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Landing sites and **mars sample return: environmental implications on present day habitable samples?**

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*LANDING SITE CONFERENCE: PARTICIPATION AWARDED WITH TRAVEL SUPPORT BY ESA

OBJECTIVE (iMOST, 2018)	iMOST (2018), The Potential Science and Engineering Value of Samples Delivered to Earth by Mars Sample Return, (co-chairs D. W. Beaty, M. M. Grady, H. Y. McSween, E. Sefton-Nash; documentarian B.L. Carrier; plus 66 co-authors), 186 p. white paper. Posted August, 2018 by MEPAG at https://mepag.jpl.nasa.gov/reports.cfm.
1. Geological environment(s)	Sedimentary System, Hydrothermal, Deep Subsurface groundwater, Subaerial, Igneous terrane
2. Life	Carbon chemistry, biosignatures-ancient, biosignatures-modern
3. Geochronology	
4. Volatiles	
5. Planetary-scale geology	
6. Environmental hazards	
7. ISRU	

Focus: Habitability of the upper centimeters of the regolith. Follow the water.. and the temperature.

*"**An environment is habitable if it is capable of supporting the activity of at least one organism**" Cockell, C. S.; Bush, T.; Bryce, C.; et al., Habitability: A Review, Astrobiology Volume: 16 Issue: 1 Pages: 89-117*

Requirements: T> 255 K and RH (water activity) > 0.6: *Rummel, J.D. et al 2014. A New Analysis of Mars Special Regions: Findings of the Second MEPAG Special Regions Science Analysis Group (SR-SAG2). Astrobiology14, 887-968.*

Water ice does not exist on the surface at the selected landing sites. Requirements for life in the regolith: an additional requirement for habitability is the existence of salts that may allow for transiently stable brines or at least that may hold water as hydrates.

presence of H_2O signal

presence of Cl-salts and sulfates for water absorption and potential brine formation.

What we know from Curiosity at Gale crater:

***There are organics**: Freissinet, C.; Glavin, D. P.; Mahaffy, P. R.; et al.] Organic molecules in the Sheepbed Mudstone, Gale Crater, Mars, Journal of Geophysical Research-Planets Volume: 120 Issue: 3 Pages: 495-514 Published: MAR 2015*

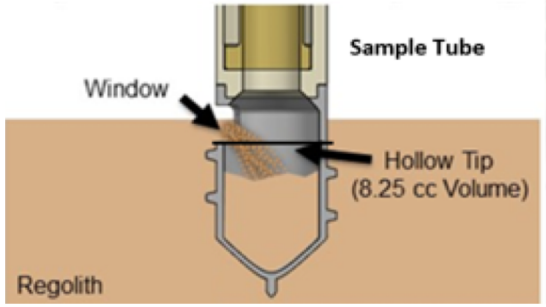
***There is fixed nitrogen**: Stern, Jennifer C.; Sutter, Brad; Freissinet, Caroline; et al. Evidence for indigenous nitrogen in sedimentary and aeolian deposits from the Curiosity rover investigations at Gale crater, Mars, Proceedings of the National Academy of Sciences of the United States of America Volume: 112 Issue: 14 Pages: 4245-4250 Published: APR 7 2015*

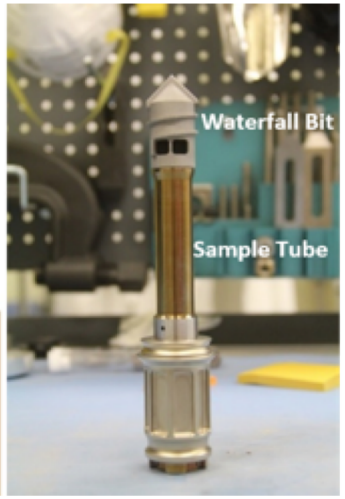
***"Plausible correlations of the background methane values with atmospheric water vapor and with surface temperatures point to physical or chemical surface (or dust) processes, or microseepage release."** : Webster, Christopher R.; Mahaffy, Paul R.; Atreya, Sushil K.; et al., Background levels of methane in Mars' atmosphere show strong seasonal variations, Science Volume: 360 Issue: 6393 Pages: 1093, 2018*

Which samples may be most interesting to evaluate if the present-day Martian regolith is inhabited? And to assess the amount of water available?

"Mars 2020 will carry total of 42 tubes, of which 5 (witness blank tubes) will be flown pre-loaded with a range of witness materials designed to accumulate molecular and particulate contaminants. In a major test program using analogue samples, collected cores were typically ~**12.7 mm** in diameter and **60 mm long**, amounting to an average of 10-15 grams of martian material per tube " iMOST report 2018.

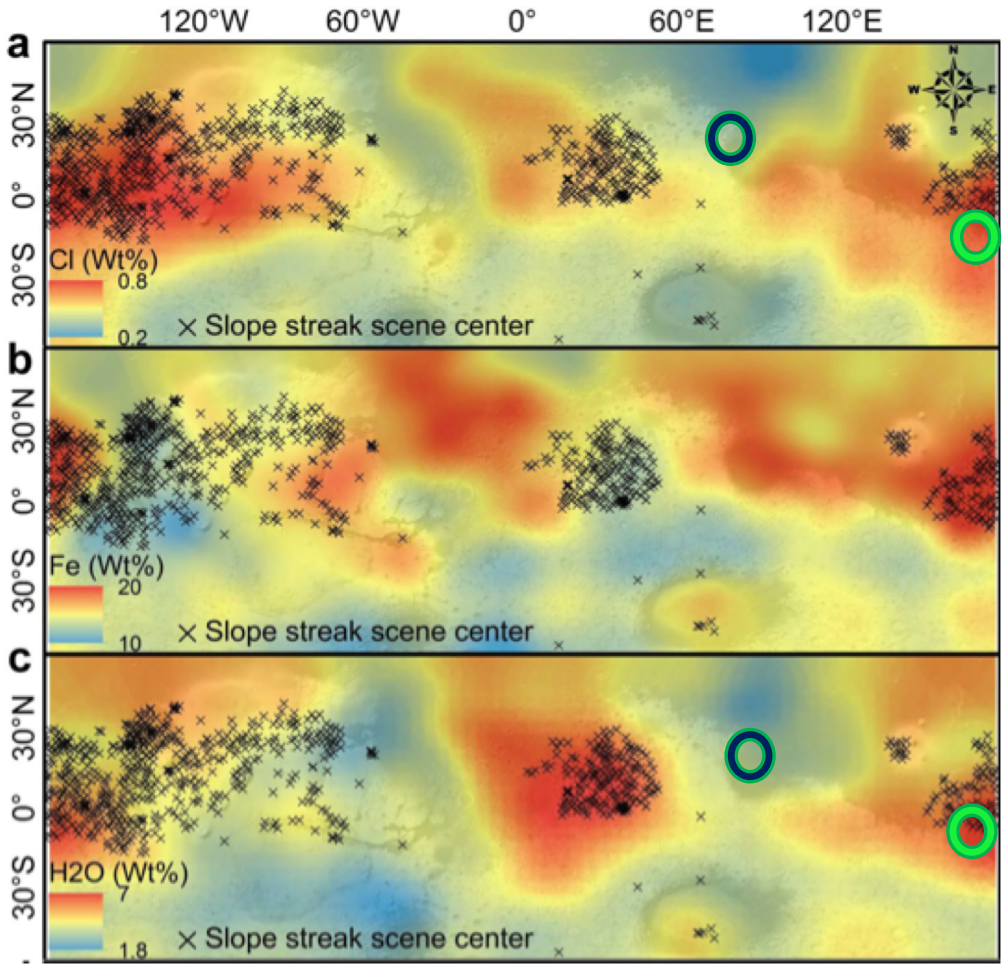
iMOST (2018), The Potential Science and Engineering Value of Samples Delivered to Earth by Mars Sample Return, (co-chairs D. W. Beaty, M. M. Grady, H. Y. McSween, E. Sefton-Nash; documentarian B.L. Carrier; plus 66 co-authors), 186 p. white paper. Posted August, 2018 by MEPAG at https://mepag.jpl.nasa.gov/reports.cfm.





Water availability: subsurface H_2O and Cl-salts for brines

Data from the Gamma Ray Spectrometer (GRS) aboard the 2001 Mars Odyssey (https://grs.lpl.arizona.edu/grs-web/specials/Smoothed_rebinned_map_data).



"*Martian slope streaks as plausible indicators of transient water activity*" Bhardwaj, Anshuman; Sam, Lydia; Martin-Torres, F. Javier; et al. Scientific Reports Volume: 7 (2017).

Figure 1. Global distribution of slope streaks and chemical parameters. (a) **Cl concentration** [30, 31]. (b) Fe concentration [31, 32]. (c) **Water-equivalent hydrogen concentration** [30, 31].

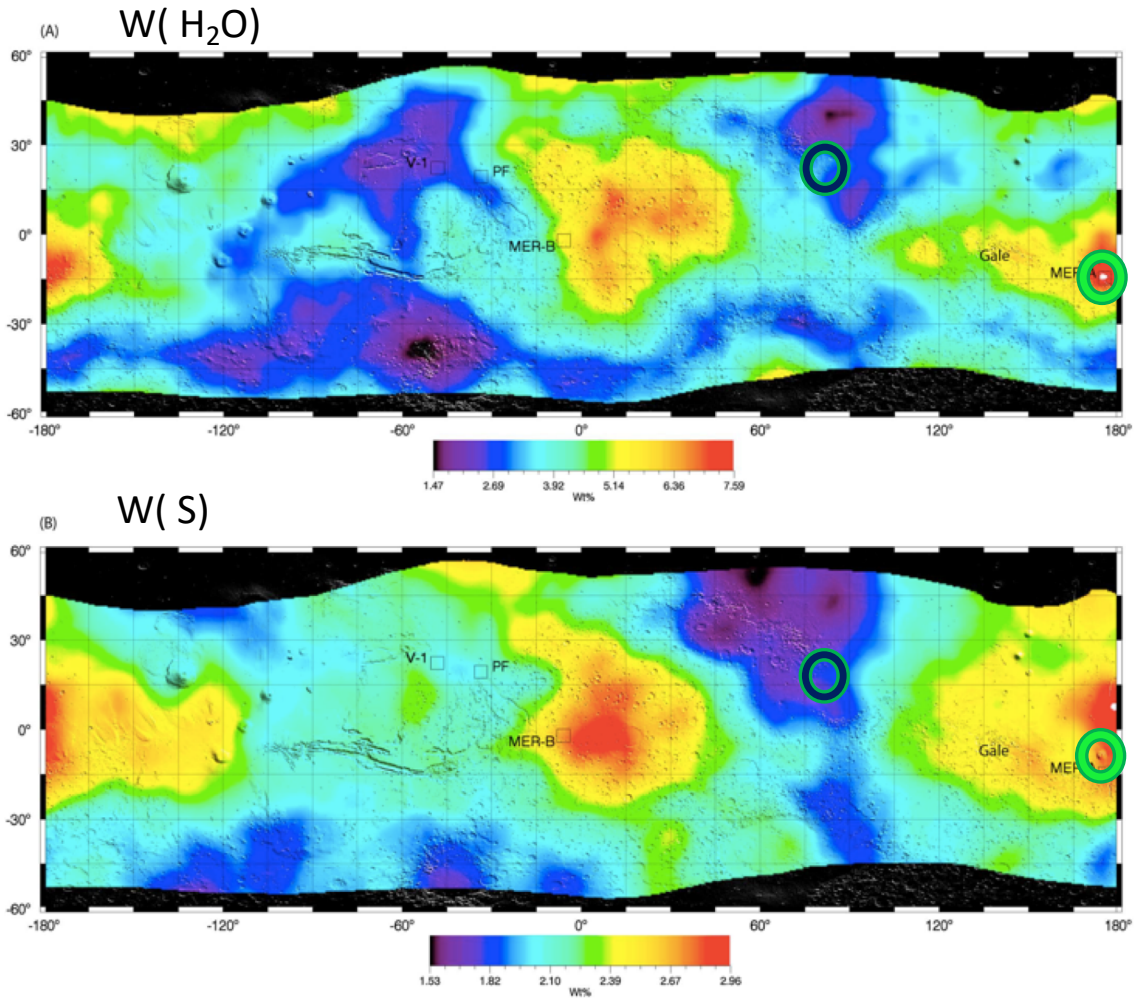
[30] Keller, J. M. et al. Equatorial and midlatitude distribution of chlorine measured by Mars Odyssey GRS. J. Geophys. Res-Planet 111(E3), doi:10.1029/2006JE002679 (2006).

[31] Boynton, W. V. et al. Concentration of H, Si, Cl, K, Fe, and Th in the low-and mid-latitude regions of Mars. J. Geophys. Res-Planet 112(E12), doi:10.1029/2007JE002887 (2007).

[32] Ody, A. et al. Global maps of anhydrous minerals at the surface of Mars from OMEGA/MEx. J. Geophys. Res-Planet 117(E11), doi:10.1029/2012JE004117 (2012).

Location	Lat (degN)	Long (degE)
Columbia Hills	-14.5711	175.4374
Jezero	18.4463	77.4565
Midway	18.2747	77.0480
NE Syrtis	17.8899	77.1599

Water availability: subsurface H_2O and S (sulfates)



Karunatillake, S., J. J. Wray, O. Gasnault, S.M.McLennan, A. D. Rogers,S.W.Squyres, W. V. Boynton, J. R. Skok, L. Ojha, and N. Olsen (2014), Sulfates hydrating bulk soil in the Martian low and middle latitudes, Geophys. Res. Lett., 41, 7987–7996, doi:10.1002/2014GL061136.

Figure 1. **(a) Map of stoichiometrically equivalent H2O mass fractions** as percentage, w(H2O), derived from GRS γ spectroscopy. Equirectangular projection uses east longitude notation. Scale bar at bottom indicates the color-coded w(H2O) values, which range from 1% to 8% within the 5° Å~ 5° spatial resolution limit. Overlain on Mars Orbiter Laser Altimeter-derived topography with landing sites identified as V-1 (Viking 1), PF (Pathfinder), MER-B (Opportunity Rover at Meridiani), MER-A (Spirit Rover at Gusev), and Gale (Curiosity Rover). Black hue defines the boundary of chemical data. **(b) Map of stoichiometrically equivalent S mass fractions as percentage**, w(S), derived from GRS γ spectroscopy. Scale bar at bottom color codes w(S) values, which range from 1% to 3% (stoichiometrically equivalent to 2.5% to 7.5% of SO3) within the 10° Å~ 10° spatial resolution limit.

Location	Lat (degN)	Long (degE)
Columbia Hills	-14.5711	175.4374
Jezero	18.4463	77.4565
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What about the temperature for replication and metabolism? what happens at Gale at the subsurface?

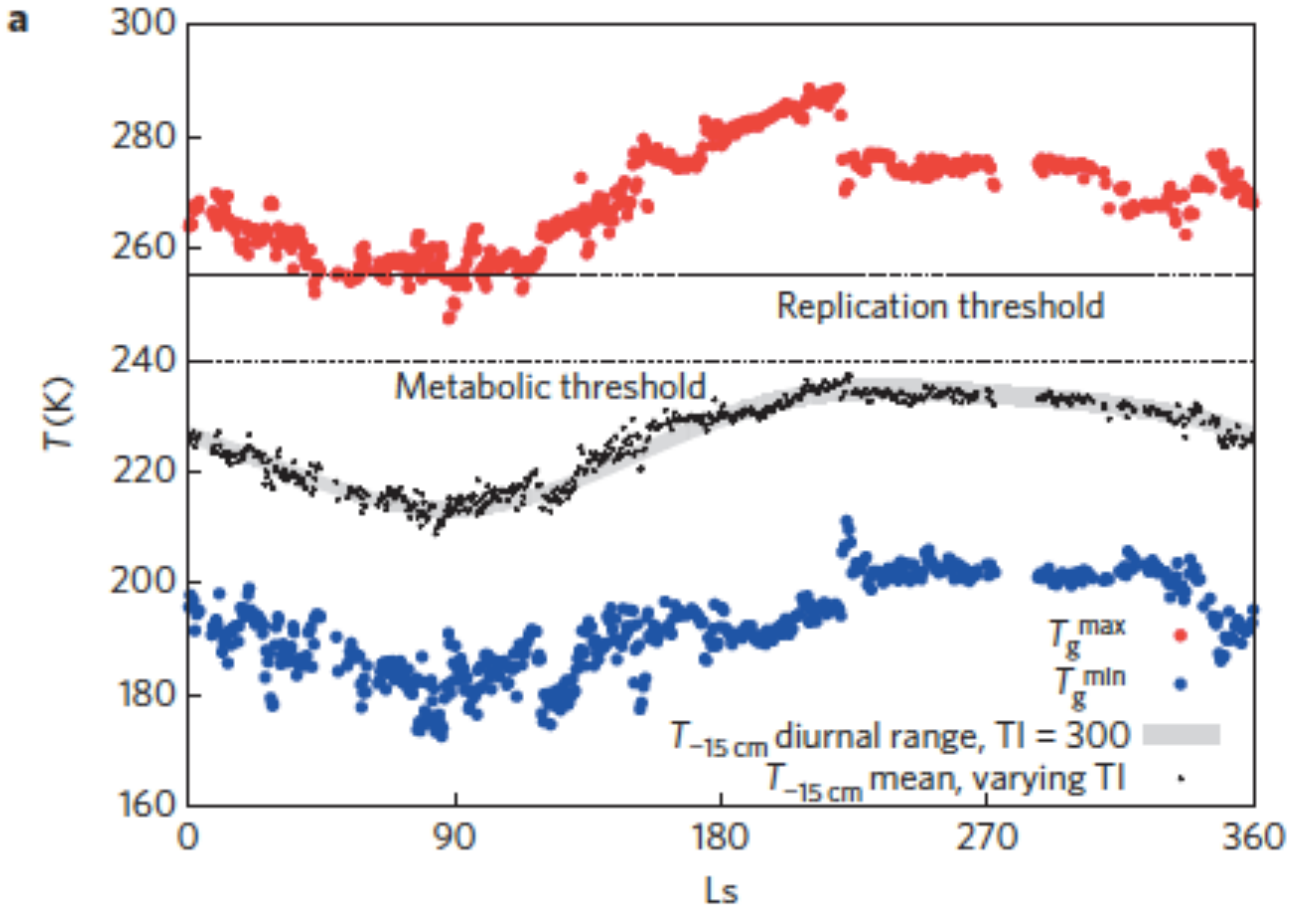


Figure 2 (s) Surface and subsurface temperatures, night-time H2O VMR and air temperature. a, During a few hours every day, the surface is above the thermal threshold for microbial replication (…).

"Transient liquid water and water activity at Gale crater on Mars" Martin-Torres, F. Javier; Zorzano, Maria-Paz et al. Nature Geoscience Volume: 8 Issue: 5 Pages: 357-361 (2015)

REMS data from the REMS Archive at the PDS Atmosphere Node. http://pds-atmospheres.nmsu.edu/data_and_services/atmospheres_data/Mars/Mars.html

Subsurface Thermal Model

$$\frac{dTz(t)}{dt} = \left(\frac{TI}{\rho Cp}\right)^2 \frac{\partial^2 Tz(t)}{\partial^2 z}. \qquad (1)$$

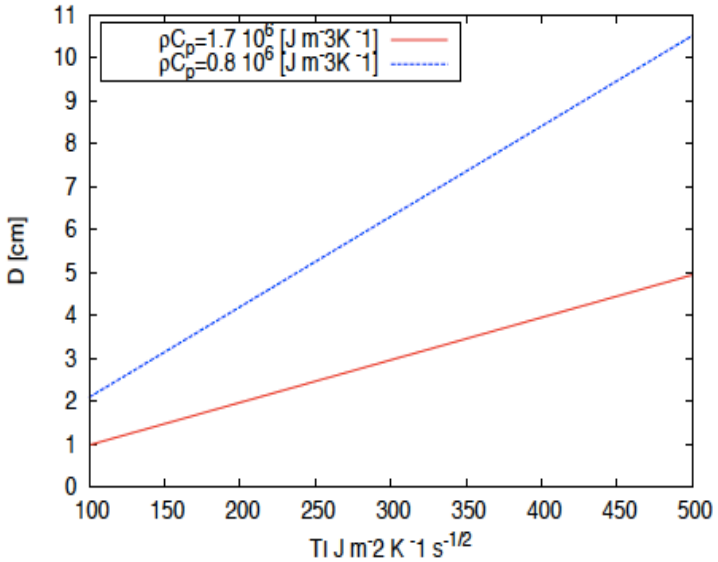
$$D = \sqrt{\frac{2}{\omega}}\left(\frac{TI}{\rho Cp}\right)$$ Penetration depth

For pure sinusoidal forcing, at the surface, z = 0,

$$T_{z=0}(t, Ls) = T_{-\infty} + \Delta T_{z=0}\ sin(\omega t + \phi)$$

with $\omega = 7{,}2710^{-5} s^{-1}$ the Mars (diurnal) rotation frequency and $2\Delta T_{z=0} = Tmax_{z=0} - Tmin_{z=0}$, the amplitude of the surface diurnal thermal oscillation, ϕ the phase shift with respect to the local time and $T_{-\infty}$, for sinusoidal forcing, the diurnal mean of the surface temperature

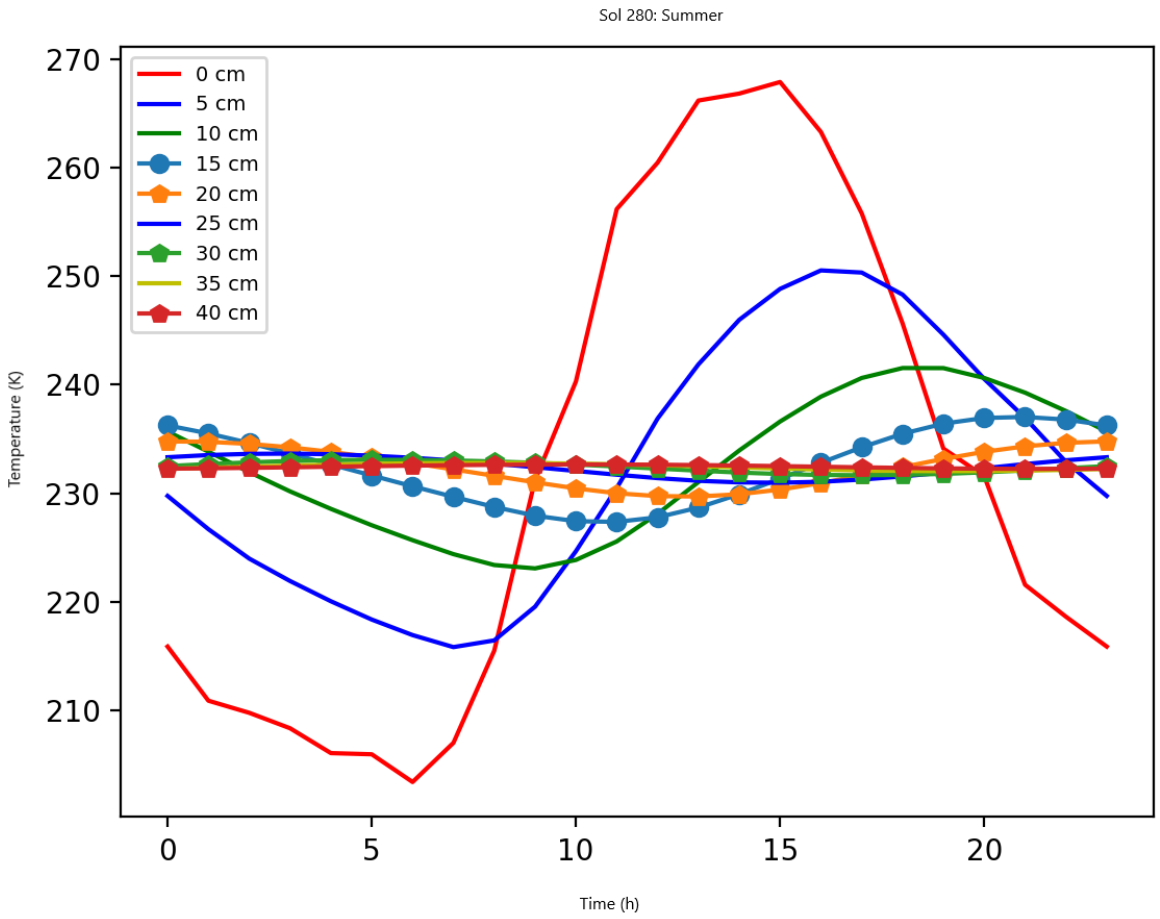
$$Tz(t) = T_{-\infty} + \Delta T_{z=0}\, e^{-z/D}\, sin\left(\omega t - \frac{z}{D} + \phi\right)$$



The diurnal periodic excitation of the surface by solar radiation leads to a strongly damped heat wave into the ground that decays with the penetration depth D. This graph shows the variation of the thermal penetration depth D with thermal inertia (TI) and volumetric heat capacity ρCp.

The amplitude of the thermal variation within the soil decreases exponentially with depth z, in such a way that at a **depth of about 3 times the penetration depth D** the temperature converges to a fixed temperature $T_{-\infty}$

What can the thermal models tell us about the subsurface?



For the general case, the surface temperature is measured remotely (example: TES [1] planet wide) or in-situ (example: REMS [2]/Curiosity at Gale) and the equation can be solved to "predict" the subsurface T

$$\frac{dTz(t)}{dt} = \left(\frac{TI}{\rho Cp}\right)^2 \frac{\partial^2 Tz(t)}{\partial^2 z}$$

Upper boundary condition: Tz=0 measured T

Lower boundary condition: zero subsurface flux

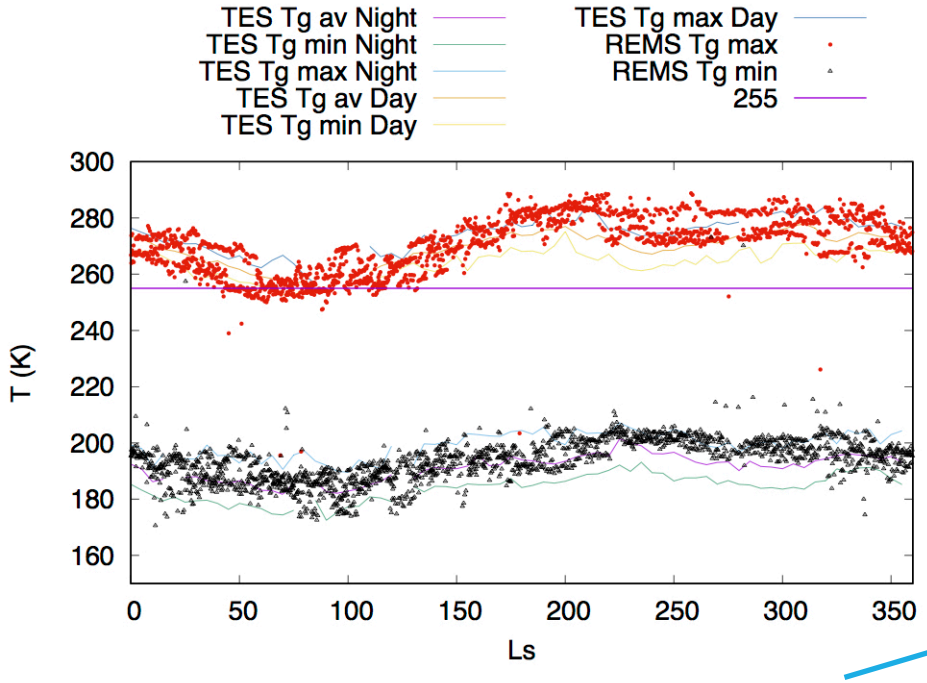
$$D = \sqrt{\frac{2}{\omega}}\left(\frac{TI}{\rho Cp}\right)$$ Penetration depth

[1] *Mars Global Surveyor. Thermal Emission Spectrometer (TES) http://tes.asu.edu/data_tool. Data Processing. User´s Guide- Version 1.6. October 15, 2006*

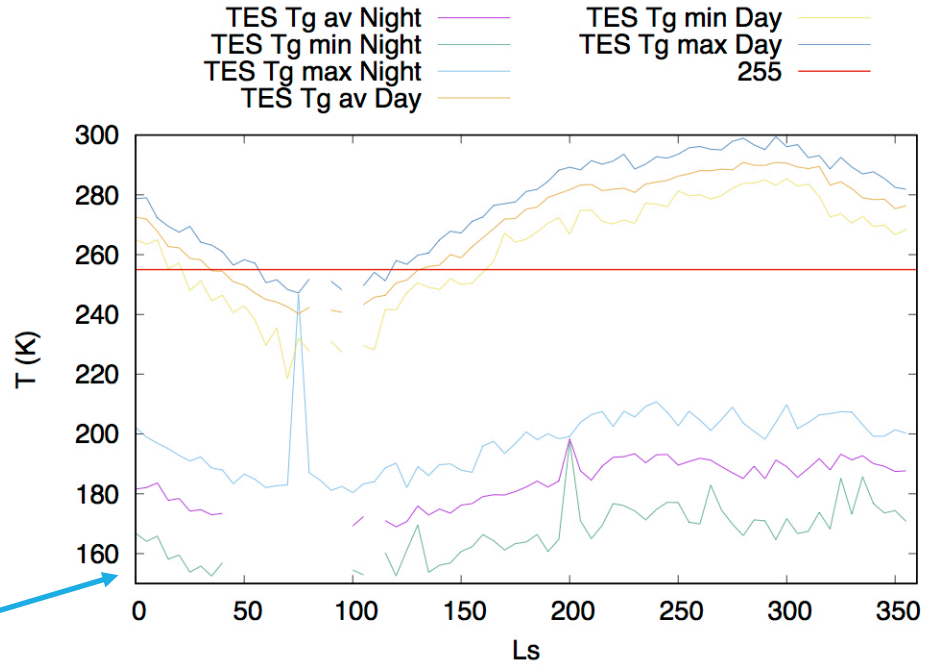
[2] *REMS data from the REMS Archive at the PDS Atmosphere Node. http://pds-atmospheres.nmsu.edu/data_and_services/atmospheres_data/Mars/Mars.html*

Surface T (maximal and minimal)

GALE: VALIDATION

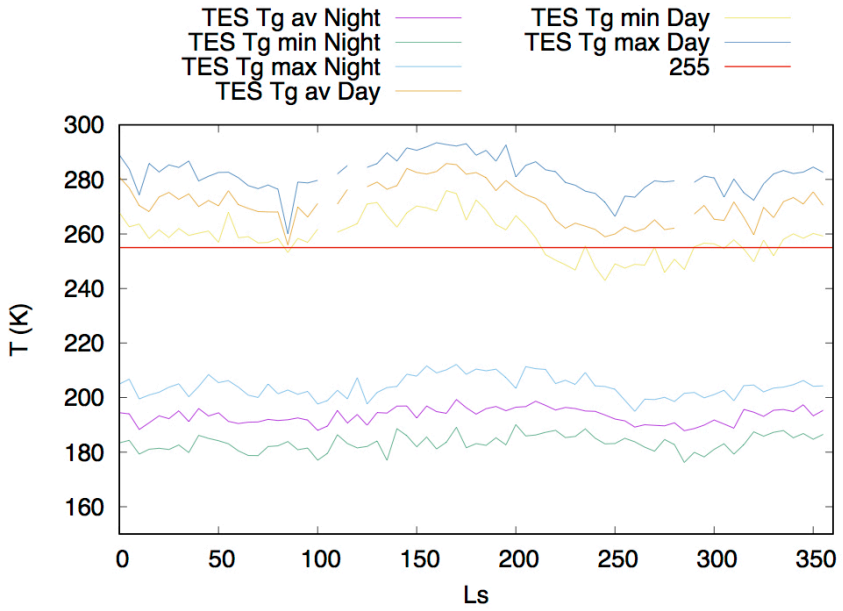


COLUMBIA HILLS

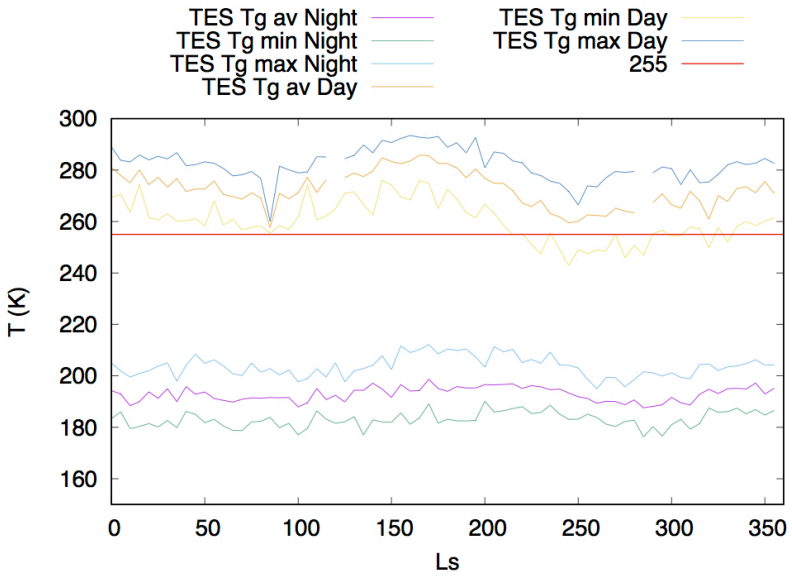


Colder nights!

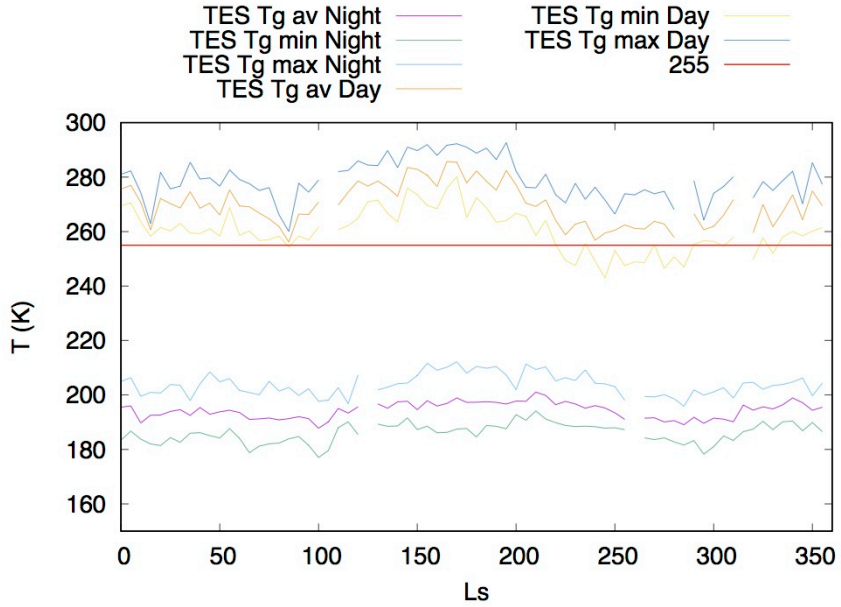
Mars Global Surveyor. Thermal Emission Spectrometer (TES) http://tes.asu.edu/data_tool. Data Processing. User´s Guide- Version 1.6. October 15, 2006



Jezero

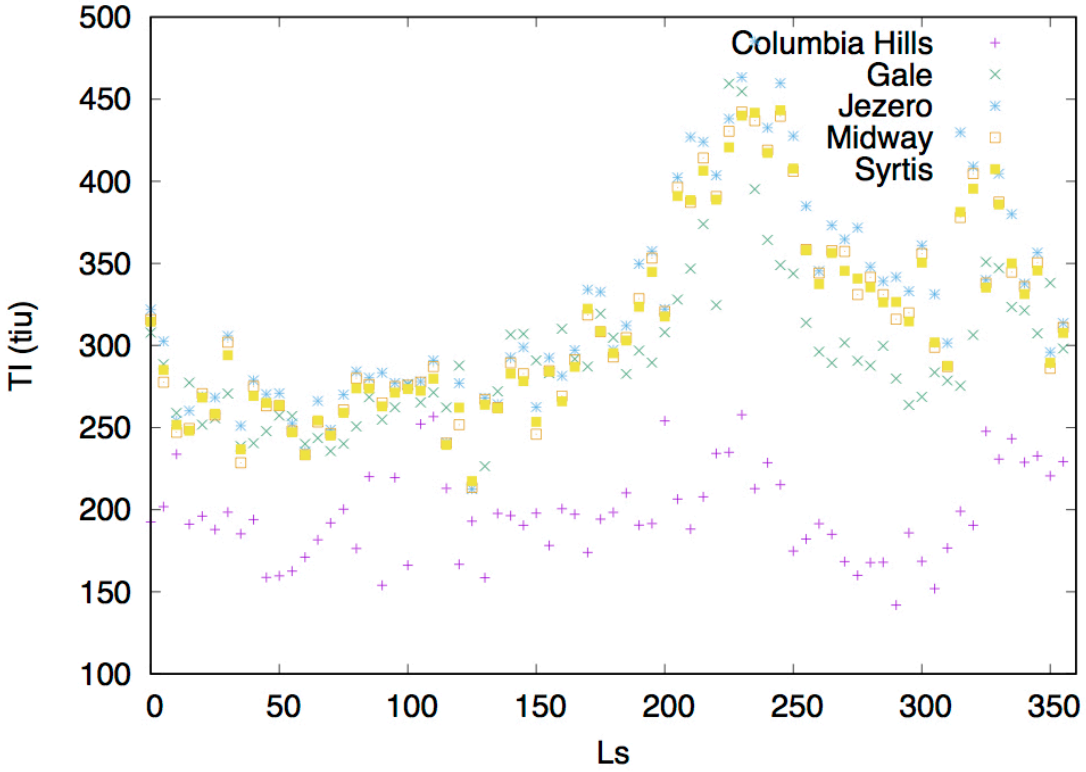


Midway



Syrtis

Thermal Inertia

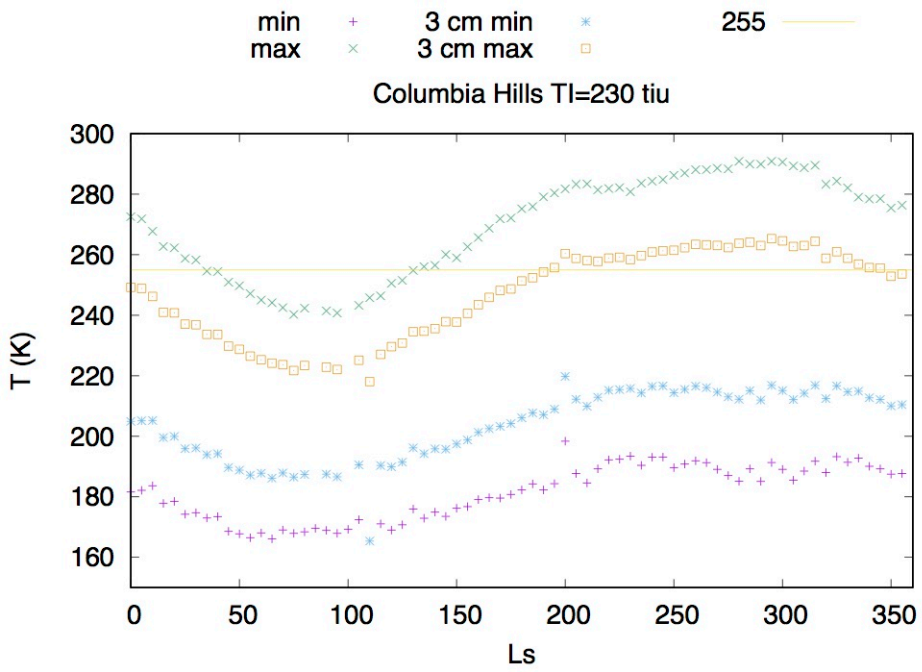


$$D = \sqrt{\frac{2}{\omega}}\left(\frac{TI}{\rho Cp}\right)$$ Penetration depth

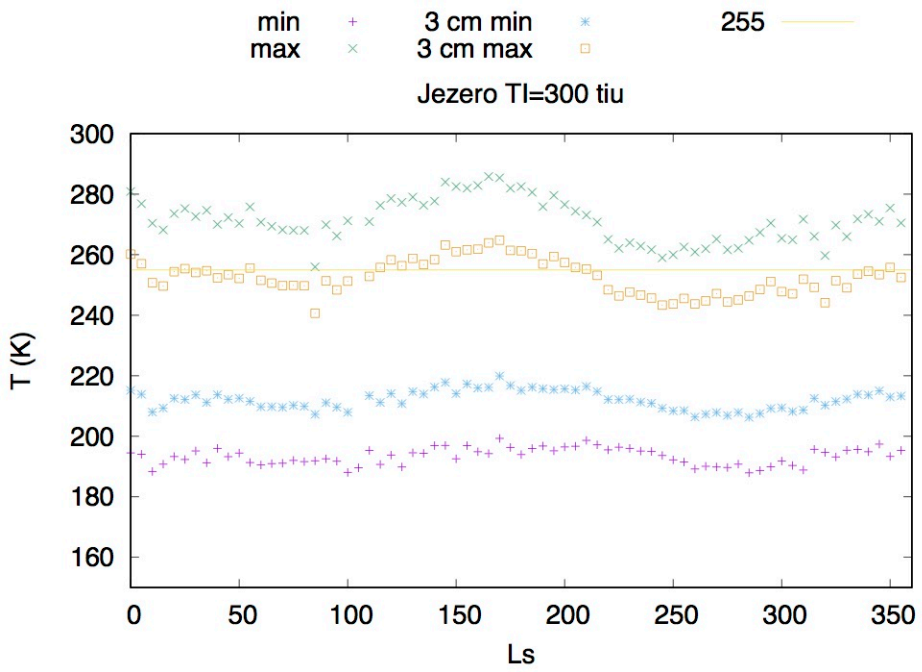
For all the other parameters equal, then
If TI is higher then thermal penetration depth
D is larger

Example: at 3 cm, T> 255 K is met at all sites

COLUMBIA HILLS



JEZERO



Night-time water activity at the surface (>0.6)

$$MMR = \frac{MW}{MD} \times \frac{RH}{100} \times \frac{e_w(T)}{\left(P - \frac{RH}{100} \times e_w(T)\right) \times 1000}$$

$$VMR = \frac{MD}{MW \times MMR \times 1000}$$

MW=18.0160 g mol^{-1}, MD=43.3400 g mol^{-1}

$$e_w(T) = 6.11 \times e^{22.5 \times \left(1 - \frac{T_K}{T}\right)}$$

$$ew_{liq(T_g)} = 6{,}112 \cdot EXP\left[\frac{17{,}62 \cdot (T - 273{,}14159)}{243{,}12 + (T - 273{,}14159)}\right]$$

With REMS H_2O VMR

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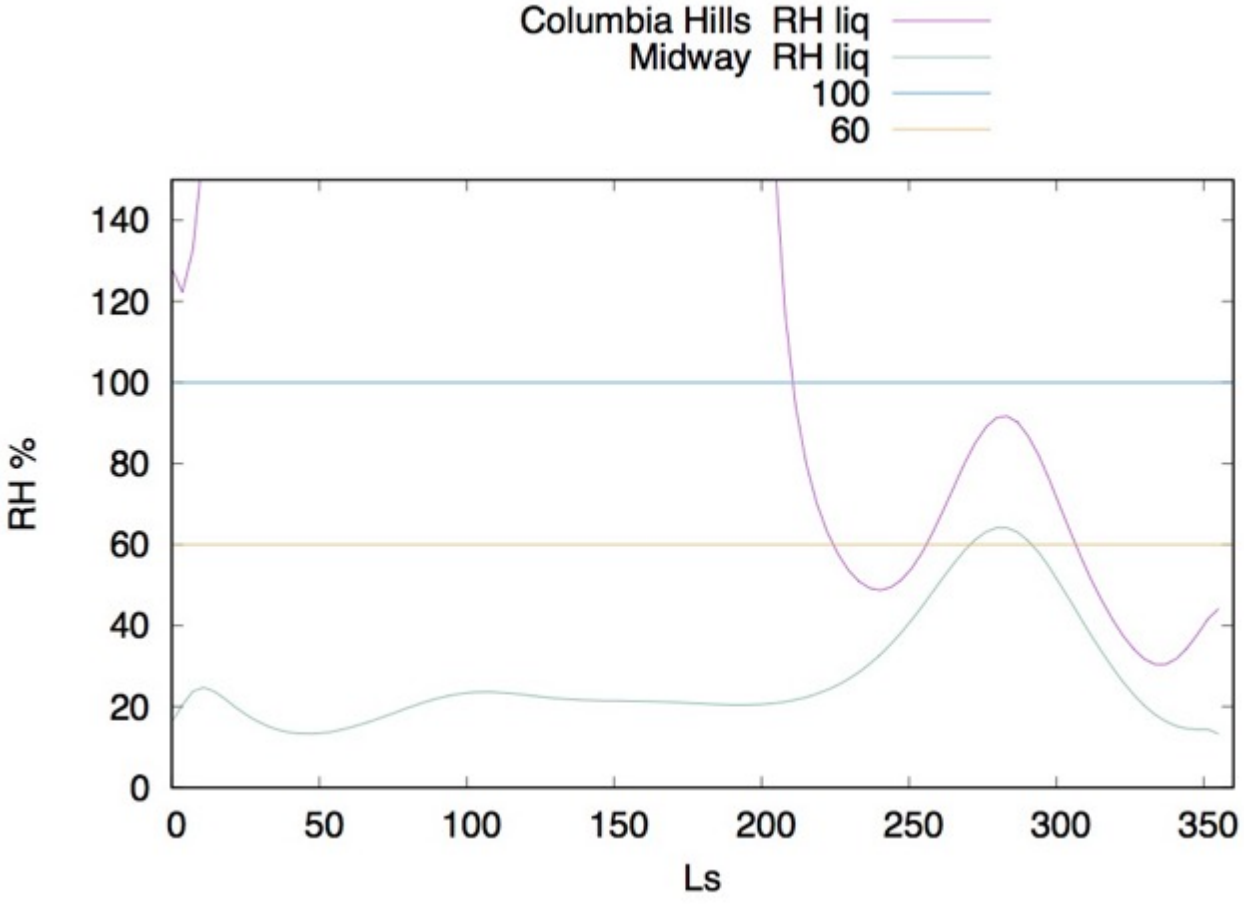
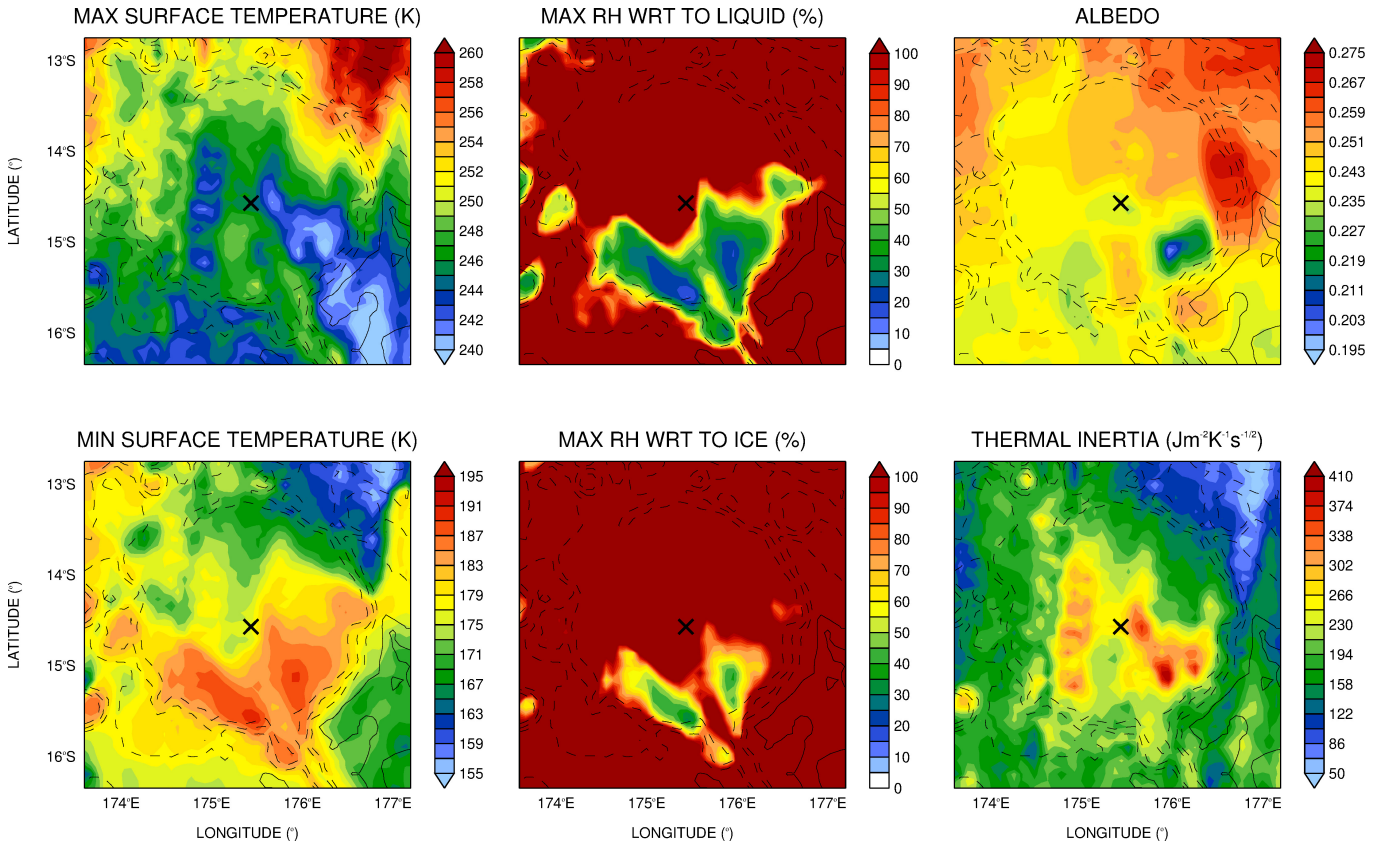


Columbia Hills Mesoscale analysis, MarsWRF, Ls 90°



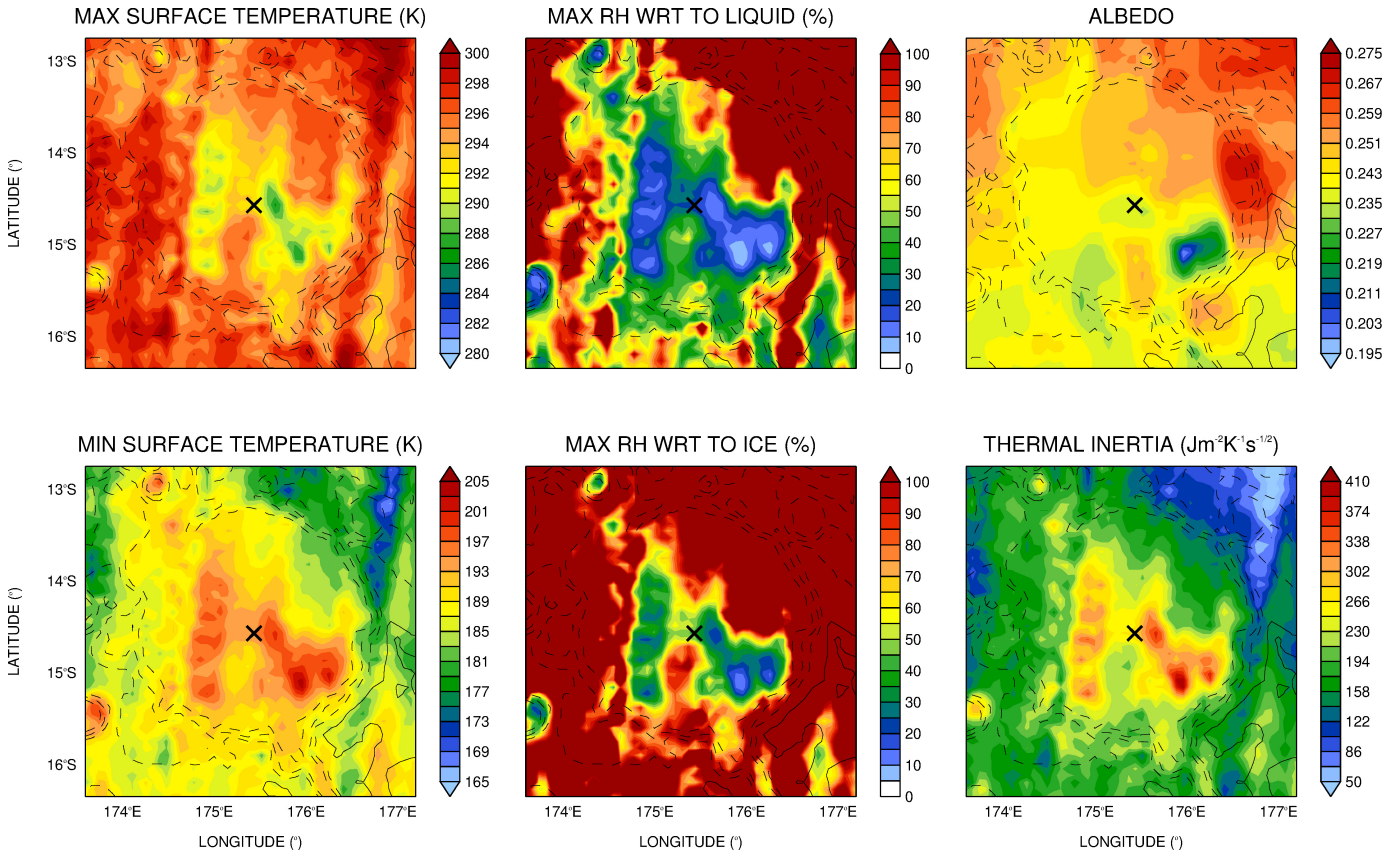
MarsWRF Output with REMS H2O VMR.

Solid/Dashed lines: Positive/Negative orography contours every 500 m.

Star: Columbia Hills (~14.6º, 175.4ºE);

Model output for **4th grid (~4.382 km)**

Columbia Hills Mesoscale analysis, MarsWRF, Ls 300°



MarsWRF Output with REMS H2O VMR: Ls 300°

Solid/Dashed lines: Positive/Negative orography contours every 500 m.

Star: Columbia Hills (~14.6º, 175.4ºE); Model output for **4th grid (~4.382 km)**

Columbia Hills, ancient hot springs and a shallow lake (Spirit Rover landing site).

At large scale: Columbia Hills *may be a more habitable place on present day Mars up to a depth of 5 cm (allowing for cell reproduction)* because:

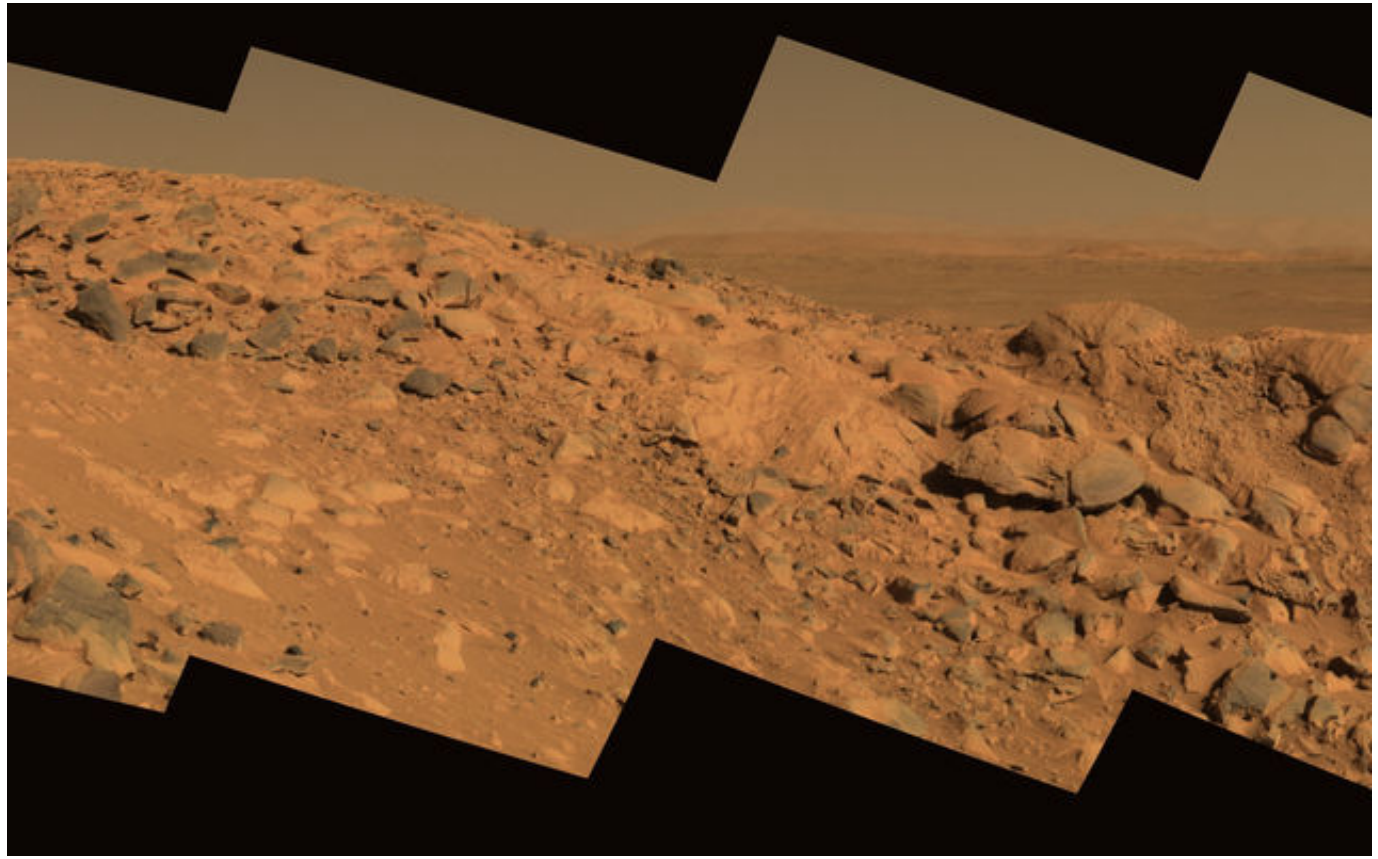
It has greater Cl% and S% which allow for atmospheric water absorption.
It shows **greater signal of H_2O** absorption.

It may go above the condition for liquid water activity > 0.6 at night time and have during the day temperatures above the T=255 K limit of replication (both conditions are not met simultaneously and thus out of equilibrium processes related to brines are desired).

The site has high potential for significant water resources that may be of use for future exploration in the form of water-rich hydrated minerals.

View of Columbia Hills from the Mars Exploration Rover Spirit

Image Credit: NASA/JPL-Caltech/Cornell



Science evaluation criteria for Mars 2020 landing site selection

Criterion 1:
The site is an astrobiologically-relevant ancient environment and has geologic diversity that has the potential to yield fundamental scientific discoveries when it is a) characterized for the processes that formed and modified the geologic record; and b) subjected to astrobiologically-relevant investigations (e.g., **assessment of habitability** and biosignature preservation potential).

Criterion 2:
A rigorously documented and returnable cache of rock and regolith samples assembled at this site has the potential to yield fundamental scientific discoveries if returned to Earth in the future.

Criterion 3:
There is high confidence in the **assumptions, evidence, and any interpretive models** that support the assessments for Criteria 1 and 2 for this site.

Criterion 4:
There is high confidence that the highest-science-value regions of interest at the site can be adequately investigated in pursuit of Criteria 1 and 2 within the prime mission.

Criterion 5:
The site has high potential for **significant water resource**s that may be of use for future exploration-whether in the form of **water-rich hydrated minerals, ice/ice regolith or subsurface ice.**

Key Questions for Deciding on the Mars 2020 Rover's landing Site

The mission takes the next step by not only seeking signs of habitable conditions on Mars in the ancient past, but also searching for signs of past microbial life itself.

- Can the Mars 2020 rover achieve all of the mission's scientific objectives at this site?
- Does the area show signs in the rock record that it once had the right environmental conditions to support past microbial life?
- Does the area have a variety of rocks and "soils" (regolith), including those from an ancient time when Mars could have supported life?
- Did different geologic and environmental processes, including interactions with water, alter these rocks through time?
- Are the rock types at the site able to preserve physical, chemical, mineral, or molecular signs of past life?
- **Is the potential high for scientists to make fundamental discoveries with the samples cached by the rover, if potentially returned to Earth someday?**
- **Does the landing site have water resources (water ice and/or water-bearing minerals) that the rover could study to understand their potential use by future human explorers?**
- Can the rover land and travel from place to place without facing significant hazards posed by the terrain?