INVESTIGATING MERCURY'S MANTLE EVOLUTION THROUGH BOTH GEOPHYSICAL AND GEOCHEMICAL ANALYSES. P. Bose[1], M. S. Duncan[1], and S. D. King[1] ([1]Department of Geosciences, Virginia Tech, Blacksburg, VA, USA [priyanka18@vt.edu])

Introduction: Geochemical and geophysical data were obtained from Mercury with the MESSENGER mission during its four year orbit of the planet [1]. Geochemically, the surface lavas of Mercury were found to be Fe-poor, but were also Mg-rich and contained abundant sulfides (particularly MgS and CaS) [2]. These findings indicated that these melts were generated from a highly reduced mantle, unlike the Earth [3]. Geophysically, MESSENGER collected density and gravity profiles of the innermost planet [1], which elucidated the structure of Mercury's interior: a thin crust (~38 km), a small mantle (~400 km), and a large iron-rich core (~2000 km) [4]. The MESSENGER results provide preliminary constraints on the evolution of Mercury's interior, but much more research is needed to learn more about this geochemical endmember of the terrestrial planets.

The youngest surface lava on Mercury, the Northern Volcanic Plains (NVP), was deposited ~3.5 Ga [5], and is the largest smooth igneous province on Mercury's surface [6]. This deposit was likely generated by large scale volcanism over a protracted period of time [7]. MESSENGER obtained geochemical data on this region, leading to a NVP melt volume estimate of 4–8.5x10^6 km^3 [6]. Thus, focusing on this region of the planet provides a chemical and temporal constraint for the thermochemical evolution of Mercury's interior. However, the evolutionary path of Mercury is not well known. Understanding how this geochemical endmember evolved will provide insights into the formation of the terrestrial planets, and how a thin highly reduced mantle affects planetary evolution.

Motivation: While prior studies investigated how Mercury thermochemically evolved [8-11], their findings are not consistent with MESSENGER's geochemical findings. These models used peridotite as a mantle analog [12,13], which is significantly more Fe rich than MESSENGER's data observed. Thus, the use of peridotite is not correct. Though an Fe and sulfur-free (CMASN) solidus was calculated from MESSENGER's geochemical composition [3], when compared to prior thermochemical evolution models [11], the average mantle's thermal profile does not predict enough melt to form the NVP. As such, more investigations are required to understand how Mercury's interior evolved and formed melt.

Methods: We built a two-layer 1D thermal model for Mercury which tracks the thermal evolution of Mercury's mantle and core as the planet cools to its current state [e.g., 8,14]. This model utilizes the geodynamic parameters determined from the MESSENGER mission to calculate the thermal fluxes between Mercury's core and mantle. To test the validity of the model, we will vary the initial temperatures of the mantle and core, and the mantle viscosity to ensure that the model produces realistic results. As part of this model, we will track the mantle's melt fraction via an evolving adiabat, solidus, and liquidus. The model will also calculate the thermal profile of Mercury as the solid inner core begins to form [8,15]. This will constrain how inner core formation affects the thermal fluxes from the core to the mantle. Inner core crystallization is controlled by the melting curve of Fe-S alloys parameterized from experimental data as in previous studies [8,15,16]. This will also allow us to change the amount of S in the core.

To make this model more geochemically rigorous, we performed several pMELTS [17] runs on four proposed Mercury mantle compositions: the preliminary Mercury Mantle (PMM), the pre-melting Northern Volcanic Plains (NVPC), the carbonaceous chondrite ALH85085 (CH), and the enstatite chondrite Indarch (EH) [2,18-20] to determine preliminary S-free solidi for the Mercurian mantle, which will be added to the thermal model. Both the CH and EH compositions were used prior as analog compositions for Mercury due to their highly reduced state [19,20]. However, neither the CH nor EH compositions are realistic as they represent compositions that are not seen within the MESSENGER data. The CH composition is too Fe-rich and Na-poor, while the EH composition is too Si-rich to accurately portray the composition of Mercury's surface lavas based on MESSENGER data. These pMELTS runs were performed at conditions relevant to Mercury's interior (1000–2100 °C and 1–3 GPa) to constrain estimates of the mantle solidus, liquidus, melt composition, and melt fraction. These runs were also performed at an oxygen fugacity (fO_2) fixed at the iron-wüstite buffer (IW). While this is more oxidized than what is expected for Mercury's interior, performing these runs at lower fO_2 did not produce significantly different results. Due to the limitations of pMELTS, we did not include the minor oxides: P_2O_5, K_2O, and NiO in any runs.

Preliminary Results: From our thermal model, the thermal profile of Mercury's mantle and core were determined (Fig. 1). These models do not yet include inner core growth or mantle melting. Without an inner core, the temperature of both the mantle and core generally decreases at the same rate over 4.5 Gyr, with a slight increase in mantle temperature during the first 1 Gyr after formation. The thermal increase in the mantle during the first 1 Gyr after formation is due to the superheated state of the core as seen previously [8]. However, as the planet cools past 1 Gyr, the mantle loses heat to space. The thermal evolution model will be used as a tool to assess how melt formation within the mantle affects the planet's thermal state as the planet evolves.

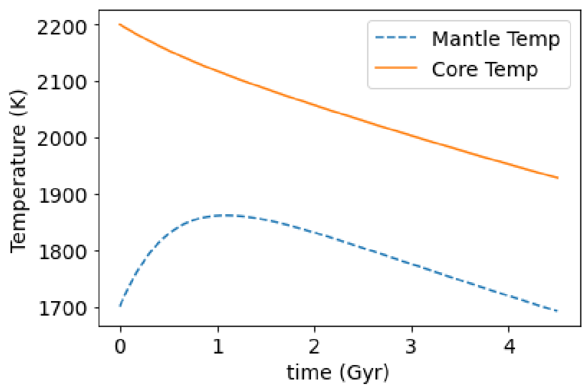

Figure 1: The thermal profile of Mercury's mantle and core without any inner core solidification. The solid orange line is the core temperature, while the dashed blue line indicates the mantle temperature.

From our MELTS modeling (Fig. 2), we determined the preliminary solidi for each S-free composition tested (PMM, NVPC, CH, and EH). The PMM and CH compositions generally follow the CMASN and Earth solidi trends respectively. The NVPC and EH solidi occur at cooler temperatures than the PMM and CH. The locations of these preliminary S-free solidi indicate which compositions are useable as proxies for Mercury, and which compositions were not, based on how much melt could be produced when these data are compared to the average thermal profile of Mercury's mantle. The NVPC and EH compositions are possible proxies for Mercury's mantle, while the PMM and CH compositions may not be. The PMM and the CH follow a similar trend as the Earth and CMASN solidi, which were already determined to not create enough melt for the NVP formation. Given the position of the NVPC and EH S-free solidi, these compositions may produce enough melt within the mantle to form the NVP. While these estimates are based on modified compositions from prior studies, this preliminary result provides intuition about the location of potential S-bearing solidi for Mercury's mantle. The MELTS data indicate how varying levels of major oxides in the melt affect the potential location of S-free solidi within Mercury's mantle when these runs are performed under Mercury-relevant conditions.

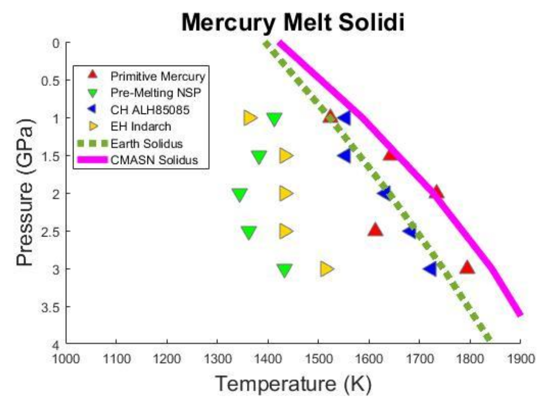

Figure 2: The preliminary solidi of the four compositions tested (PMM: red upward triangles [18], NVPC: light green downward triangle [2], CH: blue left-facing triangles [19], and EH: yellow right-facing triangles [20]) compared to the two prior known solidi: peridotite-based [olive dashed line; 13] and CMASN [solid pink line; 3].

Conclusions: The thermal profile of Mercury's interior provides insight into the transfer of energy that occurs in a planet with a thin mantle. To further make this model geochemically rigorous, we will add the solidi from the MELTS runs (S-free) to determine a range of potential compositions that could accurately reflect Mercury's mantle. Through this investigation, we will obtain intuition on how a thin highly reduced mantle affects mantle melting, and mantle dynamics within the inner solar system. The next steps include adding the inner core formation calculations and MELTS S-free solidi to the thermal model.

References: [1] Solomon et al. (2001) *Planet. Space Sci., 49.* [2] Nittler et al. (2018) *Mercury: The View After MESSENGER*, p.*30-51.* [3] Namur et al. (2016) *EPSL, 439.* [4] Margot et al. (2018) *Mercury: The View After MESSENGER*, p.*85-113.* [5] Byrne et al. (2016) *GRL, 42.* [6] Vander Kaaden et al. (2017) *Icarus, 285*. [7] Thomas and Rothery (2019) *Elem., 15.* [8] Grott et al. (2011) *EPSL, 307.* [9] Hauck et al. (2013) *JGR, 118.* [10] Michel et al. (2013) *JGR, 118.* [11] Tosi et al. (2013) *JGR, 118.* [12] Takashi (1990) *JGR, 95.* [13] Hirschmann, (2000) *G3, 1.* [14] Hauck et al. (2018) *Mercury: The View After MESSENGER*, p.*516-543.* [15] Stevenson et al. (1983) *Icarus, 54.* [16] Hauck et al. (2004) *EPSL, 222.* [17] Smith and Asimow (2005) *G3, 6.* [18] Anzures et al. (2020) *GCA, 286.* [19] Weisberg et al. (1988) *EPSL, 91*. [20] Berthet et al. (2009) *GCA, 73*.