LIFETIME OF A DUST DEVIL TRACK AND DUST DEPOSITION RATE IN GUSEV CRATER. Ingrid J. Daubar[1], Lujendra Ojha[2], Matthew Chojnacki[3], Matthew Golombek[1], Ralph Lorenz[4], James Wray[5], Kevin Lewis[2]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA (ingrid@jpl.nasa.gov) [2]Johns Hopkins University. [3]University of Arizona. [4]Johns Hopkins University APL. [5]Georgia Institute of Technology.

Introduction: Dust devils (DDs) are common on Mars, having been observed both from orbit and the ground. They form dust devil tracks (DDTs) (Fig. 1) when surface dust is entrained by the dust devil and removed or disturbed, exposing a substrate with a contrasting albedo and/or grain size. The amount of dust raised by terrestrial DDs has been measured in situ by aircraft [1], but we don't have that luxury on Mars. Martian dust lofting has been quantified based on the optical depths of observed DDs [2–6]; however, there are many uncertainties in those methods [7]. In the absence of in situ measurements, we have developed a new method of calculating the amount of dust lofted by DDs.

Method - Albedo Changes: To address challenges in quantitative photometry on HiRISE data [8,9], we use relative albedos to measure changing absolute brightness in successive images [10]. Using a ratio of two dark-corrected surface samples within a single image mediates contributions of atmospheric effects to the signal incident on the focal plane, such as diffuse skylight scattering and along-path modifications. This technique also reduces issues with imperfect absolute radiometric calibration between HiRISE images [8]; see [10] for details.

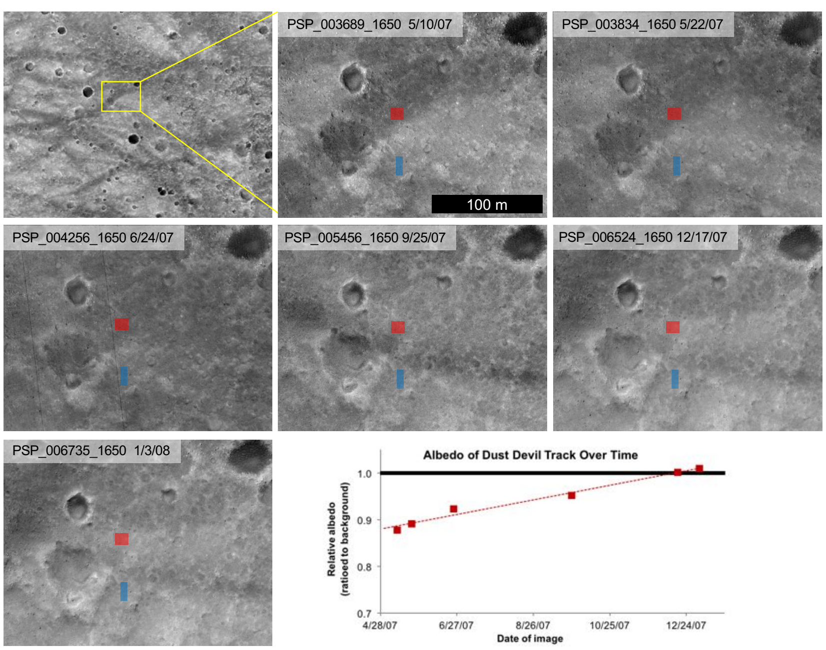

Fig. 1. *Dust devil track (DDT) in six successive HiRISE images.* ***Lower Right:*** *Relative albedo plotted over time of a sample within DDT (red, upper ROI; 154 m²) relative to the background (blue, lower ROI; 140 m²), and the best fit linear function describing its fading. Estimated minimum lifetime of 217 days is calculated to be when the curve reaches A_{rel}=1, i.e. when the DDT brightens to match the albedo of the surroundings.*

Method - Spectral Analysis: CRISM [11] VNIR (0.4-1.0 µm) observations are used to examine the spectral differences between fresh DDTs and their surroundings. Atmospheric corrections are performed using the standard "volcano scan" technique, which removes atmospheric CO_2 via division by a scaled transmission spectrum derived from observations taken of Olympus Mons [12]. The average spectrum of the DDT is normalized to average spectrum from a background region (BK) that lacks DDTs. This spectral ratio lacks residual artifacts and highlights the spectral variation between the DDT, where dust has been removed, and the dust-covered background surface. The largest difference in the reflectance spectra between DDT and BK occurs at 700 nm, which can be correlated to dust cover thickness [13]. We compute the spectral difference between the DDT and background for all sites and use the change in reflectance value at 700 nm to derive an upper limit for the dust thickness lofted by the DD in order to form the DDT. Specifically, the relationship between the change in reflectance at 700 nm and dust thickness can be described by the following empirically derived relationship [13]:

$$r = r_{BK} - (r_{BK} - r_{DDT})\, e^{(-A.m)}$$

where r is the change in reflectance, r_{DDT} is the reflectance of the DDT, r_{BK} is the reflectance of the background, m is the mass per area of the deposit (g/cm²), and A is a mass absorption coefficient (empirically determined to be 504 cm²/g) [13]. The terms can be rearranged to solve for the mass per area m:

$$m = \ln[r_{DDT}/(r_{BK}-r_{DDT})] * (-1/A)$$

Assuming a density ρ_d of the dust, the thickness (t in microns) of dust cover is given by:

$$t = m/\rho_d * 10{,}000$$

The empirical estimate of A is consistent to within 20% for deposits with spectral contrast higher than 0.2. However, for smaller deposits where dust may not completely cover the surface, estimates can vary by up to a factor of two.

Results: We performed this analysis at a site adjacent to the Columbia Hills near the Mars Exploration Rover Spirit, at -14.59°N, 175.49°E. Here frequent multitemporal HiRISE coverage allows measurement of

DDT albedo change over time (Fig. 1).

A linear trend was found to fit the change in relative albedo over time (Fig. 1), and a minimum estimated lifetime for this example DDT was calculated to be 217 (Earth) days. This is in good agreement with times observed by landers to accumulate enough dust to reach an optical depth of one, ~100-400 sols [14–17]. This DDT lifetime is also comparable to the fading timescale of MER tracks, <1 Mars year [18], although that type of textural change may take longer to obscure than a purely substrate-exposure feature such as DDTs.

The absolute TES albedo for the surrounding area without DDT is 0.232, sampling from the global bolometric TES albedo map. Using the relative albedo of the DDT we calculated, we get an absolute albedo for the dark DDT of 0.204 at the time of the initial HiRISE observation (5/10/07). This is very close to the absolute albedo measured by Pancam instrument on the Mars Exploration Rovers [19], which reported an albedo of 0.20 for the DDT in which Spirit landed, compared to 0.30 for bright areas outside the track [20].

The same DDT was sampled in CRISM observation FRT0000553B (Fig. 2), taken just a month before the first HiRISE image in the series. The observed spectral reflectance difference between the dark DDT and the surrounding bright background was computed. At 750 µm the reflectance difference is ~0.21. Thus we estimate 2.2×10^{-4} g/cm^2 of dust was removed by the dust devil. If the amount of material in this layer covered the surface as a continuous fill with a density close to that of drifted dusty material observed by landers, 1.0-1.3 g/cm^3 [21], then the layer would be ~17-22 µm thick. This is in broad agreement with the results of in situ measurements of dust thickness removed to form terrestrial DDTs, which are expected to be similar to martian DDTs: ~2 µm [22] and ~2.5-50 µm [23]; numerical modeling results that indicate a range of 1-8 µm for the thickness [24]; and estimates based on martian DDT observations of 2-40 µm [25] and ~8 µm [3].

We do not know exactly how fresh this particular DDT is; thus this is a minimum amount of dust removed. Further study of more DDTs in this region will minimize the effects of this source of error.

We can then combine this estimated dust thickness of ~17-22 µm with the fading lifetime calculated above to get a dust settling rate. Since the DDT was present in the CRISM image dated 28 days previous to the first HiRISE image, we can use a minimum fading lifetime of 245 days. This yields a dust settling rate of ~25-33 µm/yr (Earth years). This is close to rates reported in the literature, which range as widely as 0-250 µm/yr [26], but more generally fall in the range 0.1-24 µm/yr [14,27–29]. This is a maximum dust settling rate, if the DDT is erased not only by airfall of dust but also by horizontal redistribution.

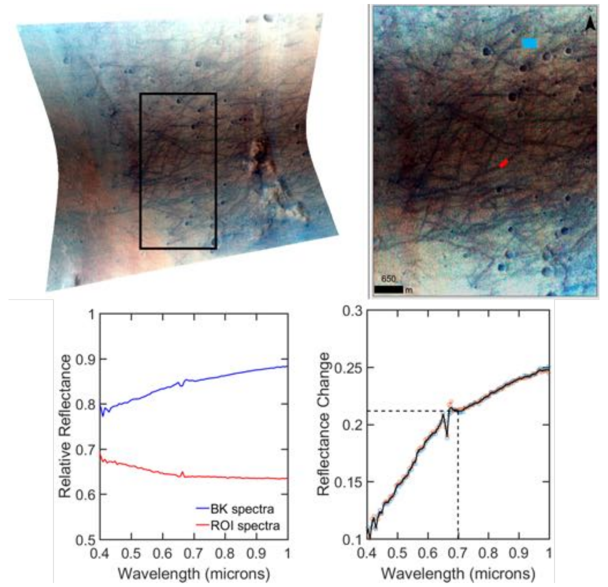

Fig. 2: Top: *CRISM FRT0000553B (2007-04-13) showing dust devil tracks (L). Black rectangle shows location of close up (R). Samples of background (blue) and DDT (red) shown.* ***Bottom:*** *(L) Spectra for background (blue) and DDT (red). (R) Reflectance difference between the background and DDT.*

Conclusions and future work: We have demonstrated a new method of determining the dust lofted by dust devils and the rate of dust settling with results comparable to other methods. In future work we will apply this to multiple sites around Mars. Comparison of dust settling rates at DDTs varying with season and local surface properties will lead to a better understanding of the constraints on DDT formation and persistence.

References: [1] Gillette, D.A. & Sinclair, P.C. (1990) *Atmos. Env*. 24A, 1135–1142. [2] Metzger, S.M., et al. (1999) *GRL* 26, 2781. [3] Greeley, R. et al. (2006) *JGR* 111, 1–16. [4] Cantor, B.A., et al. (2006) *JGR* 111, 1–49. [5] Reiss, D., et al. (2014) *PSS* 93, 54–64. [6] Thomas, P.C. & Gierasch, P.J. (1985) *Science* 230, 175–177. [7] Balme, M. & Greeley, R. (2006) *Rev. Geophys*. 44, 1–22. [8] Delamere, W.A., et al. (2010) *Icarus* 205, 38–52. [9] McEwen, A.S., et al. (2007) *JGR* 112, E05S02. [10] Daubar, I.J., et al. (2016) *Icarus* 267, 86–105. [11] Murchie, S.L., et al. (2007) *JGR* 112, 1–57. [12] McGuire, P.C., et al. (2009) *PSS* 57, 809–815. [13] Wells, E.N., et al. (1984) *Icarus* 58, 331–338. [14] Kinch, K.M., et al. (2007) *JGR* 112, E06S03. [15] Arvidson, R.E., et al. (1983) *Science* 222, 463–468. [16] Landis, G.A. & Jenkins, P.P. (2000) *JGR* 105, 1855. [17] Lorenz, R.D. & Reiss, D. (2015) *Icarus* 248, 162–164. [18] Geissler, P.E., et al. (2010) *JGR* 115, E00F11. [19] Bell, J.F., et al. (2003) *JGR* 108, 8063. [20] Golombek, M.P., et al. (2005) *Nature* 436 (7047), 44–48. [21] Golombek, M.P., et al. (2008) *The Martian Surface*. pp. 468–497. [22] Reiss, D., et al. (2010) GRL 37, L14203. [23] Metzger, S.M., et al. (2011) *Icarus*. 214, 766–772. [24] Michaels, T.I. (2006) *GRL* 33 (19), 6–9. [25] Balme, M.R., et al. (2003) *JGR*. 108, 5086. [26] Christensen, P.R. (1986) *JGR* 91, 3533–3545. [27] Aharonson, O. (2003) *JGR* 108, 5138. [28] Pollack, J.B., et al. (1979) *JGR* 84, 2929. [29] Golombek, M.P. & Bridges, N. (2000) *JGR* 105, 1841–1853.