UNSUPERVISED DEFINITION OF CHEMICALLY DISTINCT PROVINCES AT MARS. O. Gasnault[1], [1] Centre d'Etude Spatiale des Rayonnements (CNRS/UPS, 9 av. du Colonel Roche, BP 4346, 31028 Toulouse Cedex 4 – France, Olivier.Gasnault@cesr.fr)

Introduction: The Martian surface composition at global scale has been inferred by *Mars Odyssey* through gamma-ray spectrometry. This technique has been successful so far in determining the distribution of hydrogen, silicon, iron, chlorine, thorium and potassium in the shallow subsurface [1].

Here we propose to conduct a multivariate analysis of these maps to define broad regions without any a priori knowledge but the remote-sensed abundances of the six chemical elements cited above. We show that at least seven distinct provinces can be defined that way.

This study complements the one by *Taylor et al.* [2] that uses a different method and looks for correspondences with soil-free geological features.

Methods: At first sight, the cloud of points in the data space is continuous. This is typical of compositional mixing both at the surface and by the broad spatial resolution of the instrument (about 600 km). On the other hand the histograms and the maps show non-uniform distributions of the elements. This justifies the search of patterns in the 6-dimensional data space.

To achieve such an analysis, we first standardize the data sets (mean equal to zero and variance equal to one) to make them comparable. Then we conduct a principal component analysis that define new axis with optimal variances, which helps in finding extremes or end-members [3]. In this new mathematical space, we finally conduct a hierarchical clustering analysis on the most significant principal components, using the Ward method that aims at finding compact, spherical clusters.

Results:

%	PC1	PC2	PC3	PC4	PC5	PC6
variance	33	31	18	9	6	3
cumulative	33	64	82	91	97	100

Table 1: Relative variance of the data projected on the newly defined axis (Principal Components, PC).

	PC1	PC2	PC3	PC4	PC5	PC6
$\mathbf{H}^S$	0.48	0.26	0.24	0.80	0.10	-0.02
$\mathbf{Si}^S$	-0.26	-0.55	0.28	0.34	-0.66	0.03
$\mathbf{Cl}^S$	0.47	0.40	0.16	-0.39	-0.66	-0.12
$\mathbf{Fe}^S$	0.13	-0.23	0.85	-0.30	0.35	-0.04
$\mathbf{Th}^S$	0.53	-0.41	-0.20	-0.11	0.02	0.71
$\mathbf{K}^S$	0.43	-0.50	-0.28	-0.04	0.08	-0.69

Table 2: Each Principal Component is a linear combination of the measured data with the given coefficients. The abundances of H, Si, Cl, Fe, Th, and K were standardized (mean=0, variance=1) beforehand.

Principal Component Analysis. Tables 1 and 2 summarize the properties of the principal components.

The first component is dominated by the variations in the mobile elements (H, Cl) as well as Th and K (see Figure 1). The second component, dominated by Si and Fe, put the emphasis on the differences between the montes (Tharsis, Elysium) and the northern lowlands. The three following components are respectively driven by Fe, by H, and by Si+Cl. Finally the last component bears little information.

From there, it is possible to reduce the number of dimensions for further analysis, and still account for most of the data variance.

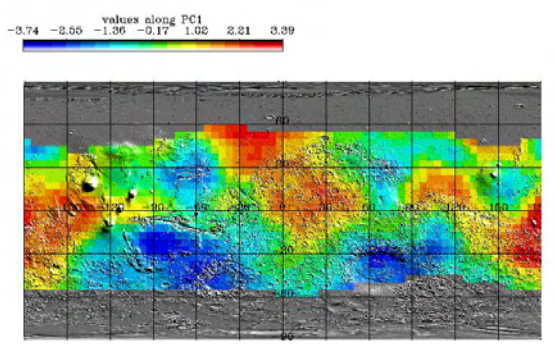

Figure 1: This map illustrates the projection of the measurements on the first principal axis, which bears the highest relative variance. The sign is arbitrary.

Clustering Analysis. The clustering analysis was conducted on the first 3 principal axes that bear 82 % of the total variance. The final number of clusters is arbitrarily chosen. We started with two clusters and incremented that number until the new cluster was either chemically ambiguous or not well-defined on the map. For each cluster the average composition is calculated. A first approximation of the uncertainty can be estimated by averaging the uncertainties within every pixel that make one cluster. Although it seems possible to go further, we chose to stop this analysis to 7 clusters that are chemically distinct within the error bars (see Figure 2).

These clusters are turned up into a map (Figure 3), where they might correspond to geochemical provinces. This map is intermediate between the Figures 1 and 2 by *Taylor et al.* [2] when the authors try to remove the effect of soils. The main difference is in the classification of the terrae around the meridian 0.

Discussion: The fact that the provinces defined on Figure 3 are geographically continuous and significantly larger than the spatial resolution of the instrument is encouraging. Isolated pixels can be discarded.

Province #1. The first province is found mainly west and north of Hellas (from Noachis to Tyrrhena terrae). In comparison to the other provinces, this one is characterized by low H (3.7 wt% water equivalent hydrogen (WEH)) and Fe (13 wt%) abundances.

Province #2. The second province is made of two entities: one encompasses Solis and Lunae planum (respectively south and north of Valles Marineris); the other one includes Hellas Planitia and Hesperia Planum eastward. This province is characterized by simultaneous low abundances of H (3.2 wt% WEH), Th (0.55 ppm), and K (0.29 wt%).

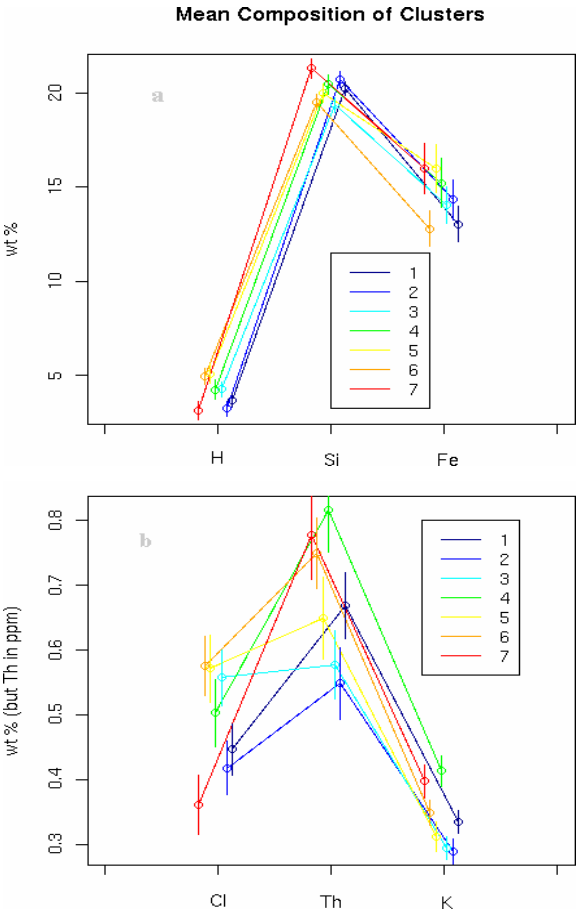

Figure 2: For each of the 7 provinces: Panel a shows the abundances of the major elements (H, Si, Fe) in wt%; Panel b shows the abundances of Cl (wt%), Th (ppm) and K (wt%)

Province #3. The third province embraces obviously the Tharsis rise, but also Alba Patera. Note that the northwest region of Elysium Mons was identified with the same signature. According to our analysis these terrains show a common chemical behavior with relatively low Si (19 wt%), Th (0.58 ppm), and K (0.29 wt%) content while Cl abundance is higher (0.56 wt%) than average.

Province #4. The northern lowlands are essentially divided into two provinces: #4 and #7. Province 4 corresponds to Acidalia Planitia (and the northwestern part of Arabia Terra). This fourth province is characterized by high abundances of Fe (15 wt%), Th (0.82 ppm), and K (0.41 wt%) relative to other province compositions.

Provinces #5 and #6. The equatorial hydrogen-rich regions previously identified [4] are divided here into two geochemical provinces. The fifth province is found in Terra Meridiani and the southern part of Arabia Terra, as well as in Elysium Planitia and continues toward Amazonis Planitia. The sixth province covers Terra Sabaea and the eastern part of Arabia Terra on one side of the planet, and Lucus Planum and the terrains southward on the other side. Of course these two provinces are characterized by strong H signal (5.0-5.1 wt% WEH). Both of them also show high Cl content (0.57-0.58 wt%). The abundance of Fe is rather high (16 wt%)) in province 5 while it is rather low (13 wt%) in province 6. Province 5 is also characterized by weaker K signal (0.31 wt%). Province 6 shows weaker Si signal (19.5 wt%).

Province #7. The last province complements province 4 to cover the northern lowlands. Province 7 can be distinguished by its relatively high abundance of Si (21.3 wt%) and low abundances of H (3.2 wt% WEH) and Cl (0.36 wt%).

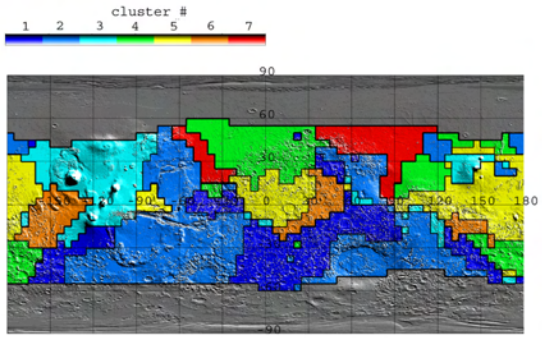

Figure 3: The 7 clusters of data points overlaid on a Martian shadow map.

References:

[1] Boynton W. V. et al. (2006) *J. Geophys. Res.*, submitted. [2] Taylor G. J. et al. (2006) *LPS XXXVII.* [3] Murtagh F. and Heck A. (1987) Kluwer Academic (ed.). [4] Feldman W. C. (2004) *J. Geophys. Res.*, 109, E09006, doi:10.1029/2003JE002160.