IS MARS WATER-RICH? OPTIMAL LANDING SITE LOCATIONS FOR THE GEOPHYSICAL DETECTION OF SUBPERMAFROST GROUNDWATER. Stephen M. Clifford, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058.

To date, efforts to determine whether Mars is water-rich have been hampered by both the limited nature of the available data and the enormous uncertainties associated with its interpretation. However, with the advent of the Mars Surveyor Program, the potential exists for delivering electromagnetic and seismic sounding instruments to the Martian surface that can answer this question conclusively. Because instrument mass and size constraints are likely to impose serious limits on the range and sensitivity of any geophysical sounding device, a critical factor to the success of such investigations will be the identification of landing sites where the potential depth to groundwater is minimized. Hydrologic, topographic, and latitudinal considerations suggest that the NW interior of the Hellas impact basin (elevation < -5 km), and four other low-lying sites near the equator (elevations < -2 km), are the locations best suited for the geophysical detection of subpermafrost groundwater. The rationale behind these selections is discussed in greater detail below.

Groundwater as an unambiguous indicator of a water-rich Mars. More than any other potential observation, the detection of subpermafrost groundwater would provide unambiguous evidence that Mars is water-rich ([1], sections 6.2 and 8). This conclusion is based on the fact that the cryosphere (that region of the crust where the temperature remains continuously below the freezing point of H_2O, Fig. 1) is the primary thermodynamic sink for crustal water. That is, under the influence of the planet's geothermal gradient, water in the crust will preferentially diffuse from the higher temperature (higher vapor pressure) depths to the lower temperature (lower vapor pressure) near-surface crust, where it ultimately condenses in the cryosphere as ground ice. Calculations of the efficiency of this process suggest that, given a sufficiently large reservoir of groundwater at depth, a geothermal gradient of 15 K/km will supply enough H_2O to completely saturate the pore volume of the cryosphere in as little as 10^7 years. For this reason, a necessary precondition for the widespread occurrence of groundwater is that the cold-trap represented by the cryosphere must first be saturated with ice. Given reasonable estimates of crustal pore volume, thermal conductivity, and heat flow, this appears to require an inventory of H_2O equivalent to a global ocean at least 400 m deep [1, section 2].

Note that in the case where the planetary inventory of groundwater is smaller than the storage capacity of the cryosphere, virtually all of the available H_2O will be rapidly cold-trapped into the frozen crust. Under these conditions, the occurrence of any subpermafrost groundwater is necessarily transient and restricted to regions of anomalous geothermal heating, where it may originate from the melting of nearby ground ice or the introduction of juvenile water in association with major volcanic centers or igneous intrusions.

Thus, the potential detection of groundwater at multiple and widely separated locations across the surface appears compatible with only one conclusion -- that Mars is water-rich. Yet, even in the case of a water-rich Mars, the successful detection of groundwater is not assured. Limitations of instrument range and sensitivity will require that prospective landing sites be carefully chosen to minimize the potential depth of groundwater beneath the surface. Aside from the inventory of groundwater itself, the two factors that will affect this distance most are the thickness of the cryosphere (which varies as a function of latitude) and the local elevation of the surface.

The effect of latitude and topography. The thickness of cryosphere at any location is essentially a function of four variables: crustal thermal conductivity, geothermal heat flow, ground ice melting temperature, and the mean temperature at the surface. Of these, only the mean surface temperature is expected to vary in a systematic way – with present day values ranging from a high of approximately 218 K at the equator to a low of ~154 K at the poles. Given geologically reasonable values of the remaining three variables, this latitudinal decline in mean surface temperature is expected to result in a progressive thickening of the cryosphere from about 2.3 km at the equator to in excess of 6.5 km at the poles. While local values of cryosphere thickness are likely to vary significantly from these globally-averaged values, it is clear that – all other factors being equal – the choice of an equatorial landing site minimizes the depth of frozen ground that must be penetrated by a geophysical sounder.

While the effect of latitude on cryosphere thickness represents an important consideration in the selection of potential landing sites, it alone is insufficient to guarantee that the depth to groundwater is minimized. This point is best illustrated by the pole-to-pole cross section of the Martian crust presented in Figure 1 – which illustrates the potential relationship between the cryosphere, topography, and groundwater, for hypothetical groundwater inventories equivalent to a global layer 10, 100, and 250 m deep (for a more complete discussion, see section 2.3 in [1]). Note that for a groundwater system in hydrostatic equilibrium, the water table conforms to a surface of

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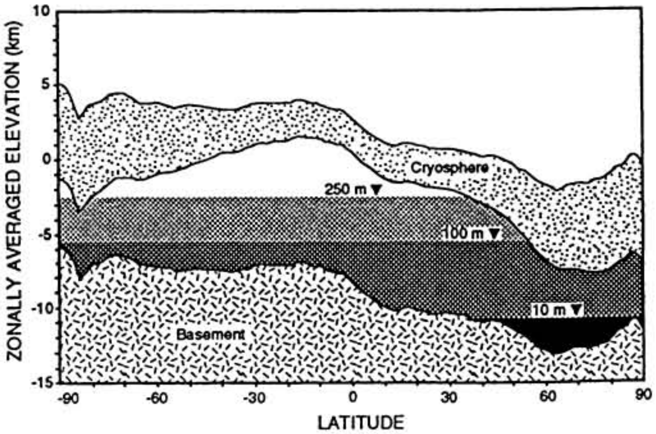

Figure 1. A hypothetical pole-to-pole cross section of the Martian crust illustrating the potential relationship of the topography, cryosphere, and groundwater, for three different groundwater inventories (after [1], Fig. 7).

Table 1. Five potential sites for conducting geophysical soundings for subpermafrost groundwater.

Site Location	Latitude Range	Longitude Range	Elevation
Eos Chasma	6-12°S	32-39°W	<-3 km
Amazonis Planitia	28-33°N	152-163°W	<-3km
SE of Elysium	2-11°N	179-198°W	<-2 km
Isidis Planitia	6-22°N	263-279°W	<-2 km
NW interior of Hellas	35-42°S	296-307°W	<-5 km

constant geopotential. In contrast, the base of the cryosphere mirrors the first-order variations in surface topography. As a result, the vertical distance separating the water table from the base of the cryosphere can range from zero, in regions of low elevation, to many kilometers, in regions of higher elevation (see section 2.3 and Plate 1 of [1] for a more complete discussion of potential volatile stratigraphy).

Prospective landing sites for the geophysical detection of subpermafrost groundwater. From the preceding analysis it is clear that low latitude and low elevation are the two most important criteria for selecting a landing site that minimizes the potential depth to subsurface water. A review of the USGS Mars Digital Terrain Model suggests that the four best locations which satisfy these criteria are Eos Chasma (9°S, 36°W), Amazonis Planitia (31°N, 158°W), Isidis Planitia (15°N, 270°W), and a region located about 1800 km SE of Elysium Mons (6°N, 188°W). A fifth site, located in the NW interior of Hellas (36°S, 300°W) was included because it represents the lowest spot on the planet and, despite its higher latitude, may still have the closest proximity to any reservoir of subsurface groundwater. Further details concerning each of these locations are presented in Table 1.

While the design of geophysical sounders capable of detecting subpermafrost groundwater at depths of several kilometers or more may prove challenging within the mass and size constraints of the Mars Surveyor Program, it is difficult to imagine any experiment or observation that would shed more light on the current volatile inventory and hydrologic nature of Mars.

References: [1] Clifford S.M. (1993) *JGR, 98*, 10,973-11,016.