COMPOSITE GLACIAL SYSTEMS ON PHLEGRA MONTES, MARS: APPLICATION OF SHALLOW RADAR (SHARAD) ICE-DEPTH AND THICKNESS ESTIMATION TO SURFACE GEOMORPHOLOGY

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Introduction: New evidence from the Shallow Radar (SHARAD) sounding experiment on the Mars Reconnaissance Orbiter (MRO) is presented in this study of composite glacial systems in the Phlegra Montes region (30°N-52°N) of the mid-northern latitudes of Mars consisting mostly of water-ice (**Fig. 1**). Composite glacial systems are a combination of lobate debris aprons (LDAs) fed by higher elevation and up-valley lineated valley fills (LVFs), creating complex, overlapping, ice-rich systems. Among all viscous flow features (VFFs) on Mars, composite glacial systems are the largest reservoir of ice [1].

The goal of this study is to characterize and better understand Mars' cryosphere in terms of the current water budget and recent evolutions in its subsurface water-ice content. Ice-depth and thickness at Phlegra Montes is estimated for distinct landforms such as the identified composite system (**Fig. 2**). Previous literature characterized these systems as debris-covered glacial systems equivalent to terrestrial deflated rock glaciers [2-5], which results to a slower response to changes in past climate compared to pure water-ice systems. Dynamically, it is interesting to note that Phlegra Montes also spans the mid-latitude glacial-periglacial continuum indicative of complex, icy surface processes.

Methods: This research uses the SHARAD dataset [6] with imagery from the Context Camera (CTX; 6 m/px), High-Resolution Imaging Science Experiment (HiRISE; 25 cm/px), and Thermal Emission Imaging System (THEMIS Night IR; 100m/px) to characterize the depth of subsurface ice at the study site. Phlegra Montes is a region that bounds a 1400 km long massif northeast of Elysium Mons. It has been proposed as a candidate human landing site on Mars and as a high-value target for cryospheric science and its potential for in-situ resources (i.e. water-ice) [7].

We integrate numerous datasets to form a grid-map of ice presence and geomorphology: 1543 2D SHARAD power radargrams and clutter simulations, grid-maps of radar surface power return, ice consistency, and geomorphology derived from the Subsurface Water Ice Mapping (SWIM) team [14]. These datasets were analyzed and correlated using ArcMap 10.8, JMARS, SeisWare 10.1 and image editing software. Two-way time delay radargrams were converted to depth using the dielectric permittivity values in a two-layer model of free space (ε'=1.0) and water-ice (ε'=3.15), which is useful for calculating the elevation of basal interfaces of ice-rich bodies such as LDAs. We derived loss tangent values from measured reflected surface and subsurface powers to test the ice purity.

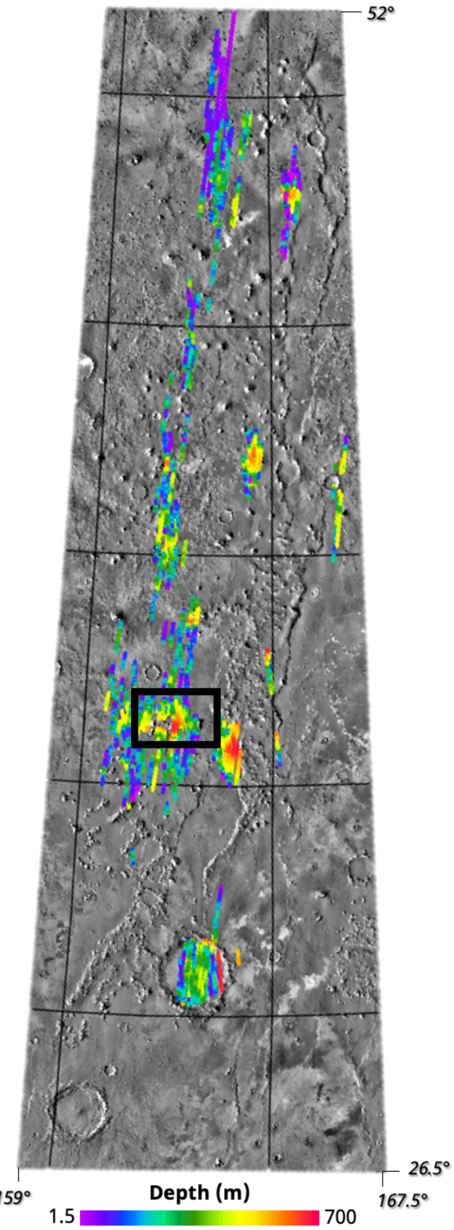

Fig 1. Estimated ice depth map of Phlegra Montes derived from regional potential subsurface reflectors (PSRs). Black inset box refers to highlighted compound glacial system in Fig. 2A.

Results: From the 1543 SHARAD tracks mapped, we found several basal reflections and/or potential subsurface reflectors (PSRs), one of which is a well-documented composite system [5] (**Fig. 2**). SHARAD

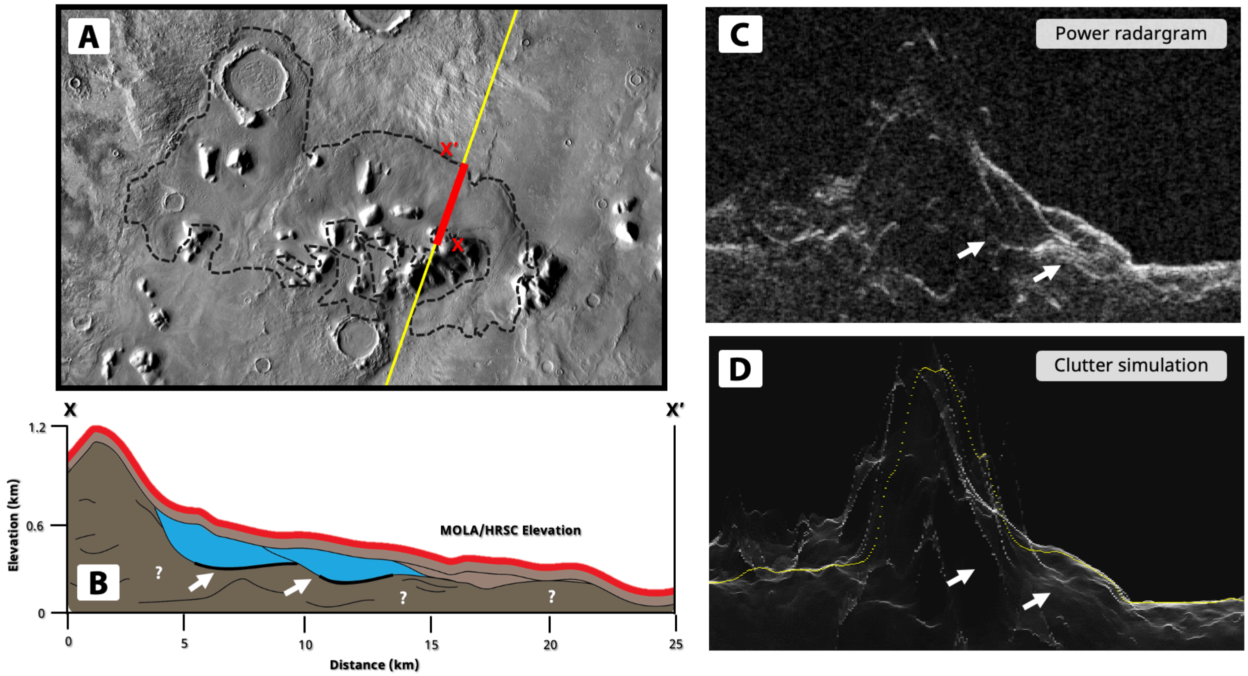

Fig 2. **(A)** THEMIS Day IR Imagery of the composite glacial system in Phlegra Montes overlain by orbit track 68020. **(B)** Cross-section schematic of composite system interpreted from radargrams. **(C) and (D)** SHARAD power radargram and cluttergram 6802001000. White arrows point to possible terraces hosting lobate flows.

observations were able to distinguish two separate icy bodies in a possible topographic terrace similar to high alpine, terrestrial glaciers (**Fig. 2C**).

Ice thickness and Volume. After depth correction, the average ice thickness was calculated to be 189.68 m with a maximum thickness of 580.1 m and a total area of 5492.46 km^2. With this, ice volume of the composite system was then calculated to be ~1041.81 km^3 with a total mass of 955.03 Gt water equivalent (w.e.)

Dielectric and Compositional Properties. From [5], who studied a large LDA to the east of the composite system, we assume 88–90% ice purity for a stratified deposit of pure ice (ε' = 3.15) overlain by regolith*, making the* bulk dielectric permittivity value ε' = 3.6, which corresponds to 4.0 m of lag deposit. In correlation with THEMIS IR imagery, there is also a visible contrast in surface geology/material where the terrace slope breaks, which may be indicative of different surface materials.

Discussion: This is first composite system detected and characterized by SHARAD in the Martian mid-latitudes. Its significance and existence can help us better define the anatomy and process of formation of debris-covered glaciers and ice bodies on Mars. Although the formation of composite systems is unknown, there are three current hypotheses:

1. *Episodic event:* Flows are indicative of various periods of obliquity on Mars [8, 9]
2. *Single event:* An initial flow immediately followed by a mass wasting event of debris top (mantled deposits) [10, 11]
3. *Deflation event:* A remnant glacial system from regional-scale glaciation event(s) that have been protected by debris from sublimation [1, 12]

There are also several radar non-detections which may be due to (a) surface roughness causing increased radar scattering and reduced nadir signal return, (b) increased attenuation within the surface debris layer, (c) increased attenuation within the compound system bulk interior, (d) roughness of the basal interface and/or (e) reduced dielectric contrast at the basal interface [13].

Future Work: To better characterize the topography in the region, we are processing data from the Colour and Stereo Surface Imaging System (CaSSIS) and High-Resolution Stereo Camera (HRSC) cameras to produce digital terrain models (DTMs; (30m/px) of the area and CTX and HiRISE stereo imagery via SOCET-CET and NASA Ames Stereo Pipeline platforms to investigate specific regions at higher resolution. SHARAD coverage is increasing, and we look forward to making a final determination for the total ice volume within the region.

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