MERCURY'S EARLY HISTORY: IMPACTS, TIDES, AND CONVECTION.

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Introduction: The surface of Mercury has been globally resurfaced about 4 Gy ago, a time corresponding to a period of high flux of impactors on the terrestrial planets known as Late Heavy Bombardment (LHB) [1]. As a consequence of the basin-scale impacts associated with the LHB, thermal anomalies form in the mantle that can modify the convection pattern and the melt production rate [e.g., 2].

The relatively small thickness of the mantle of Mercury [3, 4] and the high temperature at the core mantle boundary in the early phases of the planet's evolution [5], imply that a large fraction of the mantle is at relatively high temperatures. This situation increases tidal dissipation, which, despite Mercury's small radius, is expected to be significant because of the planet's large orbital eccentricity and small distance from the Sun.

In this work we investigate the effects of large impacts and tidal energy dissipation on the convection of Mercury during the early phases of its evolution. In particular, we track the melt production during the early evolution with the goal of identifying the expected eruption locations on the surface and the associated depth of the source regions.

Impacts: We estimate the thermal anomalies in the mantle generated by large impacts using standard scaling laws [6]. We use impactor sizes between about 100 km and 250 km, which are compatible with basin sizes of 1550 km (corresponding to the Caloris basin) and 2300 km (corresponding to the High-Mg region, possibly the remnant of an ancient basin, [7]) if the impact velocity is in between 15 km/s and 55 km/s and the impact angle is 45°, as appropriate for Mercury [8].

Rheology for convection and tides: Extremely different timescales characterize convection and tides. To consistently model the rheological response of mantle materials for these two processes it is necessary to employ a timescale-dependent rheology. We adopt the Andrade pseudo-period model [9, 10] which includes the rheological effects of temperature, pressure, grain size, and forcing period. The model parameters are obtained by fitting torsional oscillation data for olivine at forcing periods no longer than 1000 s [9]. We extrapolated the model to longer periods to test its applicability to convection and tidal problems. Figure 1 shows the dynamic viscosity as a function of the period. At very large forcing periods, corresponding to convective timescales, and for a reasonable range of parameters, the viscosity compares favorably with the reference viscosities commonly adopted in convection studies [e.g., 5, 11]. At timescales relevant to the post glacial rebound process, the viscosity also matches the value inferred from geodetic observations [e.g., 12]. These findings indicate that the Andrade pseudo-period model is appropriate to consistently evaluate the rheological response of the mantle for convective and tidal processes. Note that the values of the viscosity appropriate for convection and tides differ by about three orders of magnitude (Figure 1).

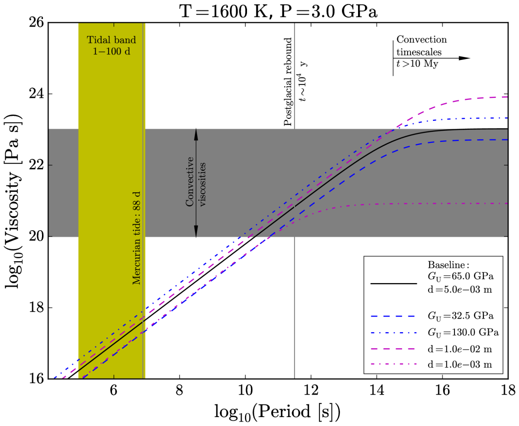

Figure 1: Viscosity as a function of the forcing period for the Andrade rheological model at T = 1600 K and P = 3 GPa. The baseline model has an unrelaxed shear modulus $G_U = 65$ GPa and a grain size d = 5 mm. The other models are obtained by varying a single parameter as indicated by the legend. Additional parameters correspond to melt-free olivine [for additional details see 9 and 10].

Convection: We simulate the thermal convection of Mercury's mantle using the finite-volume code GAIA [13]. We run both 2D-cylindrical and 3D-spherical simulations using the temperature- and pressure-dependent rheology described above. Impacts are treated as instantaneous temperature anomalies calculated using scaling laws. The contribution of tidal dissipation (below) is included as an additional source term in the energy equation. When the temperature exceeds the solidus, we assume all the melt to be instantaneously extracted to the surface and we set the

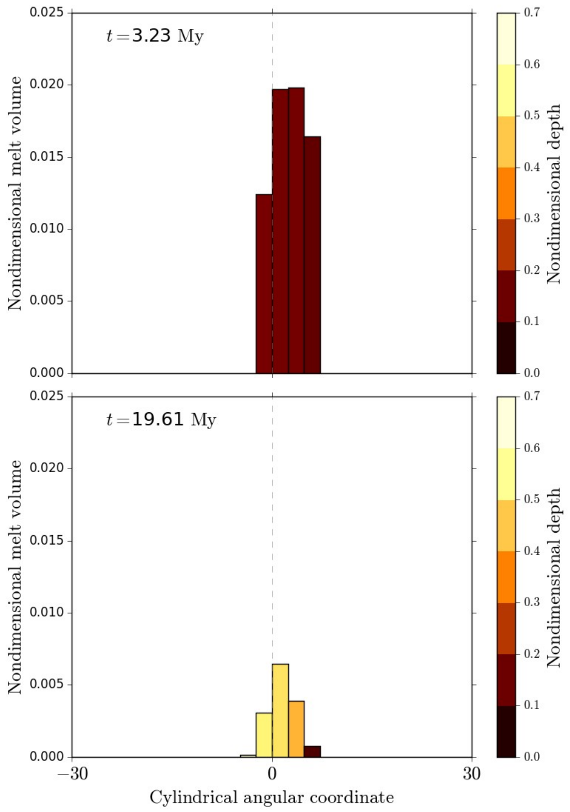

Figure 2: Histograms of the melt volume produced as a result of an impact (occurring at 0°) at two different epochs (*t* indicates time after the impact). Diameter and velocity of the impactor equal to 100 km and 48 km/s, respectively. Note that initially the melt comes from the melt pond near the surface (top), while later melt originates deeper in the mantle (bottom).

temperature at the local solidus.

Tides: We use the temperature field computed from the convection code to calculate the mantle radial temperature profile at each time-step during the simulation. The temperature profile is used to compute the rheology of the mantle as a function of depth. Under the assumption of spherically symmetric properties of the planet, we calculate the tidal potential Love number k_2 to estimate the global energy dissipation induced by the tides, and account for this contribution when computing the temperature field in the next time-step of the convection code. We assume a fully liquid core, compatible with the expected late initiation of the inner core growth [e.g., 5]. Accordingly, we assume that the dissipation during the early phases of the planet's evolution occurs only in the mantle. As a first assessment of the contribution of the tides, we also assume that tidal energy is evenly dissipated in the mantle.

Results and outlook: In this study we revisit the work of [2] by using the post-MESSENGER value for the thickness of the mantle of Mercury (about 400 km, instead of 600 km), by considering a series of basin-forming impacts (and not only the Caloris-forming impact), and by including the tides as an additional source of energy. In the aftermath of a basin-forming impact, melt is initially formed from near-surface material, as expected. However, the thermal anomaly associated with a big impact induces melting at depth that resurfaces well after the impact happened (Figure 2). We will present results where we test the effect of impact parameters, amount of radiogenic heat sources, as well as tidal energy dissipation on the melt production and depth of the source region.

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References: [1] Marchi S. et al. (2013), *Nature, 499*, 56—91. [2] Roberts J. H. and Barnouin O. S. (2012), *JGR-Planets, 117*, E02007. [3] Hauck S. A. II et al. (2013), *JGR-Planets*, *118*, 1204—1220. [4] Rivoldini A. and Van Hoolst T. (2013), *EPSL, 377*, 62—72. [5] Tosi N. et al. (2013), *JGR-Planets*, *118*, 2474—2487. [6] Pierazzo E. et al. (1997), *Icarus*, *127*, 408—423. [7] Weider S.Z. et al. (2015), *EPSL, 416*, 109—120. [8] Le Feuvre M. and Wieczorek M. A. (2008), *Icarus*, *197*, 291—306. [9] Jackson I. and Faul U. H. (2010), *PEPI, 183*, 151—163. [10] Padovan S. et al. (2014), *JGR-Planets*, *119*, 850—866. [11] Plesa A.-C. et al. (2015), *JGR-Planets*, *120*, 995—1010. [12] Kaufmann G. and Lambeck K. (2000), *PEPI*, *121*, 301—324. [13] Hüttig C. and Stemmer K. (2008), *G^3*, *9*, Q02018.