

GEOCHEMICAL PROPERTIES OF ROCKS AND SOILS IN GUSEV CRATER, MARS: APXS RESULTS FROM CUMBERLAND RIDGE TO HOME PLATE. D. W. Ming¹, R. Gellert², R. V. Morris¹, A. S. Yen³, R. E. Arvidson⁴, J. Brückner⁵, B. C. Clark⁶, B. A. Cohen⁷, I. Fleischer⁸, G. Klingelhöfer⁸, T. J. McCoy⁹, D. W. Mittlefehldt¹, M. E. Schmidt⁹, C. Schröder¹, S. W. Squyres¹⁰, & J. Zipfel¹¹; ¹NASA Johnson Space Center, Houston, TX 77058 (douglas.w.ming@nasa.gov), ²University of Guelph, Guelph, Canada, ³Jet Propulsion Laboratory, Pasadena, CA, ⁴Washington University, St. Louis, MO, ⁵Max-Planck-Institut für Chemie, Mainz, Germany, ⁶Lockheed Martin Corporation, Littleton, CO, ⁷Marshall Space Flight Center, Huntsville, AL, ⁸Institut für Anorganische und Analytische Chemie, J. Gutenberg-Universität, Mainz, Germany, ⁹Smithsonian Institution, Washington, DC, ¹⁰Cornell University, Ithaca, NY, ¹¹Forschungsinstitut und Naturmuseum Senckenberg, Frankfurt, Germany.

Introduction: The Mars Exploration Rover Spirit landed in Gusev crater on Jan. 4, 2004. Spirit has traversed the Gusev crater plains, ascended to the top of Husband Hill, and entered into the Inner Basin of the Columbia Hills. The Athena science payload onboard Spirit has recorded numerous measurements on the chemistry and mineralogy of materials encountered during nearly 2 Mars years of operation within the crater. Rocks and soils have been grouped into classes based upon their unique differences in mineralogy and chemistry [1-3]. Some of the most significant chemical discoveries include the composition of Adirondack class flood basalts [4-6]; high sulfur in Clovis and Peace Class rocks [7,2]; high P and Ti in Wishstone Class rocks [7,2]; composition of alkalic basalts [2,6]; very high S in Paso Robles class soils [7,2], and the possible occurrence of a smectite-like chemical composition in Independence class rocks [8].

Water has played a significant role in the alteration of rocks and soils in the Columbia Hills. The occurrence of goethite and ferric sulfate alone suggests that liquid water was involved in their formation [3]. The pervasively altered materials in Husband Hill outcrops and rocks may have formed by the aqueous alteration of basaltic rocks, volcanoclastic materials, and/or impact ejecta by solutions that were rich in acid-volatile elements [2].

The objective of this paper is to provide an update on the health of the Alpha Particle X-ray Spectrometer (APXS) and to expand the geochemical dataset from sol 470 to sol 1368. Specific objectives are to (1) update the rock and soil classifications, (2) characterize elemental relationships among the major rock and soil classes, and (3) evaluate the involvement of water in the formation or alteration of the materials in these classes.

New Geochemical Classes: Geochemical diversity for rocks and soils was encountered by the APXS during Spirit's journey over Husband Hill and down into the Inner Basin from sol 470 to 1368. The APXS continues to operate nominally with no changes in calibration over the course of the mission. Germanium has been added to the APXS dataset with the confirmation

that it occurs in many rocks and soils throughout Gusev crater (Fig. 1).

Twelve new rock classes and one new soil class were identified at the Spirit landing site since sol 470 based upon the diversity in APXS geochemistry and Fe mineralogy determined by the Mössbauer Spectrometer. The new rock classes are Irvine (alkaline basalt), Independence (low Fe outcrop), Descartes (outcrop similar to Independence with higher Fe and Mn), Algonquin (mafic-ultramafic igneous sequence), Barnhill (volcanoclastic sediments enriched in Zn, Cl, and Ge), Fuzzy Smith (very high Si and Ti rock), Elizabeth Mahon (high Si, Ni, and Zn outcrops and rocks), Halley (hematite-rich outcrops and rocks), Montalva (high K, hematite-rich rock), Everett (high Mg, magnetite-rich rock), Good Question (high Si, low Mn rock), and Torquas (high K, Zn, and Ni magnetite-rich rock). One new soil class (Gerturde Weise) with subclasses Kenosha Comets (very high Si soil) and Eileen Dean (high Mg, magnetite-rich soil) were identified near Home Plate.

Alteration Processes: Aqueous processes have played a major role in the formation and alteration of rocks and soils on Husband Hill and in the Inner Basin. Nearly all materials encountered by Spirit experienced some degree of aqueous alteration; however, several materials have geochemical properties that indicated extensive alteration by water. Aluminum enrichment in Independence class materials appears to be caused by weathering and the possible formation of a smectite-like phase (Fig 2., see [8]). Independence class rocks along with Wishstone and Watchtower class rocks also have enrichments in P that may be indicative of leaching and the precipitation of secondary phosphates (Fig. 3, [2]). The rock Fuzzy Smith and the soil Gertrude Weise exhibit geochemical signatures of very high Si and Ti enrichments and depletions in most other elements suggesting extensive aqueous leaching of these materials probably by acidic solutions (Figs. 2 & 3, see [9, 10, 11]). Many of the rocks and soils around Home Plate have enrichments in the volatile elements, Cl, Br, Ge, K, and Zn. These elements may have accompanied hydrothermal fluids

that reacted with and aided in the aqueous alteration of rocks and soils [12]. The most notable case of elemental mobilization and reprecipitation is the Paso Robles class soils (Arad, Berkner Island, Mount Darwin). These very high S soils are enriched in elements that are mobilized by acidic solutions and their compositions likely reflect the host materials where those acidic solutions leached the host's elements and transported them to the soil deposit [13].

Geochemical indicators of impact mixing processes are not as evident as the indicators for aqueous alteration processes. The geochemical marker for impact processes is enrichment in Ni; however, igneous fractionation and aqueous processes (including hydrothermal alteration induced by an impact event) complicate the interpretation of Ni enrichments from meteoritic inputs. Descartes class materials appear to be impact derived materials not necessarily by geochemical signatures, but supported by the fact that clasts of different materials (i.e., Wishstone) are embedded in a matrix of materials that are geochemically similar to Independence class materials. Slight enrichment in Ni and depletion in Mg and Fe of Descartes materials compared to typical Adirondack basalts may indicate Ni enrichment from a meteoritic source although aqueous processes cannot be excluded.

Volcanic and associated hydrothermal processes appear to be very prominent in the Inner Basin, particularly for Home Plate materials. The association of the volatile elements (K, Zn, Cl, and Ge) with sediments and materials around Home Plate suggests that fluids rich in these volatile elements interacted and altered these materials. These elements are generally associated with hydrothermal solutions that move through a host rock or ore body. The morphological characteristics of Home Plate suggest that the sediments are of volcanoclastic origin [10,12,13].

References: [1] Squyres, S.W., *et al.* (2006) *JGR*, 111, doi:10.1029/2005JE002562. [2] Ming, D.W., *et al.* (2006) *JGR*, 111, doi:10.1029/2005JE002560. [3] Morris, R.V., *et al.* (2006) *JGR*, 111, doi:10.1029/2005JE002584. [4] Gellert, R., *et al.* (2004) *Science*, 305, 829-832. [5] McSween, H.Y., *et al.* (2004) *Science*, 305, 842-845. [6] McSween, H.Y., *et al.* (2006) *JGR* 111, doi: 10.1029/2005JE00247. [7] Gellert, R. *et al.* (2006) *JGR*, 111, doi:10.1029/2005JE002555. [8] Clark, B.C., *et al.*, (2007) *JGR*, 112, doi:10.1029/2006JE002756. [9] Squyres, S.W., *et al.* (2007) *Science*, 316:738-742. [10] Arvidson, R.E., *et al.* (2008) *Science* (submitted). [11] Morris, R.V., *et al.* (2007) *AGU, EOS*, 88(52), Abst. P21C-02. [12] Schmidt, M., *et al.* (2008) *JGR* (submitted). [13] Yen, A.S., *et al.* (2008) *JGR* (in press).

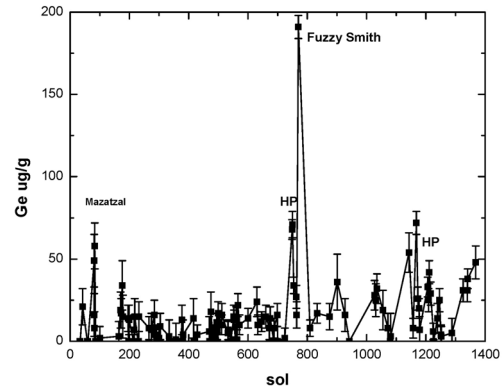


Figure 1. Distribution of germanium in all Gusev rocks and outcrops is shown as a function of when the rock was encountered by Spirit. Germanium was uniquely identified in the float rock Fuzzy Smith on sol 770. This discovery prompted a recalibration of the Spirit APXS data to include Ge.

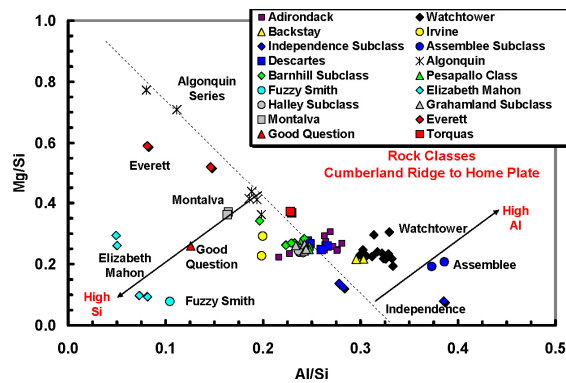


Figure 2. Elemental Mg/Si vs. Al/Si for the Husband Hill and Inner Basin outcrop and rock classes and subclasses. The dashed line represents the expected trend for igneous fractionation based upon the Martian meteorites.

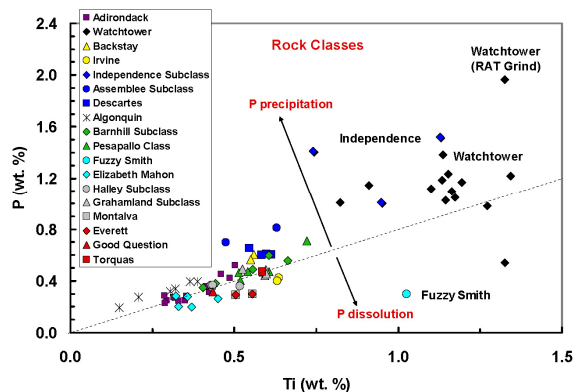


Figure 3. Phosphate mobility as indicated by P vs. Ti for Husband Hill and Inner Basin outcrops and rocks. The dashed line represents the slope of the line for the P/Ti ratio derived from the Martian meteorites.