EPSC Abstracts
Vol. 12, EPSC2018-197, 2018
European Planetary Science Congress 2018

Growth and Structural Style of Thrust Systems on Mars

Christian Klimczak (1), Corbin L. Kling (2) and Paul K. Byrne (2)
(1) Structural Geology and Geomechanics Group, Department of Geology, University of Georgia, Athens, GA 30602, USA (klimczak@uga.edu), (2) Planetary Research Group, Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27612, USA

1. Introduction

Evidence suggests that large thrust fault systems, with lengths greater than the thickness of the brittle lithosphere, are widespread within the southern highlands on Mars [e.g., 1, 2]. As is typical for any large-scale fault, these thrust systems likely consist of complex zones of deformation involving one or more fault planes, a zone of intensely sheared rock (the fault core [3]), and a fault damage zone surrounding the fault core. On Mars, understanding of fault zone complexity and fault rock properties from field observations is limited, such that large faults are generally approximated as a single, large slip plane. However, more detailed knowledge of the growth and structural style of thrust systems on Mars is critical in light of the upcoming NASA InSight mission for understanding the strength properties and seismic behavior of faults in the Martian lithosphere [4].

Sub-surface thrust fault architecture, geometry, and amount of tectonic uplift resulting from cumulative slip on the faults are together expressed at the surface as an asymmetric ridge. This morphology is interpreted as fault-related anticlinal flexures in the hanging wall of the fault, with one steep and one gentle slope, representing the fore– and backlimb, respectively, and a fault surface break at or near the base of that forelimb (Figure 1a). Several such landforms possess a few thousand meters of relief and are hundreds of kilometers long [e.g., 2]. Characterizing the map patterns and along-strike morphology of such landforms provides more information on the three-dimensional shape of their fault planes and slip distributions (described below), which offer clues to fault growth and structural styles of the thrust systems.

2. Growth of Martian Thrust Faults

We studied map patterns and growth geometries of 20 large thrust fault-related landforms across Mars, with a total of 25 individual fault segments, by assessing the changes of topography across the length of each of the mapped landforms [5] (Figure 1b). This methodology is commonly applied to Terran faults, including thrust systems [e.g., 6]. Because of low erosion rates on Mars [7], the observed fault-related topography essentially reflects the cumulative amount of accommodated offset on the faults. The observed topographic variations along the landforms [5] (Figure 1a) may thus be interpreted as cumulative slip distributions. Our results indicate that, although there is great variability in how these faults have grown, their slip distributions can be characterized as either symmetric or asymmetric. Some 14 fault systems show symmetric profiles (Figure 1b, left panel), with six showing asymmetric profiles (Figure 1b, right panel). Supported by our map observations, we interpret many of the asymmetric slip distributions as representing fault growth influenced by interactions with other nearby structures. A few examples may also show fault tip restrictions arising from, for example, changes in material strength from lithology or fracture density [8−9]. Symmetric slip distributions, in contrast, are indicative of fault growth that has largely been unaffected by such barriers or other nearby faults [e.g., 10].

3. Thrust System Structural Style

Large thrust systems are widespread across Mars, and feature a broad range of orientations. They are typically found as isolated landforms that do not show any arrangements in, for instance, long continuous mountain belts with multiple aligned and parallel landforms as major thrust systems on Earth do. The isolated structures show lengths of ~150 to ~400 km with uplifts of 1000 to 2500 m, but the Phlegra Montes, a set of landforms in the northern lowlands, is almost 1400 km long and boast uplifts of as much as 3400 m. All topographic expressions were found to be asymmetric ridges in cross section, with a surface break at the forelimb (e.g., Figure 1a). The lengths and amounts of uplift found for these landforms show that substantial mountain building took place on Mars and, given the widespread geographic distribution of these landforms across the planet, that it occurred on a global scale.

Mountain building on Earth is either directly or indirectly related to plate tectonics. Whether some primitive form of plate tectonics occurred on Mars is debated [11], but there is no evidence for globally distributed, Earth-style plate tectonics preserved in its geologic record [12]. Mountain building on Mars, if related to some form of plate tectonics, would likely involve structural styles of faulting comparable to thrust belts on Earth, including multiple, long, sinuous thrust fault traces and complex landform morphology. Although the formation of thrust belts, such as found on Mercury [13], does not require plate tectonics, the lack of such morphological evidence supports the view that Earth-style plate tectonics, and associated formation of thrust-belt-style faulting, did not prevail in the geologic history of Mars.

Given that large-scale thrust faults on Mars are thought to penetrate to depths of ≥30 km [2,14,15], and based on the relatively simple map patterns and asymmetric cross-sectional topography of landforms in our study areas, the structural style of the thrust faulting analyzed here is comparable to Terran intra-plate, basement-block faulting and associated fault-propagation folding. Martian thrust systems are thus analogous to faulting associated with the Laramide orogeny in the western United States or the late-Cretaceous block and inversion tectonics in central Europe.

4. Summary and Conclusions

We observe a wide diversity in thrust fault displacement distributions that can be broadly categorized into symmetric and asymmetric shapes. This diversity is likely caused by a combination of factors including regional variations in rock properties and lithospheric structure, as well as fault interaction and linkage. The widespread distribution of these structures across Mars, their broad set of orientations, their straightforward, linear map patterns with only one or a few segments as part of a single major structure, their isolated occurrence, and their simple asymmetric cross-sectional topography do not correspond to Earth-like plate-tectonic-style thrust belts. Instead, our observations support a style of faulting analogous to that of intra-plate basement-block faulting and associated fault-propagation folding of near-surface units. This view will help provide constraints when interpreting fault-induced seismicity detected by the InSight mission, which will land on the Red Planet in November 2018.

5. References

[1] Watters, T. R.: JGR, Vol. 98, pp. 17049–17060, 1993. [2] Egea-González, I. et al.: Icarus, Vol. 288, pp. 53–68, 2017. [3] Caine, J. S. et al.: Geology, Vol. 24, pp. 1025–1028, 1996. [4] Klimczak, C. et al.: LPS XLIX, March 19–23, Abstract #1083, The Woodlands, TX, USA, 2018. [5] Kling, C. L. and Klimczak, C.: LPS XLVII, March 21–25, Abstract #2888, The Woodlands, TX, USA, 2016. [6] Haiyun, B. et al.: JGR, Vol. 123, pp. 2484–2501, 2018. [7] Golombek, M.P. and Bridges, N. T.: JGR, Vol. 105, pp. 1841–1853, 2000. [8] Manighetti, I. et al.: JGR, Vol. 106, pp. 13667–13696, 2001. [9] Davis, K. et al.: JSG, Vol. 27, pp. 1528–1546, 2005. [10] Nicol, A. et al.: JSG, Vol. 18, pp. 235–248, 1996. [11] Barlow, N.: Mars: An Introduction to its Interior, Surface and Atmosphere, Cambridge University Press, 2008. [12] Zuber, M. T.: Nature, Vol. 412, pp. 220–227, 2001. [13] Byrne, P. K. et al.: Nature Geosci., Vol. 7, pp.301–307, 2014. [14] Schultz, R. A., and Watters, T. R.: GRL, Vol. 28, pp. 4659–4662, 2001. [15] Mueller, K. et al.: EPSL, Vol. 408, pp. 100–109, 2014.

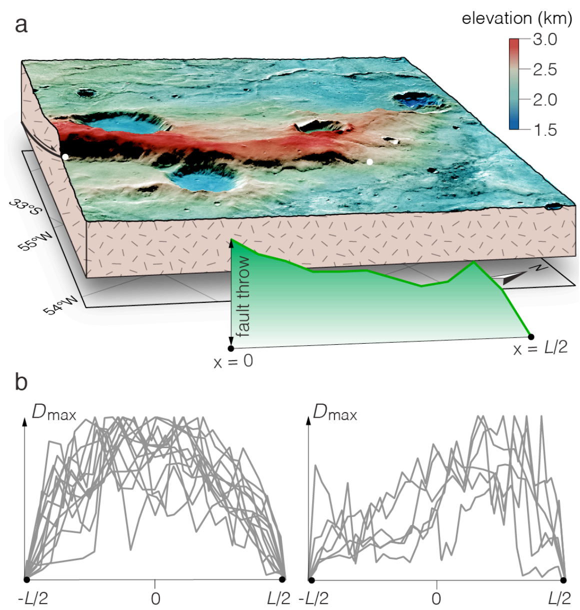

Figure 1. Thrust fault growth on Mars. (a) Block diagram showing the northern half of Ogygis Rupes, an example of a large thrust fault-related landform on Mars. Its slip distribution is shown in the foreground. (b) Symmetric (left) and asymmetric (right) slip distributions normalized by fault length (L) and maximum displacement (D_{max}) of all analyzed structures.