GEOLOGIC MAP OF THE OLYMPUS MONS VOLCANO, MARS. J.E. Bleacher[1], D.A. Williams[2], P.J. Mouginis-Mark[3], D. Shean[4], R. Greeley[2*], [1]Planetary Geodynamics Laboratory, Code 698, NASA GSFC, Greenbelt, MD, 20771, Jacob.E.Bleacher@nasa.gov, [2]School of Earth & Space Exploration, Arizona State University, Tempe, AZ, 85282, [3]Hawaii Institute of Geophysics and Planetology, University of Hawaii. [4]Malin Polar Science Center, Applied Physics Lab, University of Washington, Seattle, WA, 98105 [*]Deceased.

Introduction/Background: We have completed a first draft of a Mars Data Analysis Program-funded project to map the morphology of the Olympus Mons (OM) volcano, Mars, using ArcGIS by ESRI. The final product of this project is to be a 1:1,000,000-scale geologic map. The scientific questions upon which this mapping project is based include understanding the volcanic development, including identification of volcanic unit source areas, and subsequent modification by structural, aeolian, and possibly glacial processes.

Methods: To address our science questions we conducted morphology mapping at ~ 1:300,000 scale using the Context Camera (CTX) and High Resolution Stereo Camera (HRSC) image mosaic as our base data. This scale enables a distinction between sinuous rilles and leveed channels, which is fundamental for interpreting abundances among, and changes between, tube- and channel-forming eruptions. We have combined our map with Mouginis-Mark's Planetary Geology & Geophysics-funded geologic map of the Olympus Mons Caldera that was produced at 1:200,000 scale and provides additional detail of the summit region.

Results: We identified 34 units that are divided among Flank Units, Scarp and Apron Units, Plains Units, and Crater Materials. The Flank Units include 13 units, plus 7 caldera units. The basic morphological difference across the flank involves mottled and channeled units. The channel unit is typified by sub-parallel linear flows with levee structures. The mottled unit is hilly at the horizontal scale of 10s to 100s of meters. We did not delineate units that display the same morphology but appear to be the result of a different eruptive phase unless a unique source is inferred. Because a motivating question involves the identification of flank unit sources we subdivided channels and mottled units according to their apparent origin. These include Fan-sourced, Ridge-sourced, and Flank units (which can be traced to the caldera or have a source that is unclear). Fans and ridges are up to 100 m in height. Fans are delta-shaped whereas ridges are elongate, generally radial to the caldera. We identify a fan's apex as a location point.

We differentiate three scarp and three apron units. Generally, our Ravine Scarp unit and Etched Scarp units are comparable to the Slope 1 and Slope 2 units of Basilevsky et al. [1]. The Ravine Scarp Unit is steep (30-35 degrees) and displays sharp ravine-like features whereas the Etched Scarp Unit is shallower (7-15 degrees) and displays a less sharp, etched morphology. We also delineate Stepped Scarp which forms a series of topographic, down-stepped benches. This unit often separates the other scarp units from the Main Flank Units. Our Apron units include Chaotic, Arcuate Ridged, and Muted and generally follow the characterizations of Milkovich et al. [2].

The Plains Units are subdivided into Aureole units (including blocky, ridged and smooth), low shields, fissures, channel networks, smooth/platy unit and a knobby unit. Crater Materials include an impact crater cavity unit (and raised rim) and the ejecta blanket unit where identified. We also identify structural features, including scarps, ridges, and faults. We delineate sinuous chains of depressions or rilles from the channel unit as a linear feature. These generally form a trough that does not display levees.

Geologic History, New Insights: The volcanic history in the map area involves Olympus main flank eruptions followed by eruptions from low shields and fissure vents in the plains surrounding OM. These flows appear to embay main flank channels and tabular flows at the distal margin of the volcano, beyond the scarp materials, to the North, East, and South. Werner [3] conducted crater counts of select regions of the main flank and suggested that the volcano was largely in place by 3.8 Ga, and Basilevsky et al. [4] conclude that plains volcanism to the SE was occurring at 25-40 Ma. The main flank is dominated by mottled and channeled units of varied origin. We observe a transition from mottled- to channel-dominated surfaces with distance from the caldera. The mottled units are in some cases distributed randomly about the main flank, but tend to be located proximal to eruptions sites (fan apex, ridge crest, or the caldera), whereas channels are located distally from eruptions sites. We interpret the mottled units to represent near vent lava flows in which significant channels and tubes have not developed (e.g., near vent sheet flows [5]). The dominance of this unit at the summit matches favorably with the subdued Aos1 unit of Morris and Tanaka [6]. In some cases we see that the mottled terrain results from channels that are below the detection limit for our mapping. In addition, these features might also be covered by dust or ash. With respect to azimuth around the main flank we observe that fans and rilles are less common on the NE and SW flanks of the volcano.

In contrast to our preliminary mapping [7], we do not map lava tubes as a unique unit. We identified four morphologies that we think are indicative of the presence of lava tubes, including 1) raised ridges, 2) sinuous chains of rimless pits or rilles, 3) lava fans, and 4) raised rim depressions of non-impact origin [8]. The features cited here are typically seen in terrestrial shield volcano flow fields in relationship with tubes. In general, the identification of one of these features alone is not indicative of a lava tube, but if two or more are identified together (adjacent or superposed) we feel confident that they reveal the presence of a tube. Based on this inference and superposition relations between inferred tubes and channels, we no longer identify a consistent burial of tubes by channels. Instead, we recognize that the apparent burial of some tubes is the result of ridge-sourced channels, which are essentially a product of the same eruption.

McGovern and Morgan [9] note asymmetries between the NW and SE flanks. They observe that the NW flank has the longest distance between caldera and scarp, displays lower flank extensional faults, where as the SE flank is shorter (caldera to scarp) and displays upper compressional terraces (also seen by [10]) and lower upthrust blocks. Both of these portions of the flank display concave up surfaces whereas the NE and SW flanks display more uniform slopes. They suggest that Olympus Mons has experienced volcano-wide spreading to the NW and SE as a result of a weaker, pre-Tharsis substrate. Mapping shows that the NE and SW scarps are completely embayed by young lavas, whereas the SE and NW flanks display exposed scarp material.

If the conclusions of McGovern and Morgan [9] are correct and the volcano is spreading to the NW and SE, then subsequent intrusion of magma into the volcano would likely exploit those spreading centers along the NE and SW flanks to reach the surface, as is seen on the Hawaiian volcanoes where rift zones open roughly parallel to the coast as the volcanoes spread into the ocean. Although we see a paucity of fans and possible eruption sites along these sections of the volcano it is possible that we have simply identified the readily noticed features related to lava tube breakouts and misinterpreted effusive spreading centers. If spreading centers exist along these sections of the volcano then magma might have been more easily delivered to these sections of the volcano, possibly explaining why the scarps are heavily buried in these sectors.

Future Work: Our current efforts are focused on additional higher resolution mapping and data analysis related to the map product. These efforts include 1) the identification of lava tubes and their products on the flanks of OM, 2) the interactions between volcanic rocks and frozen volatiles on OM, and 3) the volcanic-tectonic development and constraints of the eruptive frequency of the volcano.

References: [1] Basilevsky et al., (2005), Solar System Research, 39, 2, 85-101. [2] Milkovitch et al., (2006), Icarus, 181, 388-407. [3] Werner, S. (2009) Icarus, 201, 44-68. [4] Basilevsky et al. (2006) Geophys. Res. Lett., 33, L13201, doi:10.1029/2006GL026396. [5] Swanson, D. (1973) Geol. Soc. Am. Bull., 84, 615-626. [6] Morris and Tanaka (1994) USGS Misc. Inv. Series Map I-2327, Scale 1:2M and 1:1M. [7] Bleacher et al., (2007), JGRE 112, doi:10.1029/2006JE002826. [8] Bleacher et al., (2011), LPSC 42, #1805. [9] McGovern and Morgan (2009) Geology, 37, 139-142, doi:10.1130/G25180A.1. [10] Byrne et al., (2009) Earth and Planetary Sci. Lett., 281, 1-13.