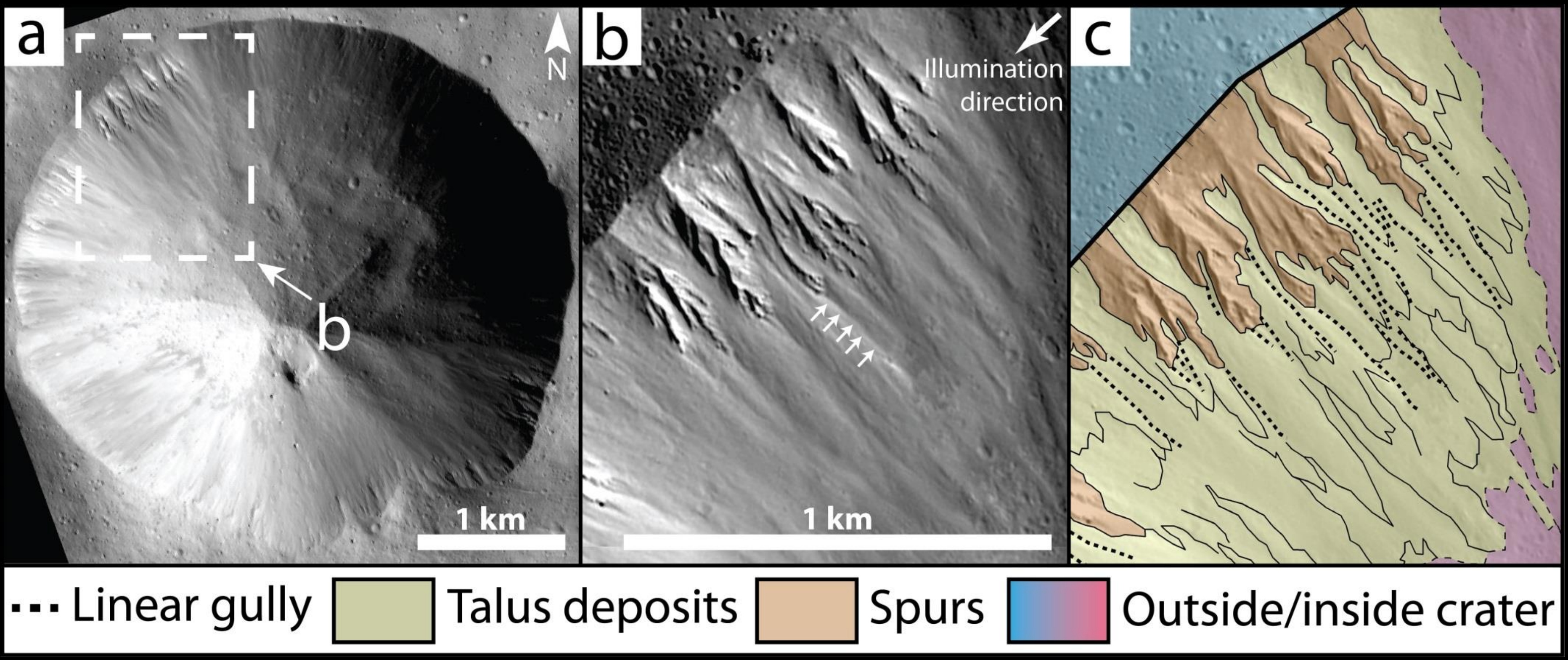
Vesta







Krohn et al., 2014



Crater on Vesta/ Granular flows

Interpreted by some as wet flows….!

Zero g experiences

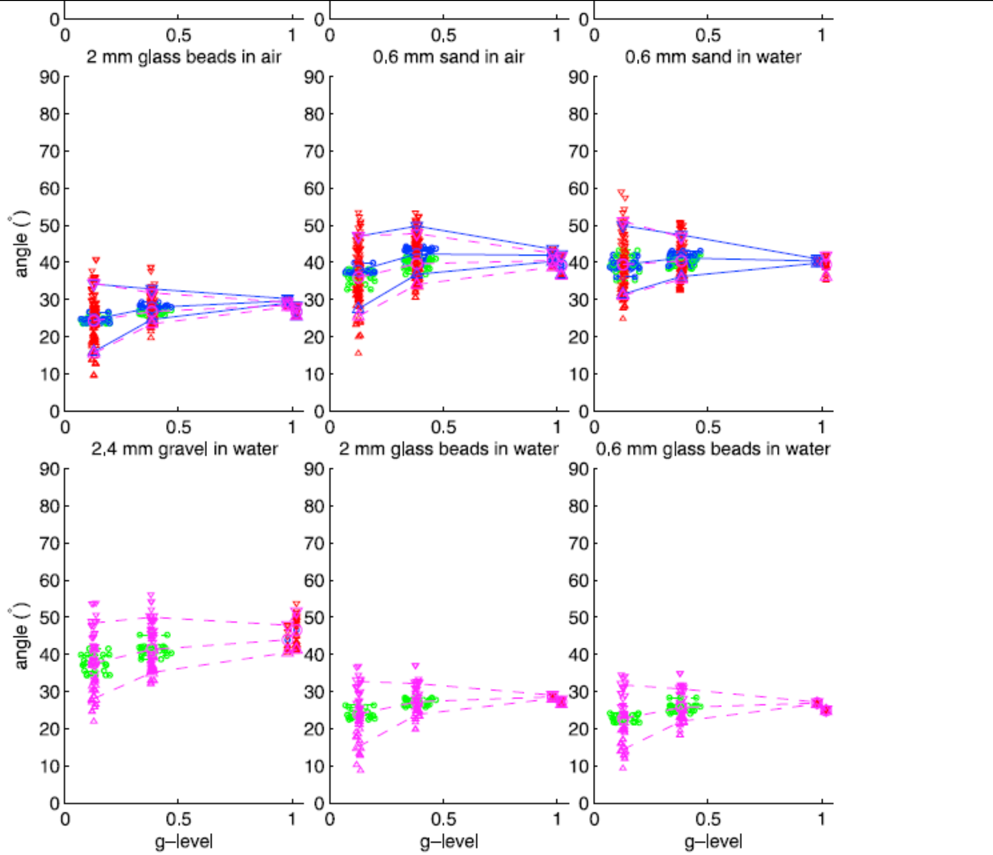


Figure 8. Time-averaged angle, static angle of repose and dynamic angle of repose for each sediment. Individual observations indicated by triangles. Values plotted at 0.98 *g* are control measurements in the flight at 1 *g* and values plotted at 1.02 *g* are control measurements on the ground at 1 *g* (uncorrected for camera and setup angle). Maximum is calculated as 90% percentile from static angles (see Figure 6) and minimum is calculated as 10% percentile from dynamic angles.

Kleinhans et al., JGR-Planets, 2011

« Our data suggest that asteroids with g ≈ 0.02 could have static slope angles of repose up to 50° and dynamic angles of repose less than 20° for loose angular granular material.”