DRAFT Findings Related to "Special Regions"

The MEPAG Special Regions Science Analysis Group (SR-SAG)

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Key Points To Be Presented

Bounds to the Problem:

1. Use of a specified "period of protection" (proposal: 100 years) allows for effective distinctions between what is and is not a special region.
2. Use of an analytically derived depth (5m) for naturally occurring special regions, allows consideration of the environments most relevant to most missions.

Key Findings:

1. We can reach consensus on threshold parameters for 'propagation' of terrestrial organisms: T *and* a_w. None of the other known limits to life are practically useful for this analysis.
2. The distribution of T and a_w can be modeled using thermodynamics in combination with observational data; these models have predictive value down to scale of relevance to biology.
3. Where Mars is in equilibrium, T and a_w in the near-surface environment are well below the propagation thresholds. However, some parts of Mars may be in long-term disequilibrium. Such environments may a) exceed the propagation threshold values and b) have geologic expression.
4. Spacecraft-induced "special regions" need to be considered on a case-by-case basis, not by *a priori* generalizations.

Team Roster

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Clarification of Terms

Probability of geological conditions can be estimated, probability of growth cannot

Synonym: reproduce, NOT grow, survive, or extend

<u>Special Region</u>

"A region within which terrestrial organisms are likely to propagate, or a region which is interpreted to have a high potential for the existence of extant martian life forms."

Bounds to the Problem.

Period of Protection

- Timeframe: **100 Years**
  - Proposed by the NASA PPO, acceptable to the SR-SAG after significant discussion.
  - This is a MAJOR difference compared to PREVCOM study, which considered protection of Mars forever.
  - Primary implication: Don't need to consider future climate change as a result of the obliquity cycle (order of 10E4 years). **For practical purposes, the climate will be the same 100 years from today as it is today.**

A Practical Depth Consideration

Although all of Mars (in 3-D) is protected, the part that has practical relevance is that which can be reached by spacecraft contamination.

- 0-5 m: The maximum depth of penetration of a crashing spacecraft (up to 2400 kg) can be shown to be about **5m**. This is the volume within which naturally occurring special regions matter for most missions.
- >5 m. The SR-SAG proposes that mission proposers involving deliberate subsurface access deeper than 5 m be required to present a specific analysis of the possibility of special conditions, natural or induced, at their proposed landing site, down to their designed access depth.

Finding #1. Threshold values for propagation.

Limits to Terrestrial Life

Although there are many general limits to terrestrial life, the SR-SAG found only three to be of practical use in setting implementation guidelines for ‘special regions’.

- Temperature
- Activity of water
- UV as a mitigating factor against dispersion at the surface (not discussed in this presentation)

Temperature Threshold

Metabolic studies:

Citation	Measurement	Temperature min	Metabolic Category
Christner (2002)	Uptake [^{3}H]thymidine and [^{3}H]Leu (***E.coli***)	-15°C	Maintenance
Gilichinsky *et al*. (2003)	Assimilation of [^{14}C]glucose	-15°C	Maintenance
Junge *et al*. (2004)	Respiration by CTC	-20°C	Survival?
Junge et al. (2006)	Protein Synthesis	-20°C	Maintenance
Kappen *et al*. (1996)	CO_2 exchange Lichens Uptake and loss	-12°C to -20°C	Survival/Maintenance?
Rivkina *et al*. (2000)	incorporation of ^{14}C-labeled acetate into glycolipids	-20°C	Maintenance/Replication? Calculated DT=160 days but not shown to be cell division
Rivkina *et al*. (2002)	evolution of methane by a community of methanogenic archaea	-20°C	Survival?
Wells and Demming (2006)	viral infectivity and production	-12°C	microbial evolution (lateral gene transfer) and community succession

Water Activity Threshold

Table 1. Water potentials, water activities, and various effects, all at ~20°C(?)*

Water potential (MPa)	Water activity	Effect
0	1.0	Pure water
-0.03	0.999	Mean water film thickness = 4 µm at this Ψ_m
-0.1	0.999	Mean water film thickness = 1.5 µm at this Ψ_m
-0.5	0.996	Mean water film thickness = 0.5 µm at this Ψ_m
-1.5	0.99	Mean water film thickness = 3 nm at this Ψ_m
-4.0	0.97	Mean water film thickness < 3 nm (< 10 H_2O molecules thick)
-10	0.93	Mean water film thickness < 1.5 nm (< 5 H_2O molecules thick)
-40	0.75	Mean water film thickness < 0.9 nm (< 3 H_2O molecules thick)
-2.7	0.98	seawater
-41	0.75	saturated NaCl solution
-168	0.29	Saturated $CaCl_2$ solution
-0.14	0.999	Ψ_m at which microbial motility ceases in a porous medium
-4 to -7	0.97 to 0.95	Lower Ψ_m limit for growth of *Bacillus* spp.
-2.5 to –12.5	0.98 to 0.91	Lower Ψ_s limits for growth of various plant pathogenic fungi
-17	0.88	Lower Ψ_m limit for growth of *Arthrobacter* spp.
-10 to -20	0.93 to 0.86	Ψ_m at which microbial respiration becomes negligible in soil
-50	0.69	Lower Ψ_s limit for growth of *Rhizopus*, *Chaetomium*, *Aspergillus*, *Penicillium*
-65	0.62	Lower Ψ_s limit for growth of *Xeromyces* and *Saccharomyces* (growth in 83% sucrose solution)

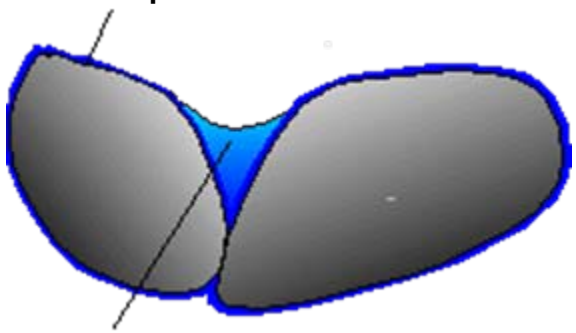
*Compiled from Papendick and Campbell (1981), Harris et al. (1981), Griffin et al. (1981), Potts (1994).

Thin Films, Solutes

We can assume that thin films and salts are both present on Mars. However, effects of both are implicit in the water activity, which can be calculated without knowing the details of either.

THIN FILMS

Adsorbed (hygroscopic) water adheres tightly to soil particles.



Capillary water coheres to adsorbed water and to itself. Surface tension produces the curved water-air interface.

SOLUTES

The presence of solutes reduces a_w.

a_w	Note
1.0	Pure water
0.98	seawater
0.75	saturated NaCl solution

Finding #2. Consensus Planetary Thermodynamic Model.

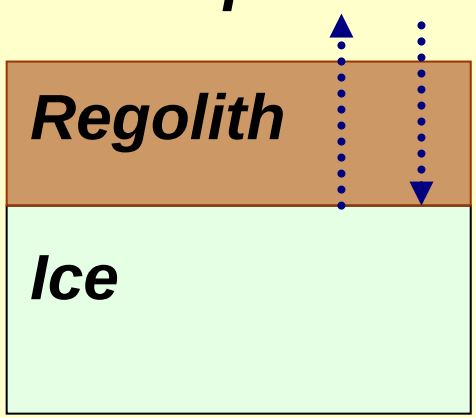
Equilibrium Thermodynamics

Water activity (a_w) is related to relative humidity (rh) as follows:

$$a_w = rh/100$$

The relative humidity is defined as the ratio of the partial pressure of water [$p(H_2O)$] and the vapor pressure of ice [$Pv(H_2O)$].

$$rh = p(H_2O)/Pv(H_2O)*100.$$

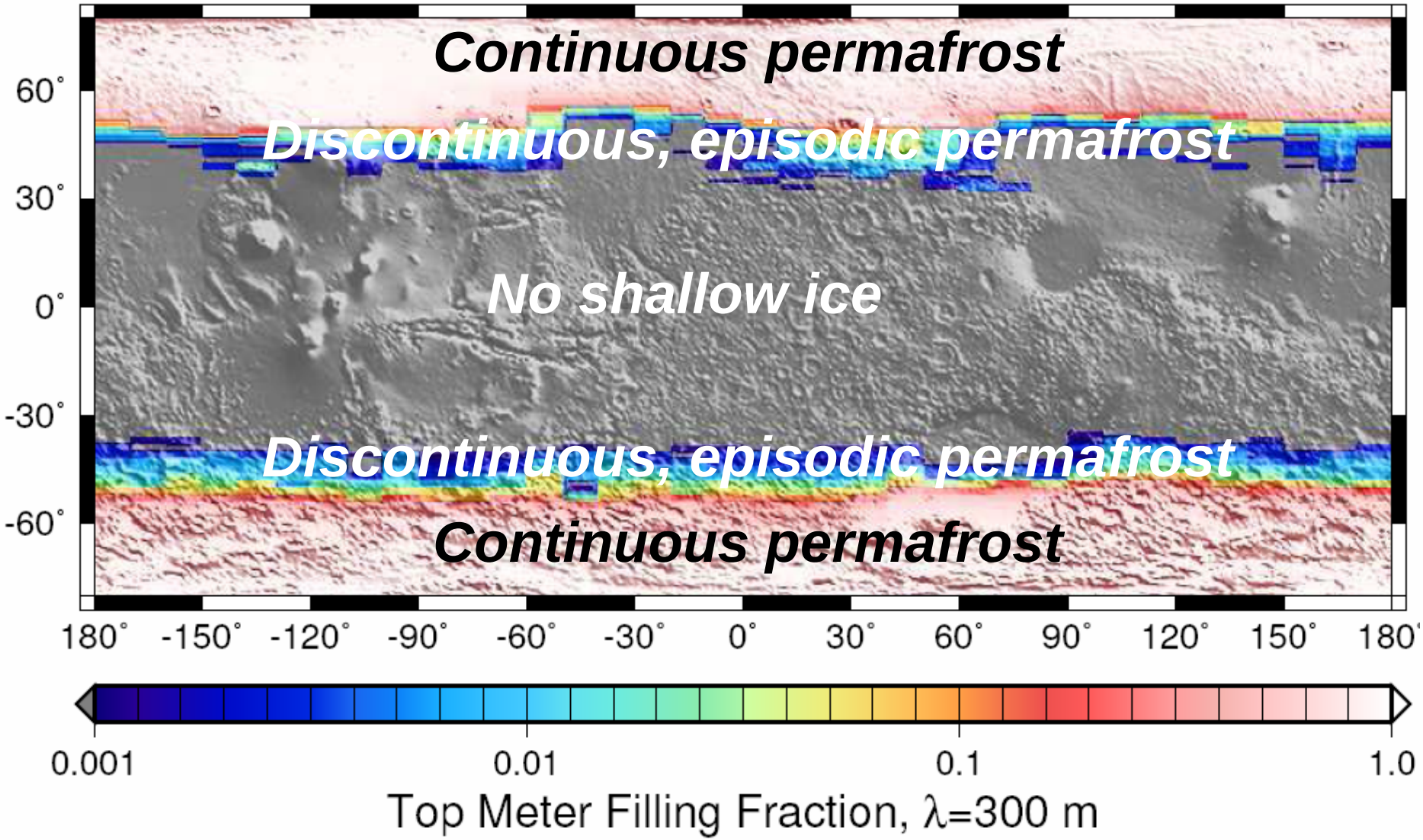


$p(H_2O)$ varies with time and location on Mars, but averages about 0.8 microbar.

at equilibrium, $Pv(H_2O)$ equals $p(H_2O)$, referred to as the frost point.

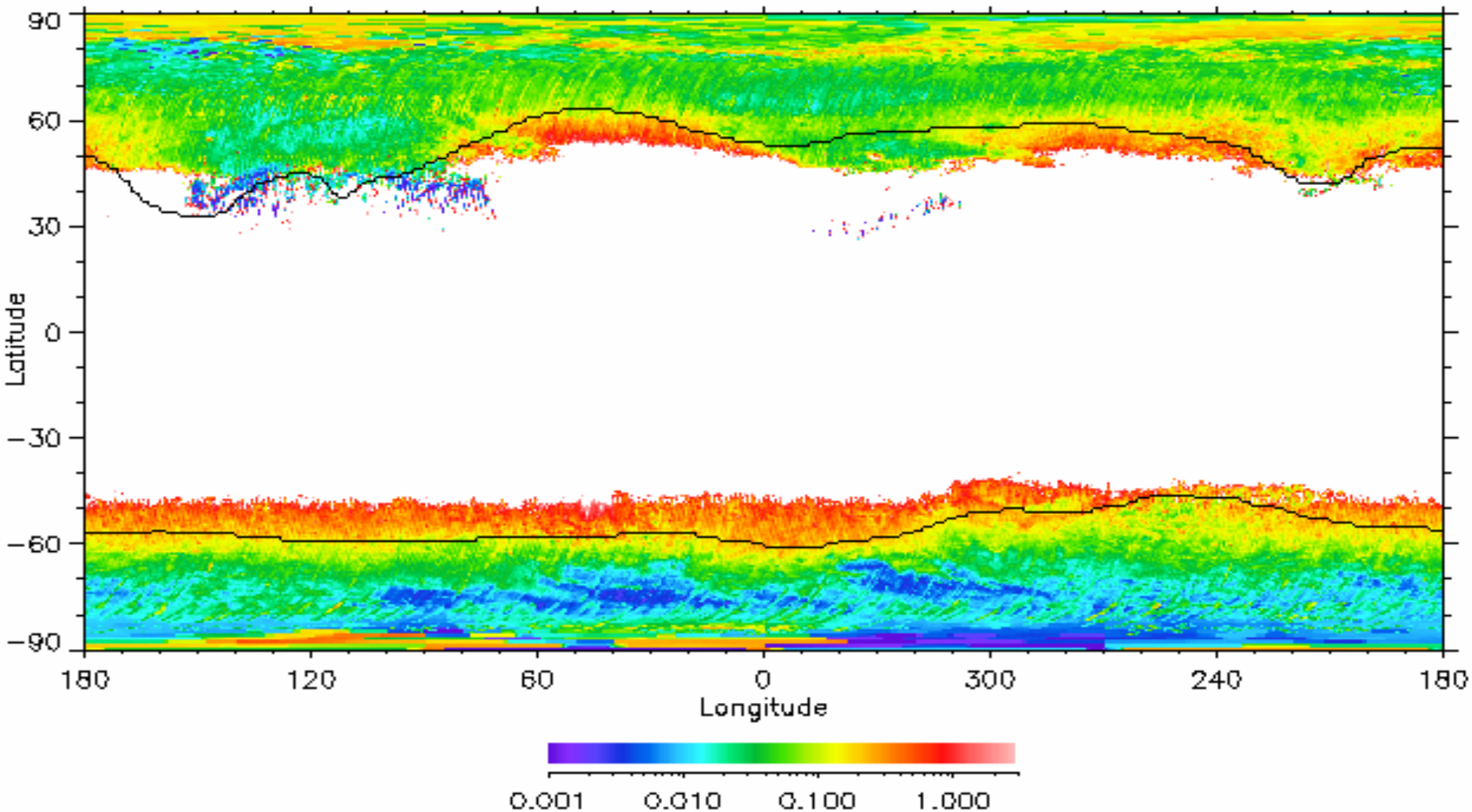
***Calculated T = 195-200 K,* AGREES WITH TES OBSERVATIONS**

Planetary Thermodynamic Model



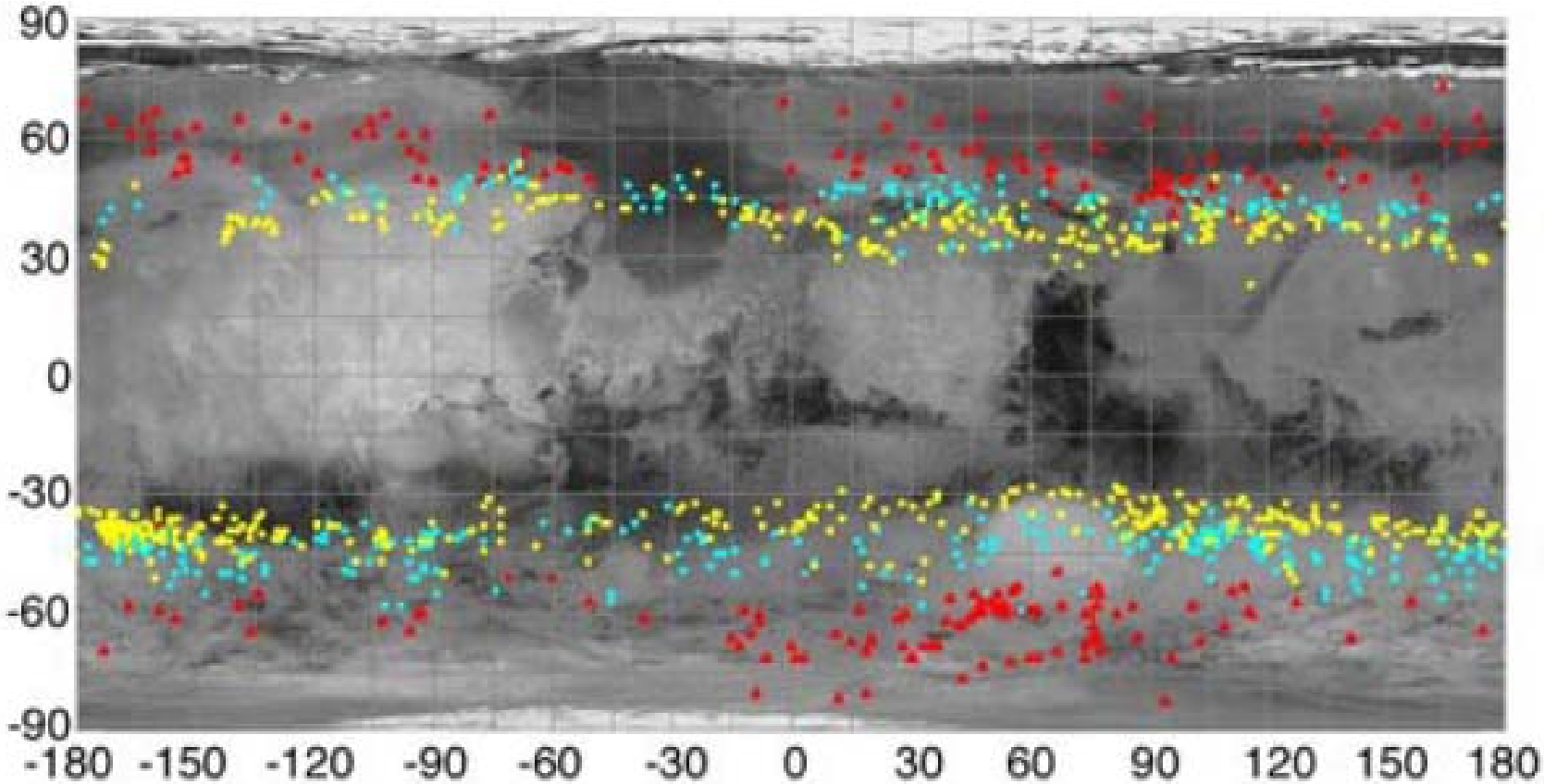
Aharonson and Schorghofer (in press)

Theoretical Ice Table Depth



Mellon and Feldman (2005)

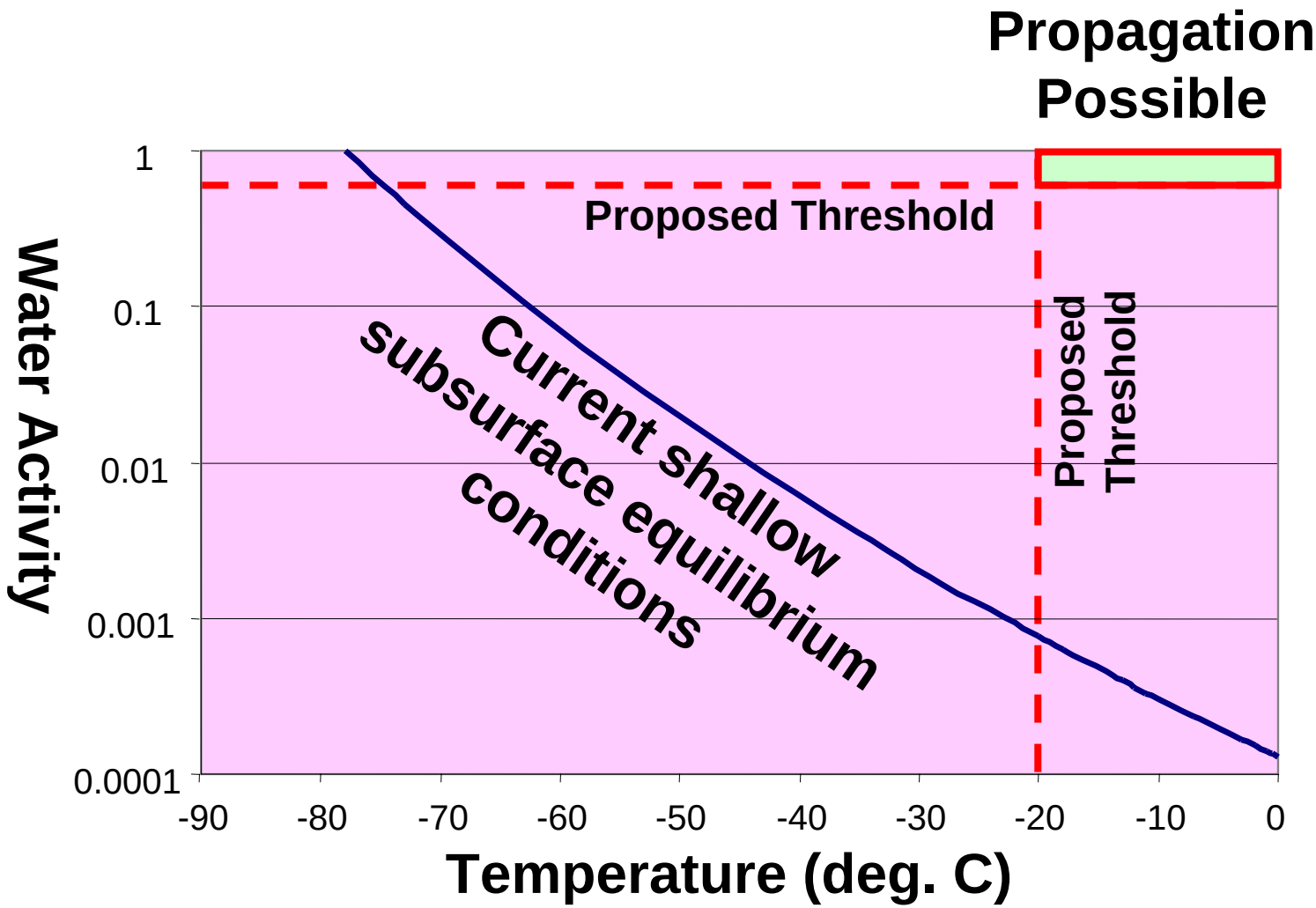
Map of Observed Ice-related Textures



The distribution of various dissected mantle textures (Milliken and Mustard, 2003).

- Localized removal (yellow).
- Knobby/wavy texture (cyan).
- Scalloped texture and total mantle cover (red).

Biology-Geology Relationship



Selected Literature Related to Modern Mars Water

Possible liquid water on Mars at **earlier geologic times**	Wallace, D. and C. Sagan (1979) Carr, M. H. (1983) Clow G. D. (1987) McKay C.P. and Davis W.L. (1991) Grotzinger, J.P. et al. (2005)
Orbital configuration consistent with liquid water in modern times **if a source were present**	Haberle R. M., McKay C.P., Schaeffer J., Cabrol N.A., Grin E.A., Zent A.P., Quinn R (2001), Zent A.P., Fanale F.P., Salvail J.R., Postawko S.E. (1986), Richardson & Mischna 2005
Mechanisms for producing modern transient liquid in **certain geological environments**	Farmer C. B. (1976) Mellon M. T. and Phillips R. J. (2001) Hecht M. H. (2002) Costard F., Forget F., Mangold N. , Peulvast J. P. (2002) Christensen, Phil (2003?)

The SR-SAG conclusions are consistent with all of the above.

Finding #3. Disequilibrium environments

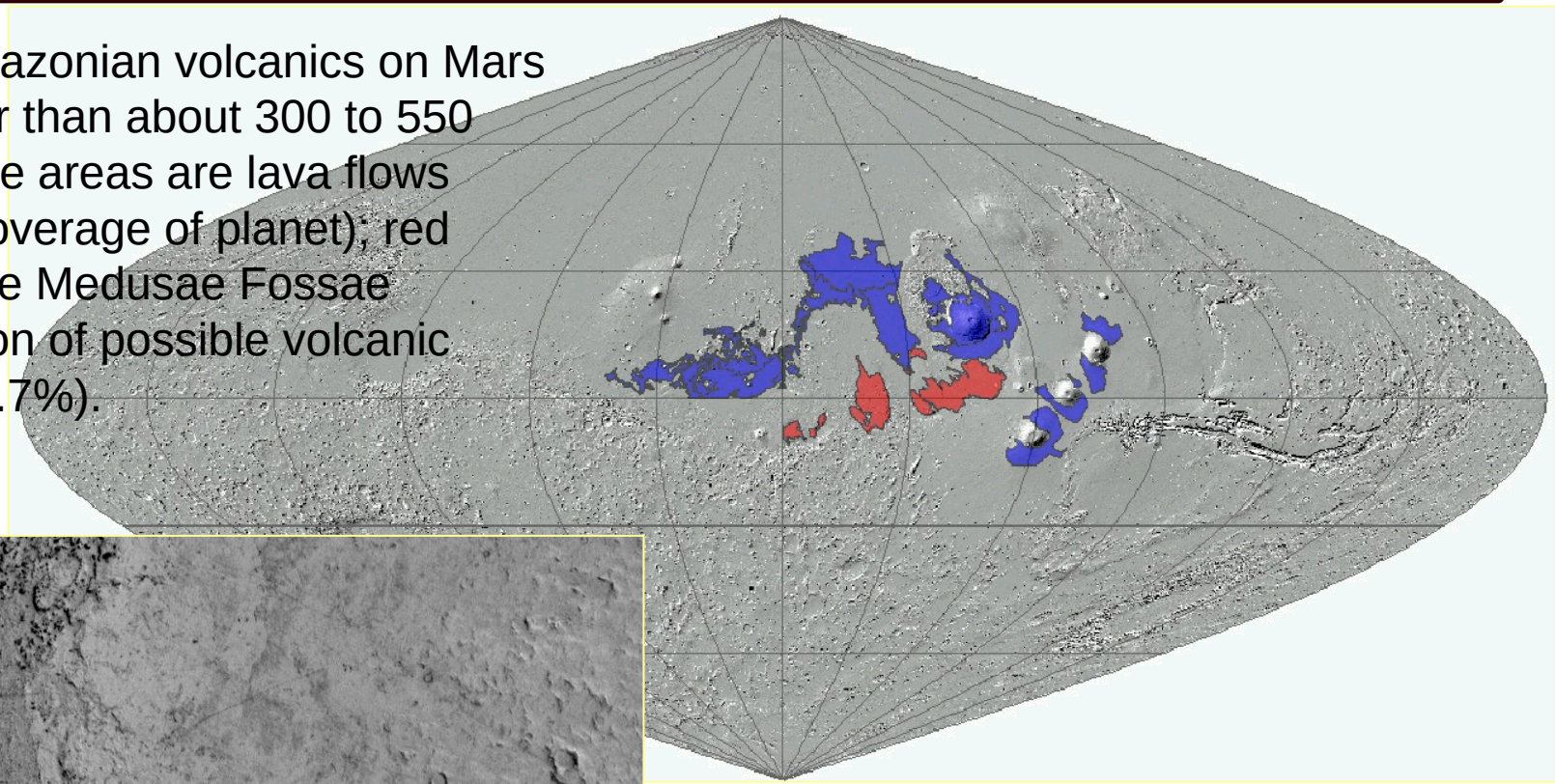
Disequilibrium Environments

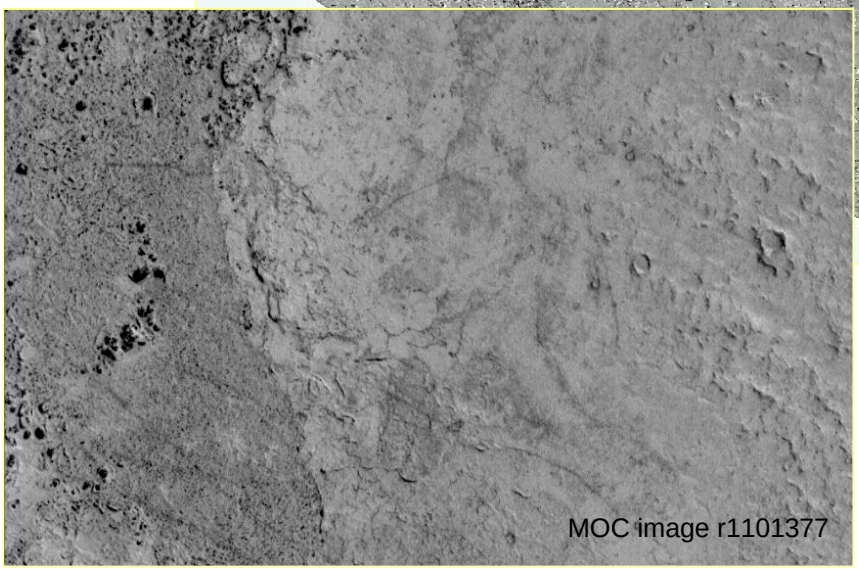
Certain geological processes can result in local conditions that are out of equilibrium with respect to their planetary setting on timescales from about 10^2 to 10^5 years. For such environments the potential for modern liquid water could be significant.

Note: For this purpose, it is necessary to define a time-averaged (e.g. annual), rather than instantaneous, equilibrium.

Young Volcanics

Late Amazonian volcanics on Mars (younger than about 300 to 550 Ma). Blue areas are lava flows (2.8% coverage of planet); red areas are Medusae Fossae Formation of possible volcanic origin (0.7%).

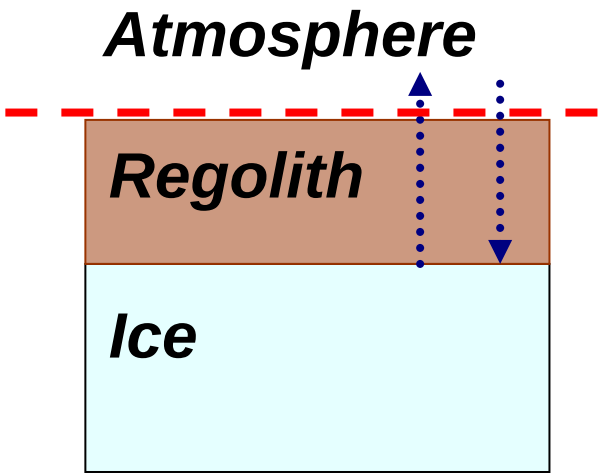




Three distinct, apparent volcanic surfaces (Elysium Planitia) progressively younger from right to left (appearing rugged and cratered, bright and partly incised, and dark, respectively).

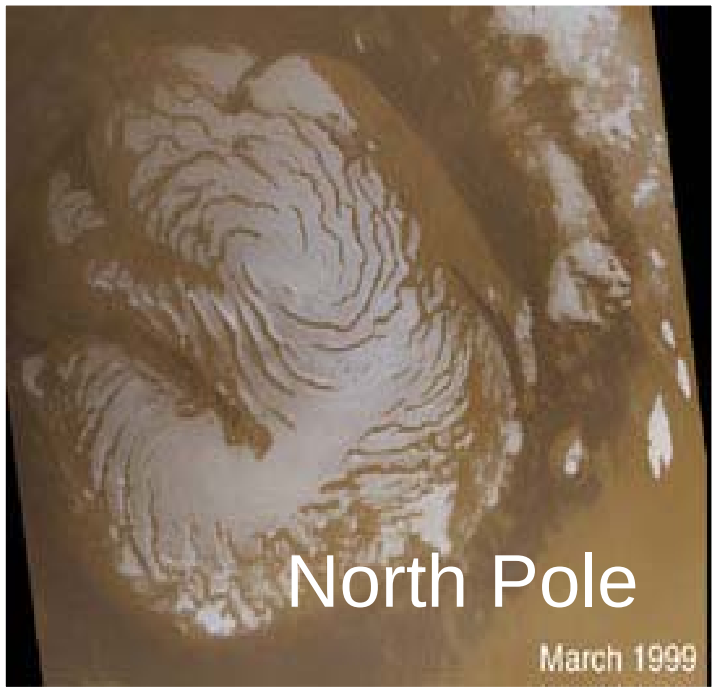
Semi-permeable Crusts

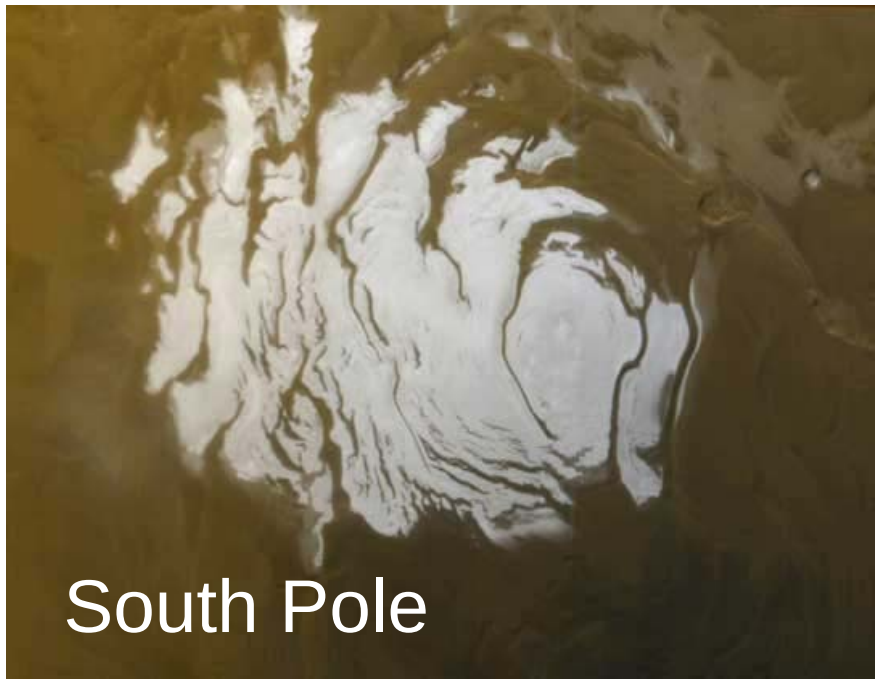
- Some desert crusts on Earth have formed by processes that could have operated on Mars. **ALL** have measurable permeability.
- Ice below a desert crust on Mars will sublime away when heated, unless there is recharge.



Polar Ice Caps

- <u>Special Mention</u> – The polar cap material is **NOT** a disequilibrium environment. It is much too cold for liquid water.





Implications

Clear potential for current near-surface liquid water	Other mechanisms that might give rise to disequilibrium environments, known or possible on Mars
• Recent gullies and associated mantles	• Geothermal vents • Heating by major recent impacts • Heating by recent volcanic activity • Glaciers (long-term) • Sites where albedo over shallow ice has changed recently • Landslides exposing cold ice
All have recognizable geologic expression	

Finding #4. Spacecraft-Induced Special Regions

Spacecraft-Induced Special Regions

It is possible for spacecraft to induce environments on a time scale of seconds to years that may satisfy the threshold conditions for propagation.

- Short-term spacecraft considerations
  - Rocket plumes
  - On surface activities (eg sampling – scoop, drill, RAT, melt probes)
  - Burn-up, break up, and surface impact
- Long-term spacecraft considerations
  - Perennial heat sources, i.e., RTGs

Best evaluated on a case-by-case basis.

Summary

Using the SR-SAG's boundary parameters and key findings,

- Most of the martian surface/shallow subsurface can be shown to be either too cold ($<^{-}20^{o}C$) or too dry ($a_w<0.6$) for terrestrial microbial reproduction (i.e., non-special).
- Using the SR-SAG's criteria, some martian geologic environments are "not non-special". For planetary protection purposes such environments must be treated as "special regions".
- Spacecraft may induce conditions that would qualify as a special region, even when one was not present before the spacecraft arrived. These are best evaluated on a case-by-case basis.

Backup Slides

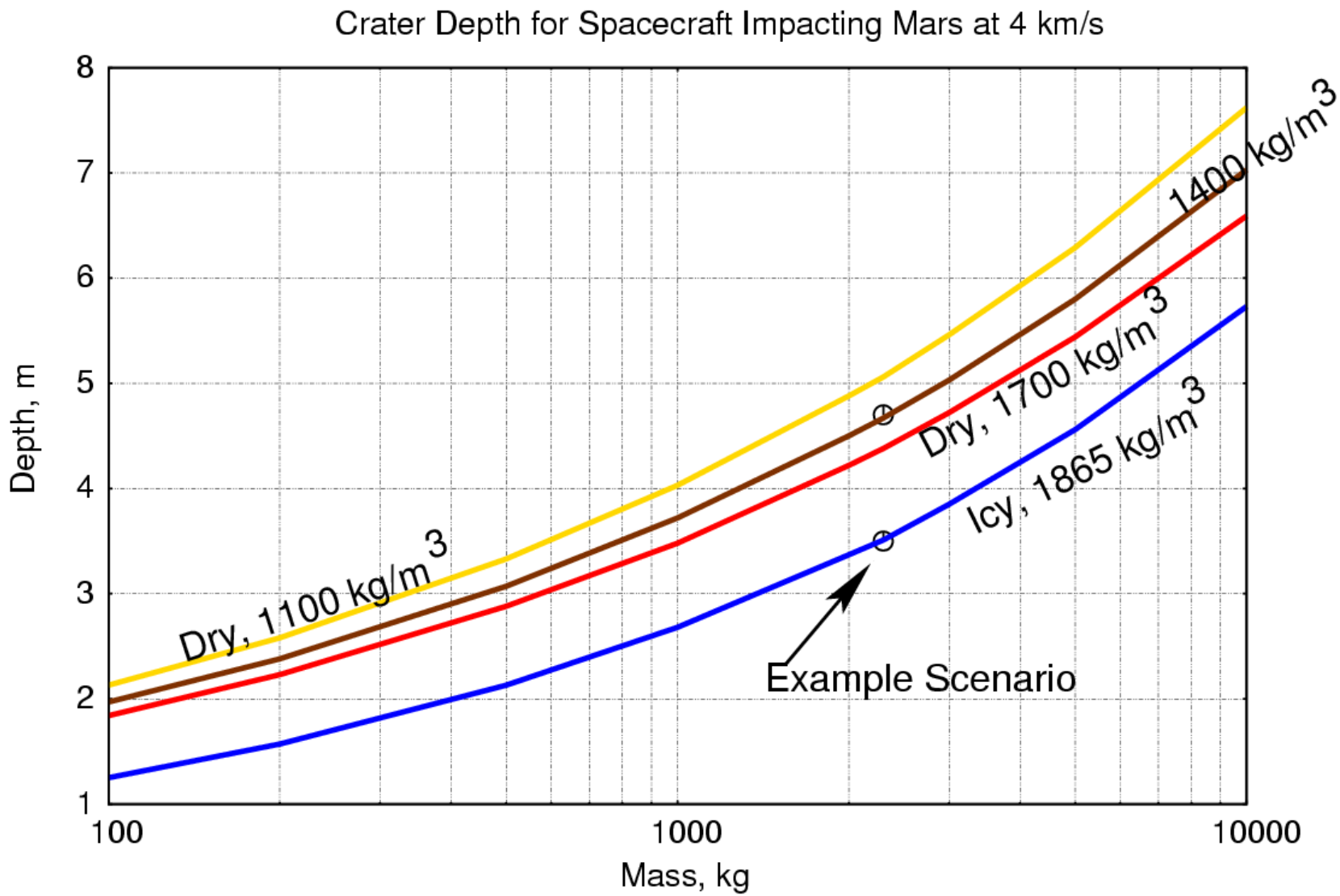
Duration of Spacecraft Heating

- For temperatures below about +5C, as long as the heating is not sustained for more than 24 hours/year, the potential for propagation is deemed to be insignificant (because the reproduction rate for terrestrial organisms at such temperature is very low).
- This may help in the evaluation of certain mission situations (e.g. heating by a descent engine, heating by a sampling drill, etc.).
- It should be the responsibility of the proposing or implementing project to prepare an analysis of the possibility of induced special regions for their mission, for consideration by the appropriate approval entities.

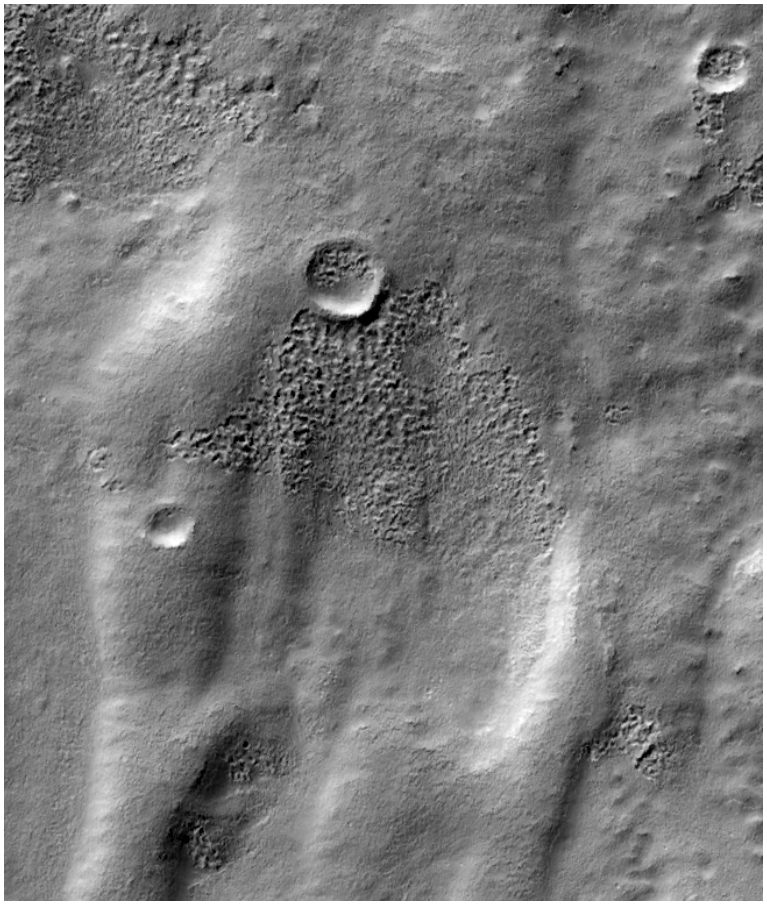
Discussion Point

- There is a low, but non-zero probability that many sites on Mars could be affected by heating associated with impact and volcanic events during the future 100 year period of protection.
- SR-SAG considered, but rejected, a geological probability threshold.
- SR-SAG did agree to limit assignment as ‘special’ to those cases where heating took place within the past 1000 years, and to ignore the possibility of future heating events.

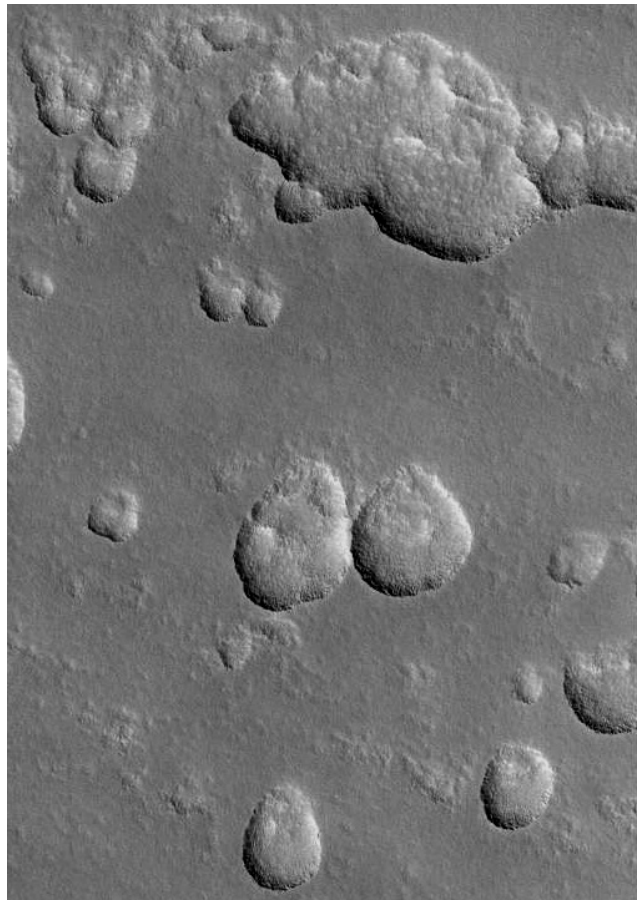
Crater Depth vs. Spacecraft Mass
4 km/s Impact



Textures related to Frozen Ground



Knobby texture,
MOC M00-00174, 42º S 141º E



Scalloped texture,
MOC M23-01836, 55º N 207º E

Images from Milliken and Mustard (2003) showing various styles of dissected mantle. (Each image is ~3km in width.)