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The cooling history and global contraction of Mercury

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Mercury's thermochemical history has been characterized by global contraction in response to planetary cooling. Such contraction has been recorded in the form of tectonic landforms. However, estimates substantially vary between < 2 km (Watters et al., 2021) and up to 8 km (Byrne et al., 2014), depending on whether small-scale ridges are considered to contribute to global contraction. A recent study by Broquet and Andrews-Hanna (2025) revisited Mercury's tectonic record and found global contraction values of 8.3 ± 4.3 km, with a conservative range of 6.3 ± 3.2 km when considering only primary tectonic landforms.

Here, we model Mercury's thermal evolution and global contraction using 3D geodynamic simulations. Our geodynamic models build upon that of Fleury et al. (2024) and use the mantle convection code GAIA (Hüttig et al., 2013), which solves the conservation equations of mass, momentum and energy from 4.5 Ga to present day under the assumption of homogeneous mantle composition, Newtonian rheology, and negligible inertia. Our models employ surface temperature variations caused by the combined effects of the 3:2 spin-orbit resonance and the low obliquity of Mercury, as well as crustal thickness variations derived from gravity and topography data (Fleury et al., 2024). For the first time, we account for a laterally variable crustal thermal conductivity considering crustal porosity variations (Broquet et al., 2024). The effects of melt extraction on the regional contraction are also investigated. While previous models (Peterson et al., 2021; Tosi et al., 2025) have considered only fully extrusive scenarios, where the entire amount of melt produced in the interior is instantaneously extracted at the surface, we test both intrusive and extrusive cases as well as different intrusive to extrusive ratios and depths for placing the magmatic intrusions. Predicted present-day global and laterally varying contraction are compared to tectonic strain from Broquet and Andrews-Hanna (2025).

Our models typically predict 5–10 km of global contraction today. The average thickness of the crust is found to have no substantial effect on global contraction estimates. When considering porosity and its effect on thermal conductivity, we find that regions covered by a thick, porous crust are warmer during the early evolution and experience a more pronounced cooling later on, which leads to substantially larger contractional strain compared to the rest of the planet. Assuming different megaregolith thicknesses, as well as a linear or exponential decrease of conductivity with increasing porosity (Henke et al., 2016), affects global contraction values by up to ± 10%. Similarly, magmatic intrusions, typically located at the crust-mantle boundary, provide a

local heat source that keeps the lithosphere warm over prolonged time periods, thus affecting the record of planetary contraction on a regional scale. These analyses show that planetary contraction is far from isotropic, which has implications for our understanding of Mercury's tectonic record. More detailed comparisons of our planetary contraction estimates with that inferred from shortening landforms will provide important insights into the interior processes and cooling history of Mercury.