IMPACT-RELATED HEATING AND THE CESSATION OF THE MARTIAN DYNAMO: EARLY RESULTS. J. H. Roberts[1], R. J. Lillis[2], M. Manga[3], H. V. Frey[4], [1]UC Santa Cruz, Department of Earth and Planetary Science, [2] UC Berkeley, Space Sciences Laboratory, [3]UC Berkeley, Department of Earth and Planetary Science, [4]Planetary Geodynamics Laboratory, NASA/GSFC. Corresponding Author's Email: jhr@ucsc.edu

Introduction: Although Mars currently has no global dynamo-driven magnetic field, widespread crustal magnetization [1] provides strong evidence that such a field existed in the past. The absence of magnetization in the large, old basins Hellas and Argyre suggests that a dynamo operated during the early to mid-Noachian [2], but stopped once the core-mantle heat flow became unfavorable for core convection [3]. Recent work [4] indicates that, within 100 Myr, >15 giant impacts (leaving craters>1000 km in diameter) occurred and the global magnetic field disappeared. These impacts [5], have the potential to deliver significant amounts of heat to the interior [6,7]. Here we investigate a possible link between the giant impacts during the early and mid-Noachian and the cessation of the Martian dynamo at or about the same time.

Impact Ages: Quasi-circular depressions (QCDs) identified in MOLA topography and circular thin-crust areas (CTAs) identified in crustal thickness maps [8] have been associated with both exposed and buried impact structures [9]. The combined population of QCDs and CTAs provides the best estimate available of the N(300) crater retention ages (CRAs) for large Martian basins [9] N(x) is the cumulative number of superimposed craters of diameter > x km per 10^6 km^2. CRAs show a strong clustering between N(300) = 2.5 and 4.0 (or 4.1 and 4.2 Gyr in model age [10]), implying a 'peak' in crater production. We take from [9] the times, locations and sizes of 20 giant impacts.

Convection Model: Impact heating may alter the CMB heat flow in two ways. The temperature increase in the mantle resulting from the impacts may inhibit core cooling, causing the heat flow to drop. Alternately, the large lateral temperature differences in the warmer mantle may drive more vigorous convection, promoting core cooling, and raising the CMB heat flow. It is not obvious which effect should dominate, but a net reduction of >1% in the CMB heat flow is required to stop a subcritical core dynamo [11].

We model thermal convection in the Martian mantle using the 3D spherical finite-element convection code CitcomS [12], using a temperature- and pressure-dependent viscosity. We apply isothermal and free-slip boundary conditions at the surface and core-mantle boundary (CMB), and include internal heating from radioactive decay. At the times indicated by the impact age model described above [9], we apply an instantaneous temperature increase of 300 K inside a hemispherical region centered on the location of the corresponding impact at a depth of 238 km. The size of the heated region scales with the size of the impact basin [6, 13], with the largest being 1190 km for Utopia. The model was run for several hundred Myr, until after the Utopia impacts had occurred. We also ran a control case in which the impact heating was not applied in order to examine the effect the impacts have on the thermal evolution.

Results: The convective pattern is dominated by very long-wavelength (ℓ = 2,3) sheet-like upwellings (Fig. 1). The upwellings are associated with very low heat flow at the CMB beneath them, and high heat flux immediately to either side (Fig. 2).

Figure 1: Temperature field for a convection model with impact heating. Yellow isosurface is T=1720 K. Blue sphere marks the surface of the planet, red sphere is the core. Model has Ra = 4.1 × 10^7, E = 157 kJ/mol, V = 8 cm^3/mol, internal heating rate 8.6× 10^{-8} W m^{-3}

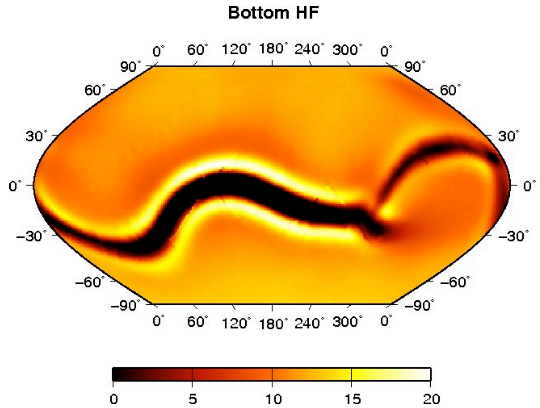

Figure 2: Map view of the CMB heat flux for the case shown in Fig. 1. Scale is in mW m^{-2}. Heat flow is very low beneath the upwelling, but high immediately to either side of it.

The CMB heat flux is affected very little by the impacts, however. Figure 3 shows the time evolution of the global heat flow at the surface and CMB for both the cases with and without impacts. The mantle is mostly heated internally, but a basal heat flow of about 1 TW persists for the duration of the calculations which may be enough to drive a core dynamo [3, 14]. The temperature increase imposed by the larger impacts appears as a rise in the surface heat flux of 1-2 TW depending on the size of the impact over a period on the order of 20 Myr, followed by a drop, as the temperature anomaly diffuses into the deeper mantle and is advected away. The temperature perturbation is largely erased before it reaches the CMB and there is only a 2% drop in the CMB heat flow in the impact-heated case relative to the control.

Discussion: Dynamo activity may be very sensitive to core-mantle heat flow if the core is in a subcritical dynamo regime [11],. A decrease in heat flow of 1% can cause the strength of the global magnetic field to drop by three orders of magnitude [11]. Thus, a small drop in the CMB heat flow can result in the cessation of the dynamo. While the decrease of 2% seen in our models is technically sufficient to precipitate the end of the dynamo, this is not likely to be the case. In order for the impacts to stop the dynamo, the basal heat flow must be poised ≤ 2% above the critical value, a quantity that is not well known. Given that the core would likely have been already cooling secularly at this time, these impacts either had no impact on the dynamo's death or brought it about slightly earlier than otherwise would be the case. Hence, we cannot conclude that there is a strong causal link between the Noachian giant impacts and the cessation of the Martian dynamo. Our results suggest that the similar timing of these events may be a coincidence.

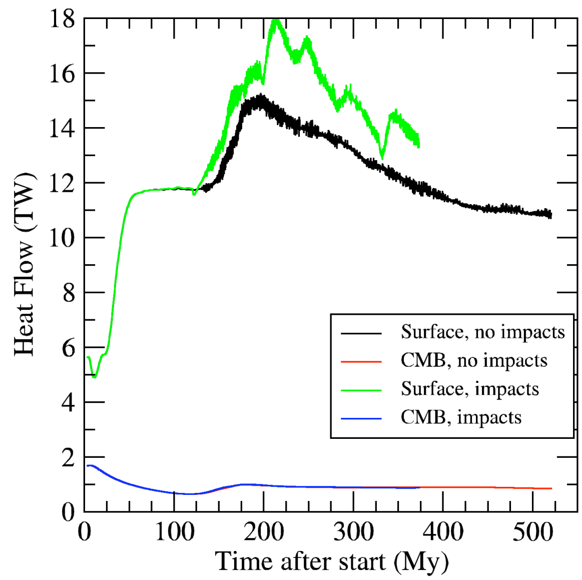

Figure 3: Global heat flow as a function of time for the cases with and without impacts. The impact heating causes significant rises in heat flow at the surface, but the not at the CMB.

We have not yet conducted an exhaustive search of parameter space, Certain parameters may be subject to a high degree of uncertainty, namely the depth at which the heat is deposited by the impact, the size of the region that is heated, and the magnitude of the temperature increase, Future work will examine the effects of changing these values. However, unless the depth, extent, and/or magnitude of the impact heating is dramatically larger than that considered here, the impact heating will not be felt at the CMB.

References:

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