INVESTIGATING GEOCHEMICAL RELATIONSHIPS BETWEEN MARTIAN SOILS AND ROCKS.

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Introduction: Since January 2004, the twin rovers Spirit and Opportunity of the Mars Exploration Rover (MER) mission have been investigating their respective landing sites using the Athena Science Payload [1]. This scientific payload includes the Alpha Particle X-ray Spectrometer (APXS) instrument [2], whose role is to determine the elemental composition of the materials found at the martian surface. Thanks to their unexpected longevity, the complementary suite of instruments onboard the 2 rovers has characterized many different sites, and the APXS instruments have analyzed ~250 samples of soils and rocks (Table 1).

Kind of target	Gusev	Meridiani
Undisturbed rocks	43	34
Brushed rocks	36	9
Abraded rocks	15	28
Soils	46	28
Total	**140**	**99**

Table 1: Number of APXS rock and soil measurements by site and kind of target (until sol 810).

This large number of APXS measurements makes it possible to use numerical multidimensional analysis techniques such as Principal Component Analysis (PCA) [3] to describe and interpret the compositional variability of the martian surface. For example, it has been shown that when APXS data of Spirit are analyzed using PCA, samples define a series of clusters, and that these compositional groups are consistent with independent 'geological' classifications of the rocks encountered in the Columbia Hills [4].

In this work we extend the PCA approach to analyses from both landing sites with a particular emphasis on assessing the degree of similarity of the soil components.

Method: PCA is a mathematical technique that reduces the dimensionality of a complex system into a smaller number of dimensions which account for most of the data variance [3]. It transforms a number of potentially correlated variables (here: the elemental abundances) into a smaller number of uncorrelated variables: the "principal components" (PC), whose covariance matrix is diagonal. The first "principal component" accounts for as much of the data variance as possible and each succeeding component accounts for as much of the remaining variance as possible. The data may then be plotted in PC-space, on axes which highlight the compositional variance in a way which is not necessarily apparent on more simple elemental or oxide variation diagrams.

In this study, a PCA has been performed using the 16 elements measured by the APXS instrument: Na, Mg, Al, Si, P, S, Cl, K, Ca, T, Cr, Mn, Fe, Ni, Zn and Br. The data used for the definition of the principal components are all data of Opportunity (Meridiani) until sol 810, with the exception of Heat Shield Rock, a sample of obvious non-martian provenance [5]. In contrast to our previous PCA of MER data [4], elemental concentrations are not normalized, such that determination of the principal components is dominated by the major elements.

Results: The first two principal components account for ~95% of the total variance. In the PC1 vs. PC2 plane the data form two branches which converge in a sort of V shape (Figure 1). The left-hand branch is dominated by soils and is parallel to the vector of Fe, while the other is dominated by rocks, and approximately parallel to the vector for S. Undisturbed rocks occur in the vicinity of the convergence point of the two branches, with the exception of 'Berry Bowl', a sample concentrated in hematite-rich spherules. RATed rocks (other than 'Bounce Rock', ejecta similar to the Martian meteorite EETA79001 [6]) form the other extremity of the branch. Brushed rocks plot between undisturbed and RATed rocks (Fig. 1).

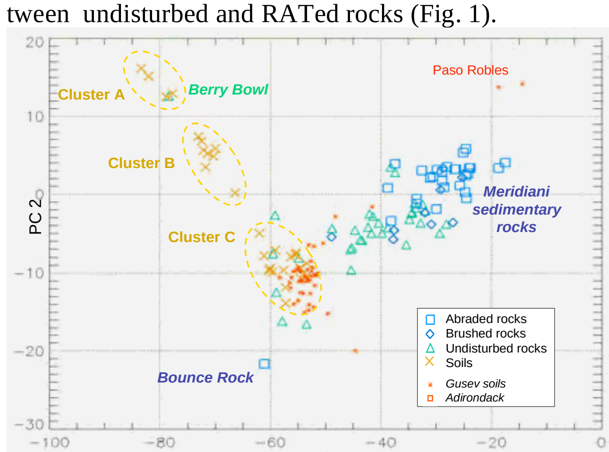

Figure 1. Scatter plot of the measurement points in the plane of the first two principal axes of the new basis computed by the PCA.

The results of the PCA for Meridiani samples have been analysed further using a hierarchical clustering method which compares the point-to-point Euclidian distance in principal component space to define statistically significant clusters. This analysis can be used to suggest that the 28 soil samples from Meridiani belong to 3 distinct groups (clusters A, B, and C, as shown in Fig. 1) although we cannot exclude the possibility that these groups may be an artefact of the small number of samples.

In order to compare Meridiani soils with those encountered by Spirit, soils from Gusev have also been plotted into this space of principal components (Figure 1). Note that Gusev data were not used for the definition of the components in this exercise, but that Gusev soils generally fall near the convergence point of Meridiani soils and rocks. The exception are soils from 'Paso Robles' which occur near the data for RATed Meridiani rocks.

To illustrate the differences in composition between clusters derived from the PCA (e.g. [7]), the average composition of each Meridiani soil and rock group, normalized to the composition of average (basaltic) Gusev soil, is shown in Figure 2. Cluster C contains the majority of Meridiani soils (16 samples) and it has a composition almost identical to that of the Gusev soils. For the case of soils from 'Paso Robles' (interpreted as evaporite-like materials [8]) samples are significantly enriched in sulphur and phosphorus. Indeed, as noted above, in many respects they resemble RATed Meridiani rocks, not only being enriched in P and S, but also depleted in Na, Al and Cr (Fig. 2). Samples of cluster A are the least numerous of the Meridiani soils (4 samples). Their principal compositional characterisitic is that they are enriched in Fe and Ni relative to soils from group C (Fig. 2), in agreement with the fact that the alignment of soil analyses in Fig. 1 is parallel to the vector of Fe in this principal component space. This observation may be related to the fact that the undisturbed soils in Meridiani often contain a significant number of hematite-rich spherules. In this respect it is of note that the Berry Bowl analysis plots in group A, consistent with the idea the observed spread in Meridiani soil composition may be related to a variable proportion of hematite-rich material. It is also of note that groups A and B consist of samples of undisturbed soil only, while group C is made of samples of various kinds : 7 undisturbed, 5 disturbed, 3 trench floor and 1 trench wall, suggesting that concentrations of hematite do not occur below the soil surface.

Discussion and conclusion: The results presented above demonstrate the use of independent mathematical tools such as PCA to assess and interpret compositional variations. For example, we show that soils from Meridiani are significantly more variable in composition than soils from Gusev, but that they share a common component. This component is basaltic soil which seems to exist everywhere on Mars [9, 10]. This ubiquitous presence may result from the transport of a mobile globally mixed dust which coats the surface of rocks to various degrees. Indeed, the fact that data for Meridiani rocks define a linear array which extends from an endmember represented by RATed outcrops to a 'Gusev-like' soil component is consistent with a surface coating. Alternatively, the same observations may be explained if local physical and chemical conditions leading to soil production are similar at the two landing sites.

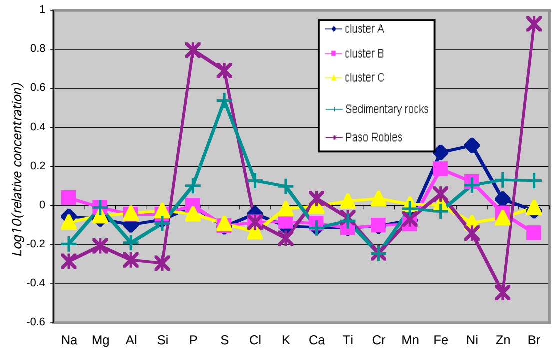

Figure 2. Elemental concentrations of the main Meridiani components relative to average Gusev soil (log scale).

Another point of note is that if local enrichment in hematite were due to simple elimination of the sulphur-rich component of the local rocks, one may expect samples to occur on 'mixing lines' from RATed rocks to cluster A. The fact that this is not the case would imply that basaltic sand (group C) actively participates in the physical or chemical process which concentrates the hematite-rich material in soils such as those of cluster A. Finally, the Meridiani rocks and the altered Paso Robles soil would appear to have compositional similarities, although the unaltered starting material has not, as yet, been identified.

References: [1] Squyres S.W. et al. (2003) *JGR*, 108, 8062. [2] Rieder R. et al. (2003) *JGR*, 108, 8066. [3] Murtagh, F. and Heck, A. (1987) *Dordrecht: Kluwer Academic*. [4] Treguier E. et al.(2006) LPSC 37,#1956. [5] Arvidson R. E., Squyres S.W. (2005a) AGU Spring Meeting, #P31A-02. [6] Squyres S.W. et al. (2006) *JGR*, 111, E12S12, doi:10.1029/2006JE002771, [7] Chevrel, S.D. et al. (2002) *JGR*, 107 5132. [8]Arvidson, R.E., et al. (2005b) JGR 111, E02S01, doi:10.1029/2005JE002499, [9] Squyres, S.W. et al. (2004a) *Science* 305, 794–799. [10] Squyres, S.W. et al. (2004b) *Science* 306, 1698–1703.