

GLOBAL CONCENTRATIONS OF THORIUM, POTASSIUM, AND CHLORINE: IMPLICATIONS FOR MARTIAN BULK COMPOSITION. G. Jeffrey Taylor¹ and William V. Boynton², ¹Hawaii Inst. of Geophys. and Planetology, SOEST, U. Hawaii, Honolulu, HI 96822 (gjtaylor@higp.hawaii.edu), ²Lunar and Planetary Lab, Univ. of Arizona, Tucson, AZ 87521 (wboynton@lpl.arizona.edu).

Introduction: The Mars Odyssey Gamma-Ray Spectrometer (GRS) has provided a global inventory of the composition of the Martian surface, with implications for the planet's bulk composition. Taylor et al. [1] discussed K, Th, and FeO abundances. We extend that here to bulk Cl abundances and use the data to assess the bulk planetary abundances of volatile elements. This has implications for previous models for the bulk composition of Mars [e.g., 2-6], and allows us to place constraints on the average H₂O concentration in materials accreting to Mars. The results indicate that K/Cl in Mars is close to chondritic and that K/Th is double that of the bulk silicate Earth. In turn, this hints that all volatiles are greater in Mars than in Earth, or at least in the materials accreting to Mars, including H₂O.

GRS data: The GRS spectrometer system and data reduction methods are described in Boynton et al. [2007 JGR, 2008 Bell book]. Gamma rays are produced by the decay of radioactive K and Th and by neutron scattering and capture by Cl. The Cl data are restricted to a region roughly extending from 45° south to 45° north latitude where hydrogen concentrations are low enough to allow correction for the moderating effects of hydrogen on neutrons. We call this the H-mask, which gives the curvey boundaries to the Cl map shown in Fig. 1. The data encompass all data obtained from June 2002 through January 2006.

Data for Th, K, and Cl are shown in Fig. 1. All three elements vary in concentration by factors of 3–4 across the Martian surface. K and Th are strongly correlated and reflect a bulk Mars K/Th ratio of about 5000 [1], compared to a terrestrial value of 2900. K and Cl are uncorrelated. This is not surprising as they are easily fractionated by release of Cl gases from magmas near the surface and during eruptions, by aqueous alteration of surface materials, and by the large solubility of Cl salts in water. Thus, Cl concentrations reflect magmatic abundances, loss from magmas, and redistribution by surface and groundwater. The role of water in Cl redistribution is supported by a positive correlation of Cl with H₂O [7-8].

Chondritic Cl/K: In spite of the lack of correlation between K and Cl, their mean concentrations are roughly chondritic. Using the data within the H-mask and summing the millions of individual spectra, we find a global mean of 0.48 wt% for Cl and 0.32 wt% for K. This gives a Cl/K ratio of 1.5 ± 0.1 (uncertainty

is one standard deviation), compared to 1.24 for CI chondrites [9]. If we ascribe the highest Cl concentrations to relatively recent volcanic additions (see the high-Cl region around and to the west of the Tharsis Montes in Fig. 1), and omit that area from the global mean, the ratio falls to 1.4 on the Martian surface. This is still higher than the chondritic ratio, but surprisingly close.

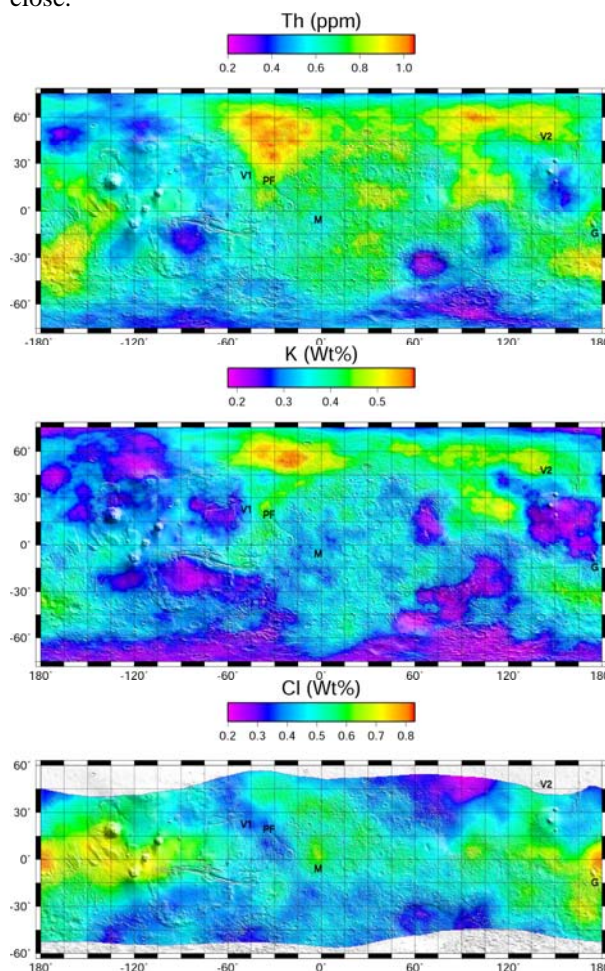


Fig. 1. Th, K, and Cl concentrations on the Martian surface, as measured by the Mars Odyssey GRS.

Does the roughly chondritic relative abundance of K and Cl reflect the bulk planet value? This was addressed for K and Th by Taylor et al. [1]. Two factors argue that the surface reflects the mean crustal composition. First, the Martian crust was continuously bombarded during most of its formation. This not only mixed previously-formed surface and subsurface

rocks, but also formed a regolith that could be continuously reworked as the crust grew. Second, isotopic data for Martian meteorites indicate that the Martian crust has not been recycled into the mantle [10]. Thus, what went into the crust as it was constructed by magmatism, stayed in the crust. This includes the fine-grained portions of the regolith built over time, producing at least some of the pervasive dust on the surface.

Th, K, and Cl are all highly incompatible elements during igneous processing. Unless highly fractionated liquids are involved so that phosphate minerals or K-feldspar precipitate, the ratios of the three elements will remain roughly constant. This is likely to be the case even if the Martian mantle is heterogeneous, as seems likely, although there are clearly different reservoirs with varying K/Th and other trace element characteristics [11-12].

K and Cl are moderately volatile elements: the temperatures for condensation of half of each element are 1006 Kelvin for K and 948 Kelvin for Cl [13]. Th is refractory. K/Th has been shown to be almost double that of Earth. We now see that Cl/Th is also roughly double, indicating that moderately volatile elements are approximately uniformly enriched in Mars compared to Earth. The elements are, however, highly depleted compared to CI chondrites: K/Th is 5000 in Mars and 19,000 in chondrites; Cl/Th is 7500 in Mars and 23,400 in chondrites.

Bulk planet Th, K, and Cl: Estimating the bulk chemical composition of a planet is always model dependent, and our attempt here is no different. If we assume (there are always plenty of assumptions) that we know the bulk crustal concentrations of Th, K, and Cl from their surface mean concentrations, we can calculate the total inventory of those elements in the crust, if we know the volume of the crust. Using a thickness of 57 km [14], for the crust and assuming that the silicate mantle extends to a depth of 1760 km, we estimate that the crust comprises 4.6 wt% of silicate Mars. If that amount of crust represents the average amount of partial melting of the mantle over time, then assuming a bulk distribution coefficient of 0.001 for each element and using the standard equilibrium partial melting equation, this results in an average mantle concentration of 0.028 ppm Th, 150 ppm K, and 220 ppm Cl. It turns out that with 4.6 wt% melting and a crustal volume as assumed, that half the total inventory of these elements is in the crust and half in the mantle. Thus the primitive mantle (more properly, bulk silicate Mars) has 56 ppb Th, 300 ppm K, and 440 ppm Cl. These are in accord with values given by Dreibus and Wanke [2-5], except for Cl, which they

underestimated because it is so depleted in Martian meteorites.

Implications for water and accretion: Dreibus and Wanke [3] estimated the water content in Mars from Cl abundance, by using the solubilities of H₂O and HCl in silicate melts. Following their approach (see p. 231 of [3]), but using our estimate of 440 ppm Cl in bulk Mars, we calculate a H₂O concentration in bulk silicate Mars of 400 ppm. This is a large amount, enough to cover Mars to a depth of over 1 km if all were released into the atmosphere. It is more likely, as Dreibus and Wanke [2-5] point out, that much of this accreted water was consumed by reacting with metallic iron during accretion, accounting at least in part for the high FeO content of the Martian interior [1-6, 15]. Alternatively, moderately-volatile elements such as K and Cl may have been decoupled from H₂O during planetary accretion. In this case, the high FeO is inherent in the materials accreting to Mars; we note that the HED parent body (Vesta) has a high FeO abundance coupled with low volatiles. The important point is that Mars appears to have accreted with higher concentrations of volatile elements, including chlorine and possibly water, than did the Earth. If our assessment of bulk crustal Cl greatly overestimates its abundance, for example because Cl has been systematically concentrated near the surface over time, then we are left with the problem of why two moderately-volatile elements, K and Cl, were so severely fractionated in the solar nebula.

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