MARS ODYSSEY GAMMA RAY DATA INCLUDING CALCIUM: IMPLICATIONS FOR THE HETEROGENEITY OF MARTIAN SURFICIAL MATERIALS AND CRUSTAL EVOLUTION. H. E. Newsom[1], L. S. Crumpler[1,2], R.C. Reedy[1], M. J. Nelson[1], M. T. Petersen[1], L. G. Evans[3], G. J. Taylor[4], J. M. Keller[5], D. M. Janes[5], W. V. Boynton[5], K. E. Kerry[5], J. M. Dohm[5], S. Karunatillake[6], B.C. Hahn[7], and the GRS team [1]Univ. of New Mexico, Institute of Meteoritics, Dept. of Earth & Planetary Sci., Albuquerque, NM 87131, USA newsom@unm.edu, [2]New Mexico Museum of Natural History and Science, Albuquerque, New Mexico, USA, [3]Computer Sciences Corporation, Latham, Maryland, USA, [4]Hawaii Institute of Geophysics and Planetology and NASA Astrobiology Institute, Honolulu, Hawaii, USA. [5]Lunar and Planetary Lab, Univ. of Arizona, Tucson, Arizona 85721, USA. [6]Department of Astronomy, Cornell University, Ithaca, New York 14853, USA, [7]Department of Geosciences, Stony Brook University, Stony Brook, NY 11794-2100.

Introduction: The Mars Odyssey Gamma Ray Spectrometer (GRS) data is used to determine the abundance of elements in the upper few tens of centimeters of the surface [1,2]. The spatial resolution of the GRS data is very low (~440 km) as the instrument is not collimated. Because of the shallow depth of penetration of the signal, the GRS data primarily reflects the composition of the surficial materials [3]. Prior to the GRS data, the studies of the early landing site soils and remote sensing data suggested that the surficial material on Mars was similar in composition, and large areas of mantled terrain on Mars represented the deposition of a globally homogenized dust. Recent rover data also shows that there is a current dust component that occurs as a thin (easily churned up by rover wheels) bright dust deposit (**Fig. 1**) observed at the MER landing sites [4] and which also occurs over large areas of Mars as seen in remote sensing observations [5].

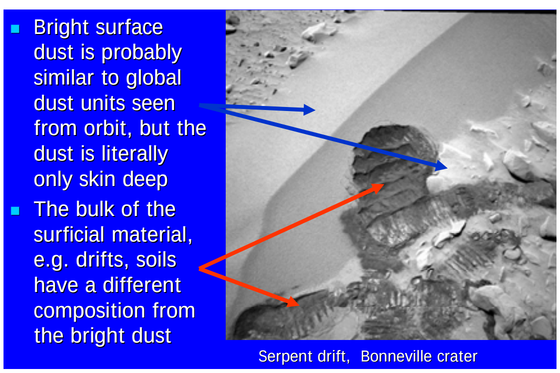

Fig. 1. Relationship between thin bright dust covering the principal surficial materials at the Gusev MER Sprit landing site. The Odyssey GRS senses primarily the surficial materials and near surface bedrock.

We have used the GRS data to test the homogeneity of these materials, and found that the prior assumptions were incorrect for the large mantled areas in Arabia, Tharsis, and Amazonis. The GRS data shows distinct variation in abundances of many elements for these mantled regions [3]. In addition the variability of surface chemistry seen in the GRS results by Newsom et al. [3] implies that the presumably homogeneous bright material seen in **Fig. 1** is less than 10's of cms thickness over most areas and does not significantly contribute to the GRS data.

We report here on our studies of the surficial materials and the important question of the relationship or possible chemical fractionations between the surficial materials and the underlying bedrock. New data for calcium provides additional information about the chemical variations on the martian surface and the possible role of alteration in the evolution of surface materials, consistent with the recent discoveries of phyllosilicates in the martian crust [6].

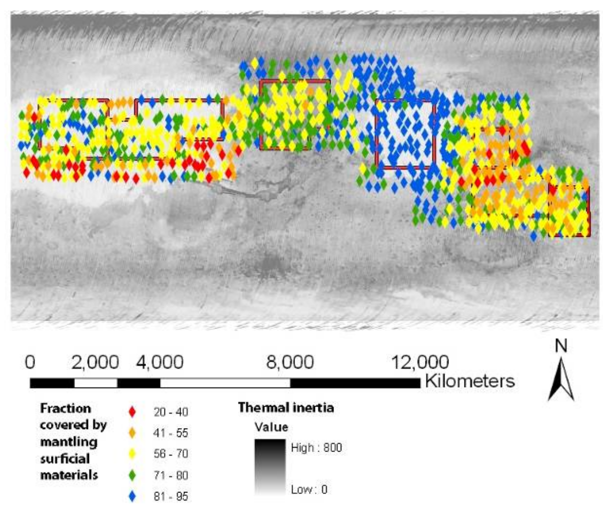

Fig. 2. MOC locations and estimated amounts of mantling obtained by examination of the high-resolution images superimposed on a thermal inertia map [5]. The 7 areas selected for analysis in the study by Newsom et al. [3] are outlined.

Chemistry of the mantled terrains on Mars: To investigate the nature of the surficial materials without interference from bedrock, three regions heavily mantled with surficial materials (**Fig. 2**) were selected, along with other large areas that represent possible compositional end-members. GRS data for H, Cl, Fe, Si, K, Ca and Th were obtained for each area (**Fig. 3**). The areas are inclusively chemically homogeneous, given the spatial resolution and analytical uncertainty of the GRS data.

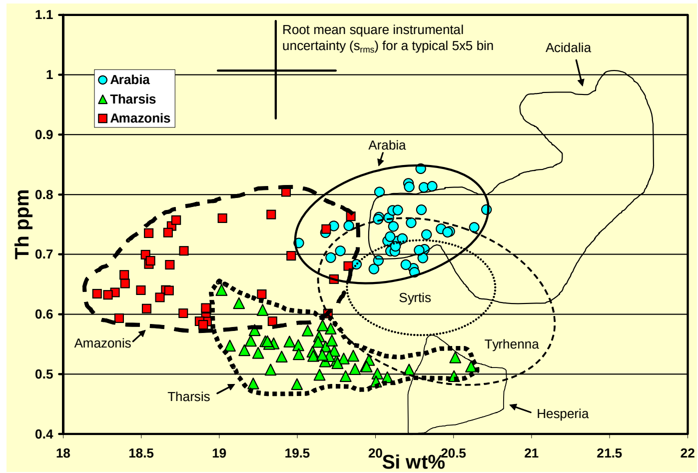

Fig. 3. A plot of 5 degree by 5 degree smoothed and rebinned data for Th and Si for seven selected areas. The data show the distinct compositions of the three mantled regions, Arabia, Tharsis, and Amazonis, and the diversity of compositions in the other areas.

The three mantled terrains provide a test of whether surficial materials on Mars are globally homogenized. Our study of the MOC images of these areas and the TES thermal inertia map [5] confirm that very little bedrock is exposed in these areas and that the surficial materials have buried the underlying topography to a depth of at least several meters (**Fig. 2**). Cl is distinctly higher in the Amazonis area compared to the Tharsis or Arabia regions, while for K, Arabia is distinctly higher than Tharsis and Amazonis. For Th, there is an increasing trend from Tharsis to Amazonis to Arabia. The mantled areas have similar Fe (not shown, but Arabia has a distinctly higher Si concentration (**Fig. 3**).

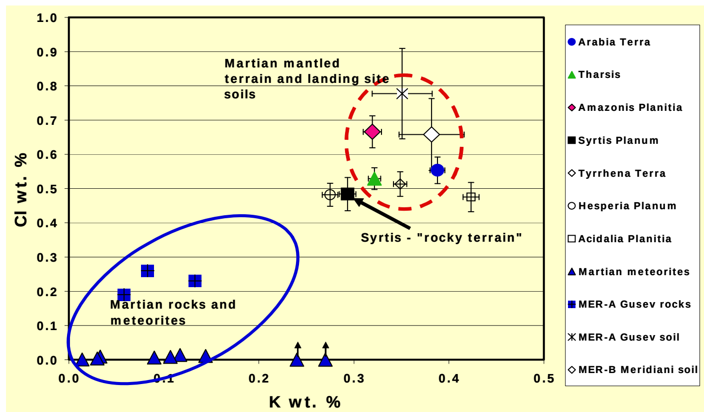

Fig. 4. Lower abundances of K and Cl in less-mantled areas such as Syrtis Major Planum and Hesperia Planum could be due to lower concentrations in the exposed bedrock. A mixing model shows that Syrtis Major Planum could be a mixture of an enriched model soil composition and bedrock with lower abundances of Cl and K.

Limited bedrock exposures in the mantled areas makes it unlikely that an extreme bedrock composition could explain the variations. The observed chemical differences among the areas may be due to variations in the protolith compositions, extent of alteration of the protolith regions, or post soil formation processes.

Chemical fractionations and the possible enrichment of surficial materials in Cl, K and Th compared to source rocks: The Cl, K, and Th abundances are substantially enriched in all of the areas relative to most basaltic martian meteorites and the Gusev basaltic rocks. The extent to which the abundance of Cl, K, and Th in the surface reflects the underlying crust depends on the composition of the bedrock in these areas. The simplest assumption adopted by Taylor et al. [7] is that the composition of the surficial materials reflects the crustal composition, much like terrestrial loess [8]. However, if the bedrock on Mars (like martian meteorites) is generally lower in Cl, K and Th than the soils, then the average surface composition from the GRS data is an upper limit for the composition of the crust, and some fractionation process has enriched the surficial materials in these elements.

We have constructed a mixing model between plausible soil and rock compositions to obtain the Syrtis composition (e.g. **Fig. 4**). Assuming a bedrock fraction of 50% requires a rock composition intermediate between the soil and average meteorite abundances and implies that about 35% of the Th and K are present in the crust compared to 50% for the assumption that the crust is the same as the surface abundances. The case with an exposed bedrock abundance of 26% requires lower rock concentrations, but requires a greater enrichment of K and Th in the soil or dust relative to the rocks (factor of about 4), and implies that only about 10% of Th and K are partitioned into the crust or that bulk Mars has lower abundances with significant implications for martian thermal history that may not be reasonable [3].

Aqueous processes could have enriched K and Th, which can be fluid mobile under low pH conditions [8]. These elements also share the characteristic of being incompatible during igneous fractionation and are enriched in the mesostasis during the final stages of crystallization of basalts [9]. Preferential alteration and aeolian erosion of the mesostasis could also enrich the soils. This component could be due to erosion of rocks altered early in Mars history.

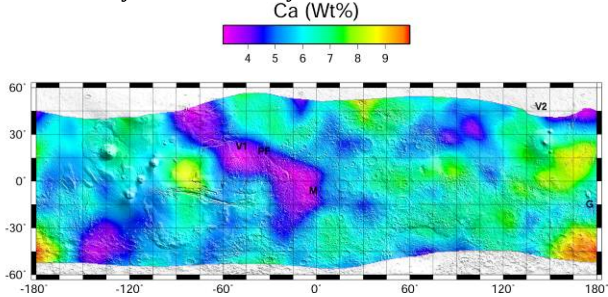

Fig. 5. Calcium concentrations in wt% for areas within approximately 45 degrees of the equator, because of greater uncertainties in the GRS data where ice is present at higher latitudes [1]. The GRS data used in the current study represents about 70% of the surface area of Mars.

Chemical fractionations and the possible depletion of surficial materials in calcium compared to source rocks: New results for calcium: Calcium is an important major element that is present in the minerals plagioclase and pyroxene in the martian crustal rocks (**Fig. 5**). The uncertainty for the current Ca GRS data is about 1 wt% for most areas. The Ca GRS data can be compared with the landing site data from Karunatillake et al., [10], which is based on an evaluation of the rock and soil compositions at each landing site. The agreement [11] is within about 20% except for Spirit, which sits in an area with a more complicated regional geology.

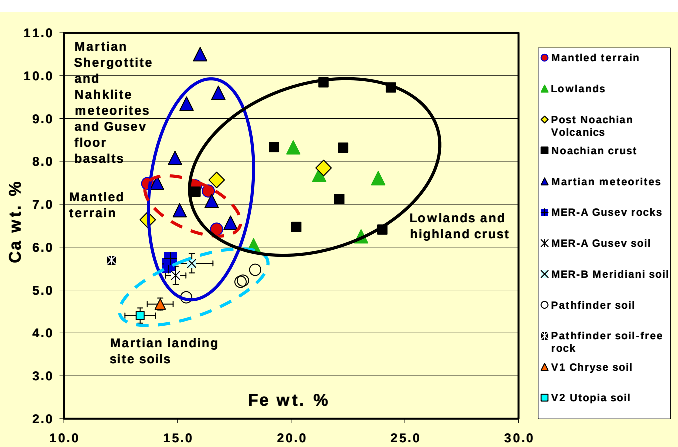

Fig. 6. Compositions of martian materials including mantled materials, showing the distinct variations in different GRS regions with high and low Ca abundances, compared to landing site soils and martian meteorites and rocks on the floor of Gusev crater.

The substantial variations in the abundance of Ca observed in the GRS data at a variety of locations not associated with sulfate occurrences (**Fig. 6**), support the conclusion of Newsom et al., [3] based on other elements, that the surficial materials on Mars have not been homogenized. The composition of the surficial materials therefore, reflect derivation from local source rocks with different compositions or the effects of chemical alteration and chemical transport, either of the soil itself, or of the local source rocks.

Implications for landing site soil formation and evolution: In an earlier study [12], we investigated the origins of an apparent depletion of calcium in soils analyzed at the Viking and Pathfinder sites compared to common martian basaltic meteorites. That study suggested that erosion of altered, Ca-depleted rocks could lower the Ca concentration of the present martian soil compared to fresh basaltic rocks. During alteration, calcium is removed from crustal rocks as observed in the Columbia Hills, and depleted in the paleosol data at the Lonar crater in a basaltic province in India [13]. The alteration processes probably occurred early in Mars history, long before formation of the present soils. The abundance of Ca in the landing site soils can be compared with the martian surface materials in **Fig. 6**, and with respect to the histogram of the Ca data for the belly band of Mars in **Fig. 7**. The low concentrations of Ca in landing site soils relative to most of the martian crust is consistent with the possibility that the current soils at the landing sites were derived from altered materials low in calcium.

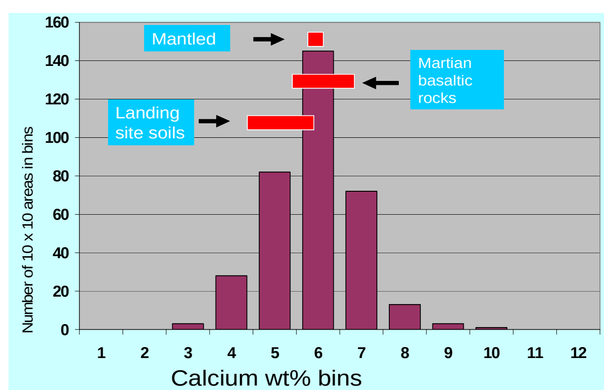

Fig. 7. Histogram of Ca wt% abundance within approximately 45 degrees of the equator.

Another implication of the model for the origin of the soil by erosion of ancient altered crust is that the soils must be relatively young to maintain the heterogeneity in the soils. Therefore, sinks must be present to maintain the disequilibrium over geological time scales. MER observations of soil settling into fractures (e.g. Anatolia) and filling depressions and craters suggests that the upper crust can provide some of the necessary sinks (e.g. Nelson et al., [12]).

Sequestering of the missing Ca in the early regolith is another possibility [14].

Evidence for the local derivation of surficial materials on Mars: Given the evidence against large areas of globally homogenized surficial materials on Mars, is there other evidence that the chemical variation seen in the GRS data partly reflects the local composition of the crust? In areas where distinct spectral signatures of martian rocks occur in TES near-infrared reflectance [15], there is some apparent correlation with composition. The mineral maps and GRS data shown in **Fig. 8** indicate that the abundance of Ca in the vicinity of the Syrtis Major Planum correlates to some extent with the signatures of high-Ca vs. low-Ca pyroxene. In particular, the greater abundance of low-Ca pyroxene to the north and the south of the Syrtis volcano is reflected in lower Ca concentrations (**Fig. 8**.).

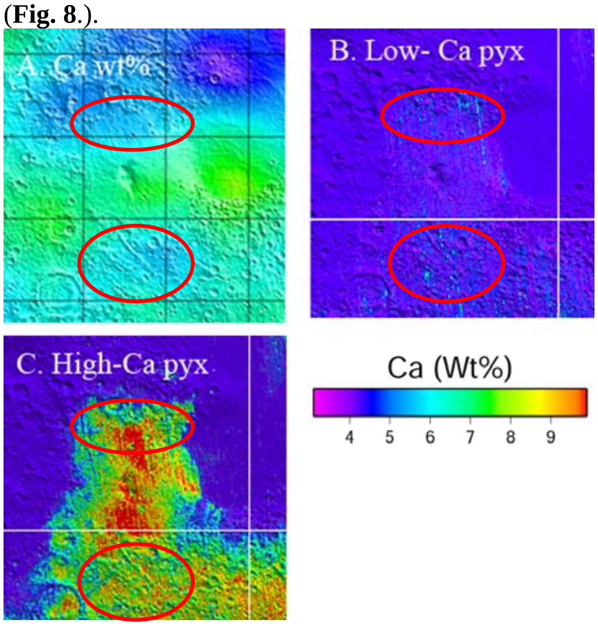

Fig. 8. A. Calcium abundance (see fig. 7). B, C. maps of high-Ca pyroxene, and low-Ca pyroxene respectively from the TES data [15] for the area of Syrtis Major Planum and the area to the north. Note that the areas with red circles have lower Ca and show evidence of low-Ca pyroxene.

The heterogeneity of the different distinct regions on Mars, including the mantled areas, suggests that the data for many elements is revealing variations in the composition of the crust of Mars (although possibly not for Cl, Th and K, as mentioned above). However, the high resolution imagery suggests that these crustal regions may include materials that were weathered early in the history of Mars, and may include sediments deposited at that time [16].

The implication from the GRS data is that for some elements, we are seeing a reflection of real variations in the chemistry of the crust of Mars, partly due to the original formation of the crust. When data for additional elements, such as aluminum is verified we will be able to address important issues such as the Ca/Al ratio of the martian crust. Current models for the evolution of the mantle and crust of Mars are based on data for martian meteorites, which may not be representative of the crust. For example, the martian meteorites, and Gusev basaltic rocks, have a super chondritic Ca/Al ratio, which implies retention of garnet in the source regions for the magmas that formed the meteorites. We will be able to verify if this holds for Mars in general.

Conclusions: These early results from the GRS experiment provide important new information about surficial materials their origin from the martian crustal materials, and the composition of the martian crust. Important conclusions include:

- Mantled regions, Arabia, Tharsis, and Amazonis, have distinctly different compositions and do not represent a thick globally homogenized deposit.
- The surficial materials seen in the GRS data, and the landing site soils may be enriched in K and Th (as well as Cl) compared to the crustal bedrock on Mars.
- Variations in soil and surficial material abundances imply a relatively young age for martian soils, and imply that sinks are present in the martian crust for sequestering older soils.
- The depletion of Ca in landing site soils, but not mantled terrains, relative to the martian crust, suggests their derivation from ancient altered terrains.
- Important chemical signatures of the crust of Mars, such as the Ca/Al ratio, and U/Th ratio will soon be available from the GRS data.

References: [1] Boynton W. V. et al. (2004) *Space Science Reviews*, *110*, 37-83. [2] Boynton W. V. et al. (2006) *JGR*, submitted. [3] Newsom H E. et al. (2006) *JGR* 112, E03S12. [4] A.S. Yen. et al, (2005) *Nature*, *436*, 49-54. [5] N. E. Putzig et al., 2005 *Icarus* 173, 325-341. [6] Newsom (2005) *Nature* 438, 570. [7] Taylor G. J. et al. (2006) *JGR*, 111, E03S06. [8]Taylor S. R. and McLennan S. M. (1985) *The continental crust*, Blackwell. [9] Burger P. et al, (2006) *LPS XXXVII* #2317. [10] S. Karunatillake et al., 2007, *JGR* submitted. [11] H. E. Newsom et al. (2007) *LPS XXXVIII*, #2056. [12] Nelson M. J. et al. (2005) *Geochim. Cosmochim. Acta*, *69*, 2701-2711. [13] Newsom H. E. et al. (2007) *LPS XXXVIII.* [14] G. J. Taylor et al., *LPS XXXVIII,* #1485. [15] Bandfield J. L. et al. (2002) *JGR 107* E6, 5042. [16] J.M. Dohm et al. (2007) *Icarus*, (2007), doi: 10.1016/ j.icarus.2007.03.006. Supported by NASA Mars Odyssey project and NASA MFRP (H. Newsom).