

Supporting Information for:
Lower melt focusing efficiency governs the formation of
extremely thin oceanic crust at superfast spreading centers

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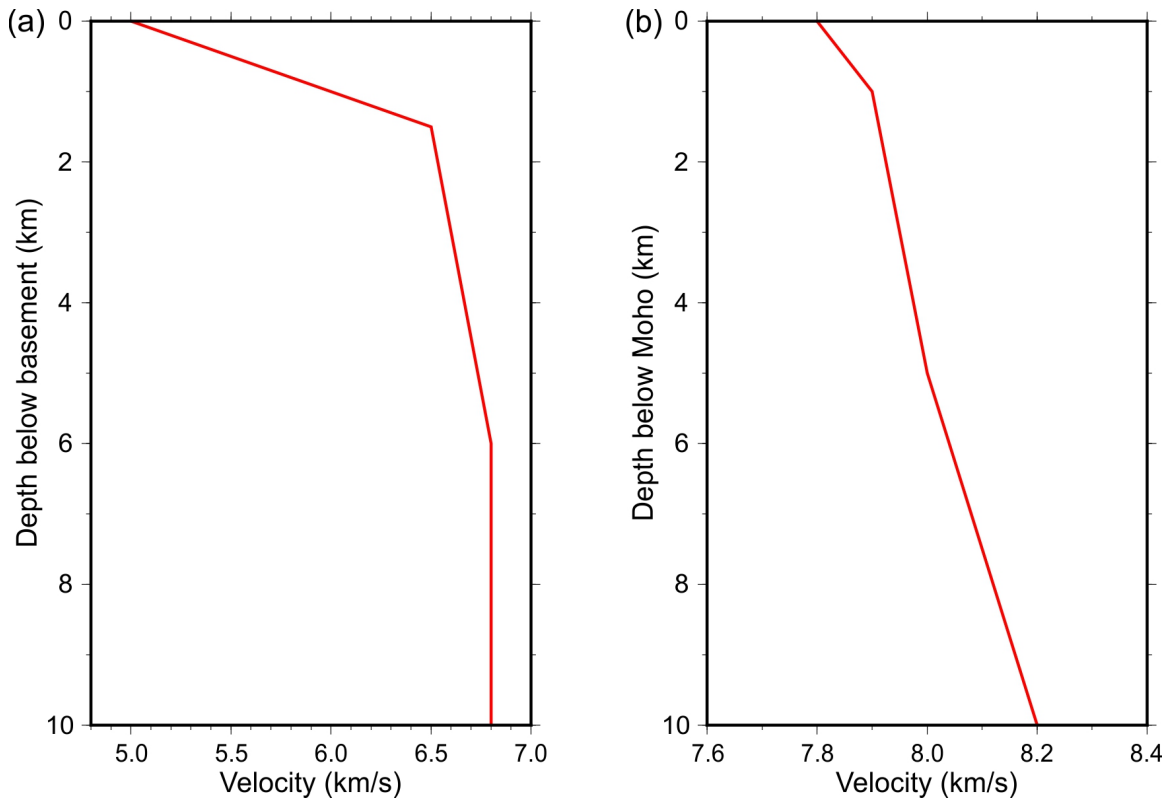


Figure S1: Initial 1D velocity setting for the crust **(a)** and the mantle **(b)** used in the tomographic inversion.

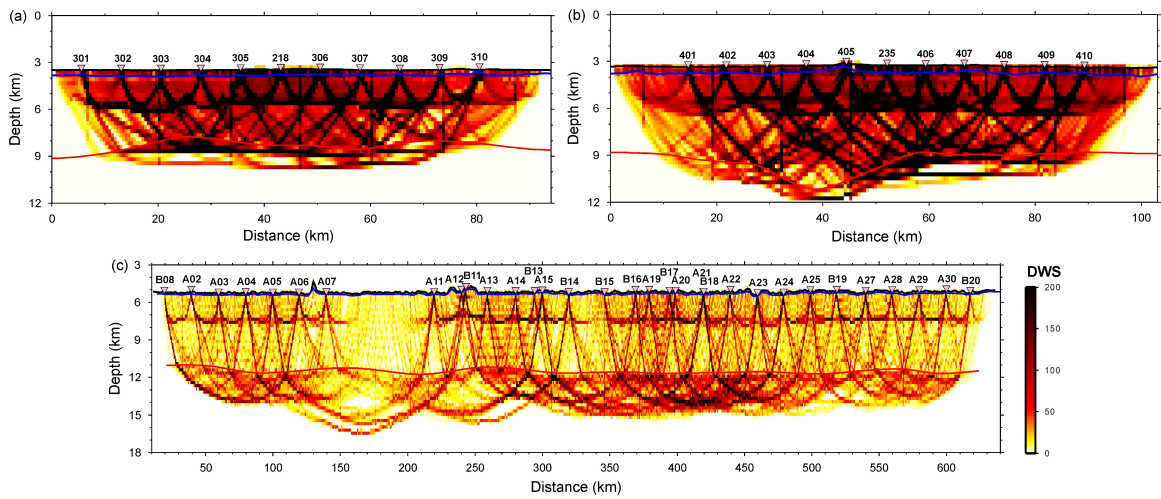
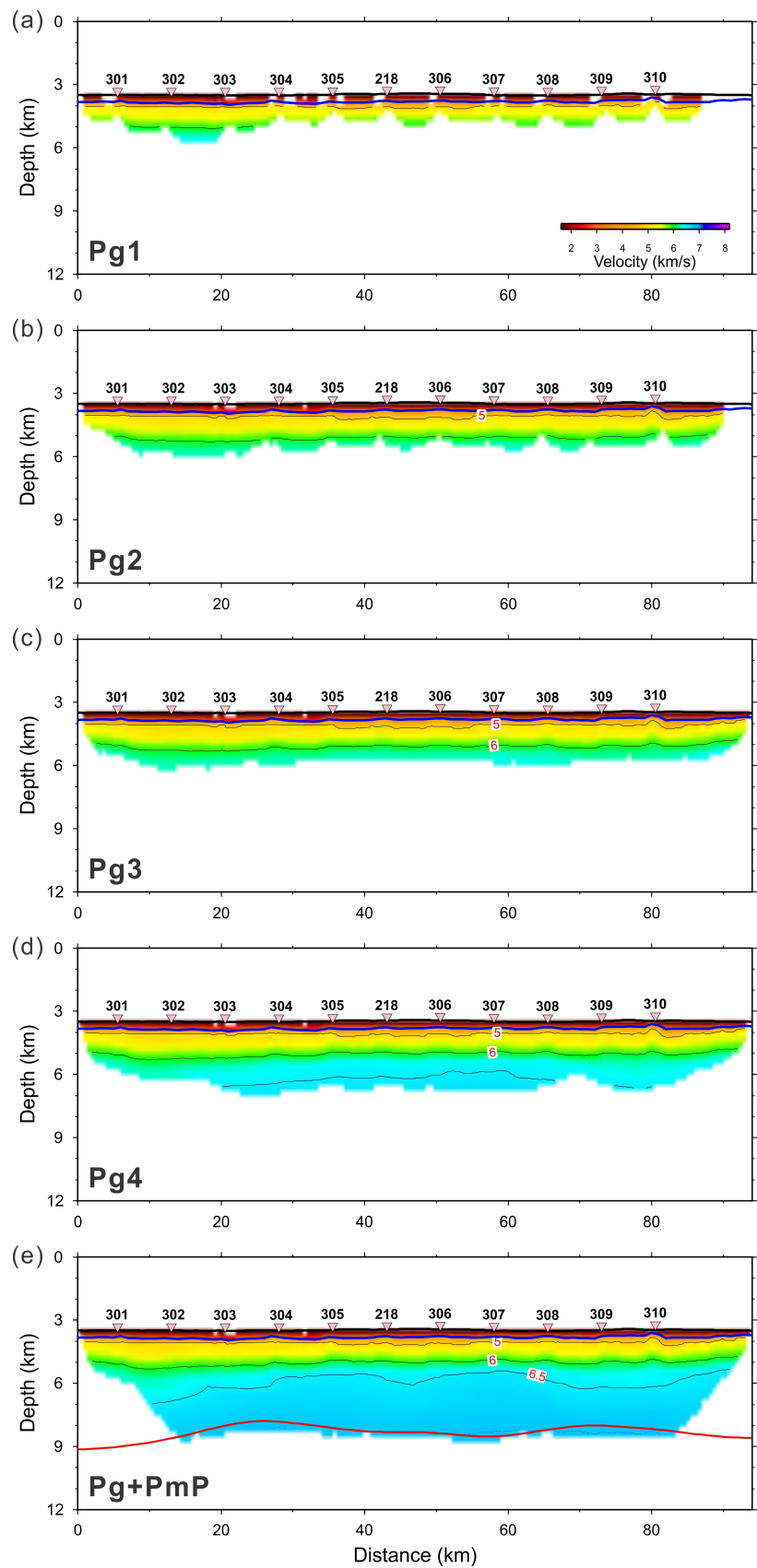


Figure S2: The derivative weight sum (DWS) of the final velocity models for **(a)** p300, **(b)** p400, and **(c)** NoMelt profiles, showing the ray coverage density. Pink inverted triangles show the OBS locations. The black, blue, and red lines represent the geometries of the seafloor, basement, and the Moho.



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Figure S3: Results of each step of inversion under layer-stripping top-down approach for profile p300. See Fig. S1 for the initial velocity setting. Pink inverted triangles show the OBS locations. The black, blue, and red lines represent the geometries of the seafloor, basement, and the Moho.

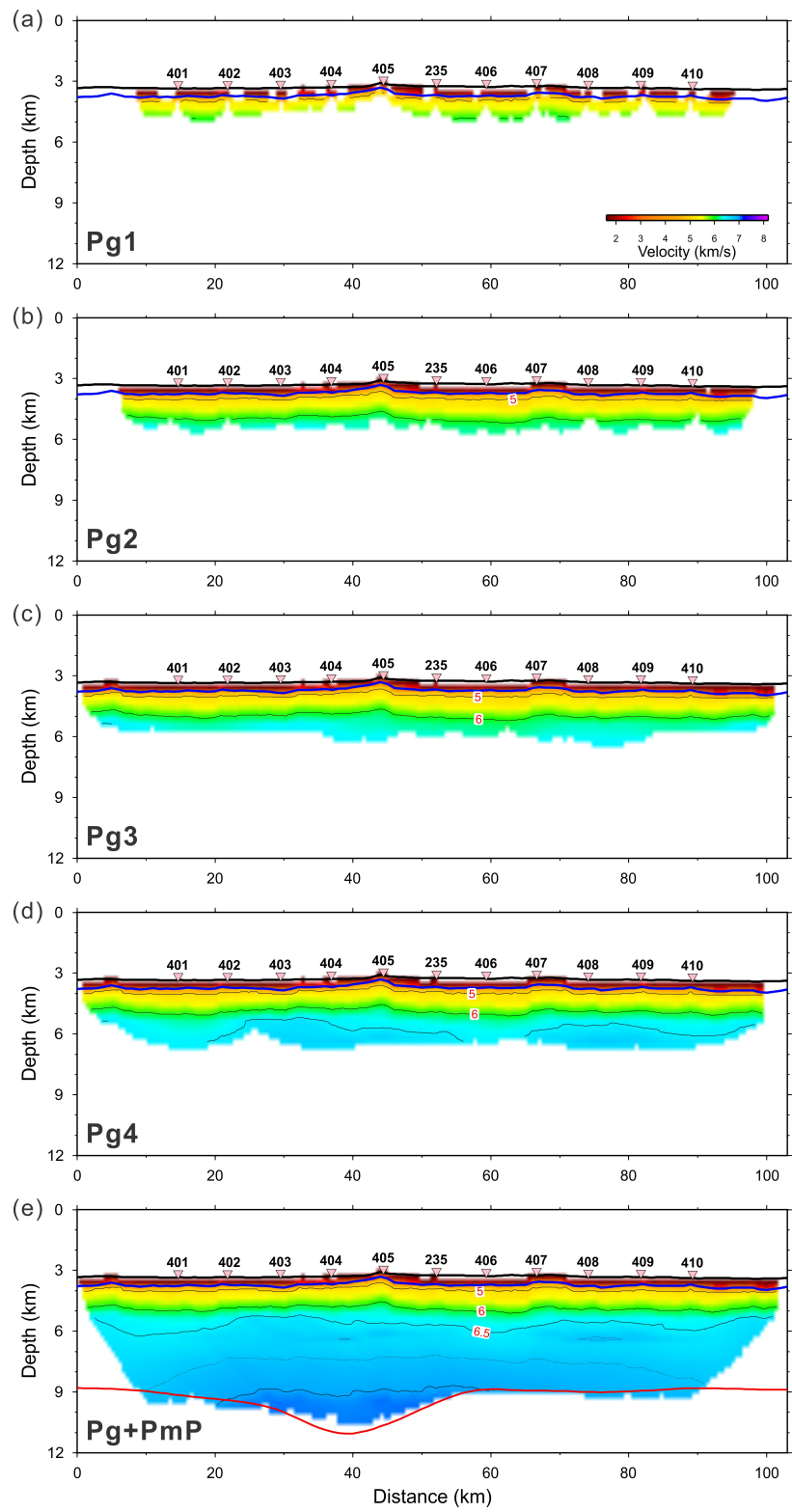


Figure S4: Results of each step of inversion under layer-stripping top-down approach for profile p400. See Fig. S1 for the initial velocity setting. Pink inverted triangles show the OBS locations. The black, blue, and red lines represent the geometries of the seafloor, basement, and the Moho.

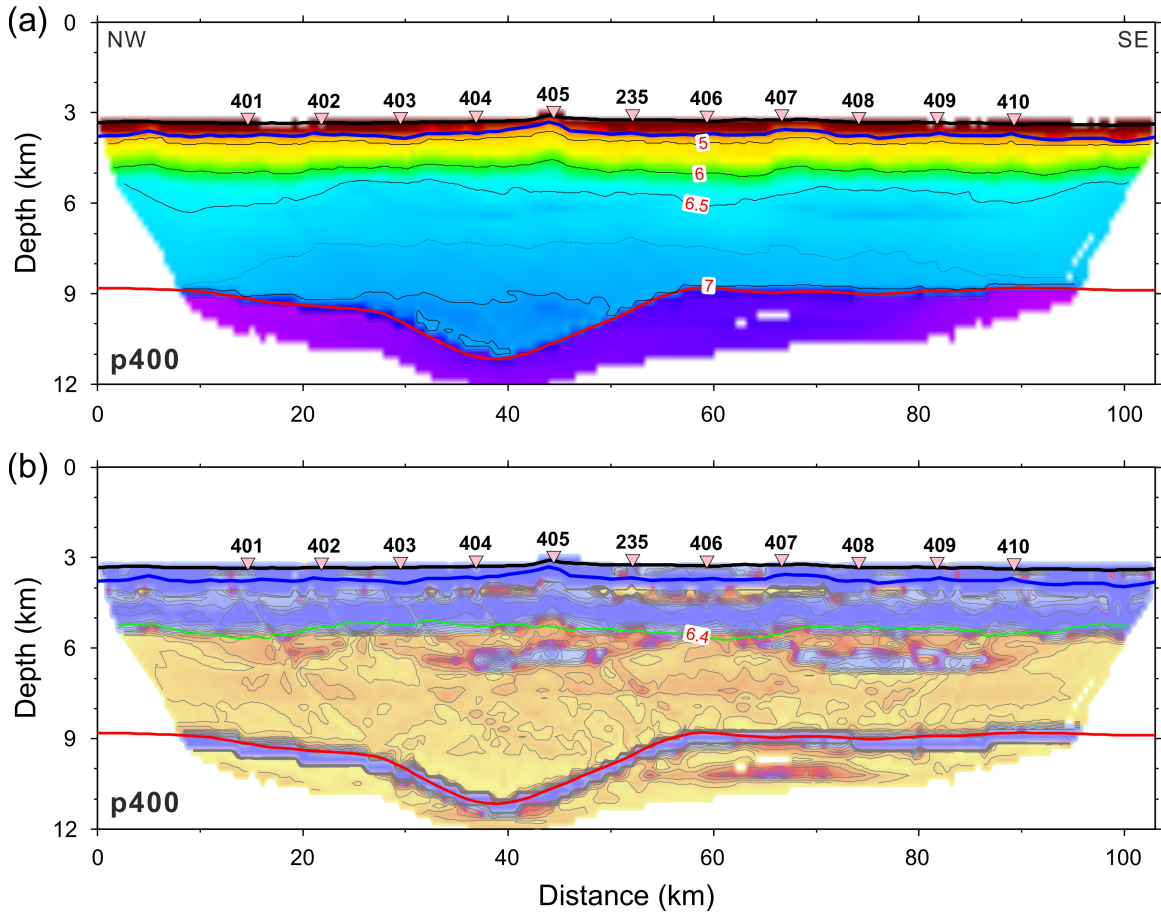


Figure S5: Seismic results along profile p400. (a) Seismic velocity model and (b) its associated vertical velocity gradient model. This profile traverses the 21 Ma oceanic crust formed at an HSR of 61 mm/yr in the Guatemala Basin. This profile crosses an area that was affected by widespread petit-spot volcanism in the Cocos plate (Naif et al., 2023) and therefore shows thickened crust at model distance 30-60 km. Pink inverted triangles show the OBS locations. The black, blue, and red lines represent the geometries of the seafloor, basement, and the Moho.

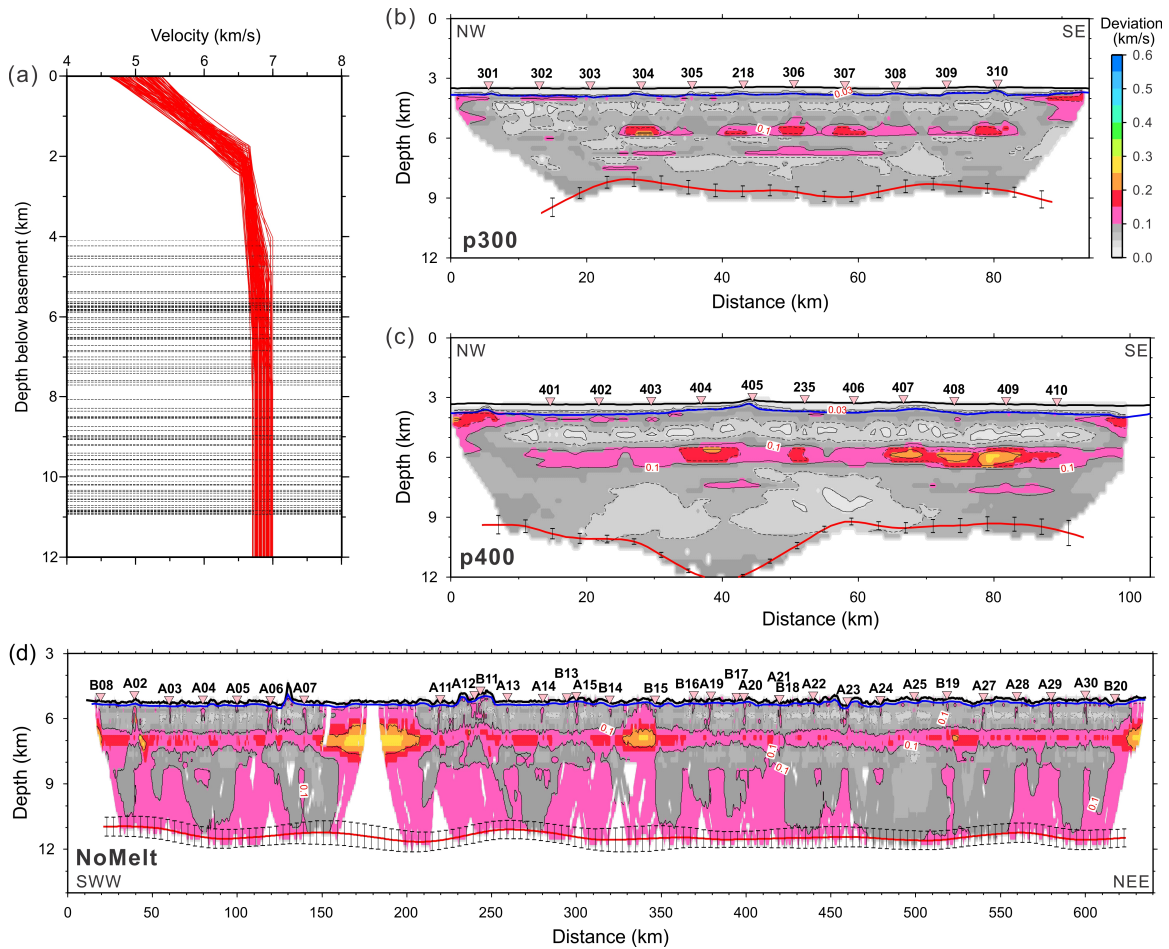


Figure S6: The result of uncertainty tests. (a) 1D Initial velocity models for the uncertainty tests. The red lines mark the perturbed one hundred initial 1D velocity structures while the dashed black lines show the perturbed one hundred initial Moho depths. (b-d) shows the velocity deviation for profiles p300, p400, and NoMelt, respectively. The red line and error bars represent the average Moho depth and deviation range. Pink inverted triangles show the OBS locations. The black, blue, and red lines represent the geometries of the seafloor, basement, and the Moho.

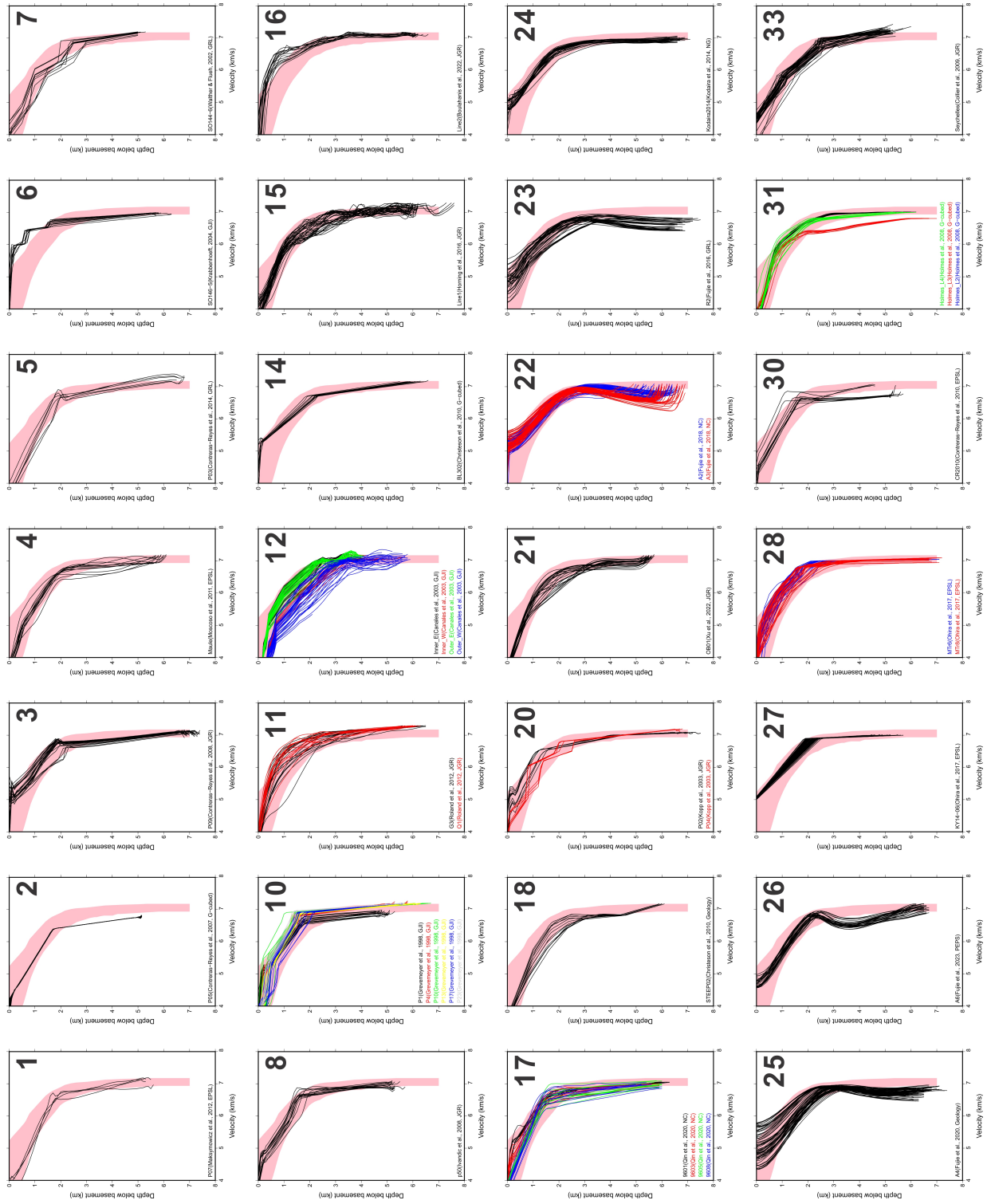


Figure S7: 1D depth-velocity profiles from different wide-angle seismic profiles included in the global compilation. Samples are taken at 5 km intervals along-profile. Panels are numbered corresponding to profile references in Supplementary Data S3. The pick region shows the magmatic crustal structure compiled by [Grevemeyer et al. \(2018\)](#)

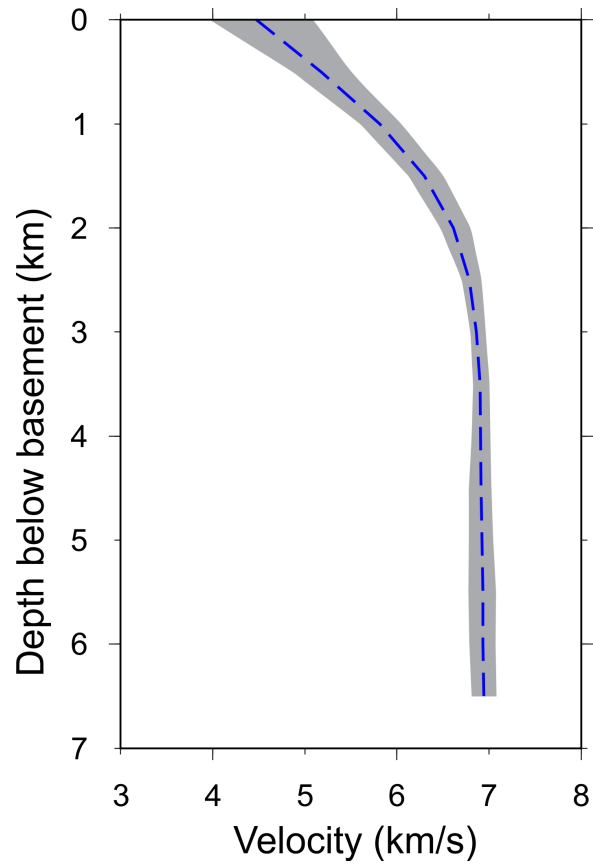


Figure S8: Typical magmatic oceanic crust ensemble based on our global compilation. The grey area marks a compact ensemble that includes 50% of magmatic crust between Q1 and Q3 at different depth level. See Fig. 3c for the box plot of global ensemble. The dashed blue line denotes the global average oceanic structure.

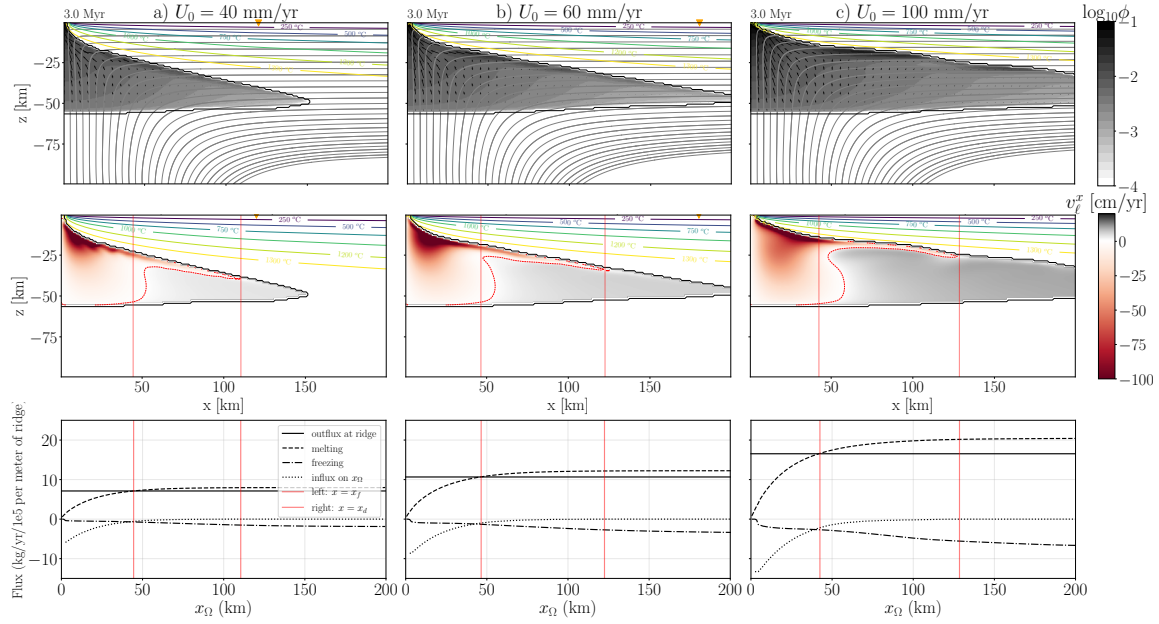


Figure S9: Results of reference models for half-spreading rates **(a)** $U_0 = 40$ mm/yr, **(b)** $U_0 = 60$ mm/yr, **(c)** $U_0 = 100$ mm/yr. Top panels: porosity maps with grey mantle streamlines and colored temperature contours. Middle panels: horizontal liquid velocity (v_l^x) map showing the focusing of melt to the ridge axis. Bottom panels: flux contributions due to outflux at the ridge, melting and freezing (net generation), and influx on a moving vertical boundary that moves laterally with $x = x_\Omega$. The left vertical red line represents the focusing distance (Katz, 2008) and marks the transition from positive (i.e., focusing towards the ridge axis) to negative (i.e., focusing away from the ridge axis) v_l^x values. The right vertical red line marks the lateral extent of the decompaction channel. Reference parameters: $\eta_0 = 10^{18}$ Pa s, $\zeta_0 = 40\eta_0$, $K_0 = 10^{-7}$ m², $T_p = 1,375^\circ\text{C}$.

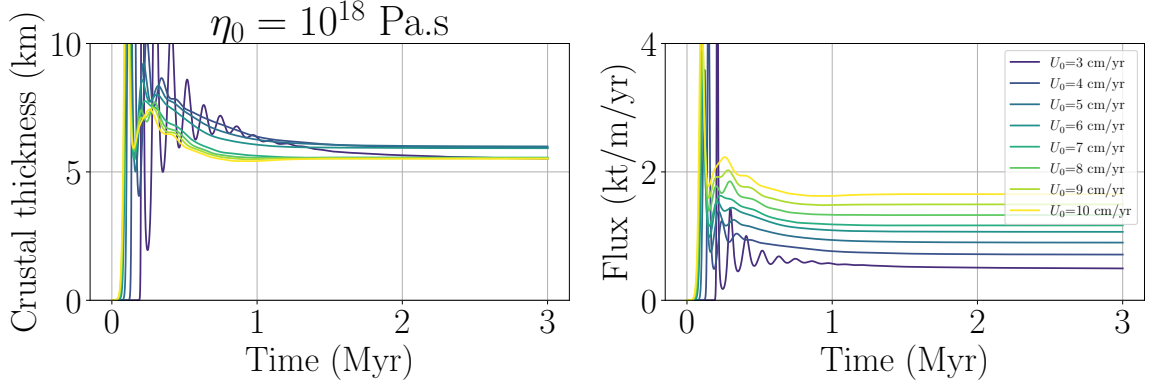


Figure S10: Evolution of crustal thickness (left panel) and melt flux (right panel) at the ridge axis over time. Colored lines represent simulations with different half-spreading rates. All models reach steady-state, defined as the state in which crustal production and distribution of partial melt are roughly constant, after ~ 2 Myr of model evolution. Reference parameters: $\eta_0 = 10^{18}$ Pa s, $\zeta_0 = 40\eta_0$, $K_0 = 10^{-7}$ m², $T_p = 1,375^\circ\text{C}$.

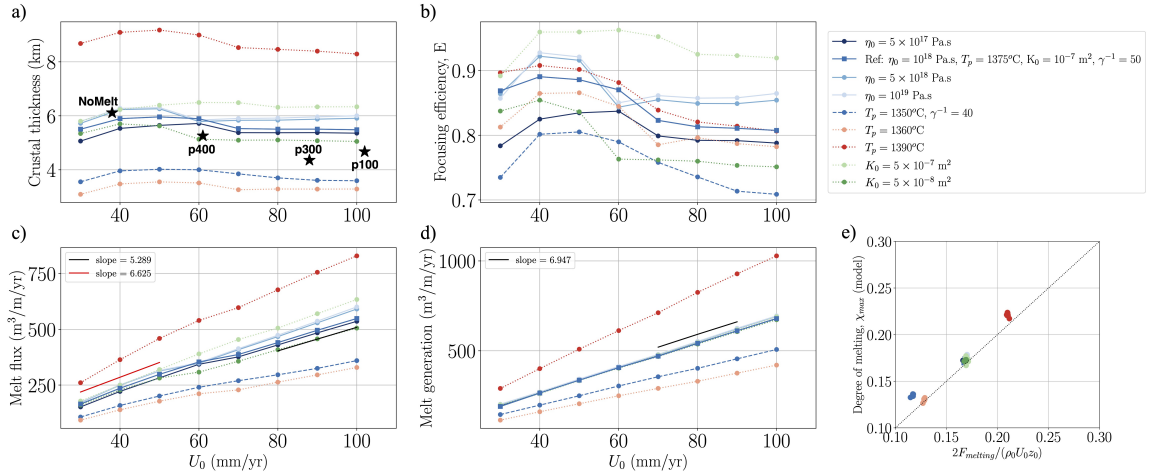


Figure S11: Summary of steady-state numerical simulations of mid-ocean ridge two-phase flow dynamics. Crustal thickness (a), focusing efficiency (b), melt flux at the ridge axis, $f_{outflux}$ (c), and melt generation rate, $f_{melting}$ (d) varying with half-spreading rate U_0 . The reference models (blue squares) have reference shear viscosity $\eta_0 = 10^{18}$ Pa s, mantle potential temperature $T_p = 1375^\circ\text{C}$, reference permeability $K_0 = 10^{-7}$ m², and the inverse Clapeyron slope $\gamma^{-1} = 50$ K/GPa. The colored curves indicate the parameters varied relative to the reference models. The black stars represent the average thickness and spreading rate for each seismic profiles discussed in this study. (e) Scaling of degree of melting, χ_{max} , from each simulation as a function of melt generation and spreading rate.

Table S1: Velocity parameters at different depths from global compilation of magmatic oceanic crust. The minimum, medium, and maximum values of typical oceanic crust (TOC) are from Q1, Q2, and Q3 of global value, respectively.

Range of depth below basement (km)	Minimum value of TOC (Q1, km/s)	Medium value of TOC (Q2, km/s)	Maximum value of TOC (Q3, km/s)	Minimum global value (km/s)	Maximum global value (km/s)	Average global value (km/s)	Standard deviation (km/s)
0-0.25	3.972	4.575	5.089	2.370	5.950	4.472	0.745
0.25-0.75	4.901	5.262	5.504	3.261	6.518	5.181	0.477
0.75-1.25	5.604	5.846	6.051	4.516	6.908	5.816	0.364
1.25-1.75	6.126	6.323	6.504	4.832	6.999	6.299	0.329
1.75-2.25	6.472	6.657	6.801	5.165	7.037	6.614	0.268
2.25-2.75	6.703	6.827	6.915	5.552	7.117	6.787	0.206
2.75-3.25	6.793	6.887	6.965	6.021	7.187	6.862	0.175
3.25-3.75	6.828	6.918	7.006	6.386	7.321	6.900	0.177
3.75-4.25	6.804	6.939	7.015	6.394	7.267	6.907	0.180
4.25-4.75	6.779	6.952	7.024	6.467	7.318	6.914	0.193
4.75-5.25	6.782	6.963	7.046	6.376	7.372	6.924	0.214
5.25-5.75	6.776	6.989	7.075	6.303	7.379	6.931	0.241
5.75-6.25	6.786	7.003	7.072	6.252	7.381	6.934	0.259
6.25-6.75	6.813	7.028	7.081	6.245	7.393	6.945	0.280
6.75-7.25	6.910	7.049	7.092	6.431	7.300	6.988	0.386
7.25-7.75	6.981	7.062	7.100	6.755	7.296	7.043	1.137

References

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