EVIDENCE OF PHYLLOSILICATE IN *WOOLY PATCH* – AN ALTERED ROCK ENCOUNTERED ON THE SPIRIT ROVER TRAVERSE, Alian Wang[1], Larry A. Haskin[1], Randy L. Korotev[1], Brad L. Jolliff[1], Paulo de Souza Jr.[2], Alastair G. Kusack[3], and the Athena Science Team, [1]*Dept. Earth and Planetary Sciences, Washington University in St. Louis, St. Louis, MO 63130;* [2] CVRD Group, Vitória, ES, Brazil; [3]Honeybee Robotics, 204 Elizabeth St., NY, NY 10012. (alianw@levee.wustl.edu).

In the course of examining rocks along the traverse of the Spirit rover toward the Columbia Hills [1, 9], we noticed that the chemistry of a rock named "*Wooly Patch*" was neither basaltic as the rocks near the landing site [8] nor slightly altered basalt inferred from regolith in plains trenches [10]. The major cation ratios appear to match those of phyllosilicates [11]. The presence of phyllosilicate minerals on Mars has been predicted [12]; reasons for the rarity or absence of phyllosilicates have also been discussed [13]. We have thus done as detailed an analysis of *Wooly Patch* as the data enable, which suggests phyllosilicates of kaolinite, serpentine, and chlorite types, plus some feldspar and pyroxene are prime candidates to constitute *Wooly Patch*.

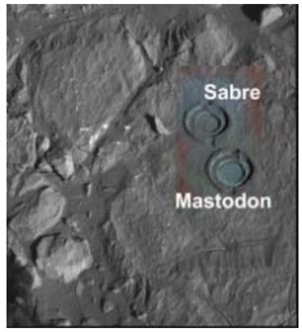

Fig. 1 Wooly Patch with 2 abraded holes

***Wooly Patch* Investigation:** *Wooly Patch* was encountered by Spirit at the foot of *West Spur*, a peninsula stretching northwestward from Husband Hill in the Columbia Hills. *Wooly Patch* was selected by the Spirit science team for detailed investigation because its morphology suggested a flat lying, light toned, possibly layered outcrop. Pancam [3] images were taken before the final approach of the Spirit to *Wooly Patch,* and both Pancam (Fig.1) and MiniTES [7] observations were made after Spirit backed off from it. The rock temperature was extremely low (209°K) when the MiniTES spectrum was taken, thus was not interpretable. Measurements using the microscopic imager [4], the Mössbauer spectrometer [6], the alpha particle X-ray spectrometer [5], and the Rock Abrasion Tool (RAT) [15] were made on three targeted areas: as-is surface at *Mammoth* (showing multiple fractures or veins), as-is surface and a RAT-abraded hole at *Sabre* (near a narrow vein), and an abraded hole at *Mastodon* (away from any apparent veins or fractures).

Morphology and Hardness: The as-is surfaces of *Wooly Patch* were covered by fine-grain dust, which forms clusters of mm to sub-mm size and accumulated densely in the surface depressions. *Wooly Patch* has a network of narrow fractures; most of them are straight, but slightly curved near the edge or corners of the rock and where they cross each other. Microscopic images show signs of possible erosion at the edges of some fractures (Fig. 2).

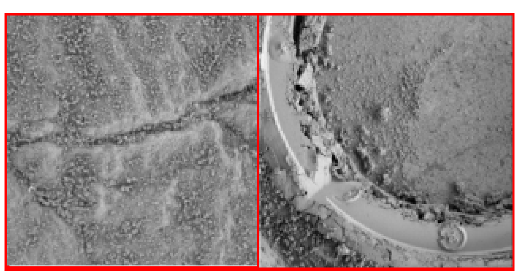
Fig.2 Microscopic images: left, asis-surface at Sabre; right, abraded hole at Mastodon (frame size ~ 3 cm).

The specific grind energies (roughly corresponding to the hardness of the material being abraded) are 4.63 J/mm3 for Sabre and 3.88 J/mm3 for Mastodon, both lower than those for the Plains basalt (52.1-84.6 J/mm3) and lower than Clovis (6.20 J/mm3). Compared with terrestrial rocks, the values for Wooly Patch are in the range of limestone to volcanic ash (6.0-2.8 J/mm3). Wooly Patch is a much softer rock than the Plains basalts.

Post-grinding microscopic images (Fig. 2) show that the interior of *Wooly Patch* does not look like the dark and ground-polished subsurfaces of the plains basalts (e.g. *Humphrey*, [4,8]). The Wooly Patch interior is porous and fine-grained, as indicated by its relatively light-toned coloring, with only a few dark patches. A fracture is present in the RAT-abraded hole at *Sabre*, one that was not removed by 5.2 mm of grinding. Fine-grained and highly porous cuttings were pressed into cake-like clusters with surprisingly smooth surfaces at the edge of the abraded hole (Fig.2). The sizes of RAT holes are slightly larger than the diameter of the RAT grinding bits, suggesting that the rotating brush on the RAT removed additional rock material; this was not observed with the harder plains basalts.

Chemistry and Fe-mineralogy: When comparing the elemental chemistry of the interior of *Wooly Patch* with the plains basalts and other investigated *West Spur* rocks (through sol 291), the most striking feature is that *Wooly Patch* has the lowest Ca & K concentrations, and the highest Al (abraded *Sabre*) and P concentrations. Compared to plains basalt, it has also relatively high Ti, low Cr & Mn, similar to other *West Spur* rocks. When all of the rocks investigated by Spirit (through sol 291) are plotted as CaO vs. SO_3 mole% (Fig. 3a), they form a linear trend for *West Spur* rocks, from *Wooly Patch* to *Clovis*. This linear trend approaches the 1:1 line of CaO:SO_3 mole%, which suggests a two end-member mixture hypothesis for *West Spur* rocks: *Wooly Patch* (abraded *Mastodon*) as the silicate end-

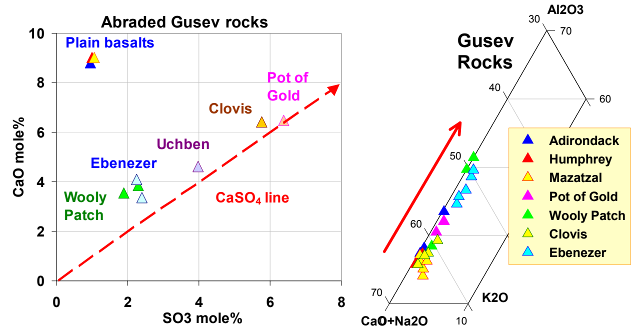

Fig. 3 Chemical trends in Gusev rocks

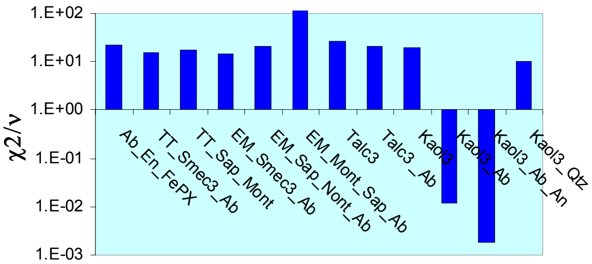

Fig. 4 Comparison of the results from Mass-balance mixing analysis for abraded Sabre: the two models with kaolinite-serpentine are 3-4 order of magnitude better than the others.

member, and sulfates (mainly $CaSO_4$) as another end-member. On a Al_2O_3-K_2O-CaO+Na_2O ternary plot of Spirit rocks, the data form a trend of increasing Al_2O_3 with decreasing CaO+Na_2O, starting from plains basalts to *Wooly Patch,* with *Ebenezer* at an intermediate position. It is thus important to understand the silicate mineralogy of *Wooly Patch*. The major difference in the Mössbauer spectrum of *Wooly Patch* from the plains basalt is a lack of olivine (absence of $Fe^{2+}_{olivine}$). In addition, *Wooly Patch* is more oxidized (Fe^{3+}/Fe_{total} >0.60) than any of the plains basalts (~0.17-0.1), but less oxidized than *Clovis* (>0.9) where crystalline goethite was found [9].

Silicate Mineralogy: We used three methods to evaluate the silicate mineralogy of *Wooly Patch*: a rough evaluation using the cation molar ratios of major elements, a normative modal analysis, and a mass-balance mixing analysis [14] based on elemental composition from APXS measurements but using the results of Mössbauer analysis to constrain the Fe-oxides.

In the mass-balance mixing analysis, 43 mineral assemblages were tested for both abraded *Sabre and Mastodon*. They include 4 basaltic assemblages without olivine and K-feldspar, 20 assemblages using typical terrestrial (or end-member) smectite group minerals with (or without) remaining basaltic minerals (i.e. pyroxene & feldspar), 6 assemblages using talc group minerals with (or without) remaining basaltic minerals, 7 assemblages using kaolinite group minerals with (or without) remaining basaltic minerals, and 6 assemblages using mixtures of smectite and kaolinite groups with (or without) remaining basaltic minerals.

Figure 4 shows the χ^2/ν values of 12 assemblages (which have χ^2/ν below 200 and do not give negative mineral modes) among all 43 tested assemblages for abraded *Sabre*. Good least-square mixes have χ^2/ν values <1. Only two of the assemblages satisfy that criterion; they are the combinations of kaolinite $[Al_4(Si_4O_{10})(OH)_8]$, antigorite $[Mg_6(Si_4O_{10})(OH)_8]$, and greenalite $[(Fe^{2+}, Fe^{3+})_{6-4}(Si_4O_{10})(OH)_8]$, plus albite, or albite and anorthite. The best fit has a mass ratio of phyllosilicates to basalt minerals ~ 1.7. The analysis for *Mastodon* gives a similar result but a lower ratio of phyllosilicates to basalt minerals (~1.5), with the remaining silicate minerals being albite and enstatite. A slightly higher proportion of phyllosilicates at Sabre is consistent with a deeper than 5.2 mm fracture seen in its abraded surface mentioned above.

The first-order information we gained from a mass-balance mixing analysis is which mineral assemblages ***cannot*** account for the measured composition, such as the basaltic assemblages and the smectite and talc assemblages for *Wooly Patch*. It also indicates which assemblage can account for the measured composition. It does not, however, demonstrate that mineral assemblage being actually present.

Although the best match for the compositions of abraded *Sabre* and *Mastodon* involves a combination of kaolinite–antigorite–greenalite plus some basaltic minerals, it does not indicate that these exact phyllosilicates are actually present in the interior of *Wooly Patch*. Nevertheless, from the mixing results we may surmise that silicate minerals (or their mixtures) with ratios of interstitial cations (Mg, Fe, Al, Ca) to tetrahedral cations (Si, Al) similar to kaolinite–antigorite–greenalite are prime candidates to constitute *Wooly Patch*. These minerals appear to be kaolinite, Mg-Fe serpentines, and Mg-Fe chlorites.

The Mössbauer spectrum of *Wooly Patch* has a wider Fe^{2+} doublet split than the plains basalt, and a broad Fe^{3+} doublet. The primary result does not exclude the potential existence of phyllosilicates (e.g. dioctahedral smectites) [16]. Serpentine, chlorite, and kaolinite can be formed in low temperature hydrothermal environments. Kaolinite can also be formed by chemical weathering and sedimentary deposition in acidic low-Ca environments.

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References: [1-8] S. W. Squyres et al.; R. E. Arvidson et al.; J. F. Bell III et al.; K. E. Herkenhoff et al.; R. Gellert et al.; R. V. Morris et al.; P. R. Christensen et al.; H. Y. McSween et al.; Science Vol 305, p793-845, 2004 ; [9-10] S. W. Squyres et al. ; L. A. Haskin et al. Submitted to Nature; [11] W. A. Deer et al., Sheet Silicates, 1963 ; [12] J. L. Gooding, Icarus, V99, p28-41, 1992 ; [13] R. V. Morris, JGR, V106, p5057-5083, 2001 ; [14] Korotev R. L. et al. (1995) *JGR,* **100**, 14403–14420; [15] S. P. Gorevan et al. JGR, **108**, ROV9, 2003; [16] P. A. de Souza Jr., Laboratory Robotics and Automation **11**, 3-23, 1999.