THE HABITABILITY OF THE PHOENIX LANDING SITE: A COMPARATIVE ASSESSMENT C.R. Stoker[1], P.D. Archer, Jr.[2], D. Catling[3], B. Clark[4], J. Marshall[5], P. Smith[2], S. Young[6], and the Phoenix Science Team [1]NASA Ames Research Center, Moffett Field, CA 94035, Carol.Stoker@nasa.gov, [2] Lunar and Planetary Laboratory, University of Arizona, Tucson;[3]University of Washington, Seattle,WA 98195; [4] Space science Inst. Boulder CO 80301, 5SETI Institute, Mountain View CA 94043, [6]Tufts University, Department of Chemistry, Medford, MA 02155

Introduction: The Phoenix landing site was chosen to sample near surface ground ice in the Northern Plains discovered by the GRS experiment on Mars Odyssey [1]. One goal of that sampling was to determine whether this environment may have been habitable for life at some time in its history. The unifying theme of the Mars Exploration program, as laid out in the MEPAG roadmap, is the search for life on Mars [2]. Given our current understanding of life, the potential for habitability in a specific time and space encompasses three factors: (1) the presence of liquid water (P_{lw}), (2) the presence of a biologically available energy source (P_e), and (3) the presence of the chemical building blocks of life (e.g. C, H, N, O, P, S) in a biologically available form (P_{ch}). In addition to these factors, temperature and water activity must be high enough to support growth. Since these three factors must be simultaneously present, MEPAG further defined a Habitability Index, HI= 100 * $P_{lw}\, P_e\, P_{ch}$, which is the product of the probability represented by each of the three factors, and posited that a life detection mission could not be justified unless a previous mission had determined HI to have a combined probability greater than 50. Thus a quantitative evaluation of habitability is a precursor requirement for sending a mission to search for life.

Another useful guide to determine where and when life detection missions are justified is the probability that signatures of life are preserved in the environment and can be observed. We call this the Detectability Index (DI). Factors affecting DI include how long before present that habitable conditions occurred, and whether the environment is conducive to organic preservation of a record of life. This paper evaluates HI and DI at the Phoenix landing site and shows how it compares with other sites visited on Mars.

Approach: Each of the above probabilities can further be decomposed into sub-elements or observables that combine for its evaluation. Each probability is computed using the formula $P_n=\Sigma F_{ni}W_i/\Sigma W_i$ (Eq. 1), which is the normalized sum of relevant factors, weighted relative to each other by the importance of each factor, and (in some cases) the certainty associated with the observation. In equation 1, Fni are the factors identified, and Wi are their weights. In all cases, the factors are assigned a value from 0 to 1. Weights estimate the relative importance of each factor, or the uncertainty in the analysis of the factor, and are also in the range 0 to 1.

P_{lw} is comprised of two main factors: F_o, observations (chemical or morphological) that suggest liquid water; and F_{th}, theoretical models that show ice melting is possible. Observations that suggest liquid water may have occurred include 1) heterogeneous subsurface ice morphology including the presence of possible segregated ice located in a polygon trough area as compared to ice cemented soil located in the polygon center; 2) carbonate minerals were observed by both the Thermal Evolved Gas Analysis (TEGA) and Wet Chemistry Laboratory (WCL) instruments; and 3) microscopic evidence for chemical etching of soil particles is observed. However, none of these observations constitute unambiguous evidence of liquid water in the local area, so this factor is assigned a medium value.

Theoretical considerations for the presence of liquid water involve both a mechanism to emplace water at the landing site and climatic conditions that support stable or even transient liquid water. Snow was observed on Mars by the LIDAR instrument and SSI camera [3] and near surface ground ice is also an available water source. The Mars North Polar region (and the landing site) experiences periodic climate change associated with the variation in orbital parameters causing conditions that are far warmer than at present, and sufficient to cause surface melting of pure liquid water [4]. This factor is assigned a high value.

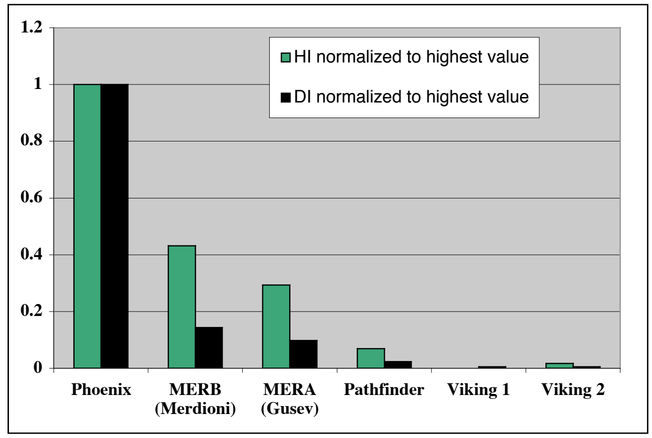
The evaluation of P_e considers the presence of energy available to biological systems. At the surface, solar energy is available and is a dominant energy source. However, the presence of strong ultraviolet radiation may result in sterlization if metabolism is not active enough to overcome high rates of organic destruction. In the subsurface, below the photic zone, metabolism is only possible if chemistry supports oxidation reduction reactions (redox pairs) for chemoautotrophy. Perchlorate salt was identified in the soil by the WCL, probably in the form of $MgClO_4$[5]. The reduction potential of perchlorate and chlorate (1.287V; 1.03V) makes these compounds ideal electron acceptors for microbial metabolism and they are utilized as an energy source by numerous species of microbes [6]. Perchlorate reducing bacteria grow by the oxidation of organic carbon or inorganic electron donors (H_2, H_2S, or Fe_2+) coupled to the reduction of perchlorate. They have can grow under a wide range of environmental conditions including in Antarctic soils, and have a broad range of metabolic capabilities including (of relevance to Mars) the oxidation of soluble and insoluble ferrous iron. Since both Sunlight and chemical energy are available in the same zone where liquid water can occur, P_e is assigned a high value.

P_{ch} is the probability of presence of chemical conditions conducive to life. Factors evaluated in P_{ch} include the presence of organic carbon, presence of soluble ions of biogenic elements, presence of other elements known to support metabolism, and the presence of nontoxic chemical conditions. CHNOPS sources. The presence of carbonate(s) and the alkaline pH means that in addition to the atmospheric reservoirs of C (as CO_2 and CO), there is an abundant source of readily available C in the soil. H is available from H_2O. There is no information on fixed nitrogen on Mars. Although some terrestrial organisms are capable of converting atmospheric N_2 to nitrate, it is energy-intensive and biochemically complex so nitrates in the soil would be a very important nutrient source. WCL ISE for nitrate detection was masked by its response to perchlorate ions. However, in Atacama Chile, where perchlorate forms in the driest terrestrial deserts, nitrate also occurs in uncommonly high abundances. The aggressive oxidants in the martian atmosphere may produce nitric acid which then can be scavenged by the soil to produce nitrates. Hence, the occurrence of perchlorates is consistent with nitrates in the soil. In addition to sources in the atmosphere (O_2, O_3, H_2O_2) and various photochemical oxidizing non-molecular forms (OH radical, O*, O-, etc.), the perchlorate salts provide a storehouse of relatively readily available oxidizing power. No measurements of P content are available for Phoenix samples but phosphorus-containing minerals are abundant in all MER samples, including strong enrichments in Ca phosphates in some suites of materials in the Columbia Hills. Martian meteorites contain phosphates extractable using mildly acidic solutions (pH 5 or lower). It is inferred that P is as abundant in martian soils as in terrestrial soils, although the alkaline pH implies from limited solubility of most plausible minerals that P will be present at trace but sufficient quantities for metabolism. No sulfates were detected in Phoenix samples, but sulfate has been identified in many locations on Mars. Because of global dust storms, it is anticipated that some fraction of globalized dustcontaining S is present in the topmost polar soils at least. All sulfates of major cations except $CaSO_4$ are highly soluble, and should provide trace quantities which are as bioavailable as most terrestrial non-oceanic environments.

Finally, the measured pH of 8.3 is only slightly alkaline, comparable to most semiarid soils, and ideal for a broad range of organisms. The WCL has also measured ions of Potassium, Calcium, and Magnesium, recognized nutrients for microbial growth, that are in the normal range for terrestrial soils. Based on these considerations, P_{ch} is assigned a high value.

Results: An evaluation of Equation 1 shows that the HI for the Phoenix site is higher than for any other landing site previously visited. Figure 1 shows how

Figure 1. Habiltability and Detectability index, normalized to 1.



the landing sites compare, with all sites normalized to the highest HI. Since many of the factors in the calculation are uncertain, the absolute value of the HI is similarly uncertain, but the general conclusion is that the Phoenix landing site is the most habitable.

The conclusion is even stronger that the Phoenix site has the highest value of DI. The presence of organics at the Phoenix landing site is still an open issue [7], but organics were not found at the Viking site, and were not looked for at the other sites. So, organic preservation at all sites is not a distinguishing characteristic. Therefor, the comparitive value of DI scales based on whether conditions allowing liquid water occurred in modern or ancient times. We assign a value to this factor of 1/t where t=1 for modern, t=2 for Amazonian, and t=3 for Hesperian or Noachian. Thus, DI is correspondingly lower for the other landing sites where habitable conditions occurred during ancient times.

In summary, Phoenix landed at a location on Mars with a higher potential for detecting life than any site previously visited and sampled icy material that periodically may be capable of sustaining modern biological activity. The payload selected provided key information about the potential habitability of this environment and the data suggest habitable conditions have occurred in modern times.

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