MANTLE CONVECTION AND TWO EPISODES OF MARTIAN DYNAMO ACTIVITY. Mark J. Wenzel[1], Michael Manga[1] and Robert J. Lillis[2,3], [1]Dept. of Earth and Planetary Science, U. C., Berkeley, 307 McCone Hall, Berkeley, CA 94720; mjwenzel@eps.berkeley.edu, manga@seismo.berkeley.edu, [2]Dept. of Physics, U. C., Berkeley, [3]Space Science Laboratory, U. C., Berkeley, 7 Gauss Way, Berkeley, CA 94720, rlillis@ssl.berkeley.edu.

Introduction: The current absence of an internally generated magnetic field on Mars, and its past existence, constrain the heat flux from the core to the mantle [1]. These constraints have been critical in testing models of martian mantle convection [1-2]. Lillis et al. [3] argue for not one but two episodes of dynamo activity on Mars. Here we explore parameter space with a numerical model of thermochemical mantle convection to determine the conditions under which the heat flux grew higher than the threshold for dynamo activity twice in early martian history.

Lillis et al. [3] use electron reflection magnetometry to investigate the magnetic anomaly signatures of the 20 largest Martian volcanoes. Most show magnetic lows characteristic of thermal demagnetization of crust in the presence of no significant global field. However, one of the oldest volcanoes, Hadriaca Patera, appears to be a magnetic source, suggesting thermoremanent magnetization following its last major period of magmatism. Its emplacement post-dated the Hellas impact, which is thought to post-date the cessation of an early dynamo. Lillis et al. compare the relative ages (according to the Hartmann and Neukum [4] cratering time-scale) and magnetic signatures of these 20 volcanoes and 7 giant impact basins and conclude that, ~300 Myr after the cessation of an early dynamo, a second dynamo episode may have started around ~3.85 Gyr ago and lasted for 100-350 Myr. Given the uncertainty in dates, we try only to match the constraint that the dynamo was 'on'—active—at 400 Myr and 800 Myr after the formation of the planet, and 'off' between those times and afterwards.

Model: We use the numerical model Citcom with tracers for isoviscous thermochemical convection in a 2D Cartesian geometry. We consider thermochemical convection to determine the influence of a possible overturn of a compositionally distinct layer near the core, which may cause a heat flux 'spike' (e.g., [5]). The calculations covered the first few hundred million to the first few billion years of martian history. The initial conditions are a dense layer of thickness *d* with a small periodic perturbation in temperature throughout the mantle. The aspect ratio of the box is 6:1. We varied the buoyancy number, B, the Rayleigh number Ra, and the initial temperature difference between the core and the mantle. $B = \Delta\rho_c/\rho\alpha\Delta T$ and $Ra = \rho g\alpha\Delta T D^3/\kappa\mu$, where $\Delta\rho_c$, ρ, α, ΔT, g, D, κ, and μ are compositional density difference between the two layers, density, thermal expansivity, temperature drop across the convecting fluid, gravitational acceleration, layer depth, thermal diffusivity, and viscosity, respectively. B was set to 0.1, 0.5, 1.0, or 2.0; Ra to 5×10^5, 1×10^6, 3×10^6, or 1×10^7. The non-dimensional temperature boundary conditions were 0 at the top and 1 at the bottom (implicitly, the core temperature); the depth of the dense layer was 0.3 that of the entire mantle thickness; the effects of radioactive heating were not included. The initial temperature of the mantle was set to 0, 0.8, or 1.0. The results of these forty-eight permutations are described below.

Results: The initial heat flux is in good agreement with analytical results for half-space cooling, until convection starts (Fig. 1). The onset of convection can be measured in two ways: By the increase in kinetic energy, and by the departure of the heat-flux curve from the half-space cooling model. The initiation of convection as measured by the kinetic energy increase occurs in close agreement with the predictions of a simple linear stability analysis. With Ti = 0.8 or 1.0, deviations of the core heat flux from the analytical predictions are delayed relative to the onset of convection. This delay is shorter with higher Ra. There is also a difference in the time of peak kinetic energy and heat flux that decreases with higher Ra.

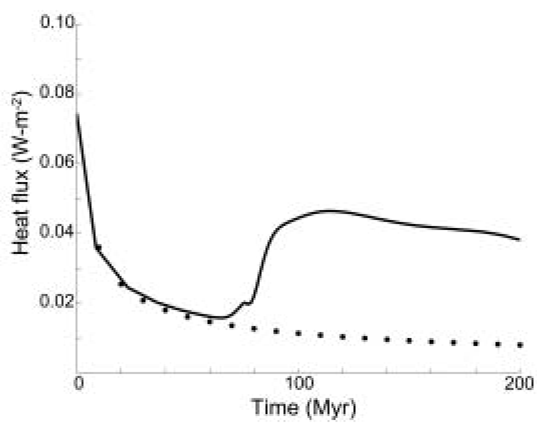

Figure 1: Heat flux v. time. Dotted line is analytical solution. Solid line is result from numerical simulation. The departure from the analytical solution marks the onset of convection.

The observations of Lillis et al. are that the second period of dynamo activity occurred in the Middle-Late

Noachian. The bulk of Tharsis was in place by the late Noachian [6]. We speculate that the large upwelling that formed Tharsis may have been accompanied by an increase in heat flux from the core as warm material at the core-mantle boundary was removed and replaced with cooler material. This may occur by plume formation or overturn of a chemically distinct layer. If this is the case, then the most Mars-like cases may be those where the heat flux peak and kinetic energy peak are closest in time, i.e., those with high Ra and low B.

References:

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