Thermomechanical modeling of the subduction zone thermal structure

The subduction zone thermal structure used in the geochemical modeling and analysis performed here is based on the 2D thermomechanical models described in van Keken et al. (2011) with minor modifications as described in van Keken and Wilson (2023). The models have a kinematically prescribed slab surface with fixed geometry and imposed velocity. We use a time-dependent solution of the heat-advection diffusion equation with the velocity in slab and mantle wedge determined by solution of the Stokes equations assuming a non-linear stress- and temperature-dependent rheology appropriate for the deformation of olivine. The models used here are evolved for 40 Myr which causes a near-steady state thermal structure as described in van Keken and Wilson (2023). We focus first on the Mariana subduction zone between 12-22°N. For this we use the "South Mariana" subduction zone model from van Keken and Wilson (2023) which has a cross-section profile with a strike that is close to the convergence direction and is yields a thermal structure very close to that obtained in a full 3D curved model (Bengtson and van Keken, 2012). We also use the "Cascadia" model as a proxy for warmer subduction environments, such as may be encountered during flat slab subduction or subduction in the early Earth, and the very cold endmember "Tonga" model for comparison, both from van Keken and Wilson (2023) (Figs. S7 and S8). All models and software to reproduce the models are available in the Zenodo archive (https://zenodo.org/doi/10.5281/zenodo.7843967) cited in van Keken and Wilson (2023). A detailed tutorial on generating the D80 model is provided in in Github (https://github.com/cianwilson/vankeken_wilson_peps_2023). We have also included an independent Zenodo link in this paper that provided the thermomechanical data we used for our redox model (https://doi.org/10.5281/zenodo.13733394).

The primary driving force for wedge convection is coupling between wedge and descending slab. We employed "D80" models following prior van Keken and Wilson (2023), where the slab is fully decoupled from the overriding plate to a depth of 80 km. The slab is fully coupled below this depth. This results in the formation of a cold corner in the mantle wedge to 80 km depth consistent with geophysical observations. Below this depth the slab surface heats rapidly due to the induced corner flow in the hot mantle wedge (Fig. S1a). The "D80" models have additional assumptions such as a relatively high mantle potential temperature (1422°C) and a plate cooling model for the incoming lithosphere. We have compared the Marianas results with the "D80new" models from van Keken and Wilson (2023) which feature a lower mantle potential temperature (1350°C) and an error function profile. We found the change in these assumptions had minimal impact on the geochemical model results.

Our models do not include shear heating along the plate interface. While this has been suggested to be one of the factors explaining the difference between the exhumed metamorphic rock record and the thermal models used here (Penniston-Dorland et al., 2015), it has been noted that the shear heating at the plate interface is both limited by the brittle-ductile transition (e.g., Abers et al., 2020) and inefficient in heating up the slab interior below it (e.g., van Keken et al., 2018). It also has minimal effect on the slab mantle studied here (see van Keken and Wilson, 2023 and discussion in the main text).

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