**What caused landslides in Valles Marineris, Mars – the sequel?** A. Duffy[1], A. D. Schedl[1] *(1) Physics Dept., West Virginia State University, Institute, WV 25112-1000 USA,* schedlad@wvstateu.edu

**Introduction:** Akers et al. [1] proposed that impacts and landslides in Valles Marineris may be causally linked if 1) an impact crater and landslide are the same age and 2) if this landslides lay in a region where there is a ≥ 50% chance that a particular crater caused this landslide. Out of 56 well dated landslides, only 6 landslides and 3 impact craters met both of the above conditions. This suggests that Marsquakes are a better explanation for most landslides than meteorite impacts. In this study, we examined craters at distances where there was a 5-50% probability of an impact causing a corresponding landslide.

**Methods:** Valles Marineris provides a unique opportunity to investigate whether there is a relationship between meteorite impacts and landslides on Mars. Quantin et al. [2] dated landslides in Valles Marineris using isochron diagrams [3]. Bigot-Cormier and Montgomery [4] examined gradients of stable slopes and landslides to show that rocks in Valles Marineris could withstand ground accelerations up to 0.2 $g_{Mars}$. Using this latter maximum strength one can develop equations relating crater diameter to the radius of a region outside of which there is <5% probability of landslide. If the landslide and meteorite impact are different ages or the landslide falls in the <5% region a causal link is ruled out. The equation is:

$$R = \frac{g_{Earth}}{g_{Mars}}\left[\frac{c}{10^{1.38}}\left(\rho_m^{-0.11}\rho_t^{1/3} g_{Mars}^{0.22} L^{-0.13} D_{tc}/1.8\right)^{1/0.22}\right]^{1/3}$$

$\rho_m$ = density of meteorite; $\rho_t$ = density of target, Mars; $g_{Mars}$ = gravitational acceleration of Mars; $L$ = meteorite diameter; $D_{tc}$ = transient crater diameter $c$ = seismic efficiency and $R$ is the radius of the region outside of which there is <5% probability of landslides.

Degradation state can be used as a proxy for age. Crater degradation states range from 1-4 where 1 is most modified (eroded) and 4 is least modified [5]. For this study we initially examined impact craters ≥40 km diameter and at distances from Valles Marineris defined by the 5% probability curve for meteorite impacts causing landslides. Within this region the majority of craters are degradation state 1 and thus older than Valles Marineris, >3.5 Ga. There are no craters within this region that are degradation state 4. For craters in this region with degradation states 2 and 3 preliminary ages were determined using the equation of Neukum [6]. Most of these craters (150) were ≥3.5 Ga, so they cannot be linked to landslides in Valles Marineris. The rest of the craters were subdivided into two populations. Those between 2.0 Ga and 3.5 Ga and those <2.0 Ga. For these using the program JMars® crater dimensions were measured and used to calculated binned average-areal-crater densities. These densities were then plotted on an isochron diagram [3] and a rough age of the large impact was determined. Ages were also determined through regression using the program CratterStats [7]. We are presently analyzing crater between 10 and 40 km diameter.

**Results:** Craters > 120 km in the 50-5% probability region are ≥3.5 Ga, so meteorite impact did not produce landslides in Valles Marineris. For other craters ≥40 km diameter and between 2.0 and 3.5 Ga, there are 14 craters that lie between the $c = 10^{-3}$ and $10^{-4}$ 5% probability lines and 9 craters that lie above $c=10^{-3}$ the 5% probability line. There are 8 landslides in that age range, so these landslides are unlikely to be all explained by meteorite impact (Figure 1). Approximately 40 landslides are <2.0 Ga and there are only 13 craters with ages in this range. Many of these craters lie above the $c = 10^{-3}$ 5% probability line and hence are unlikely to be linked to landslides (Figure 2). For impacts between 10 and 40 km diameter and of degradation state 4, 71 of 76 impact craters lie above the $c = 10^{-3}$ 5% probability line. Recent work [8, 9] suggests that large impacts have seismic efficiencies of $c = 10^{-4}$ to $3\text{x}10^{-4}$, so impact origin for the landslides is less probable. Again, results are consistent with marsquakes causing most of these landslides.

**References:** [1] Akers C. et al. *LPS XLIII*, Abstract #1932. [2] Quantin, C. et al. (2004) *Icarus, 172*, 555–572. [3] Hartmann, W. K. and Neukum G. (2001) *Space Sci. Rev.*, *96*, 65-194. [4] Bigot-Cormier, F. and Montgomery, D. R. (2007) *EPSL*, *260*, 179-186. [5] Robbins S. J. et al., (2012) *JGR, 117,* E05004. [6] Neukum G. (1983) Ph. D. Dissertation, Univ. of Munich, 186. [7] Michael, G. G. and Neukum, G. (2010) *EPSL*, *294*, 223-229. [8] Meschede M. A. et al. (2011), *Geophys. J. Int. 187*, 529-537. [9] Sleep, N. S. and Lowe, D. R. (2014), *Geochem. Geophys. Geosyst. 15*, 1054-1070.

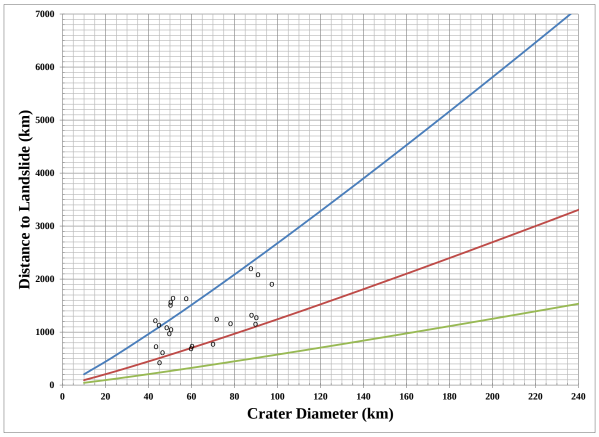


**Figure 1:** Distance from Landslide to Impact for 5% Probability of Landslides for crater impacts ≥ 2 and ≤ 3.5 Ga. Blue line is c $=10^{-3}$; red line is c $=10^{-4}$; and green line is c $=10^{-5}$. Circles represent crater diameter and distance to impact.

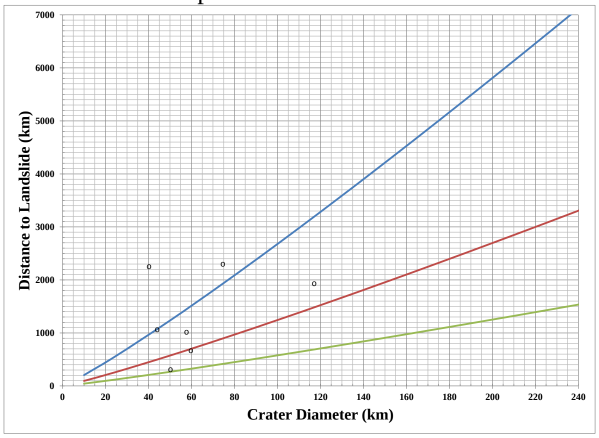


**Figure 2:** Distance from Landslide to Impact for 5% Probability of Landslides <2 Ga. Blue line is c $=10^{-3}$; red line is c $=10^{-4}$; and green line is c $=10^{-5}$. Circles represent crater diameter and distance to impact.