CONSTRAINTS ON MARTIAN SOIL COMPOSITION AS INFERRED FROM VIKING XRFS AND PATHFINDER APXS AND IMP DATA N. T. Bridges and J.A. Crisp, Jet Propulsion Laboratory, California Institute of Technology (MS 183-501, 4800 Oak Grove Drive, Pasadena, CA 91109; nathan.bridges@jpl.nasa.gov)

Introduction

With the successful operation of the Alpha Proton X-Ray Spectrometer (APXS) during 1997's Mars Pathfinder (MPF) mission, geochemistry data are now available from three sites on Mars. APXS raw spectra for six soils and five rocks have been converted to compositional abundances [1,2]. The Viking Lander X-Ray Fluorescence Spectrometer (XRFS) successfully measured elemental abundances of nine soils at Viking 1 and eight soils at Viking 2 [3-5]. Although the three landing sites are located in different parts of Mars, the soils exhibit broad similarities, with an iron-rich chemistry similar to that of palagonite [5-7]. However, the Pathfinder soils show some significant differences from Viking soils [1-2], notably an enrichment in silica and depletion in sulfur. The XRFS samples consisted of near-surface and deep (up to 22 cm) soils acquired by a collector head at the end of a retractable boom [4,8]. It was possible to collect and analyze pebbles as large as 2 cm, but only soil, some in the form of consolidated clods, was sampled [4,8]. In contrast, the APXS measured materials in situ. This resulted in MPF "rock" analyses that probably had a significant dust component [2,9] and, as explored here, "soil" analyses that may have contained a rocky component.

We examine several possibilities to explain these differences and other attributes of the APXS and XRFS data sets: 1) The APXS soil measurements actually sampled a mixture of Viking-like soil and small bits of high-silica, low-sulfur rock, 2) The soils were derived from high-silica rocks mixed with a minor component of globally-homogenized dust; these soils are chemically distinct and have a separate geologic history from the Viking soils, 3) The weathering environment was different at the Pathfinder landing site compared to the Viking sites, and 4) Uncertainties in the XRFS and APXS measurements result in reported elemental abundances different than those that are actually present. We show that none of the possibilities can be discounted, but that an MPF soil distinct in composition from Viking soils is best supported by the available data.

Methods

Elemental abundance measurements at the Viking and Pathfinder landing sites were taken from published values [1,4]. The APXS does not measure absolute abundance, so either the analysis total must be normalized to an assumed value or the abundance of one of the elements must be assumed and the other elements re-normalized accordingly. To properly compare these soils to Viking soils and recognizing that Martian soils are probably highly oxidized [5], total iron was recast as Fe_2O_3. Because the XRFS measures absolute abundances, Viking data were not changed. To compare the relative differences in elemental abundances between the Pathfinder and Viking soils, Pathfinder rock and soil compositions were divided by the average Viking compositions for each oxide (Figure 1).

Images of APXS soil sites were examined to estimate the fraction of small rocks and characterize geologic context. IMP (Imager for Mars Pathfinder), super-resolution IMP [10,11], rover front camera monochrome, and rover rear camera color images were used. The multiple image data sets were acquired under a range of phase angles, allowing assessment of lighting geometry effects.

Results

The Pathfinder soil and rock compositions, normalized to 98% weight percent oxides with iron as Fe_2O_3, relative to Viking soils are shown in Figure 1. The horizontal line represents the average Viking composition for each oxide, with the short, black horizontal lines being the standard deviation of Viking compositions. As a group, Pathfinder rocks and soils are richer in SiO_2, TiO_2, and (except for A-2) Al_2O_3 relative to Viking soils. They are depleted in SO_3. Pathfinder soils also have more MgO than Viking soils. Silica and sulfur abundances in Pathfinder soils are between that in MPF rocks and Viking soils. Expressing iron as FeO instead of Fe_2O_3 increases non-iron oxide abundance by only 2% and decreases iron oxide by ~ 8%, resulting in minimal changes.

The IMP and rover images indicate that sites A-4 and A-5 are probably the most rocky soils and A-10 and maybe A-15 the least. The dark color of Mermaid Dune, upon which A-15 is located, indicates it may contain an armor of basaltic particles [12,13]. If this is the case, then site A-15 can be considered rocky, with a rock composition lower in silica than the large rocks measured by the APXS. The location of site A-2 is not known precisely and could consist of pure soil, mostly rock, or some mixture. The APXS results from this site are also suspect because the totals are only 68.6% [1], perhaps due a complex APXS viewing geometry [13]. A-8 is on a surface that has been interpreted as a hardpan soil and has mechanical characteristics distinct from unconsolidated soils. Therefore, sites A-2 and A-8 are not considered and site A-15 is modeled as possibly rocky or rock-poor. Because the silica and sulfur contents of MPF soils are between those of MPF rocks and Viking soils, the rockiness of APXS soil sites would be expected to be proportional to silica content and inversely proportional to sulfur content if the sites consisted of a mixture of MPF-like rocks and Viking-like soils. Unfortunately, there is no apparent correlation. The most rocky looking sites, A-4 and A-5, are the least silicic of the soils (48.0±2.4 and 47.9±2.4 weight % SiO_2, respectively) and A-4 has the highest abundance of SO_3 (6.5±1.3 wt. %) [1], exactly the opposite of what would be expected. A-10 has fairly high SO_3 (6.2±1.2) and low silica (48.2±2.4) as would be expected for a soil that is low in rockiness. However, A-10 still has more silica than A-4 and A-5 and sulfur values between A-4 and A-5. Compared to other soils, A-15 has somewhat low sulfur (5.2±1.0), but falls in the midrange of silica contents (50.2±2.5), making it neither "rock-like" nor "soil-like."

Discussion

The differences between Pathfinder and Viking soils and the results presented above leave open the question of the true nature of the MPF soils. Based on soil mechanics tests, morphology, and spectral measurements, it is likely that pure drifts were not analyzed at the Pathfinder site [13]. In addition, there are several challenges with extracting and reducing data from the APXS that could affect the reported oxide abundances. The total oxide abundance as measured from the APXS X-ray mode has been set to 98% because it is assumed that other oxides, mainly P_2O_5, Cr_2O_3, and MnO, account for the remaining 2%. The amount of Na_2O is also poorly known and can vary ±40 relative % from the reported value [1]. Recent calibrations of APXS data indicate that MnO and Cr_2O_3 have abundances of 0.3-0.4 and 0.9 wt.%, respectively, and C can account for no more than 0.5-0.7 wt.% of the soil composition (T. Economou, personal communication, 1999). The amount of phosphorus is not yet computed. Hydrogen cannot be measured by any of the modes of the APXS. Typical Martian soil may have as little as 0.5 or as much as 4 wt. % water adsorbed or bound in minerals [14,15]. Assuming a high amount of water (4%), 0.5% C, and 2.5% other unmeasured oxides lowers the APXS totals to 93 wt. %. This puts the lowest silica MPF soils, A-4 and A-5, slightly below 45 wt.% SiO_2, the maximum found for the Viking soils (sample C-9 [4]), but still outside the field of most Viking soils. MPF sulfur is also lowered, making its content lower than before and even more unlike Viking (Figure 1). Therefore, enhanced abundances of unknown components change the abundances of measured MPF oxides only minimally and not enough to make significant differences in comparison to Viking soils.

Based on this preliminary study, it seems like the Pathfinder soils are truly richer in silica and poorer in sulfur than the Viking soils and that this is not due to the effect of rocky components that are observable by the IMP and rover cameras. Variabilities in soil properties, regardless of the presence or absence of small bits of rock, probably has some effect. For example, soil mechanics experiments indicate that sites A-4 and A-10 consist of cloddy material. This is consistent with their sulfur-rich composition, for crusty materials at the Viking sites were also the richest in SO_3 (9-9.5 wt.%) [4,5]. Another factor may be that the true rock abundance cannot be gauged in images, due either to resolution limitations or the coating of rock bits by dust. For example, if sub-mm-scale silica-rich sand were a component of the landing site soils, it would not be seen in IMP and rover images, especially if it was buried by dust or soil. A mixture of silica-rich granules derived from the apparently high-silica rocks at the MPF site and globally-homogenized Viking-like dust may explain the APXS data. It is also possible that silica cement is present in variable amounts within the MPF soils. Alternatively, the weathering environment at the Pathfinder landing site may have been different than that at the Viking sites (perhaps because of more water at the MPF site after the Ares and Tiu Valles floods), resulting in soils richer in silica and poorer in sulfur than elsewhere on Mars.

The difficulties in comparing APXS and XRFS data combined with problems reconciling chemical and image data sets has bearing on the planning of future Mars landers and rovers. Such missions should carry a suite of calibrated analytical instruments to detect all major and minor elements, including hydrogen and carbon. There must also be sufficient visual documentation of sample location and surrounding terrain before and after acquisition. Taking these measures will insure greater success in understanding the geochemistry of Martian soils.

[1] R. Rieder et al., *Science, 278*, 1771-1774, 1997. [2] H.Y. McSween et al., *J. Geophys. Res.*, in press, 1999. [3] B.C. Clark et al., *J. Geophys. Res., 82*, 4577-4594, 1977. [4] B.C. Clark et al., *J. Geophys. Res., 87*, 10,059-10,067, 1982. [5] A. Banin et al., *Mars*, Univ. Ariz. Press, p. 594-625, 1992. [6] C.C. Allen et al., *Icarus, 45*, 347-369, 1981. [7] R.V. Morris et al., *J. Geophys. Res., 95*, 14,427-14,435, 1990. [8] B.K. Baird et al., *J. Geophys. Res., 82*, 4595-4624, 1977. [9] N.T. Bridges et al., *Lun. Planet. Sci. XXIX*, 1534, 1998. [10] T.J. Parker, *Lunar Planet. Sci. XXIX*, 1817, 1998. [11] T.J. Parker, *Fall AGU Meeting, Abstract 5470*, 1998. [12] Rover Team, *Science, 278*, 1765-1768, 1997. [13] H.J. Moore et al., *J. Geophy. Res.*, in press, 1999. [14] A.S. Yen et al., *J. Geophy. Res., 103*, 11,125-11,133, 1998. [15] A.S. Yen and B. Murray, *Lunar Planet. Sci. XXX*, 1999.

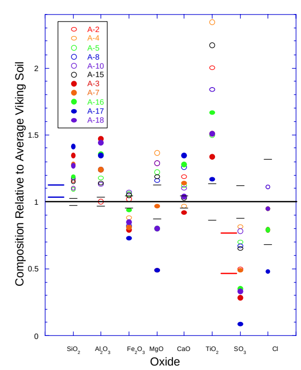

Figure 1: Compositions of Mars Pathfinder materials measured by the APXS relative to average Viking XRFS soil compositions. Abundances are expressed in weight percent oxides, with all iron assigned to Fe_2O_3. Pathfinder analyses are normalized to 98 wt. % total oxides. Open circles are soils and solid circles are rocks. Small black horizontal lines show the standard deviation of Viking soil compositions relative to the average. Solid blue and red lines show the change in range of SiO_2 and SO_3 compositions, respectively, for Pathfinder soils if analyses are normalized to 93% total oxides.