STRESS CALCULATIONS FOR THRUST FAULTS IN THE SOUTHERN THAUMASIA REGION, MARS

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Summary: Surface displacements, material trajectories, Coulomb stress change, and dilational normal strain were calculated using the Coulomb program for thrust faults in southern Thaumasia, Mars. Timing of the thrust faults was determined from the Coulomb stress change calculation. Fluid pathways through the faults were determined from the dilational strain calculations.

Introduction: Material displacements and trajectories, Coulomb stress change, and dilational normal strain were calculated for lobate scarps in the southern Thaumasia region, Mars. These calculations are important for understanding the tectonic and volatile history of this area. Timing of the lobate scarps and locations of fluid flow pathways were determined in this study. Timing of thrust faulting at the southern margin of Thaumasia can be used to work out the history of Thaumasia and its relation to Tharsis.

Because Thaumasia is a significant portion of Tharsis, understanding its history will contribute to the understanding of the volcanotectonic history of the Tharsis region [1]. Understanding the volcanotectonic history of Tharsis is critical to understanding the tectonic and geologic evolution of Mars [2]. Tharsis is the largest volcanotectonic province on Mars and has been active throughout Mars' history [1,2,3,4]. Unraveling its complex history will give new information about the evolution of Mars.

Lobate scarps are landforms seen on the Moon, Mercury, and Mars, and are characterized by a steeply dipping scarp face, a gently dipping back slope, and a trailing syncline [5,6]. On Mars, they are found in Noachian terrain with relief on the order of a few hundred meters, although some stand up to 1200 m above the surrounding highlands [6,7]. Based on deformation of impact craters, these features are compressional structures and are the expression of surface breaking thrust faults [6-9].

The faults below the lobate scarps are assumed to deform the entire thickness of the brittle lithosphere and scarp topography is primarily controlled by fault geometry [6,10,11]. This relationship has been used to model the geometry of the thrust faults at depth in the southern Thaumasia region on Mars [6].

Regional and Geologic Setting: The Thaumasia region is a major volcanotectonic province of Tharsis that lies south of Valles Marineris and is at the southern edge of Tharsis (Figure 1). It includes a tectonic plateau with high interior plains and surrounding highlands [1]. Tharsis is surrounded by many radial graben and a large system of concentric wrinkle ridges (and thrust faults) that extends over the western hemisphere of Mars [1,2].

The Thaumasia region consists of diverse rock types, tectonic structures, and erosional and depositional features [1]. The Thaumasia Plateau is the dominant feature, extending nearly 2900 km in length and is ~4 km above the surrounding terrain [1,12]. The surrounding plains consist of cratered highlands to the south, ridged plains to the east, and lobate lava flows from Daedalia Planum to the west [1]. For detailed stratigraphy see [1] and [13].

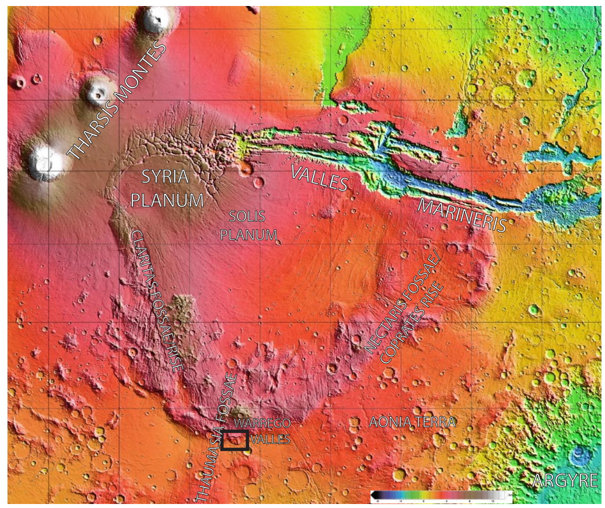

Figure 1. Index map showing the Thaumasia region, Mars. Key locations are labeled. Study area is shown in black box. Base image is MOLA topography. MOLA topography scale shown in lower portion of image.

Thaumasia volcanotectonic activity occurred early in the development of Tharsis [1]. The tectonic histories of Mars and Thaumasia are recorded as the distribution and ages of fault and ridge systems [1,2]. Approximately 15,000 tectonic structures, which include faults, graben, wrinkle ridges, and broad and narrow ridges, were mapped and dated by [13] for the Thaumasia region. The majority of structures mapped by [2,7] were extensional, while a smaller fraction were compressional features. Tectonic activity began and peaked during the Noachian and declined during the Hesperian through the Amazonian [1,2].

Methods: The forward mechanical dislocation program Coulomb (available at http://quake.usgs.gov/research/deformation/modeling/coulomb/index.html) [14,15] was used to predict surface displacements, material trajectories, Coulomb stress changes, and dilational normal strain associated with thrust faulting in southern Thaumasia. This approach has been used successfully to model the surface displacements of the Amenthes Rupes thrust fault [10].

The sense, magnitude, and distribution of offset were input for the faults, and stresses and material displacements were calculated by using stress functions for an elastic half-space [10]. A fault surface is idealized as a rectangular plane, with dip angle θ and vertical depth of faulting x. The magnitude of displacement was estimated by using displacement/downdip fault height (*D*/*H*) scaling to be ~1.3 km. This value is consistent with other large thrust faults, such as Amenthes Rupes [10]. The displacement distribution along the fault is taken to be linear along both strike and dip for the simplified geometry of the study region. Based on results from [10], the faults are not modeled to be listric at depth.

The fault geometry in the study area in southern Thaumasia is considered (box in Fig. 1; Fig. 2). Here the geometry has been simplified (faults are linear and the northernmost fault is not segmented). It was inferred that fault 1 (Fig. 2) was a pure thrust fault, with the compression direction being ~ due N-S. Faults 2 and 4 have a small component of right lateral strike slip motion, and faults 3 and 5 have a small component of left lateral strike slip motion. Evidence for this can be seen in Fig. 2, where the crater on fault 4 has been offset right laterally.

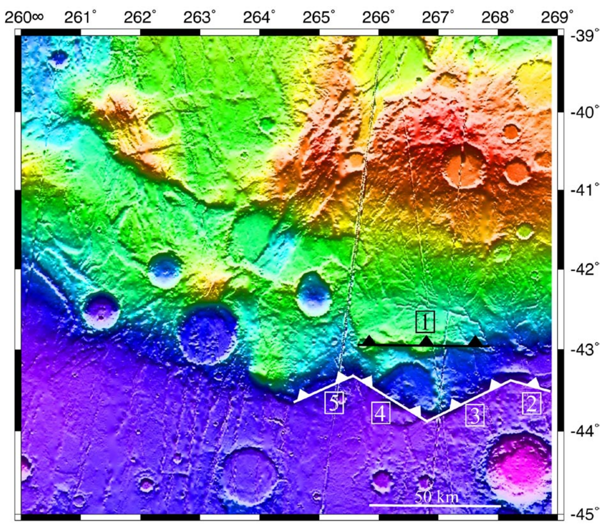

Figure 2. Fault map showing the approximate location and simplified geometry of the faults in this study (shown in black and white). Triangles are on the upper plate. Faults numbered for simplicity. Red: high elevation, purple: lowest elevation. Warrego Valles are located in the green area above fault 1. Base image MOLA digital elevation model, resolution of 200 px/degree. North is up.

Results: Broadly, a Coulomb stress increase occurs along strike and at obtuse angles to the fault tips in map view, indicating enhanced (triggered) slip. The faults are likely to propagate along strike in these areas of positive Coulomb stress change [14]. A thrust fault that cuts the entire brittle layer of the crust, such as this one [6], relieves stress over a wide area in its cross section, and inhibits failure on nearby thrust faults [14], therefore the two faults (fault 1 and faults 2-5) could not have been active at the same time. The tendency of this system to propagate along strike may account for the small fault at the eastern edge of the array (fault 2).

Areas where dilational normal strain is positive (i.e. volume increase) are potential conduits for fluid flow. Positive dilational strain occurs in from the crest of the anticline down the backslope, encompassing the majority of the upper plate and extends along strike. Therefore, the areas between faults 1 and 2-5 and behind (north) of fault 1 are potential conduits of fluid flow. Fluid would migrate parallel to the fault array.

Discussion: The geological and tectonic histories of the Tharsis and Thaumasia regions on Mars are complex. The study area focuses on a small region in southern Thaumasia with similarly complicated tectonic and geological histories. Surface distortion and displacement, dilational normal strain, and Coulomb stress change were calculated for this portion of Thaumasia. In general, triggered slip would occur along strike, resulting in E-W growth of the thrust-faulted plateau margin. Surface distortion and displacement are largest where three faults (1, 3, and 4) interact near the center of the fault array, with the upper plate of fault 1 being higher than that of the linked faults 2-5. Motion on faults 2-5 would impede motion on fault 1, and therefore, motion on fault 1 cannot be contemporaneous with motion on faults 2-5. This implies that fault 1 formed prior to faults in the southern array (most likely faults 3 and 4), and that when these faults formed, motion and growth of fault 1 ceased. This type of age relation is common in terrestrial thrust fault systems, where the faults get younger away from the compression direction [16].

Fluid flow would most likely occur in the anticlines formed by distortion and displacement in the upper plates of the faults. This is especially important for the easternmost portion of the study area because Warrego Valles, a large well developed dendritic drainage system, occurs on the upper plate of fault 1 (Fig. 2). A detailed investigation at the topography at the mouth of these valleys and the changes in slope should further constrain timing of the incision of this valley system and will contribute to timing constraints for liquid water on the surface of Mars.

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