THE ROLE OF OCEANIC, CONTINENTAL & CRATONIC LITHOSPHERE ON MANTLE CIRCULATION

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1. INTRODUCTION

- Downwellings & upwellings represent the coupling between the mantle and lithosphere, yet there is much still to learn about their evolutions
- Mantle models do not consider the complexity of the lithosphere and it is often modelled as a rigid lid with constant viscosity & density
- We implement oceans, continents, & cratons with different densities, viscosities & thicknesses
- We aim to investigate the effect of surface conditions on upper mantle dynamics

2. METHODS

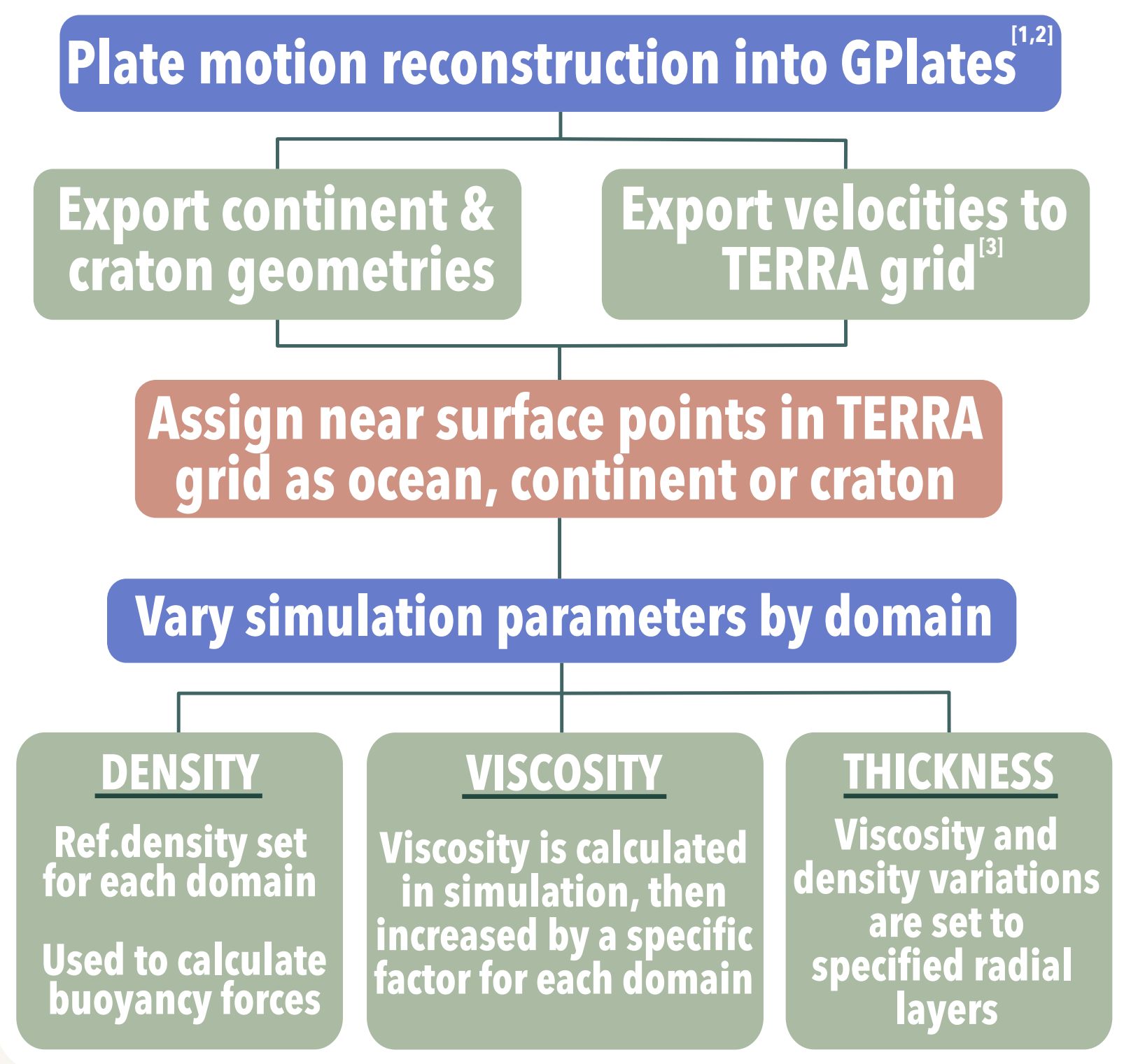


Plate motion reconstruction into GPlates[1,2]

Export continent & craton geometries

Export velocities to TERRA grid[3]

Assign near surface points in TERRA grid as ocean, continent or craton

Vary simulation parameters by domain

DENSITY
Ref.density set for each domain
Used to calculate buoyancy forces

VISCOSITY
Viscosity is calculated in simulation, then increased by a specific factor for each domain

THICKNESS
Viscosity and density variations are set to specified radial layers

INITIAL CONDITIONS:

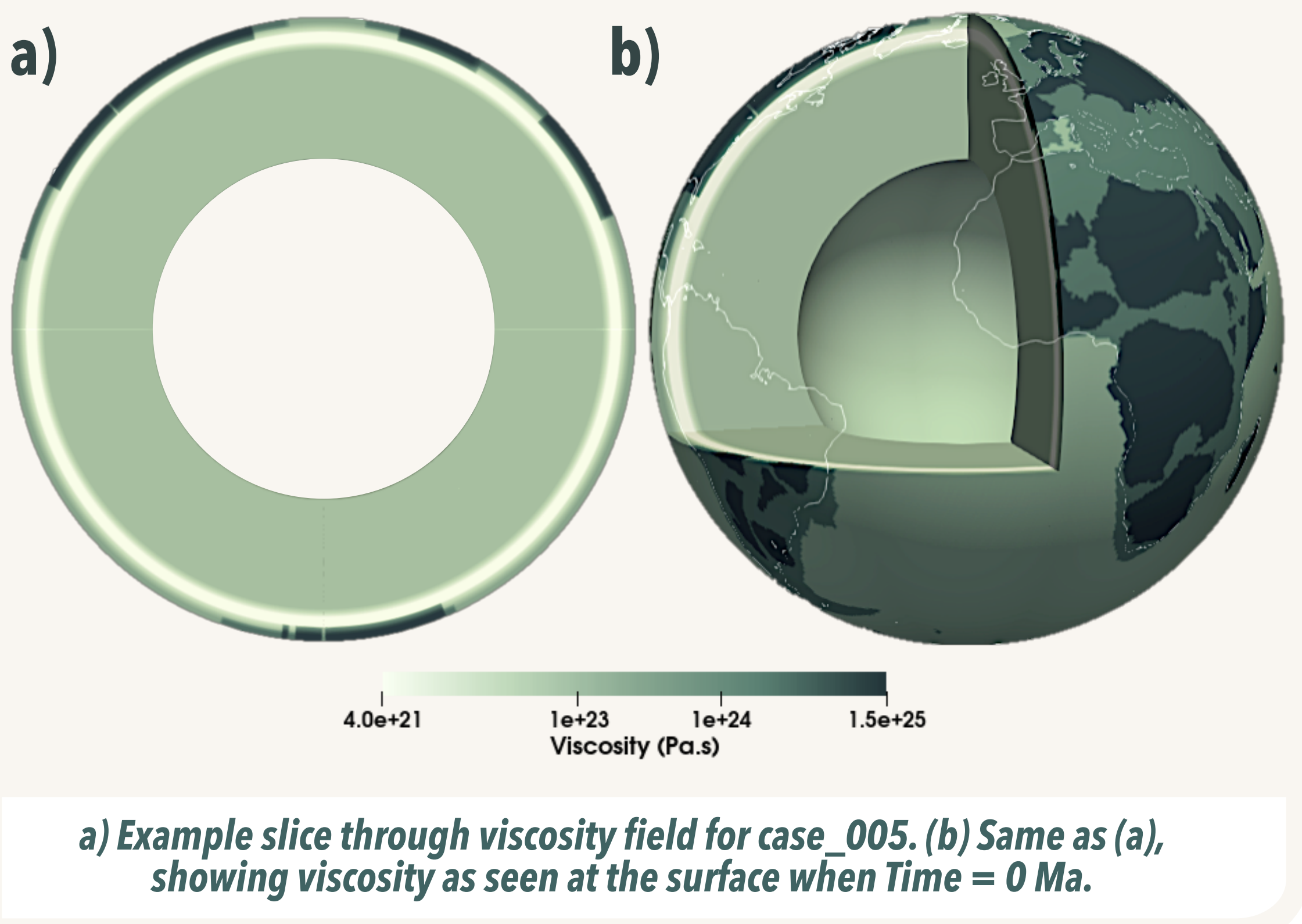
Rayleigh No ≈ 10^7
Ref. Density = 4.5×10^3 Kg m^{-3}
Ref. Viscosity = 4×10^{21} Pa s
Model Duration = 500 Myr

Scan QR code to view full initial conditions & model set ups

RADIAL VISCOSITY FACTORS:

LITHOSPHERE x100
90 km
UPPER MANTLE = REF. VISC
660 km
LOWER MANTLE x30
2890 km

MODEL NO.	DESCRIPTION
Case_000	REFERENCE CASE
Case_001	Viscous continents & cratons
Case_002	V. viscous cratons
Case_003	Weak continents, viscous cratons
Case_004	Thick viscous cratons
Case_005	Thick viscous continents, v.thick viscous cratons
Case_006	Weak, thick continents, v.thick viscous cratons
Case_007	Buoyant, viscous continents & cratons



a) Example slice through viscosity field for case_005. (b) Same as (a), showing viscosity as seen at the surface when Time = 0 Ma.

3. MANTLE TEMPERATURE & SLAB SINKING

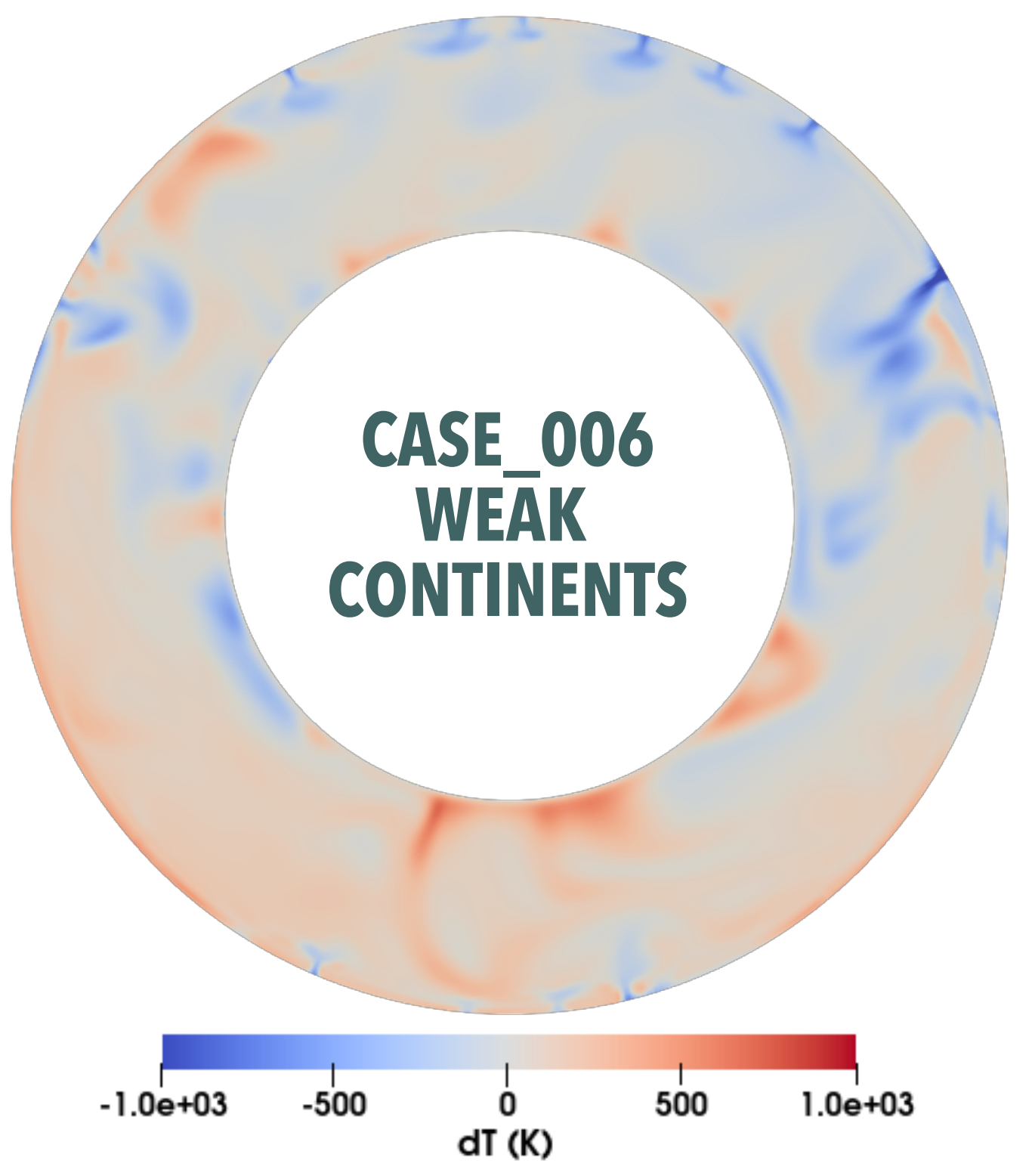
WEAK CONTINENTS = LOWER MANTLE TEMPERATURE

Thickness of lithosphere exacerbates temperature anomaly

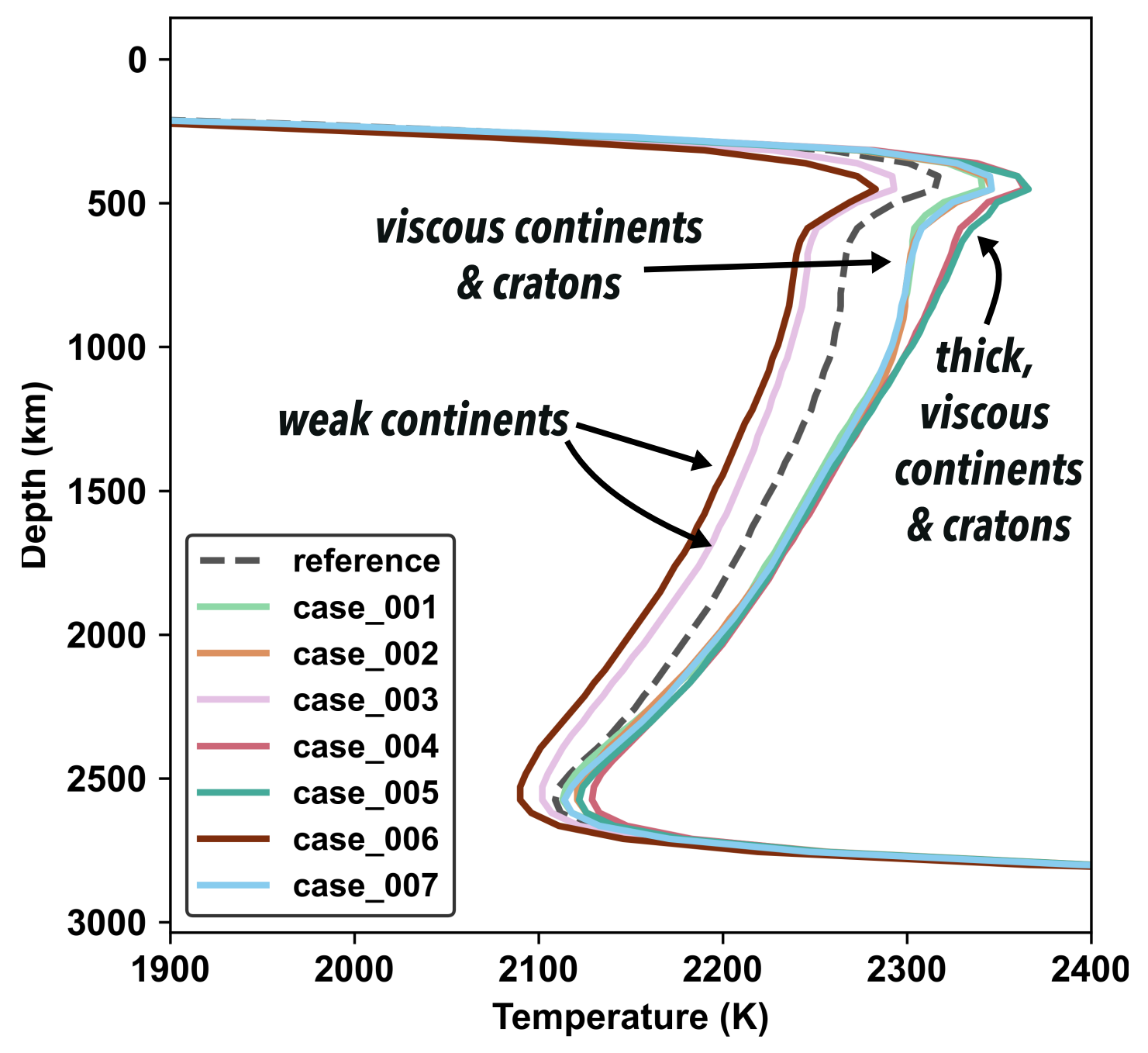
Colder mantle temperatures cause most slabs to stall in the upper mantle

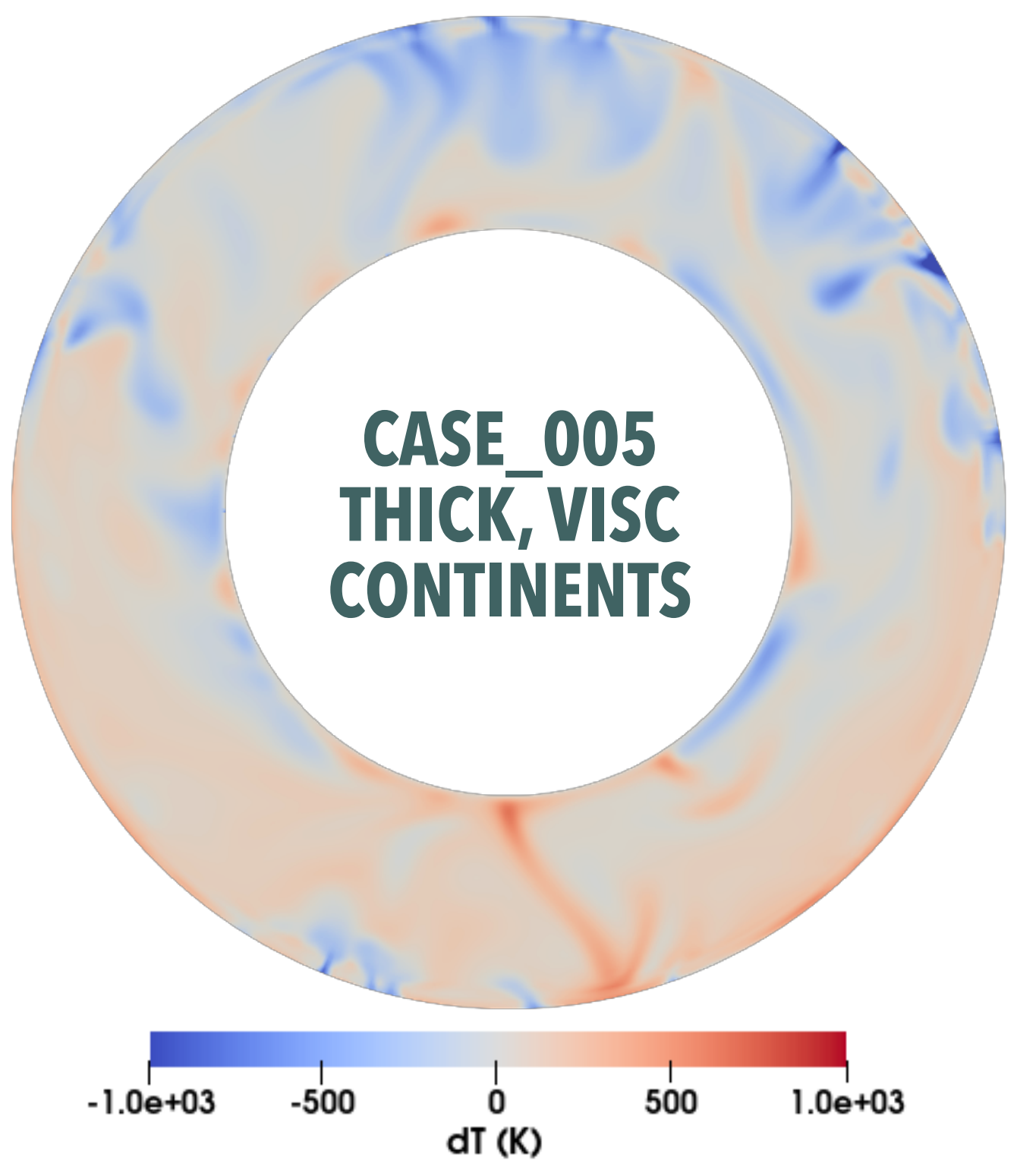
All slabs eventually pass through transition zone

Slabs descend slower for case_006 relative to case_005



AVERAGE RADIAL TEMPERATURE TIME = 0 Ma





VISCOUS CONTINENTS & CRATONS = GREATER MANTLE TEMPERATURE

Thick continental lithosphere associated with hotter average mantle temperatures in the upper 1300 km

Most slabs quickly descend and thicken through transition zone

Lithosphere buoyancy has little effect on simulation

Increasing viscosity contrast beyond x100 has little effect on simulation

Lithosphere properties can alter dynamics throughout the mantle

4. RELATIONSHIP BETWEEN MANTLE CIRCULATION AND SUPERCONTINENTS

SPATIAL RELATIONSHIP BETWEEN MANTLE & LITHOSPHERE STRUCTURES:

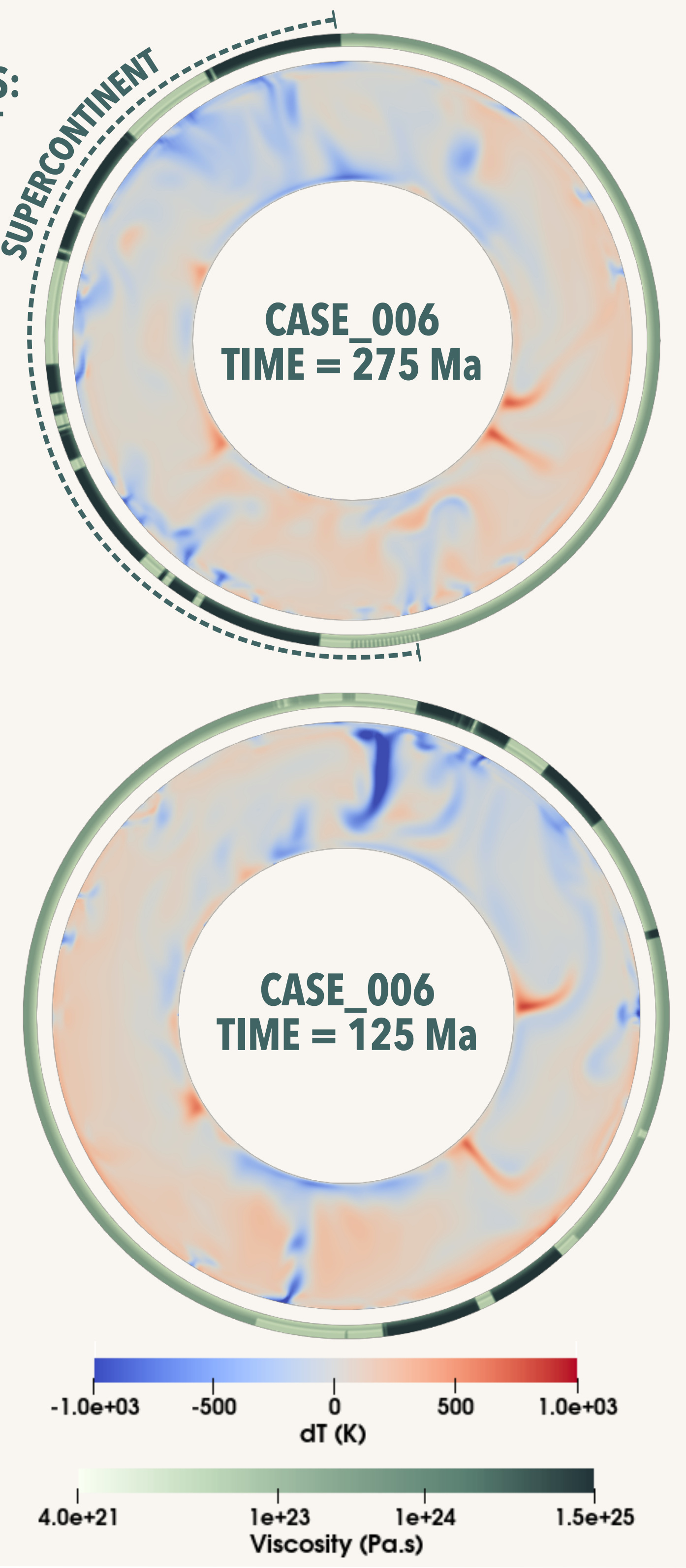
During supercontinent amalgamation, downwellings are localised beneath supercontinent with weak continents (case_006)

In other models, downwellings are proximal to the edges of the continents and cratons, suggesting that great viscosity contrasts may facilitate subduction

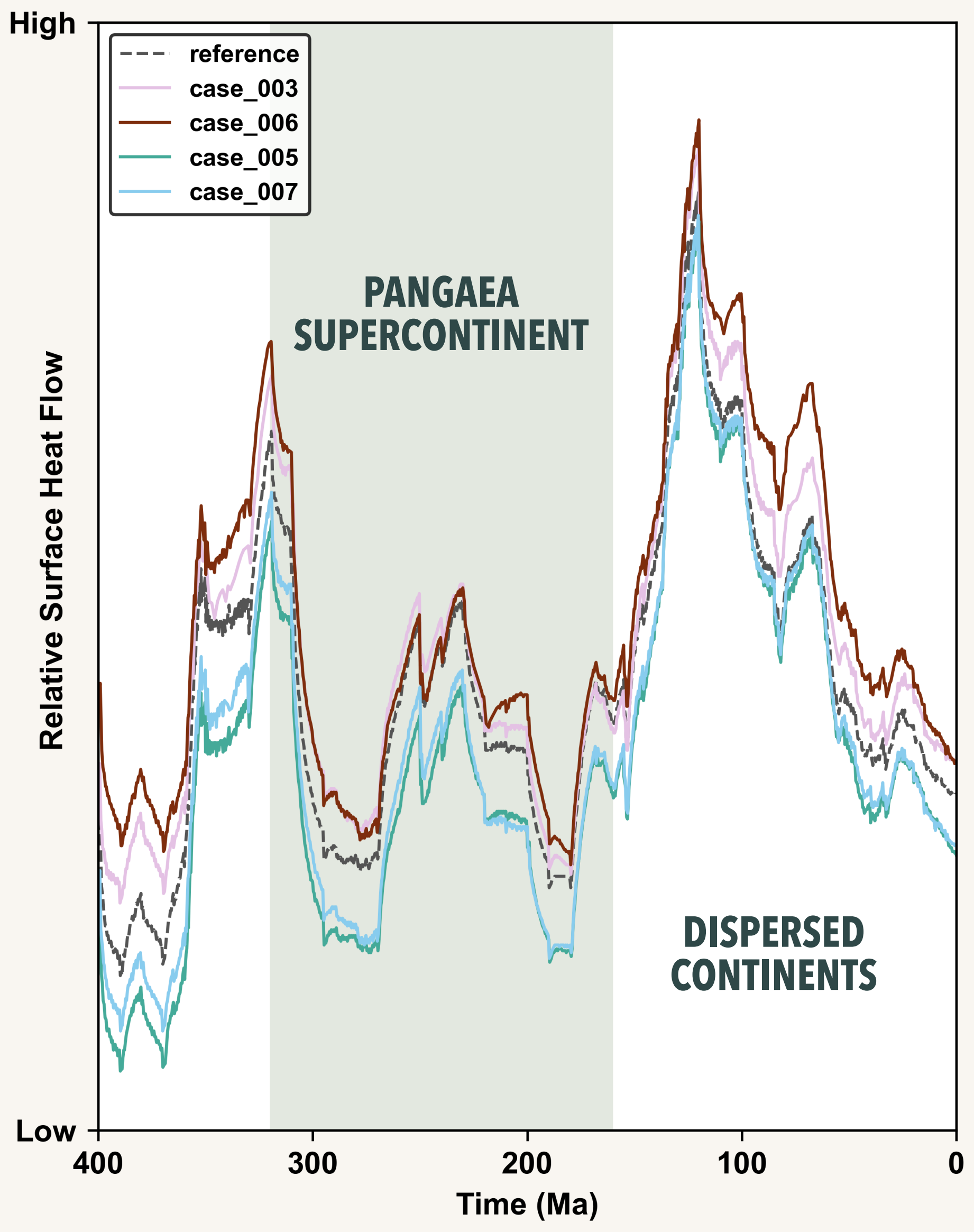
Where continents are weak, it takes longer to develop significant instability beneath viscosity contrast at the surface for slabs to descend through transition zone

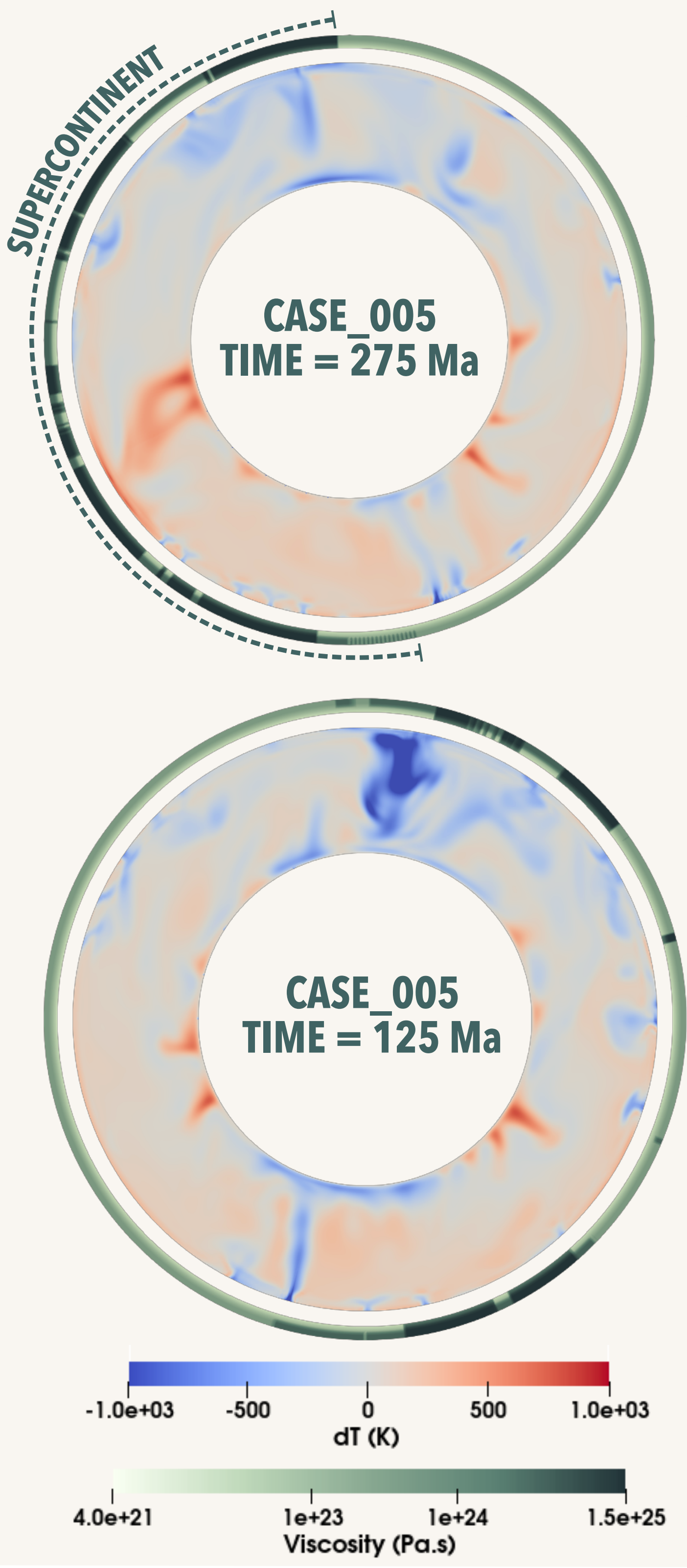
In our hottest model (case_005, 275 Ma) the large upwelling ascends beneath the more viscous cratonic core of the supercontinent

Thick lithosphere exacerbates the variation in mantle temperature; both the hottest and coldest models have thick continents and very thick cratons



NORMALISED SURFACE HEAT FLOW THROUGH TIME





SUPERCONTINENT AMALGAMATION VS DISPERSAL:

Periods of continent dispersal have greater surface heat flow; mantle temperature is therefore lower during supercontinental breakup

Slabs are often more coherent in case_006, where instabilities require some time to develop

Downwellings preferentially descend at greatest viscosity contrasts

Supercontinents may have a lot of viscosity contrasts in relatively smaller area due to the distribution of continents and cratonic cores

When continents are weak, downwellings are localised at the x1000 viscosity contrast between continents and cratons

When continents and cratons are strong, downwellings localise at the continent-ocean boundary

5. CONCLUSIONS

Viscosity structure of the lithosphere can significantly alter whole mantle dynamics

Great viscosity contrasts will act to localise downwellings

Whilst the average mantle temperature varies across simulations, and this may be exacerbated by lithosphere thickness and buoyancy, the greatest changes are a function of time

Weak continents require more time to develop instabilities whilst a viscous continental lithosphere descends rapidly through the mantle

May have implications on the duration of a mantle convection and supercontinent cycles

FUTURE WORK:

Implement temperature dependent viscosities to better represent Earth-like dynamics

Compare outputs to seismic tomographic models to determine optimum lithosphere configuration for Earth-like simulations

Consider other surface parameters which may influence slab sinking (i.e. plate velocity)

6. REFERENCES

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[3] Baumgardner, J.R., 1983. A three-dimensional finite element model for mantle convection. University of California, Los Angeles.

7. ACKNOWLEDGEMENTS

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