A GEOPHYSICAL PERSPECTIVE ON THE MAJOR ELEMENT COMPOSITION OF MARS' MANTLE.

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Introduction. The internal structure of a planet provides essential clues about its origin and evolution. At present we can only claim insight into the internal structure of the Earth and Moon. Seismology has provided by far the most specific information on the interior of these two bodies. However, because no seismic data are available for Mars, it is neccessary to look elsewhere for constraints on the Martian interior.

Using the available geophysical data, i.e. mean moment of inertia in combination with mean martian density, have been used to place constraints on the mantle density profile for an assumed core composition and size [1-3]. The study by [4] employed compositions of martian meteorites in combination with models of the planet's radial density distribution to infer the physical structure of the martian mantle. Other attempts, exemplified by [6], started off with a model of the martian mantle and core composition, which had been derived independently of any geophysical constraints [7], to experimentally determine modal mineralogy along a model pressure-temperature profile and then to use it to calculate a mantle density profile. This could then be used to constrain the size of the core. Concerning the latter, recent attempts at retrieving information on its state and size using the second degree tidal Love number, suggested it to be fluid [8,9]. However, the large observed value of k_2 can also be interpreted as the mantle being softer than the assumed elastic solid model because of the presence of partial melt at depth [8,9].

Purpose. The aforementioned studies are essentially forward modeling approaches and therefore provide no information on the range of physical models that are actually consistent with the known geophysical parameters for Mars. In view of this limitation, we employ an inverse method as described in [10] to constrain martian composition and thermal state directly from geophysical observations. The method allows composition and temperature to be transforemd directly to parameters such as mineralogy, Mg# (MgO/(MgO+FeO)$\times$100), bulk mantle and core physical properties, which are all fundamental to our understanding of Mars.

The data used in the inversion are, mean moment of inertia (I), mean density ($\overline{\rho}$), second degree tidal Love number (k_2), tidal dissipation factor ($\overline{Q}$) and of course mean radius (R). The observed values of these parameters are, respectively, 0.3635±0.0012, 3935±0.4 kg/m^3, 0.163±0.017, 92±11 and 3389.5 km [8, 9, 11].

Method of Analysis. Our model of Mars is assumed spherically symmetric and divided into three layers of variable thickness, corresponding to crust, mantle and core. Crust and mantle layers are parameterized using composition c, thickness d and temperature T, whereas the core is modeled using the parameters radius, density, P and S wave velocity. Mars' chemical composition is modeled using the model system CaO-FeO-MgO-Al$_2$O$_3$-SiO$_2$. For a given model configuration that specifies mantle composition and thermal state, the inversion procedure consists of the following steps:

- Gibbs free energy minimization is used to compute equilibrium mineral modes at the pressure and temperature conditions of interest.

- Physical properties in the form of density, P and S-wave velocity are then estimated from the computed mineralogy as function of depth.

- From these radial profiles, mean mass, mean moment of inertia, tidal Love number and tidal dissipation are calculated and compared to the observations.

Results. Our results (figure 1) point to an FeO enriched Martian composition relative to the Earth [12], as also inferred from geochemical analyses of the SNC meteorites [7]. Most other elements occur in proportions that are close to the Martian model composition derived from the SNC's. This is further indicated by the bulk silicate Mg# and Mg/Si ratios (figure 1 F & G). Derived Martian mantle geotherm are shown in figure 2. Our mantle mineralogy (figure 3) generally encompasses the mineralogy found in previous studies, except for the absence, in our models, of a thin perovskite-bearing layer just above the CMB. Because its presence depended on the size and composition of the core, which could not be determined independently, most previous studies assumed perovskite to be stable, although the question remained open, inasmuch as core size could not be answered definitely. Concerning the latter, we found a core with a radius of around 1680 km, a density of $\sim$6.7 g/cm^3, and most probable CMB temperatures of $\sim$1800 °C (figure 4). Combining these results with recent laboratory measurements of melting relations in the Fe-FeS system and accompanying density measurements [13,14], we interpret our results, as implying a molten core, in concert with other recent findings, and containing $\sim$22-25 wt% S.

Based on our results, we concur with earlier conclusions [15], which were based on more limited data then available, that it is not possible to fit the requirement of a bulk CI chondritic Fe/Si ratio with the available geophysical data (figure 1 H). Based on these conclusions, the CI chondrite accretion model for Mars, and the terrestrial planets in general, probably needs to be reexamined. We propose that the building blocks might possibly be found among the ordinary chondrite groups L and LL, as their compositions concur with our estimates, and also match the oxygen isotopic composition of the SNC's.

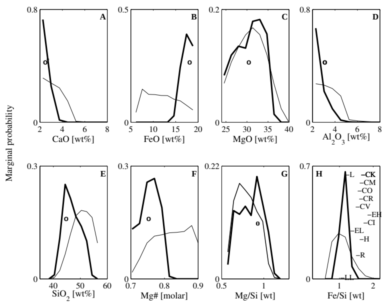

Figure 1: Prior (thin line) and posterior (thick line) marginal *pdf*'s depicting sampled bulk silicate compositions for the CFMAS elements (A-E) bulk silicate Mg# (F), bulk silicate Mg/Si ratio (G) and bulk Fe/Si ratio as well as Fe/Si ratios for chondritic meteorite groups (H). In figures A-G circles indicate the SNC model Martian composition of DW. Note that as the elemental concentrations are plotted in wt% and not as $\log(wt\%)$, their distributions will appear skewed.

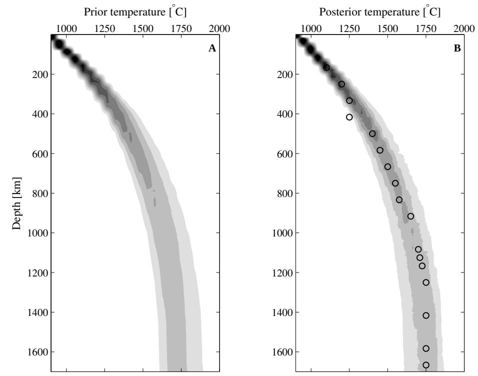

Figure 2: Prior (A) and posterior (B) sampled mantle areotherms. At the 30 fixed depth nodes a histogram reflecting the marginal probability distribution of sampled temperatures is calculated. By lining up these marginals, temperature as a function of depth can be envisioned as contours directly relating their probability of occurrence. Shades of gray between white and black indicating, respectively, least and most probable outcomes, with each contour line defining an equal-sized probability density interval for the distributions. The experimental temperature data points from [6] are indicated by circles.

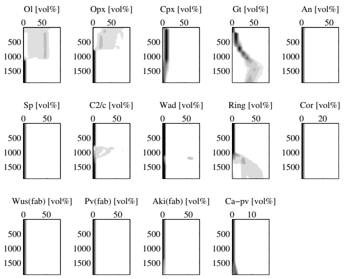

Figure 3: Posterior marginal modal mineralogy as a function of depth down to the CMB. In some of the plots, e.g. Wus and Pv, minerals do not seem to be stable. This is because these minerals are only stable for a few models. See main text for further discussion. Shades of gray as in figure 4.

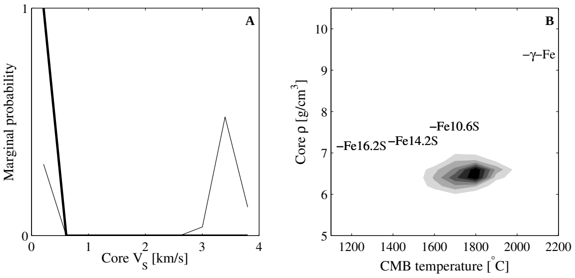

Figure 4: Additional core properties - (A) depicts sampled prior (thin line) and posterior (thick line) marginal *pdf*'s for sampled S wave velocities in the core. Note that the posterior *pdf* is flat for velocities corresponding to solid cores. (B) shows sampled posterior core densities as a function of CMB temperatures with experimental determinations of melting temperatures for a number of compositions in the Fe-S system included (from [15]). Shades of gray as before.

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