USING MARS ODYSSEY GRS DATA TO ASSESS MODELS FOR THE BULK COMPOSITION OF MARS. G. Jeffrey Taylor[1], W. Boynton[2], H. Wänke[3], G. Dreibus[3], and J. Brückner[3] [1]Hawai'i Institute of Geophysics and Planetology, SOEST, University of Hawai'i at Manoa, 1680 East-West Rd., Honolulu, HI 96822 (gjtaylor@higp.hawaii.edu). [2]Lunar and Planetary Lab, Univ. of Arizona, Tucson. [3]Max-Planck-Institut für Chemie, Mainz, Germany.

Introduction: Planetary bulk compositions provide crucial evidence for testing models of planetary accretion and differentiation. Major questions can be addressed by comparing the bulk compositions of the terrestrial planets: Did temperature and chemical gradients exist in the solar nebula and, if so, do the compositions of the terrestrial planets reflect such gradients? What was the extent of radial mixing of planetesimals and embryos during accretion? Did magma oceans always form as a natural consequence of accretion of large planetary embryos? Did magma ocean dynamics vary in their nature or vigor with planet size and planetary compositions? What physical and chemical processes took place during and shortly after accretion? Were volatiles lost? Was metallic iron oxidized? Were siderophile elements efficiently scavenged into metallic cores? What were the compositional effects of the last stages of accretion?

As the outer most terrestrial planet, Mars plays a central role in answering these questions. Models of the Martian bulk composition have been made on the basis of the compositions of Martian meteorites [e.g., 1,2]. These have been supplemented by additional data from Mars Pathfinder [e.g., 3-4]. The Gamma-Ray Spectrometer (GRS) onboard Mars Odyssey has now obtained a global dataset for several elements, including elements useful for determining the bulk chemical composition of Mars. We focus on K, Th, and especially the K/Th ratio to assess the abundances of moderately volatile elements, and on the bulk FeO content. These allow us to assess models of the volatile inventory on Mars compared to Earth, Moon, and Vesta and the amount of oxidation of metallic iron.

Is the surface representative of the entire crust? Several arguments suggest that the GRS measurements of the upper few tens of centimeters represent the entire crust. First, for the ancient highlands early impacts must have produced a megaregolith up to a few tens of kilometers thick. This would have at least stirred up the upper crust. Second, dust and soils on the surface may represent a rough average of the upper crust, analogous to sediments on Earth [5,6]. Third, much of the Martian surface has been shaped by lava flows. These flows were undoubtedly accompanied by a greater volume of intruded magmas, which make up much of the crust. Thus, the surface flows reflect the composition of deeper intrusives. Fourth, isotopic studies of Martian meteorites show that the Martian mantle differentiated early, producing an ancient, enriched crust [e.g., 7-9]. Our GRS data show that most of the crust is enriched in incompatible elements compared to Martian meteorites [10], indicating derivation from undepleted mantle. There is no evidence for recycling of the ancient crust, so it preserves the geochemical record of the primitive mantle composition. Although aqueous processes may fractionate K from Th [e.g. 11], the total range in K/Th on Mars is modest, suggesting that fractionation has been modest.

Differing styles of differentiation: The distribution and concentrations of K, Th, and Fe on Mars differs dramatically from that of the Moon. On the Moon, there is a wide range in K and Th concentrations (Fig. 1), reflecting the presence of large areas of cumulate rocks that have little K, Th, or Fe (not shown in Fig. 1), and other areas of highly differentiated rocks rich in incompatible elements (dubbed KREEP by lunar scientists). These materials formed in a global magma ocean. In contrast, the range in K and Th on Mars is relatively modest. There is no evidence for regions rich (evolved rocks) or poor (cumulates) in K or Th. This suggests that the early differentiation of Mars either did not involve a magma ocean or that the processes operating in it were very different from those on the Moon. There are no regions particularly low in Fe that might be feldspathic cumulates, though a deep magma ocean on Mars would probably crystallize garnet, thereby sequestering Al in the interior. Mars appears to have differentiated early, but in a style different from the Moon. This may make it easier to extract information about the planet's bulk composition.

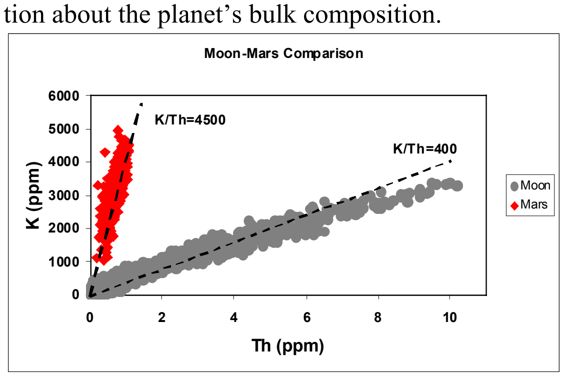

Figure 1. K vs. Th for the Moon [11] and Mars. Lines of equal K/Th are not best fits to the data.

Moderately volatile elements: Martian meteorite data indicate that Mars contains chondritic abundances of some moderately volatile elements, such as Mn and P [e.g., 3,4]. It appears to be depleted in K compared to CI chondrites, on the basis on comparison of the ratio of K to a refractory incompatible element (Th, U, La, etc.) to that in chondrites or other planetary bodies. Martian meteorites, however, formed by melting depleted mantle sources, raising the possibility that K (and other moderately volatile elements) were fractionated from Th, U, or REE. Our GRS data may provide a more robust estimate of the depletion of moderately volatile elements in Mars.

We summarize data for K, Th, and K/Th in the Martian crust (including SNC meteorites for comparison), bulk Earth and average continental crust, the Moon, and Vesta (assuming HED meteorites come from Vesta). Lunar Prospector data [11] show that K and Th are tightly correlated (Fig. 1), so we use the well-determined composition of high-K KREEP [12] to determine the lunar K/Th. The data confirm that Mars is enriched in K compared to Earth (or more properly, less depleted compared to CI chondrites), though perhaps not quite as much as inferred by Wänke and Dreibus [1], as McLennan argues [13]. Mars is substantially less depleted than the Moon and Vesta.

What caused these variations in K/Th? One possibility is that Mars accreted more volatile materials than did Earth, perhaps due to its location farther from the Sun. If so, then it is surprising that Vesta did not also accrete more volatile materials. The Moon is severely depleted in volatiles, perhaps because of its violent formation involving a giant impact with the primitive Earth. Could the formation of Vesta have also involved a large impact?

Oxidized iron: The conventional view is that Mars is enriched in FeO (about 18 wt%) compared to Earth (8 wt%) [1,2]. This estimate stems from the FeO/MnO ratio in Martian meteorites and the undepleted abundance of Mn in Mars. The logic seems unassailable. FeO does not fractionate strongly during magmatic processes unless conditions are very reducing (so metallic iron forms) or oxidizing (so phases containing tri-valent iron fractionate). Thus, surface rocks ought to reflect the FeO of the mantle [2]. Data from Martian meteorites and the Viking and Pathfinder landing sites [e.g., 3,4] are consistent with high FeO in the Martian mantle. Our global GRS data is consistent and if anything suggests possibly higher values. FeO ranges from about 17 to 24 wt% across the surface, with the southern highlands containing less than the northern plains. One caveat: it may be possible to produce rocks rich in FeO by fractionation at depth in water-bearing magmas [15].

The higher FeO in Mars compared to Earth may have been caused by oxidation of metallic Fe on Mars, probably by accreting H_2O. The presence of substantial water would be consistent with higher volatiles on Mars. Much of the original H_2O would have been used up, however, in oxidizing metallic iron, leaving the Martian mantle with less water than Earth [16].

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Table 1. Variations in K/Th.

	K	Th	K/Th
Mars Average Crust[1]	3100	0.71	4300
Mars Meteorites[2]	1100	0.24	4150
Mars Bulk Silicate[3]	305	.056	5450
Earth Continental Crust[4]	11000	4.2	2600
Earth Bulk Silicate[5]	260	0.094	2770
Moon High-K KREEP[6]	8000	22	360
Vesta HED Meteorites[7]	420	0.40	1050
CI chondrites	558	.029	19200

(1) Odyssey GRS data, 50 S to 60 N. (2) All types; data from literature. (3) Ref 1; (4) Ref 6. (5) Ref. 14. (6) Ref. 12 (7) Eucrites and diogenites; literature data.