

Supplementary Material for: The Superpile Cycle: the reorganisation of basal mantle structures coupled to the supercontinent cycle.

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1. Extended Data Tables

Table S1: Reference model initial conditions for simulation investigating the stability of basal mantle structures (BMSs).

Parameter	Symbol	Value	Units
Surface temperature	T_s	300	K
CMB temperature	T_{CMB}	4000	K
Internal heating rate	H	4.0×10^{-12}	W kg^{-1}
Reference density	ρ	4500	kg m^{-3}
Gravitational acceleration	g	10	m s^{-2}
Thermal conductivity	k	4	$\text{W m}^{-1} \text{K}^{-1}$
Specific heat capacity	C_p	1000	$\text{JK}^{-1} \text{kg}^{-1}$
Reference viscosity	μ_0	4.0×10^{21}	Pa s
Thermal expansivity	α	2.5×10^{-5}	K^{-1}
Lithosphere viscosity multiplication factor	$\Delta\mu_i$	100	-
Lower mantle viscosity multiplication factor	$\Delta\mu_{LM}$	30	-
Viscosity - depth dependence	Va	1	-
Viscosity - temperature dependence	Ea	1.5	-
Basally heated Rayleigh number	Ra_H	$\approx 3 \times 10^6$	-
Internally heated Rayleigh number	Ra_H	$\approx 5 \times 10^7$	-

Table S2: Molar compositions of three particle lithologies (harzburgite, lherzolite, and basalt)[3]

	Harzburgite	Lherzolite	Basalt
SiO₂	36.184	38.819	52.298
MgO	56.559	49.894	15.812
FeO	5.954	6.145	7.121
CaO	0.889	2.874	13.027
Al₂O₃	0.492	1.963	2.244

Table S3: Parameter space for suite of models where models 000-004 have varying CMB temperature, 005-007 have varying plate velocity at the surface, 008-013 have different viscosity structures, 014-016 have different thickness of a basal primordial layer, 017-019 changes the density of a 300 km thick primordial layer, and 020-023 implement different plate motion histories with different reference frames.

Model No	CMB temp. (K)	Plate vel. (cm/yr)	Visc. profile	Primordial layer thickness	Density of primordial layer	Plate motion history
Ref	4000	2.3	v1	-	-	Mu
001	4250	2.3	v1	-	-	Mu
002	4500	2.3	v1	-	-	Mu
003	3500	2.3	v1	-	-	Mu
004	3000	2.3	v1	-	-	Mu
005	4000	9.1	v1	-	-	Mu
006	4000	4.5	v1	-	-	Mu
007	4000	1.5	v1	-	-	Mu
008	4000	2.3	v2	-	-	Mu
009	4000	2.3	v3	-	-	Mu
010	4000	2.3	v4	-	-	Mu
011	4000	2.3	v5	-	-	Mu
012	4000	2.3	v6	-	-	Mu
013	4000	2.3	v7	-	-	Mu
014	4000	2.3	v1	150	3%	Mu
015	4000	2.3	v1	300	3%	Mu
016	4000	2.3	v1	75	3%	Mu
017	4000	2.3	v1	150	1%	Mu
018	4000	2.3	v1	150	5%	Mu
019	4000	2.3	v1	150	10%	Mu
020	4000	2.3	v1	-	-	Me
021	4000	2.3	v1	-	-	NNR
022	4000	2.3	v1	-	-	OV
023	4000	2.3	v1	-	-	SSL

2. Extended Data Figures

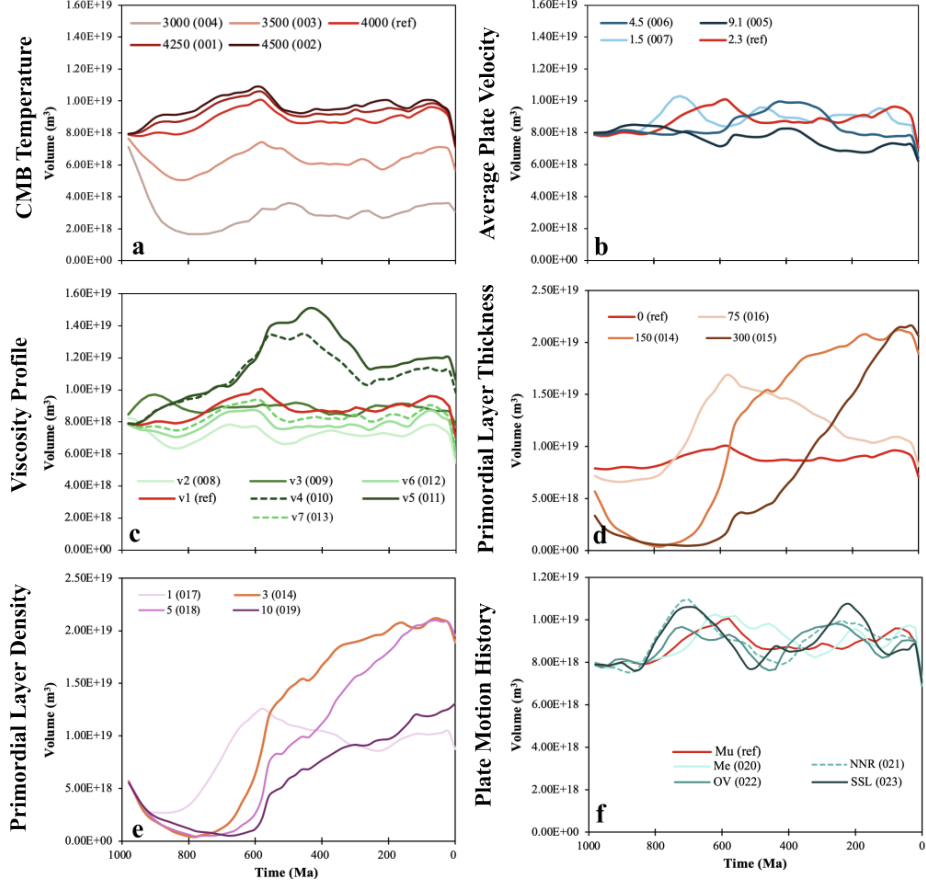


Figure S1: Volumes of material defined as LLSVP-like in the lowermost 800 km of the mantle across each simulation, grouped by the varying parameter (CMB temperature, average plate velocity, viscosity profile, primordial layer thickness, primordial layer density, and plate motion reconstruction).

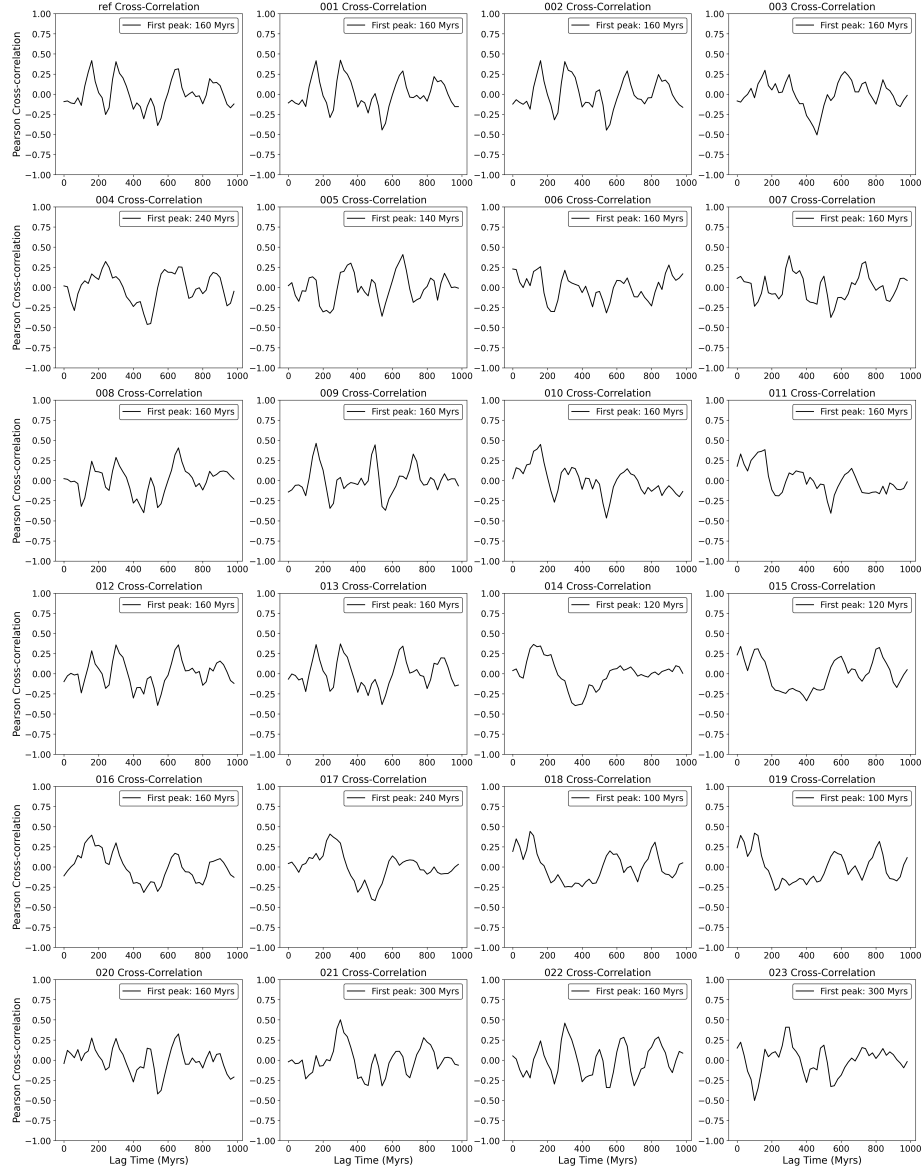


Figure S2: Example slab (defined in yellow by -300 K thermal anomaly) in reference model, showing the time taken to sink through the mantle. Additionally, hot material is shown to be mobile about the CMB and migrates away from slabs as they sink.

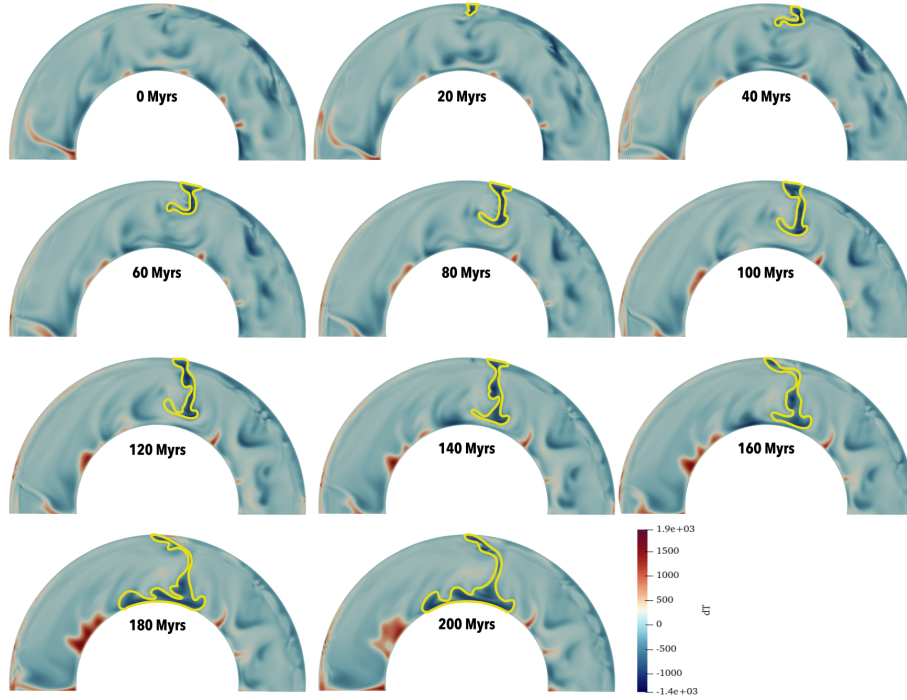


Figure S3: Results of cross correlation algorithm for each simulation showing cycling trend in positive correlations and lag time of the first significant peak in Pearson cross-correlation value. Cross-correlations for each model compare the relationship between the change in Basal Mantle Structure volume and the global length of subduction zones. Significant peaks (considered in selecting first peak) are defined by positive Pearson correlation coefficients greater than 0.2.

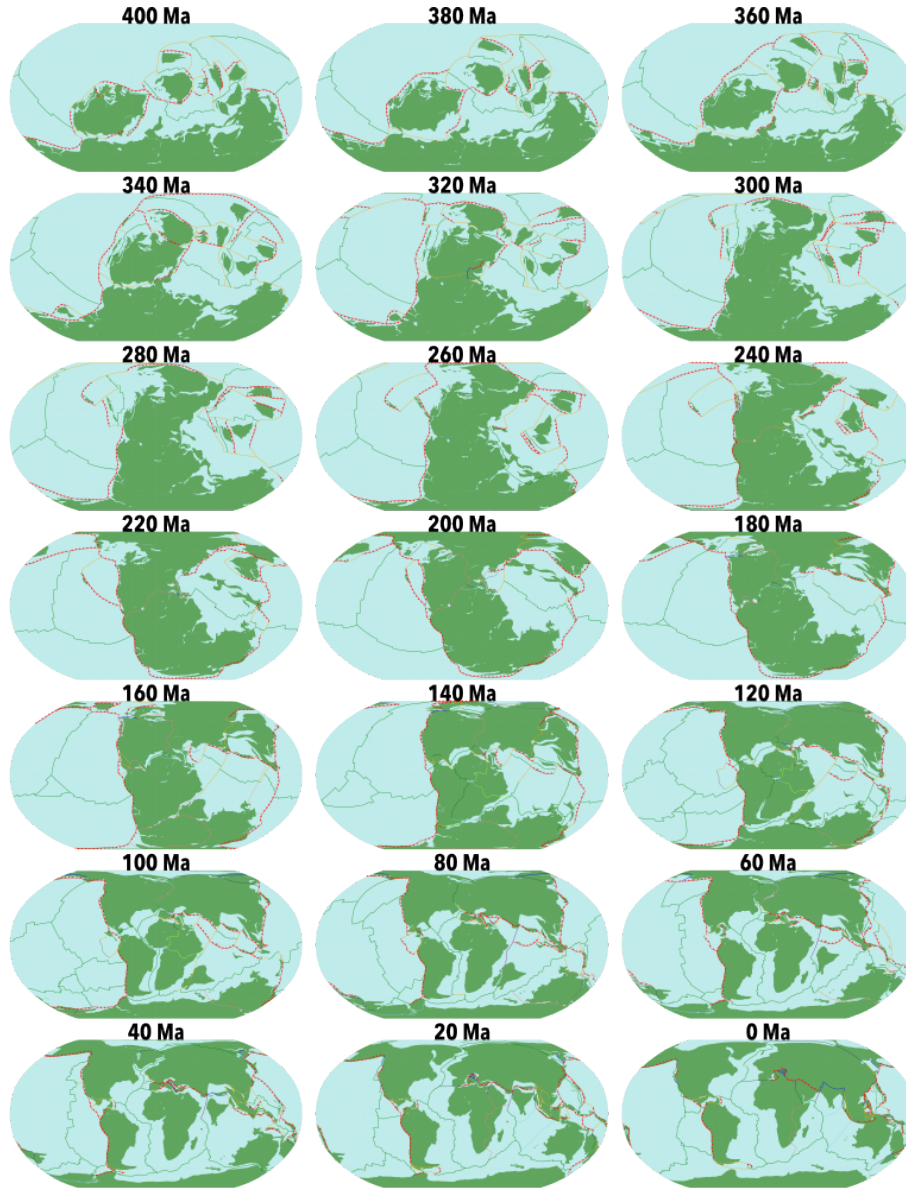


Figure S4: Global GPlates [1] reconstruction through time from the plate motion history of [2] showing the evolution of subduction zones, and their relative stability between ~ 320 -100 Ma initially surrounding Pangaeian supercontinent, and evolving into the Pacific Ring of Fire. Red - subduction zones, green - spreading ridges.

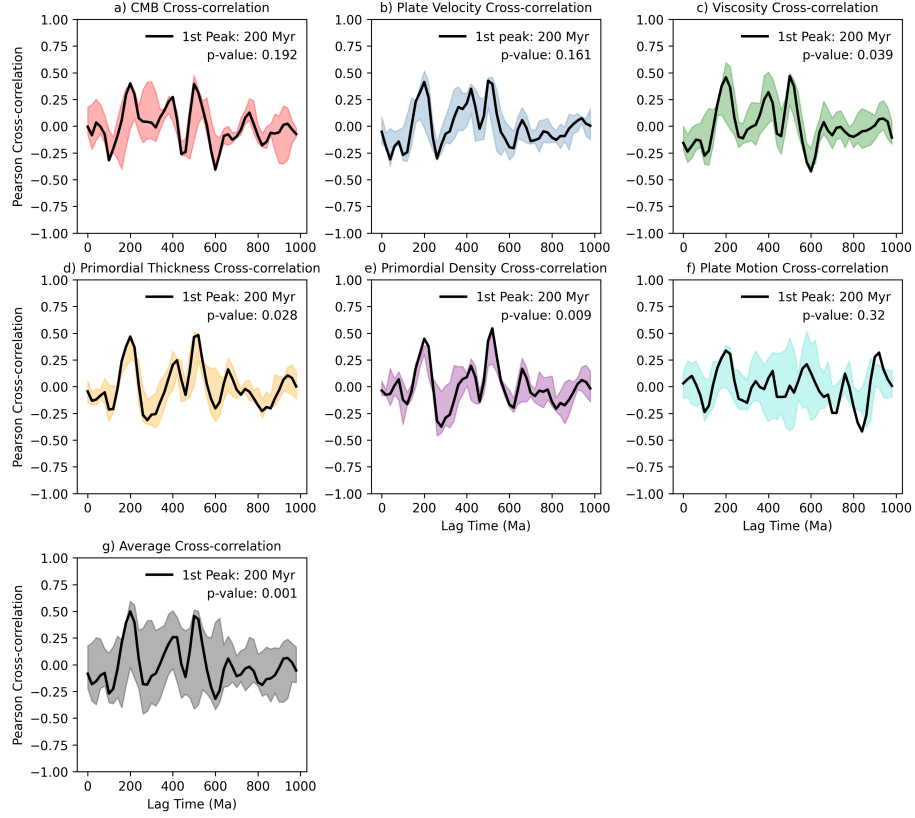


Figure S5: Results of cross-correlation algorithm showing the relationship between global length of subduction zones and the change in dominant spherical harmonic degree across basal mantle structures through time. (a-f) Black lines show the average cross-correlation for models with different CMB temperatures, plate velocities, viscosities, primordial layer thicknesses, primordial layer densities, and plate motion histories, respectively. Coloured space represents the range of values across each individual model. g) average across all of the models. P-values are calculated from Monte-Carlo simulation with 1000 iterations.

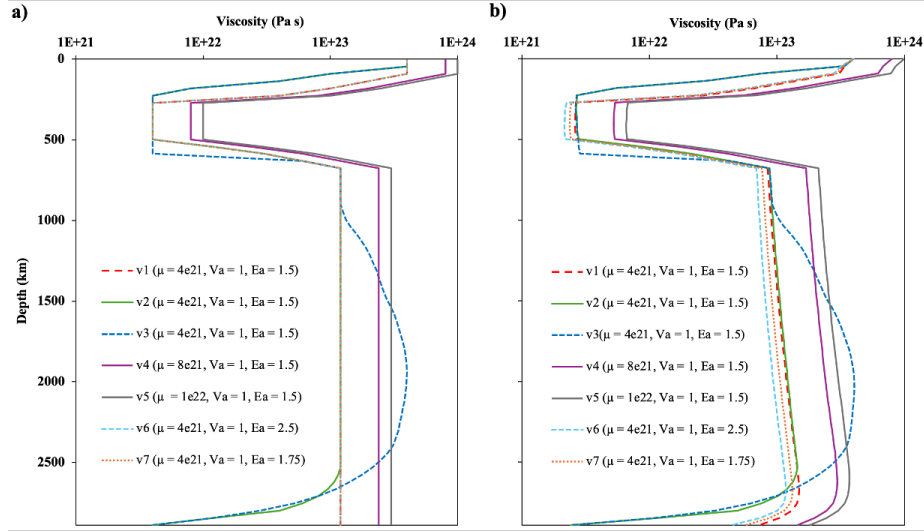


Figure S6: 7 different viscosity profiles used throughout the parameter space of this study at (a) the beginning of the simulations and (b) at the end of the simulations, once the effect of temperature dependence is more developed.

References

- [1] Müller, R.D., Cannon, J., Qin, X., Watson, R.J., Gurnis, M., Williams, S., Pfaffelmoser, T., Seton, M., Russell, S.H., Zahirovic, S., 2018. Gplates: building a virtual Earth through deep time. *Geochemistry, Geophysics, Geosystems* 19, 2243–2261.
- [2] Müller, R.D., Flament, N., Cannon, J., Tetley, M.G., Williams, S.E., Cao, X., Bodur, Ö.F., Zahirovic, S., Merdith, A., 2022. A tectonic-rules-based mantle reference frame since 1 billion years ago—implications for supercontinent cycles and plate–mantle system evolution. *Solid Earth* 13, 1127–1159.
- [3] Panton, J., Davies, J.H., Myhill, R., 2023. The stability of dense oceanic crust near the core-mantle boundary. *Journal of Geophysical Research: Solid Earth* 128, e2022JB025610. doi:<https://doi.org/10.1029/2022JB025610>.