DUST INFALL ONTO PHOBOS AND DEIMOS CAN EXPLAIN THEIR CARBONACEOUS REFLECTANCE SIGNATURE, PERHAPS OVERLYING A MARS-IMPACT-ORIGIN CORE: A HYPOTHESIS. M. Fries[1], M. Cintala[1], A. Steele[2] and L.C. Welzenbach[3], [1]NASA Johnson Space Center, Mail Code XI2, Houston, TX 77058 [2]Geophysical Laboratory of the Carnegie Institution for Science, Washington DC 20015 [3]Planetary Science Institute, Tucson, AZ 85719. Email: marc.d.fries@nasa.gov

Introduction. Discussions of Phobos' and Deimos' (henceforth P&D) origin(s) include an unresolved conflict: dynamical studies which favor coalescence of the moons from a large impact on Mars [1,2], versus reflectance spectroscopy of the moons showing a carbonaceous composition that is not consistent with martian surface materials [3-5]. One way to reconcile this discrepancy is to consider the combined options of a Mars-impact origin for Phobos and Deimos, followed by deposition of carbon-rich materials by interplanetary dust particle (IDP) infall. This is significant because, unlike asteroidal bodies, P&D experience a high IDP flux due to their location in Mars' gravity well. We present some relatively simple, initial calculations which indicate that accreted carbon may be sufficient to produce a surface with sufficient added carbon to account for P&D's reflectance spectra. If this is true, then a major objection to an impact origin for P&D is resolved.

An Infall-Derived Carbonaceous Component: Exploring the notion of a dust-rich coating for P&D can be distilled into three lines of discussion: IDP mass, regolith composition, and reflectance spectra comparison.

1) Calculations of the IDP Component in P&D Regolith: Flynn [6], noting that IDP infall onto Mars is almost three times that of Earth despite Mars' smaller size, calculates an influx of 12×10^6 kg/year for the planet, of which he estimates is ~10% wt. carbon [6]. We can perform a first-pass calculation of IDP accumulation on P&D with these assumptions: 1) Mars' gravity well dominates IDP flux, resulting in the same flux for P&D as for Mars, 2) An invariant infall flux for 4 Ga (true flux was probably greater in the past), 3) 10% carbon in IDPs by mass. These assumptions should be refined in further work. Using the relative surface areas of Phobos, Deimos, and Mars as factors to calculate the portion of this infall that lands on the moons, we estimate that Phobos currently accretes IDP material at a rate of 128 kg/year and Deimos at 41 kg/year. If we estimate that P&D formed 4 Ga ago [7] then Phobos has accrued a total of 5.12×10^{11} kg of IDP material and Deimos 1.64×10^{11} kg. We can estimate the thickness of this layer (r_{COAT}) as if it forms a homogenous coating by subtracting its mass from each moons' mass, calculating the volume of both the resulting core (V_{CORE}) and coating (V_{COAT}) with their respective density values, add these mass values (V_{TOT}), calculate the radii of spheres of size V_{TOT} and V_{CORE}, and find r_{COAT} by subtraction. This amounts to a layer (r_{COAT}) 208 cm and 308 cm thick for P&D, respectively, using near-surface density values of 1.6 and 1.1 g/cm^3 established as upper limits by [9]. One important, future refinement to this method involves how the infall rate for P&D is calculated. Here, we simply use a ratio of each moon's surface area to that of Mars and multiply by Mars' infall flux. A more sophisticated treatment of the infall flux geometry is needed, and may change the infall value by a substantial amount. Data are needed on actual infall rates for Mars and P&D, which have not been measured over a lengthy period.

We can also address whether this hypothesis merits additional work with a calculation of the minimum case needed for infall mass contribution. In other words, what is the minimum infall mass needed to strongly affect reflectance spectra, and is that minimum case feasible? Hiroi and Pieters [10] found that reflectance spectra of olivine and pyroxene were obscured, and the spectrum flattened, by adding only 2 wt.% carbon black. We assume a minimum case of 2% infall carbon with a layer 1 cm thick on P&D, sufficient to exceed the reflectance penetration depth. Assuming IDPs contain 10 wt.% carbon, 3.8×10^7 and 2.6×10^7 years are required to deposit 2 wt.% carbon in a 1 cm thick layer on P&D. P&D are believed to be in excess of 4 Ga old [7], so at least this minimum case is possible, although with the caveat that impact gardening effects are not factored in. A more sophisticated treatment of infall rate versus impact gardening rate and depth is required in order to accurately estimate the abundance of IDP carbon in P&D regolith.

2) P&D Have Unusually Fine-Grained Regoliths Consistent with High IDP Content: The density of P&D regolith is low (1.6 and 1.1 g/cm^3) and unusually fine-grained [9]. Deimos has been cited as having "the lowest radar albedo of any radar-detected Solar System object" [9] due to a "powdery" regolith [*ibid*], and Phobos is also unusually low even with excavated material from Stickney crater integrated into whole-body measurements. P&D also retain infall material into their regolith as evidenced by burial of older craters, and the grooves on Phobos seem to support a model of a thick, granular regolith overlying a more rigid core. Thomas *et al* (2000)[11], looking at Stickney crater in particular, found that regolith extended to a maximum of 100m depth within Stickney. Horstman and Melosh (1989)[8] examined linear chains of pits on Phobos and found that the best explanation for them is drainage of a thick, loose regolith into cracks emplaced in a more coherent material below. Based on distances between the pits, they find that Phobos has, "a nearly uniform regolith thickness of approximately 300 m" [8, also 12]. This can be interpreted with a model whereby a relatively robust P&D assembled from Mars-impact ejected material, and then accreted additional material afterwards. The range of values for contribution of IDP material, re-accretion after impact gardening [13 and refs therein], and potential accretion of fine material post-aggregation need to be explored in future work.

3) Comparison of IDP Reflectance Data with P&D: The reflectance spectra of P&D have defied an exact match to asteroid reflectance class(es), but are similar to D-type carbonaceous asteroids overall [5 and refs therein], with the Stickney crater environs similar to T-type asteroids of unknown composition [5]. Some carbonaceous chondrites are similar, but only after heating to remove water of hydration [14]. Many IDPs are naturally anhydrous as a consequence of their high surface area/volume, and tend to be optically dark due to carbon content and nanometer-scale metallic particles [15]. There is a similarity in slope between chondritic porous IDPs and P&D (Figure 1).

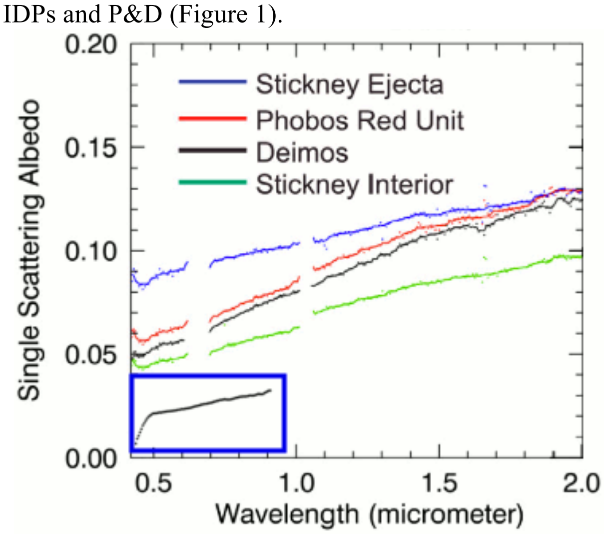

Figure 1: Reflectance spectra of P&D, adapted from [16]. Reflectance spectrum of a "pristine" chondritic porous IDP in blue box (lower left), offset for clarity by ½ of true values [15]. Note the similar slope.

Conclusions and Implications: We propose the hypothesis that P&D feature sufficient carbon from IDPs in their regolith to impose a carbonaceous signature to their reflectance spectra. If true, this generates the following implications:

Mars-Impact Formation for P&D: While formation of P&D from Mars impact ejection is currently an attractive explanation for the origin of the moons from a dynamical standpoint, it has difficultly explaining the apparent carbonaceous composition of the moons versus the severely carbon-depleted martian surface. Post-formation accretion of a thick, carbon-rich infall layer explains this discrepancy and alleviates a major argument against an impact formation mechanism.

In Situ Resource Utilization (ISRU): If true, the hypothesis indicates that surface-accessible material on P&D is probably a poor source of water, but contains abundant carbon. Material from the original core should be similar to martian surface material, but is likewise likely dehydrated by ejection shock.

P&D as a Record of Martian Surface Infall: Mars' surface is severely depleted of carbon as evidenced by multiple NASA missions capable of ppb-level carbon detection (Vikings 1&2, Mars Science Laboratory), even though the planet currently receives $2x10^6$ kg/yr of infall carbon [6]. The carbon has evidently been oxidized, as evidenced by weight-percent levels of perchlorate oxidizer noted by Mars Phoenix and MSL, and so the record of carbon infall has been lost. That record is preserved on P&D, however, allowing quantitative assessment of historical carbon input and refinement of our understanding of past martian surface/atmospheric redox conditions.

Testing the Hypothesis: The next steps should include a more rigorous analysis of the expected IDP infall mass onto P&D, refining the flux rate in particular. An in-depth comparison between the reflectance spectra and other physical properties between P&D and IDPs is also needed. The most robust means of testing this hypothesis is a sample return mission, such as the Mars Moons eXploration (MMX) mission under consideration by JAXA.

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