EXTENSION ACROSS TEMPE TERRA AND SIRENUM PROVINCES ON MARS FROM MEASUREMENTS OF FAULT SCARP WIDTHS

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A new method of determining extension across grabens and rifts on Mars has been developed and applied to the Tempe Terra and Sirenum provinces. In principle, determining extension across grabens and rifts is fairly simple provided that the structures are not heavily modified by subsequent geologic processes. Available evidence suggests that most extensional structures on Mars are bounded by steeply dipping normal faults (1). If the dip of the fault is known, or can be approximated, then the throw (vertical displacement) between the upthrown (footwall) and downthrown (hanging wall) blocks is directly related to the extension or horizontal slip between the blocks. To estimate the vertical relief or throw across a fault, methods such as measuring the length of shadows or photoclinometry have been utilized (2, 3, 4). However, these methods have somewhat restrictive conditions for their use and can be both time consuming and impractical in certain situations. In this abstract, measurement of fault scarp widths are used with information on fault scarp slope and fault dip to estimate extension across normal faults in two provinces around Tharsis on Mars.

Most extensional structures on Mars are simple grabens, which are bounded by two inward dipping normal faults, with flat floors and equal scarps (1, 2, 3). As is the case for lunar simple grabens (5), mass wasting has considerably reduced fault scarp slopes on Mars (2, 3). Photoclinometric measurement of 628 simple graben scarp slopes throughout the western hemisphere of Mars (2, 3, 6) indicate an average slope of 8.6° (with a Poisson distribution-standard deviation ±2.9°). Higher fault scarps that bound rifts on Mars appear to have a steeper slope. Photoclinometric measurements of 200 large slopes on Mars indicate an average slope of 20° (with a normal distribution standard deviation ±9.6°). In addition, faults bounding simple grabens on Mars dip about 60° (with a loosely bracketed variability of 15°; 3, 5).

Simple measurement of normal fault scarp width (perpendicular to surface strike) can then be used to estimate fault throw and extension. All simple graben fault scarps are assumed to slope 8.6° and all rift and larger, more heavily modified graben fault scarps are assumed to slope 20°. The width of the scarp, W_s, can then be used to calculate the extension, $E_x = (W_s \tan S_o)/\tan\alpha_o$, with an average slope, S_o, and average fault dip, α_o. The formal uncertainty in this estimate, assuming independent variables, is $\sigma_{E_x} = \{E_x^2 [dS^2/(\cos^2 S_o \sin^2 S_o) + d\alpha^2/(\cos^2\alpha_o \sin^2\alpha_o)]\}^{1/2}$ (7), 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). In practice, the width of all simple graben scarps and larger, more heavily modified faults scarps are measured and summed separately; the extension and uncertainty are then calculated. The formal uncertainty in extension is 0.7 to 0.8 times E_x. Note that this uncertainty is dominated by the uncertainty in the fault dip, which can easily vary by 15°. For example, uncertainties of up to 15% in determining height or slope from photoclinometry (2) only decreases the formal uncertainty in extension to 0.6 times E_x. As a result, the new method described in this abstract allows estimates of extension across normal fault structures on Mars that are only slightly more uncertain than estimates using photoclinometry. We apply this method of measuring extension to fault scarps in Tempe Terra and Sirenum Fossae, where lighting conditions in Viking images are not entirely favorable for photoclinometry.

Tempe Terra is a large plateau of cratered highland and plains (Noachian through Hesperian age) on the northeast flank of Tharsis. It is cut by a series of narrow northeast-striking grabens that are Noachian through Hesperian in age (8). A series of wider and deeper grabens and rifts formed along the axis of the plateau in the Middle to Late Noachian (8), along with a volcanic center. Most of these grabens formed roughly radial to Tharsis during two main pulses of deformation (9, 10).

We measured fault scarp width across a northwest-southeast traverse through Tempe Terra (40.5°N, 89.5°W to 30.8°N, 76°W), which is roughly perpendicular to most of the structures and passes just to the south of the volcanic center but through the deep Tempe Terra rifts. A total of 272 scarp widths were measured; 201 simple graben scarp widths summed together to 71.4 km; 71 larger, more modified scarp widths summed together to 54.1 km. All together the scarps indicate about 17.6 km of extension with a formal uncertainty of ±13.4 km. For comparison, Tanaka and Golombek (11) found about 19±12 km of extension across Tempe Terra based on measured elongation of pre-existing craters.

Sirenum Fossae is located on the southwestern flank of the Tharsis rise. Twenty-six narrow structures are located at a distance of about 2500 km from the Pavonis tectonic center of Tharsis (9). These structures are oriented radially to this center and deform Noachian and Hesperian age rocks. The structures are very narrow in available Viking images (commonly comprising only a few pixels in the digital data base) and are either simple grabens or modified tension cracks. The region is devoid of local tectonic and volcanic centers and therefore may represent the circumferential extension due solely to Tharsis generated stresses.

We measured the perpendicular widths of each fault scarp, assuming each structure is a simple graben bounded by 2 scarps and determined a total scarp width of 28.9 km. Applying our method, the total extension is 2.5 ± 1.7 km across the region. This must be considered a minimum estimate of the extension, given that some of the structures may be tension cracks, which require more extension than similar width grabens. A total of about 1 km of extension was estimated by Tanaka and Chadwick (12), based on an oversimplified approach in which extension was assumed to be dependent on graben width.

The Sirenum and Tempe Terra regions each occupy about an eighth section of the roughly circular Tharsis rise. Nevertheless, the extensional strain accommodated by each is very different (roughly 3 km versus 18 km). Estimates of extension across other regions, such as Alba Patera (8 km; 4) and Valles Marineris (16 km, based on Chadwick and Lucchitta, 13, steep fault dip determinations and Schultz, 14, interpretations of structure), both of which also occupy up to an eighth section of Tharsis, further underscores this variation in circumferential extension around Tharsis. If Sirenum extension does, in fact, solely represent Tharsis regional stresses, then the total circumferential strain due to this stress source is only 20 km. However, total circumferential strain around Tharsis from the preliminary numbers cited above is roughly 45 km, not including the Thaumasia province. If the extension across Thaumasia is of the same order as the extension across Tempe Terra, total circumferential strain around Tharsis is of order 60 km. These results provide the first quantitative comparison of the heterogeneous strain among the various provinces around the Tharsis rise.

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