FROM GLOBAL RECONNAISSANCE TO SAMPLE RETURN: A PROPOSAL FOR A POST-2009 STRATEGY TO FOLLOW THE WATER ON MARS.

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Introduction. Since the mid-1990's, the stated strategy of the Mars Exploration Program has been to "Follow the Water". Although this strategy has been widely publicized, its degree of influence -- and the logic behind its current implementation (as reflected in mission planning, platform and instrument selection, and allocation of spacecraft resources) – remains unclear.

In response to this concern, we propose an integrated strategy for the post-2009 exploration of Mars that identifies the scientific objectives, rationale, sequence of missions, and specific investigations, that we believe provides the maximum possible science return by pursuing the most direct, cost-effective, and technically capable approach to "following the water". This strategy is based on the orbital identification, high-resolution surface investigation, and ultimate sampling of the highest priority targets: near-surface liquid water and massive ground ice (potentially associated with the discharge of the outlfow channels or the relic of a former ocean). The analysis of such samples, in conjunction with the data acquired by the necessary precursor investigations (to identify the locations and characterize the environments of the optimum sampling sites), is expected to address a majority of the goals and high priority science objectives identified by MEPAG.

Goals and Rationale. Since the inception of the Mars Surveyor Program of the mid-1990's, the search for water has been identified as the common thread of Mars research -- its abundance and distribution having important implications for understanding the geologic and climatic evolution of the planet; the potential origin and continued survival of life; and the accessibility of a critical in-situ resource for sustaining future human explorers. For these reasons, it was argued, a strategy to "follow the water" would necessarily benefit all of Mars research.

The unique role and importance of water was more recently affirmed by the identification and prioritization of scientific goals, objectives and measurements undertaken by the Mars Exploration Payload Analysis Group (MEPAG) [1], where the determination of the 3-dimensional distribution and state of H_2O was identified as the single highest-rated objective of the Mars Exploration Program (Table 1).

Of the planet's estimated 500 – 1000 m global inventory of H_2O [2], ~0.000001% is found in the atmosphere, while ~5-10% is thought to be stored as ice in the perennial polar caps and layered terrain. This leaves ~90-95% of the planetary inventory of H_2O that is unaccounted for, the vast bulk of which is believed to reside, as ground ice and groundwater, within the planet's crust.

Although the belief that Mars is water-rich is supported by a wide variety geologic evidence, our ignorance about the heterogeneous nature and thermal evolution of the planet's crust effectively precludes geomorphic or theoretical attempts to quantitatively assess the current geographic and subsurface vertical distribution of ground ice and groundwater [3]. For this reason, any exploration activity (such as drilling) whose success is contingent on the presence of subsurface water, must be preceded by a comprehensive high-resolution geophysical survey capable of assessing whether local reservoirs of water and ice actually exist. Terrestrial experience has demonstrated that the accurate identification of such targets is likely to require the application of multiple geophysical techniques [4] – investigations that are most effectively conducted on (or in close proximity to) the planet's surface.

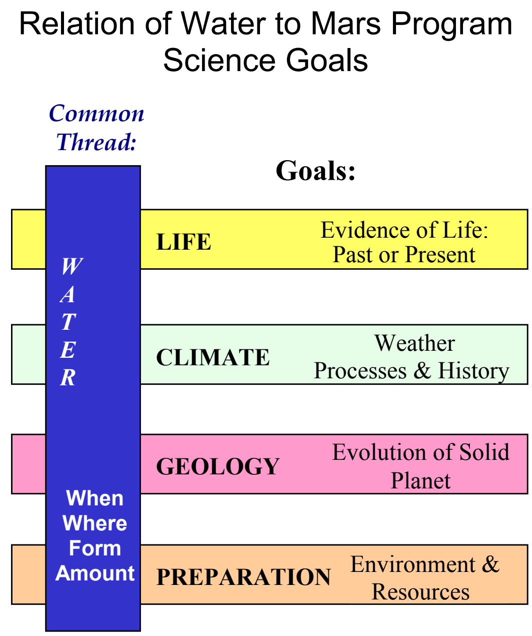

Figure 1. Rationale for the "Follow the Water" strategy.

Unfortunately, the relative fraction of the Martian surface that can be investigated by a single lander, rover, or even aerial platform, is extremely small, requiring a prohibitively large number of spacecraft to conduct a global reconnaissance on any time frame shorter than several human lifetimes. Therefore, given the significant uncertainties that exist in our knowledge of the distribution of subsurface H_2O, how do we most effectively employ the limited number of opportunities that we will have to address this issue following the last of the currently planned missions in 2009?

Because conducting a high-resolution 3-dimensional global survey of the distribution of subsurface water on Mars exceeds our present (and foreseeable) technical capabilities and resources, we propose that initial efforts be focused on a more efficient and achievable task – emphasizing the identification and location of the most important and accessible H_2O targets. Of the potential volatile targets identified by the Mars' planetary science, astrobiology, and human exploration communities, those of greatest interest are: liquid water, massive deposits of near-surface ground ice (associated with the ponded discharge of the outlfow channels or the relic of a former ocean), and the polar layered deposits [1].

Table 1 – *MEPAG priority and traceability of "Follow the Water" strategy.*

Goal	Investigation	Priority	Measurements
Life	Map the 3-D distribution of water in all its forms.	1	I.A.1.a.
Climate	Determine the processes controlling the present distribution of H2O, CO2 and dust.	1	II.A.1.d&c.
	Characterize the history of climate change recorded in the stratigraphy of the polar layered deposits and residual ice caps.	2	II.B.2
Geology	Determine the present state, distribution and cycling of water on Mars.	1	III.A.1.a,b,c&d.
Preparation	Understand the distribution of accessible water in soils, regolith, and Martian groundwater system.	3	IV.A.3.a&b.

With regard to the first two of these targets, an additional requirement is imposed by our desire to obtain samples for in-situ and Earth-based analysis. Thus, the geographic location and subsurface extent of a target must be known with sufficient resolution to guide the placement of a drill.

In this abstract we propose an integrated strategy and sequence of missions for the geophysical exploration of Mars that we believe represents the fastest, most cost-effect, and technically capable approach to identifying, investigating, and ultimately sampling the most probable occurrences of near-surface liquid water and massive ground ice. This strategy is based on a synthesis of input from a wide range of sources; however, it owes its greatest debt to the authors and participants of the Mars Program Office white paper "A Strategic Framework for the Exploration of the Martian Subsurface" by Beaty et al. [5], in which the basic elements of this strategy were first proposed.

Global vs. Local Investigations. One of the most critical issues for developing a coherent geophysical strategy to assess the distribution of subsurface water is the appropriate role and timing of global vs. local investigations. The principal attributes of local investigations (such as lander-based GPR) are their relative simplicity and their ability to "map" local variations in dielectric properties (that are potentially indicative of variations in lithology and volatile content) at high resolution. However, given the natural scale and variability of crustal properties, the structure, lithology, and distribution of H_2O, is likely to differ significantly from one location to another [3]. Therefore, to have any confidence in accessing a particular volatile target, drilling operations must necessarily be limited to those sites where local geophysical investigations have already been performed.

A strategy to search for water by proceeding directly to the use of high-resolution local surveys has a significant drawback – for while such surveys may help determine the local distribution of volatiles to high precision, they provide no global context. Thus, while a high-resolution investigation might suggest the presence of a specific volatile target at a depth of 500 m at one location, it could well miss the opportunity – located only 20 km away – where that same volatile target was present at a depth of 100 m. Differences of this magnitude could well be critical to the success or failure of any follow-on drilling effort.

The above argument suggests that local investigations aree most effectively employed following the completion of an initial global geophysical reconnaissance. Although such surveys may be unable to resolve the fine-scale distribution of ground ice and groundwater, they can aid in the identification of moderate- and regional-scale characteristics that can be used to identify the most promising local sites for further study. In this way, global investigations can be used to target local surveys (conducted by local surface networks, rovers, and other techniques) that can verify and map the distribution of potential volatile targets at a resolution sufficient to direct the placement and operation of both shallow- and deep-subsurface drills.

Proposed Strategy. Based on the above reasoning, we propose a two-phase approach to the search for subsurface water on Mars. The first consists of missions devoted to characterizing the large-scale global distribution of liquid water and massive ground ice within the crust. Currently, the most promising candidates for such a reconnaissance are: (i) a polar-orbiting synthetic aperture radar/sounder, and (ii) a 20+-station global geophysical and meteorological network A second "high-resolution" phase would then follow this initial global reconnaissance with more focused investigations of the most promising local (<10 km^2 in area) sites identified from the global data.

Polar-Orbiting Synthetic Aperture Radar/Sounder. An orbital radar sounder has a distinct advantage over other water-detecting geophysical methods in that, given an optimal design, such a sounder has the potential to provide global coverage at moderate resolution using a single spacecraft – a potential that no other technique comes close to approaching.

The first attempt at such an investigation will be made by the 2003 Mars Express mission, which will include a multi-frequency radar sounder called MARSIS. Given ideal conditions, MARSIS is designed to detect the presence of liquid water at depths as great as several km. In 2005, MARSIS will be followed by another orbital sounder called SHARAD, that will fly aboard the Mars Reconnaissance Orbiter. SHARAD will operate at higher frequencies in an effort to improve its resolution of potential water-related targets at shallower depth. Unfortunately, because both Mars Express and the Mars Reconnaissance Orbiter include a number of other high-level investigations, MARSIS and SHARAD have been forced to accept some compromises in mission and spacecraft design that have limited their potential capabilities.

A dedicated orbital SAR/Sounder mission would offer opportunities for a number of significant technical and operational improvements – not the least of which would be absence of resource and compatibility issues associated with the need accommodate other instruments. Among the most significant potential enhancements would be (1) the adoption of a low altitude, slowly migrating polar orbit – thus insuring global coverage with overlapping footprints that will permit data from adjacent orbits to be processed coherently to improve cross-track resolution and enhance clutter rejection., (2) increased power to improve signal-to-noise -- ideally ~10 kW (supplied by an RTG) vs. the 60 W available to MARSIS, and (3) optimized antenna design (i.e., increased size and better geometry) for both the SAR and Sounder.

Other desired enhancements include improvements in the number and range of operational frequencies, bandwidth, receiver sensitivity, utilization of alternate signal waveform designs and the use of two (or more) receivers – either boom-mounted on the same orbiter or achieved by simultaneous operation with compatible radars on other polar-orbiting spacecraft. This potential for orbital interferometry could greatly aid the 3-dimensional characterization of the crust – helping to discriminate between structural, lithologic and volatile signatures in both the near- and deep-subsurface.

A polar orbiting radar Sounder offers a unique ability to carry out such tasks by investigating and mapping the observed and derived electromagnetic properties of the subsurface on a global basis -- information that may provide significant insights about the vertical structure and evolution of the crust. This is particularly true over the polar layered deposits, whose combination of favorable location (due to the high density of orbital ground tracks) and expected low-loss attenuation characteristics may permit a Sounder to obtain a detailed look at the deposits' stratigraphy and basal topography – providing invaluable information relevant to understanding their climatic and deformational history.

Although the unambiguous identification of crustal H_2O may be difficult or impossible using orbital sounding alone, the geometry and contrast associated with those targets of greatest scientific interest (i.e., near-surface liquid water and massive lenses of ground ice) are expected to be sufficient that, under favorable observing conditions (and with the additional interpretive context provided by the analysis of other remote sensing data), the best examples can be identified and mapped with reasonable confidence. At a minimum, an orbital Sounder will provide information on local subsurface properties that can be used to identify the most promising sites for further study (e.g., by subsequent higher-resolution surface and airborne investigations), as well as assist in ruling out those areas whose local characteristics are either inconsistent with the presence of subsurface water or preclude its detection.

Additional scientific and mission synergy would result from the inclusion of the SAR a synthetic aperture radar on the same polar orbiting spacecraft. The addition of the SAR radar would allow investigations of the shallow subsurface, mapping the potential occurrence of buried channels, craters , and other features that could provide important insights into the nature and evolution of the Martian landscape.

Global Geophysical and Meteorological Network. The most logical follow-up to the flight of an advanced orbital SAR/Sounder is a global Geophysical and Meteorological Network consisting of at least 20-stations. Although this number will not provide sufficient spatial coverage to verify in detail the global interpretations derived from the flight of an advanced orbital Sounder, they will provide an opportunity for surface-based seismic and electromagnetic observations that can be used to independently test the large-scale volatile distribution, stratigraphy, and structure of the crust.

When distributed in clusters of 3-5, such stations are also capable of providing the more localized studies needed to investigate and further refine our understanding of the true nature of the most promising volatile sites identified by the orbital SAR/Sounder. The ability of such a Network to discriminate between lithologic and volatile units would be greatly enhanced by the inclusion of multiple geophysical investigations onboard each station, such as magnetotelluric and permitivity instruments, active and passive seismometers, and ground penetrating radar (GPR). Such a mission might also include the acquisition of local compositional and thermophysical data that could assist in interpreting the geophysical sounding results and help characterize the global range of material properties that might be encountered by subsequent drilling efforts.

A logical compliment to the geophysical investigations conducted by such a Network, would be the inclusion of meteorological instruments to provide global and regional measurements of atmospheric pressure, temperature, and wind speed – data that would prove invaluable to the further refinement of general circulation and climate models. A key requirement for both types investigations would be that the individual stations be long-lived (>4 years), providing a sufficient baseline to assess interannual variations in weather as well as the frequency of large-scale seismic events.

Such a Geophysical and Meteorological Network could be emplaced in a single mission (with penetrator-style stations dispersed from a polar-orbiting bus) or be built up incrementally, over two or more successive launch opportunities. In 2009, the four-station NetLander mission will provide an important demonstration of the potential return from network science – effectively doubling (in a single mission) the number of surface locations visited on the planet since the flight of Pathfinder in 1996.

High-Resolution Characterization and Sampling of Local Sites. An expected result of the first phase of global reconnaissance will be the identification and prioritization of the most probable sites for the occurrence of near-surface liquid water and massive ground ice as a prelude to sending more focused investigations. The most logical progression of follow-on missions would be: (1) a high-resolution ground-based survey to verify the nature and extent of the most promising site(s) for the occurrence of near-surface liquid water or massive ground ice, (2) a drill to investigate and sample this target, and (3) a vehicle to return these samples to Earth for further study.

Hi-Resolution Site Survey & Sample Acquisition Rover. While a number of potential platforms could be employed to carry out a high-resolution geophysical and environmental site survey, the one that provides the greatest mission flexibility is an MSL-class Rover. Equipped with high-frequency GPR, an active seismic investigation (including a large array of deployable geophones), and other geophysical instruments, the Rover's principal task would be to conduct the most technically capable investigations possible to verify the true nature of the local target, determine its spatial extent (at a sufficiently high resolution to guide the placement and successful acquisition of samples by a drill), and assess the geology and surface properties of the surrounding area to provide an understanding of the target's context and identify any potential landing hazard's to a follow-on drill and sample return vehicle.

A useful enhancement of this mission would be the ability for the Rover to collect surface samples (including, perhaps, shallow – 1-2 m – drill cores) from the surveyed area, perform preliminary in-situ analyses, and cache the samples in an onboard canister that could be transferred to a future sample return vehicle.

50-100 m-Capable Drill. Once the location and nature of a high-priority volatile target has been verified (to as high a probability as is possible by geophysical methods), the next obvious mission would be to send a Drill capable of reaching, investigating (w/downhole instruments), and acquiring samples for eventual return to Earth. Samples of liquid water or massive ground ice would provide the very highest probability of finding evidence of extant (or at least geologically recent) life, as well as insights into the aqueous geochemistry and isotopic evolution of the Martian crust and groundwater. When combined with selected samples of intervening regolith and rock cored by the drill, and the data obtained during the precursor Rover site survey, such a mission would provide an enormously detailed environmental and stratigraphic record for sample interpretation.

To minimize complexity and enhance stability, the preferred platform for a 50-100 m drill would be a stationary lander – guided to its optimum sampling location by terminal guidance and a beacon deployed by the precursor Rover.

Sample Return Vehicle. As with the targeting of the Drill, the landing of a Sample Return Vehicle would be aided by the radio beacon deployed by the precursor Rover. Cached drill cores, and surface samples obtained by the Rover during its site characterization survey, could then be transferred to the Sample Return Vehicle by the Rover for return to Earth. Another alternative, that would simplify surface operations, would be to incorporate the return vehicle on the drilling platform itself.

Summary. Knowledge of the distribution and state of subsurface water is of fundamental importance to astrobiology, human exploration, and to our understanding of how Mars has evolved as a planet. We believe that the "Follow the Water" strategy and mission sequence outlined here represents the most direct and cost effective approach for addressing the goals and high priority science objectives identified by MEPAG.

References: [1] MEPAG Science Goals Document, 2000; [2] Carr, M. H., Icarus, 68, 187-216, 1986; [3] Clifford, S.M., *Lunar Planet. Sci Conf. XXVIII*, 1998; [4] Stoker, C. *Mars Deep Water Sounding Workshop Summary*, http://astro-biology.arc.nasa.gov/worshops/1998/marswater/index.html, 1998; [5] Beaty, D. et al., *Analysis of the Potential of a Mars Orbital Ground-Penetrating Radar Instrument in 2005*, Mars Program Office White Paper, 2001.