Supplementary Information for

Sluggish thermochemical basal mantle structures support their long-lived stability

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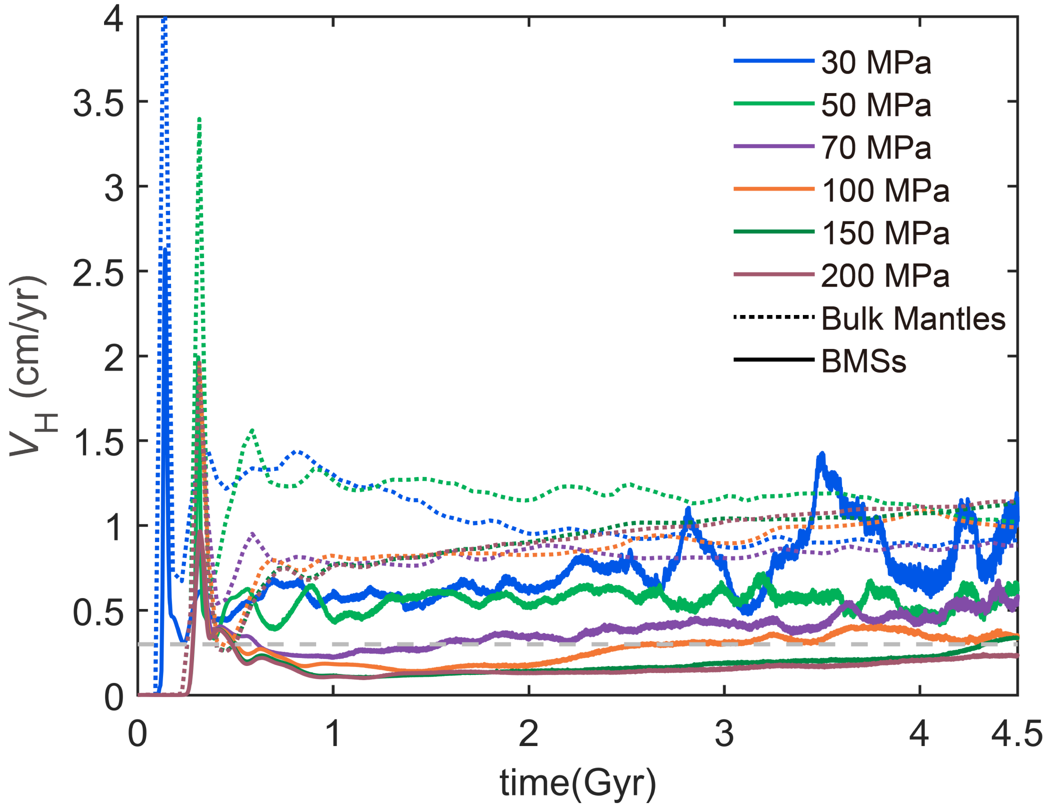
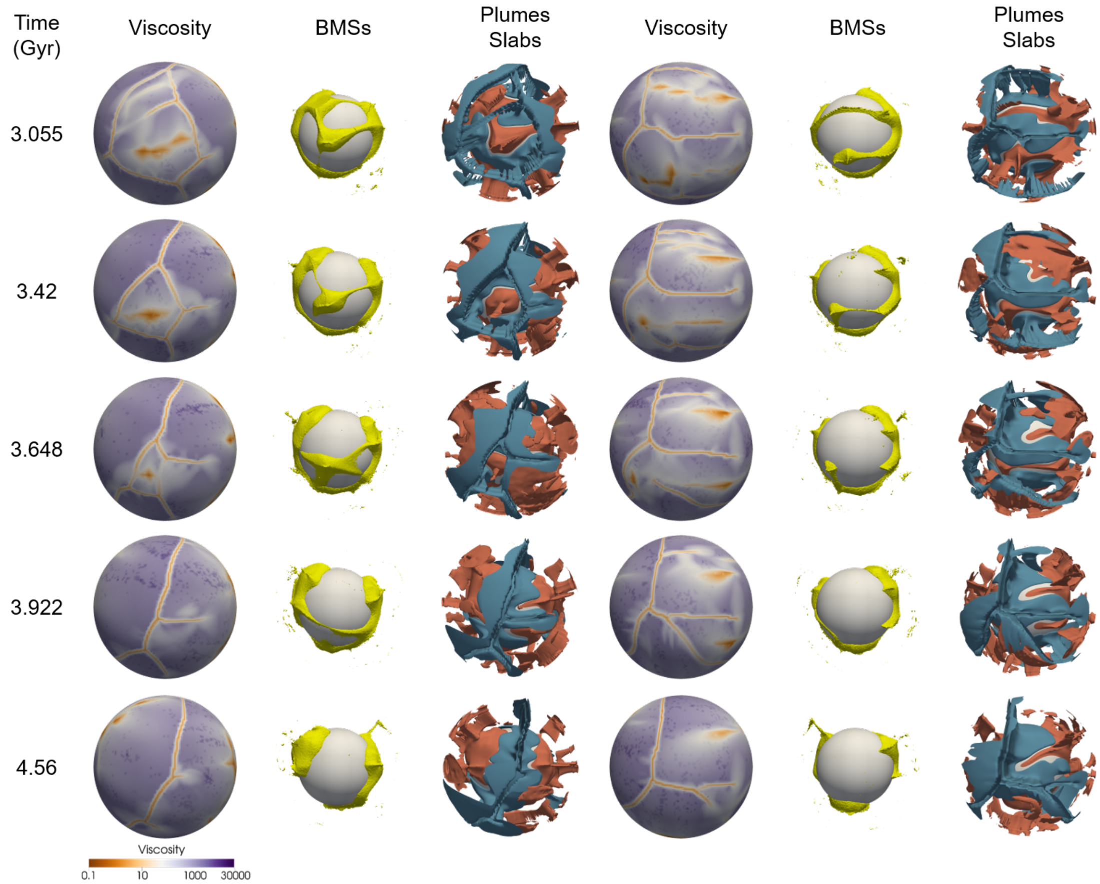
This file includes:

Supplementary Figures 1-8
Supplementary Tables 1-2

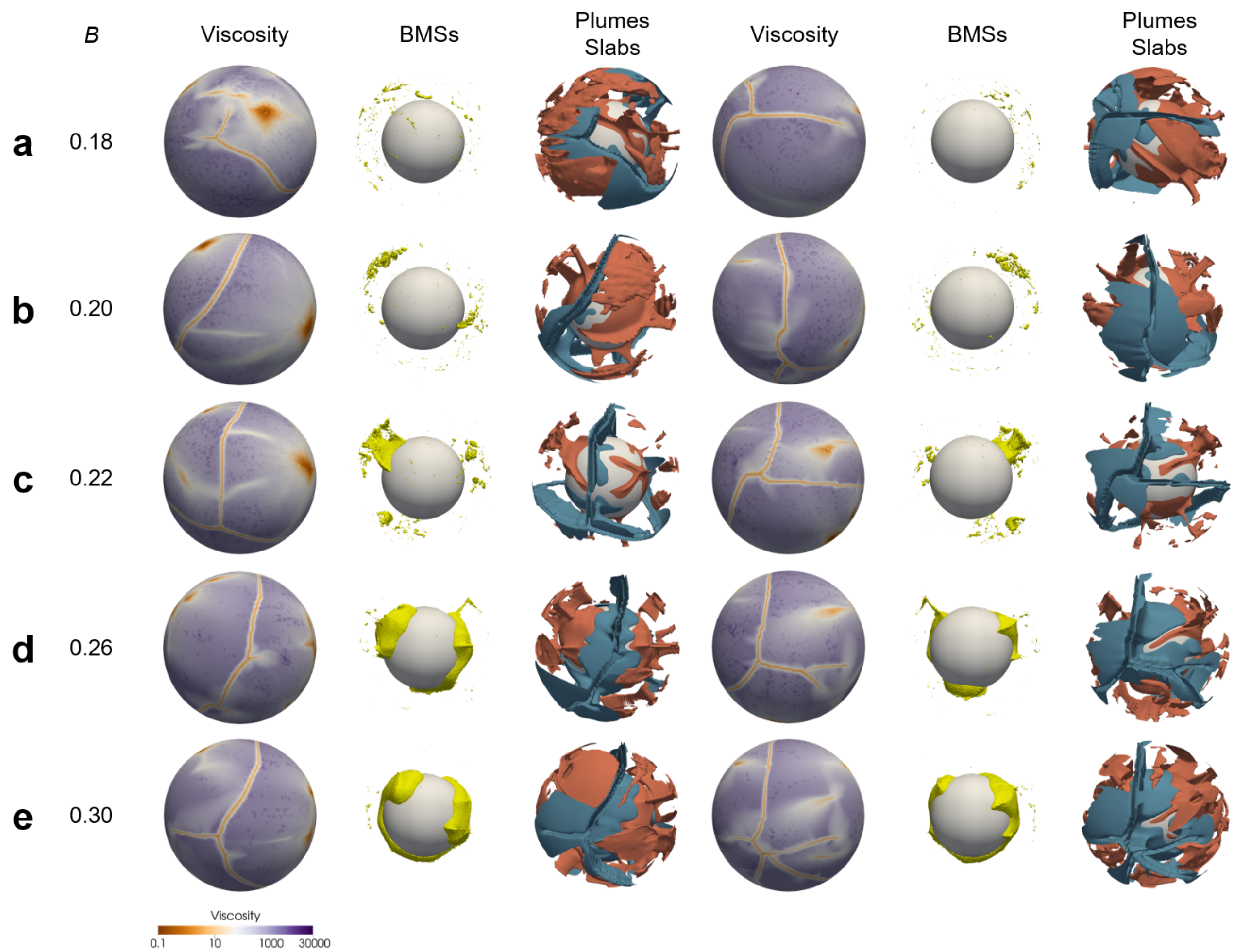
SUPPLEMENTARY FIGURES AND TABLES



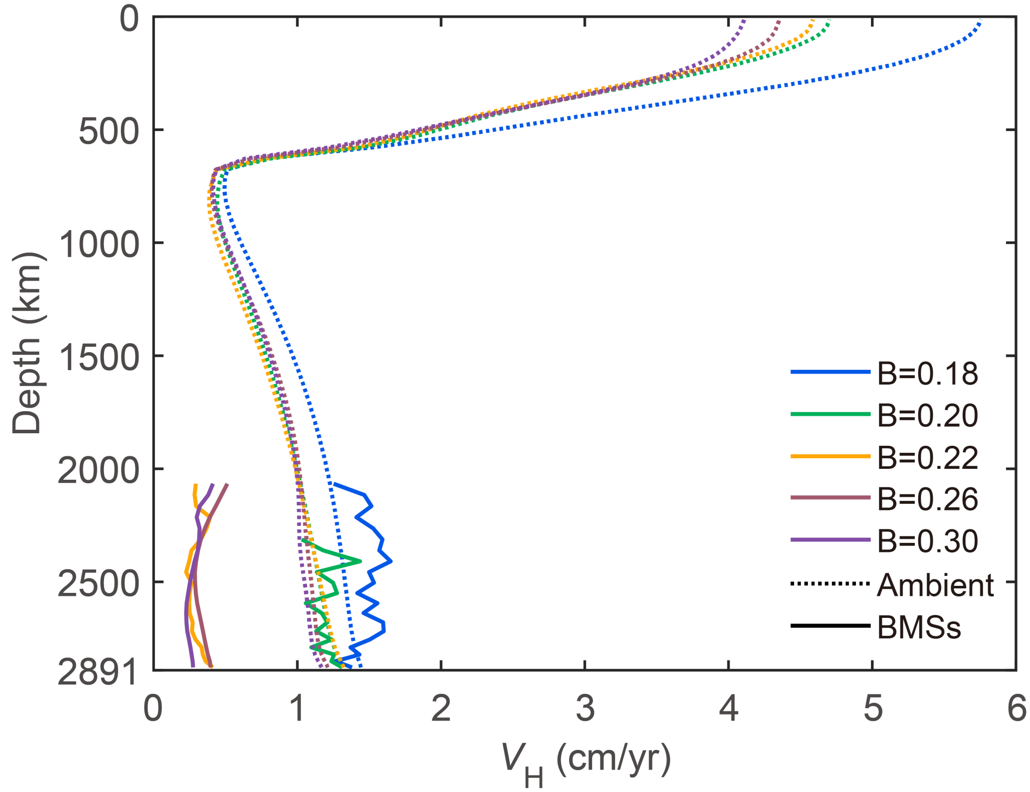
Supplementary Figure 1. Averaged horizontal velocities of BMSs and the bulk mantles as a function of time. The root-mean-square horizontal velocities of BMSs (BMSs; solid lines) and the bulk mantles (dashed lines) between the depth of 2000 km and the CMB for the cases with yield stress of 30 (blue), 50 (green), 70 (purple), 100 (orange), 150 (dark green), and 200 (brown) MPa. The gray dashed line corresponds to a velocity of 0.3 cm/yr.



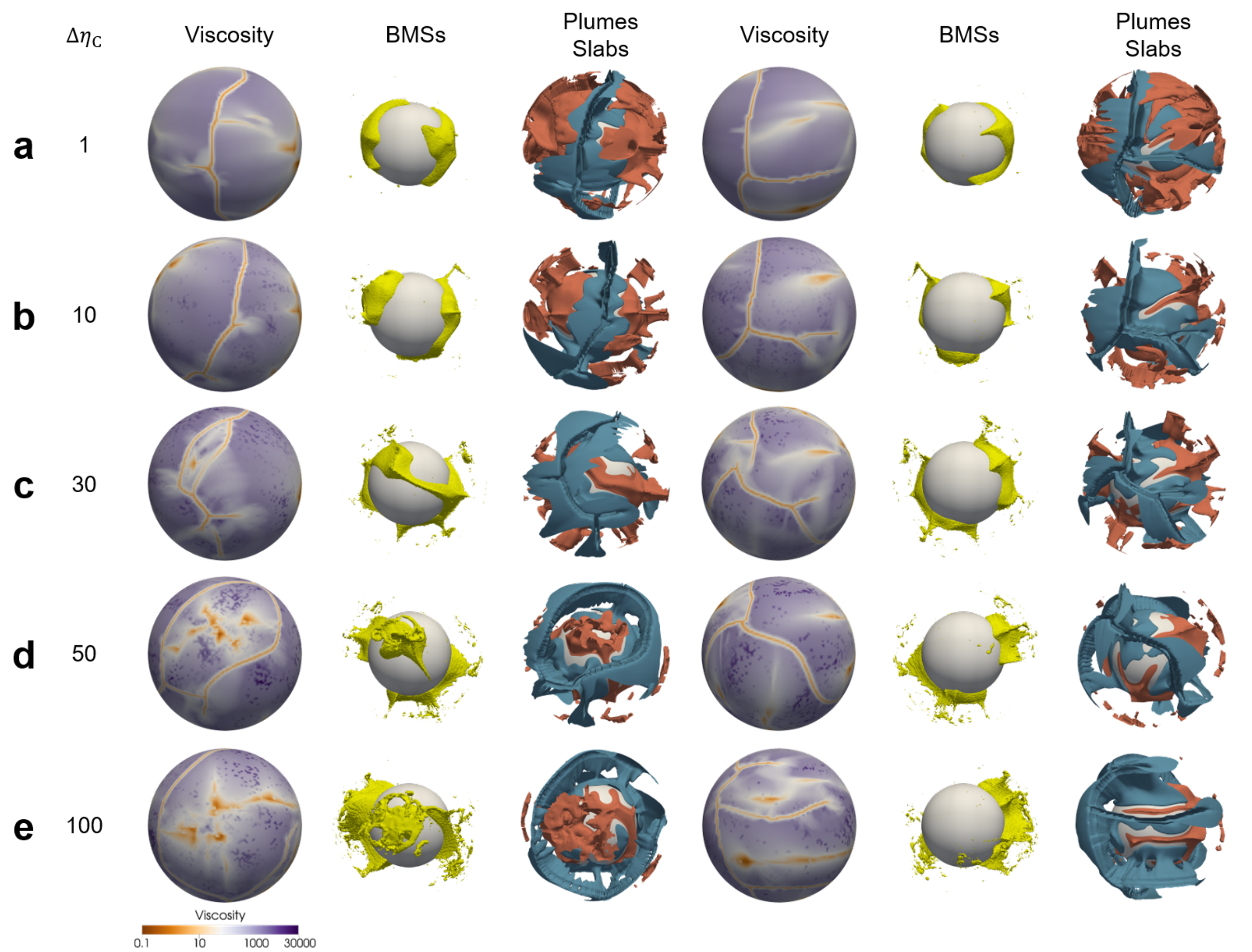
Supplementary Figure 2. Temporal evolution of viscosity, basal mantle structures, plumes, and slabs for the thermo-chemical case with yield stress of 100 MPa. Viscosity at the surface (columns 1 and 4), basal mantle structures (isosurface of the composition with contour level $C = 0.5$, columns 2 and 5), plumes (isosurface of non-dimensional temperature with contour level $f_{\mathrm{p}} = 0.5$, columns 3 and 6, orange), and slabs (isosurface of non-dimensional temperature with contour level $f_{\mathrm{s}} = 0.1$, columns 3 and 6, blue). Columns 4–6 show the opposite hemisphere of columns 1-3.



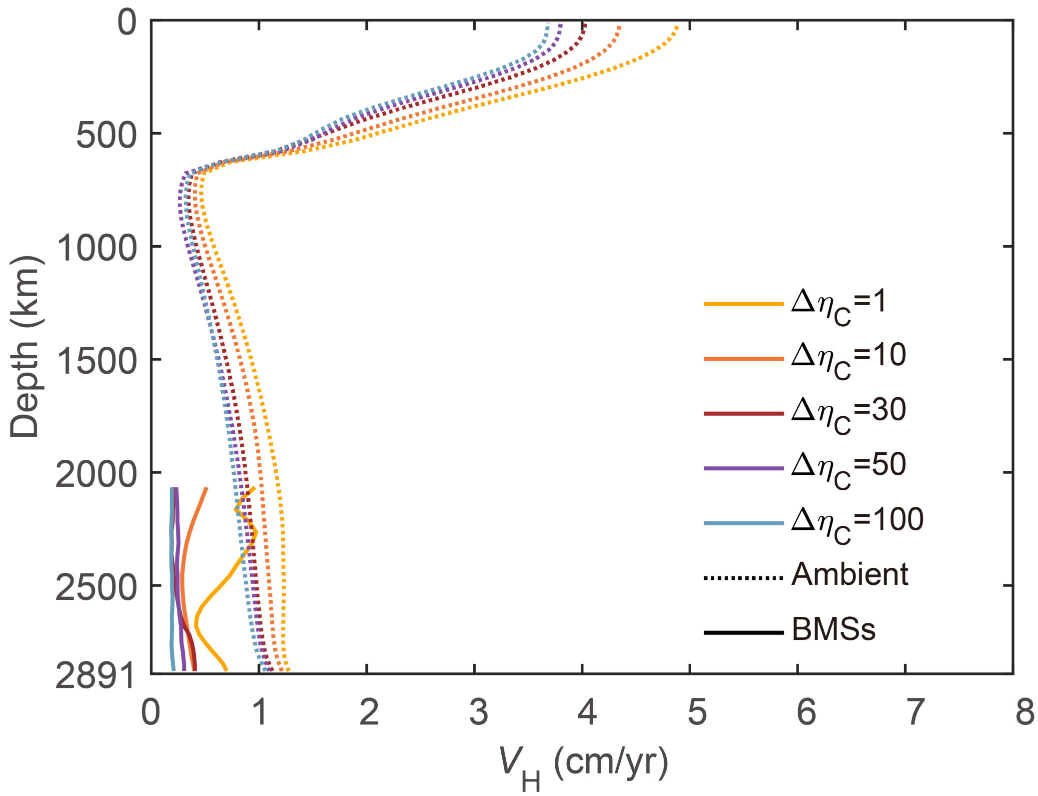
Supplementary Figure 3. Viscosity, basal mantle structures, plumes, and slabs in the models with different buoyancy ratios at *t*=4.56 Gyr. Viscosity at the surface (columns 1 and 4), basal mantle structures (isosurface of the composition with contour level $C = 0.5$, columns 2 and 5), plumes (isosurface of non-dimensional temperature with contour level $f_{\mathrm{p}} = 0.5$, columns 3 and 6, orange), and slabs (isosurface of non-dimensional temperature with contour level $f_{\mathrm{s}} = 0.1$, columns 3 and 6, blue). Columns 4–6 show the opposite hemisphere of columns 1-3. From row **a** to row **e**, buoyancy ratios are 0.18, 0.20, 0.22, 0.26, and 0.30 with the same yield stress of 100 MPa and chemical viscosity contrast of 10.



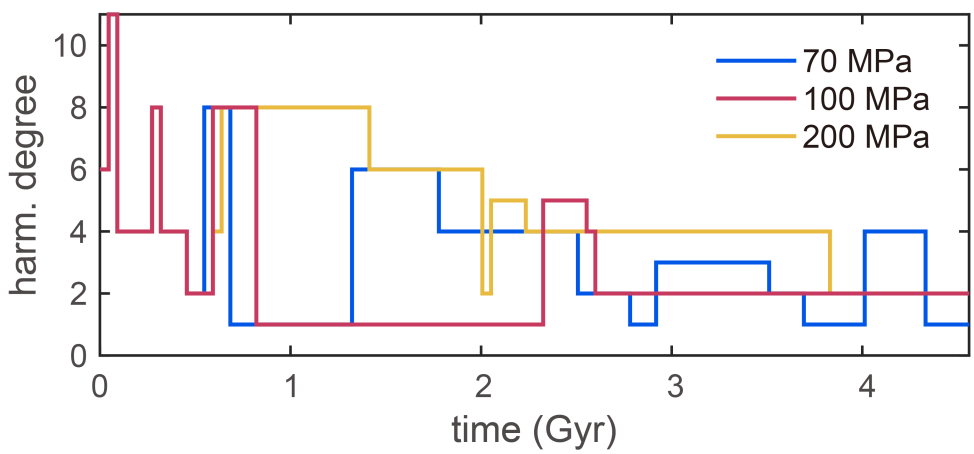
Supplementary Figure 4. 1-D profiles of horizontal velocities of basal mantle structures and the ambient mantles for models with different buoyancy ratios at *t*=4.56 Gyr. 1-D profiles of horizontal velocities of basal mantle structures (BMSs; solid lines), and the ambient mantles (dotted lines) with different buoyancy ratios: 0.18 (blue), 0.20 (green), 0.22 (yellow), 0.26 (brown), and 0.30 (purple).



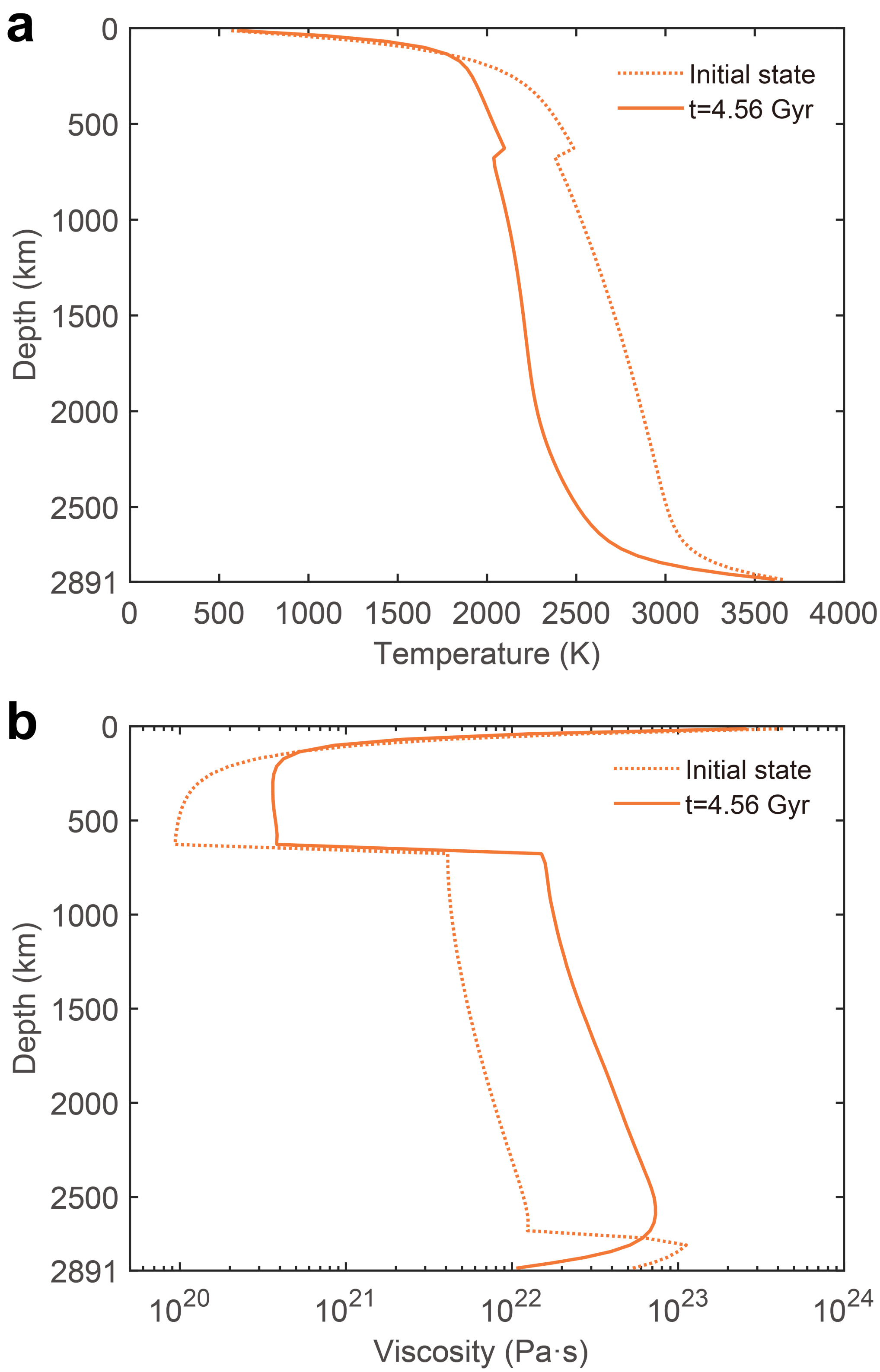
Supplementary Figure 5. Viscosity, basal mantle structures, plumes, and slabs in the models with different chemical viscosity contrasts at *t*=4.56 Gyr. Viscosity at the surface (columns 1 and 4), basal mantle structures (isosurface of the composition with contour level $C = 0.5$, columns 2 and 5), plumes (isosurface of non-dimensional temperature with contour level $f_{\mathrm{p}} = 0.5$, columns 3 and 6, orange), and slabs (isosurface of non-dimensional temperature with contour level $f_{\mathrm{s}} = 0.1$, columns 3 and 6, blue). Columns 4–6 show the opposite hemisphere of columns 1-3. From row **a** to row **e**, chemical viscosity contrasts are 1, 10, 30, 50, and 100 with the same yield stress of 100 MPa and buoyancy ratio of 0.26.



Supplementary Figure 6. 1-D profiles of horizontal velocities of basal mantle structures and the ambient mantles for models with different chemical viscosity contrasts at *t*=4.56 Gyr. 1-D profiles of horizontal velocities of basal mantle structures (BMSs; solid lines), and the ambient mantles (dotted lines) with different chemical viscosity contrasts: 1 (yellow), 10 (orange), 30 (brown), 50 (purple), and 100 (light blue).



Supplementary Figure 7. The dominant degree of harmonic spectrum of temperature in the lower mantle as a function of time for models with different yield stresses. The harmonic spectrum of the temperature field is depth-averaged in the depth of 2000~2891 km corresponding to the depth of BMSs in models and the harmonic degree of maximum spectral amplitudes is selected at each time step.



Supplementary Figure 8. 1-D profiles of temperature and viscosity for models with yield stress of 100 MPa and chemical viscosity contrast of 10. a Temperature profiles of the initial state and at *t*=4.56 Gyr. **b** Viscosity profiles of the initial state and at *t*=4.56 Gyr.

Supplementary Table 1. Model Parameters.

Parameter	Symbol	Value	Units	Non-dimensional
Non-dimensional parameters				
Reference Rayleigh number	$\mathrm{Ra_s}$			1.0×10^{8}
Surface dissipation number	$\mathrm{Di_s}$			1.2
Heating rate	H	7.08×10^{-12}	W $\mathrm{kg^{-1}}$	17.273
Compositional heating ratio	ΔH_{C}	7		
Compositional parameters (for thermo-chemical models)				
Buoyancy ratio	B			0.26
Initial thickness of the dense layer	h_{DL}	173	km	0.06
Physical & thermo-dynamical parameters				
Acceleration of gravity	g	9.81	m $\mathrm{s^{-2}}$	1.0
Mantle thickness	D	2891	km	1.0
Reference adiabat	T_{as}	1600	K	0.64
Super-adiabatic temperature difference	ΔT_{s}	2500	K	1.0
Surface density	ρ_{s}	3300	kg $\mathrm{m^{-3}}$	1.0
Surface thermal expansion	α_{s}	5.0×10^{-5}	$\mathrm{K^{-1}}$	1.0
CMB thermal expansion	α_{b}	1.0×10^{-5}	$\mathrm{K^{-1}}$	0.2
Surface thermal diffusivity	κ_{s}	1.14×10^{-6}	$\mathrm{m^2\ s^{-1}}$	1.0
Heat capacity	C_p	1200	J $\mathrm{kg^{-1}\ K^{-1}}$	1.0
Surface Grüneisen parameter	γ_{s}	1.091		
Density jump at z = 660 km	$\Delta\rho_{660}$	400	kg $\mathrm{m^{-3}}$	0.1212
Clapeyron slope at z = 660 km	Γ_{660}	-2.5	MPa $\mathrm{K^{-1}}$	-0.0668
Viscosity law				
Reference viscosity	η_0	8.56×10^{20}	Pa s	1.0
Viscosity ratio at z = 660 km	$\Delta\eta_{660}$	30		
Activation energy	E_{a}	526	kJ/mol	25.3
Activation volume	V_{a}			4.303
Compositional viscosity ratio	$\Delta\eta_{\mathrm{C}}$	1-100		
Surface yield stress	σ_0	10-200	MPa	8.6×10^{4}-1.7×10^{6}
Yield stress gradient	$\dot{\sigma}_z$	0	Pa/Pa	0

Supplementary Table 2. Statistics of the numbers and CMB area of BMSs of cases with different yield stresses at t=4.56 Gyr.

Yield stress (MPa)	Numbers of BMSs	Area of BMSs
10	0	0.0287
30	0	0.0468
50	1	0.1071
60	1	0.0736
70	2	0.1057
80	2	0.1438
90	2	0.2355
95	2	0.2266
100	2	0.2506
120	1	0.4152
150	1	0.4859
170	1	0.4170
200	1	0.4251