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Long-runout landslides and the long-lasting effects of early water activity on Mars

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We thank Shaller (2016) for his Comment on our recent paper (Watkins et al., 2015), in which we used high-resolution image and spectral data to constrain long-distance landslide transport mechanisms in Valles Marineris, Mars. We proposed a clay lubrication transport model involving the entrainment of clay-bearing trough-floor materials based on three main lines of support: the discovery of hydrated silicates in the outer zone of Ius Labes, correlated morphostructural observations consistent with the presence of these hydrated silicates in the basal sliding zone of the landslide, and the well documented friction-reducing mechanical properties of clay minerals.

Shaller's Comment first critiques a supposed lack of consideration of the extensive literature related to terrestrial long-runout landslides and clay engineering properties, claiming that there is only a single existing study (Watson and Wright, 1969) citing field evidence for clay-assisted long-distance landslide transport. On the contrary, terrestrial clays commonly form long-runout earthflows involving fine-grained slope material that liquefies and runs out downslope (e.g., Baum et al., 2003). While we agree that there is no perfect terrestrial analog for Valles Marineris long-runout landslides—as is expected given that they exhibit unparalleled morphological characteristics and occur under a different atmospheric pressure and gravitational regime—aspects of the role of clay in the Portuguese Bend landslide (Kerr and Drew, 1967) and the Blackhawk landslide (Shreve, 1968; Johnson, 1978) in particular may be representative of elements of Valles Marineris landslide emplacement. The lack of clay mineral availability on other solar system bodies where long-runout landslides are observed indeed suggests that clay lubrication is unlikely to be the dominant transport mechanism in those settings, but this certainly does not preclude its viability to explain some aspects of landslide transport on Mars.

Shaller also takes issue with the saturation state of the Martian clays, claiming that any clay deposits involved in landslide transport were likely dry and that full saturation and liquid water are required to obtain sufficiently low frictional properties to lubricate the landslide base. However, we argue that it is reasonable to assume that Martian smectites entrained at the base of Valles Marineris outer zones may behave in a thixotropic manner, as it has been demonstrated that hydrous minerals can remain in a hydrated state (i.e., contain H_2O molecules in their interlayer) on the surface of Mars even in present-day conditions (Bish et al., 2003). This is observed spectroscopically (a 1.9 μm absorption band) in many Martian terrains with smectites, including Ius Chasma (e.g., Mustard et al., 2008; Roach et al., 2010). Further, experimental testing of clay-bearing material from landslide sliding surfaces shows that low values of clay content (<7%) at high shear stresses cause rapid liquefaction (Gratchev et al., 2006), supporting the notion that smectite clay could have contributed to the reduction of basal friction in Valles Marineris landslide transport.

Lastly, Shaller suggests that the morphological data are consistent with the displacement of chasma wall material rather than the entrainment of trough-floor materials, as we proposed, and cites his thesis (Shaller, 1991) in support of this conclusion. We considered this hypothesis, but ruled it out based on detailed spectral examination of Valles Marineris landslide source regions, in addition to morphological study. Observations of compositional variability within the source regions and lack of regional correlation between wall rock composition and landslide outer zone composition indicate that the upper wall composition is unlikely to play a strong role.

We thank Shaller for further highlighting the necessity of continued research related to long-distance transport of long-runout landslides on Mars and on Earth, and for providing testable hypotheses that can be explored by future work. We investigate many of these matters in more detail in a comprehensive manuscript on this topic currently in revision for *Icarus*.

REFERENCES CITED

Baum, R.L., Savage, W.Z., and Wasowski, J., 2003, Mechanics of earth flows, in Ragucci, X., ed., Proceeding of the 9th International Conference on Liquid Atomization and Spray Systems, Sorrento, Italy.

Bish, D.L., Carey, J.W., Vaniman, D.T., and Chipera, S.J., 2003, Stability of hydrous minerals on the martian surface: Icarus, v. 164, p. 96–103, doi:10.1016/S0019-1035(03)00140-4.

Gratchev, I.B., Sassa, K., Osipov, V.I., and Sokolov, V.N., 2006, The liquefaction of clayey soils under cyclic loading: Engineering Geology, v. 86, p. 70–84, doi:10.1016/j.enggeo.2006.04.006.

Johnson, B., 1978, Blackhawk landslides, California, USA, in Voigt, B., ed., Rockslides and avalanches, Volume 1: Amsterdam, Elsevier Scientific Publishing Company, p. 481–504, doi:10.1016/B978-0-444-41507-3.50022-2.

Kerr, P.F., and Drew, I.M., 1967, Clay mobility, Portuguese Bend, California: Short Contributions to California Geology: Special Report, v. 100, p. 3–16.

Mustard, J.F., et al., 2008, Hydrated silicate minerals on Mars observed by the Mars Reconnaissance Orbiter CRISM instrument: Nature, v. 454, p. 305–309, doi:10.1038/nature07097.

Roach, L.H., Mustard, J.F., Swayze, G., Milliken, R.E., Bishop, J.L., Murchie, S.L., and Lichtenberg, K., 2010, Hydrated mineral stratigraphy of Ius Chasma, Valles Marineris: Icarus, v. 206, p. 253–268, doi:10.1016/j.icarus.2009.09.003.

Shaller, P.J., 1991, Analysis and implications of large Martian and terrestrial landslides [Ph.D. thesis]: Pasadena, California, California Institute of Technology, 586 p.

Shaller, P.J., 2016, Long-runout landslides and the long lasting effects of early water activity on Mars: Comment: Geology, v. 44, p. e386.

Shreve, R.L., 1968, The Blackhawk landslide: Geological Society of America Special Papers, v. 108, p. 1–48, doi:10.1130/SPE108-p1.

Watkins, J.A., Ehlmann, B.L., and Yin, A., 2015, Long-runout landslides and the long-lasting effects of early water activity on Mars: Geology, v. 43, p. 107–110, doi:10.1130/G36215.1.

Watson, R.A., and Wright, H.E., 1969, The saidmarreh landslide, Iran: Geological Society of America Special Papers, v. 123, p. 115–140.