# Phoenix Mars Mission


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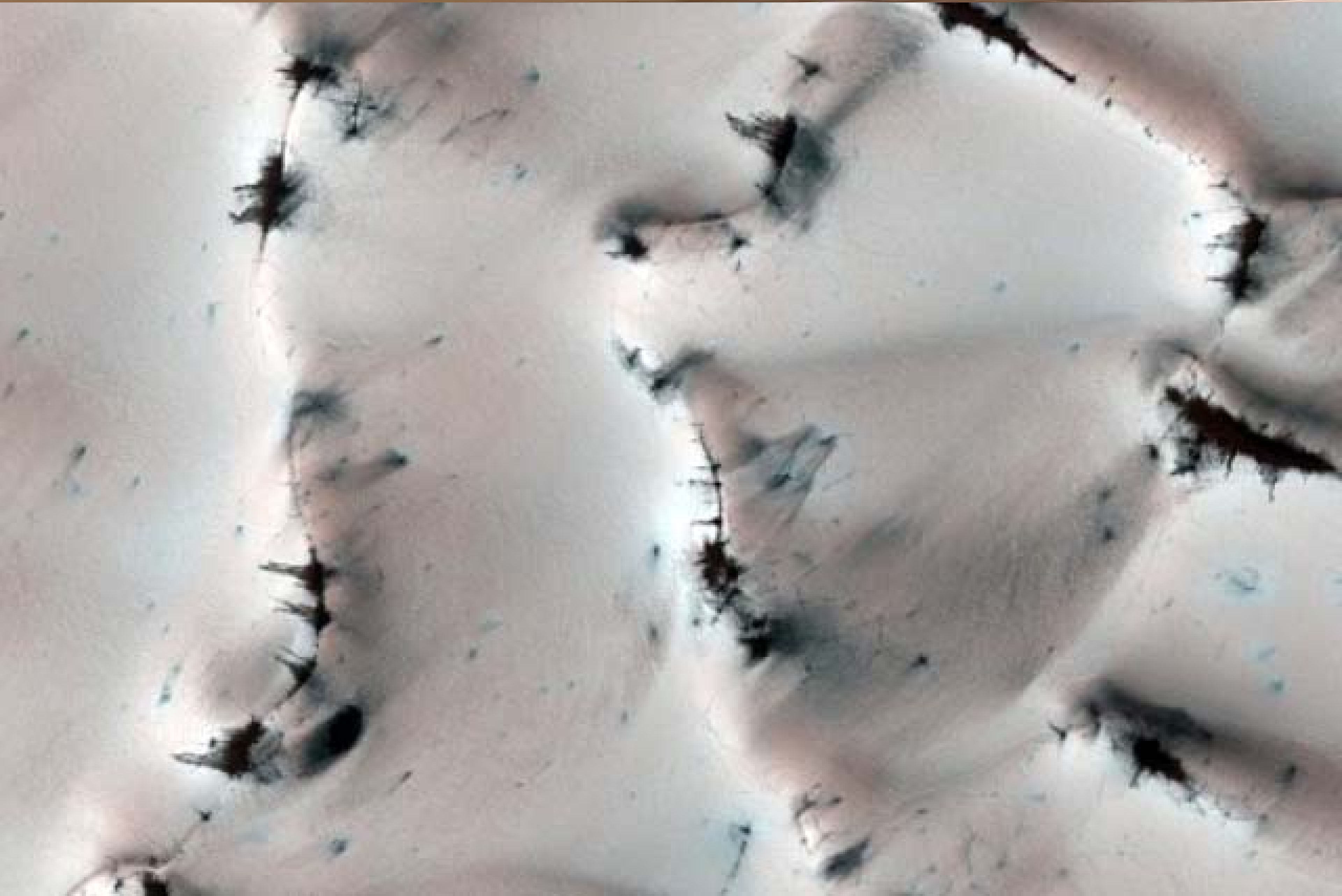
# Why Mars Polar Science?

(at the time of MPL)

- **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**

# $CO_2$ ice in the South

# Frosted dunes in the North



# North Polar Layer Deposits – Climate Record

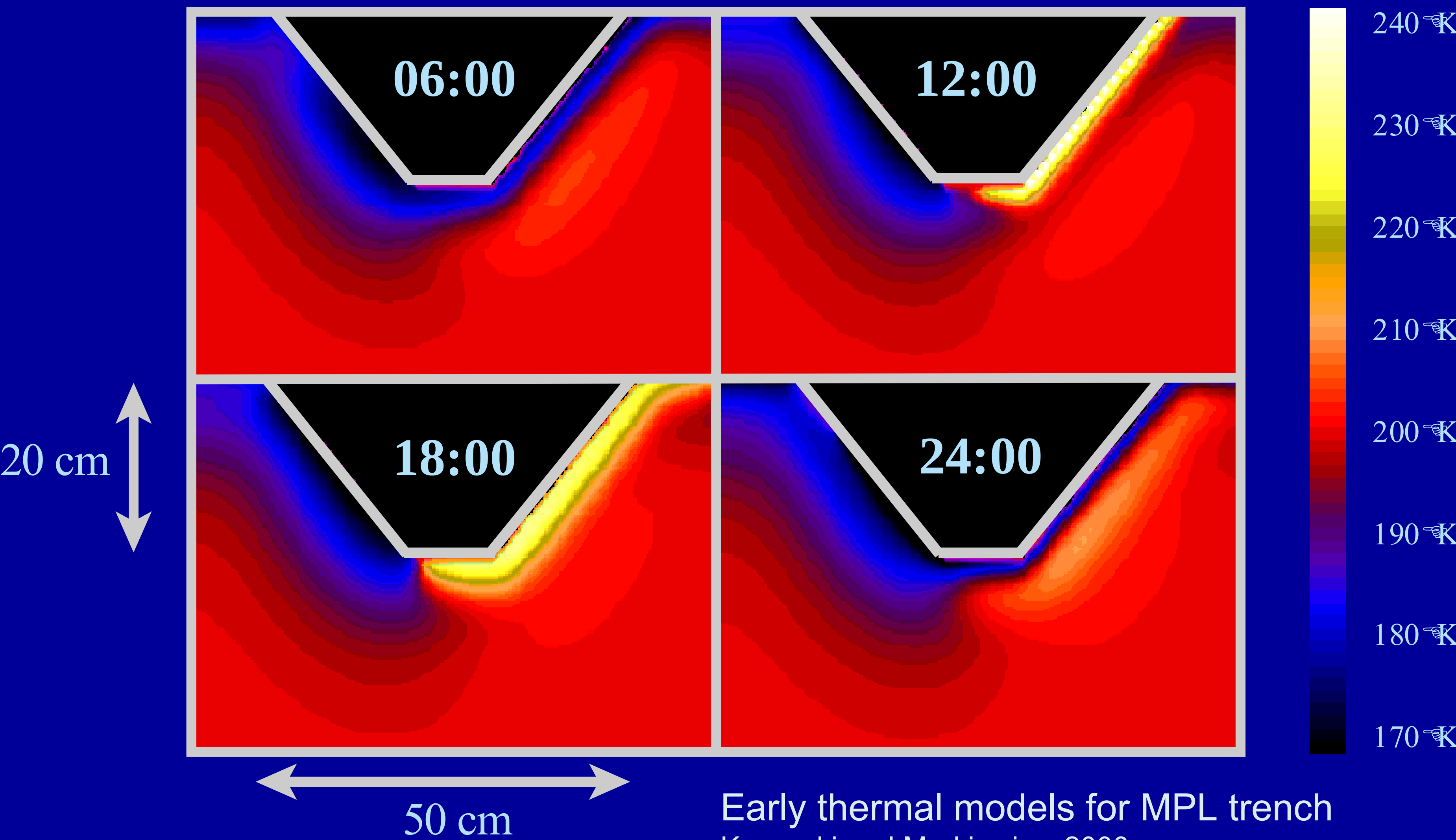

Burst of spring


More HiRISE Martian polar spring

# Mars polar regions are very dynamic!

# Temperature distribution in the soil

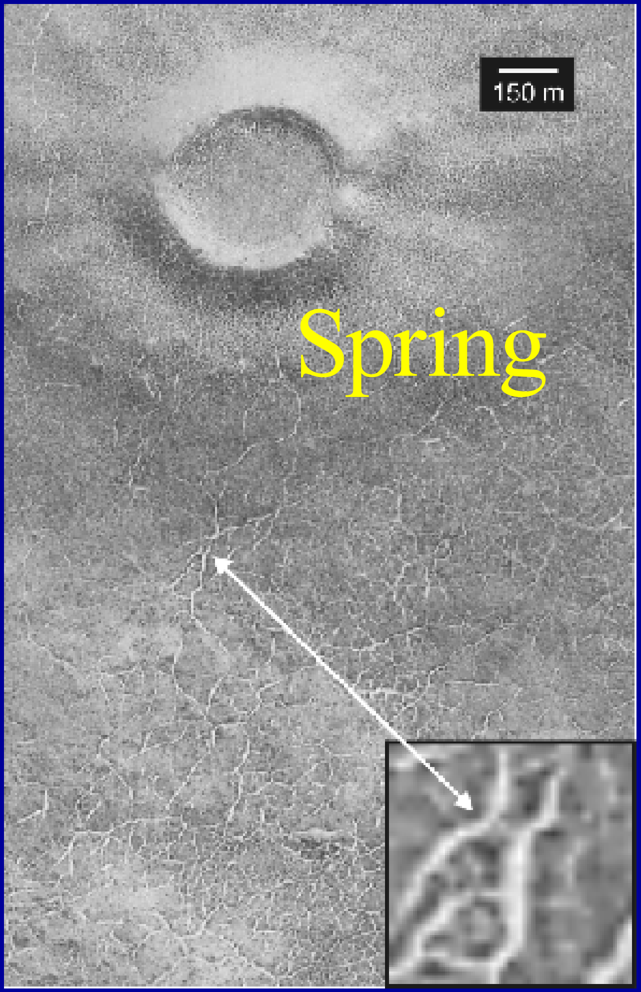
## Water ice condensation (frost) is possible



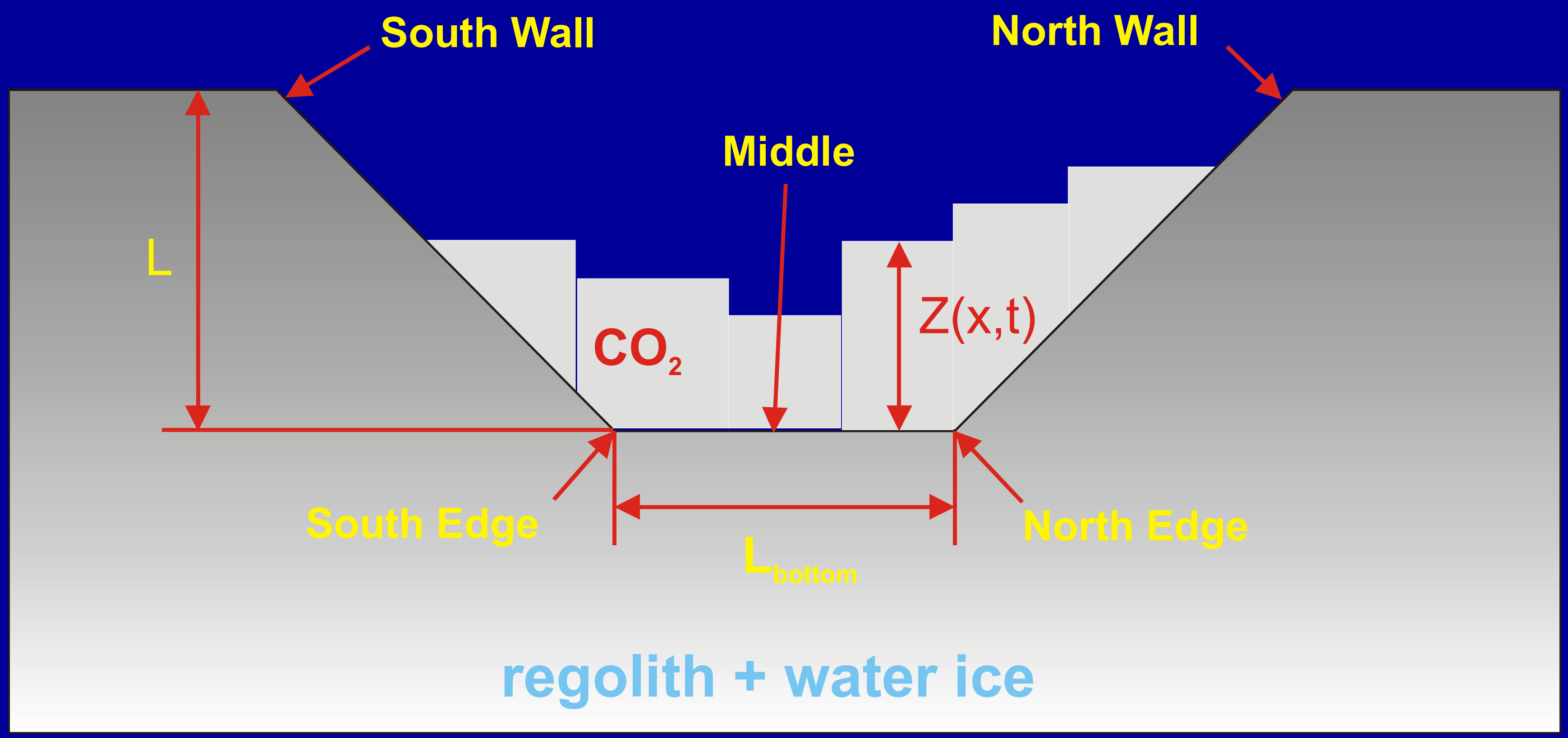

Early thermal models for MPL trench

Kossacki and Markiewicz, 2000

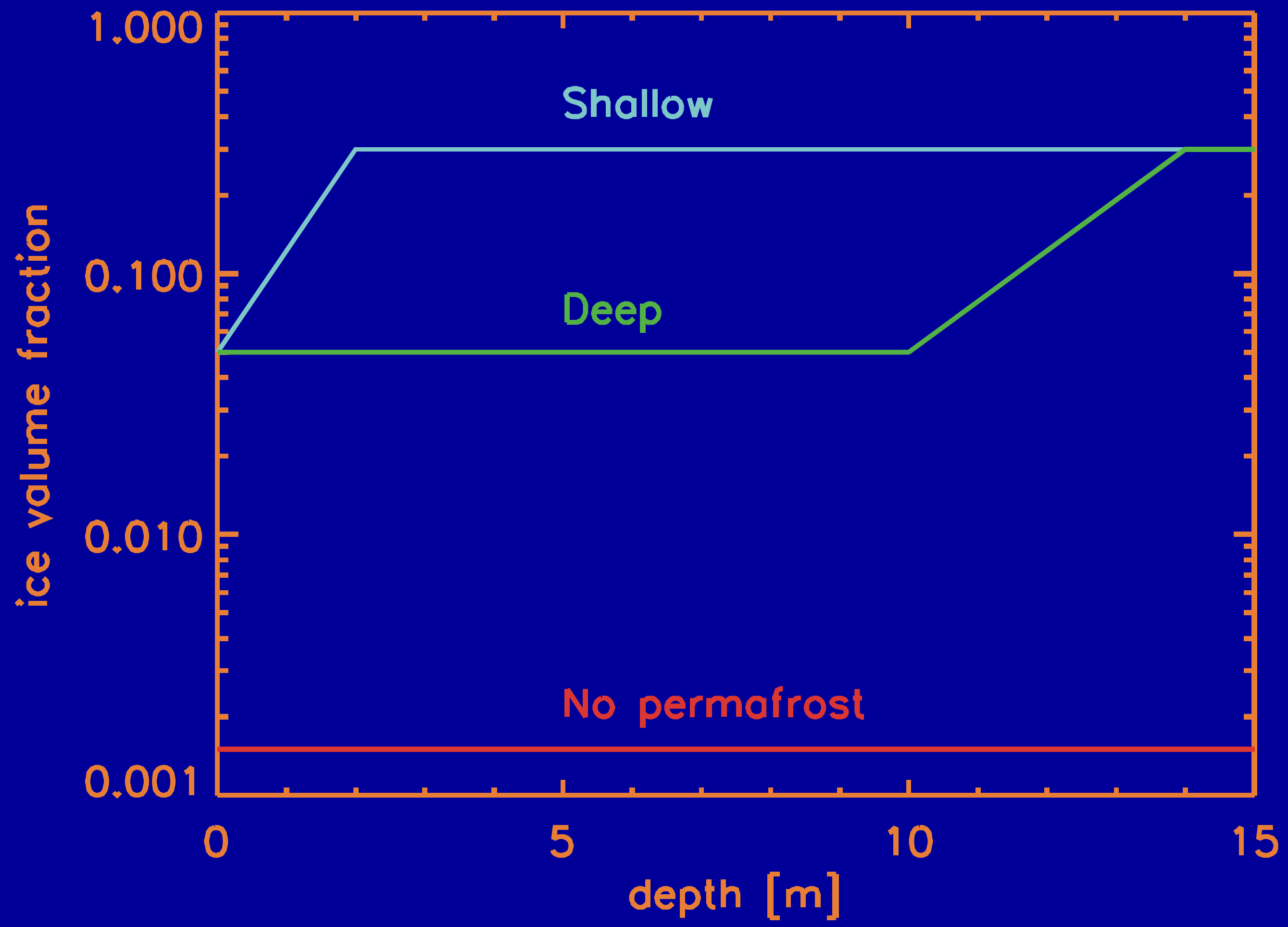
# $CO_2$ Ice in Polygonal Throughs in Malea Planum: Subsurface $H_2O$, MOC images and TES surface temperature

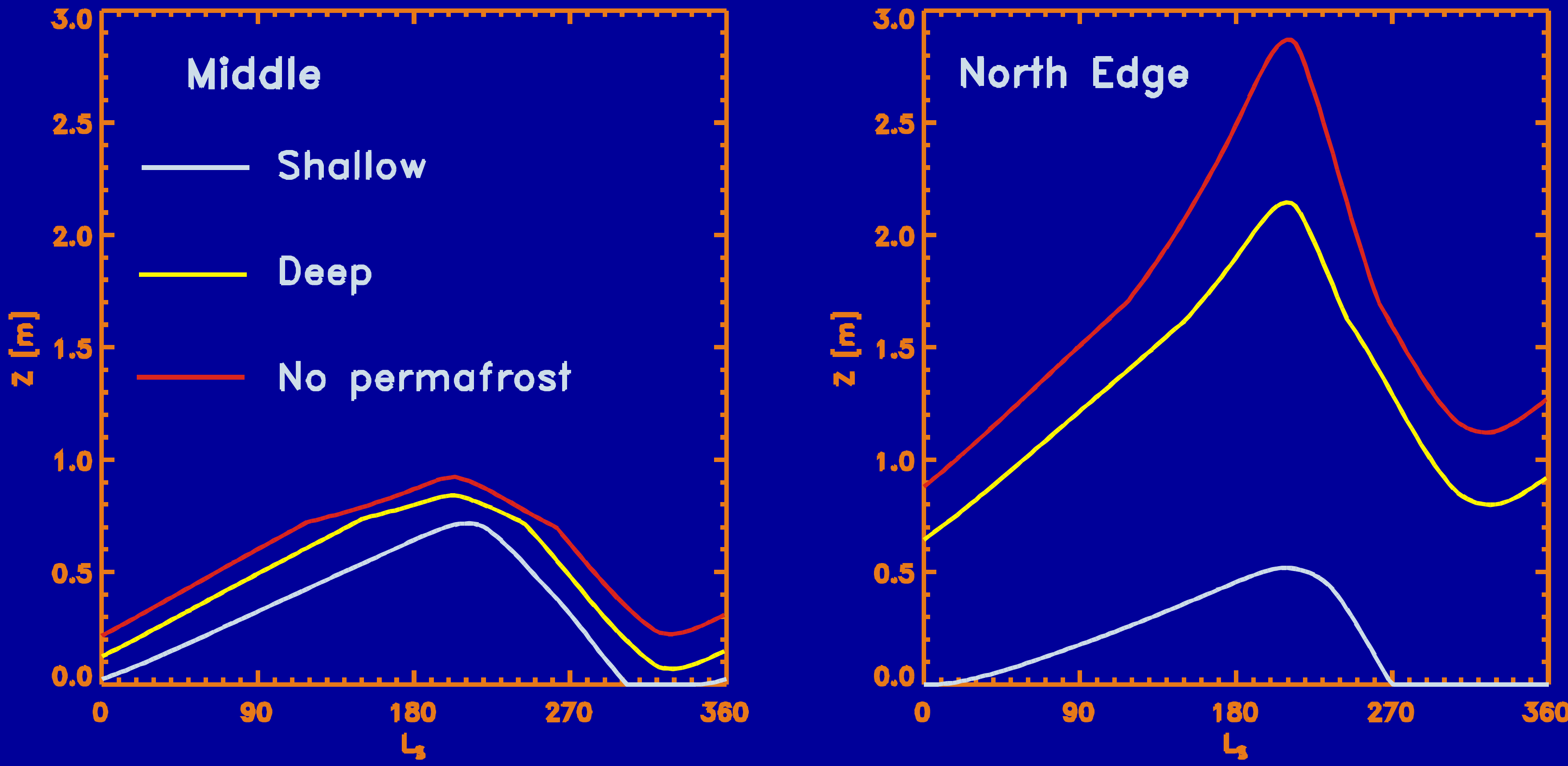
# Sketch of the model of a polygonal crack

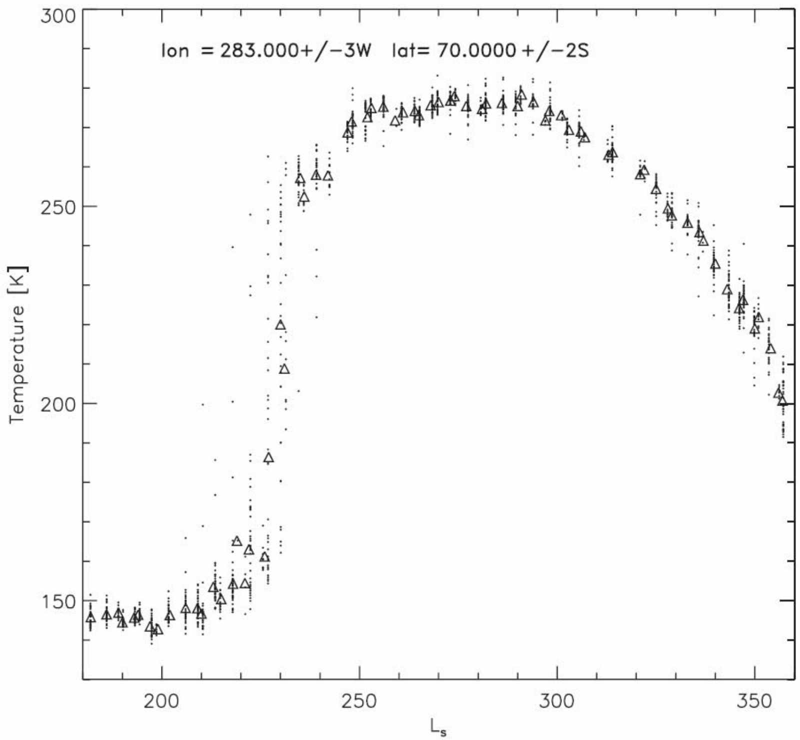


# Initial models of water ice in the permafrost



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





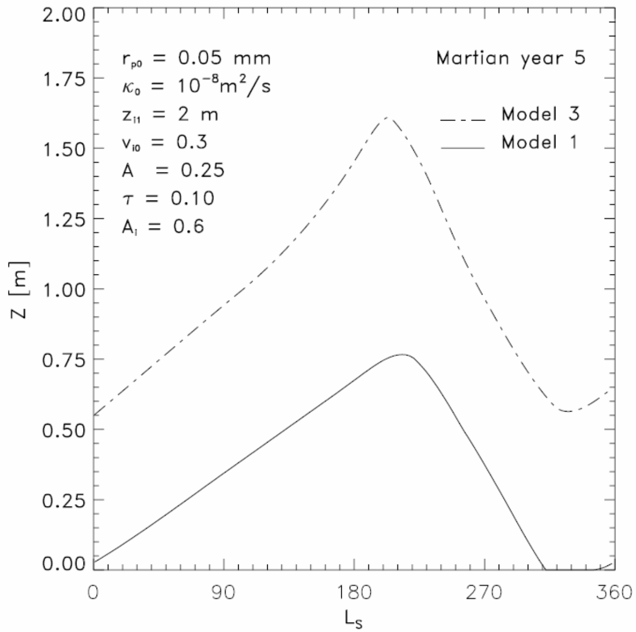
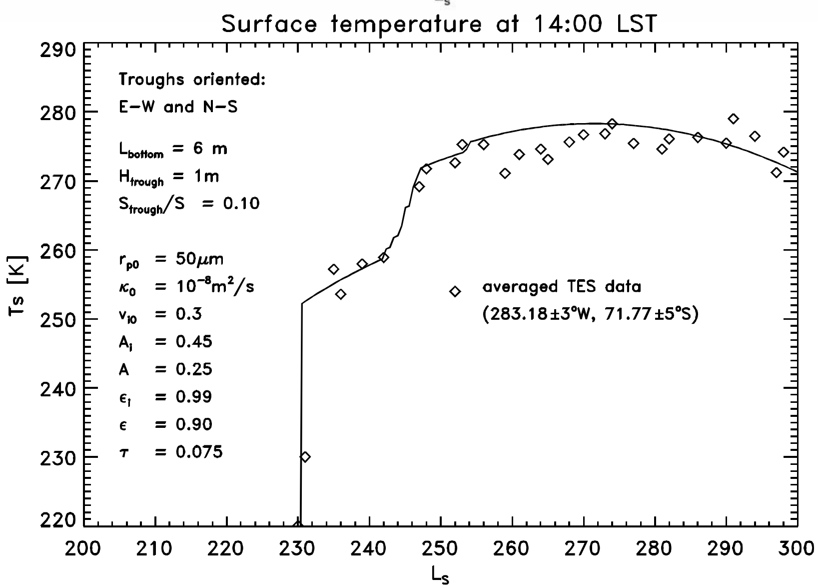
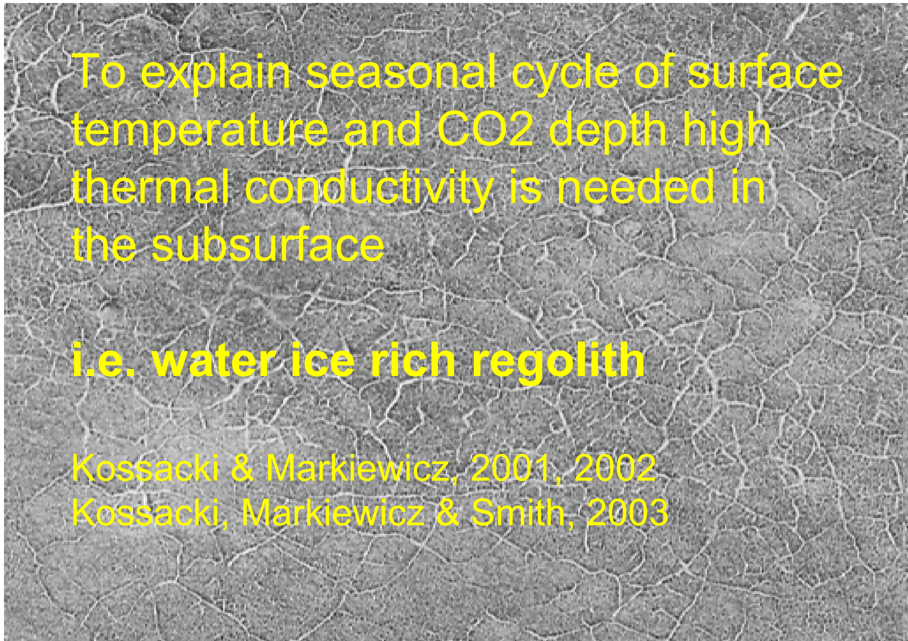
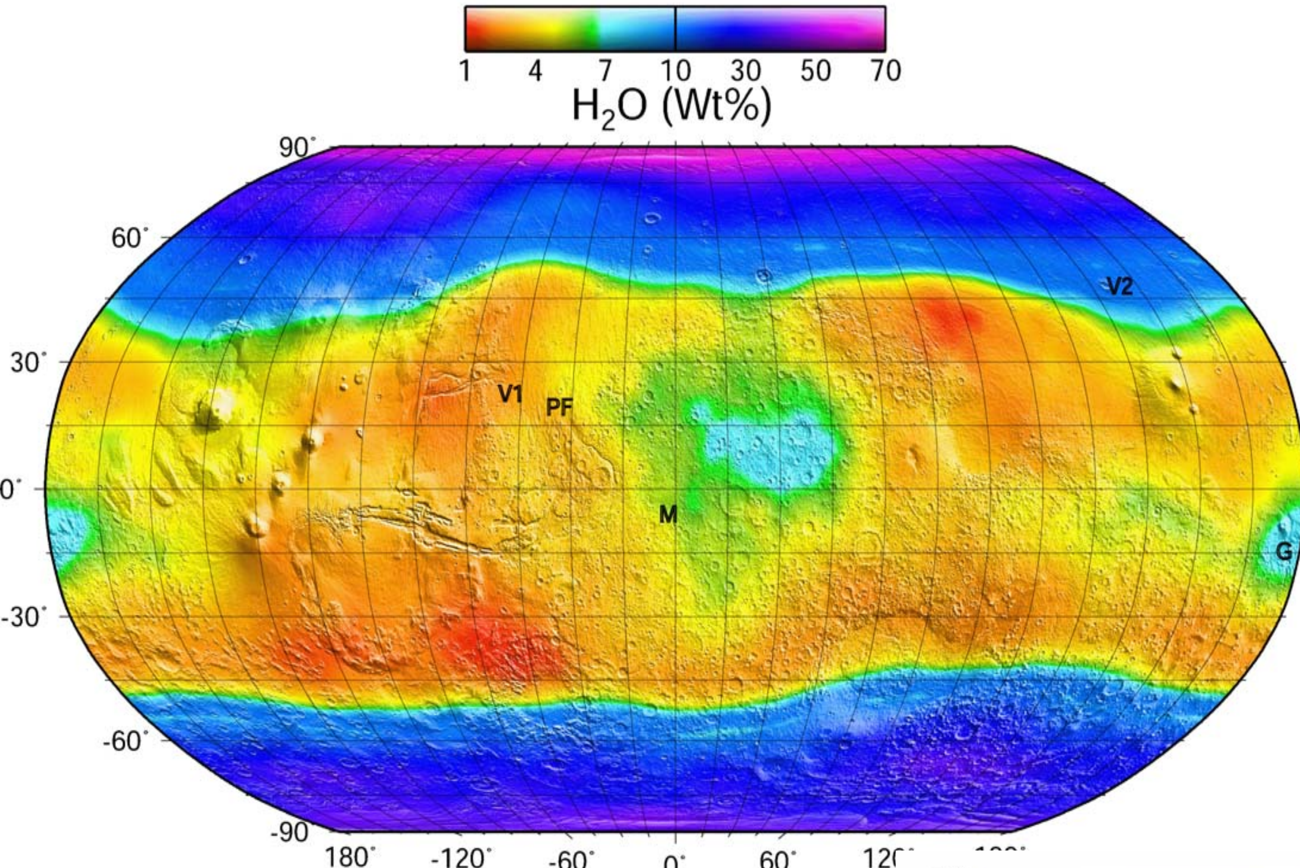
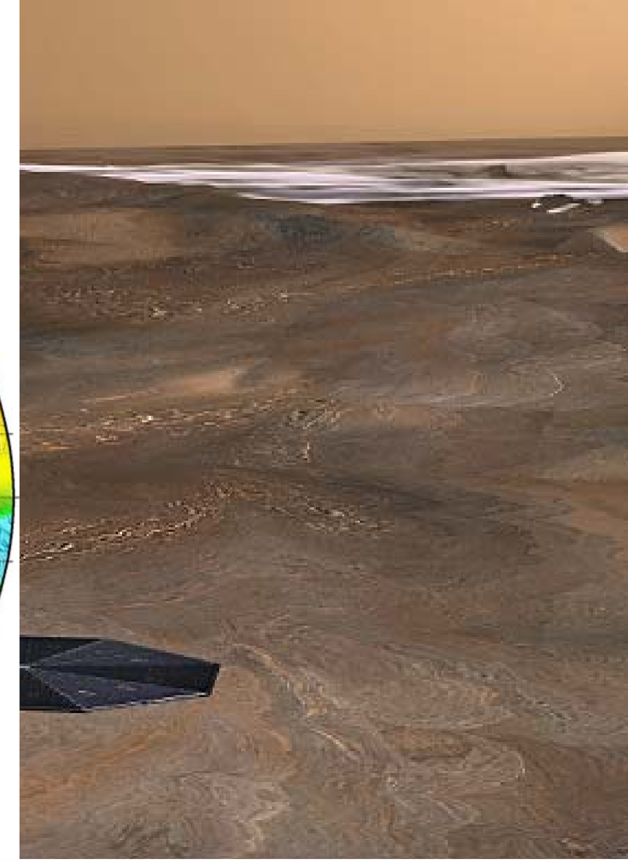



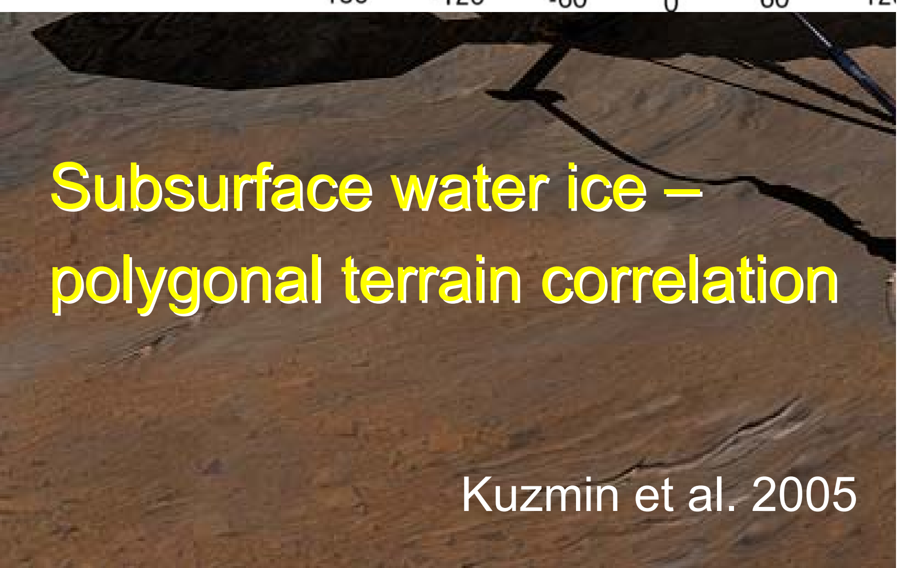

**FIG. 9.** Thickness $Z$ of $CO_2$ ice in the middle of the trough versus $L_S$ for one set of parameters and two different models of the water ice table.



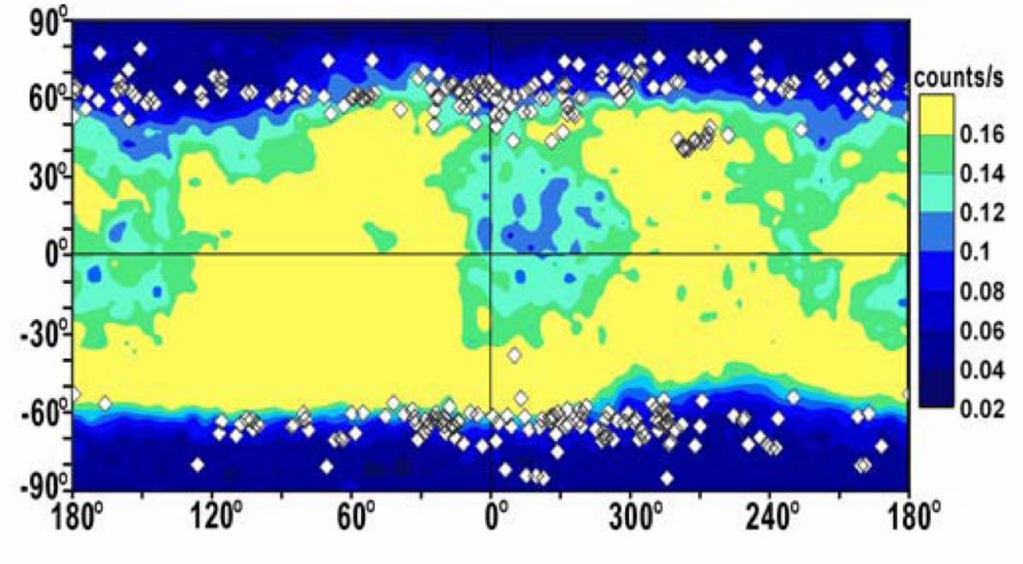







Subsurface water ice – polygonal terrain correlation




Kuzmin et al. 2005

# Ice-Table Pre-Landing Estimates

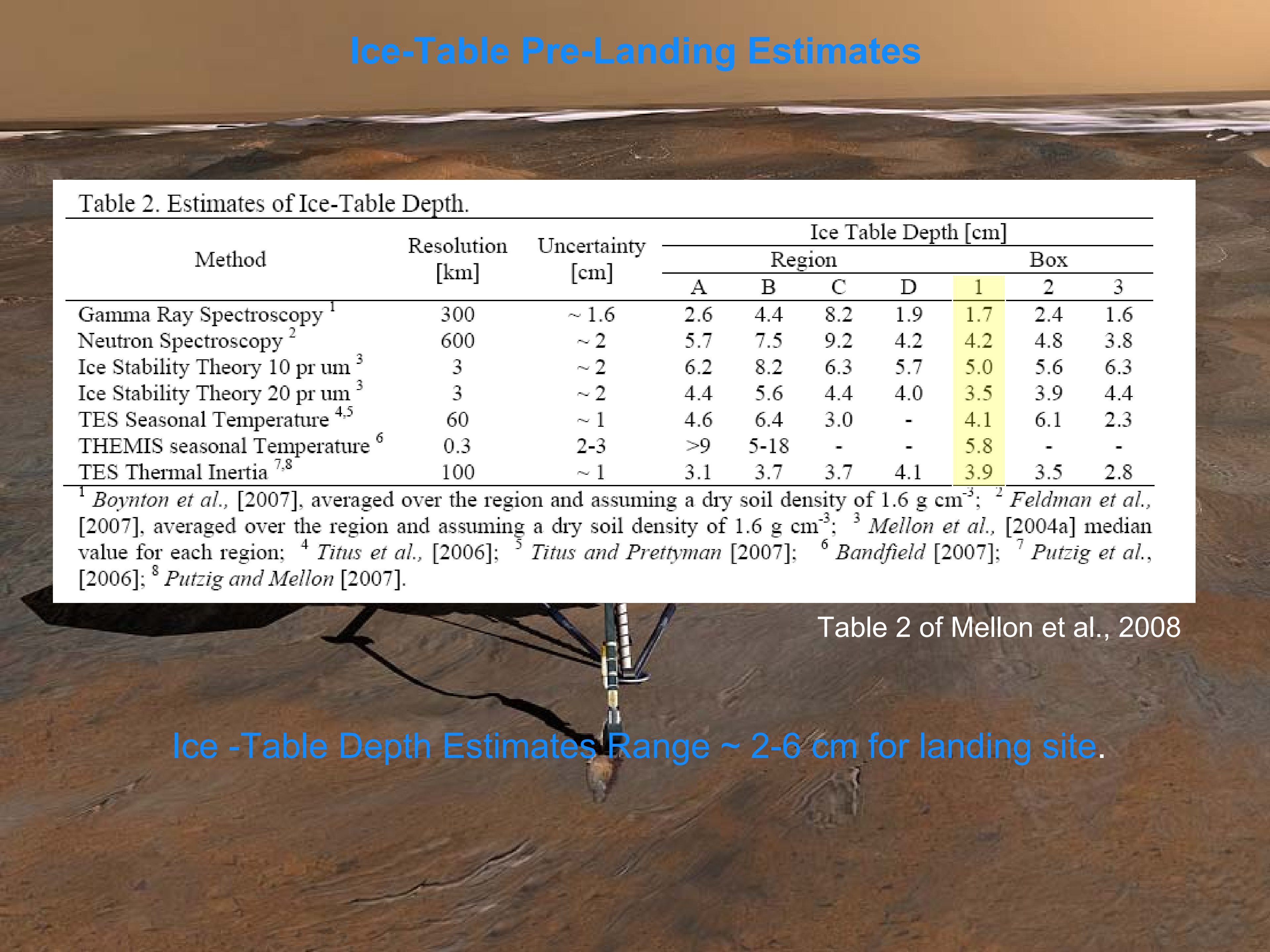


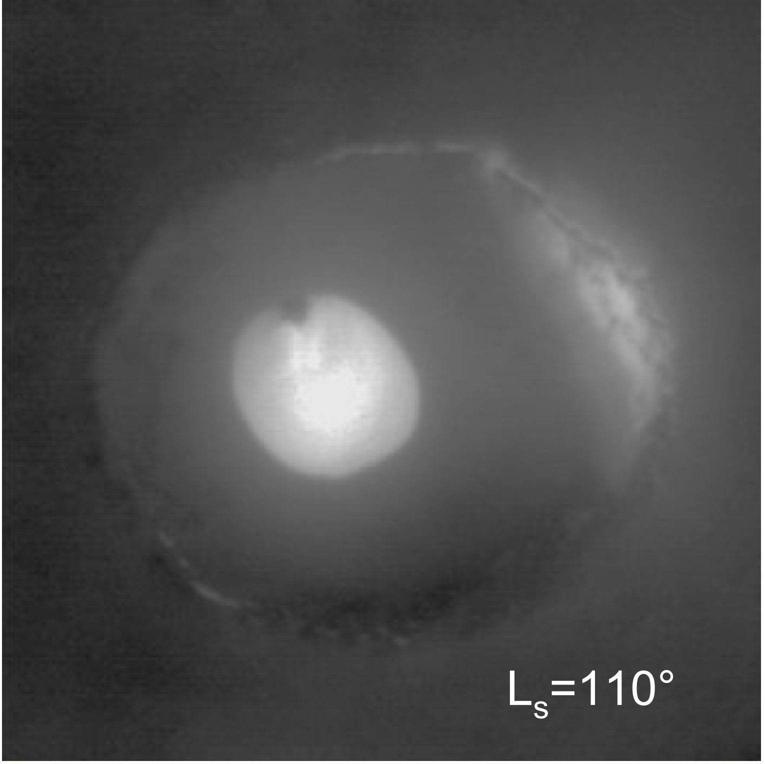
Table 2. Estimates of Ice-Table Depth.

| 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 |

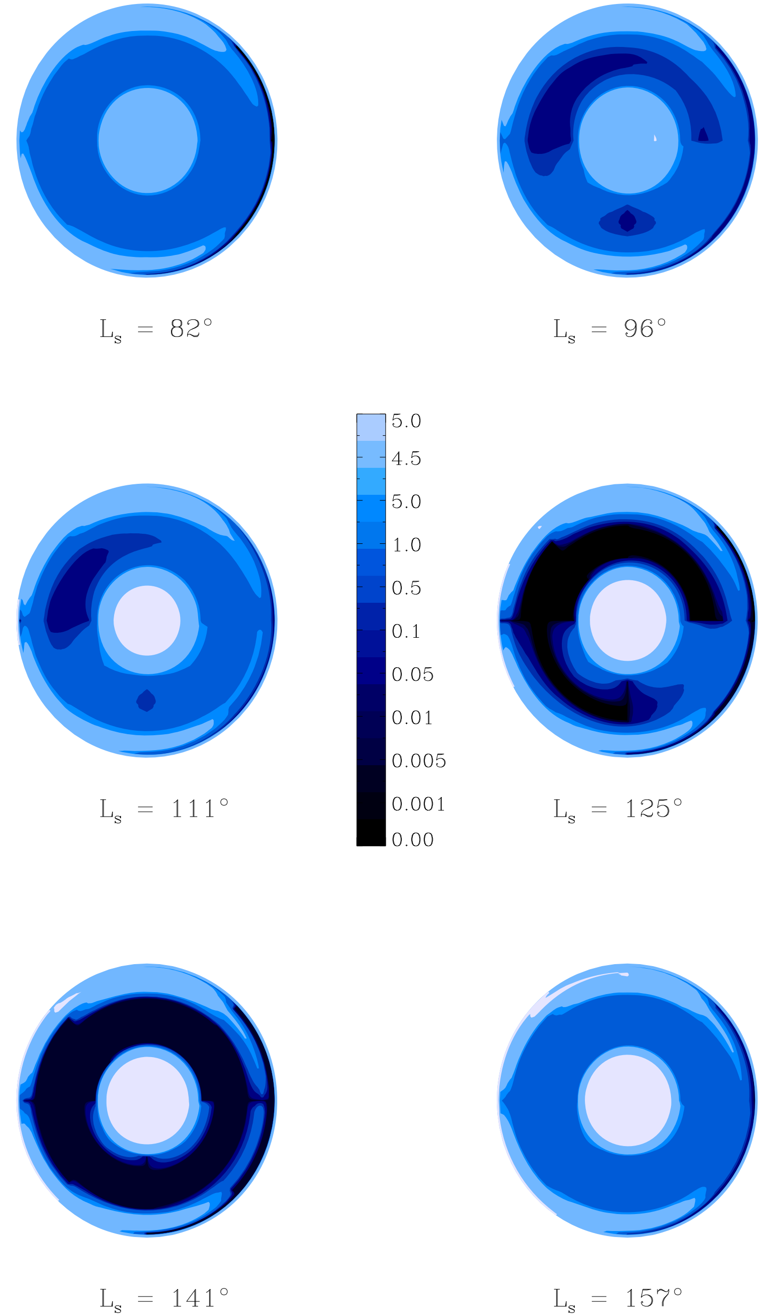
[1] *Boynton et al.*, [2007], averaged over the region and assuming a dry soil density of 1.6 g cm$^{-3}$; [2] *Feldman et al.*, [2007], averaged over the region and assuming a dry soil density of 1.6 g cm$^{-3}$; [3] *Mellon et al.*, [2004a] median value for each region; [4] *Titus et al.*, [2006];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





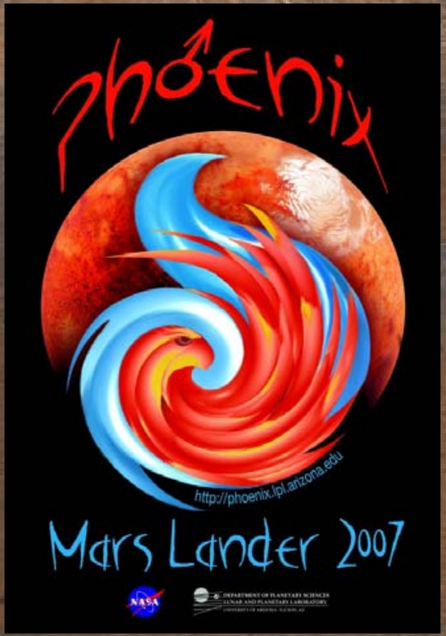



Markiewicz and Kossacki, 2006


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

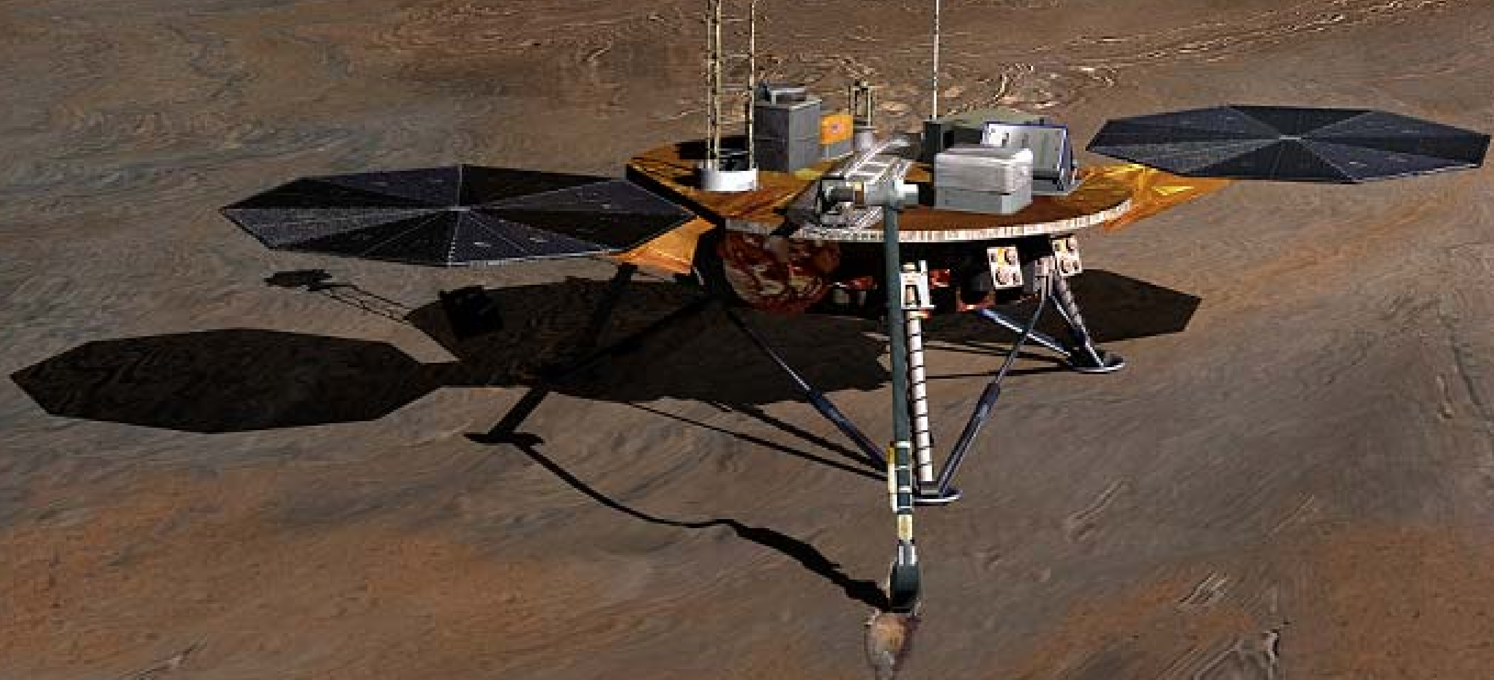
# Why Phoenix?

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

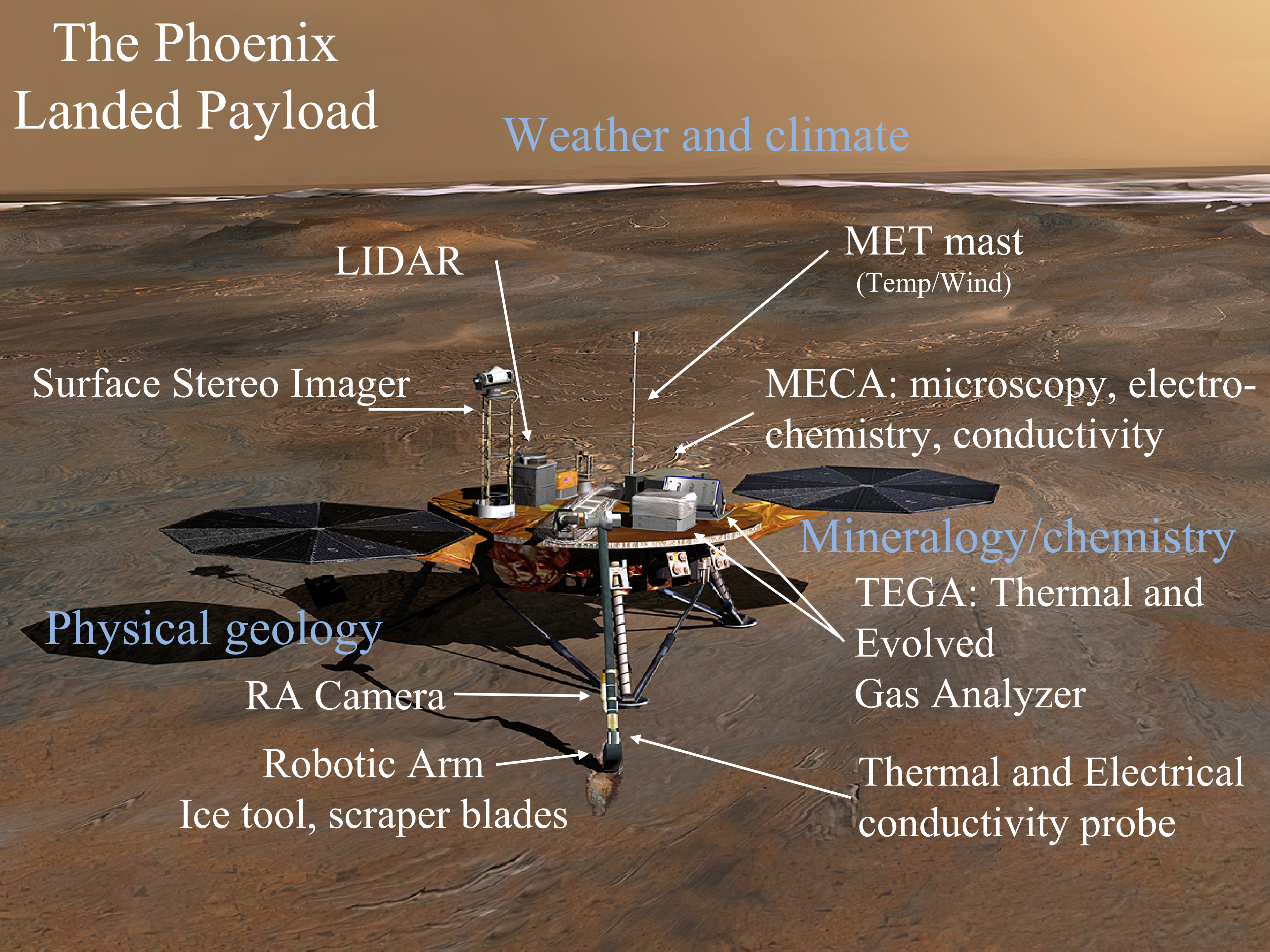


# Phoenix top level objectives

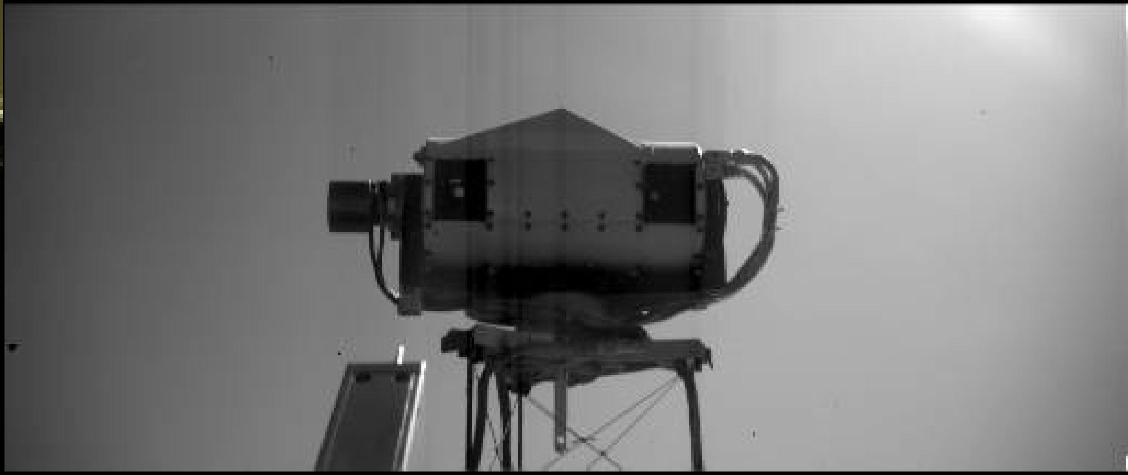
- Find water ice

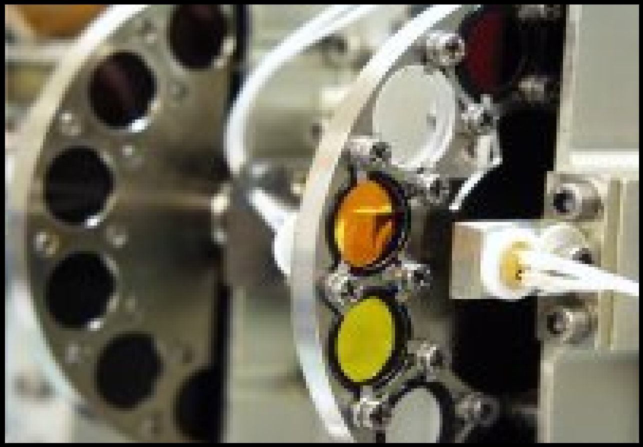


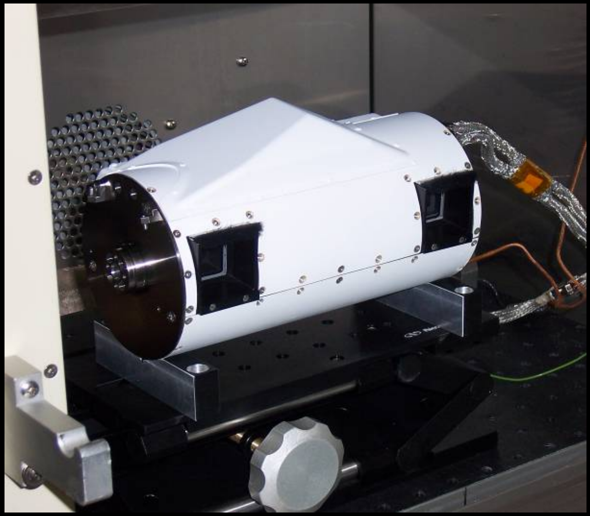
- Estimate habitability of the near surface environment


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

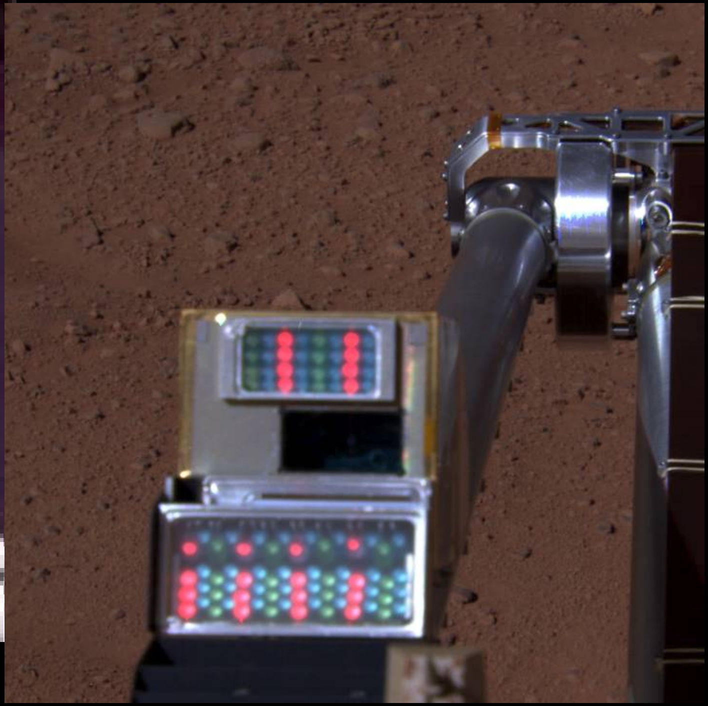
# Surface Stereo Imager (SSI)



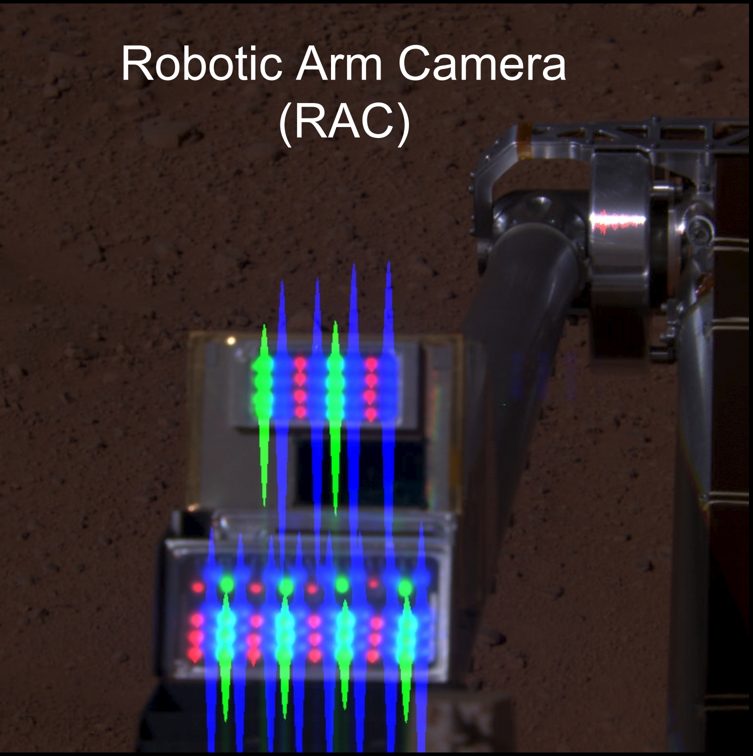




# Robotic Arm Camera (RAC)



# What is RAC?

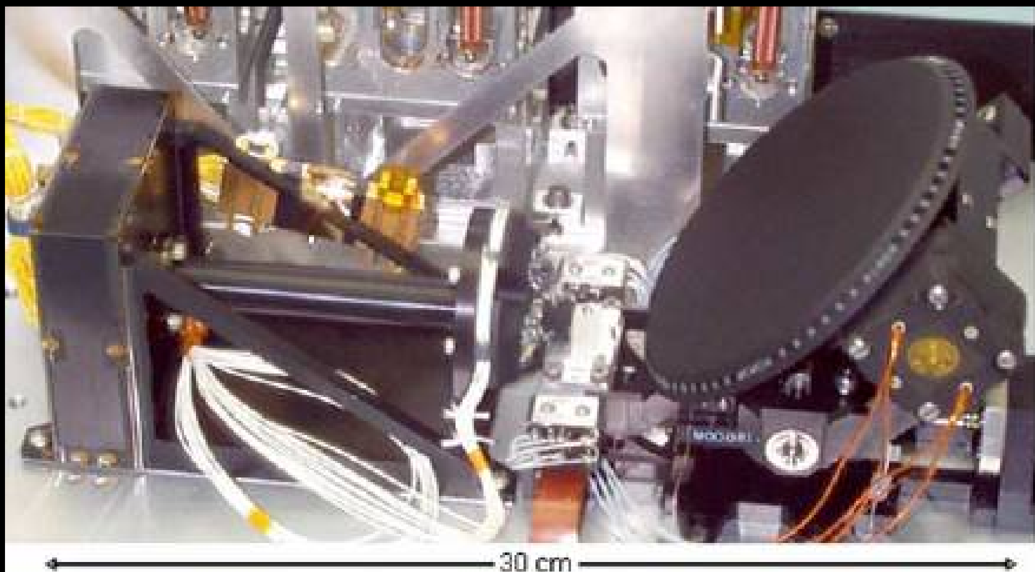



**Imaged by SSI**

- 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)



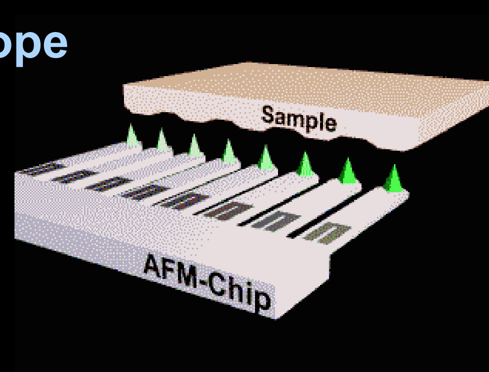

**Atomic Force Microscope AFM**

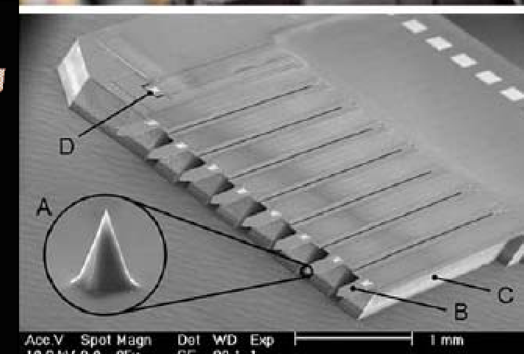
**50 nm/px**



**Optical Microscope OM**

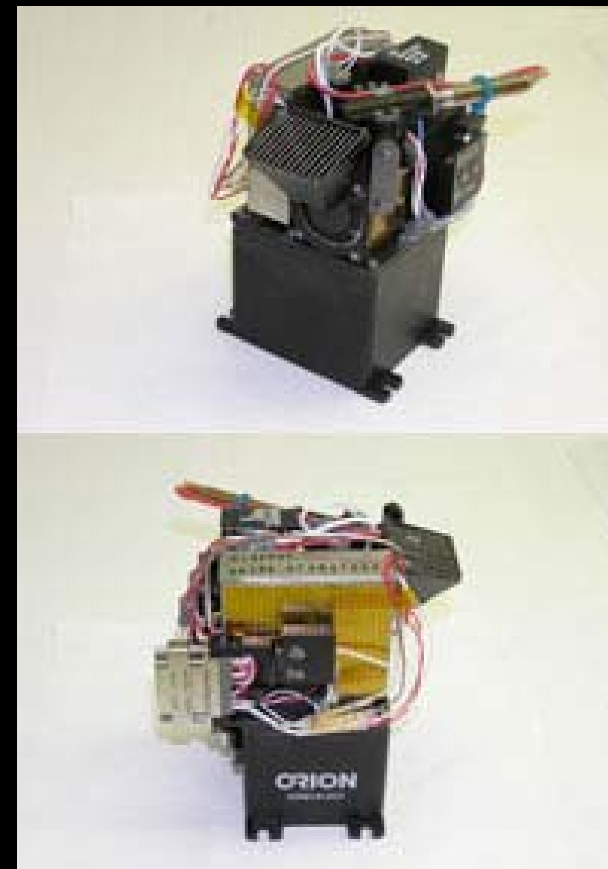
**4 µm/px**



# TEGA & WCL

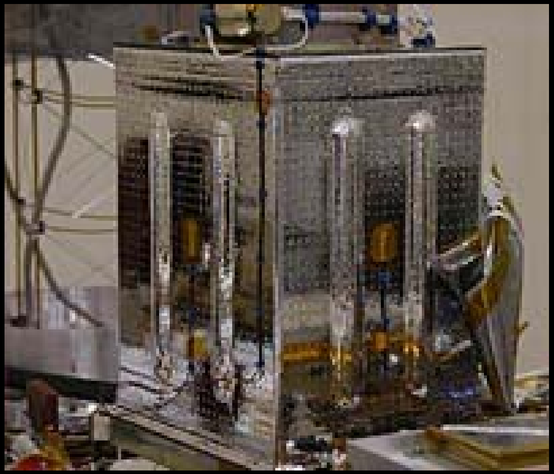
Thermal and Evolved Gas Analyzer
**( TEGA)**



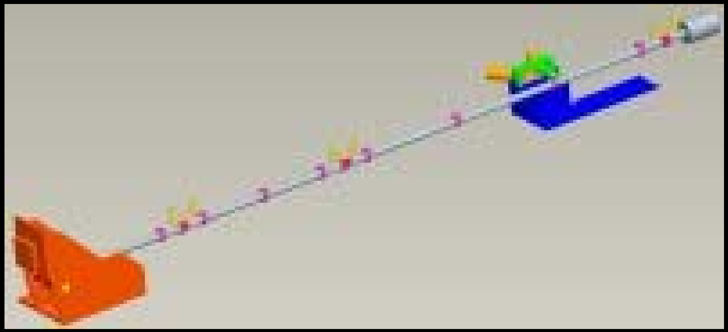

Wet Chemistry Lab
(WCL)

# MET & TECP

Thermal and Electrical Conductivity Probe (TECP)



Meteorological Station
**( MET)**



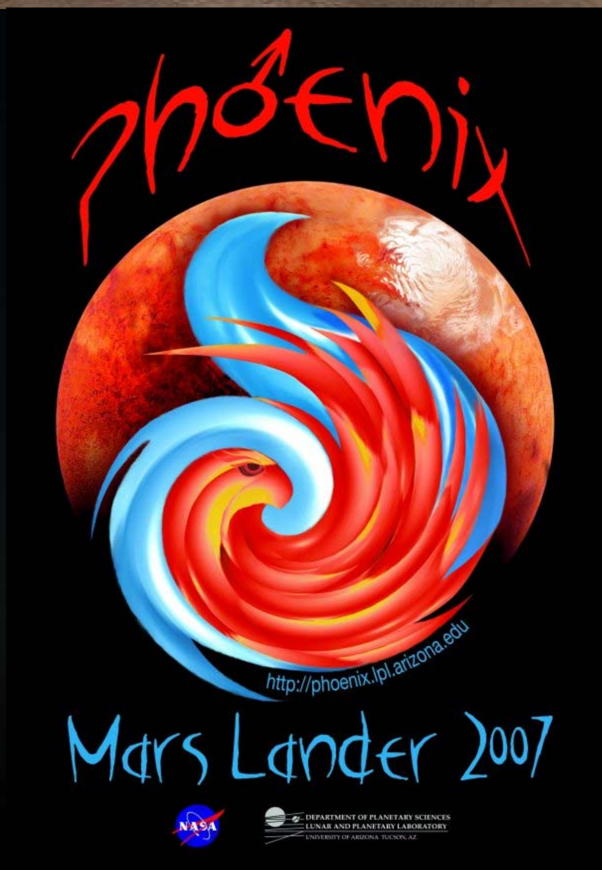

First results

Science 3 July 2009

More details in articles

JGR Planets 115, 2010

# Phoenix launch


After launch

After launch

# Why Are These People Concerned?

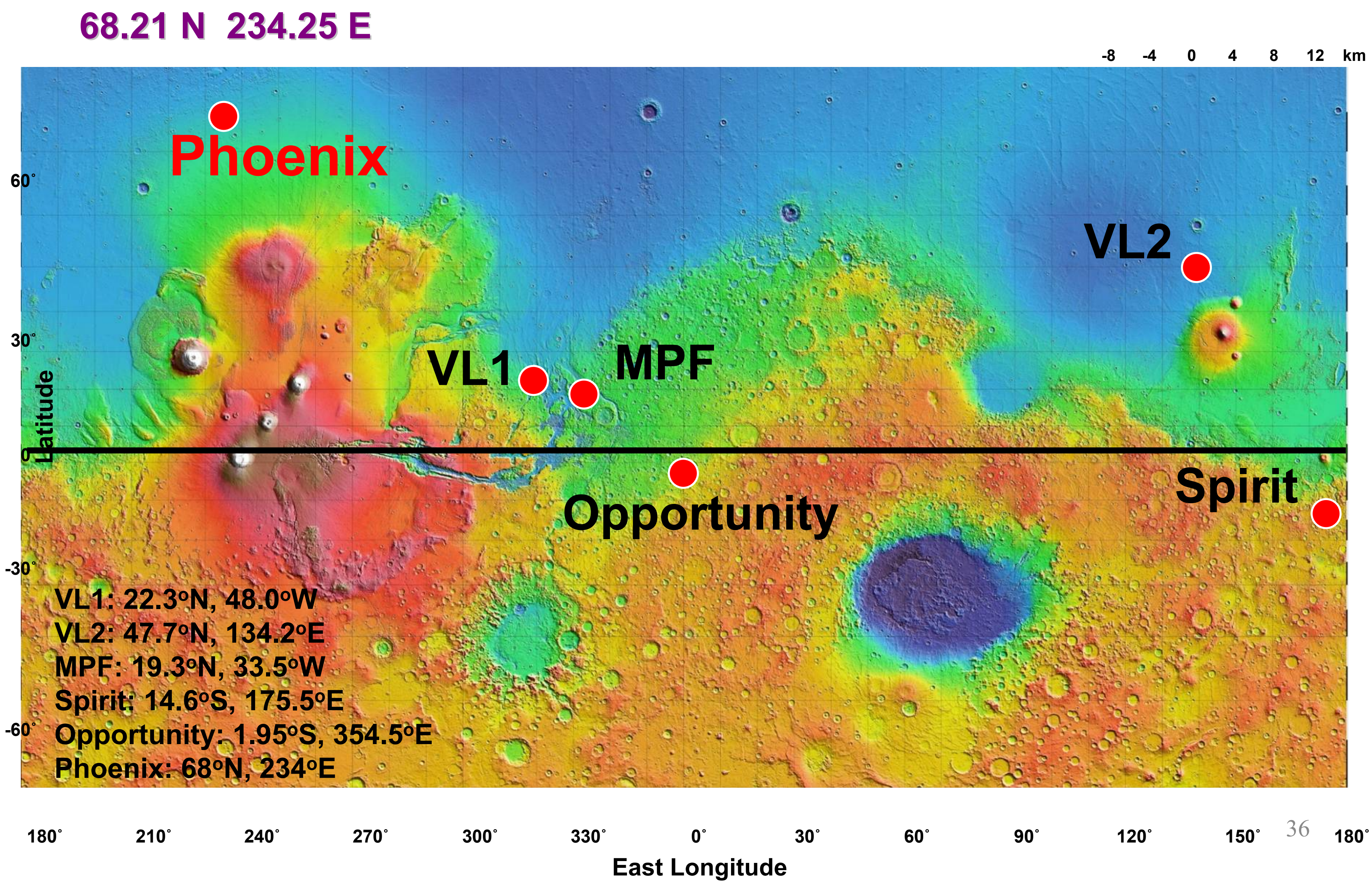
# Phoenix: May 25, 2008

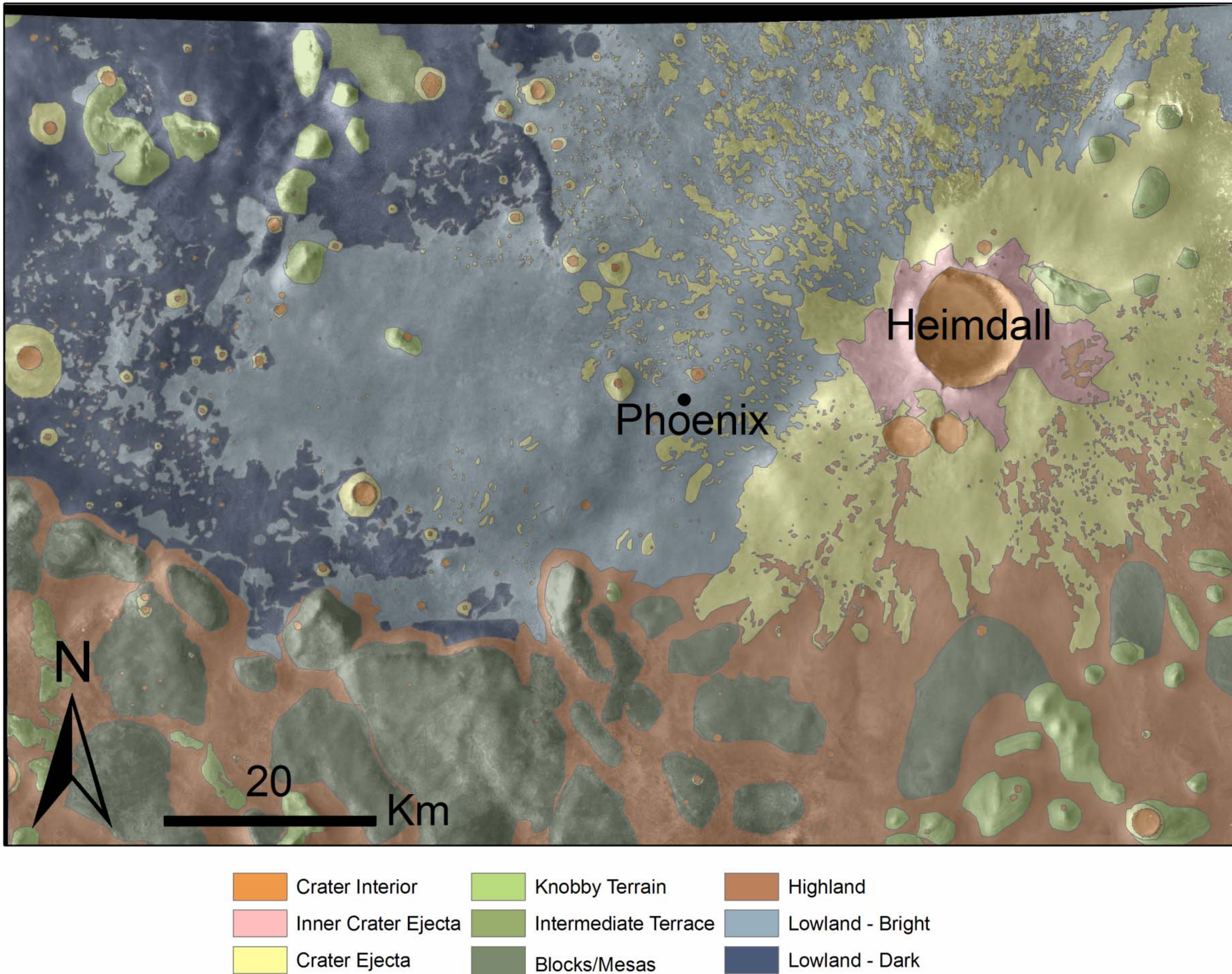
Landed and ready to go for at least three months


"Oh-My Gosh"
Not to worry, we landed 22 km away from the rim!


F. Poulet para-skiing Glacier d'Argenti

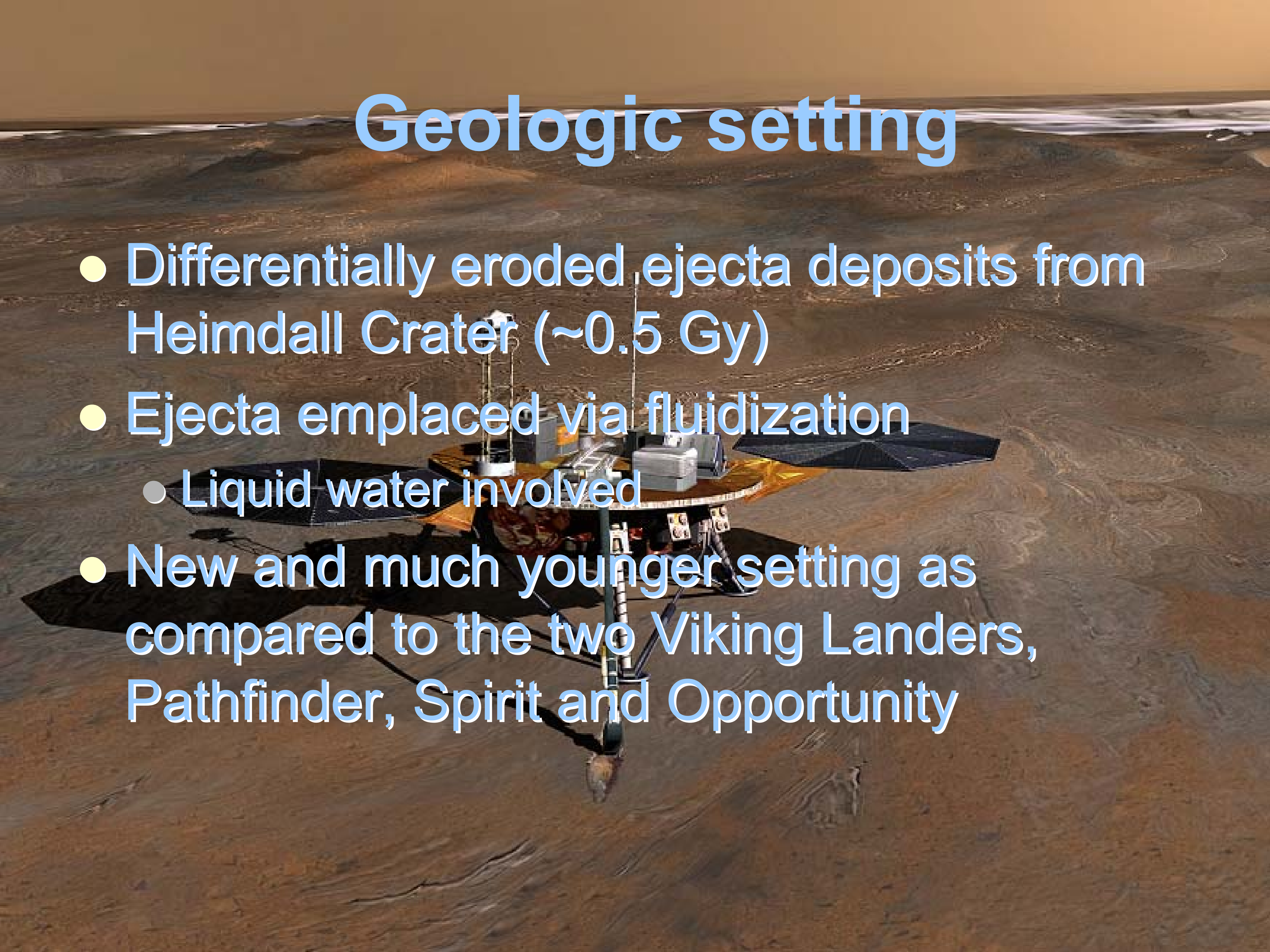
# Phoenix Landing Site Is Much Farther North Relative to the Other Landers





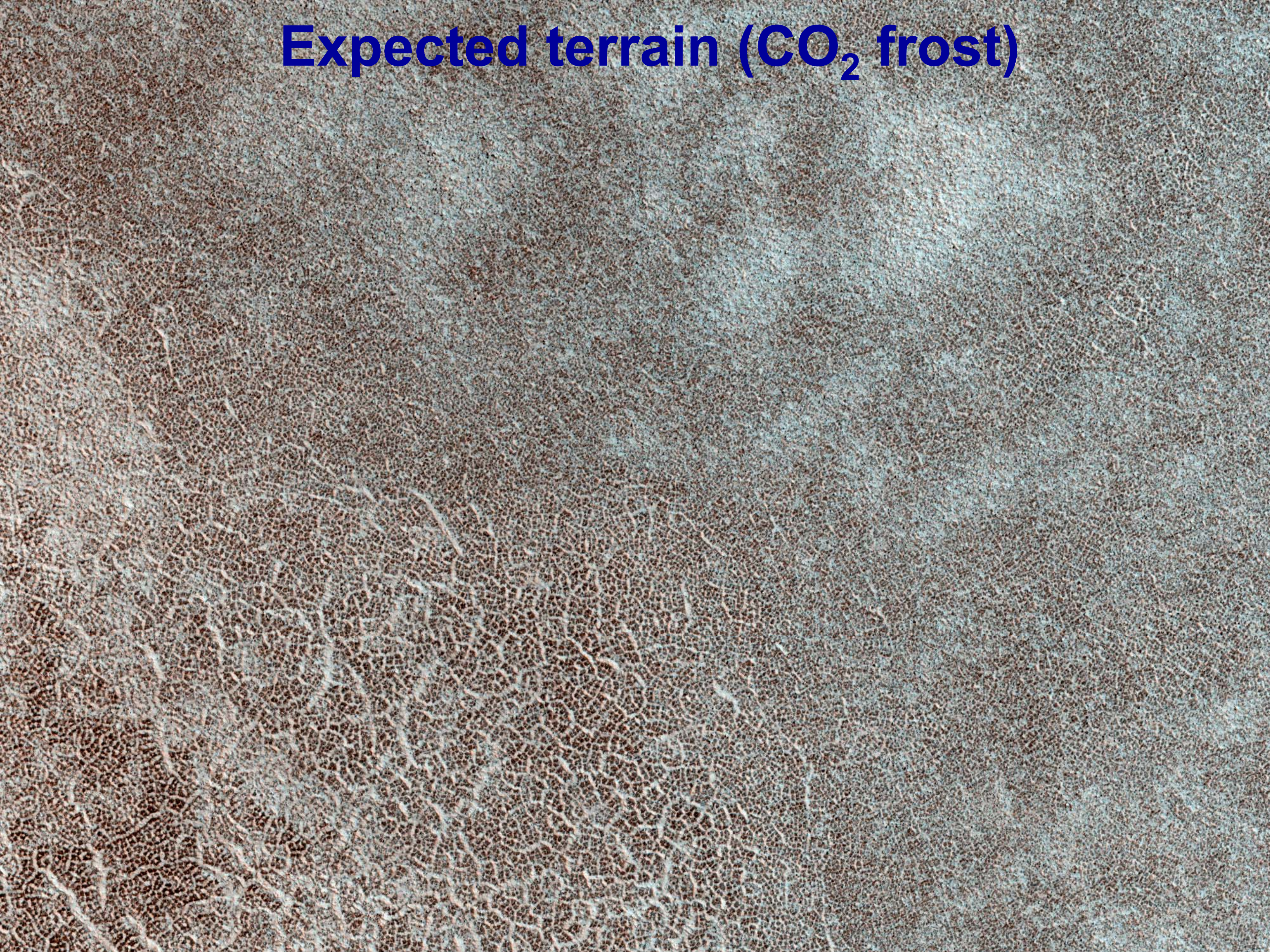
Heimdall
Phoenix
N
20
Km
Crater Interior
Inner Crater Ejecta
Crater Ejecta
Knobby Terrain
Intermediate Terrace
Blocks/Mesas
Highland
Lowland - Bright
Lowland - Dark

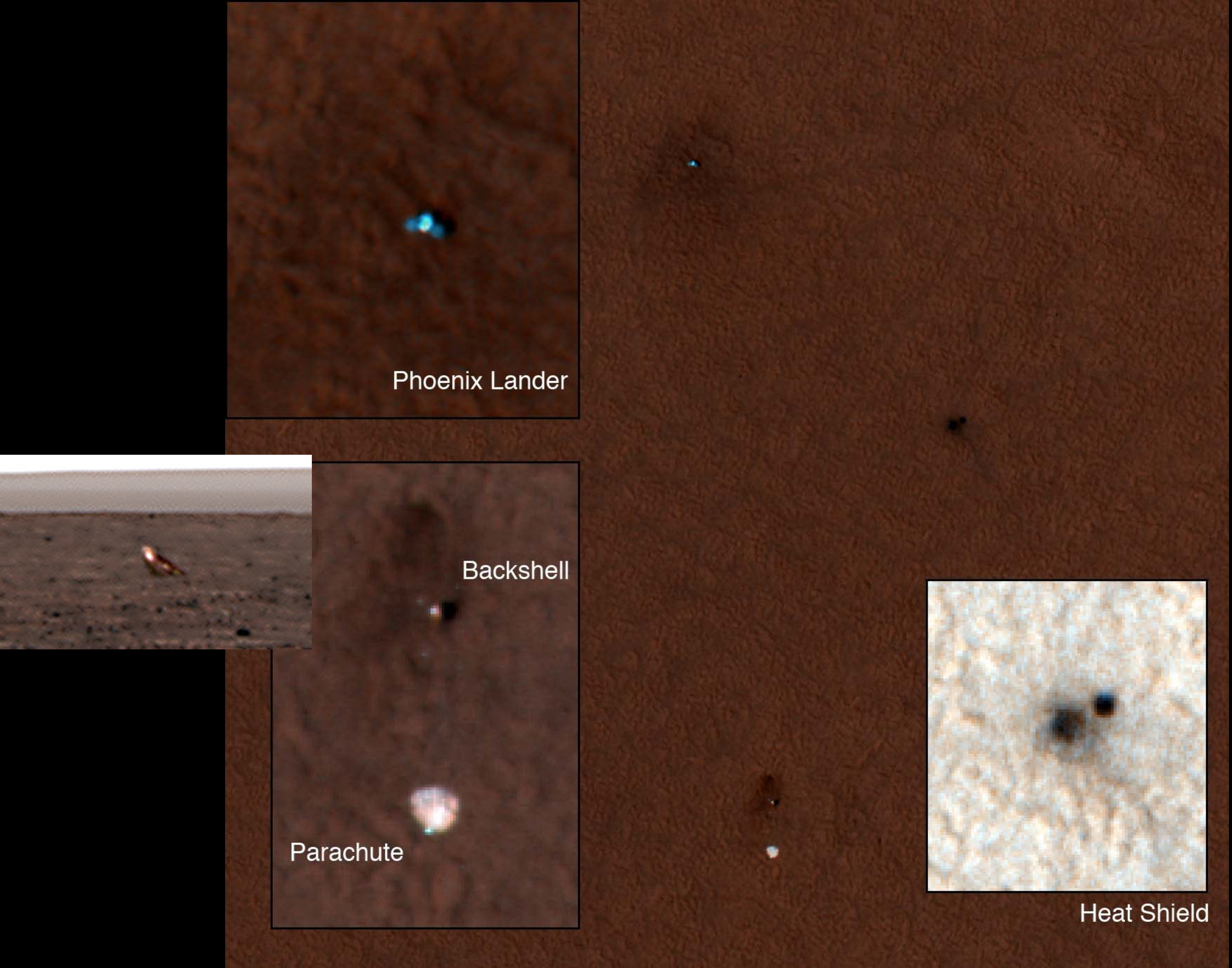
# Geologic setting



- 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)





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

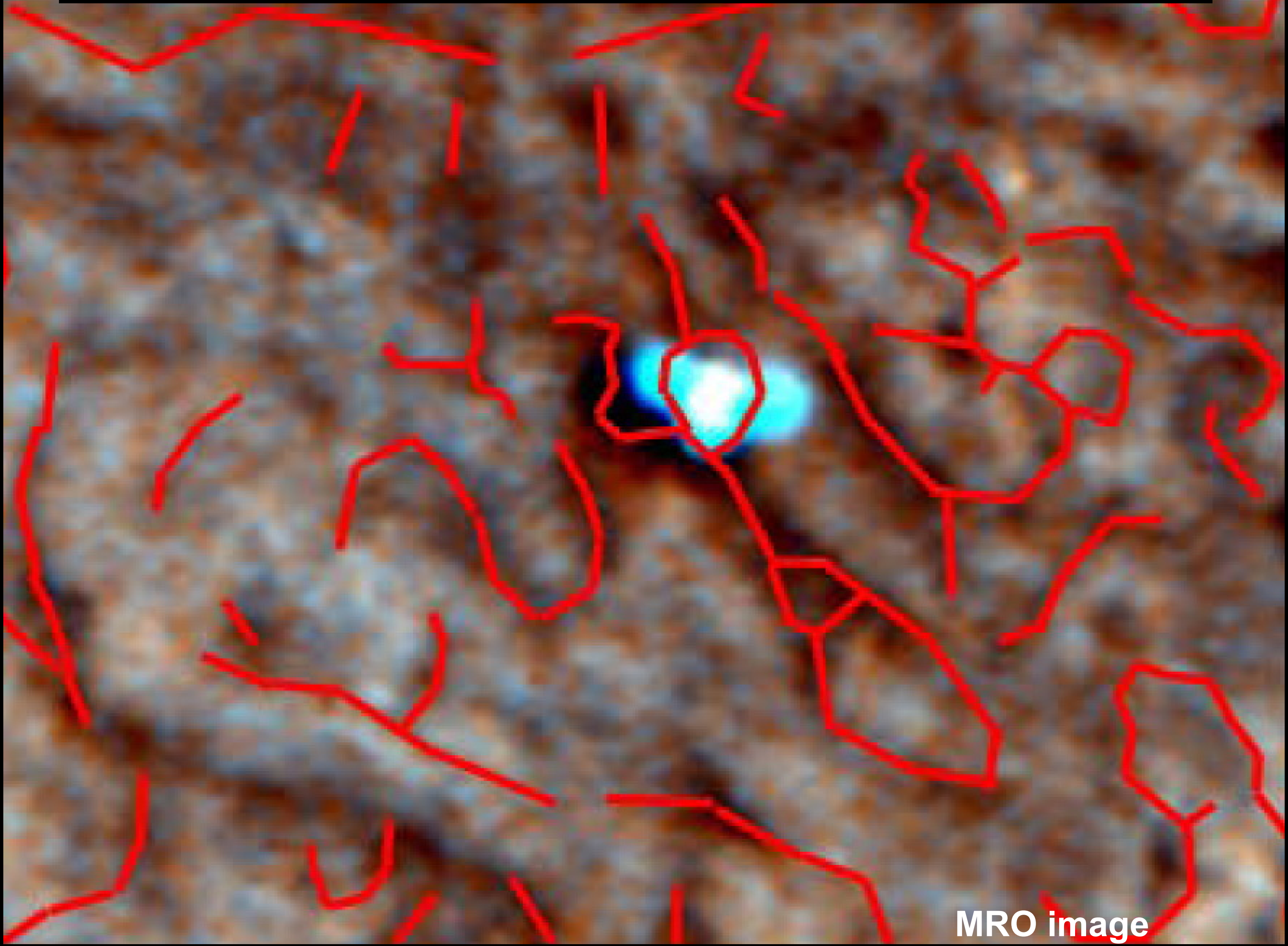
Thickness of excavated regolith 10 cm (predicted depth to ice)

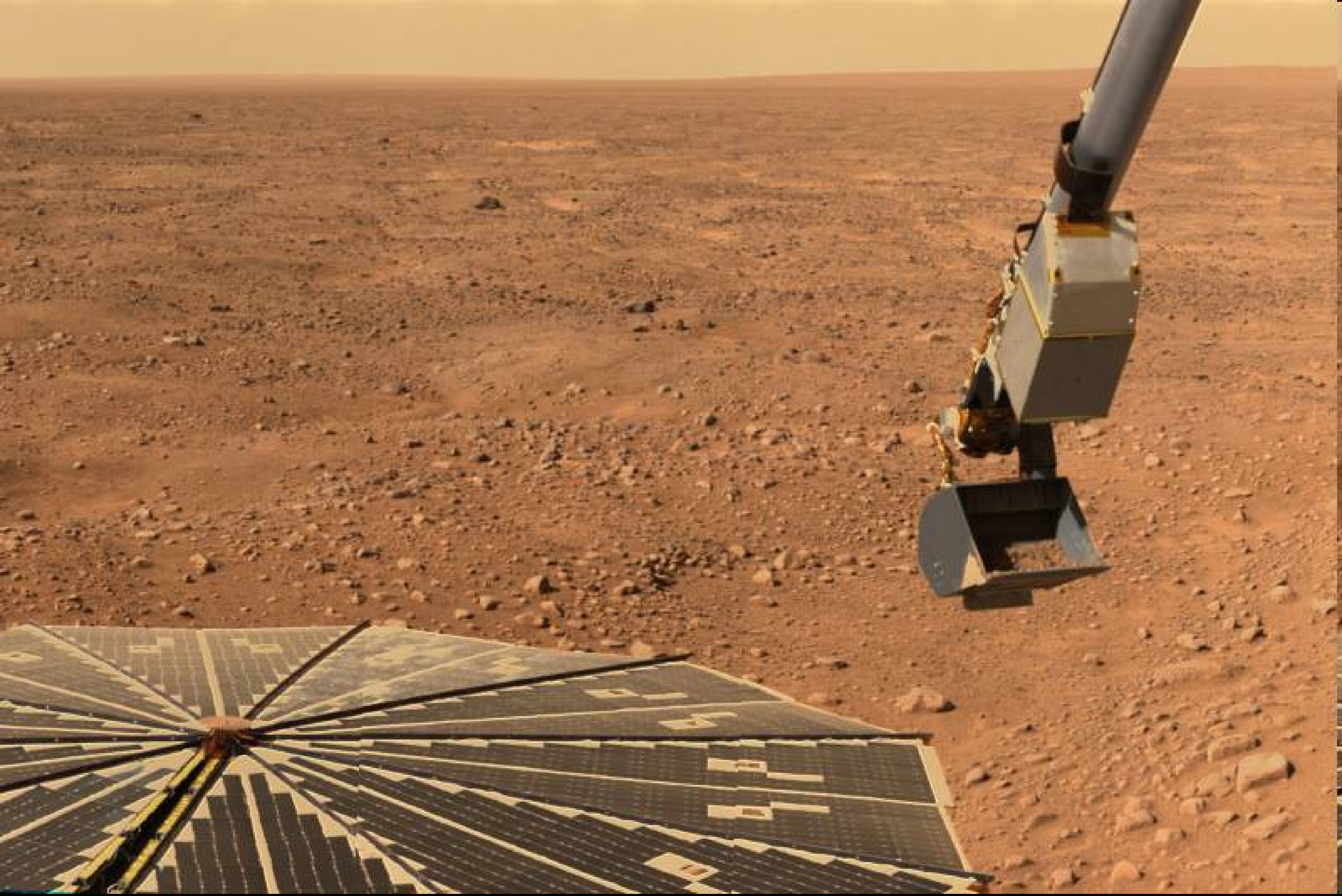
Radius of excavated area 1m (scale of the Lander)

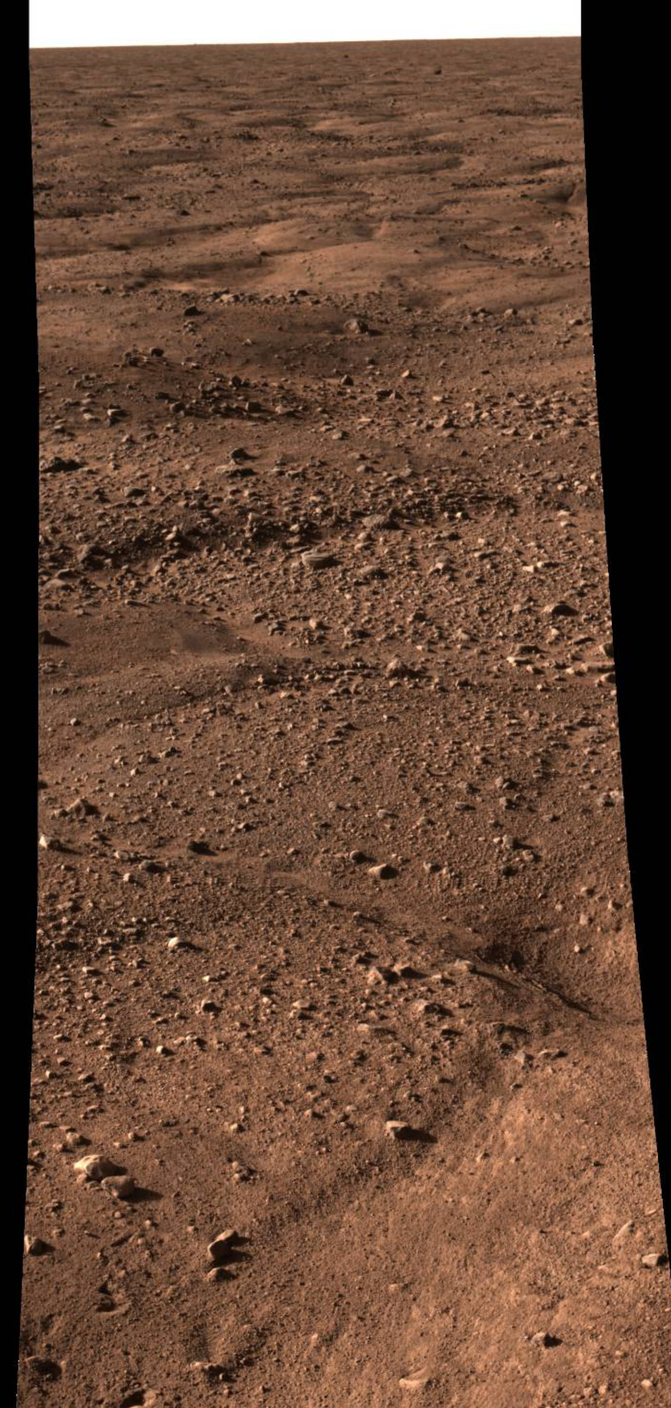
Results in 1 mm thick cover

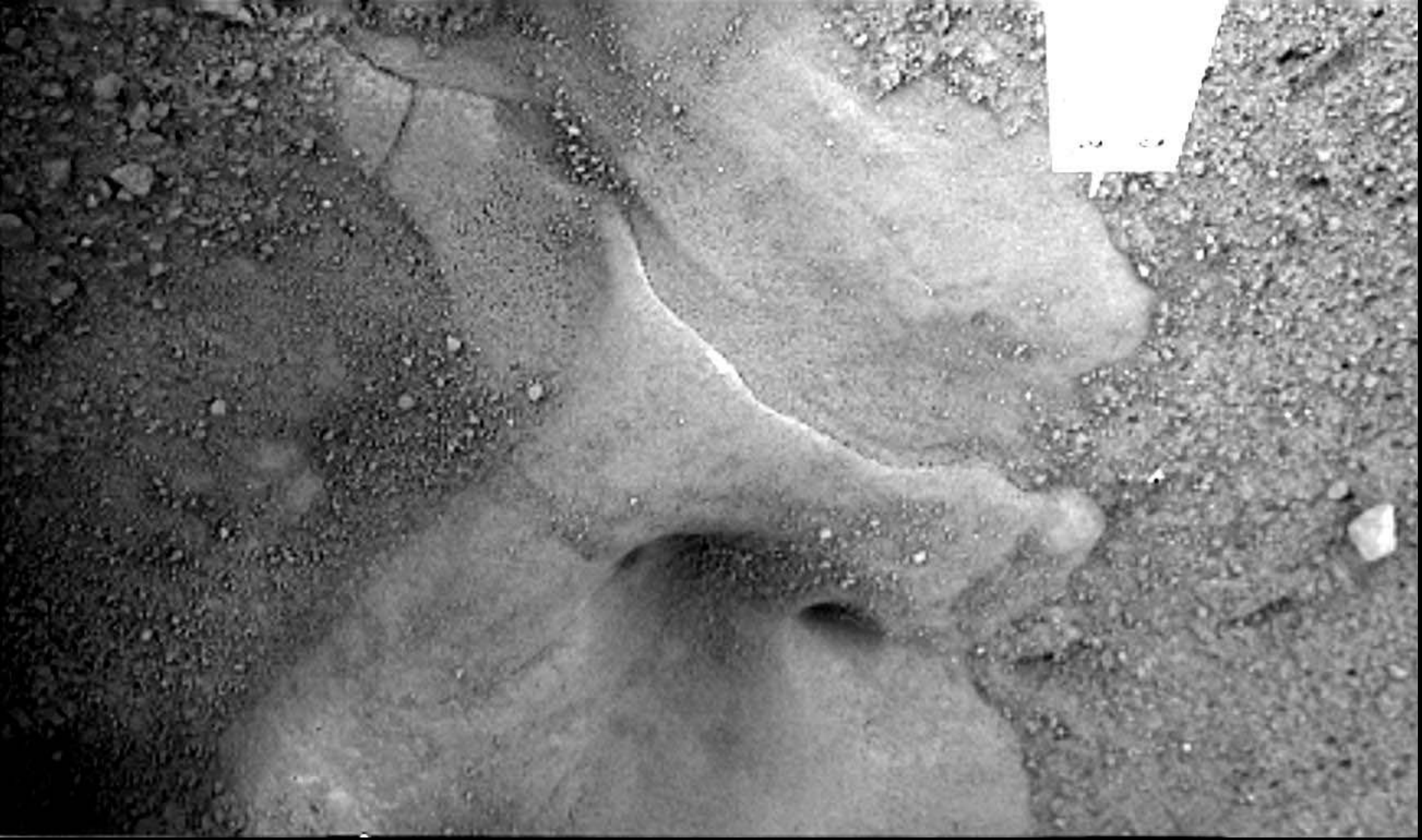
Or is it darker because fines where blown away?

# 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

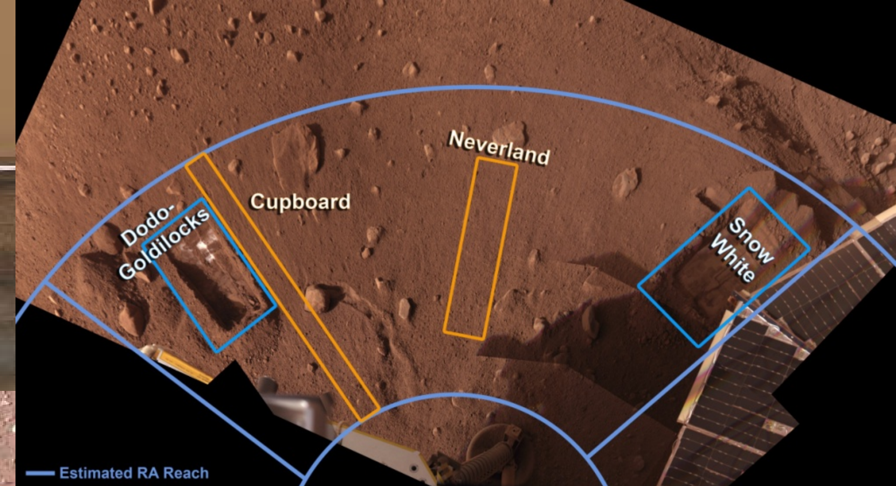
in twilight

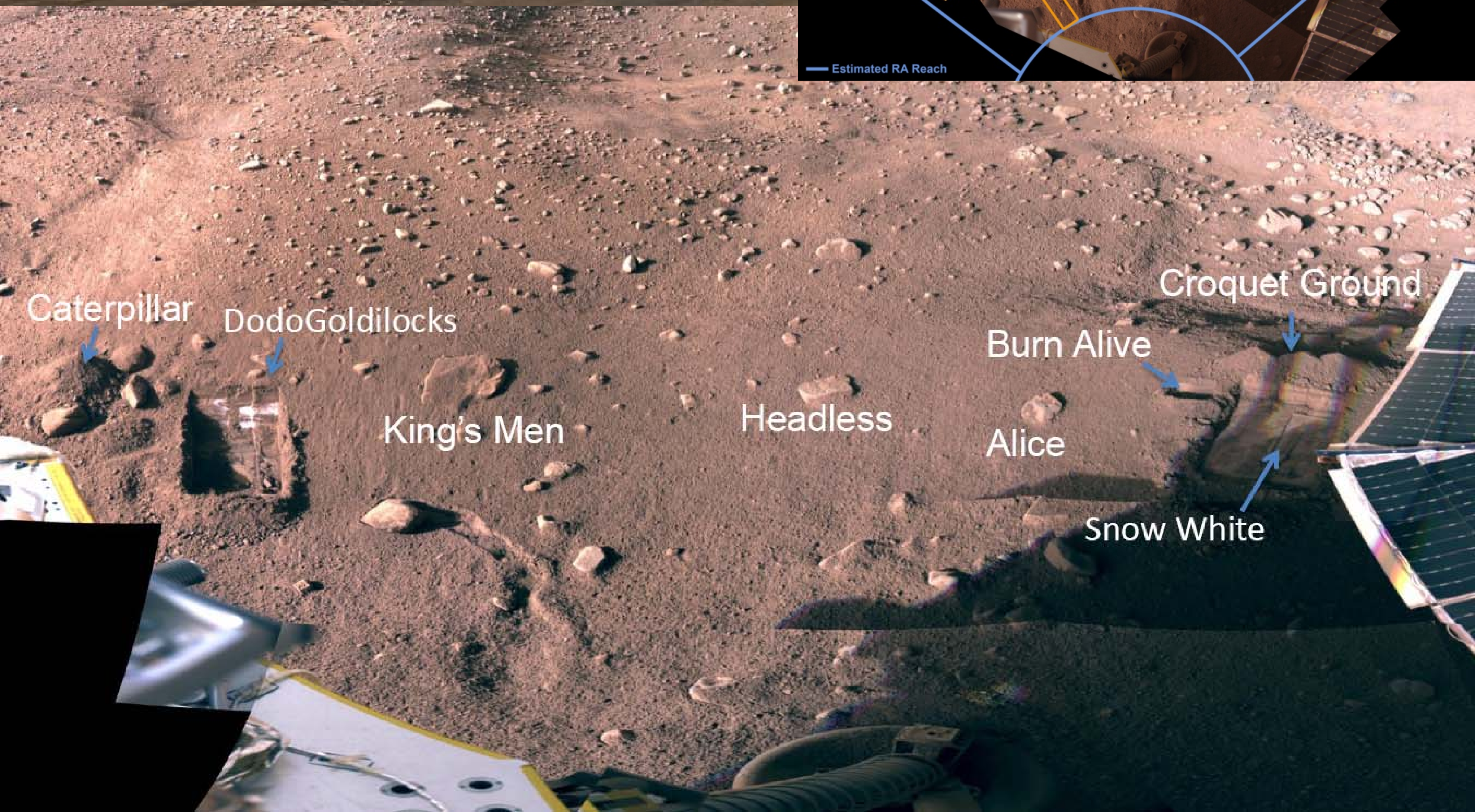
Pore ice

or

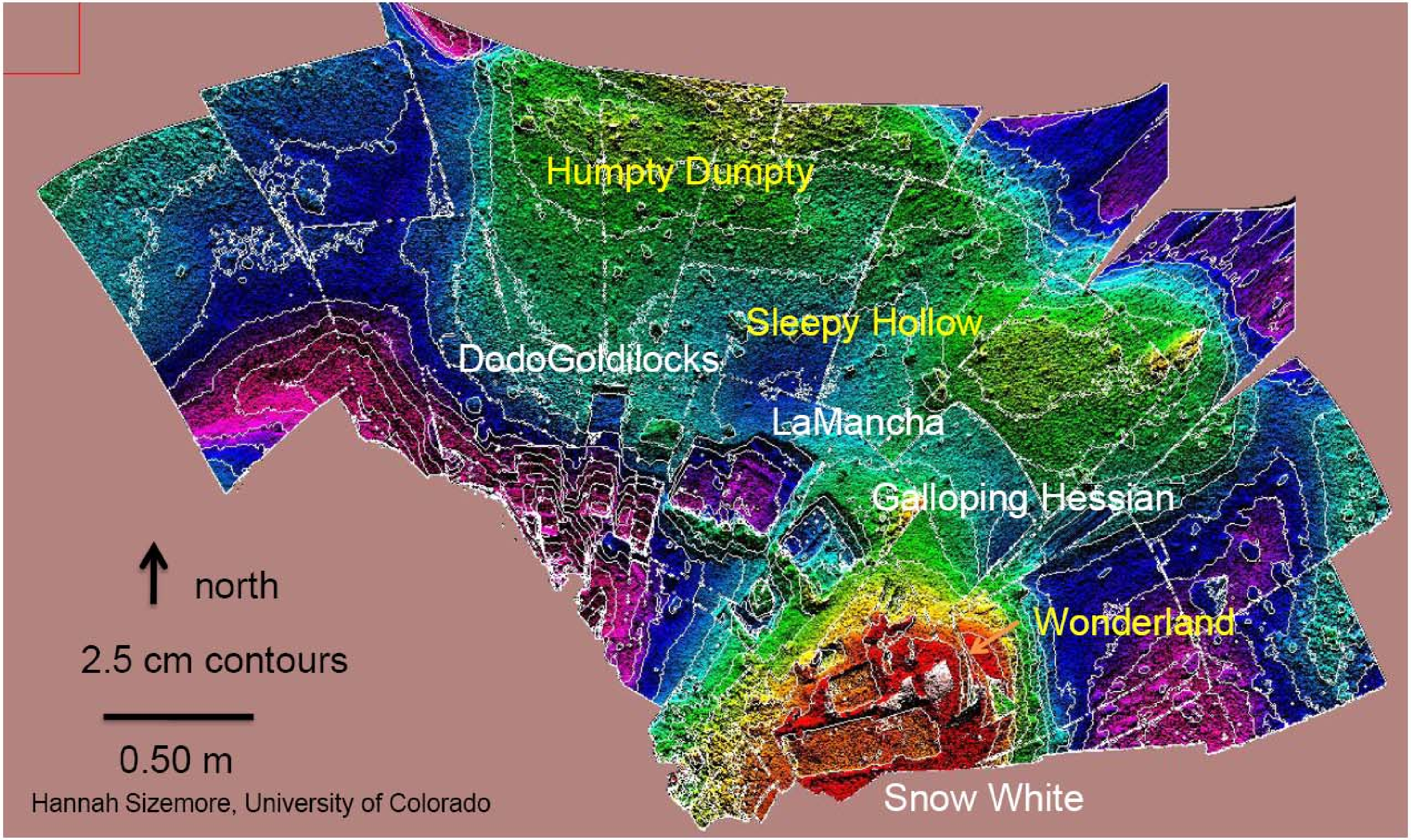
pure ice
with dust cover?

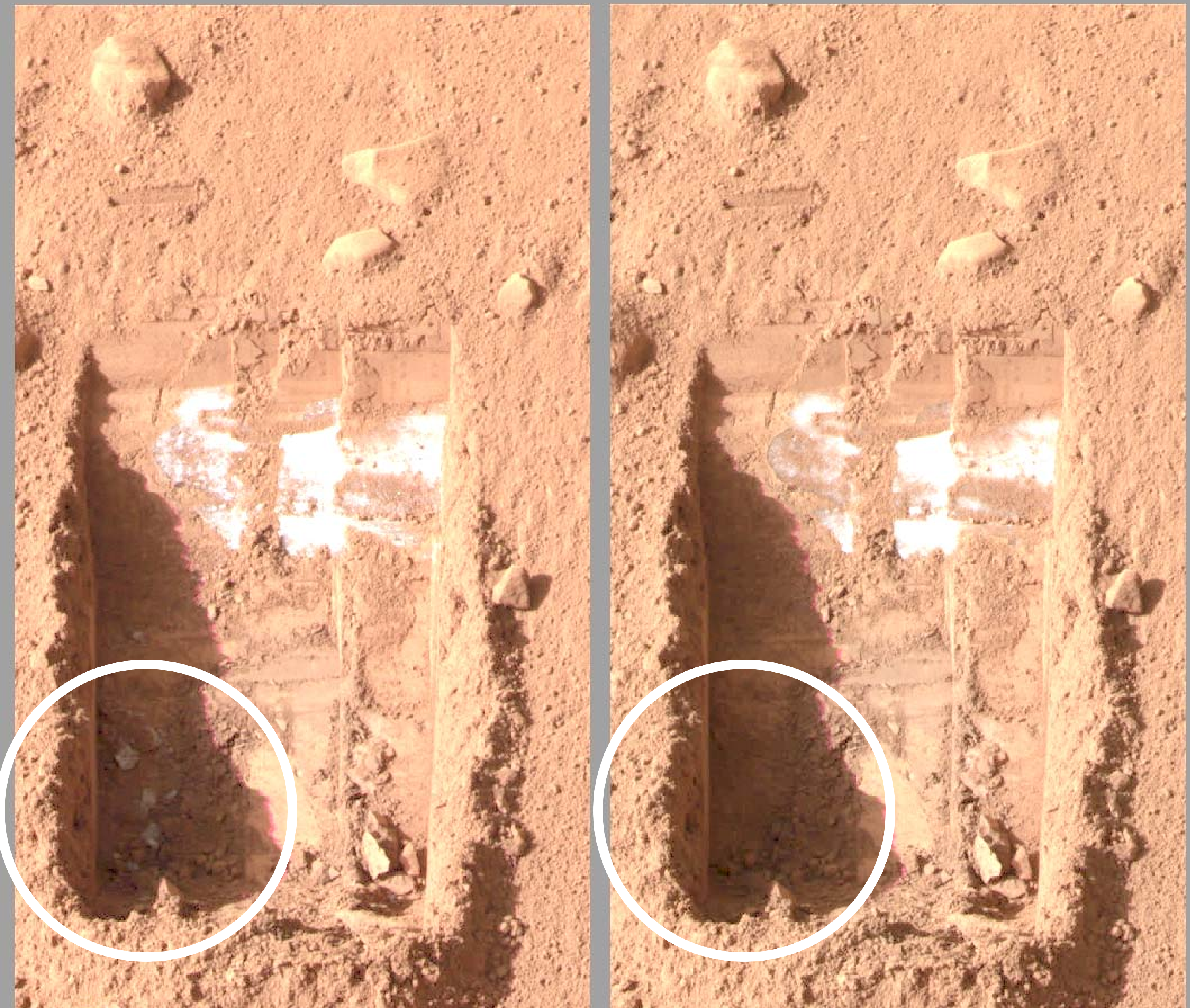
# Digging Area



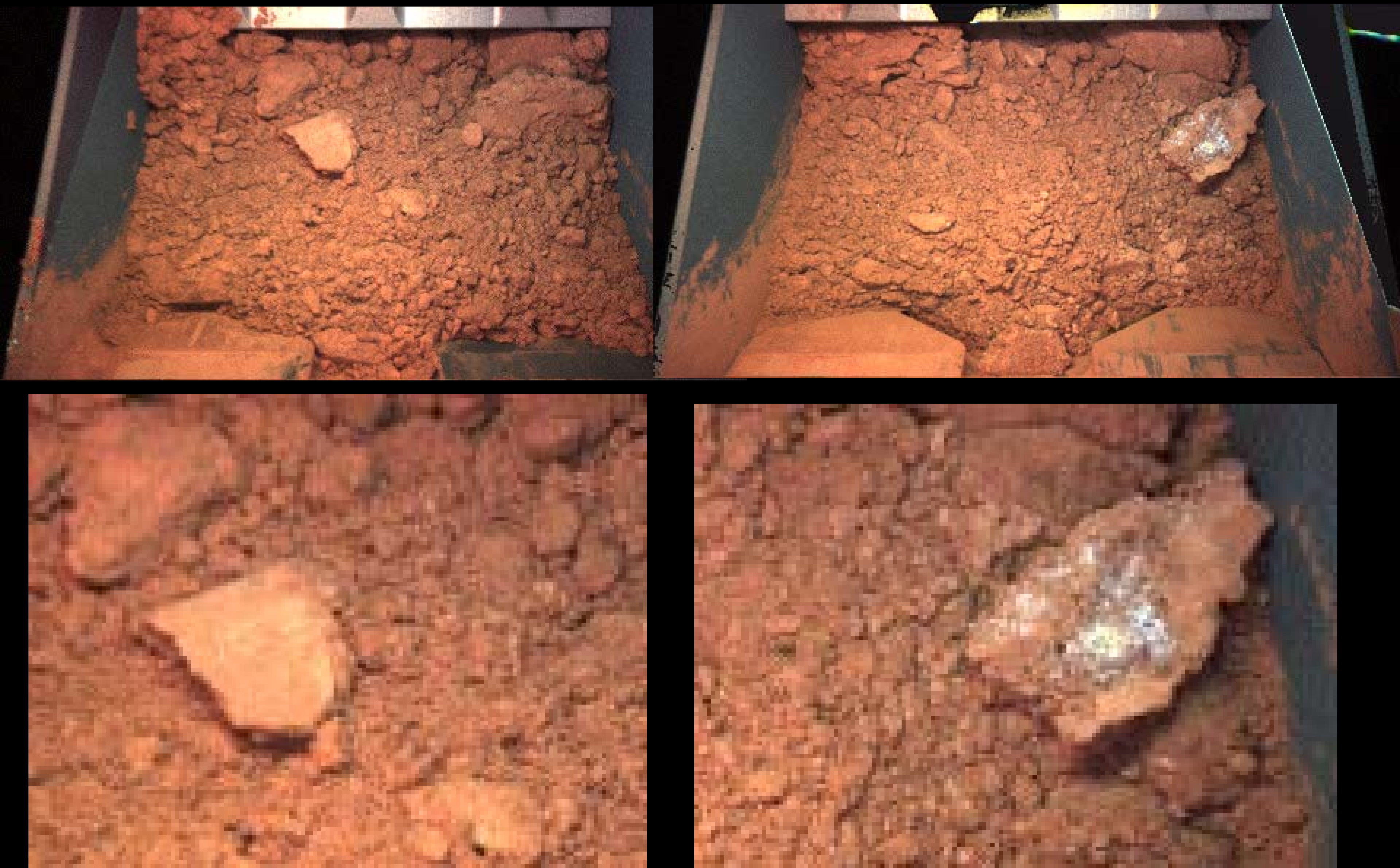
# Topographic Map of Polygons and Robotic Arm Work Space





Ice
Sublimes

# First Scoops Sol 9/11

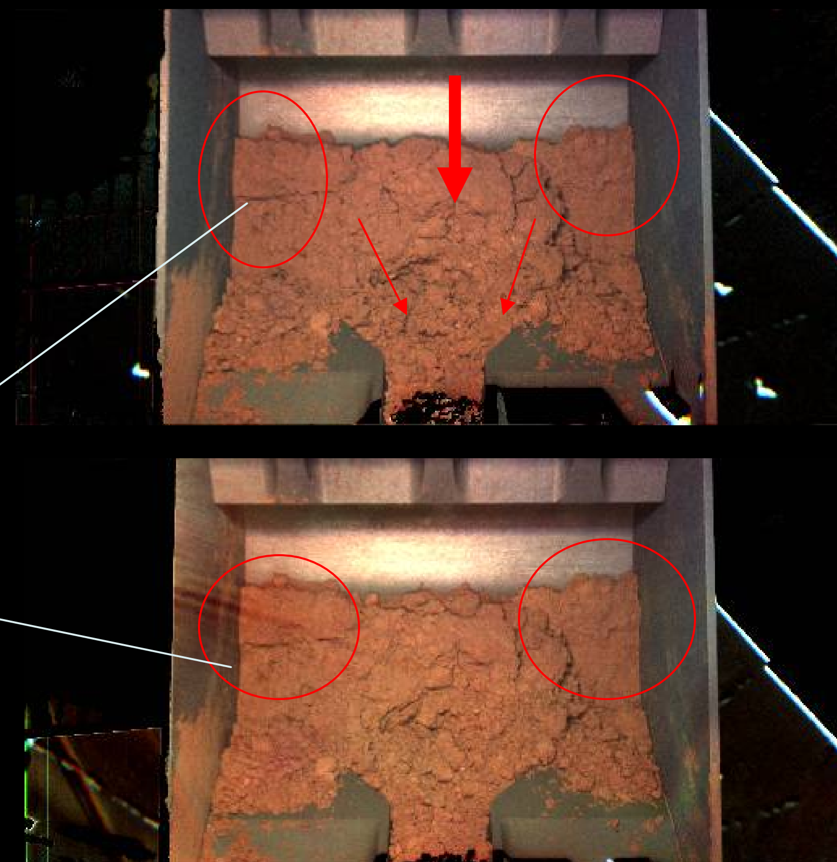


# SOL 15

# SOL 16

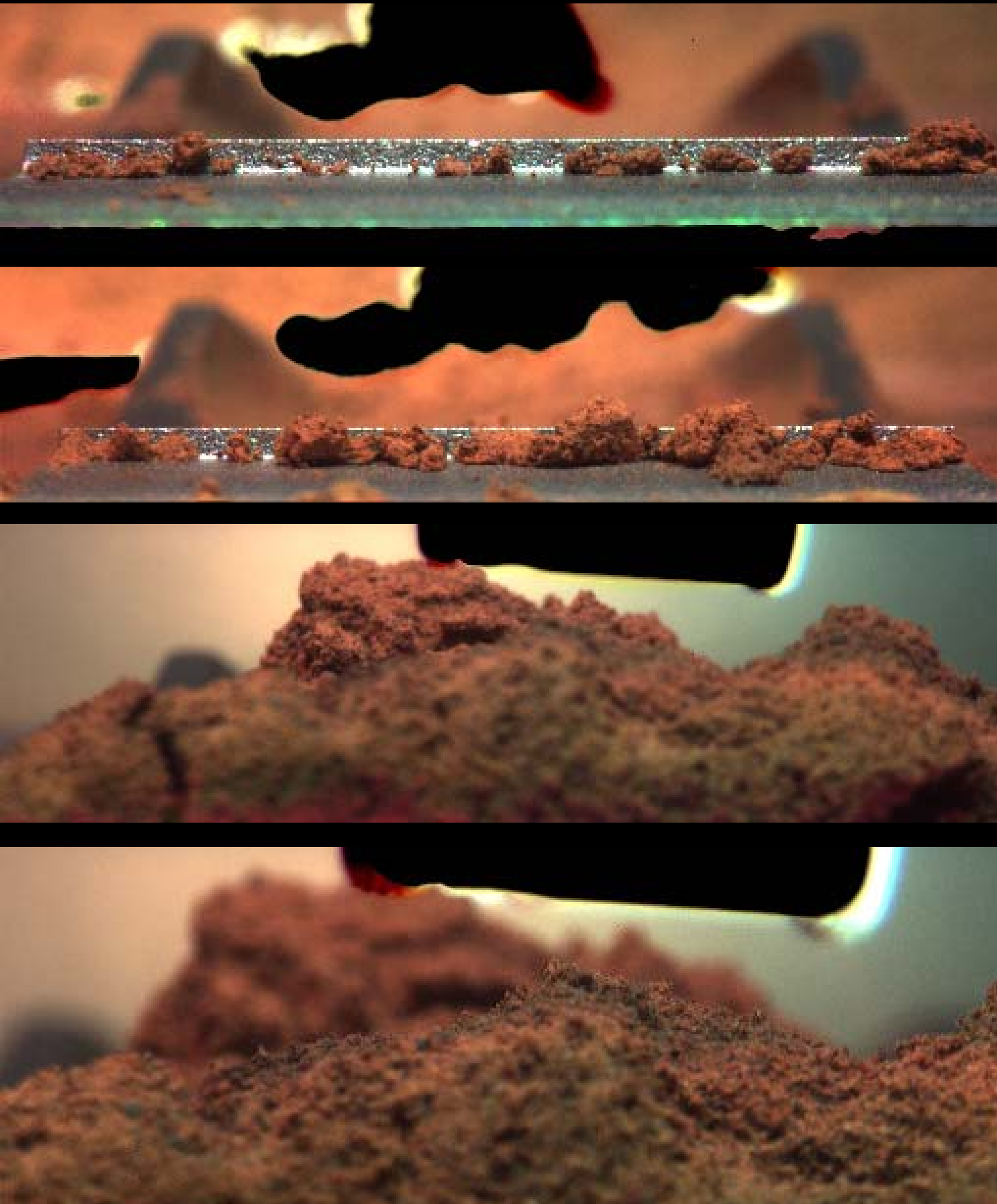
# Overnight Changes

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



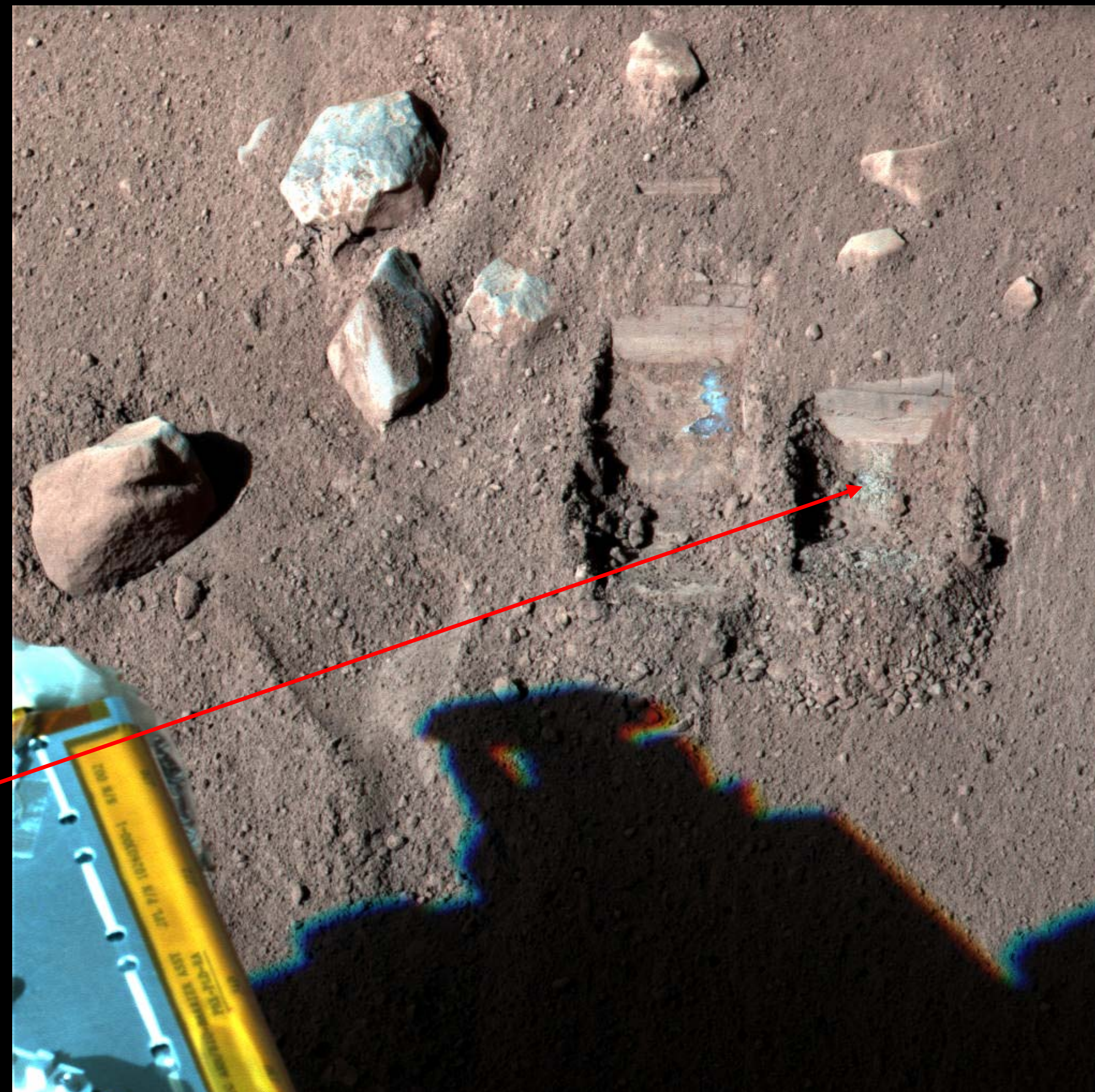
No large particles!


Soil collected after rasping in Snow White

# 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

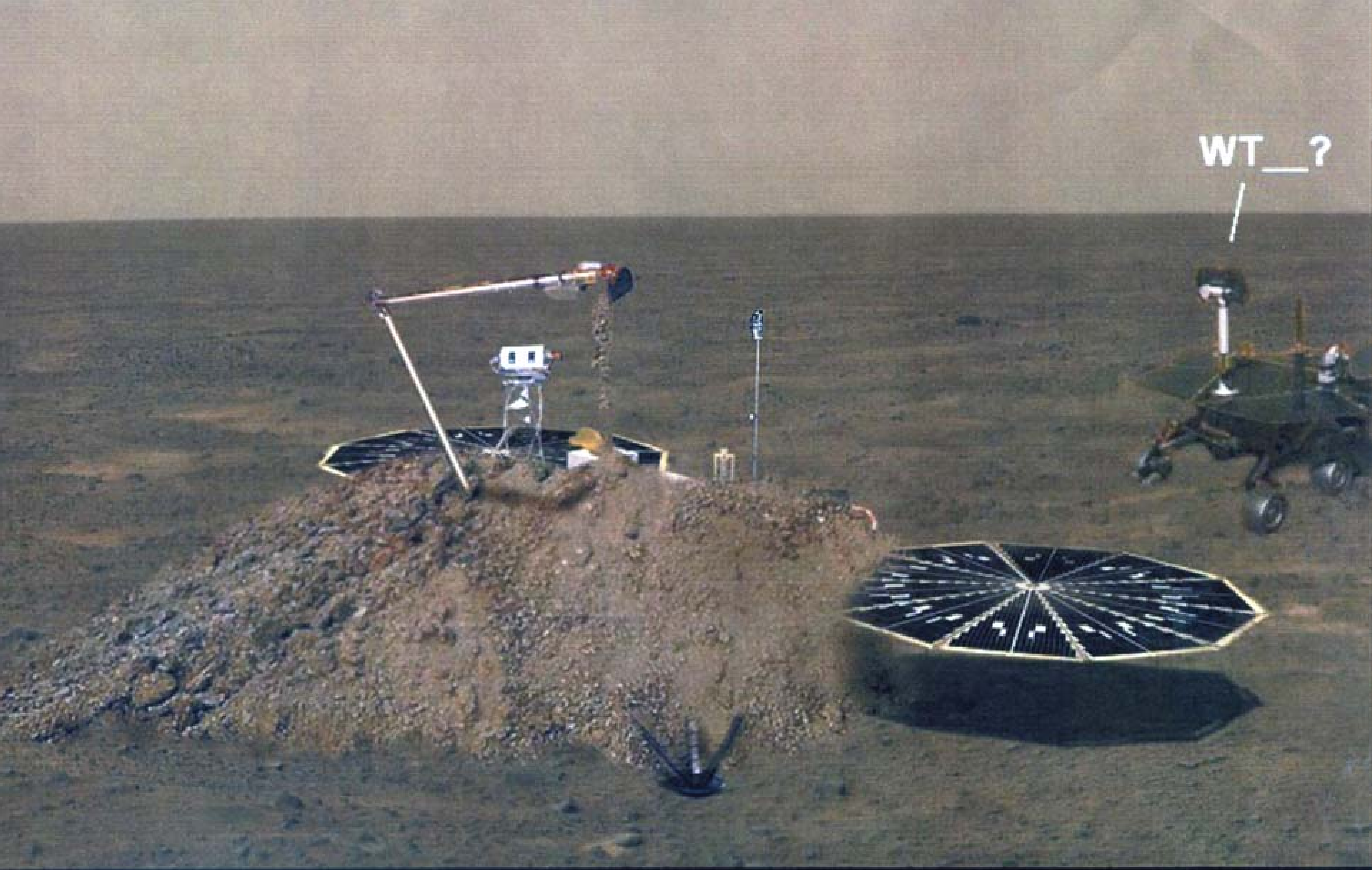


# Challenges of Putting Martian Soil into TEGA

Soils were cohesive

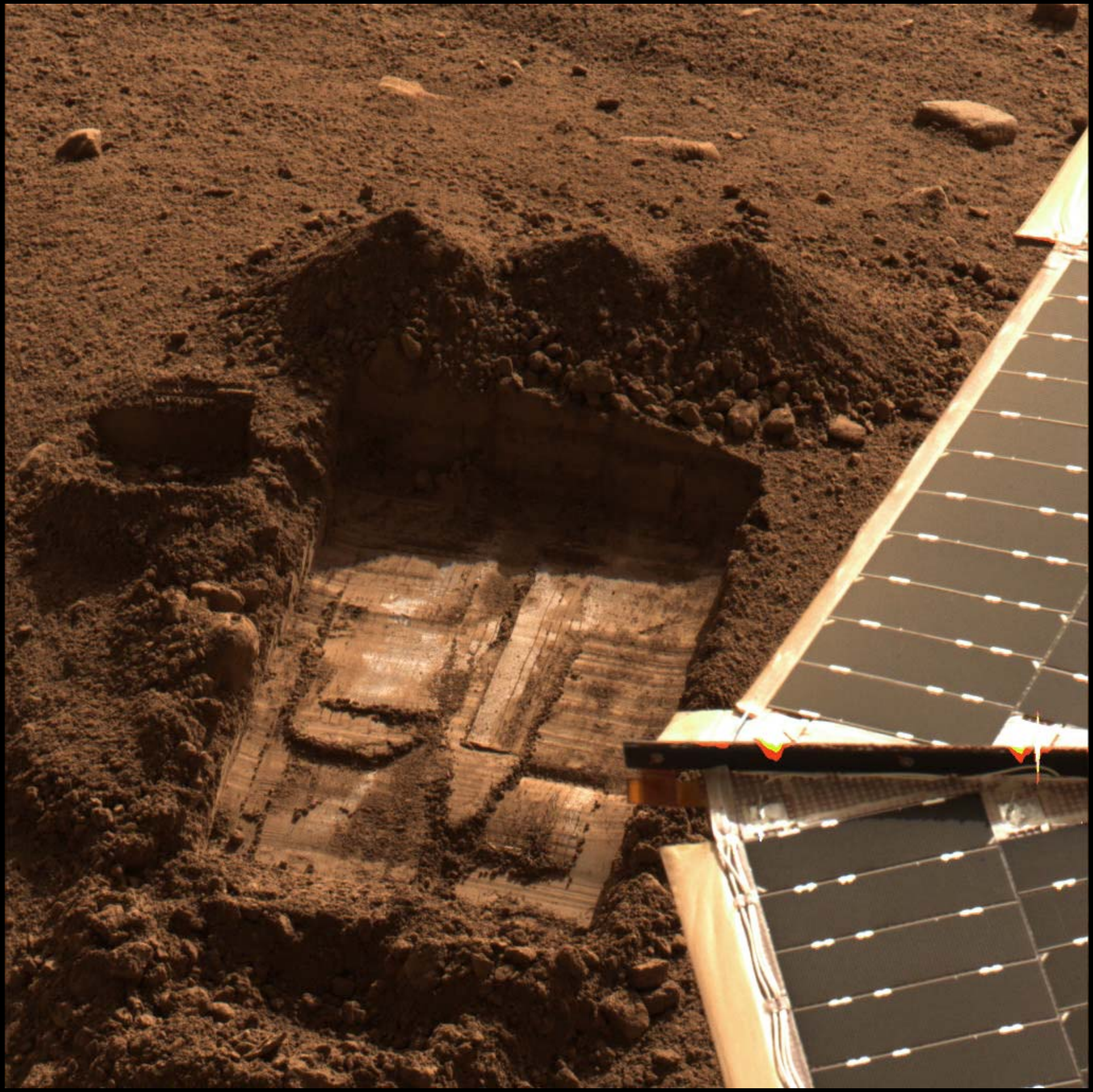
Candidate causes:

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

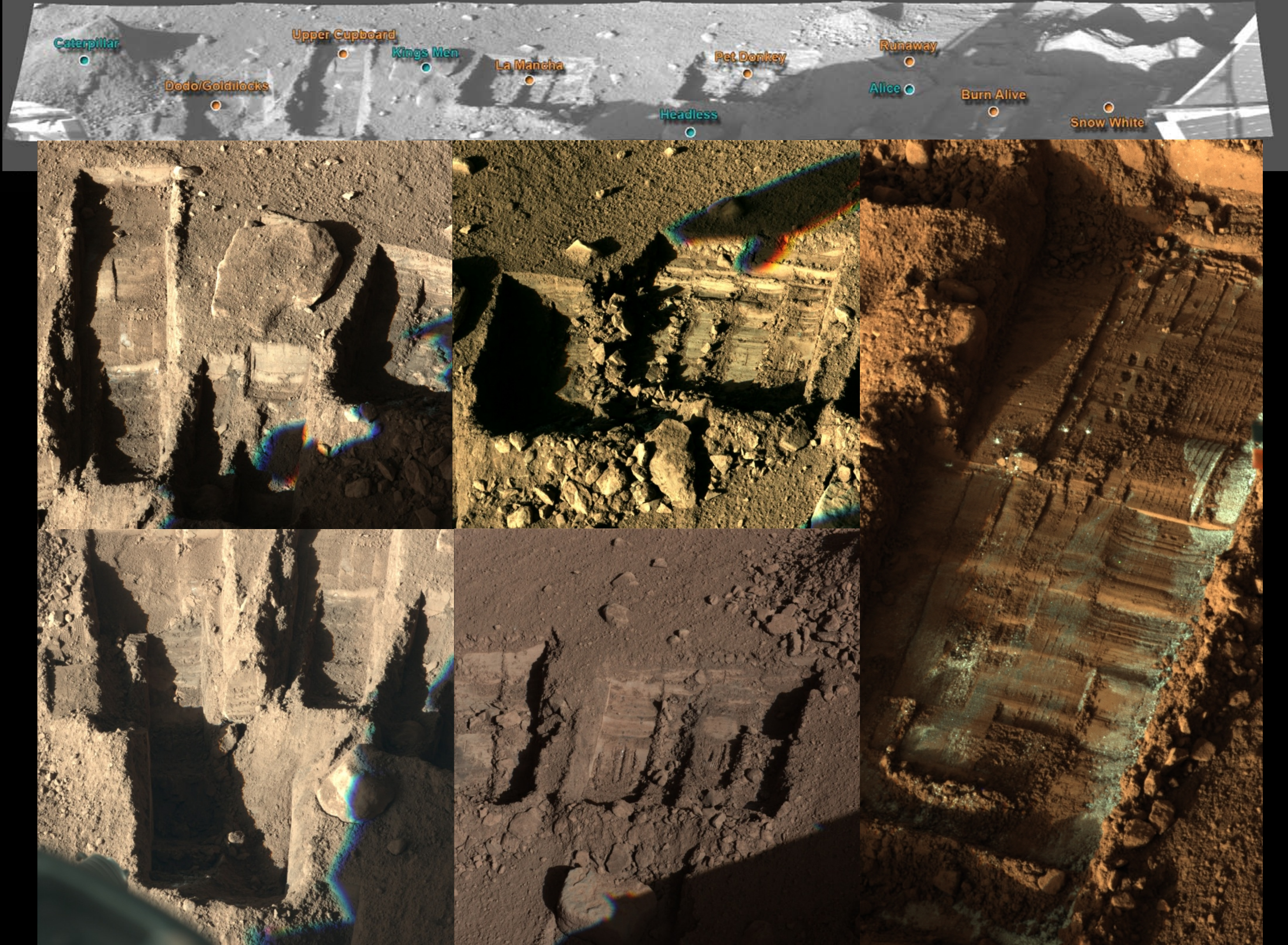



Phoenix attempts another sample delivery!

# Snow White trench – middle of polygon



# Snow White Trench and Drill Holes

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

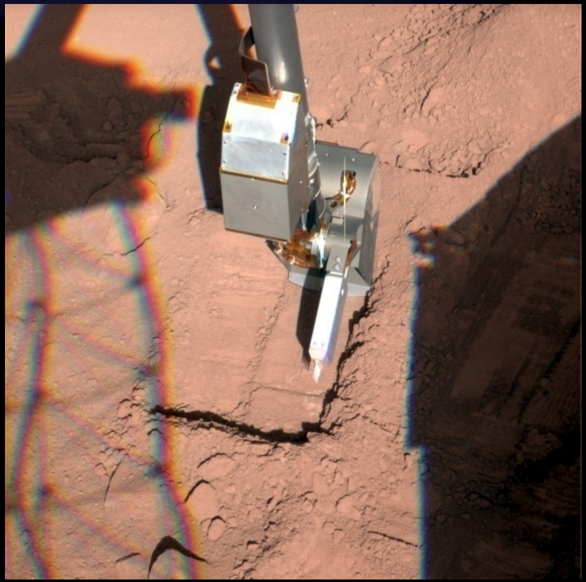
# Summary from imaging

- 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.

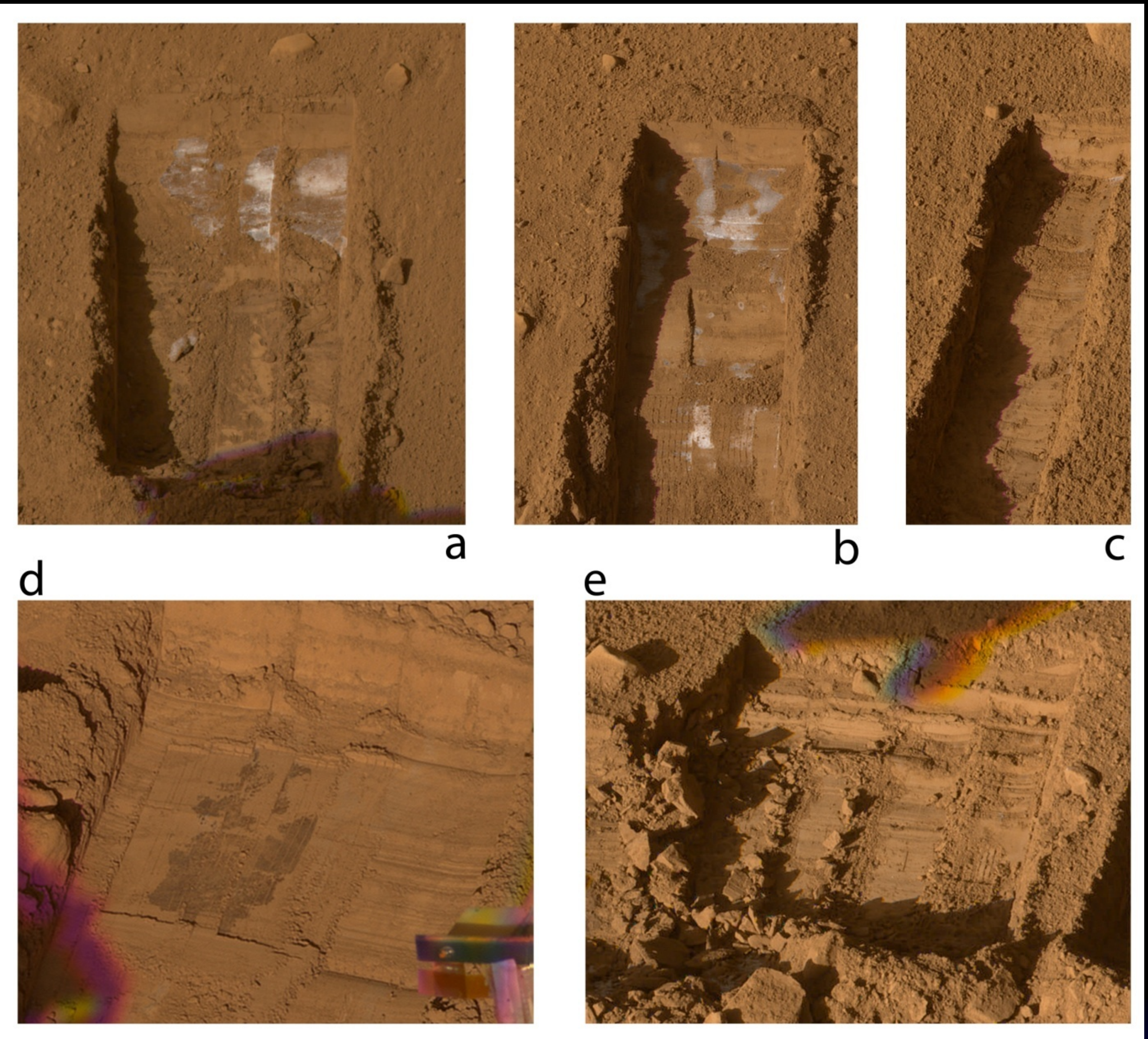
- Subsurface ice consistent with prediction.
- Depth of subsurface ice varies by 10x.
- Wide range of ice textures, concentration, and physical characteristics.

# 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.

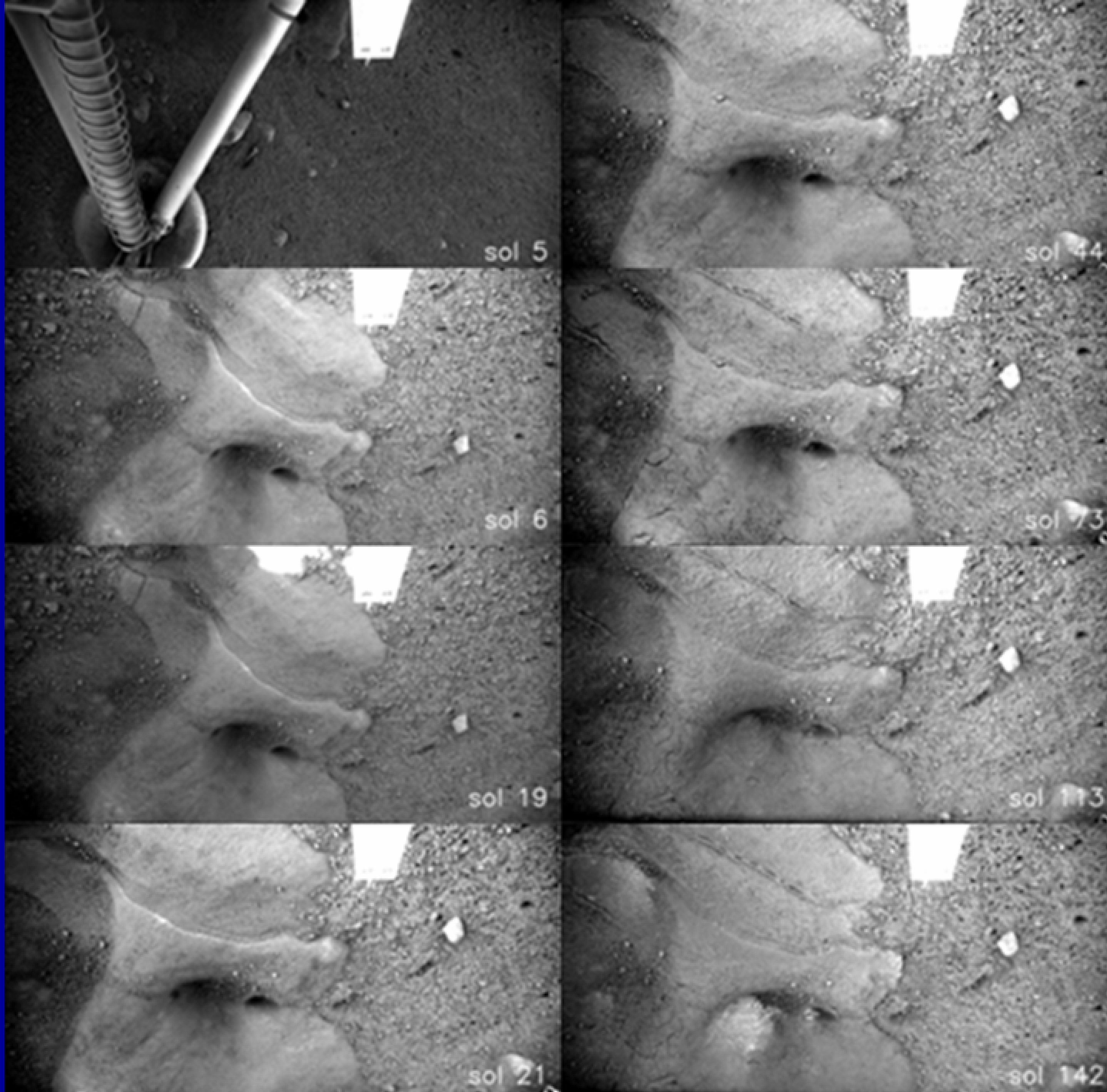


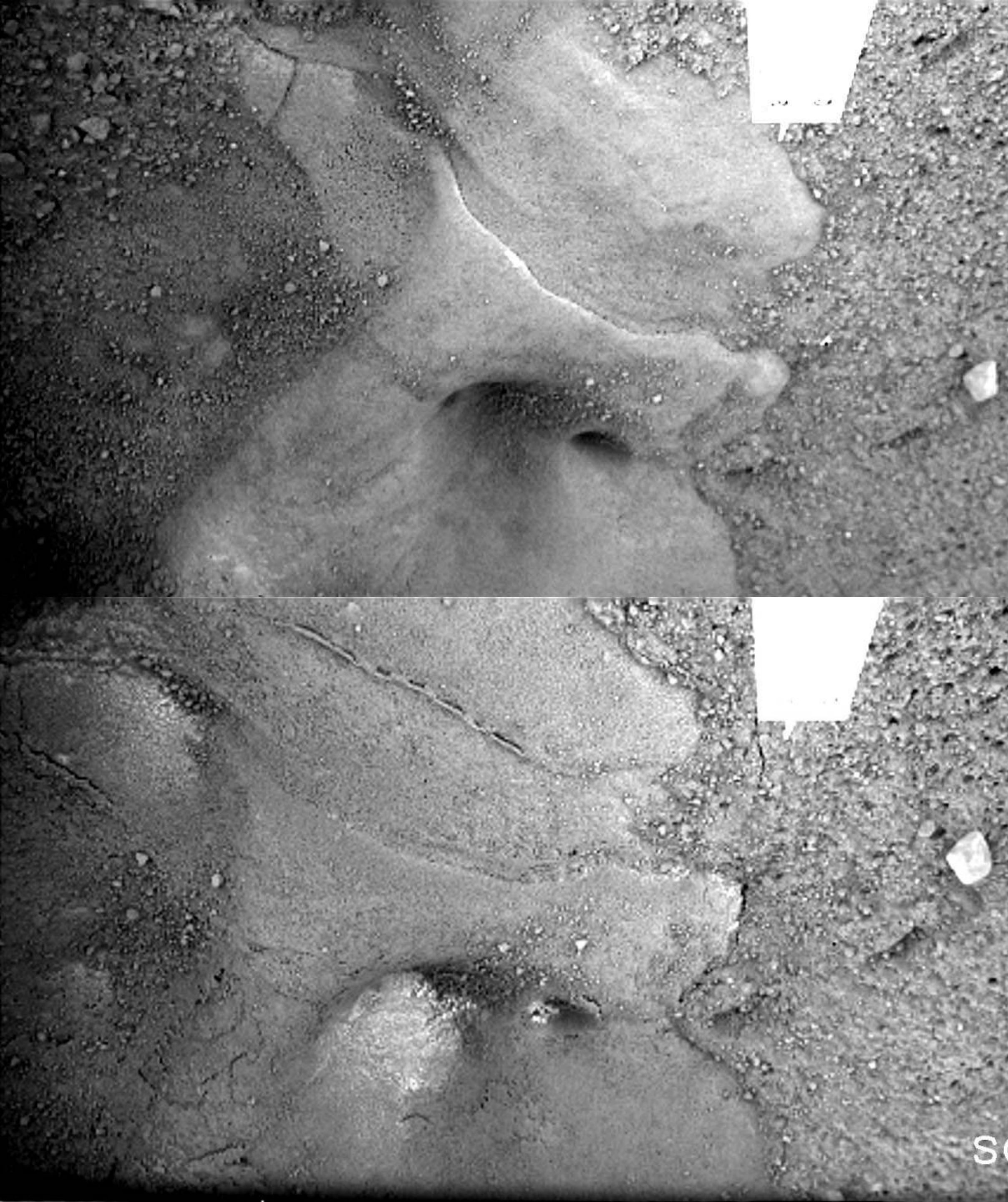
From Mellon et al., 2009

- 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

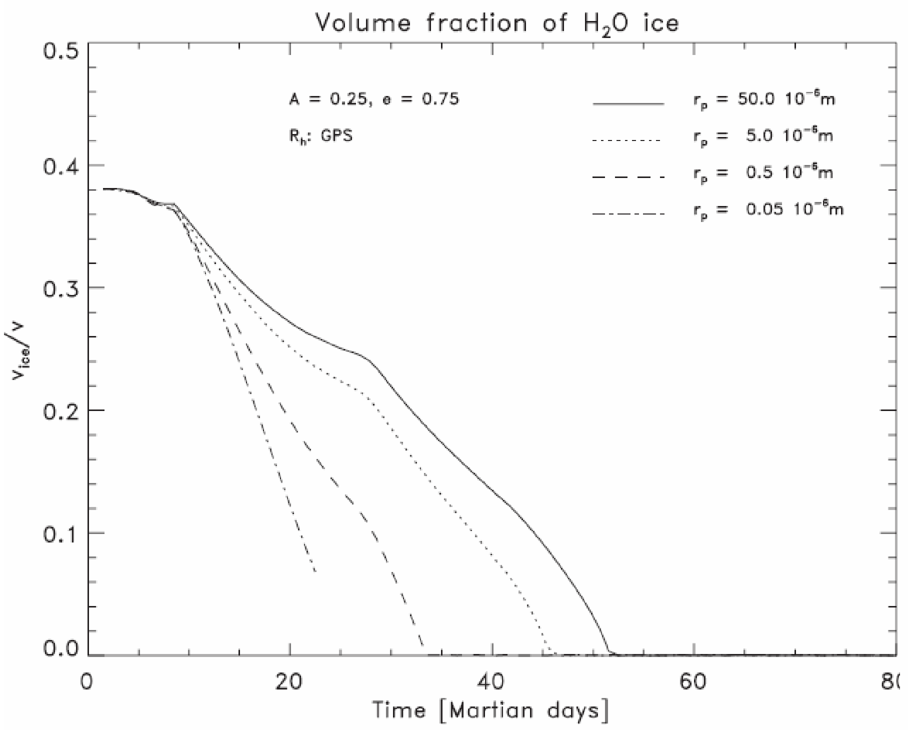
Snow Queen
Sol 21


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

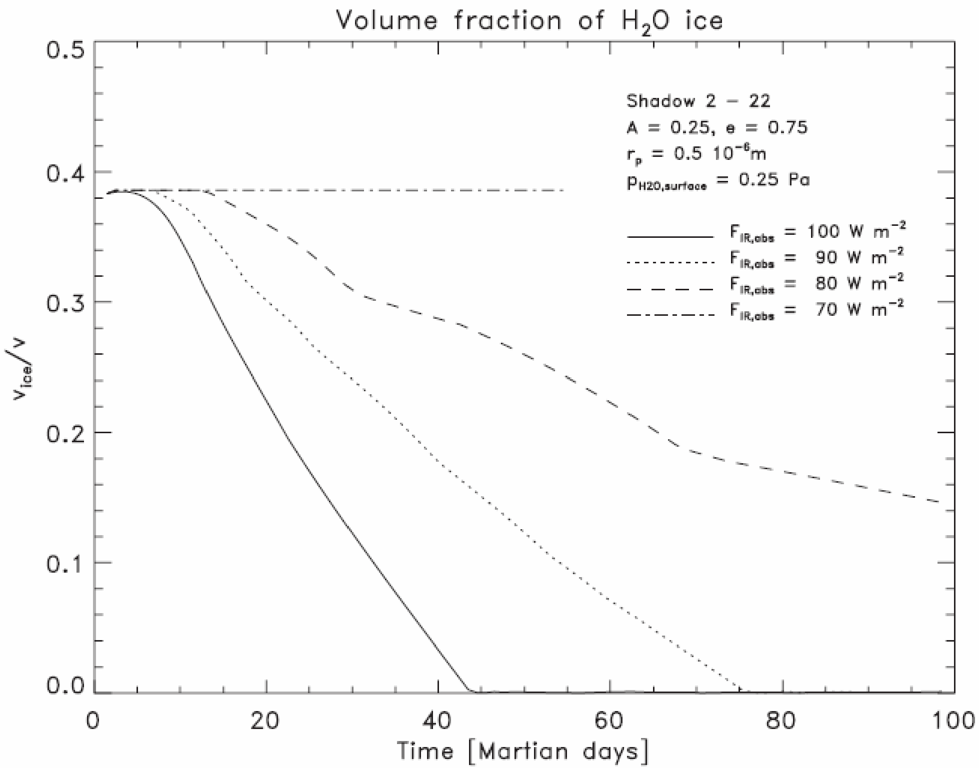


Sol 6

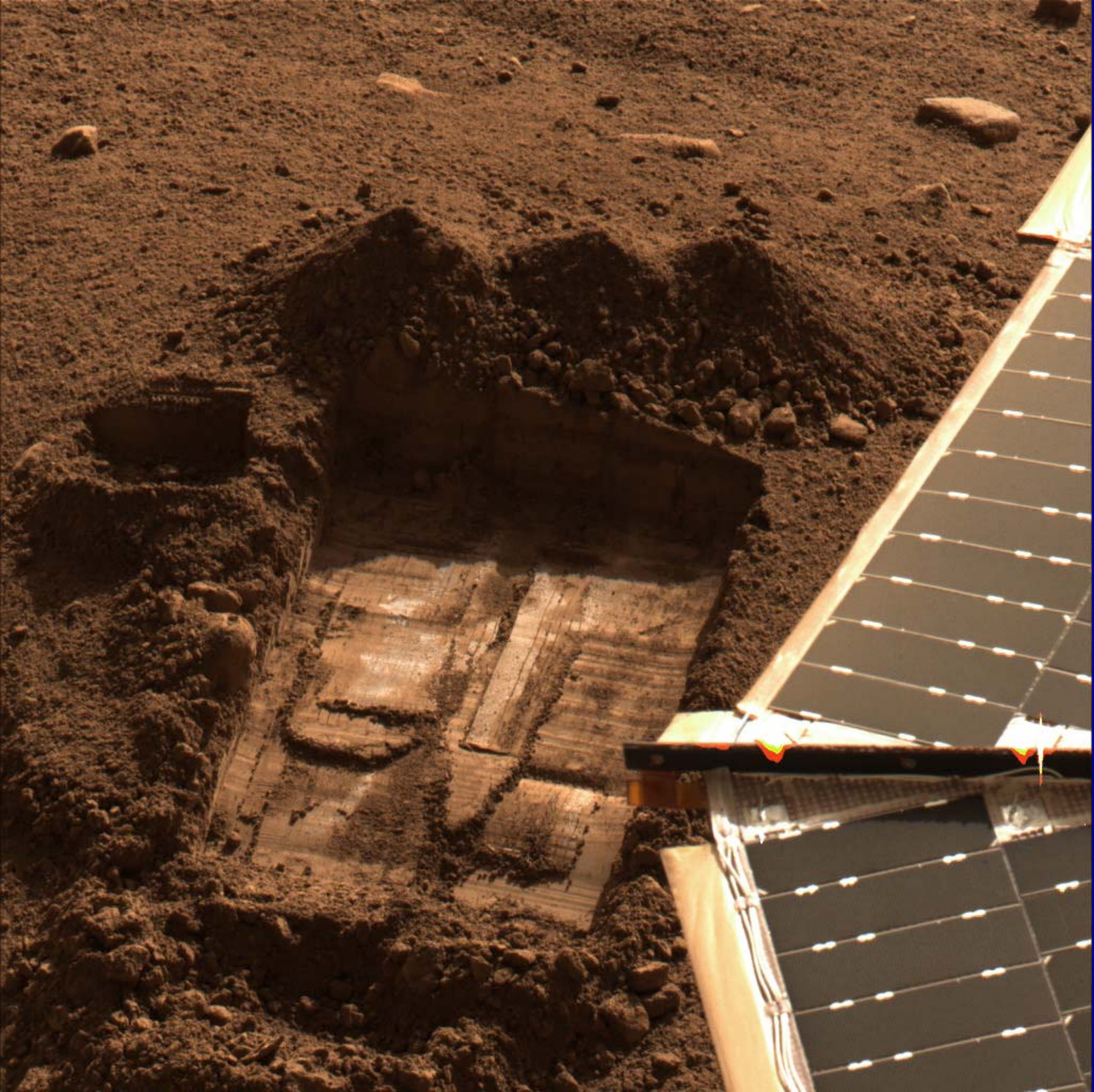
Sol 142



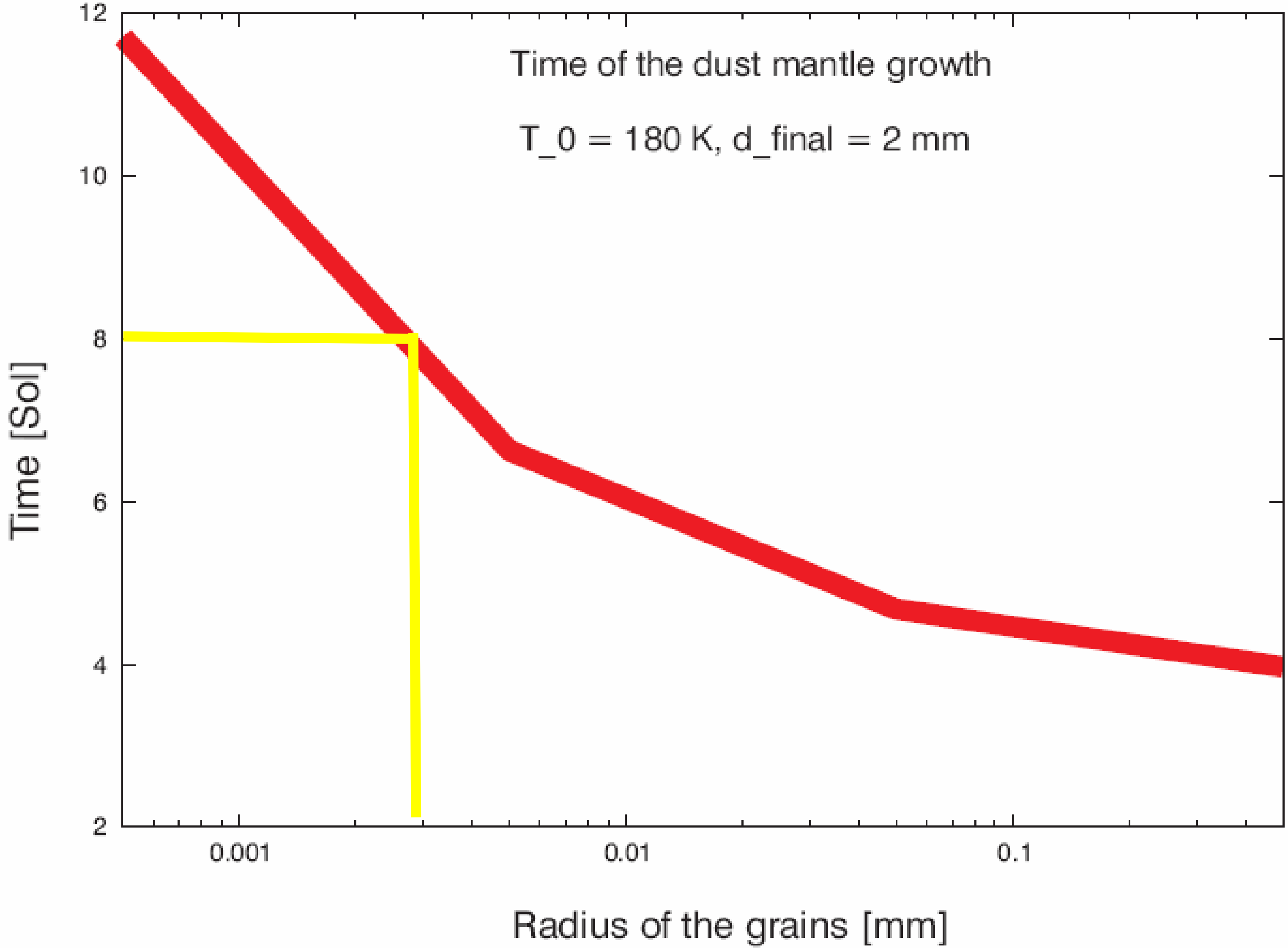

**particle size**




**Energy input**
**- difficult to constrain**

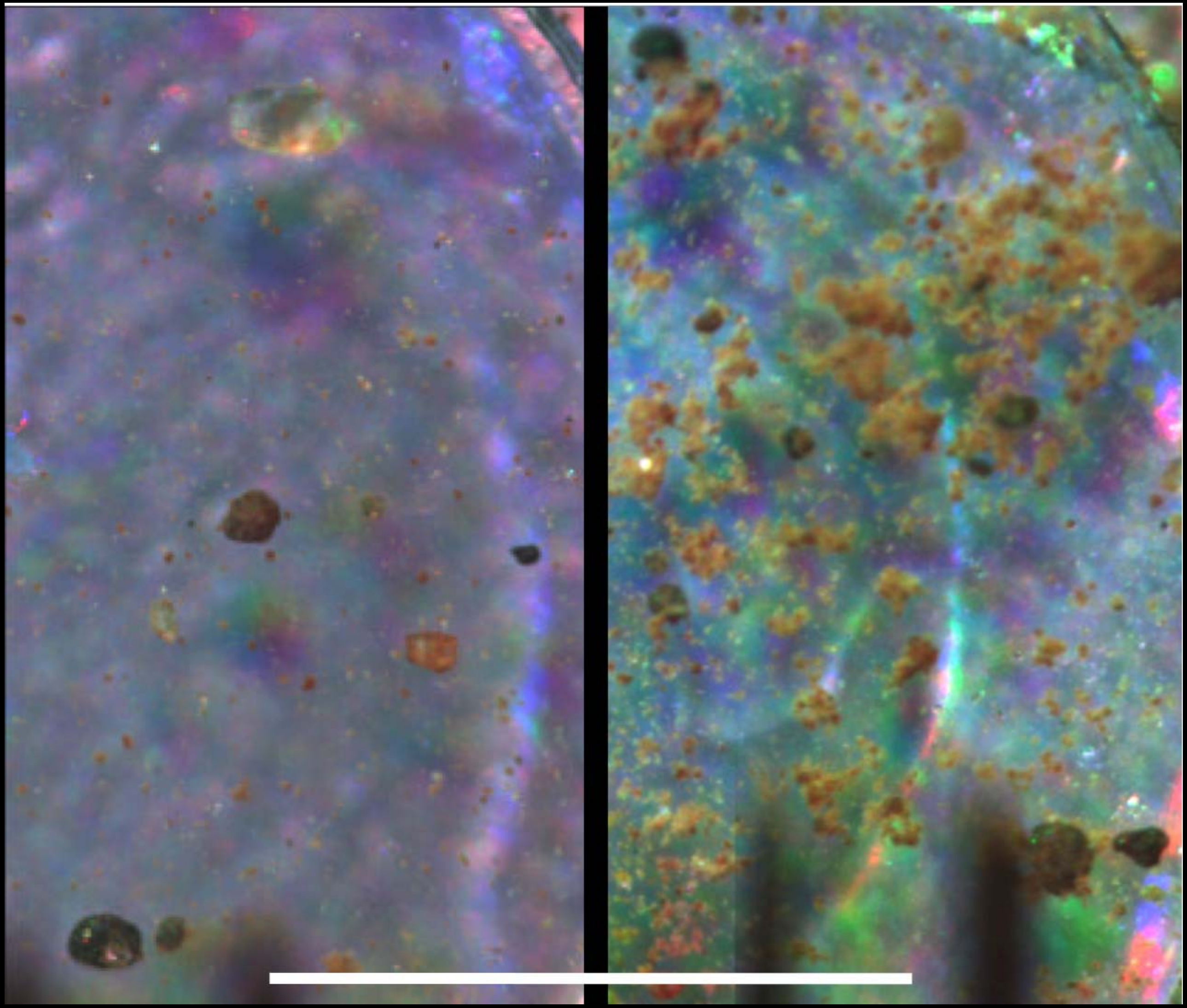


2 mm
dust mantle
formed
in
about 8 sols




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

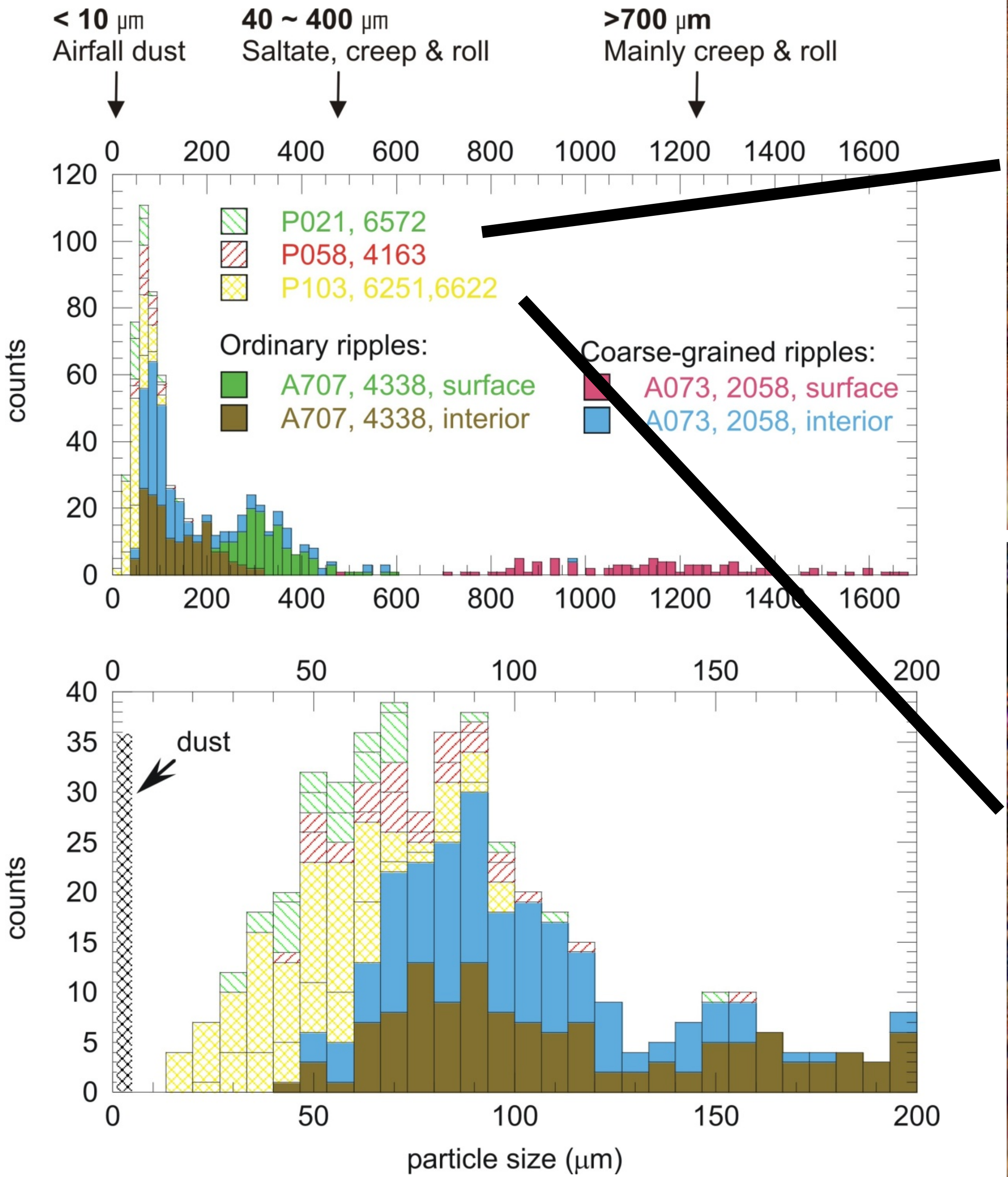
# Soil in the Optical Microscope

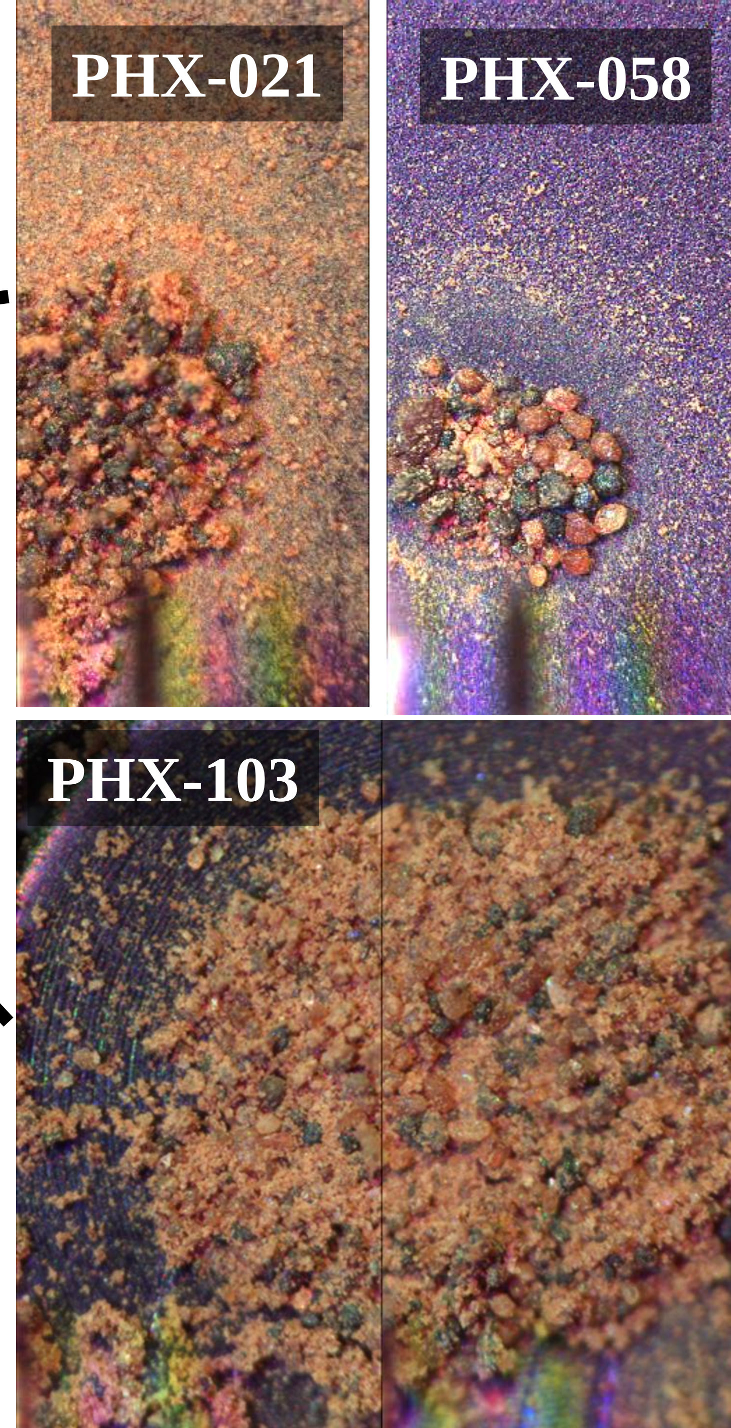


# Soil on the Strong Magnet Substrate
# Optical Microscope Image
# (surface sample)

- 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:<br>Submicron, magnetic, | ~ Martian airborne dust |
| Translucent, red-to-brown particles:<br>Silt-/sand-sized, substantially magnetic | glassy, common origin?,<br>tectites from Heimdall or volcanic glasses with crystalline magnetic inclusions (Fe, more likely Ti-magnetite) |
| Opaque, black particles:<br>Silt-/sand-sized, substantially magnetic | common origin (likely), basaltic particles containing Ti-magnetite, crystalline? |
| Whitish particles,<br>some of them cube-shaped or rod-shaped ...<br>silt-sized, magnetic properties? | perchlorates, chlorides, carbonates?<br>Why not invisible coatings on each partcile? |

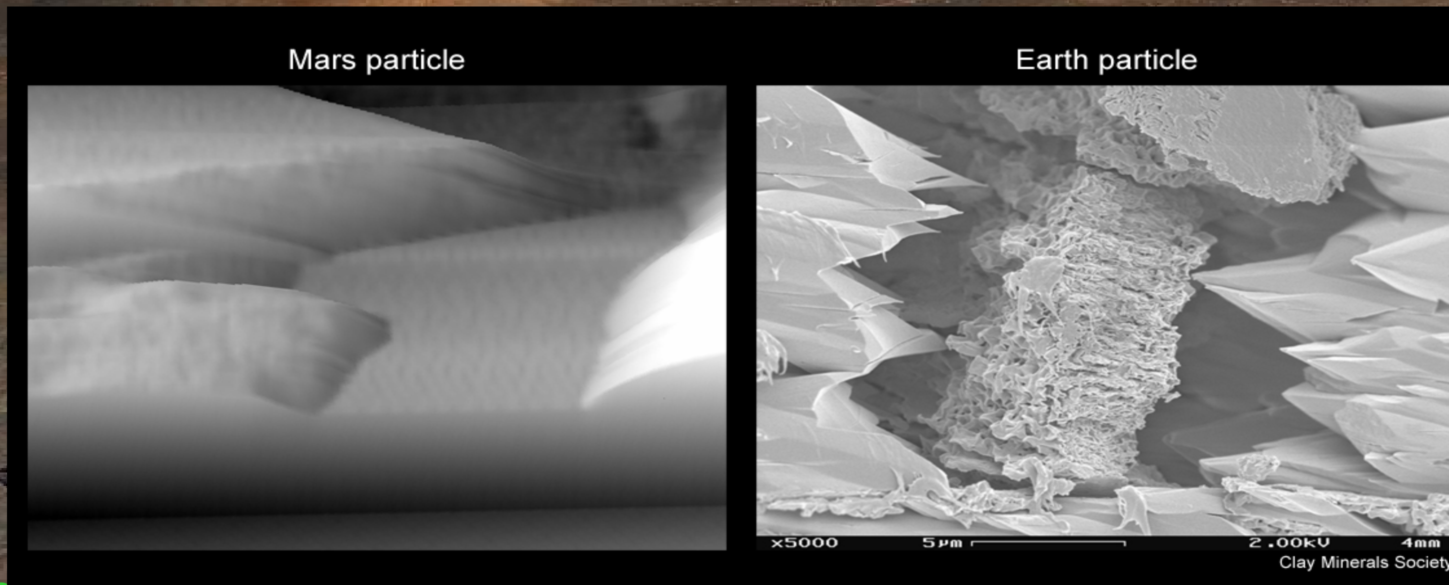
***Global component in PHX soil?***

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

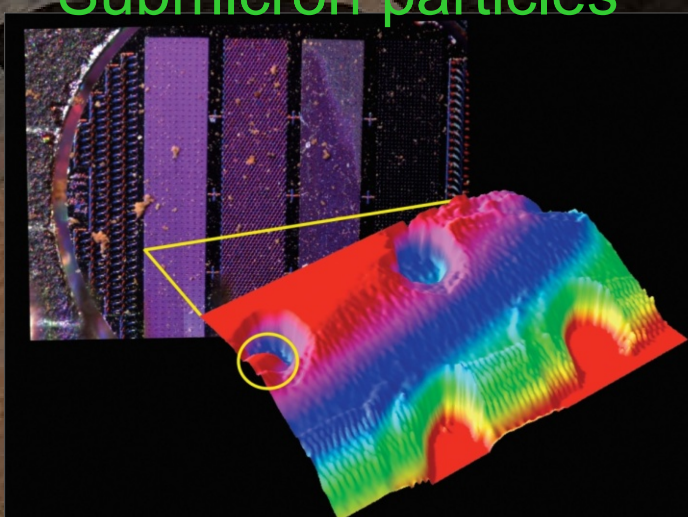
***Alteration by continuous presence of water vapor/ice?***

**WG, 06-Mar-2009**

# Mineralogy: AFM



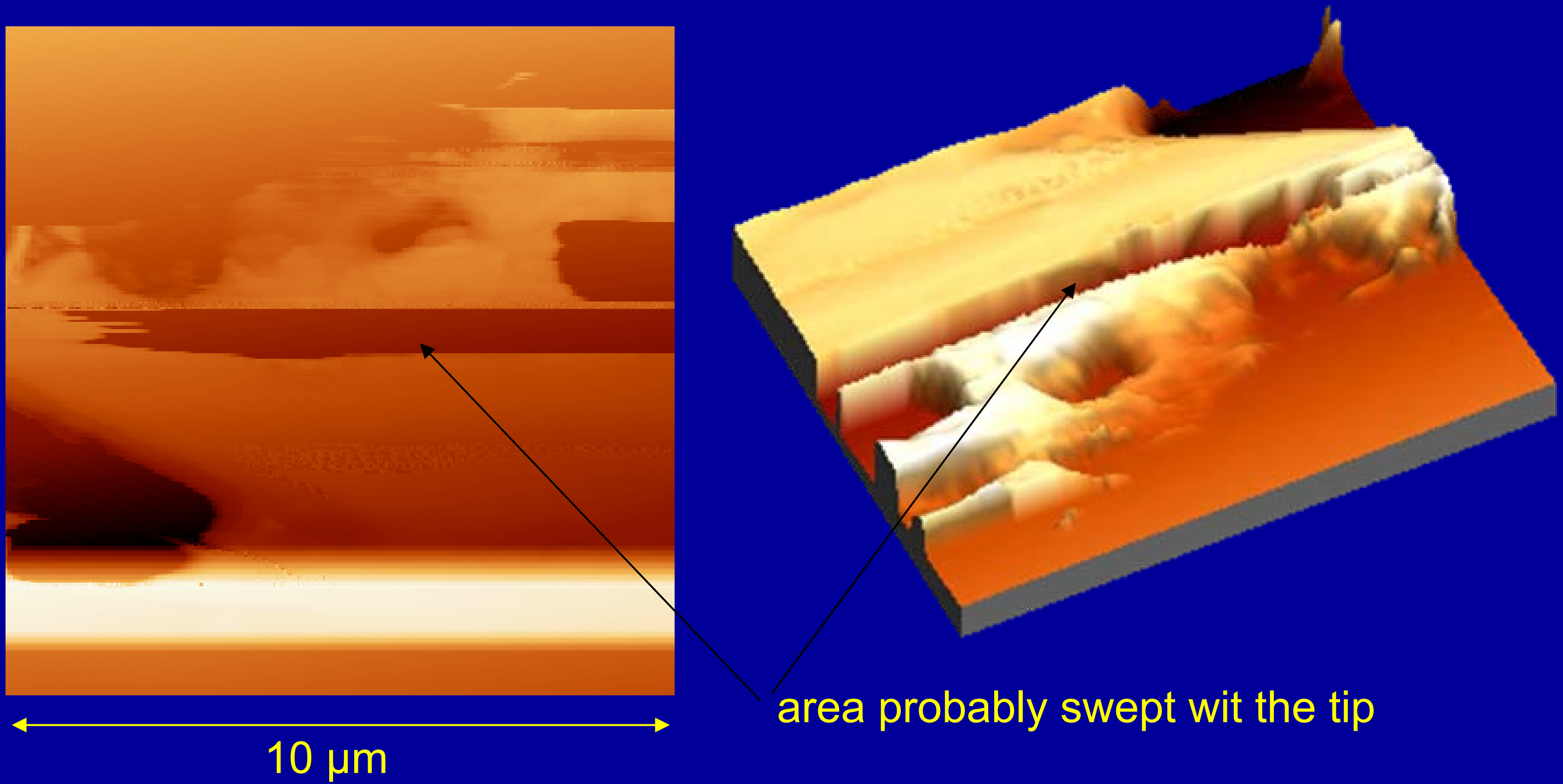

Submicron particles



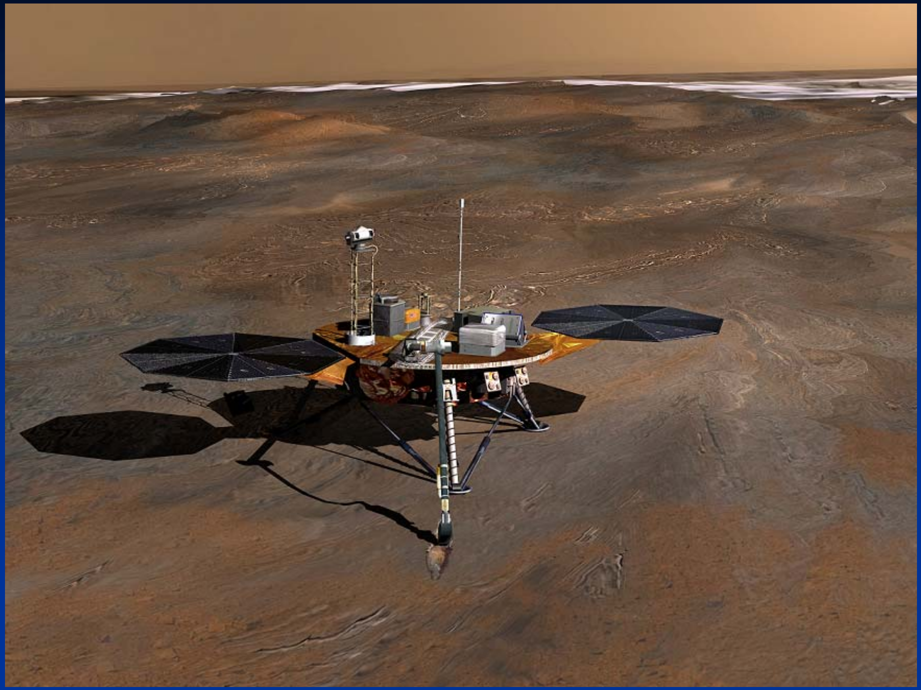
The AFM sees what is very similar to sheet silicates ( clay minerals )

Sorceress from Sol 79

# AFM - very fine conglomerates at target A substrate #60



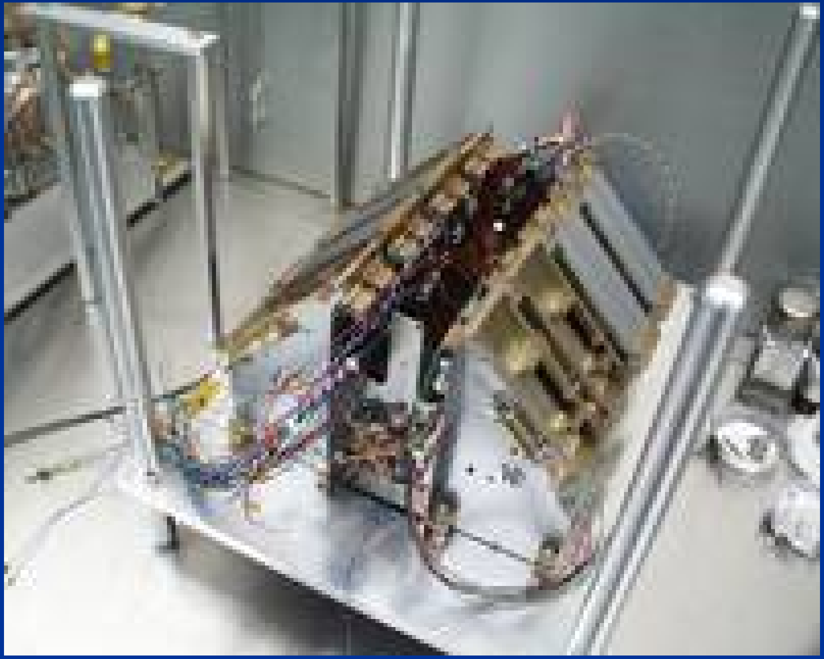

error signal -> z coordinate not calibrated!



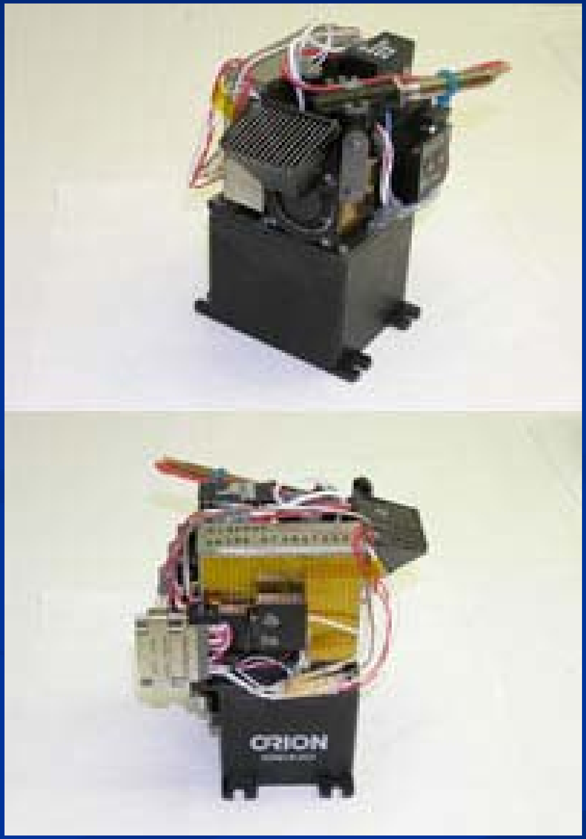
# Chemistry Results of the Phoenix Mission

M. Ramy El Maarry

# The Instruments



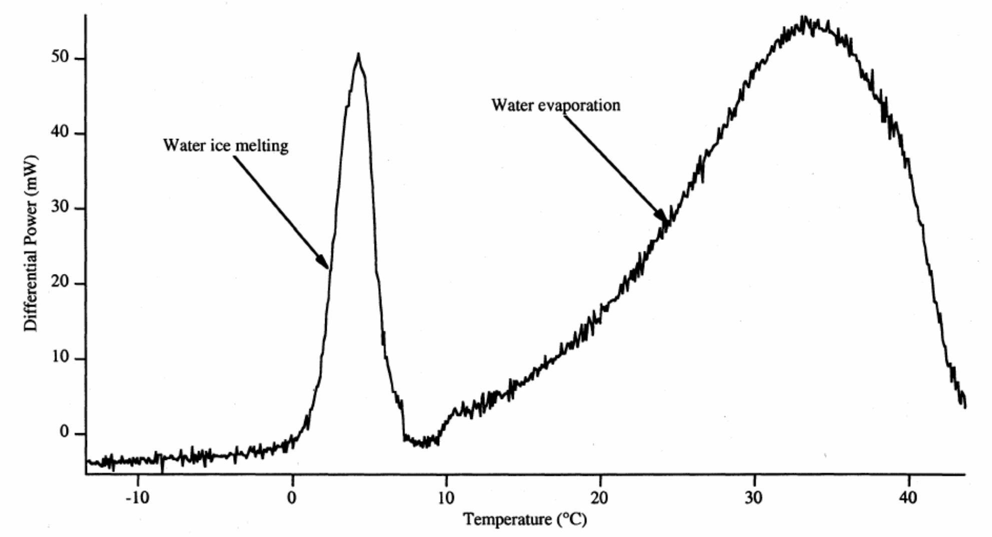
Thermal and Evolved Gas Analyzer **(TEGA)**




Wet Chemistry Lab
(WCL)

# Thermal and Evolved Gas Analyzer (TEGA)

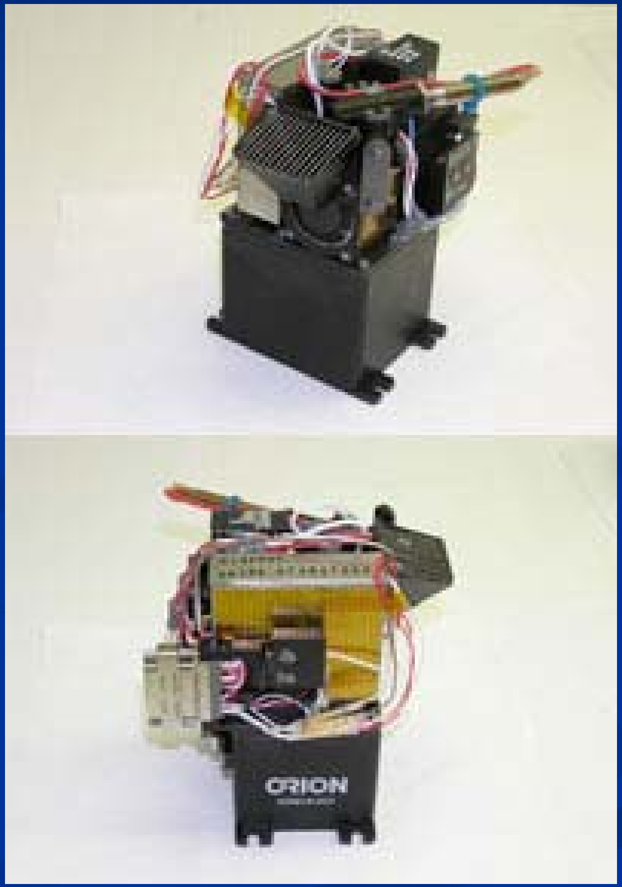
- Comprises two main components:
- ⇒ A thermal analyzer that investigates phase transitions
- ⇒ An evolved gas analyzer that detects and quantifies the amount of volatiles during sample heating
- Sample is heated in a stage-like manner (up to 35 °C, 350 ° C, 1000 ° C)
- Analyzed 5 Martian icy-soil samples




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)

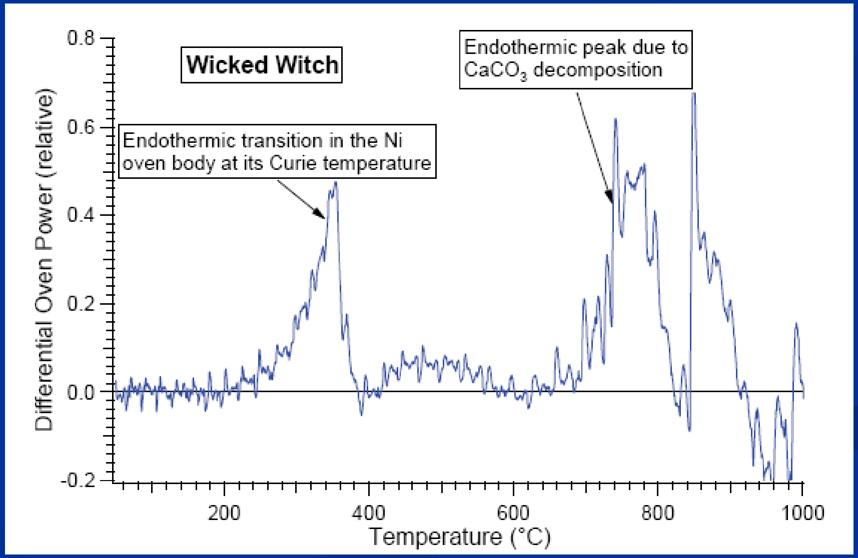
# Implications

- 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)



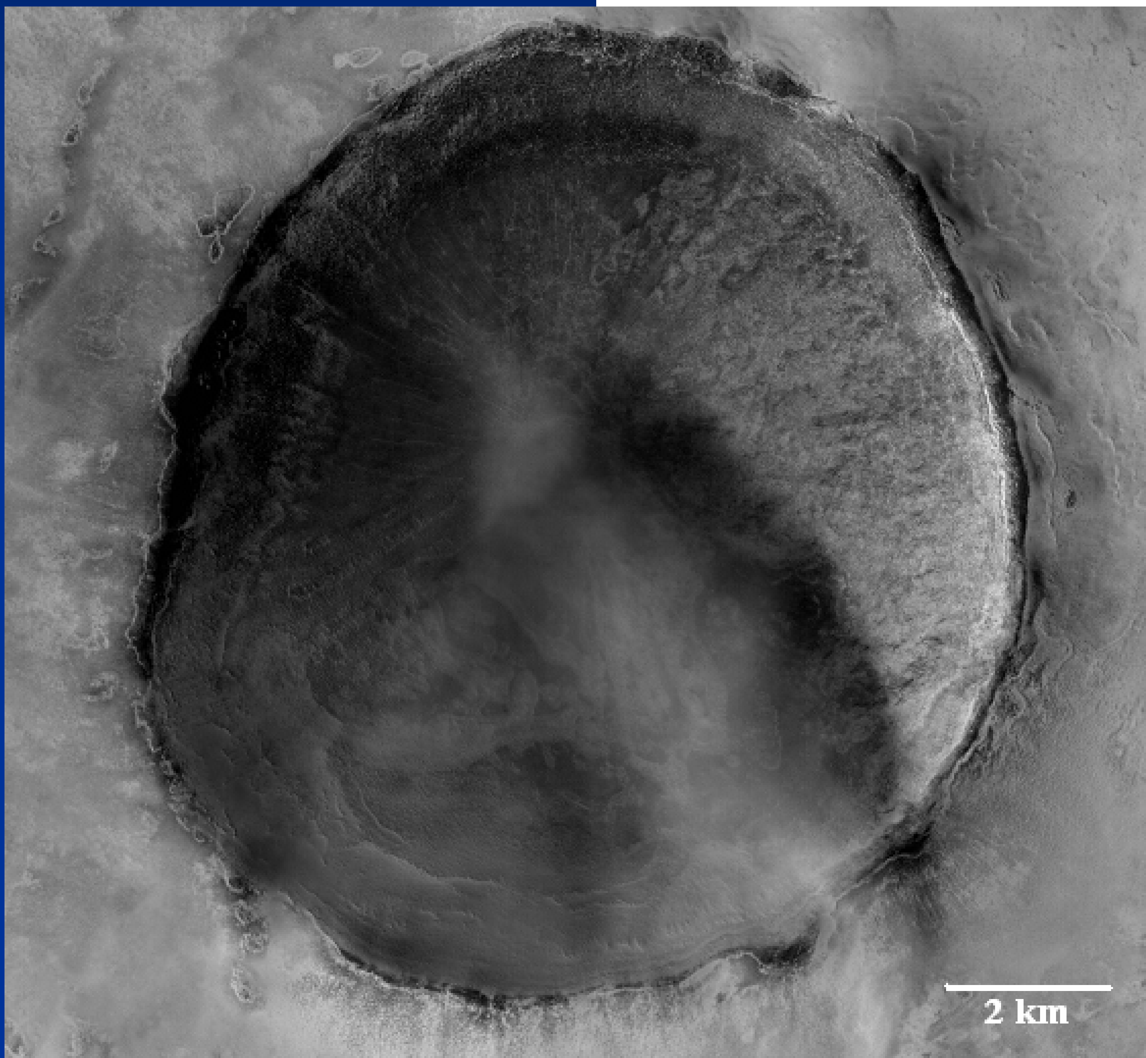

Boynton et al., LPSC 2009

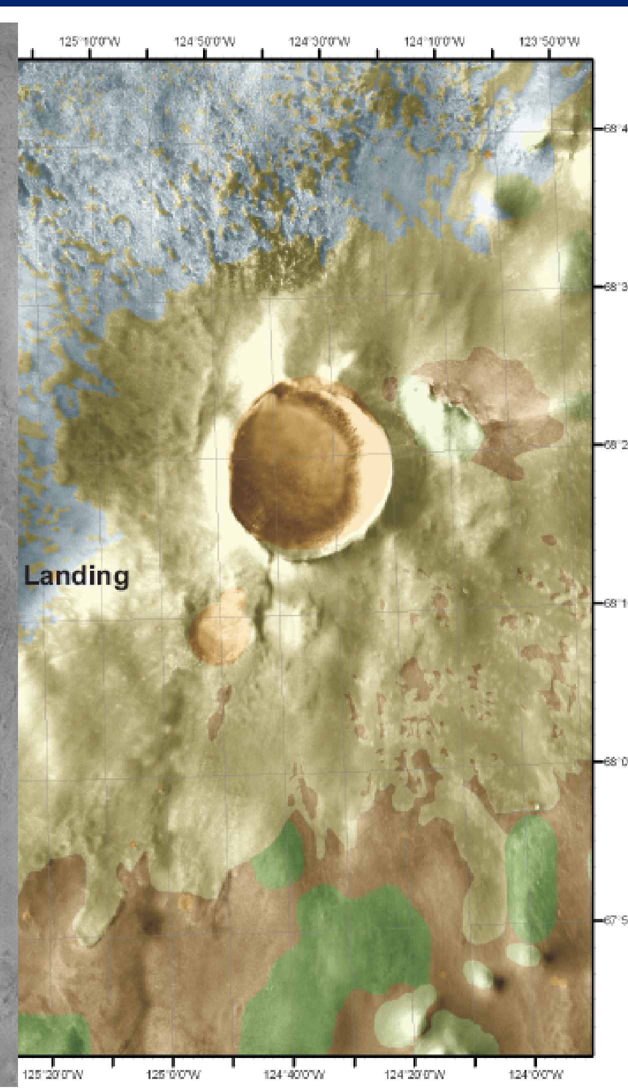
# Implications

- 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.

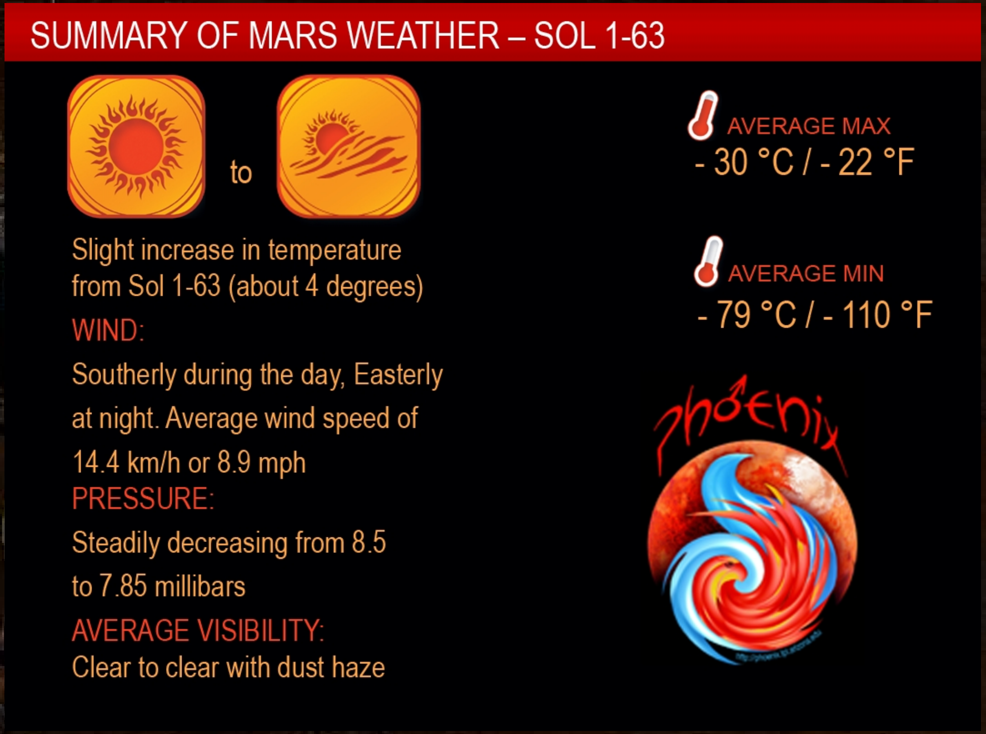
→ Acts as an energy source for some life forms!

# 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.

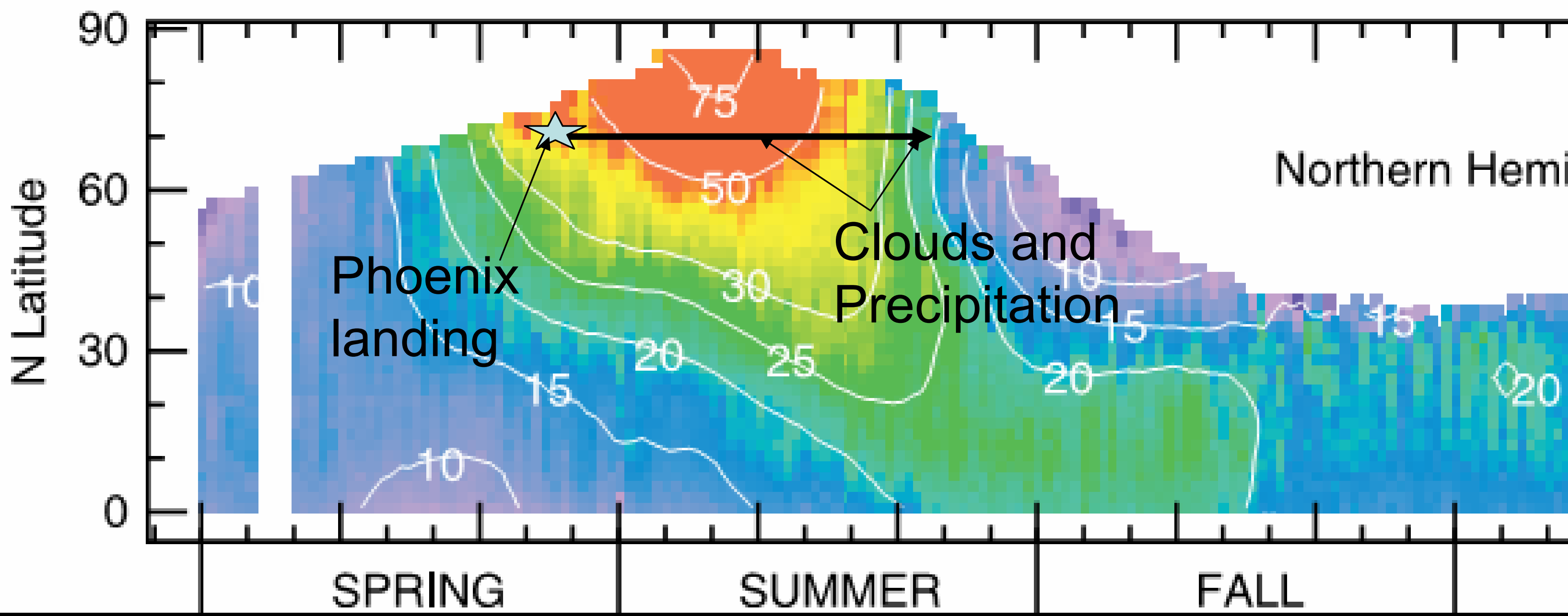
# Atmospheric Science
# General Weather

- 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

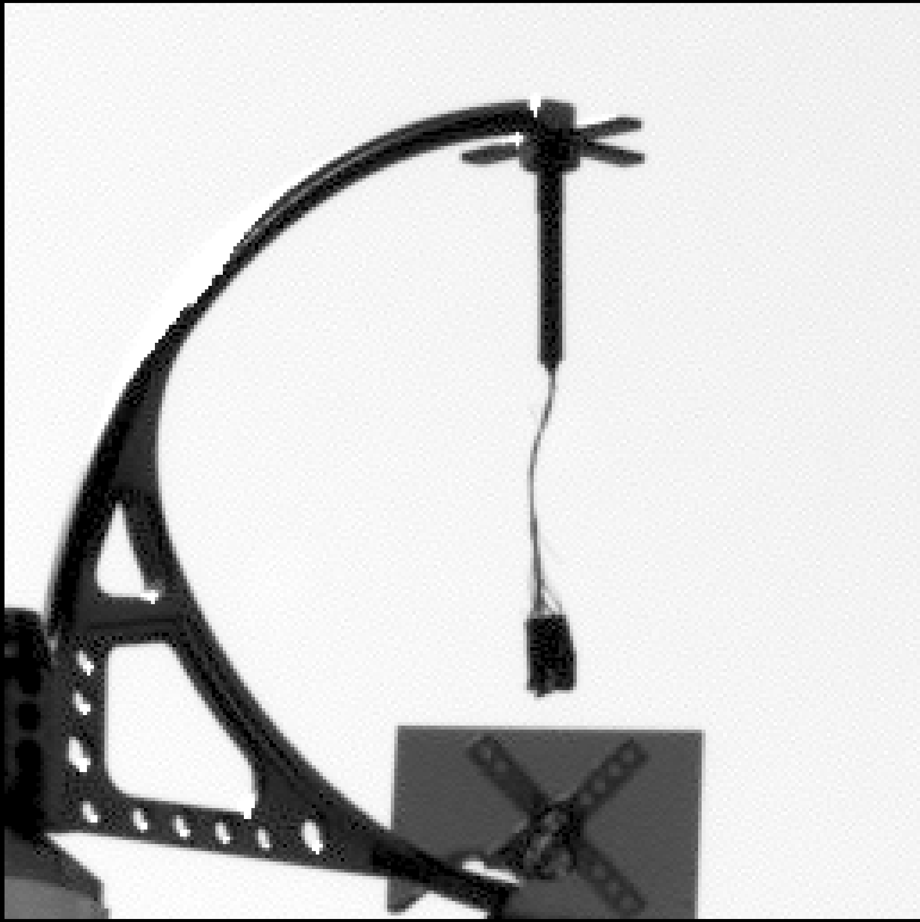
## Thermal Emission Spectrometer (Smith, JGR, 2002)



# Images from the SSI camera

# Winds on Mars

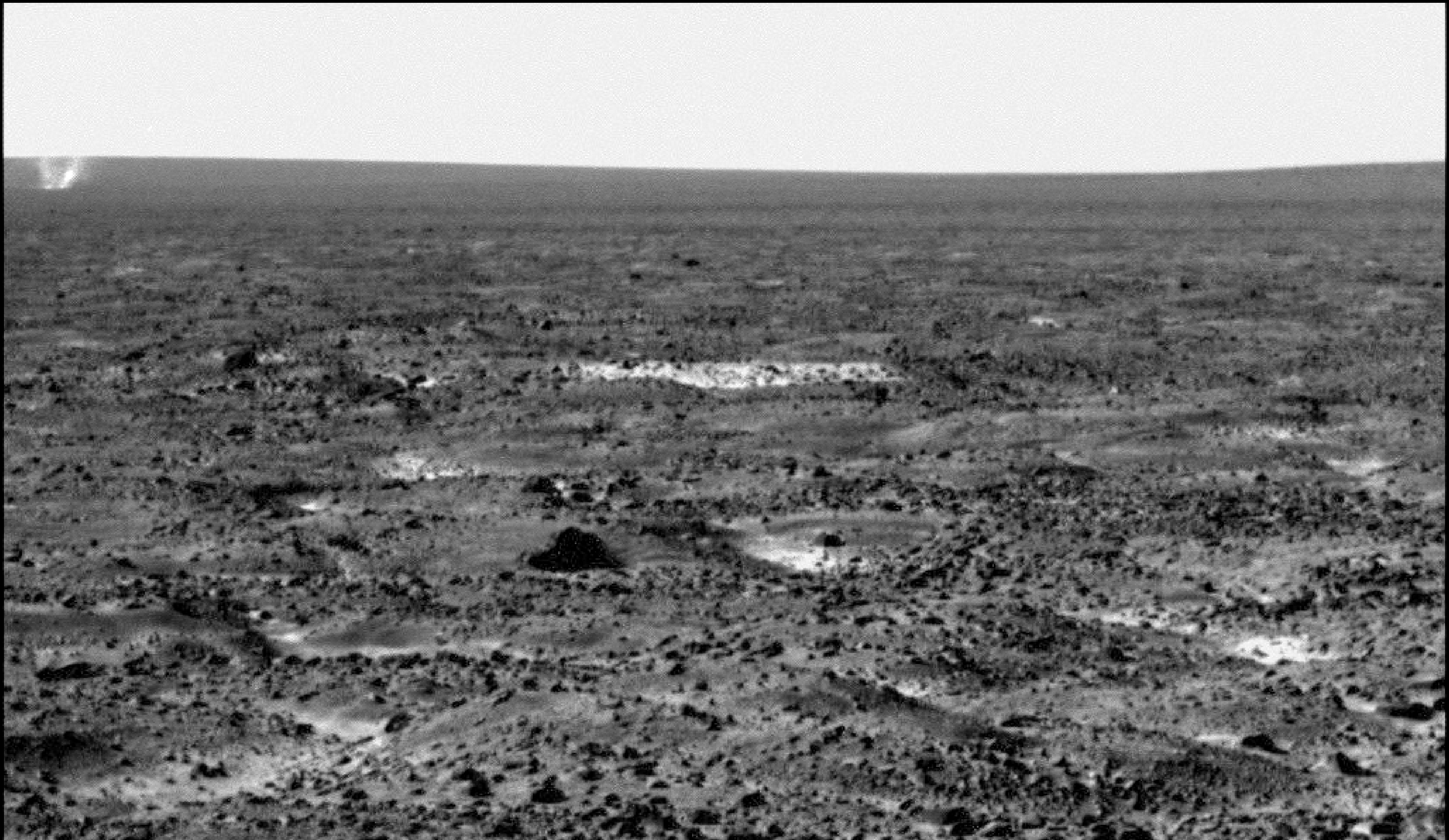
## The Telltale



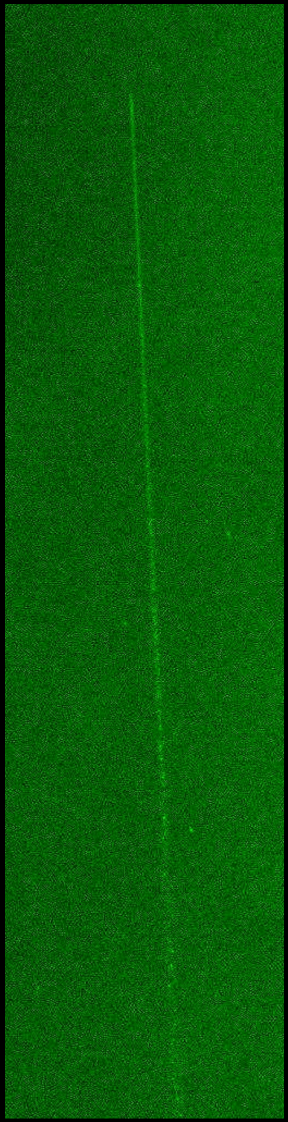
Winds from all directions
about 5m/s

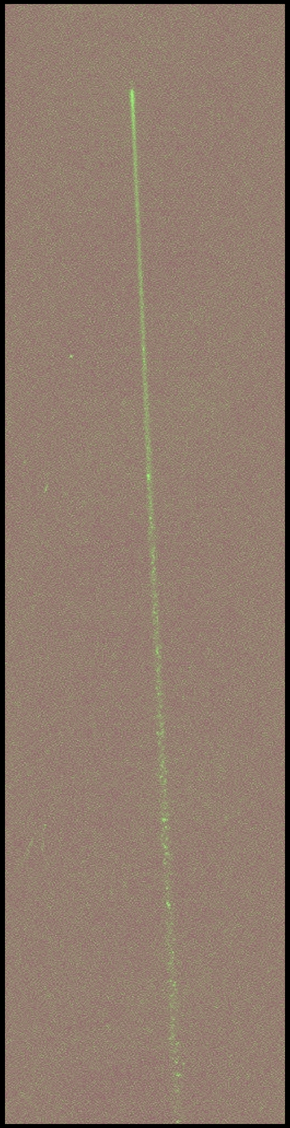
# Winds on Mars

## Dust Devils

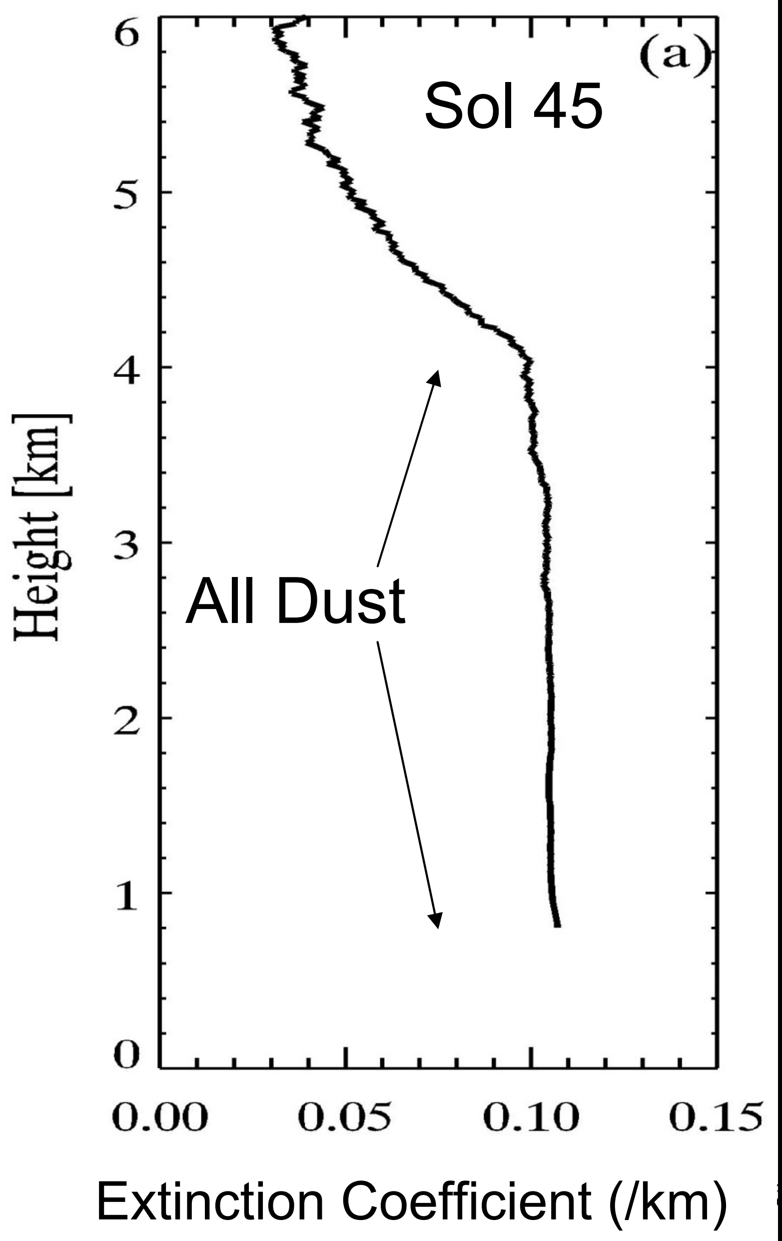


# MET/Lidar

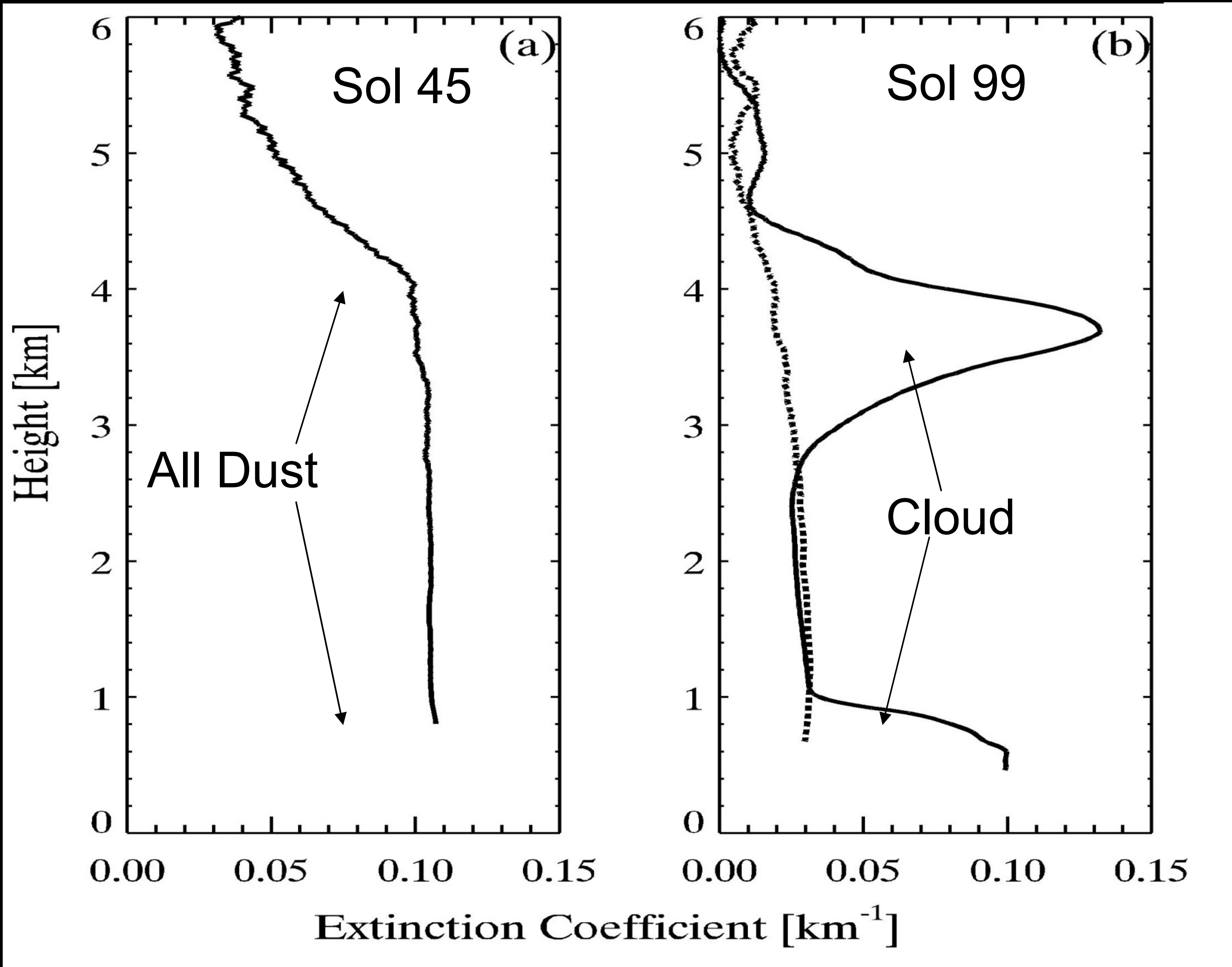





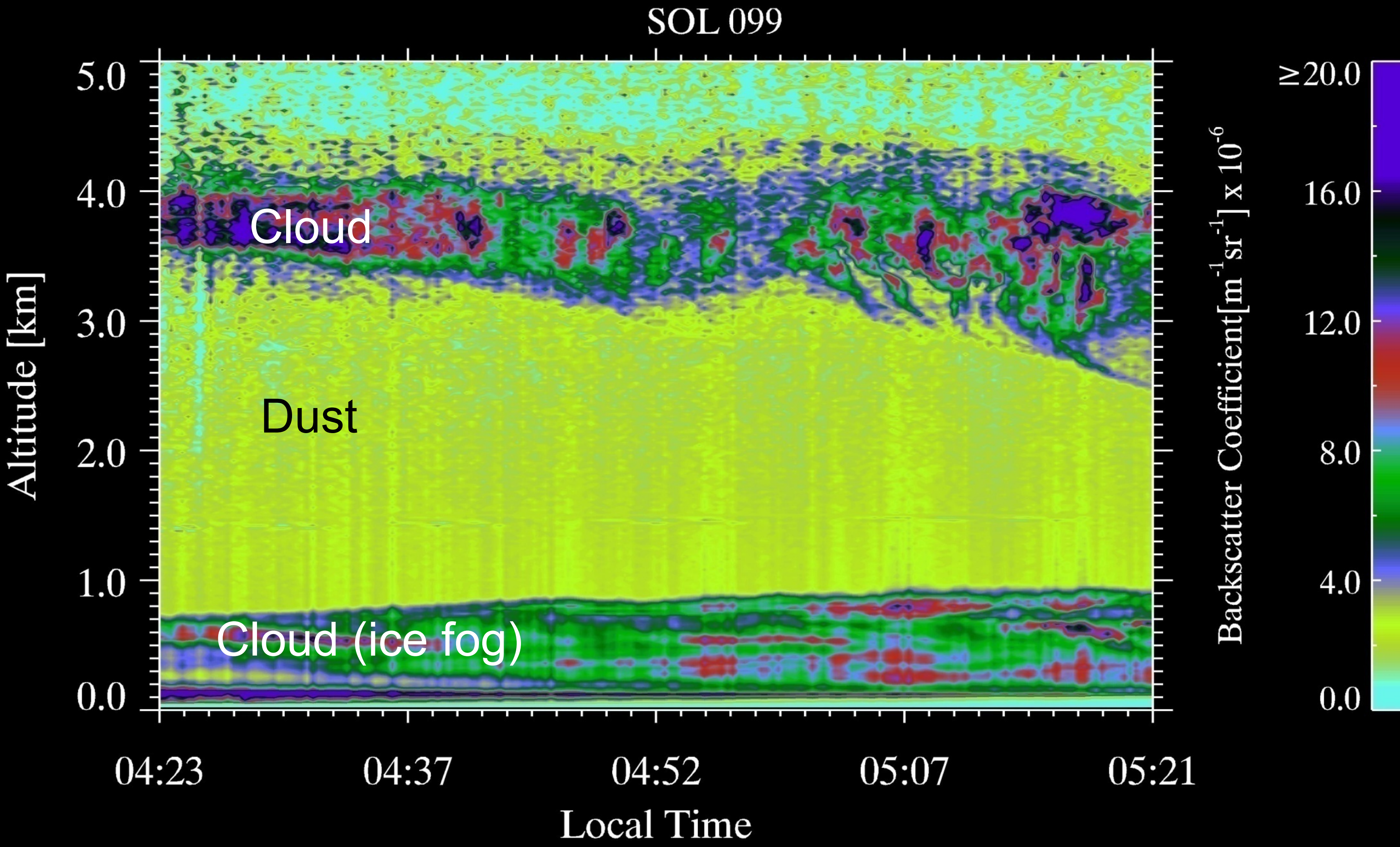
# Height Distribution of Dust and Ice



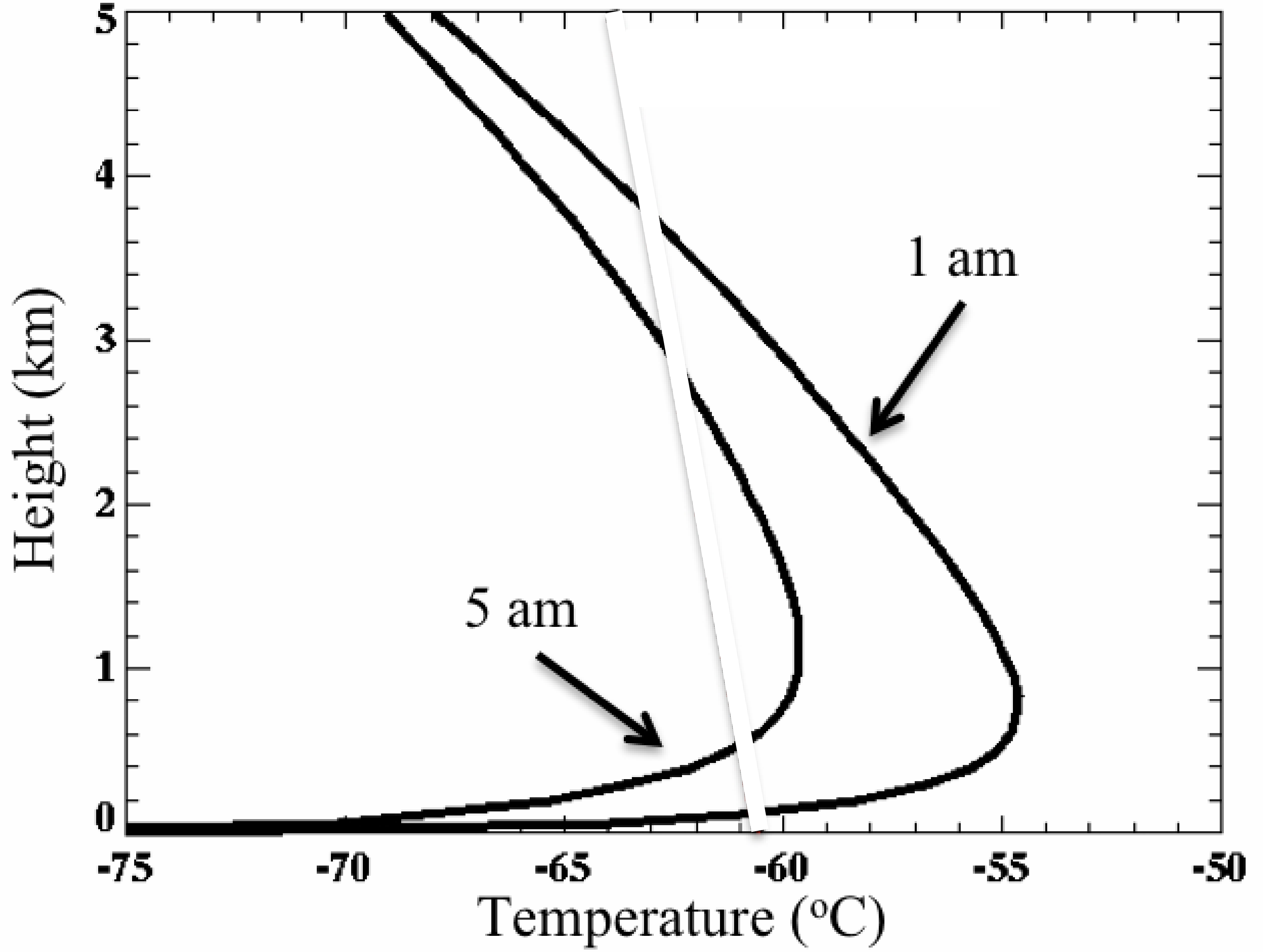
# Height Distribution of Dust and Ice



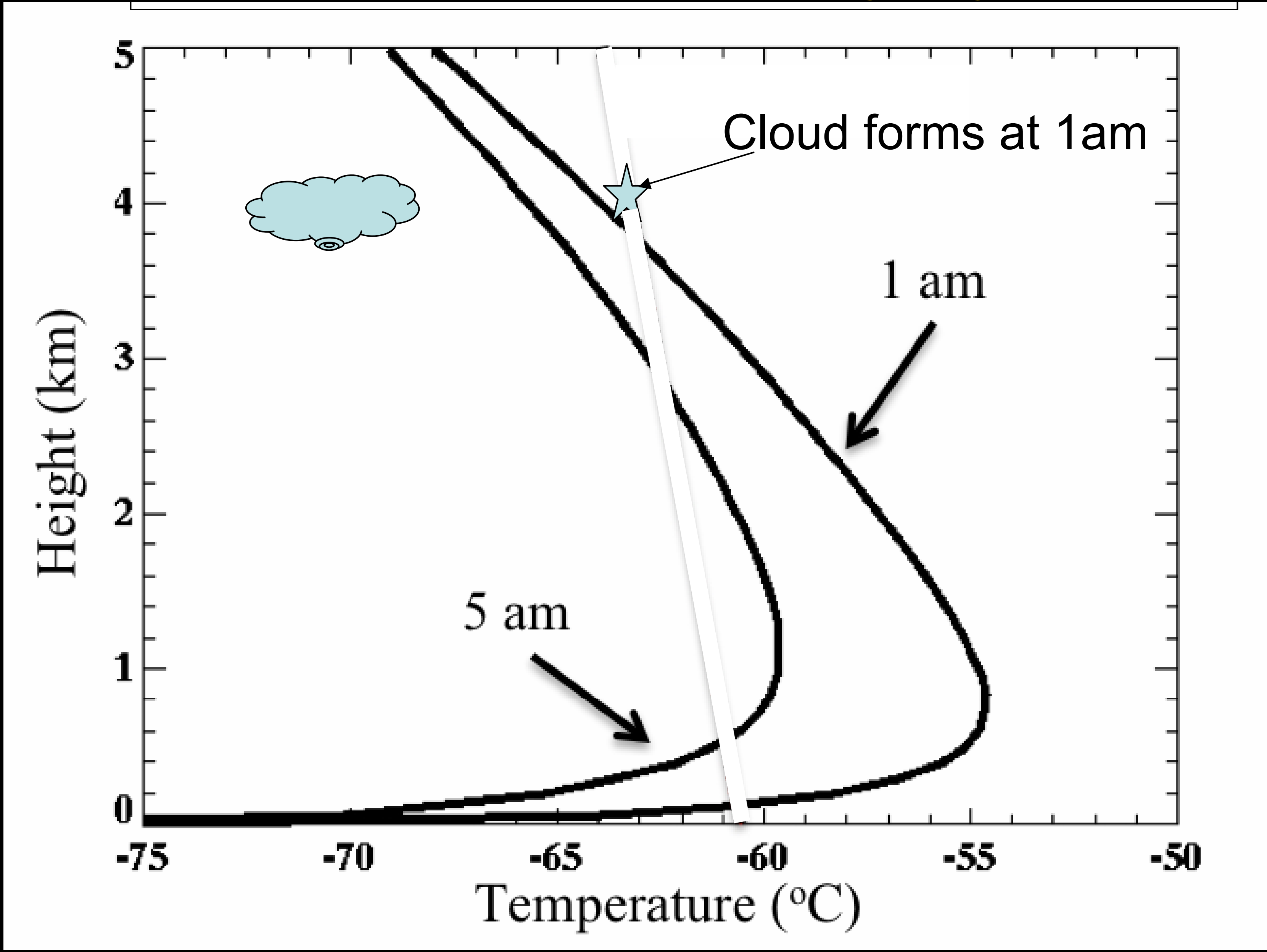
# Lidar Measurements of Dust and Clouds



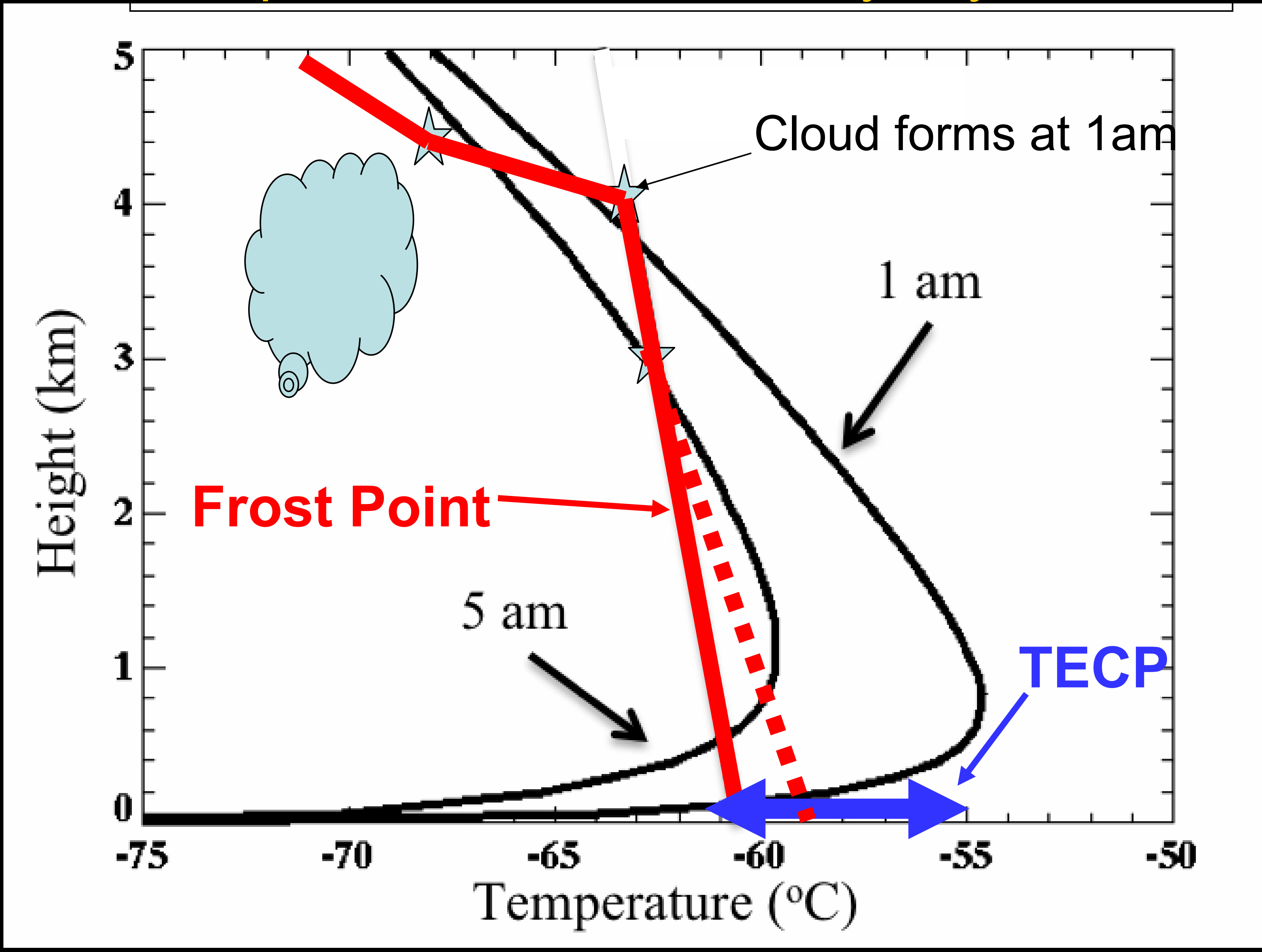
# Temperatures from Boundary Layer Model



# Temperatures from Boundary Layer Model

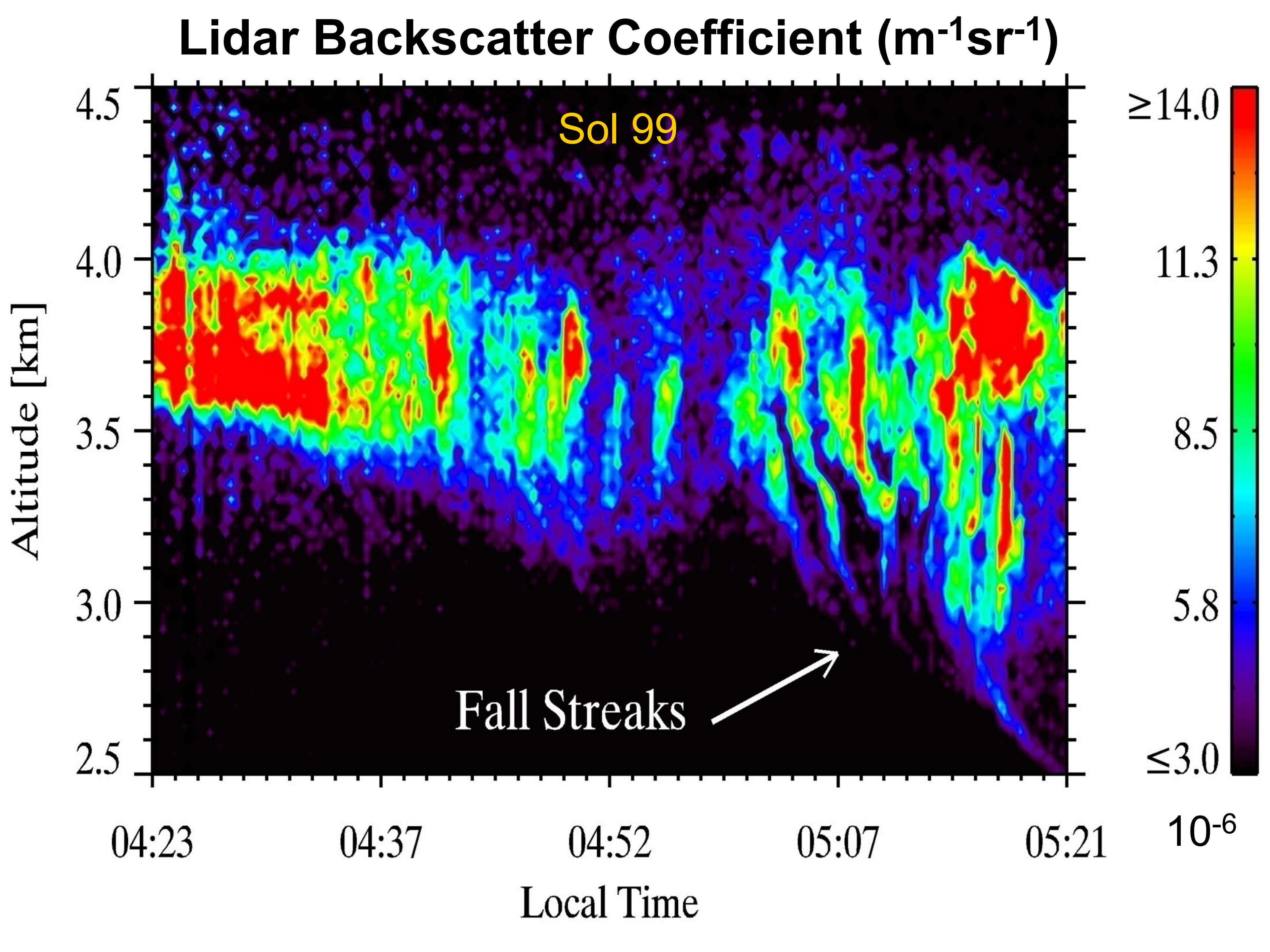


# Temperatures from Boundary Layer Model



# Precipitation

# (Snow)


Lidar Backscatter Coefficient ($m^{-1}sr^{-1}$)
Sol 99
4.5
4.0
3.5
3.0
2.5
Altitude [km]
Fall Streaks
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/

Sol 126
SSI camera

Horizon Movie

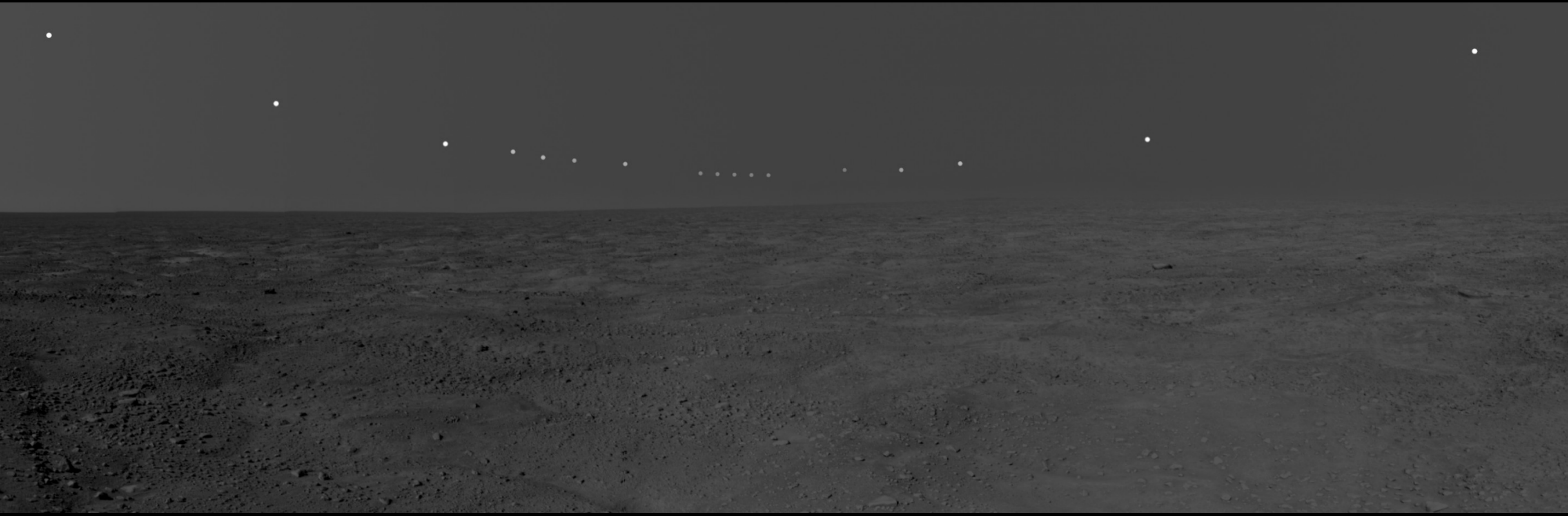
12:54 PM

LTST

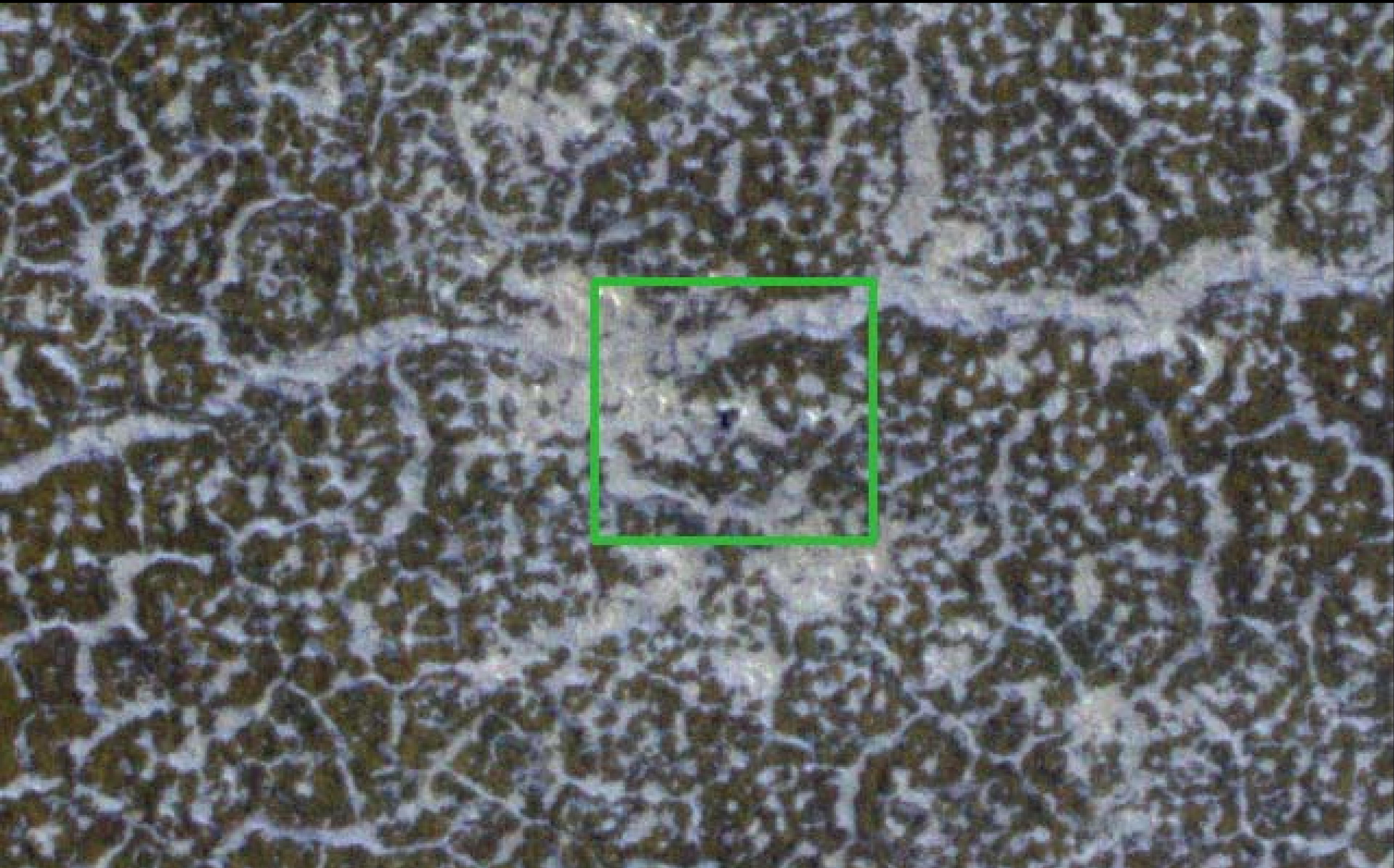

Winter is Approaching
Phoenix Cannot Survive


Loss of communication on sol 152

# Dog Days of Martian Summer



# Phoenix Feb 2010



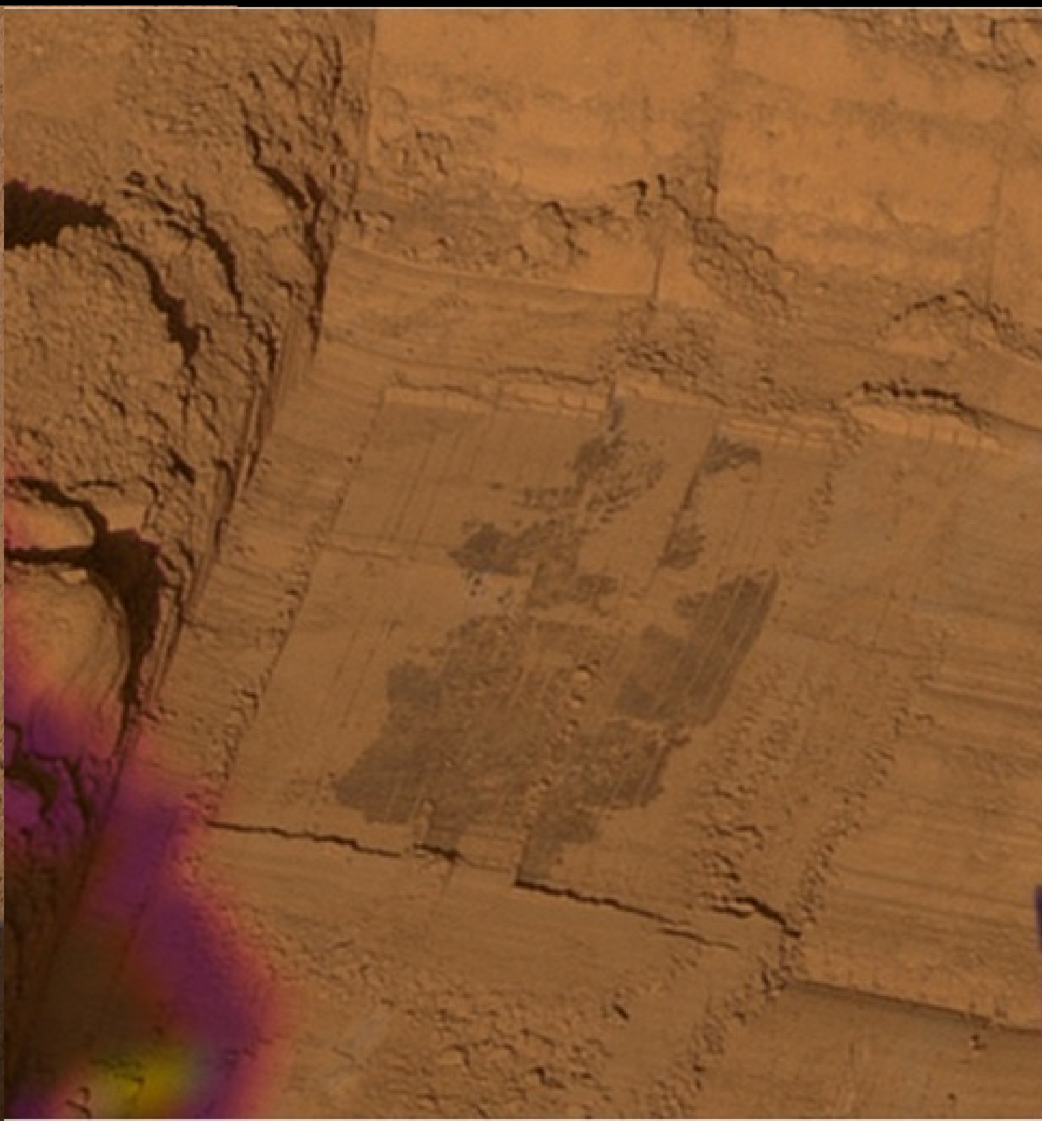
# Results

- 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

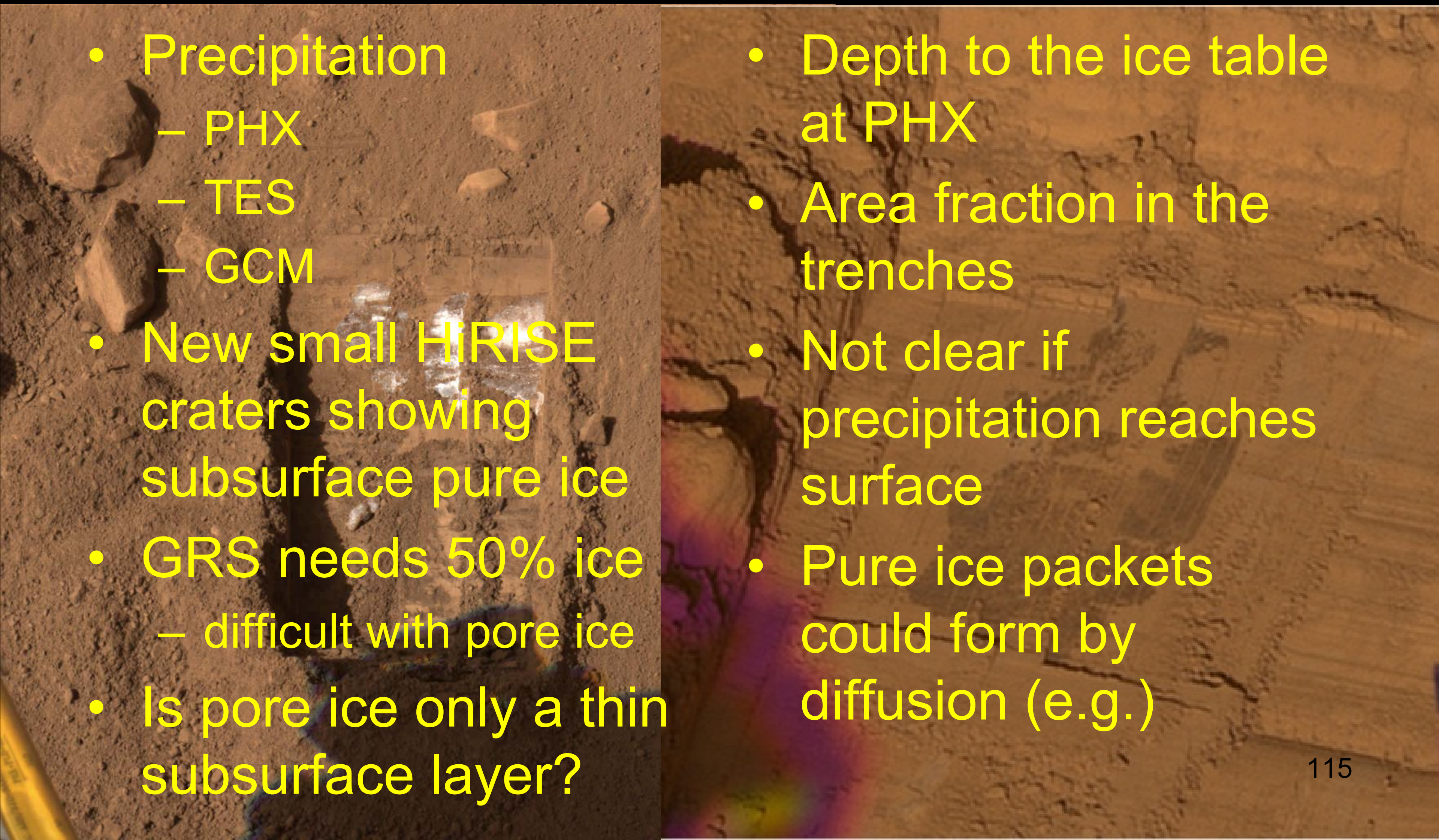
See Science and JGR special issues for much more

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

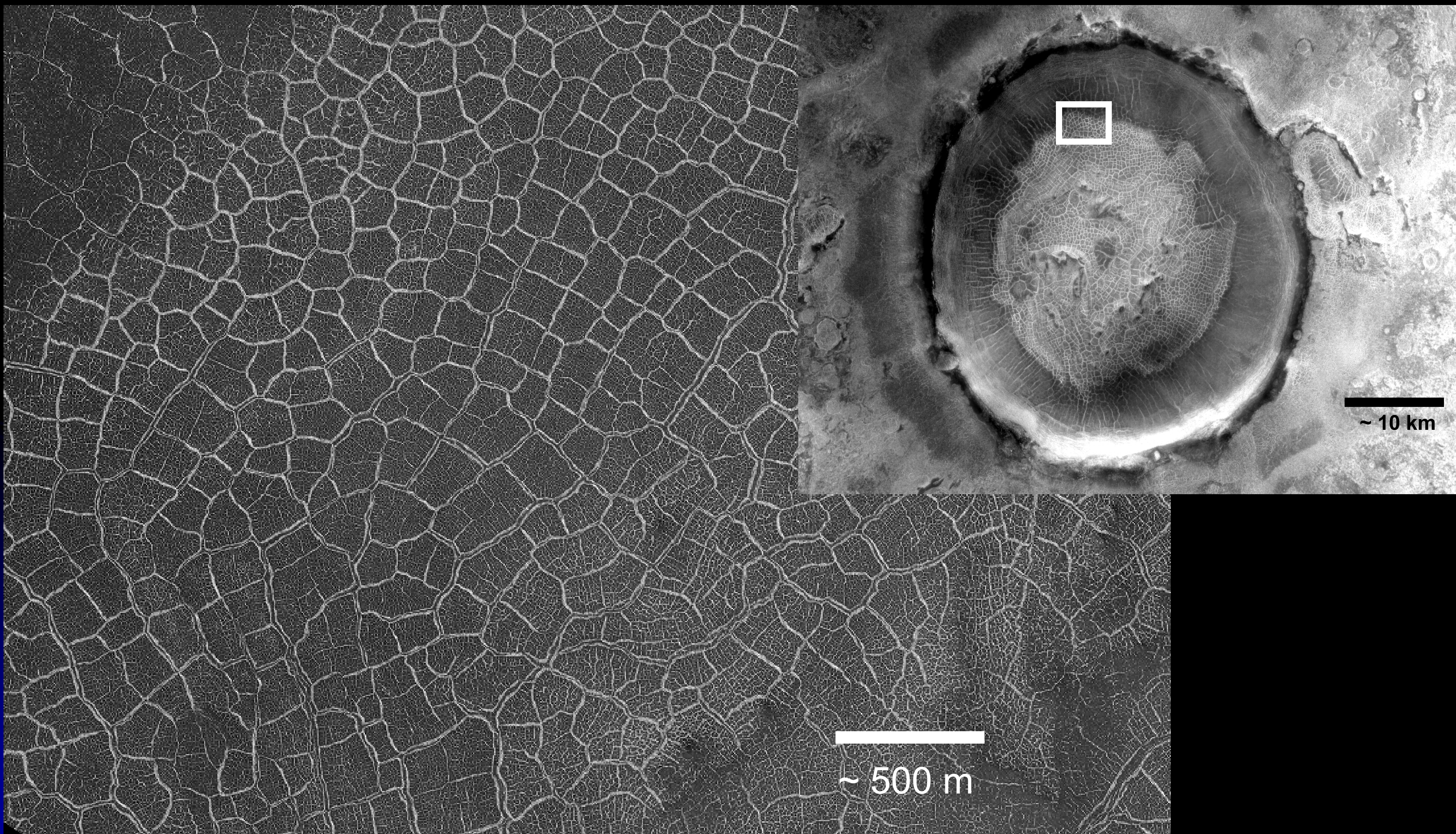


- Precipitation
  - PHX
  - TES
  - GCM
- New small HiRISE craters showing subsurface pure ice
- GRS needs 50% ice
  - difficult with pore ice
- Is pore ice only a thin subsurface layer?

- Depth to the ice table at PHX
- Area fraction in the trenches
- Not clear if precipitation reaches surface
- Pure ice packets could form by diffusion (e.g.)

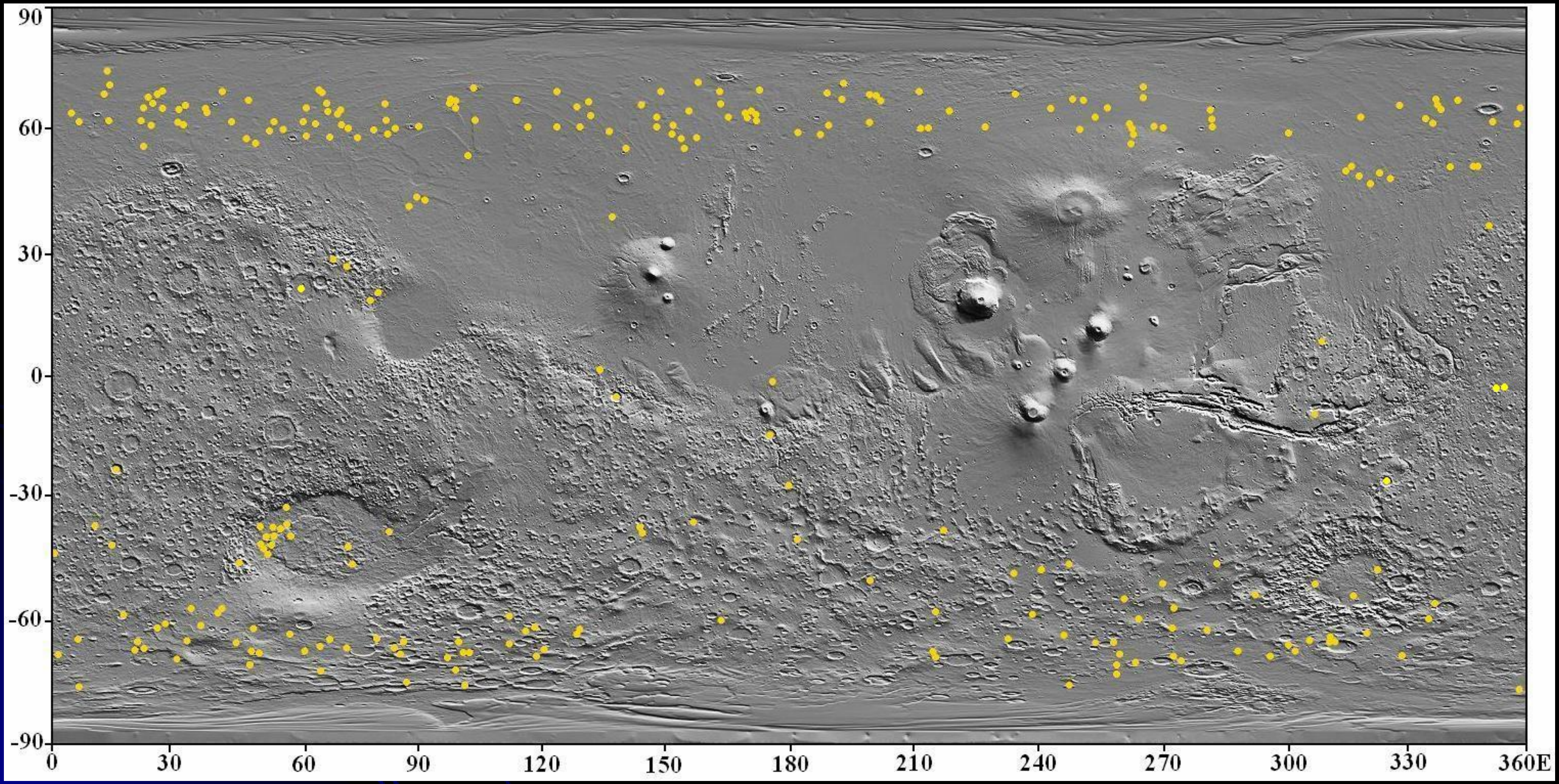
# Crater Floor Polygons

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

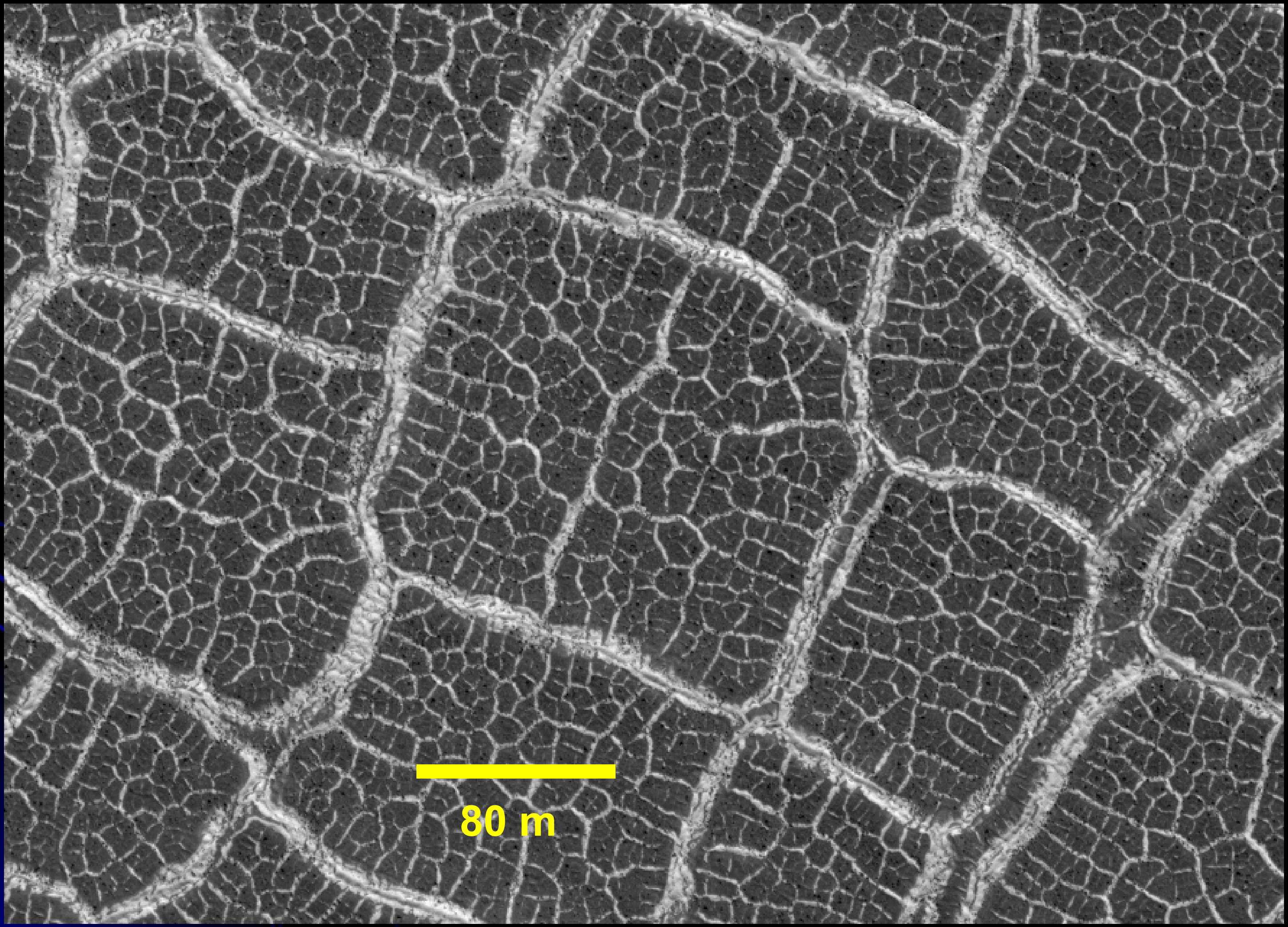


# Distribution

⇒ Features located in 262 craters so far..



# Detailed Morphology

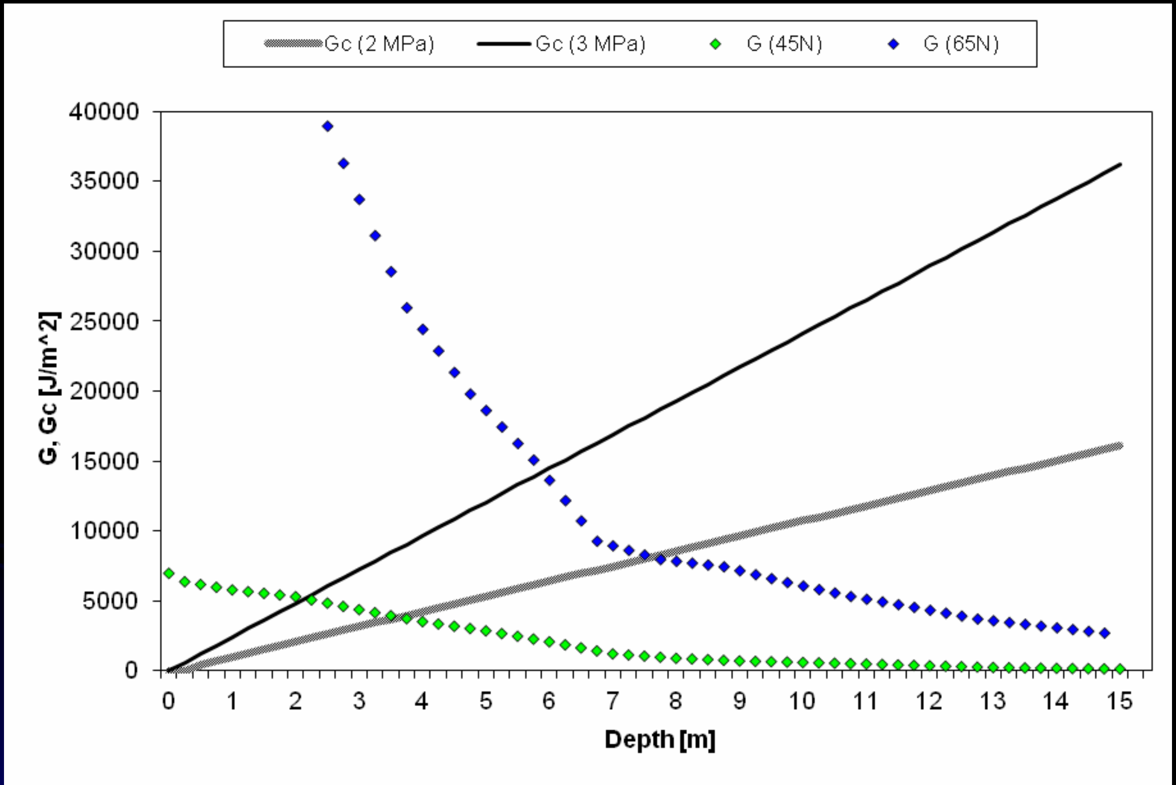


# Analogs on Earth
# 1) Ice-Wedge Polygons..

# Analogs on Earth
# 2) Desiccation polygons

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

# Results



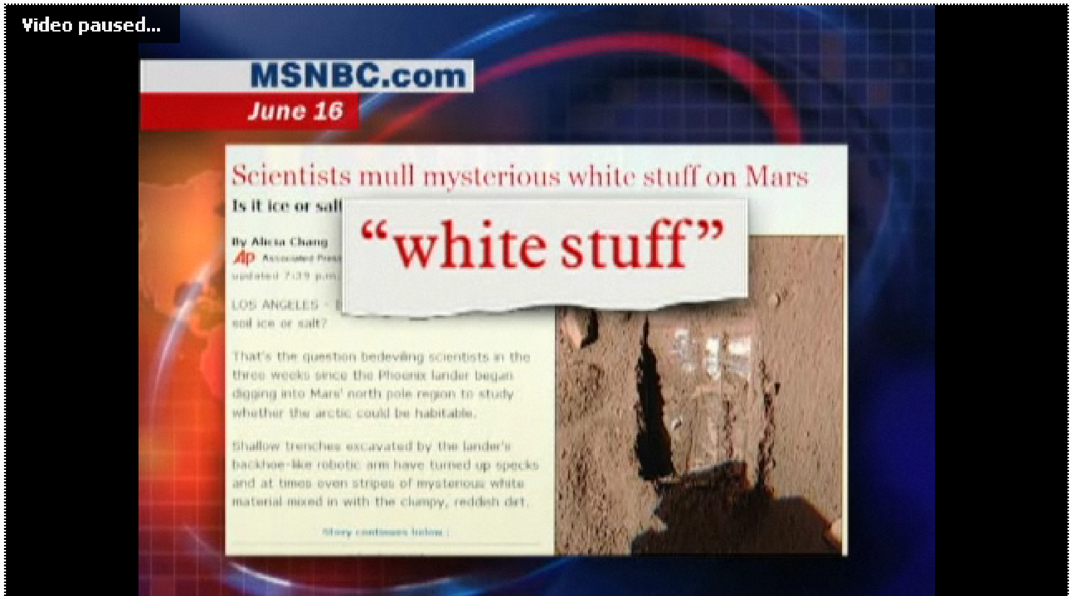

➔ $G = G_c$ at:

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

Sign Up or Log In to The Daily Show to comment.

### Episode clips: June 18, 2008

- Headlines - White Stuff on Mars (01:27) Views: 60,269 — NOW PLAYING
- There Will Be Flood (03:33) Views: 79,160
- Wet Hot American Bummer (01:58) Views: 63,439



### Related Videos

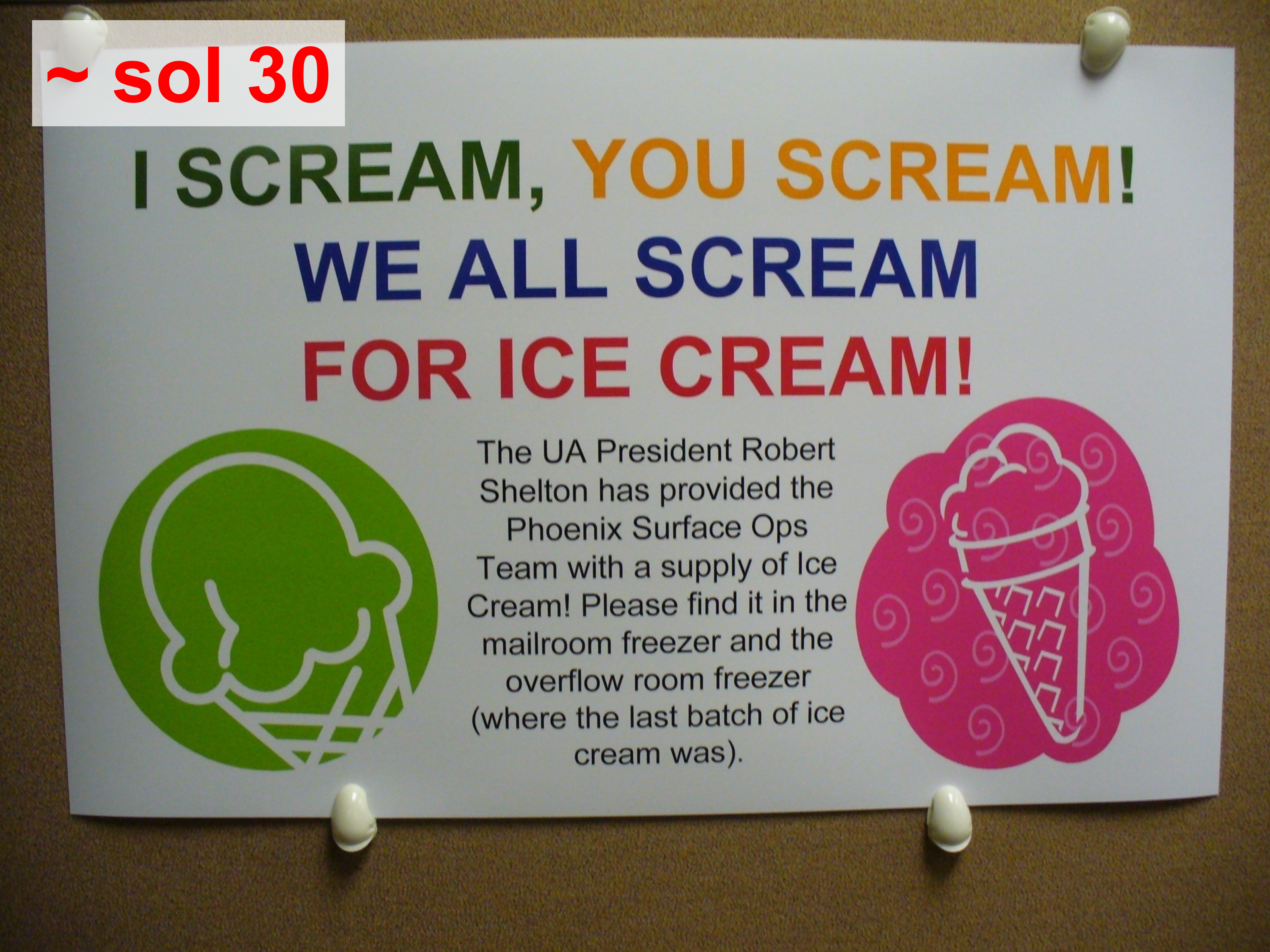
- Headlines - Mars Attacked! (2:35) Views: 1,319
- Headlines - Wet It

# Surface Operations Team in Tucson

THE UNIVERSITY OF ARIZONA.
Lunar and Planetary Laboratory


MECA
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

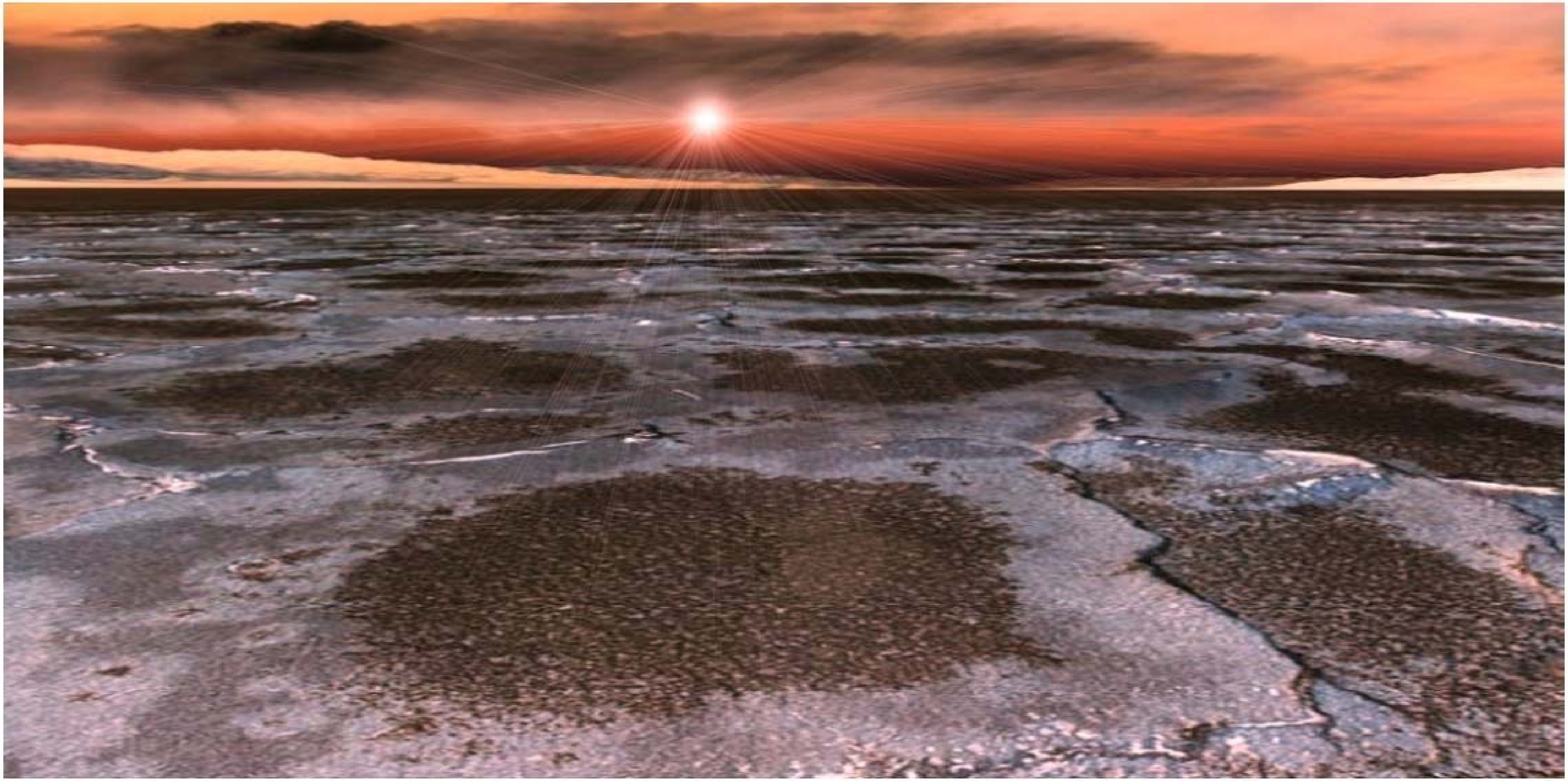
# Polar devil

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.

THROUGH THE EYES OF THE PHOENIX ONLINE COMPETITION

SPACEUROPE blogspot.com EXPLORING SPACE. SEEDING EVOLUTION.



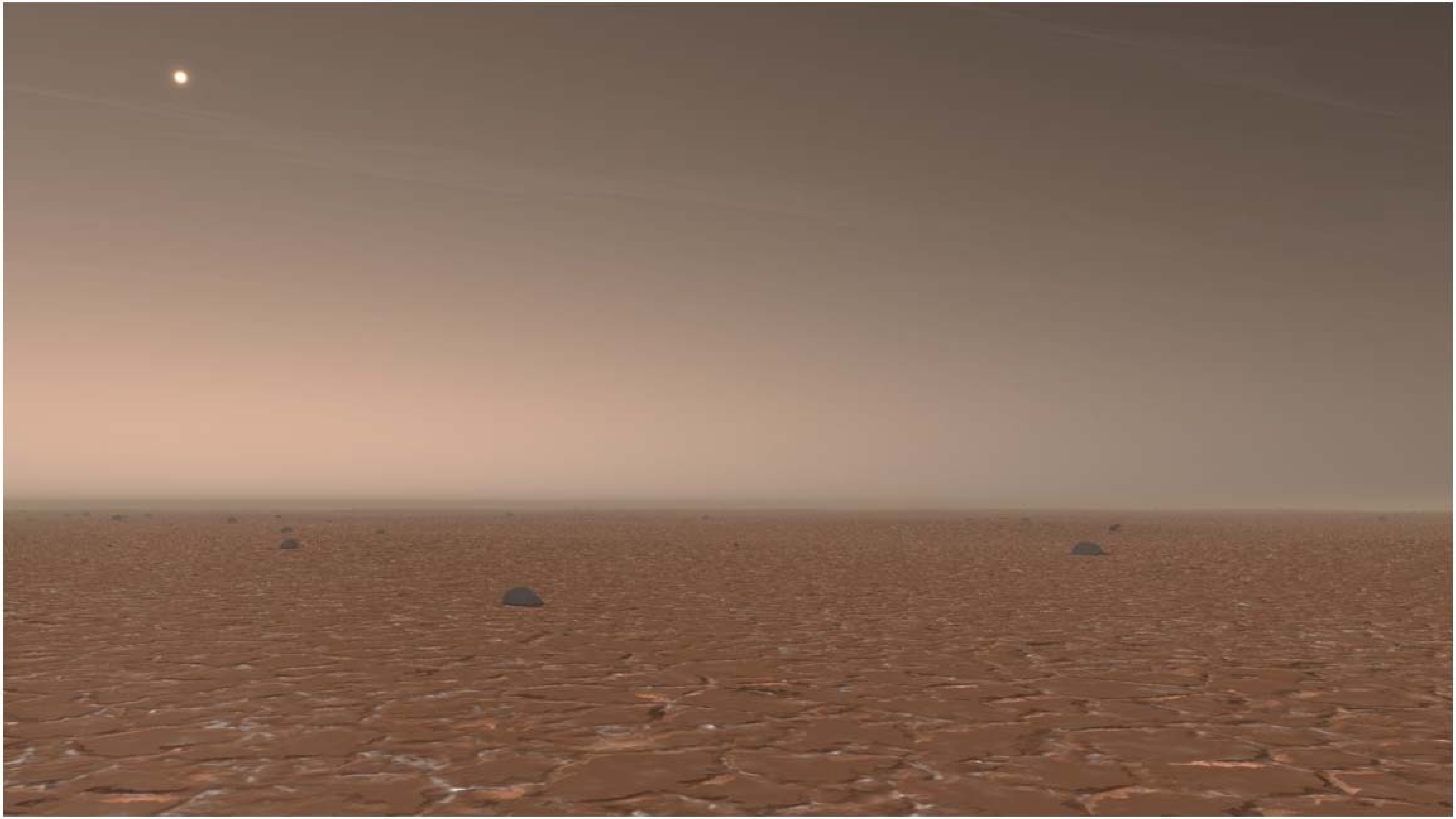
# Untitled

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").

THROUGH THE EYES OF THE PHOENIX
ONLINE COMPETITION

SPACEUROPE
blogspot.com
EXPLORING SPACE. SEEDING EVOLUTION.



# So few rocks

Doug Ellison - 29 -Leicester, UK

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