

EVOLUTION OF MERCURY'S CORE DYNAMO. K. M. Soderlund¹ and G. Schubert² ¹Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, 78758 (krista@ig.utexas.edu). ²Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, 90095 (schubert@ucla.edu).

Introduction: Measurements by the MErcury Sur-
face, Space ENvironment, GEOchemistry, and Rang-
ing (MESSENGER) spacecraft have provided a wealth
of new information about Mercury's magnetic field and
its evolution, which highlight several characteristics of
the Hermian field that are unique across the solar sys-
tem. First, the magnetic field is characterized by a dipole
that is displaced by ~ 0.2 planet radii toward the north
pole and tilted less than 3° from the rotation axis [1]. In
addition, the magnetic field is unusually weak compared
to other planets with a mean surface field strength of ap-
proximately $0.4 \mu\text{T}$ [1]. Similar to the Earth, however,
the magnetic field appears to be long-lived with evi-
dence of ancient (~ 3.8 Ga) remnant crustal magnetiza-
tion; the strength of this early field is difficult to con-
strain, with estimates ranging from the present day value
to Earth-like values of $\sim 50 \mu\text{T}$ [2]. In this study, we in-
vestigate the evolution of Mercury's core and magnetic
field using interior models and dynamo theory.

Convection and Magnetic Field Generation: Plan-
etary magnetic fields are most likely generated by dy-
namo action, where thermo-compositional convection
of an electrically conducting fluid drives electrical cur-
rents and generates a magnetic field. For Mercury, there
are several lines of evidence supporting a liquid iron-
alloy core [3-5]; a solid iron inner core may also be pre-
sent, but must be smaller than ~ 1325 km to fit geodetic
constraints [6]. The dominant light element in Mer-
cury's core is typically assumed to be sulfur [7], but sil-
icon may also be present [5]; however, the relative S and
Si contents are not well constrained [8].

Core convection can be driven by thermal and/or
composition buoyancy sources, such as secular cooling,
radiogenic heating, and inner core growth that contrib-
utes both latent heat and light element release. However,
in bodies where the core cools to the liquidus tempera-
ture in the bulk fluid, precipitation of iron provides an
additional buoyancy source [6,9-10]. In this "iron snow"
regime, the iron crystals are relatively heavy and will
sink into the non-snow zone below where they re-dis-
solve. These liquid droplets of nearly pure iron are
denser than their surroundings and can drive composi-
tional convection in the non-snow zone. This process
also releases light elements that will buoyantly rise
through the core. Here, we simulate the evolution of
Mercury's core and estimate the compositional contri-
bution to magnetic field generation.

Interior Model: We use an established interior
model of Mercury [6] that assumes a four layer structure
consisting of a silicate crust, silicate mantle, fluid outer
core composed of an iron-rich Fe-FeS alloy with an im-
posed sulfur concentration, and optional solid inner core

of pure iron. Silicon is neglected here since its concen-
tration and behavior at high pressures and temperatures
are not well known. The models assume a spherically
symmetric planet that obeys hydrostatic equilibrium and
satisfies Poisson's equation. Iron snow is taken into ac-
count through modification of the temperature and sul-
fur concentration profiles [6], and an adiabatic core is
imposed for simplicity. If no inner core is present, the
temperature profile is anchored at the center by specifi-
ying the temperature excess with respect to the melting
temperature of the liquid alloy. In models with an inner
core, its radius is imposed and the core and melting tem-
peratures are assumed to be equal at the inner core
boundary.

We have carried out six series of models that demon-
strate how the core would evolve in time for different
initial core sulfur contents, χ_s^0 , ranging from 1 to 11
weight percent in 2 wt% increments. For each χ_s^0 value,
we begin the model sequence with a sufficiently hot
central temperature to prohibit any iron crystallization
within the core. The central temperature excess is then
reduced in 10 K increments until a solid inner core
forms. After this point, the inner core's radius is pro-
gressively increased in 50 km increments. Note that the
sulfur content of the fluid outer core increases with inner
core size to conserve the total core mass as well as the
mass of core sulfur. In order to estimate the timeline for
core evolution, we calculate the core mantle boundary
(CMB) temperature difference between each consecu-
tive model and assume that the core cools at a constant
rate of 60 K/Gyr, based on intermediate rates from [11].

Magnetic Field Estimates: Power generated by
convection must overcome ohmic dissipation in order
for a dynamo to be maintained. Following a common
approach to estimate the dynamo's magnetic field
strength [12], we assume a balance between Ohmic dis-
sipation and volumetric convective power derived from
the interior models ($\phi = gf$, where g is gravitational ac-
celeration and f is mass flux in units of $\text{kg m}^{-2} \text{s}^{-1}$) and
employ mixing length theory such that:

$$B_{ML} = 1.1 \mu_0^{\frac{1}{2}} \rho^{\frac{1}{6}} (gfD)^{\frac{1}{3}}$$

In order to compare against observations, we calculate
the surface magnetic field as

$$B_s = 0.05 B_{ML} (R_c/R_M)^3$$

to reflect partitioning between poloidal and toroidal
field components and upward diffusion from the top of
the dynamo region at radius R_c to the planet surface at
radius R_M . Here, we assume a 1/20 pre-factor following
the partitioning of Mercury-like dynamo models [13].

Results: The schematic in Figure 1 shows the evolution of a representative core model with $\chi_s^0=5$ wt% sulfur. Iron first precipitates near the core mantle boundary (Fig. 1a), and the inner core begins to form thereafter (Fig. 1b). An intermediate snow layer then develops at mid-depths with additional cooling (Fig. 1c). As the inner core continues to grow, the intermediate snow layer thickens until it extends to the inner core boundary (Fig. 1d). The top boundary of the lowermost snow layer, however, is quasi-stationary; as a result, the deep snow zone is eventually overtaken by the inner core such that only the shallow snow zone remains (Fig. 1e). In the final stage, iron snow occurs throughout the liquid core (Fig. 1f).

Figure 2 shows the magnetic field strength as a function of time and core crystallization regime for this model series. In Regime 1 (cyan markers), iron sinking from the snow zone into the layer below will drive convection and dynamo action. A substantial increase in magnetic field strength occurs in Regime 2 (red markers) due to the onset of inner core growth, which provides an additional buoyancy source. Two dynamo regions develop in Regime 3, where convection is driven by iron falling from the snow zone above as well as sulfur rising from either the underlying snow zone (blue square markers) or the inner core boundary (blue diamond markers). Here, the lower convecting region often produces the stronger dynamo, but has a weaker contribution to the surface field because it is located deeper within the planet. In Regime 4 (orange markers), the magnetic field in the dynamo region is similar to that of the upper snow zone in Regime 3. The magnetic field strength then decreases with subsequent cooling, coincident with the recurrence of Regime 2 (red markers); here, the thickness of the deep convection layer decreases as the inner core grows until the outer core becomes stably stratified and the dynamo turns off (Regime 5, black markers).

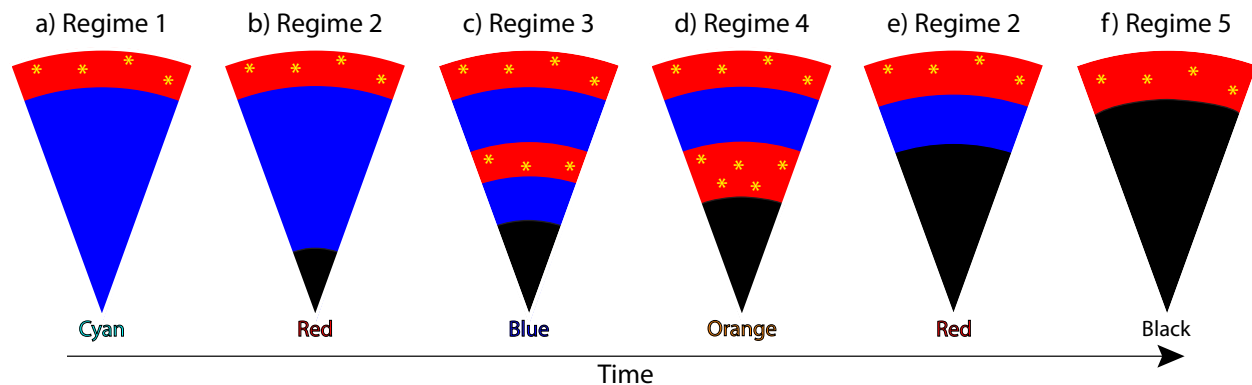


Figure 1: Schematic showing the evolution of core crystallization for an initial core sulfur content of 5 weight percent. Blue denotes fluid regions where iron snow does not occur, red with yellow asterisks denote regions with iron snow, and black denotes the solid inner core. The colors named on the bottom of each regime correspond to the marker colors used in Figure 2.

Implications: These preliminary results suggest that Mercury's core may have evolved through a series of core crystallization regimes that are likely associated with different convection characteristics (e.g., vigor and geometry) and magnetic field properties (e.g., amplitude, morphology, and secular variation).

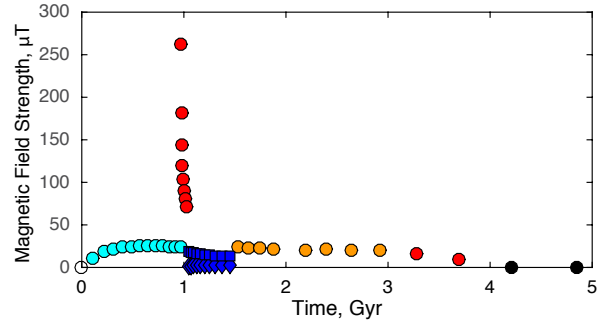


Figure 2: Magnetic field strength due to compositional convection as a function of time for a core with 5 wt% sulfur. The colors correspond to the core crystallization regimes identified in Figure 1. In Regime 3 (blue markers), the deep (shallow) convection zone is denoted by diamonds (squares).

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