A PROPOSAL FOR AN INTEGRATED GEOPHYSICAL STRATEGY TO "FOLLOW THE WATER" ON MARS, S. M. Clifford[1], J. A. George[2], C. R. Stoker[3], G. Briggs[3], and D. W. Beaty[4]. [1]Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston, TX 77058, clifford@lpi.usra.edu. [2]NASA Johnson Space Center, Houston, TX 77058, jeff.george@jsc.nasa.gov. [3]NASA Ames Research Center, Moffet Field, CA 94035, cstoker@mail.arc.nasa.gov, gbriggs@ mail.arc.nasa.gov. [4]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, David.Beaty@jpl.nasa.gov.

Introduction. The search for subsurface water has become a primary focus of Mars exploration. Its abundance and distribution (both as ground ice and groundwater) have important implications for understanding the geologic, hydrologic, 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, a principal goal of the Mars science, astrobiology, and the HEDS programs is to determine the 3-D distribution and state of subsurface H_2O, at a resolution sufficient to permit reaching any desired volatile target by drilling [1]. The three targets most often discussed are: groundwater, massive deposits of near-surface ground ice (associated with the ponded discharge of the outlfow channels or the relic of a former ocean), and ice-saturated frozen ground. Based on the present best estimates of mean annual surface temperature, crustal thermal conductivity, geothermal heat flow, and groundwater freezing temperature, the mean thickness of frozen ground on Mars is expected to vary from ~2.5-5 km at the equator to ~6.5-13 km at the poles [2]. However, natural variations in both crustal heat flow and thermal conductivity are likely to result in significant local departures from these predicted values. The recent discovery of "young" fluvial-like features, emanating from the slopes of local scarps, raises the possibility that liquid water may also exist episodically at shallow (~100 – 500 m) depth [3]; however, the true nature and absolute age of these features remains highly uncertain.

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 [4]. 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 [5].

In this abstract we propose an integrated strategy for the geophysical exploration of Mars that we believe represents the fastest, most cost-effect, and technically capable approach to identifying the state and distribution of subsurface water. Challenges and alternatives to this strategy will be invited and discussed during the week-long *Conference on Geophysical Detection of Subsurface Water on Mars* that will be held at LPI August 6-10, 2001.

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 [4]. 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 are 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 aerobots, dense local surface networks, 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 [1].

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 volatiles within the top ~5-10 km of the crust. Currently, the most promising candidates for such a survey are: (i) a polar-orbiting radar sounder/interferometer (consisting of two or more spacecraft with radars that operate at the same frequencies), and (ii) a 20+-station global geophysical network, employing both seismic and electromagnetic techniques. The second "high-resolution" phase would then follow this initial global reconnaissance with more focussed investigations of promising local sites ($<10^2$ km^2 in area) identified from the global data.

Polar-orbiting radar sounder/interferometer. 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 multifrequency radar sounder called MARSIS. Given ideal conditions, MARSIS is designed to detect the presence of liquid water at depths ranging from ~1 – 5 km. MARSIS represents a major milestone in the study of water on Mars, because it marks the transition from debates over poorly constrained geomorphic and theoretical analyses to discussions of actual data regarding the potential distribution of water and ice in the subsurface.

However, because Mars Express includes a number of other high-level investigations, MARSIS has been forced to accept some compromises in mission and spacecraft design that have limited its potential capabilities. Chief among these is the high eccentricity of the spacecraft's orbit, which significantly reduces both the time at which MARSIS is at its optimal sounding altitude and its ability to utilize data from previous orbits to reduce noise and improve resolution. For this reason, even a simple reflight of MARSIS in a more circular orbit would realize significant benefits – permitting data from adjacent orbits to be coherently processed to create an effective 2-dimensional aperture that would virtually eliminate cross-track clutter and increase cross-track resolution [6].

Additional improvements that could be made to future orbital radar investigations include enhancements in antenna size and geometry, transmitted power, number and range of operational frequencies, bandwidth, receiver sensitivity, utilization of alternate signal waveform designs and the flight of two (or more) receivers – either boom-mounted on the same orbiter or, ideally, located on separate polar-orbiting spacecraft. The opportunity for orbital interferometry, created by flying radars on multiple spacecraft, 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 [6].

Global geophysical surface network. Although a ~20+-station seismic and electromagnetic network will not have sufficient spatial resolution to verify the orbital radar sounder observations in detail, the seismic and electrical properties of the crust, assessed by such a network mission, could provide an important independent test of the large-scale volatile distribution and stratigraphy inferred from the radar data. Higher-resolution studies could also be performed in local regions by distributing the geophysical stations in clusters of 3-4, providing important data on crustal properties that could significantly aid the identification of lithologic and volatile units. This ability would be further enhanced by the inclusion of multiple geophysical investigations, such as seismometers, magnetotelluric instruments and GPR, onboard each station. Such a mission might also include the acquisition of local compositional and thermophysical data that could assist in both interpreting the geophysical sounding results and characterizing the global range of material properties that might be encountered in drilling. A network of this type could be emplaced by either a single mission (with stations dispersed from a polar-orbiting bus) or be built up incrementally, over two or more successive launch opportunities. The four-station NetLander mission in 2007 is an important first step in this effort, which could potentially be augmented (by CNES, NASA, or ESA) with the additional stations required to create a 20+-station global network in 2009.

High-Resolution Characterization of Local Sites. An expected result of the first phase of global reconnaissance will be the identification and prioritization of candidate sites for more focussed investigations. There are a variety of potential platforms and instruments that might be employed in such an effort, ranging from high-density surface networks to aerial surveys conducted by aircraft, aerobots, or balloons. For this reason, the only requirement for this type of investigation is an operational one – that, whatever its design, it be capable of resolving the location of a potential volatile target at sufficiently high spatial resolution to guide the placement and operation of a follow-on drilling investigation.

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. Developing a comprehensive geophysical strategy to address these issues represents the next logical step in any effort to "follow the water". The single most important investigation in such an approach would be the flight of an advanced, polar-orbiting radar sounder/interferometer that could potentially be flown during the second half of this decade. Such a mission would be most logically followed by a 20+-station global geophysical network to provide complimentary data on the global- and regional-scale seismic and electromagnetic properties of the crust.

In recognition of the importance and technical complexity of these issues, the *Conference on Geophysical Detection of Subsurface Water on Mars* is being held to:

- clarify the reasons why a global geophysical reconnaissance of Mars is needed,
- identify the types of investigations (orbital, global surface network, and high-resolution local) that are best suited for determining both the state and 3-dimensional distribution of subsurface water,
- assess the diagnostic limitations and potential environmental complications associated with such investigations, and
- determine what other areas of Mars science would benefit from the acquisition of this proposed suite of geophysical data.

Given the enormous base of experience that already exists in these areas within the terrestrial research and exploration communities, the participation of terrestrial scientists is actively encouraged.

References: [1] MEPAG Science Goals Document, 2000; [2] Clifford, S. M. and T. J. Parker, *Icarus*, in press 2000; [3] Malin, M. and K. Edgett, *Science* 288, 2330-2335, 2000; [4] Clifford, S.M., *Lunar Planet. Sci Conf. XXVIII*, 1998; [5] Stoker, C. *Mars Deep Water Sounding Workshop Summary*, http://astrobiology.arc.nasa.gov/worshops/1998/marswater/index.html, 1998; [6] Beaty, D. et al., *Analysis of the Potential of a Mars Orbital Ground-Penetrating Radar Instrument in 2005*, Mars Program Office White Paper, 2001.