MISALIGNMENT OF LAVA FLOWS FROM TOPOGRAPHIC SLOPES REVEALS AMAZONIAN UPLIFT OF ARSIA MONS, MARS. J. Chadwick[1], S. Fink[1], W. Tucker[1], B. Waring[1], and P. McGovern[2], [1]Dept. Of Geology, College of Charleston, Chaleston, SC, 29424, chadwickj@cofc.edu; [2]Universities Space Research Association, McGovern@lpi.usra.edu.

Introduction: Paleotopography techniques employ physical features that conform to the topography that existed at the time of their formation. These features, such as lava flows, channels, and flat crater floors, no longer conform to topography if it changes due to subsequent tectonic or magmatic processes. Comparison of the orientations of these features with modern topographic slopes allows for reconstruction of the original topographic orientation and the change that has occurred. These features have been applied to previous studies of regional-scale topographic change in the Tharsis area of Mars [1,2].

Groups of long, thin lava flows with consistent flow directions on relatively flat plains can serve as particularly reliable indicators of "paleo-topography," and the differences with modern slope directions indicate any tilting of the topography that has taken place since the flows were emplaced. In the lowlands to the south of Olympus Mons, Chadwick et al. [3] mapped a group of 80 long, thin lava flows that indicated downhill directions that were different from the current topographic slopes measured in Mars Orbiter Laser Altimeter (MOLA) data. Modern slope directions in this area had an average angular offset of 15.4° +/- 9.8°, rotated in the clockwise direction from the lava flows. This change indicated tilting of the plains due to subsidence of nearby Olympus Mons. Flexural modeling indicated that the observed tilting was caused by subsidence of up to 2.1 km at the center of Olympus Mons induced by the addition of 1.3×10^5 to 1.4×10^6 km^3 of volcanic material, or about 1–10% of the total volume of the present-day Olympus Mons edifice. Crater size-frequency measurements for the tilted lava flows indicate that the subsidence took place in the past 210 ± 40 Ma, and indicate a substantial portion of the present-day Olympus Mons edifice may have been added.in the late Amazonian.

In this new study, paleotopographic methods and flexural modeling are being applied to detect and measure topographic change at Arsia Mons, one of the largest volcanoes in the solar system and the southernmost of the three large volcanoes known as the Tharsis Montes near the equator of Mars. Arsia is about 440 km in diameter and its summit is over 9 km above the surrounding plains, and the volcano has a pronounced summit caldera about 110 km wide. Lava flows within the caldera are estimated to be as young as 40-100 million years [4], indicating that like Olympus Mons, relatively recent magmatic activity occurred at this volcano, perhaps accompanied by topographic changes, including regional subsidence resulting from the addition of extrusives and intrusives or uplift induced by intrusion or thermal effects.

Methods: Identification and mapping of lava flows and topography surrounding Arsia Mons were conducted using methods described in Chadwick et al. [3]. A large group of roughly parallel, long (> 50 km) lava flows were initially identified to the south of Arsia Mons (Figure 1) in moderate resolution Mars Odyssey Thermal Emission Imaging System (THEMIS) daytime mosaics and in corresponding Mars Orbiter Laser Altimeter (MOLA) Mission Experiment Gridded Data Record mosaics (MEGDR). The mapping data were co-registered in ENVI image processing software (Exelis, Boulder, CO), and overlaid with topographic contours derived from the MOLA data. This revealed a large region to the south of Arsia where the lava flows were no longer perpendicular to the contours, indicating topographic change since the flows were emplaced.

Higher resolution Mars Reconnaissance Orbiter (MRO) context camera (CTX) image swaths with 6 m spatial resolution were mosaicked and georeferenced to form a high-resolution base mosaic to map the orientations of 34 long, thin lava flows (Figure 1). These flows generally flow away from Arsia and generally southwest toward Daedalia Planum. Most of these flows are not oriented radially to the center of Arsia, and any significant topographic change centered on the volcano would therefore tilt the topographic slope directions relative to the flow orientations. The centerlines of the flows were carefully digitized in the CTX mosaic, and the start and end point geographic locations were used to create straight-line vectors to represent their azimuthal orientations. These were compared with the topographic slopes immediately surrounding each flow in the MOLA data (average slope in a 30 km diameter circle around the center of each flow), to characterize the regional topograhic change.

Results: The 34 mapped flows in the study area indicate the topography has tilted following their emplacement. Misalignemnts of modern slope directions from the flows range from -2.0° (clockwise) to +24.4° (counterclockwise) relative to the paleoslope directions indicated by the lava flows (Figure 2), with an average of +7.3° (6.3° standard deviation). In a situation with no topographic tilting, the average would be expected to be near 0°, with a similar number of misaligned flows in the clockwise and counterclockwise directions. Most of the slopes and corresponding flows (22) are misaligned by more than 5°, and all of these are in the counterclockwise direction (Figure 2). This reorientation is consistent with uplift centered on Arsia Mons (or subsidence to the south of the flows) in the time since the flows were emplaced.

The identification of uplift of Arsia Mons contrasts with the loading-induced subsidence identified at Olympus Mons using these same methods [3]. Given the young ages of flows identified in the Arsia caldera (as young as 40 myr), an increase in the vigor of a mantle upwelling or significant sill-like intrusions beneath the edifice in the interim following the emplacement of the rotated flows on the flanks may be the best explanation for the broad region of uplift.

The mapped lava flows are Amazonian in age [5] but their higher crater densities suggest they are older than the most recent caldera flows noted in [4]. In this study, new crater counts are being conducted using CraterTools and CraterStats software to establish a more refined age of the affected plains to better constrain the maximum age of the deformation. The diameters of all unambiguous impact craters in the areas of deformation are measured using the methods described in [6].

Geophysical Modelling: The angular misalignment between paleo- (lava flows) and modern (MOLA) slope directions is now being used to model the magnitude of flexural deformation that would cause the observed tilting of the volcano flanks. The vertical displacements of different models are subtracted from the MOLA topography, yielding a "pre-deformation" surface. Essentially, the predicted deformation from a loading model is subtracted from the current topography to "restore" the topography at the time of flow emplacement. Successful estimates of uplift produce slope azimuths similar to those indicated by the mapped flows (see [4] for details).

To model the observed flexure, we are using the finite element program COMSOL Multiphysics, which offers flexibility in terms of model geometry, loading modes, and time sequencing. COMSOL has been used to model lithospheric flexure, magma chamber inflation, and intrusive loading in large volcanic edifices and radiating dike systems on Venus [7, 8, 9].

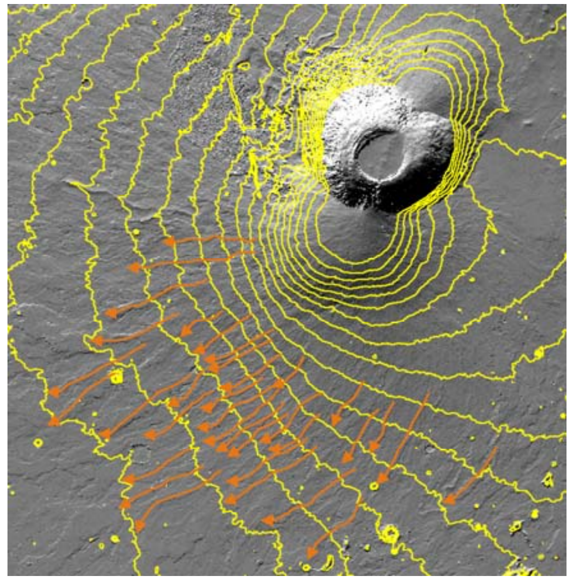

Figure 1. Map of the Arsia Mons region (top right; caldera is 110 km across for scale); 500 m contours (yellow) up to 10,000 m height. Mapped lava flows (orange) on the plains to the south are consistently misaligned with local "downhill" slope directions.

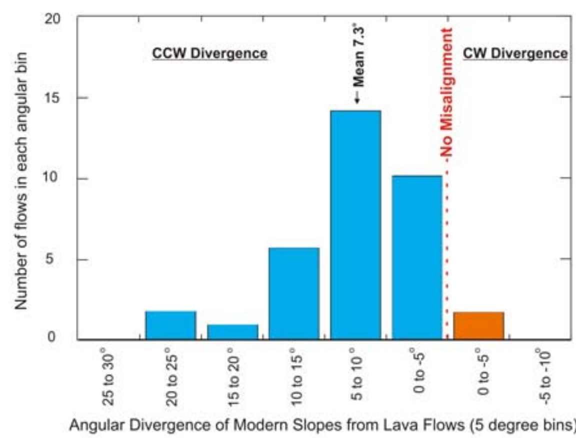

Figure 2. Angular distribution of lava flows relative to local slopes. Most slope directions are misaligned in a counterclockwise (CCW) direction from the corresponding lava flow orientations, best explained by uplift of Arsia Mons after the flows were emplaced.

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