Beyond Equilibrium

Kinetic Thresholds and Rheological Feedbacks Create a Potentially Complex 410 in Slab Regions

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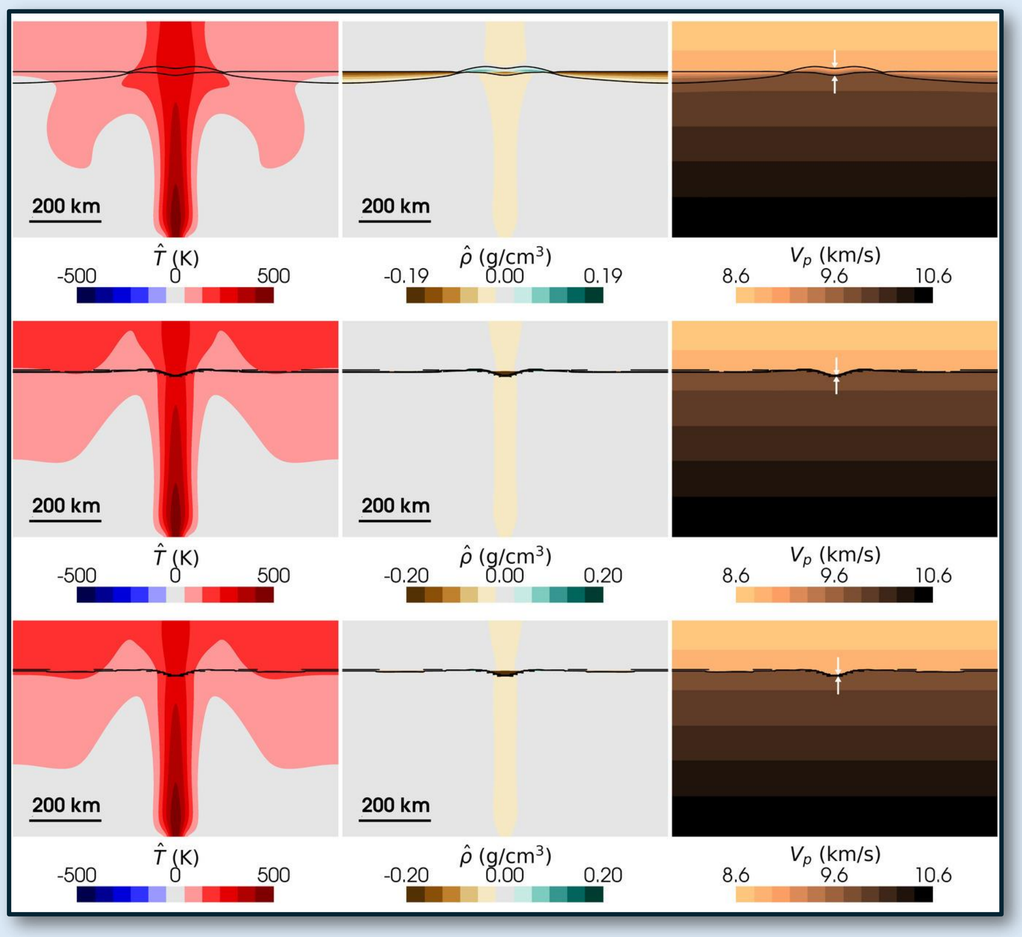
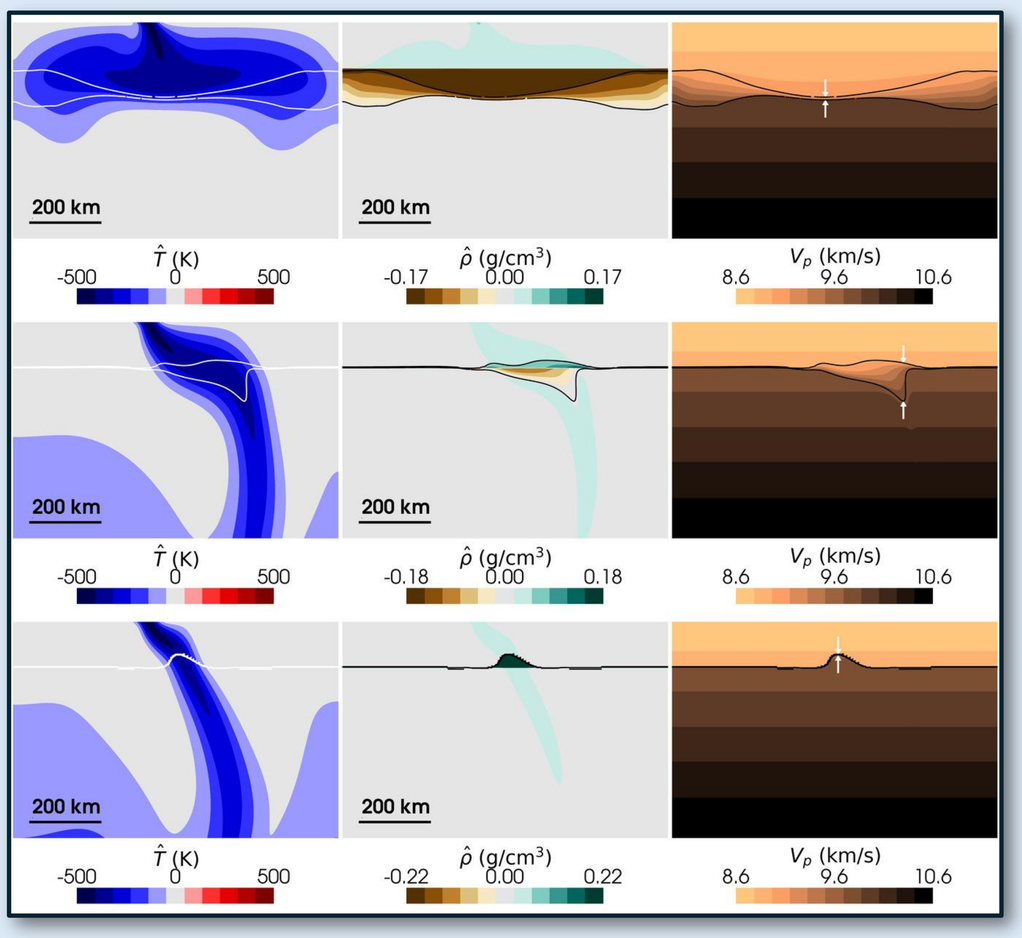
Question: *how do reaction kinetics shape the 410 in plume/slab environments?*

Simulation Snapshots



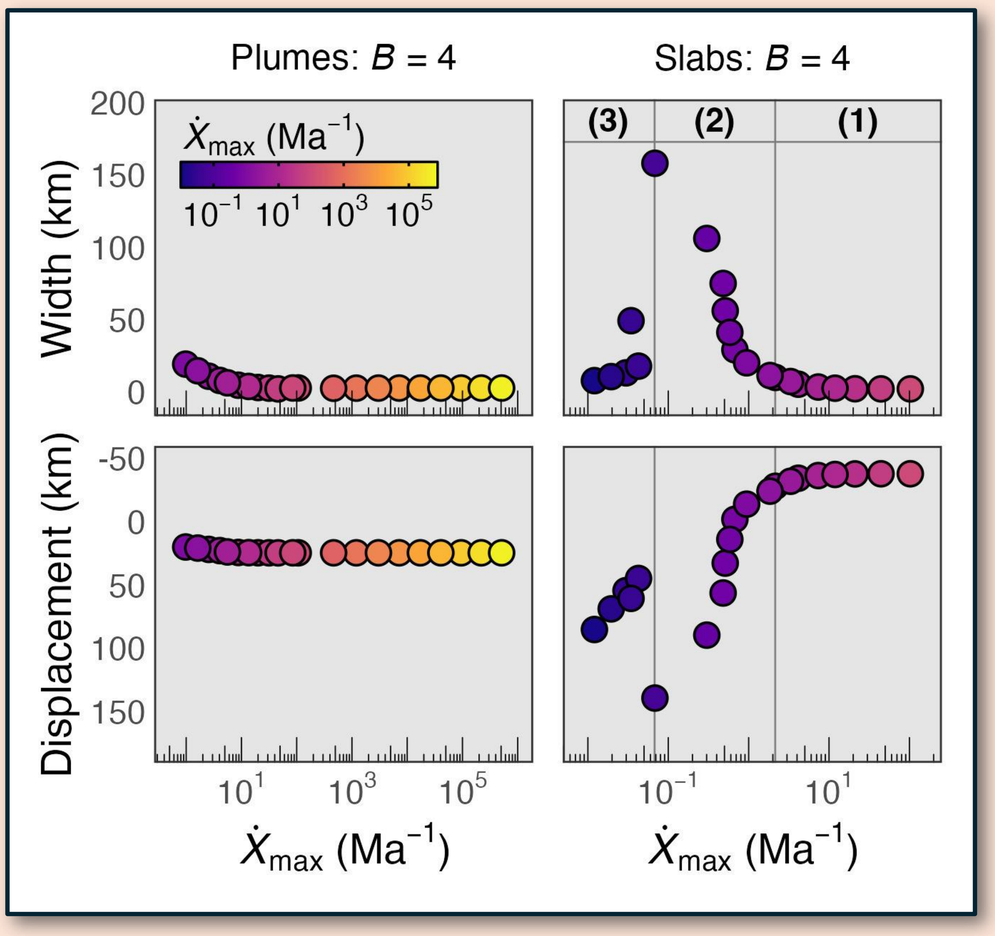
Plume simulations with intermediate strength contrasts showing ultra-sluggish (top row), intermediate (middle row), and quasi-equilibrium (bottom row) kinetic regimes after 100 Ma evolution. Panels show dynamic temperature (left column), dynamic density (middle column), and pressure-wave velocity (right column). Thin lines highlight the 10% and 90% wadsleyite volume fraction contours. The white arrows (right column) indicate where the 410 structure was measured.



Slab simulations with intermediate strength contrasts showing ultra-sluggish (top row), intermediate (middle row), and quasi-equilibrium (bottom row) kinetic regimes after 100 Ma evolution. Panels show dynamic temperature (left column), dynamic density (middle column), and pressure-wave velocity (right column). Thin lines highlight the 10% and 90% wadsleyite volume fraction contours. The white arrows (right column) indicate where the 410 structure was measured.

410 Structure: Displacement and Width

Plumes are insensitive to reaction kinetics; slabs exhibit distinct threshold behavior, forming diagnostic 410 structures



Measured 410 displacement and width versus maximum reaction rates $\dot{X}_{max}$ in plume and slab simulations with intermediate strength contrasts after 100 Ma. Structure of the 410 near plumes (left column) shows minimal dependence on $\dot{X}_{max}$, with both displacement and width remaining nearly constant across seven orders of magnitude variation in $\dot{X}_{max}$. In contrast, 410 structure near slabs (right column) changes distinctly across three kinetic regimes: (1) quasi-equilibrium at high $\dot{X}_{max}$, where 410 widths are narrow and elevated; (2) an intermediate regime where decreasing reaction rates $\dot{X}_{max}$ progressively widen and deepen the 410; and (3) an ultra-sluggish regime at low $\dot{X}_{max}$, where the 410 narrows while deepening, and slabs completely stall and pond.

- *Plumes produce sharp 410s regardless of reaction rates; slabs show three distinct kinetic regimes controlling discontinuity structure*
- *Rheology modulates kinetic effects: strong slabs descend slowly allowing complete reaction; weak slabs descend fast amplifying metastability*
- *Seismic observations of 410 structure in subduction zones can constrain reaction rates but require independent rheological constraints*

Data Availability

All data, code, and relevant information for reproducing this work are archived on the OSF (Kerswell, 2026a) and Zenodo (Kerswell, 2026b) repositories. All code within these repositories is MIT Licensed and free for use and distribution (see license details). ASPECT version 3.0.0 (Bangerth et al., 2024) was used for the computations in this study and is freely available under the GPL v2.0 or later license.

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