ON THE SILICON CONTENT OF MERCURY'S CORE AND IMPLICATIONS FOR CORE MINERALOGY, STRUCTURE, AND DENSITY. Yingwei Fei[1], Valerie J. Hillgren[1], Anat Shahar[1], and Sean C. Solomon[2], [1]Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015 (fei@gl.ciw.edu), [2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015.

Introduction: Constraints on the identity and the amounts of light elements in Mercury's large metallic core are scarce, but we expect that all terrestrial planetary cores share some common compositional features imparted during the core-mantle differentiation process. Differences in physical conditions at the time of the core-forming events, such as pressure (P), temperature (T), and oxygen fugacity (fO_2), should lead to distinct core compositions for the different terrestrial planets. Recent Earth accretion models [1-2], constrained by siderophile-element partitioning data, point toward reduced conditions during early Earth accretion, starting at a log fO_2 4.5 below the iron-wüstite (IW) buffer up to 20% of the final accreted mass. Under such reduced core-forming conditions, silicon (Si) is expected to be the dominant light element in Earth's core on the basis of Si partitioning behavior between silicate and metal [3-4]. Mercury could have accreted under still more reduced conditions [5], suggested by its low FeO content in surface silicates and its large core size. As a consequence, substantial Si could have been incorporated into Mercury's core. Here we use experimental Si partitioning data to explore a range of possible Si contents in the core, constrained by accretion conditions. For a given Si content, we predict core structure, guided by the phase relations in the Fe-Si system and the crystallization sequence. We further evaluate core size and moment of inertia from the computed density profiles, derived from new density measurements of face-centered cubic (fcc) iron and the effect of Si on the density of the Fe-Si alloy.

Experimental Data and Results: This study aims to develop models for Mercury's core structure from geochemical constraints and high-pressure experimental data. We start with planetary accretion models that lead to a Si-bearing iron core from phase relations in the Fe-Si system. The state of the core and its thermal structure are next examined on the basis of melting relations at pressures relevant to the conditions of Mercury's core. Finally, we compute core density profiles from in-situ density measurements of Fe and Fe-Si alloys at high pressure and temperature.

Si partitioning data. Si solubility in metallic iron, equilibrated with silicate, as a function of P, T, and fO_2 has been extensively investigated with piston-cylinder and multi-anvil high-pressure devices up to 25 GPa [4, 6-11]. The experimental results show that the Si content of iron metal increases with increasing T and decreasing fO_2, but the effect of pressure on Si solubility over a wide pressure range is still debated. Because core-mantle differentiation in Mercury likely occurred in a magma ocean environment at relatively low pressure (< 7 GPa) and presumably under highly reduced conditions, the most relevant experimental observations are the partitioning data between liquid metal and silicate melt at pressures below 7 GPa, which are relatively well constrained and span a wide range of oxygen fugacity [4, 10-11]. For metal-silicate equilibration at 5 GPa and in the temperature range 2200-2500 K during the formation of Mercury's core, the Si content in the core could range from 5 wt% to 35 wt%, corresponding to FeO contents in mantle silicate from 4 to 1 wt%, respectively.

Melting relations in the Fe-FeSi system. The Fe-FeSi system has a eutectic point at about 26 wt% Si at high pressure [12]. The Si content of a solidified inner core is thus controlled by the bulk Si content in the core. Unlike the melting relations in the Fe-FeS system, Si partitions almost equally between solid and liquid on the Fe-rich side of the eutectic [12]. The effect of Si on the iron melting temperature is markedly less than that of S at high pressure. The temperature depression at the eutectic point is about 400 K at 21 GPa in the Fe-FeSi system [12], compared with 900 K in the Fe-FeS system [13]. The effect of Si on the iron melting temperature is about -16 K/wt% Si and the minimum temperature for a liquid outer core is 1860 K at the core-mantle boundary (CMB) (for a CMB pressure of 10 GPa) for a core composition with 15 wt% Si.

If Mercury's core contains more than 26 wt% Si, a solidified inner core would consist of FeSi, as FeSi is the first solid phase to crystallize in the Fe-FeSi system [12]. The FeSi phase has a high melting temperature at high pressure, but the precise pressure dependence of the melting curve is still controversial [14, 15]. From recent melting experiments [14], the minimum temperature at the CMB would be 2200 K for an FeSi core in order to maintain a liquid outer core.

Phase transformations in the Fe-FeSi system. FeSi undergoes a phase transition from a cubic ε-FeSi phase (B20 structure) to a high-pressure phase with CsCl-structure (CsCl-FeSi) at 24 GPa and 1900 K, where the Clapeyron slope of the transition boundary is negative [14, 16]. If Mercury has an FeSi solid inner core, then the inner core will feature a density jump. The depth of the density jump in the inner core depends on the core

thermal structure and is constrained by the phase-transition boundary.

Fe is stable in the fcc phase over the entire *P-T* conditions of Mercury's core. Models of Mercury's internal structure to date have considered only fcc-Fe as the solid inner core component [17-21], a reasonable assumption if S is considered to be the only light element in the core. However, adding Si to Fe in the inner core will substantially expand the stability field of the body-centered cubic (bcc) phase [22, 23]. The stability fields of fcc, bcc, and fcc+bcc are complex functions of pressure, temperature, and Si content and require further high-pressure experiments to be fully understood. Nonetheless, the mineralogy (bcc phase, fcc phase, or both phases) of the inner core likely depends on the Si content in the core.

Density measurements of Fe and Fe-Si alloys. Depending on the Si content of Mercury's core, there are several possible mineralogical models of the inner core consistent with phase relations in the Fe-FeSi system. In order to compute the core density profiles from phase equilibrium data, we need to know the equations of state of fcc-Fe, ε-FeSi, and CsCl-FeSi, and the effect of Si on the density of the Fe-Si alloy. The liquid density of Fe-Si alloys must also be modeled properly. We have accurately determined the equation of state of fcc-Fe by in-situ synchrotron X-ray diffraction measurements with an internally-heated diamond cell over the *P-T* range applicable to Mercury's core [24]. We have also determined the effect of Si on the density of the Fe-Si alloy [25]. Combined with available data on the equations of state of ε-FeSi and CsCl-FeSi [26, 27] and the liquid density of Fe-Si alloys [28, 29], we calculate the core density profiles for a range of core Si contents from 0 to 33.5 wt% (FeSi end-member). The density distribution in the core, combined with mantle and crustal density models [21], allows us to further assess core size and moment of inertia, providing constraints for interpreting geophysical observations (second-degree gravity field, obliquity, and forced libration amplitude) to be made by the MESSENGER spacecraft mission.

Discussion: Previous models for the internal structure of Mercury were based on the presumption of an Fe-S core [17-21]. We present new models for an Fe-Si core. Si in Mercury's core is a natural consequence of planetary accretion under highly reduced conditions [5]. We have examined the possible mineralogy of Mercury's inner core when it crystallized from Fe-Si melts. A layered structure, with a sharp density change, is expected for an FeSi core. Moreover, because Si partitions equally between the liquid outer core and the solid inner core, compositional buoyancy would not be a driving force for outer core convection, which could affect the generation of Mercury's magnetic field. The temperature required for a liquid outer core in the Fe-Si system is higher than for a Fe-S core. Such a higher temperature would affect thermal evolution models.

An Fe-Si core of Mercury may be regarded as one end-member among possible models for core composition. There is no compelling reason to exclude S in the core on the basis of cosmochemical arguments. The Fe-Si-S system forms two immiscible liquids at pressures below 14 GPa [30], the implications of which regarding outer core stratification have been discussed [5]. From the crystallization sequence and Si partitioning between liquid and solid [30], Mercury's inner core could consist of FeSi. In such a case, Mercury could have a complexly layered core structure, with two layers in the inner core separated by a phase transition and two liquid layers in the outer core separated by a liquid miscibility gap.

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