SINUOUS CHANNELS ON THARSIS MONTES (MARS) RIFT APRONS

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BACKGROUND AND INTRODUCTION

Volcanism on Mars is extensive and diverse with a variety of volcanic landforms [1]. Global volcanism was very active during the Noachian and Hesperian period (4.1 - 3.0 Ga) based on the observation of widespread interpreted volcanic surfaces before settling into vent volcanism in Tharsis, Elysium and Circum-Hellas [2]. Volcanic activity later began to localize onto Tharsis and Elysium during the Amazonian (<3 Ga) [2]. Tharsis is a topographic highland of volcanic activity on Mars [1]. Occupying a quarter of the planet's surface volcanic landforms on Tharsis bear many similarities to basaltic volcanoes on Earth, including the Hawaiian Islands and basaltic volcanic American southwest [1]. Key differences between terrestrial and martian volcanoes include size, tectonic setting, and lower gravity [1].

Effusive volcanic channels are formed by the eruption of lava that has seemingly eroded into the substrate [3]. Unlike channelized lava flows, which are constructional landforms built by the propagation of lava flowing between stationary levees [4], [5], effusive volcanic channels are negative relief features. Sinuous rilles, first observed on the Moon, are a classic example of effusive volcanic channels (figure 2) [3]. Effusive volcanic channels are thought to form by sustained lava flowing turbulently over underlying material with a lower melting point which results in either thermal, mechanical, or thermomechanical erosion [3-4],[6-7]. Effusive volcanic channels can form a variety of morphologies from simple rille-like landforms to thin wide flows [8],[9]. Sinuous rilles are channels lacking observed levees typically originating from subcircular depressions with shallowing depths along their lengths, with several suggested formation mechanisms including but not limited to erosional lava flows [10], apparent incision because of high standing topography or partial drainage [7], and melting beneath turbulent flows [9].

The Tharsis Montes are three SW-NE oriented shield volcanoes that straddle Tharsis. Listed from youngest to oldest (SW to NE): Arsia Mons, Pavonis Mons, and Ascraeus Mons [1-2],[10-11]. These volcanoes were constructed primarily from the effusion of lava flows (similar to terrestrial shield volcanoes) and possible episodes of explosive activity [11]. Although the main shield-building phase of the Tharsis Montes stopped ~3.55 Ga, resurfacing continued until more recently [2]. Age dates of the flanks and caldera surfaces indicate activity persisted until around 500 to 100 Ma [2].

STUDY AREAS

Arsia Mons is a shield volcano approximately 17.7 km high and ~430 x 430 km across prior to the development of the rift aprons; the southernmost of the Tholis Montes (Figure 1) [2],[11]. Arsia Mons displays relatively smooth flanks composed of lava flows with gentle slopes of ~5° [11]. The rift apron slopes range from 1° to 4° [2]. The Arsia rift aprons begin at an elevation of 12-13 km and are oriented N38°E and S21°W [11] similar in trend to the whole Tharsis Montes [11]. They extend ~ 275 - 300 km. Surface age estimates of the main Arsia shield are ~500 Ma - 3.5 Ga while the rift aprons are estimated at ~100 Ma - 2 Ga [2]. The major events in building Arsia were the main shield building phase, followed by the construction of the rift aprons and ending with the caldera filling and low shields construction [11].

Pavonis Mons is located northeast of Arsia on the equator and is the center Tharsis Montes (Figure 1). It is the shortest of the Tharsis Montes at 14 km elevation [11]. Pavonis is ~375 km with flank slopes of ~4.1 - 4.6 degrees [11]]. On Pavonis, the northern rift apron faces N43°E extending ~100 - 110 km while the southern rift apron is made up of two separate parts: an older apron oriented S31°W and a younger apron oriented S15-18°W [11]. Both rift aprons begin at ~7 km elevation. The rift apron slope is at ~1° [2]. The main events of Pavonis' construction were 1) the main shield building event; 2) the formation of a debris apron to the northwest; 3) the rift aprons developing; and 4) the subsequent surfacing [11].

Ascraeus Mons is the youngest (main edifice ~ 3.6 Ga; rift apron ~1 - 1.5 Ga) and tallest (~ 18.2 km) of the Tharsis Montes [10],[11]. The volcano has flank slopes of ~7.4°. The northern rift apron begins at 6 km of elevation and is oriented N38°E while the southern apron (also made up of two separate parts) begins at 8.5 km of elevation and is oriented S25°W and S4°W [11]. The main events of Ascraeus can be classified into three parts 1) mainshield building; 2) rift apron building; 3) late stage resurfacing [10].

Our study area comprises the six rift aprons that drape the NE-SW regions of the Tharsis Montes (Figure 1). We defined our study area based on the Skinner et al. [2006] geologic map. We identified and investigated effusive volcanic channels that originate on the rift aprons including those that extend into the surrounding plains. We did not include channelized lava flows as we were only focused on channels likely formed by lava thought to have eroded into the substrate (akin to sinuous rilles). We omitted any features which were heavily modified or mostly buried along their length (i.e., channel segments).

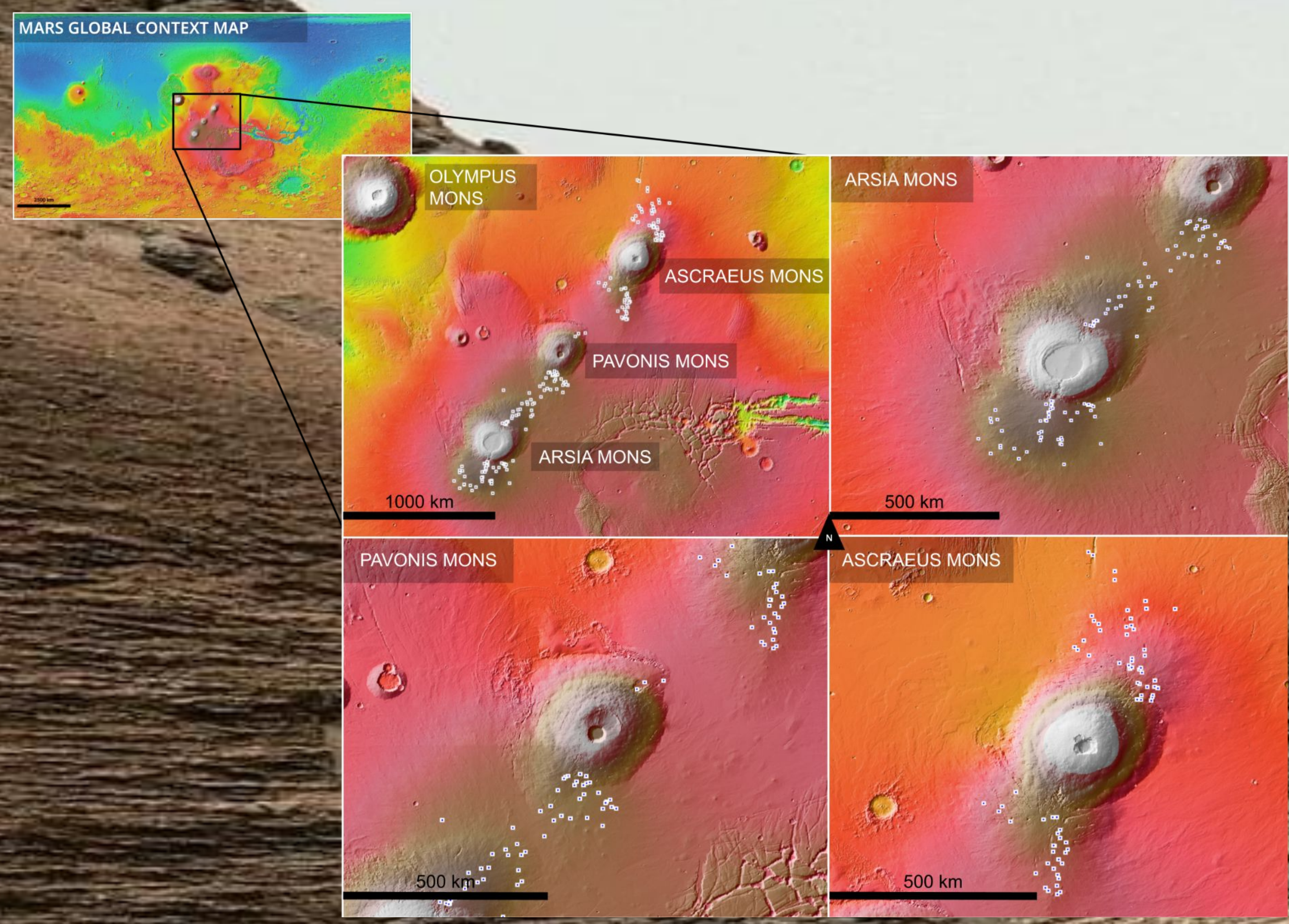

Figure 1: Colorized MOLA topography of Mars with Tharsis Montes labeled. Warmer colors indicate higher elevations, while cooler colors indicate lower elevations. Labels denote locations of observed effusive volcanic channels.

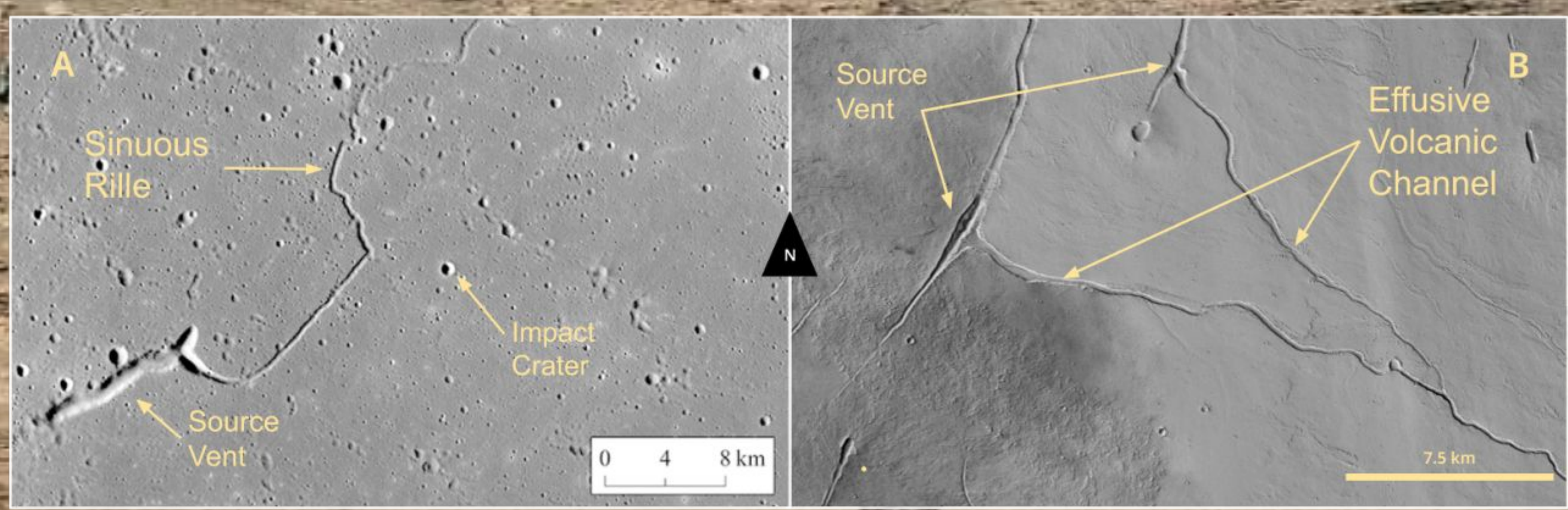

Figure 2: Examples of a lunar sinuous rille in comparison with an effusive volcanic channel observed in our study. Panel A is High-resolution Kaguya Terrain Camera image sourced from the Atlas of Lunar Sinuous Rilles provided by the Lunar Planetary Institute. Illumination is from the west. Panel B is visible MRO CTX (~5 m/px). Illumination is from the west. Panel A is lunar rille #115 (Rima Delisle) located in Mare Imbrium. Panel B show two sinuous volcanic channels (rated 5) located on Ascraeus' southern rift apron.

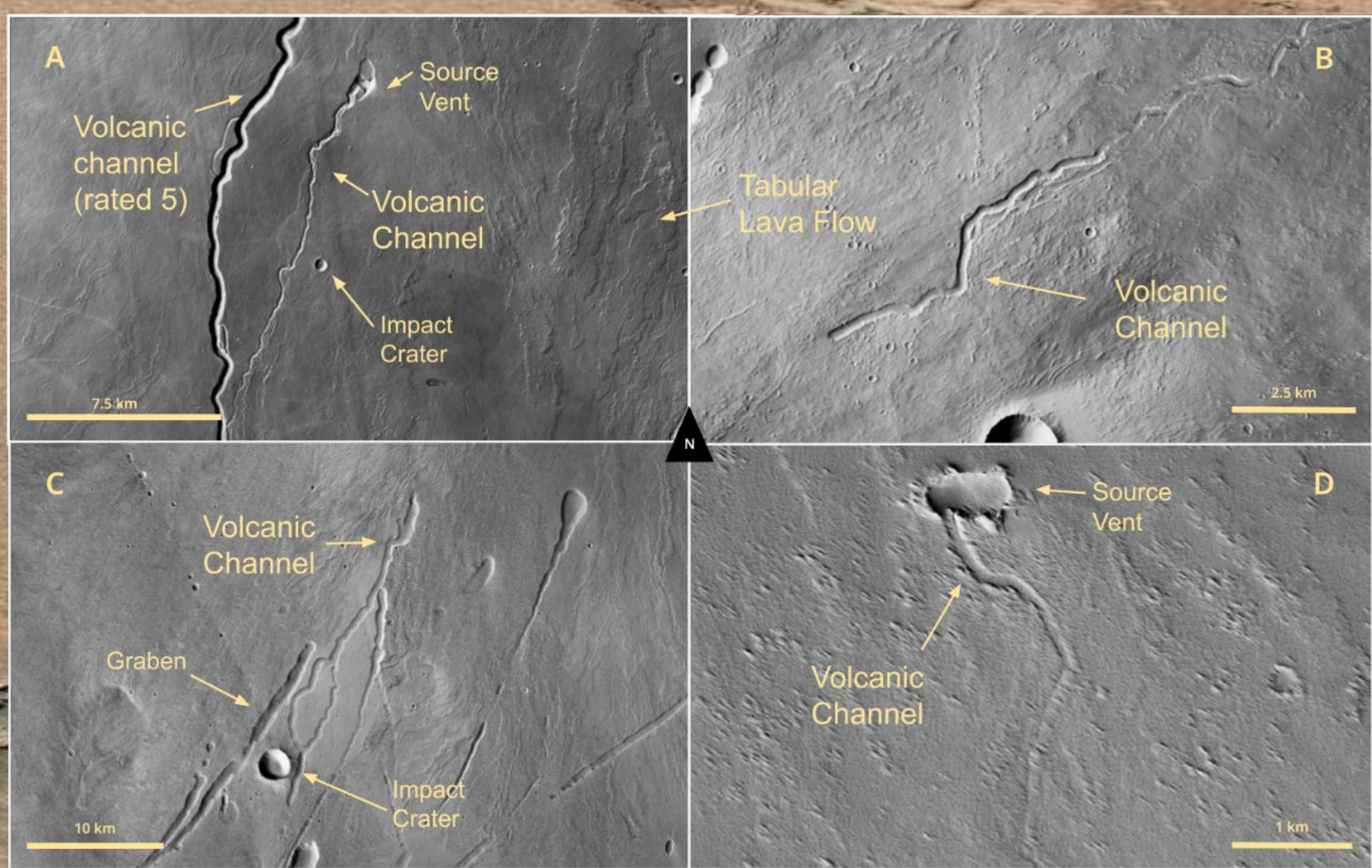

Figure 3: Examples of effusive volcanic channels observed in this study in context with other geologic landforms. All images are visible CTX (~5 m/px), with illumination generally from the west. Panels A and D are located on the southern Ascraeus rift apron. Panel B is located on the northern Arsia rift apron. Panel C is located on the southern Pavonis rift apron. Note the graben in panel C which are tectonic features.

DATA

- Mars Orbiter Laser Altimeter (MOLA) global topography at ~463 m/px [Zuber 1992; Smith et al 2001]
- Mars Odyssey Thermal Emission Imaging System (THEMIS) infrared data at 100 m/px [Christensen et al., 2004]
- Mars Reconnaissance Orbiter (MRO) Context Camera (CTX) at ~6m/px [Malin et al. 2007
- MRO High Resolution Science Experiment (HiRISE) at ~0.5 m/px [McEwen et al., 2007]
- Mars Express High Resolution Stereo Camera (HRSC) digital elevation models (DEM) at ~50 - 70 m/px resolution [Neukum 2004]
- Java Mission-planning and Analysis for Remote Sensing (JMARS) GIS

METHODOLOGY

We mapped the distribution of effusive volcanic channels on the Tharsis Montes' rift aprons. First, we created a geospatial dataset by identifying channels consistent with effusive volcanism. Each feature was mapped as a single point (latitude, longitude) located at the source or uppermost reach of the channel. We identified channels using the Mars Odyssey Thermal Emission Imaging System (THEMIS) infrared data at 100 m/px [Christensen et al. 2004] and the Mars Reconnaissance Orbiter (MRO) Context Camera (CTX) at ~6m/px [Malin et al. 2007]. Where present, detailed investigation of a given feature utilized the MRO High Resolution Science Experiment (HiRISE) at ~0.5 m/px [McEwen et al., 2007]. Using Mars Global Surveyor Mars Orbiter Laser Altimeter (MOLA) at resolution ~463m/px [Zuber 1992; Smith et al 2001] and Mars Express High Resolution Stereo Camera (HRSC) digital elevation models (DEM) at ~50 - 70 m/px resolution [Neukum 2004], we conducted preliminary morphologic analyses of a subset of channels in the form of along-channel length profiles, which allowed us to compute a length, average slope, and 'source'. All geospatial and topographic analyses were conducted in the Java Mission-planning and Analysis for Remote Sensing (JMARS) GIS.

In order to distinguish between collapse, tectonic, explosive, and aqueous features that resemble effusive volcanic channels, we created a ranking system to assess our confidence in channel formation. A ranking of 1 or 2 demonstrated little or no confidence in a volcanic origin while a ranking of 4 or 5 indicated likely or very likely volcanic origin. A score of 3 represented that the channel was inconclusive. We determined confidence based on the following criteria: identification of a probable volcanic source (e.g., sub circular or linear source depression), associated deposits, proximity to volcanic terrain, and morphological comparison to previously identified features on Mars and the Moon.

To assess channel length, slope, and morphology down slope, we drew along-channel profiles down the center of channels, using methods outlined in Hurwitz et. al [2013] (Figure 5). Some channels displayed secondary channels, but for this preliminary survey we focused only on the dominant channel.

FUTURE WORK

Next steps will include completing length, width, and (where possible) depth measurements of all observed effusive volcanic channels. We will also calculate channel sinuosities. We will compare our measured and calculated metrics with lunar and other Martian examples. Additionally, we will account for channel morphology (i.e., cross-sectional and along-channel morphologies). For a subset of channels, we will model the volume of erupted material and other eruption parameters. This work will form the foundation of a senior thesis culminating in a written manuscript.

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PRELIMINARY OBSERVATIONS

We created a geospatial database of 167 effusive volcanic channels on the 6 rift aprons of the Tharsis Montes shield volcanoes - Arsia Mons, Pavonis Mons, and Ascraeus Mons. While the presented work is ongoing, we have made the following preliminary observations. The largest number of channels were located on the Arsia Mons rift aprons with 72 channels total (25 on the North apron and 47 on the South apron), while the smallest number of channels were observed on Pavonis Mons (3 on the north apron and 24 on the south apron). To date, we have measured the lengths of 92 channels, which range from ~1.5 to ~240 km with an average length of ~24 km. Observed channels occurred at a mean elevation of ~7.3 km above the Martian datum. Observed channels had a mean slope of 0.86 degrees.

PRELIMINARY CONCLUSIONS

1. More effusive volcanic channels are observed and thus preserved on the rift apron of the oldest Tharsis Montes - Arsia Mons.
2. Longer channels are observed on the rift apron of the tallest Tharsis Montes - Ascraeus Mons.
3. The lowest slopes occur on the rift apron of the shortest Tharsis Montes - Pavonis Mons.

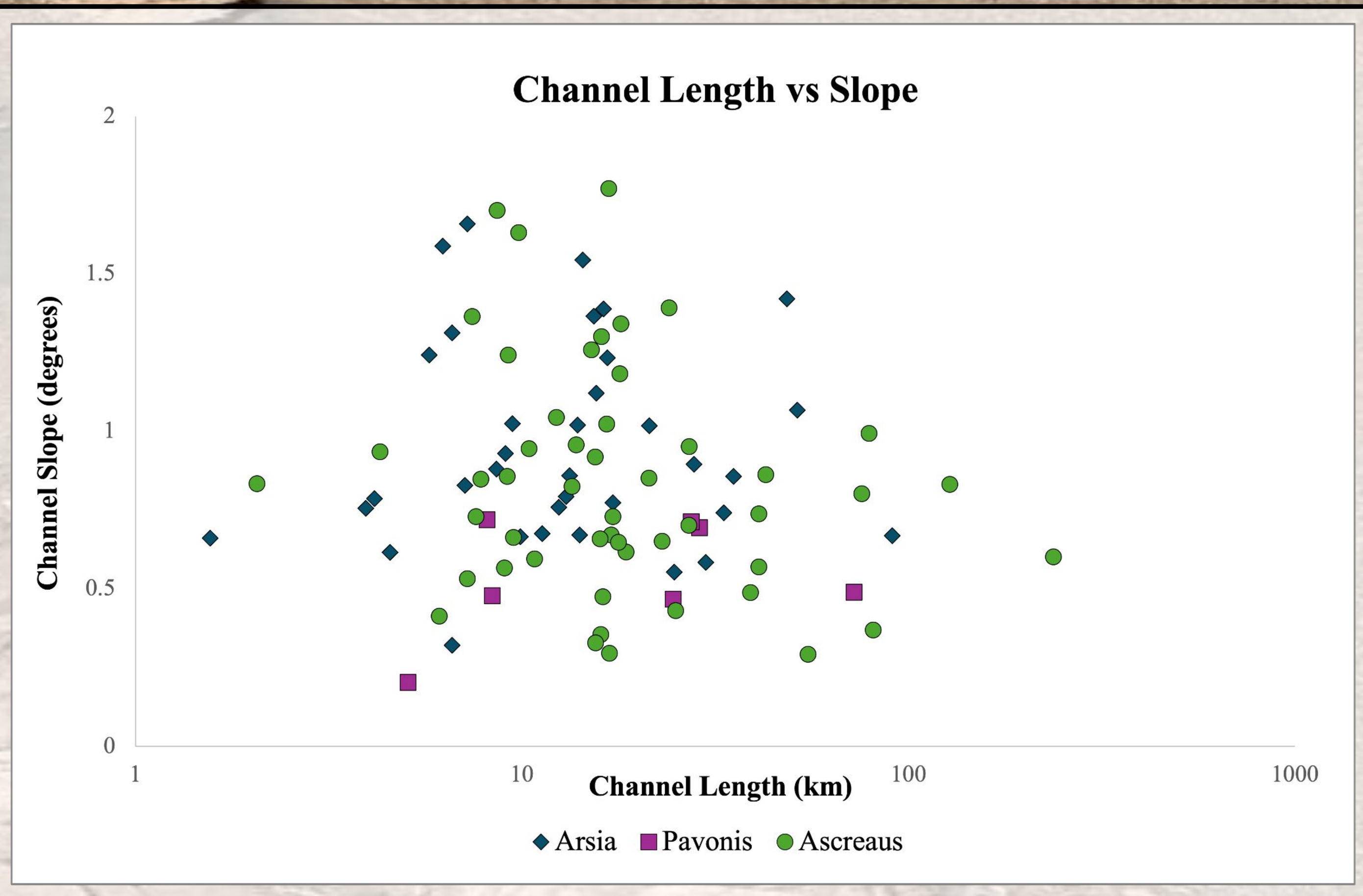

Figure 4: Relationship between average channel slope and length of channel. Channels occur across a narrow range of slopes but lower slope are observed on Pavonis while Ascraeus Mons hosts longer channels

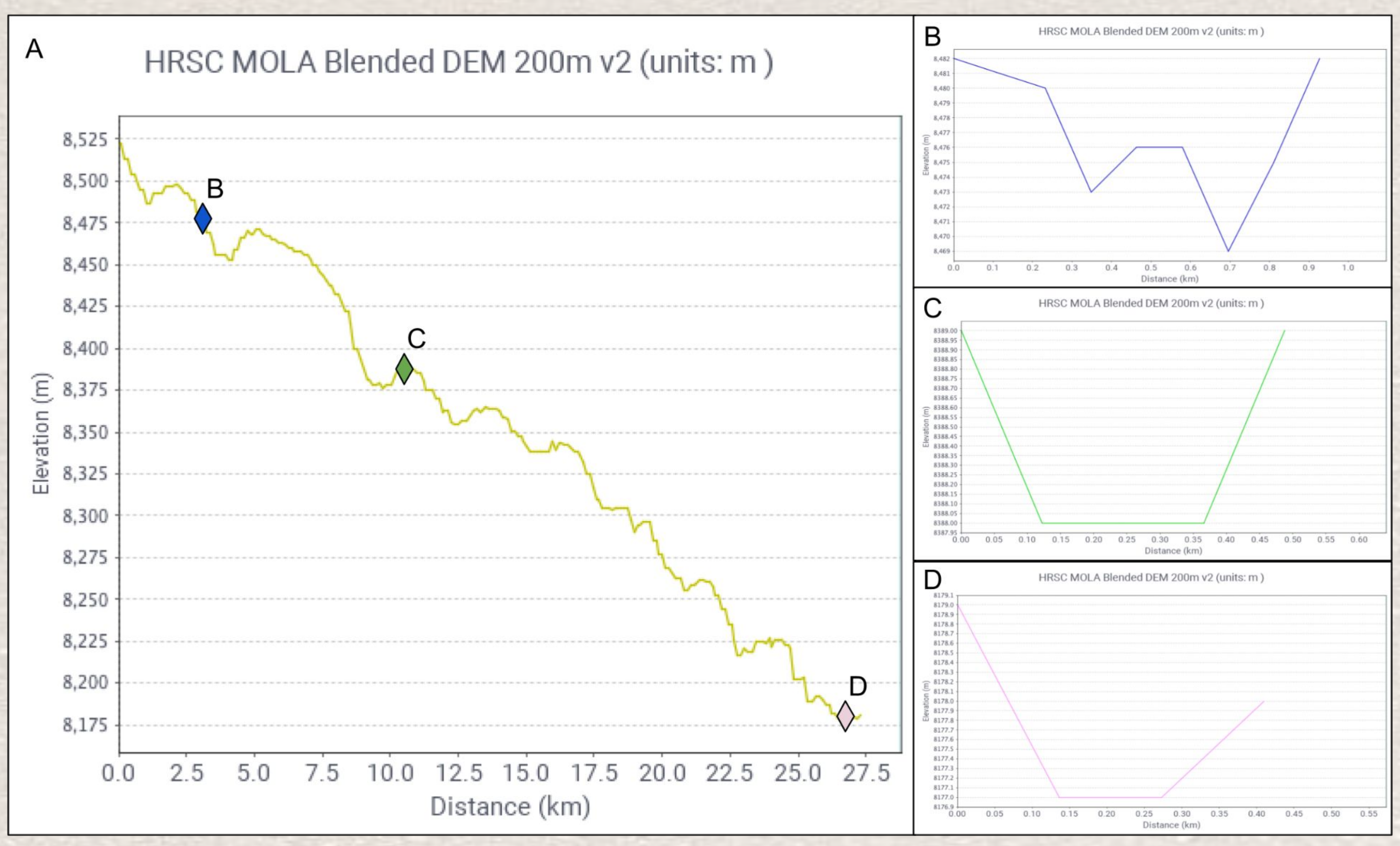

Figure 5: Longitudinal and cross-sectional profiles using MOLA Digital Elevation Model at 463 m/pixel. Panel A is a longitudinal profile of channel C from Figure 3. Panels B, C, and D each depict a cross sectional profile taken at the respective labeled diamonds on panel A.