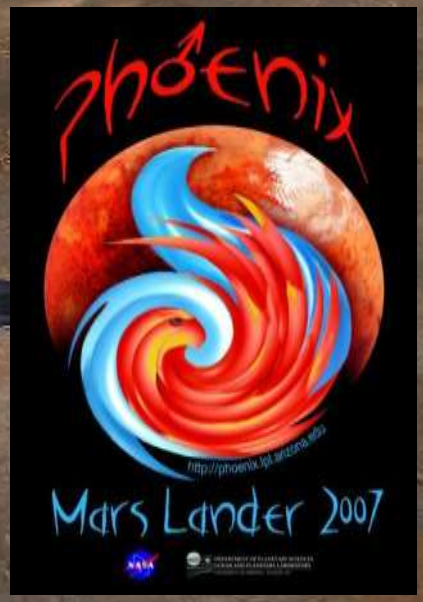
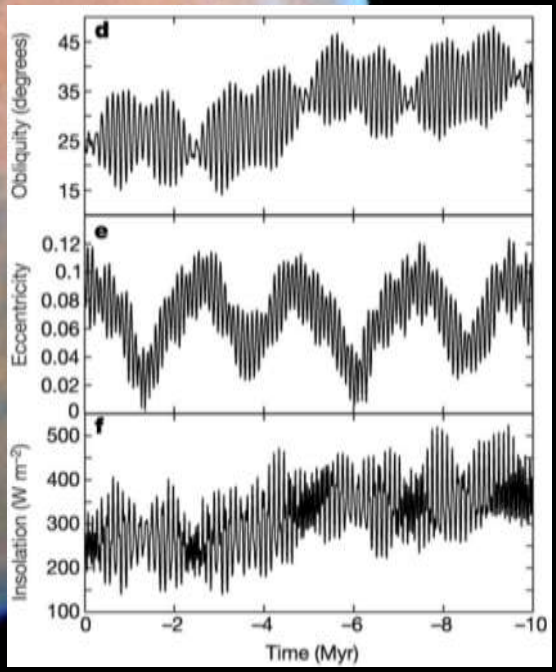
Mars Polar Science and the Phoenix Mars Lander Mission



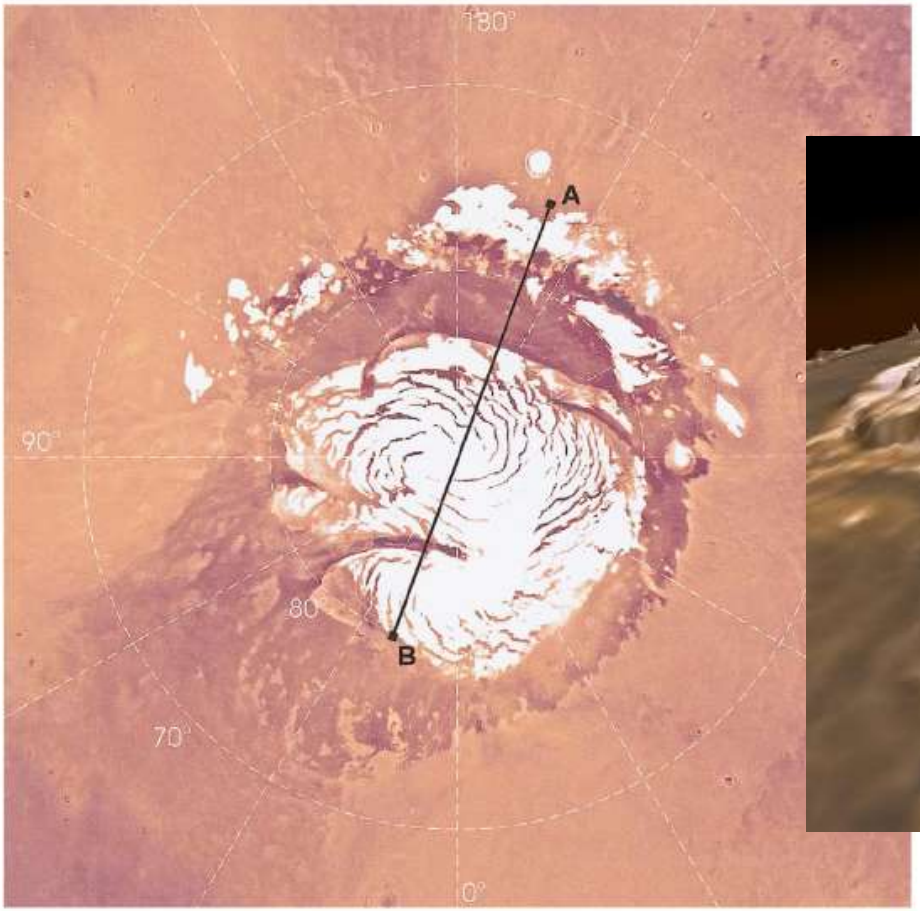
W.J. Markiewicz
Max Planck Institute for Solar System Research
with lots of inputs from
R. El Maarry, W. Goetz, H.U. Keller, M. Lemmon, M. Mellon, G. Portyankina, P. Smith, J. Whiteway,
The Phoenix Team

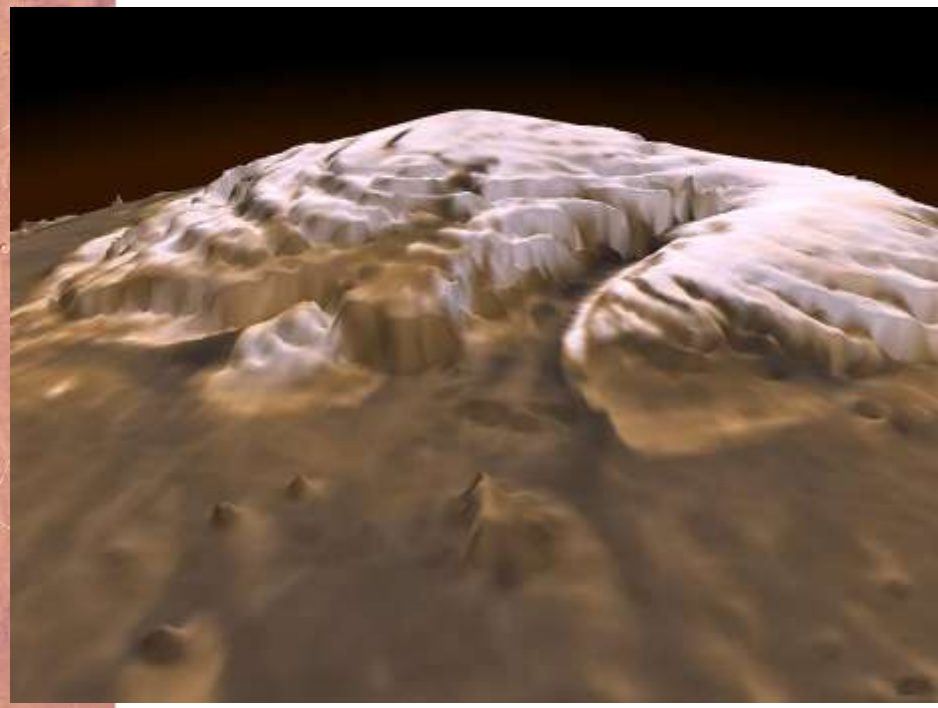
Simple Mars facts

- About half the size of Earth
  - gravity on surface about 1/3g
- Twice as far from the Sun as Earth
  - One Martian year is nearly two Earth years
  - solar strength is ¼
- Very thin atmosphere
  - 6.35 mbar at surface
  - mean surface temperature 210K
- Two small moons
  - variations in obliquity (Laskar, 2002)
  - climate change

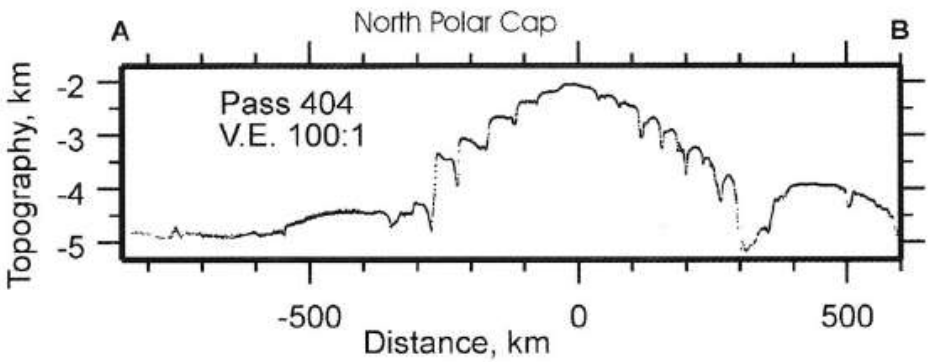


(a)

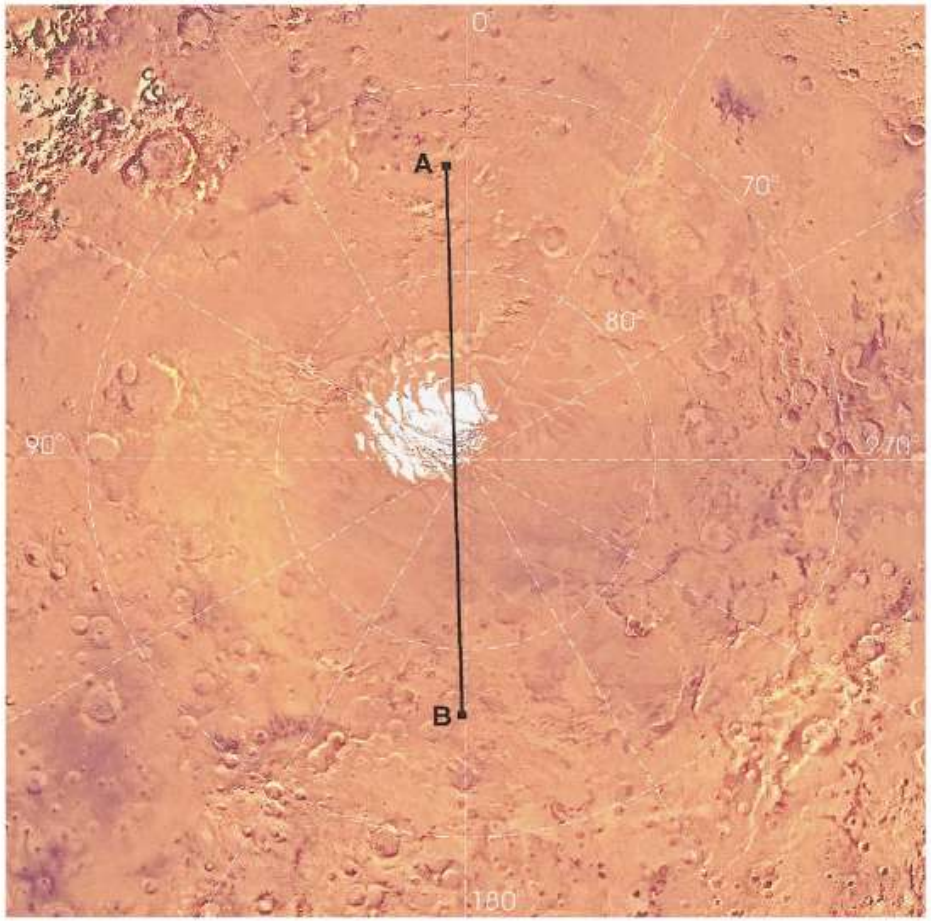

180°
0°
90°
80°
70°
0°
A
B



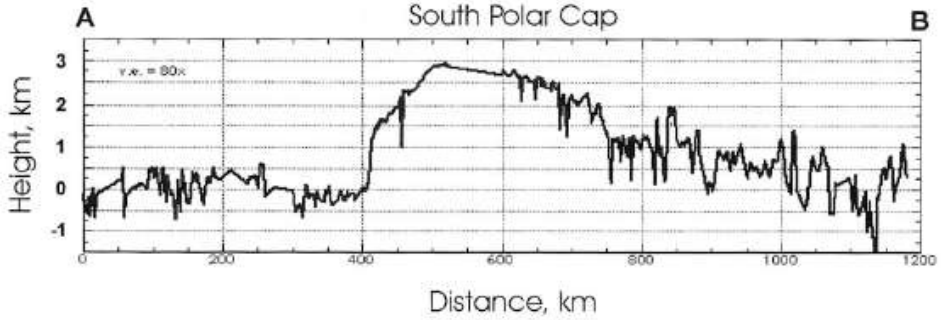
(b)


North Polar Cap
A
B
Pass 404
V.E. 100:1
Topography, km
-2
-3
-4
-5
-500
0
500
Distance, km

(c)


0°
70°
80°
90°
270°
180°
A
B

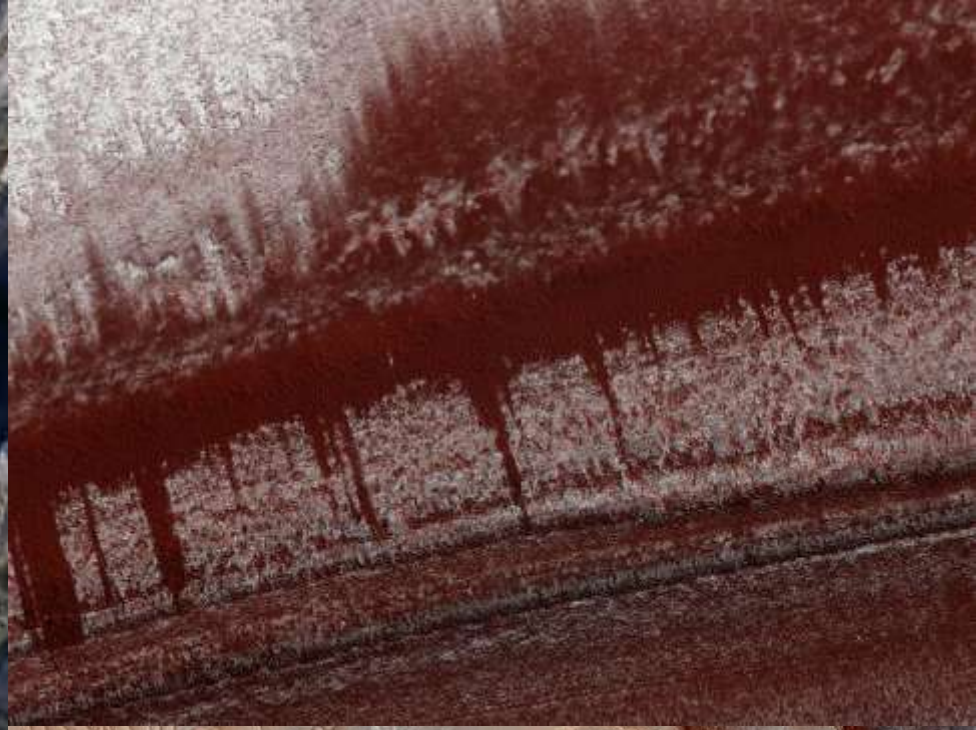
(d)


A
South Polar Cap
B
v.e. = 80x
Height, km
3
2
1
0
-1
0
200
400
600
800
1000
1200
Distance, km

Why Mars Polar Science?

- **Study of the present seasonal cycle**
  - **Changes are observed**
  - **Constrains for climate models**
- **Water**
  - **Permafrost postulated**
  - **Gamma ray data implies near surface water ice**
- **Climate record**
  - **Polar Layered terrains**

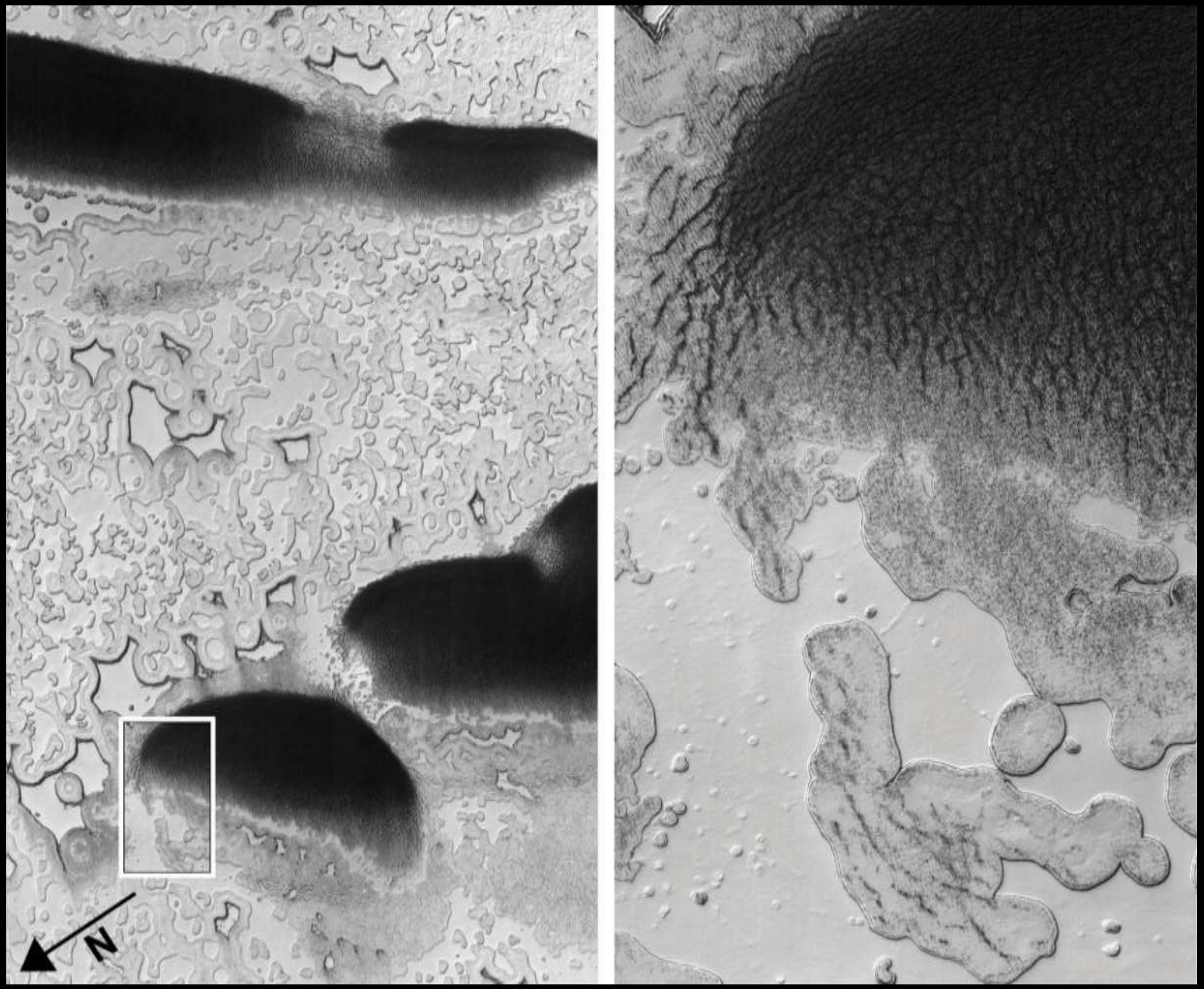
Polar layered deposits
Climate record?



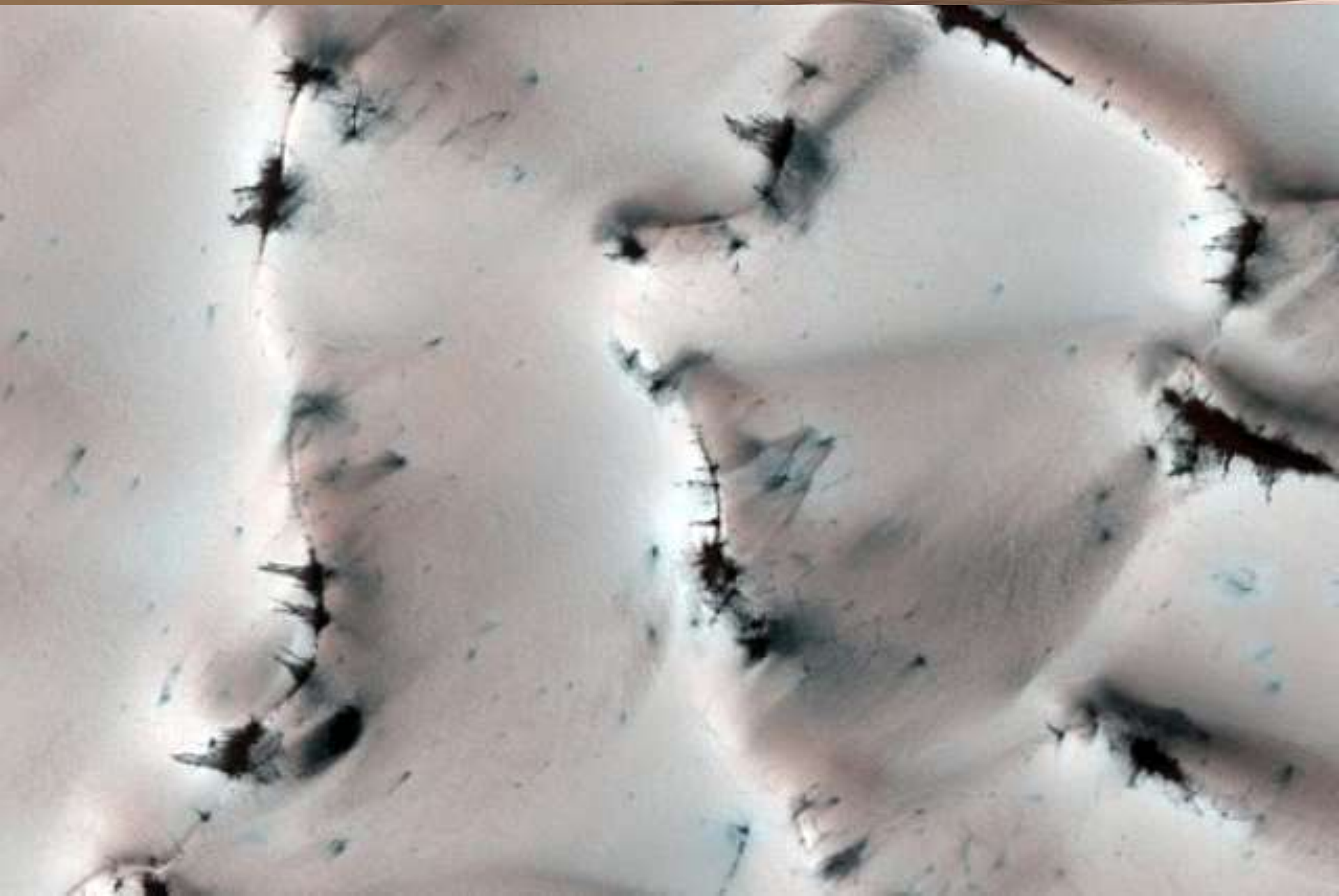
North Polar Layer Deposits – Climate Record

CO_2 ice in the South

CO_2 ice in the South



Frosted dunes in the North

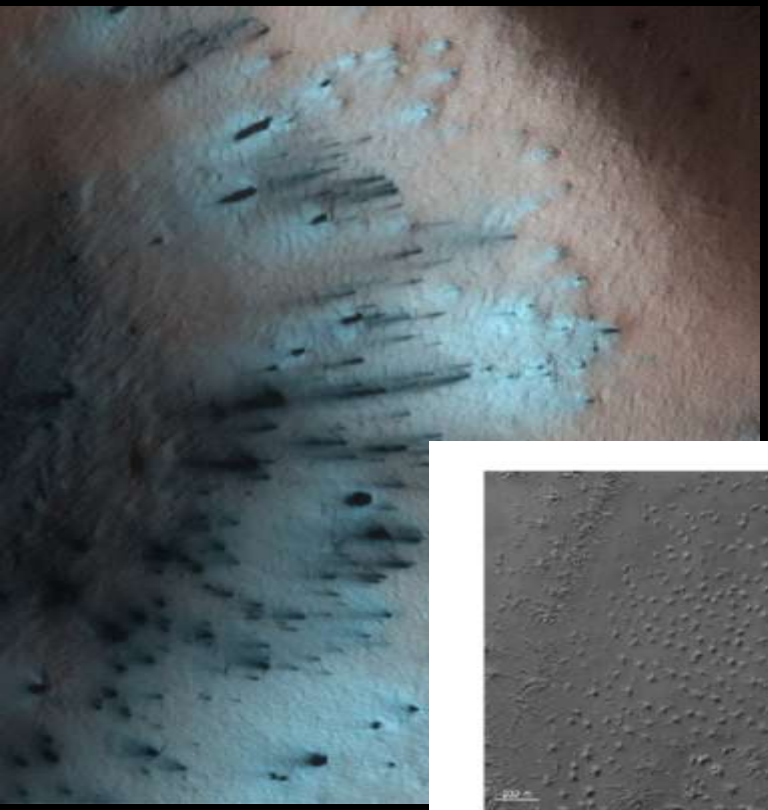


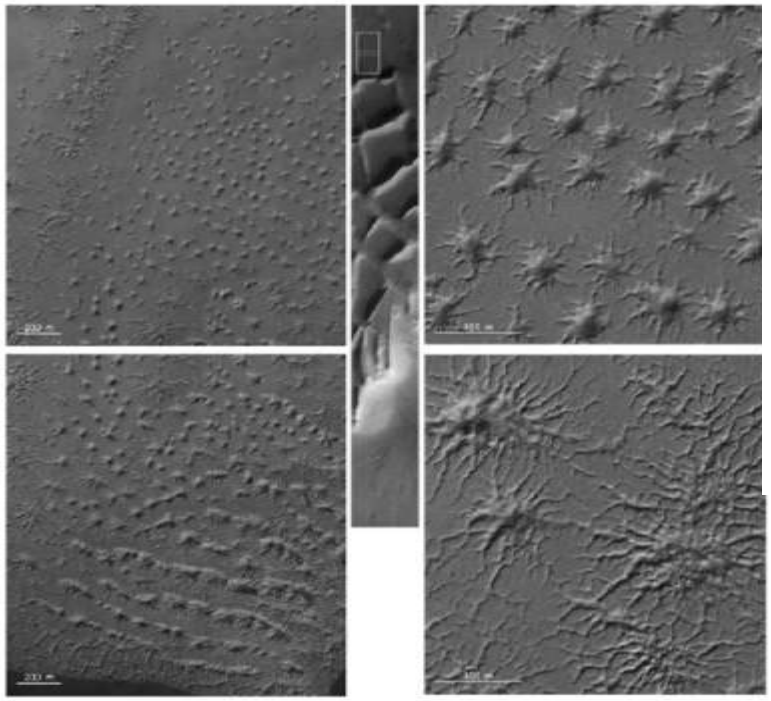

Burst of spring

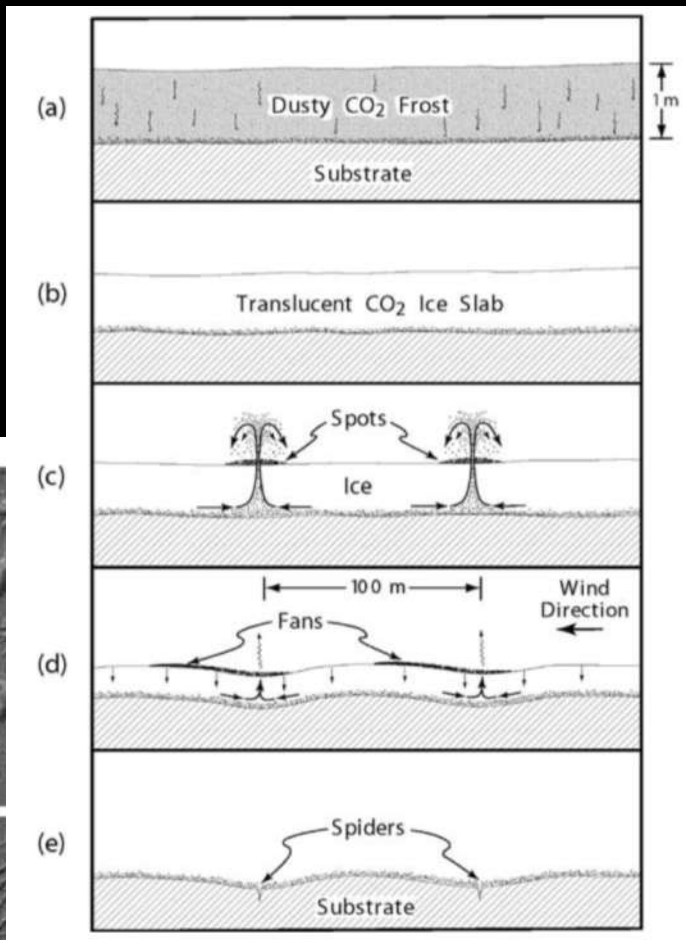

More HiRISE Martian polar spring

Mars polar regions are very dynamic!

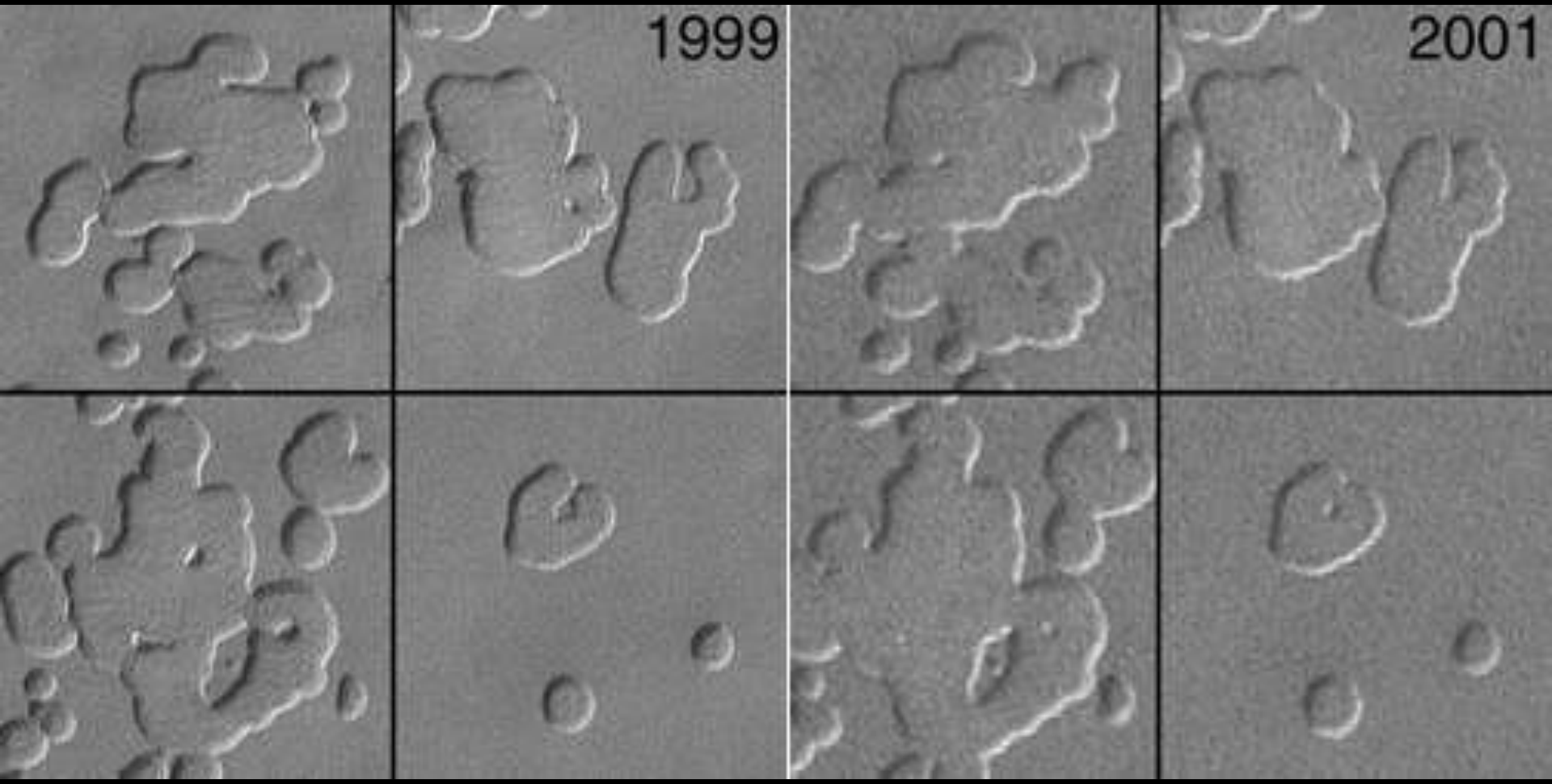
“Spiders” on Mars – a form of (micro) cryo-volcanism



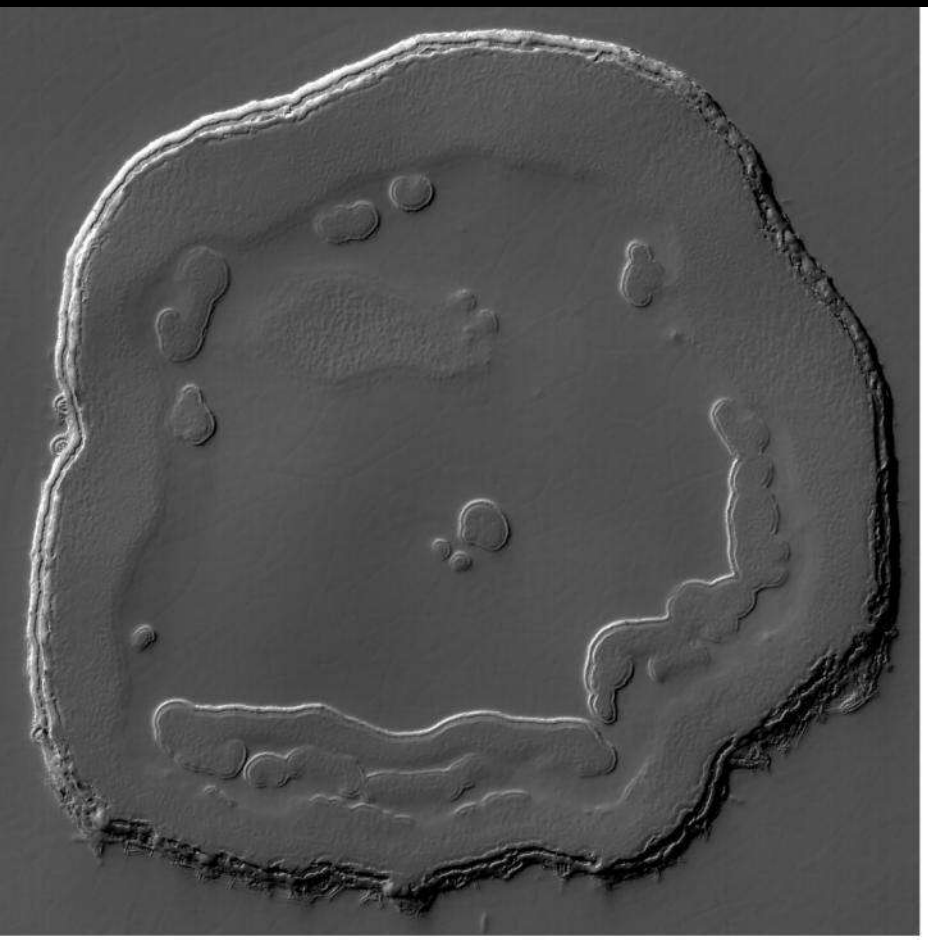




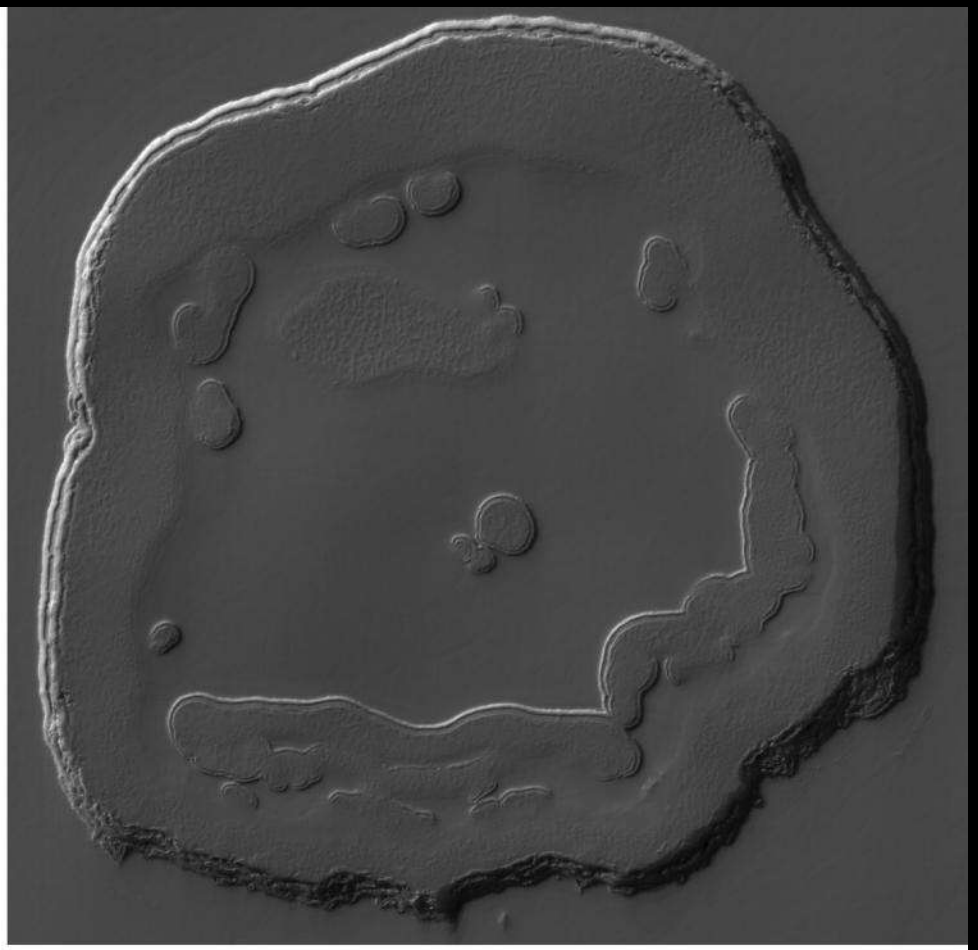
Observed changes lead to physical understanding



Observed changes lead to physical understanding



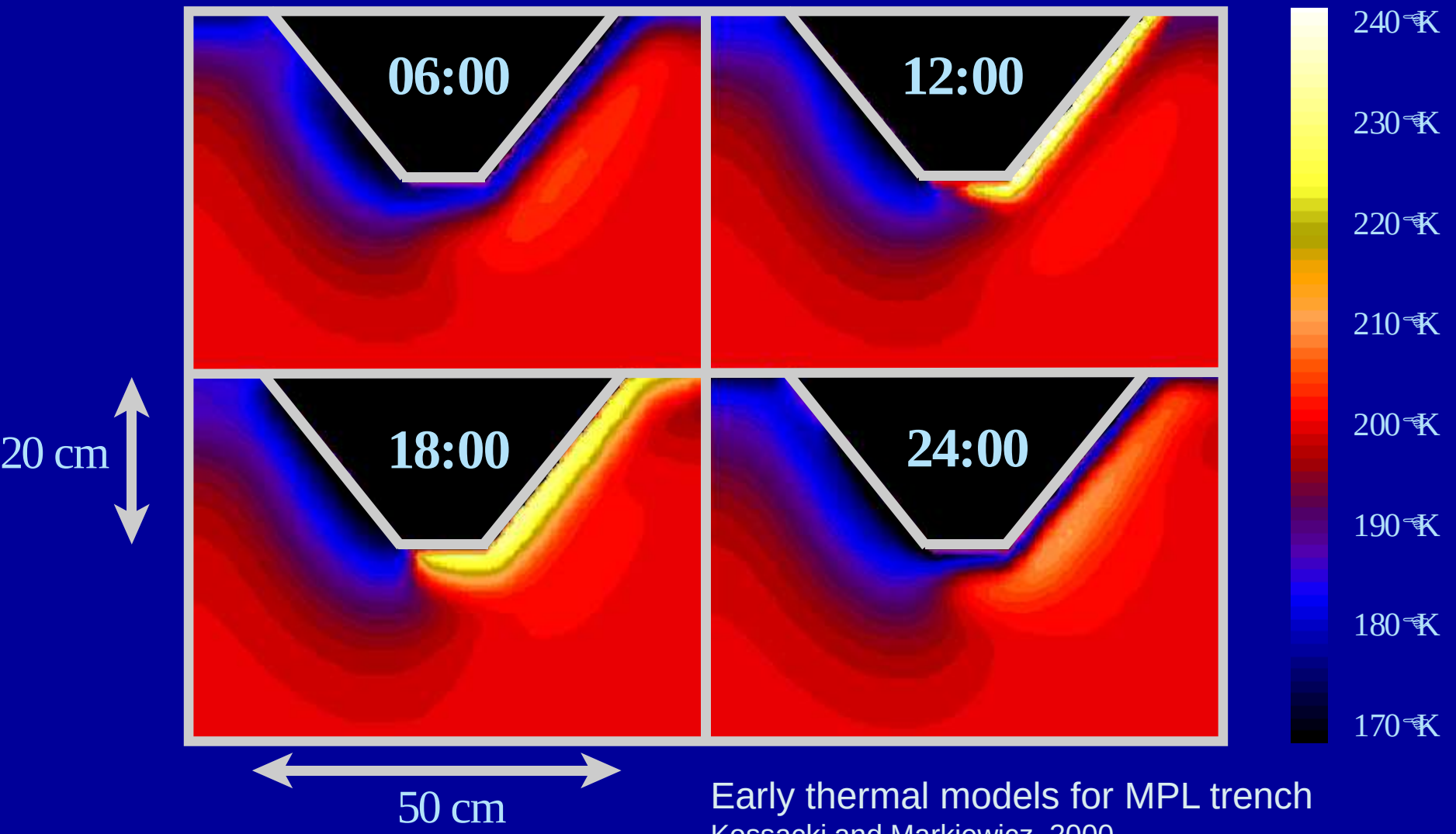
PSP_004000_0945, June 4 2007



ESP_020746_0945, December 30, 2010

Temperature distribution in the soil

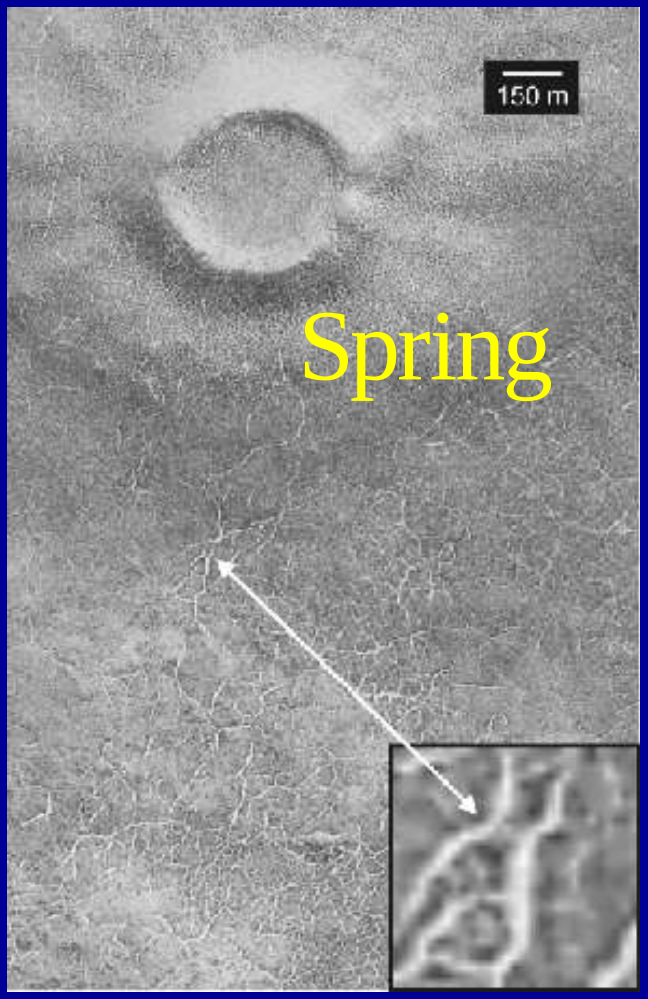
Water ice condensation (frost) is possible



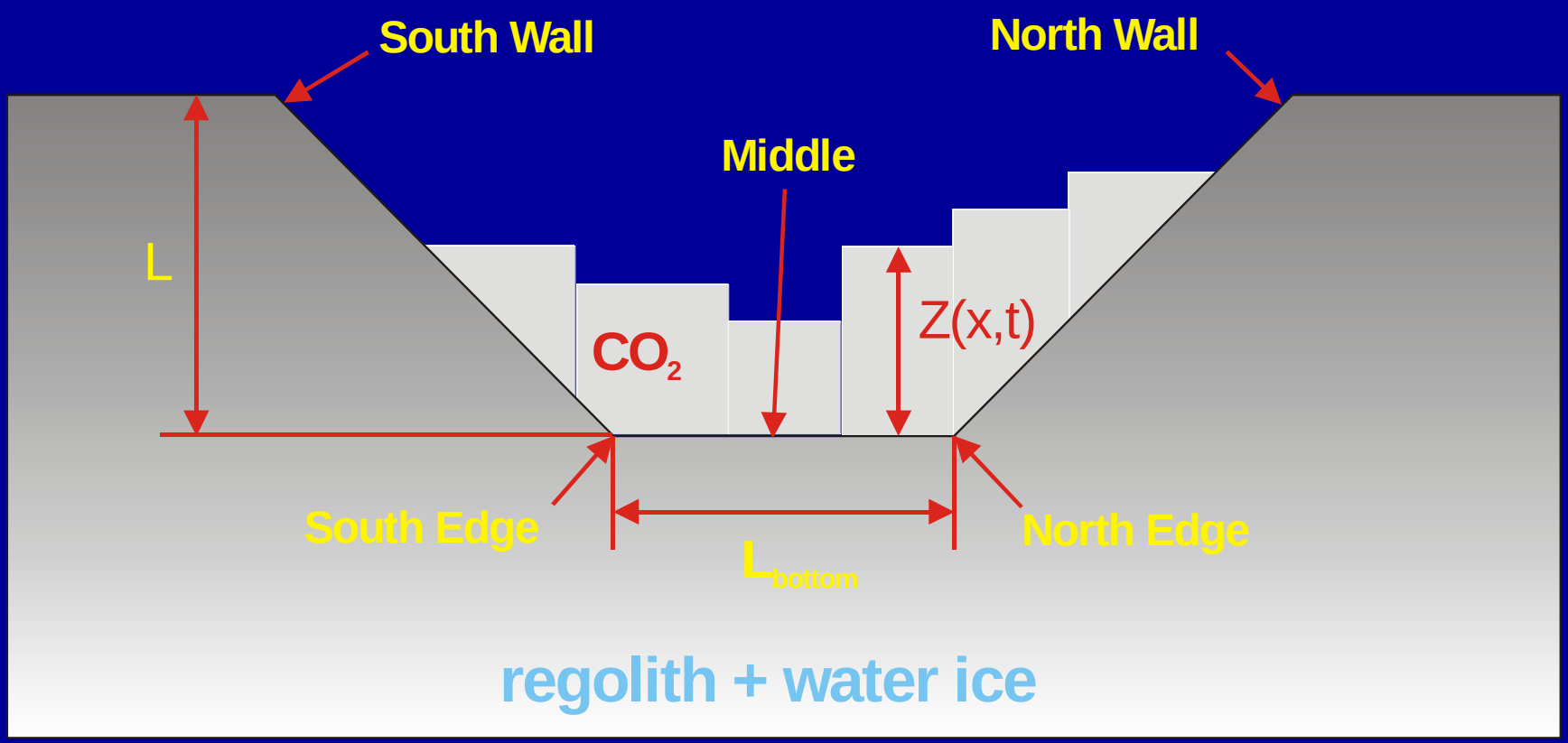
Early thermal models for MPL trench

Kossacki and Markiewicz, 2000

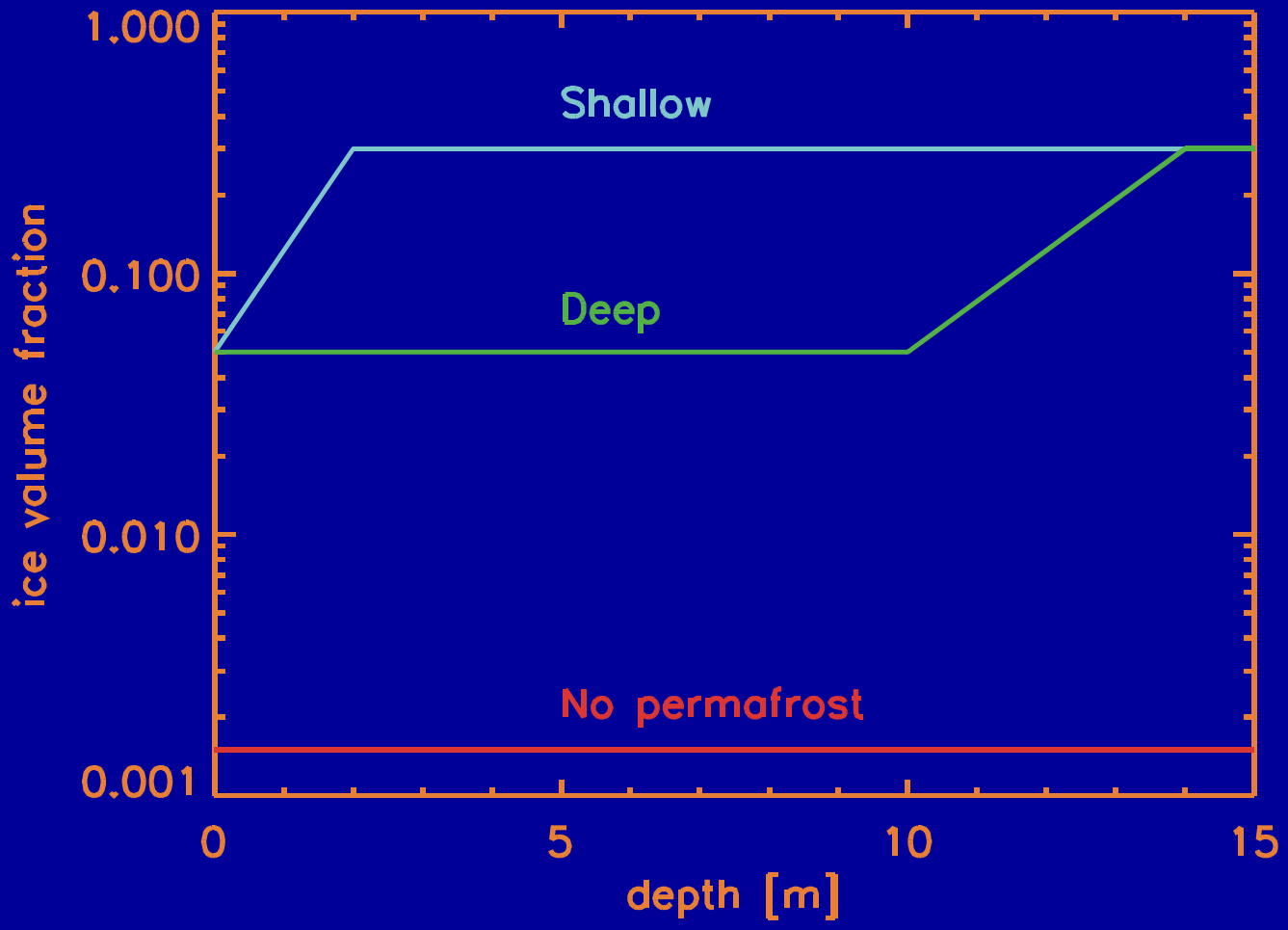
CO_2 Ice in Polygonal Throughs in Malea Planum: Subsurface H_2O, MOC images and TES surface temperature



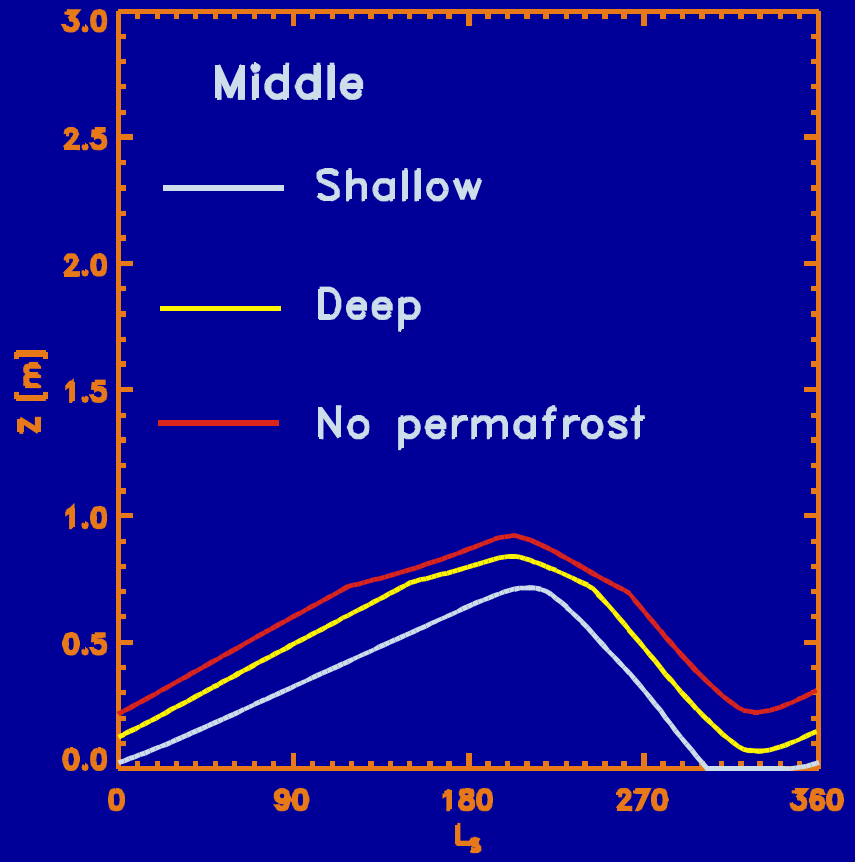
Sketch of the model of a polygonal crack

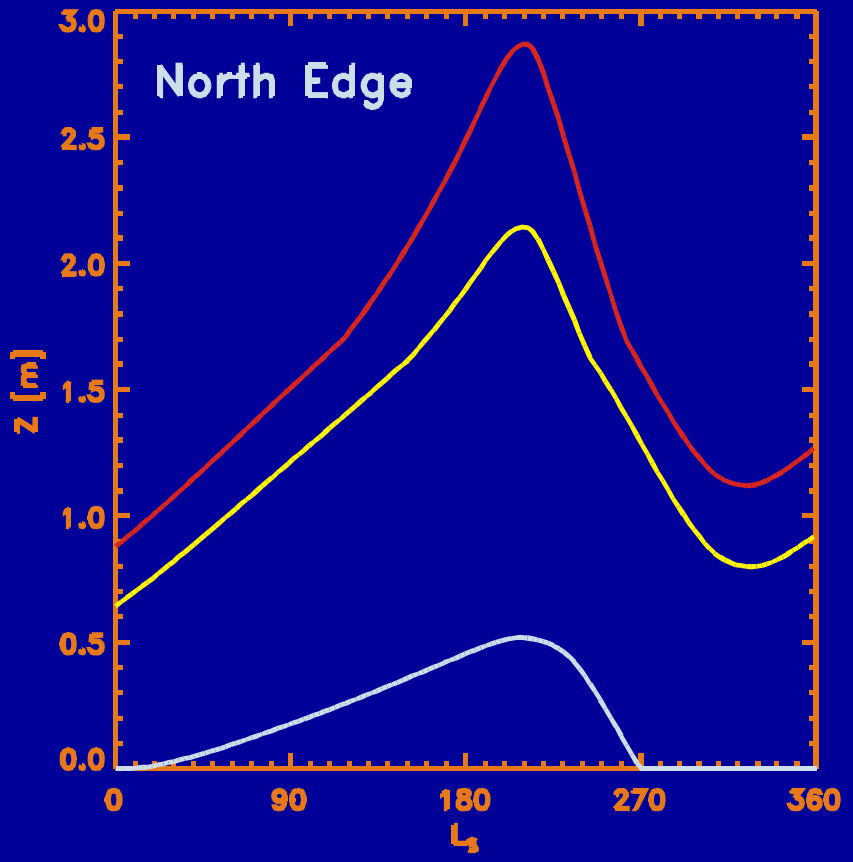


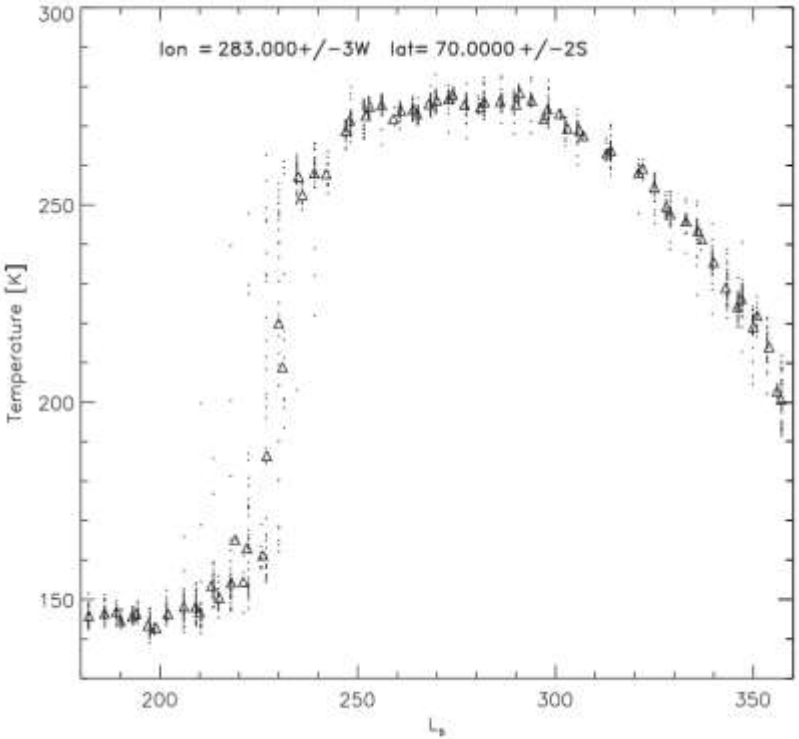
Initial models of water ice in the permafrost



The role of the permafrost subsurface water ice otherwise no seasonal cycle







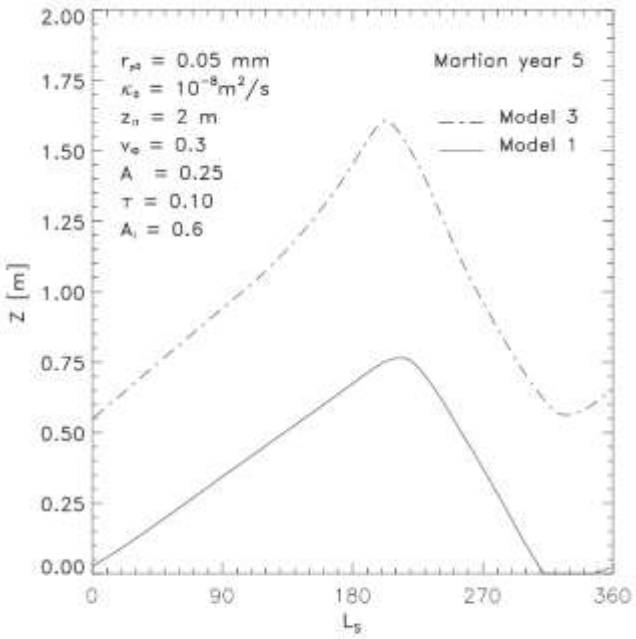
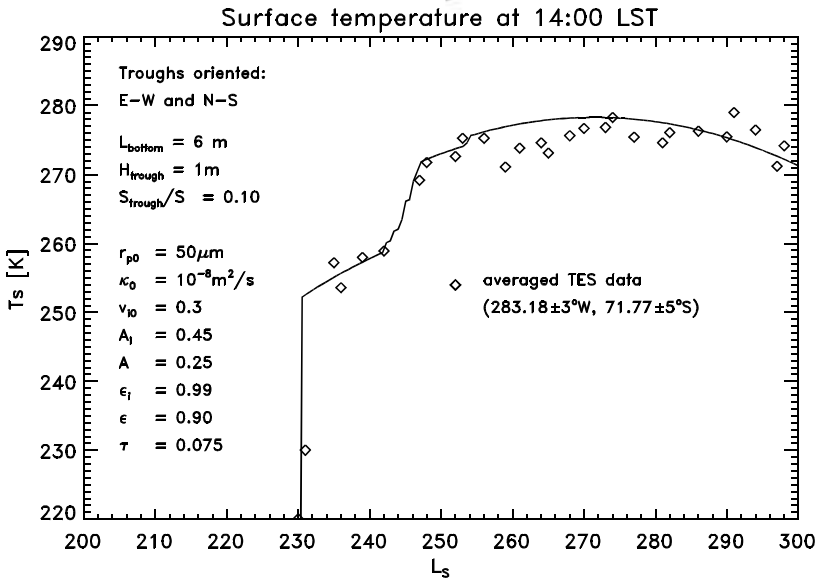
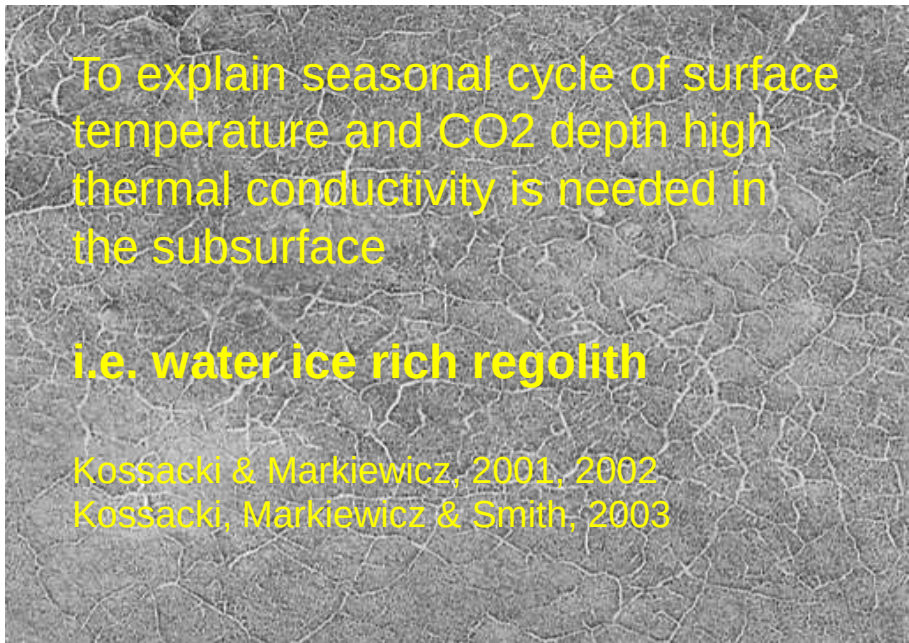
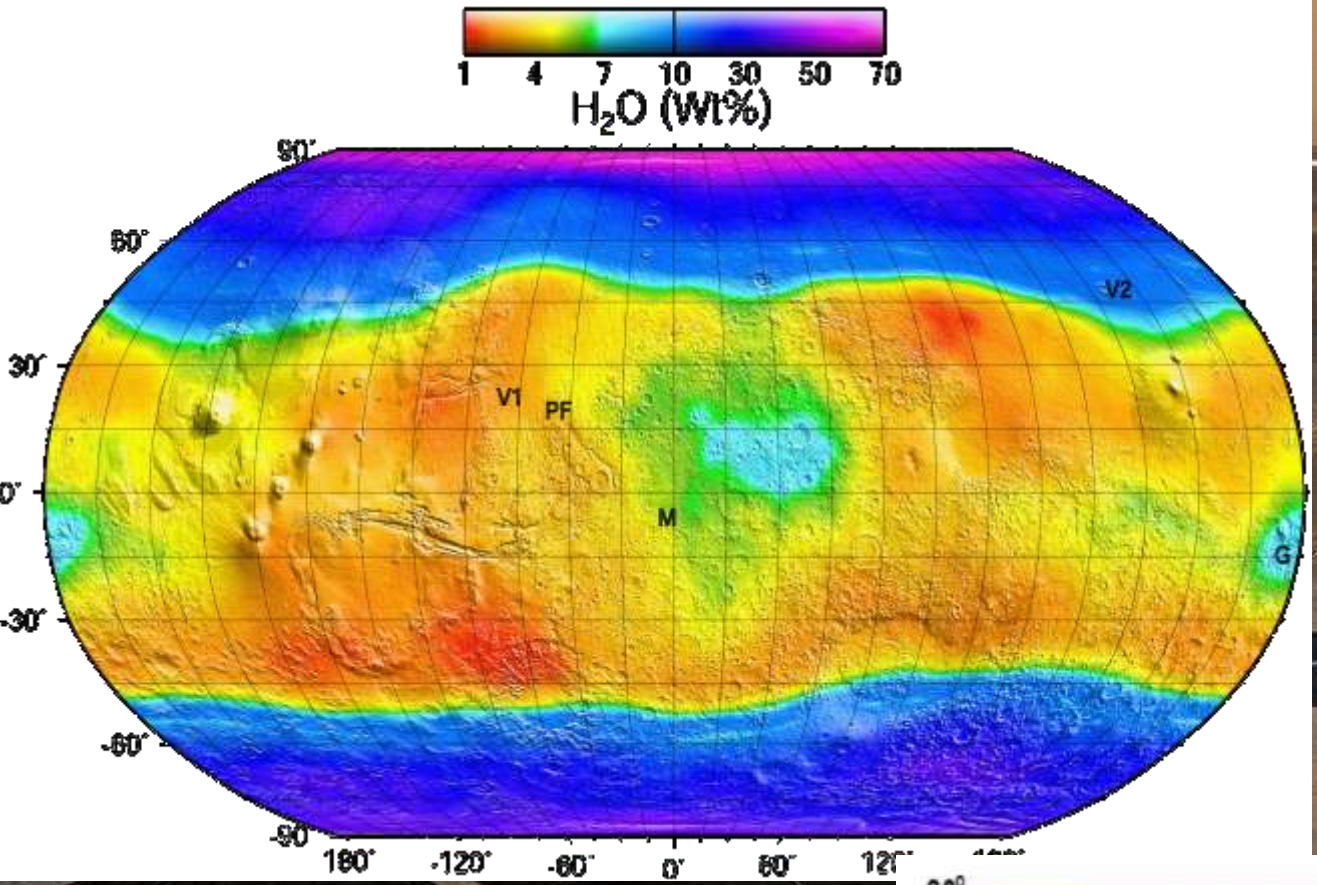
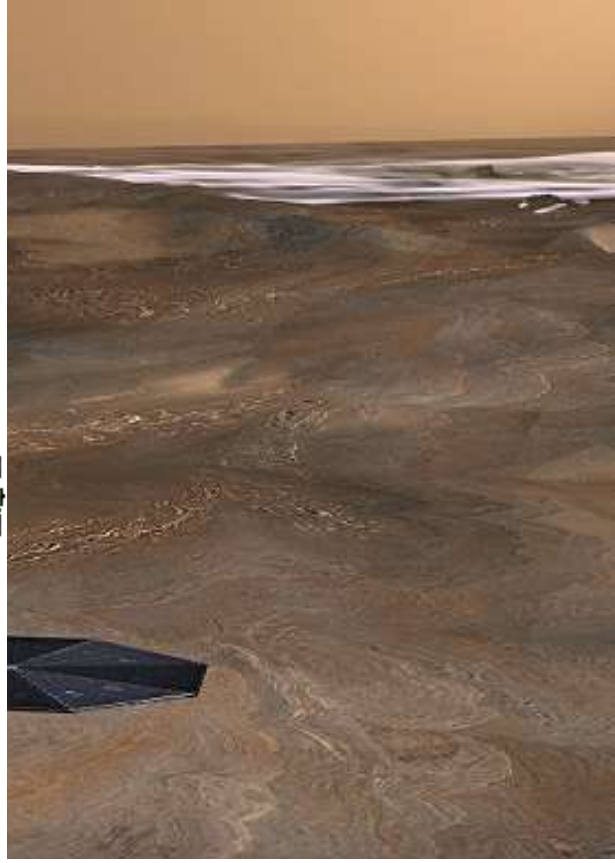


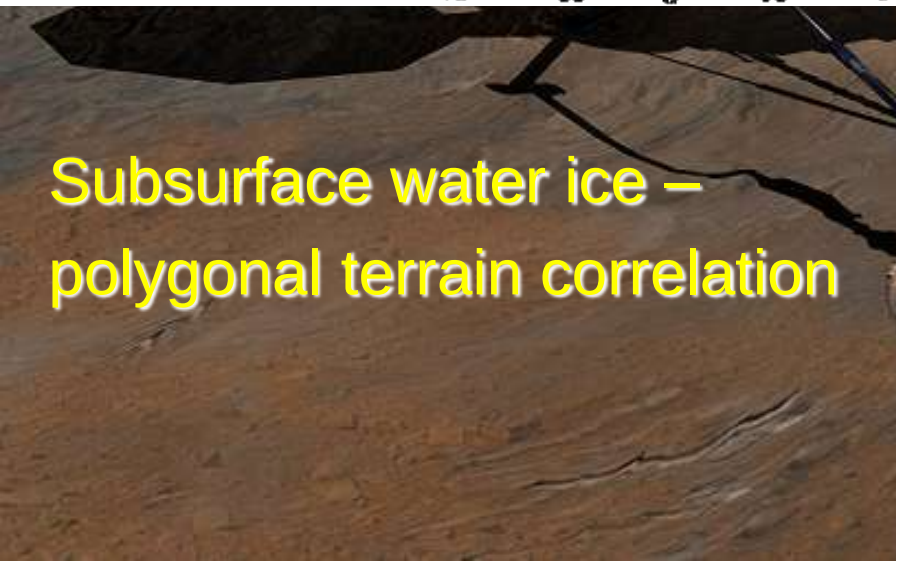
FIG. 9. Thickness Z of CO_2 ice in the middle of the trough versus L_s for one set of parameters and two different models of the water ice table.



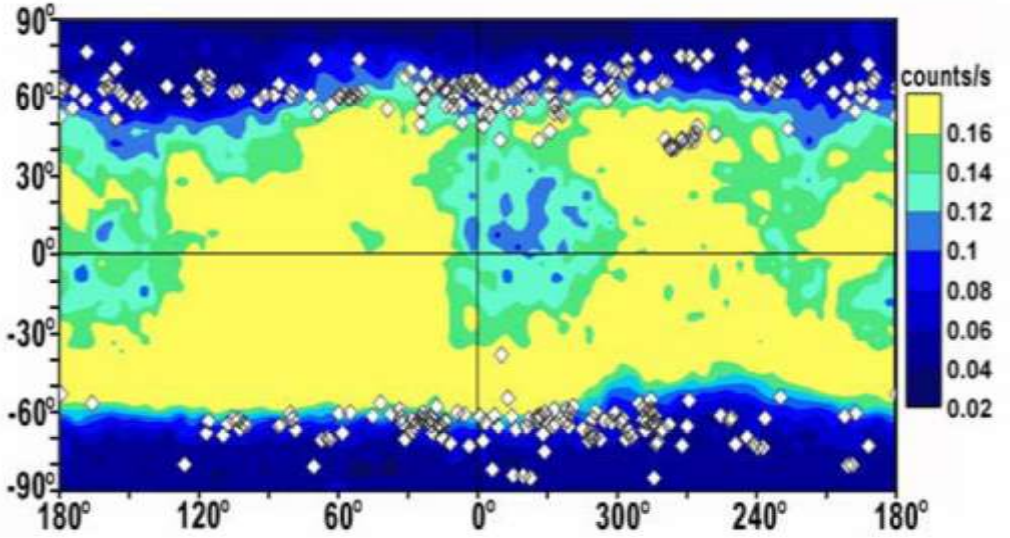








Subsurface water ice –
polygonal terrain correlation



Ice-Table Pre-Landing Estimates

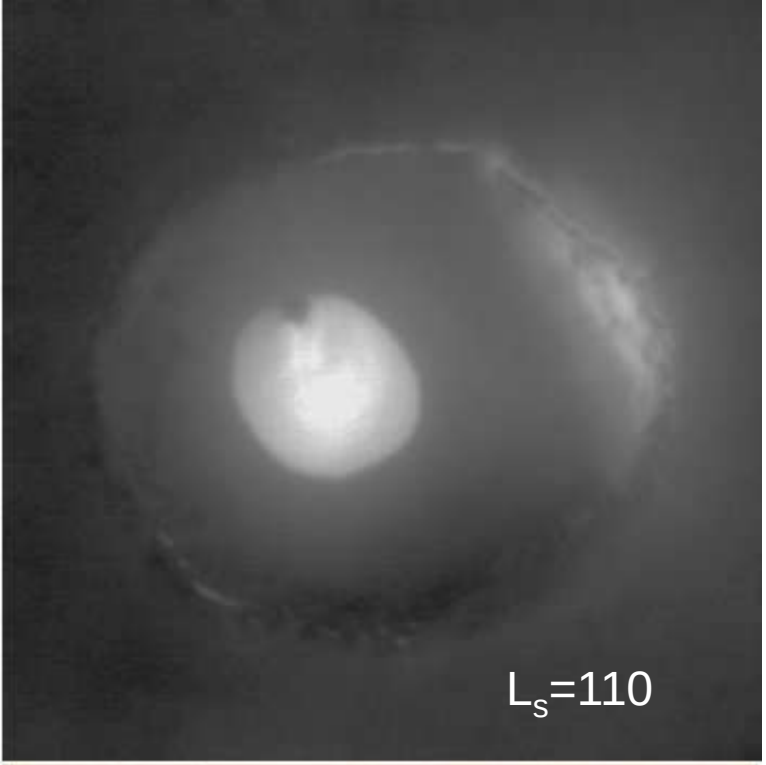
Table 2. Estimates of Ice-Table Depth.

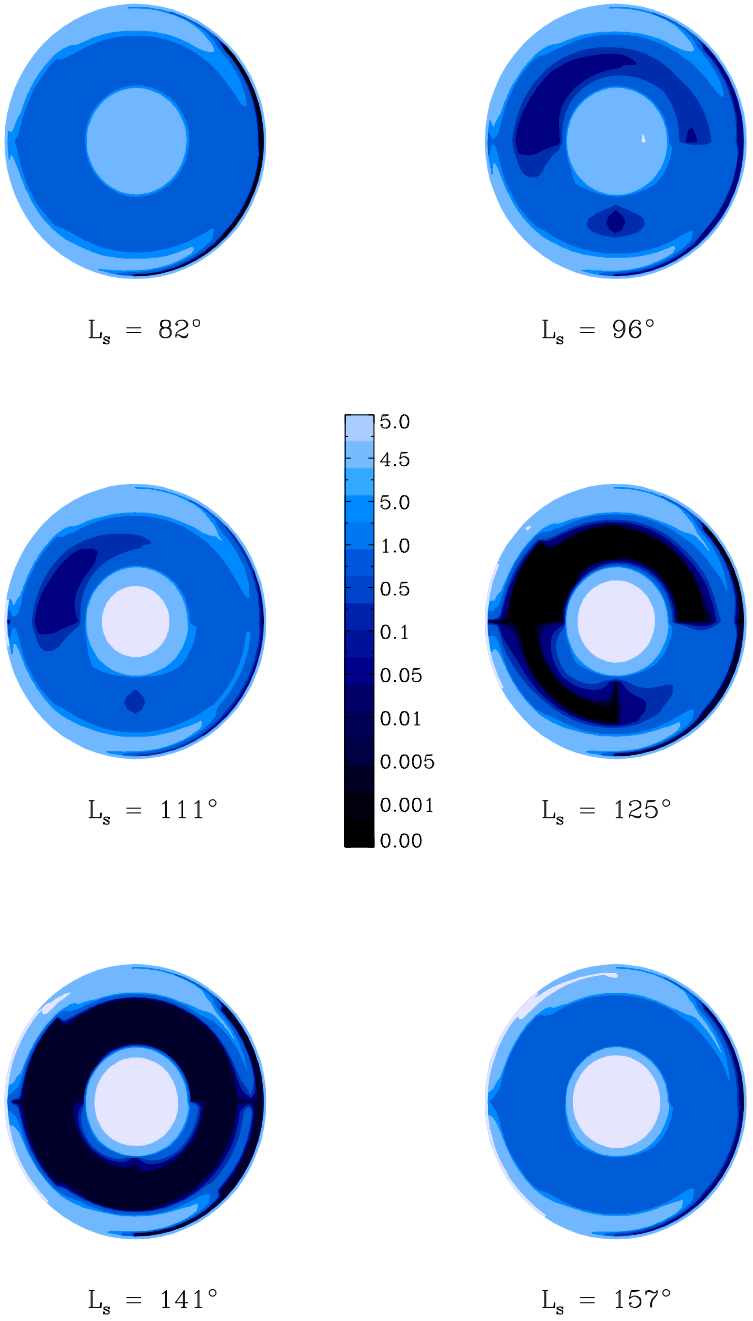
Method	Resolution [km]	Uncertainty [cm]	Ice Table Depth [cm]						
			Region				Box		
			A	B	C	D	1	2	3
Gamma Ray Spectroscopy [1]	300	~ 1.6	2.6	4.4	8.2	1.9	1.7	2.4	1.6
Neutron Spectroscopy [2]	600	~ 2	5.7	7.5	9.2	4.2	4.2	4.8	3.8
Ice Stability Theory 10 pr um [3]	3	~ 2	6.2	8.2	6.3	5.7	5.0	5.6	6.3
Ice Stability Theory 20 pr um [3]	3	~ 2	4.4	5.6	4.4	4.0	3.5	3.9	4.4
TES Seasonal Temperature [4,5]	60	~ 1	4.6	6.4	3.0	-	4.1	6.1	2.3
THEMIS seasonal Temperature [6]	0.3	2-3	>9	5-18	-	-	5.8	-	-
TES Thermal Inertia [7,8]	100	~ 1	3.1	3.7	3.7	4.1	3.9	3.5	2.8

[1] *Boynton et al.*, [2007], averaged over the region and assuming a dry soil density of 1.6 g cm^{-3}; [2] *Feldman et al.*, [2007], averaged over the region and assuming a dry soil density of 1.6 g cm^{-3}; [3] *Mellon et al.*, [2004a] median value for each region; [4] *Titus et al.*, [2006]; [5] *Titus and Prettyman* [2007]; [6] *Bandfield* [2007]; [7] *Putzig et al.*, [2006]; [8] *Putzig and Mellon* [2007].

Table 2 of Mellon et al., 2008

Ice -Table Depth Estimates Range ~ 2-6 cm for landing site.



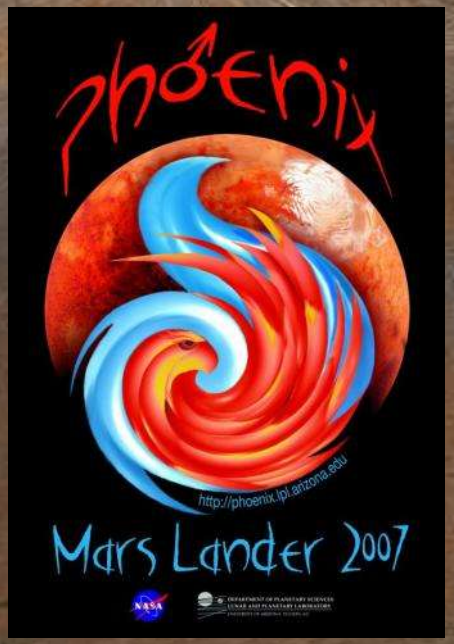


Markiewicz and Kossacki, 2006

Crater floor around ice patch is full of polygons
Ice rich substrate (at some time only?)
Thermal contraction/expansion or desiccation?

Why Phoenix?

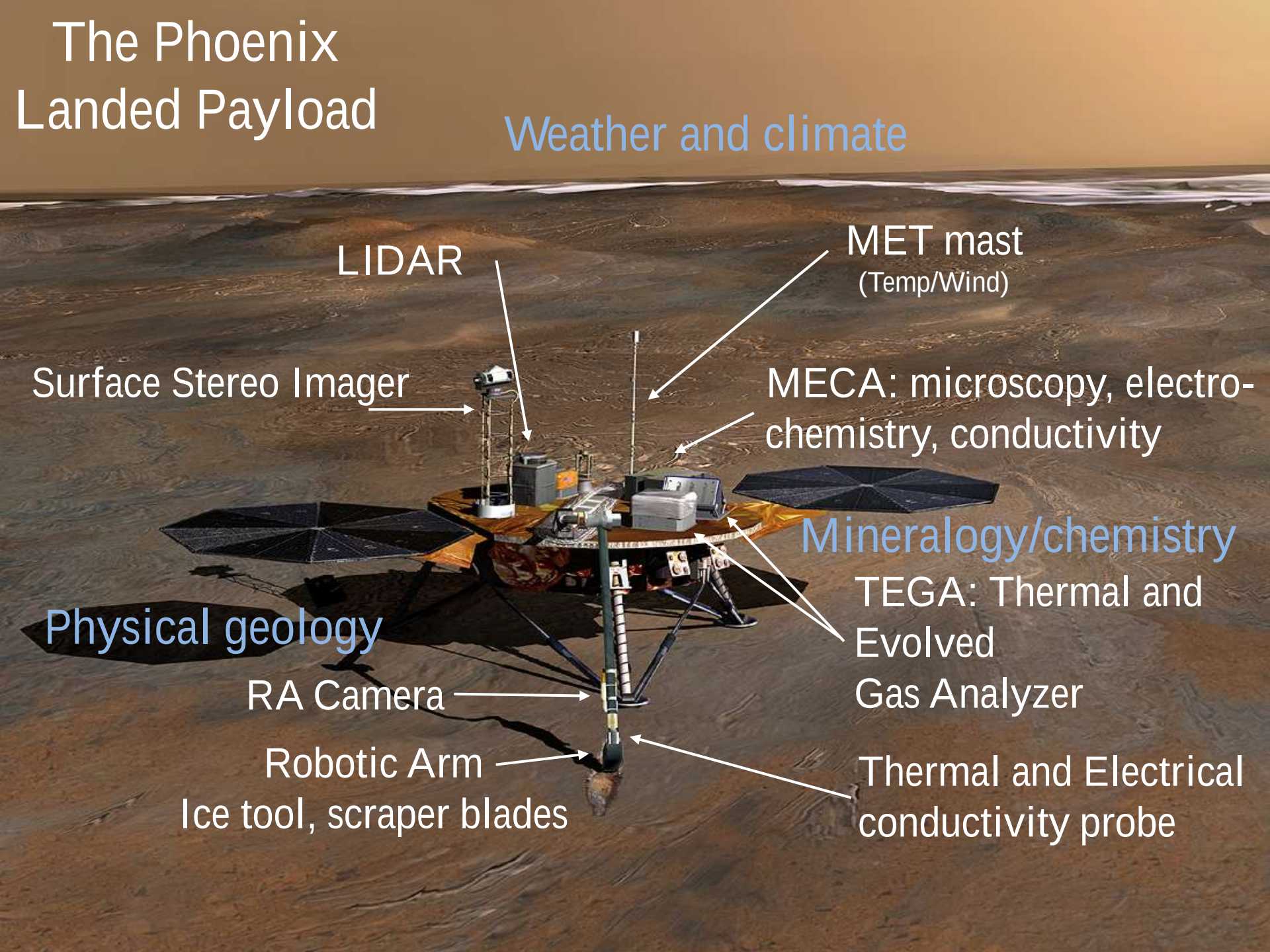
- Mars Polar Lander crushed
- 2001 Mars Lander cancelled
- …
- Here comes Phoenix



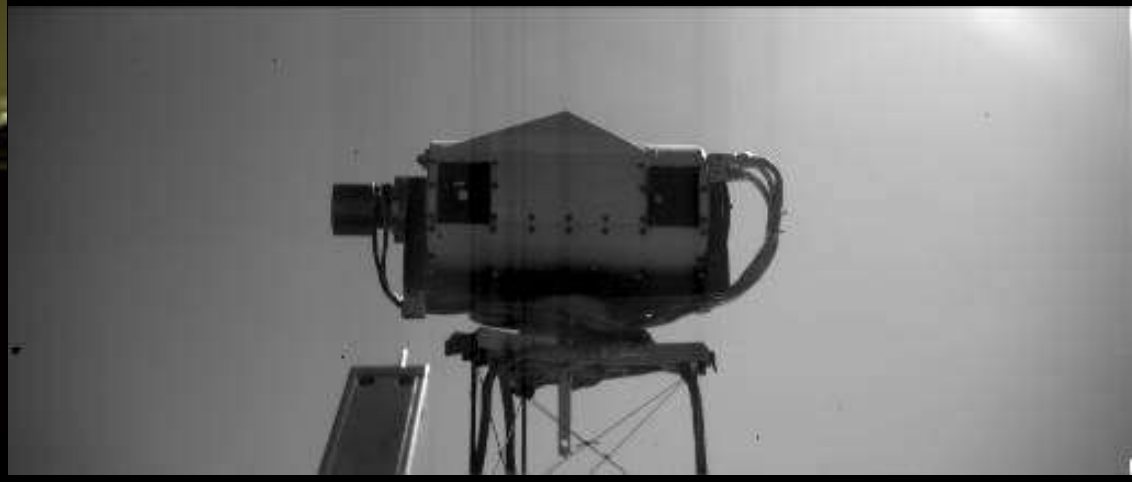
Phoenix top level objectives

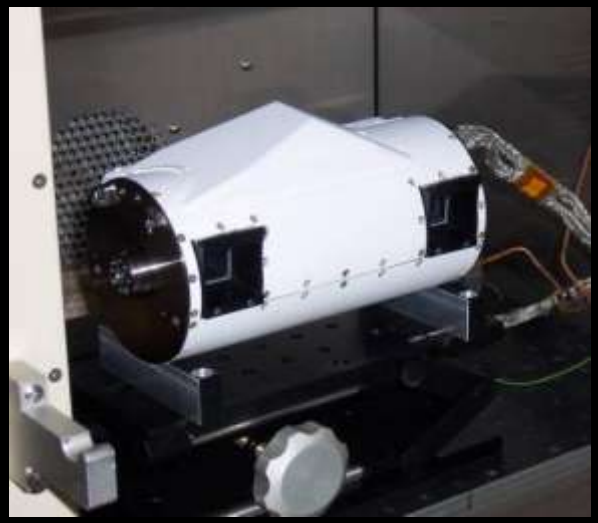
- Find water ice

- Estimate habitability of the near surface environment

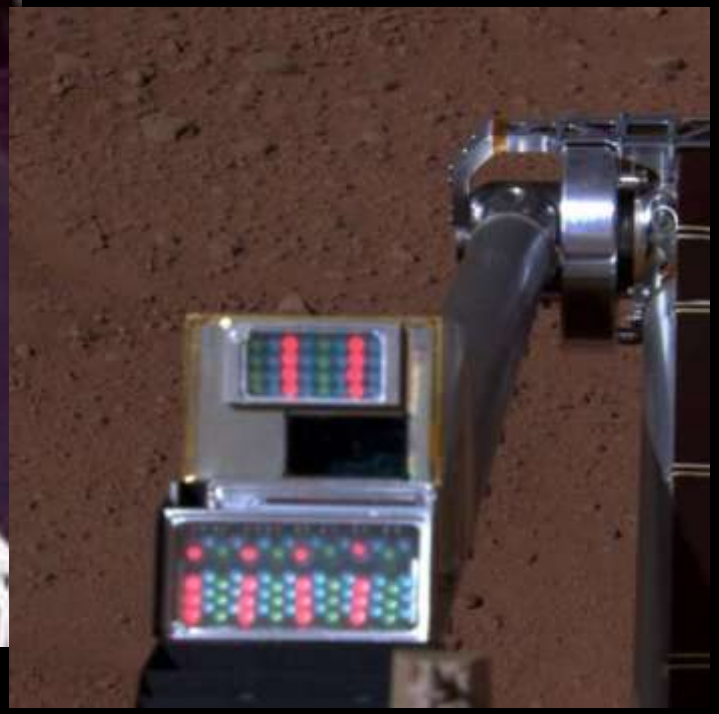

The Phoenix
Landed Payload
Weather and climate
LIDAR
MET mast
(Temp/Wind)
Surface Stereo Imager
MECA: microscopy, electro-
chemistry, conductivity
Mineralogy/chemistry
TEGA: Thermal and
Evolved
Gas Analyzer
Physical geology
RA Camera
Robotic Arm
Ice tool, scraper blades
Thermal and Electrical
conductivity probe

Surface Stereo Imager (SSI)

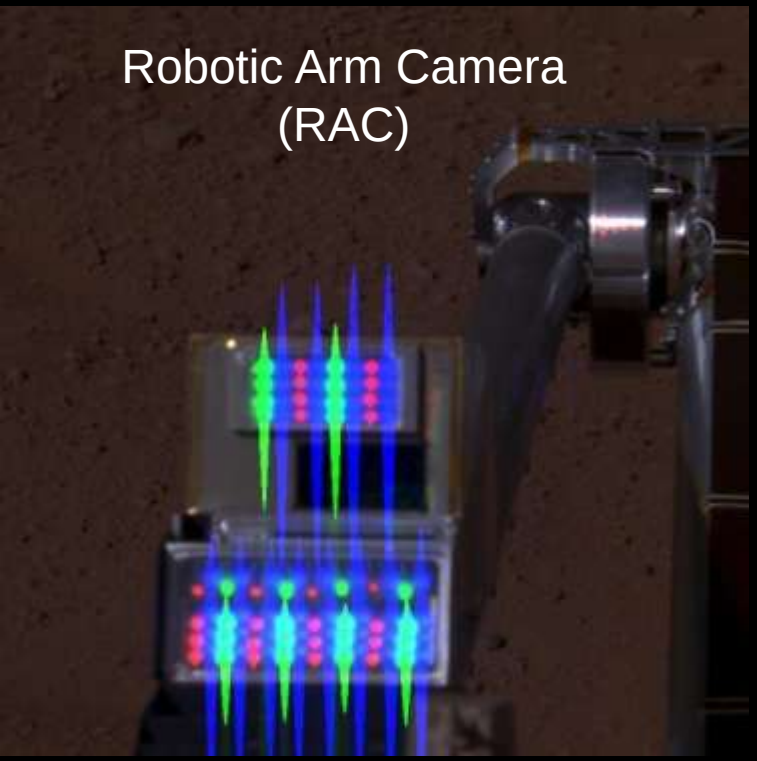




Robotic Arm Camera (RAC)



What is RAC?

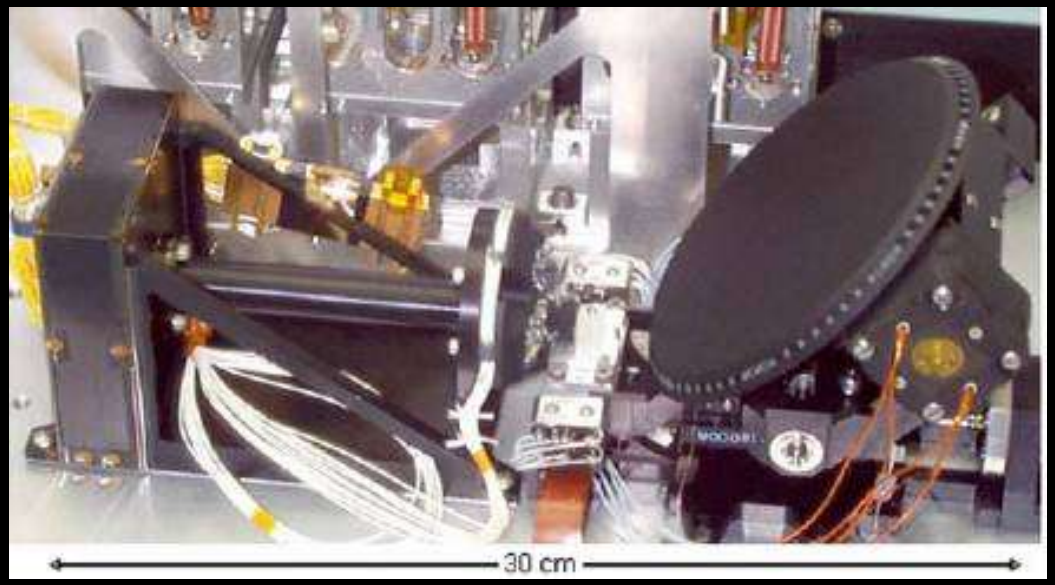


Imaged by SSI

- A first variable focus camera on a planetary mission
  - Resolution down to 23 µm/px
- Obtains colour images by illuminating target with LEDs
- It is attached to the Robotic Arm and hence mobile

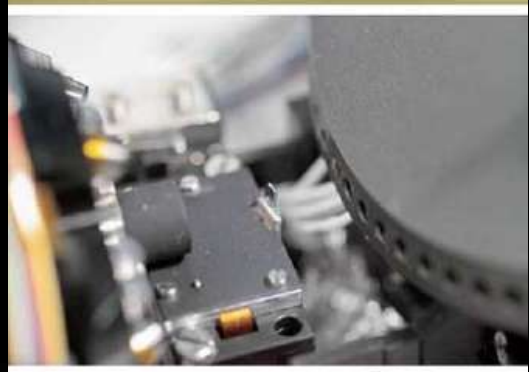
MPS

Microscopy, Electrochemistry, and Conductivity Analyzer (MECA)



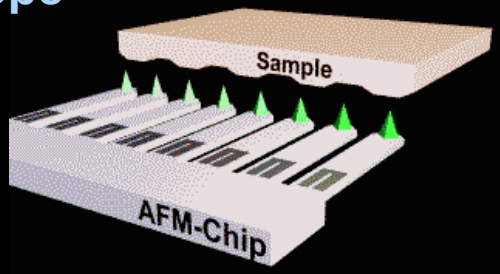
Atomic Force Microscope AFM

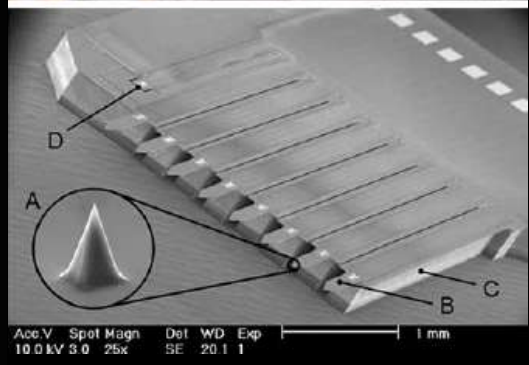
50 nm/px



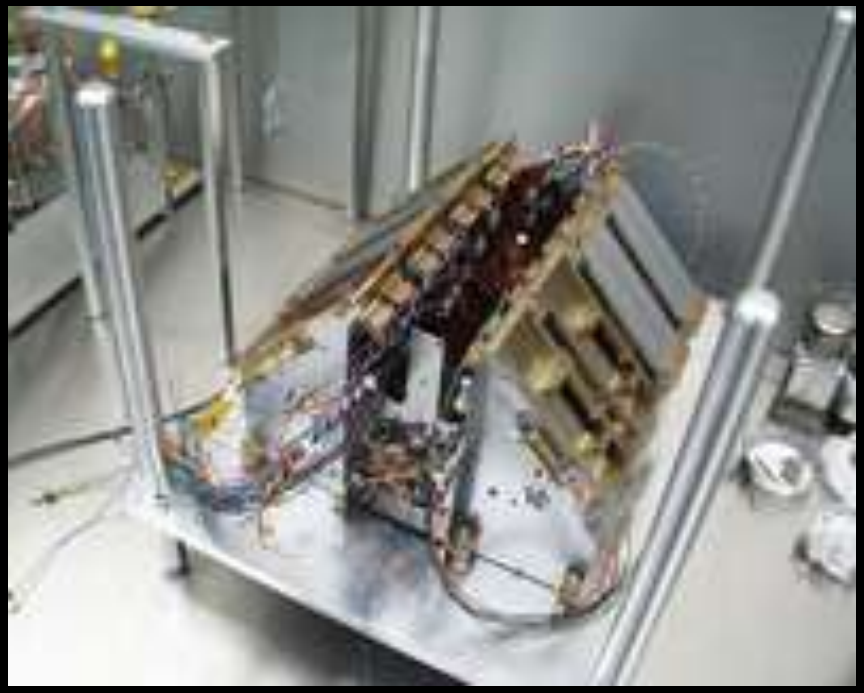
Optical Microscope OM

4 µm/px

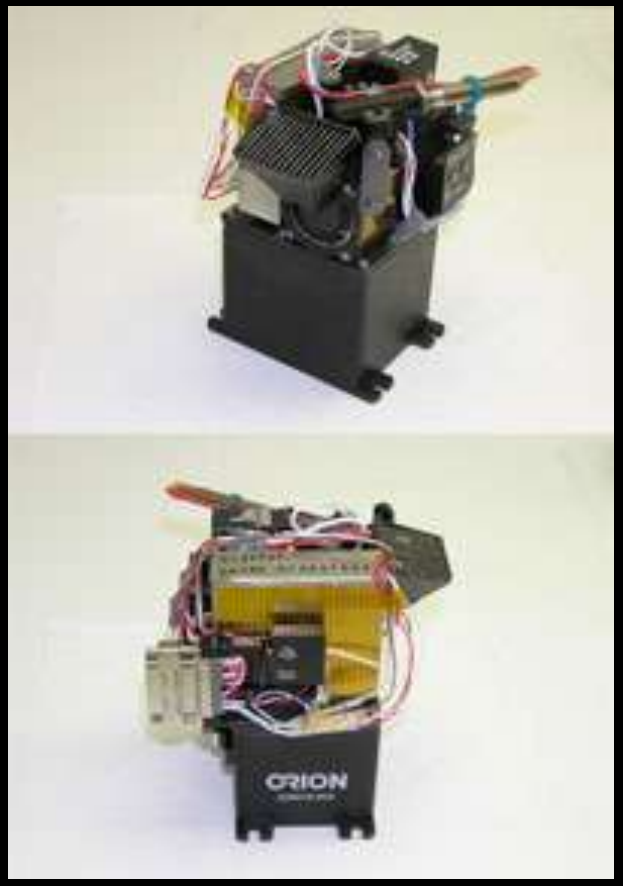




TEGA & WCL



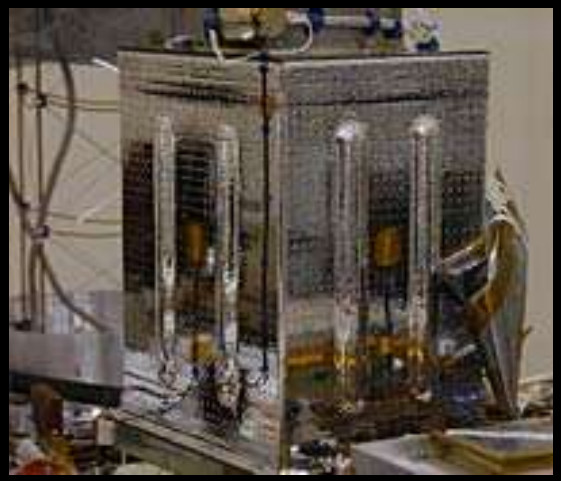
Thermal and Evolved Gas Analyzer
(TEGA)



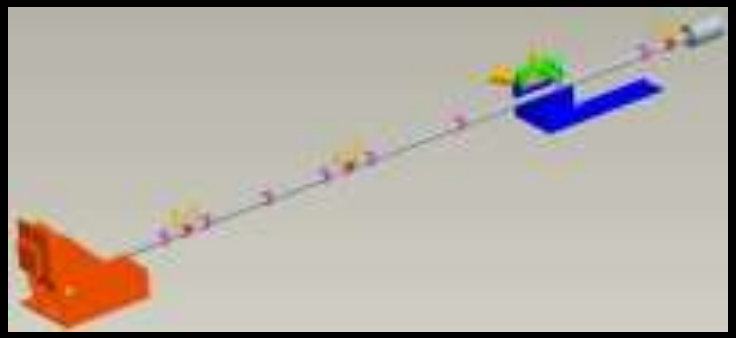
Wet Chemistry Lab
(WCL)

MET & TECP

Thermal and Electrical Conductivity Probe (TECP)



Meteorological Station **(MET)**



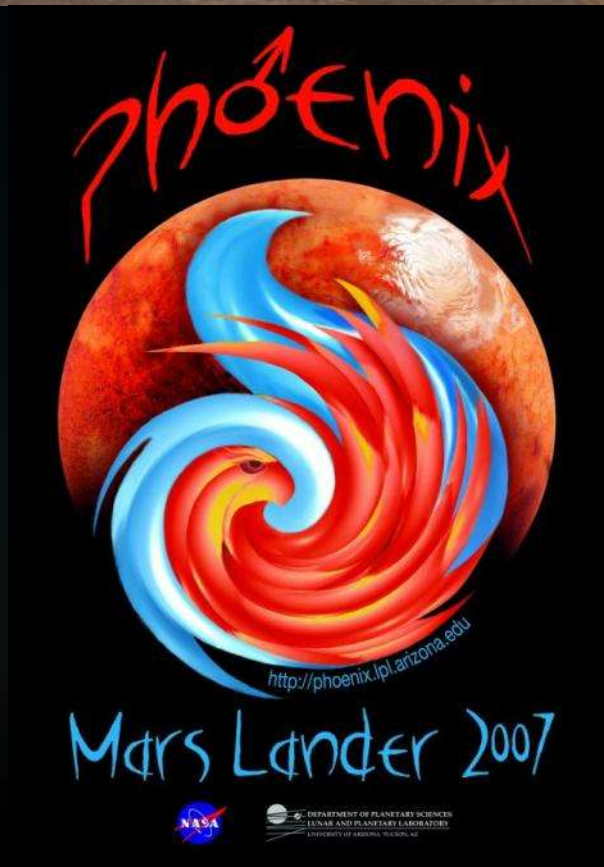
First results

Science 3 July 2009

More details in articles

JGR Planets 115, 2010

Phoenix launch



After launch

After launch

Why Are These People Concerned?

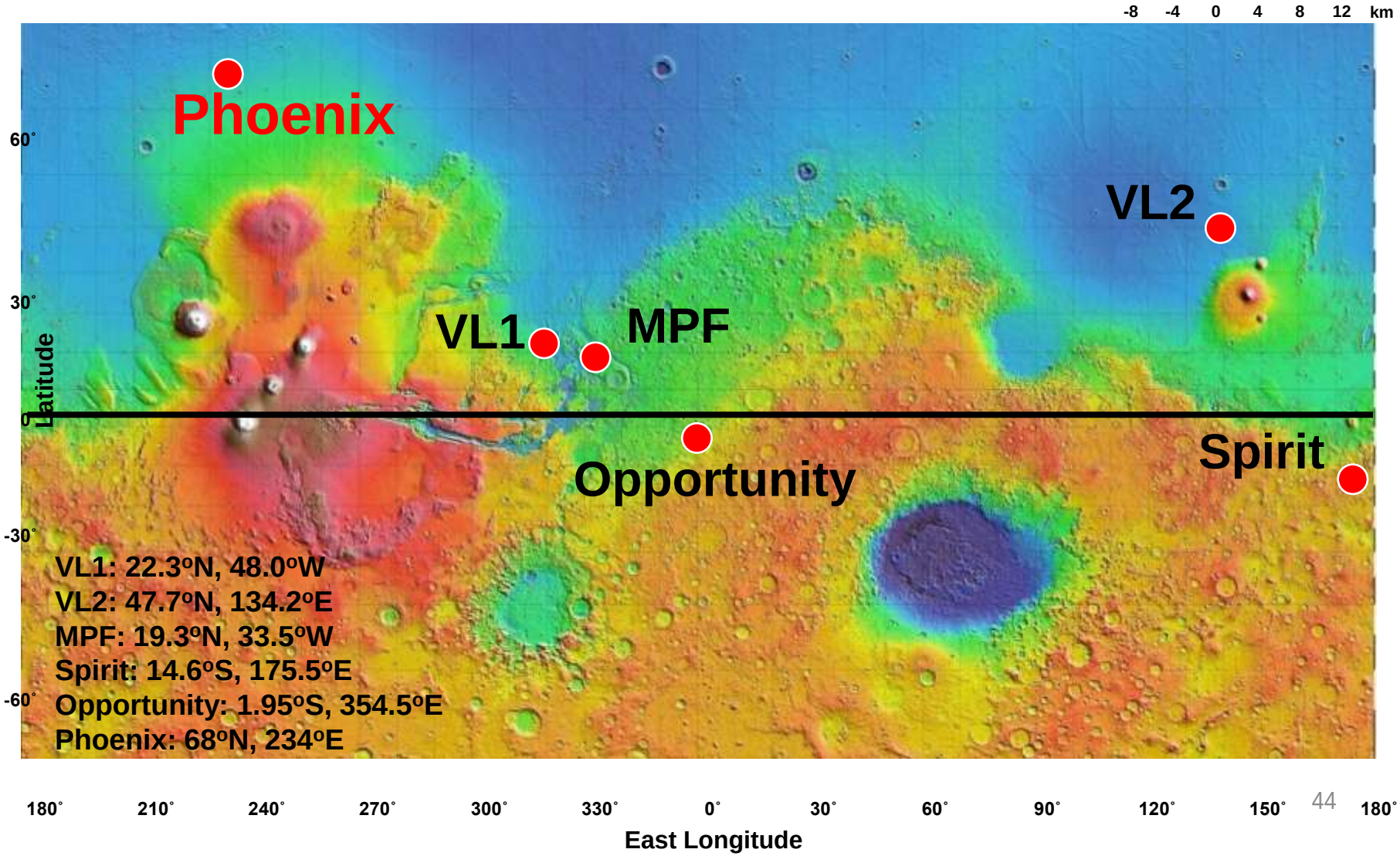
Phoenix: May 25, 2008

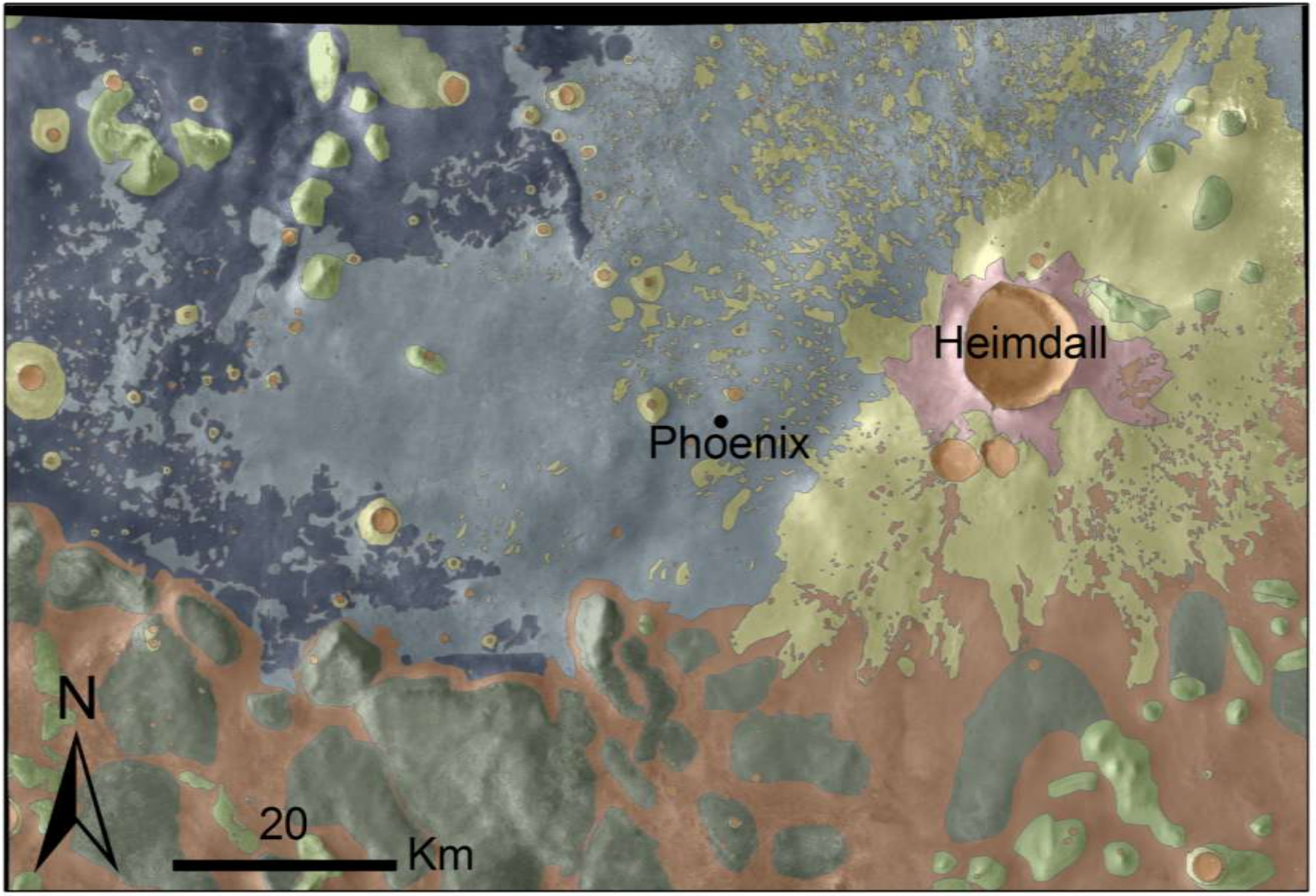
“Oh-My Gosh”

Not to worry, we landed 22 km away from the rim!

Diter Schmitt para-skiing from Brocken?

Phoenix Landing Site Is Much Farther North Relative to the Other Landers

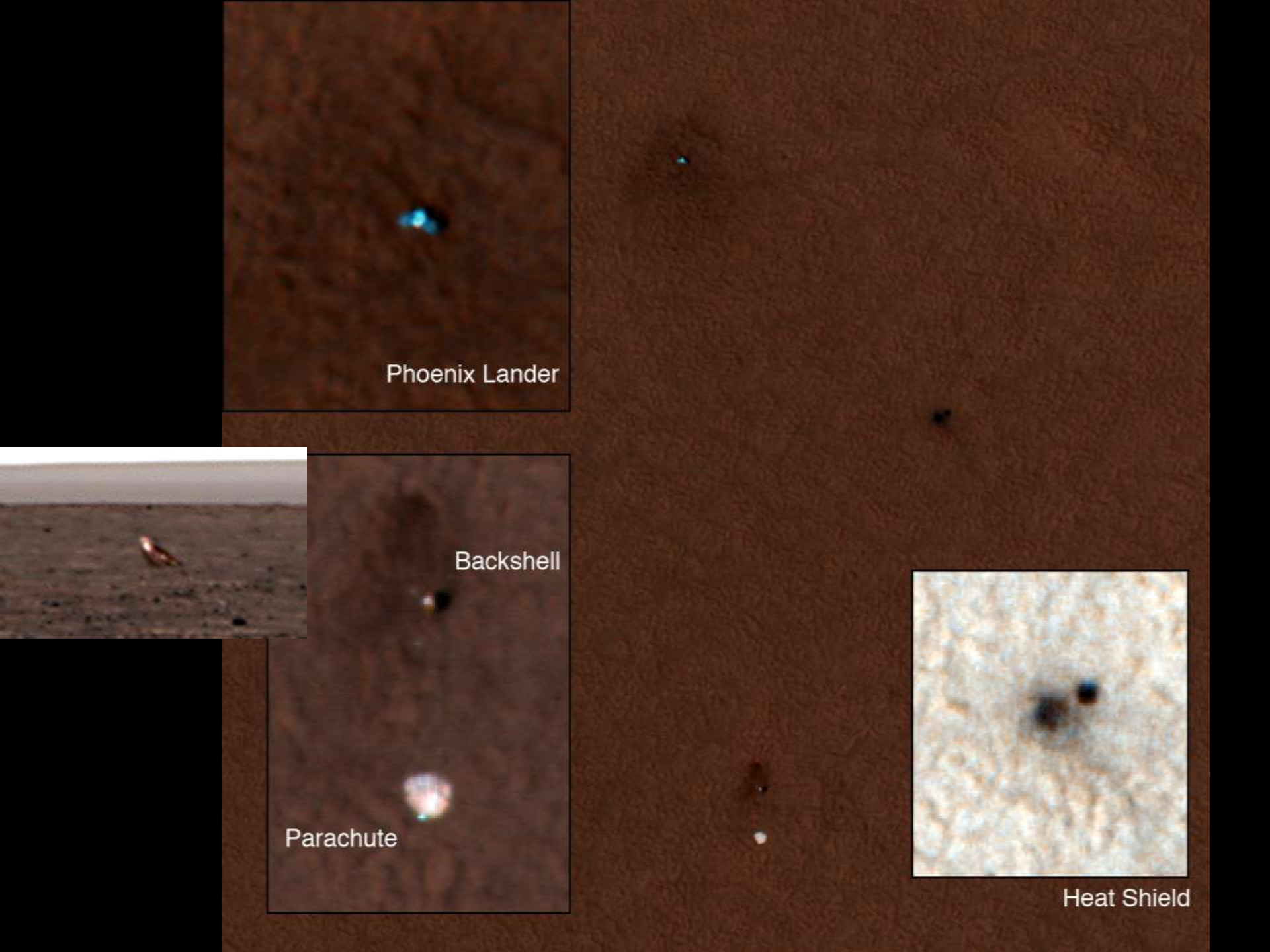



Heimdall
Phoenix
N
20
Km
Crater Interior
Inner Crater Ejecta
Crater Ejecta
Knobby Terrain
Intermediate Terrace
Blocks/Mesas
Highland
Lowland - Bright
Lowland - Dark

Geologic setting

- Differentially eroded ejecta deposits from Heimdall Crater (~0.5 Gy)
- Ejecta emplaced via fluidization
  - Liquid water involved
- New and much younger setting as compared to the two Viking Landers, Pathfinder, Spirit and Opportunity

Expected terrain (CO_2 frost) orbiter image


Phoenix Lander
Backshell
Parachute
Heat Shield

Note the dark circular oval around Phoenix

Coarser grains ejected by the retro-rockets?

Radius of the oval 10 m

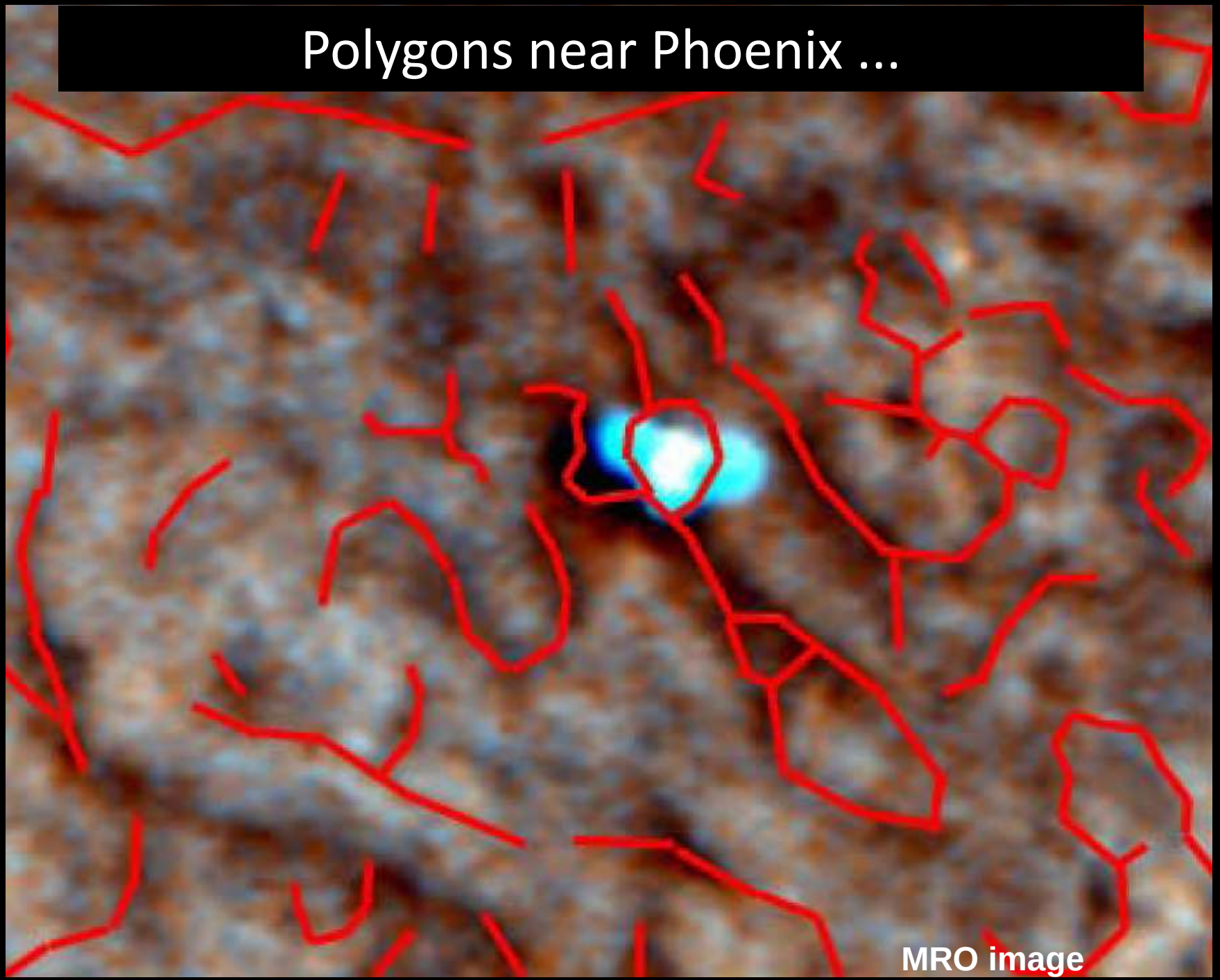
Thickness of excavated regolith 10 cm (predicted depth to ice)

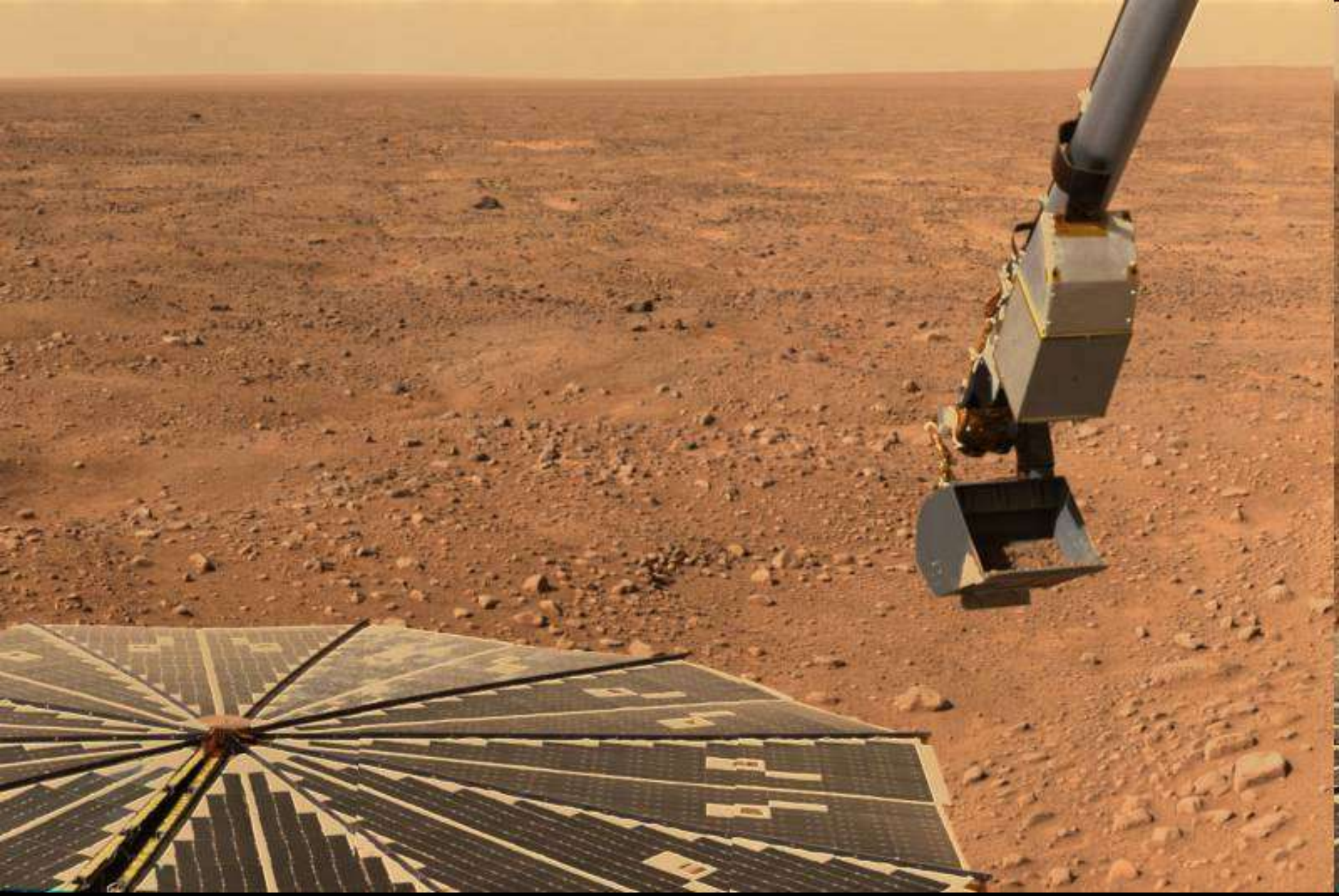
Radius of excavated area 1m (scale of the Lander)

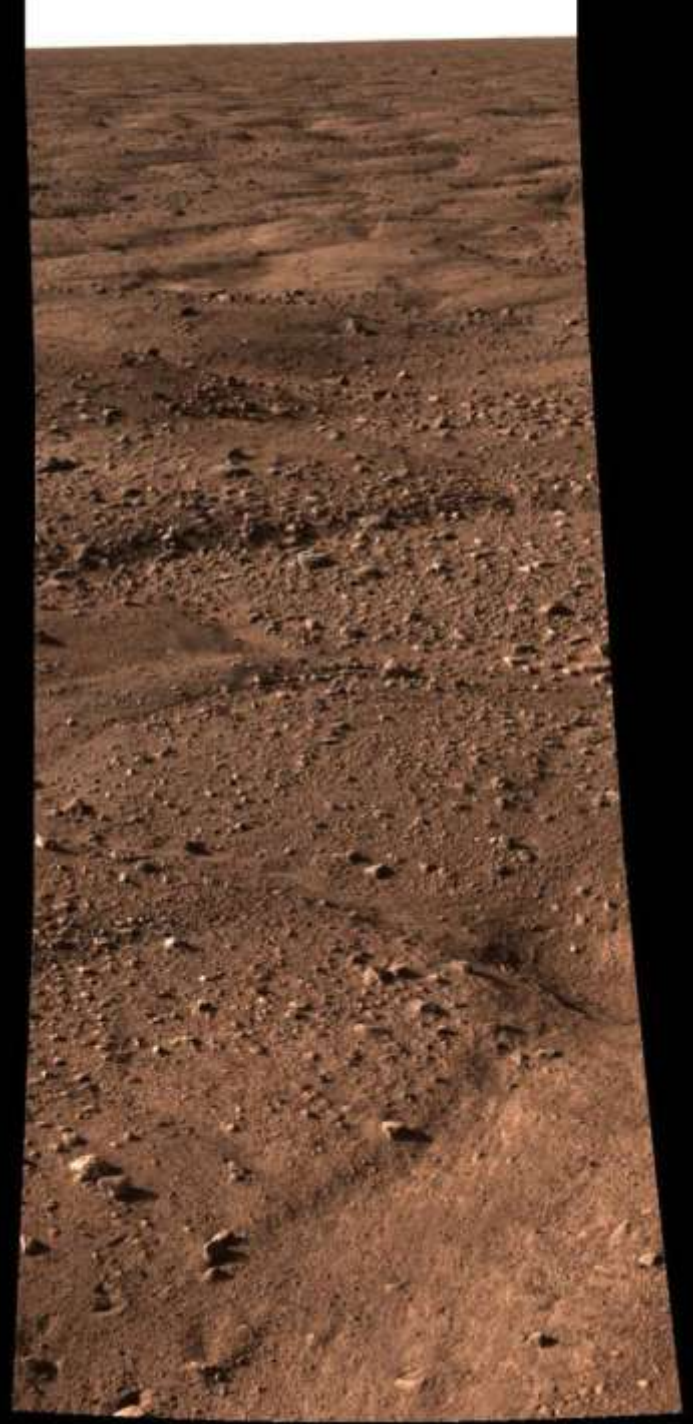
Results in 1 mm thick cover

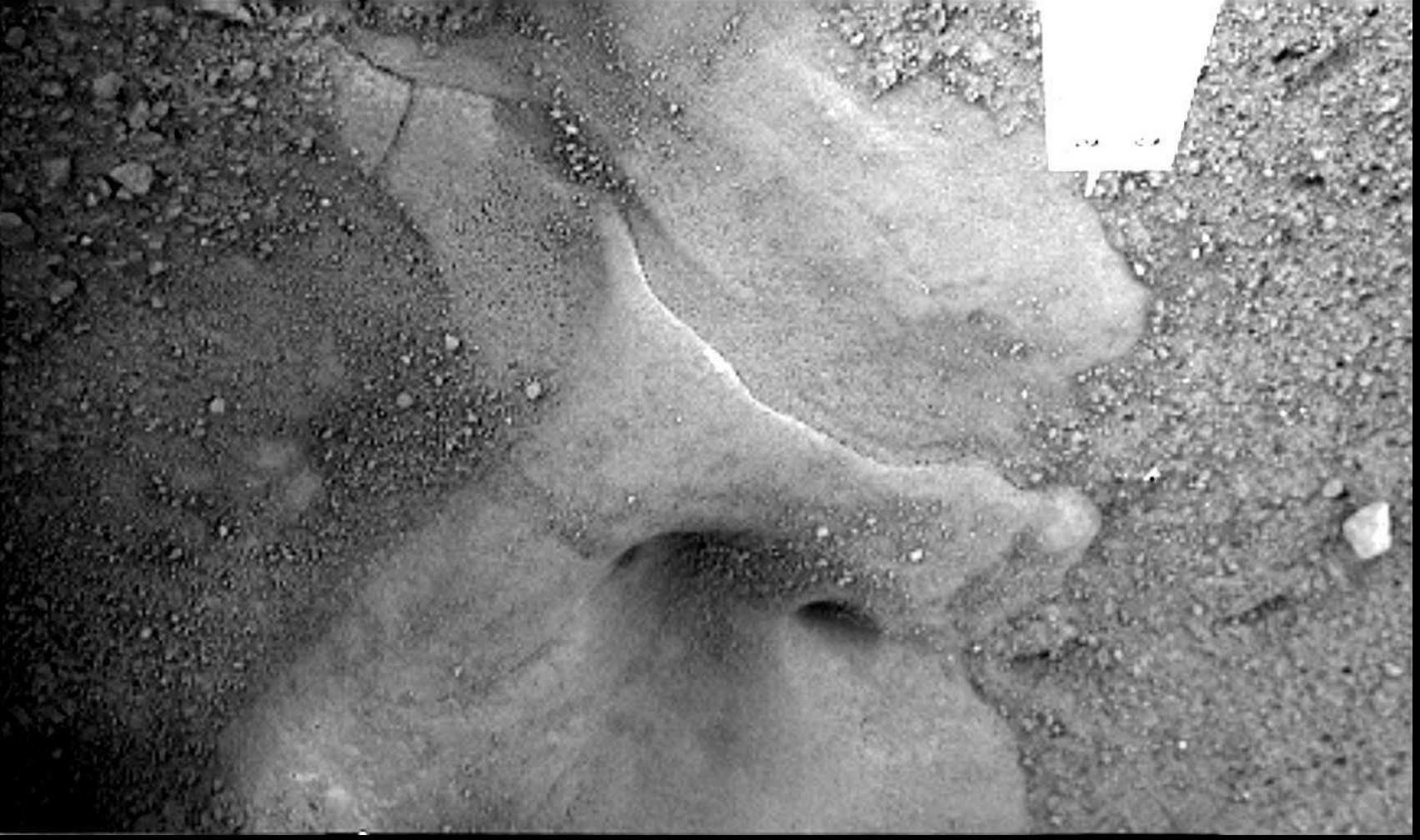
Or is it darker because fines where blown away?

Polygons near Phoenix ...









Snow Queen

First RAC image under the Lander

We think we found water ice!

Note the pebble on the right

Holy Cow

"Holy Cow" Mosaic Credit: Marco Di Lorenzo, Kenneth Kremer NASA/JPL/UA/Max Planck Institute/Spaceflight

Holy Cow in forward scattering illumination

and 95 sols later

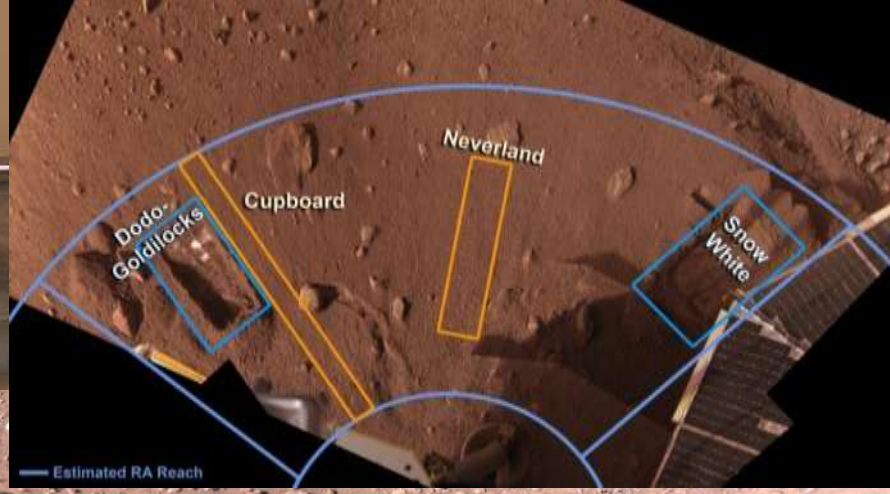
in twilight

Pore ice

or

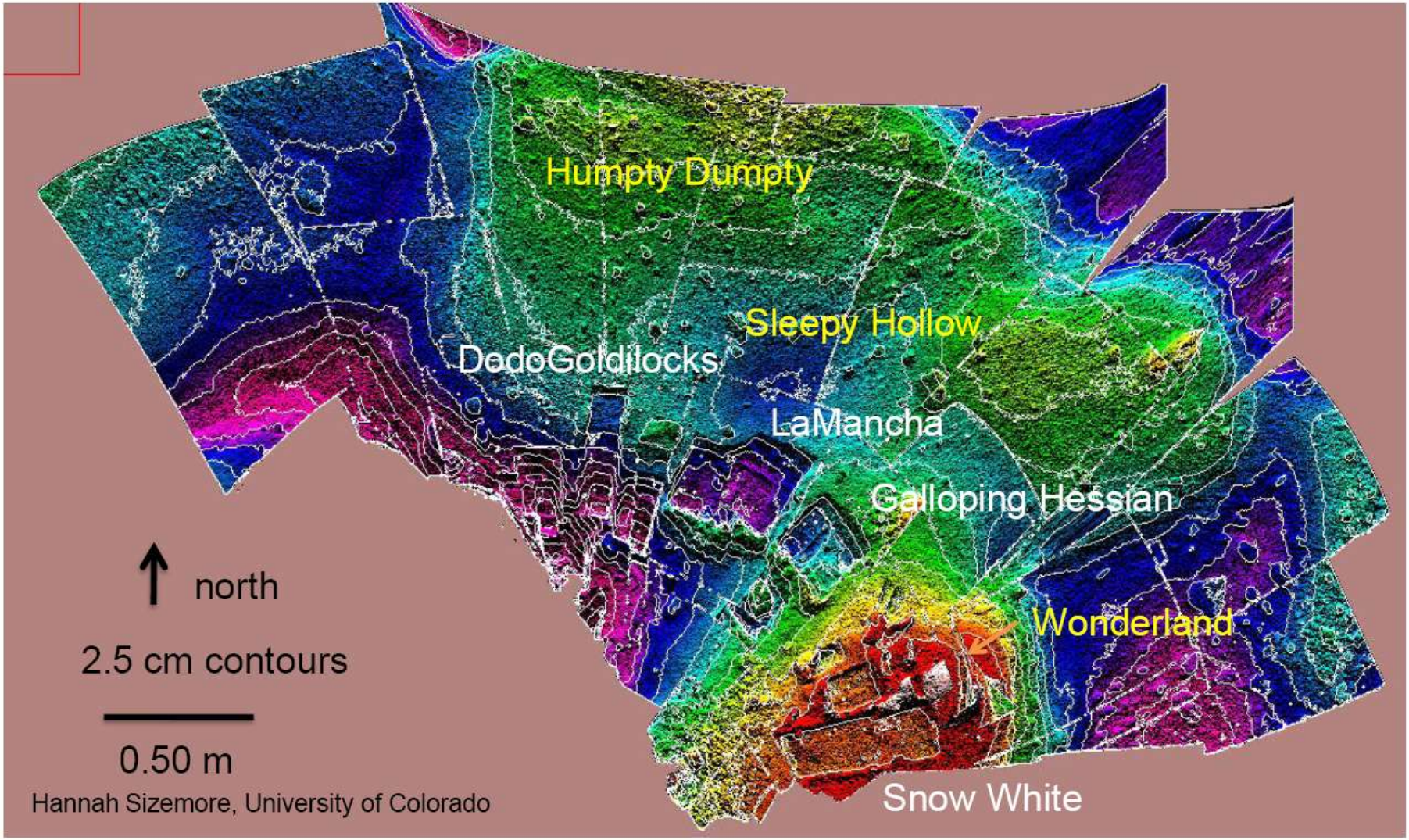
pure ice
with dust cover?

Digging Area



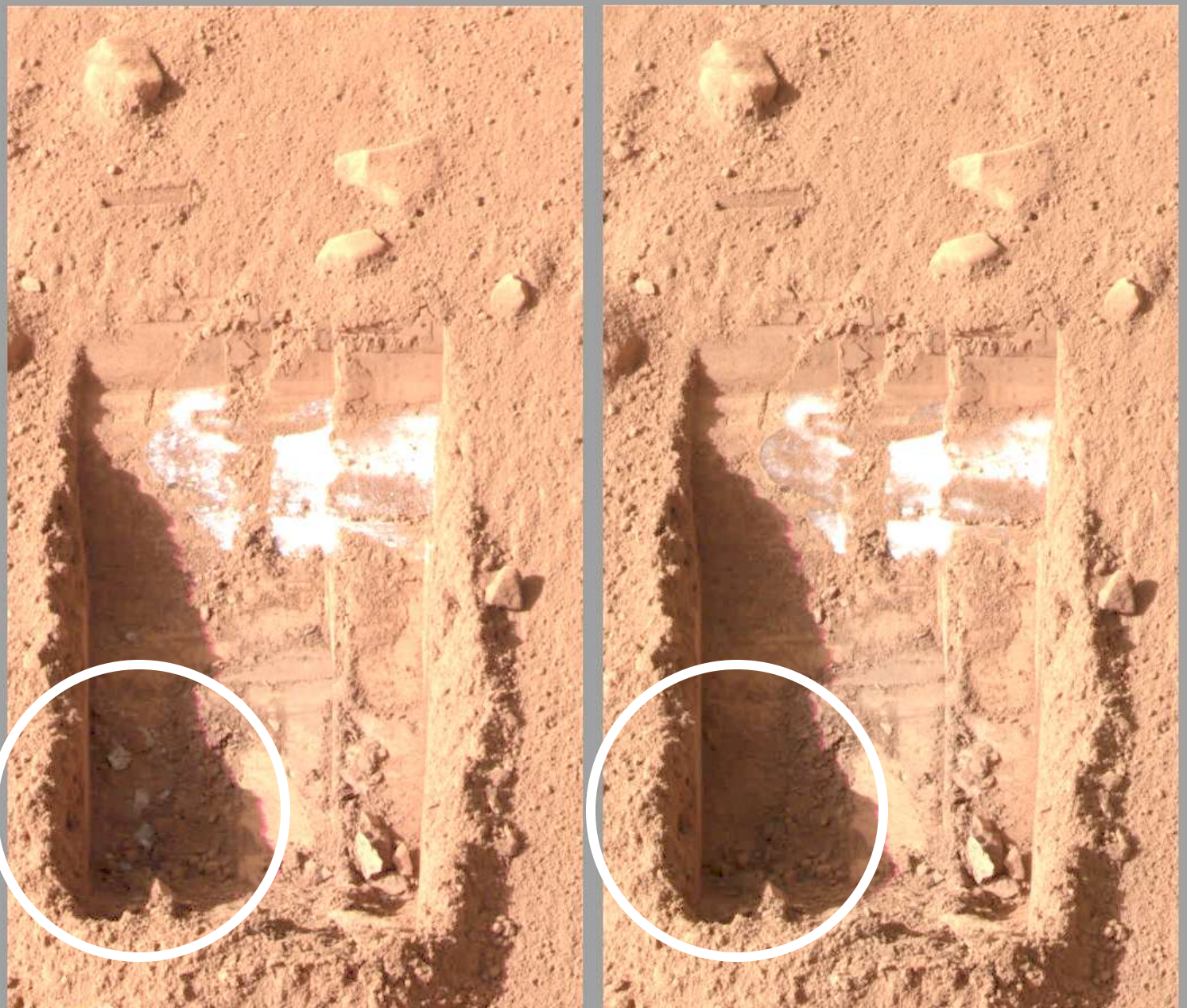
Caterpillar
DodoGoldilocks
King's Men
Headless
Alice
Burn Alive
Croquet Ground
Snow White

Topographic Map of Polygons and Robotic Arm Work Space



Sol 20

Sol 24



Ice
Sublimes

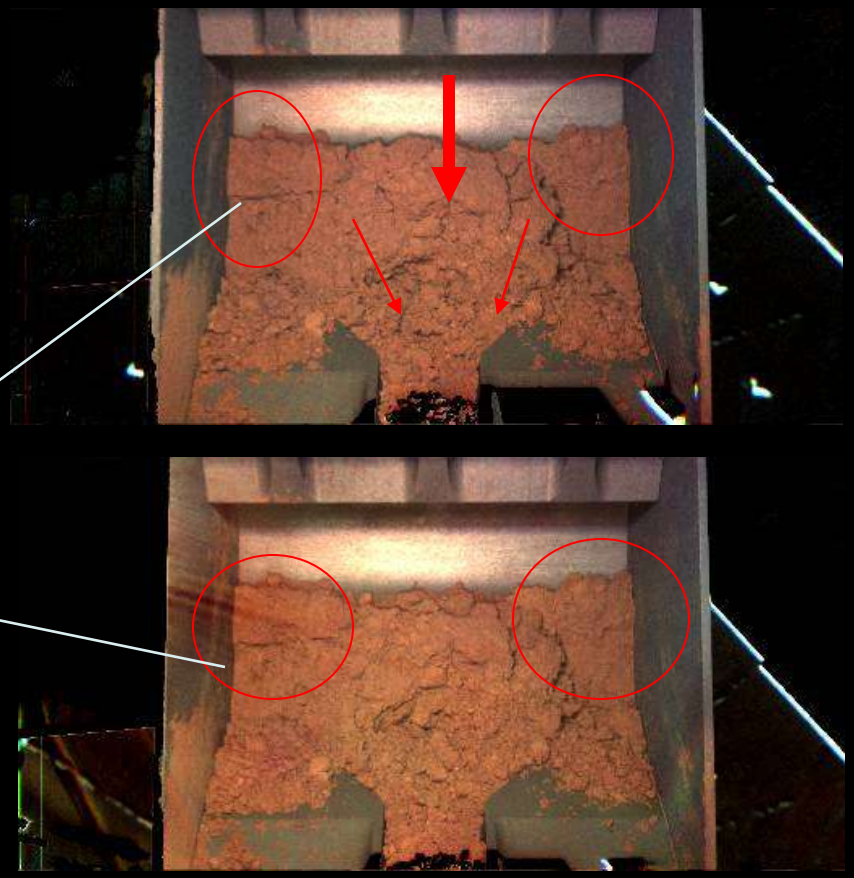
First Scoops Sol 9/11

SOL 15

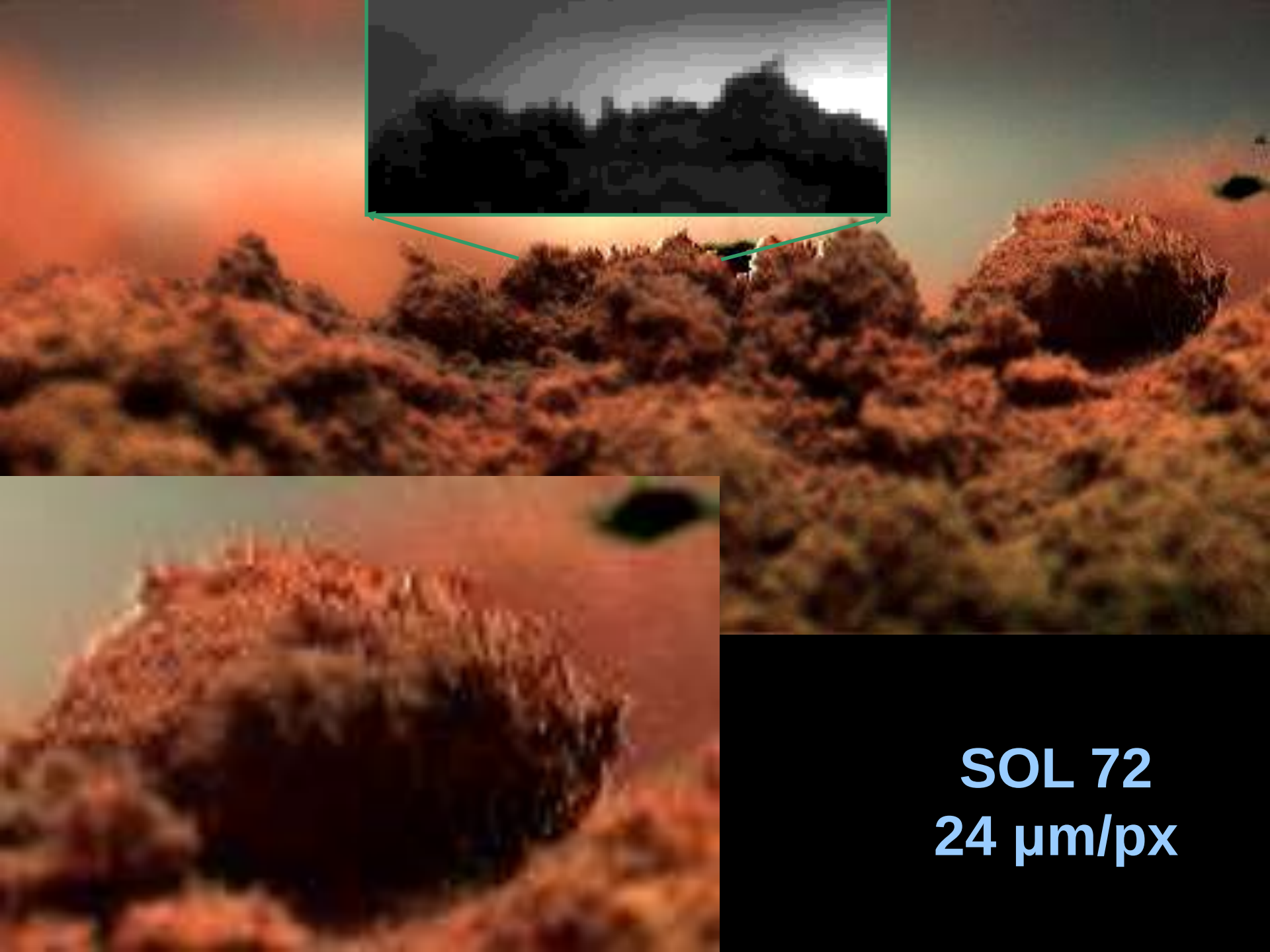
SOL 16

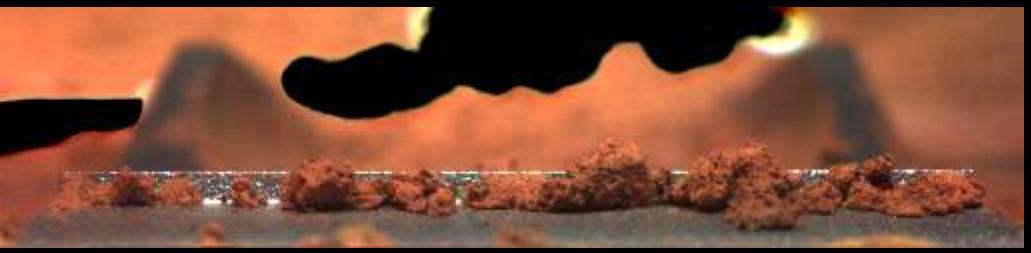
Overnight Changes

Downward movement is seen only in the middle section in a collapse-like manner. Material in the corners is stabilized by adhesion to the side walls.



unchanged


SOL 72
24 µm/px

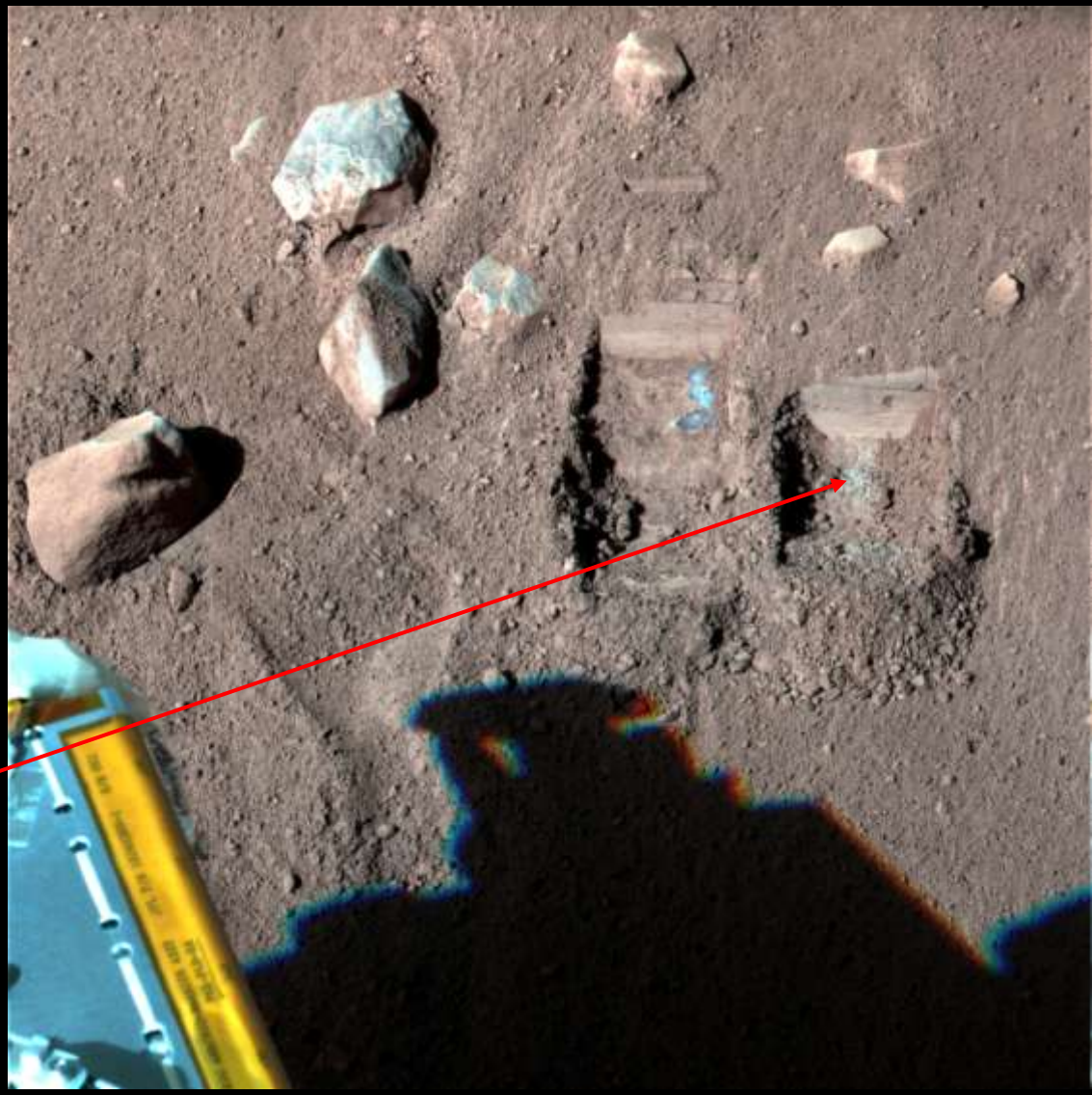


Soil collected after rasping in Snow White

No large particles!

Baby Bear
TEGA's First Sample

- Baby Bear was a surface sample acquired by the Robotic Arm scoop from the Goldilocks Trench on Sol 12
- First of 6
  - 1 oven failed, one unused



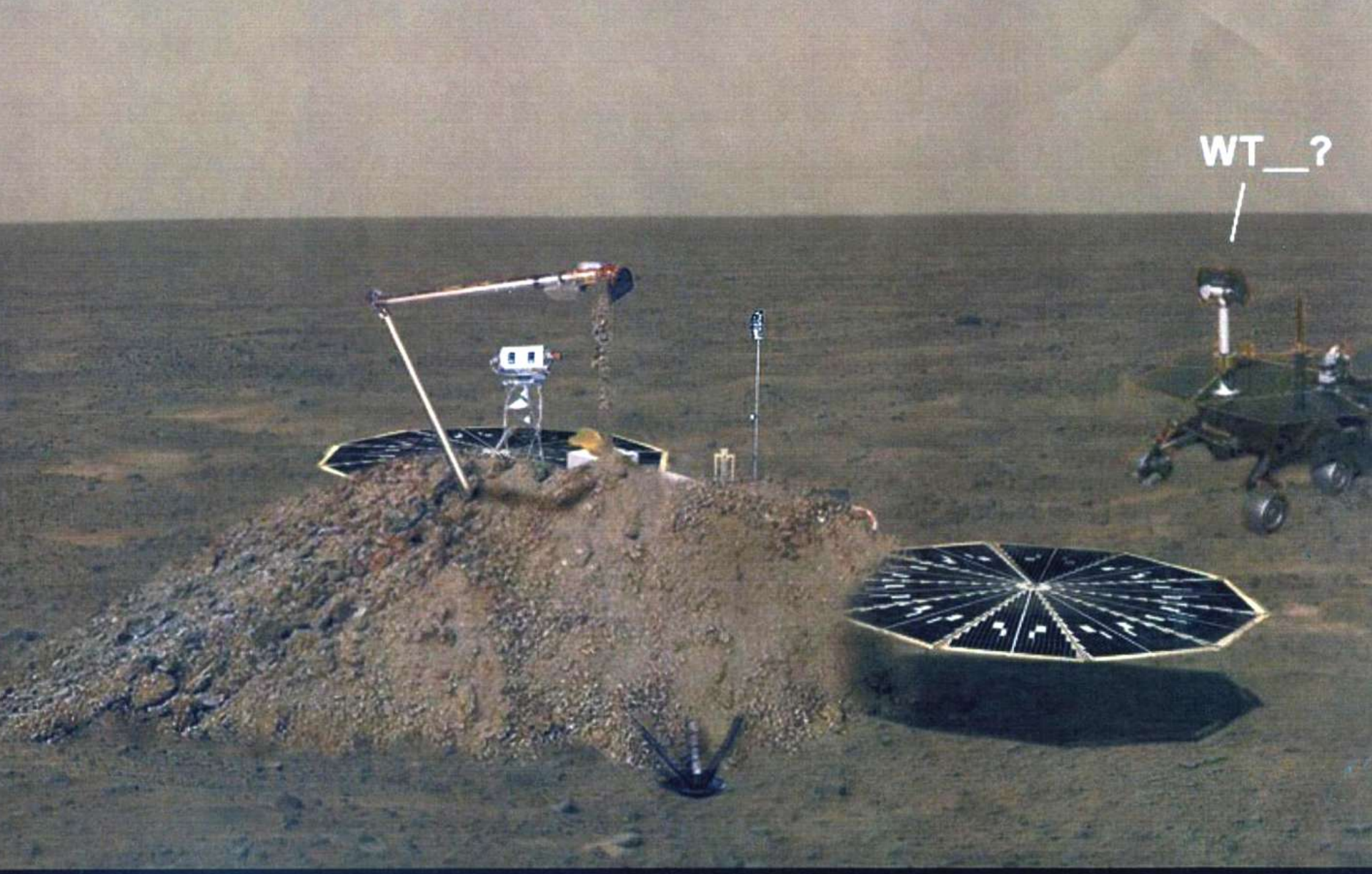
TEGA Surface Sample

Challenges of Putting Martian Soil into TEGA

Soils were cohesive

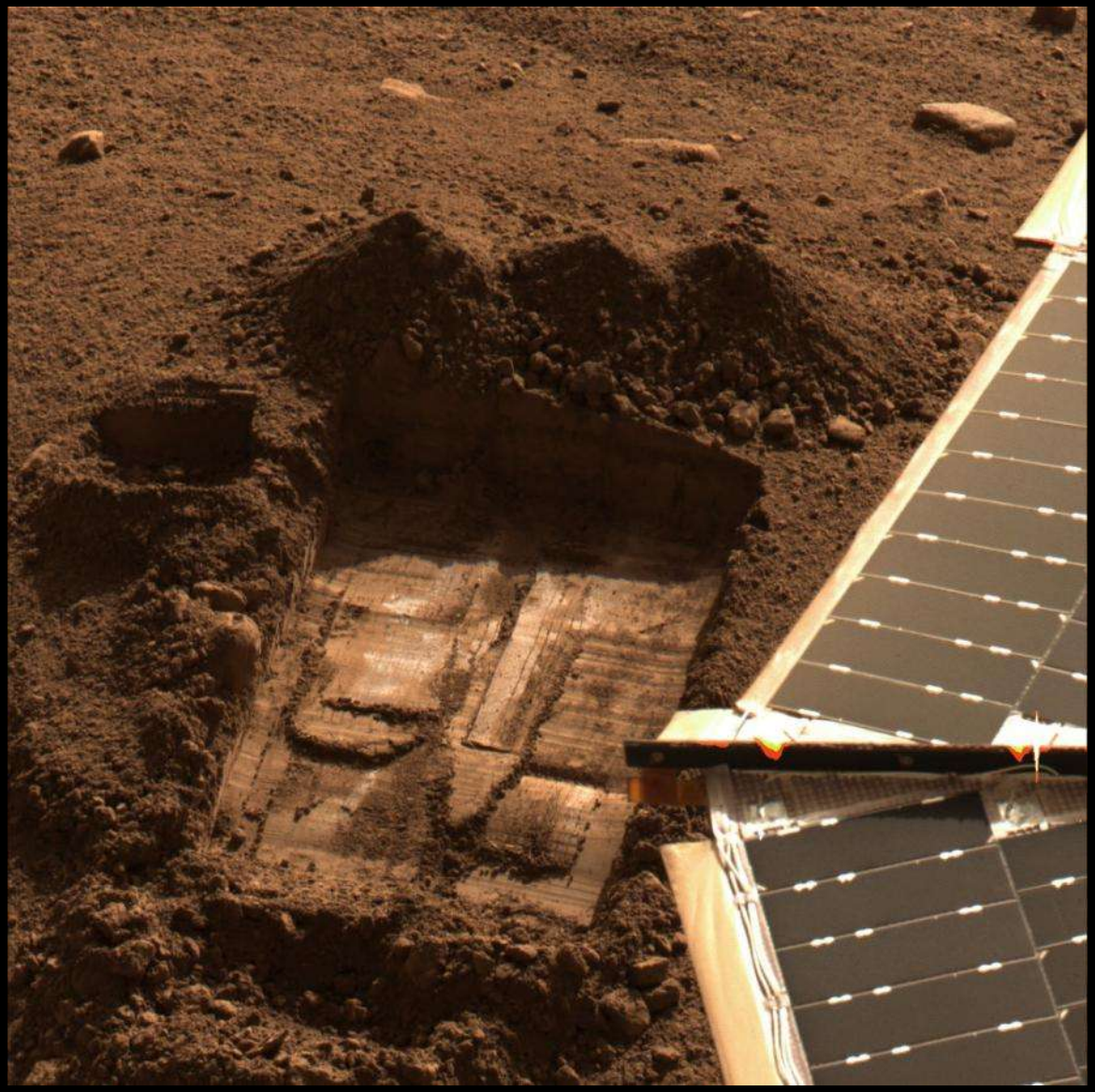
Candidate causes:

- Weak van der Waals forces
- Electrostatic interaction
- Moisture (although unlikely)
- Salt cementation
- Particle-particle interaction (fine-grained with larger particles)

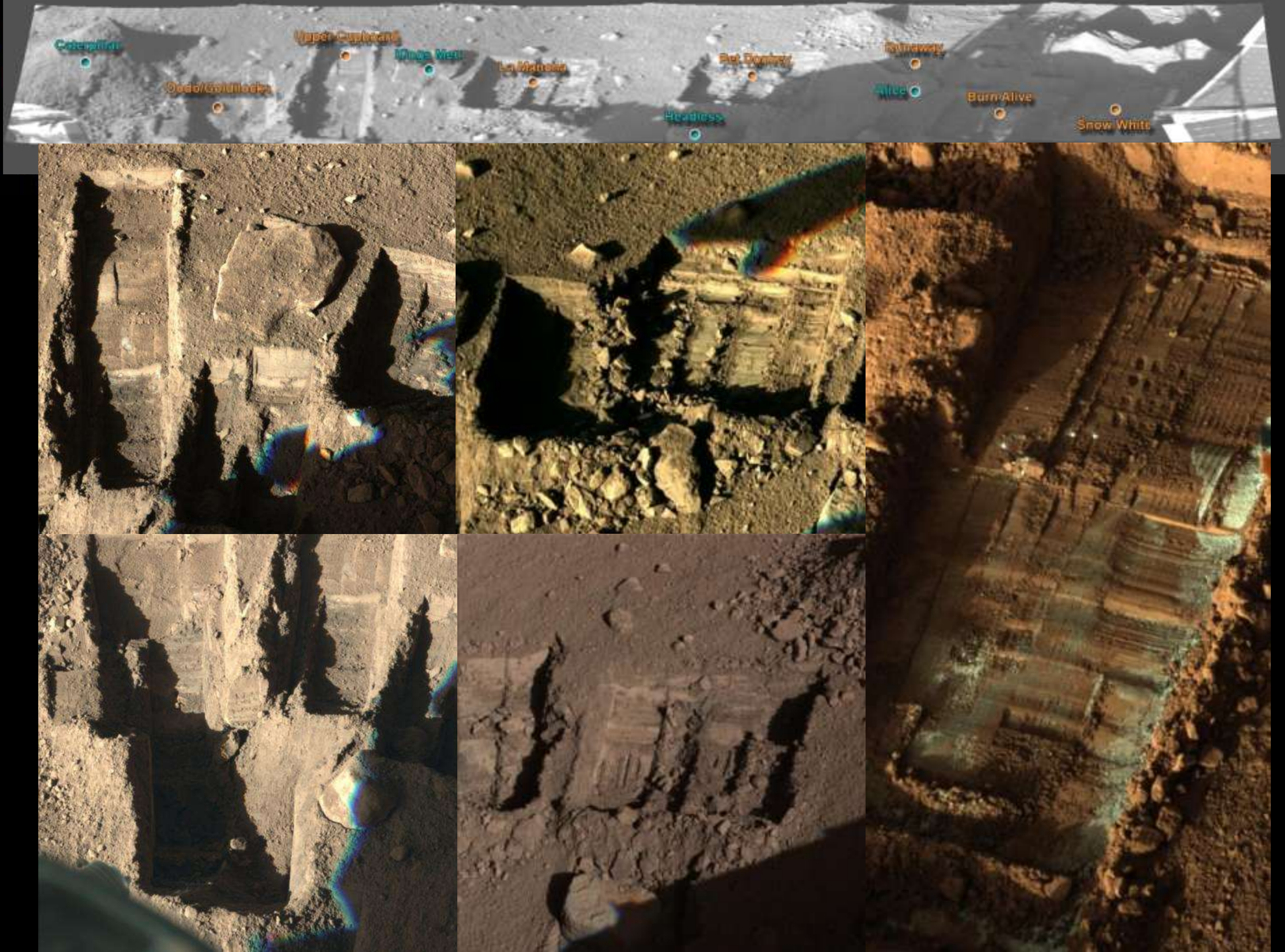


Phoenix attempts another sample delivery!

Snow White trench – middle of polygon



Snow White Trench and Drill Holes



Caterpillar
Upper Cupboard
Dodo/Goldilocks
La Mancha
Headless
Pet Donkey
Runaway
Alice
Burn Alive
Snow White

Summary from imaging

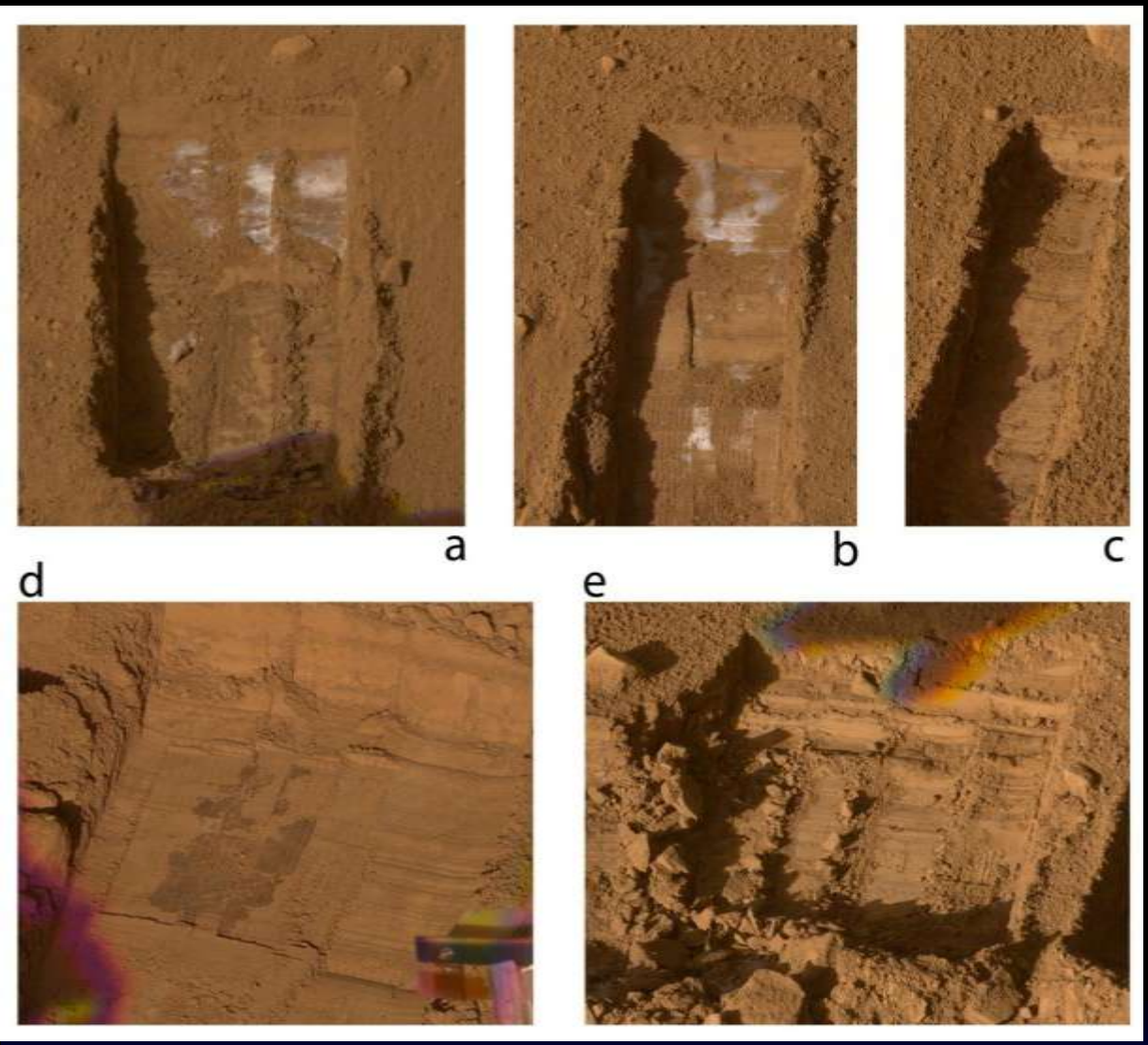
- Polygonal ground seen from orbit is real.
- Found polygons of superimposed sizes.
- Morphology consistent with present activity.
- Topography and stratigraphy consistent with sand wedge formation.

- Subsurface ice consistent with prediction.
- Depth of subsurface ice varies by 10x.
- Wide range of ice textures, concentration, and physical characteristics.

Ground Ice Everywhere

- Extensive trenching by Robotic Arm.
  - Covered a range of geologic contexts in polygonal terrain (troughs and interiors)
- Trenching by the descent thrusters

Types of ice



Light Toned Ice

- Low soil content.
- Friable.
- 10% of trenched area.
- Unusual concentration

Ice Cemented Soil

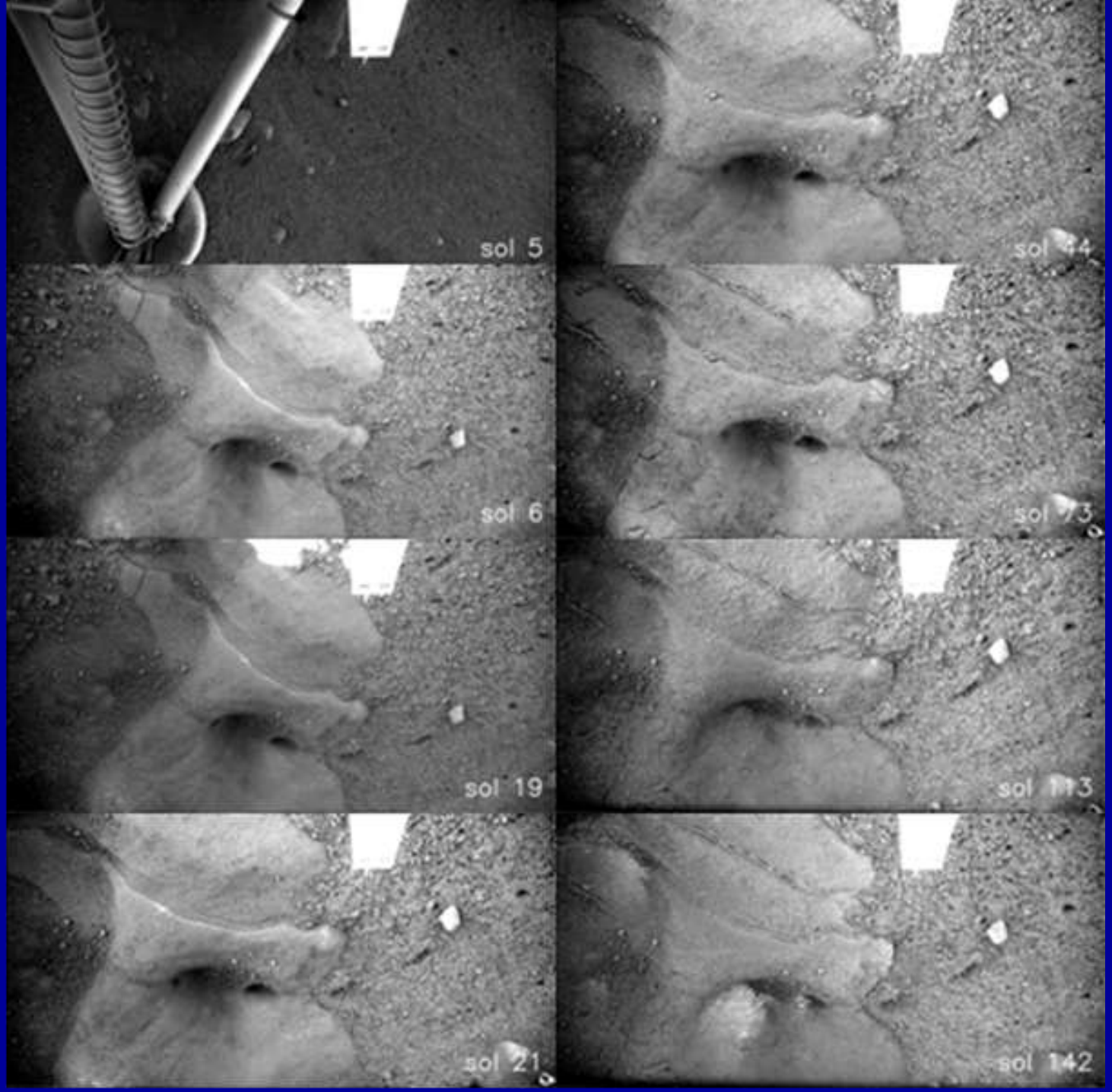
- Dark toned or hard soil
- Matrix supported soil with ice in pores.
- 90% of trenched area.

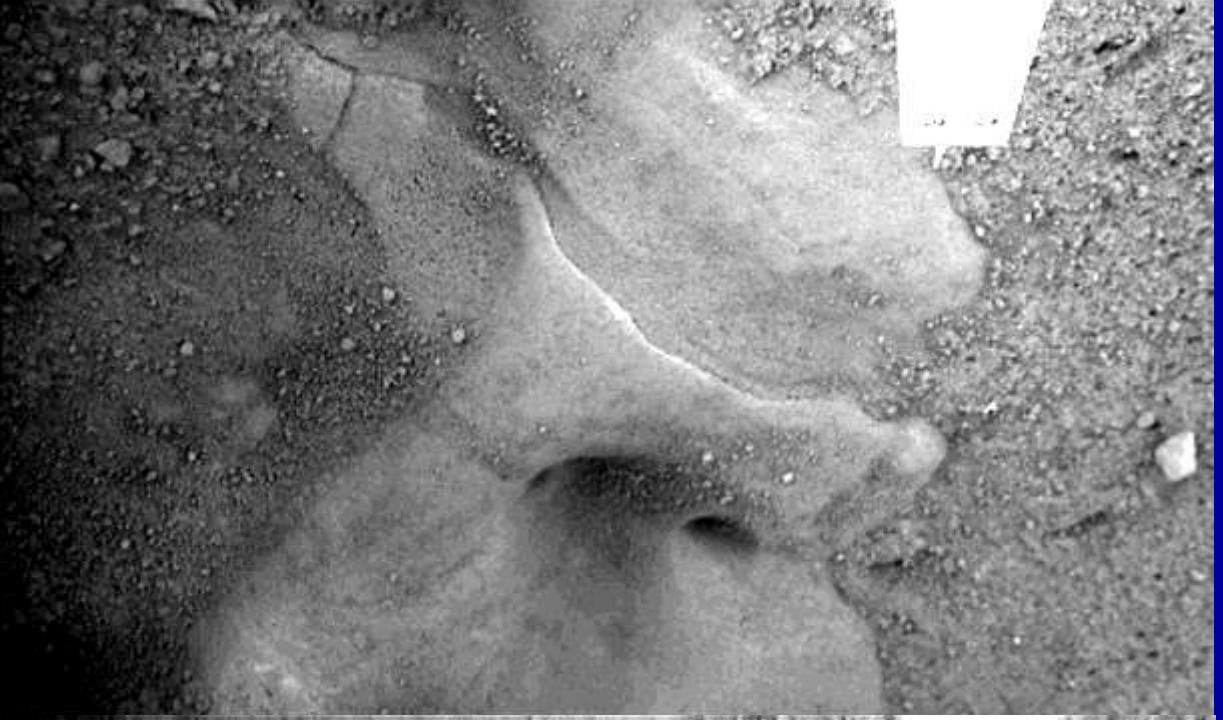
From Mellon et al., 2009

- Soil is friable and fragile
- Soil is made up mostly from fine grained material interspersed with ~100 μm particles (< 20 Vol%)
- Soil is very cohesive and adhesive
- Soil changes once isolated from ground
  - **cemented by a volatile agent (water)**
  - **timescale of order hours to sols**

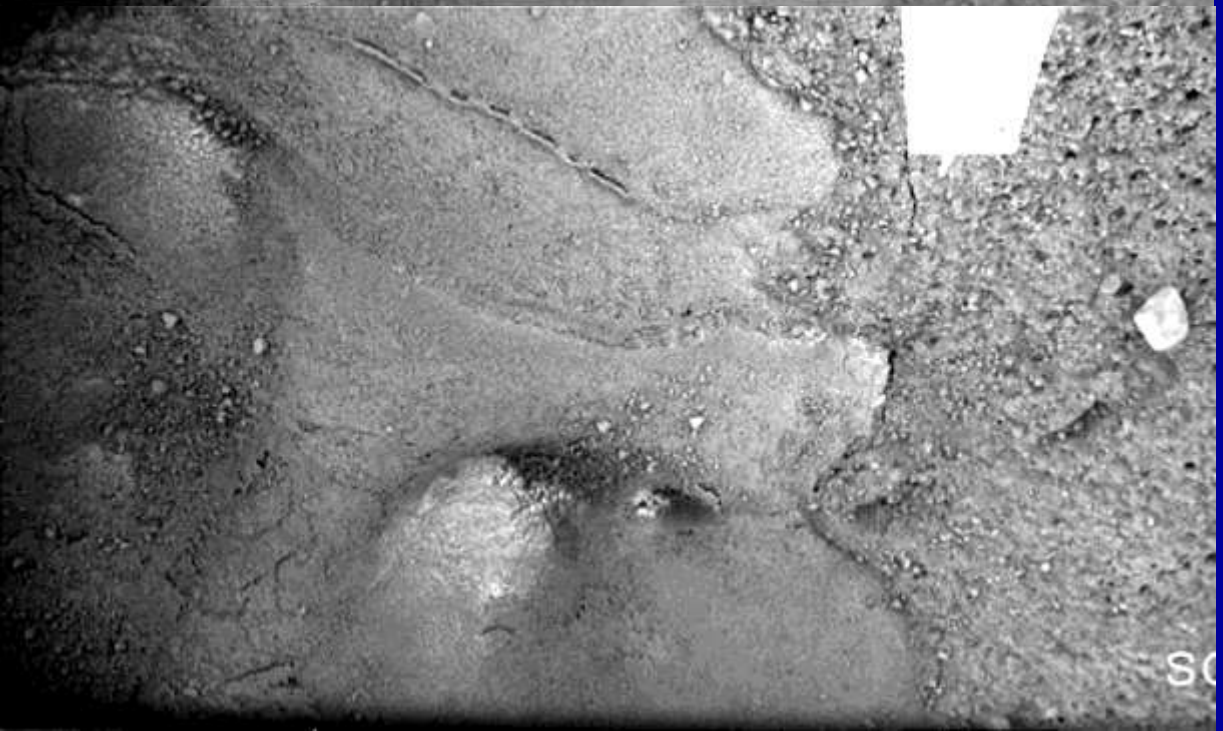
Dominant soil component are micron-sized and possibly smaller grains clumping together due to coating of water

Snow Queen
Sol 21

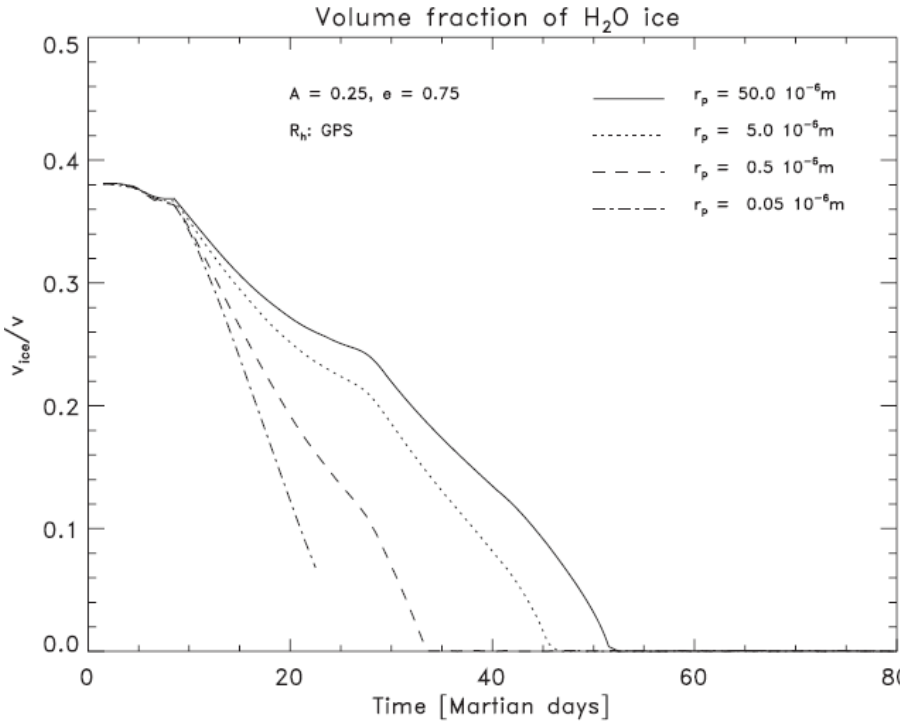

sol 5
sol 44
sol 6
sol 73
sol 19
sol 113
sol 21
sol 142



Sol 6

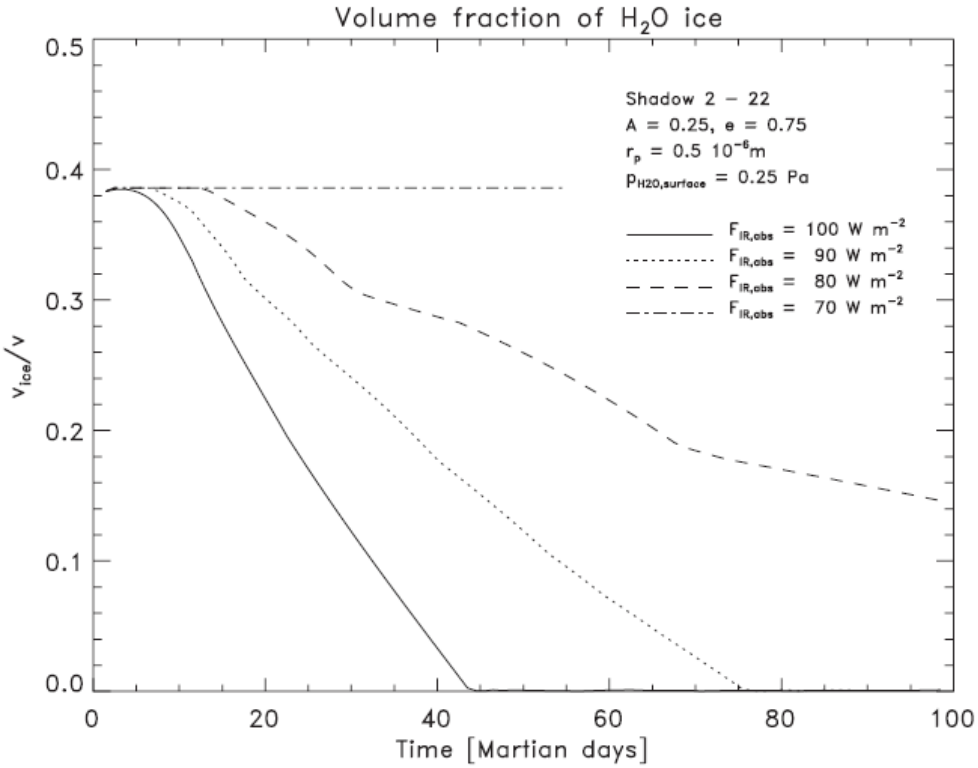


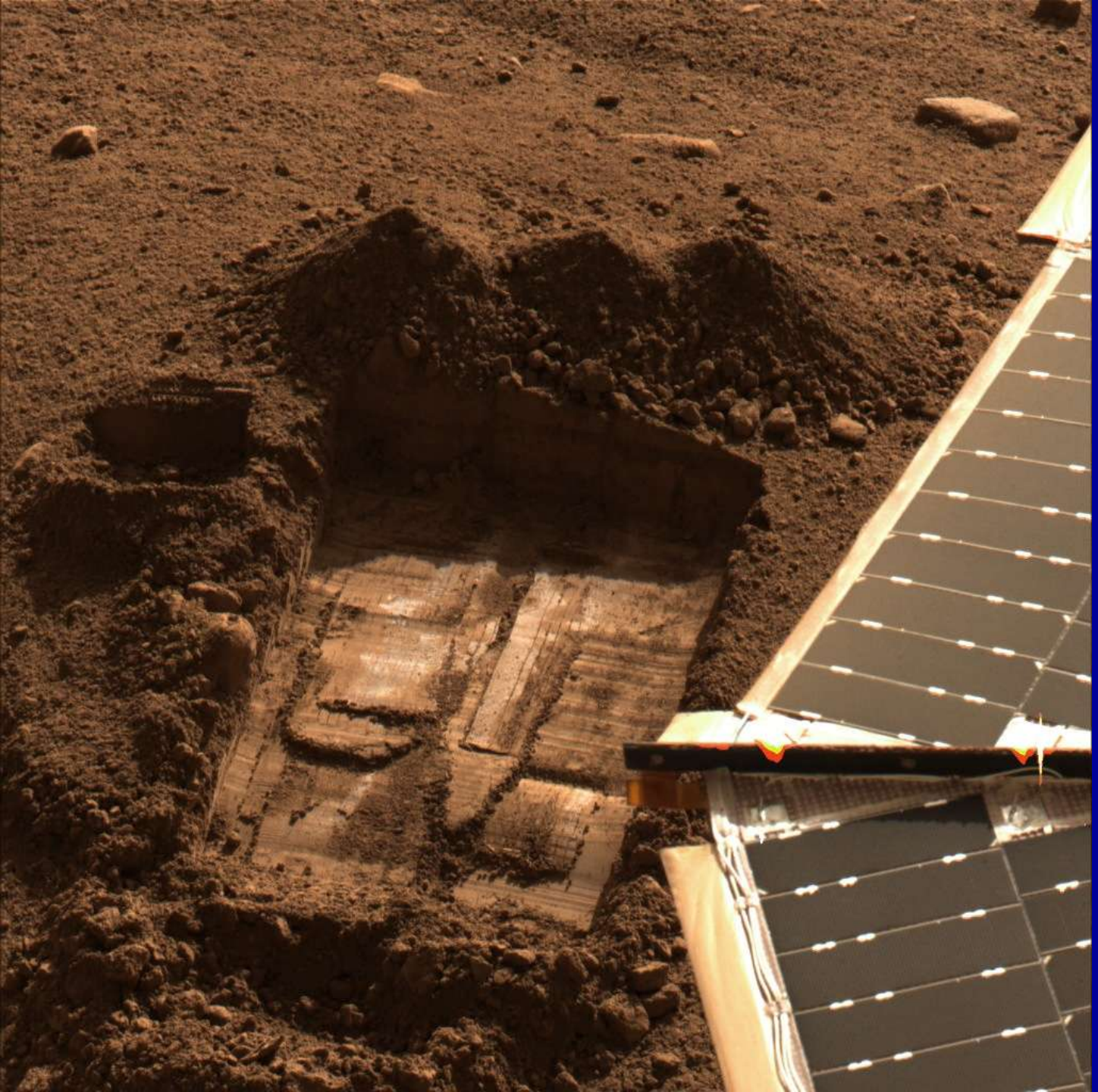
Sol 142



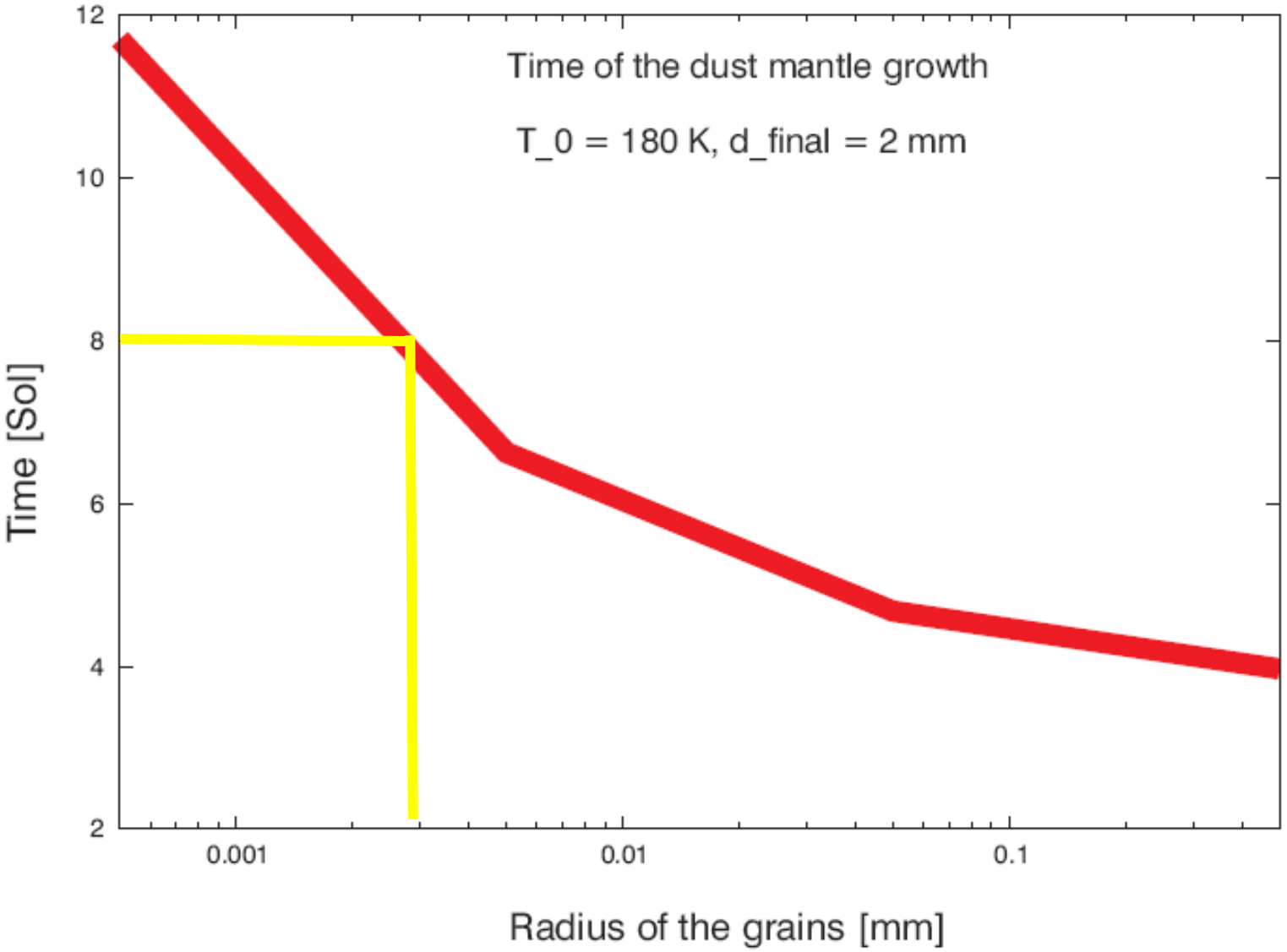
particle size

Energy input
- difficult to constrain



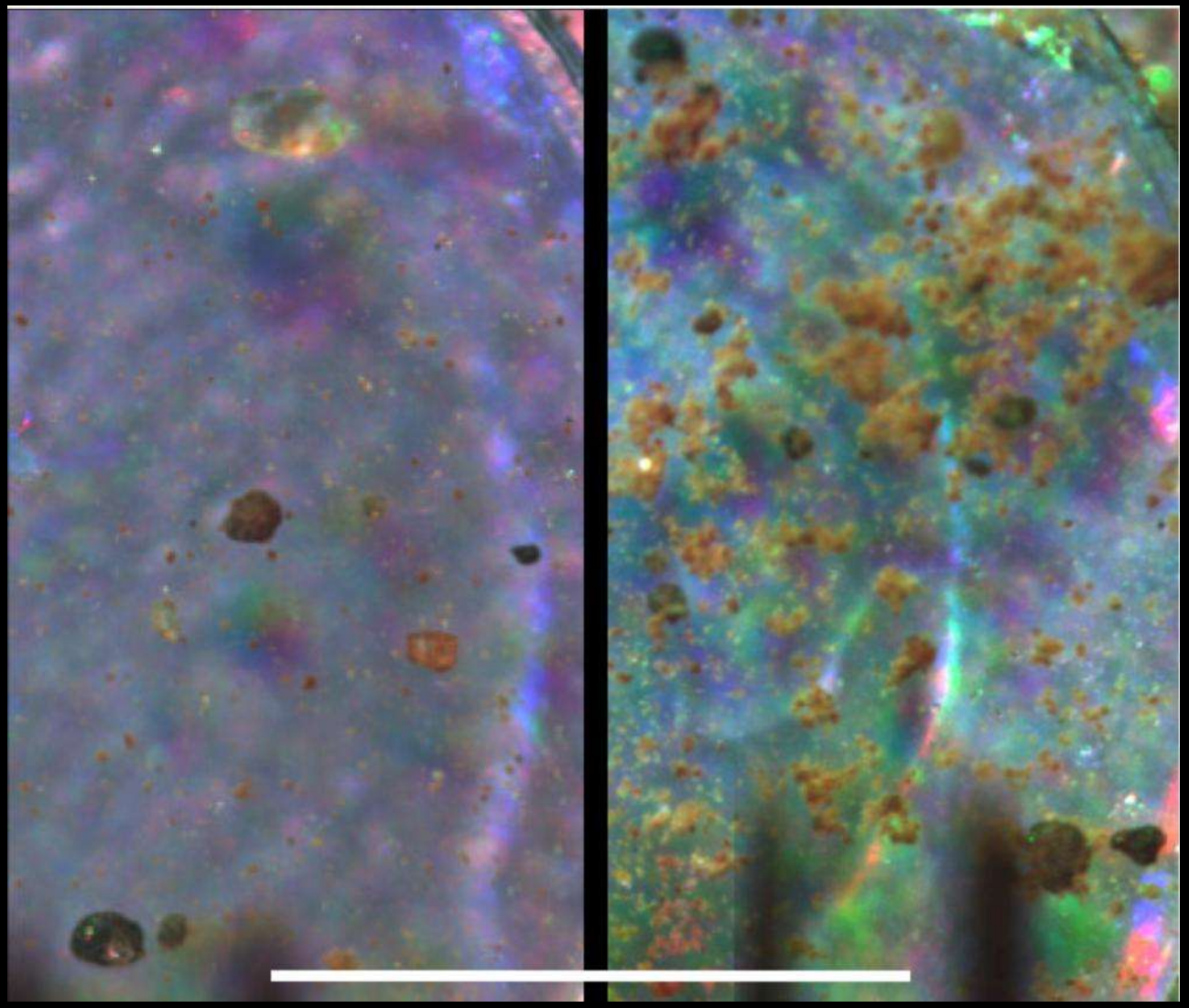


2 mm
dust mantle
formed
in
about 8 sols



Formation of 2 mm dust mantel is consistent with μm sized grains which is consistent with atmospheric dust and Phoenix imaging at all scales.

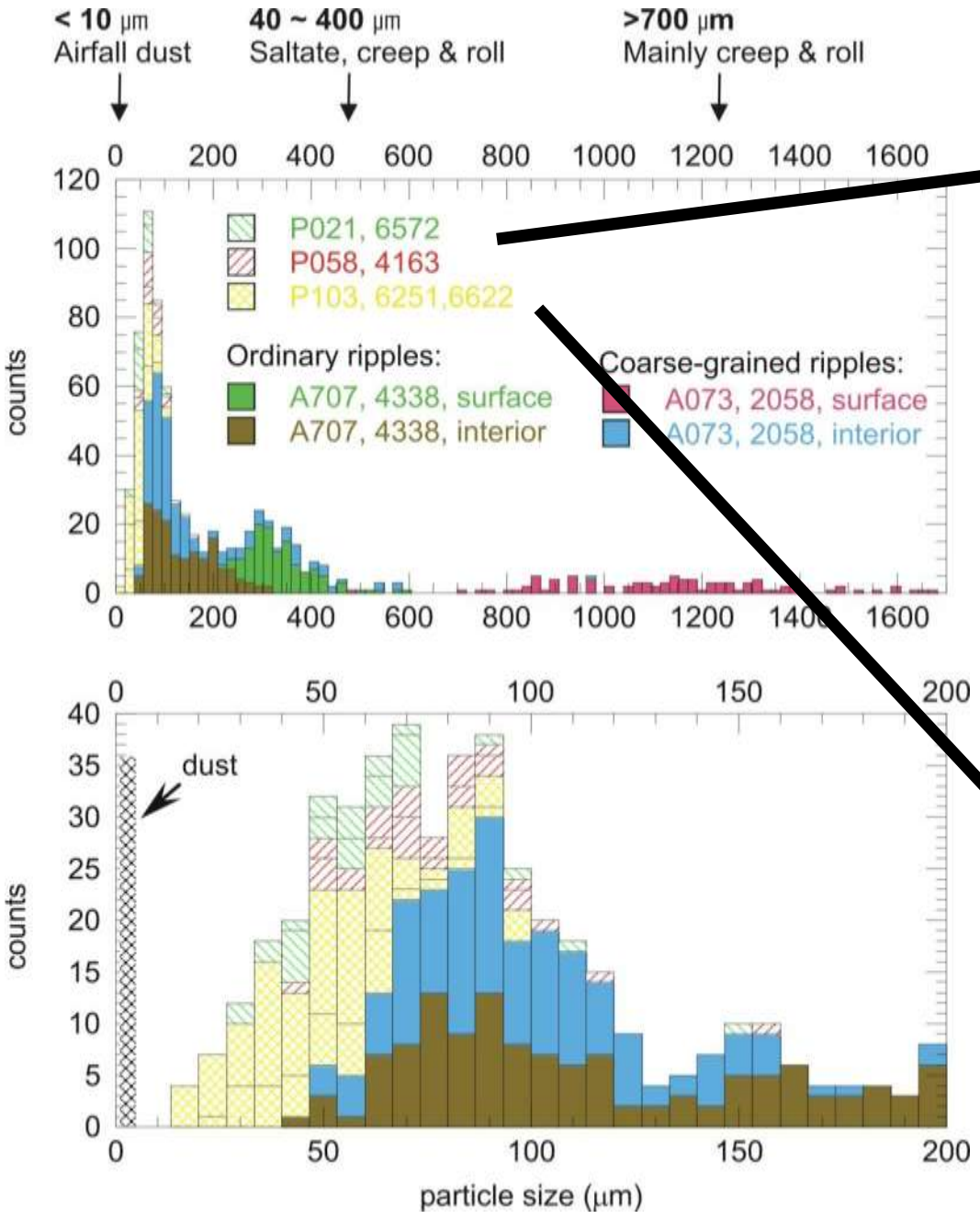
Soil in the Optical Microscope

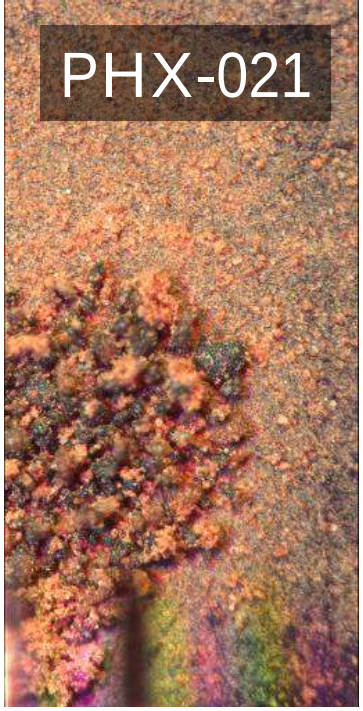


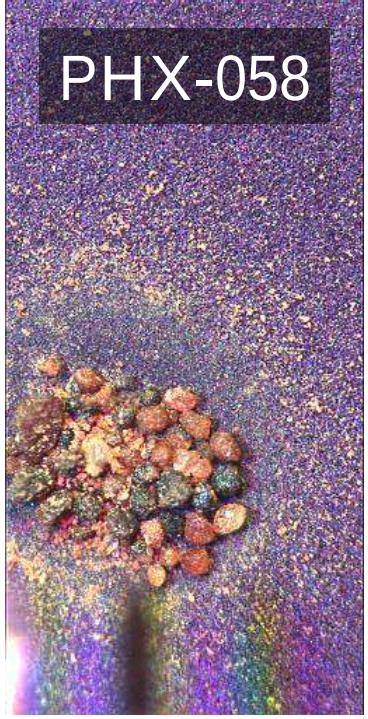
Soil on the Strong Magnet Substrate Optical Microscope Image (surface sample)

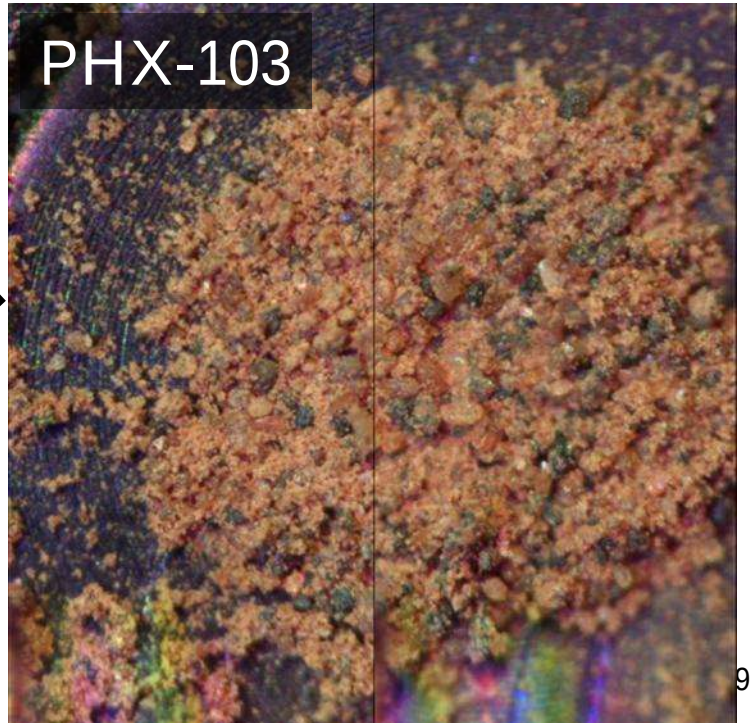
- Candidate red pigment phase
  - Nanophase Fe-oxides
- Candidate magnetic phase
  - Magnetite (Ti-bearing)

Size Distribution: MER-PHX





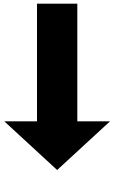




A Bimodal Size Distribution with „holes“ ...

MER-A:
Apparently lacking particles: 450 - 800 μm

PHX:
Apparently lacking particles: 20 - 30 μm, 200 - 1000 μm



The PHX site may well be a special place ...

W. Goetz et al., JGR, 2010

Conclusions/Questions on Soil at the PHX Landing Site

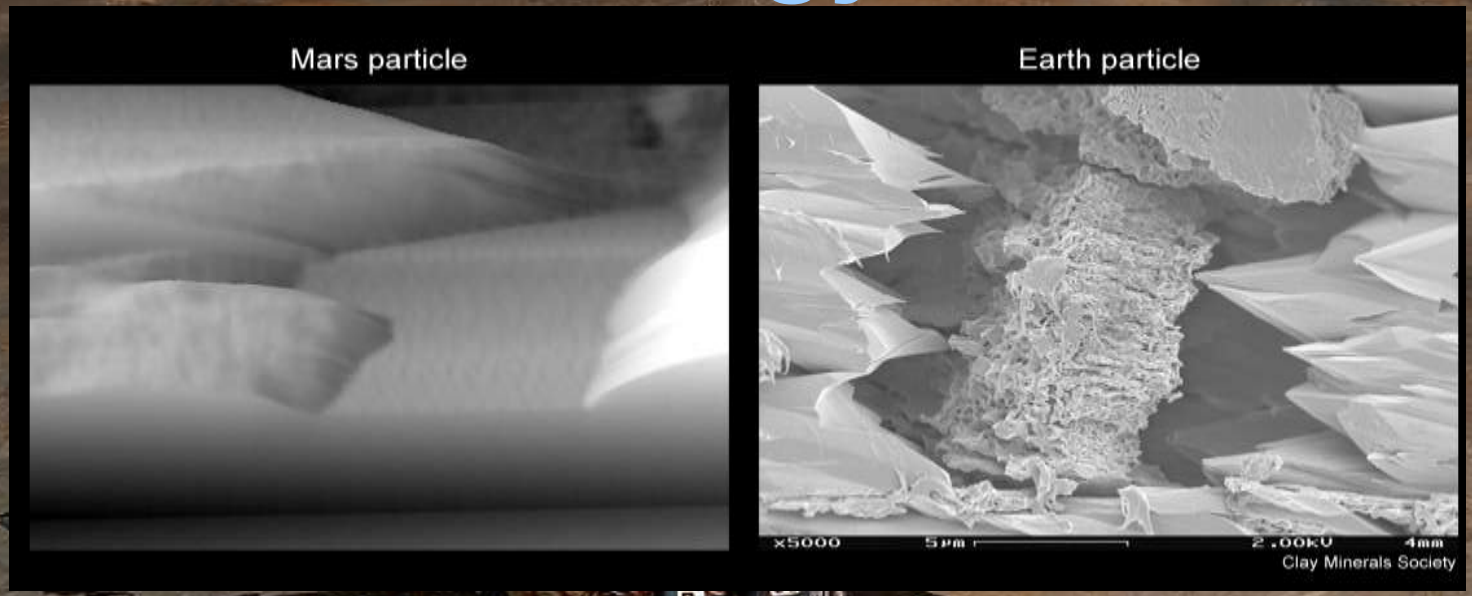
Data	Interpretation
Bimodal size distribution, different from MER	different weathering at the PHX site?
Orange dust: Submicron, magnetic,	~ Martian airborne dust
Translucent, red-to-brown particles: Silt-/sand-sized, substantially magnetic	glassy, common origin?, tectites from Heimdall or volcanic glasses with crystalline magnetic inclusions (Fe, more likely Ti-magnetite)
Opaque, black particles: Silt-/sand-sized, substantially magnetic	common origin (likely), basaltic particles containing Ti-magnetite, crystalline?
Whitish particles, some of them cube-shaped or rod-shaped ... silt-sized, magnetic properties?	perchlorates, chlorides, carbonates? Why not invisible coatings on each partcile?

Global component in PHX soil?

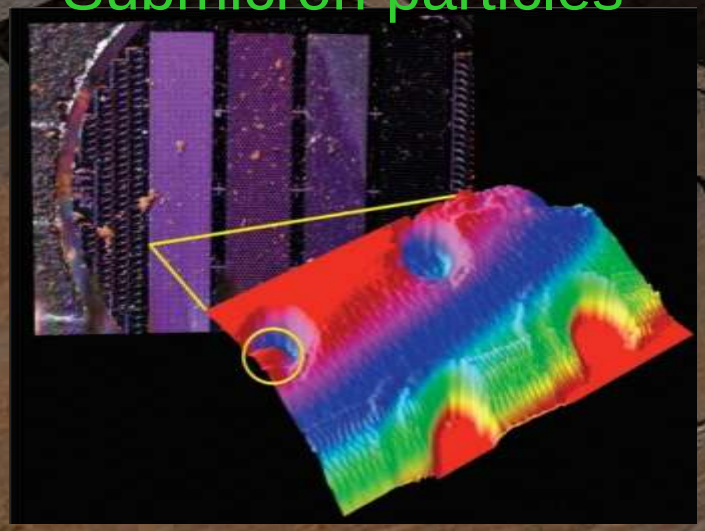
Comparison to soil at „classical“ sites (VL1, MPF, Gusev plains)?

Alteration by continuous presence of water vapor/ice?

Mineralogy: AFM



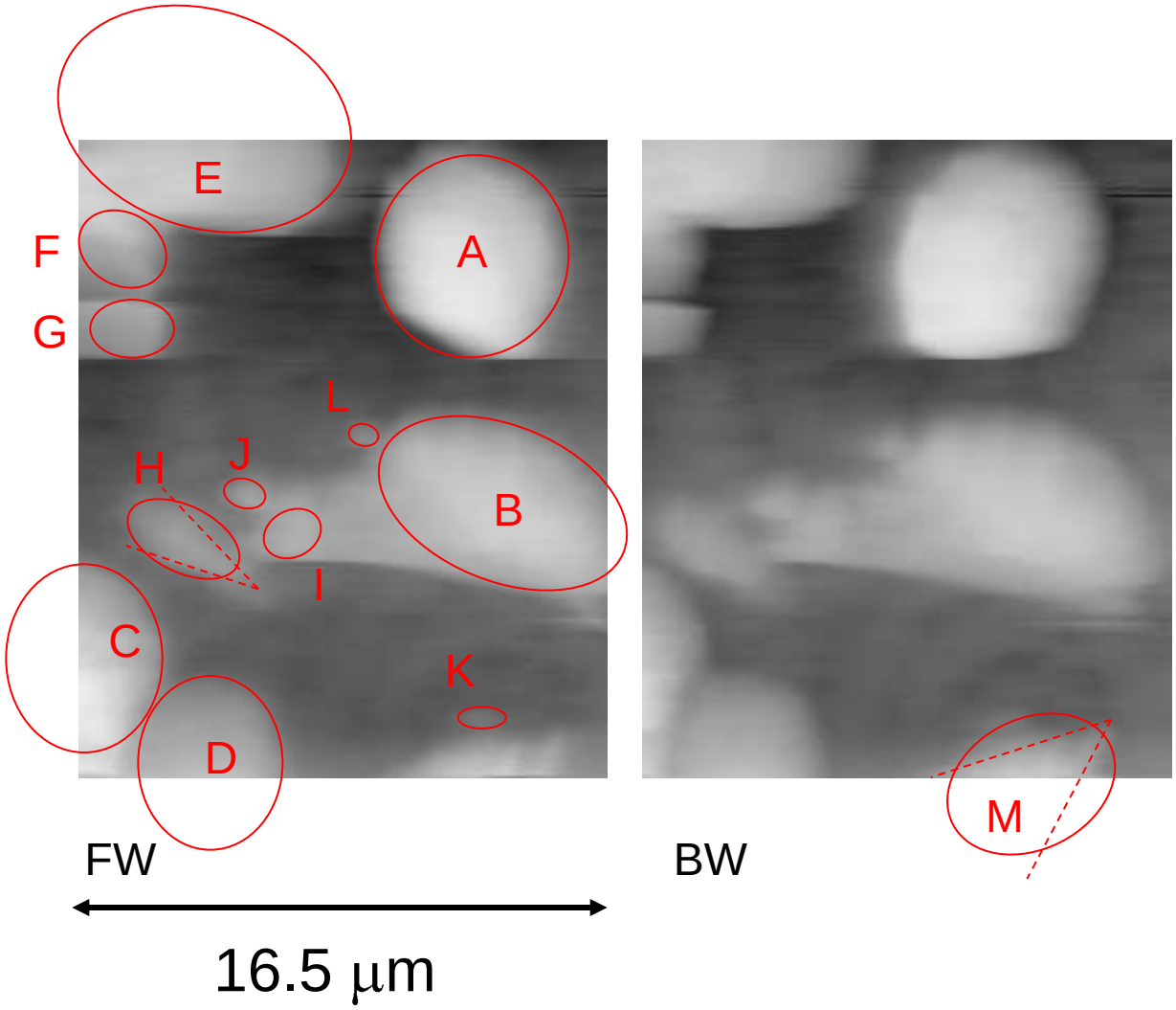
Submicron particles



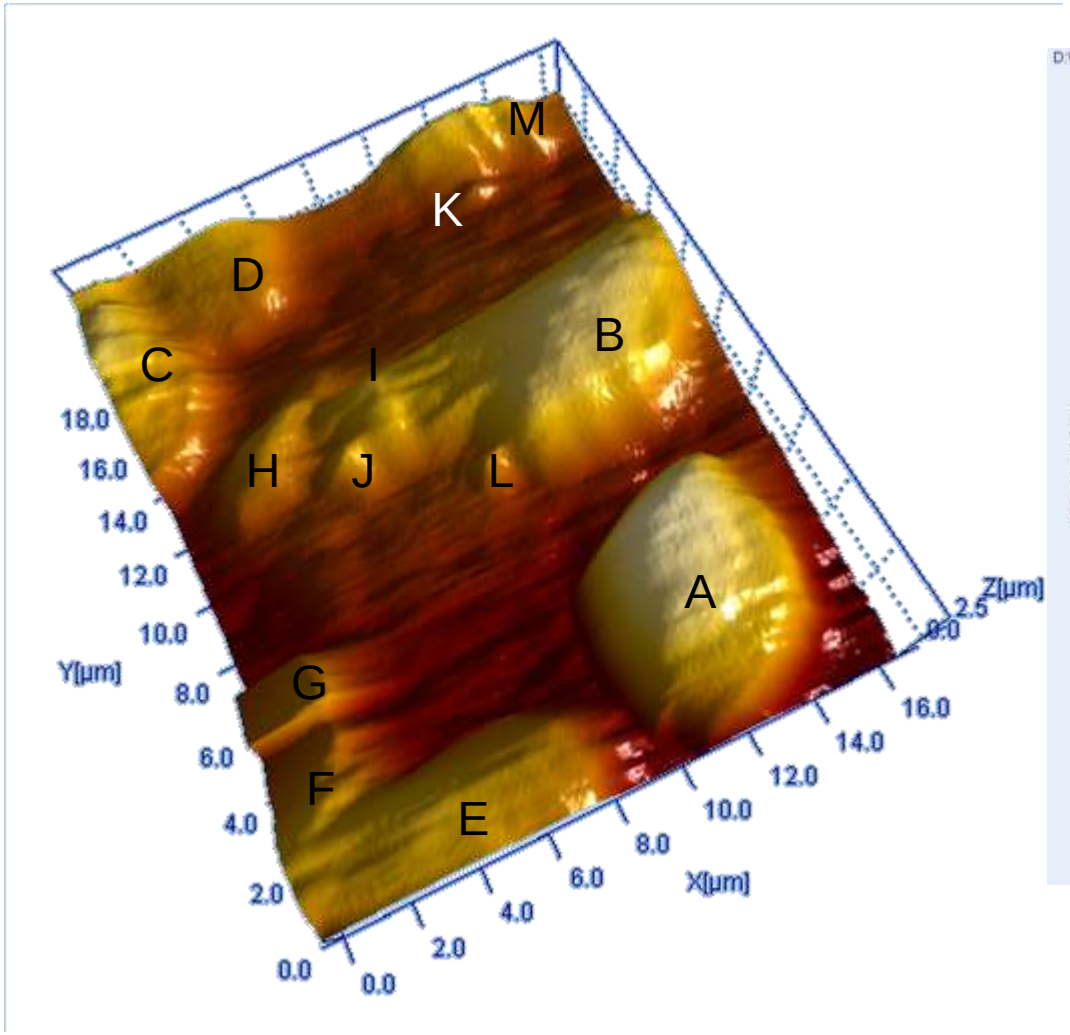
The AFM sees what is very similar to sheet silicates (clay minerals)

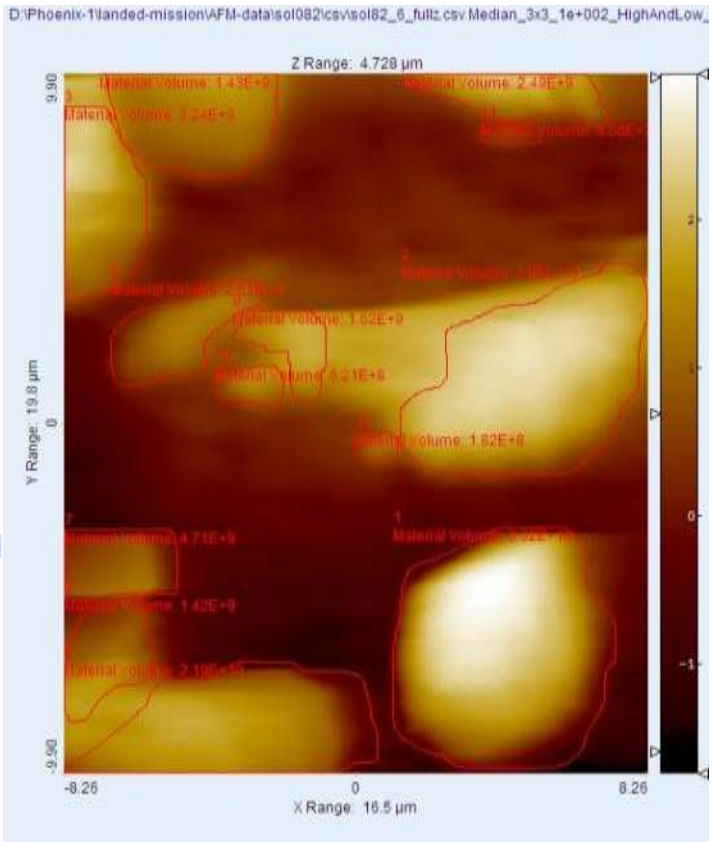
Sorceress from Sol 79

AFM - Sol 82, second scan



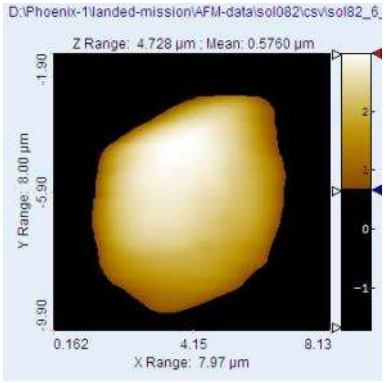
3D, plane fit, median filter

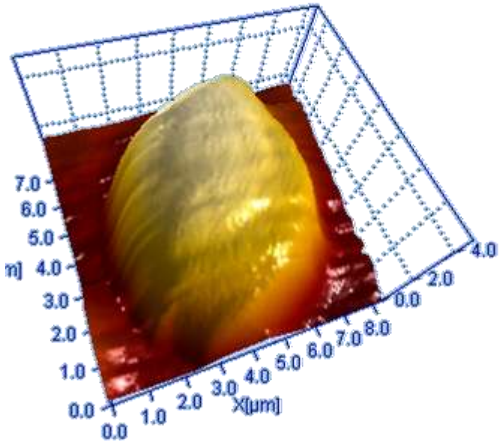




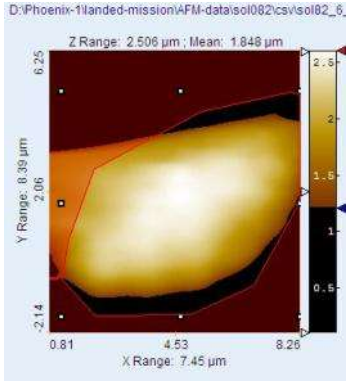
details about the particles

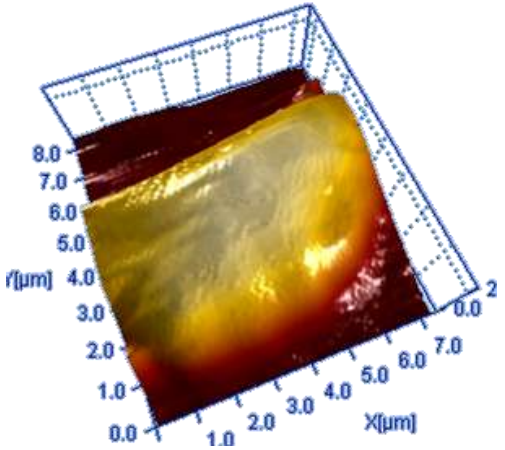
particle A
area: 27 µm^2
volume: 35.4 µm^3

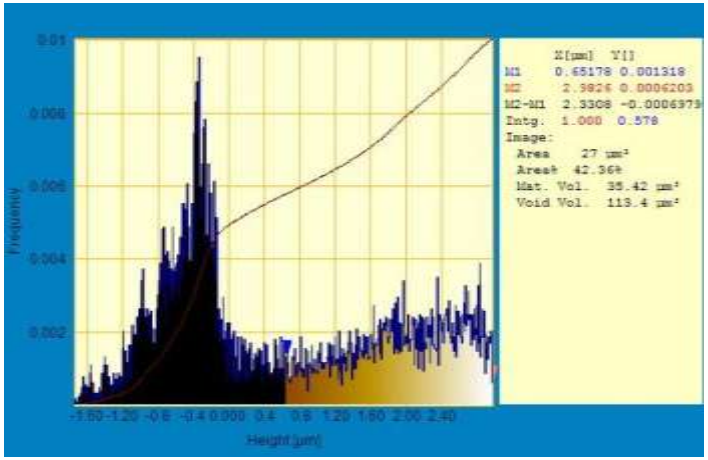


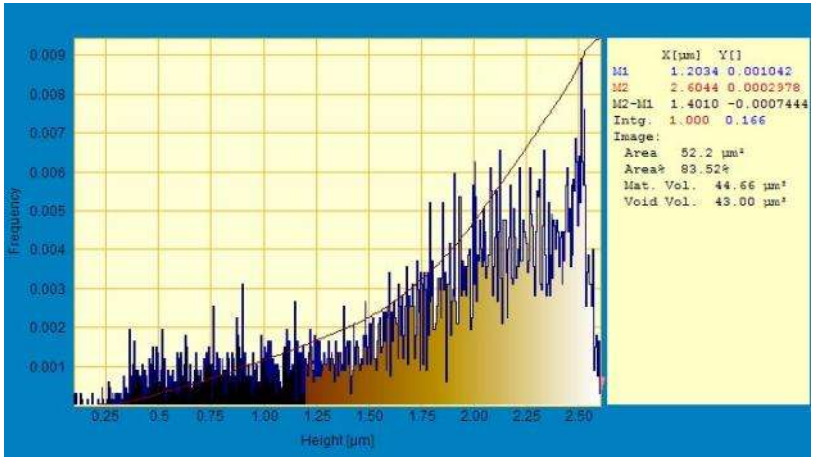


particle B
area: 52.2 µm^2
volume: 44.6 µm^3

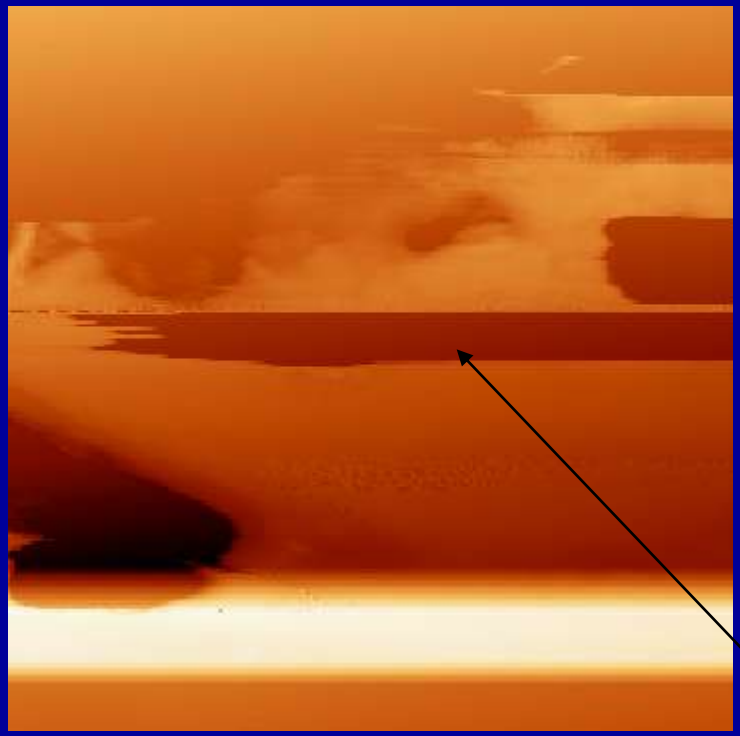




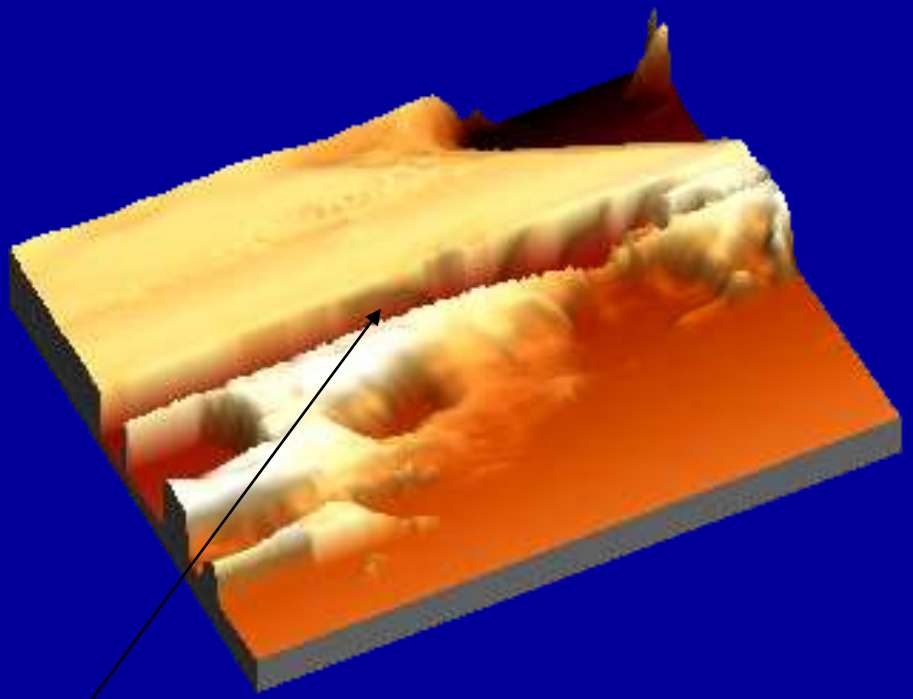




AFM - very fine conglomerates at target A substrate #60



10 µm

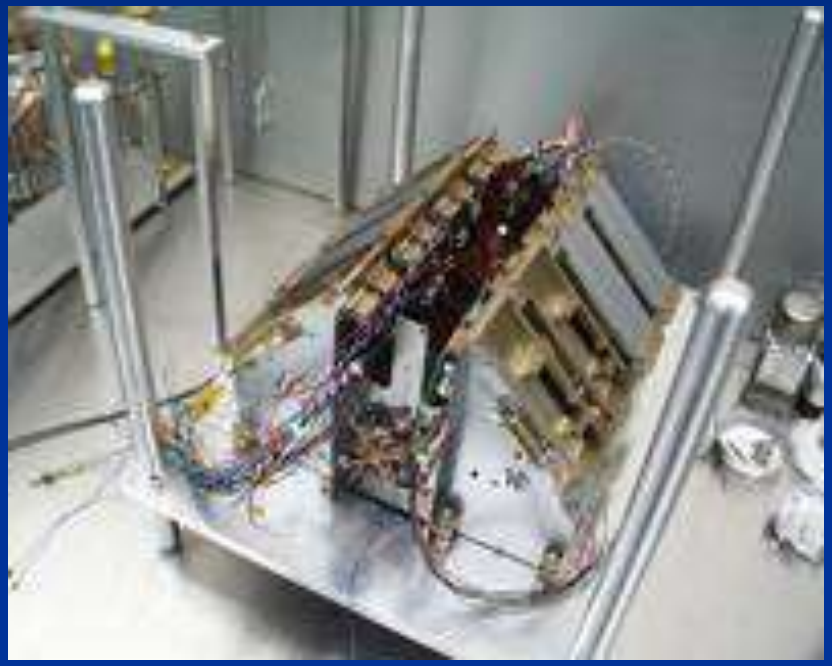


area probably swept wit the tip

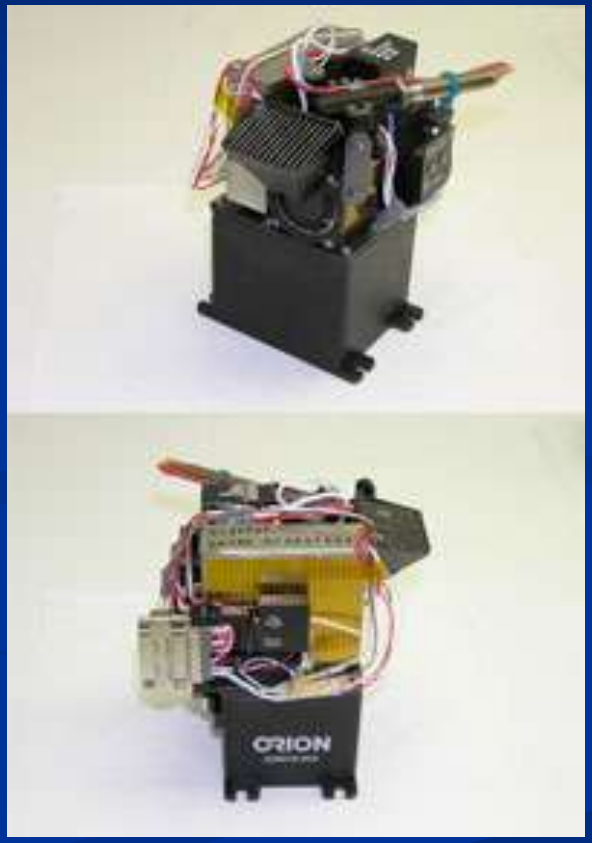
error signal -> z coordinate not calibrated!

Chemistry Results of the Phoenix Mission

The Instruments



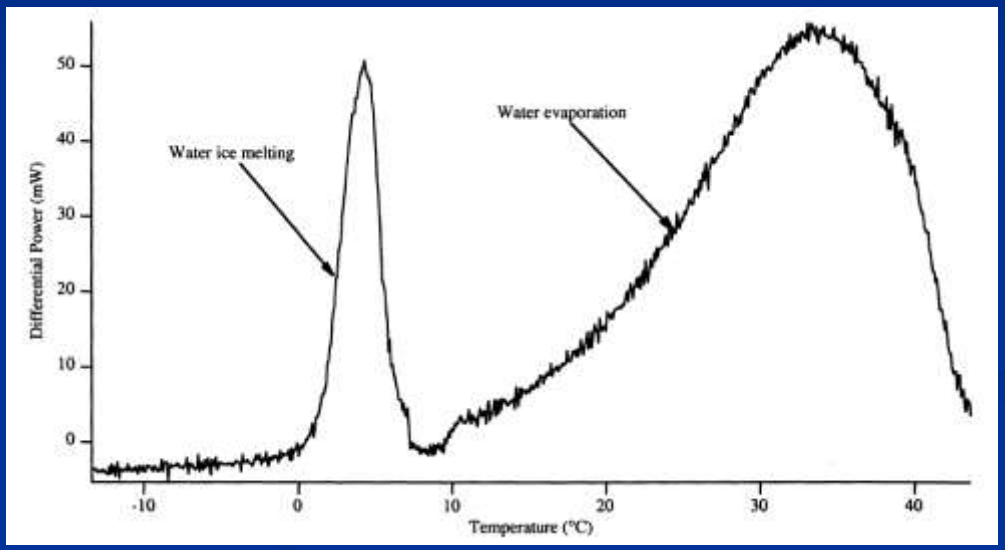
Thermal and Evolved Gas Analyzer **(TEGA)**



Wet Chemistry Lab
(WCL)

Thermal and Evolved Gas Analyzer (TEGA)

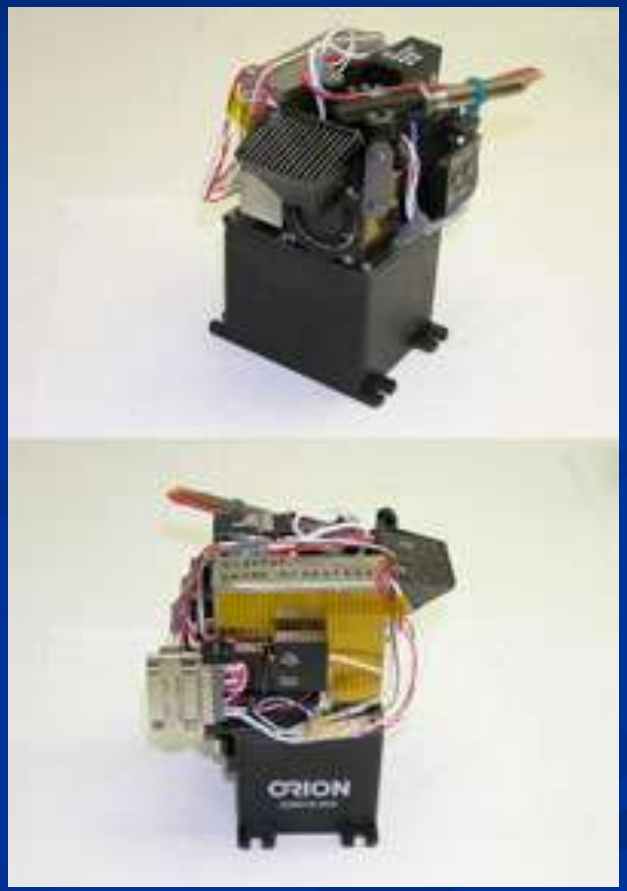
- Comprises two main components:
- ⇒ A thermal analyzer that investigates phase transitions
- ⇒ An evolved gas analyzer that detects and quantifies the amount of volatiles during sample heating
- Sample is heated in a stage-like manner (up to 35 °C, 350 ° C, 1000 ° C)
- Analyzed 5 Martian icy-soil samples



Boynton et al., 2001

Wet Chemistry Lab (WCL)

- Comprises 4 individual "chambers" for analysis (2-days analysis)
- Soil is mixed with preheated leaching solution.
- A sensor array measures pH, Eh, electrical conductivity, and concentrations of selected soluble inorganic ionic species.
- On the second day an acid is added and titration experiments are performed for detection of sulfates
- 3 chambers were filled and measured, the 4th was used as a calibration blank



Important findings

- Soil pH
- Carbonates
- Perchlorates

Soil pH

- What does a soil pH mean?
- Previous measurements/estimates on the surface of Mars (Mars Exploration Rovers, Viking)
- This is the first time a direct measurement of soil pH is made for a Martian soil

➔ 8.2 ± 0.5 (mildly basic)

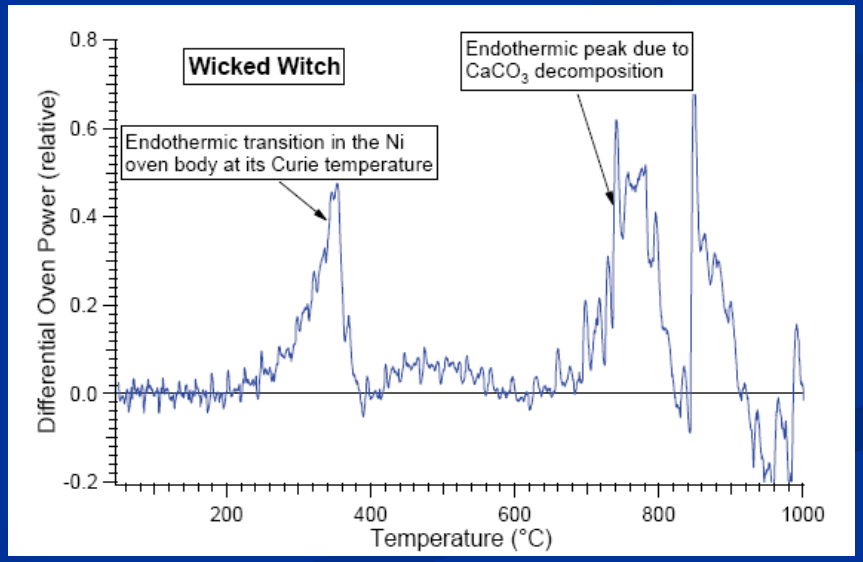
Implications

- Could possibly indicate an old "sea-water" like environment.
- Stable environment for carbonates and many clay minerals.
- More hospitable to life!
- Shows that Martian conditions are more variable than previously thought

Carbonates

- Salts of carbonic acid
- Detection means
  - Endothermic peak between 735 °C and 818 °C (TEGA)
  - Buffering action with addition of acid (WCL)

➔ Calcium carbonate the highest candidate (calcite, aragonite, ikaite)



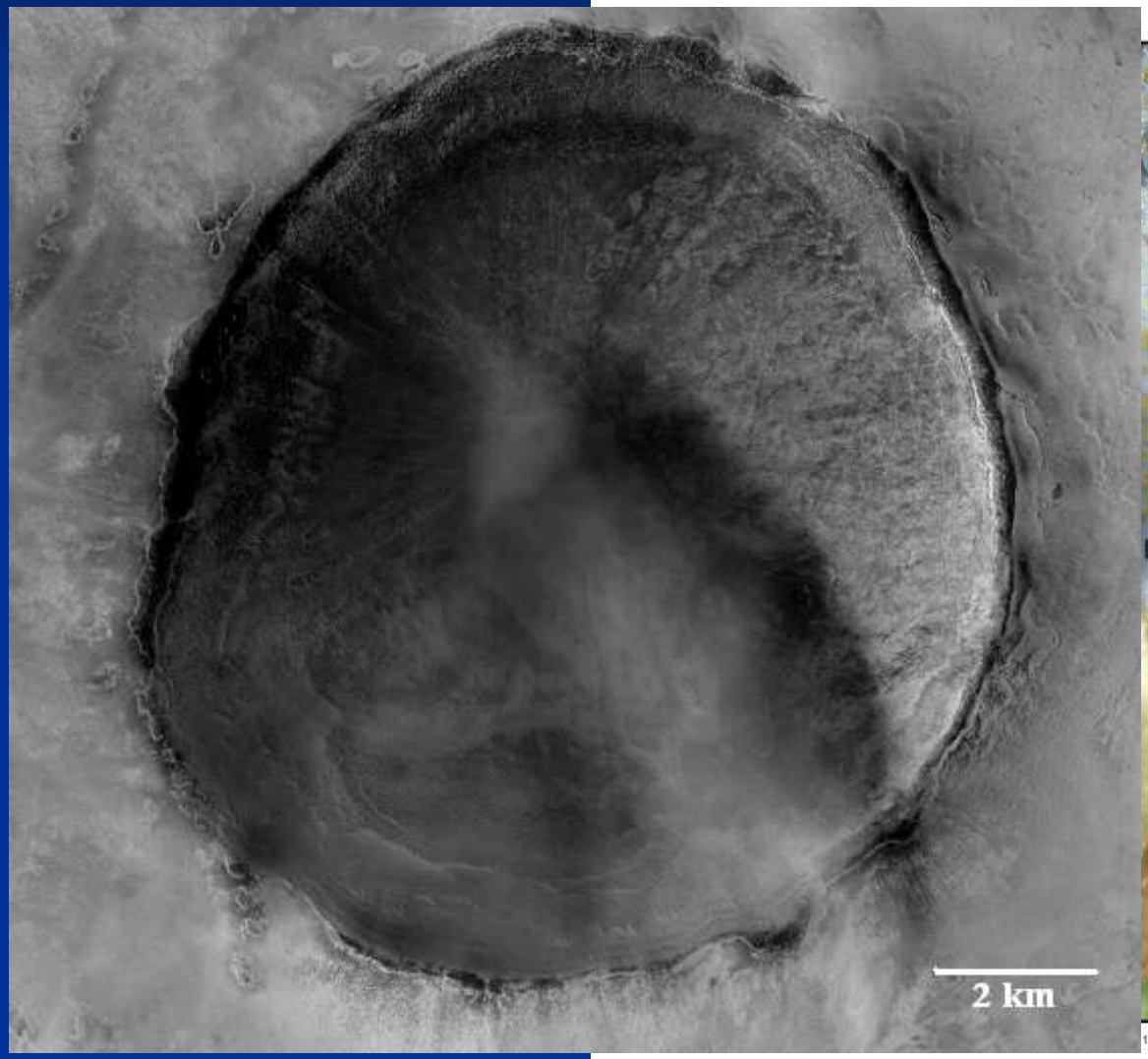
Boynton et al., LPSC 2009

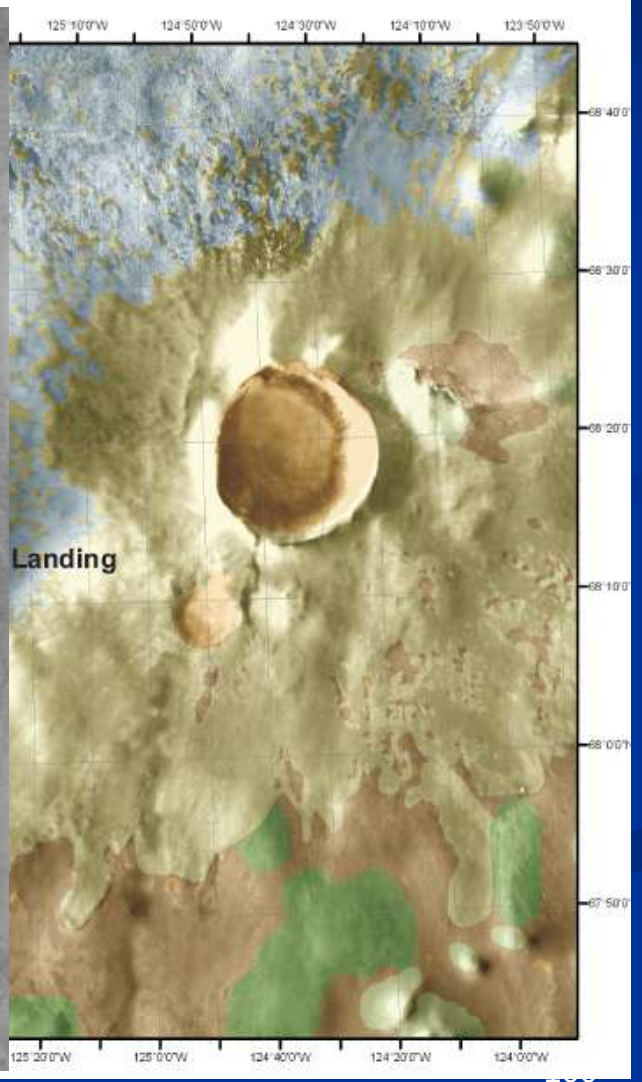
Implications

- Modes of formation
  - Oceanic sedimentation.
  - Alteration of Basaltic material in a silicate-H_2O-CO_2 system.
  - Hydrothermal alterations. (volcanic or impact generated in the Martian case)

➔ Strongly implies that the region has "experienced" water in a liquid phase for some time of its history

Heimdal Crater





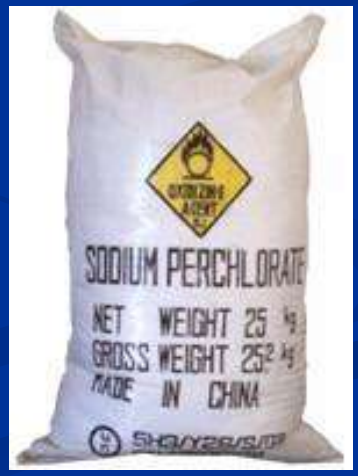
Perchlorates

- General formula: M $[ClO_4]_n$
- Detection method

⇒ Signal increase in the Hofmeister anion sensor, coupled with a decrease of the Ca^{2+} signal from its calibration level (WCL)

⇒ Evolution of a gas species with molecular mass of 32 (O_2) in the TEGA

➔ Charge balance calculations strongly indicate that the perchlorate is in the form: Mg $[ClO_4]_2$



Implications

- Mode of formation
  - Exposure of chlorides (from volcanic vents) to sunlight and/or UV radiation for extensive amount of time
  - Seen on Earth in only very arid regions (ex. Atacama desert)

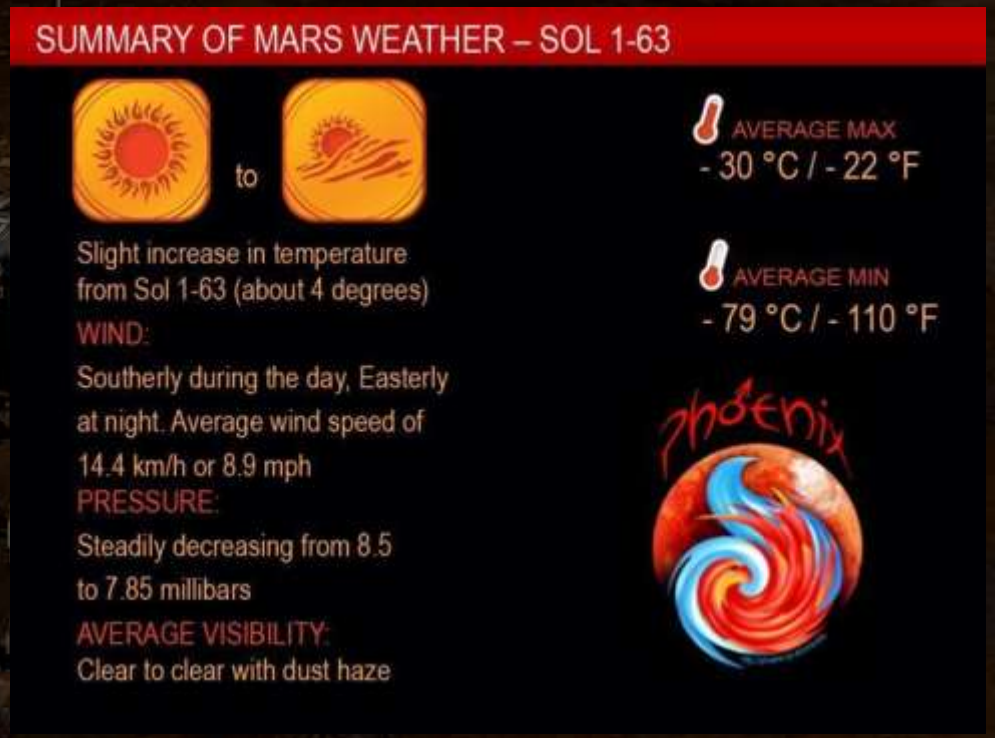
- → Magnesium perchlorate and other alkali earth perchlorates are deliquescent, and have freezing temperatures in the -45 °C to -70 ° C range!
- → If present as a global component, could be responsible for formation of gullies, as well as having major implications on the water cycle on Mars.
- → Acts as an energy source for some life forms!

Summary TEGA and WCL

- The TEGA and WCL have detected carbonates (most probably as calcite), and perchlorates in the Martian soil.
- For the first time, a direct measurement of soil pH has been attained. The soil at the Phoenix landing site is slightly basic (~8.2)
- The Phoenix landing site is the most "potentially" habitable environment encountered on the surface of Mars so far.
- The Phoenix mission has shown that the surface-atmospheric interactions play a bigger role than previously thought in regulating the climate and hydrological cycle of Mars.

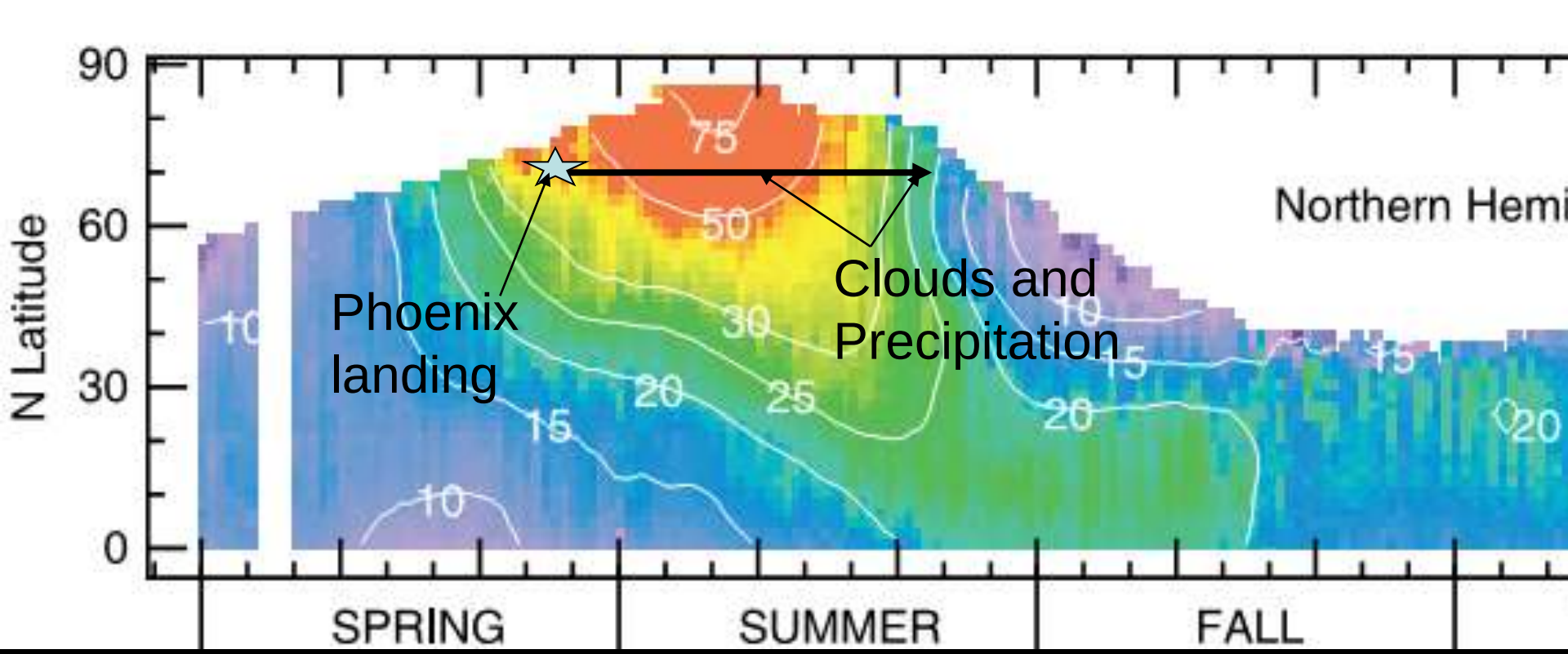
Atmospheric Science
General Weather

- Temperature rose till the Summer solstice, and since then has been steadily dropping.
- Atmospheric pressure has been decreasing in the order of 0.01 millibar (1 Pascal) per day.



Atmospheric Water Vapour

Thermal Emission Spectrometer (Smith, JGR, 2002)



Images from the SSI camera

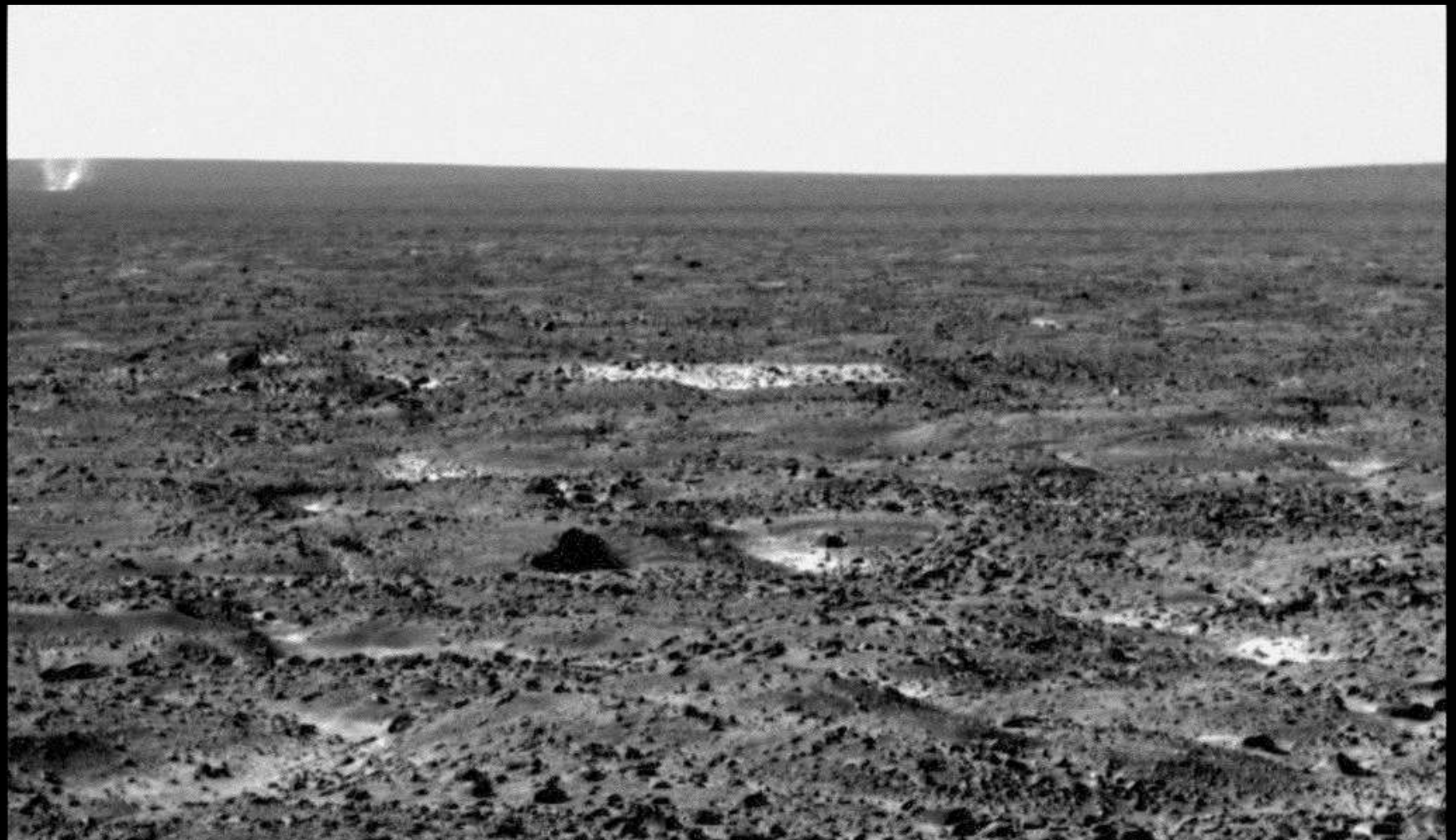
Winds on Mars

The Telltale

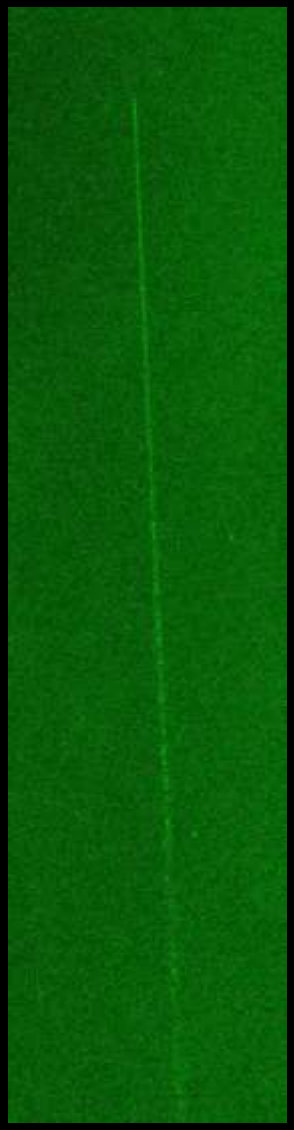
Winds from all directions
about 5m/s

Winds on Mars

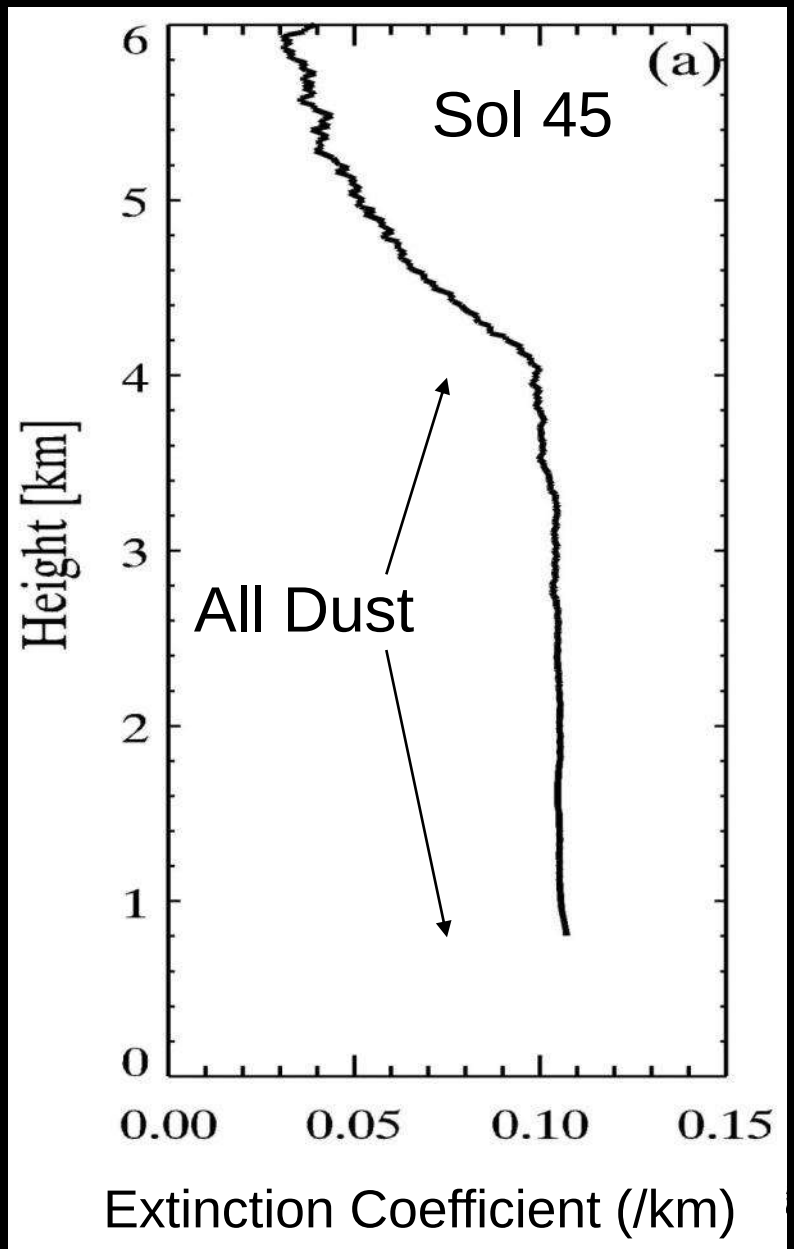
Dust Devils



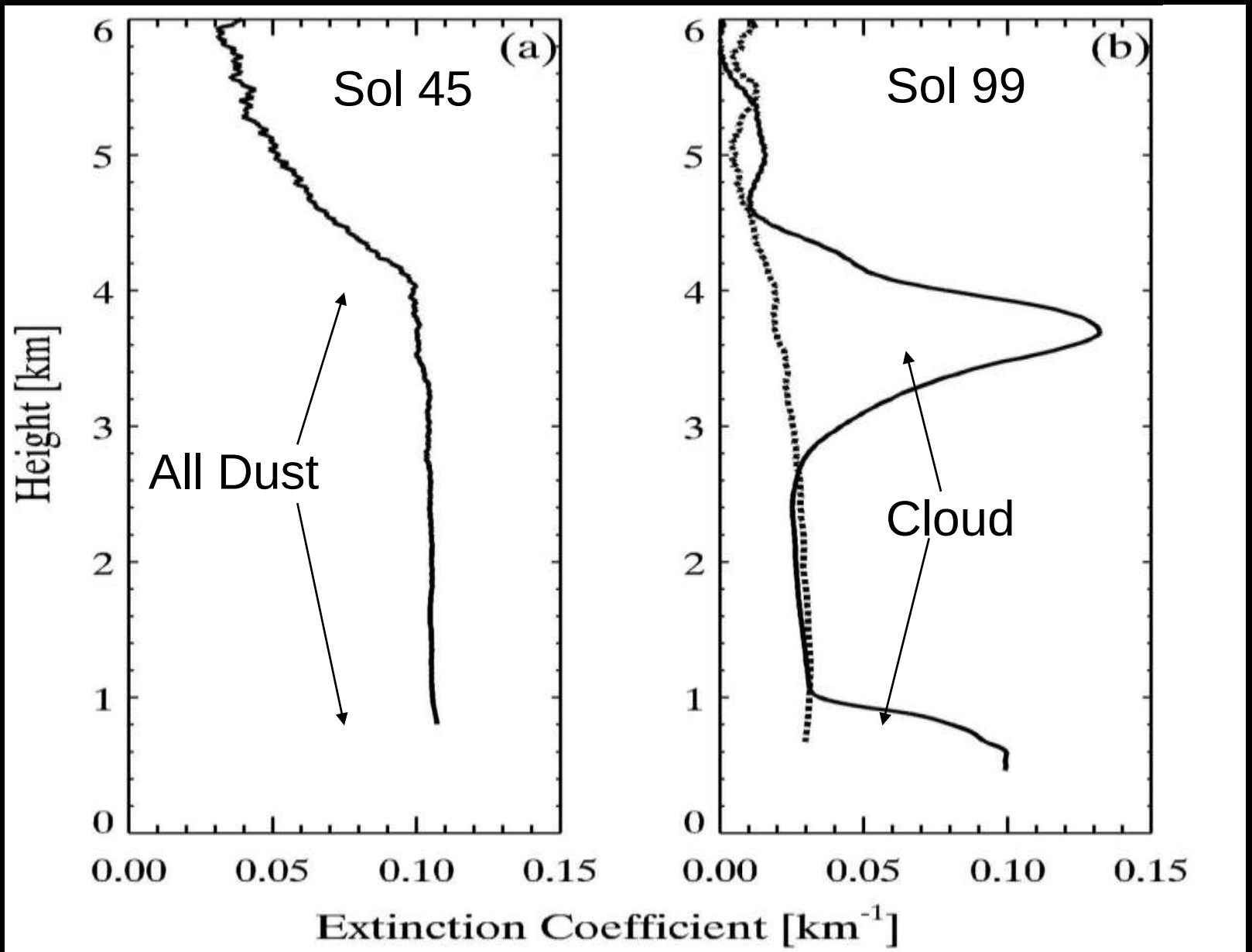
MET/Lidar



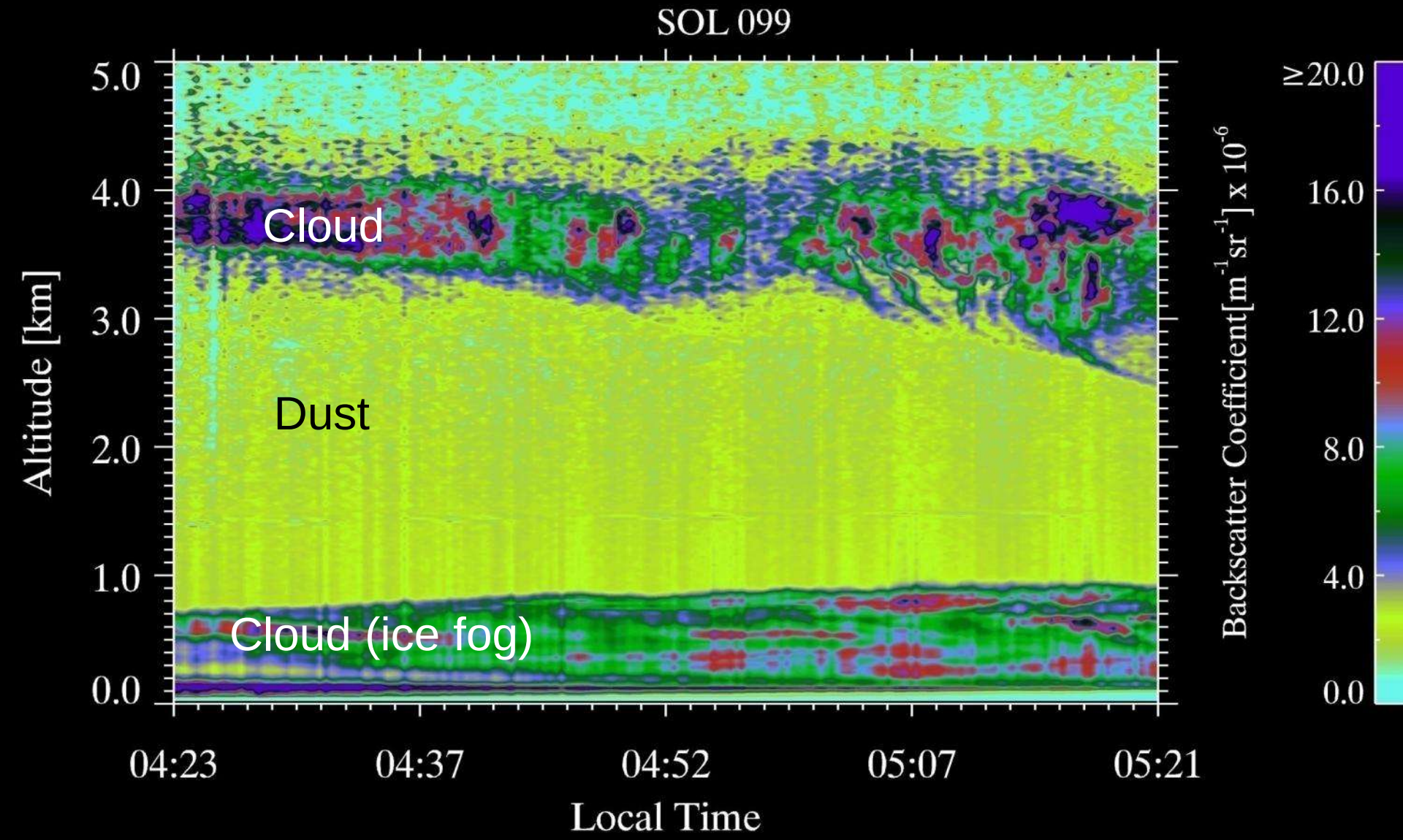
Height Distribution of Dust and Ice



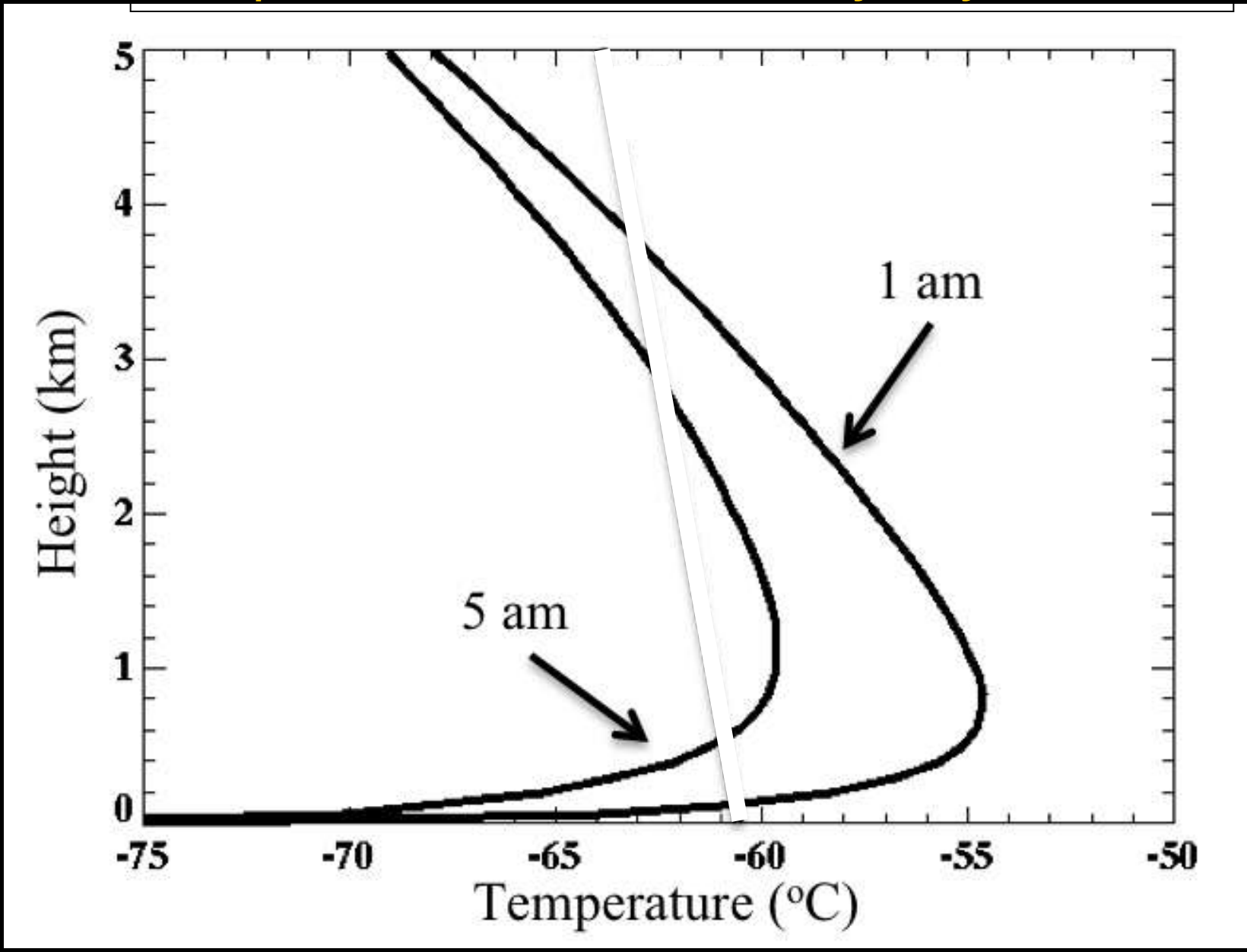
Height Distribution of Dust and Ice



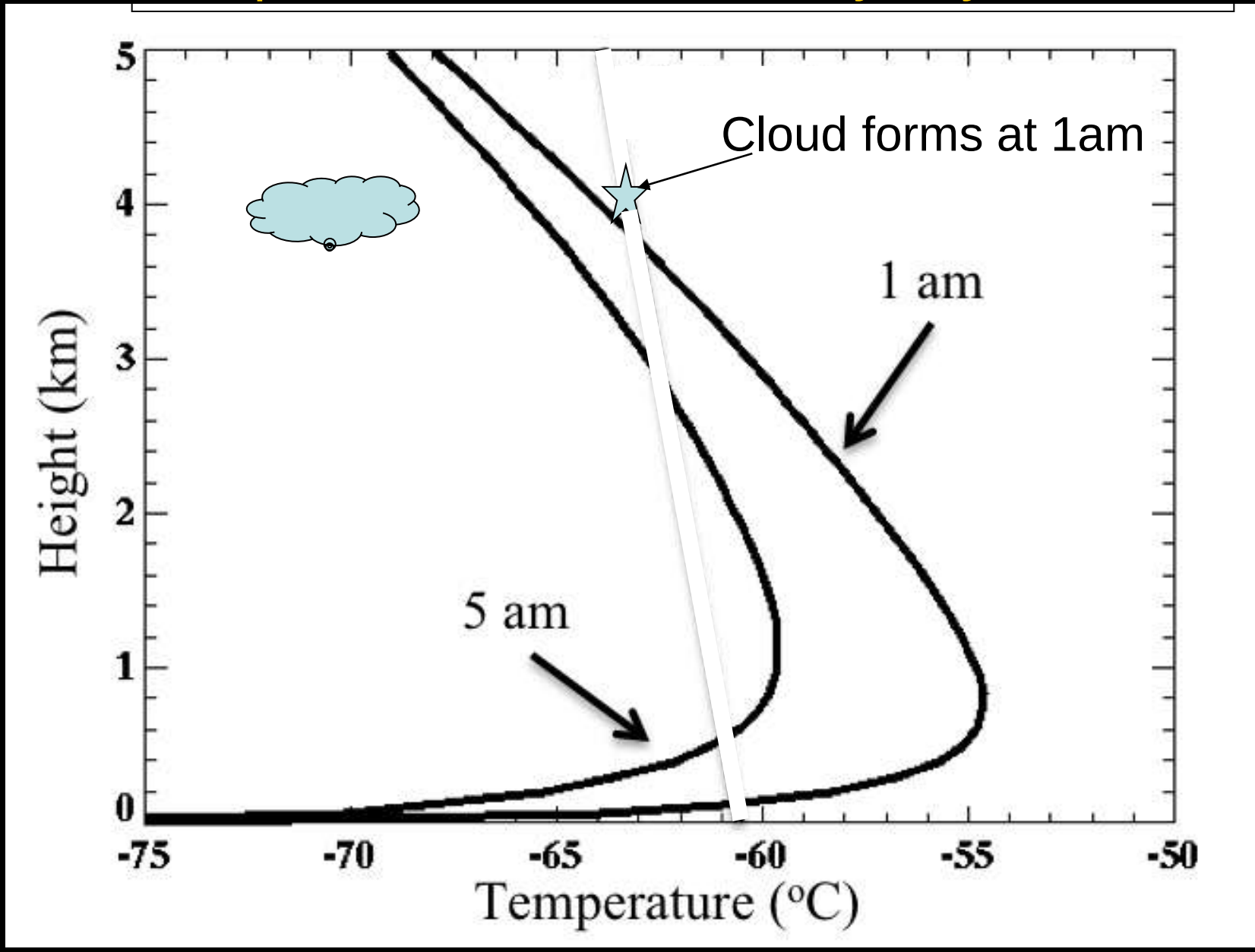
Lidar Measurements of Dust and Clouds



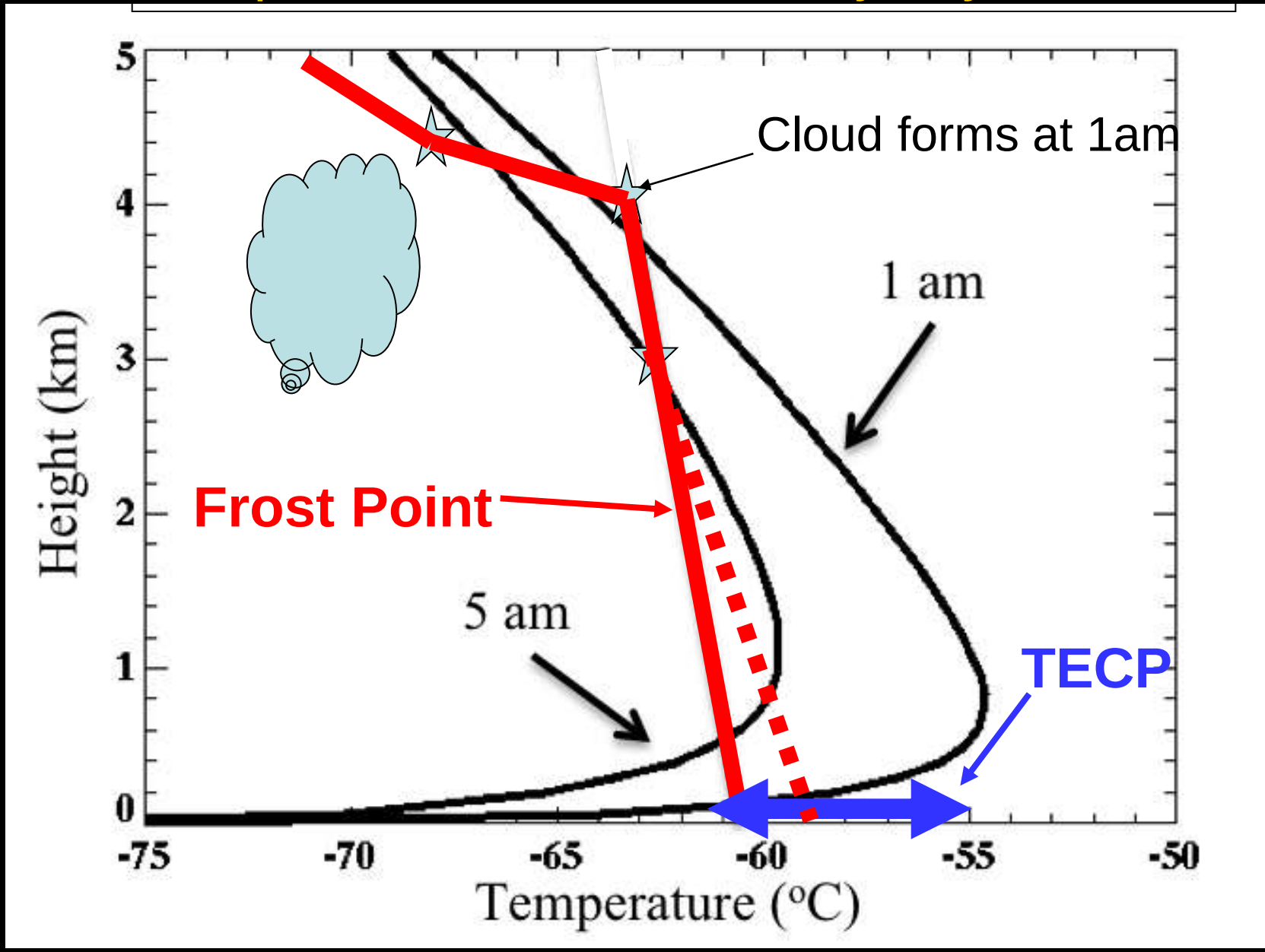
Temperatures from Boundary Layer Model



Temperatures from Boundary Layer Model

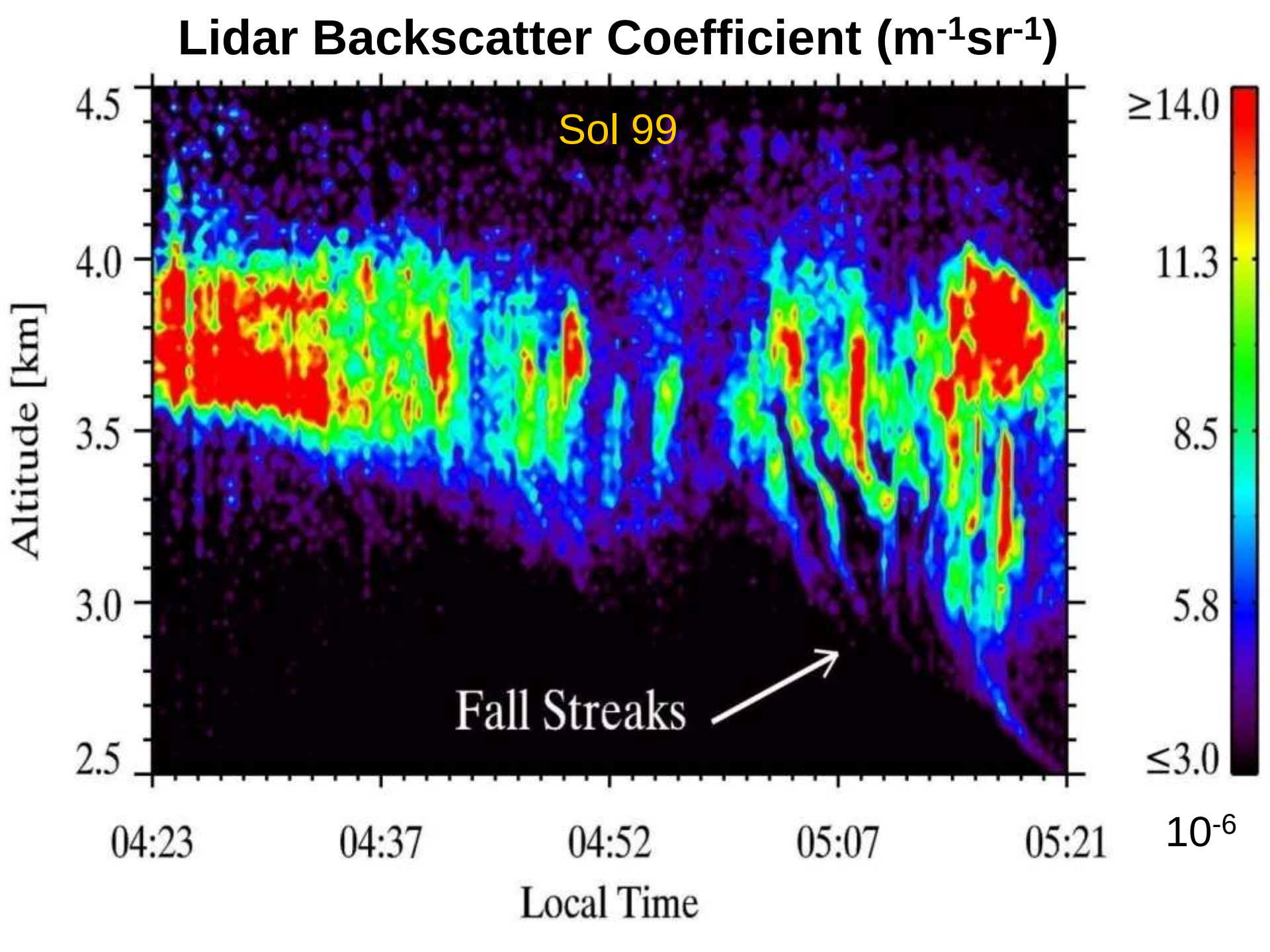


Temperatures from Boundary Layer Model

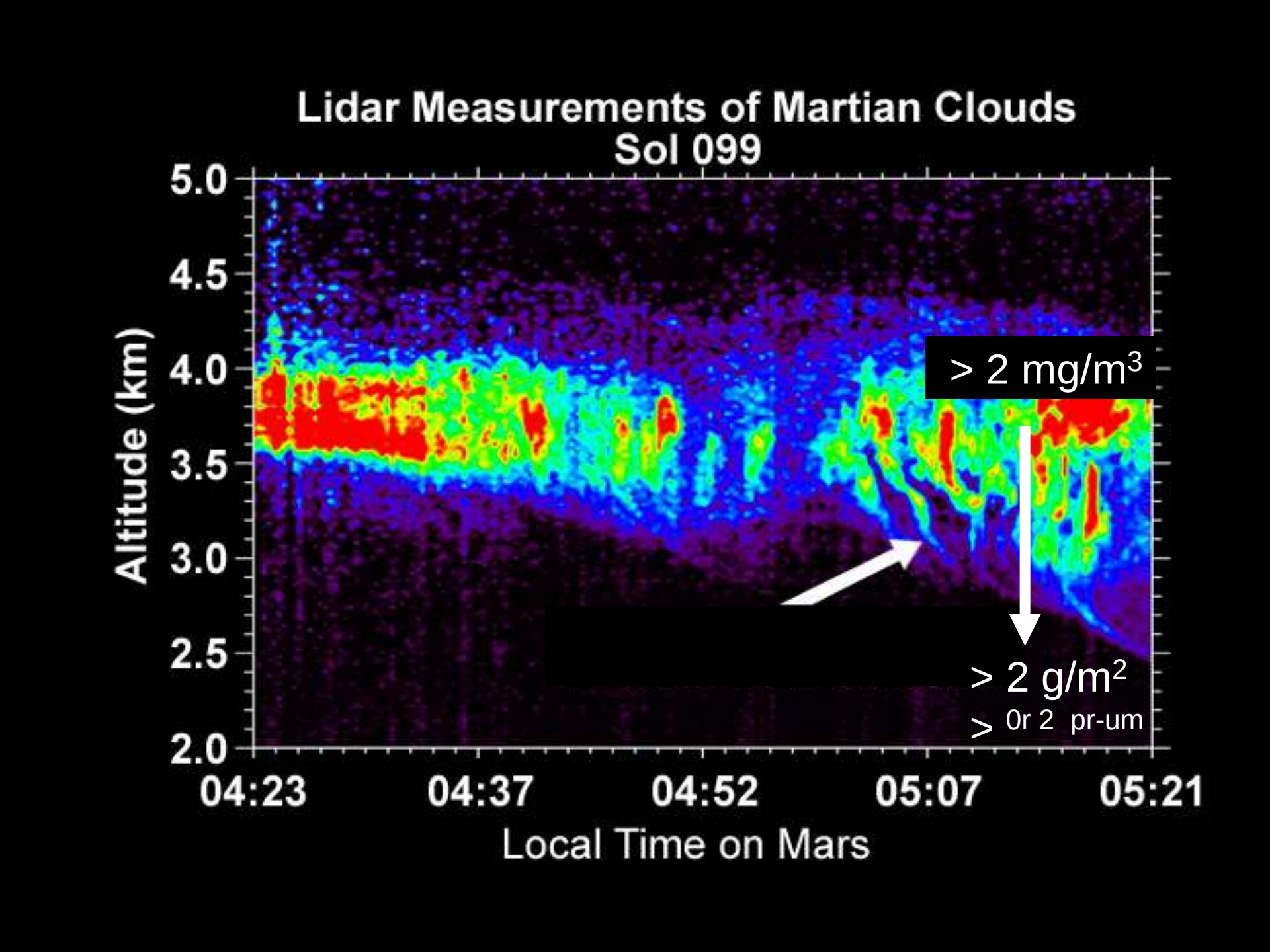


Precipitation

(Snow)


Lidar Backscatter Coefficient ($m^{-1}sr^{-1}$)
Sol 99
Fall Streaks
Altitude [km]
4.5
4.0
3.5
3.0
2.5
04:23
04:37
04:52
05:07
05:21
Local Time
≥14.0
11.3
8.5
5.8
≤3.0
10^{-6}


Fall Streaks
http://australiasevereweather.com/


Lidar Measurements of Martian Clouds
Sol 099
Altitude (km)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
04:23
04:37
04:52
05:07
05:21
Local Time on Mars
> 2 mg/m3
> 2 g/m2
> 0r 2 pr-um

Sol 126
SSI camera

Horizon Movie

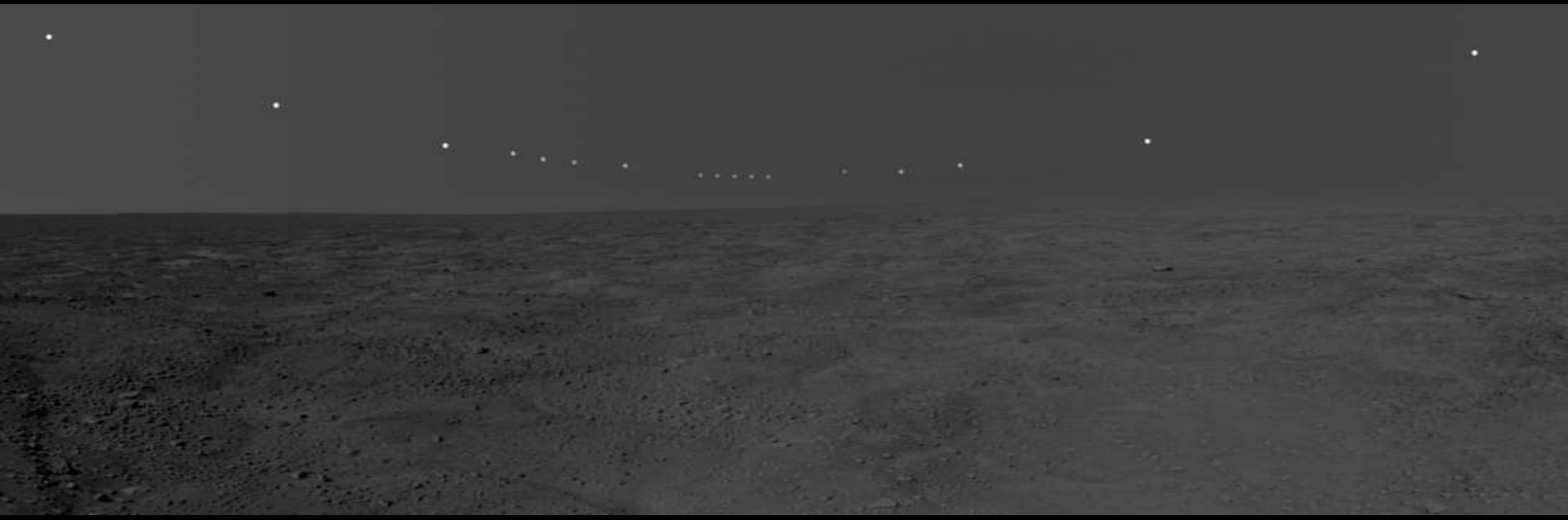
12:54 PM

LTST

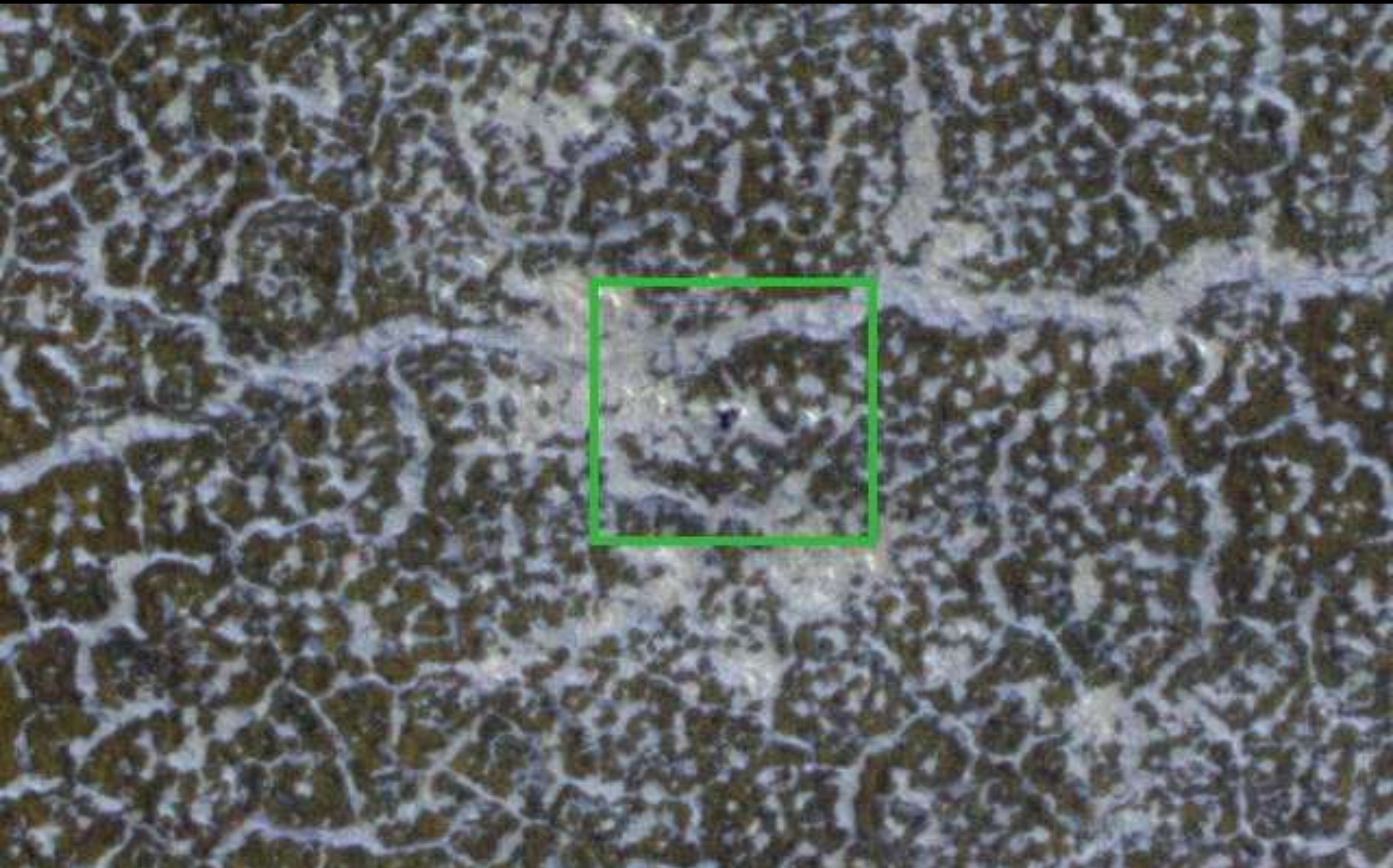

Winter is Approaching
Phoenix Cannot Survive


Loss of communication on sol 152

Dog Days of Martian Summer



Phoenix Feb 2010



Results

- Alkaline soil, calcium carbonate rich with clays
- Small amounts of Na, K, Ca, Cl, Mg
- Larger abundance of perchlorate
  - If concentrated lowers freezing point of water to -70 C
  - Perchlorate-reducing microbes are found on Earth
  - May form in upper atmosphere and be common on Mars
- No sulfates! They were expected from rovers
- Liquid water was active in this soil

See Science and JGR special issues for much more

What is more common on Mars pore or pure?
Past thoughts pore ice - more recent maybe pure ice

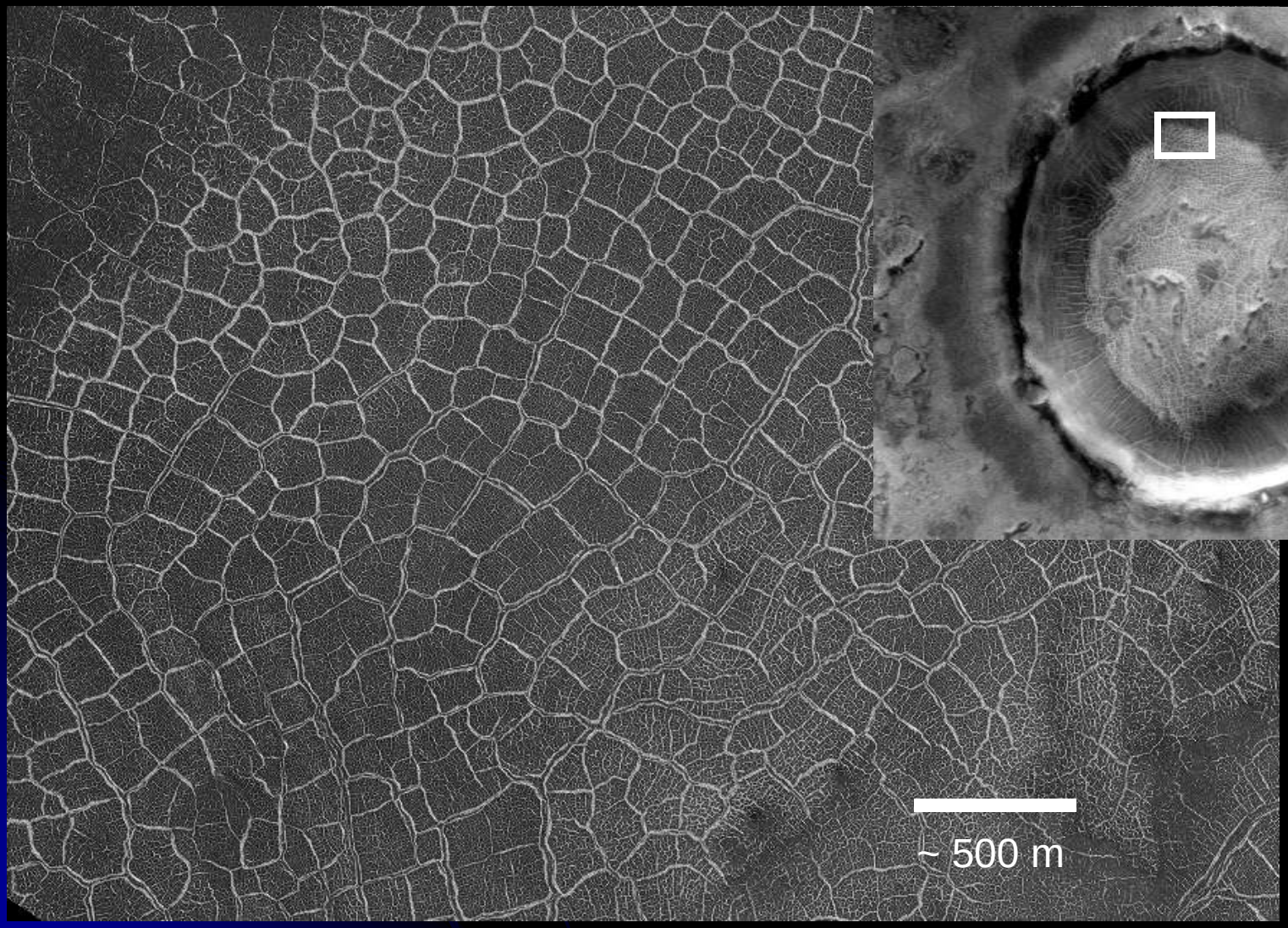
What is more common on Mars pore or pure?
Past thoughts pore ice - more recent maybe pure ice

- precipitation
  - PHX
  - TES
  - GCM
- New small HiRISE craters showing subsurface pure ice

- depth to the ice table at PHX
- are fraction in the trenches
- not clear if precipitation reaches surface
- pure ice packets could form by diffusion (e.g.)

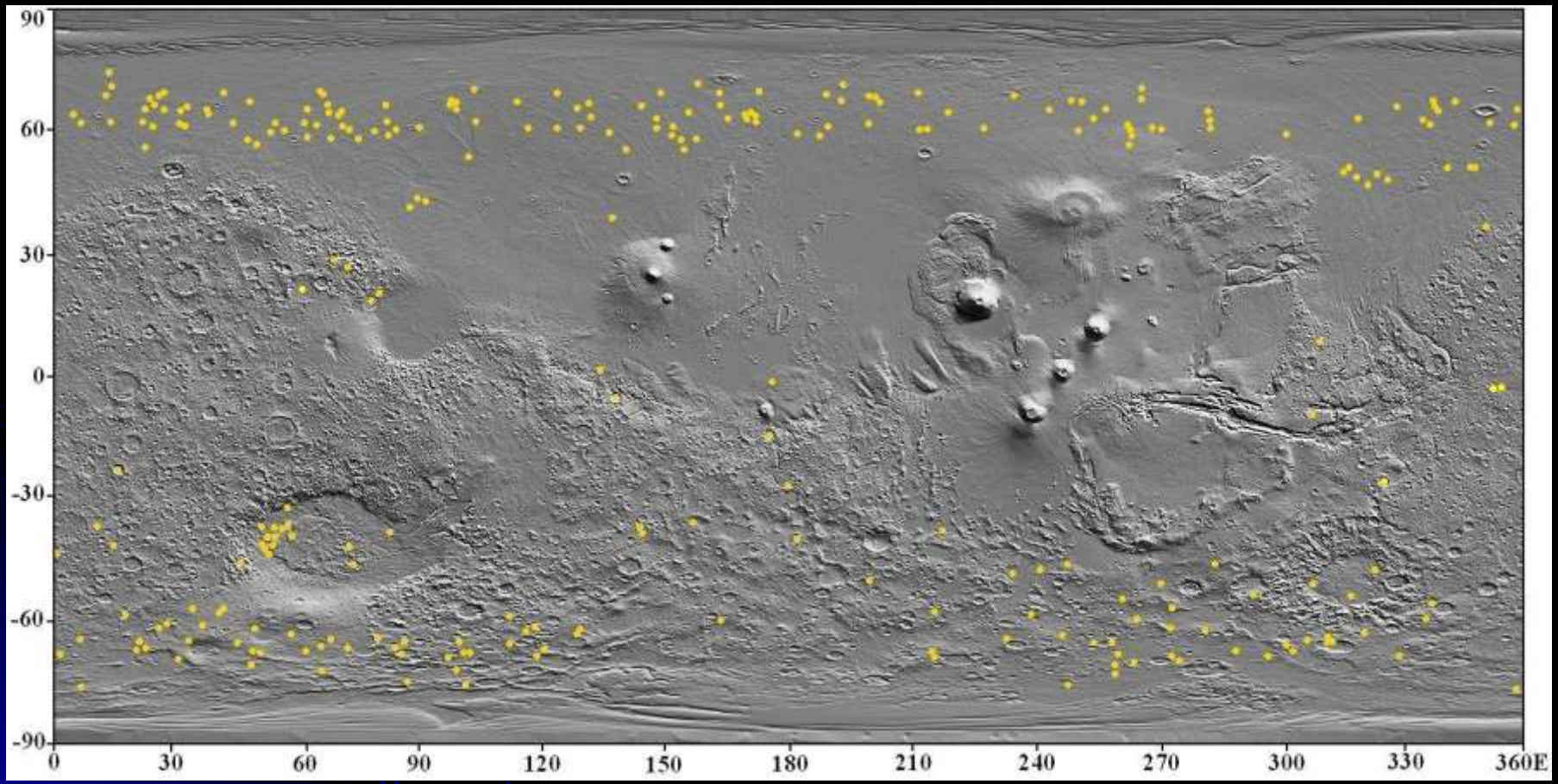
Crater Floor Polygons

Ramy El Maarry et al., JGR, submitted, 2010

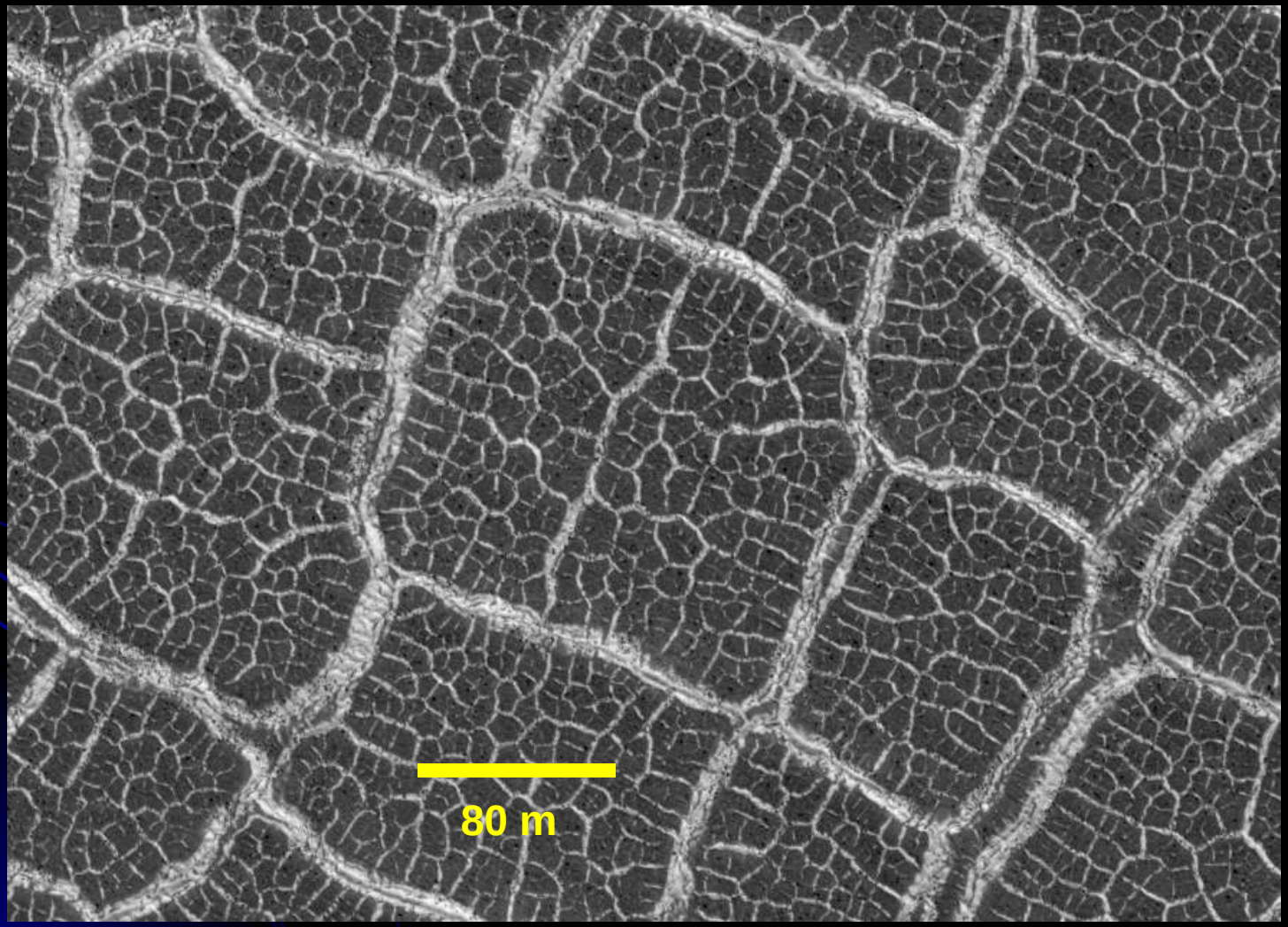


Distribution

⇒ Features located in 262 craters so far..



Detailed Morphology

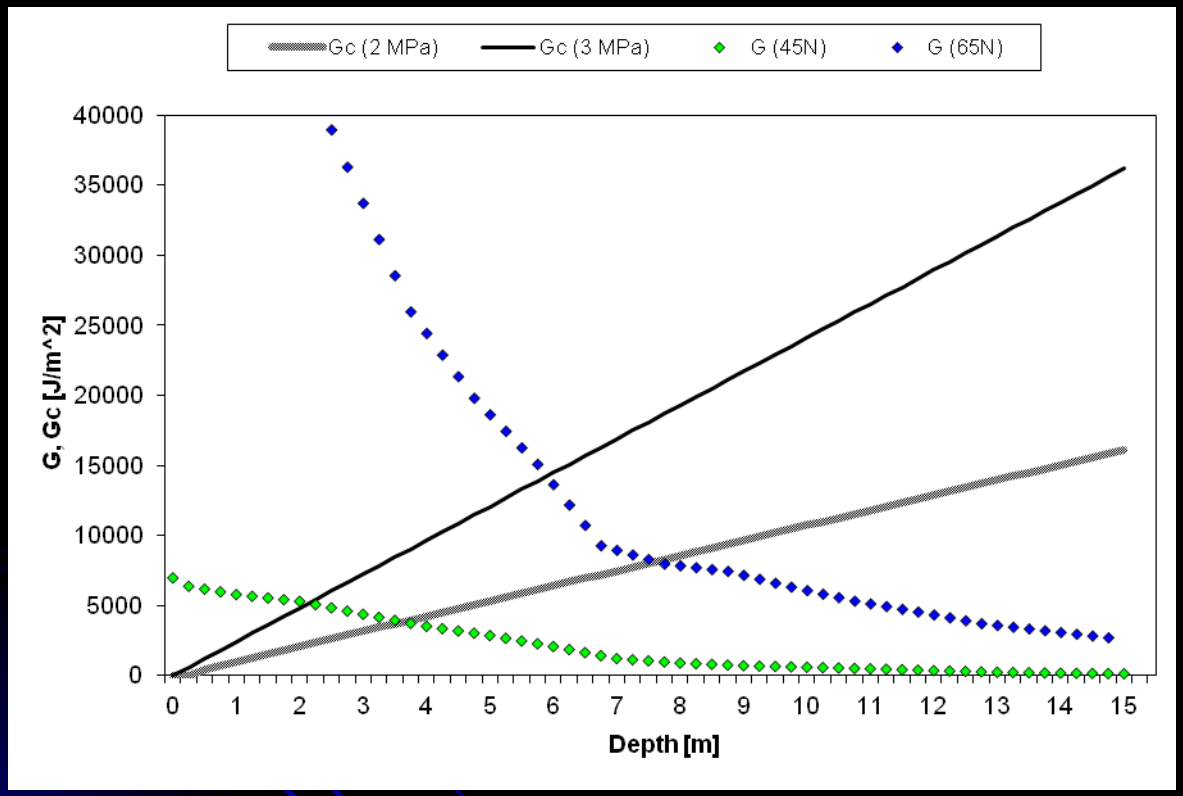


Analogs on Earth
1) Ice-Wedge Polygons..

Analogs on Earth
2) Desiccation polygons

- Desiccation polygons can range in size from 15 to 300 m in width (Neal et al., 1968)

Results



➔ $G = G_c$ at:

6 m for 3 MPa TS.

7.5 m for 2 MPa TS

G=0 corresponds to the transition to compressive regime

June 18, 2008: Headlines - White Stuff on Mars

Wednesday June 18, 2008

Headlines - White Stuff on Mars

We cannot yet confirm life on Mars but it seems we might be able to confirm nightlife on Mars.

Tags: Headlines, science, NASA, Mars

Views: 60,269	2 comments	100% Thumbs Up	Rate:	SHARE

Comment

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Episode clips: June 18, 2008

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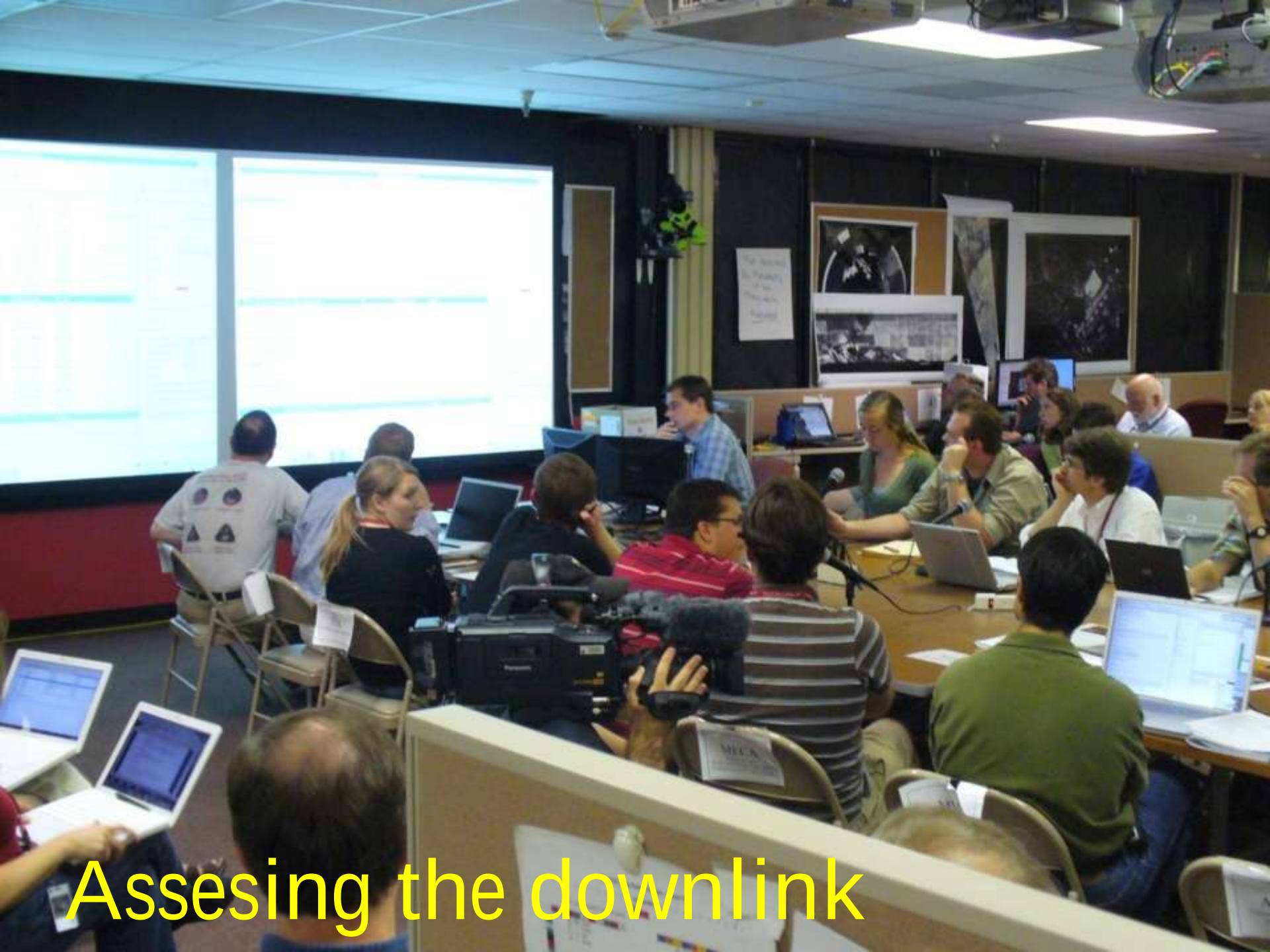
Headlines - Mars Attacked! (2:35)
Views: 1,319

Headlines - Wet It

Surface Operations Team in Tucson

THE UNIVERSITY OF ARIZONA.
Lunar and Planetary Laboratory

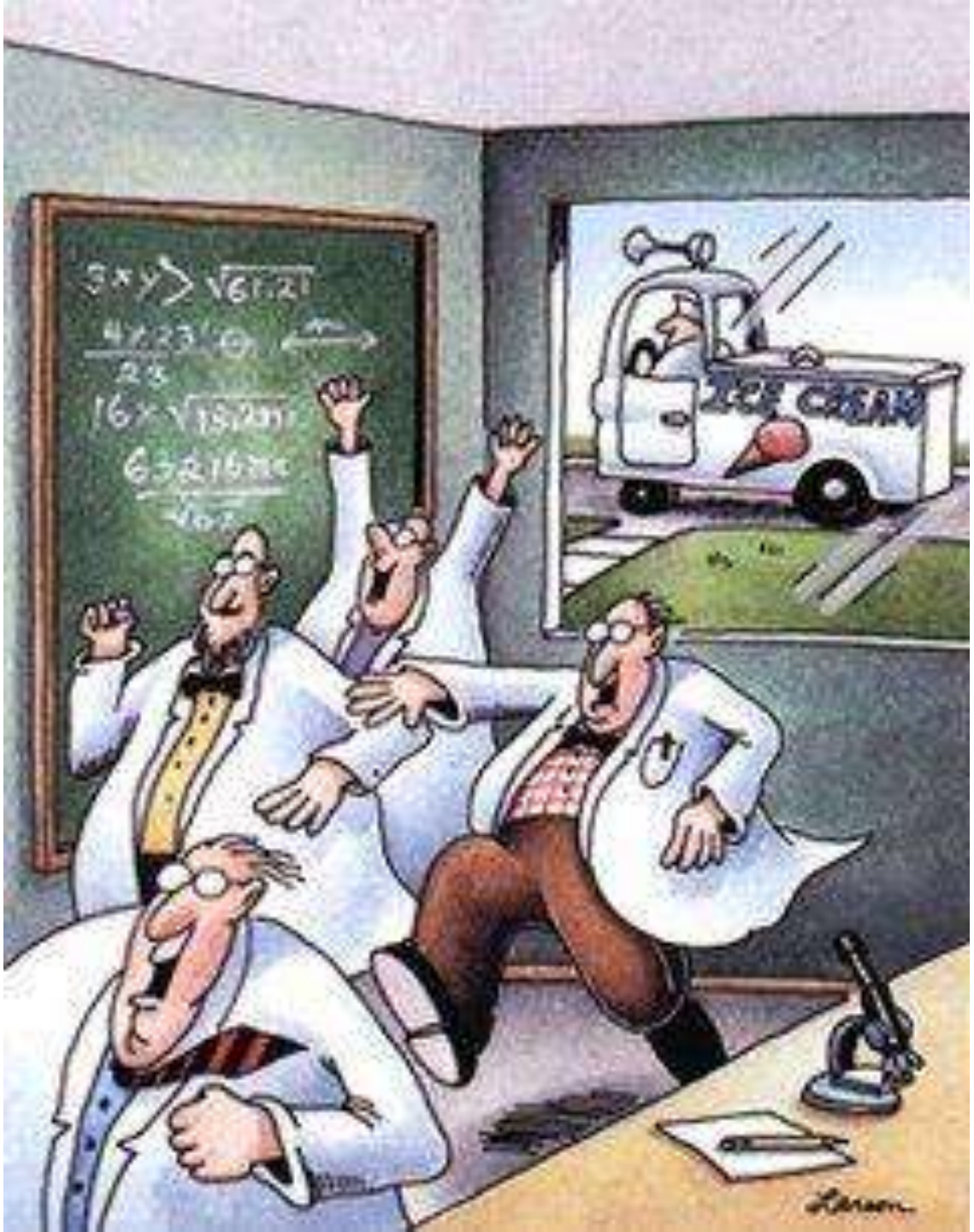

Assesing the downlink

Where did everybody go?

~ sol 30

I SCREAM, YOU SCREAM!
WE ALL SCREAM
FOR ICE CREAM!

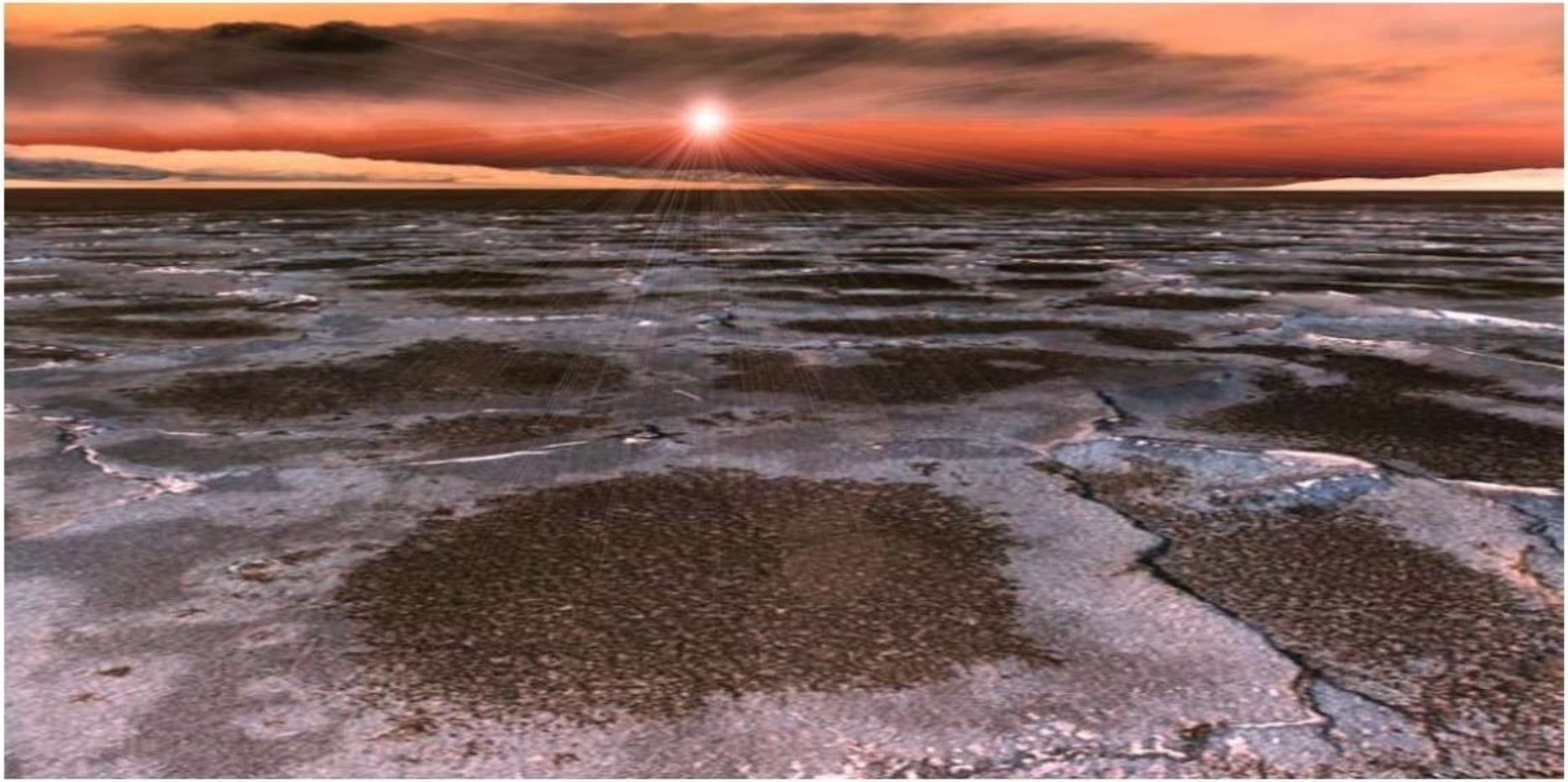
The UA President Robert Shelton has provided the Phoenix Surface Ops Team with a supply of Ice Cream! Please find it in the mailroom freezer and the overflow room freezer (where the last batch of ice cream was).


ICE CREAM
Larson

Polar devil

José Amaral - 42 -Algueirão, Portugal

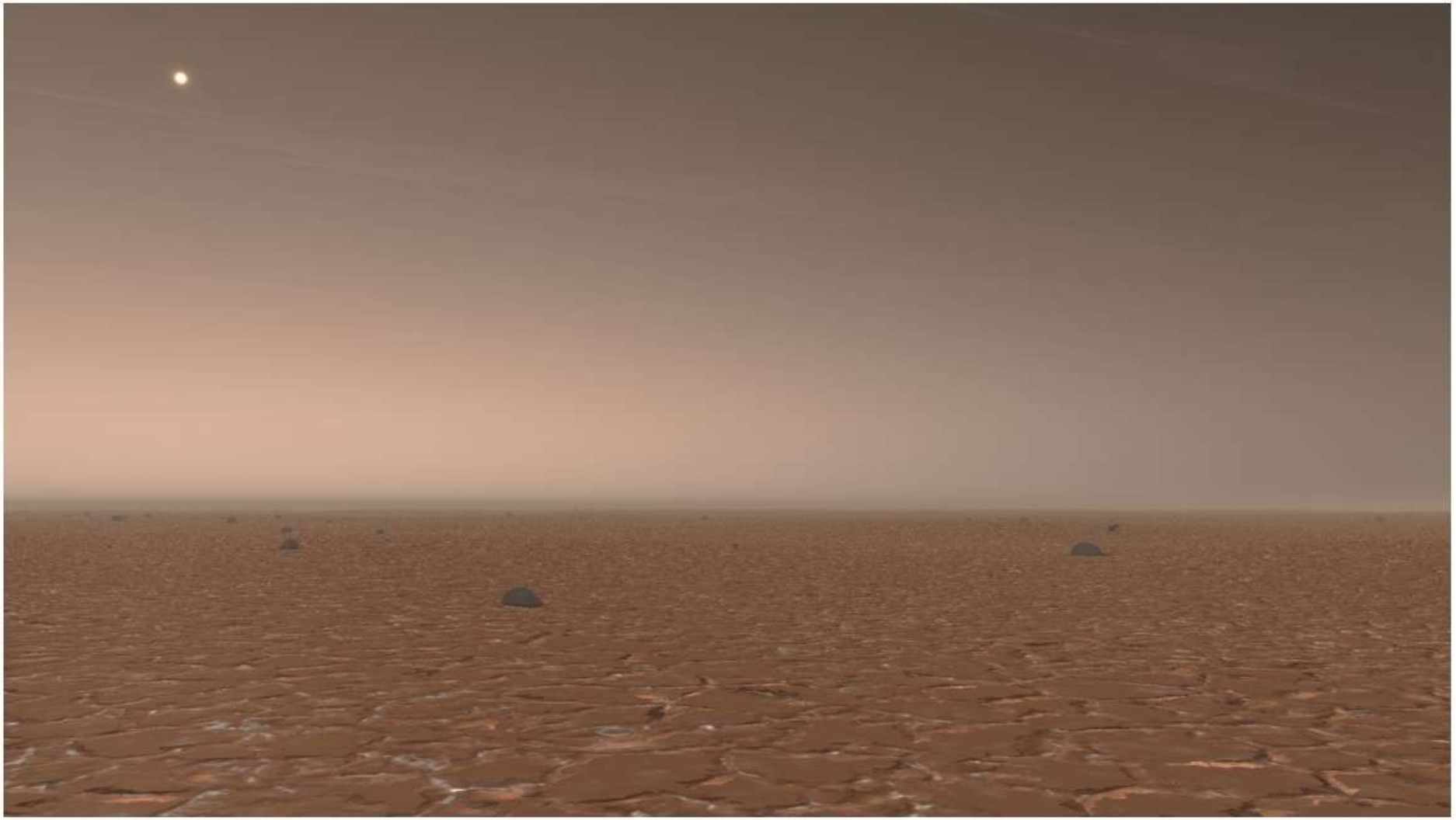
Technique used in the participant's work: Inspired by the image showing dust devils in the north pole of Mars I have used an image from an earth's dust devil applied over an Atacama desert ground image.



Untitled

Brian Cameron - 40 - Oxford, UK

Technique used in the participant's work: Stretched and colour enhanced from an original picture found on Google Images of Death Valley Salt Flats.
Then manipulated in Paint Shop Pro Ver 7.04 (stretched 300% on the horizontal, converted to negative image, enhanced the red channel and added a "Sunburst").



So few rocks

Doug Ellison - 29 -Leicester, UK

Technique used in the participant's work: 3DS Max 9 with procedural textures..

THROUGH THE EYES OF THE PHOENIX
ONLINE COMPETITION

SPACEUROPE
blogspot.com
EXPLORING SPACE. SEEDING EVOLUTION.