Gullies on Mars -- Water or Not?

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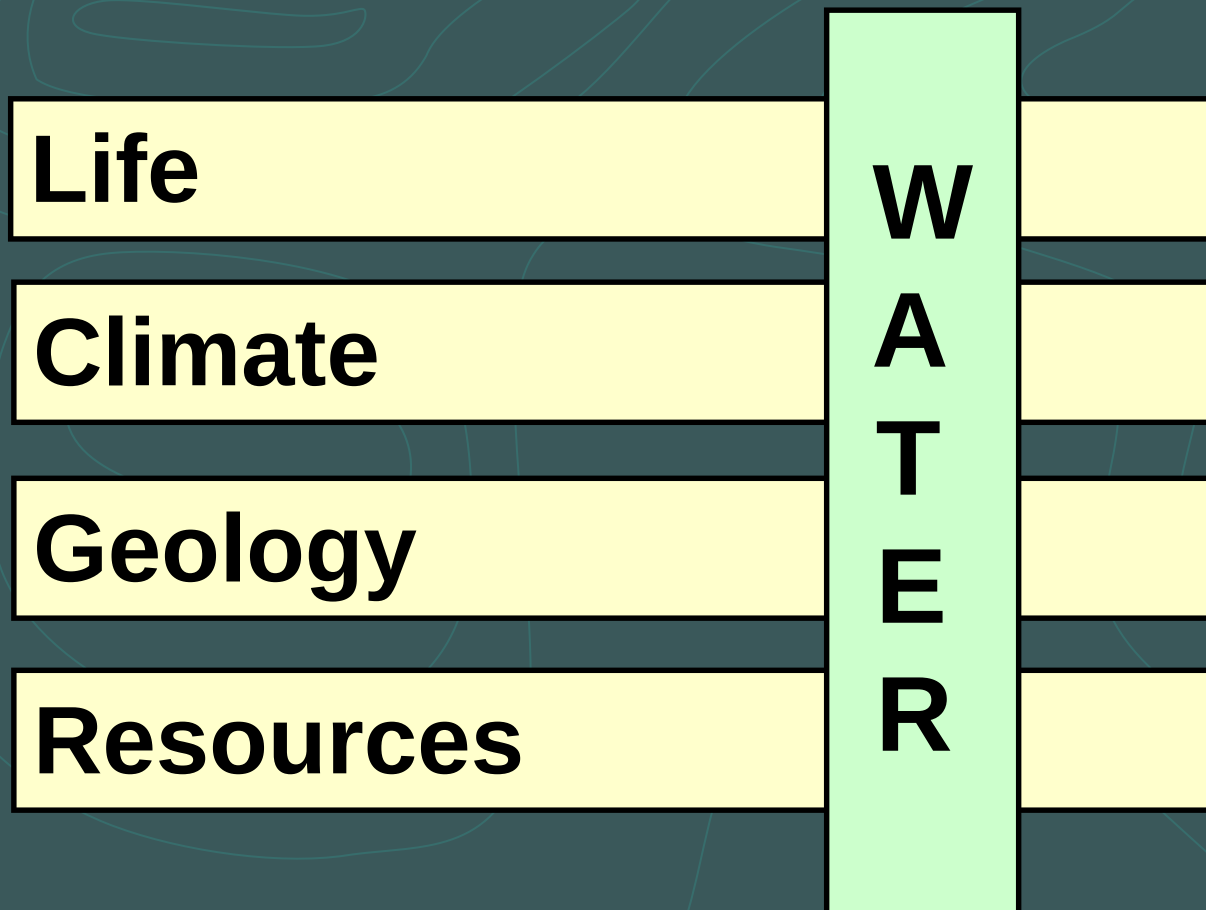
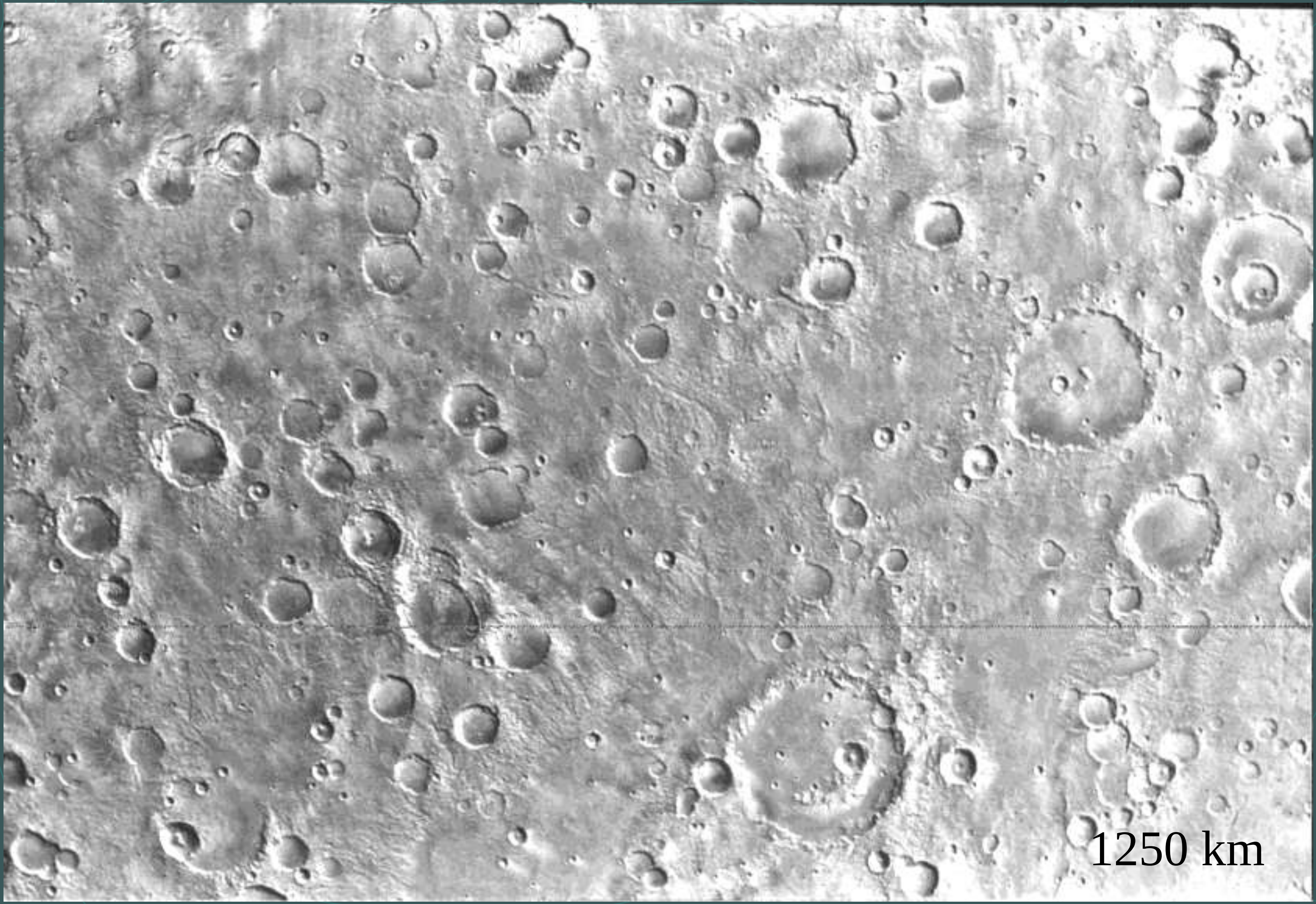
NASA Mars Exploration Strategy: “Follow the Water”



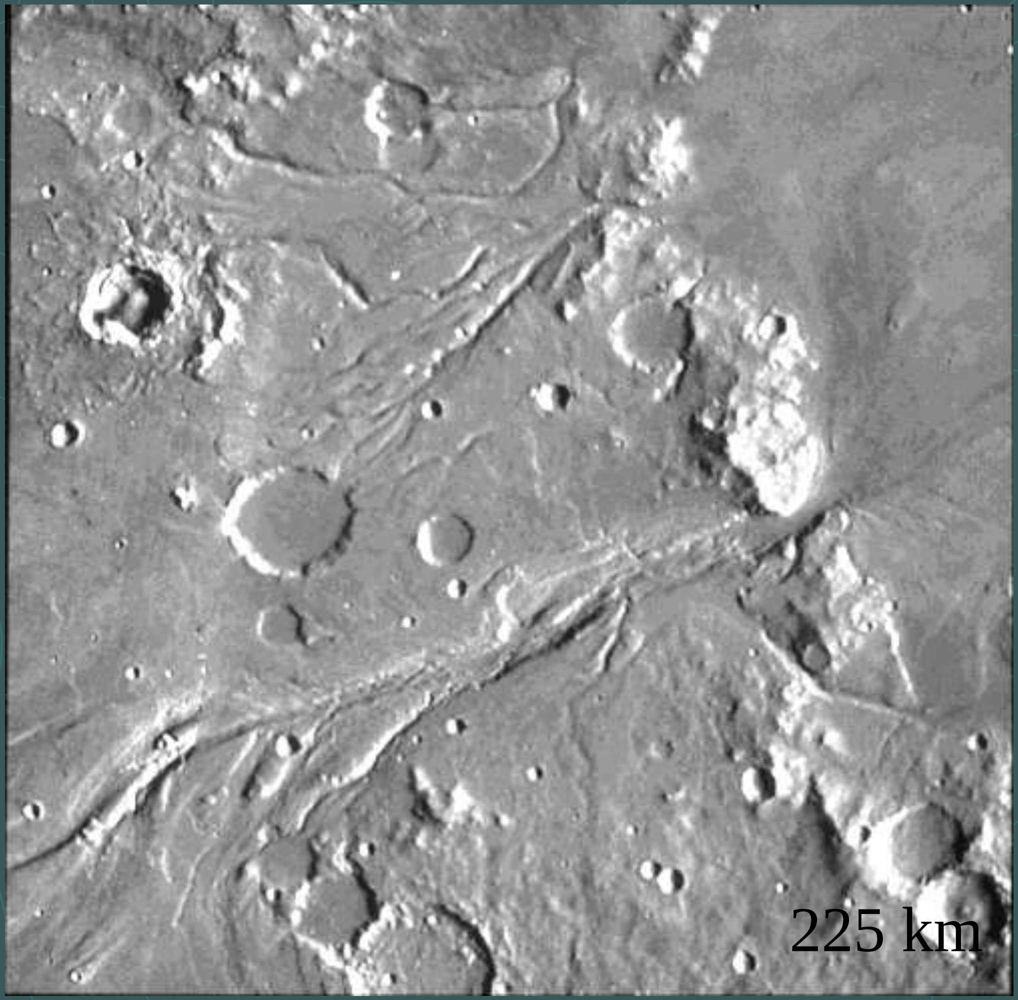
Evidence of Water on Mars

- Distant Past
  - Crater Degradation and Valley Networks
  - 'River' Channels
  - Flat Northern Lowlands
  - Meteorites
    - Carbonate in ALH84001
    - Clay in nakhlites
  - MER Rover Sites Discoveries
    - Hydrous minerals: jarosite!
    - Fe_2O_3 from water (blueberries etc.)
    - Silica & sulfate & phosphate deposits
- Recent Past (Any liquid?)
  - Clouds & Polar Ice
  - Ground Ice

Valley Networks and Degraded Craters



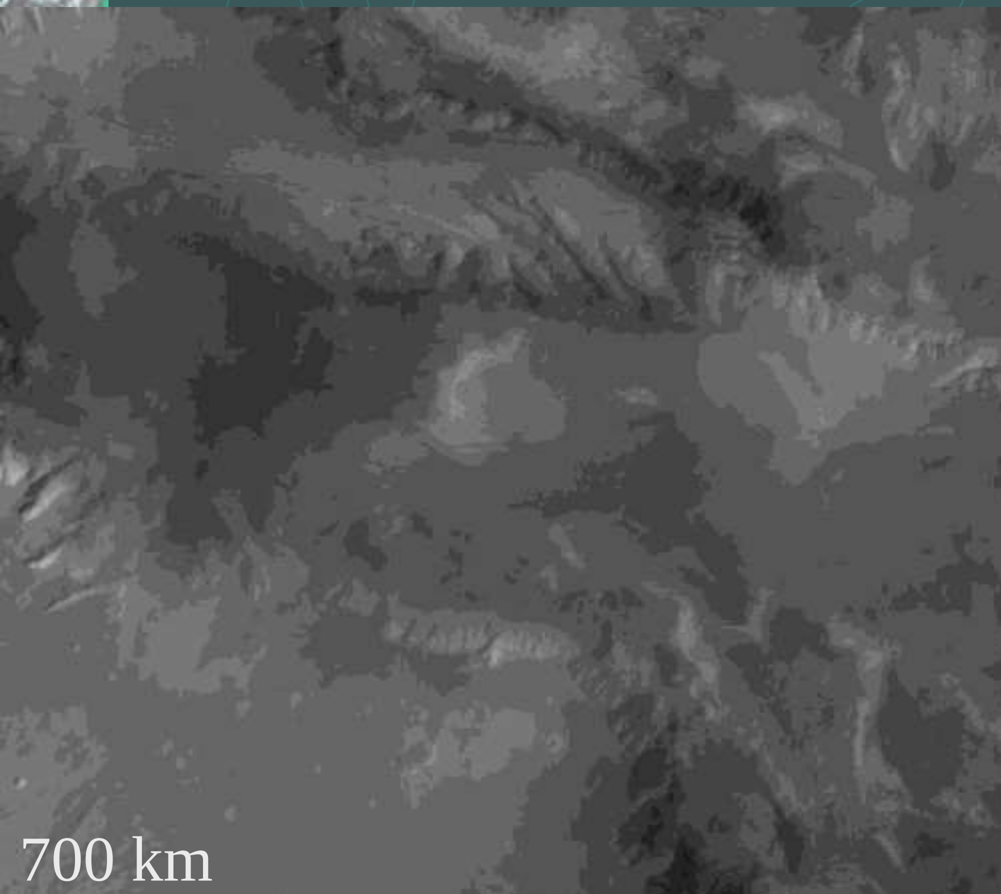
River Channels - Giant Floods!



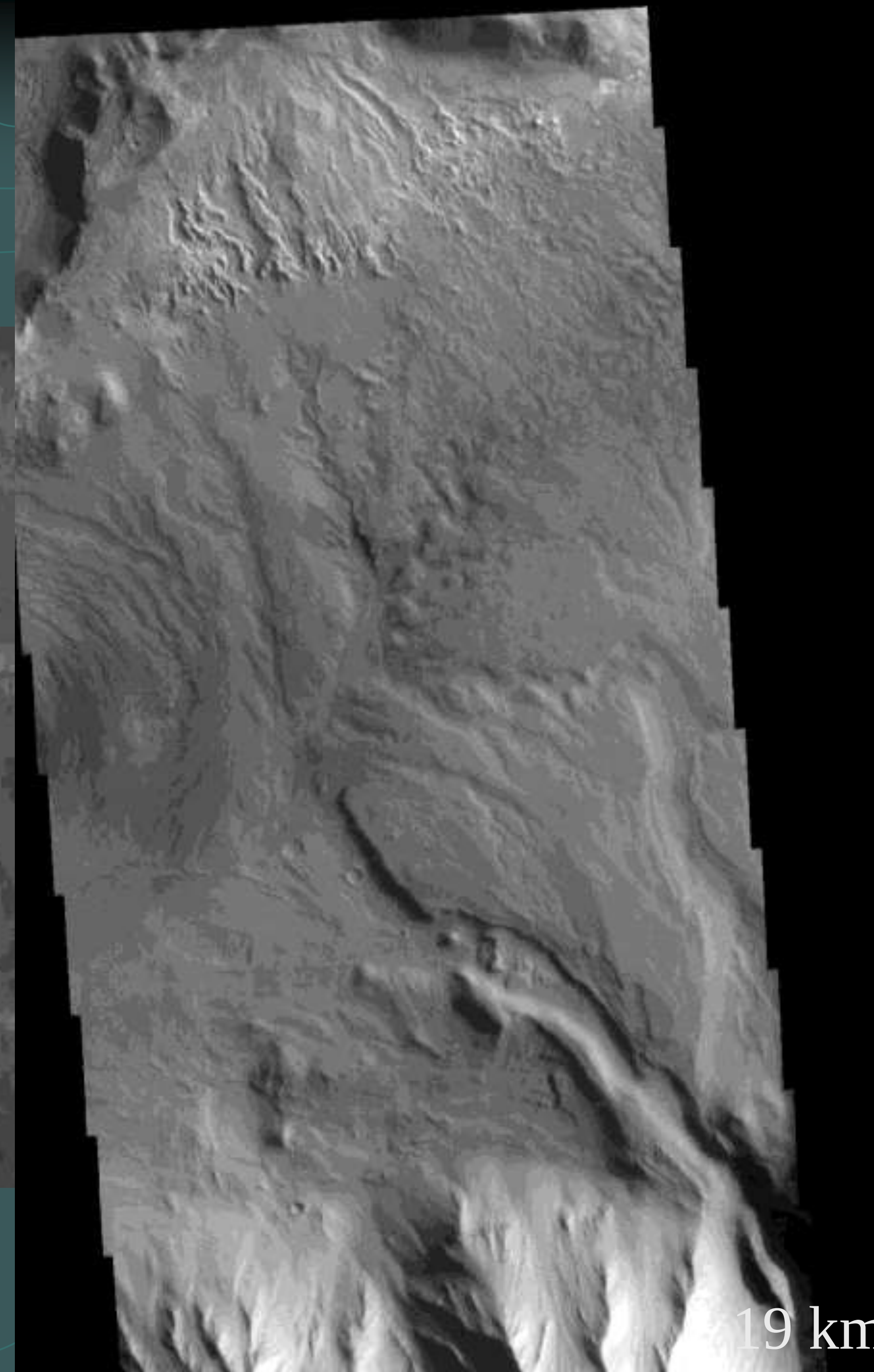
10 km craters

River Channels - ‘Normal’ Flows

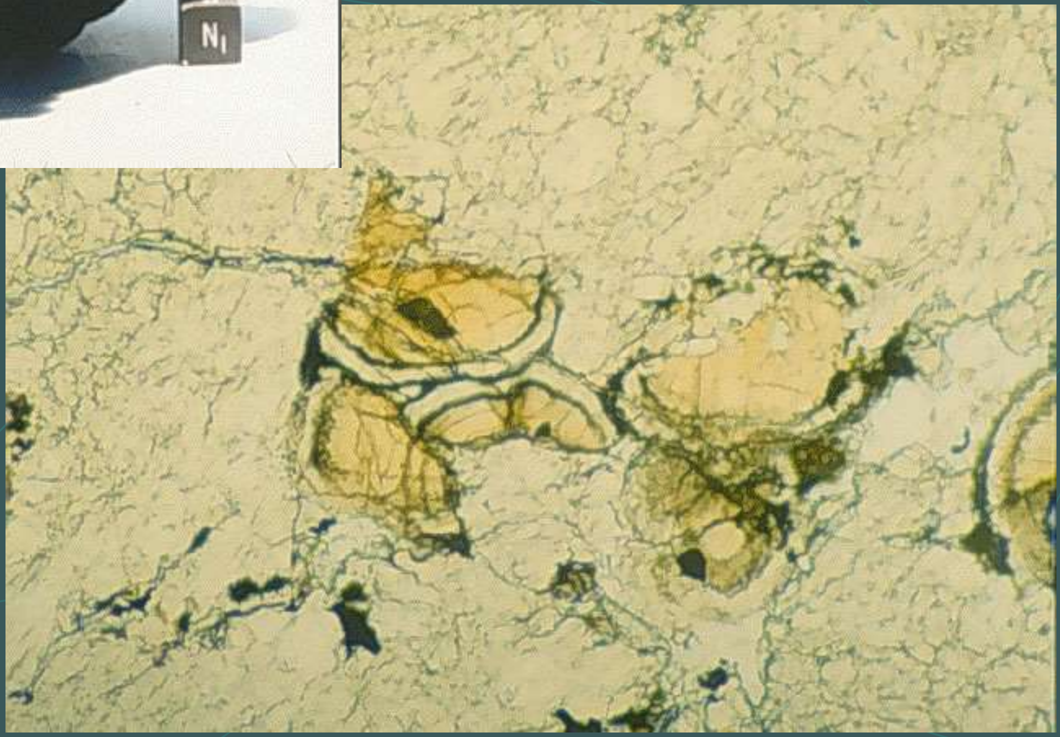
River Channels from Rain?



- *Science*, July 2, 2004



Ancient Martian Meteorite ALH84001

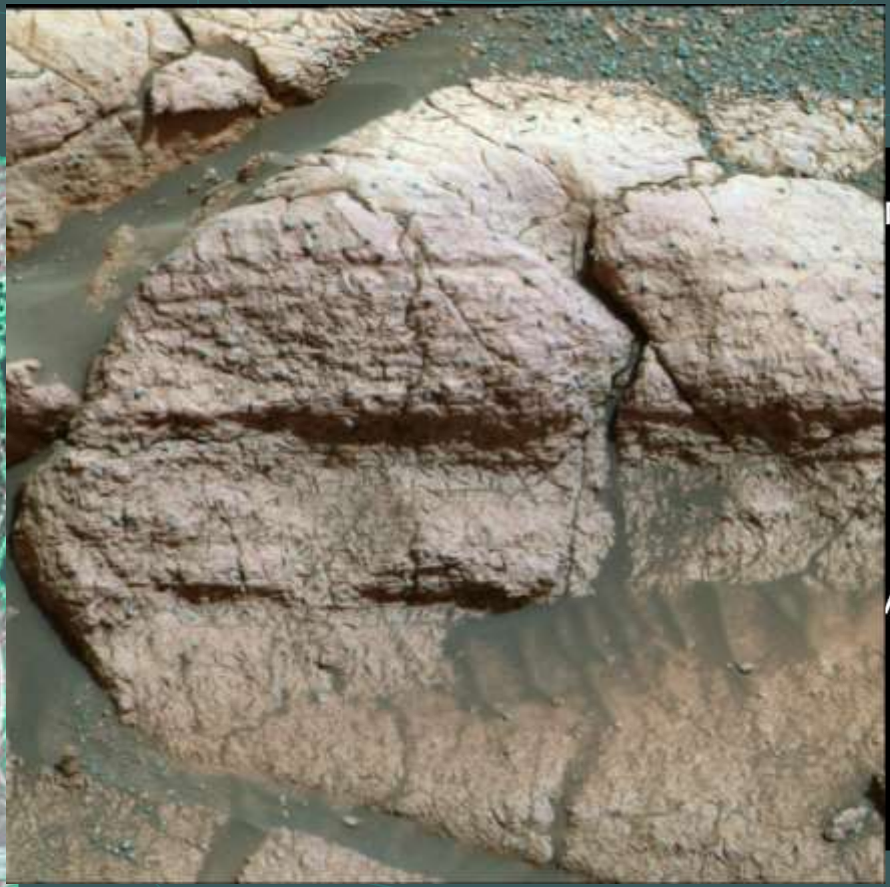


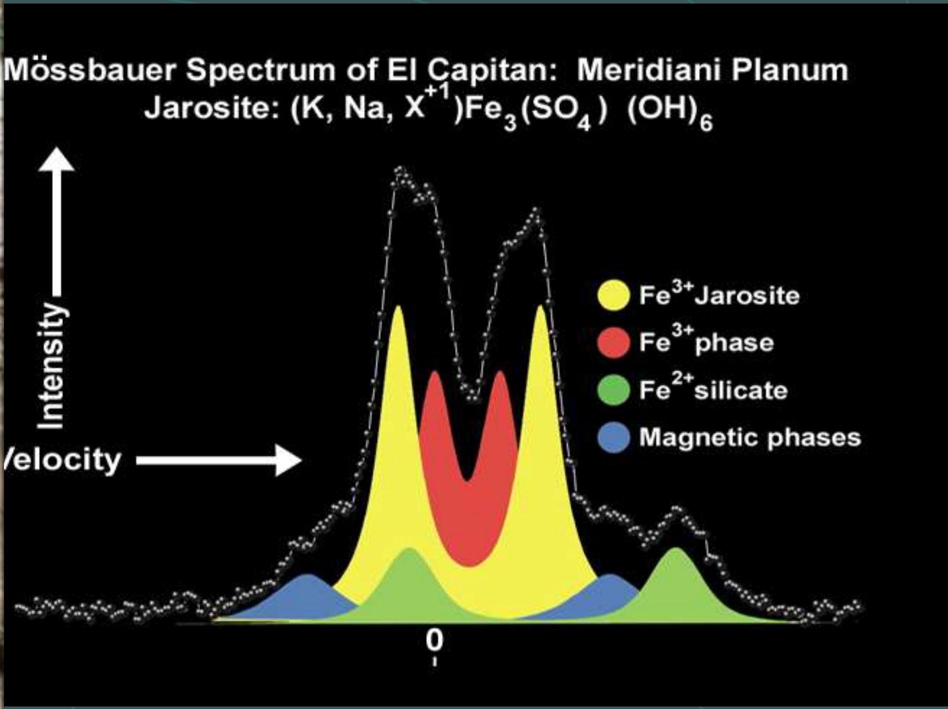
MER Opportunity - Heatshield and parachute.

Jarosite - A Water-bearing Mineral Formed in Groundwater

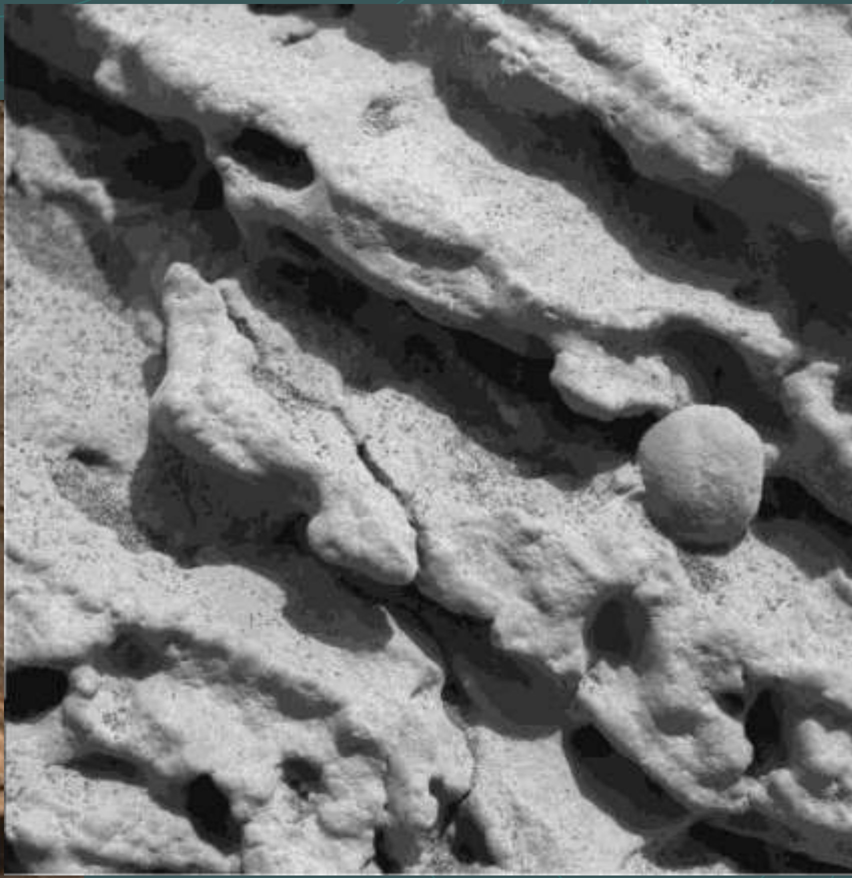
$KFe_3^{3+}(SO_4)_2(OH)_6$

2 Jarosite = $K_2SO_4 + 3\ Fe_2O_3 + 3\ H_2SO_4$



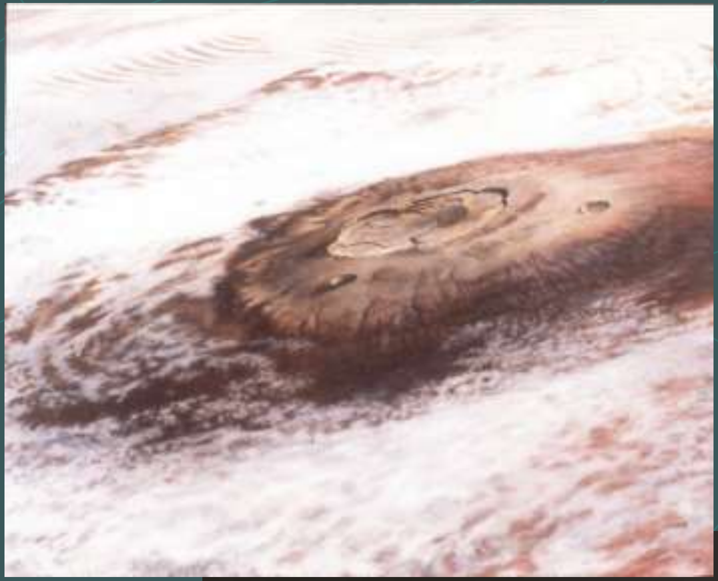


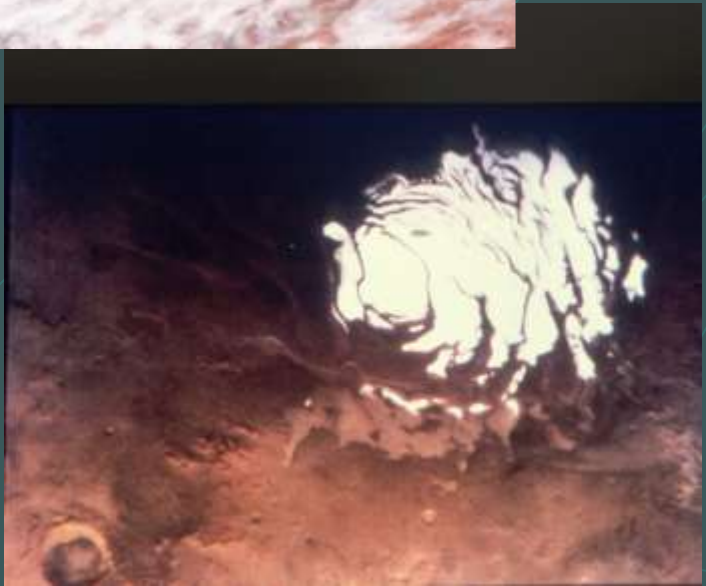
Hematite is in "Blueberries," which still suggest water.



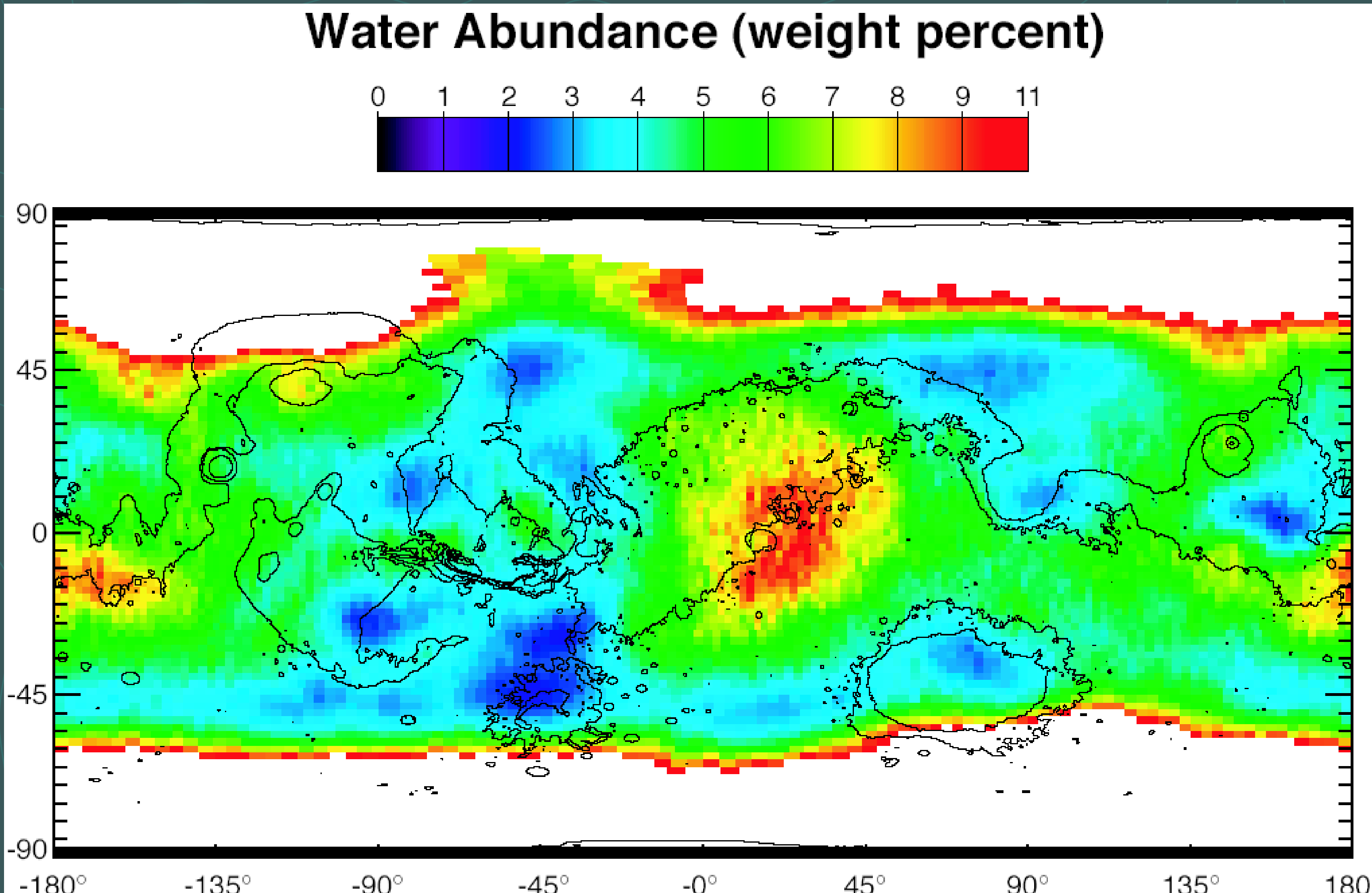
MER Spirit: Columbia Hills

H_2O Now:
Clouds & Polar Caps





Ground Ice – Mars Orbiter GRS



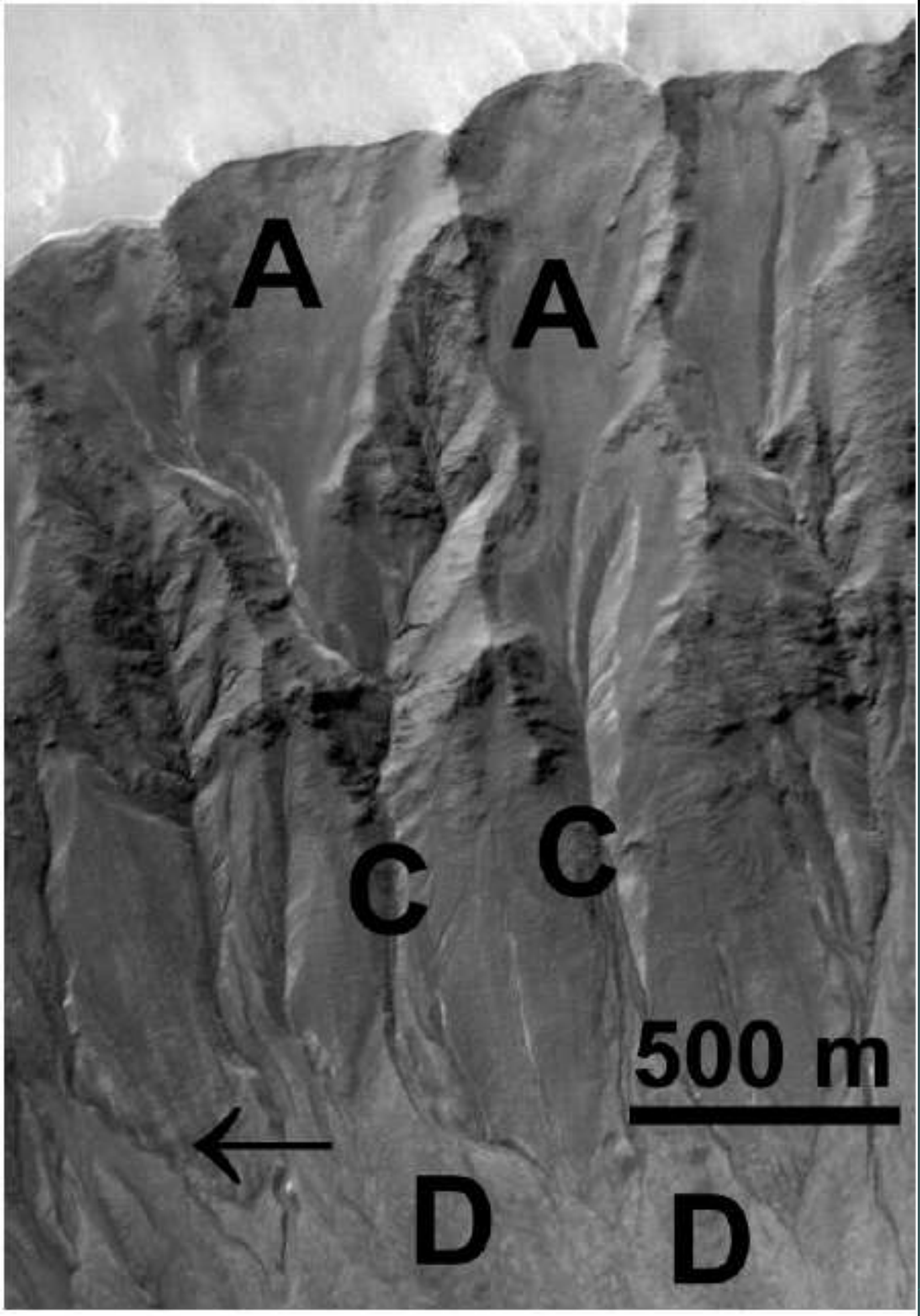
Water abundances within a few meters depth of the Martian surface. Wm. Feldman. AAAS talk & *Los Alamos Nat'l. Lab. Press Release*, 15 Feb. 2003. (SPACE.com report, 16 Feb. 2003)

So, Water on Mars !!

- So? Apparently, Mars has/had lots of water.
- Lots of evidence for ancient liquid water (> ~2 billion years ago), both surface and underground.

Martian Gullies - Liquid Water or Not?

- Material flows down steep slopes, most commonly interpreted as water-bearing debris flows [Malin and Edgett (2000) *Science* **288**, 2330].
- Liquid water is difficult to produce and maintain near Mars' surface, now.
- Could water be stable (enough) recently at Mars' surface?



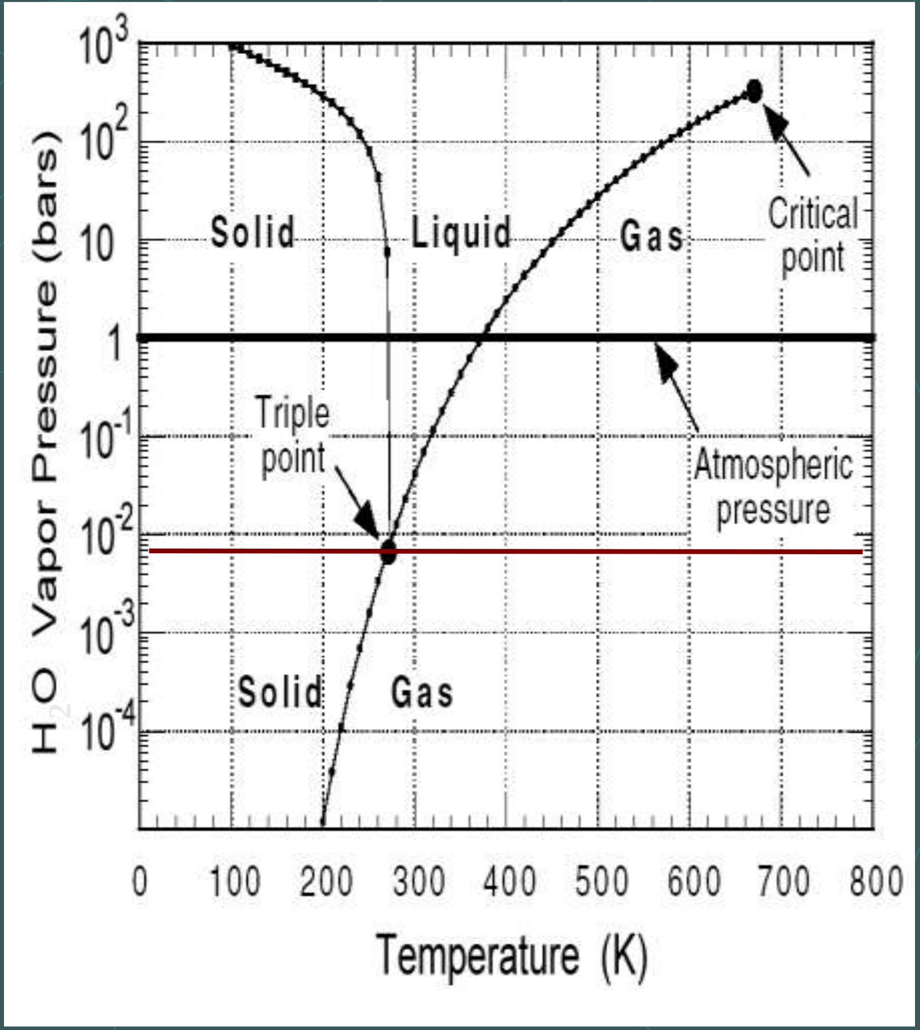
Mars Gully

- Mass flow on steep slopes
- **A**lcoves - sources of material
- **C**hannels - many sinuous, with levees
- **D**eposits - cones of debris, common with distinct lobate toes.
- Best analogs - water-rich debris flows

Most Earth analogs involve liquid water

Problems making liquid water

- Too cold! Except occasionally
  - Heat source
  - Antifreeze
- Pressure too low?
  - Antifreeze
  - Form liquid at higher pressure, eject to surface
  - Form liquid rapidly at surface, and make flow before it freezes/boils away.

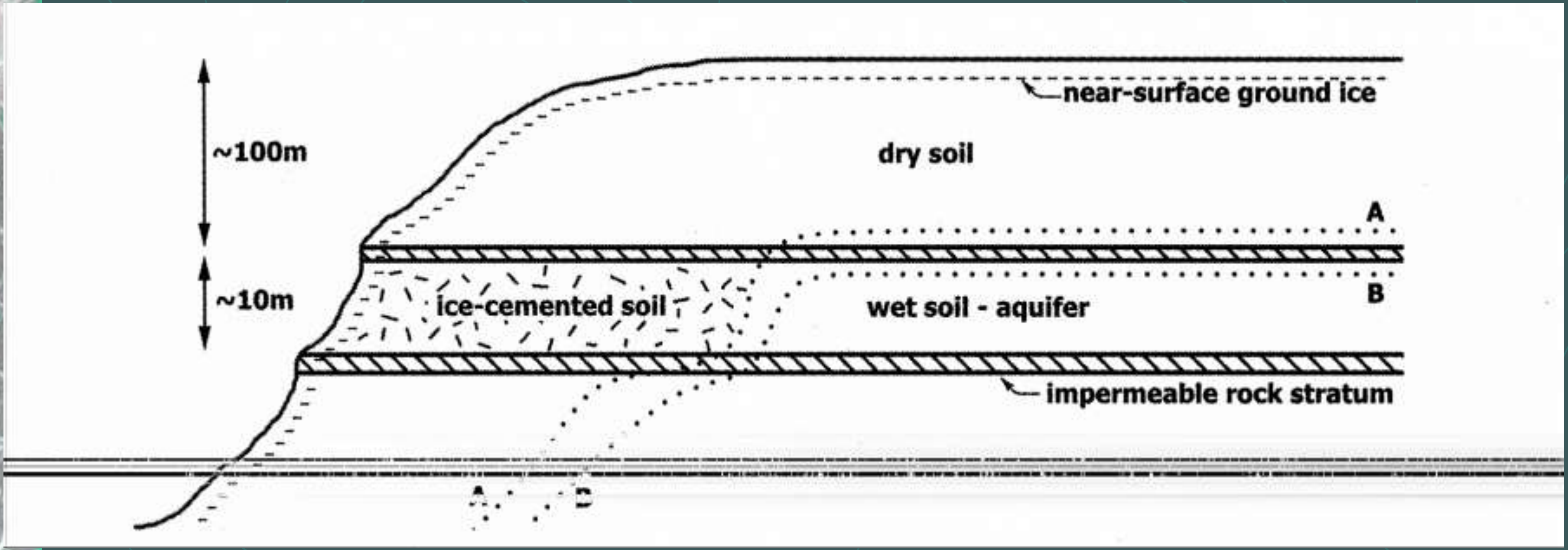


Internal Liquid Water - Groundwater.

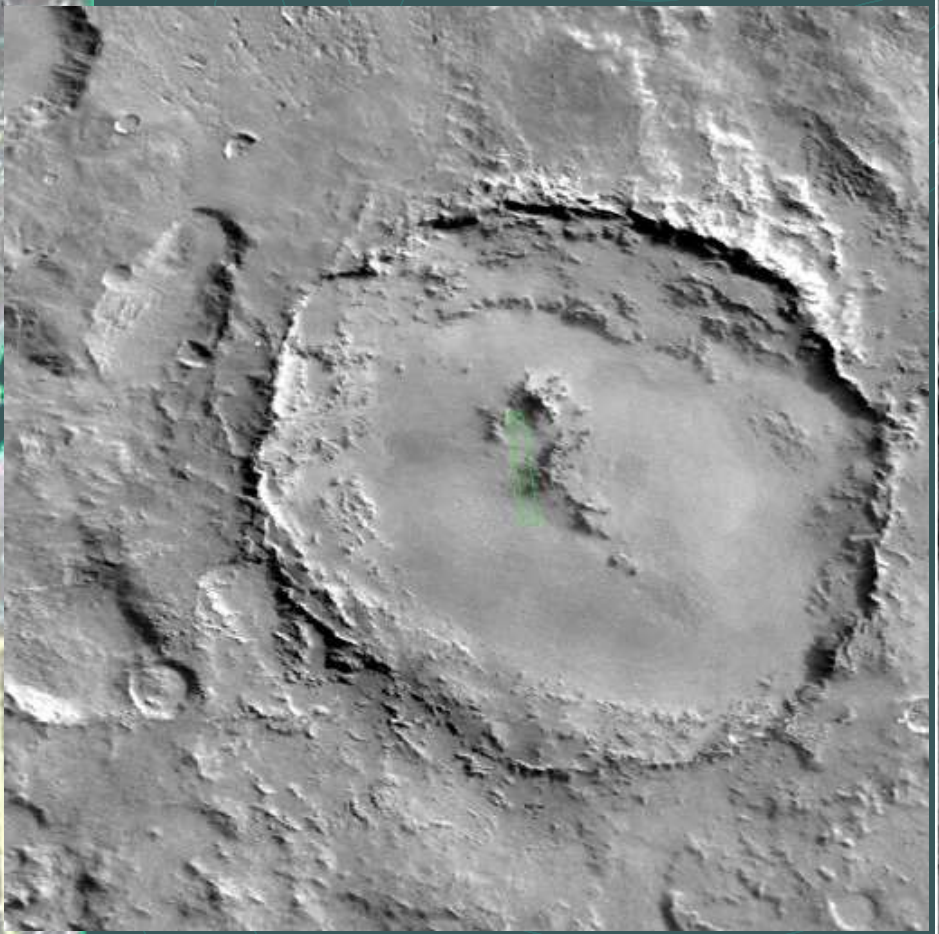
- Sunlight heats proper slopes (mid-latitude pole-facing) just right (Malin & Edgett)
- **Only enough solar heating when Mars' spin axis tilted more than today (Costard et al.)**
- Internal heat is enough - insulated by deep fluffy dust (Mellon) [implies regional aquifers]
- Heat from shallow magma (Hartmann)
- Water erupts from depth (Gaidos)
- No heat needed, water is briny (Burt et al.)

Pressurized (Burst Pipe)

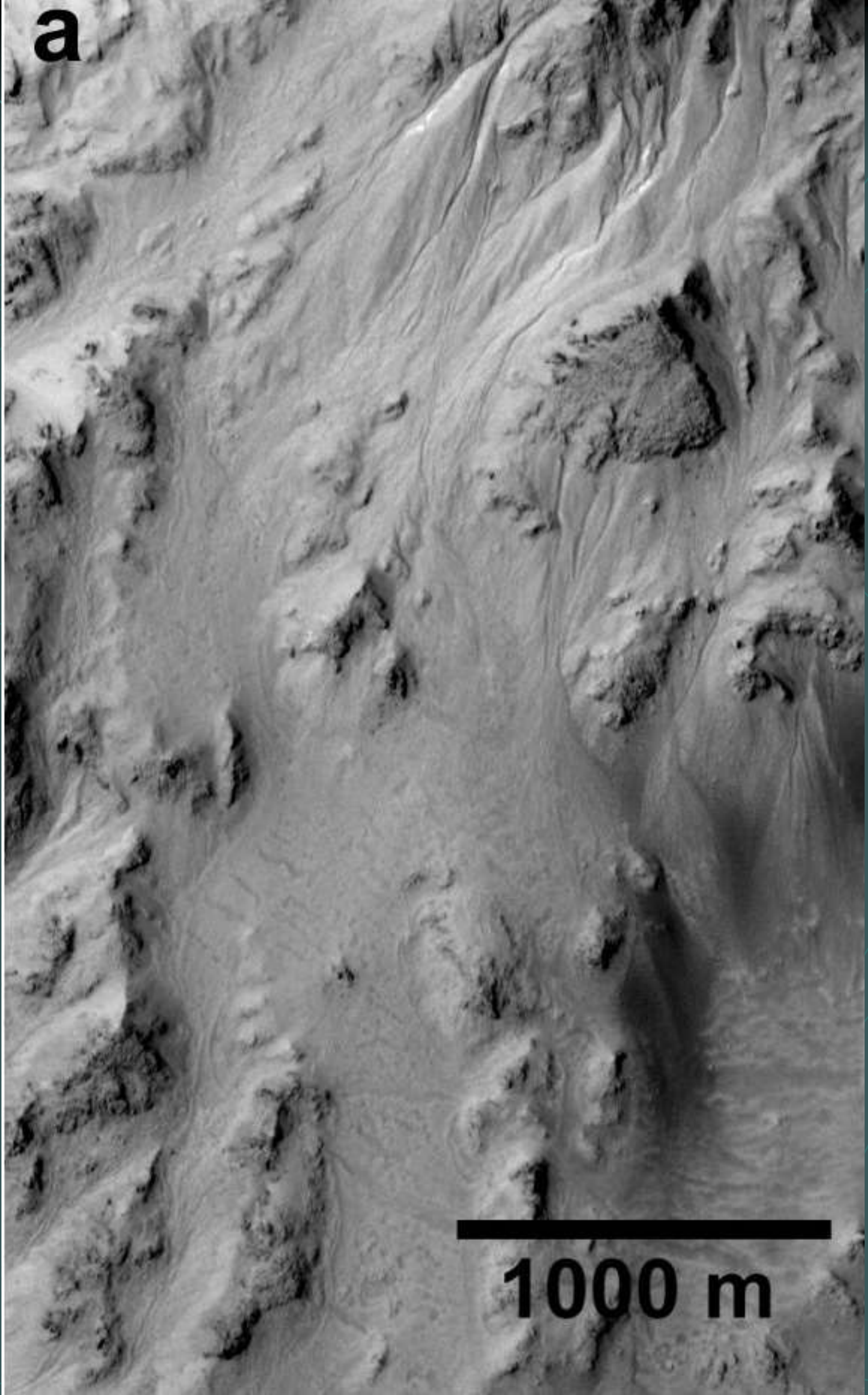
- Liquid water trapped, bounded by impermeable layers of rock, ice, frozen soil.
- In cooling climate or annual cycle, water begins to freeze.
- Volume increase on freezing pressurizes liquid.
- Excess pressure breaks rock. Whoosh!

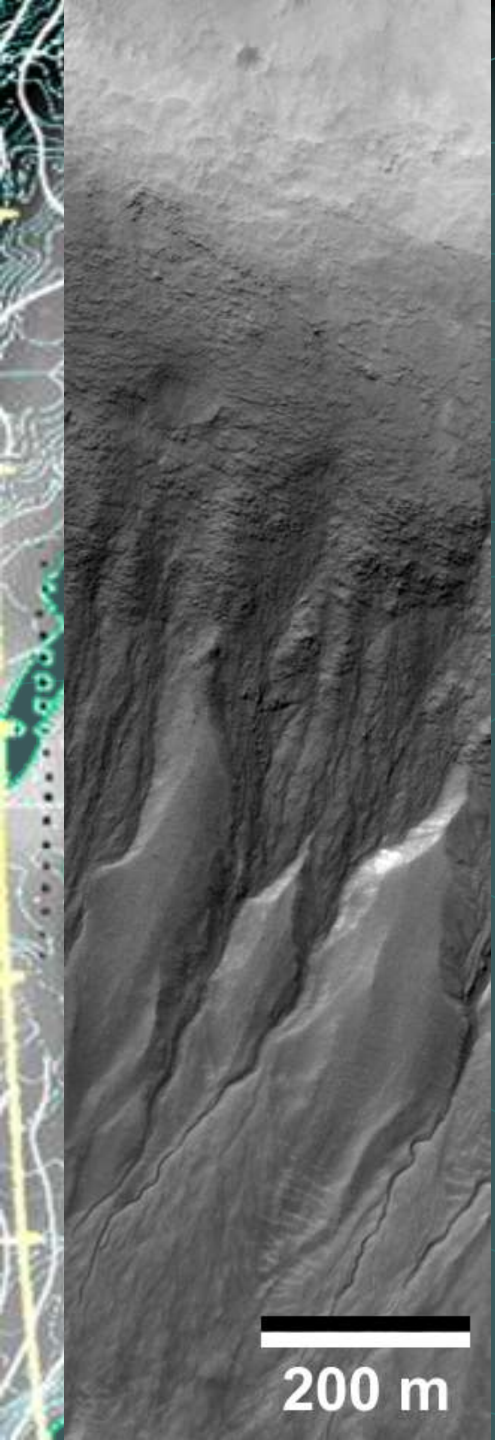


Impermeable Layers ?

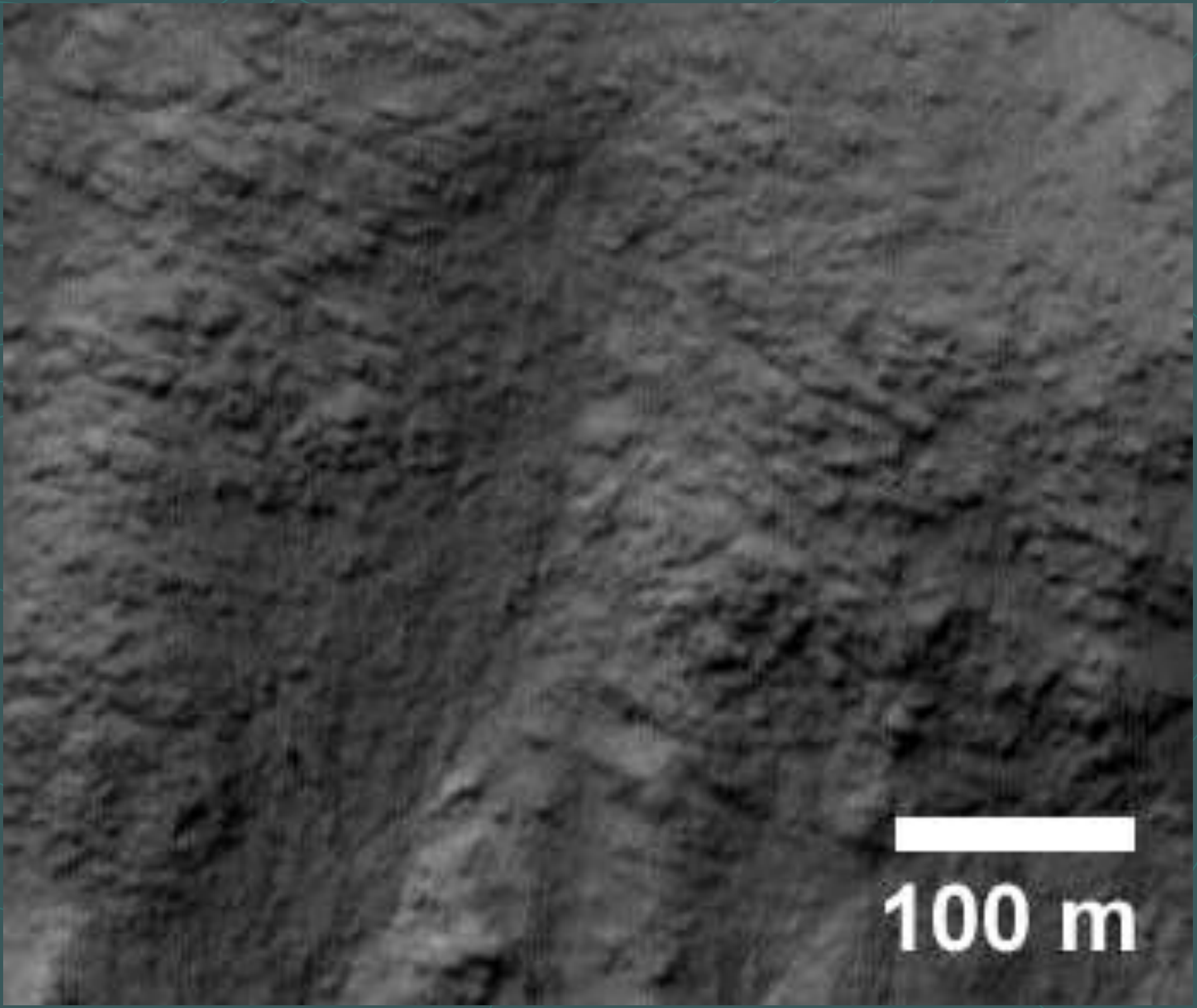


Central Peak, Hale impact basin





Crater wall: Newton area

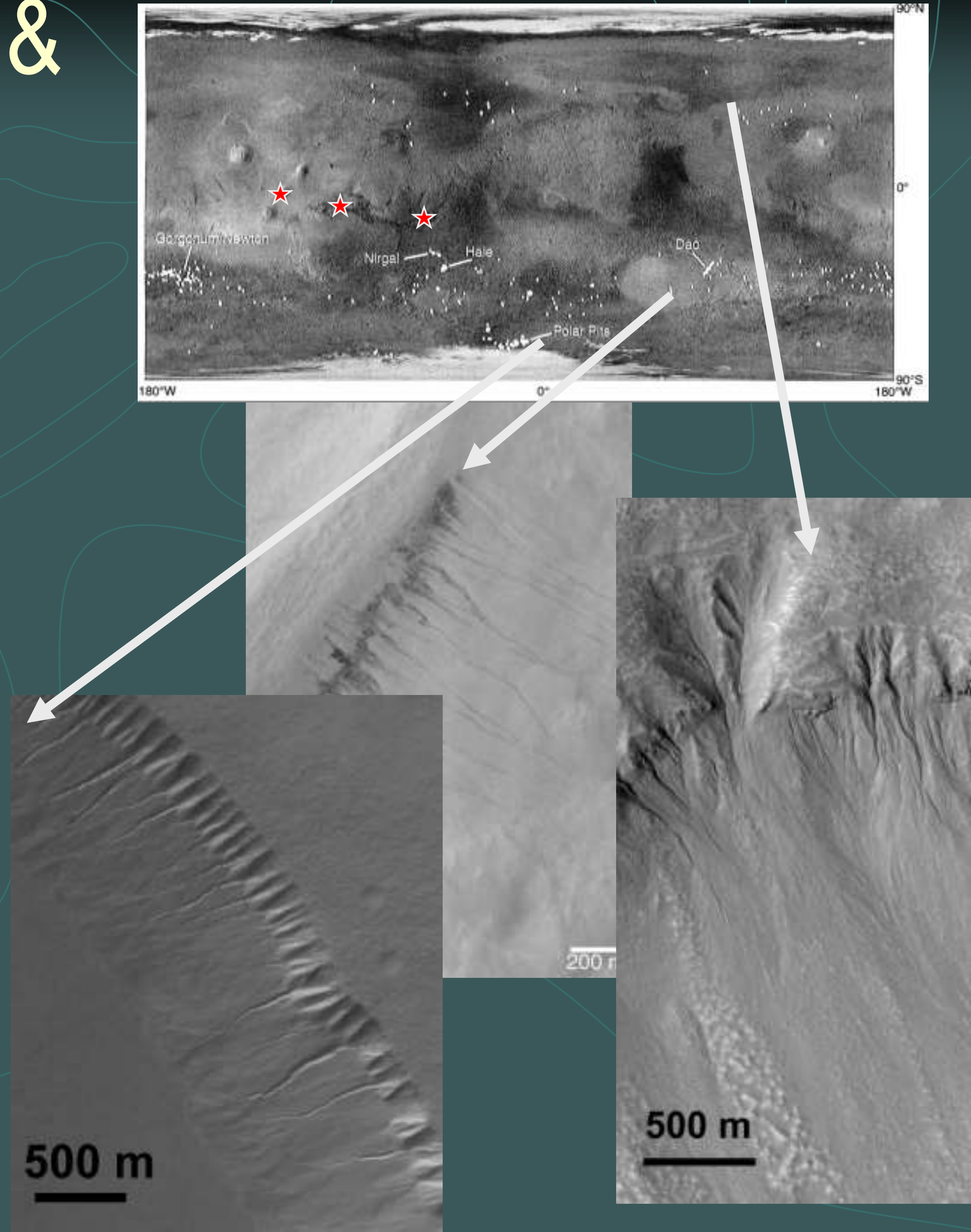


Liquid Water from Snowmelt. Christensen (2003)

- Wind-blown snow accumulates on pole-facing slopes (i.e., mantling deposits).
  - BUT, snow accumulates in lee of obstacles, I.e. on equator-facing slopes.
- Top anneals to ‘impermeable’ layer.
  - Own weight provides a few extra millibars pressure.
  - Sunlight into snow heats it to melting.
- Gullies form <u>beneath</u> snowcover!

Most Altitudes & Latitudes

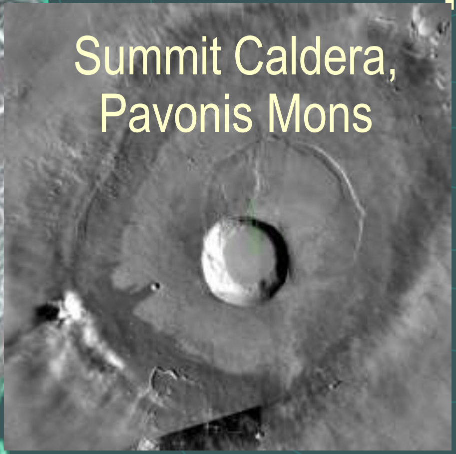
- Altitude
  - Pavonis summit
  - Hellas floor
- Latitude
  - S. peri-polar (75S)
  - Equatorial
  - N. peri-polar (69N)
- Altitude/Latitude e.g.,
  - Pavonis / Capri
  - Hale / Hellas

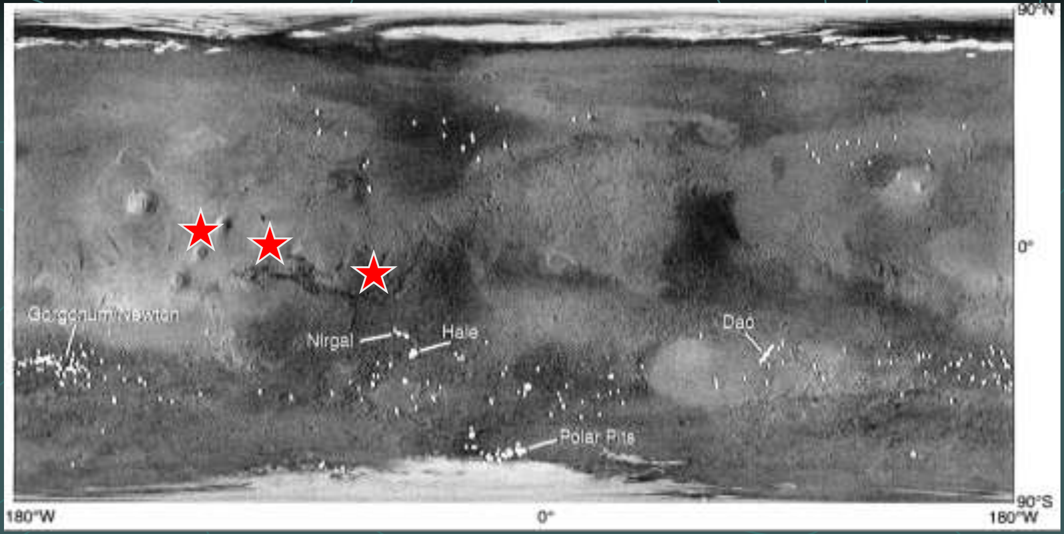


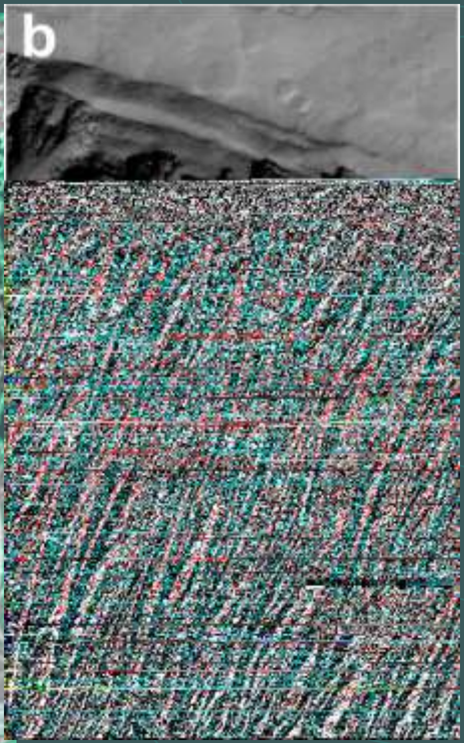
Ground Ice Melting ?

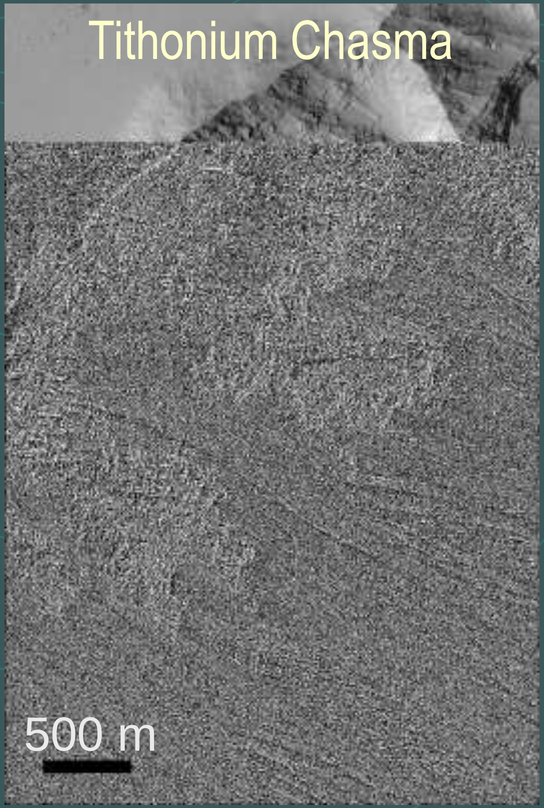
- Ground ice preserved from past climate epoch (higher obliquity)
- Sunlight warms slopes, causes melting & fluidization of debris.
  - Quicker than the melt water can evaporate/boil away.
- Wind can remove dust and expose fresh ice to produce additional flows.

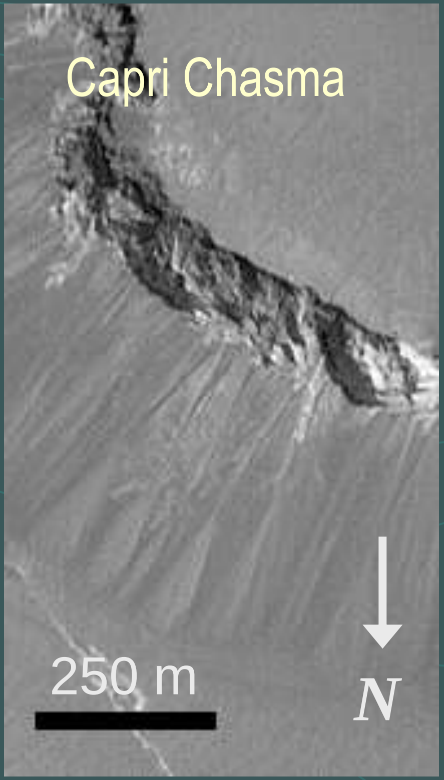
Near-Equatorial Gullies











Trouble all around.

- Solar heating on slopes? (Obliquity, snowmelt)
  - Gullies on slopes of all orientations.
  - Gullies at all latitudes and elevations.
- Pressurized aquifers? (Water, brine)
  - Most gullies on broken and/or unlayered rock.
  - How could groundwater get to tops of isolated peaks?

Why consider ‘dry’ mechanisms?

- No liquid today at Mars’ surface
- Liquid water barely stable near Mars’ surface
- Skepticism about generation of liquid water
  - Pressurizing aquifers in broken rock of crater walls?
  - Bringing water to mountain-tops?
  - ‘Just right’ melting of ground ice / snow?
- Good Earth Analogs
  - ‘Sand’ etc.
  - Snow
  - Pyroclastic

Analogs: Sand

Click here to view the video

Analog: Snow

- Advantages
  - Dry snow is abundant
  - Forms very large flows
  - Abundant in steep slopes of large vertical relief
  - Extensive study - avalanche safety
- Disadvantages
  - Rheology complicated in detail
  - Can partly melt in large flows

Snow as a Fluid

Sinuous Channels: Sionne & Gotthard

Analog: Pyroclastics Mt. St. Helens 1980

Figure 300.—Perspective view of a single lobe of deposits from July 22 eruption showing slightly raised levees and central channel. Persons are standing at edge of channel just inside levees. Dashed line marks approximate crest of levees. Lobe turns to right just behind persons. Photograph taken at station B (fig. 298).

- Wilson & Head (1981) USGS. PP 1250

The Argument:
Morphology $\Rightarrow$ Rheology $\Rightarrow$ Composition

- "Morphology $\Rightarrow$ Rheology" is dicey
  - Must understand all physics completely!
  - E.g., lava flow inflation not recognized early
- "Rheology $\Rightarrow$ Composition" is not unique
  - Gully levees, sharp-front flows suggest Bingham flow law
  - Consistent with water-'granule' slurries, gas-supported or dry granules, some lavas, some emulsions, etc.

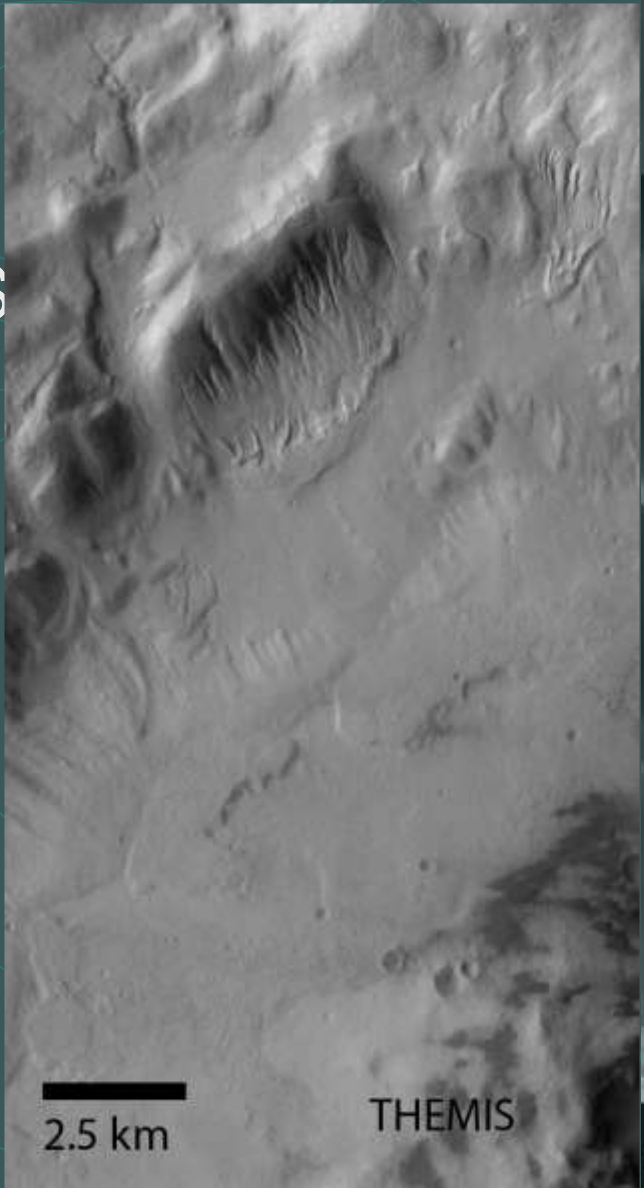
Dry / Gas-supported Flows are Legitimate Alternatives. Advantages & Disadvantages

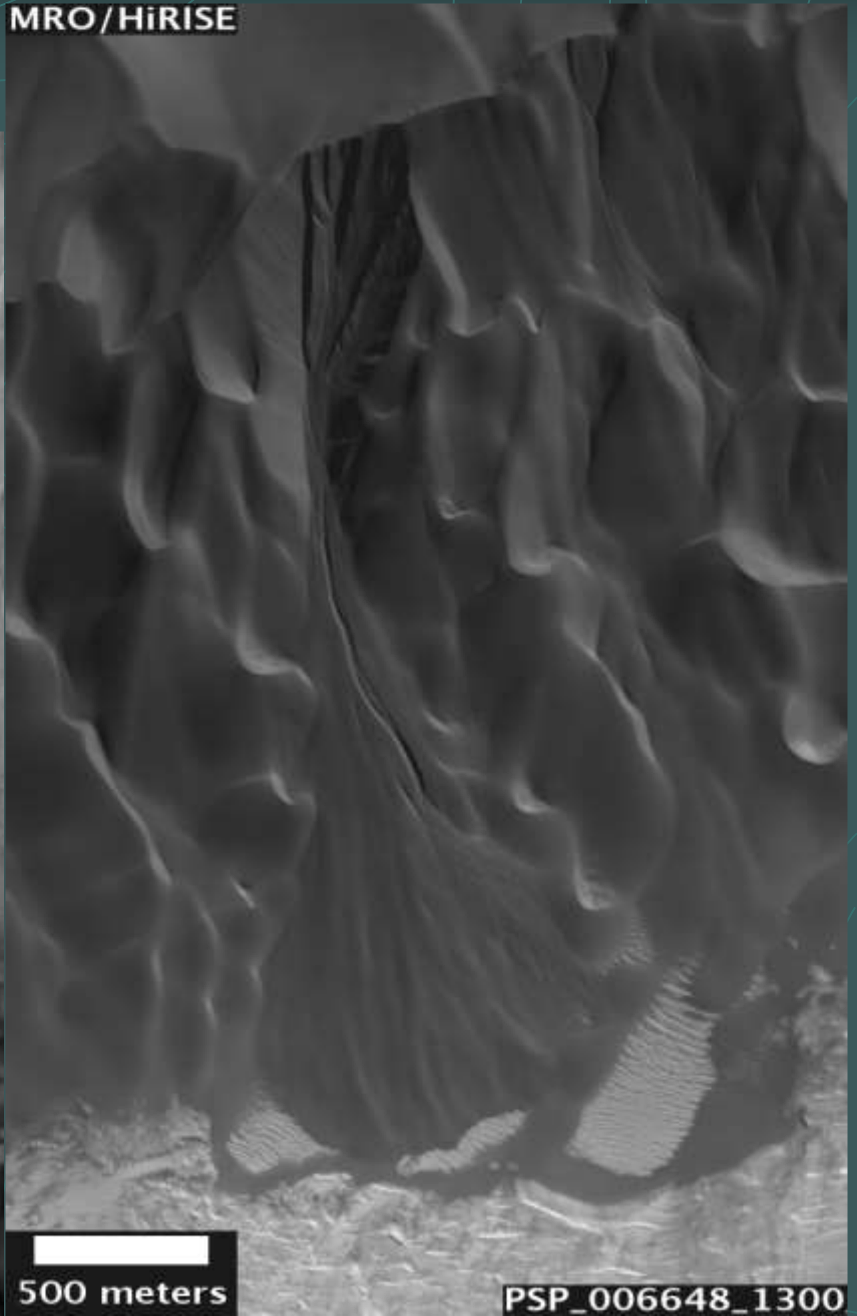
- Require nothing unobserved (only slopes, grains, gas)
- Extensive theoretical, experimental bases

- No exact analogs on Earth, not near so much dry dust / sand.
- Theory, experiments only at much smaller length scales

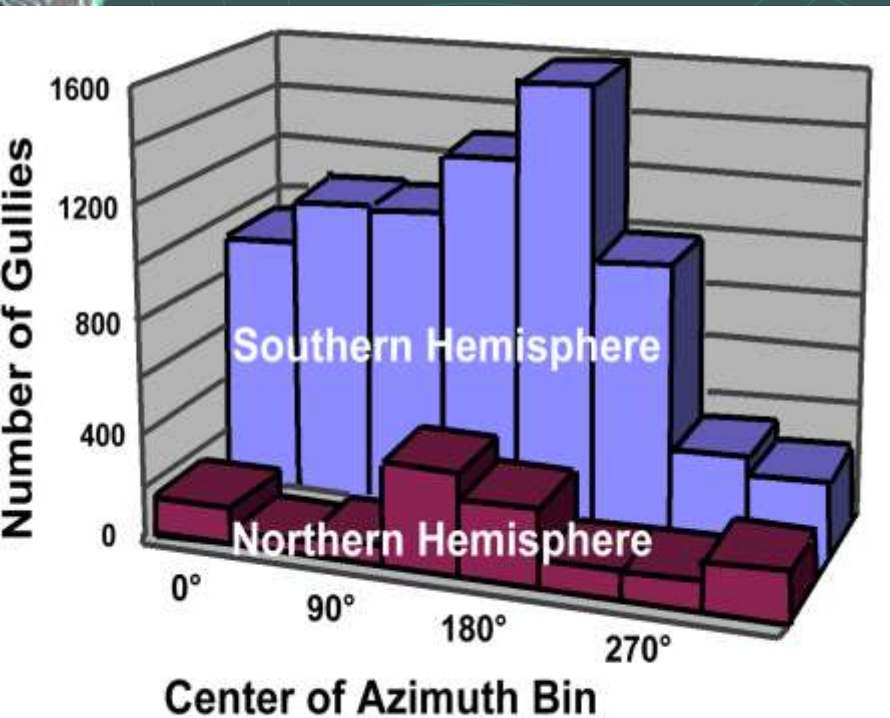
More to come!

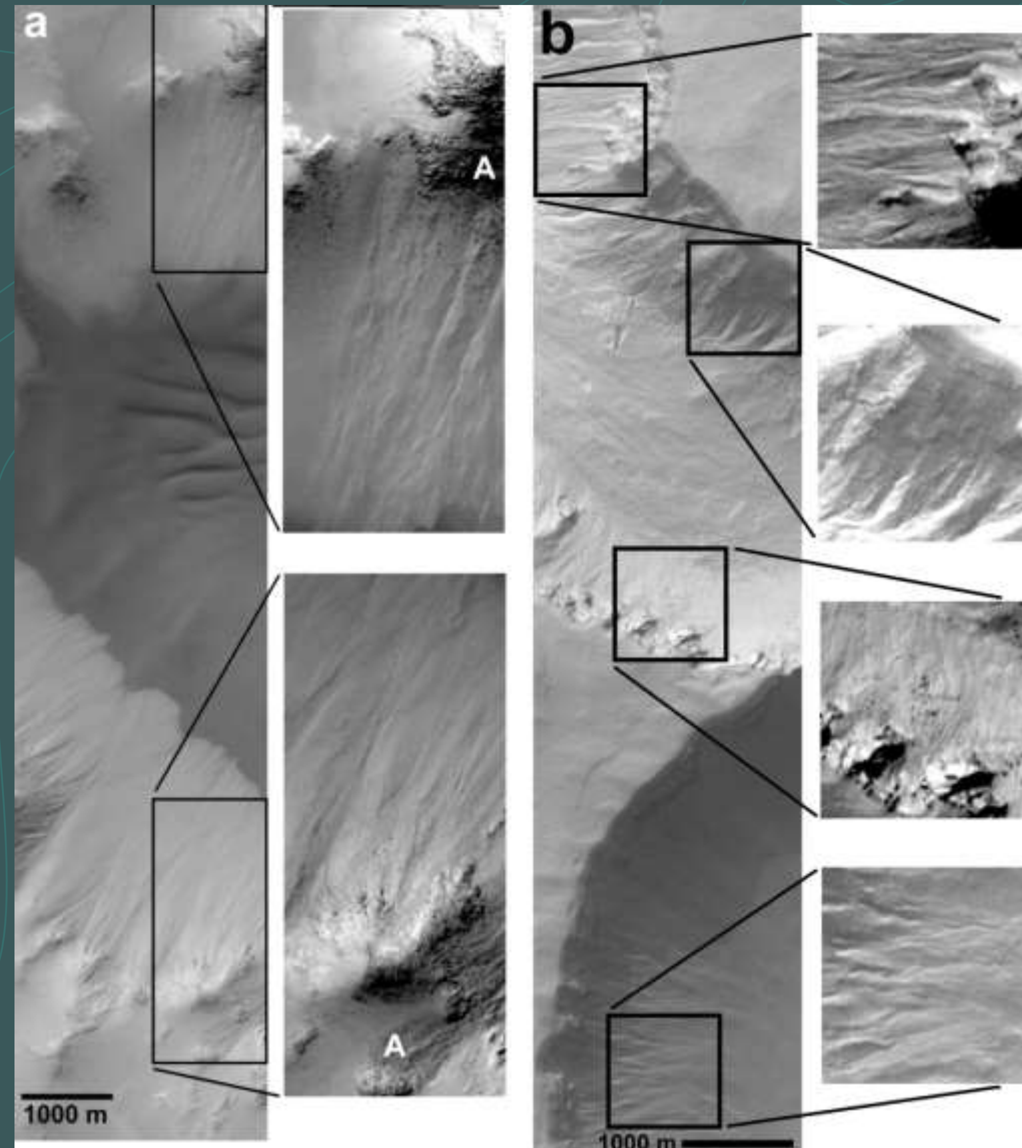
- Imagery
  - THEMIS
  - CTX
  - HiRISE
- Topo.
  - HiRISE
- Spectra
  - CRISM





Not Pole-facing !!





Edgett et al. (2003) *LPSC* **XXXIV**, Abs. #1038.

A *preference* **for south-facing** in **both hemispheres.**

Problems and Unknowns

- Regional / global distribution of gullies
  - Consistent with dry(±gas) flows?
  - Different in the past?
- Local distributions of gullies
  - Consistent with dry(±gas) flows?
- Theory / Experiments
  - Are results at meter scale relevant?
  - Can dry(±gas) flows really meander?

Argument by Analogy

- "… this word analogy is urged, as giving great force to the reasoning. But it must be recollected, that precisely the point in question is whether there is an analogy." Whewell W. (1853) *Of a Plurality of Worlds: An Essay.* London.
- … is risky at best.