The Hunt for Liquid Water, Life and Landing Sites on the Surface of Mars Today

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Abstract: As the debate rages on about past or present life on Mars, the prevailing assumption has been that the liquid water essential for its existence is absent because pressures and temperatures are too low. This study presents data, anecdotal and experimental evidence to challenge that assumption.

1.0 Introduction and Background

"Liquid water does not exist on the surface of Mars...Without liquid water, life as we know it cannot exist."

Principal Viking investigator Norman Horowitz made these statements over two decades ago, establishing the contemporary paradigm of a barren Mars today. Since that time, a wealth of new knowledge has been accumulated in the form of images and data on soil, air composition and climate from the robotic probes of the 90s, Pathfinder and Mars Global Surveyer (MGS). We now have extensive pressure and temperature data from all three probes (Figure 1a and Figure 1b) demonstrating pressures above the triple point and temperatures above freezing for long periods of time, meeting the criteria for liquid water. Pathfinder also found 20…C variations along its mast, suggesting ice can melt on the surface even with air temperatures above it below freezing. Spacial variations in temperature may also permit ice to melt against sunlit, smooth, dark rocks despite immediately adjacent temperatures being below zero. Other issues of concern include boiling, evaporation and stability. Under observed Martian pressures, there exists only a 7°C window exists between freezing and boiling. Though narrow, the Viking orbiter observed such a window. As for stability, even if liquid water could exist, skeptics argue, it would be rapidly driven off by high evaporation rates into the dry atmosphere. On the other hand, frost was observed to persist at Viking s Utopia Planitia landing site, implying condensation and stability.

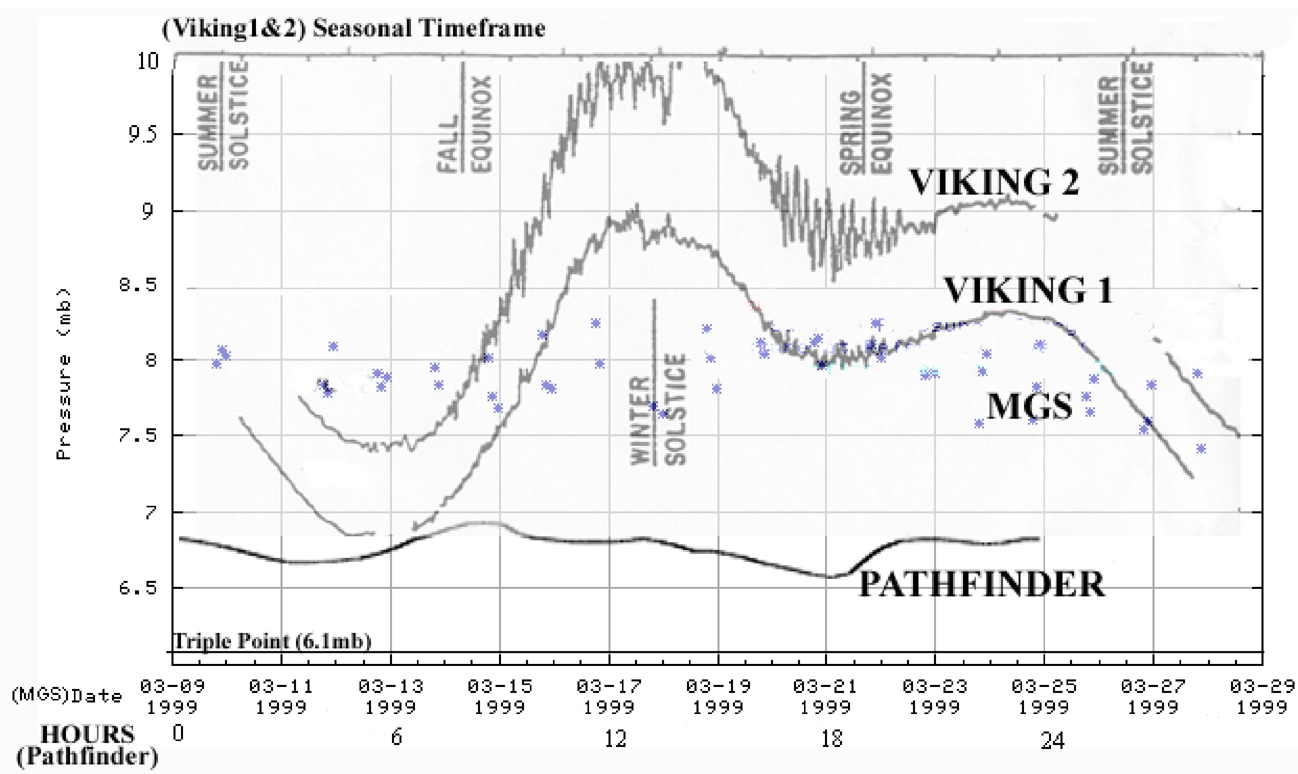


Figure 1a. Probe Pressure Data

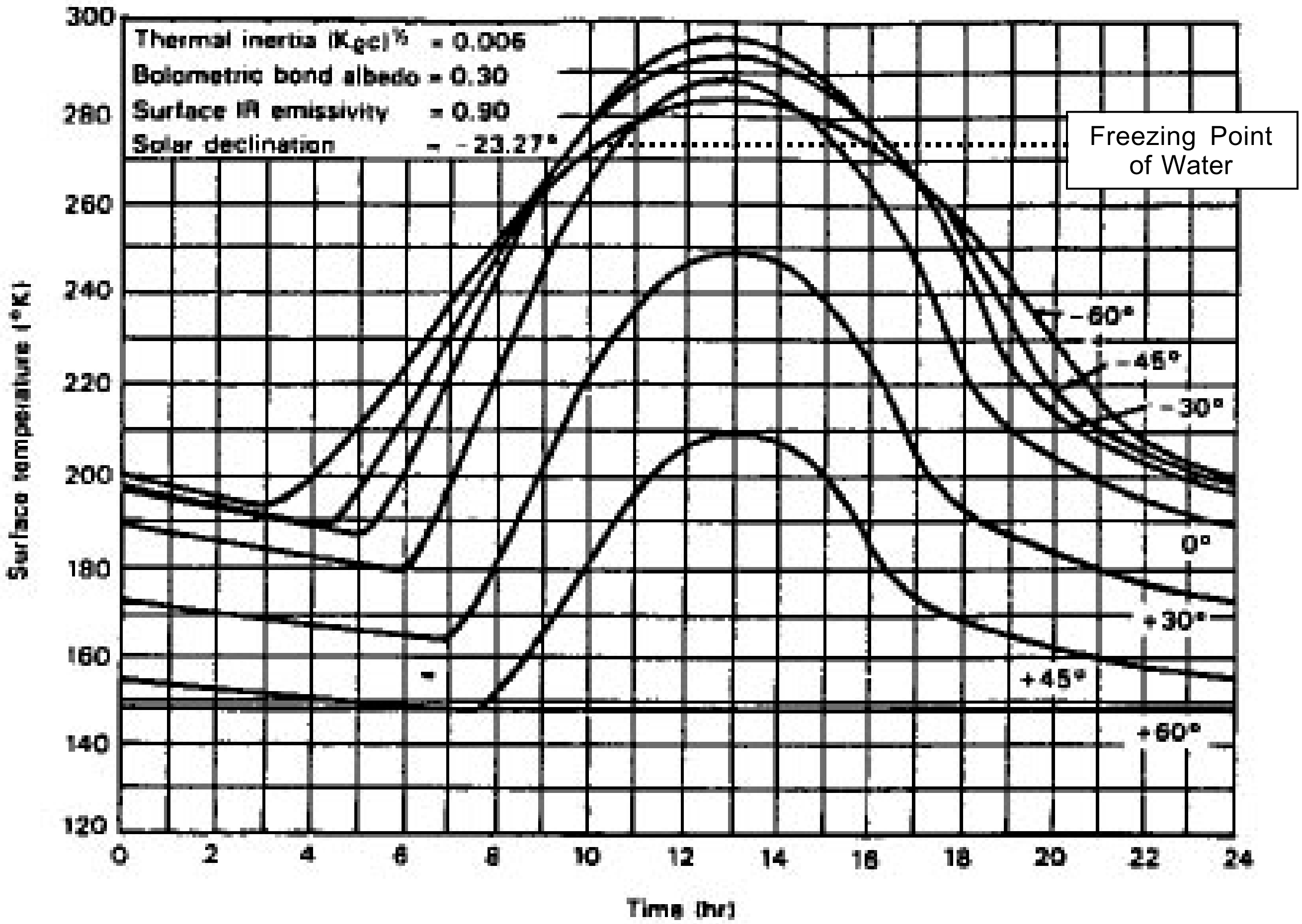


Figure 1b. Viking Temperature Data

If conditions are stable and above the triple point, thermodynamics dictate that liquid water must exist. But does it? The results of this study suggest it can, although precariously. Can life exist in water that remains liquid for just a few hours a day? The answer is less clear. To resolve the questions raised above, a multi-tiered study of theoretical models, empirical evidence and experiments has been performed.

2.0 Theoretical Considerations

Martian Atmospheric Conditions

The Martian atmosphere is composed almost entirely of $C0_2$, with minor fractions of O_2, water vapor and trace gases (Table 1). The NASA-Ames AEPS study[1] analyzed this atmosphere and concluded that it can be treated as an ideal gas.

MAJOR	**Composition**	**Percentage**
	Carbon Dioxide (CO_2)	95.32
°	Nitrogen (N_2)	2.7
°	Argon (Ar)	1.6
°	Oxygen (O_2)	0.13
°	Carbon Monoxide (CO)	0.08
MINOR	**Composition**	**ppm (parts per million)**
°	Water (Vapor) (H_2O)	210

TABLE 1: Compositions of Martian atmosphere

As such, the laws governing its behavior can be summarized as follows:

The Knudson number, is on the order of 10^{-5}, where:

$$K_n = \frac{\lambda}{L}$$

λ = mean free path
L = container dimension

Dalton law of additive pressure

$$P_{mix} = \sum_{i=1}^{k} P_i(T_{mix}, V_{mix})$$

Where P_{mix} = pressure of a gas mixture,
P_i = pressure of one composition of the mixture,
T_{mix}, V_{mix} = temperature and pressure of the mixture.

Amagat s law of additive volume

$$V_{mix} = \sum_{i=1}^{k} V_i(T_{mix}, P_{mix})$$

Fick s law

$$M = -D\frac{\partial C}{\partial x}(H_2O)$$

Where M is evaporation or sublimation rate, D is a property of the binary diffusion coefficient, and C denotes concentration.

Psychrometry

For a multiphase medium, evaporation is governed by partial pressure and temperature differences between each component on the surface and in the air stream, according to the following equation:

$$S_2 - S_1 = nN\left[\bar{C}_v\, N \ln\frac{T_2}{T_{IN}} + \bar{R}\ln\frac{V_2}{V_{IN}}\right] + nO\left[\bar{C}_v\, O \ln\frac{T_2}{T_{IN}} + \bar{R}\ln\frac{V_2}{V_{IN}}\right]$$

Heat/mass transfer analysis

Using the preceding equations together with ones that govern the flow of fluids, heat, and mass, a mathematical model of the Martian climate system accounting for conduction, convection, radiation, evaporation, sublimation, atmospheric properties and soil properties can be constructed (Figure 2)[2]. Such a model has been used by Haberle[3] et al to indicate that liquid water is not only feasible, but potentially stable for up to 150 days/year near the equator.

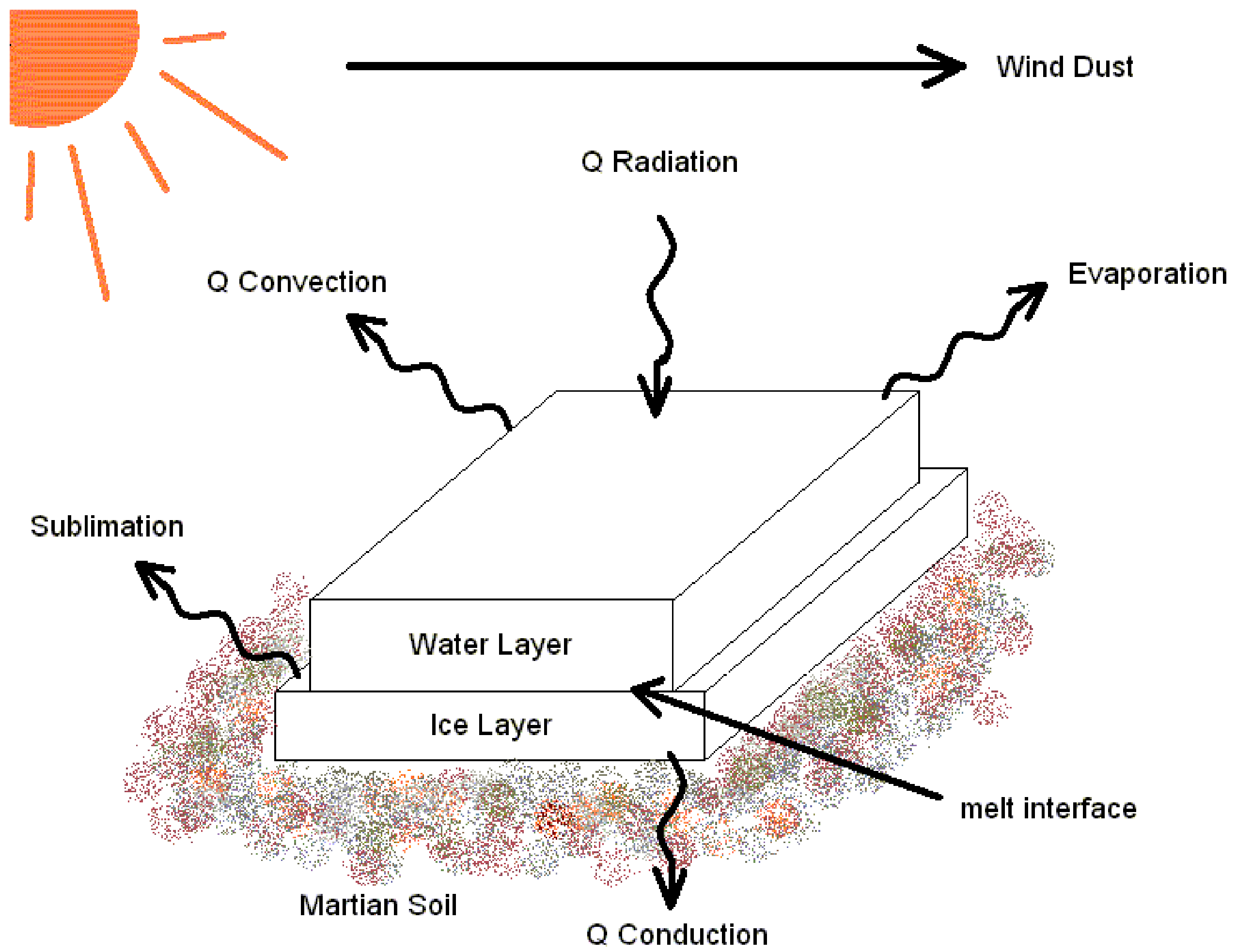


Figure 2: Water on Mars Thermal Model

Thermodynamics

The phase diagram for pure water (Figure 3) shows the pressures and temperatures at which water can exist in a solid, liquid, or vapor form. As seen from this diagram, liquid water cannot exist below 6.1mb. Since Martian pressures range between 3-10mb and temperatures frequently fall in the 0-7…Cwindow, between freezing and boiling, thermodynamics dictate that liquid water must exist at certain times. A question frequently asked is whether the abscissa in Figure 3 is total pressure or partial pressure of water vapor. If the former, the pressure on Mars is frequently above the triple point. If the latter, the pressure would always be below it since the partial pressure of water vapor in the atmosphere is only a fraction of a millibar. This question will be addressed in the experimental methods section of this paper. Another issue is water purity. The triple point diagram is for pure distilled water. Water with brine, sand, or impurities such as on Mars, would have a depressed freezing/melt point, shifting the boundaries of Figure 3 down and increasing the probability of liquid water.

Empirical Evidence

The porous plate sublimator used in all astronaut EMU's (Extravehicular Mobility Units) since the Apollo program makes use of the fact that water goes directly from ice to vapor at pressures below the triple point. The design of this sublimator incorporates a feedwater tank under pressure that supplies water to the plate, a ventilation gas loop, a liquid cooled garment loop that carries body and equipment heat from the EMU to the sublimator, and associated pumps, fans, batteries, diverter valves, tubing and ancillary equipment.

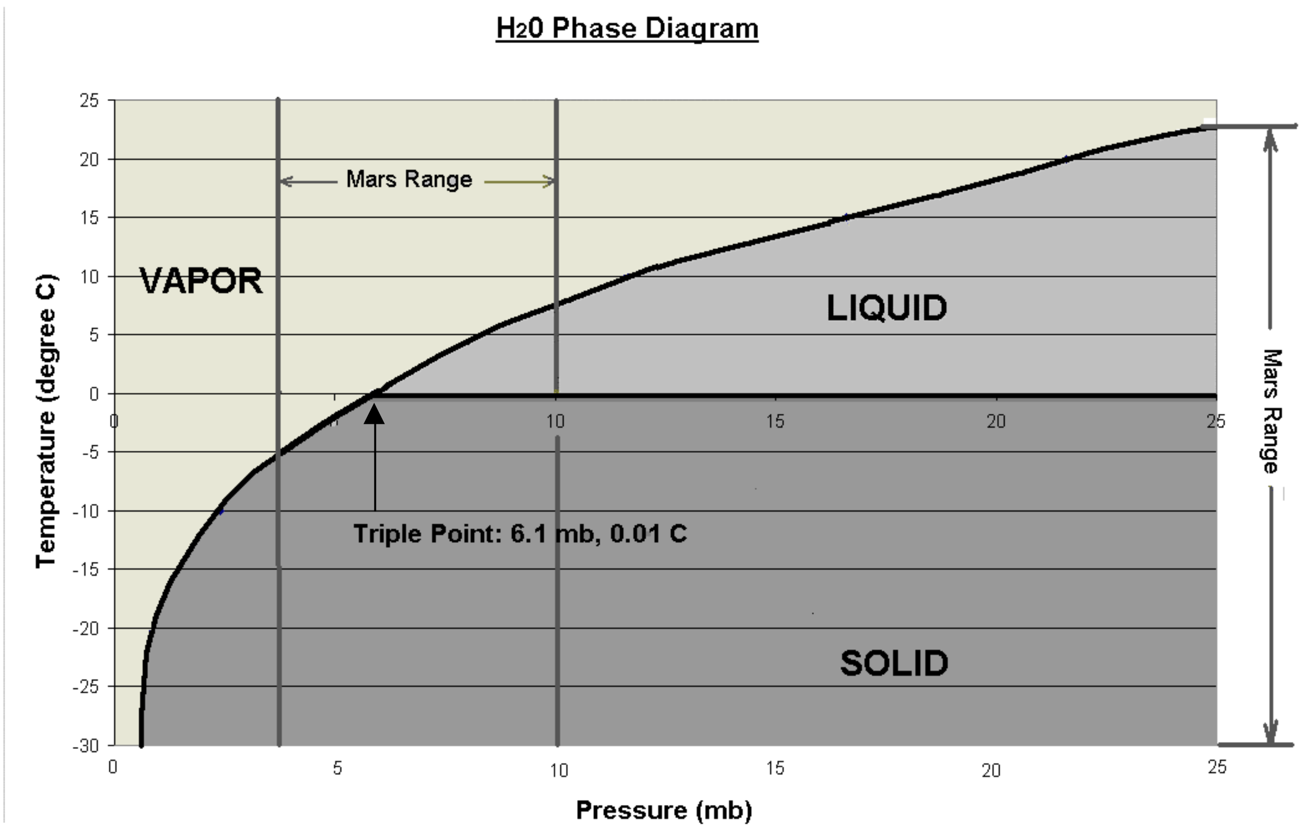


Figure 3. Triple Point Diagram. Source: handbook of Chemistry and Physics

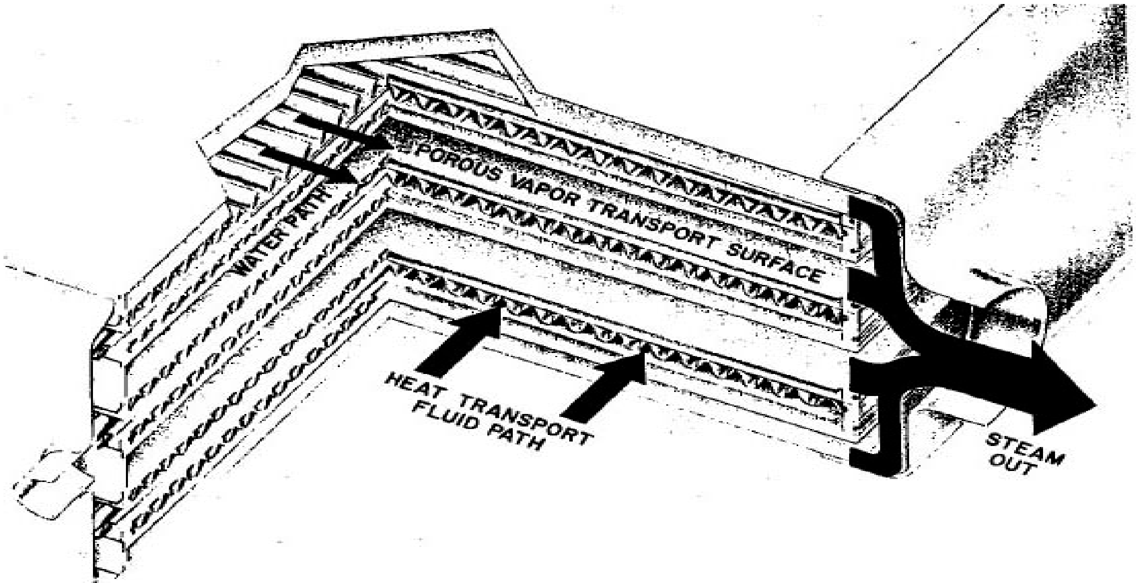
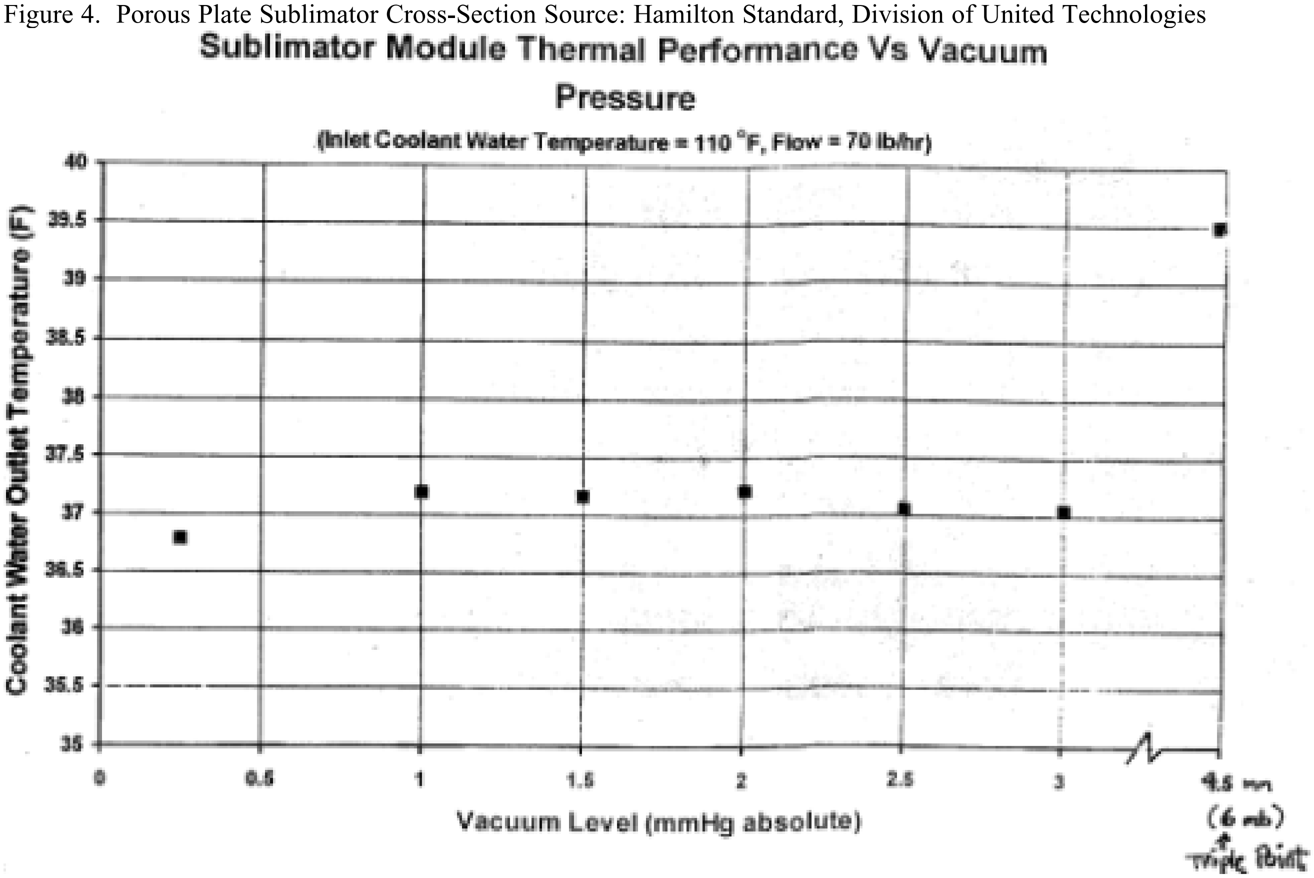


Figure 4. Porous Plate Sublimator Cross-Section Source: Hamilton Standard, Division of United Technologies



5. Sublimator performance. Source: Hamilton Standard, Division of United Technologies

The system functions as follows:

An ice layer forms within the porous plate when the feedwater tank directs water to it because it is exposed to ambient vacuum. As long as heat is not supplied to it, this ice layer stays intact. However, when the suit ventilation and liquid cooled garment loops enter the sublimator carrying body and equipment heat (Figure 4), the ice layer sublimates to steam in direct proportion to the amount of heat being carried in. The feedwater tank resupplies water to the sublimator plate in proportion to heat loss, until its eight-pound supply is exhausted. The passage of heat from the suit, air and water loops to the sublimator takes place by conduction through aluminum heat exchanger fins integral to the design. As a consequence of this design, ambient pressures rising above the triple point will cause the ice layer on the plate to melt when heated. If this happens, unlike traditional water boilers or evaporators that continue to operate at low pressures, the unit will experience "breakthrough" and stop functioning. Such functional degradation is rapid and marked and has been observed in suit testing within vacuum chambers. Test data has established that this process occurs at pressures above 3.5mb with Mars-like temperatures (Figure 5).

The implication is inescapable. If sublimation is indeed replaced by evaporation at Martian pressures in a vacuum chamber on Earth, evaporation from a liquid phase must occur on Mars as well. It must be added, however, that since the sublimator tests described here were for EMU performance, not Mars simulation, this evidence for liquid water is circumstantial.

3.0 Experimental Evidence

Protocol:

Simulating Martian conditions in a bell jar was the objective of the experimental phase of this study. An ice cube in a glass funnel placed inside a bell jar containing Drierite (a desiccant), calibrated thermometers, and dry ice (to create a CO_2 atmosphere) was kept under Martian pressures by a vacuum pump. A lamp placed over the bell jar simulated Martian sunlight (38% of Earth) and time, temperature and pressure readings were recorded (Figure 6). The end point for each run was defined as the first appearance of a water droplet or film.

Results:

Over 80 runs were made, 23 using tap water and the remainder using distilled water, diluted sea water, bacterial culture media and other mixtures. Typical results are shown for tap water in Figures 7-9 and are summarized as follows:

As seen in figure 7, with mean atmospheric temperature of 26…C, liquid water was observed at pressures between 12 mb and 16 mb. These runs, taken at higher pressures than Martian conditions, demonstrated that the sublimation process is total-pressure-driven and not driven by the partial pressure of water vapor, since the latter was below the triple point.

At a mean ice temperature of 0…C, as seen in figure 8, liquid water was observed at pressures between 3 mb and 10 mb, Mars like conditions. This data demonstrates that liquid water can exist under these simulated Martian conditions.

Figure 9 shows transient results for a typical run. At the beginning of the experiment, the ice cube is frosted over, yielding no liquid water even when touched by a warm body. Half way through the experiment, temperatures have grown significantly and the pressure has dropped. It is at this time that micro-ice crystals and vapor films are observed on the sides of the funnel. The ice cube has also changed appearance, changing its white exterior for a glossy one. Towards the end of the experiment, white and frozen films are seen, suggesting concurrent sublimation at low pressures.

Figure 6. Experimental setup

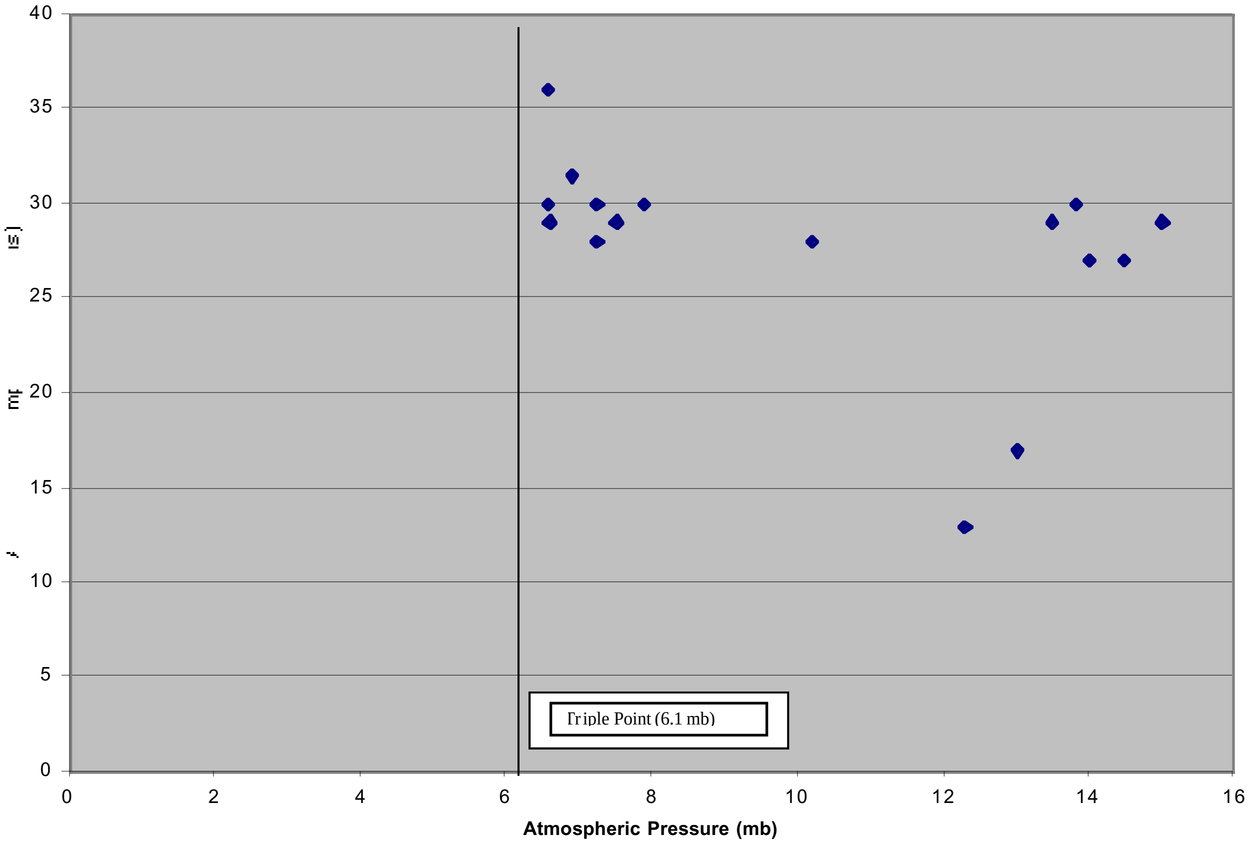


Figure 7. Atmospheric temperature vs. pressure endpoints

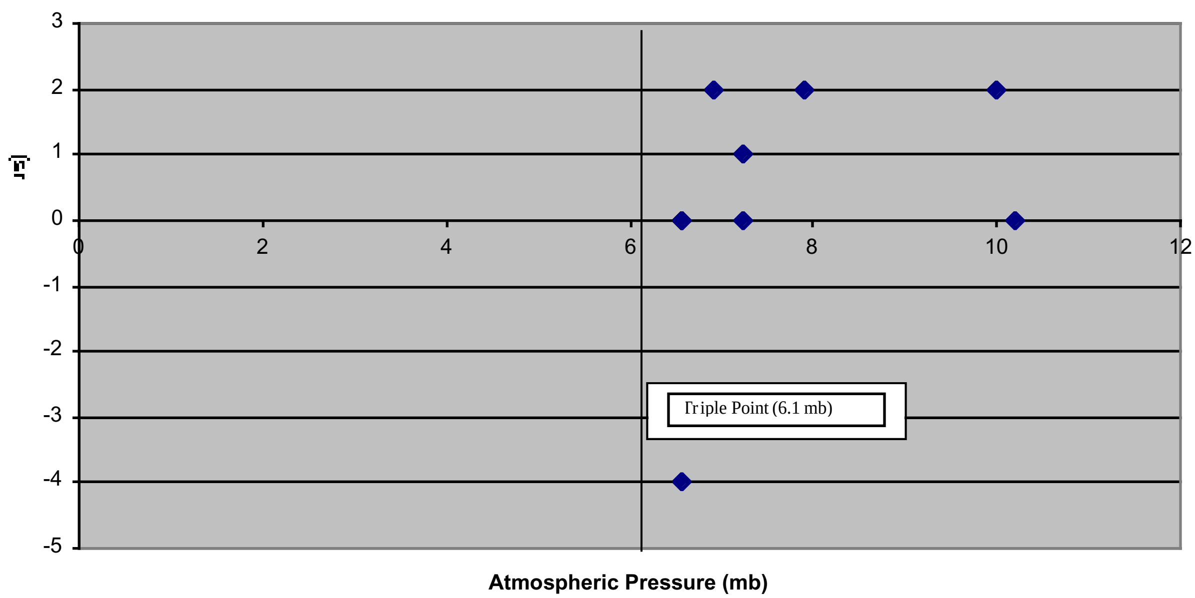


Figure 8. Ice cube temperature vs. pressure endpoints

Run #16

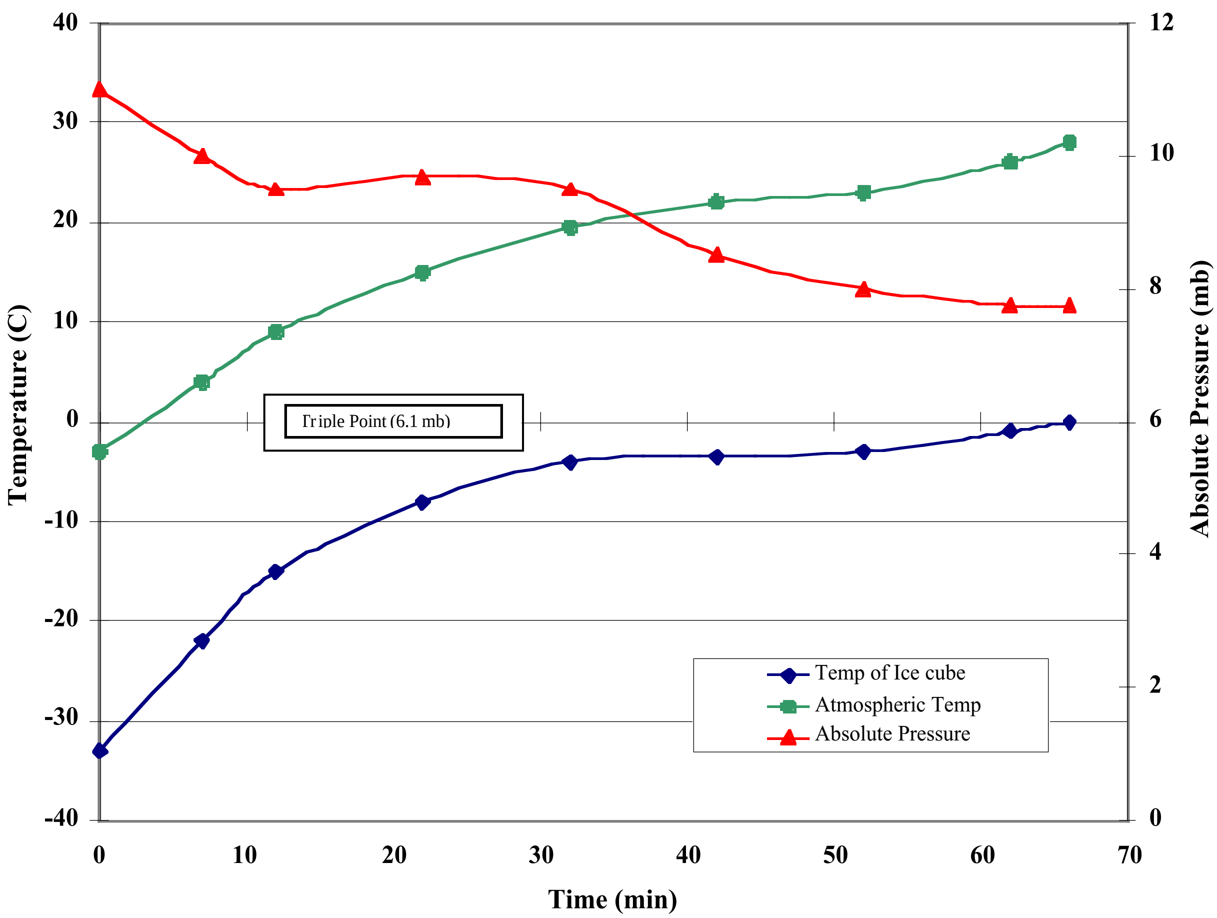


Figure 9. Transient temperature and pressure graph

Discussion and Errors:

The protocol had certain inherent errors. First, observations were subjectively based on the eyes of the observer. To counter this, a team of observers was utilized, as well as photographs and videotape recordings. Secondly, the atmosphere provided was pure CO_2, not the exact mix of the Martian atmosphere specified by Table 1. However, since 95% of the atmosphere is CO_2 and the remaining 5% is either inert or trace gases, this is a reasonable approximation. Thirdly, although Drierite, a desiccant, was used to keep the bell jar free of water vapor, humidity sensors were not available to test exactly how dry. The Drierite, on the other hand, contained an indicator that would change color when exposed to persistent water vapor. Since it never did, we can reasonably assume water vapor quantities were extremely low. Fourthly, the dual thermometers used to measure air and ice cube temperatures recorded different data depending on the placement within the ice cube and air stream. This was likely caused by radiant heating of the thermometer bulbs by the sun lamps. As such, actual atmospheric temperatures were likely lower than the sensed air temperatures, an error having little effect on the final results because temperatures were within the Martian range, as shown in figure 1b. Lastly, ice was seen to swivel on its own, suggesting the presence of a liquid film, when a visual confirmation of liquid could not be made.

Conclusions:

The purpose of the bell jar experiment was to determine the feasibility of liquid water under Martian conditions. This condition was met. Additionally, we can conclude that total pressure drives the phase change of water, not the partial pressure of water vapor in the atmosphere.

4.0 Implications

Implications for Geology:

McKay et al[4] have assumed the absence of liquid water as a significant geologic force for billions of years (Figure 10). If it can be shown that water persists in liquid form today, it would shift the timeline and paradigm of the forces that shaped the planet.

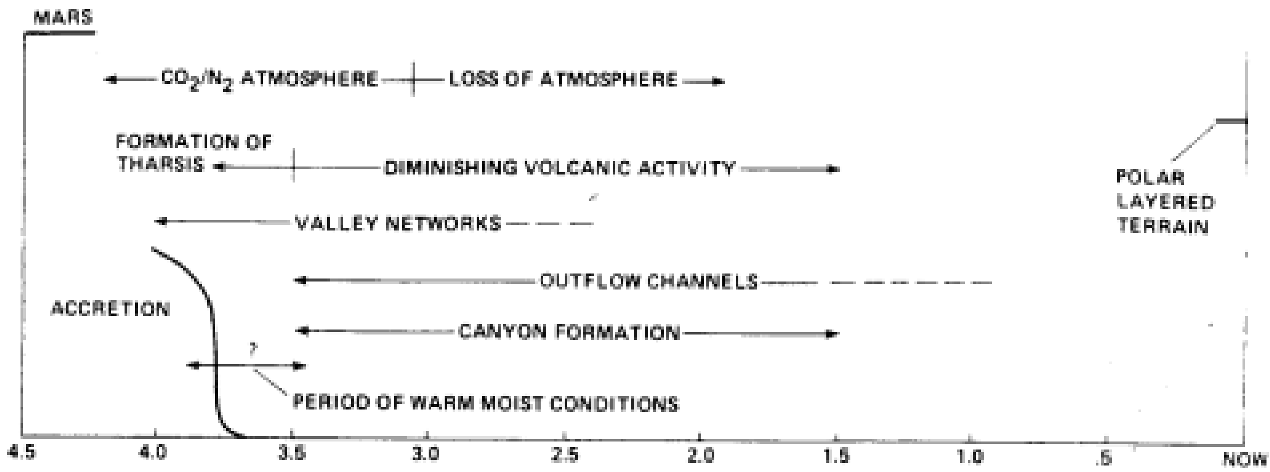


Figure 10. Geologic history of Mars. McKay and Stoker (ref. 4)

Implications of Life:

The viability of liquid water on the Martian surface may provide an environment for fringe organisms that live in conditions far more extreme than a temporary film of cold water. If extremophiles can be found living in ice 2.3 miles below the frozen surface of Lake Vostok in Antartica[5], why not Archea, Eubacteria, or Protista on Mars? Sites that demonstrate the possibility of liquid water may likely be temperate enough to sustain such life today.

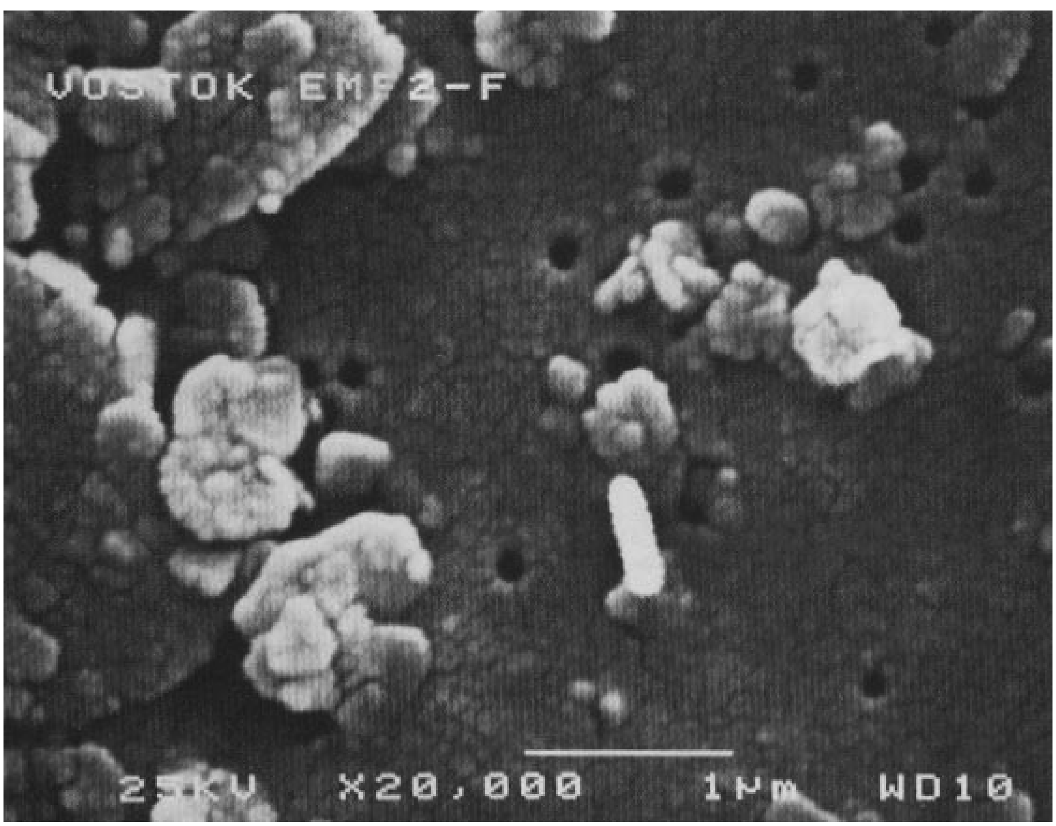


Figure 11. Extremophiles found in Antartica. (ref. 5)

Implications for Landing Site Selection:

If liquid water were on the surface today, it would not only shift the paradigm of how geologic forces shaped the planet, but effect human mission planners who assume its absence. On-site water would provide resources for drinking, oxygen, and hygiene, saving the cost of shipping it from Earth or making it on the surface. Decreased mass, complexity and power requirements would decrease costs, possibly even making the difference between an affordable or extravagant mission. The question then becomes how best to locate water, and after having done so, how to let it influence landing site selection. One way of doing this is by using theoretical models such as Haberle s[6]. Another is by utilizing Mars Global Surveyor mapping data.

Global Surveyor Mapping Data.

The presence of liquid water on the Martian surface would greatly impact human landing site selection, and we have presented evidence for it under simulated Mars conditions. The next phase of this study will evaluate the feasibility of these conditions on the planet itself and map the locations where they might occur. Haberle s theoretical model provides one method of doing this and another is the utilization of mapping data from Mars Global Surveyor.

MGS, currently in orbit, records pressures and temperatures using radio occultation. Microwave radiation is transmitted by the spacecraft into the Martian atmosphere and received at tracking stations on Earth. Analyzing the phase shift of these waves provides data for specific longitudes, latitudes and time of day. Table 2 shows MGS pressure and temperature profiles for a site in Hellas Crater collected this way. Although the data suggests a liquid phase cannot exist, trend analysis may show otherwise. It s important to note that temperature and pressure increase as one nears the surface from higher elevations (Figure 9), and that the vertical resolution of the MGS oscillator can only approximate abrupt topographical surface changes.

Indeed, "sounding" the atmosphere within a canyon is possible in only rare cases[7] and radio occultation may prove over-generalized for deep and chaotic surfaces like Hebbes and Ophir Chasma. If so, another way of determining conditions in these sites would be to extrapolate surface data to lower depths using theoretical models, pressure decay curves, and other techniques. This approach, using figure 9 for pressure augmentation and the Monte Carlo radiant interchange analysis of spherical cavities for temperature is one we hope to utilize in the future. This analysis may reveal higher probabilities for liquid surface water than expected from current MGS data. For example, if the pressure was only a scant 15mb instead of 10mb at the bottom of Vallis Marinaris, the probability of liquid water would nearly triple and the span between freezing and boiling would nearly double (see cross-hatched region of Figure 12).

Martian Weather Observation

This martian weather observation is brought to you courtesy of the **MGS Radio Science Team**. The time of the atmospheric measurement and the local time of the measurement on Mars are specified on a 24 hour clock. The elevation is with respect to a standard martian reference surface (geoid). The typical atmospheric pressure on the surface of the Earth is approximately 1000 millibars (1 bar).

Date of Measurement	04-02-1998
Time of Measurement	09:51 GMT
Local Time on Mars	18:38
Latitude	33.5 degrees S
Longitude	63.2 degrees E
Elevation	-7137 meters
Surface Temperature	2.0 Fahrenheit
	-16.7 Celsius
Surface Pressure	9.94 millibars
Martian Season	Middle Summer

Table 2. MGS Observation Data Source: MGS Website

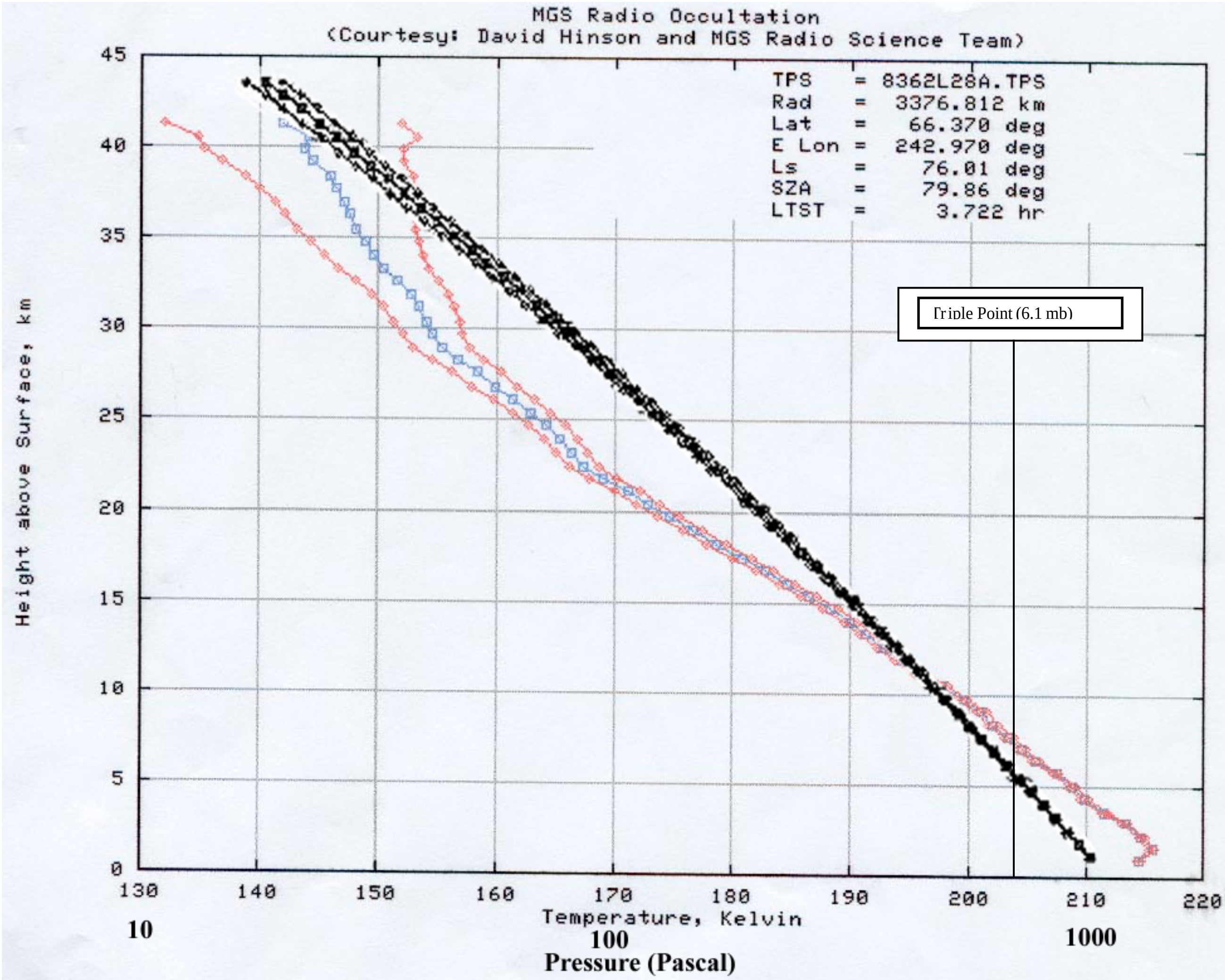


Figure 12. Altitude vs. Temperature/Pressure (MGS) Source: MGS Website

5.0 Summary and Future Work

By examining Viking, Pathfinder, and MGS data, theoretical considerations, and a simulation experiment, we have set down the conditions under which liquid water can exist on the surface of Mars today and found clear indications that it does. Since liquid water is a deciding factor on where to send human missions, it would also influence landing site selection. Two approaches to finding such sites have been discussed: the theoretical approach of Haberle at NASA Ames and the use of MGS data to extrapolate desirable sub-datum level landing sites.

The experimental protocol described was only used for pure liquid water. Future work involves testing water in soil under Martian conditions, a study currently underway by Quinn et al at NASA Ames, and a study incorporating microbial life in simulated Mars soil samples, which we hope to perform shortly. If these tests yield positive results, they could form the basis of a Pathfinder-like proposal to search for liquid water and surface microbes on Mars itself.

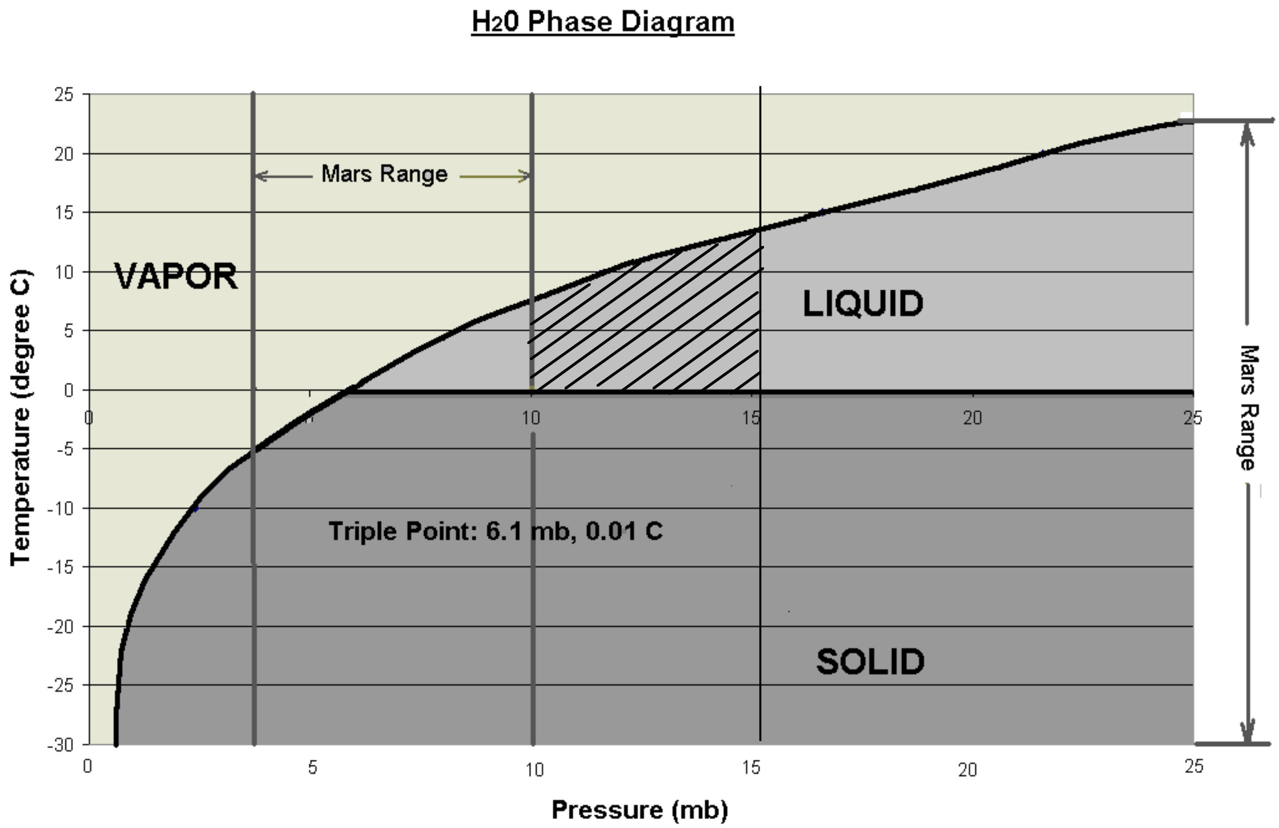


_Figure 10. Triple Point diagram showing range for liquid water at 15mb

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