FIELD RECONNAISSANCE GEOLOGIC MAPPING OF THE COLUMBIA HILLS, GUSEV CRATER FROM MER SPIRIT ROVER and HiRISE OBSERVATIONS. L. Crumpler[1], R. Arvidson[2], D. Blaney[3], N. Cabrol[4], P. deSouza[14], W. Farrand[5], J. Farmer[11], R. Greeley[11], J. Hurowitz[3], K. Lewis[6], T. McCoy[7], A. McEwen[8], H. McSween[9], D. Ming[10], R.V. Morris[10], J.W. Rice, Jr.[11], M. Rice[12], S. Ruff[11], M. Schmidt[7], C. Schröder[15], S. Squyres[12], A. Yen[3], and A. Yingst[13], [1]New Mexico Museum of Natural History & Science, 1801 Mountain Rd NW Albuquerque, NM, 87104,USA, larry.crumpler@state.nm.us, [2]Washington Univ, St. Louis. MO, USA, [3] Jet Propulsion Laboratory, Pasadena, CA, USA, [4]NASA Ames Research Center, Moffett Field, CA , USA, [5] Space Science Institute, Boulder, CO, [6] California Institute of Tech, Pasadena, CA, [7] National Museum of Natural History, Smithsonian, Washington, DC, [8] University of Arizona, Tucson, AZ, [9] Univ of Tennessee, Knoxville, TN, [10] Johnson Space Center, Houston, TX, [11]Arizona State University, Tempe, AZ, [12] Cornell Univ, Ithaca, NY, [13] Planetary Science Institute, Tucson, AZ, [14]Tasmanian ICT Centre, CSIRO, Hobart, Aus, [15]Johnnes Gutenberg-Universität, Mainz, Germany

Introduction: This study summarizes field reconnaissance geologic observations and mapping made from the rover perspective during Spirit's traverse through the Columbia Hills. These surface observations ("ground truth") include in situ documentation of local chemical, mineralogical, and lithologic variations within generalized terrain units that are mappable in orbital MRO/HiRISE image data. The observations are then used to define more widespread Columbia Hills geologic material units based on a comparison of HiRISE image characteristics of the defined material units.

Field Geologic Mapping on Mars: The use of combined orbital and surface data follows basic terrestrial field geologic mapping methodology in which fieldwork may be preceded with an examination of air photos, and preparation of a preliminary photogeologic map of the area to be mapped on foot. The photogeologic map then serves as an hypothesis or framework that is tested directly during the surface traverse. The methods for initial photogeologic map preparation are similar to that used for preparing planetary geologic maps from orbital remote sensing data alone [*1*]. Except in this case the map is modified and the details are expanded once determinations are made of lithology and stratigraphic relationships from in situ examination of outcrops. *For the first time, we have done this on Mars. Historically, the following discussion presents the results of the first field reconnaissance geologic mapping on another planetary surface.*

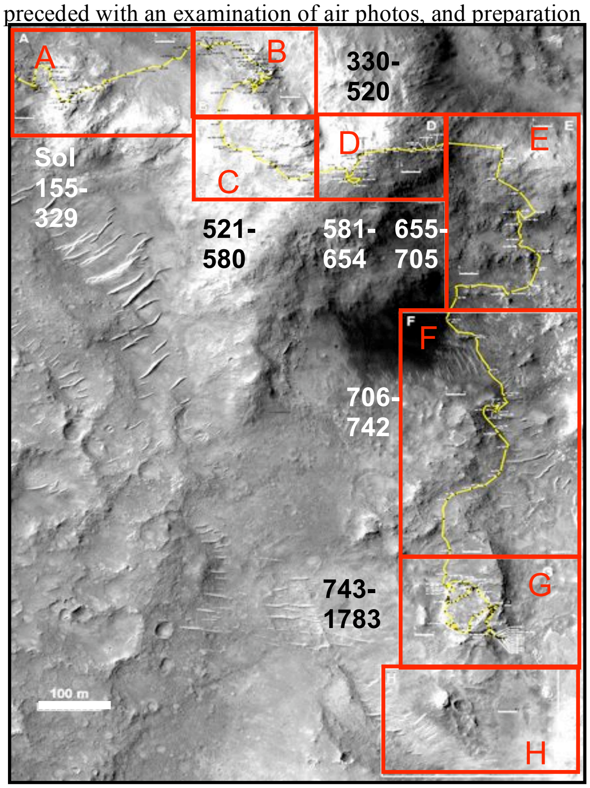

Figure 1. Location of eight areas of distinctive lithology identified in MRO/HiRISE image of the central Columbia Hills, Gusev Crater. Sols over which traverses occurred (along yellow line) are shown for each area. Red boxes (A-H) outline the principal areas of distinctive materials and morphology. Note 100 m scale bar in lower left. MRO/HiRISE image PSP_001513_1655_RED.

MRO/HiRISE Images. HiRISE images resolve submeter surface features (0.25 to 1.3 m/pixel) [*2*], a level of detail comparable to high-altitude air photos applicable in some terrestrial geologic mapping situations. HiRISE has monitored the MER Spirit site regularly and there are 14 images at the time of this writing spread over a variety of seasons (L_S values) and emission angles. Two images have been especially useful for identifying surface details and for use in stereoptic viewing used in defining map units: PSP_001513_1655 (sol 1026) and PSP_001777_1650 (sol 1046). The traverse through the Columbia Hills is divided for purposes of this discussion into several areas that follow natural divisions in the morphology and relief both in HiRISE images and rover images combined with outcrop analyses (Fig. 1 A-H). The stereo data results in true "air photo" type mapping.

MER "Field" Data. Based on these and other HiRISE images several distinct units are mapped along the traverse within the Columbia Hills [*3*], including units characterized and placed in geologic context both with the Athena instruments and from rover-based imaging. Figure 2 shows an example of rover-based imaging (for example, [*9*]). Important defined units include both substrate (layered clastic outcrops) and surficial ("float" and landslide) materials. Small craters are more abundant on the upper slopes where float and surficial debris are relatively thin and craters are better retained. Small craters are otherwise notably sparser within the Columbia Hills than the later plains [*4*] because of the poor retention on slope debris.

Conclusions: We have assembled the first geologic map prepared from surface observations on Mars. In situ chemical data (APXS and Mössbauer) as well as estimates of chemical states from multi-spectral (Pancam and mini-TES) remote sensing, indicate that in contrast to the relatively distinctive lithologic characteristics, chemistry and mineralogy varies widely across most of the mapped units. This reenforces the initial impression [*5*] that Columbia Hills rocks,

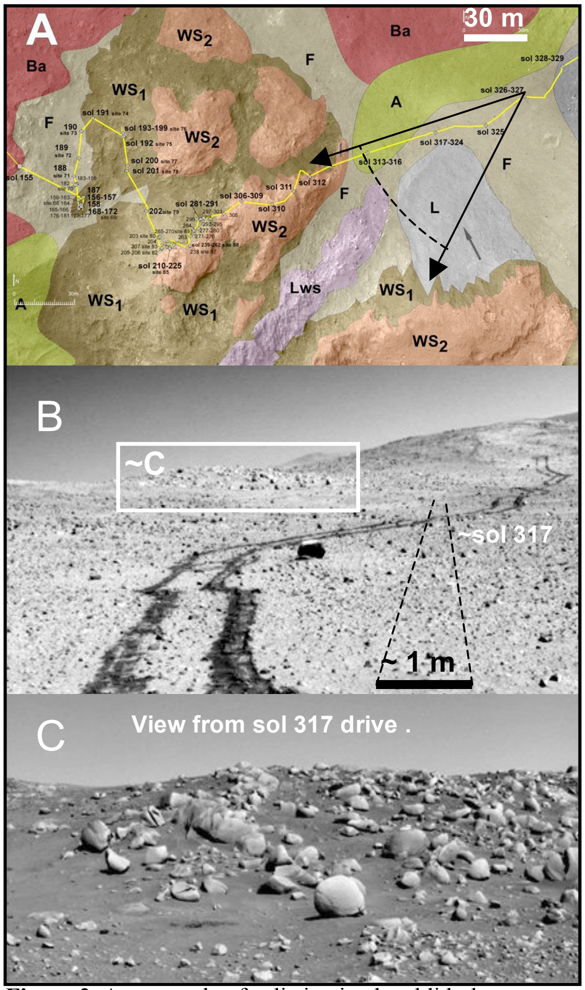

Figure 2. An example of a distinctive local lithology mapped from orbital (*MRO/HiRISE*) and surface-based (*MER*) observations within area A of Figure 1: an unconformable boulder unit, "*Lws*" (landslide?), filling a former trough, now eroded and exposed. **A**. Recon geology (area A in Figure 1) from combined *MER* traverse and *HiRISE* data. The trough post-dated the emplacement and subsequent back wasting of the fine-grained, locally laminated unit capping the West Spur (unit *WS$_2$*). Other units shown: *L*, landslide; *Ba*, Adirondack basalt; *A*, mobile fines; *F*, float. Scale bar is 30 m. **B.** View from sol 326 position in direction of arrows in A. 2N155391817RSD9600P1755L. **C.** View from sol 317 position of *unit Lws*. 2P154507282RSD9300P2560L7.

although potentially of simple lithology, have undergone locally variable degrees of alteration and bear associated chemical complexity. One hypothesis under consideration is that variable types of alteration of the lithologies occurred over a long spread of time, both syn-depositional and post-erosional, and that considerable water locally ponded and locally infiltrated along prominent fractures and local topographic lows. This moved solutions and deposited minerals in complex arrangements not strongly tied to local lithology. Nonetheless, classifications of the observed rocks on the basic of elemental chemistry using APXS [*6*] and Fe mineralogy using Mössbauer analysis [*7*], as well as spectral classes [*8*], show some correlations with the more distinctive lithologies identified in this mapping and in along-track clast analysis [*9*].

Despite this complication of chemistry and mineralogy, distinctive megascopic lithologic variations can be identified and correlated across the image map units. The easiest distinction, and in contrast to terrestrial mapping the most obvious one, appears between float and substrate. In many places the float itself envelopes the surface as a finite layer that has been preferentially ablated as a unit on the upslope side, frequently along very well defined contacts. Likewise, it appears that many of the clastic lithologies examined in outcrops are draped over an unobserved Columbia Hills substrate. Back-wasting of less indurated units capped by more indurated rock layers, such as those forming the basal slopes and ridges of West Spur, were clearly important erosion processes at an early date. But the landforms developed from those processes have been subsequently rounded and the

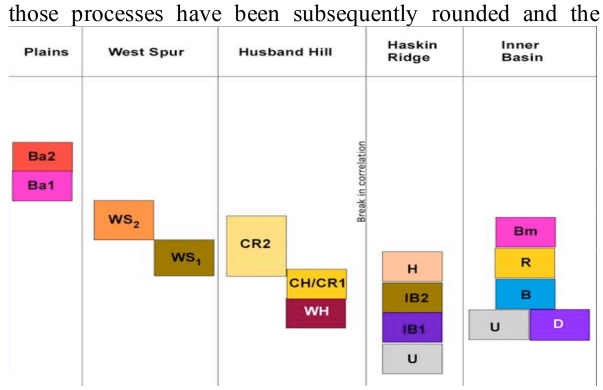

Figure 3. Preliminary stratigraphy within the Columbia Hills. Many of the older units occur between Haskin Ridge and Home Plate south of Husband Hill .

lower slopes partially covered with local slope debris. A preliminary stratigraphy (Fig. 3) shows promise in resolving the timing of some units. But there is as yet no correlation for important widely separated units such as, for example, the West Spur capping units and Home Plate.

Probably a more important long-term result of this project is the recognition of the type of outcrop exposure and types of complications that will be important to understanding and interpreting the field relations as in situ mapping progresses on Mars. We have also shown the non-trivial result that geologic units are complex but mappable at human and rover scales of observation on Mars. The potential for globally identifiable stratigraphic relationships that this implies bodes well for detailed understanding of a true global Martian geologic chronology determined from field geology.

References: [1] Wilhelms, D.E., (1990) *in* Greeley, R. and Batson, R.M., *Planetary Mapping,* New York, Cambridge U. Press, p. 208-260. [2] McEwen et al., (2007) *JGR* 112, E05S02. [3] Arvidson, R., et al., (2008), *JGR* 113, E06S01. [4] Haldemann1, A. et al. (2006), Lunar and Planetary Science , XXXVII **abs 1231**. [5] Squyres, S., et al., (2006) *JGR*, 111. [6] Ming et al. (2008), *JGR* 113, E12S39. [7] Morris et al. (2008), *JGR* E12S42. [8] Farrand et al.,(2008) *JGR* 113, E12S38. [9] Yingst et al. (2008), *JGR* 113, E12S41.
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