DUST DEPOSITION RATES AT THE MER LANDING SITES. K. M. Kinch[1], J. Sohl-Dickstein[2] and J. F. Bell III[3], [1]Cornell University, Department of Astronomy, 408 Space Sciences Building, Ithaca, 14853-6801 NY, USA, kmk66@cornell.edu , [2]UC Berkeley, Redwood Center for Theoretical Neuroscience, [3]Cornell University, Department of Astronomy.

Introduction: The Panoramic Cameras[1,2] (Pancams) on the Mars Exploration Rovers routinely image the Pancam calibration targets (caltargets) on the rover decks in conjunction with imaging of the Martian terrain. The number of caltarget images acquired runs to several tens of thousands, with good temporal coverage. Dust deposition on the rover deck causes changes to the well-characterized reflection properties of caltarget surfaces. Trends of dust deposition and removal at the MER landing sites can thus be followed in this dataset and dust reflection properties can be derived.

Dataset: We present an analysis based on caltarget images from the first 170 sols of Spirit's mission and from the first 150 sols of Opportunity's mission. This was a period of reasonably quiescent atmospheric conditions and no dust removal from the caltargets is observed during this period. The dataset was further reduced to cover only a limited range of incidence angles between 35 and 15 degrees. Also the plane of incidence was required to be at least 30 degrees off the plane of emergence in order to avoid any specular or opposition effects. The resulting reduced dataset can be successfully analyzed using a simple diffusive reflectance model.

Model: In the diffusive reflectance formalism the reflectance r_0 of a two-layer medium is described by the equation:

$$r_0 = r_{Dust}\left[\left(1+\frac{1}{r_{Dust}}\frac{r_{Sub}-r_{Dust}}{1-r_{Sub}r_{Dust}}e^{-4\gamma\tau}\right)\Big/\left(1+r_{Dust}\frac{r_{Sub}-r_{Dust}}{1-r_{Sub}r_{Dust}}e^{-4\gamma\tau}\right)\right]$$

as derived e.g. by Hapke[3]. Here τ is interpreted as the optical depth of the deposited dust layer, r_{Sub} is the reflectance of the clean substrate and r_{Dust} is the reflectance of an optically thick dust layer. γ is given by:

$$\gamma = \frac{1-r_{Dust}}{1+r_{Dust}}$$

and so r_0 is determined by only 3 independent parameters, τ, r_{Sub} and r_{Dust}.

Data analysis: The 7 different well-characterized substrates on the caltarget allows us to determine τ and r_{Dust} from the set of caltarget images by use of the diffusive reflectance model and comparison with the known r_{Sub} - values. The procedure is described in full detail in [4]. In brief the method was the following: A simple correction for atmospheric scattering was performed based on comparison between shadowed and sunlit regions of the caltarget and radiance values derived from caltarget images were converted into best estimates of reflectance factors as a function of time for the 7 caltarget substrate regions. The derived reflectance factors were then fitted to the diffusive-reflectance model and values for τ, r_{Sub} and r_{Dust} were derived in the 11 distinct Pancam wavelength bands. A single scaling factor was subsequently applied to the derived values for r_{Sub} and r_{Dust} in order to make the derived reflectances consistent with known preflight values for the substrates. This scaling factor was found to be 0.84 for Spirit data and 0.79 for Opportunity; the deviation from the ideal value of 1 is mainly caused by deficiencies in our model treatment of atmospheric scattering. These deficiencies are thus corrected for by scaling to the known substrate reflectances.

Results: The derived optical depths of dust deposited on the caltarget surfaces was found to be well described by the equation:

$$\tau(t) = \int_o^t \alpha \cdot \tau_{Atm}(t')dt' = \alpha \cdot \int_o^t \tau_{Atm}(t')dt'$$

with τ_{Atm} the independently-measured atmospheric optical depth and α a derived constant. In other words: The optical depth of dust deposited on a given sol was found to be proportional to the optical depth in the atmosphere on that sol with a single wavelength-dependent constant of proportionality, α, valid over the entire period of 170 sols on Spirit, 150 sols on Opportunity. The derived α-values fall with rising wavelength from 0.0059 at 432 nm to 0.0034 at 1009 nm for Spirit and from 0.0050 at 432 nm to 0.0032 at 1009 nm on Opportunity. Within the estimated uncertainty of 30% on the α-values they are in agreement between the two rovers. The derived α-values are also consistent with dust deposition data from MER and Mars Pathfinder solar cells [4]. We suggest that these rates may be used for rough predictions of dust deposition rates during future missions, particularly during periods of reasonably quiet atmospheric conditions [4].

Deposited dust layers. Figure 1 shows smoothed curves of dust deposition data at 5 different wavelengths

for Spirit (top) and Opportunity (bottom). These curves are generated by multiplying the derived α-values by the integration of the atmospheric optical depth in accordance with the equation for $\tau(t)$ given above. The declining rate of growth of the dust layers is a direct consequence of the declining atmospheric optical depth in the period. The optical depths at the end of the period studied is equivalent to a physical depth of roughly one dust grain diameter.

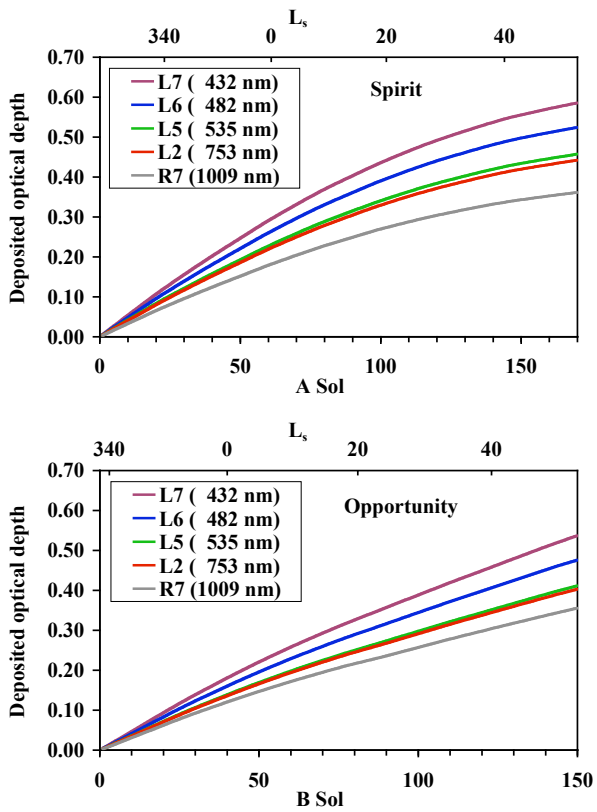

Fig.1: Optical depth of dust deposited on the Pancam caltargets as a function of time for Spirit (top) and Opportunity (bottom) at 5 different wavelengths. The uncertainty on the optical depth values is estimated as 30%.

Dust reflectance. Figure 2 shows derived optical reflectance data compared to Martian surface reflectances measured by MER[5,6] and Mars Pathfinder[7] as well as ground-based telescopic reflectance data[8]. The derived reflectances are consistent with previous data from bright regions of the Martian surface. Dust at the Opportunity site appears considerably brighter than at the Spirit site as has been noted in other observations [9]. We suggest that the brighter dust at the Opportunity could be due to a smaller average grain size or possibly a component of dust derived locally from the bright bedrock at the site.

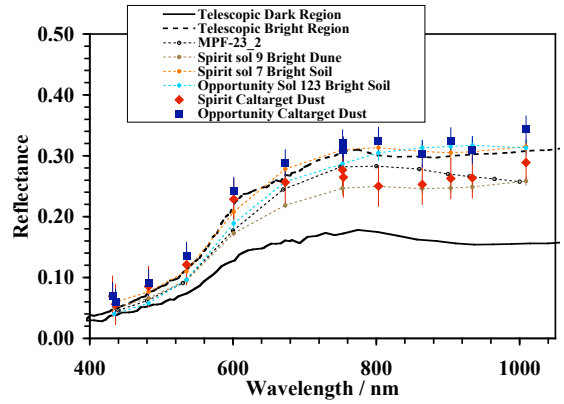

Fig.2: Estimated reflectance factors for dust deposited on the Spirit (red) and Opportunity (blue) caltargets as compared to Martian surface reflectance data from other sources.

Conclusions: Pancam caltarget images from the first 170 sols of the Spirit mission and the first 150 sols of the Opportunity mission were analyzed using a diffusive-reflectance two-layer model. Dust reflectances consistent with data from bright regions of the Martian surface were derived. Airfall dust at the Opportunity site appears considerably brighter than at the Spirit site. During the period studied the optical depth deposited in any sol was observed to be proportional to the atmospheric optical depth on that sol with a single wavelength-dependent proportionality factor. This proportionality factor ranges from 0.3 % to 0.6 % dependent on wavelength. Dust deposition data from MER and Mars Pathfinder solar cells are consistent with this model, and we suggest that it will be useful also for rough prediction of dust deposition during future missions. At the end of the 170/150 sol period the amount of dust deposited on the Pancam caltargets amounted to a physical depth of about one dust grain diameter. More detailed information can be found in [4].

References: [1] Bell J.F. III et al (2003) *JGR, 108(E12),* 8063. [2] Bell J. F. III et al. (2006) *JGR, 111(E02S03),* doi:10.1029/2005JE002444. [3] Hapke B. (1993) *Theory of reflectance and emittance spectroscopy,* Cambridge Univ. Press. [4] Kinch K. M. et al (2007) *JGR, 112, doi:10.1029/2006JE002807*. [5] Bell J.F. III et al (2004) *Science, 305,* 800-806. [6] Bell, J.F. III et al (2004) *Science, 306,* 1703-1709. [7] Bell J.F. III et al (2000) *JGR, 105,* 1721-1755. [8] Mustard J.F. and Bell J.F. III (1994) *JGR Lett. 21,* 353-356. [9] Yen, A.S. et al (2005) *Nature 436,* 49-54.