

**CHEMISTRY OF MARTIAN SOILS FROM THE MARS EXPLORATION ROVER APXS INSTRUMENTS.** D. W. Mittlefehldt<sup>1</sup>, R. Gellert<sup>2</sup>, A. Yen<sup>3</sup> and the Athena Science Team, <sup>1</sup>NASA/Johnson Space Center, Houston, TX, USA (david.w.mittlefehldt@nasa.gov), <sup>2</sup>University of Guelph, Guelph, ON, Canada, <sup>3</sup>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.

**Introduction:** The martian surface is covered with debris formed by several mechanisms and mobilized by various processes. Volcanism, impact, physical weathering and chemical alteration combine to produce particles of sizes from dust to boulders composed of primary mineral and rock fragments, partially altered primary materials, alteration minerals and shock-modified materials from all of these. Impacts and volcanism produce localized deposits. Winds transport roughly sand-sized material over intermediate distances, while periodic dust storms deposit a global dust layer of the finest fraction. The compositions of clastic sediments can be used to evaluate regional differences in crustal composition and/or weathering processes. Here we examine the growing body of chemical data on soils in Gusev crater and Meridiani Planum returned by the Alpha Particle X-ray Spectrometer (APXS) instruments on the rovers Spirit (MERA) and Opportunity (MERB), following on earlier results based on smaller data sets [1-4].

**Methods and Caveats:** Currently, there are APXS analyses for 49 soils from Gusev crater and 34 from Meridiani Planum. These were evaluated using multivariate statistical techniques. Agglomerative Hierarchical Clustering (AHC) was used to group soils into statistically significant clusters. The resulting dendograms were evaluated to select truncation levels based on the degree of similarity to yield between 6 and 10 clusters. Further testing used Factor Analysis (FA), which determines redundancies of variables in a data set and combines them linearly into new variables, or factors, that describe the variability of the data set. Loadings of the initial variables on the factors and factor scores, which indicate similarities among observations, can be used to evaluate possible causes of the chemical variability of the data.

Several cautions are needed. Not all data are created equal. Analysis conditions varied resulting in varying degrees of precision for individual analyses, and APXS analysis yields differing degrees of precision and accuracy for different elements. Initially, all data were treated as being of equal quality, but we also did some tests to evaluate the effects of analytical quality on test outcomes. Statistical tests are predicated on the assumption of random sampling of the parent population. Human intervention is very much a part of choosing APXS analysis targets.

**Discussion:** Initial evaluation of soils noted that bright dust deposits at both landing sites are quite similar in composition, and suggested that these represent manifestations of the global dust layer [4]. We have reexamined this issue through AHC of undisturbed soils using only light elements (Na-P) which will be strongly affected by even as little as a 7  $\mu\text{m}$  thick layer of dust [5]. If patches of a globally uniform dust layer are present, AHC should group these soils from both rovers into a single cluster - this is not observed. Significant clustering of MERA with MERB soils occurs only at the third highest level of dissimilarity (Fig. 1); the bright dust deposits [4] cluster at this level.

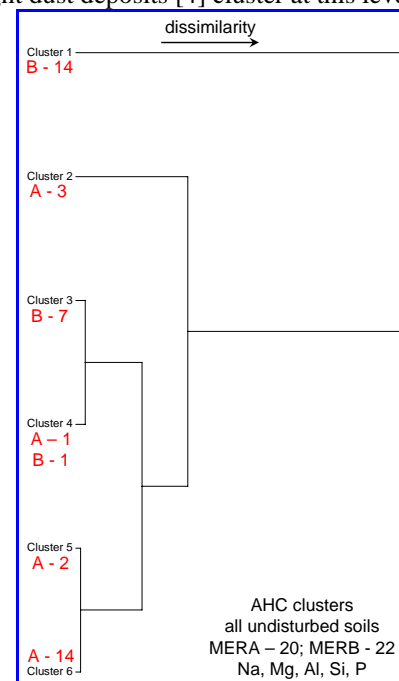


Figure 1. Dendrogram of clusters defined for undisturbed soils using the light elements most susceptible to surface dust contamination. Red labels give the rover and number of soils in each cluster.

Does this mean that a global dust unit is absent at the rover sites? Probably not. One plausible interpretation is that the global dust unit is discontinuous at the sub-cm scale and/or  $<7 \mu\text{m}$  thick such that even the light elements in analyses are dominated by the coarser, regionally derived grains. Alternatively, the bright dust deposits [4] may represent a combination of global dust with local dust reworked and mixed locally. Caution: if instrument performance on one or

both rovers changed subsequent to calibration, there could be systematic biases that explain the AHC result. This would have to have occurred before first deployment of the APXS, as the first soils from each rover cluster separately, and the first soils for a given rover cluster with much later analyzed soils from that rover.

A similar result is obtained when evaluating all soils – undisturbed, disturbed and trenched – using all 16 elements. Soils from Gusev crater cluster separately from those from Meridiani Planum, and clusters from the two regions join only at the second highest level of dissimilarity. This suggests that all soils at the two landing sites are dominated by regionally derived materials, regardless of soil type, and that regional crustal rocks are distinct in composition.

Because MERA and MERB soils are quite dissimilar, they were evaluated separately by FA. The MERB spherule-rich soils (cluster 1; Fig. 1) have very distinct Fe-Ni-rich compositions [4] that would dominate FA of MERB soils, so they were excluded. Also excluded are light-toned soils rich in sulfates and/or P from MERA (four soils).

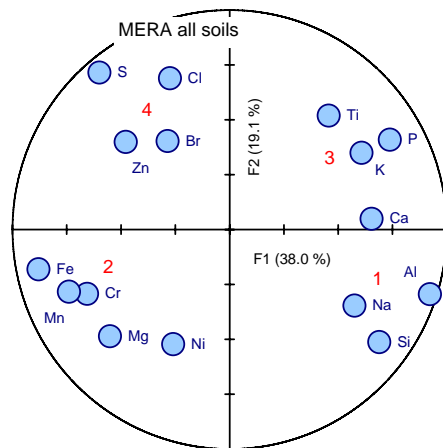


Figure 2. Variable loadings on factors 1 and 2 for MERA soils (n = 45).

Factor analysis on MERA soils loads elements into four distinct groups on factors 1 and 2, which account for ~57% of the variability of the data (Fig. 2). Group 1 consists of Na, Al and Si; elements contained in plagioclase plus silica. Calcium is not closely associated with this group, but in mafic igneous rocks, plagioclase and augite are significant Ca hosts. Group 2 consists of elements contained in ferromagnesian silicates and chromite. Group 3 consists of incompatible elements that would be contained in mesostasis phases of mafic igneous rocks. Group 4 consists of acidic anions plus Zn. In accord with Mini-TES results [6], the simplest interpretation is that the Gusev soils are formed dominantly by physical weathering and/or impact induced destruction, and that chemical weathering is of

secondary importance. If chemical weathering dominated, the very similar loadings of group 3 elements would not be expected; they are contained in distinct phases in mafic igneous rocks that would weather differently resulting in fractionation. Physical transport causes separation of phases, probably based on density and size, and this engenders chemical variations represented by groups 1-3. Grouping of anions apart from major cations supports the view that the former elements occur as alteration rinds on grains formed by acidic vapors, rather than as distinct sulfate and halide phases [8].

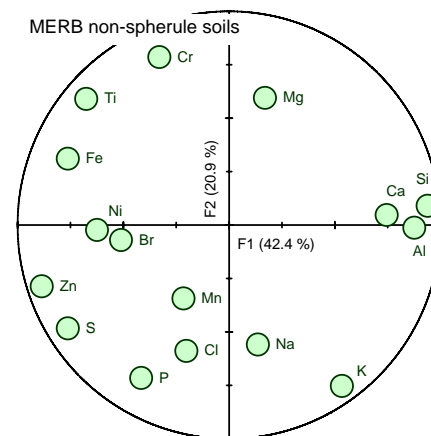


Figure 3. Variable loadings on factors 1 and 2 for MERB soils, excluding spherule-rich soils (n = 17).

The picture is quite different for MERB (Fig. 3). Factors 1 and 2 account for ~63% of the variability, but there is little grouping of element loadings. The exceptions are Al, Si and Ca. Sodium is quite separated from the group, indicating that variation in plagioclase content of the soils is not the cause. Factor 3 separates Ca from Al and Si. A plausible interpretation is that there is variation in a number of secondary aluminosilicate phases containing a range of cations. The random distribution of other elements on this plot was unexpected. Mössbauer results for non-spherule soils show that 50-80% of the Fe is contained in olivine and pyroxene [8], yet Fe and Mg have very different factor loadings. The results suggest that there is insufficient variation in composition for the size of the data set.

**References:** [1] Gellert R. et al. (2004) *Science* 305, 829. [2] Rieder R. et al. (2004) *Science* 306, 1746. [3] Soderbloom L.A. et al. (2004) *Science* 306, 1723. [4] Yen A. S. et al. (2005) *Nature* 436, 49. [5] Rieder R. et al. (2003) *JRG 108(E12)*, 8066. [6] Christensen P.R. et al. (2004) *Science* 305, 837. [7] Clark B.C. and Yen A. (2006) *Eos Trans. AGU* 87(52), P43A-04. [8] Morris R.V. et al. (2006) *JGR* 111, E12S15.