

**QUANTIFYING THE COMPLETE MINERAL ASSEMBLAGES IN ROCKS OF GUSEV CRATER, MARS.** H. Y. McSween<sup>1</sup>, S. W. Ruff<sup>2</sup>, R. V. Morris<sup>3</sup>, R. Gellert<sup>4</sup>, and the Athena Science Team. <sup>1</sup>Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996 USA (mcsween@utk.edu), <sup>2</sup>Department of Geological Sciences, Arizona State University, Tempe, AZ 85287 USA, <sup>3</sup>NASA/Johnson Space Center, Houston, TX 77058 USA, <sup>4</sup>Department of Physics, University of Guelph, Guelph, ON, Canada N1G 2W1.

**Introduction:** Determining the complete mineralogy of Mars rocks by remote sensing has remained a challenge, because of inherent limitations in the minerals that can be detected and uncertainties in spectral modeling. A subset of the igneous rocks of Gusev crater provide a unique opportunity to determine modal mineralogy, because of limited alteration and the analytical capabilities of the Athena instrument package. Here we estimate the absolute (wt. %) abundances of Fe-bearing minerals from Mössbauer spectra (previously reported only as “areas for component subspectra” [1]), and compare these results to the normative mineralogy calculated from APXS elemental analyses [2]. We also test our preferred mineralogy by comparison of Mini-TES spectra with synthetic thermal emission spectra.

**Method:** For this study, rocks generally had been RAT-ground, or –brushed if no abraded samples were available. We used only rocks for which both APXS and Mössbauer spectra were available, and that had experienced limited alteration ( $\text{Fe}^{3+}/\text{Fe}_{\text{Total}}$  ratios generally  $\leq 0.45$  and absence of detectable goethite). APXS chemical analyses were recast into normative mineralogy, using Mössbauer-determined  $\text{Fe}^{3+}/\text{Fe}_{\text{Total}}$  ratios [1]. For each rock, Mössbauer subspectral areas were converted to weight percentages of olivine, pyroxene (combined low-Ca and high-Ca, because Mössbauer data are indistinguishable), ilmenite, magnetite, hematite, and nanophase oxides. This involved careful modeling of the Fe contents of each of these phases as constrained by both normative mineral compositions and Mössbauer parameters. The weight percentages of Fe-bearing phases were then renormalized to 100% minus the normative proportions (wt. %) of Fe-absent phases (plagioclase and apatite). The preferred mineral assemblage consists of the transformed Mössbauer phase abundances plus the normative abundances of the minerals not detected by Mössbauer.

Deconvolution of Mini-TES spectra for Gusev rocks has generally been hampered by downwelling radiance and dust contamination problems [3]. However, synthetic thermal emission spectra using these assemblages were calculated using the preferred mineral abundances.

Unfortunately, the approach above cannot be used to determine the mineralogy of highly altered rocks on the Columbia Hills or at Meridiani Planum. The Fe contents of alteration phases cannot be modeled

accurately, and the presence of phyllosilicates renders normative mineralogy suspect.

**Results:** The various igneous rock classes in Gusev were defined by [4], based on their elemental compositions. The transformed Mössbauer mineral abundances for representative samples of these classes are compared with normative mineralogies in Fig. 1. Adirondack basalts (represented by Humphrey) show remarkably good agreement. Agreements for most other rock classes are also reasonable but not quite as good. Except for Wishstone, none of these other classes had been RAT-ground (because grinding diamonds were lost later in the mission), and all these rocks show somewhat greater alteration (see  $\text{Fe}^{3+}/\text{Fe}_{\text{Total}}$  values in Fig. 1). The discrepancies can be explained in part by the difference in depths of measurement for Mössbauer (several mm) and APXS (a few tens of microns) spectra, coupled with the realization that all Gusev rocks have altered exteriors [5]. Dissolution of olivine in the outer portions of rocks, as hypothesized by [6], is confirmed by the lower olivine abundances in normative versus Mössbauer data for most rock classes.

**Thermal Emission Spectra:** Representative synthetic spectra, calculated using the preferred mineral abundances, are shown in Fig. 2. Comparison of synthetic spectra with Mini-TES spectra of the same rock classes can provide an independent test of the preferred mineralogy. The agreement for Adirondack class basalts is excellent, and deconvolution of another rock of this class (not analyzed by Mössbauer and APXS) shows similar mineralogy [3]. Agreements for other rock classes (Fig. 2) are not as good in the middle wavenumber region but better at low wavenumbers. Unmodeled components such as sulfate and glass may account for some of these discrepancies. Also, fits are not as good for rocks with higher amounts of sodic plagioclase.

**Conclusions:** Because of surface alteration, even in RAT-brushed rocks, Mössbauer spectra (which probe more deeply than APXS, Mini-TES, or Pancam spectra) provide the most accurate assessment of mineralogy. However, the Mössbauer results must be modeled to transform subspectral areas into phase weight percentages and renormalized to take into account Fe-absent phases that Mössbauer cannot detect. Comparison of synthetic thermal emission spectra with Mini-TES spectra are broadly consistent with these mineral assemblages and compositions, but differences result from unmodeled phases.

**References:** [1] Morris R. V. et al. (2006) *JGR 111*, E02S13. [2] Gellert R. et al. (2006) *JGR 111*, E02S5. [3] Ruff S. W. et al. (2006) *JGR 111*, E12S18. [4] Squyres S. W. et al. (2006) *JGR 111*, E02S11. [5] Haskin L. A. et al. (2005) *Nature 436*, 66-69. [6] Hurowitz J. A. et al. (2006) *JGR 111*, E02S19. [7] McSween H. Y. et al. (2006) *JGR 111*, E09S91.

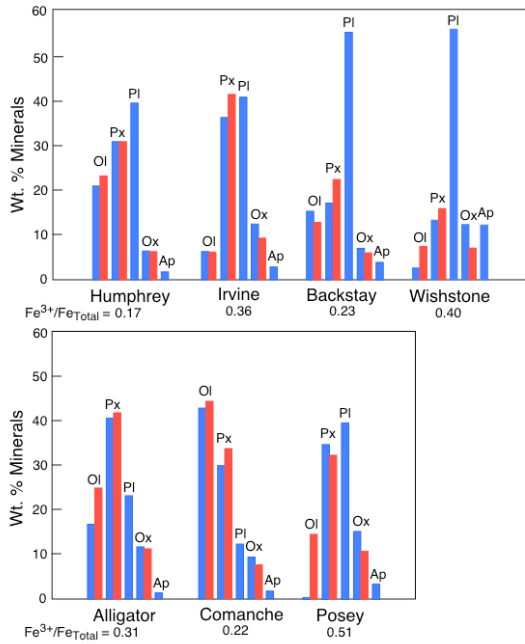


Fig. 1. Histograms comparing the mineral abundances in representative samples of each rock class [4] determined from Mössbauer spectra (red bars) and normative mineral abundances calculated from APXS analyses (blue bars). Rock classes and petrochemical classifications [7] are: Adirondack basalt (Humphrey), Irvine basalt, Backstay trachybasalt, Wishstone tephrite, Peace picrite (Alligator), Algonquin tephrite (Comanche), and Home Plate basalt (Posey).

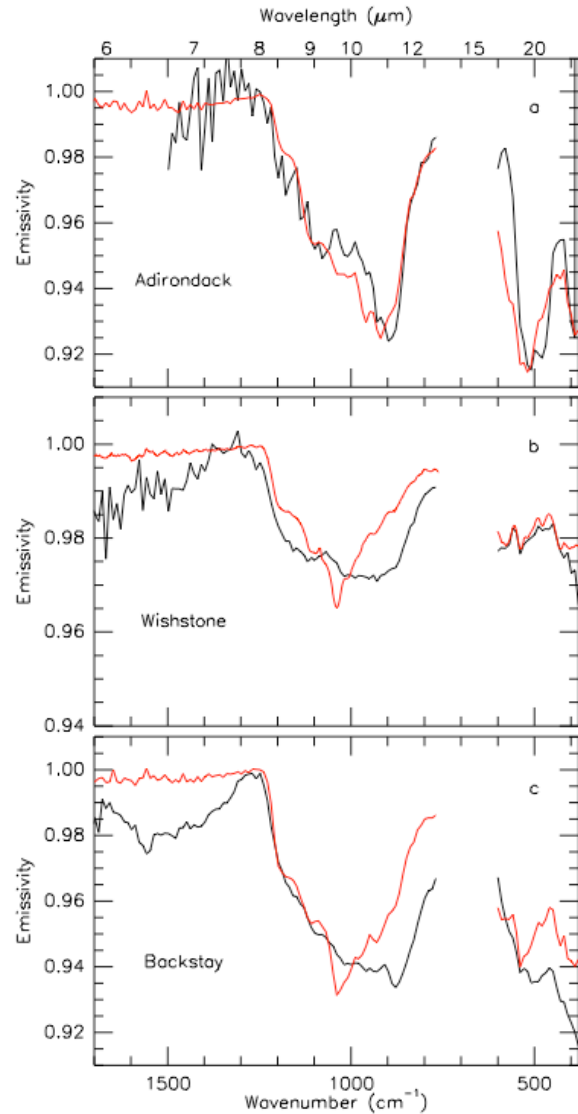


Fig. 2. Examples of measured Mini-TES spectra (black) and their synthetic equivalents (red) produced from APXS/MB-derived mineralogy. (a) Adirondack Class demonstrates a case where the measured spectrum is well fit by the synthetic spectrum, an indication of an accurate set of derived mineral modes. (b) Wishstone Class shows good agreement at low wavenumbers (<600) but a poor fit between 800-1200  $\text{cm}^{-1}$  likely due to a discrepancy in plagioclase composition, differences in the actual vs. modeled phosphate phase, and the presence of an unmodeled sulfate surface-alteration phase. (c) Backstay Class is not well fit by its synthetic equivalent probably due to a combination of unmodeled pigeonite, possible disordered plagioclase or perhaps even a feldspathoid phase in the rock.