GEOCHEMICAL AND MINERALOGICAL INDICATORS FOR AQUEOUS PROCESSES ON THE WEST SPUR OF THE COLUMBIA HILLS IN GUSEV CRATER. D. W Ming[1], R. V. Morris[1], R. Gellert[2,3], A. Yen[4], J. F. Bell, III[5], D. Blaney[4], P. R. Christensen[6], L. Crumpler[7], P. Chu[8], W. H. Farrand[9], S. Gorevan[8], K. E. Herkenhoff[10], G. Klingelhöfer[3], R. Rieder[2], D. S. Rodionov[3,11], S. W. Ruff[6], C. Schröder[3], S. W. Squyres[5], and the Athena Science Team. [1]NASA Johnson Space Center, Mail Code SX, Houston, TX 77058, USA (douglas.w.ming@nasa.gov); [2]Max-Planck-Institut für Chemie, Mainz, Germany; [3]Insitut für Anorganische und Analyicshe Chemie, J. Gutenberg-Univerität, Mainz, Germany; [4]Jet Propulsion Laboratory, Pasadena, CA 91109, USA; [5]Department of Astronomy, Cornell University, Ithaca, NY 14853, USA; [6]Department of Geological Sciences, Arizona State University, Tempe, AZ 85287, USA; [7]New Mexico Museum of Natural History and Science, Albuquerque, NM 87104, USA; [8]Honeybee Robotics, New York, NY 10012, USA; [9]Space Science Institute, Boulder, CO 80301, USA; [10]U.S. Geological Survey, Flagstaff, AZ 86001, USA; [11]Space Research Institute IKI, Moscow, Russia.

Introduction: The primary objective of the MER *Spirit* and *Opportunity* Rovers is to identify and investigate rocks, outcrops, and soils that have the highest possible chance of preserving evidence of water activity on Mars. The Athena Science Instrument Payload onboard the two rovers has provided geochemical and mineralogical information that indicates a variety of aqueous processes and various degrees of alteration at the two landing sites.

Light-toned rocks on the Gusev crater plains appear to have coatings or alteration rinds that may have resulted from limited aqueous alteration on the surfaces of basaltic rocks [1,2]. Hematite and high $Fe^{3+}/Fe_{(total)}$ occur at the surfaces of some rocks [3] and high concentrations of elements highly mobile in water (i.e., S, Cl, and Br) occur in rock veins, vugs, and coatings [4]. Soil trenches that were excavated with the rover's wheels exhibited higher $Fe^{3+}/Fe_{(total)}$ ratios and mobile element concentrations (i.e., S and Mg) at the bottom of soil trenches than for surface soils, suggesting the translocation/transportation of these phases by water [5-7]. One scenario for the formation of rock coatings or rinds and translocation of mobile elements in Gusev crater is that thin films of water may have mobilized elements and nanophase particles, and altered the surfaces of rocks.

The objective of this paper is to describe the geochemical and mineralogical indicators for aqueous processes on the West Spur of the Columbia Hills, which lie approximately 2.6 km to the southeast of the landing site. *Spirit* encountered the contact between the "plains" of Gusev crater and the Columbia Hills on sol 156. The West Spur of the Columbia Hills rises about 20 meters above the contact with the Gusev plains. The Athena science payload analyzed several rocks and outcrops over the next 150 sols (sol 156-306) (Fig. 1).

Geochemical, mineralogical and morphological indicators for aqueous processes: Outcrops and rocks on West Spur appear extensively altered or different "rock" types on the basis of coherency as measured by resistance to abrasion by the Rock Abrasion Tool or RAT when compared to basalts on the Gusev plains. Approximately 10-20 times less energy was required to grind into these outcrops and rocks as compared to equivalent grind depths for the "plains" basalts. Several of the outcrops and rocks had high $Fe^{3+}/Fe_{(total)}$, ranging from 0.6 to 0.9, and the iron mineralogy was dominated by nanophase-Fe^{3+} oxides, hematite, and magnetite. A Fe^{2+}-silicate phase (possibly pyroxene or a glass phase) was the only silicate Fe^{2+} phase detected by the Mössbauer spectrometer (MB) in the outcrops

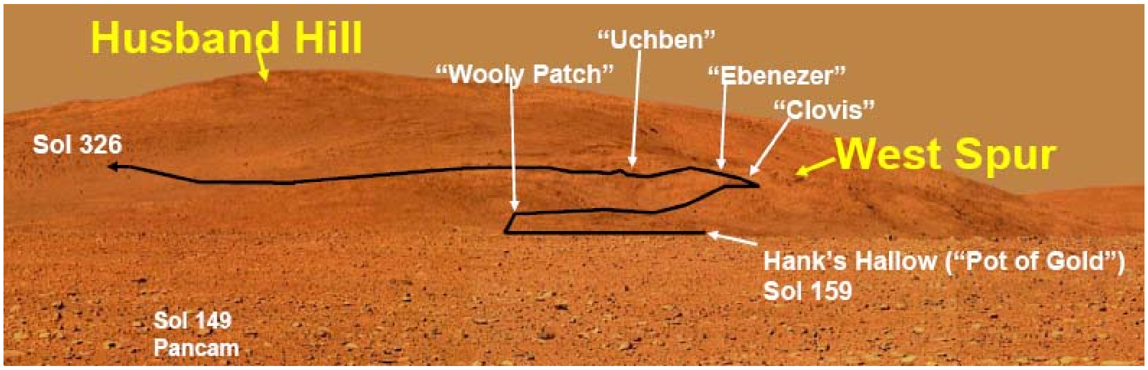

Figure 1. Pancam image (approx. true color) of the Columbia Hills from the Gusev "plains." Several outcrops and rocks examined by the Athena Instrument Science payload are shown along *Spirit's* traverse over the West Spur.

Figure 2. Pancam image (approx. true color) of a RAT hole and RAT "daisy wheel" brushing on the West Spur outcrop "Clovis."

and rocks on the West Spur. Goethite (α-FeOOH) was identified by MB in the outcrop "Clovis" (Fig. 2).

Br, Cl, and S concentrations measured by the Alpha Particle X-ray Spectrometer (APXS) beneath outcrop surfaces exposed by grinding with the RAT (grind depths ranged between 3.4 and 8.9 mm) were higher than subsurface concentrations in Gusev plains basalts (Fig. 3). Silicon, Ti, Al, and Fe compositions of West Spur outcrops are very similar to the average composition of undisturbed soil surfaces on the adjacent Gusev plains. The only exception is a higher Al content in an outcrop target "Wooly Patch_Sabre." West Spur outcrops also have higher Mg contents than Gusev plains basalt and soil surfaces. Positive correlations exist for Ca vs. S and for Mg and Ca vs. Cl, which suggest that the S and Cl phases in the outcrop materials may be Ca-sulfates, and Mg- and Ca-chlorides.

Several layered rocks and outcrops such as the outcrop "Uchben" (Fig. 4) were encountered near the summit of the West Spur. Close examination of these layered rocks by the Microscopic Imager (MI) suggested that some layers were more resistant to physical weathering than other layers and that the materials consisted of moderately- to poorly-sorted rounded to angular grains.

Possible Aqueous Processes: Outcrops and rocks appear to be extensively altered by aqueous processes as suggested by their relative "softness," high $Fe^{3+}/Fe_{(total)}$, iron mineralogy dominated by nanophase Fe^{3+}-oxides and hematite, high Br, S and Cl concentrations, and the occurrence of goethite in "Clovis." Goethite can only form in the presence of water in contrast to hematite that can form by aqueous and non-aqueous processes. These outcrops and rocks may have formed by the alteration of basaltic rocks, volcaniclastic materials, and/or impact ejecta by solutions that were rich in volatile elements (i.e., Br, Cl, S). However, it is not clear whether aqueous alteration occurred at depth (e.g., metasomatism), by hydrothermal solutions (e.g., associated with volcanic or impact processes), by aqueous vapors from volcanic eminations (i.e., acid fog weathering), or by low-temperature solutions moving through the West Spur materials. The layered rocks and outcrops on the West Spur (e.g., "Uchben") appear to be sedimentary in nature and deposited in a fluid, e.g., air fall deposits from volcanic ash or impact materials. Regardless of their formation processes, water had a major role in the alteration and formation of the outcrops and rocks on the West Spur of the Columbia Hills.

References: [1] H.Y. McSween et al. 2004. *Science*. **305**:842. [2] A.S. Yen et al. 2005. *LPSC XXXVI*. [3] R.V. Morris et al. 2004. *Science*. **305**:833. [4] R. Gellert et al.. 2004. *Science*. **305**:829. [5] A.S. Yen et al. 2005. *Nature* (in review). [6] L.A. Hasken et al. 2005. *Nature* (in review). [7] A. Wang et al. 2005. *LPSC XXXVI*.

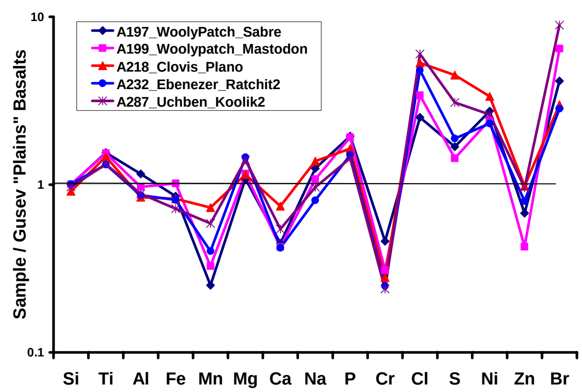

Figure 3. Compositions (mole %) of West Spur outcrops and rocks (APXS analyses in RAT holes) compared to the average interior composition of Gusev plains basalts.

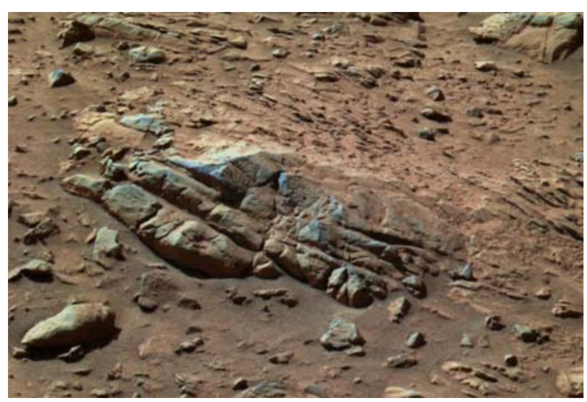

Figure 4. Pancam image (false color) of a layered outcrop "Uchben" near the summit of the West Spur.