POSSIBLE NI-RICH MAFIC-ULTRAMAFIC MAGMATIC SEQUENCE IN THE COLUMBIA HILLS: EVIDENCE FROM THE *SPIRIT* ROVER. D. W. Mittlefehldt[1], R. Gellert[2], T. McCoy[3], H. Y. McSween Jr.[4], R. Li[5] and the Athena Science Team, [1]NASA/Johnson Space Center (david.w.mittlefehldt@nasa.gov), [2]University of Guelph, [3]Smithsonian Institution, [4]Univeristy of Tennessee, [5]Ohio State University.

Introduction: The *Spirit* rover landed on geologic units of Hesperian age in Gusev Crater. The Columbia Hills rise above the surrounding plains materials, but orbital images show that the Columbia Hills are older [1, 2]. *Spirit* has recently descended the southeast slope of the Columbia Hills doing detailed measurements of a series of outcrops. The mineralogical and compositional data on these rocks are consistent with an interpretation as a magmatic sequence becoming increasingly olivine-rich down slope. The outcrop sequence is Larry's Bench, Seminole, Algonquin and Comanche. The "teeth" on the Rock Abrasion Tool (RAT) wore away prior to arrival at Larry's Bench; the data discussed are for RAT brushed surfaces.

APXS data: The compositional data show systematic trends related to location. The compatible elements Mg, Cr (Fig. 1) and Ni increase, while incompatible elements Al, Ca, Ti (Fig. 1) and P decrease in outcrops measured during the downhill traverse. These trends are reflected in CIPW normative mineralogy (on a S- and Cl-free basis with assumed Fe^{3+}/total Fe = 0.056). Down slope, normative plagioclase+orthoclase decrease, while olivine+low-Ca pyroxene increase; Comanche target Palomino has ~77% normative olivine+low-Ca pyroxene. Bulk rock mg# (using total Fe) also increases in the sequence from ~48 in Larry's Bench to ~65 in Comanche.

The structural attitudes of the outcrops with respect to the slope are poorly constrained at present; we do not know whether down slope equates to down section. The total elevation change across the sequence is ~28 m. Nor do we have control on possible lateral changes in units. Nevertheless, the systematic compositional trends observed in these outcrops are most simply interpreted as resulting from a series of related rocks. These trends are consistent with the lower southeast slope of Columbia Hills consisting of a sequence of mafic-ultramafic magmatic rocks, either a single emplaced unit that underwent crystal accumulation or a series of related units showing systematic compositional variations. At present we cannot distinguish whether the rocks were emplaced as intrusions or on the surface.

Caveat Emptor: Because we are unable to grind rock surfaces, the APXS data will be influenced by alteration rinds if present. In addition, because of sur-

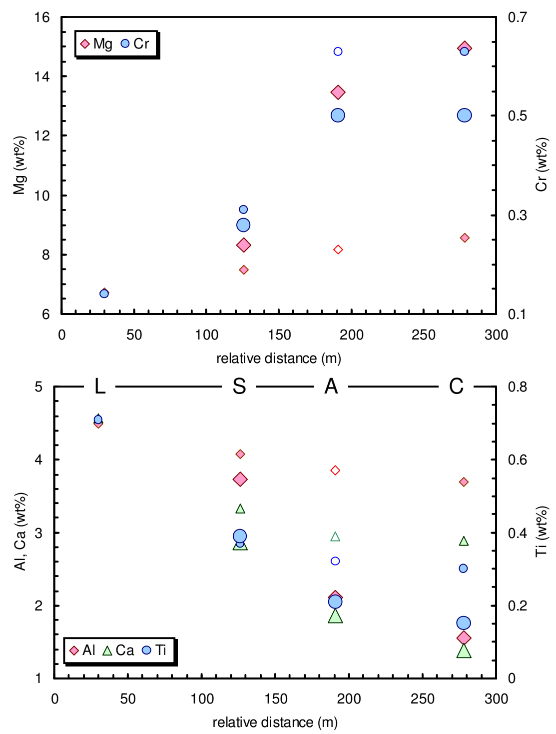

Figure 1. Compatible elements Mg and Cr increase and incompatible elements Al, Ca and Ti decrease in the outcrop sequence: Larry's Bench, Seminole, Algonquin, Comanche. The relative distance is straight-line map distance between outcrops from an arbitrary starting point. Large symbols - more complete brushings; small symbols - less complete brushings; open symbols - pre-brushed target. The data plotted are as measured.

face roughness, the brushing will not have been 100% effective at removing dust coatings (Fig. 2). Thus, post-brush analyses will represent mixtures of dust coatings with possibly altered outcrop. We did pre- and post-brush analyses on Algonquin target Iroquet. The major changes with dust removal were substantial decreases in Na, Al, P, K, Ca and Ti, and a large increase in Mg (Fig. 1). Similar differences are observed when comparing poorly brushed Comanche target Horseback with well brushed target Palomino. The S content decreases with brushing, but even the most well brushed target has ~1 wt% S attesting to either residual dust or alteration. For comparison, martian meteorites contain <0.3 wt% S. It is unlikely, however, that variations in dust coating or alteration rinds would generate geochemical trends with location. We conclude that the general trends are real, but possibly are modified by dust and/or alteration.

Figure 2. Portion of Pancam false-color image (P2575, Sol 690, L4, L5 and L6 filters) of Algonquin target Iroquet showing RAT brush. Hollows on the outcrop surface caused by cracks still contain dust, which contaminate the post-brush analysis.

Discussion: Mini-TES observations of the outcrops in the sequence from Larry's Bench to Comanche are dominated by olivine [3]. Geochemical trends are consistent with a magmatic sequence becoming increasingly ultramafic downhill. In mafic-ultramafic rocks, Mg, Cr and Ni are compatible elements and fractionate together. This is observed for the younger martian meteorites (Fig. 3). The putative "Algonquin" magmatic sequence follows the martian meteorite trend for Cr-Mg. However, the "Algonquin" rocks show substantially higher Ni for a given Mg content than do martian meteorites. This cannot be explained by simple addition of cumulus olivine to a mafic parent (arrows).

Two possible explanations for the divergent Ni-Mg trend for the Columbia Hills rocks are; (i) the rocks are not primary magmatic rocks, but rather are lithified regolith of mafic-ultramafic rock fragments and soil contaminated by meteoritic debris, or (ii) ancient martian magmatism sampled more a Ni-rich mantle source than did the younger magmatism represented by martian meteorites. Similar anomalous Ni contents were found for several rock classes on Husband Hill [5].

The first mechanism is implausible. It leaves unexplained why there should be a systematic variation in composition with location. A high Ni content in a regolith implies gardening to mix meteoritic debris in with surface rubble. Thus, *a priori*, rock compositions ought to be homogenized or randomly varying across the surface. Even more difficult to understand is the correlation of Mg (Mars-derived) with Ni (meteorite-derived) in this scenario. Thus, we do not think the first mechanism is correct.

The second mechanism also has problems precisely because Mg and Ni fractionate together; Ni^{2+} readily substitutes for Mg in mafic minerals [e.g. 6]. Thus, there is no obvious mechanism to enrich some martian mantle sources in Ni and not others based on major phases. One possibility might be that the source of Columbia Hills magmas was enriched in Ni-bearing sulfides compared to that of the younger martian magmas. A Ni-rich sulfide such as pentlandite rather than a low-Ni sulfide like pyrrhotite is needed to plausibly explain the ~700 µg/g Ni excess in the high-Mg Columbia Hills rocks. It is not obvious that the sulfide content of the rock should correlate with the olivine content as implied by Fig. 3.

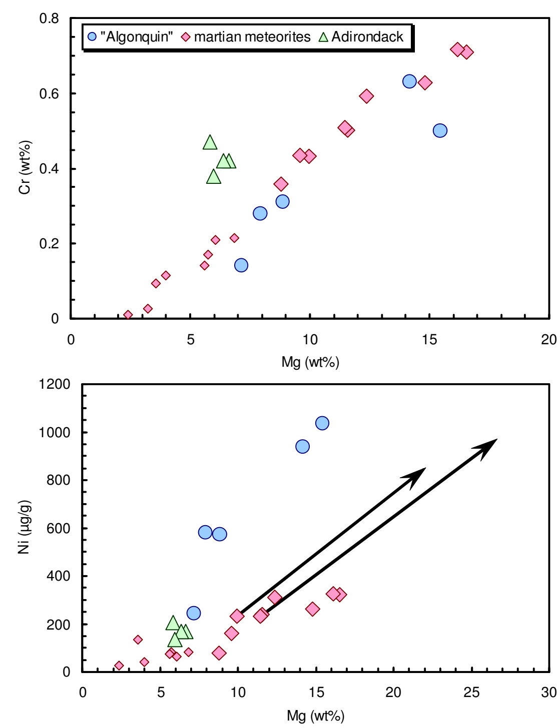

Figure 3. Cr vs. Mg and Ni vs. Mg for the putative "Algonquin" magmatic sequence compared to younger martian meteorites (basalts and lherzolites) and Gusev Plains Adirondack class basalts [4]. Large symbols are used for martian meteorites containing early, Mg-rich olivine. Arrows show the effects of hypothetical olivine accumulation on compositions of two olivine-phyric basalts.

References: [1] Martinez-Alonso S. et al. (2005) *JGR, 110,* doi:10.1029/2004JE002327. [2] Milam K. A. et al. (2003) *JGR, 108,* doi:10.1029/2002JE002023. [3] Ruff S. W. et al. (2006) *LPSC 37,* this volume. [4] McSween H. Y. Jr. et al. (2006) *JGR,* in press. [5] Ming D. W. et al. (2006) *JGR,* in press. [6] Jones J. H. (1995) *Rock Physics and Phase Relations, A Handbook of Physical Constants,* AGU, 73.