RELATIONSHIP BETWEEN UPLIFT, FAULTING, AND STRAIN ACROSS VALLES MARINERIS, MARS, **Richard A. Schultz**, Geomechanics–Rock Fracture Group, Department of Geological Sciences, Mackay School of Mines, University of Nevada, Reno, NV 89557-0138 (schultz@mines.unr.edu) and **David A. Senske**, Sterling Software/Jet Propulsion Lab, Pasadena, CA 91109.

Summary. Topography adjacent to central Melas Chasma and Coprates Chasma is probably related to flexural uplift and unloading due to trough voids, with effective elastic lithosphere increasing in thickness from the eastern terminus to Melas Chasma. Topography farther west is not fit by the uplift profiles and is probably not directly related to trough faulting. These results indicate that the choice of topography for use in strain calculations must be made with some caution given that only certain regions of high topography (i.e., central and eastern troughs only) can be confidently attributed to the flexural signatures of uplifted lithosphere.

Introduction. Valles Marineris troughs are thought to represent a system of large grabens associated with localized lithospheric uplift [1]. Uplift may have augmented Tharsis stresses [2] and contributed to anomalously large graben depths [3] in the Valles Marineris region. The uplift mechanism is tested quantitatively for the first time by comparing calculated upward deflections of an unbroken elastic plate or spherical shell, unloading because of rift-graben mass deficits, to the observed topography. Deflections suggest that the Martian effective elastic lithosphere increases in thickness from eastern Coprates Chasma to central Melas Chasma. Thickness of the lithosphere beneath the western troughs is not constrained. However, the models consistently underestimate the width of high topography in the central and western parts, as well as relief throughout the rift system. Thus the topography does not reflect solely a response to rift-graben formation, because the observed uplift is broader than that expected from trough volume. We infer that the large depths of Valles Marineris troughs may be associated with faulting of locally thick lithosphere.

Previous estimation of extensional strains on Mars have concentrated on shallow grabens (< 1 km deep) in the Tharsis region [4–6]. Plescia [4] computed both local and regional strains for the Ceranius Fossae location in northern Tharsis, finding significant variations in local strain, measured between adjacent grabens; cumulative regional strains averaged over complete traverse lengths are about 8 km. Although these values could be viewed as typical of surficial extensional strains due to Tharsis loading [6], strains apparently are also heterogeneous (i.e., variable in magnitude and direction) from region to region in Tharsis [6].

Assessment of the contribution of uplift to extensional strain requires a comparison of strain due to faulting to that due to uplift. Such preliminary studies [5,6] have concluded that measured strains from graben sets can be much greater (e.g., factor of 8 in Valles Marineris region) than values calculated from models of uplift. Although high topography and uplift are genetically related in many well documented examples on Earth, the relationship has not been as clear-cut for Valles Marineris, leading to some uncertainty in the quality of strain comparisons.

Methods. Large grabens can act as negative loads on a planetary lithosphere, leading to flexural uplift and some isostatic compensation of the mass deficit [7]. This situation is analogous to the effect of a positive load such as volcano or mascon, which promotes downward deflection of the lithosphere. Flexural profiles were evaluated for several traverses across Valles Marineris; endpoints were selected by identifying inflection points in concave-downward topography. Horizontal strains due to uplift are calculated from the uplift profiles. The horizontal extension and strain accommodated by trough normal faults are estimated by measuring vertical offset of inferred correlative strata such as Upper Hesperian rocks [8] across each major fault and summing along the traverse.

Results. The results for the central and eastern parts of Valles Marineris are consistent with a lithosphere that was flexed upward in response to mass deficits associated with trough depressions. In contrast, any such flexural relief due to Ius Chasma must provide only a negligibly small component of the topography west of Melas Chasma. Thus the locally high topography in the Valles Marineris region appears to be associated with faulting in the eastern and central troughs, and some other mechanism in the western trough region. One possibility is that uplift inferred for the Syria Planum region, which adjoins the western troughs [9], also produced the lobe of high topography that extends through the western and north-central trough region. That uplift occurred during Noachian through Early Hesperian time [9], before major faulting in Valles Marineris

(Late Hesperian). This combination of two sources of uplift (Syria Planum and the trough mass-deficit response) appears sufficient to explain the principal topographic characteristics of the Valles Marineris region.

If faulting penetrates the entire lithosphere [9], a broken-plate model may be more appropriate than the continuous plate model used above. The broken-plate model was evaluated by using trough depths as the amplitude of plate deflection. The resulting concave-upward profile does not match the observed topography for reasonable elastic thicknesses, and the width of the associated rift-flank uplift was much smaller than the wavelength of the topography. We conclude that faulting at Valles Marineris did not penetrate, or decouple, the entire lithosphere. More refined methods for obtaining effective elastic thickness and for evaluating the role of postseismic relaxation of faulted crust could be employed when improved gravity and topography data become available from future Mars missions.

Local, incremental strains due to uplift along a traverse oriented perpendicular to trough strike are strongly nonuniform and heterogeneous. Local strains vary from zero far from troughs to maximum values over the troughs. Strains due to faulting are comparable to the local uplift strains over trough locations. Although fault strains are calculated using a range of plausible dip angles (50°–70°), the fit of uplift curves to topography is not sufficiently refined to more tightly constrain admissible values of dip at present, given uncertainties in the topography data. However, the range of dip angles used apparently provides a reasonable estimate of the magnitude of fault-related extension and strain.

Local fault extension varies along strike, increasing from 6–13 km in easternmost Coprates Chasma to 17–40 km in central Melas Chasma. Extension due to uplift also increases with values comparable to the fault extension. However, horizontal extensional strains are surprisingly constant with strike. The increase in extension appears related to constant strain of a lithosphere that varies in thickness systematically along the trough system. Regional horizontal strains due to uplift are relatively constant along the trough system. These values are comparable to the local strains due to faulting, suggesting that a large fraction of the extension in the Valles Marineris region is associated with large normal faults in the troughs.

Uplift and horizontal extensional strain are related mechanically, making the ongoing comparisons by various investigators of calculated (uplift) to measured (graben) strains potentially significant. An approach used in previous studies entails calculating horizontal strains due to an arbitrary topographic profile that is assumed to be indicative of lithospheric uplift. Strain is related to the increase in surface area (unit depth across the profile) of the flexed shape relative to the unflexed initial profile. However, because horizontal strains and bending stresses in a flexed plate are proportional to its elastic thickness, calculation of strain using that method implicitly assumes an elastic thickness for the Martian lithosphere of unity (1 km), an unphysical result. Future use of topography as indicators of uplift should first demonstrate a relationship between topography and uplift as well as plausible values of the effective elastic thickness for use in strain calculation.

Conclusions. Strains attributed to uplift of lithosphere beneath Valles Marineris troughs are calculated for plausible values of effective elastic thickness and compared to those accommodated by large normal faults in the troughs. Average regional strain due to uplift is comparable in magnitude to the fault strain for the central and eastern parts of the trough system. Topography in the western trough system (e.g., Ius and Tithonium Chasmata) does not appear to be related directly to trough faulting and lithospheric uplift, so strain calculations for that region cannot be used in a comparison of uplift and faulting strains. Extension due to faulting increases systematically from east to west (into Melas Chasma) while extensional strain remains relatively constant, implying constant extension of thickening lithosphere. The large inconsistencies between model (uplift) and observed (fault) strains for Valles Marineris, suggested by some previous work, are not supported by the present detailed investigation because only topography that can be attributed to uplift is used here to calculate uplift strains.

References. [1] e.g., Hartmann, *Icarus* **19**, 550–575, 1973; Wise et al., *Icarus* **38**, 456–472, 1979. [2] Banerdt et al., in *Mars*, 249–297, 1992. [3] Lucchitta et al., *JGR* **99**, 3783–3798, 1994. [4] Plescia, *JGR* **96**, 18,883–18,895, 1991. [5] Chadwick and Lucchitta, *LPS* **XXIV**, 263–264, 1993. [6] Tanaka and Chadwick, *LPS* **XXV**, 1397–1398, 1994; Golombek et al., *LPS* **XXV**, 443–444, 1994. [7] e.g., Weissel and Karner, *JGR* **94**, 13,919–13,950, 1989. [8] Schultz, *JGR* **96**, 22,777–22,792, 1991. [9] Tanaka and Davis, *JGR* **93**, 14,893–14,917, 1988.