LAST PLACE TO BOIL AWAY, FIRST PLACE TO LOOK: THE HUNT FOR WATER AND LIFE ON MARS
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ABSTRACT
The primary goals of the robotic exploration of Mars are to characterize the geology and climate of the planet; determine whether or not life ever arose and establish the planet’s suitability for human exploration. Inseparable in this quest is the hunt for water and ancient seas. To date, the landing sites associated with the quest have been driven in equal measures by geology and conservatism (i.e., a safe place in which to land). This study uses principles of physics and thermodynamics to target alternative landing sites that might maximize the probability of finding water, past and present and extant life as well. The phase diagram of water together with predictions of temperature and pressure at specific locations is used with elevation data from MOLA (Mars Orbiter Laser Altimeter) to predict locations where water in liquid form last existed on the surface and may, with accompanying extremophiles, exist today. Calculations at Candor Chasma and Hellas are presented as examples of how the principles of physics may be applied to choose landing sites of the future that would optimize the goals of robotic exploration.

KEYWORDS
Mars, liquid water, landing sites, water phase diagram, atmospheric pressure, Candor Chasma, Hellas, Mars probes

ABBREVIATIONS

INTRODUCTION
Follow the water: long the mantra of NASA’s robotic program to explore Mars. Follow the water to discover life, extinct or extant, and the other things. To date, geology, and the safety net of relatively flat landing sites have played the major role in looking for water, ancient or otherwise. But thermodynamics has a role to play, too. Hence the title, Last Place to Boil Away, First Place to Look. Consider the following: If you were a liquid water droplet millions or billions of years ago, and realized the atmosphere above you was disappearing, and oceans were boiling away, where would you rather be, in a high place or low place, in a warm place or cold place? Physics dictates low and warm, since that’s what it takes to stay liquid. The lower the altitude, the higher the pressure, and only the combination of higher pressures and warmer temperatures will keep you and any life forms that you support from freezing, boiling or sublimating away. Granted, such places are rare on Mars today but they were plentiful in the past. And they may exist today. Finding them is the subject of this presentation.

TARGETS OF OPPORTUNITY, PAST AND PRESENT
Logically, if you were an alien from Earth landing on Mars, such as Viking, Pathfinder, Spirit or Opportunity, and your task was to “follow the water,” you would likely take the low, warm road to find it because that’s where liquid water and any life forms within would have survived the longest. This road has not been taken for two reasons. First, low warm places are not as easy land in; and second, we have assumed there is no liquid water left on the surface today anyway and decided to look for signs of past water only. Past or present, physics can help. It leads us, in fact, to an entirely different set of landing sites from the ones we have visited thus far. To understand why, we must start with the water phase diagram.

THE PHASE DIAGRAM OF WATER AND CONDITIONS ON MARS
1. There is no liquid water on the surface of Mars today; the pressure is so low that ice sublimates to water vapor without ever passing through a liquid phase. This statement, popularized by Norman Horowitz, the Cal Tech Nobel laureate, reflected the thinking in the years immediately prior and subsequent to the Viking missions. The recent article in Nature, Evidence from HRSC Mars Express for a Frozen Sea (Murray, et. al., 2005), is a case in point. The authors surmised a frozen sea at southern Elysium (+5° south, 150° east) close to the Martian equator. While adding to the growing body of knowledge about recent geologic activities that lend credence to active hydrothermal processes (with tantalizing hints of microbial life), it repeats an oft-stated misconception that detracts from its central theme. Specifically, the statement, “Ice is unstable at the surface of Mars due to sublimation in the 6-mbar atmosphere,” is misleading. While a frozen sea certainly could exist at temperatures below freezing, ice is definitely not unstable. A close look at the water phase diagram of Figure 1 reveals why. The triangular region marked off shows the window of opportunity in which water can exist as a liquid under Martian datum level (mean surface altitude) conditions today. At a 10mbar surface pressure, the liquid state exists between 0 and 7°C. This window will be narrower at lower pressures and wider at higher pressures but as long as the pressure remains between 6.1 and 10 mbar, it exists.
Figure 1. A selected portion of the water phase diagram (Weast, 1973-74). The phase diagram illustrates when pure water exists as a solid, liquid, or vapor as a function of pressure and temperature. Triangle at the left end of the liquid region indicates conditions for liquid water at Mars datum level.

nonetheless. Surface pressure data from the Viking and Pathfinder landers have always been in this window, with a 6.7 to 10 mbar pressure range. The above authors’ claim of instability and sublimation is feasible only under two conditions:

1. At higher elevations (hundreds or thousands of kilometers above datum level) where the total pressure will always be below the triple point of 6.1 mbar or

2. If the partial pressure of water vapor cannot build to the total pressure within the boundary layer above the ice source.

Neither of these conditions likely exists at Elyssium, the site of the above authors’ proposed frozen lake. Firstly, Elyssium is located approximately 2 km below datum level, where total pressure should always be above the triple point and secondly, unless strong winds exist to disrupt the boundary layer, the partial water vapor pressure should always build to levels approaching total pressure. In other words, the surface of this frozen lake should pass through a liquid phase as temperatures climb above freezing. If this happens, the fundamental question then becomes the fate of this liquid phase. Will it boil, evaporate, or pool after it melts, and for how long?

This question is crucial because it speaks to nothing less than the stability of liquid water and its link to life. If liquid water can still form and pool on Mars then the presence of such standing water increases the possibility of extant life. If it is the evaporation (boiling) rate, not the sublimation rate that determines the fate of the standing water, one must ask the next question: Assuming frost, snow or ice is available at or near the surface (an entirely different question not addressed here), then under what conditions will it form into a liquid and remain that way for more than a few seconds?

**EVAPORATION RATE AND THE LIKELIHOOD OF STANDING WATER ON MARS TODAY**

Studies by Kuznetz and Gan (2000, 2002); Quinn and McKay (2000); Hecht (2002) and most recently by Moore and Sears (2005) exposed ice to simulated Mars datum level conditions and demonstrated conclusively that it will pass through a liquid phase as long as the temperature rises above freezing and remains below the boiling point. Typical results are shown in Figure 2, which shows water drops falling from an ice cube above 0°C in a Mars vacuum jar (desiccator). Kuznetz and Gan (2002) also photographed the melting sequence of frost on a simulated Martian rock as it first forms a ring, then coalesces to stable water droplets after it melts. In these studies, water was not only observed to form after the ice or frost melted, but once formed, lingered for substantial time periods due to slow evaporation rates. How slow is the evaporation rate? Kuznetz and Gan (2002) found evaporation rates averaging 0.023 g/cm²-h in a Mars simulation vacuum jar controlled to temperatures between -2 to +20°C, and pressures of 6.3-14 mbar with and without advection. Quinn and McKay (2000), Ingersol (1970) and Hecht (2002) found similar scales of evaporation, and Moore and Sears (2005) reported rates around 1 mm/hr. These rates are slow enough to permit standing water to remain liquid as long as it does on Earth, assuming ice is present and a heat source above the freezing point is there to melt it. Climate modeling studies by Haberle (2000) supported these lab findings, predicting in excess of 135 days per year (668 Earth days) during
which conditions along Mars’ equatorial region could support liquid water (innermost contour areas of Figure 3, surrounded by lines labeled “135”). These are not “unstable,” conditions as the Nature authors maintain, but “metastable,” as Hecht (2002) pointed out. (A glass of water on a table top on Earth is similarly metastable).

Examining the liquid-phase area in the phase diagram of Figure 1 provides further insight. If standing water drops can linger between 0 and 7°C at 10 mbar, they should linger longer at the higher pressures that occur at lower elevations on Mars. The window of opportunity at 15 mbar, for example, is 7 times greater than at 6.3 mbar (0 to 14.9°C, vs 0 to 2°C on the phase diagram before boiling occurs) and 12 times greater at 25 mbar. By inference, the odds of standing water in the northern lowlands should be substantially greater than in the southern highlands, an intuitively obvious finding since water flows toward the lowest level. This is predicated by the temperature cooperating, i.e., staying between the freezing and boiling points for extended periods of time at the lower elevations.

THE INFLUENCE OF ELEVATION

Returning to our central thesis, if the window of opportunity for liquid water increases at higher pressures, where then are the locations associated with these pressures? These would be the places where water would have boiled away last, leaving its most recent signature, as well as fossil traces if they exist. These would also be the places where standing water and extant life, if it exists at all, may reside. Insight to such locations is provided by a combination of data from Viking Lander 1; MGS’ MOLA-Mars Global Surveyor’s Mars Orbital Laser Altimeter, which shows the depth of Candor Chasma in Figure 4; and by the MGS’ Radio Science instrument, which shows the depth-pressure profile over Hellas in Figure 5.

Three approaches can be used to employ these data sets in the search for optimum locations. In the first, Viking Lander 1 (VL1) pressure and elevation data at Chryse Planitia are referenced against elevations at other locations derived from the Mars Orbital Laser Altimeter (MOLA). The difference can be used to extrapolate the pressure at these other elevations. In the second approach, pressures measured by the MGS radio occultation instrument at these same surface locations can be compared to the pressures deduced by Approach 1. In the third, the logarithmic relationship between altitude and pressure, as shown in Figure 5, can be extrapolated to lower depths below datum level and compared to the other approaches. Examples of how this might be done for Candor Chasma and Hellas follow.

Figure 3. Predicted durations (given in Mars sols per year on each contour line) suitable for liquid water brine on Mars. From the Mars Global Climate model (Haberle, 2002).

Figure 4. The topography of Mars from MOLA, with a closeup of Candor Chasm, showing elevation on a graded scale. (http://ltpwww.gsfc.nasa.gov/tharsis/Mars_topography_from_MOLA_-80_-70_-10_0.html)

In Approach 1, the elevation of Viking Lander 1 (VL1) is known from MOLA to be -3683 meters, while the peak pressure recorded by VL1 was 9.0 mbar (near Ls=270,
northern winter solstice). Extrapolations of pressure at lower elevations were made assuming an atmospheric scale height of 13 km (corresponding to a temperature of 250° K). The pressure calculated this way at Candor Chasma, located at ~5000 meters (about 1.3 km below VL1), is roughly 10 mbar (−9 × exp(1.3/13) ≈ 9 × 1.11). The pressure at the low point in Hellas, on the other hand, between ~7500 and ~8000 meters, could be as high as 14 mbar (using a low point for Hellas of 4.5 km below VL1 yields −9 × exp(4.5/13) ≈ 9 × 1.414, or 12.7 mbar.

**Table 1. Martian Weather Observations at Hellas**

| Date of Measurement: | 04-01-2004 |
| Time of Measurement: | 09:23 GMT |
| Local Time on Mars: | 03:41 |
| Latitude: | 39.9 degrees S |
| Longitude: | 66.9 degrees E |
| Elevation: | -6860 meters |
| Surface Temperature: | -77.4 Celsius (-107.3 Fahrenheit) |
| Surface Pressure: | 11.40 millibars |
| Martian Season: | Early Fall |

**DISCUSSION AND SUMMARY**

Mars is a fascinating planet in many respects, one of them thermodynamically. A glass of water there could sublimate, freeze, boil or remain liquid for hours, perhaps days on end. Depending on location, all four processes could occur at the same place over the course of a single day. MGS Radio Science Weather Reports have observed a preponderance of such locations from orbit, typically at higher elevations above datum level. The Landers, on the other hand, (VL1, VL2 and Pathfinder) have only seen pressures above the triple point, probably owing to the lower elevations at their landing sites.

This study has focused on using the water phase diagram and data from surface probes and orbiters to identify landing sites that could maximize the probability of liquid water, past and present. Sites such as Candor Chasma and Hellas have been shown to be locations where pressures of 10-14 mbar could be routinely expected. The heat trap effect at depressions such as these will also drive up the temperature. The Inner Gorge of the Grand Canyon, for example (elevation 670 meters), is substantially warmer than the 2300-m high South Rim. In mid-April the daytime temperature in the Inner Gorge exceeds 85°F and cools only slightly at night, while night-time temperature on the South Rim fall below the freezing point of water. By inference, this suggests daily temperature excursions at Candor and Hellas, taken together with higher pressures should translate to increased residency time in the liquid water envelope between freezing and boiling. The appeal of Hellas and Candor increases with hypotheses such as Hynek’s (2004), that vast ancient seas may have covered Hellas in the distant past, and Malin and Edgett’s (2000a,b) statement that MGS MOC observations strongly indicate that the deepest parts of Vallis Marineris were not brecciated but layered. If true, the bottom of these locales would have been the last refuge for large amounts of water on Mars; any life that...
may have existed at the time, and their fossilized remains
that may exist today. All of this begs the question asked
by physics: Might not these and other places like them be
the most ideal landing sites to look for liquid water and
life on Mars today? If so, identifying and targeting these
areas should be a priority. After landing, such a rover might
“predict-correct” over a wide area like a “water witch”,
fine tuning the location of surface or subsurface water
with a suite of instruments such as an alpha X-ray proton
spectrometer, temperature, pressure and water vapor
sensors.

The human exploration program would also benefit from
a high probability water site. Other than the obvious need
for a reliable, low cost water source, the design of a blue
collar space suit may well hinge on higher pressure,
warmer temperature locales. Current suits function by
sublimation, a process that will not work at datum level or
below. They are also far too heavy. A key to cutting mass
and complexity is to design a suit to its climate of intent,
as protective clothing does on Earth. Studies indicate that
a suit designed for Candor or Hellas might be more like
an Arctic coverall than the thermos bottle-like designs
that exist today (Kuznetz, 1989). Pressures above the
triple point and warmer temperatures may not only be the
key to finding environments that support liquid water and
life, but maximize human exploration potential as well.

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REFERENCES

present day Mars. Proceedings of the First NASA Ames
Astrobiology Conference, NASA Ames Res Center,
Moffett Field, CA.

Icarus 156: 373-376.

San Francisco.

Hynek, B. 2004. Opportunities Great Lakes. University of
Colorado report, Astrobiology Magazine.

Science 168: 972-973.

Kuznetz, L. 1991. Space suits and life support systems for
the exploration of Mars. National Science Foundation
Fellowship, NASA Ames Research Center, Moffett Field,
CA.

Kuznetz, L.H. and Gan D. 1999. The hunt for liquid water
on Mars today. Third Mars Society Conference, Mars
Society, Boulder, Colorado.

Kuznetz, L. H. and Gan, D. 2002. On the existence and
stability of liquid water on the surface of Mars today.

Malin, M. and Edgett, K., 2000a. Evidence for recent
groundwater seepage and surface runoff on Mars. Science
288: 2330.

Malin, M. and Edgett, K., 2000b. Sedimentary rocks on
early Mars. Science 290: 5498. 1927

McKay, C. and Stoker, C. 1989. The early environment
and its evolution on Mars: Implications of Mars. Reviews

liquid water on Mars. Journal of Geophysical Research
Planets, in review.

Murray, J., Muller, J., Neukum, G. Werner, S., Gassett, S.
2005. Evidence from HRSC Mars Express for a frozen

Experiment, Space Science Division, NASA Ames
Research Center, Moffett Field, CA.

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