PHLEGRA MONTES: CANDIDATE LANDING SITE WITH SHALLOW ICE FOR HUMAN EXPLORATION.

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Introduction: Human exploration and settlement of Mars is of interest to SpaceX [1] as well as NASA, ESA, and CNSA (China). H_2O is essential for drinking, growing food, and producing oxygen and hydrogen, but avoiding polar regions is important to keep temperatures moderate and for solar power. MRO/HiRISE working with JPL has been imaging candidate landing sites for SpaceX. This effort is focused on the northern mid-latitudes because of low altitudes, the known presence of shallow ice down to 39°N [2], and milder winters than the southern middle latitudes. Human Mars landers will likely target flat landing sites (slopes <5°) that are relatively free of large boulders and dust.

Based on topographic data and HiRISE images, two regions stand out as most promising: Arcadia Planitia and Phlegra Montes (Fig. 1). Arcadia Planitia is especially flat and has extensive apparently boulder-free areas. Phlegra Montes probably also has dozens of acceptable areas (>200 m diameter) plus other advantages. In the Phlegra Montes there are Noachian and Hesperian terrains likely to provide diverse materials in addition to regolith and ice, and there are hills that provide north- and south-facing slopes. Shallow ice is stable down to lower latitudes on pole-facing slopes [3], and surface temperatures are higher on equator-facing slopes. A landing site on a flat area near north- and south-facing slopes might be ideal.

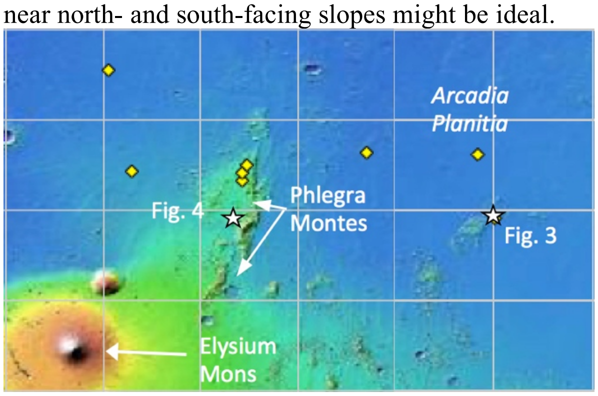

Figure 1. Location map on color-coded altimetry from 20–60° N, 140–200° E. Yellow diamonds indicate ice-exposing impacts [2]. Locations of Figs. 3 and 4 are marked with white stars.

Geology of Phlegra Montes: This 1,400 km long set of elevated features extends from 30-52° N and 160-170° E. The large-scale topography is that of asymmetric linear-to-arcuate ridges interpreted as nine major and several minor thrust-fault structures [4]. The hills are heavily modified by glacial flow landforms, some of which have radar-sounding returns interpreted as nearly pure ice under a debris layer [5–8]. The bedrock composition is poorly known because of Amazonian modification, but basaltic compositions have been detected in nearby Erebus Montes [9].

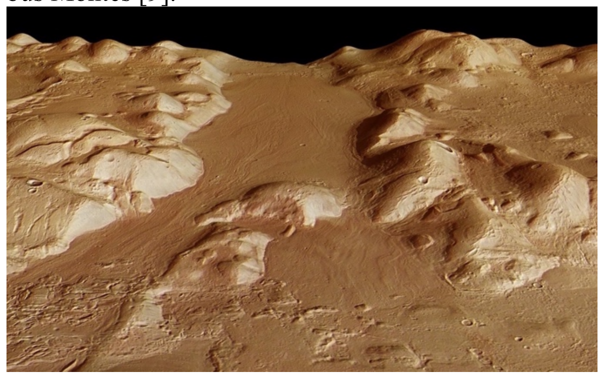

Figure 2: HRSC perspective view of a portion of southern Phlegra Montes. ESA/DLR/FU Berlin. (http://www.esa.int/spaceinimages/Images/2011/12/Phlegra_Montes_in_perspective2

Evidence for Shallow Ice: Icy flow geomorphologies are ubiquitous in Phlegra Montes [10] (Fig. 2). One location has been interpreted to have had over 1 km ice thickness [11]. Remnant debris-covered glaciers in the Phlegra Montes have been estimated to contain tens to hundreds of km^3 of ice today [12]. Interpretation of eskers suggests wet-based glaciation occurred in southern Phlegra Montes [13]. The mid-latitude flow features are presently covered by at least a few meters and perhaps tens of meters of rocky debris [14]. However, there are recent impact sites exposing clean ice from <1 m depth near here [2], including one example at 39.1°N latitude (Fig. 3). Thermokarst features in this region have been identified equatorward of 30N [15] and are also interpreted as contemporary presence of ice. A recent study [16] has found a high consistency of ice across the Phlegra-Arcadia area using various datasets. Ice-exposing craters in the Phlegra-Arcadia region of Mars are typically found on terrain with ubiquitous polygonal pattern, few boulders and sometime near thermokarst landforms. Polygons of this size (≤10 m) form by thermal contraction cracking of ice beneath a thin layer of regolith [17]. Our working hypothesis is that nearby terrains with ~10 m scale polygons, or thermokarst landforms, have shallow ice today.

Boulders: The "Golombek rule" is that an acceptable landing site has zero boulders detected in full-resolution HiRISE images [18]. This rule is based on the fact that HiRISE boulder detection is complete at >1.5 m diameter, and given exponential extrapolation to 1-m diameter (typically 0.5 m high), even a single boulder detection could result in >1% chance of the lander failing due to a boulder. The SpaceX Starship is a very different landing system from past NASA landers, and the tolerance for boulders may differ, but are still best avoided.

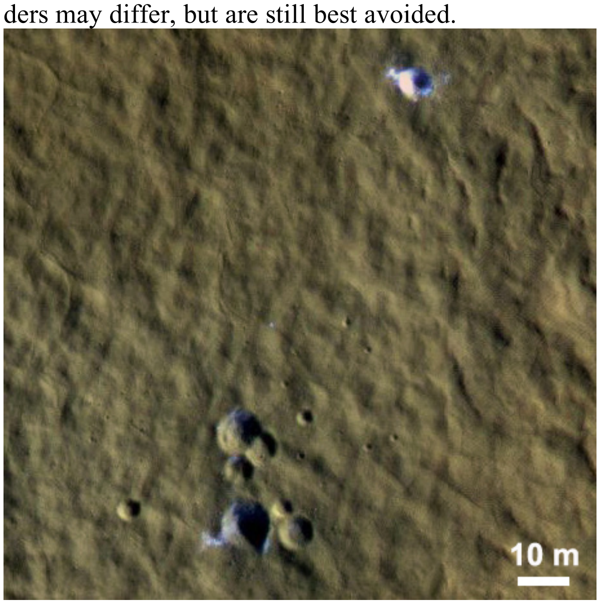

Figure 3: New ice-exposing impact crater cluster east of Phlegra Montes (HiRISE ESP_029467_2195).

There are now >100 HiRISE images from 30-40° N and 160-166° E, about half at full resolution. (We are assuming that above 40°N is unacceptable due to low winter temperatures and the polar hood). Although this is extremely sparse coverage (<5%), there are at least 7 images showing large areas (>200 m) with no boulders and with polygons that may indicate shallow ice (Fig. 4). These areas have moderate to moderately-low thermal inertia [19], high albedo [20], and a low dust cover index [21] suggesting near surface materials are dominantly dry sandy soils with a thin coating of dust.

Slopes: MOLA data indicates regional (35-km) slopes range from 0-20° over Phlegra Montes; roughness mapping shows relatively low small-scale roughness typical of the middle to high latitudes [22]. Polygonal terrain at the Phoenix landing site is relatively smooth [17]. There are currently 5 good HiRISE stereo pairs over promising locations (that appear flat and are nearly boulder free); at least one digital terrain model (DTM) will be completed by the time of the conference.

Future Data Needs: Waiting for new impact events to confirm shallow ice at new sites from 30-40° N could take decades. A recent study [23] concluded that Polarimetric Synthetic Aperture Radar on a future Mars orbiter is needed to map the distribution of ice within the top few 10s of meters. Additional HiRISE-class images are needed in potential landing sites, including stereo coverage.

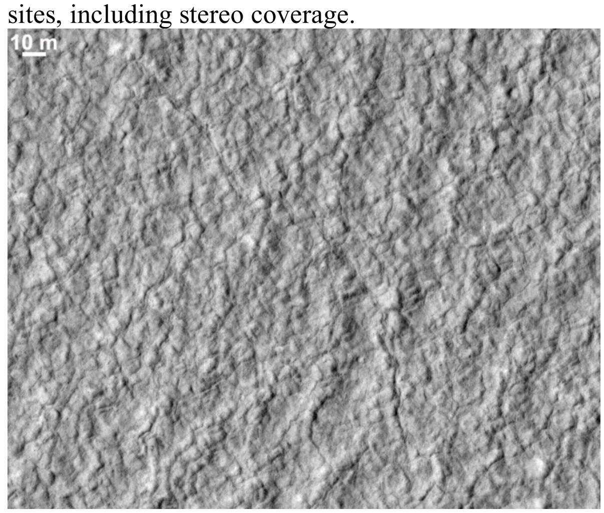

Figure 4. 300-m wide area with polygons and no resolved boulders, located at 38.7 N, 163.88 E. A DTM will be produced here to determine small-scale slopes. Portion of ESP_035362_2190.

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