EXPERIMENTAL CONSTRAINTS ON THE THERMAL STRUCTURE OF THE MARTIAN INTERIOR AND MARTIAN MAGMATISM. Y. Fei[1] and C. M. Bertka[1,2], [1]Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Road, NW, Washington DC 20015; fei@gl.ciw.edu, [2]American Association for the Advancement of Science, 1200 New York Avenue, NW, Washington DC 20005; cbertka@aaas.org.

Introduction: Past space missions to Mars have provided important constraints on the planet's internal density distribution [1,2]. However, the thermal structure of the Martian interior remains highly uncertain. Although theoretical calculations have provided some basic knowledge of the thermal evolution of Mars [e.g., 3-9], the results from these computer simulations are strongly dependent on the model parameters. Estimating Martian core temperature is difficult because of the uncertainty in the chemical composition and physical state of the core. Knowledge of the physical state of the core is critical for placing bounds on core temperatures. Several lines of observation may shine some light on the physical state of the core. These observations include the present day weak Martian magnetic field and the existence of a strong magnetic field in the early history of Mars as discovered by Mars Global Surveyor. However, ultimate confirmation of the physical state of the core has to rely on future missions that will provide seismic data.

If the physical state of the Martian core is known, core temperatures can be estimated from melting temperature of the core materials. Cosmochemical constraints indicate that Mars has a sulfur-bearing iron-nickel core. Our experimental study of melting relations in the system Fe-Ni-S at high pressures provides essential data to estimate the core temperatures.

Recent data from Mars Global Surveyor revealed the distribution of Martian crust and provided new insight into Mars's thermal history [e.g., 9]. Understanding mantle convention on Mars is critical for explaining the crustal dichotomy and magma production on Mars [7, 10]. Our experimentally determined melting relations in an iron-rich mantle composition up to core-mantle boundary pressures provide important constraints on thermal history models.

Experimental Procedure: We used a multi-anvil high-pressure apparatus to simulate the pressure-temperature conditions of the Martian interior. Experiments were conducted using an 8/3 high-pressure cell assembly [11] that is capable of generating pressures up to 28 GPa, covering the entire range of Martian mantle pressures and the upper portion of the core pressures. For the melting relations of the Martian core, we used a model core composition in the Fe-Ni-S system [12]. The starting materials were Fe-Ni-S mixtures, created by mixing pure metallic Fe, Fe-Ni alloy, and FeS. The starting materials were loaded into either MgO or boron nitride capsules. Sample temperatures were measured with a W5%Re-W26%Re thermocouple. The quenched samples were examined by X-ray diffraction and with an electron microprobe. Backscattered electron images, chemical composition maps, and quantitative chemical analyses were obtained with a JEOL-SUPERPROBE JXA-8900 electron microprobe. Melting of the samples was determined on the basis of quenched textures and composition maps.

Melting experiments of the Martian mantle were performed on a model mantle composition [12]. The starting material was made by mixing spectroscopically pure oxides [13]. The starting material was loaded into a rhenium capsule. The melting curve was determined over the entire pressure range of the Martian mantle. Phase identification and quantitative chemical analyses were done by Raman spectroscopy and X-ray diffraction and with the electron microprobe.

Results and Discussions: We have determined the melting relations in a model Martian core composition up to 25 GPa. The eutectic temperature in the Fe-Ni-S system increases linearly from 1200K at 18 GPa to 1400K at 25 GPa [14]. The eutectic temperatures are taken as the minimum required for a partially molten Martian core. We further determined the liquidus temperature for the model core composition that defines the minimum temperature required for a completely molten liquid core.

Predicting the physical state of the Martian core requires inferring a core-mantle boundary temperature. As there is no independent information to use when estimating core temperature, the question of the physical state and the temperature of the core are intimately coupled. For a given chemical composition of the core, the experimentally determined melting temperature at the core-mantle boundary provides the minimum temperature for a liquid outer core. Whether or not the Martian core had a solid inner core depends on the relationship between the thermal profile and the melting curve as a function of pressure, and the thermal evolution through history. Mars Global Surveyor discovered crustal magnetic sources in ancient southern highlands terrain, suggesting that Mars had a strong magnetic field in the planet's early history [15]. The strong global magnetic field in early Martian history may be the product of an early Martian dynamo driven by thermal or chemical convection, similar to the generation of the Earth's magnetic field [16]. Models of thermal evolution of Mars [16, 17] suggest that core heat flow decreases rapidly for the first 1Gyr of the planet's history. One possible scenario for the absence of a present day magnetic field is that the rapid cooling could have quickly frozen the core. Once the core was solidified convection would no longer be possible and the dynamo would cease to exist. Under this scenario, the present core temperature could be very low (less than 1400K) because of the low Fe-Ni-S eutectic temperature at the pressures applicable to Mars. Alternatively, the early magnetic field could be generated by thermal convection in an entirely liquid core, but because of the rapid cooling, the core cooled to a level at which its heat was released by conduction alone [16]. The present core of Mars could still be totally liquid, but no longer convective. This scenario would also be consistent with the present day weak Martian magnetic field. For an entirely liquid core, the inferred core temperature would be greater than 1800 K.

Our experimentally determined melting curve of the Martian mantle provides an upper bound temperature required for a solid mantle. It also provides constraints on the mantle rheological properties for a given areotherm. Current models of thermal evolution predict high mantle temperature because of inefficient heat loss due to the formation of lithosphere in the early Martian history. The range of depths at which melting occurs is directly related to the shapes of the solidus and the model areotherm. On the basis of these thermal models [e.g., 6-8], it is possible that mantle temperatures exceed the mantle melting temperatures at pressures of approximately 2 to 4 GPa, corresponding to a depth of 15-350 km. Detailed comparison between the experimentally determined melting curve and model areotherm should provide insight to the volcanic history of Mars and mantle plume generation.

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