MEASUREMENT OF TECTONIC STRAIN BASED ON CRATER ELONGATIONS: AN IMPROVED TECHNIQUE APPLIED TO TEMPE TERRA, MARS; **K. L. Tanaka**[1] and **M. P. Golombek**[2], [1]U.S. Geological Survey, Flagstaff, AZ 86001, [2]Jet Propulsion Laboratory, Caltech, Pasadena, CA 91109.

Introduction. Dozens of elongated craters in the Tharsis region of Mars clearly appear to be deformed by normal faults and grabens [1]. Thus, elongated craters should provide a useful tool in the quantitative estimation of strain. In practice, however, several factors make this technique problematic, including (1) nontectonic processes and structural controls may produce elongated craters upon and (or) following impact; (2) strain estimates must deal with averaging individual strain vectors of varying magnitude, trend, location, and age; and (3) tectonic strain varies in trend and magnitude as a function of age and location. Given these factors, a careful approach should be taken to adjust for nontectonic elongations and to minimize the effects of geologic variables when estimating tectonic strain from crater elongations.

Previous analyses of crater elongation have resulted in greatly varying estimates of extension, which is likely due to overly simplistic measurement techniques. Thomas and Allemand [1] selected the most intensely faulted and elongated craters in the Tharsis region and measured their elongation perpendicular to the trend of the dominant fault direction. Obviously, these measurements would yield local strain maxima, rather than area averages (they cite ~10% extension for Tempe Terra). A later study on the Tempe Terra region [2], which included all measurable Noachian craters, resulted in a much smaller mean strain (1.9%). This result agrees with our estimate of strain deduced from measurement of fault-scarp widths [3]). Neither of the crater-based studies independently measured the orientation of strain (they simply assumed it to be perpendicular to structural trend) or quantified nontectonic elongations.

Methodology. The method presented herein minimizes measurement bias by measuring both the magnitude and orientation of the strain vector and provides some independent basis to assess nontectonic elongations. Using the Viking Mars Digital Image Mosaic (MDIM; 231 m/pixel resolution), the minimum diameter of a crater was measured interactively on the computer by fitting the largest circle possible within the interior crater rim. (Obviously, craters at the junctions of MDIM mosaics could not measured in this manner and were excluded.) With the circle in place, a maximum diameter was measured (both length and orientation) if a section (or opposing sections) of the rim extended significantly past the fitted circle, both circumferentially (across an arc of >30°) and radially (>500 m or more than 2 pixels of the MDIM). Elongations measured this way are reproducible to within ±5° in trend and ±250 m in length. We also counted the number of structures (normal faults and wrinkle ridges) that crosscut each crater. The same measurement approach was used to measure the elongations of similar-size, fresh-appearing craters in the same region that generally appear to postdate most of the structural deformation.

Results. We measured the widths and, where present, the elongated lengths and trends of 80 degraded (Noachian) craters and 70 fresh-appearing (Hesperian and Amazonian) craters. The craters range in size from 6 to 50 km in diameter. Only 7 of the fresh craters have significant elongations, and these show no collective, preferred orientation (according to statistical tests of sample uniformity at the 95% confidence level). Most of these appear to be due to low-angle impacts possessing obvious asymmetric ejecta patterns; another crosses a large fault scarp, which appears to control its elongation (see [1]).

In contrast, 32 of the 80 Noachian craters have significant elongations, which collectively show a preferred NW-SE trend (Figure 1). (The clustering of elongations exceeds the 2-sigma range in dispersion for a random uniform sample, which means that the distribution is nonuniform at the 95% confidence level.) Note that most of the elongation trends are roughly perpendicular to general normal-fault trends in Tempe Terra (most of the faults trend between N30°–60°E and some between N60°–80°E in easternmost Tempe Terra). The resultant vector of all the strains yields a mean strain of 1.1% trending N38°W; when weighted by crater diameter, the result is 0.9% at N40°W.

If the resultant strain vector calculated for all craters includes random nontectonic elongations, the magnitude of the strain vector would be lower than the actual tectonic strain (however, the orientation should be hardly affected). To remove their effect, our study indicates that about 10% of large, fresh craters in the Tempe Terra region have nontectonic elongations. Thus, an even higher percentage of the Noachian craters (which have undergone much greater erosional modification) should have anomalous elongations. Based on this reasoning, many if not all of the ten craters (13%) with elongations not normal to structural trends in Tempe Terra may be attributable to nontectonic elongation. Thus, a more representative estimate of the mean tectonic strain can be calculated by removing these ten presumably nontectonically elongated craters. Our result, weighted by crater width, indicates a mean strain of 1.96% oriented at N38°W.

Using this preferred estimate of mean strain, the strain across the cumulative crater width of 1,688 km (for all 80 craters) indicates 33.1 km of total extension. These craters appear to be crosscut by 335 structures (297 normal faults oriented perpendicular to and 38 wrinkle ridges aligned with the strain direction), yielding an overall average of ~100 m of extension (or compression normal to the extensional strain trend) per structure. Thus, our result is consistent with values of 50–130 m of strain deduced from photoclinometric studies of simple graben and wrinkle ridges in various areas of the Tharsis region of Mars (as reviewed in [2]).

Moreover, our results compare closely to our other approach for the same region, which derives extension from measurements of normal-fault scarp widths [3]. Two structural traverses across Tempe Terra yield estimates of 21.9 and 23.3 km of extension (slightly revised from earlier results in [3]), whereas the crater-elongation data across ~1,000-km-wide Tempe Terra suggest ~19.6 km of extension across the same region. The structural measurements indicate an average extension of 110 m per fault (a total of 45.2 km of extension across 410 normal faults), which is in excellent agreement with the average (100 m) derived from the crater-elongation measurements. Our strain estimates can be accommodated by existing simple kinematic brittle deformation models for individual grabens and wrinkle ridges and for the broad deformation of the Tharsis province and do not require an exotic tectonic mechanism (such as thin-skinned gravity sliding invoked to account for the much higher strains derived by [1]). Finally, we believe that the consistent results from each of our two methods of estimating strain (based on independent datasets—crater elongations and fault widths) confirms the validity and accuracy of each method.

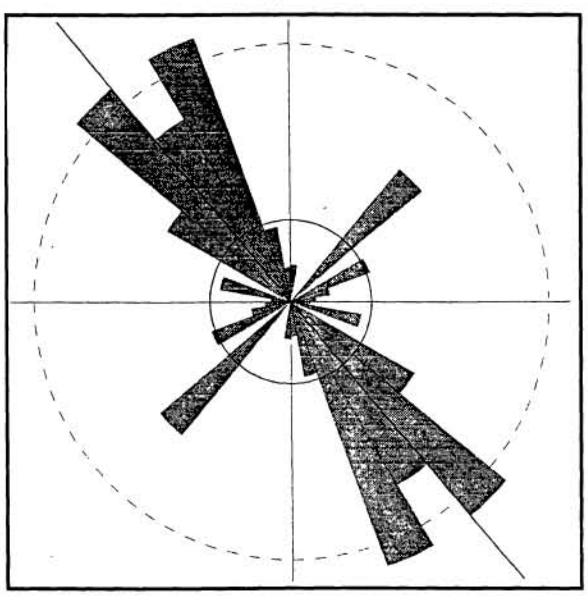

Figure 1. Rose diagram showing measured strains for all degraded (Noachian) impact craters of Tempe Terra included in this study (strains weighted by crater width). Data binned in 10° intervals. Solid circle shows mean value for a uniform distribution. Dashed circle shows mean value plus two standard deviations for a uniform random distribution (note that the data exceed this value in two places). Vector resultant (solid line) trends N40°W.

References. [1] Thomas P.G. and Allemand P. (1993) *JGR 98,* 13,097. [2] Tanaka K.L. and Golombek M.P. (1994) *LPS XXV,* 1377. [3] Golombek M.P. et al. (1994) *LPS XXV,* 443.