CHEMICAL DIVERSITY ALONG THE TRAVERSE OF THE ROVER SPIRIT AT GUSEV CRATER.

R. Gellert[1], J. Brückner[2], B. C. Clark[3], G. Dreibus[2], C. d'Uston[4], T. Economou[5], G. Klingelhöfer[6], G. Lugmair[7], D. W. Ming[8], R. V. Morris[8]. R. Rieder[2], S. W. Squyres[9], H. Wänke[2], A. Yen[10], J. Zipfel[11].
[1]Depart. Physics, CPES, Univ. of Guelph, On N1G 2W1, Canada, rgellert@uoguelph.ca, [2]Max-Planck-Institut für Chemie, Mainz, Germany, [3]Lockheed Martin Corp., Littleton, CO, USA, [4]Centre d'Etude Spatiale Rayon, Toulouse, France, [5]Lab. Astrophys. Space Res., E. Fermi Inst., Univ. Chicago, USA, [6]Inst. f. Anorgan. Analyt. Chemie, Univ. Mainz, Germany, [7]UCSD, Scripps Inst. Oceanography, La Jolla, CA, USA, [8]Johnson Space Center, Houston, TX, USA, [9]Center Radiophys. Space Res., Cornell Univ. Ithaca, New York, USA, [10]Jet Propulsion Lab., Pasadena, CA, USA, [11]Forschungsinst. Naturmuseum Senckenberg, Frankfurt/Main, Germany.

Overview: The Alpha-Particle-X-ray Spectrometer (APXS) [1] is part of the in situ payload of the Mars Exploration Rovers [2]. It has determined the chemical composition of soils and rocks along the nearly 6 km long traverse of the rover Spirit. The measuring method – a combination of PIXE and XRF using Cm244 sources - allowed the unambiguous identification of elemental compositions with high precision. Besides sample triage and quantification of salt-forming elements as indicators for aqueous alteration, the APXS also delivered important constraints to mineralogy intruments (i.e., Mossbauer (MB), MiniTES, Pancam) on minerals and rock types. The mineralogy instruments on the other hand provided constraints on minerals used for APXS normative calculations and, e.g. allowed the attribution of S to sulfate, instead of sulfide or elemental sulfur.

This abstract gives an updated overview of the data obtained up to our current rover position on sol 720 at the eastern base of the Columbia Hills. We will emphasize elemental correlations that imply the presence of certain minerals that can not be identified by the MER mineralogy instruments.

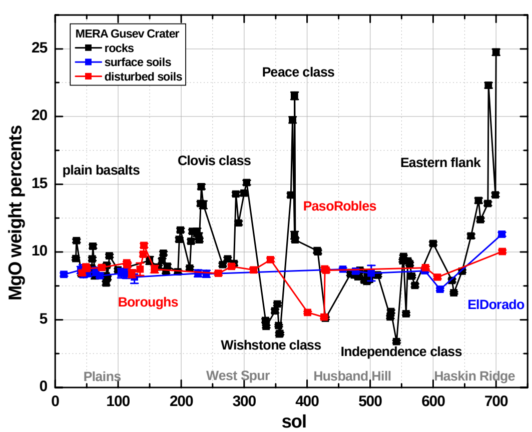

Fig. 1 Rover traverse over 6 km at Gusev. Changes in MgO wt. % concentrations illustrate the chemical variability. Main rock classes and soils discussed in the paper are labeled.

Soils: The soil composition at Gusev is very similar to all other landing sites. The MER APXS could for the first time on Mars determine the trace elements Ni, Zn and Br in the soils [3,1]. The soil is basaltic in character although there is a significant amount of S and Cl with a remarkably constant S/Cl ratio [3]. Surface soils are unchanged along the traverse. This endorses the hypothesis of a global dust mixing model. Nevertheless, recently a large dune field visible from orbit called El Dorado was investigated by APXS that is different from the "global soil composition." A surface soil and one scuffed subsurface target were investigated. Both spots show higher Mg than other soils at Gusev, not correlated with higher S. The El Dorado bed forms are the first surface soils that deviate significantly from other Gusev surface soils by increased Mg and Ni and low S and Cl, most likely due to an enrichment in olivine and removal of dust by wind.

Subsurface soils show a higher variability along the trek of Spirit. Although some trenches, especially one in a shallow hollow presumably filled with airborne dust, revealed no differences, several trenches and scuffs showed significant deviations from the surface. In the Boroughs trench on the Gusev plains, Mg, S and Br increased compared to the surface. In the Columbia Hills a scuffed subsurface soil called Paso Robles revealed more than 30 wt. % SO_3 accompanied by increased Fe. This patch contains the highest sulfate content measured so far on Mars. With more than 5 wt % P2O5 it also shows the highest phosphate content [4,5].

Plains basalts: The composition of the various basaltic float rocks investigated on the plains is in general that of primitive or picritic basalts [4,6].

Columbia Hills: The composition as well as the variability along the traverse changed dramatically once the rover reached the base of the Columbia Hills, see Fig 1. At West Spur the rover encountered a group of rocks and outcrops in the **Clovis class**; which are enriched in Mg, S, Cl and Br. These elements were even present in deep RAT holes that argues for an aqueous alteration [5]. After leaving West Spur, several rocks of the **Wishstone class** where encountered on the northwest flank of Husband Hill that had high P and Ti contents, elevated plagioclase abundance, less Mg and Fe, and very low Cr. Measurements on the undisturbed, brushed and successive abraded rocks revealed a good correlation of Ca with P, indicating abundant Ca-phosphates as the carrier of the nearly 5 wt. % P_2O_5. A portion of the elevated Ti is present as ilmentite, consistent with MB results [7].

Peace class outcrops are particular interesting because they exhibit highly elevated S contents, which is persistent even when the outcrop is abraded approximately 5 mm. S increases when entering the interior of the rock in parallel with Mg. Interestingly MB identified relatively unaltered Fe minerals such as olivine and magnetite in this material. This indicates that unaltered basaltic fragments were cemented by Mg and possibly Ca sulfates [5].

Watchtower class consists of outcrops that are very homogeneous in composition for the APXS. It exhibits many of the Wishstone features indicating that Watchtower and Wishstone might share the same source. The major chemical difference between the two classes is higher Mg in Watchtower class. The relatively homogeneous composition of Watchtower outcrops paired with big differences in the Fe^{2+}/Fe_{total} measured by MB [7] suggests that the material was altered to various degrees under isochemical weathering with relative low water to rock ratio.

Independence class consists of outcrops and float rocks that contain low Fe content, as low as 4 wt. % FeO, much lower than any known Martian materials yet. It is also characterized by a highly variable enrichment in several minor and trace elements. So far, we have confirmed enrichments in Cu, Ni, Cr, Y, and Sr and possible enrichments of Zn, Ga, Co and Ba. These findings as well as the remaining composition led to the hypothesis that Independence class rocks may contain clay minerals such as montmorillonites [8]. MB identified an abundance of very resistant iron phases in these rocks such as ilmenite and chromite [9].

Backstay and Irvine are basaltic float rocks in the Columbia Hills that are relatively unaltered with distinct compositions from the plains basalts.

Outcrops and float rocks of different compositions were encountered recently on the easterly descent from Husband Hill. Several outcrops more than hundred meters apart have similar compositions, indicating that it is a major constituent of the eastern side of Husband Hill. Its composition is dominated by high Mg, Fe and Ni, and lower Al and Ca. APXS normative calculation indicate that up to 50 % olivine and variable pyroxene comprise these ultramafic materials, which is supported by MB [9]. The El Dorado dune field is in the vicinity of this extended outcrop and its composition might reflect a local input from this newest rock class.

Magnets: Beside rocks and soils the APXS also monitored the dust accumulation on magnets designed to catch magnetic particles of the airborne dust [10]. Figure 2 shows the APXS results over one Martian year. The magnets are only partially covered with a thin layer of dust instead of an infinite sample that complicates the usual APXS data analysis routine. Nevertheless, the peak area ratios with the usual soil revealed important results. After dust buildup in the beginning of the mission a "cleaning" event is visible after sol 300. Si and Ca as well as S and Cl go down in parallel. However, Ti, Cr and Fe continue to increase after sol 300, indicating that magnetite is a magnetic component of the airborne dust. The magnets on rover Opportunity revealed similar results.

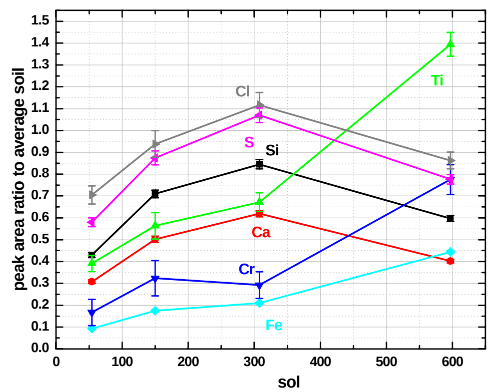

Fig. 2 Dust coverage on the capture magnet observed with the APXS over time. S and Cl are deposited in parallel and compared to soils they are enriched versus Si and Ca.

References: [1] Rieder R. et al. (2003) *JGR, 108(E12)*, 8066. [2] Squyres S.W. et al. (2003) *JGR, 108(E12)*, 8062. [3] Gellert R. et al. (2004) *Science, 305*, 829-832. [4] Gellert R. et al. (2006), *JGR, in press.* [5] Ming D.W., et al., (2006), *JGR, in press.* [6] McSween H.Y., et al., (2006), *JGR, in press.* [7] Morris R.V. et al. (2006) *JGR, in press.* [8] Clark B.C. et al. (2005) *AGU Fall Mtg.* [9] Morris R.V. et al. (2006) *LPSC XXXVII*. [10] Madsen, M.B, et al., (2003), *JGR, 108(E12)*, 8069.

Acknowledgements: The APXS was mainly funded by the Max-Planck-Society and, in part, by the German Space Agency (DLR) [grant No. 50QM0014 and 50QM0005]. R.G. acknowledges funding by Canadian Space Agency (CSA) for MER operation. Funding for Athena science team members was provided by NASA contracts through Cornell and JPL. We acknowledge the unwavering support of JPL engineering and MER operations staff.