EFFECTS OF BASIN-FORMING IMPACTS ON THERMAL EVOLUTION OF MARS. J. H. Roberts[1], and J. Arkani-Hamed[2], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723 (James.Roberts@jhuapl.edu), [2]Dept. of Physics University of Toronto, 60 St. George St., Toronto, ON, Canada M5S 1A7

Introduction: Several giant impact basins of mid-Noachian age have been identified on Mars [1,2]. The youngest of the basins [1,3] are either weakly magnetized or completely demagnetized [4], indicating that a strong global magnetic field [5] was not present at the time those basins formed. Eight of the basins (Acidalia, Amazonis, Ares, Chryse, Daedalia, Hellas, Scopolus, and Utopia) are sufficiently large that the impact heating associated with their formation could have penetrated below the core-mantle boundary (CMB). Coupled models of 1D parameterized and 2D axisymmetric thermal evolution in the core and mantle [6,7] in response to the shock heating from a single giant basin-forming impact showed that dynamo activity could be crippled. However, the average interval between the largest impacts [1,3] is less than 20 My, which is longer than the timescale for resumption of weak to moderate dynamo activity following impacts of this size [2,6].

Here, we expand the mantle convection models into 3D in order to model multiple basin-forming impacts closely spaced in time. Our goal is to quantify how subsequent giant impacts may delay the recovery time and obtain a better estimate of the time scale for restoration of post-impact core dynamo activity. Because the disappearance of the magnetic field exposes the early atmosphere to solar wind activity, constraining the history of the dynamo is critical for understanding climate evolution and habitability of the surface.

Modeling: We start with an initially adiabatic core and convecting mantle, and model the thermal evolution of the interior for 300 My, until the time of the Daedalia impact. We model mantle convection using the finite element code CitcomS in 3D spherical geometry [8,9], subject to the extended Boussinesq approximation. The mantle viscosity is temperature- and pressure-dependent. We model thermal evolution in the core with a 1D parameterized model [6,7]. We use the locations, dimensions and Hartmann-Neukum model ages determined from N(300) crater counts [1,2] for the eight largest basins mentioned above. For each impact, we have computed the shock pressure in the core and mantle using ray-tracing, and determined the waste heat following passage of the shock using scaling laws [10,11]. The temperature perturbation for Daedalia is shown in Figure 1.

At the time and location of an impact [1] we introduce a temperature perturbation resulting from shock heating into the core and mantle. We restrict the mantle temperature to the solidus [7,12], and assume that the impact melt does not participate in the mantle dynamics. Stratification of the core occurs very quickly compared to mantle dynamics [13], and we horizontally average the temperature in the core. We then let the coupled core and mantle thermal evolution models proceed until the time of the next impact, and repeat until all the impacts have occurred.

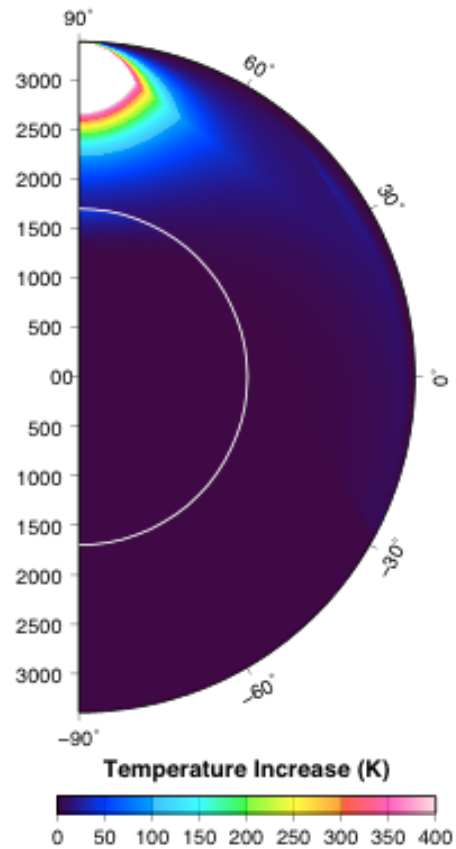

Figure 1: Temperature increase (before taking melting into account) from the formation of Daedalia basin at 10 km/s. Temperature profile is axisymmetric about the impact axis, shown here at the top of the figure; this does not correspond to the geographic pole. CMB is indicated by the white curve. Plot assumes all waste heat is converted to a temperature increase; in reality latent heat of melting will consume a portion of the mantle heating, moderating the maximum temperature increase.

Thermal Evolution: The Daedalia impact immediately heats the core and mantle below it. This produces a hot, buoyant region in the mantle, which rises

and spreads out, promoting formation of a mantle plume beneath it (Figure 2a-e). More rapid mixing rates in the core, however result stable stratification of the core and the temporary cessation of mantle convection. The hot outermost core cools by conduction into the overlying mantle, causing a temporary spike in the heat flux across the core mantle boundary (Figure 3, top), and into the cooler core below. A layer at the top of the core becomes adiabatic. The bottom of this convecting layer grows downward over time.

Over the next few My, additional mantle upwellings form far from the impact site, unaffected by the impact. After ~30 My, the Daedalia upwelling is no longer the dominant structure. The heat from the impact (including the heating initially deposited in the outer core) has heated the entire mantle (Figure 2f). After 32 My, the Ares impact occurs, followed shortly by Amazonis, forming other mantle upwellings (Figure 2g). The Amazonis upwelling spreads out beneath the stagnant lid, and multiple smaller-scale upwellings continue (Figure 2h). Each of these impacts also stratify the core and reset the thickness of the convecting outer layer. In Figure 3 (bottom), we show the growth and resetting of the convective thickness for the full sequence of impacts. Each impact occurs before the heat from the previous is fully removed, causing the core temperature to increase over time.

Conclusions: An impact forming a basin of diameter > 1700 km may result in stable stratification of an initially adiabatic core, insulating the inner core and halting core convection. Each subsequent impact occurs before the core has fully recovered from the previous one. The thickness of the convecting core layer never exceeds ~600 km until after the entire sequence of impacts. A weak to moderate dynamo can likely resume a few My after each impact except Scopolus.

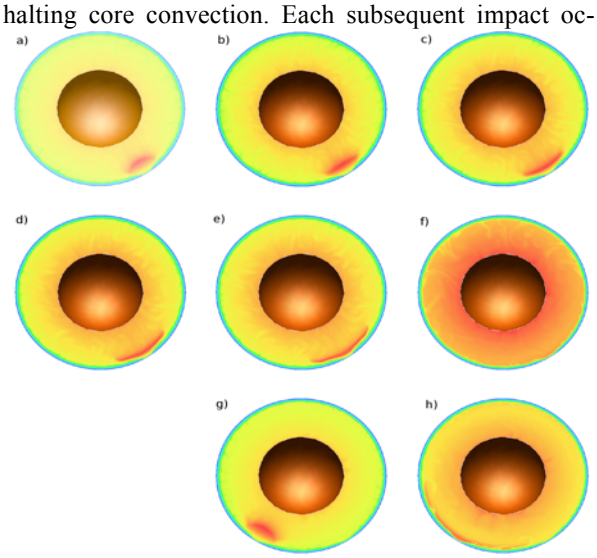

Figure 2: Mantle temperature profile on a plane through the Daedalia and Amazonis impact basins at the time of the Daedalia impact (a), after 10 ky (b), 40 ky (c), 120 ky (d), 250 ky (e), 29 My (f) at the time of the Amazonis impact (Da + 45 My) (g), and 2 My after Amazonis (h).

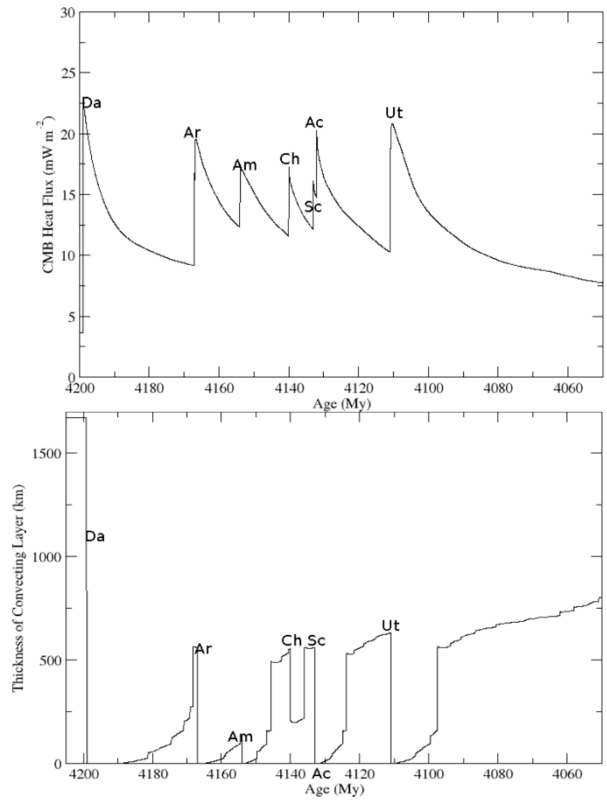

Figure 3: Evolution of the CMB heat flux (top) and thickness of convecting outer layer of the core (bottom). Each impact (labeled with the first two letters of the respective basin name) causes an upward spike in the heat flux and a downward spike in the convective thickness. Note that Acidalia occurs so soon after Scopolus that the core does not develop a convecting layer in between these two events.

References: [1] Frey H. V. et al. (2008) *GRL, 35*, L13203. [2] Mannoia L. M. and Frey H. V. (2014) *LPSC, 45*, 1892. [3] Robbins et al., 2013, *Icarus, 225*., 173-184. [4] Lillis R. J. et al. (2008) *GRL, 35*, L14203. [5] Acuña et al., 1999, *Science, 284*. 790 [6] Arkani-Hamed J. (2012) *PEPI, 196-197*, 83-96. [7] Roberts and Arkani-Hamed (2014) *JGR, 119*, 729-744. [8] Zhong S. et al. (2000) *JGR, 105*, 11,063-11,082. [9] Tan, E. et al. (2014), *GGG, 7,* Q06001. [10] Pierazzo E. et al. (1997) *Icarus, 127*, 208-223. [11] Watters W. et al. (2009) *JGR, 114*, E02001. [12] Roberts J. H. and Arkani-Hamed J. (2012), *Icarus, 218*, 278-289. [13] Arkani-Hamed J. and Olson P. (2010) *GRL, 37*, L02201.