Don't Forget About…

(Factoring in Everything for Successful Mars Exploration)

Panel Discussion

Topic:
In Situ Resource Utilization

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Why Are In Situ Resources Important?

- **Using In Situ Resources means reduced transportation requirements from Earth and a larger source of materials than might otherwise be available**
- **Of the many in situ resources available on Mars, perhaps the most valuable is water**
- **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 and icy soils
    - Lineated Valley Fill (LVF), Lobate Debris Aprons (LDAs), Concentric Crater Fill (CCF)
  - Hydrated minerals
    - Chlorides, Phyllosilicates, Sulfates, etc.
  - "Average regolith"
- **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

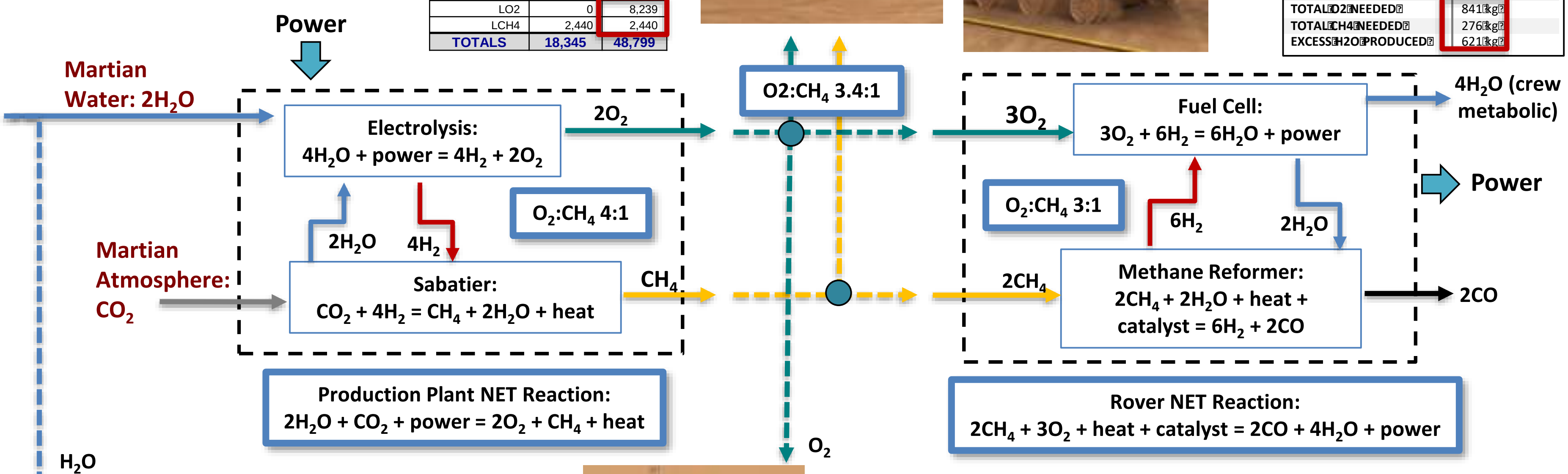
How Would a Human Mars Mission Use Abundant Water?

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

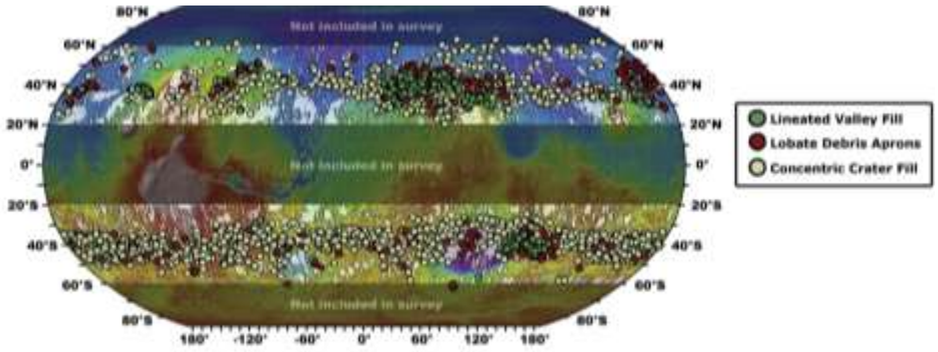


	CLOSED-LOOP H_2O, O_2	OPEN-LOOP H_2O, O_2	OPEN-LOOP + LAUNDRY
H_2O CLOSED-LOOP MAKEUP	970	0	0
O_2 CLOSED-LOOP MAKEUP	2480	0	0
LAUNDRY	0	0	14660
EVA	0	3072	3072
FOOD REHYDRATION	0	1070	1070
MEDICAL	0	107	107
DRINK	0	4280	4280
FLUSH	0	134	134
HYGIENE	0	856	856
TOTAL	**3450 kg**	**9519 kg**	**24379 kg**

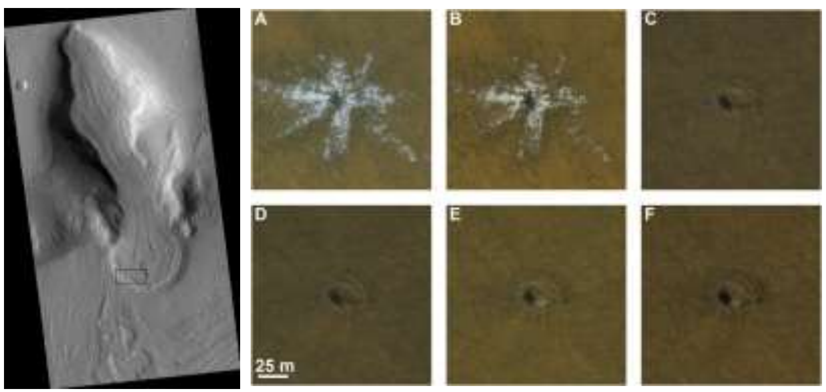
25 tons of water provides robust open-loop life support for a crew of 4 for 500 days

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

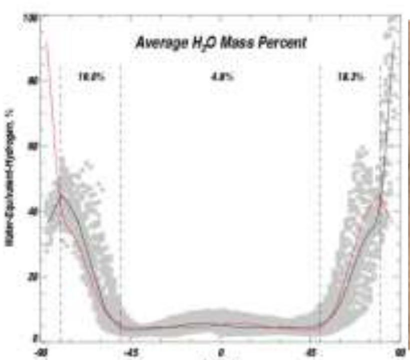
Where Have We Seen Martian Water Sources?



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]***

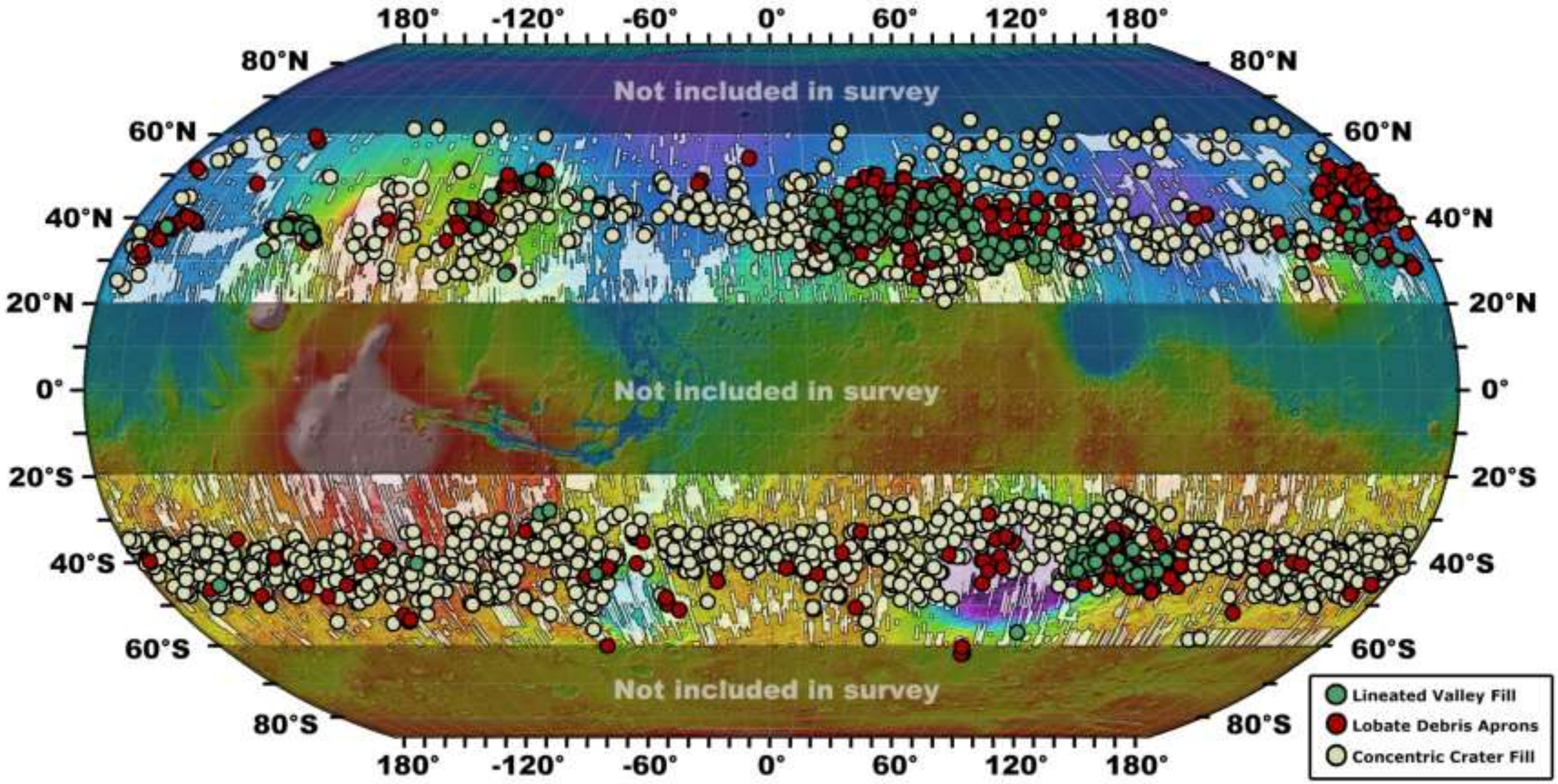
However:

- 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

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



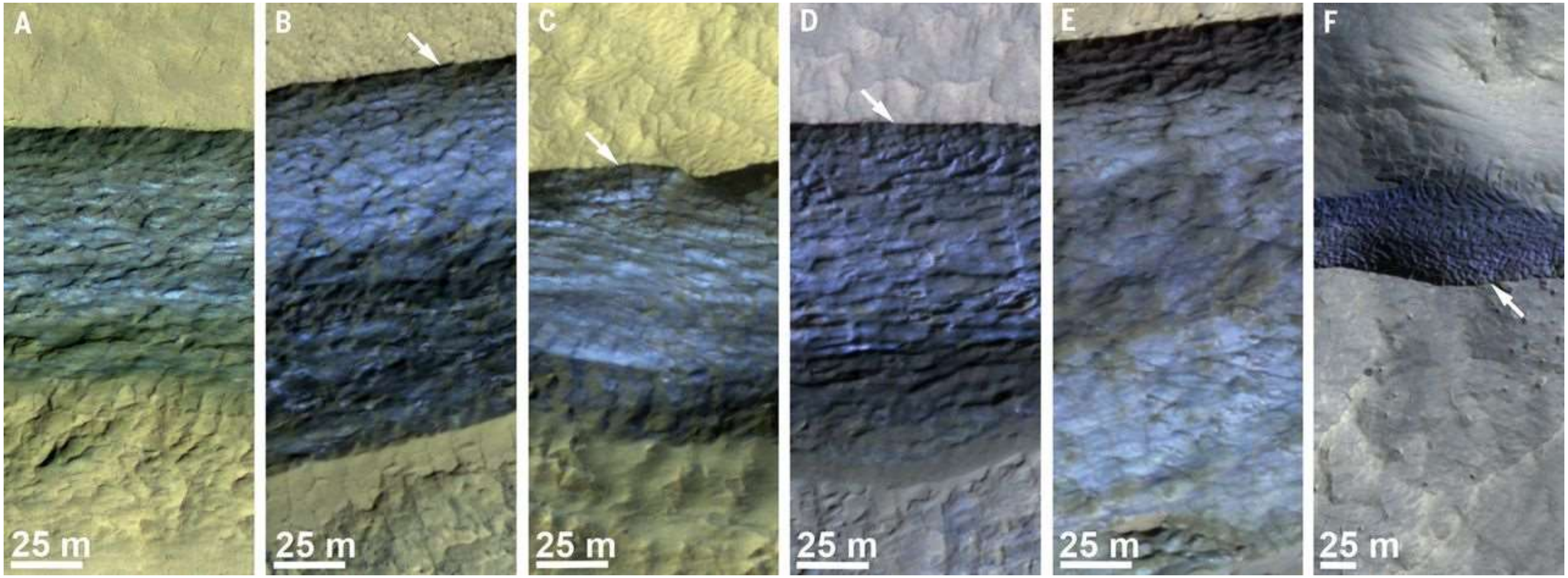
Patterns of accumulation and flow of ice in the mid-latitudes of Mars during the Amazonian

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

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

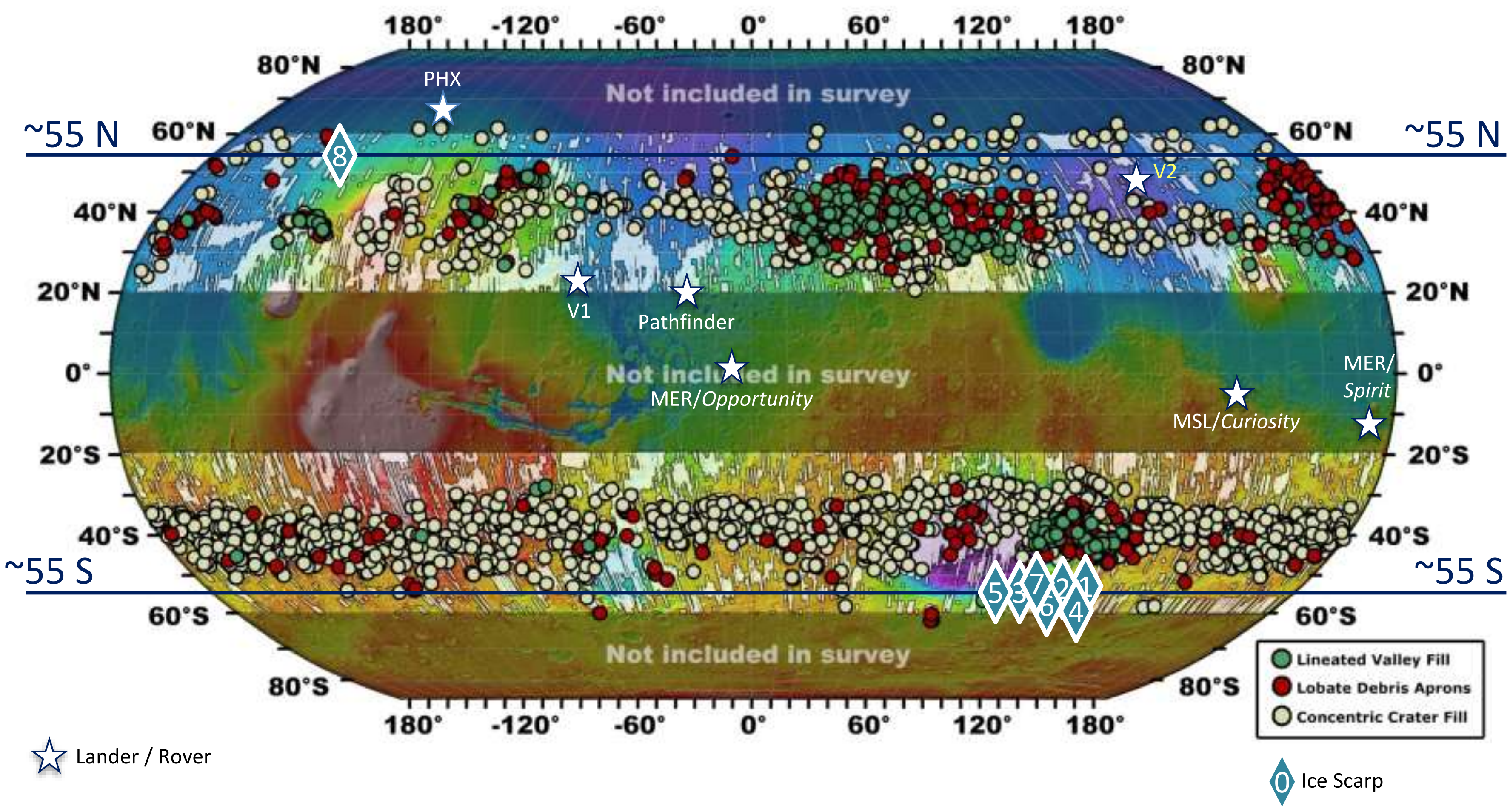
Discovery of Exposed Ice Scarps

- A recent article in *Science* by C. Dundas, et.al. (*Science,* vol. 359, January 12, 2018) 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
- This presentation briefly summarizes the significance of this discovery and implications for future human Mars missions



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 Milanković Crater in the northern hemisphere."**



What are Landing Site Implications for Human Missions?

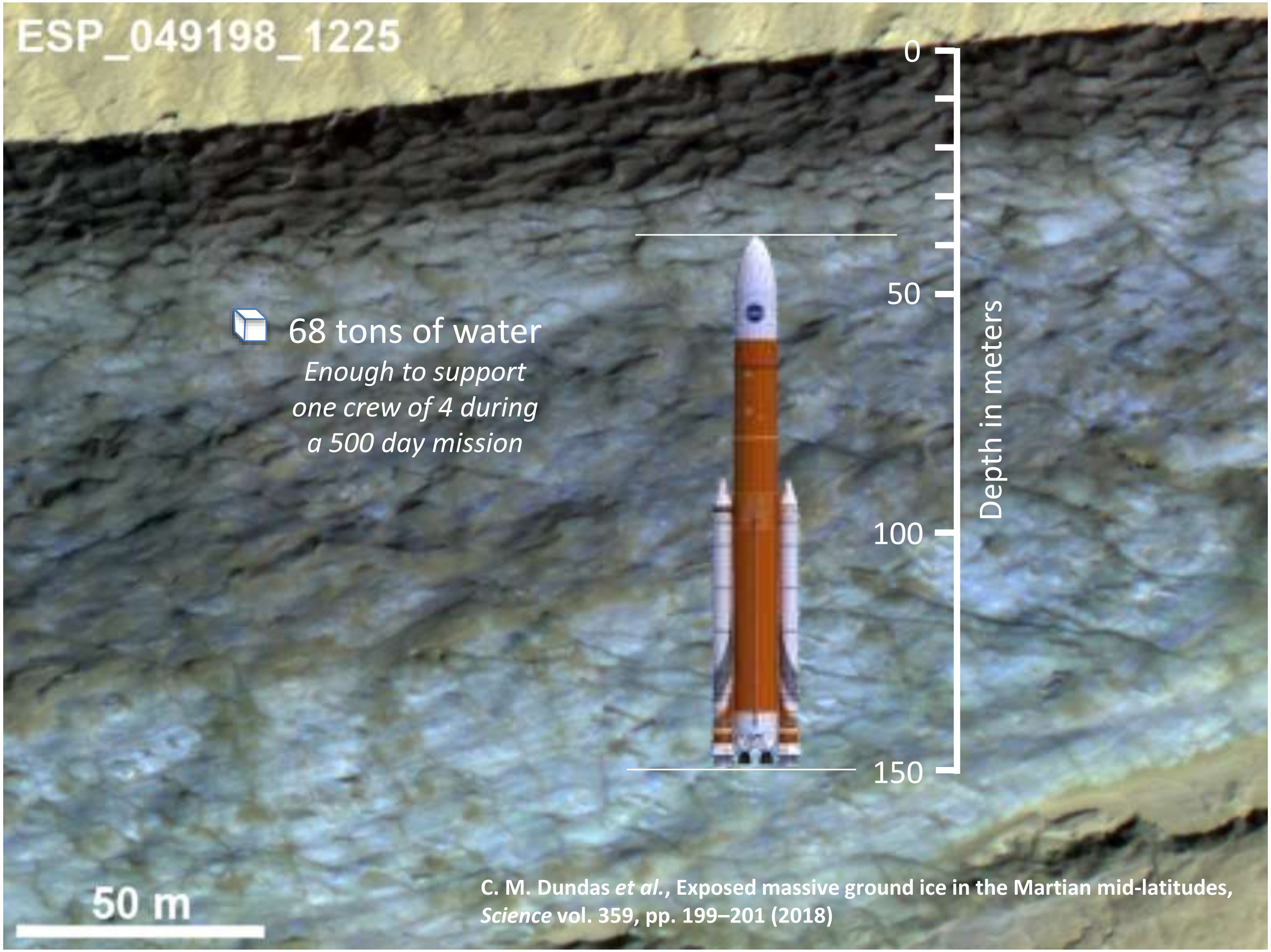
- Assuming that massive quantities of water becomes a significant factor in landing site selection for future human missions then the locations of these scarps may become leading candidates.

- So far only eight scarps have been identified.
- These scarps are at a relatively high latitude and are clustered in just two regions.

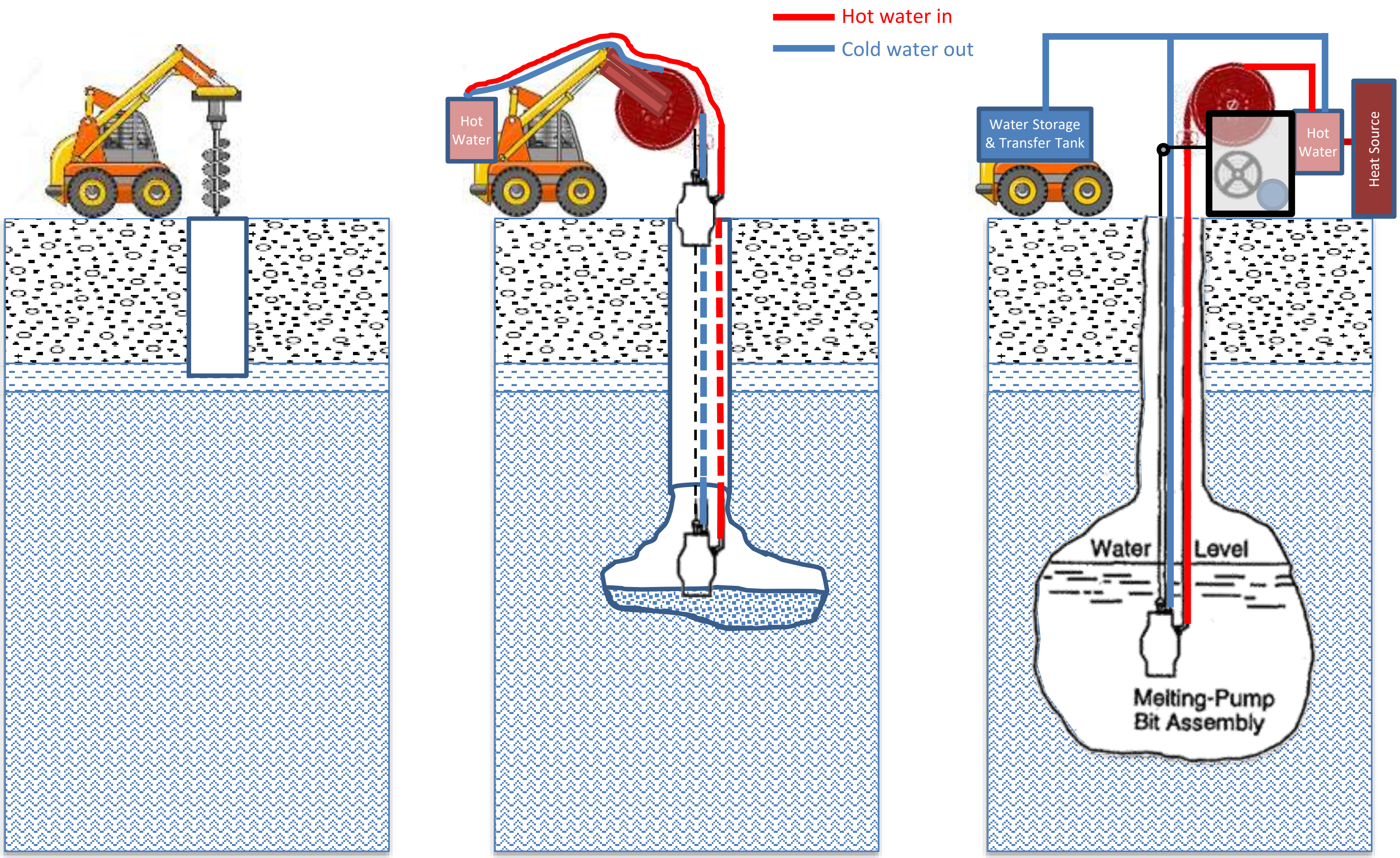
- However, because these scarps are associated with LVF, LDAs, and CCF, <u>any</u> of the other identified locations with these features becomes a candidate site.
- These other locations are spread across all longitudes and extend to lower latitudes, some approaching 20^{o}.

- Because these are buried deposits, a new radar specifically designed to look at these shallow features would be advisable to characterize the size and depth of specific candidate deposits.

How Much Water Ice Could Be In These Formations?



Subsurface Water Well Development: Rodwell Approach



Phase 1: Drill through overburden into top of ice.

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

Phase 3: Steady state operation.

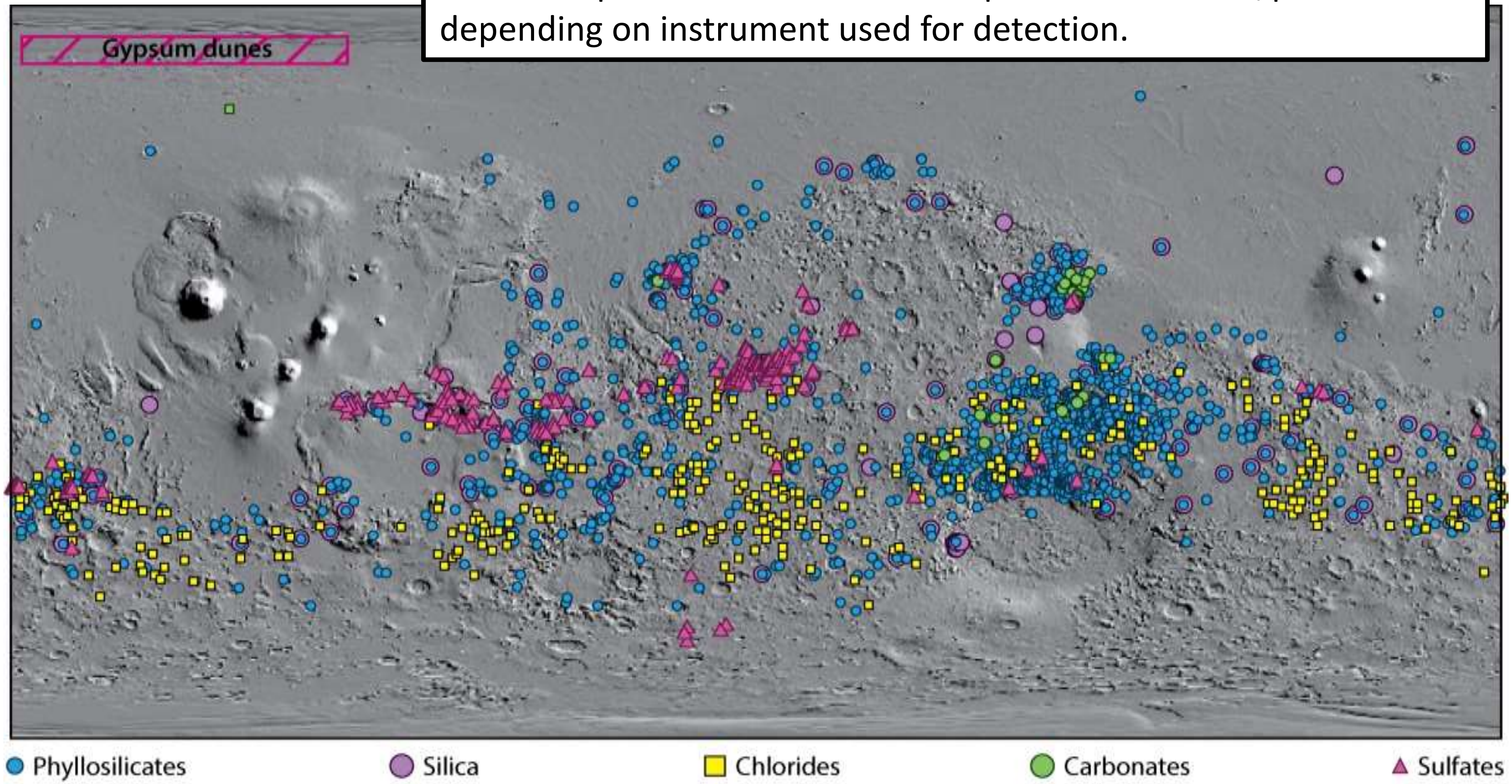
Summary

- **A group led by Dr. Colin Dundas (USGS/Flagstaff) has recently published a paper in *Science* describing their discovery of eight exposed water ice scarps on Mars.**
  - The amount of water visible in these scarps alone is quite massive compared to any proposed human Mars mission need.
  - These terrain features also confirm the composition of suspected water ice deposits seen in radar data at other locations on Mars.
- **Implications for human Mars mission landing site selection.**
  - The link between a water ice signature and suspected water ice seen in radar data opens up many potential landing sites in the Martian mid-latitude region if water accessibility is a driving site selection criterion.
  - A different radar – one designed for shallow targets – will likely be needed to refine the size and depth of probably water ice deposits.
- **The Rodriguez Well concept.**
  - Several concepts have been assessed (at different levels of fidelity) for accessing and retrieving water from buried ice.
  - The Rodriguez Well has substantial terrestrial experience and shows promise as a viable concept for Mars applications.
- **Future work**
  - Continue search for additional examples of exposed ice scarps
  - Engineering experiments to understand the Rodwell's viability under Martian environmental conditions

Backup

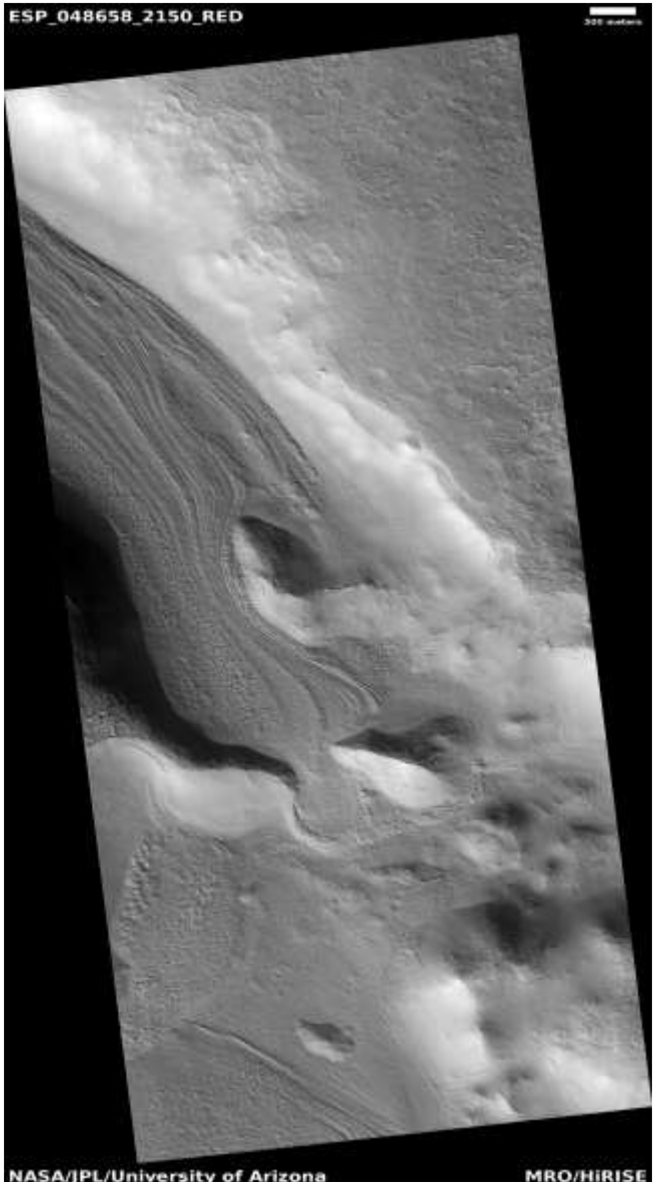
Map of Aqueous Mineral Detections

Note: footprint size is from 3x6km spots to 18-2000m/pixel depending on instrument used for detection.



From Ehlmann and Edwards (2014)

What is Lineated Valley Fill?

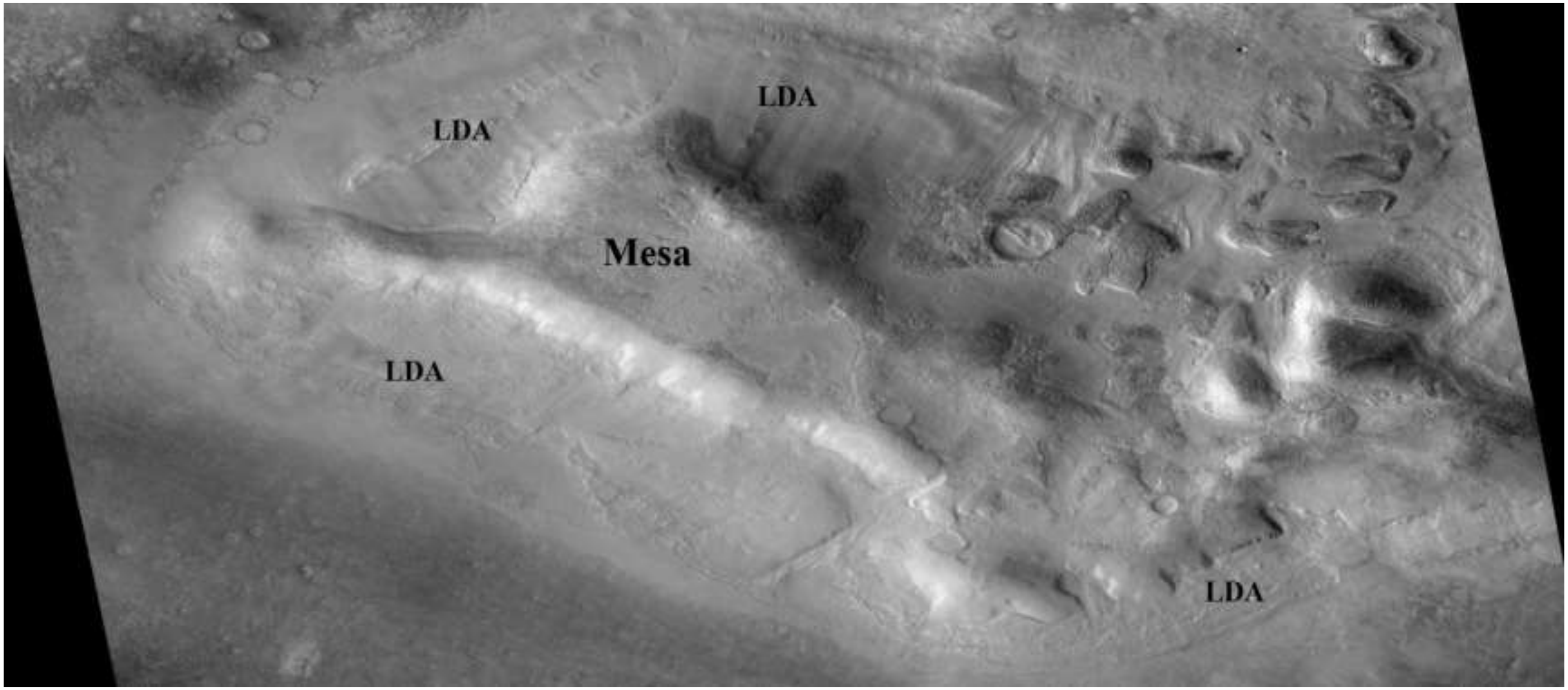


Lineated Valley Fill is a feature seen on the floors of some channels on Mars, exhibiting ridges and grooves that seem to flow around obstacles. These features bear a strong visual resemblance to some terrestrial glaciers.

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

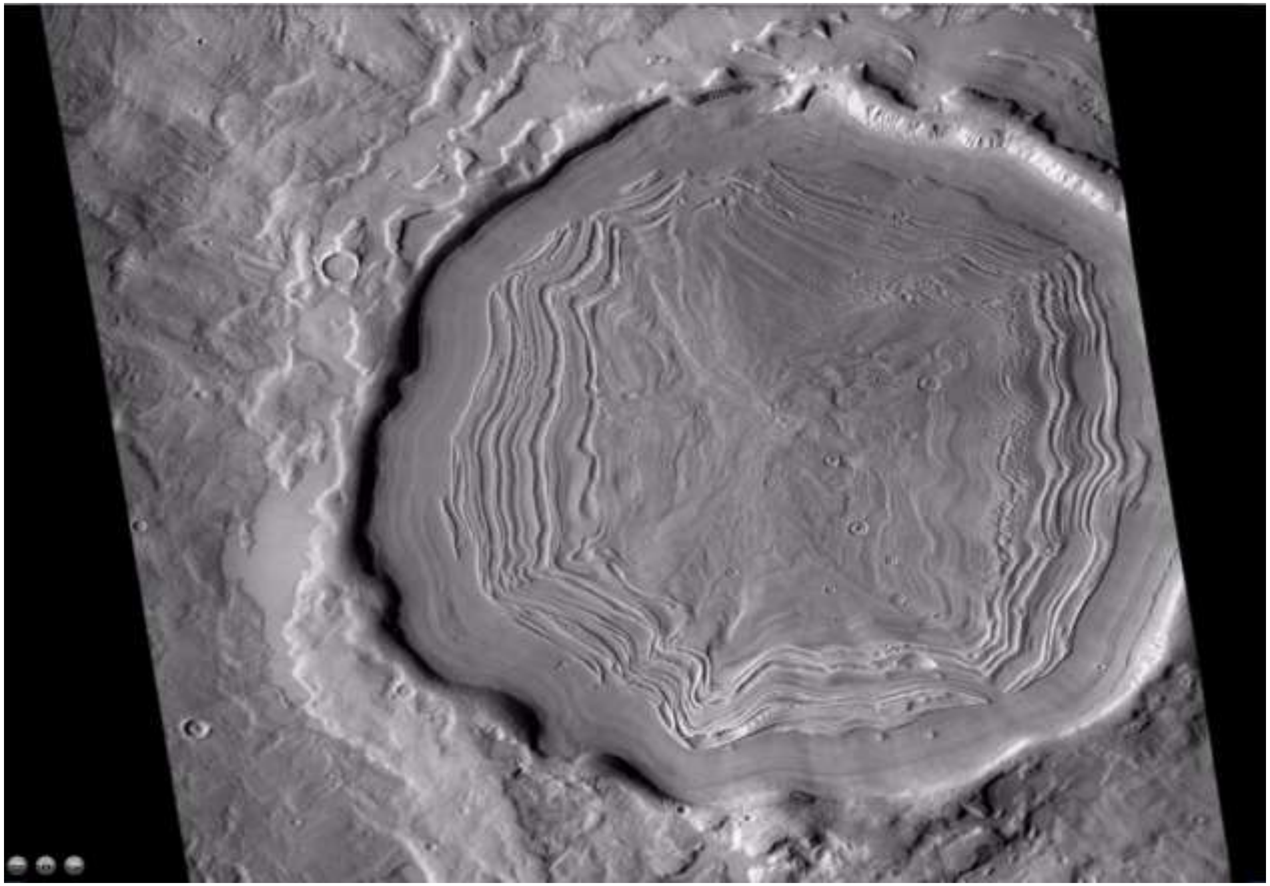
What are Lobate Debris Aprons?

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?

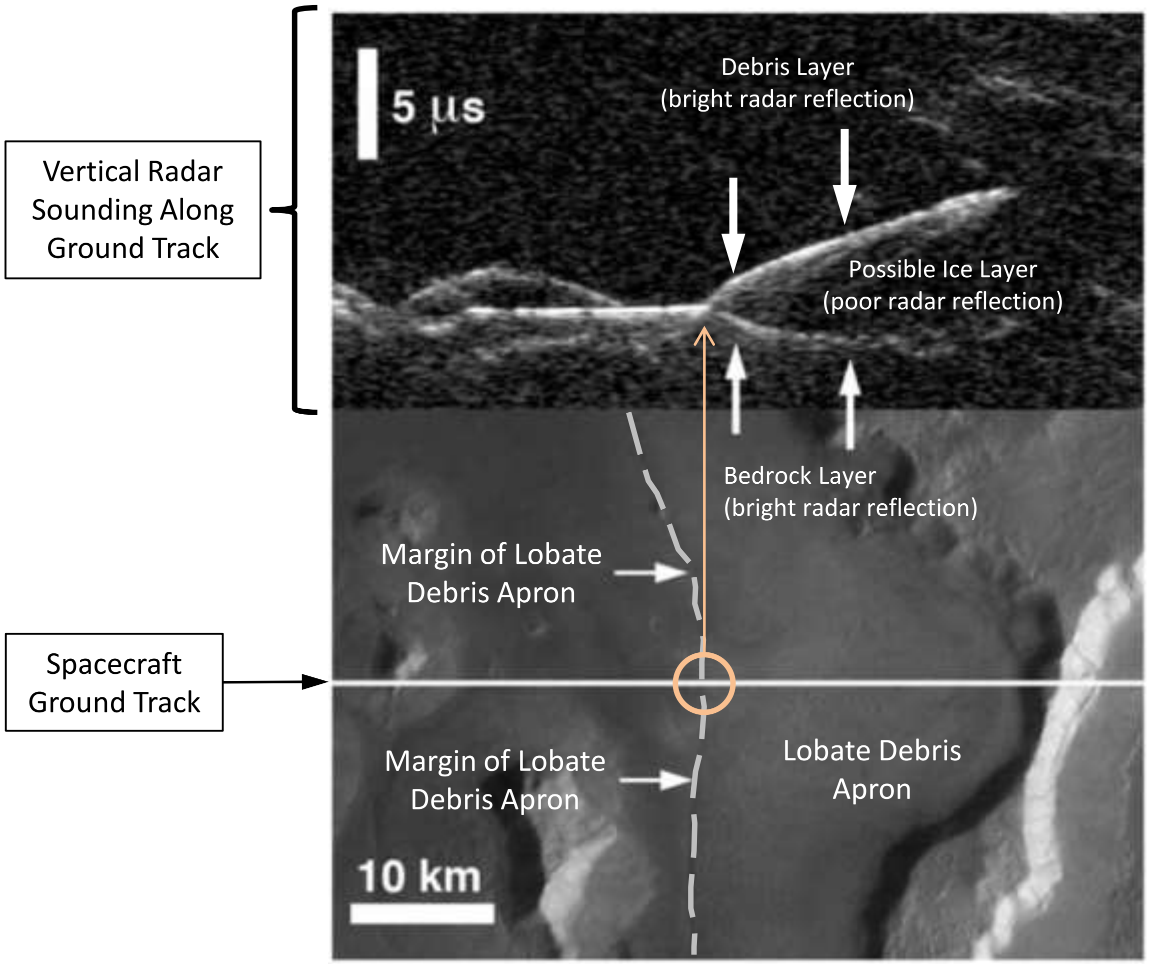
Concentric crater fill is a terrain feature where the floor of a crater is mostly covered with a large number of parallel ridges.



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?

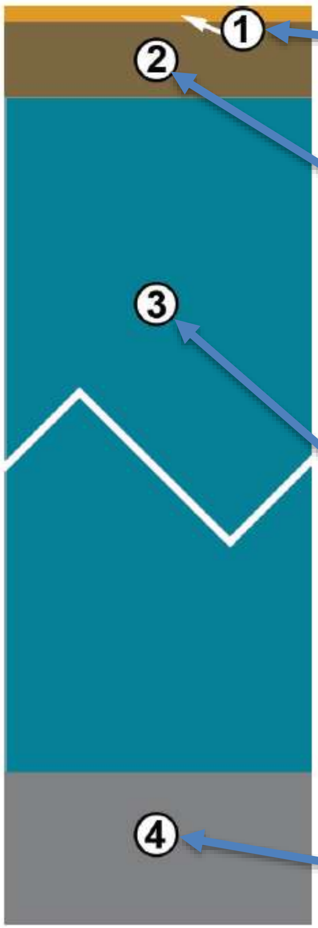
While searching for subsurface aquafers, the MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding; on *Mars Express*) and SHARAD (SHAllow RADar; on *Mars Reconnaissance Orbiter - MRO*) radars gathered data indicating these terrain features could be debris covered ice.



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.

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)

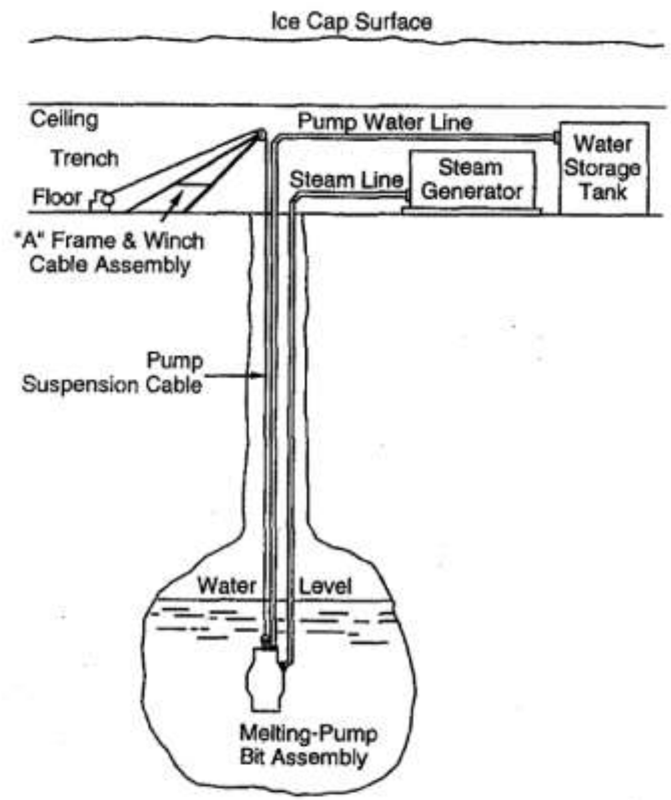


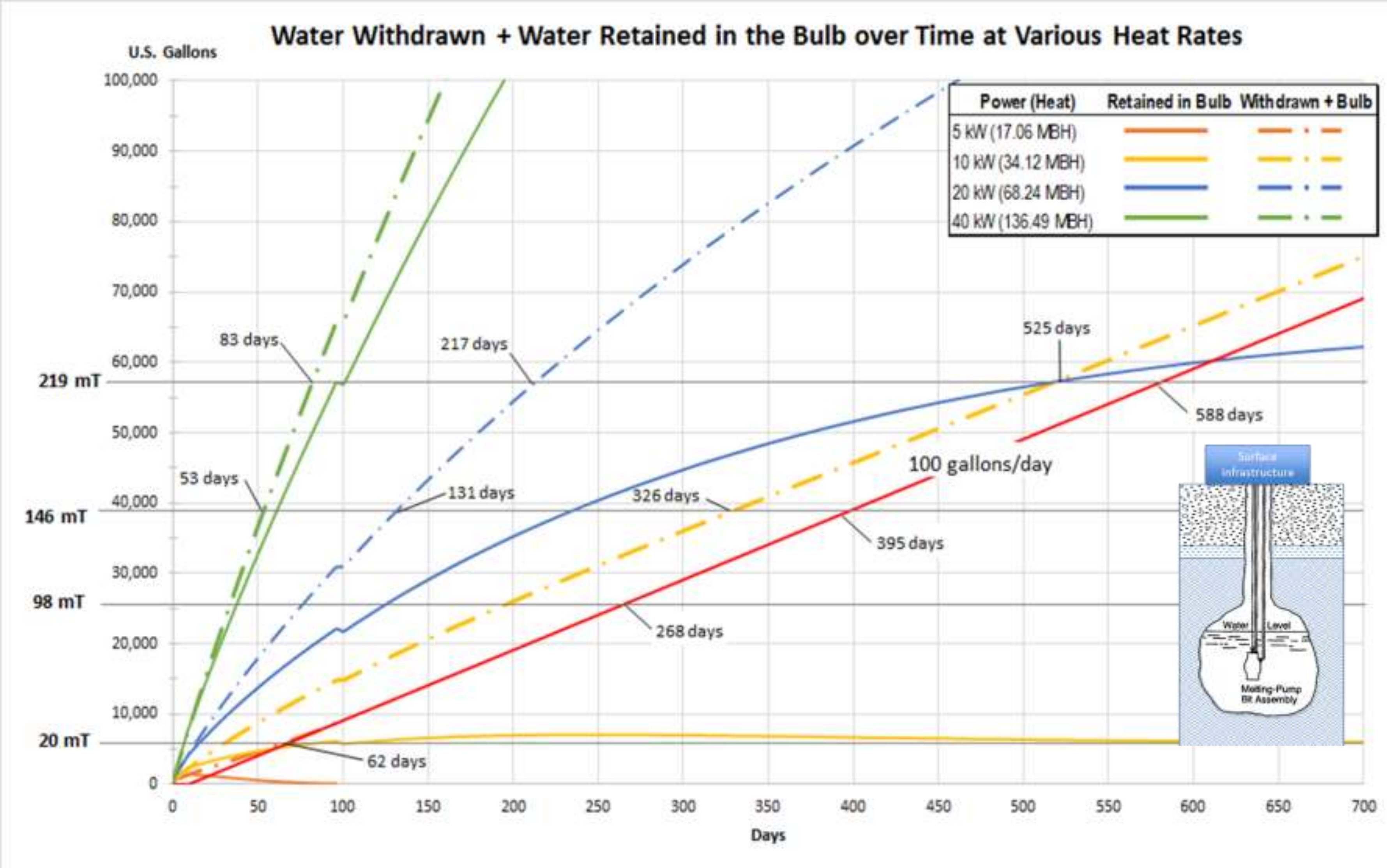
Figure 1. Camp Century water well equipment (from Clark 1965).

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

Conceptual System and Notional Conops

- **Conduct a local site survey to identify the specific location for the Rodwell**
  - Identify the thinnest debris depth
  - Determine the firn layer depth (if any) and identify cracks, voids, etc.
- **Drill through the debris layer**
  - Use mechanical drill
  - Case the hole to prevent debris from collapsing into the hole and to allow some TBD pressurization of the reservoir
- **Drill into ice layer**
  - Drill down to a depth sufficient for ice to support the overlying debris layer and bypass any firn, cracks, voids, etc.
  - Several technology options exist for this step; further evaluation/tests are needed to select "best" option
    - Mechanical, electro-thermal, hot water, hybrid
- **Melt ice and store water in subsurface reservoir**
  - Power needed to melt ice and water extraction rate are coupled and both are tied to the specific use scenario
- **Options exist to cease operations between crews or to keep Rodwell in continuous operation**
  - Dependent on surface mission scenario and overall campaign – future work required
- **Option to store water above ground or use the Rodwell reservoir for storage**
  - Future work required

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



Note: assumes -80° C ice

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