**MEASUREMENTS OF ELEMENTAL STRATIGRAPHY ON MARS WITH A ROVER-MOUNTED GAMMA-RAY SPECTROMETER.**

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**Introduction:** Gamma-ray spectroscopy is an established technique for measuring the absolute abundances of major (e.g., O, Na, Mg, Al, Si, Ca, Ti, Fe) and minor (K, Th, U) elements within the top 10s of cm of a planet surface. It has been successfully utilized from orbit about the Moon [*e.g.,* 1,2,3], Mars [4], Mercury [5,6], and 4 Vesta [7]. It application to surface-based measurements is more limited, having only been used on Venus [8] and 433 Eros [9] to date.

The ability of gamma-ray spectroscopy to probe elemental composition to depths of ≤ 10s of cm makes it complimentary to other measurement techniques, such as X-Ray and Alpha Particle Spectroscopy (XRS, APS), which are limited in depth sensitivity to < 100s of μm. It is unique in its ability to measure elemental composition below chemically altered or space-weathered surficial layers without the aid of a brush, grinder, or drill, each of which adds to the cost and complexity of a mission.

While gamma-ray spectroscopy has a long history of application in planetary science, its potential to make measurements of depth-dependent elemental stratigraphy is unrealized. We present a technique for using gamma rays to identify buried, compositionally distinct subsurface material without the aid of a drill, brush, grinder, or scoop. Such information could be passively obtained during a rover traverse, and would inform the rover operations team of regions in which more detailed investigations of the subsurface would be scientifically useful.

**Gamma-Ray Production:** Gamma-ray emission from stable (non-radioactive) elements occurs when Galactic Cosmic Rays (GCRs) have access to a planet surface, as is the case for airless (Moon, Mercury, asteroids) or nearly-airless (Mars) bodies. When a GCR proton with an energy > 100 MeV strikes the surface, it produces neutrons through spallation reactions with individual nuclei. This occurs to depths of several meters below the surface. These neutrons can excite stable elements through elastic scattering (denoted as n,n'γ) or capture (denoted as n,γ) reactions. The (n,n'γ) reactions require "fast" (> 500 keV) neutrons, whereas the (n,γ) reactions are induced by thermal (< 0.2 eV) neutrons. The excited nuclei decay to stability by emitting gamma rays at element-characteristic energies. A fraction of these gamma rays escape the surface and can be measured by an orbiting spacecraft or a rover.

**Depth-dependent measurements:** The probability for a gamma ray to escape the surface unattenuated is a function of its energy (see Fig.1). As a result, measurements of gamma rays from a single element at multiple energies can be used to identify any depth-dependent variability in the abundance of that element. To date, gamma-rays with energies ranging from 300 keV to 8 MeV have been used to study elemental composition, which corresponds to a range of mean free path values of 2 to 14 cm.
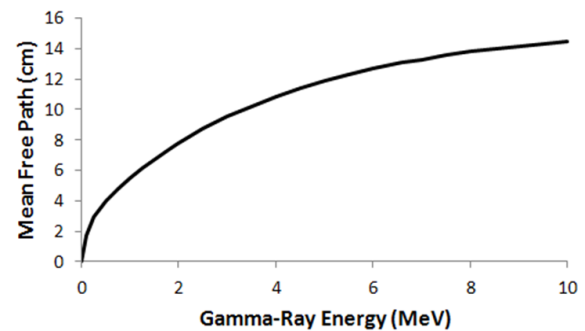


**Figure 1.** The mean free path of a gamma ray within the Martian regolith as a function of its energy.

Stratigraphy measurements are possible when multiple gamma rays from a single element are observed. For example, the MESSENGER Gamma-Ray Spectrometer measured the abundances of the elements Si, S, Ca, and Fe on Mercury using multiple gamma-ray peaks [6]. These peaks are listed in Table 1, along with their respective mean free paths.

**Table 1.** Mean free paths for several γ-rays of interest.

| Element | γ-ray Energy (MeV) | Source | Mean Free Path [cm] |
|---|---|---|---|
| Si | 1.779 | (n,n'γ) | 7.35 |
|  | 3.540 | (n,γ) | 10.27 |
|  | 4.934 | (n,γ) | 11.81 |
| S | 2.230 | (n,n'γ) | 8.24 |
|  | 5.420 | (n,γ) | 12.23 |
| Ca | 1.942 | (n,γ) | 7.68 |
|  | 3.736 | (n,n'γ) | 10.52 |
| Fe | 0.847 | (n,n'γ) | 5.06 |
|  | 7.639 | (n,γ) | 13.62 |

For MESSENGER, consistent abundances were derived for each peak for a given element, indicating that the composition is homogenous to depths of 10s of cm. This is not surprising on Mercury, given that the surface is expected to be covered by a well-mixed regolith to depths of several meters or more. This situation is

likely repeated on the moon and asteroids, however Mars and comets likely have stratigraphy at the 10s of cm scale that can be identified via gamma-ray measurements.

**Application to a Mars Rover:** A small, passive gamma-ray spectrometer can monitor multiple gamma-ray peaks coming from the same element in order to identify changes that are indicative variable elemental stratigraphy along the rover traverse path. Each measurement will take 10-20 hours to gain the statistical precision needed, which is well within the normal linger time at any site of interest. A high-energy-resolution gamma-ray detector will be required, such as the high-purity germanium systems found on the Mars Odyssey [10] and MESSENGER [11] spacecraft.

For example, consider the buried Si-rich layers that were serendipitously discovered in Gusev crater within the trench dug by the dead wheel of the Spirit rover [12] (Fig. 2a inset). This subsurface layer was interpreted as evidence for past hydrothermal activity, and was the first such evidence for aqueous alteration at the Gusev site. Had Spirit carried a passive gamma-ray spectrometer, evidence for this layering would have been identified in the multiple Si gamma rays lines and the rover team would have known to investigate further without relying on serendipitously dug trenches. Such initial reconnaissance measurements can be made by simply monitoring the ratio of these peaks over the traverse and looking for changes (see Fig. 2a).

**Laboratory Measurements:** Initial laboratory measurements have been carried out using Fe plates buried beneath sand of variable thickness. Those results (Fig. 2a) conclusively demonstrate the validity of this technique. Preparations are underway to continue these measurements for more realistic scenarios, including with buried Si-rich layers (e.g. sand) beneath layers of Mars JSC-1 simulant. We will report the results of these laboratory measurements, along with stringent limits of the elemental and depth sensitivity of this technique and its resulting applicability to future Mars rovers.

**References:** [1] Metzger, A. E., et al., (1977), *LPCS VIII*, 949-999, [2] Lawrence, D. J., et al. (1998), *Science 281*, 1484-1489 [3] Prettyman, T. H., et al., (2006), *JGR 111*, E002656, [4] Boynton, W. V., et al., (2007), *JGR 112,* E002887 [5] Peplowski, P. N., et al., (2011), *Science 333,* 1850-1853, [6] Evans, L. G., et al., (2012), JGR 117, E00L07 [7] Prettyman, T. H., et al., (2012), Science 338, 242-246, [8] Surkov, Y. A., et al., (1997), LPSC VIII, 2665-2689, [9] Evans, L. G., et al., (2001), *Meteor. Planet Sci. 36,* 1639-1660, [10] Boynton, W. V., et al., (2004) *Space Sci. Rev. 110,* 37-83, [11] Goldsten, J. O., et al., (2007), Space Sci. Rev. 131, 339-391, [12] Squyres, S. W., et al., (2008), *Science 320* [13] Feldman, W. C., et al. (1995), *Nuc. Inst.Meth. A 362*, 561-573.
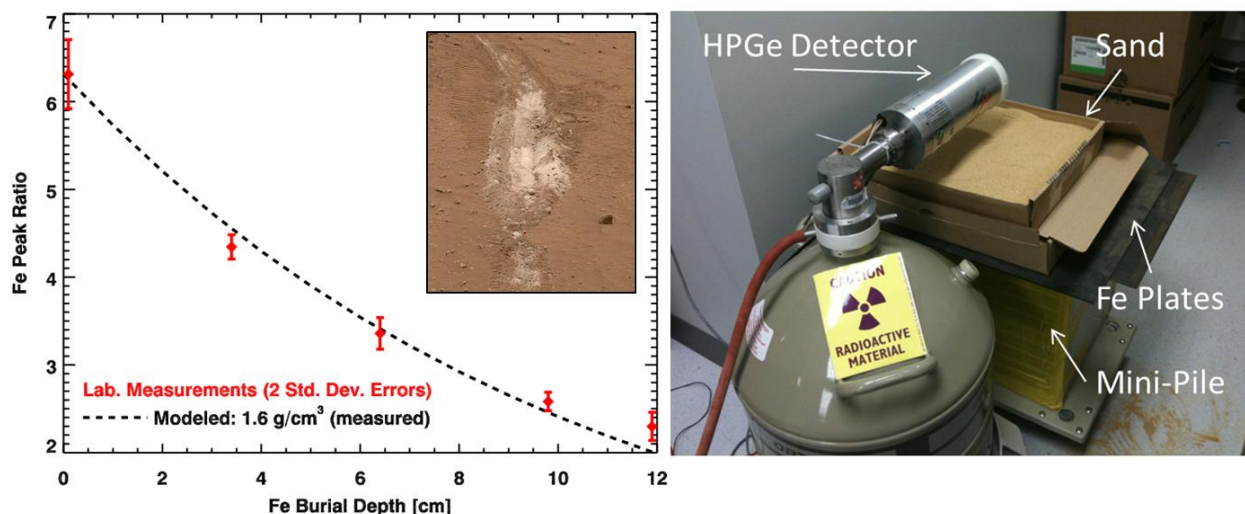


**Figure 2.** (A) The count rate ratio of the 0.846 MeV Fe peak to the 7.6 MeV Fe doublet as a function of burial depth beneath a variable layer (0 to 12 cm) of sand. This laboratory demonstration shows how the sensitivity of gamma-ray spectroscopy can be used to assess layering, and by extension to identify analogous scenarios of compositionally distinct, buried material (e.g. buried silica-rich deposits on Mars (inset), [12]). The measured ratio reproduces the predicted dependence (thick dashed line). (B) These tests utilized a "mini-pile" that alters the neutron flux from an AmBe neutron source to match that found on a planetary surface [13].