

**POTENTIAL TOXICITY OF THE MARTIAN SOIL.** J. J. Hagerty and H. E. Newsom, University of New Mexico, Institute of Meteoritics and Department of Earth and Planetary Sciences, Albuquerque, NM 87131, newsom@unm.edu.

Public interest in the exploration of Mars has recently been rekindled by the Mars Pathfinder mission and by the debates concerning the existence of ancient Martian life in the Martian meteorite ALH 84001. Scientific interest in the exploration of Mars has also led to new interest in the manned exploration of Mars, and the possible hazards from various facets of Martian geology that may be faced by future explorers. We have used new data from Mars Pathfinder along with Viking and Phobos mission data, coupled with terrestrial analogue data to predict the abundance of potentially hazardous elements in the Martian soil. By comparing these predicted concentrations to current health safety standards, we are able to make predictions about the possible toxicity of the Martian soil.

**Measured abundances in Martian soil:** X-Ray fluorescence analyses by the two widely separated Viking landers, and APXS analyses by the Mars Pathfinder mission, have provided abundant chemical information about the Martian soil. Additional data was obtained by the orbital gamma ray experiment on the Phobos spacecraft. These analyses have provided measurements in the soil of mobile elements such as S, Cl, and K. The Martian soil most likely consists of weathered basaltic material and a "salt" component which contains the enriched mobile elements [1, 2]. These mobile elements may have been added to the soil by volcanic aerosols from magma degassing, and by a hydrothermal component [3]. Volcanic aerosols have been suggested as a source of the salt component by Clark and Baird [4] and recently by Banin et al. [5]. A new acid-sulfate hydrothermal model [6], suggests that as the availability of water declines, neutral chloride hydrothermal systems evolve into vapor-dominated, acid-sulfate systems, which have the high S/Cl ratios needed to explain the chemistry of the Martian soil. The hydrothermal fluids produced by these systems flow out onto the Martian surface and evaporate to leave the salt component. The fluids may also react with pre-existing minerals or glass to produce a portion of the soil's rock component.

**Predicted abundances of potentially toxic elements:** The concentrations of mobile elements that would be contributed to the Martian soil by ancient Martian hydrothermal fluids, and volcanic aerosols, were estimated from the ratios of mobile elements to potassium in different terrestrial analogue systems [3,6]. Terrestrial analogues for hydrothermal systems include sub-aerial hot springs, hot spring deposits, and mid-ocean ridge hydrothermal systems. The best available data for terrestrial volcanic aerosols was also compiled to quantitatively evaluate the aerosol model.

The terrestrial ratio data was then multiplied (normalized) by a potassium abundance of 3000 ppm in the soil, to obtain a predicted concentration in the Mars soil. The concentration of 3000 ppm K in the Martian soil used for normalization is based on measurements by the Phobos orbital gamma ray experiment (K = 2000 - 6000 ppm) [7],

and measurements by Pathfinder (K = 1700 - 4000 ppm) [2]. Corrections to the abundances of mobile trace elements were also made to account for minor differences in the initial abundances of elements in the mantles of the Earth and Mars.

**Possible toxic hazards in Martian soil:** Assuming that a typical Martian habitat would have a dust content in the air of 1000  $\mu\text{g}/\text{m}^3$  (equal to industrial city air [8]), and assuming the 1995 Occupational Safety and Health Administration limits for 8-hour exposure [9], the measured levels of S and Cl can be hazardous for prolonged exposure, and the predicted abundances of arsenic, cadmium, and lead are likely to approach or exceed the OSHA limits [fig. 1]. For comparison, the panel on air borne particulate matter in spacecraft recommended that shuttle missions should have a maximum particle concentration less than 200  $\mu\text{g}/\text{m}^3$  for particles from 1 to 100  $\mu\text{m}$  in diameter [10].

Several types of surface activities could lead to higher dust contents than we have assumed. This includes short term activities, such as cleaning airlocks and surface equipment, or removing dust from spacesuits in an enclosed room. Breathing dust that has been introduced into space suits during donning and doffing could also be a problem.

Other factors, including mechanical fractionation of the soil could also play a role in the toxicity of the soil. The "salt" component, containing the enrichments of mobile elements, is distributed on a global scale by strong seasonal dust storms, eventually allowing the material to accumulate as surficial drift material. This drift material will most likely be smaller than the mineral and rock fragments that make up the rest of the soil analyzed by Pathfinder and Viking. Thus the smallest, most hazardous size fraction of the soil (<1  $\mu\text{m}$  diameter) may contain higher concentrations of hazardous elements than we have predicted.

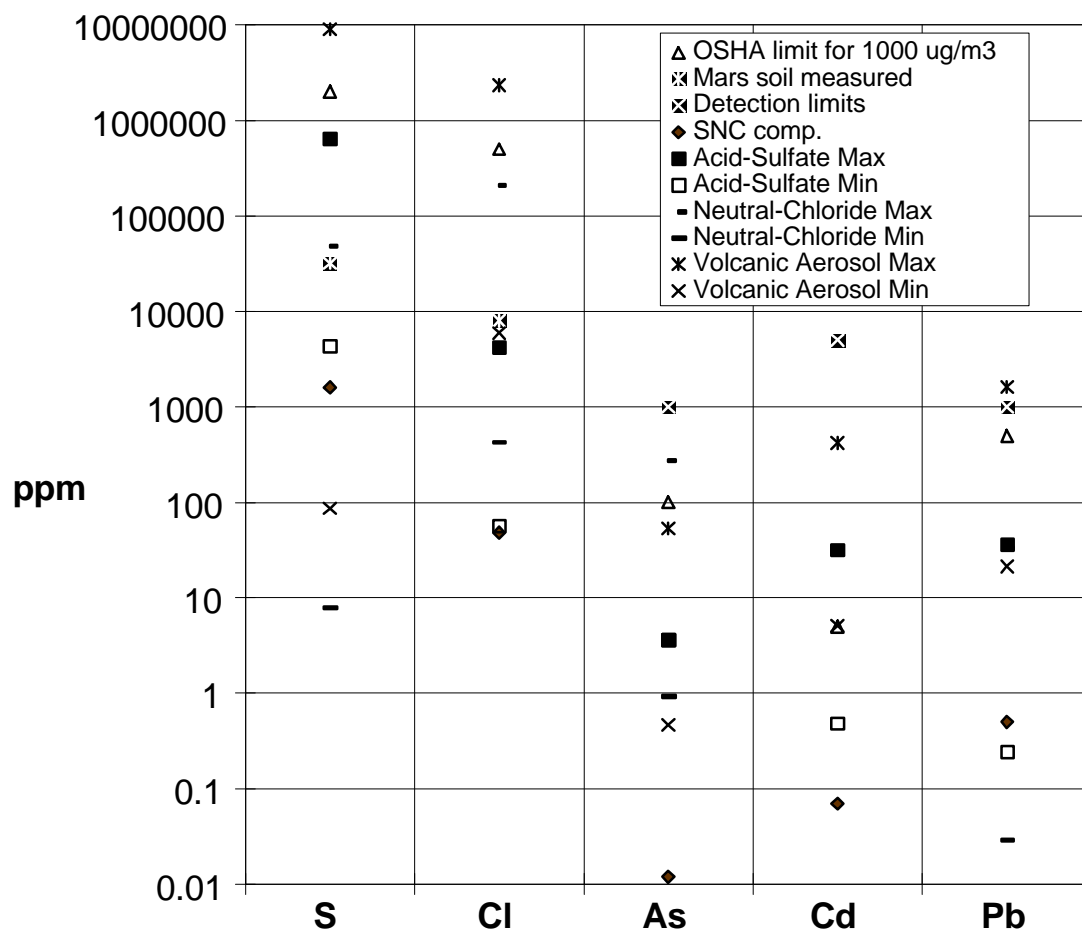
The soil at each of the three landing sites is quite similar, probably due to homogenization of the soil over billions of years. However, local enrichments of hazardous mobile elements might occur in the vicinity of volcanic fumaroles or hydrothermal deposits. Understanding of the trace element chemistry of the Martian soil will require a dedicated in situ experiment, or a sample return mission.

**Conclusions:** Models for the chemical composition of the Martian soil, volcanic aerosol emissions, and acid-sulfate hydrothermal fluids, proposed by Newsom et al. [6] and Newsom and Hagerty [3], suggest that hydrothermal and volcanic systems may release potentially toxic concentrations of mobile elements into the Martian environment. Comparison of these concentrations to recommended exposure limits shows that As, Cd, Pb, S, and Cl may reach or exceed the recommended exposure limits. Zent and McKay [10] concluded that the concentrations of Martian oxidants do not pose a threat to human explorers. They do suggest, however, that there should be strict requirements to prevent dust intake into Martian habitats.

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**Figure 1.** As, Cd, and Pb OSHA limits are shown based on limits for 8-hour exposure [9]. S and Cl limits are based on OSHA limits for prolonged exposure (PEL) [11]. Predicted concentrations in the soil from hydrothermal fluids include maximum and minimum concentrations for acid-sulfate and neutral-chloride fluids. Predicted maximum and minimum concentrations for volcanic aerosol emissions are also shown. Measured abundances or detection limits from Viking and Pathfinder are shown for Martian soil. SNC concentrations are shown for reference.