THE NEED FOR MEDICAL GEOLOGY IN SPACE EXPLORATION – IMPLICATIONS FOR THE JOURNEY TO MARS AND BEYOND. A. D. Harrington[1], R. A. Zeigler[1], and F. M. McCubbin[1], [1]Astromaterials Research and Exploration Sciences (ARES) Division, NASA Johnson Space Center, 2101 NASA Parkway Mail Code XI2, Houston TX 77058, Andrea.D.Harrington@NASA.gov.

Introduction: The previous manned missions to the Moon represent milestones in human ingenuity, perseverance, and intellectual curiosity. They also highlight a major hazard for future human exploration of the Moon and beyond: surface dust. Not only did the dust cause mechanical and structural integrity issues with the suits, the dust 'storm' generated upon reentrance into the crew cabin caused "lunar hay fever" and "almost blindness [1-3]" (Figure 1). It was further reported that the allergic response to the dust worsened with each exposure [4]. The lower gravity environment exacerbated the exposure, requiring the astronauts to wear their helmet within the module in order to avoid breathing the irritating particles [1]. Due to the prevalence of these high exposures, the Human Research Roadmap developed by NASA identifies the *Risk of Adverse Health and Performance Effects of Celestial Dust Exposure* as an area of concern [5]. Extended human exploration will further increase the probability of inadvertent and repeated exposures to celestial dusts. Going forward, hazard assessments of celestial dusts will be determined through sample return efforts prior to astronaut deployment. However, even then the returned samples could also put the Curators, technicians, and scientists at risk during processing and examination.

Figure 1. *Eugene Cernan after a spacewalk (Apollo 17)*

Lunar samples returned by the Apollo missions are the most toxicologically evaluated celestial dust samples on Earth. Studies on the lunar highland regolith indicate that the dust is not only respirable but also reactive [2, 6-9] and moderately toxic, generating a greater pulmonary response than titanium oxide but a lower response than quartz [6]. The presence of reactive oxygen species (ROS) on the surface of the dust is implicated as the potential cause of the pulmonary inflammation [10,11]. However, there is actually little data related to physicochemical characteristics of particulates and cardiopulmonary toxicity, especially as it relates to celestial dust exposure.

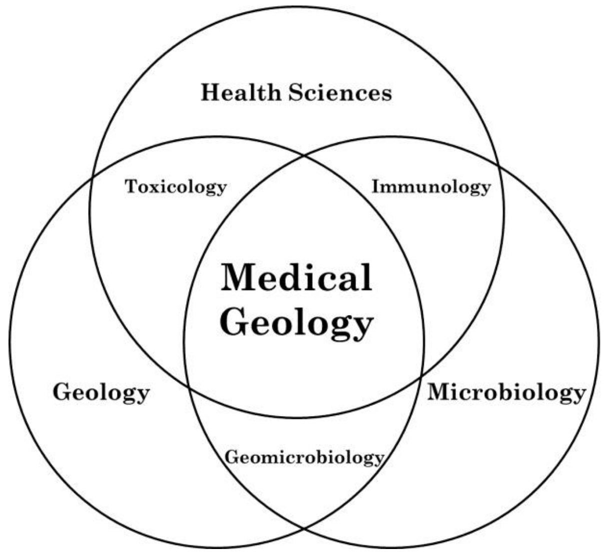

Figure 2. *Interdisciplinary Nature of Medical Geology*

New Approach to an Old Problem: The interdisciplinary field of Medical Geology, or Medical Mineralogy, developed from the desire to understand the properties of a material that contribute to pathogenesis. There are an array of different factors that can influence the health effects of natural and anthropogenic materials [12]: 1) intensity and duration of the exposure (dose), 2) exposure route, 3) chemical conditions encountered along the exposure route, 4) physicochemical characteristics of the material, 5) potential pathogens (e.g. microbial), 6) biosolubility, biodurability, bioaccessibility, and bioreactivity of the materials in the body fluids encountered along the various exposure routes, 7) the body's immune response, or bioactivity, 8) the bodies physiological processes that control absorption, distribution, metabolism, and excretion of toxins/toxicants, and 9) other confounding factors, including but not limited to age, gender, genetics, and health.

The array of fields required to address the range of factors influencing pathogenesis has helped and hindered progress. While great breakthroughs have been made, the lack of cooperation and coordination between disciplines has stymied progress overall. The field of Medical Geology was developed to bridge this gap (Figure 2).

Focus on physicochemical features. For the past few decades, the relationship between the geological environment and health has focused on the bioavailability and bioaccessibility of the chemical species. From this, great strides have been made in understanding the differences in toxicity between metal valence states. For example, toxicity between carcinogenic hexavalent chromium versus relatively benign trivalent chromium as well as the much higher acute toxicity of inorganic arsenites (trivalent) versus organic arsenates (pentavalent) [13,14]. Given the surface composition of Mars, the toxicity of iron, its valence states, and the internal structure in which it is arranged may play an important role in generating negative health outcomes.

As a Fenton metal, iron in its ferrous state can generate ROS in solution. In fact, the ferrous sulfide mineral pyrite has been implicated as the driving force behind the prevalence of coal workers pneumoconiosis in miners [11]. It has been postulated that, similar to the proposed relationship between quartz and silicosis, the ability to generate ROS is the main cause of particulate induced pulmonary inflammation [15,16]. However, more recent data investigating other reactive samples does not show that particle derived ROS is a major contributing factors in pulmonary inflammation. Instead, correlations with geochemical features, such as bulk iron, indicate that bioactivity (e.g. direct biomolecule oxidation, cellular responses) may play an even greater role than previously thought [17]. Understanding the toxicity of celestial dust and physicochemical origin of said toxicity will represent a breakthrough in both mitigating the risk for human exploration and in exposure science as a whole.

Filling the Gaps for a Journey to Mars: Given the risks involved in human space exploration, there is a very small margin for error. Therefore, risk needs to be mitigated wherever possible. By leveraging previous studies on lunar dust, the breakthroughs made over the past decade in medical geology research, and the vast on-site expertise (e.g. Exploration Integration and Science Directorate [Astromaterials Acquisition and Curation Office, Astromaterials Research Office, Exploration Mission Planning Office], Flight Operations Directorate [Astronaut Training and Mission Execution], and the Human Health and Performance Directorate [Biomedical Research and Environmental Sciences Division, Space and Clinical Operations Division, Human Systems Engineering and Development Division]), NASA Johnson Space Center is singularly positioned to understand the exposure risks, gaps in knowledge, and how to fill them.

Currently, Mars is the ultimate target for human exploration. Although a final hazard assessment of martian dust will require returned samples, a preliminary risk assessment is possible by utilizing simulants. In fact, the synthesis of an array of martian analogue samples will enable a robust initial risk assessment, which could aid in mission planning. Coordination with a Medical Geologist will be vital in this process, since a viable martian analogue for toxicological assessment will have to: 1) accurately represent martian surface and atmospheric dust, 2) be comprised of respirable materials, and 3) meet specifications needed to perform *in vitro* and *in vivo* exposures.

Conclusions: The interdisciplinary nature of Medical Geology research is representative of the direction in which all research is heading. NASA is at the forefront in recognizing the importance of utilizing a diverse collection of skillsets when tackling a problem. In order to reach for the stars, a balance of bold ideas and risk mitigation is necessary.

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