HYDROLOGICAL CHARACTERISTICS OF RECURRENT SLOPE LINEAE ON MARS BASED ON TIME-RESOLVED HIRISE ANALYSES AND COMPARISONS WITH FLUID FLOW THROUGH AN ANTARCTIC TERRESTRIAL ANALOG REGOLITH. J. S. Levy[1] and A. G. Fountain[2], [1]Oregon State University College of Earth, Ocean, and Atmospheric Sciences, Corvallis, OR 97331. jlevy@coas.oregonstate.edu [2]Portland State University Department of Geology, PO Box 751, Portland, OR 90210.

Introduction: Recurrent slope lineae (RSL) are narrow (0.5-5 m wide), relatively dark-toned, martian surface features that form on steep (25-40˚), southern-hemisphere slopes, and that appear in early spring, grow longer in the downslope direction during spring and summer, and fade during autumn and winter (Fig. 1) [1]. Based on the presence of RSL only on southern hemisphere slopes with warm summer temperatures (>250 K) and also on RSL summer-season growth and winter-season fading, [1] favors an RSL formation mechanism involving the seepage and downslope transport of a salt-bearing, water-based fluid that darkens the RSL surface through grain-wetting, and that sublimates/evaporates once flow ceases after the summer thermal optimum. Such a "wet" (water-related) RSL formation model implies a number of characteristics about RSL and the medium in which they form. Because the length of dark soil associated with RSL changes with time [1], the most basic candidate model for describing their growth is unconfined fluid flow through a porous medium ("Darcy" flow). This kind of shallow saline groundwater flow is common in terrestrial polar regions, where ground-ice and snowmelt-generated fluids flow downslope within the seasonally thawed active layer through subtle depressions in the ice-cemented portion of the permafrost. Such terrestrial features are referred to as "water tracks" [2-5].

Here, we test the "wet" RSL formation mechanism by using repeat HiRISE image data to determine whether the Darcy flow model can be used to explain the spatial patterns of RSL surface darkening. In particular, RSL growth rates are fitted to a simple groundwater flow model by fitting downslope propagation rates to K, the permeability of the regolith. Permeability is, in part, a function of the grain size in unconsolidated sediments, and is an intrinsic property of porous media (explicitly taking into account changes in flow rate resulting from the viscosity, gravity, and density of the flowing fluid).

Experimental fitting of RSL substrate permeability using HiRISE measurements of RSL growth rates tests the brine flow hypothesis by determining whether the hydrological properties of the RSL are consistent with remote sensing observations of the RSL substrate (sandy, fines-bearing regolith, typical of Mars (e.g., [6]). If K values for RSL-bearing surfaces are found to be unrealistically low (impermeable), then it suggests that RSL are formed by a mechanism other than seasonal flow (e.g., soil creep). If K values for RSL-bearing surfaces are found to be unrealistically high (overly permeable, suggesting large voids that would inhibit surface darkening from wetting), then it suggests that some form of mass wasting may be responsible for RSL formation. Finally, if K values are found to span a reasonable range for sandy regoliths, then the "wet" RSL formation model will have successfully met a critical physical prediction of the brine flow model.

Methods: The downslope propagation of RSL was measured using repeat HiRISE image data collected at Horowitz crater and Newton crater (32˚S, 140.8˚E and 42.3˚S, 201.8˚E, respectively). RSL characterized by [1] as "confirmed" (showing multiple warm season recurrences) were selected from an image pair at each site (for Newton crater, HiRISE images ESP_022689_1380 and ESP_022267_1380; for Horowitz crater, ESP_022256_1475 and ESP_22678_1475). HiRISE images were georeferenced and overlaid, so that changes from one image to the next (showing surface change with time) could be easily detected via inspection. Distances between the downslope termini of the RSL from the earlier image to the subsequent image were measured in ArcMap.

Using the HiRISE image collection metadata and RSL terminus measurements, it is possible to fit a simple groundwater hydrology model (Darcy flow) to the RSL. Displacements between RSL termini at two points in time constitute the distance traveled by putative RSL fluids. Taking the time elapsed between HiRISE images, it is possible to calculate an average downslope velocity, v, for RSL fluids (distance divided by time). For a simple unconfined aquifer, groundwater pore velocity is equal to the product of the permeability (K), the porosity (Φ), the pressure gradient (ρgΔh/l, where ρ is fluid density, g is martian gravitational acceleration, and Δh/l is the tangent of the RSL surface slope), and the inverse of the fluid viscosity (μ, Pa•s): $v = (-K \bullet \Phi \bullet \rho g \Delta h l^{-1})/\mu$.

The pressure gradient is derived from the RSL starting and ending surface slopes reported for each RSL site by [1]. For the results presented below, porosity of 0.25 is used as representative value for sedimentary deposits. For fluid properties, pure water (ρ = 1000 kg/m^3 and μ = 0.001 Pa•s) and $CaCl_2$ brine (ρ = 1400 kg/m^3 and μ = 0.009 Pa•s) [7] are both considered because RSL fluids are thought to be composed of water plus dissolved phases (possibly saturated eutectic brines) [1, 7].

Because v can be measured through repeat imaging, this leaves K as the only independent variable. By calculating the range of K values indicated by the RSL displacement measurements, it is possible to constrain the geological composition of the RSL substrate (e.g., fine sands and silts, well-sorted gravel, etc.) [8].

Results: RSL displacements were measured in Horowitz and Newton craters (37 measurements in Newton, 40 measurements in Horowitz). For both locations, the elapsed time between HiRISE image pairs was 33 Earth days. Mean RSL terminus displacements were 24 m at Newton Crater (σ = 10 m, range = 6-45 m) and 37 m at Horowitz crater (σ = 18 m, range = 9-90 m). It should be noted that these displacements do not necessarily represent a cluster about a mean displacement, but rather, may reflect different transport paths generated by different slope [3]. Based on the calculations described above, water-based permeability values for Newton Crater RSL span 2.8×10^{-9} to 1.5×10^{-8} cm^2, with an average 9.2×10^{-9} cm^2 (for brine, the mean permeability is 5.9×10^{-8} cm^2). Water-based permeability values for Horowitz Crater RSL span 3.9×10^{-9} to 3.1×10^{-8} cm^2, with an average of 1.4×10^{-8} cm^2 (for brine, the mean permeability is 9.0×10^{-8} cm^2). These K values are consistent with fine sand and silt to well-sorted sand and gravel [8], and would be a reasonable estimate for the permeability of loosely packed dark martian sands [6, 9].

Comparison with Earth: In order to verify that an elementary unconfined aquifer flow model can be used to effectively to describe RSL-like systems, an identical analytical procedure was employed to calculate the permeability of water tracks (permafrost groundwater features that form as water/brines flow through the shallow subsurface) in Antarctica (Fig. 1) [3]. Repeat Quickbird satellite images were collected in the Goldman Glacier basin of Taylor Valley (77.7˚S 162.8˚E) between 19 December, 2010 and 22 December, 2010. Apparent propagation rates of ten water tracks flowing downslope during this period range from 2.5×10^{-4} to 7.9×10^{-4} m/s, with an average of 4.8×10^{-4} m/s. Slopes in the basin range from 3˚ to 27˚, with an average of 15˚, based on slope calculations from USGS 30 m/pixel topographic data. Using equation (1), and assuming that these water track fluids are relatively-dilute saline solutions [3] with a density and viscosity similar to pure water, the soil permeability for the Goldman basin was calculated to range from 1.2×10^{-6} to 4.0×10^{-7} cm^2, with an average of 4.5×10^{-7} cm^2. These calculated permeability values can be used to compute the apparent hydraulic conductivity of the Goldman basin sediments, which can then be compared to field measurements of soil hydraulic conductivity to determine whether the elementary Darcy flow model accurately reproduces groundwater flow behavior. The hydraulic conductivity of a porous medium is the product of permeability, fluid density, gravitational acceleration, and the inverse of fluid viscosity. Calculated hydraulic conductivity values using the imaging-derived permeability estimates span 0.04 to 0.12 cm/s, with an average of 0.05 cm/s. Soils in Taylor Valley have an average hydraulic conductivity of 0.02 cm/s (range: 0.002 to 0.06 cm/s) based on infiltrometer measurements [3]. Accordingly, these results suggest that remote determination of substrate permeability from orbital flow observations may be accurate to within an order of magnitude—resolution sufficient to distinguish a range of hydrogeological regimes.

Conclusions: On the basis of the measured average growth rates, RSL-bearing surfaces were found to have a permeability consistent with sandy unconsolidated sediments—a hydrological prediction consistent with the morphology of the RSL site, as well as with the thermal inertia characteristics of the RSL surfaces. The remote determination of substrate permeability based on satellite observations of near-surface fluid flow were found to be accurate to within an order of magnitude for RSL terrestrial-analog water tracks in Antarctica. These results support the hypothesis that RSL form through the downslope flow of liquids (likely saline brines) through porous regolith near the martian surface under current climate conditions.

References. [1] McEwen, A. et al. (2011) *Science*, 333, 740-743. [2] McNamara, J.P. et al. (1999) *Geomorph.*, 29, 339-353. [3] Levy, J.S. et al. (2011) *GSAB*, 123, doi:10.1130/B30436.1. [4] Head, J.W. et al. (2007) *ISAES10*, #177. [5] Kreslavsky, M.A & Head, J.W. (2007) *7th Mars*. [6] Goetz, W. et al. (2010) *JGR*, doi:10.1029/2009JE003437. [7] Lide, D. R. (2000) *CRC Press.* [8] Bear, J. (1972) Elsevier Publishing Co. [9] Shepherd, R. (1989) *Ground Water*, 27, 633-638.

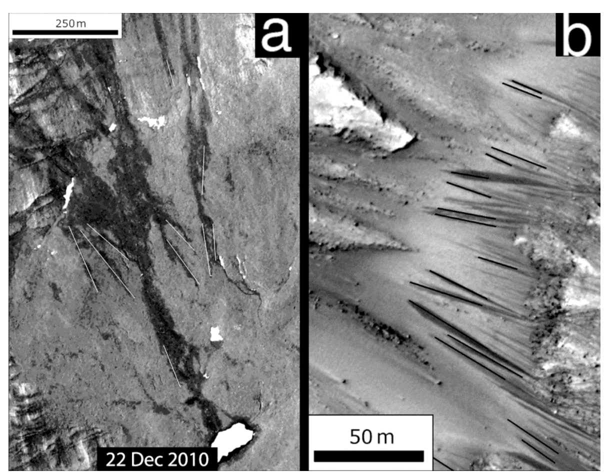

Fig 1. (a) Water tracks in Taylor Valley, Antarctica. (b) RSL on Mars. Lines indicate downslope growth from images collected earlier (3 days on Earth, 33 days for Mars). Lines (white in a, black in b) indicate measured downslope displacement from satellite images collected earlier in the same regions.