Thermal History Calculations Versus Full Convection Models: Application to the Thermal Evolution of Mercury. Hannah L. Redmond[1] and Scott D. King[2], Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, [1]redmondh@purdue.edu, [2]sking@purdue.edu

Thermal history calculations simplify the full equations of convective motion to a basic energy balance [1]. The development of thermal history calculations requires a relationship between the convective vigor, represented by the Rayleigh number (Ra), and the surface heat flow, represented by the Nusselt number (Nu)

$$Nu = Ra^{\beta}$$

where β is the exponent in the Rayleigh number-Nusselt number relation. The value of the exponent β varies considerably depending on model assumptions [2-5]. More troubling, as a planet cools, it passes through stages where different values of the exponent would be appropriate. Hence comparing thermal history calculations with more complete convection simulations seems appropriate.

Mercury is the densest of the four inner planets and contains a large, iron core that may be up to 75% the size of the planet [6] with a molten or partially molten outer core. The outer shell of the planet is most likely a silicate crust 100-300 km thick. It is believed that Mercury currently has no tectonic activity. The absence of plate tectonic features at the surface makes it difficult to determine the thermal evolution of Mercury. Normally, when core differentiation occurs in a homogeneous planet, there is a large increase in planetary volume [7] and extensional features resulting from differentiation are often observed at the surface. However, this is not the case for Mercury. It is more likely that Mercury cooled very rapidly and had completely differentiated prior to the end of the period of extensive bombardment [8]. However, in order to preserve the dynamo explanation for Mercury's magnetic field [9], mantle heat sources are needed to keep the core largely molten, protecting it against heat loss via mantle convection [10].

It is believed that the mantle of Mercury may still be convecting today [11-13], albeit a very sluggish flow. The largest support for mantle convection is the present-day, weak internal magnetic field. If a modest amount of radioactive elements still exist in the mantle, then it is possible that present-day mantle convection exists, preventing complete core solidification.

We present a series of Cartesian convection calculations with a constant viscosity and dry olivine rheology that are run for several billion years in order to compare with thermal history calculations for Mercury. In particular, we seek to address the rapid early cooling needed to achieve the compressive stress state and the need for high core and/or mantle temperatures today to maintain a molten outer core. If global contraction slowed considerably near the end of the period of heavy bombardment, illustrated by the deformation of older rock units by lobate scarps, then it is possible that Mercury is no longer in the convective regime and may be losing heat by conduction – a problem for a present-day core dynamo.

Our results thus far suggest that convection in the thin mantle of Mercury develops a long-wavelength convection pattern that may aid in the explanation of the more common broad, compressional features and, less common, extensional features observed at the surface. Our isoviscous calculations and temperature-dependent calculations produce very different results. The isoviscous calculations over estimate the vigor of convection and thus, surface heat flux (Figure 1). A temperature-dependent, dry olivine rheology with high initial mantle temperatures best models the mantle of Mercury. Starting from a uniformly hot mantle, in cases with a strong temperature-dependent rheology and at least 35% internal heating, a thick, non-tectonic lid develops within the first 200 million years. With a modest amount of radioactive heating, the mantle remains hot for most of Mercury's history with very small heat loss from the core. In fact there are periods of time for which heat actually flows from the mantle into the core. This suggests that heat-producing elements within the mantle may be keeping the outer core molten. We can reconcile the early development of a rigid lid with a mantle currently hot enough to support convection in a model that maintains sufficient heat to drive a dynamo. Through comparing thermal history calculations to our convective models and incorporating a non-Newtonian, dry, olivine rheology we hope to achieve more planetary-like results while resolving the inconsistencies in previous thermal history models of Mercury.

References: [1] N.H. Sleep, J. Geology, 87, 671-686, 1979; [2] D. McKenzie, P. Roberts, and N.O. Weiss, J. Fluid Mech., 62, 465-538, 1974; [3] U. Christensen, Tectonophysics, 95, 1-23, 1983; [4] M. Gurnis, Geophys. Res. Lett., 16, 179-182, 1989; [5] V.S. Solomatov and L.N. Moresi, Geophys. Res. Lett., 24, 1907-1910, 1997; [6] R.W. Siegfried, and S.C. Solomon, Icarus, 23, 192-205, 1974; [7] S.C. Solomon, Icarus, 501-508, 1976; [8] N.J. Trask and J.E Guest, J. Geophys. Res., 80, 2461-2477, 1975; [9] N.F. Ness et al., J. Geophys. Res., 80, 2708-2716, 1975; [10] P. Cassen et. al., Icarus, 28, 509-522, 1976; [11] D.J. Stevenson, T. Spohn, and G. Schubert, Icarus, 54, 466-489, 1983; [12] G. Schubert, M.N. Ross, D.J. Stevenson, and T. Spohn, In Mercury, pp. 429-460, 1988; [13] T. Spohn, Icarus, 90, 222-236, 1991.

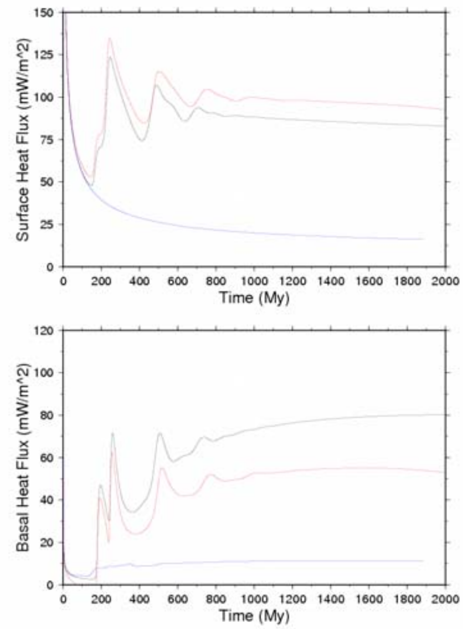

Figure 1: Comparison of constant and temperature-dependent viscosity calculations for a Ra=6e4. The black line is isoviscous only, red is isoviscous with 35% internal heating, and blue is a temperature-dependent, dry olivine rheology.