Simulated Water Well Performance on Mars

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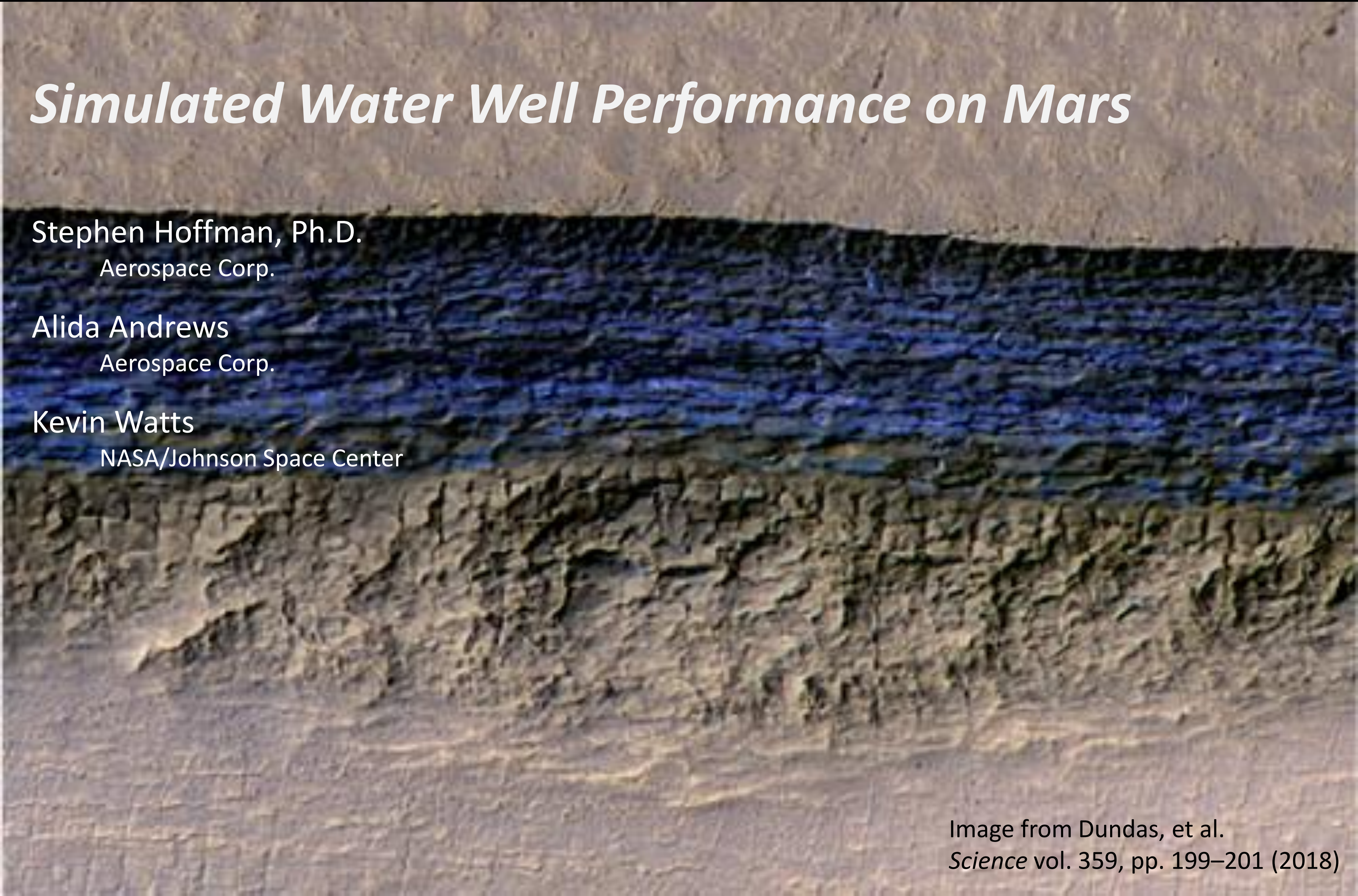


Image from Dundas, et al.
Science vol. 359, pp. 199–201 (2018)

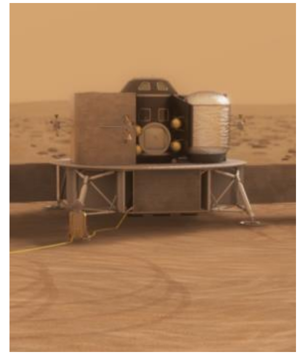
Introduction

- **Previous work by the authors addressed a pair of questions posed during studies of the Evolvable Mars Campaign (EMC): what are the implications of "unlimited" water on a human Mars mission and how would these quantities of water be acquired?**
- **That initial work documented findings associated with the following:**
  - The sources of water observed on Mars will be described
  - Uses for locally obtained water are identified and estimated quantities needed for each of these uses are presented
  - Methods for accessing local sources of Martian water are reviewed
  - Results from a simulation to estimate time and power required for one method – the Rodriguez Well
- **Rodriguez Well simulations were based on terrestrial environmental conditions, recognizing that Mars environmental conditions needed to be applied.**
- **Several parameters needed to properly implement the Rodriguez Well simulation were not adequately understood to allow for code modification; experimental data was needed**
- **This presentation describes progress since the previous presentation of results:**
  - Recent discoveries on Mars reinforcing the type and quantities of water ice potentially accessible by human crews
  - Estimates of the type of dedicated equipment needed to access this ice on Mars
  - Identification of specific changes needed in the Rodriguez Well simulation code and preliminary results of the Well performance that will result
  - Description of the experiments that will be conducted to generate the Mars-specific parameters needed for simulation modification

How Would a Human Mars Mission Use Abundant Water?

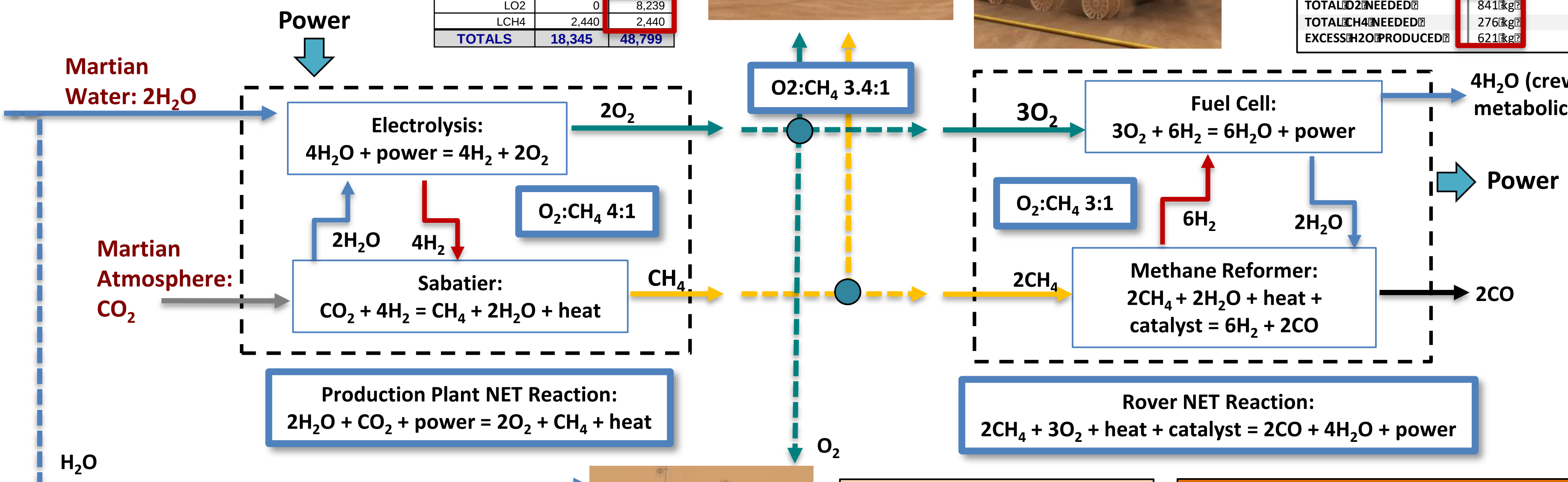
20 tons of water (plus CO_2) provides ascent fuel and oxidizer for one MAV

Subsystem	Mass (kg)	
	MDM Payload	Mars Liftoff
Crew Cabin	**3,427**	**4,122**
Structures	881	881
Power	377	377
Avionics	407	407
Thermal	542	542
ECLS	502	502
Cargo	422	1,117
Non-Prop. Fluids	295	295
1st Stage	**9,913**	**31,432**
Dry Mass	3,605	3,605
LO2	0	21,519
LCH4	6,308	6,308
2nd Stage	**5,006**	**13,245**
Dry Mass	2,566	2,566
LO2	0	8,239
LCH4	2,440	2,440
TOTALS	**18,345**	**48,799**

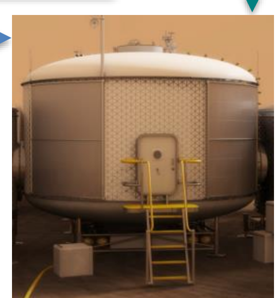


23 tons of water provides rover reactants for robust surface mobility

TRIP DURATION	14 sols
NO. OF DAYS DRIVING	9 sols
CREW	2
ROVER DRIVE TIME/DAY	9 hours
TOTAL ENERGY NEEDED	1564 kW-hrs
TOTAL O2 NEEDED	841 kg
TOTAL CH4 NEEDED	276 kg
EXCESS H2O PRODUCED	621 kg



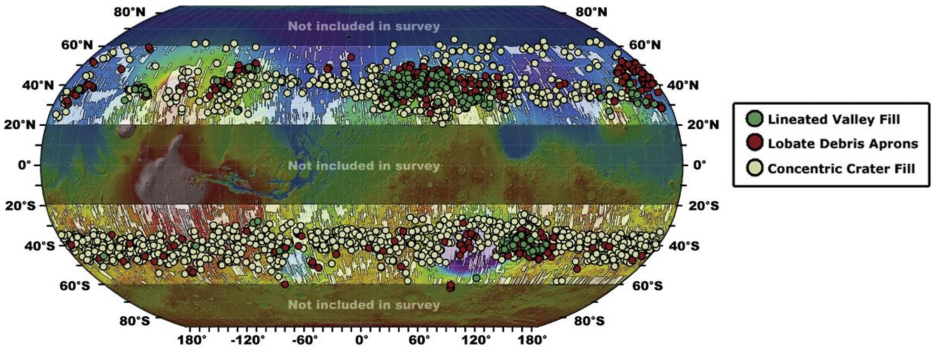
	CLOSED-LOOP H_2O, O_2	OPEN-LOOP H_2O, O_2	OPEN-LOOP + LAUNDRY
H_2O CLOSED-LOOP MAKEUP	970	0	0
O_2 CLOSED-LOOP MAKEUP	2480	0	0
LAUNDRY	0	0	14660
EVA	0	3072	3072
FOOD REHYDRATION	0	1070	1070
MEDICAL	0	107	107
DRINK	0	4280	4280
FLUSH	0	134	134
HYGIENE	0	856	856
TOTAL	3450 kg	9519 kg	24379 kg



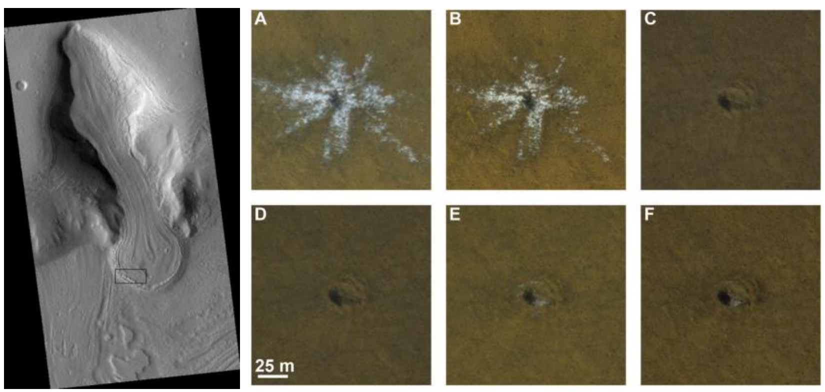
25 tons of water provides robust open-loop life support for a crew of 4 for 500 days

A total of 68 tons of water supports one crew of 4 during a 500 day mission

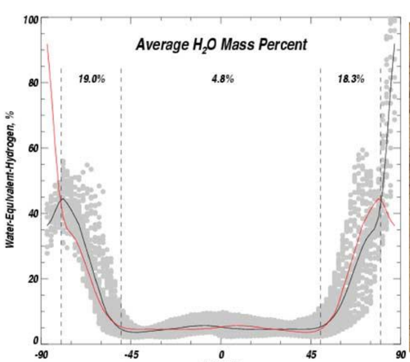
Where Have We Seen Martian Water Sources?



From Dickson et al. 2012.



From Dundas, et al., 2014



From Feldman, et al. 2004.

To date *Mars Express MARSIS and Mars Reconnaissance Orbiter (MRO) SHARAD radars* ***have failed to detect any indications of <u>liquid</u> groundwater within 200-300 m of the surface <u>anywhere</u> on Mars [Clifford, et al. 2010]***

However:

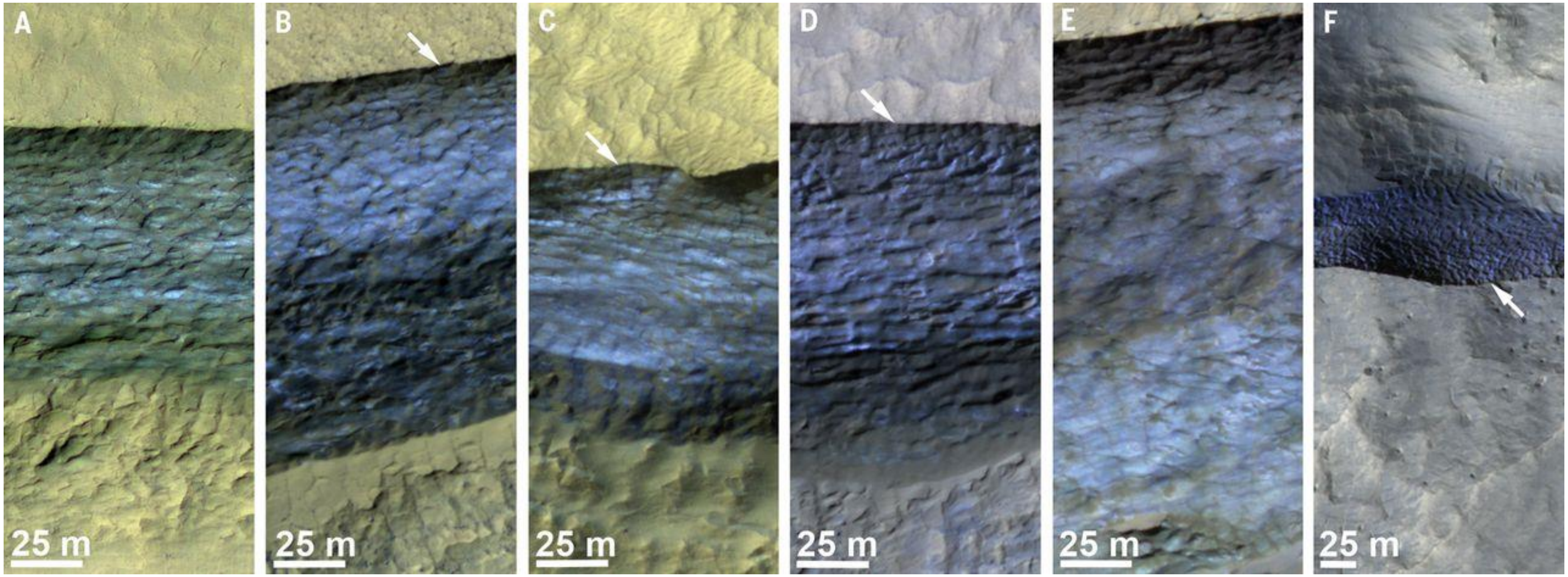
- Martian geological features suggest evidence **for large-scale *mid-latitude* glaciation** (from previous "ice ages"), potentially driven by changes in obliquity of Mars' rotation axis
- *MRO* SHARAD radar took soundings of "lobate debris aprons" (LDAs) in southern and northern regions
- Radar properties completely consistent with **massive water <u>ice</u> (100s of m thick, >90% pure) covered by relatively thin (0.5 - 10 m) debris layer** [Holt, et al. 2008]

- <u>Fresh</u> impacts detected by *MRO* HiRISE imager actually ***show* excavated, clean ice** (~1% regolith content), verified by CRISM spectrometer
- Majority of craters showing ice in mid-latitudes correspond to the suspected glacier-like features; estimated **excavation ~2 m**

- *Mars Odyssey* gamma ray/neutron spectrometer confirmed previous predictions of extensive ground ice within *one meter* of surface
  - Poleward of 50°N and S
  - Concentration highly variable ~20-90%
  - Cryosphere estimated to be 5-15 km thick [Clifford, et al. 2010]
- Predictions and orbital measurements confirmed by the *Phoenix* lander (68°N)
  - Ice excavated at 2-6 cm, up to 99% pure

Recent Discovery of Exposed Water Ice Scarps

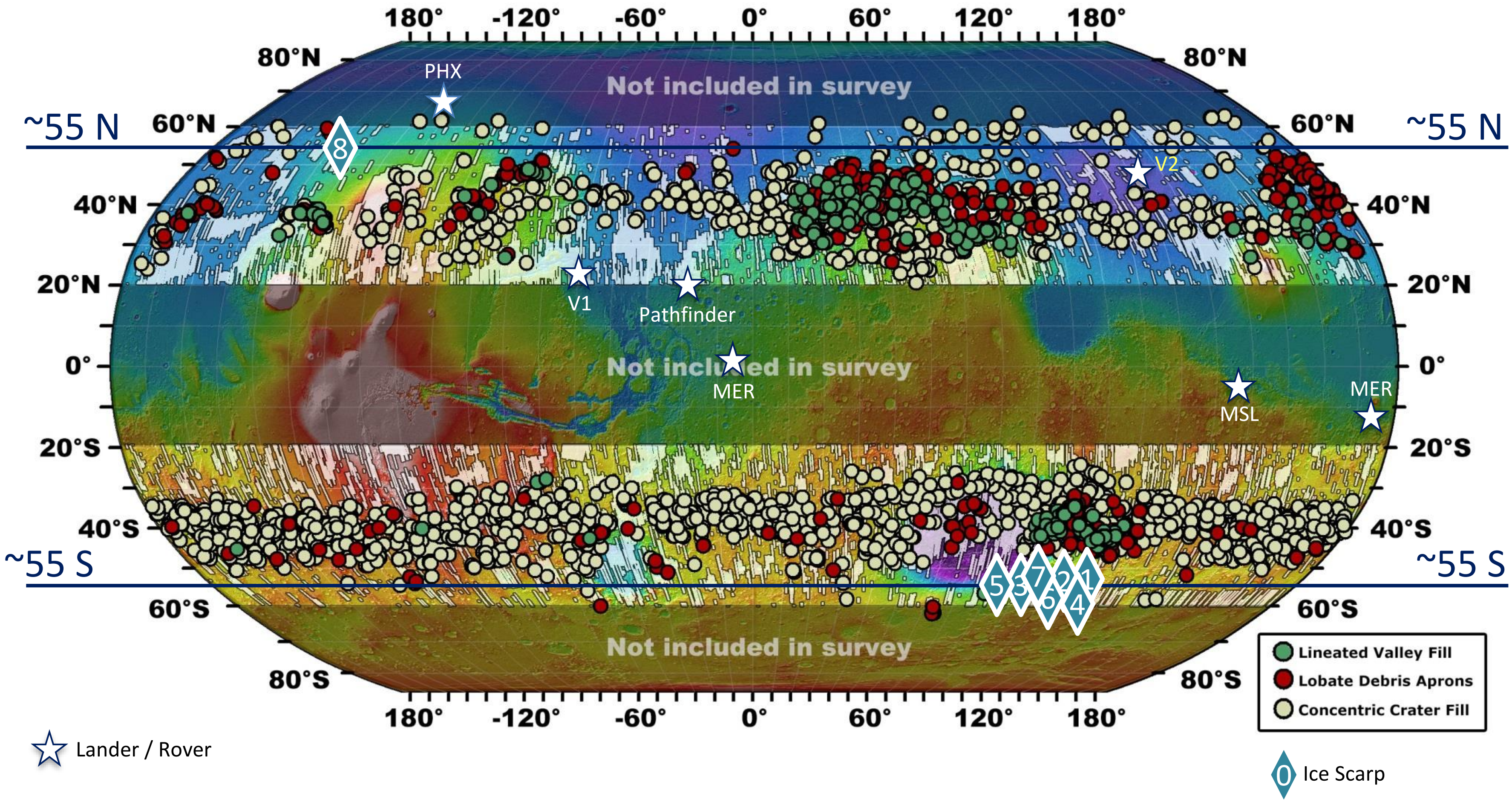
- A recent article in *Science* by C. Dundas, et al. documents the discovery of eight terrain features, the composition of which has been shown to be exposed water ice.
- The quantity of water associated with these features is massive and therefore could play a significant role in future human Mars missions
- Accessing these deposits of ice could fundamentally change the way human Mars missions are carried out



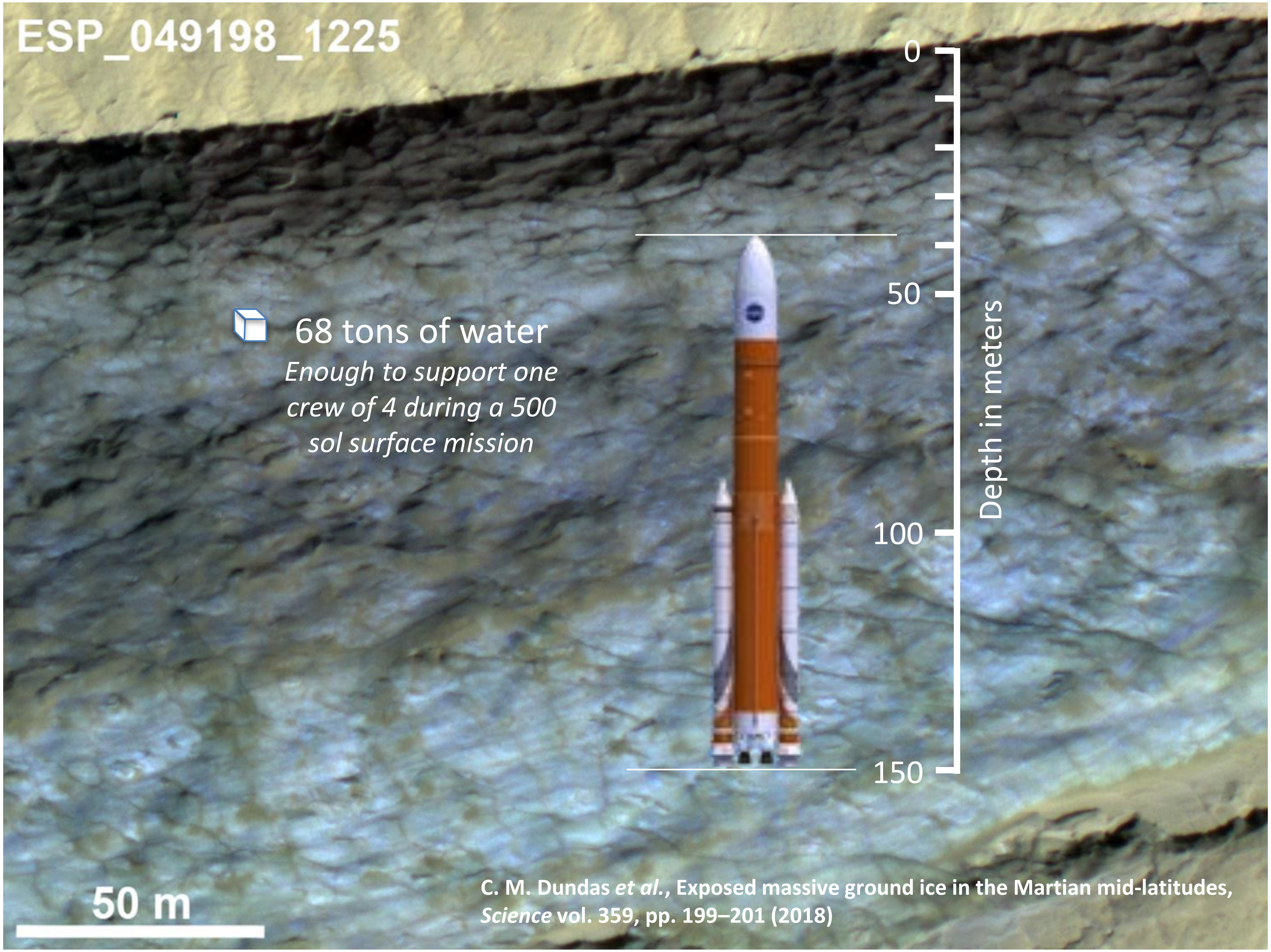
Images from Dundas, et al., *Science* vol. 359, pp. 199–201 (2018)

Where are these Scarps Located?

- Seven of the scarps "… are located in the southern hemisphere, and the eighth location is a cluster of scarps in Milankovič Crater in the northern hemisphere."



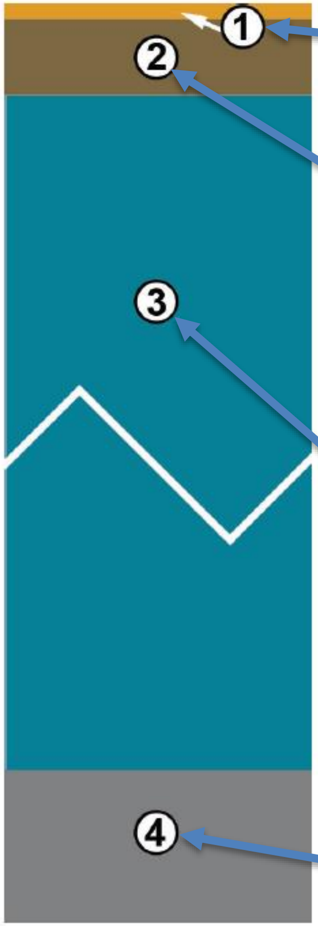
How Much Water Ice Could Be In These Formations?



C. M. Dundas *et al.*, Exposed massive ground ice in the Martian mid-latitudes, *Science* vol. 359, pp. 199–201 (2018)

Debris Protects This Ice, But How Thick Is It?

Conceptual stratigraphy of the materials exposed in the scarps.*



1. Upper dry lithic layer (dust, rocks, regolith), with a thickness of about 10 centimeters at these locations [i.e., ~50 deg. Latitude; based on models]; this is too thin to be well-expressed in the scarps. The basal contact is likely to be sharp, as observed by Phoenix.
2. Ice-rich soil (ice filling the pores of lithic material). The thickness may be variable spatially and is ≤1–2 m in places. This could be locally absent if the uppermost massive ice is covered by mass-wasted debris; however, such a layer is possible based on the difference between the depth to visible ice and the predicted depth to the top of the ice table. If such a layer exists, vertical variations in ice content due to ice modification processes are possible.
3. Massive ice with low lithic content (≤ a few vol%). This is likely to be greater than 100 m thick but may be variable; it constitutes the bulk of the material exposed in the scarps. This unit contains some vertical structure (e.g., layers with variation in lithic fraction) and lateral heterogeneity (e.g., lens with less ice at Scarp 2). It may be locally covered by a surface lag deposit, especially on the lower parts of the scarps.
4. Basal unit (bedrock or underlying regolith materials); this may contain some ice in pore space.

*C. M. Dundas *et al.*, Exposed massive ground ice in the Martian mid-latitudes, *Science* vol. 359, pp. 199–201 (2018)

Terrestrial Polar Operations: The Rodriguez Well*

- **In situ water reservoirs were first designed and built by the U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL) in the early 1960s for several U.S. Army camps located in Greenland (Schmitt and Rodriguez 1960; Russell 1965).**
  - commonly referred to as Rodriguez Wells or Rodwells
- **Snow or ice is melted and stored in place at some depth below the surface of the ice cap, eliminating the need for mechanical handling of snow and for fabricated storage tanks**
- **Water wells or Rodwells have been used at:**
  - Camp Fistclench (Greenland, 1957)
  - Camp Century (Greenland, 1959 and 1960)
  - Camp Tuto (Greenland, 1960)
  - South Pole Station (Antarctica, 1972-73 and 1995-present; currently using third Rodwell)
  - IceCube drilling operation (2004 – 2011; seasonal only)

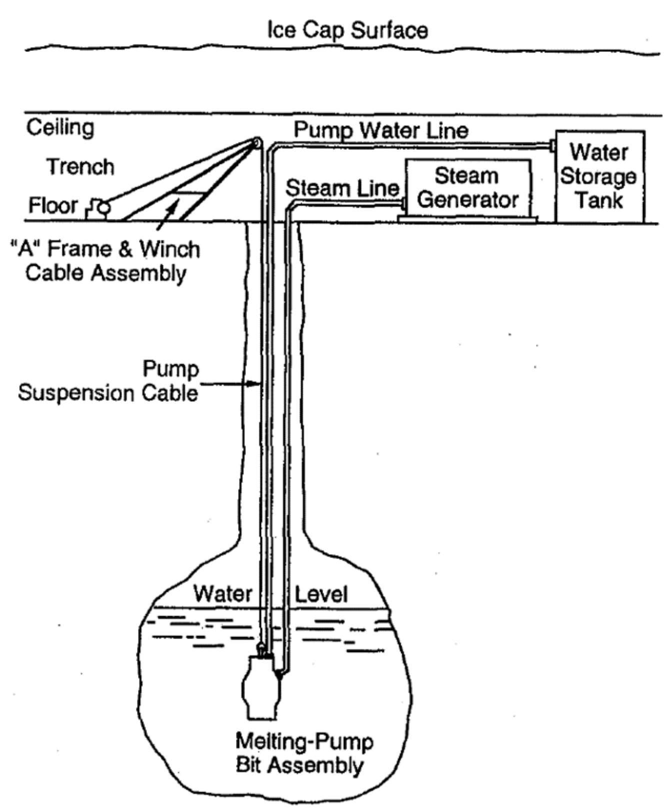
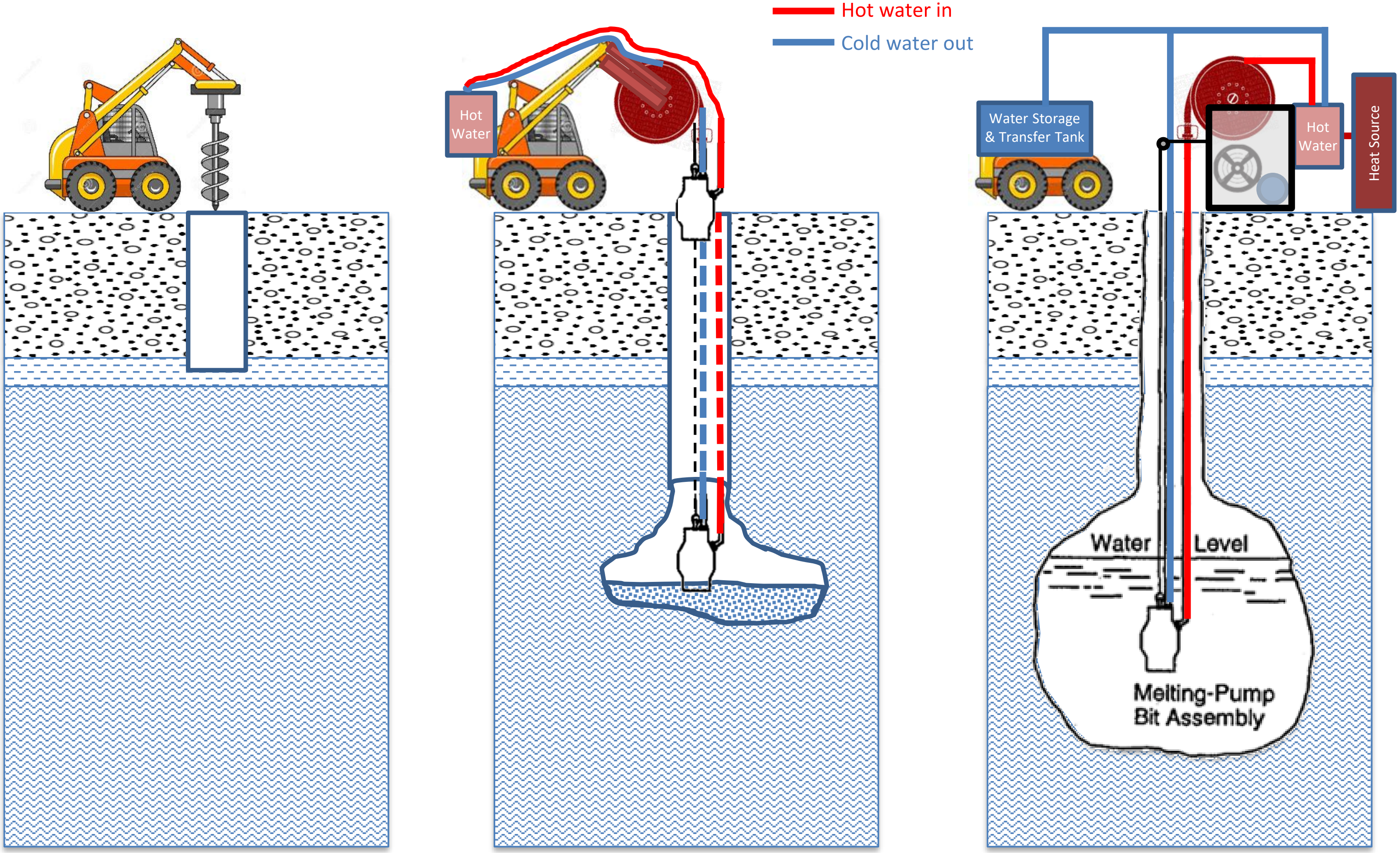


Figure 1. Camp Century water well equipment (from Clark 1965).

*Lunardini, V.J. and J. Rand (1995). Thermal Design of an Antarctic Water Well. *CRREL Special Report 95-10*.

Subsurface Water Well Development

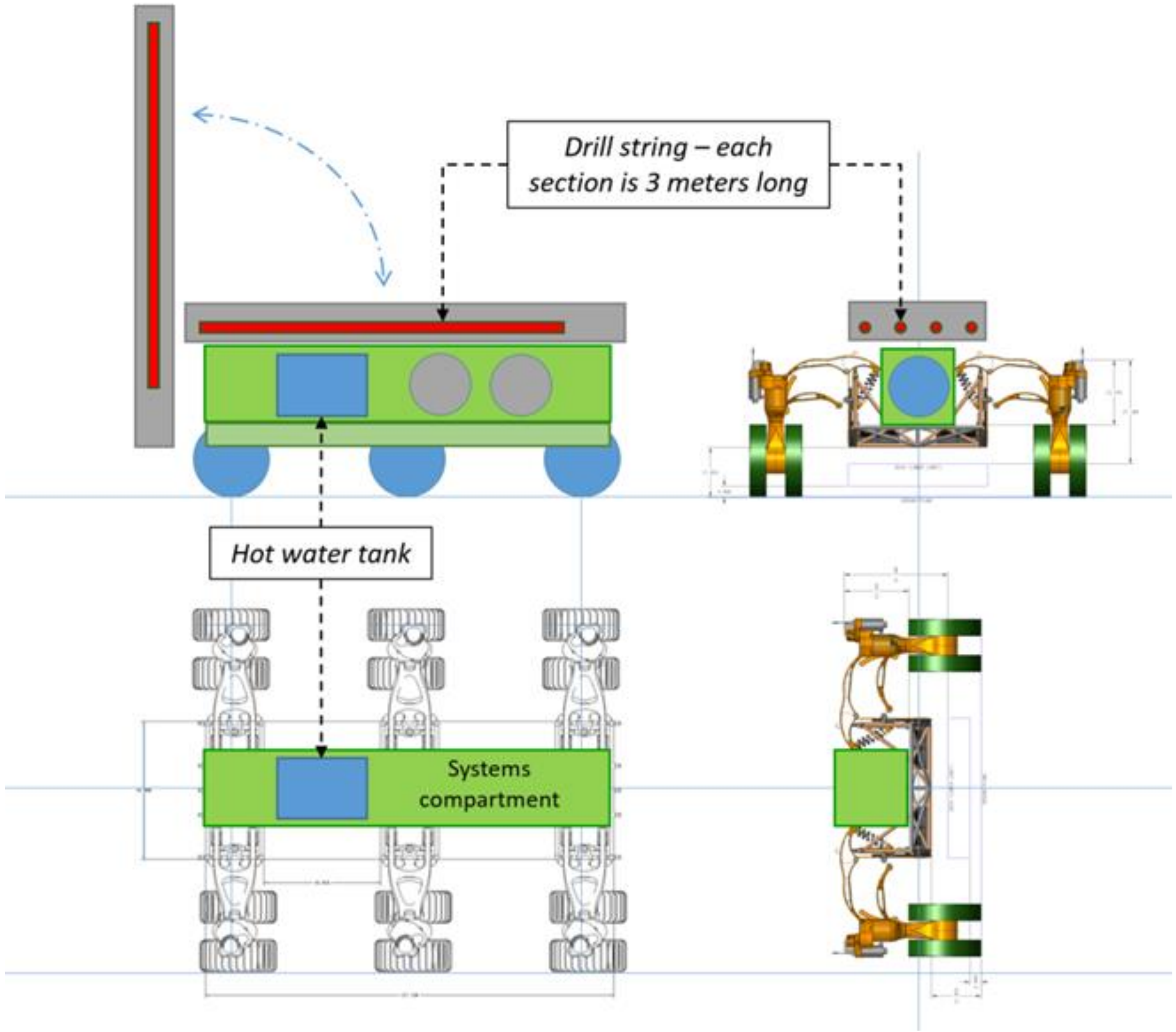


Phase 1: Drill through overburden into top of ice.

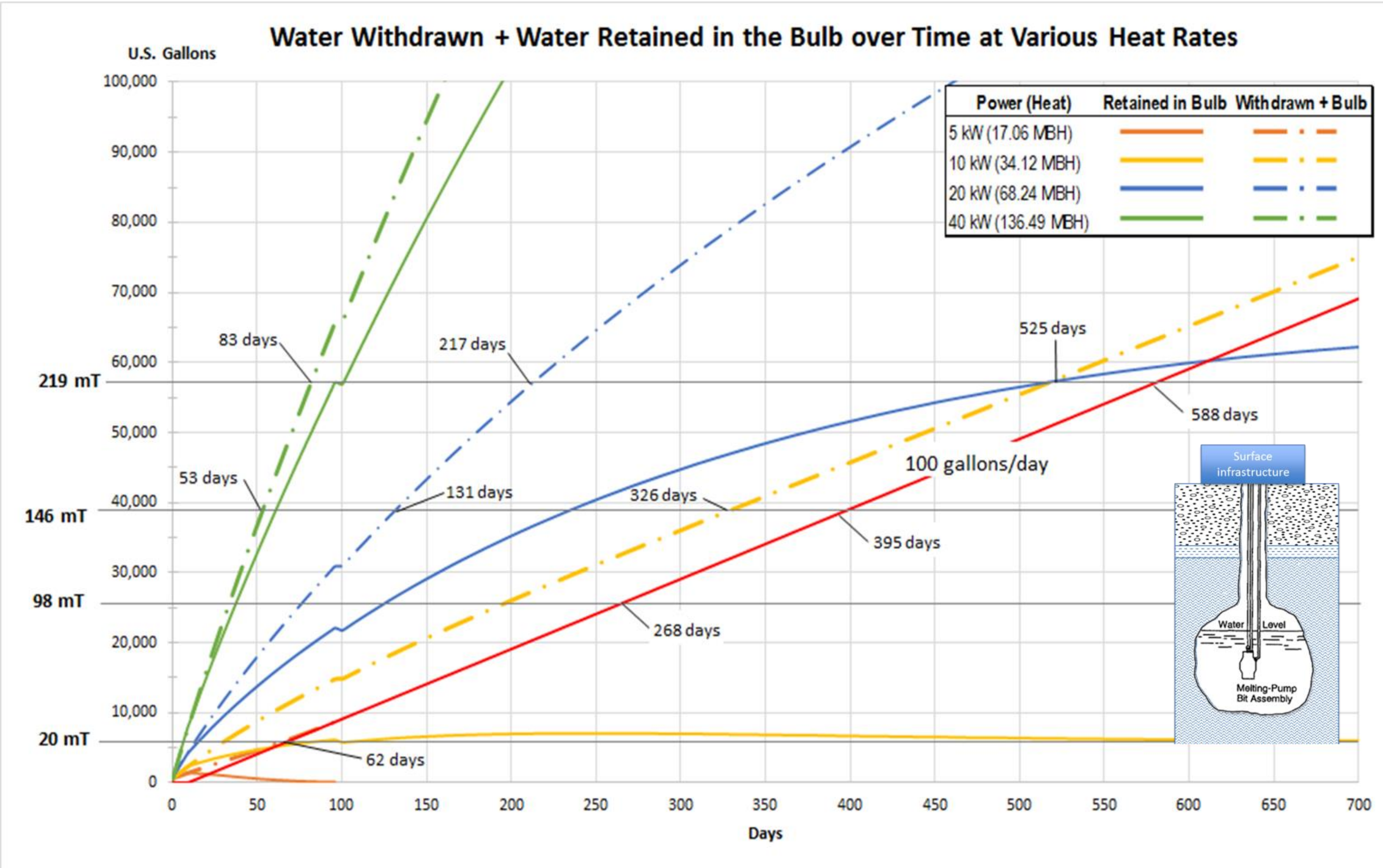
Phase 2: Melt into ice. Begin forming water pool.

Phase 3: Steady state operation.

Initial Estimate of System to Access Subsurface Ice



Predicted Time Needed to Withdraw Water at a 100 gal/day Rate



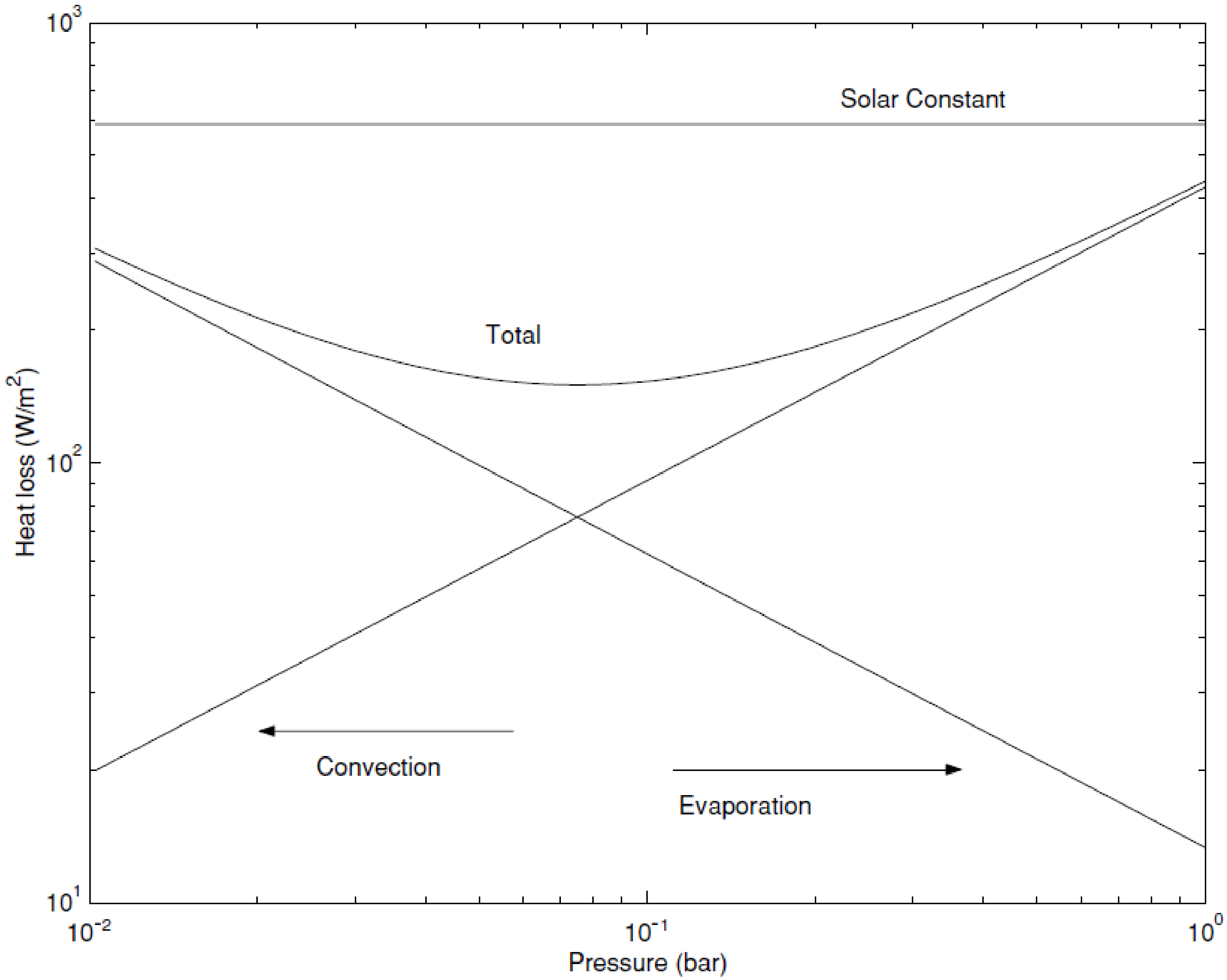
Note: assumes -80° C ice

Differences Between Existing Model and Mars Model

- **Physical / Chemical Properties**
  - Atmospheric constant pressure specific heat
  - Atmospheric gas constant
- **Heat transfer**
  - Air – water heat transfer
  - Air – ice heat transfer
  - Water – ice heat transfer (assumed to be the same on Earth and Mars)
- **Air pressure effects**
  - Atmospheric pressure ranges from slightly above the triple point of water to slightly below
  - Effects are TBD

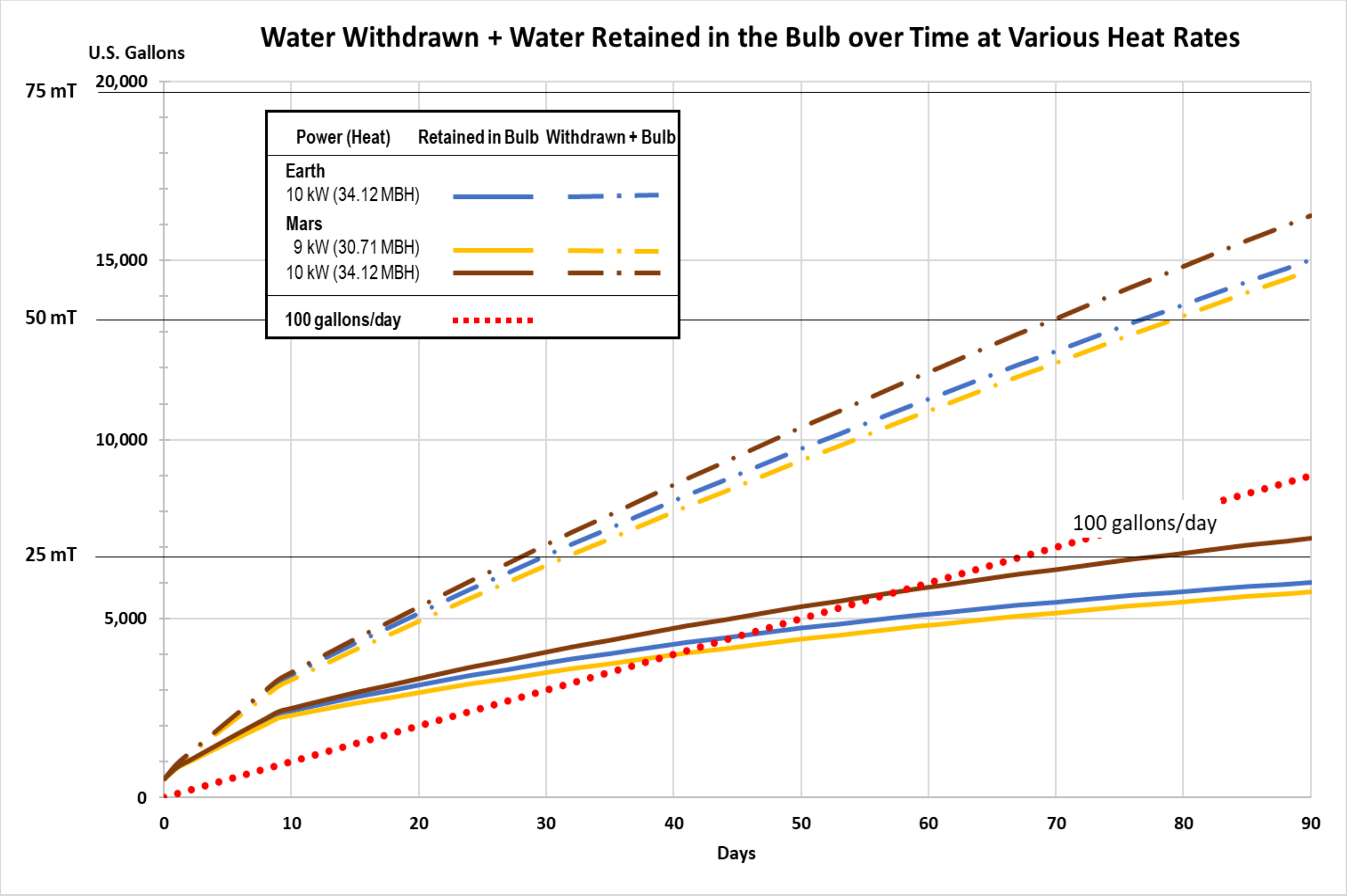
Parameter	**Earth**		**Mars**	
	(SI/metric)	(SAE)	(SI/metric)	(SAE)
Atmospheric Pressure	1013 mb	14.7 psi	8.0 mb	0.116 psi
Gas Constant	287 J/(kg-K)	53.4 ft-lbf/(lbm-R)	189 J/(kg/K)	35.1 ft-lbf/(lbm-R)
Atmospheric Specific Heat	1.01 kJ/(kg-K)	0.240 Btu/(lb-R)	0.834 kJ/(kg-K)	0.199 Btu/(lb-R)
Heat Transfer – Water to Air	5.67 W/(m^2-K)	1.00 Btu/(h-ft^2-R)	4.11 W/(m^2-K)	0.725 Btu/(h-ft^2-R)
Heat Transfer – Ice to Air	5.67 W/(m^2-K)	1.00 Btu/(h-ft^2-R)	4.11 W/(m^2-K)	0.725 Btu/(h-ft^2-R)

Example of Relevant Experimental Results



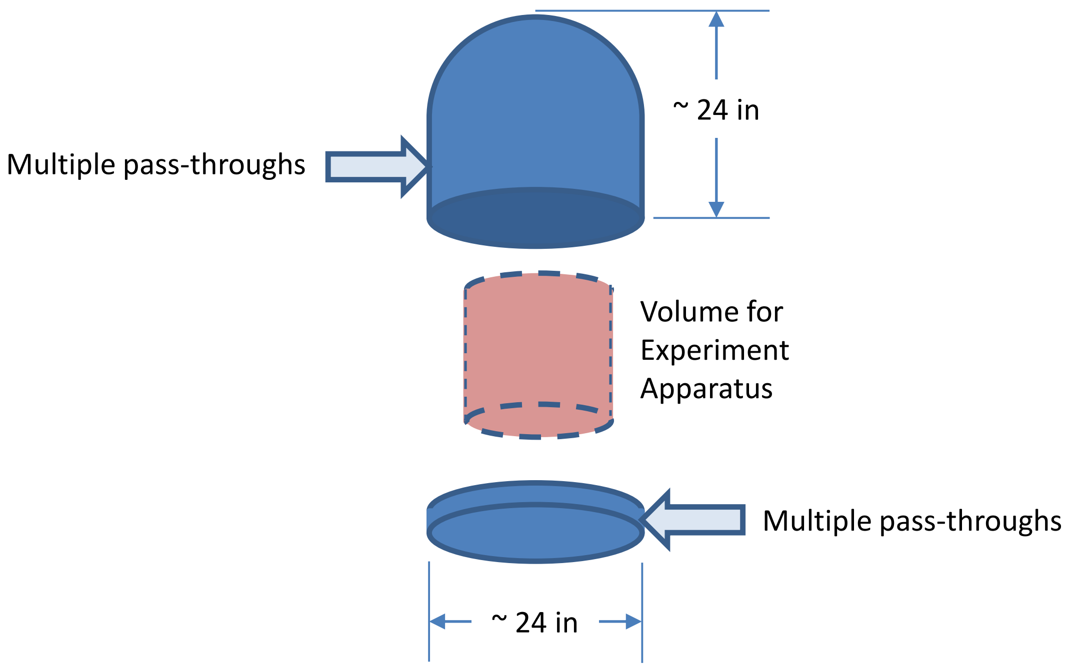
Convective heat transfer between a 273 K surface (water) and a 200 K atmosphere compared to evaporative cooling. The right-hand boundary reflects terrestrial conditions; the left reflects Martian conditions. For equivalent conditions, total heat loss is actually less on Mars than on Earth. (Hecht, “Metastability of Liquid Water on Mars”)

Rodwell Simulation Results Incorporating Mars Environmental Parameters



JSC Bell Jar Chambers

- Thermal shroud (LN_2) can be used to maintain temperature in desired range.
- Cold trap will be required upstream of roughing pump to remove water vapor.
- Pass-throughs can be used to:
  - feed CO_2 into chamber as “representative” Mars atmosphere
  - add liquid H_2O to replenish the simulated water bulb OR add heat to the liquid H_2O container OR both
  - collect data from various sensors



JSC 2-foot bell jar

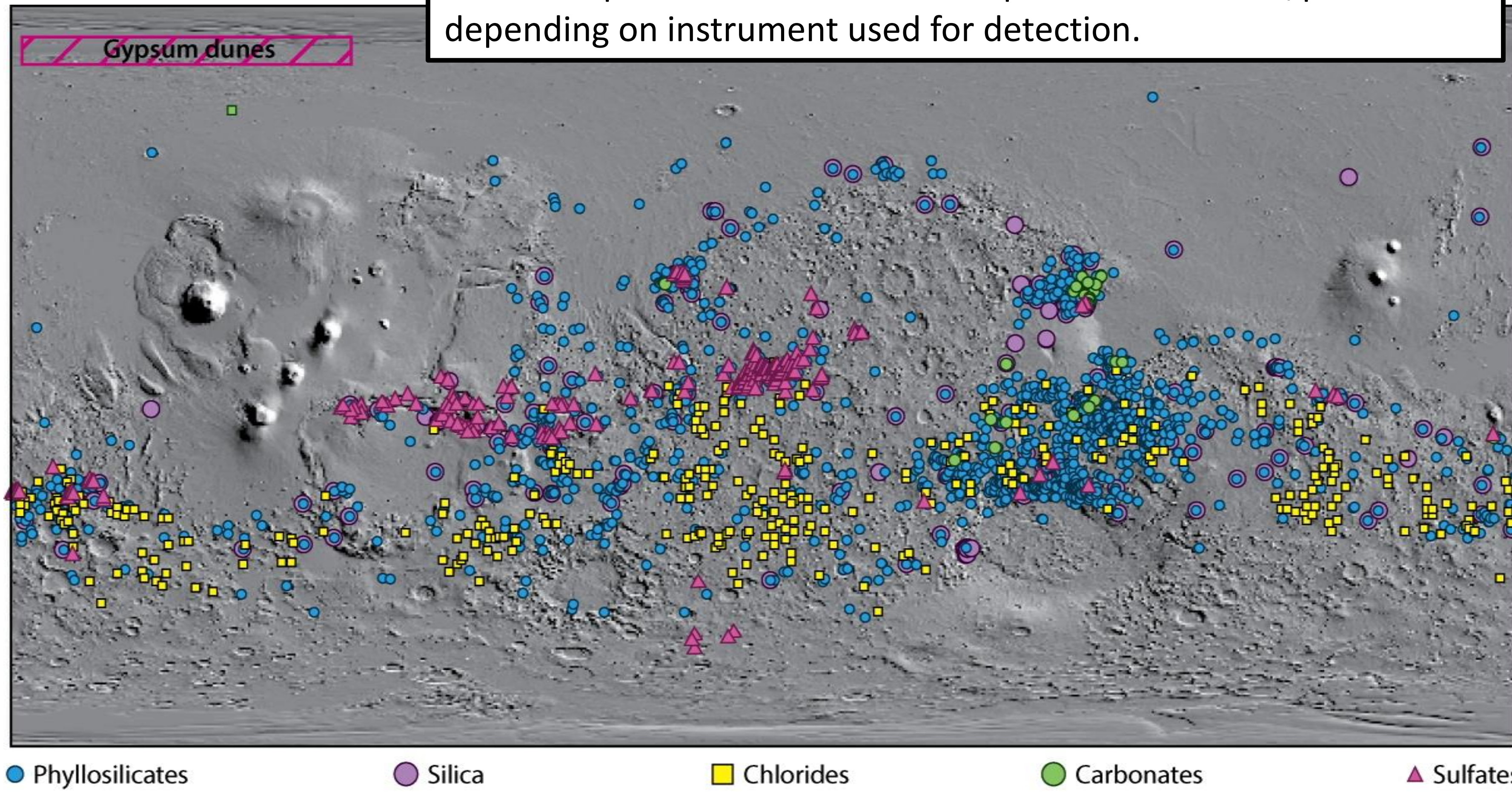
Summary

- **Work continues to understand water resources available on Mars and means to access them for human missions.**
- **New discoveries of exposed ice scarps help confirm previous radar indications as well as characterize the vertical profile of some ice deposits**
- **Based on this improved knowledge, initial estimates have been made regarding equipment needed to access ice deposits**
- **Improvements to Rodriguez Well simulations are underway**
  - Experiments are being designed to determine parameters under Mars surface environmental conditions
  - Experimental data from similar experiments is being used to understand simulation trends – results are favorable
- **Next steps include completion of experimental tasks and improving Rodwell simulation with experiment results**

backup

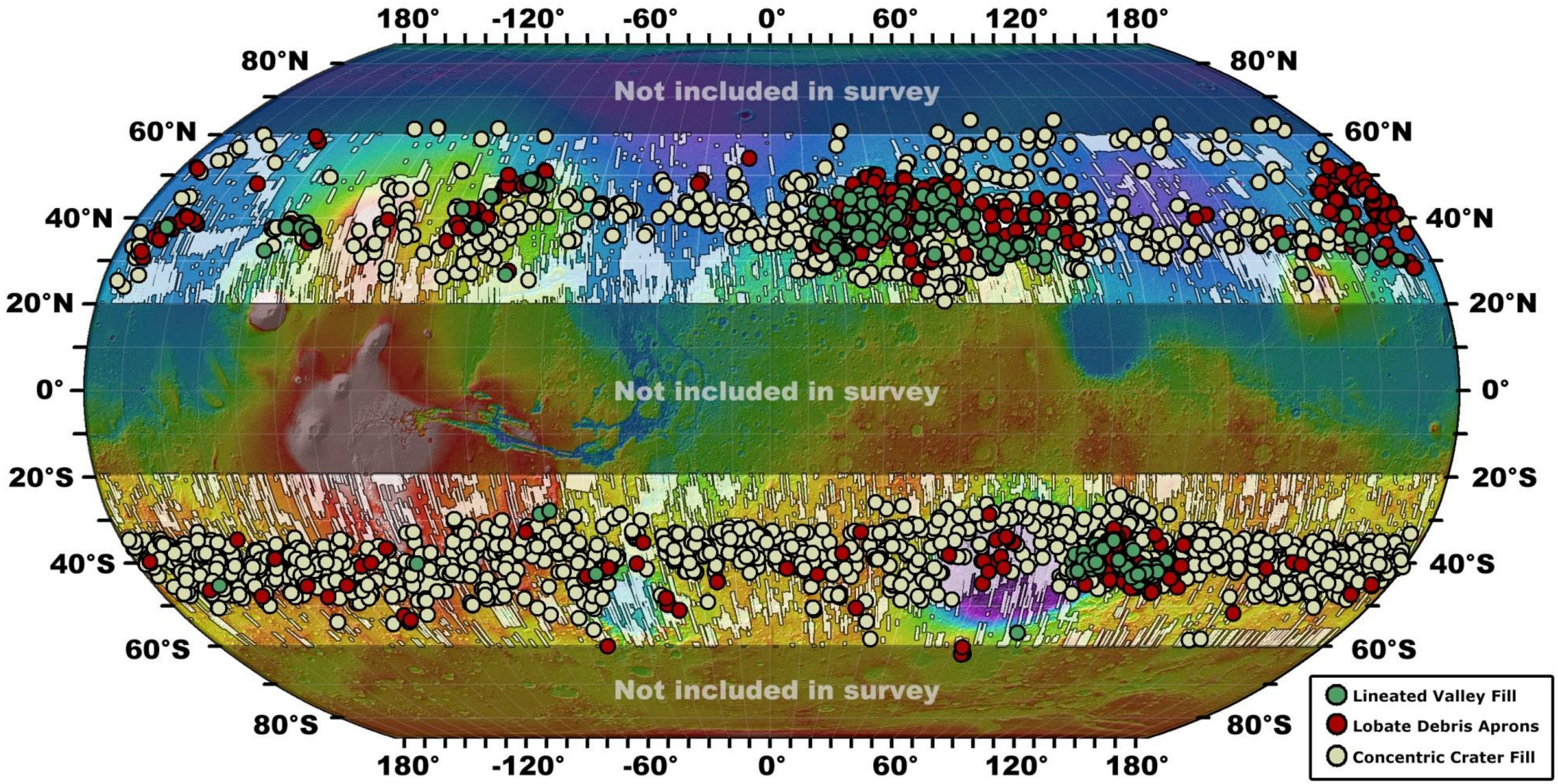
Map of Aqueous Mineral Detections

Note: footprint size is from 3x6 km spots to 18-2000 m/pixel depending on instrument used for detection.



From Ehlmann and Edwards (2014)

Where Have LVF, LDA, and CCF Features Been Seen?



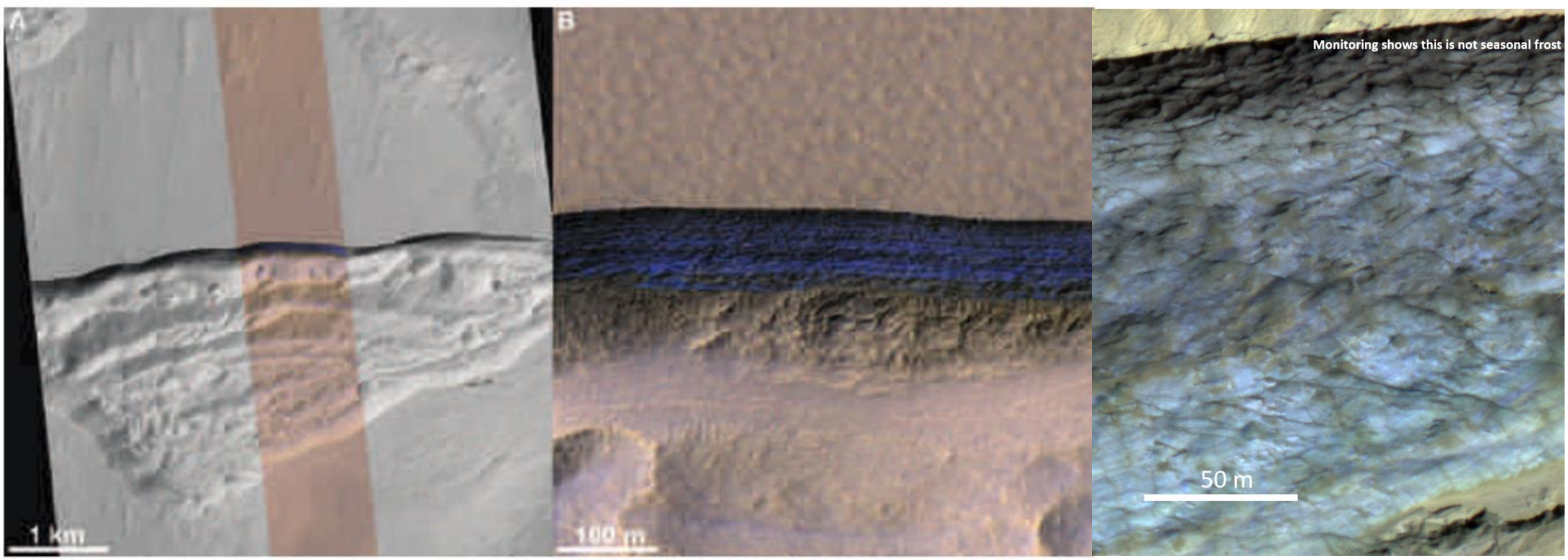
Patterns of accumulation and flow of ice in the mid-latitudes of Mars during the Amazonian

James L. Dickson, James W. Head III, Caleb I. Fassett

Icarus Volume 219, Issue 2, June 2012, Pages 723-732

A Glaciologist's "Road Cut" Through a Martian Ice Sheet

- **The Dundas team found "…eight locations that have steep, pole-facing scarps created by erosion…"**
  - "Each of the scarps is relatively blue (compared with surrounding terrain) in enhanced-color HiRISE images…"
  - "…three locations have water-ice signatures in mid-summer spectral data taken by *MRO's* Compact Reconnaissance Imaging Spectrometer for Mars (CRISM)."
- **The images below show progressively closer views of these ice scarps.**
  - These particular scarps were found in LDAs



C. M. Dundas *et al.*, Exposed massive ground ice in the Martian mid-latitudes, *Science* vol. 359, pp. 199–201 (2018)

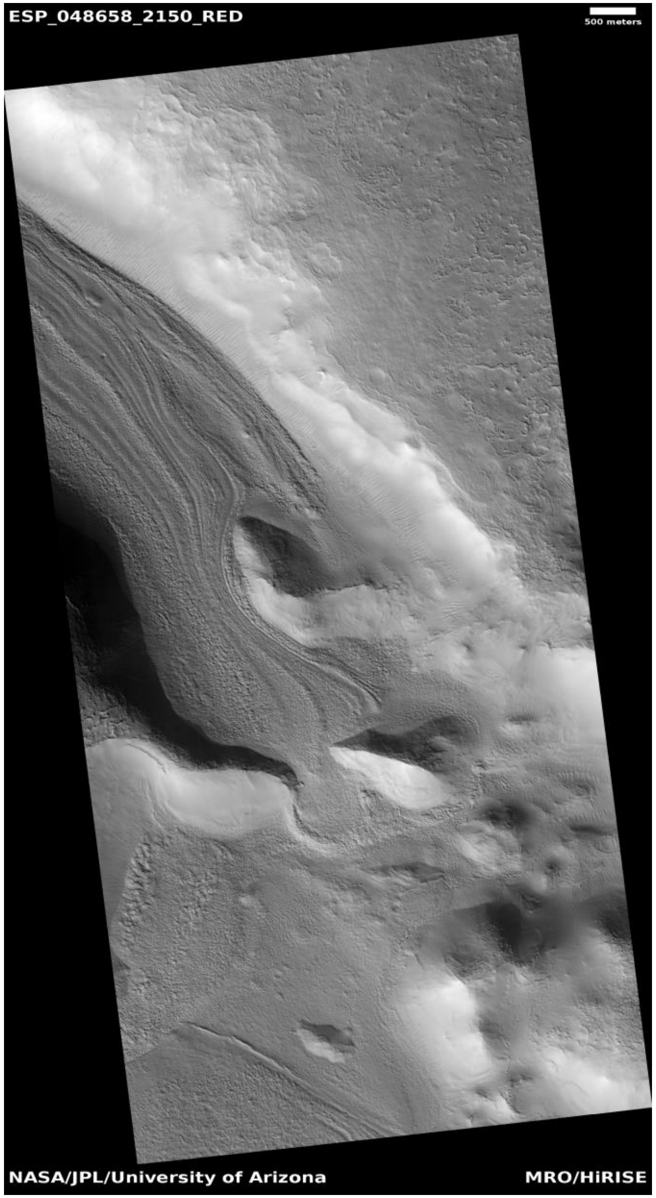
Which of These Water Sources Does the Dundas Discovery Help Confirm?

- **The ice scarps discovered by Dundas, et al. are associated with a broad category of terrain features that bear a strong resemblance to terrestrial glacial features and remnants of ice sheets.**
  - Lineated Valley Fill (LVF)
  - Lobate Debris Aprons (LDAs)
  - Concentric Crater Fill (CCF)

- **These features are typically seen in the Martian mid-latitudes (between 30º and 60º North and South).**

- **Prior to this discovery, evidence was consistent with water (ice) in these features.**
  - Visual similarity to terrestrial landforms
  - Radar sounding signatures
- **This discovery provides evidence (spectral data from CRISM) that is indicative of water (ice) in these features, significantly strengthening previous interpretations.**

What is Lineated Valley Fill?

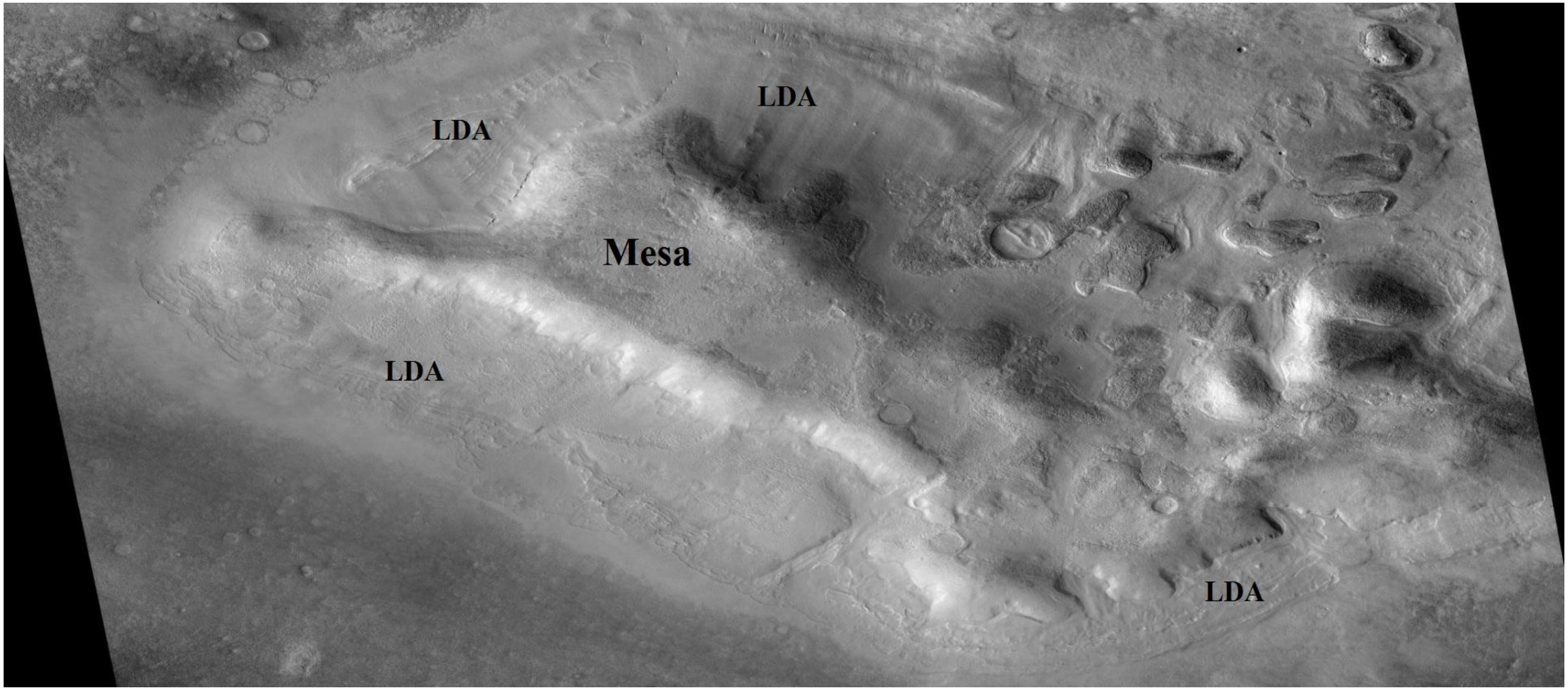


Lineated Valley Fill is a feature seen on the floors of some channels on Mars, exhibiting ridges and grooves that seem to flow around obstacles. These features bear a strong visual resemblance to some terrestrial glaciers.

The Heimdal Glacier in southern Greenland.   Credit: NASA/John Sonntag

What are Lobate Debris Aprons?

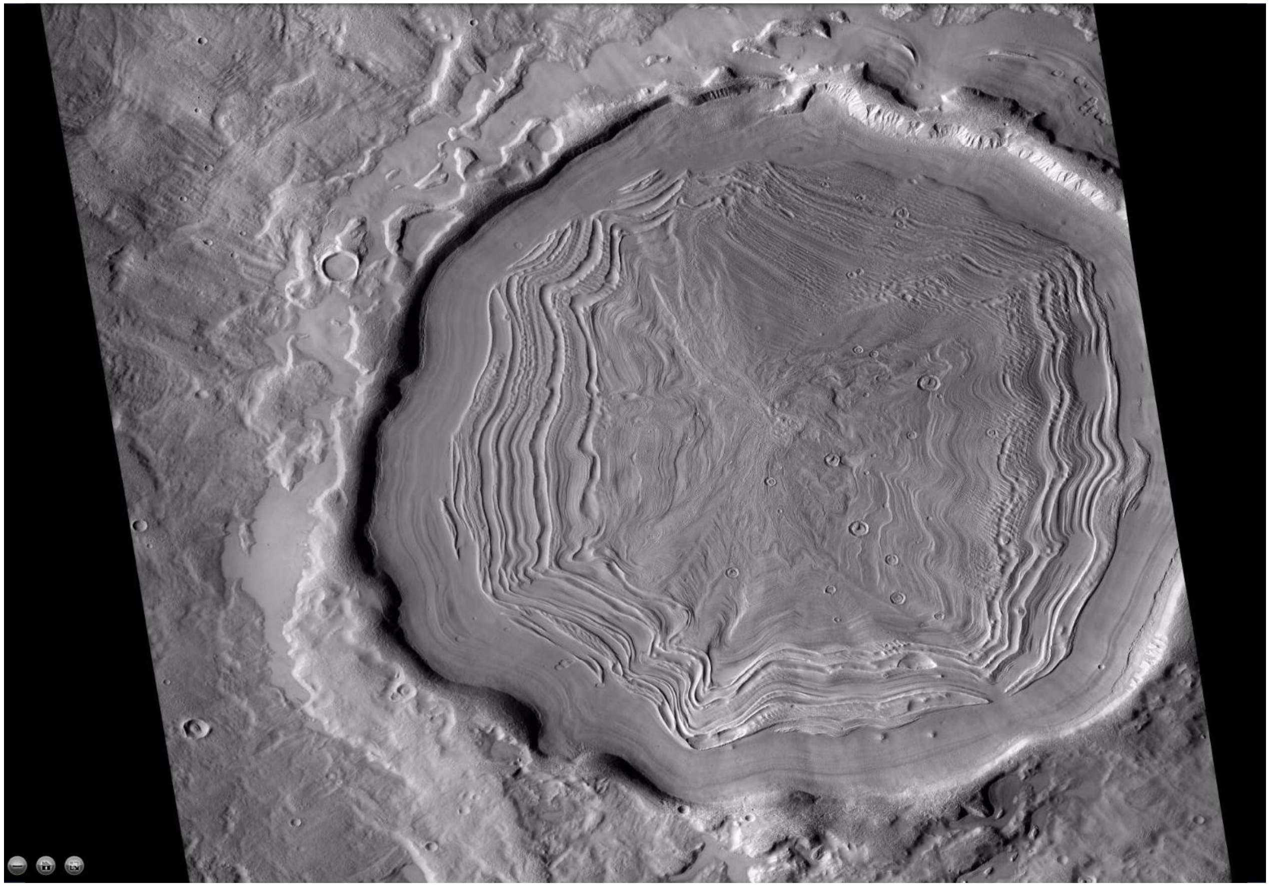
Lobate debris aprons (LDAs) are geological features on Mars, consisting of piles of rock debris below cliffs. These features, first seen by the Viking Orbiters, are typically found at the base of cliffs or escarpments. They have a convex topography and a gentle slope, suggesting flow away from the steep source cliff.



What is Concentric Crater Fill?

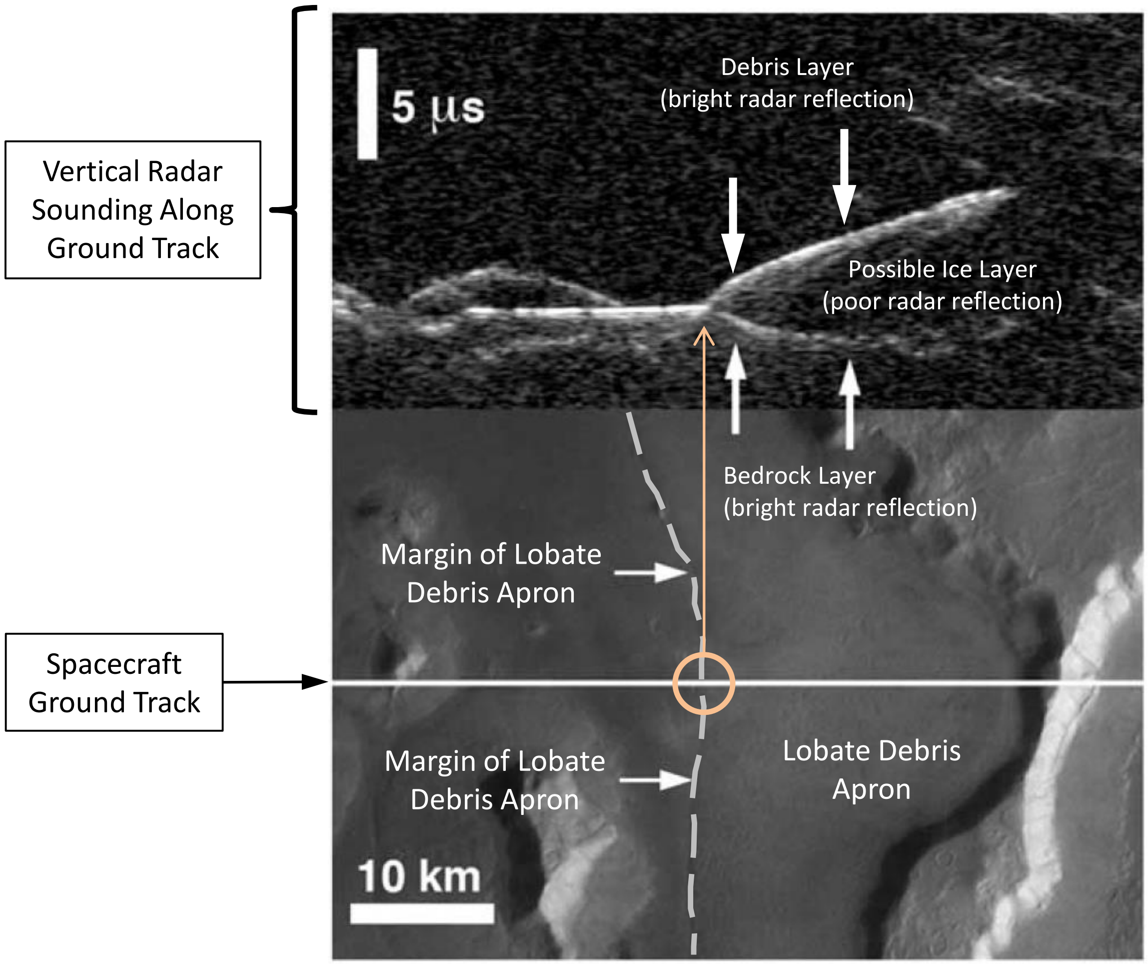
Concentric crater fill is a terrain feature where the floor of a crater is mostly covered with a large number of parallel ridges.

Modeling suggests that concentric crater fill developed over many cycles in which snow is deposited, then moved into the crater. Once inside the crater, shade and dust preserved the snow. The snow was gradually compressed into ice. The many concentric lines are created by many cycles of snow accumulation, at a time when the Mars environment could support snowfall.



What is the Radar Evidence for Debris Covered Water Ice?

While searching for subsurface aquafers, the MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding; on *Mars Express*) and SHARAD (SHAllow RADar; on *Mars Reconnaissance Orbiter - MRO*) radars gathered data indicating these terrain features could be debris covered ice.



Radar evidence for ice in lobate debris aprons in the mid-northern latitudes of Mars
Jeffery J. Plaut, Ali Safaeinili, John W. Holt, Roger J. Phillips, James W. Head III, Roberto Seu, Nathaniel E. Putzig, and Alessandro Frigeri
Geophysical Research Letters Volume 36, L02203, 2009.

Why Is This Discovery Important?

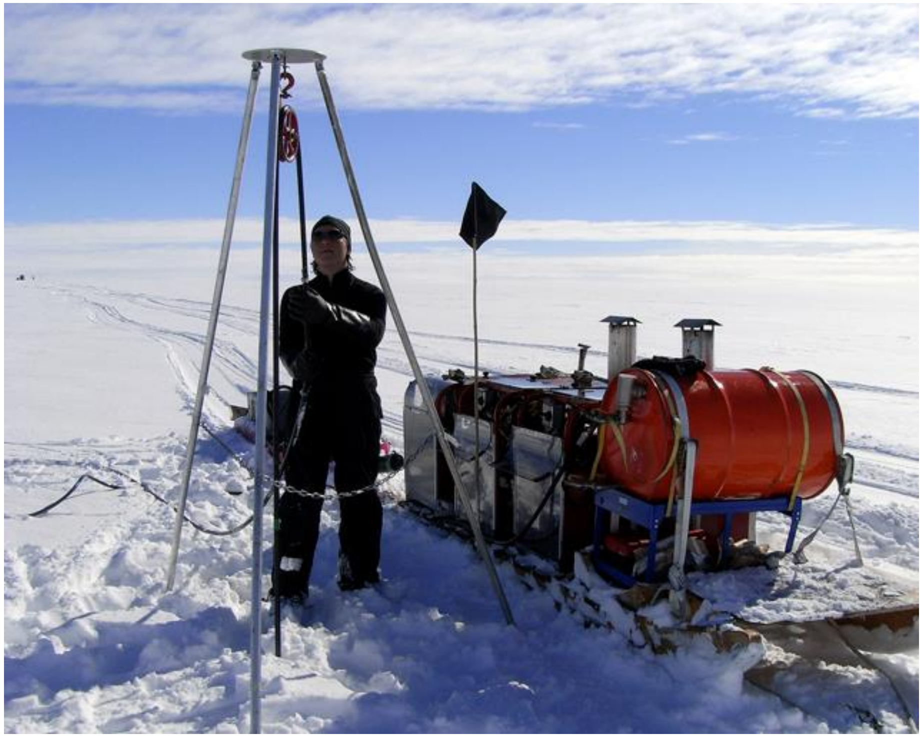
- **One facet of NASA's current Mars Exploration Program is a search for the locations and quantities of water in various forms.**
  - Subsurface liquid water aquafers
  - Surface and subsurface water ice
  - Hydrated minerals
- **This discovery by Dundas, et al. confirms that one *suspected* type of subsurface water deposit is in fact water (ice) and reveals it to be *almost pure* water.**
- **The location of deposits similar to those examined by Dundas, et al. span all longitudes and are at latitudes compatible with human missions.**
- **Access to massive quantities of water could change surface mission concepts of operation and drive site selection**
- **Availability of massive quantities of water could enable or change current assumptions for:**
  - Propellant manufacturing
  - Radiation protection
  - "Relaxed" requirements for closed loop ECLSS
  - Crop growth
  - Improved crew amenities, such as more frequent showers and laundry

Mechanical Drills Example

- **A study of available mechanical drill options for future human missions was completed in 2013**
  - Results documented in “Drilling System Study; Mars Design Reference Architecture 5.0,” JSC 66635, September 30, 2013
  - One concept – Icebreaker – was demonstrated on a debris covered glacier in University Valley, Antarctica
    - Approximately one meter of overburden
    - Physical scale and level of autonomy comparable to Mars Rodwell needs (as currently understood)

Photos courtesy of Brian Glass

Small Hot Water Drill Example



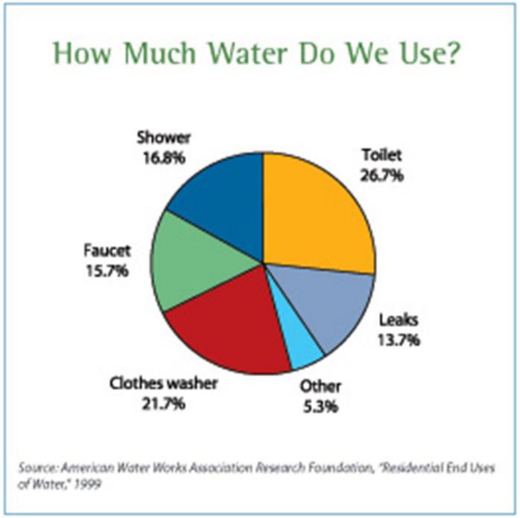
NSF Ice Drilling Development Office (IDDO) portable hot water drill. Image from: https://icedrill.org/equipment/small-hot-water-drill.shtml

- **NSF Ice Drilling Development Office (IDDO) developed a "portable" hot water drill.**
  - Transportable by light aircraft and helicopter
  - Mass data of pictured system is listed below
- **Primary use is for shot holes for seismic work, but they have also been used for access holes through a thin ice shelf.**
- **Can be rapid to operate.**
  - During one 3-month Antarctic season, drilled nearly 170 shot holes and completed four seismic transects

Type:	**Non-coring**
Number in Inventory:	**2**
Max. Depth Possible:	**Reliable and efficient to a depth of 25-30 m**
Shipping Weight:	**1590 kg (3500 lbs)**
Comments:	**Assembled for operation w/o fuel: 1000 kg (2200 lbs)**

Example Water Usage Rates

- **"Typical" U.S. family of four:**
  100 gallons/person/day (379 kg/person/day)
  - This is both indoor and outdoor usage; 70% indoor and 30% outdoor
  - Source: U.S. EPA; https://www3.epa.gov/watersense/pubs/indoor.html
- **"Typical" U.K. family of four:**
  30 gallons/person/day (112 kg/person/day)
  - Source: http://www.ccwater.org.uk/savewaterandmoney/averagewateruse
- **Summit Station, Greenland (winter):**
  ~18 gallons/person/day (68 kg/person/day)
  - Based on an average population of four people
  - Source: Haehnel and Knuth "Potable water supply feasibility study for Summit Station, Greenland"
- **Summit Station, Greenland (summer):**
  ~9.4 gallons/person/day (36 kg/person/day)
  - Based on an average population of 30 people
  - Source: Haehnel and Knuth "Potable water supply feasibility study for Summit Station, Greenland"
- **Mars Surface Crew (with laundry):**
  ~3.5 gallons/person/day (13.3 kg/person/day)
  - Based on a population of four crew
- **Mars Surface Crew (without laundry):**
  ~1.6 gallons/person/day (6.0 kg/person/day)
  - Based on a population of four crew



U.S. Family Water Usage

Observations from the 100 gal/day Withdrawal Case

- **The power values on the previous chart are ONLY for melting ice and maintaining a liquid pool of water in the subsurface cavity; *additional power* will be needed to pump water out of this cavity and to run other surface infrastructure elements.**
- **The withdrawal rate and input power are highly coupled**
  - A different withdrawal rate will result in a different shape to these results
- **For this 100 gal/day withdrawal rate**
  - For power levels above approximately 10 kW, liquid water is being created at a much faster rate than it is being withdrawn, resulting in very large subsurface water pools that will not be used
  - A power level of approximately 10 kW generates liquid water at about the rate at which it is being withdrawn
    - The water pool remains at approximately a constant volume
    - The water pool will gradually sink to lower levels, which will drive the amount of power needed to pump water from these deeper levels
  - For power levels below approximately 10 kW, water is being withdrawn faster than it is being melted and the well eventually "collapses"
    - At a power level of approximately 5 kW, the 20 mT projected need for a single crew's MAV could be withdrawn before the well "collapses" but little additional water would be made