Uncertainties in core thermophysical properties and their impact on Mercury's thermal and magnetic evolution

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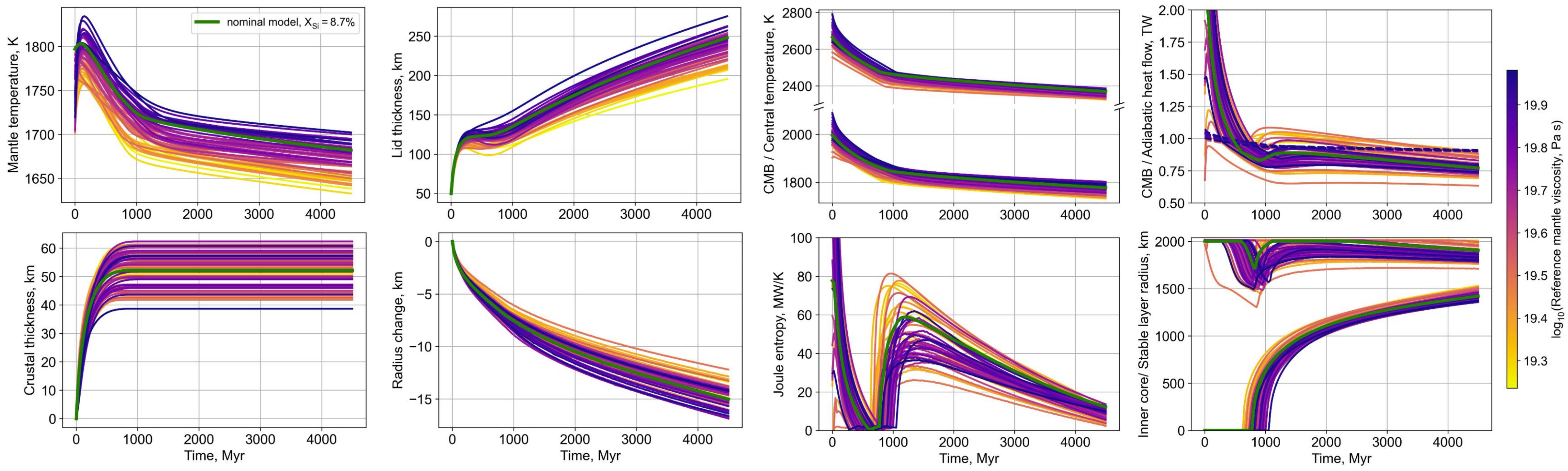
Core-mantle evolutions satisfying geophysical and geological constraints

Evolution model

- **1D core-mantle evolution** with *TEMPURA* [1] coupled to the core model of *Greenwood et al.* [2].
- Self-consistent treatment of mantle and core thermophysical properties assuming an **olivine/enstatite/diopside mantle and an Fe-Si core**.
- **50,000 Monte Carlo simulations varying 7 parameters** (mantle reference viscosity, enstatite/olivine fraction, crustal enrichment factor of heat –producing elements, initial mantle and core-mantle boundary (CMB) temperatures, outer core radius, core melting entropy factor).

Observational constraints

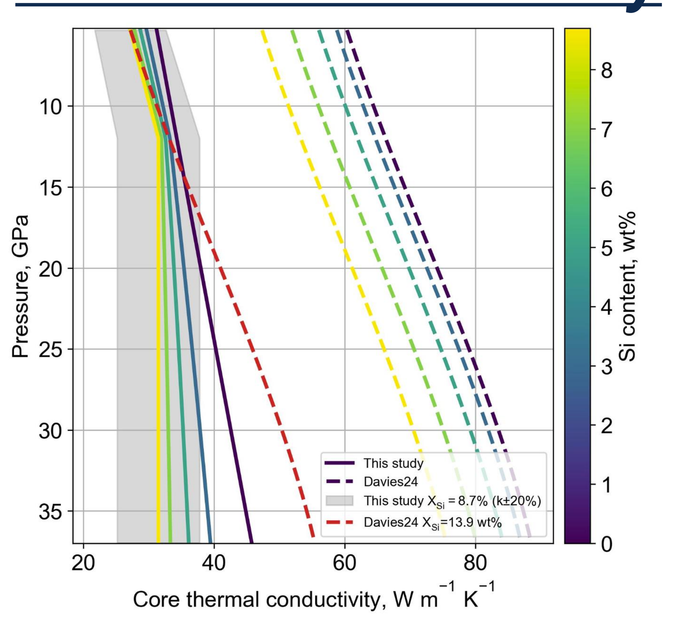
- **Crustal thickness** between 15 and 60 km [e.g., 3], produced within the first 1 Gyr of evolution [4]
- Feasibility of **present-day and early dynamo** between 4 and 3.5 Ga [5]
- **Radial contraction** beginning at least 4 Ga and evolving with a decreasing rate [6]
- **Successful models** (figure below) are characterized by low mantle viscosities favoring efficient cooling, rapid crust production, early dynamo (monitored through a Joule entropy > 1 MW/K), and early onset of radial contraction, with a present-day inner core >1300 km and a stable layer < 300 km.



How do core properties influence Mercury's global evolution?

We select a nominal model (green line) with an initial core Si concentration of 8.7 wt%. We keep all parameters fixed and vary three core properties one at a time: **thermal conductivity, melting temperature** and **latent heat**. We test the effects of alternative parametrizations of these properties according to [7] (hereafter Davies24) in the frame of comparable Mercury models with an Fe-Si core. We show that **even modest changes of core properties can have first-order effects on the evolution of both the core and the mantle, with consequences for magnetic field generation, crust production, and radial contraction.**

Thermal conductivity



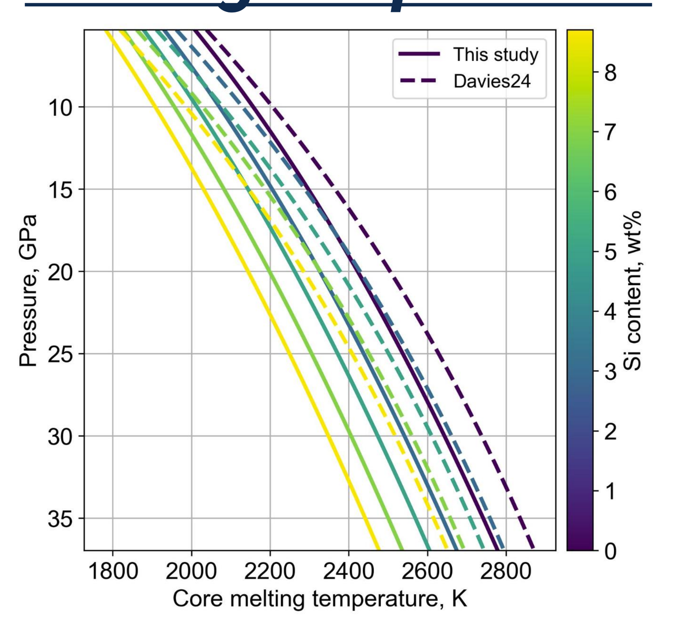
Pressure and Si-dependent thermal conductivity (solid lines):

$$k(X_{Si},P) = C_k\left(\frac{1-X_{Si}/X_{Si*}}{k_{Fe}(P)} + \frac{X_{Si}/X_{Si*}}{k_{FeSi*}(P)}\right)^{-1}$$

with $k_{Fe}(P)$ of pure Fe from [8], X_{Si*}=8.5% and $k_{FeSi*}(P)$ from [9]. The grey area denotes a ±20% range of variability with respect to $k(X_{Si}$ = 8.7%, $P)$ controlled by a conductivity factor C_k (grey area). Colors correspond to X_{Si} = 0, 3, 5, 7 and 8.7 wt% (from blue to yellow).

The parametrization of Davies24 (dashed lines) yields much higher conductivities. To match the same value at the CMB for X_{Si}=8.7%, a concentration of 13.9% would be necessary (red dashed line).

Melting temperature

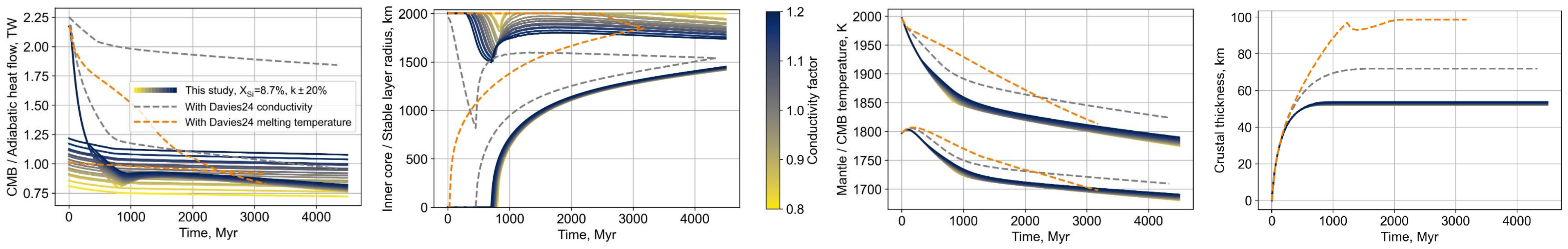


Pressure and Si-dependent melting temperature (solid lines):

$$T_{liq}(X_{Si},P) = T_{liq,Fe}(P) - (T_{liq,Fe}(P) - T_{liq,E}(P))\frac{X_{Si}}{X_{Si,E}}$$

with $T_{liq,Fe}(P)$ of pure Fe from [10] and $T_{liq,E}(P)$ for the eutectic composition ($X_{Si,E}$ = 12.5 wt%) from [11].

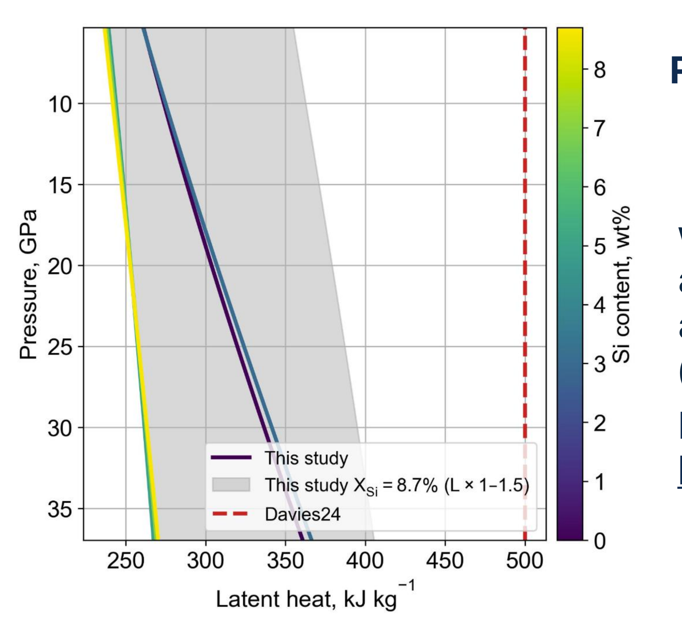
For a given Si-concentration, the parametrization of Davies24 (dashed lines) yields slightly higher melting temperatures and a steeper pressure slope.



- Uncertainties in conductivity affect core evolution (solid lines). They influence the time when CMB heat flow becomes sub-adiabatic (left), the formation of a top stable layer and its thickness (right).
- Higher conductivity of Davies24 (dashed grey lines) leads to the growth of a >1000 km thick stable layer, which shrinks to ~500 km upon inner core growth. The model would no longer be successful due to the lack of a present-day convecting layer and hence of a dynamo.
- Higher melting temperature of Davies24 (dashed orange lines) leads to the immediate nucleation of the inner core, which grows to ~1700 km until the convecting layer also vanishes.

- Uncertainties in conductivity have little effect on mantle, CMB temperature and crustal thickness (solid lines).
- Higher conductivity of Davies24 (dashed grey lines) leads to higher mantle and CMB temperatures, which cause a net increase of the crust thickness from ~52 to 72 km.
- Higher melting temperature of Davies24 (dashed orange lines) has similar but stronger effects, causing the crust to nearly double in thickness.

Latent heat

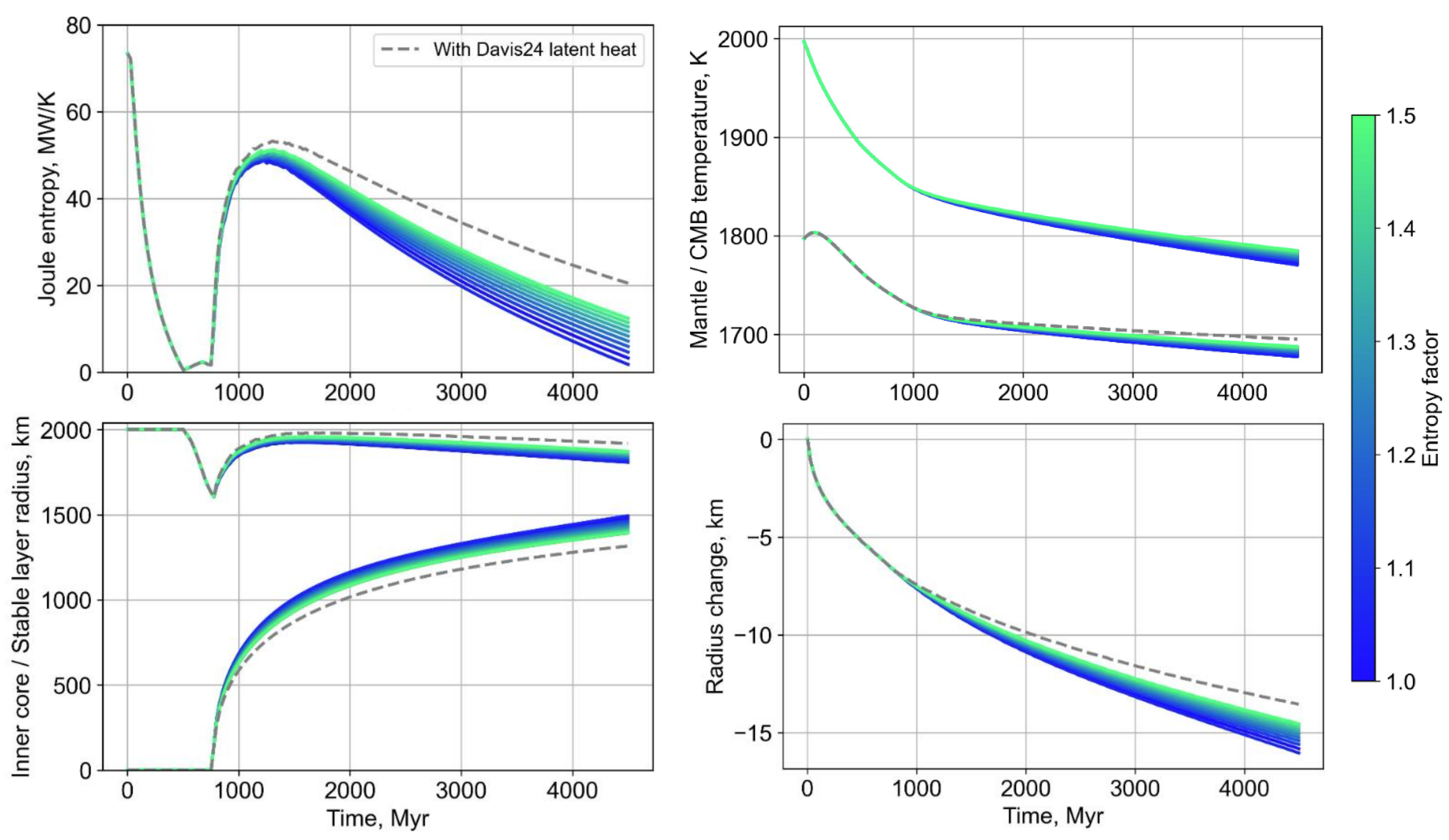


Pressure and Si-dependent latent heat (solid lines):

$$L(X_{Si},P) = C_S\Delta S_{Fe-Si}(X_{Si},P)T_{liq}(X_{Si},P)$$

with $\Delta S_{Fe\text{-}Si}$ melting entropy of the Fe-Si alloy calculated assuming ideal mixing between Fe and Si end-members. We also allow L to increase up to 50% through a constant factor C_S (grey area).

Davies24 uses a higher constant value of 500 kJ/kg (red dashed line).



- Uncertainties in latent heat affect Joule entropy, inner core and stable layer thickness (solid lines)
- Mantle and CMB temperatures are also affected, causing changes in radial contraction up to 1.5 km.
- Higher latent heat of Davies24 (dashed grey line) has similar effects, causing high Joule entropy and thus facilitating magnetic field generation.

References

[1] Baumeister et al. (2023), *A&A*, doi:10.1051/0004-6361/202245791; **[2]** Greenwood et al. (2021), *EPSL*, doi:10.1029/2021GL095198; **[3]** Padovan et al. (2015), *GRL*, doi:10.1002/2014GL062487; **[4]** Byrne et al. (2014), *Nat. Geosci.*, doi: 10.1038/ngeo2097; **[5]** Johnson et al. (2015), *Science*, doi:10.1126/science.aaa8720; **[6]** Crane & Klimczak (2017), *GRL*, doi:10.1002/2017GL072711; **[7]** Davies et al. (2014), *EPSL*, doi:10.1016/j.epsl.2024.118812; **[8]** Edmund et al., *JGR* (in review); **[9]** Berrada et al. (2021), *EPSL*, doi:10.1016/j.epsl.2021.117053; **[10]** Dorogokupets et al. (2017), *Sci. Rep.*, doi:10.1038/srep41863; **[11]** Edmund et al. (2022), *Nat. Comm.*, doi:10.1038/s41467-022-27991-9.