SCIENTIFIC BENEFIT OF A MARS DUST SAMPLE CAPTURE AND EARTH RETURN WITH SCIM.

L.A. Leshin[1,2], B.C. Clark[3], L. Forney[4], S.M. Jones[5], A.J.G. Jurewicz[5], R. Greeley[1]; H.Y. McSween Jr.[6], M. Richardson[7], T. Sharp[1], M. Thiemens[8], M. Wadhwa[9], R.C. Wiens[10], A. Yen[5], M. Zolensky[11]; [1]Dept. of Geological Sci., [2]Center for Meteorite Studies, ASU, Tempe, AZ 85287-1404; [3]Lockheed Martin Astronautics, P.O. Box 179, MS S-8000, Denver, CO 80201, [4]Dept. of Chem. Engineering, Georgia Tech., Atlanta, GA 30340; [5]JPL, 4800 Oak Grove Dr., Pasadena, CA 91109, [6]Dept. of Geological Sci., Univ. of Tennessee, Knoxville, TN 37996, [7]Div. of Geol. & Planetary Sci., Caltech, Pasadena, CA 91125, [8]Dept. of Chemistry, UCSD, San Diego, CA 92093 [9]Dept. of Geology, Field Museum of Natural History, Chicago, IL 60605 [10]LANL, Space & Atmospheric Sci., Los Alamos, NM, 87545 [11]NASA JSC, Houston, Texas 77058;, Atlanta, GA 30340. (laurie.leshin@asu.edu)

The Sample Collection for Investigation of Mars (SCIM) mission, presently a finalist for flight as a Mars Scout, proposes to return martian atmospheric dust to Earth for mineralogical, chemical, isotopic, and other studies [1]. The returned sample will consist of least 1000 martian dust particles ≥10 µm in diameter plus millions of smaller particles. Here we discuss the science gained from analyzing such a sample in terrestrial laboratories. An accompanying abstract discusses the SCIM atmosphere sample return science [2].

Background: The martian atmosphere typically contains between 10 and 400 billion metric tons of dust [3]. This dust samples the only planetary regolith besides Earth's that has been exposed to hydrolytic, atmospheric, and possibly even biologic weathering processes. Spectroscopic studies demonstrate that airborne dust is nearly indistinguishable from pervasive, bright regions of the martian surface , and several decades ago it was proposed that winds had homogenized, distributed, and deposited a global blanket of dust over the entire planet. Major and some minor element abundances in Mars' soils were analyzed by Viking and Pathfinder landers at three locations on the planet. Soils at all three sites are broadly similar in chemical composition [4-6], leading to a consensus that planet-wide processes have homogenized the fines. Because of its global nature, the martian dust provides a "grab" sample of martian crustal materials, likely including primary igneous and secondary weathered materials (e.g., silicates, Fe oxides, possibly carbonates, clays, nanocrystalline materials, and mineraloids).

Windblown particles are produced from weathering, volcanism, tectonism, and other processes that either break rocks into smaller pieces or generate fine grains. The dominance of each process on a given planetary surface is a function of that planet's environment and surface history [7,8]. *Only through quantitative analysis of martian dust can we understand the processes by which it formed*.

The fines are particularly sensitive to the action of water, and thus their study is crucial to prosecuting the Mars Exploration Program's "follow the water" strategy. For example, many fine particles on Earth are composed largely of secondary minerals because of the abundance of water on the Earth's surface, while fines on the Moon are primary minerals produced by mechanical weathering, dominantly from impacts. A recent comparison of the characteristics of Earth and Moon fines [7] hypothesizes that martian fines will record both aqueous and mechanical weathering processes, supporting the idea that both primary igneous and secondary minerals will be present in the dust.

SCIM Dust Science Topics:

Major geologic provinces/crustal chemistry: The thick martian crust is thought to consist mostly of igneous rocks, although MGS MOC images of layered deposits and dunes, and lander images of soils suggest that surficial sediments are common. There is continuing controversy over whether martian sediments formed primarily by physical degradation (preserving the igneous mineralogy) or chemical weathering (producing oxides, clays, salts, and other alteration minerals or mineraloids).

MGS TES spectra of the northern lowlands were initially interpreted as andesite [9]. As an alternative to global andesitic magmatism, Wyatt and McSween [10] have proposed that the "andesitic" TES spectra could also be interpreted as weathered basaltic rocks. Another hypothesis is presented by Minitti et al. [11], who interpret the variations in VISNIR and TES spectra as a product of variable crystallization and oxidation of basaltic magma. Both andesitic and weathered basaltic interpretations have significant implications for global water cycles. Andesite would imply significant fractional crystallization, possibly under hydrous conditions, whereas weathering of basalt would necessitate significant surface water, possibly even an ocean.

TES data indicate that basaltic igneous rock is abundant in the southern highlands [9]. However, the mineralogy of the TES "basalt" is inconsistent with martian meteorites, suggesting that these meteorites may not be representative of Mars surface rock types.

These competing hypotheses and conflicting interpretations demonstrate that the major lithologies on Mars remain relatively undefined. Microscale characterization of samples of the global dust reservoir would resolve these controversies. Because terrestrial fine sediments sample large areas, detailed chemical and mineralogical studies of these materials on Earth have been used to identify source terrain types and processes, and to estimate bulk crustal composition [e.g.,12]. Similar information has been extracted from lunar regolith fines [e.g.,13]. Trace element data for Mars come exclusively from martian meteorites which may not be representative of crustal rock types. Trace element and isotopic analysis of dust returned by SCIM will provide missing essential chemical information for interpreting surficial chemical processes as well as bulk crustal trace element composition.

Weathering/aqueous environments: Understanding chemical weathering on Mars is critical because it directly tracks the abundance and action of near-surface water. Fines are key to unraveling the nature and extent of martian weathering processes. As with igneous materials, there are many competing hypotheses concerning the mechanism(s) responsible for chemical weathering of martian materials. These range from those requiring little or no water, to those requiring high water-rock ratios. Temperature and pH are also important because they strongly influence the rates and pathways of weathering reactions. Each alteration process will produce a signature suite of secondary minerals and microstructures. For example, pedogenic weathering in a wet environment would produce well-formed clay minerals in a soil horizon, whereas low-H_2O weathering under similar T and pH conditions would yield poorly crystalline minerals or mineraloids spatially associated with the primary mineral.

Current mineralogical models of martian fines are based on an incongruent mix of spectroscopic data, in situ chemical analyses, martian meteorite secondary mineralogy, and theoretical investigations. Specific mineralogy of dust, abundance of each mineral, and spatial associations of various minerals are unknown. Fe-oxides and oxyhydroxides, which may include hematite, goethite, ferrihydrite, maghemite or poorly crystalline Fe-oxyhydroxides, and nanocrystalline hematite make up a small but important component of the martian dust [e.g.,14,15]. Similarly, carbonates are important for CO_2 sequestration, but the carbonate fraction of soil is constrained to less than a few percent [16]. Sulfate and chloride salts, inferred from landed measurements of S and Cl abundances [17], are critical for interpreting the role of acids in aqueous weathering. Detailed silicate mineralogy is likely to preserve records of chemical weathering both in secondary and in partially-weathered primary minerals.

TES results have generally portrayed the martian surface to be nearly devoid of chemical weathering products, citing pristine volcanic minerals associated with low-albedo regions [18] along with minor concentrations of secondary silicate minerals. To the contrary, as discussed previously, TES spectra of some regions have been re-interpreted as weathered basalt. Similar controversy is growing with respect to the silicate mineralogy of the dust itself. Recent results from bright-region TES spectra indicate that the dust is partially composed of plagioclase feldspar [19], implying little chemical weathering. Alternatively, these data have been interpreted to reveal zeolites [20], implying significant aqueous alteration of surface materials. Additional candidate components include smectites and palagonite, which would indicate aqueously-altered basaltic materials [15]. VISNIR attempts to seek a clays have had varied results, and it remains uncertain whether there is a clay mineral component in the dust [16]. It is also important to seek components in the dust that are unweathered, yet highly susceptible (olivine, glass) and hypothesized to be present [18].

In addition to chemical and mineralogical analysis, stable isotopic analysis (H, C, O, S) of altered and unaltered materials, compared to isotopic signatures in martian meteorite materials will constrain the environmental conditions of alteration. Such analyses derive from more than 50 years of work in isotope thermometry [e.g.,21].

Astrobiology: SCIM is not a mission that addresses the "life" issue by searching for life forms, as the collected dust is extremely unlikely to contain organisms. However, possible traces of organic compounds will be sought. Even if biosignature organics are not present, as in the Viking fines [22], refractory products may be found [23]. Laboratory analysis can seek individual organics, such as PAHs and certain amino acids, with exquisite sensitivity. The CHONPS elements in SCIM samples can be assigned to specific mineral phases and their bioavailability thus determined.

Surface-atmosphere interaction: Martian meteorites are hypothesized to record evidence of surface-atmosphere interaction in O, C, and H isotope ratios in both primary and secondary minerals [e.g.,24,25]. Through analysis of dust and atmosphere, the degree of and processes responsible for this interaction can be assessed. It will be especially important in this case for analyses of dust samples to be correlated with high-precision stable isotopic analyses of the SCIM atmospheric sample [2].

Interpretation of remote sensing data: Quantitative characterization of the chemical and physical properties of martian dust will provide "ground truth" for past and future remote sensing observations. The grain size, structure, chemistry, and optical properties of the dust will provide the data needed to interpret more quantitatively atmospheric opacity measurements from past and future missions. They will provide data for better subtraction of the atmospheric dust component from remote sensing studies of the martian surface. Knowledge of dust composition and properties will also aid our interpretations of VISNIR and thermal IR data (TES and THEMIS) from current and future missions. Finally, high-precision chemical analyses of the martian dust in bulk will allow more confident interpretations of chemical analyses provided by future landed missions (e.g., MER and MSL).

Origin of martian meteorites: Because the martian meteorites have several unique chemical characteristics, high-precision analyses of oxygen isotope, K/La, and/or Fe/Mn ratios (for example) from the returned martian dust will confirm that these rocks are indeed martian samples [26] and test how representative the meteorites are of major martian crustal rock units.

References: [1] Leshin L.A.et al. (2002) *Lunar Planet. Sci. XXXIII*, #1721. [2] Wiens R.C. et al. (2003) *this volume*. [3] Martin T.Z. (1995) *JGR* **100**, 7509. [4] Clark B.C., et al. (1982) *JGR* **87**, 10059. [5] McSween H.Y. and Keil K. (2000) *GCA* **64**, 2155. [6] Wanke H. et al. (2001). *Space Sci. Rev.* **96**, 317. [7] Basu A. and Molinaroli E. (2001) *Earth, Moon and Planets* **85-86**, 25. [8] Greeley R. and Iversen J.D. (1985) *Wind as a Geological Process: Earth, Mars, Venus, and Titan*. Cambridge Univ. Press. [9] Bandfield J.L. et al. (2000) *Science* **287**, 1626. [10] Wyatt M.B. and McSween H.Y., Jr. (2002) *Nature* **417**, 263. [11] Minitti M.E. et al. (2002) *JGR* **107**, ref # 10.1029/2001JE001518. [12] McLennan S.M. and Taylor S.R. (1984) In *Archean Geochemistry* (ed. A. Kroner, et al.), pp. 47. Springer-Verlag. [13] Taylor S.R. (1975) In *Lunar Science: A post-Apollo View*, pp. 55. Pergamon. [14] Morris R.V. et al. (2000) *JGR* **105**, 1757. [15] Banin A. et al. (1992) In *Mars* (ed. H.H. Kieffer, et al.), pp. 594. Univ. of Ariz. Press. [16] Soderblom L.A. (1992) In *Mars* (ed. H.H. Kieffer, et al.), pp. 557. Univ. of Ariz. Press. [17] Clark B.C. (1993) *GCA* **57**, 4575. [18] Christensen P.R et al. (2001) *JGR* **106**, 23823. [19] Bandfield J.L. and Smith M.D. (2002) *Icarus*, submitted. [20] Ruff S.W. (2002) *EOS (Spring AGU)*, P31A-08. [21] Friedman I. and O'Neil J.R. (1977) *USGS Prof. Paper 440-KK*, 49 pp. [22] Biemann K. et al. (1977) *JGR* **82**, 4641. [23] Benner S.A. et al. (2000) *PNAS* **97**, 2425. [24] Leshin L.A. (2000) *GRL* **27**, 2017. [25] Farquhar J. and Thiemens M.H. (2000) *JGR* **105**, 11991. [26] Longhi J. et al. (1992) In *Mars* (ed. H.H. Kieffer et al.), pp. 184. Univ. of Ariz. Press.