EFFECTS OF BASIN-FORMING IMPACTS ON THE CORE AND MANTLE OF MARS. J. H. Roberts[1], J. Arkani-Hamed[2], R. J. Lillis[3], and M. Manga[4], [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723 (James.Roberts@jhuapl.edu), [2]Dept. of Physics, University of Toronto, Toronto, ON, Canada M5S 1A7, [3]Space Sciences Laboratory, University of California, Berkeley, CA, 94720, [4]Dept. of Earth and Planetary Science, University of California, Berkeley, CA, 94720.

Introduction: Mars has no global dynamo-driven magnetic field today, but strong crustal fields [1] indicate that a global field existed in the past. Surface observations [2-3] indicate that a sequence of giant impacts occurred over a period of 100 Ma in the mid-Noachian. The youngest [4] of these (e.g. Hellas and Argyre) are demagnetized [5-6] (Figure 1), suggesting that an early dynamo stopped toward the end of the sequence. The impacts that formed these basins delivered a large amount of heat to the planetary interior, modified the pattern of mantle convection [7-8], and suppressed core cooling [9], potentially contributing to the cessation of dynamo activity [10-12]. Heating from the largest impacts can be felt at the core-mantle boundary (CMB) or below. Here, we investigate the thermal evolution of the core and mantle of Mars in response to heating by impacts large enough to form basins of the size described above. In particular, we examine the effects of the shock heating produced by such impacts on the pattern and vigor of mantle convection, on the heat flow across the CMB, and on the viability of the ancient core dynamo.

Shock Heating: Giant impacts can introduce a substantial amount of heat into the interior of the planet. We use scaling relations to obtain the transient basin diameters from the observed final basin sizes, D_b [13], and to obtain the impactor size from the transient basins [14]. The mantle is heated by a shock wave emanating from the impact location. Heating is nearly uniform within an isobaric core and decays rapidly outside this region [14]. We parameterize the impact heating as a temperature perturbation in the mantle, which is a function of the shock pressure [15-16].

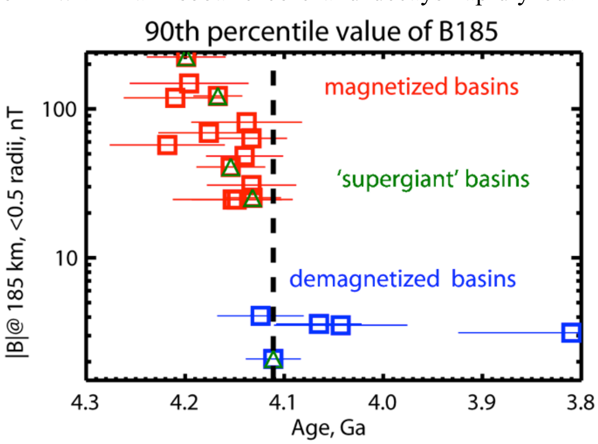

Figure 1: Crustal magnetic field magnitude at 185 km altitude within 0.5 basin radii vs. absolute model ages [4] for basins identified by [2]. The five largest basins are also marked with green triangles..

Mantle Convection: We modeled thermal convection in the Martian mantle using the 2D axisymmetric and 3D spherical finite element convection codes Citcom [17] and CitcomS [18] with the extended Boussinesq approximation [19]. The mantle viscosity was taken to be temperature- and pressure-dependent, following an Arrhenius-style law. We imposed temperature and free-slip conditions at the surface and CMB, and include radioactive heating. At times indicated by the impact age model [2], we applied an instantaneous temperature increase as determined above [16]. Each model was run until well after the giant impacts had occurred. We ignored the melt and restrict the mantle temperature to the solidus [8].

Core-Mantle Coupling: The heating from sufficiently large impactors can penetrate beneath the CMB [9,11], suggesting that a more self-consistent model of heat transfer between the core and mantle is needed to better understand core cooling [11]. The chief difficulty in such coupling is that the material properties of solid mantle rock and core fluid, and their relevant timescales are quite different. Here, we exploit the symmetry resulting from thermal stratification of the core upon impact [11], and couple a 1-D parameterization of core cooling to our 2D axisymmetric mantle convection model [17], appropriate for a single vertical impact scenario.

Results: In Figure 2, we show slices of the 3D temperature structure for a cross-section through a Utopia-sized impact at 10 km/s. The impact heats a region of the mantle as described above. This heated region rises and spreads out, forming a "thermal blanket" that insulates the mantle. An upwelling that extends to the CMB rises and punctures the thermal blanket. The blanket ultimately dissolves, leaving a degree-1 convective pattern with the upwelling beneath the impact site. The impact heating causes a rapid increase in surface heat flux.

If the projectile is sufficiently large, the impact heating penetrates into the core. We have examined such a case using the core-mantle coupling procedure described above. The core stratifies quickly [9], such that there is an extremely hot, thin layer at the top of the core. This hot layer insulates the interior, and the stratification renders the core stable to convection.

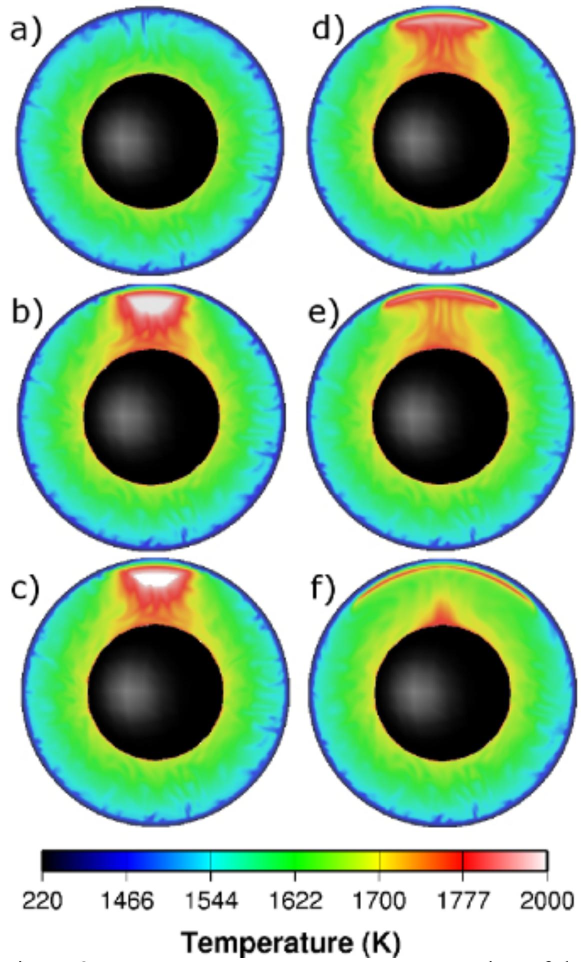

Figure 2: Temperature structure on cross-section of the mantle though the Utopia impact site immediately before (a) and after (b) the impact, after 3 ky (c), 100 ky (d), 140 My (e), and 1.8 My (f)

Once this occurs, the magnetic field can dissipate effusively in in tens of ky [10]. Core cooling results in formation of a convecting zone at the top of the core that propagates downwards as the thermal gradient becomes adiabatic at greater depths. The magnetic Reynolds number (R_m) of the convecting outer core exceeds the threshold value for the resumption of dynamo activity ($R_m \geq 10$) after about 140 My (Figure 3). However, the core does not become fully convective until several hundred My later.

Conclusions: We find that:

1. A single basin-forming impact fundamentally affects the flow field of the mantle in the entire hemisphere near the impact. Such an impact promotes the formation of an upwelling at the base of the mantle directly under the impact site, resulting in long-lived (~100 My) single-plume convection.
2. The time for the heat flow to recover from a single impact exceeds the interval between the largest basin-forming impacts (<25 My). Therefore, cumulative effects of multiple impacts are expected. The alteration of the mantle dynamics is dominated by the five largest impacts.

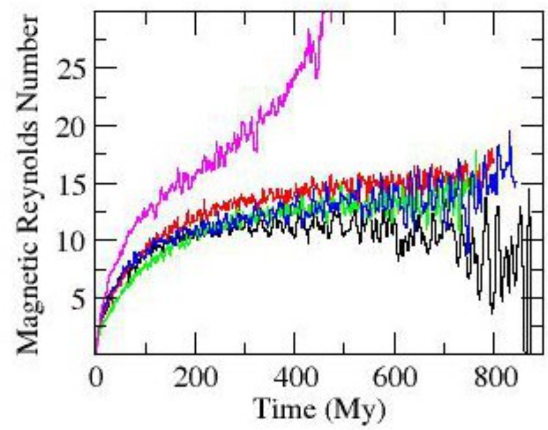

Figure 3: Magnetic Reynolds number in the convecting outer core for several models.

3. Basin-forming impacts too small to directly heat the core decrease the CMB heat flux, halting core convection, and permanently killing subcritical or weakly supercritical dynamos.
4. Larger impacts result in stable stratification of the core, insulating the inner core and halting core convection. Pre-existing dynamo activity will cease for ~100 My. An initially subcritical dynamo will not recover. The core does not become fully convective for ~1 Gy.
5. Our results are consistent with electron reflectometry observations [3] that show a lack of remanent magnetism in the younger Noachian giant impact basins [2], and the idea that the global magnetic field disappeared at the end of this sequence of basin-forming impacts [7,8,11].

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