DETECTION OF NA IN THARSIS MONTES WITH THE MARS ODYSSEY GAMMA-RAY SPECTROMETER. Patrick N. Peplowski, Johns Hopkins Applied Physics Laboratory, Laurel MD USA (*Patrick.Peplowski@jhuapl.edu).

Introduction: It is generally accepted that Mars' original (primary) crust was formed via crystallization of a magma ocean, and that primary crust is now largely obscured by a secondary crust formed by subsequent basaltic volcanism [1]. In-situ exploration by the Curiosity rover have revealed a wider range of crustal formation processes. For example, silica-rich magmatic rocks, possibly analogous to continental crusts on Earth [2], have been found. A large rock with a mugearite composition, distinct from the typical basalts found on the surface, has also been discovered [3]. And igneous clasts within the brecciated martian meteorite North West Africa (NWA) 7034 also suggest a more felsic igneous component on Mars, containing approximately 3-4 wt.% more alkalis (K_2O + Na_2O) than other SNC meteorites [4].

Are these (and other) petrologically diverse rocks isolated occurrences, serendipitously discovered? Or do they provide evidence of important new crustal formation processes that are not apparent at global scales? Measurements of the Total-Alkali to Silica (TAS) of igneous rocks on planetary surfaces provides a means to explore these questions. TAS allows for identification of petrologies indicative of various crustal formation processes [5]. Figure 1 provides a TAS diagram for Mars.

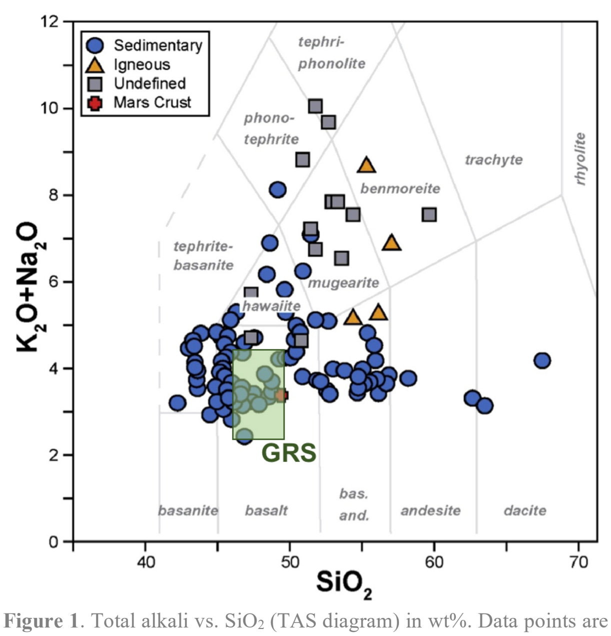

Figure 1. Total alkali vs. SiO_2 (TAS diagram) in wt%. Data points are Curiosity APXS analyses of Mangold et al. [2017], and the green box is the GRS-inferred global range of *McSween, Taylor, and Wyatt* [2009]. Figure and caption adapted from *Mangold et al.* [2017].

A global range of TAS values (green box, Fig. 1) was created using Mars Odyssey Gamma-Ray Spectrometer potassium (K) and silicon (Si) measurements, and an assumed average sodium (Na) to K ratio of 8.9. However, in-situ data (Table 1) show that K/Na varies significantly (0.74 to 9.39) at the rock-to-rock scale, undermining the validity of the MO/GRS field on the TAS diagram of Fig. 1.

	Na/K Ratio		
	Min	Mean	Max
Meridiani	2.92	3.57	4.32
Gusev	3.88	5.63	9.39
Gale	0.74	2.60	5.55

Table 1. Na/K ratio from in-situ analysis of Mars rocks at Meridiani Planum [*Rieder et al.,* 2004], Gusev crater [*McSween et al.* 2006], and Gale crater [*Schmidt et al.* 2014].

The only reliable way to place Mars global or regional composition(s) on the TAS diagram is to produce measured Na values from the MO/GRS dataset. Since the conclusion of the Mars Odyssey mission, Na was successfully characterized on the surface of Mercury using a gamma-ray spectrometer that was similar to the Mars Odyssey instrument [6, 7]. The lessons learned from that investigation enabled us to revisit the MO/GRS data and positively identify Na signatures on Mars.

Sodium Gamma-Ray Signatures on Mars: Our detection of Na on Mars uses the 440-keV gamma-ray signature produced via neutron inelastic scattering on ^{23}Na. Analysis of the signal is complicated by the present of a nuisance background gamma-ray peak at 439-keV resulting from the decay of ^{69m}Zn ($t_{1/2}$ = 13.76 hrs). ^{69m}Zn is a byproduct of GCR-induced breakup of detector housing materials (nuclei) described in [6, 7, and 8].

For MESSENGER, this background was removed using high-altitude measurements provided by MESSENGER's highly-elliptical orbit. Mars Odyssey's circular orbit doesn't provide high-altitude background measurements, so we leverage measurements of regions where 440-keV gamma rays cannot escape the surface, for example the perpetual CO_2 ice cap at the south pole, and Hellas basin, where the column density of the atmosphere is too high for low-energy gamma rays like that at 440-keV to escape into space. Thus, in these regions, any observed 440-keV gamma rays are due to background, not Mars. Figure 2 shows the 440-keV peak in the Tharsis region (low column density, ρ_c) compare to Hellas basin (high ρ_c). There is a small but

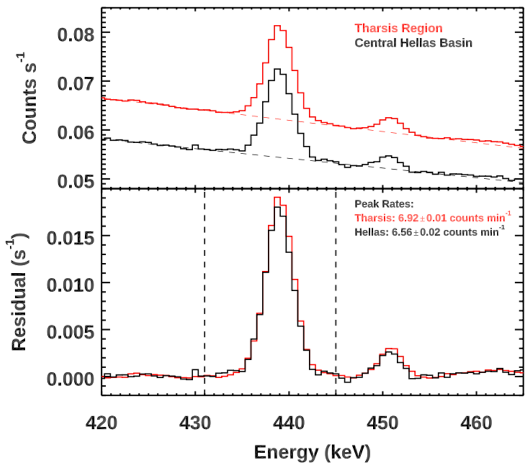

Figure 2. (Top) Gamma-ray spectrum in the energy range containing the 440-keV peak, for large regions of interest encompassing the Tharsis plateau (-35° < latitude < 45°, 220° < longitude < 275°) and Hellas Basin (-50° < latitude < -33°, 53° < longitude < 85°). Dashed lines denote fits to the continuum (non-peak) regions. (Bottom) Continuum-subtracted spectra, with the counting rates for the 440-keV peak for each location noted.

statistically significant difference between the two regions, which I attribute to Na on Mars' surface.

Limitations on Mapping: Mars has a thin, CO_2-dominated atmosphere that inhibits transport of surface-generated 440-keV gamma rays into space, where they can be detected by the Mars Odyssey GRS. The column density of the atmosphere ranges from ~6 to ~34 g cm^{-2}. GEANT4 radiation transport modeling indicates that 10 g cm^{-2} is sufficient to block 50% of the signal. Given the small magnitude of the signal (e.g. Figure 2), I concluded that Na mapping via GRS measurement is limited to regions with <10 g cm^{-2}, which includes the Tharis Montes, Tharsis plateau, and Olympus Mons.

Data Corrections: There are two important sources of variation in the 440-keV gamma-ray measurements that must be corrected prior to deriving Na concentrations on Mars. The first correction is related to changes in the column density noted earlier (See Fig. 3). As ρ_c increases, the measured rate of 440-keV gamma rays in orbit decreases. Thus, a correction is needed to determine the rate at the surface.

The second correction is related to variations in the galactic cosmic ray (GCR) flux at the surface. GCRs-produced neutrons produce the 440-keV gamma-ray signal of interest. Mars Odyssey operated for many years, over which time the local GCR flux (as represented by the solar modulation parameter, ϕ), varies significantly over the duration of the mission (Fig. 4A). The data show that the 440-keV rate decreases with increasing ϕ. Sodium measurements require summing data collected throughout the mission, therefore an empirical correction to the 440-keV

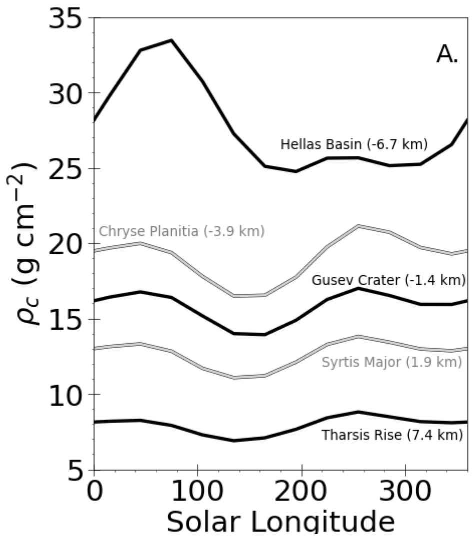

Figure 3. Sample atmosphere column density (ρ_c) values, plotted as a function of Mars seasons.

measurements is therefore needed to remove ϕ-dependent variations prior to summing the data and deriving Na concentrations.

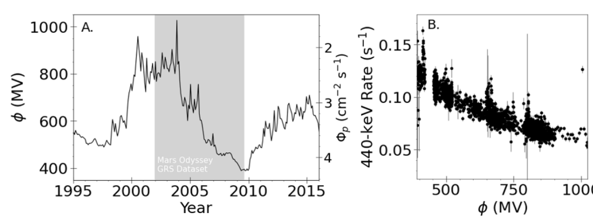

Figure 2. A. Galactic cosmic ray (GCR) behavior as a function of time during the Mars Odyssey GRS measurements. The GCR parameterization called solar modulation (ϕ; units of Mega-Volts) is shown to the left, and the integrated proton flux is shown on the right. B. MO/GRS-measured 440-keV gamma-ray rate versus ϕ.

Project Status: I have shown that the Mars Odyssey GRS dataset includes statistically significant detection of 440-keV gamma rays from sodium on Mars' surface. I have not completed the necessary data corrections to finalize the analysis and publish the results. I encourage the planetary nuclear spectroscopy community to continue the efforts described here.

References:

[1] McSween Jr, H.Y., Taylor, G.J. and Wyatt, M.B., 2009. *Science* 324, 736-739. [2] Sautter, V., et al. 2015. *Nat. Geosci*., 8, 605-609. [3] Stopar, J.D., et al. 2013. *Geochi. et Cosmochi. Acta* 112, 208-225. [4] Agee, C.B., et al. 2013. *Science*, 339, 780-785. [5] McBirney, A. Igneous Petrology, 3rd Ed., Jones and Bartlett Learning (2007). [6] Evans, L.G., et al. 2012. *J. Geophys. Res. Planets*, 117. [7] Peplowski, P.N., et al. 2014. *Icarus* 228, 86-95. [8] Evans, L.G., 2006. J. *Geophys. Res. Planets*, 111.