DISPLACEMENT-LENGTH SCALING OF JOINTS IN LAYERED DEPOSITS, SOUTHWEST CANDOR CHASMA. C. H. Okubo[1, 2], R. A. Schultz[3], A. T. Polit[1], A.S. McEwen[1], and The HiRISE Team[1], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, [2]chriso@lpl.arizona.edu, [3]Geomechanics-Rock Fracture Group, Department of Geological Sciences and Engineering, University of Nevada, Reno, NV 89557.

Introduction: Magnitudes of shear displacement along normal and thrust faults on Mercury and Mars are characteristically smaller relative to their length, compared to the displacement to length ratios of faults on Earth (Fig. 1) [1]. Displacement to length ratios are typically 6 x 10^{-3} or 6.7 x 10^{-3} for faults on Mars [2,3] and 6.5 x 10^{-3} for faults on Mercury [Watters et al., 2000]. On Earth, this ratio is typically 2–5 x 10^{-2} over a range of tectonic settings and rock types [4–8]. Faults on Mercury and Mars thus have less displacement relative to their length than faults on Earth.

Under–displacement of fractures (faults and joints) on Mercury and Mars is attributed to these planets' smaller gravitational accelerations relative to Earth [1]. Fracture displacements may be either shear for faults or dilation for joints. The ratio of a fracture's displacement to its length is a function of the deformation modulus of the surrounding rock mass, the yield strength of the rock near the fracture tip, and driving stress acting to displace the fracture [1]. Deformation modulus, yield strength and driving stress are proportional to gravity and are smaller in magnitude on Mercury and Mars relative to Earth for a constant depth, groundwater condition and intact rock strength [1].

Measurements of the displacements and lengths of fractures on Mars with sufficient accuracy for detailed displacement/length (D/L) scaling analyses are reported in the literature only for faults that exceed 10 km in length [i.e. 2,3]. Measurements of displacement and length for joints on Mars have also not been previously reported. Displacements along faults that are shorter than 10 km are predicted to scale with fault length at comparable ratios as observed on longer faults. An under–displacement of joint opening is also predicted for joints on Mars relative to joints on Earth.

Constraining the D/L scaling relations for faults and joints through the range of natural fracture lengths is vital to studies of crustal deformation on planetary surfaces. D/L scaling is applicable to investigations such as, determining rates of crustal deformation through time [3], inverting fracture–related topography for cumulative strain [9,10], stress history [11], and crustal structure [12] mapping the distribution of fracture–induced damage within the surrounding rock [13], and investigating fracture–supported fluid flow [14]. Quantification of D/L scaling relations for joints and for faults shorter than 10 km long on Mars and other planetary surfaces will facilitate crustal deformation studies over a wider range of terrains and at smaller spatial scales than can be attained with the currently available data.

Observations from Mars Global Surveyor and earlier spacecraft do not provide sufficient resolution to accurately measure displacement along faults that are less than several kilometers in length. Sufficiently accurate measurements of joint opening displacements have also been difficult to extract from these observations because the effects of erosion on the apparent joint widths are largely unconstrained in these data.

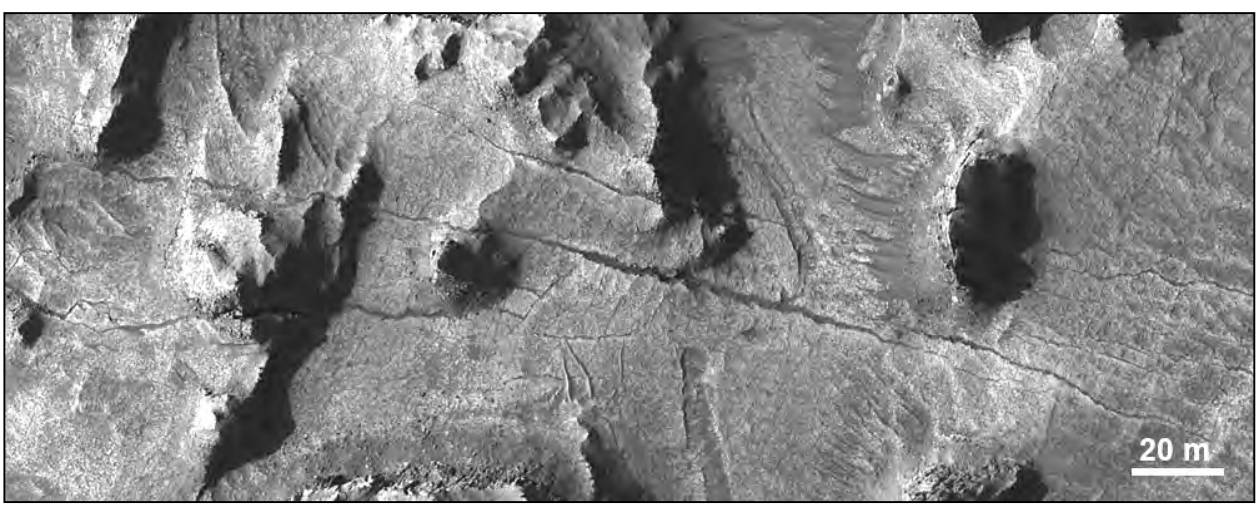

Figure 1. HiRISE image of joints within light–toned layered deposits in southwest Candor Chasma. The joints are filled by dark–toned sediment, which aids in measuring their trace length and opening displacement. Illumination is from the upper right and north is toward the top of the image. HiRISE image PSP_001918_1735.

Opening displacements for joints on Mars: Sub–meter resolution of fracture lengths and displacements on Mars are now provided by the High Resolution Imaging Science Experiment (HiRISE) camera [15] on board the Mars Reconnaissance Orbiter (MRO) [16] (Fig. 1). HiRISE observations of the layered deposits within Candor Chasma, in Valles Marineris have been acquired at ground sampling dimensions of 0.28 m to 0.26 m per pixel. At this scale, the shape of objects that are *ca.* 0.8 m can be resolved, and features as small as *ca.* 0.25 m in diameter can be detected.

These HiRISE observations are used to measure the opening displacements and lengths of joints within the layered deposits. Joint opening displacement is measured as the distance between meter–scale tie points (e.g., dovetailing asperities and bedrock layers; Fig. 1) on opposing sides of the fracture. The uncertainties associated with these measurements are within 1 pixel on each side of the joint, or conservatively 2 pixels for each measurement. Thus displacement uncertainties are 0.52 m to 0.56 m, depending on the pixel scale of the particular HiRISE image used.

Displacement and length is measured only along joints that have clear terminations. Measurements of joints that are clearly hard–linked to adjacent fractures are not reported here, as such measurements would largely contribute scatter to our D/L scaling results [e.g. 17] and deserve a separate detailed treatment.

Crosscut topography reveals that these joints are sub–vertical (Fig. 1); the trace of a joint across topographic rises and onto surrounding flat areas appears collinear in map–view. Shear displacements along these fractures are negligible. Tie points on opposing fracture walls indicate opening normal to the plane of the fracture. Also, splay fractures (indicative of shear) [18] are not observed at the fracture tips. Thus opening displacements are measured as the aperture of the joints as seen in map view. The conservative uncertainties for measurements of fracture length are 3 pixels at each joint tip, or *ca.* 0.8 m total.

The meter–scale geometries of the asperities on opposing sides of the joints are sharply defined, indicating that erosion of the joint walls is minimal. Therefore the widening of the apparent joint aperture due to erosion is regarded to be within the uncertainty of the displacement measurements.

Results: Geometrically–projected HiRISE images PSP_001984_1735 and PSP_001918_1735 are used to measure the displacements and lengths of 32 joints within the layered deposits. These joints are 97.0 m to 281.25 m in length and exhibit 0.58 m to 5.33 m of maximum displacement (Fig. 2). The average maximum displacement to length ratio for this set of joints is found to be 5.04 x 10^{-3}. This value is consistent with previous measurements of D/L for faults longer than 10 km on Mars [i.e. 2,3] and show that similar D/L scaling relations apply to fractures at the kilometer to sub–km length scale.

These data enable further analyses of the effects of modulus, fracture toughness, and gravity in D/L scaling relations on Mars vs. Earth for shorter faults and for joints. Such analyses, along with measurements of the distribution of displacement along the joints, may provide insight into the relative strengths of the layered deposits in Candor Chasma vs. the ancient highland material in Tempe Terra and elsewhere.

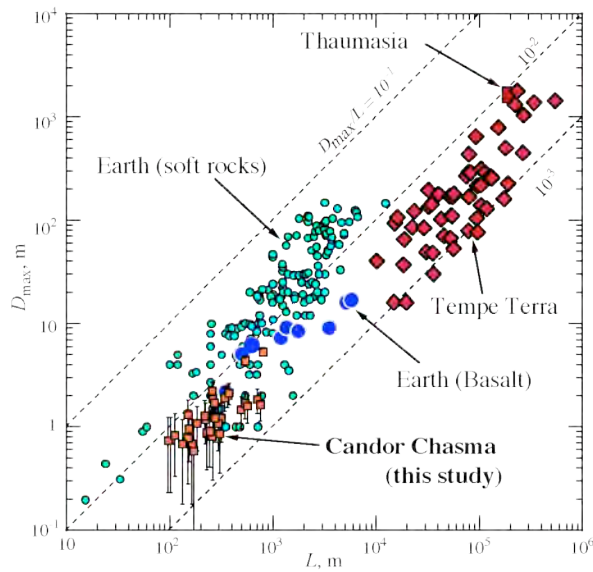

Figure 2. Displacement and length data for fractures on Earth in poorly–indurated rocks ('soft rocks') and in basalt compared to measurements of fractures on Mars. Data from [3,6,19] and this study. Error bars for length on the Candor Chasma data are shorter than the symbol width.

References: [1] Schultz R.A. et al. (2006) *J. Struct. Geol.* 28, 2182–2193. [2] Watters T.R. et al. (2000) *Geophys. Res. Lett.* 27, 3659–3662. [3] Wilkins S.J. et al. (2002) *Geophys. Res. Lett.* 29, 1884. [4] Cowie P.A. & Scholz C.H. (1992) *J. Struct. Geol.* 14, 1149–1156. [5] Clark R.M. & Cox S.J.D. (1996) *J. Struct. Geol.* 18, 147–152. [6] Schlische R.W. et al. (1996) *Geology* 24, 683–686. [7] Schultz R.A. & Fossen H. (2002) *J. Struct. Geol.* 24, 1389–1411. [8] Davis K. et al. (2005) *J. Struct. Geol.* 27, 1528–1546. [9] Okubo C.H. & Schultz R.A. (2003) *LPS XXXIV*, Abstract #1283. [10] Schultz R.A. et al. (2004) *Geology* 32, 889–892. [11] Okubo C.H. & Schultz R.A. (2006) *J. Struct. Geol.* 28, 2169–2181. [12] Polit A.T. et al. (2005) *LPS XXXVI*, Abstract #2175. [13] Okubo C.H. & Schultz R.A. (2006) *J. Geol. Soc.* 162, 939–950. [14] Okubo C.H. and McEwen A.S. (2007) *Science*, in press. [15] McEwen A.S. et al., (2007) *J. Geophys. Res.* in press. [16] Zurek R. & Smrekar S. (2007) *J. Geophys. Res.* in press. [17] Cartwright et al. (1995) *J. Struct. Geol.* 17, 1319–1326. [18] Cruikshank K.M. et al. (1991) *J. Struct. Geol.* 13, 865–886. [19] Hauber E. and Kronberg P. (2005) *J. Geophys. Res.* 110, E07003.