EXTENSION ACROSS THAUMASIA AND AROUND THARSIS ON MARS

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Thaumasia is a large region, which makes up the southern part of the Tharsis province on Mars. It is made up of ancient Noachian basement and younger Hesperian units that are complexly fractured by a number of different fault sets, including a characteristic fanning set of long, narrow grabens that appear to radiate from a point to the north on Syria Planum. Thaumasia is the only remaining region of Tharsis across which estimates of the extension have not been made [1]. However, because Viking Orbiter images in this region are not high resolution (generally a couple of hundred meters per pixel) and the scarps are narrow (generally around 0.5 km), photoclinometry cannot be used to estimate the vertical relief or throw, which is required to calculate the extension, across individual normal faults. In this abstract, the amount of extension across grabens in the Thaumasia region has been determined by measuring fault scarp widths [1]; results are incorporated into estimates of the total extension around Tharsis, providing the first quantitative estimates of the regional and total strain around Tharsis on Mars.

Measurement of the width of a normal fault scarp can be used to estimate the extension given information about the slope of the scarp and the dip of the fault. On Mars, most extensional structures are simple grabens, which are bounded by two inward dipping normal fault scarps of low slope [2, 3, 4]. Photoclinometric measurement of 665 simple graben scarp slopes throughout the western hemisphere of Mars [3, 4, 5] indicate an average slope of 8.6° (standard deviation 4.5°). Faults bounding simple grabens on Mars dip about 60° (with a loosely bracketed variability of 15°; [4]). As a result, the width of the scarp, Ws, can be used to calculate the extension [1],

\[ E_x = \frac{W_s \tan S_0}{\tan \alpha} \]

with an average slope, S0, and average fault dip, \( \alpha \). The formal uncertainty in this estimate, assuming independent variables, is \( \sigma = E_x \left[ \frac{dS^2}{(\cos^2 S_0 \sin^2 S_0)} + \frac{d\alpha^2}{(\cos^2 \alpha_0 \sin^2 \alpha_0)} \right]^{1/2} \), where dS and d\( \alpha \) are the uncertainties in the scarp slope and fault dip, respectively, which are taken from the standard deviations from the measured data set (given above). This uncertainty is 0.8 times \( E_x \), which is dominated by the uncertainty in the fault dip [1]. Decreasing uncertainties (to 15%) in determining height or slope from photoclinometry [3] or shadow measurements only decreases the formal uncertainty in extension to 0.6 times \( E_x \). As a result, this method allows estimates of extension across normal fault structures on Mars that are only slightly more uncertain than estimates using photoclinometry or shadows.

We measured fault scarp width across an arc-shaped 2000 km traverse through Thaumasia (37°S, 117.5°W to 42°S, 82.7°W). The traverse is broken up into 12 individual straight segments 50 km to 275 km in length, which are situated in areas where stratigraphic relationships and faulting history are reasonably well understood [6]. An example of the central portion of the traverse is illustrated in Figure 1, which shows that segment breaks occur along strike, so that no structures are missed.

A total of 235 scarp widths and 10 scarp shadows (which yields the throw of the fault) were measured across the traverse directly on the digital images. The summed width of the scarps is 114.2 km, yielding an extension of 10±8 km. The summed throw of the shadowed scarps is 2.5 km, which divided by tan\( \alpha \) results in 1.5±0.9 km of extension. Taken together the scarps indicate about 11.5 km of extension with a formal uncertainty of ±9 km across Thaumasia. For a total traverse of 2000 km, the regional strain is of order 0.5%.

Estimates of extension across other regions of the Tharsis province are roughly similar. Measurement of fault scarp width [1, 7] and elongation of deformed craters [8] indicate about 22±16 km and 19±12 km of extension, respectively, across Tempe Terra. Photoclinometry across grabens in the Alba Patera region suggests about 8 km of extension [9]. Structural offsets [10] and measurements of fault dip [11] in Valles Marineris suggest 16 km of extension. Formal uncertainties due to measured variations in fault dip in Valles Marineris [11] and uncertainties in fault throw in Alba, result in 16±13 km and 8±5 km of extension in these two regions, respectively. Preliminary estimates of extension across Sirenum, southwestern Tharsis, suggest about 3±2 km of extension across this region [1]. Tempe, Alba, Sirenum and Thaumasia each...
occupy about an eighth section of Tharsis; Valles Marineris and Olympus, between Alba and Sirenum (which has negligible extension), each occupy a quarter section. As a result, extensional strain varies significantly from 0.1% to 2% across different regions around Tharsis. Taken together these estimates suggest a total circumferential extension of about 60 km with an uncertainty of ±46 km. For a 2500 km radius circumference (15,700 km) these results suggest a total circumferential extension of 0.5% (0.1% to 0.7%).

These estimates of total circumferential strain can be compared favorably with lithospheric deformation models of Tharsis. Peak stresses calculated in flexural loading for a radial distance of 2500 km from the center of Tharsis are of order 100 MPa for a 200 km thick lithosphere [2]. For a thinner lithosphere (~40 km) suggested by local plate bending models [12], peak stresses are roughly a factor of 5 times greater, given that model stresses vary with lithosphere thickness [13]. Note that even though stresses as high as this would never be reached due to failure at lower stress levels, these stresses can be used to estimate the total strain predicted by the model. For a lithospheric Young's modulus of $10^5$ MPa, the flexural loading model predicts a hoop extensional strain of 0.5%. As a result, to first order lithospheric deformation models and measurement of extension around the Tharsis province agree. Further variations in lithosphere thickness or other properties must be appealed to in order to explain the variations in extension observed in the different regions of Tharsis.


Figure 1. Mosaic showing central portion (segments) of structural traverse through Thaumasia.