GROWTH AND DESTRUCTION CYCLES AND ERUPTION STYLES AT THARSIS THOLUS, MARS.
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Introduction: Tharsis Tholus is located in the Tharsis region, approx. 800 km to the ENE of Ascraeus Mons. The edifice of Tharsis Tholus is unique among Martian volcanoes as it is structurally divided into sectors suggesting a complex volcano-tectonic evolution [1-3]. The objective of this study was 1) to identify cycles of edifice growth and destruction and causes of instability, 2) to estimate the mineralogical composition of rocks and loose deposits, 3) to provide a time frame of volcanic activity, and 4) to characterize eruptive styles at Tharsis Tholus. Here, improved morphometric data of Tharsis Tholus are presented and some of the above aspects are discussed.

Methods: Medium to high-resolution imagery (HRSC, MOC-NA, CTX, HiRISE, and THEMIS) was used for geological mapping. For calculating morphometric properties of the edifice a HRSC-DTM (areoid as reference body) with a 100 m grid was created. Dating of selected surfaces was performed following the methodology of [4]. Preliminary results on the mineralogy of Tharsis Tholus were obtained from spectral data of OMEGA and CRISM instruments.

Morphometry: The edifice has a planar extension of 155 km (NW-SE) by 125 km (NE-SW) with an elevation up to 9000 m on the west flank. The volcano exhibits a strong relief and can be subdivided into five major sectors: north flank, west flank, east flank, south flank, and the central caldera (fig. 1). The slopes vary from <1° up to 27°. The convex shape is particularly noted on the north, west and parts of the south flank where flanks arise initially at slope angles of around 16° and then continuously flatten with increasing altitude to 3° to <1°. The surrounding plain is composed of Tharsis Montes lava flows circumventing Tharsis Tholus [5]. The ponding of lava on the west flank generated a relief with respect to the lava plain east of the volcano with a W-E elevation drop of 1100 m. Due to the partial burial of Tharsis Tholus by lava flows, the original basement surface, and hence, the true dimensions of the edifice are unknown. However, to the east of the volcano the tips of a large buried impact crater-rim are still preserved (fig. 1). Using the approximate extension of 41×47 km of the impact-crater rim, a rim height of about 500 m results [5] with the basement being at 500 m. The visible edifice volume is approximately 31.1×10^3 km³, however, if a basal plane at 500 m is assumed, an edifice volume of $>50\times10^3$ km³ results.

Volcano-tectonic features: The edifice of Tharsis Tholus shows the structures of at least four large deformation events. The central and most prominent structure of the volcano is its central caldera. It is bordered by a well-preserved system of concentric normal faults. Peripheral ring faults generated individual blocks that moved downslope to varying degrees into the caldera. The maximum subsidence of the caldera floor is 3000 m; the collapse volume is calculated at approx. 2160 km³. The caldera (36.7×38.9 km) has an elliptic shape oriented NW-SE.

The flanks of the volcano are characterized by four large scarps oriented radially from the central caldera. The arcuate shapes of the scarps and their orientations suggest voluminous collapses of the western and eastern volcano flanks in a sub-vertical caldera-like fashion. On the southern flank a further caldera structure is displayed by an arcuate scarp and a plateau-like plain. Due to a large impact event most of the caldera structure is now concealed.

Large parts of the volcano are cut by parallel normal faults forming grabens. These grabens post-date the large collapse structures at the volcano's flanks. In the central caldera however, the grabens are covered or absent. All the graben structures are oriented in the NE-SW direction. Minimum and maximum graben widths are 470 m and 4.36 km, respectively.

Deposits: The entire edifice is covered by a thick layer of dust and/or ash which is in strong contrast to the pristine nature of the surrounding lava plain. Where local landslides on steep walls/scarps occurred "fresh" rock is exposed. Debris avalanche deposits (DADs) associated with the large western sector collapse are still preserved to the northwest mostly as large coherent blocks. As a result of post-depositional lava coverage, the extent of the DAD is unknown but a minimum travel distance of 100 km is noted. The visible volume of the DAD is computed at approx. 102 km³. Minor landslides also occurred along caldera walls, particularly on the western and southeastern portion. Exposed sector scars and caldera walls exhibit solid lava rock in their top portion; the lower 2/3 of the

slopes are covered by talus. Single lava flow channels are still observable on flank surfaces which can be traced up to 33 km from source.

Areas of volcanic activity: Multiple areas of volcanic activity were identified: 1) flank eruptions associated with graben formation, 2) fissure eruptions, and 3) a satellite vent at the foot of the west flank forming a strato-cone. This satellite volcano has a nearly perfect conical shape and rises 1168 m above the surrounding lava plain. The visible volume is about 5.7 km^3. There are currently no indications for volcanic activity prior to or after the formation of the central caldera.

Chronology: First results of crater counting indicate that the oldest parts of the edifice were constructed at around 3.82 Ga (late Noachian) which is in agreement to results of [6]. The west flank appears to be ca. 3.73 Ga old whereas the east flank shows an age of ca. 1.08 Ga (Middle Amazonian). A fissure eruption on the south flank produced a lava flow at around 196 Ma (Late Amazonian).

Mineralogy: OMEGA data (orbits 2336_4 and 4219_4) suggest the presence of olivine-rich material only on the surface of the south flank whereas material that is enhanced in high-Ca pyroxene appears to be restricted to the north flank and parts of the central caldera floor. The lava plain surrounding Tharsis Tholus is olivine poor. CRISM data (FRT00003DF2) were studied on the east-facing scar of the west flank. The patterns of the absorption in the reflectance spectra clearly show that the surface of the west flank is covered by olivine-rich material, probably dust and/or ash. In contrast, exposed lava on the scarp has a mineralogical composition of low-Ca and high-Ca pyroxene. No phyllosilicates, sulfates or ferric oxides were detectable in the CRISM IR and VNIR image.

Discussion: The volcano-tectonic evolution of Tharsis Tholus points to a more complex history. The existence of two main loci of activity, the central caldera and the subordinate southern caldera, indicate a multipart magma storage system. Changes in lava rheology are observed (shield volcano vs. strato-cone) which indicates magma differentiation within the plumbing system of the volcano during phases of activity. The lifetime of the volcano spans more than 3.6 Ga starting prior to 3.82 Ga. Hence, the fissure eruption at around 196 Ma may not represent the final volcanic activity at Tharsis Tholus.

Scarps on the western and eastern flanks are interpreted to be structurally related to at least two large sector collapses. Their arcuate shape can be fitted by ellipses suggesting more or less vertical caldera-like collapses with the major portion of the upper flanks collapsing into the centre of the volcano and minor portions of the lower flanks collapsing laterally forming debris avalanches. Graben formations across the edifice reflect a regional-tectonic deformation superimposed on the local volcano-tectonic pattern of Tharsis Tholus. The least compressive stress of this regional stress field is oriented NW-SE which agrees with the direction of ellipticity of the central caldera and fitted ellipses to the flank scarps. The geometry of the central caldera indicates a shallow magma storage region, probably at the base of the volcano.

Future work: Periods of volcanic activity will be constrained by further crater counts on different portions of the volcano and the surrounding lava plain. As a result, a detailed chronology of events will provide estimates on magma extrusion rates. Further, geophysical modeling may elucidate new insights into the volcano-tectonic evolution of Tharsis Tholus.

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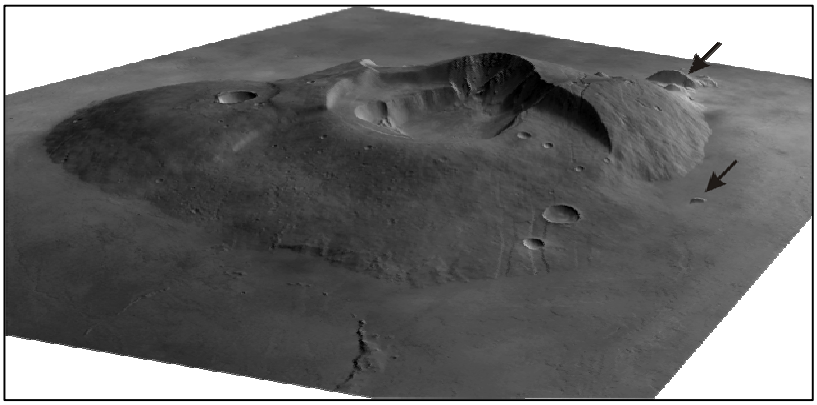

Figure 1: Three-dimensional view of Tharsis Tholus looking SW. In the foreground the buried impact crater rim is noted. Arrows point to debris avalanche deposits. HRSC-DTM of orbits 997, 1019, 1041, 1052, and 5081. Vertical exaggaration 2x.