THERMAL EVOLUTION OF THE MARTIAN CRUST THROUGH TIME.  F. C. McGroarty, 1 M. S. Duncan, 1, and M. B. Weller, 2 1Virginia Tech, 4044 Derring Hall, Virginia Tech, 926 West Campus Dr., Blacksburg, VA, USA (mcgroartyfc@vt.edu, msd19@vt.edu), 2Brown University, 324 Brook St., Providence, RI, USA (mbweller@brown.edu).

Introduction: Despite the critical role of the thermal evolution of Mars in its tectonic and volcanic history, there is currently little constraint on Mars’ specific thermal history. The current constraints arise from observed volcanics, which range from the ~4 Byr old highlands to the young crater-count ages of Olym-pus Mons [1-3], indicating that Mars has an interior that allows for melt generation throughout its history. This record of melting is contained within the crust; however, the crust has undergone a history of volcanic eruptions, resurfacing over impacts, and post-volcanic weathering. While the surface of Mars can be indirectly interrogated from orbit (e.g., spectroscopy) and directly sampled by rovers, it is significantly more difficult to determine the specific internal processes that lead to the formation of the crust and how the crust and lithosphere evolved to its current state. From gravity measurements and derived models the crust is inferred to be ~50 km thick on average, and of basaltic composition [4,5].

Previous estimates of martian thermal history were derived from a combination of meteorites and surface basalts [6]. These showed a general trend of cooling from an average mantle potential temperature of 1450°C ~4 Ga, to 1345°C today. There are also constraints on the abundances of the heat producing elements (HPE), and models that determined surface heat fluxes. We will be using these parameters to calculate areotherms and crustal structures for the martian crust over the past 4 Gyr.

Methods: In order to constrain the planetary-scale thermal evolution at the crustal-scale geochemical level, we are using a combination of observed parameters (above), geochemical models, and geodynamic models.

Geochemical: We model crustal evolution by first calculating a range of modern day areotherms. Using the thickness, heat production, heat flow, thermal conductivity, and density for the present-day crust, we are constructing the areotherms using [7-9]:

\[ T(z) = T_0 + \frac{q_i \Delta z_i}{k_i} - A_i \frac{\Delta z_i^2}{2k_i} \]

where \(T_0\) is the surface temperature in K, \(q_i\) is the heat flow with depth in W/m2, \(z\) is the depth in m, \(k\) is the thermal conductivity in W/mK [7, 10], and \(A_i\) is the volumetric radiogenic heat production of layer \(i\) in W/m3.

We begin with a reference case of an homogenous HPE distribution within the crust [4] and an undepleted lithospheric mantle [5], using the average thickness of 50 km today, and average modern heat flow of 25 mW/m2 based on previously calculated values [e.g., 11]. Because heat production in the crust is related to the abundance of HPEs, and because the abundance changes over time as a function of radioactive decay, we calculate areotherms through time. From this, we infer how the crust has evolved over time. The areotherms are used in conjunction with previously calculated adiabatic profiles [13] and a mantle solidus [12] to determine melt fraction (F), and therefore potential crustal compositions, through time.

With the new areotherms, together with thermodynamic models from Perple_X [14], we infer possible crustal characteristics (e.g., density, thickness). While the crust has thickened over time, there are questions regarding the rate of thickening (e.g., rate of volcanism) and whether it has thickened more by subsequent lava flows on the surface or by magmatic emplacement at the base. The crustal compositions modeled by Perple_X will constrain the possible scenarios by showing which are most realistic under the temperature conditions of the areotherms.

Geodynamic: We calculate average mantle temperature profiles including conductive (areotherm) and convective (adiabatic) components from fully spherical 3D solid state convection models using CitcomS [e.g., 15]. These models employ a constant boundary temperature at the surface (\(T = 220\) K) and at the CMB (\(T = 1820\) K); with an adiabat of 0.18 K/km [16]) and a Rayleigh number of 3x106, but variable internal heating rates (e.g., a non-dimensional Q of 45 which is ~66% depletion in radiogenics from chondritic values) and core fractions of 0.45 (S-bearing) and 0.4 (S-poor) of the total planet radius. From these profiles, we determine average surface heat flux and melt fraction (F) through time (here approximated by variable Q). We compare these values to the geochemically-derived values (above), in order to iterate toward a self-consistent result.

Preliminary Results: Our initial aerotherms are calculated using a surface heat flux of 25 mW/m2 for the present-day and 50 mW/m2 for 4 Ga (based on preliminary geodynamic results), values for A based on the present-day HPE concentrations [4,5] and those calculated 4 Ga, and a crustal thickness of 50 km for
the present and ~20 km for 4 Ga (Figs. 1, 2). Based on these results, we see a shift in the pressure-temperature relationship going through the crust and mantle lithosphere as the HPE concentration dwindled, combined with a thickening of the lithosphere. The comparison between the present-day and 4 Ga shows a significantly hotter lithosphere in the past, which cools to about 1660 K at about 250 km (at the intersection with the adiabat) in the present day.

Figure 1. Preliminary areotherms for the modern day (green) [4,5], and an estimate for 4 Ga (purple). Also shown are the mantle adiabats (gray lines) and solidus (orange line).

Figure 2. Preliminary areotherms from CitcomS at a fixed core fraction of 0.40 and $Q$ values decreasing from 45 to 0, showing evolution through time (~2 Ga into the future). Also shown are the mantle adiabats (gray lines) and solidus (orange line), and variable core-mantle-boundary pressures/depths based on sulfur contents (gray bands).

Conclusions: The models produced will provide insights into the crustal evolution of the planet from the time of its initial cooling through to the present day.