

DESCRIPTION OF WATER RESOURCES ON MARS THAT HAVE THE POTENTIAL TO BECOME RESERVES AS PART OF A HUMAN EXPLORATION ZONE: THE M-WIP STUDY, PART 1.

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Introduction: As part of the Human Landing Site Selection Workshop (HLS²), held October 2015 (<http://mars.nasa.gov/multimedia/webcasts/human-landing-site-selection-workshops/>), a number of candidate Mars Exploration Zones were proposed. In addition to science regions of interest, all site proposers were asked to identify one or more candidate water resource deposits within their Exploration Zone that have the potential to produce 5 metric tons of water per year. In all, 47 candidate sites were proposed by the world's leading experts in ISRU and Mars geology. The four most common candidate water resource deposits proposed include (not in priority order):

1. Mid-latitude ice
2. Deposits of poly-hydrated sulfate minerals
3. Concentrations of phyllosilicate minerals
4. Regolith.

This abstract summarizes the geological nature of the resources described above, and is part of the larger M-WIP study, a primary purpose of which was to evaluate what it would take to discover and define water “reserves”. (Reserve is the raw material in-place, not yet extracted and processed but proven to be feasible to extract and process.)

Mid Latitude Ice: As shown on Fig. 1, there is abundant geomorphic evidence that glaciers existed in the martian mid-latitudes in the recent past. However, with many of these features, we have no information about whether residual ice remains, and if so, its depth.

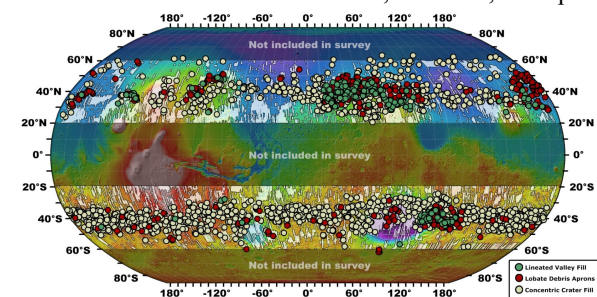


Fig. 1. Map of Mars glacial features (from Dickson et al., 2012). Remnant glacial ice is an important candidate resource.

Aqueous Minerals: The compilation of mineral detections from martian orbit (Fig. 2; Ehlmann and Edwards, 2014) shows two classes of minerals that are particularly relevant to the evaluation of martian water resource deposits: 1). Phyllosilicates, and 2). Sulfates.

Poly-hydrated sulfates. Many of the site proposers at the HLS² Workshop proposed making use of a con-

centrated deposit of poly-hydrated sulfate minerals, such as gypsum or kieserite. Such minerals can have very high concentrations of water (e.g. ~20 wt. % for gypsum), and if accumulations could be located, deposits with relatively high grade could exist.

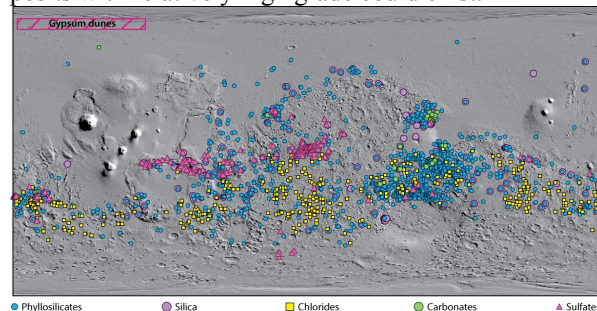


Fig. 2. Map of mineral detections from Mars (from Ehlmann and Edwards, 2014).

Phyllosilicate mineral deposits. A number of HLS² proposers also hypothesized the presence of concentrations of phyllosilicate minerals. Phyllosilicate minerals typically have lower water content than at least some poly-hydrated sulfate minerals. For example, the mineral smectite, under martian conditions, is thought to have between 2-7 wt. % water, depending on cation chemistry (Bish et al. 2003). Nevertheless, the possible existence of concentrations of phyllosilicate minerals could be an attractive exploration target.

Regolith: Finally, a number of HLS² proposers suggested that the necessary quantities of water could be obtained by processing martian regolith. Although regolith, in the strictest sense, is present essentially

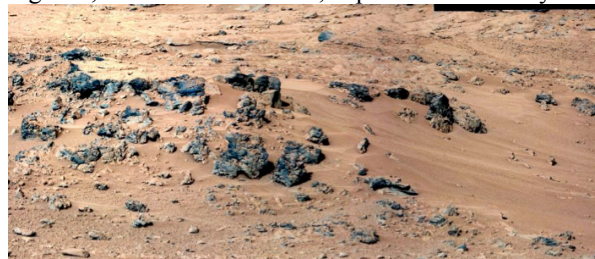


Fig. 3. Image of the Rocknest site (smooth wind-blown drift to the right), taken by MSL. Image credit JPL/NASA.

everywhere on Mars, it is not all equally amenable to ISRU operations (for example, because of too many rocks). MSL, by means of data from its various instruments, has shown that the regolith in the Gale Crater has a variety of both mechanical characteristics, as well as water content. The aeolian dust on Mars

(Fig. 3), likely contains water in a mixture of phases, including at least basaltic glass, allophane, akaganeite, basanite, and smectite, and with a comparatively low overall water concentration (e.g. 1.5 wt % water).

Some other options considered and ruled out: There are four additional options for martian water resources that were considered in the M-WIP study, and that have been determined to be impractical.

Extraction of Water from the Atmosphere. Some calculations of relevance:

- At Mars surface pressure (~6 mbar); atm density averages $\sim 0.020 \text{ kg/m}^3$, water $\sim 210 \text{ ppm} = 0.0042 \text{ g(water)/m}^3$
- 1 kg water is contained in $250,000 \text{ m}^3$ of atmosphere
- To produce 5 mt water per yr, 0.57 kg would have to be produced per hour, which means 2400 m^3 (~1 Olympic sized swimming pool) of atmosphere would have to be handled per minute, assuming 100% recovery. This is equivalent to 84,000 CFM.
- Martian atmosphere is at 1% of the pressure of the inlet pressure for compressors on Earth, thus an additional compression factor of 10^2 would have to be applied to get the same throughput.

Recurring slope lineae. Although the possible association of RSL with liquid water has recently been made (e.g. Ojha et al., 2014), they only occur on steep (angle of repose) slopes, which is a very difficult configuration for mining/transport operations. In addition, by definition, RSL are transient (seasonal). If liquid water is present, it may be so only temporarily.

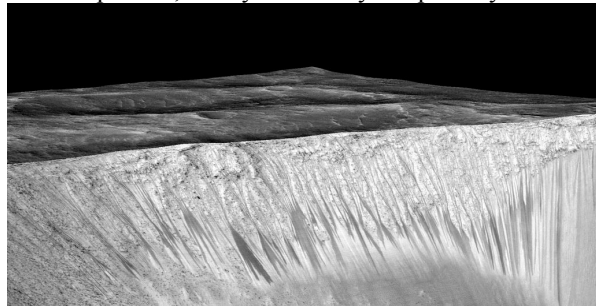


Fig. 4. Image of RSL deposits on a crater wall. Image credit JPL/NASA/Univ. Arizona.

Deep Groundwater. The MARSIS and SHARAD radar instruments would be able to detect martian groundwater, if it were present to a maximum depth of ~1 km and ~300 m, respectively. In the case of MARSIS, spatial coverage has now increased (as of Nov. 2015) to 69% of the planet. As shown in Fig. 5, we are now relatively confident that no significant water table exists anywhere on Mars within the upper 200-300 m, where the signal is strongest. Although

deeper water may exist, it is not considered practically useful (see also Rummel et al., 2014).

High-latitude ice. For the purpose of planning human missions, landing at latitudes poleward of 50° is assumed to be disallowed for engineering reasons.

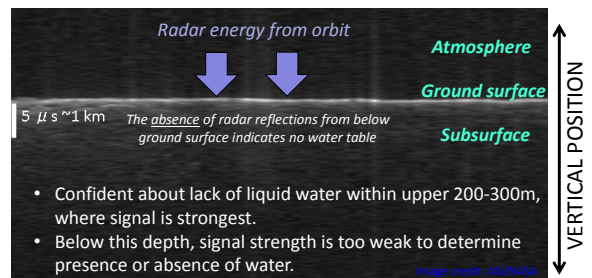


Fig. 5. MARSIS 5-MHz, radargram of the Athabasca region of Mars (4-7N, 149E). Image courtesy of Jeff Plaut.

Conclusions: Based on the above analysis, four reference cases were defined by the M-WIP team for use in engineering analysis: Case A – glacial ice; Case B – a natural concentration of poly-hydrated sulfate minerals; Case C – a natural concentration of phyllosilicate minerals; Case D – regolith with average composition as observed from in situ missions. All four of these are considered to have realistic potential to be elevated to the status of reserves, as long as there is:

1. Sufficient exploration of at least one martian site at a scale relevant to mining
2. Sufficient technology development of at least one mining/processing system that is matched to the geological resource.

These two things need to be in parallel (Fig. 6).

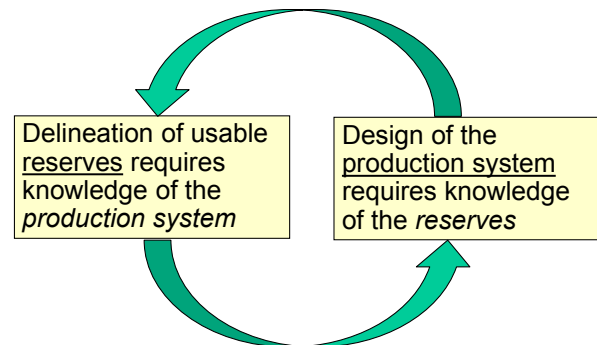


Fig. 6. The inter-relationship between exploration-production. These two things need to be advanced in parallel.

References: Dickson et al. 2012, *Icarus* 219: 723–732; Bish et al., 2003, *Icarus* 164: 96-103; Ehlmann and Edwards, 2014, *Annual Review of Earth and Planetary Science* 42: 291–315; Ojha et al. 2014, *Icarus* 231, 365-376; Rummel et al. 2014, *Astrobiology*, 14 (11): 887-968.