

GEOPHYSICAL AND GEOCHEMICAL CONSTRAINTS ON THE COMPOSITION AND STRUCTURE OF THE MARTIAN INTERIOR. C.M. Bertka and Y. Fei, Geophysical Laboratory and Center for High-Pressure Research, Carnegie Institution of Washington, 5251 Broad Branch Rd., N.W., Washington DC 20015 (email: bertka@gl.ciw.edu, fei@gl.ciw.edu).

Introduction: Data constraining the structure and composition of the Martian interior are limited. Presently, the strongest geophysical constraints we have for Mars are knowledge of the mass and radius of the planet and the moment of inertia factor. Using the mass and radius of the planet and the moment of inertia factor as constraints, two of three variables, mantle density, core size, and core density, can be calculated as a function of one of the three variables. Folkner et al. (1) recently reported a new value for the moment of inertia factor of Mars based on an improved estimate of the Martian spin pole precession rate determined from Doppler and range measurements to the Mars Pathfinder lander, 0.3662 ± 0.0017 .

Most models for the composition of the Martian mantle and core are dependent on knowledge of the moment of inertia factor of Mars (2,3,4). Dreibus and Wänke (5), however, derived a model of Martian mantle and core composition independent of the moment of inertia factor of Mars. They used element correlations between measured ratios in the SNC meteorites and chondritic abundances to derive a mantle composition with all oxyphile refractory elements present in C1 chondrite abundance ratios, and a bulk planet composition with a C1 chondrite Fe/Si ratio. Bertka and Fei (6) performed high-pressure multi-anvil experiments with an analog of the Dreibus and Wänke (5) mantle composition to determine its modal mineralogy up to core-mantle boundary pressures along a model PT profile of the Martian interior. Using the results of these high-pressure experiments, they calculated a mantle density profile for the DW model, and then calculated the moment of inertia factor as a function core composition and crustal thickness (7,8). In this abstract we summarize the results of those calculations and evaluate the Dreibus and Wänke geochemical model for the Martian interior in light of the moment of inertia factor reported by the Pathfinder team.

Despite the success of recent missions to Mars, there remains uncertainty about the internal structure of the planet, particularly the core. The weak Martian magnetic field is consistent with either an entirely solid or entirely liquid core. Earlier studies (e.g., 5,9) have presented core models based on meteoritic evidence. Fei et al. (10) and Pike et al. (11) have explored the melting relations of core compositions in the S-rich Fe system proposed by these previous studies. In this abstract we also summarize the results of those studies and their implications for models of the state of the martian core.

Density Profile Calculations: The moment of inertia factor calculated for the DW mantle and core com-

position model, constrained to maintain a bulk C1 Fe/Si ratio, is 0.354 (7,8). To maintain a C1 Fe/Si ratio requires that the DW model includes a 180 to 320 km thick crust, assuming a crust density of 2.7 to 3.0 g/cc. Without the addition of a thick crust, the DW model mantle and core composition yields a higher moment of inertia factor, 0.368, and a bulk planet composition that is deficient in iron compared to a C1 chondrite iron abundance (7,8).

For the DW mantle composition to be consistent with a moment of inertia factor of 0.3662, and a bulk C1 chondrite Fe/Si ratio, requires that the mass fraction of iron in the core is increased while the density of the core is decreased, compared to core characteristics previously calculated for compositions in the system Fe-S-Ni. Carbon and hydrogen are possible core components that may produce these results. That C and H, in addition to S, may also have been incorporated into an Fe-rich martian core has been proposed on the basis of cosmochemical arguments and solubility data for C, H and S in silicate melts and molten metallic iron (e.g., 12,13). Bertka and Fei (8) reported the results of core density profile calculations for model core compositions which include C and H. They determined the effect of including C and H in the core on the bulk planet Fe/Si.

Estimates of the amount of H and C that may have been incorporated into the Martian interior are model dependent (e.g., 12,13). Dreibus and Wänkes' (5) two component model calls for a bulk planet consisting of a mixture of a highly reduced component and a highly oxidized component. The maximum percentages of H and C in the core predicted by this model, 1.1 wt% and 9.3 wt% respectively, are most closely accommodated by the endmember phases FeH and Fe₇C₃ (8). Using a Birch-Murnaghan equation of state, Bertka and Fei (8) calculated the density of the endmember core compositions, Fe, FeS, FeH, Fe₃C, Fe₇C₃ and Fe₃O₄ as a function of pressure and temperature. For each model core composition considered, they calculated the bulk planet Fe wt%, the bulk planet Fe/Si ratio, the mass fraction of the core, the radius of the core, and the thickness of a 3.0g/cc crust by satisfying the geophysical constraints (moment of inertia factor = 0.3662, and mean density), assuming a DW mantle density profile (mantle Mg#=75) (7).

The bulk iron content of a C1 chondrite is 27.8 wt%, the C1 Fe/Si ratio is 1.71. The calculations presented by Bertka and Fei (8) showed that the addition of C and H to a S-rich Fe core can not increase the bulk Fe wt% or Fe/Si ratio to C1 values, while maintaining the constraint of a DW model mantle and a

moment of inertia factor of 0.3662. The geophysical constraints argue against the two component accretion model for the inner planets proposed by Dreibus and Wänke (5). The Fe/Si ratio and bulk iron content of Mars are not equivalent to those of a C1 chondrite. The moment of inertia factor reported by the Pathfinder team, however, is consistent with a martian mantle that is more iron-rich than the Earth's mantle, as predicted by the DW model. Given a DW model core composition of 77.8 wt% Fe, 14.2 wt% S, and 7.6 wt% Ni, the martian mantle Mg# can range from 60 to 78, assuming a martian crust 25-150 km thick with a mean density of 2.7-3.0 g/cm³. The uncertainty in mantle Mg# is slightly larger when the uncertainty in core composition is considered (7).

Melting Relations of Model Core Compositions:

Pike et al (11) performed high-pressure melting experiments with a starting Fe-Ni-S mixture of 73.5 wt% Fe, 20 wt% S and 6.5 wt% Ni. Usselman (14) also used the Fe-Ni-S system to model the earth's core and performed experiments at pressures up to 10 GPa. This composition, in addition to being identical to that used by the core study of Usselman (14), is similar to most other previously proposed martian core compositions (5,15). Pike et al. (11) reported that the eutectic temperature in the Fe-Ni-S system at martian core-mantle boundary pressures increases linearly from 925 °C at 18 GPa to 1125 °C at 25 GPa. The eutectic melting curve determined by Pike et al. (11) indicates that the addition of nickel to the model core between 18 GPa and 25 GPa decreases the eutectic temperature by approximately 75 °C from that determined by Fei et al. (10) for the Fe-FeS system. The eutectic temperatures in the Pike et al. (11) study were between 200 °C and 300 °C lower than those predicted by Usselman (14).

Given a DW model for martian mantle and core composition, and a moment of inertia factor of 0.3662, Bertka and Fei (7) calculate a core mantle boundary pressure of 25 GPa. At 25 GPa (the top of the martian core), the DW model core composition starts to melt at 1125 °C and is completely molten at about 1500 °C. If the temperature at the top of the martian core is higher than 1500 °C, an entirely liquid martian core is expected, assuming the core temperature rises faster than the liquidus temperature as a function of depth.

Discussion: We conclude that the Fe/Si ratio and the bulk Fe content of Mars are not equivalent to those of a C1 chondrite. The moment of inertia factor of Mars reported by the Pathfinder team eliminates the possibility that all of the terrestrial planets were accreted from C1 material. Future planetary accretion models will have to account for variations in bulk Fe/Si ratios between the terrestrial planets. Although the range in Fe/Si ratio and bulk Fe content calculated to be consistent with a moment of inertia factor of 0.3662 is not matched by C1 chondrites, a mixture of carbonaceous chondrites with ordinary or enstatite chondrites could

produce a bulk planet composition whose major element abundances are consistent with the geophysical constraints. As refractory element ratios are similar in all chondrites these alternative models would predict similar abundances of Al₂O₃, MgO, and CaO in the martian mantle as the DW model. Although the Mg# of the martian mantle is still uncertain, we may predict that the martian mantle is more iron-rich than the Earth's mantle, as proposed by the DW model.

Melting experiments at high-pressure in the Fe-S-Ni system indicate that it is likely that Mars has an entirely liquid core, given that current thermal models of the planet suggest that the core-mantle boundary temperature is higher than 1500 °C (e.g., 16). Assuming the absence of thermal as well as chemical convection, a sulfur-rich fluid core would result in the lack of a planetary magnetic field. An entirely fluid core is consistent with the weak magnetic field observed on Mars (17), but requires that some degree of convection is present. Uncertainty in heat flux in such a liquid core allows for the possibility of weak thermal convection.

Seismic data, which could reveal the size and state of the martian core, would greatly improve our models of the composition and structure of the martian interior.

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