Supplementary Information for: Mafic Archean continental crust prohibited exhumation of orogenic UHP eclogite

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MONTE CARLO SENSITIVITY ANALYSIS

Checks on the validity of our petrological modeling results were performed by applying a Monte Carlo sensitivity analysis to the error in proportions of ultramafic (komatiite), mafic (greenstone), and felsic (TTG gneiss) components reported by Chen et al. (2020) for Mesoarchean UCC. These ranges were: 0–36 vol. % (komatiite), 64–75 vol. % (greenstone), and 0–25 vol. % (TTG). We applied the Monte Carlo randomization procedure outlined by Palin et al. (2016) to generate 500 new estimations of the bulk Archean UCC composition. These spread mostly between the basalt and basaltic andesite fields on a conventional total alkali–silica (TAS) diagram (Fig. S4), with some positioned in the picrobasalt, tephrite, and andesite fields. This analysis was applied to both anhydrous and minimally hydrated scenarios, as described in the Methods section of the main manuscript. This procedure was not performed for felsic Proterozoic or Phanerozoic UCC, given the lower uncertainty of its composition and its strong negative buoyancy during subduction, as shown in Fig. 3. For the Archean UCC, eight discrete pressure–temperature (*P*–*T*) points were considered along the modelled path: 400 °C and 0.95 GPa, 450 °C and 1.16 GPa, 500 °C and 1.42 GPa, 550 °C and 1.72 GPa, 600 °C and 2.07 GPa, 650 °C and 2.46 GPa, 700 °C and 2.90 GPa, and 750 °C and 3.38 GPa.

Box and whisker plots (Fig. S5) for each of these *P*–*T* conditions demonstrate that crustal composition determined by Chen et al. (2020) using a komatiite–basalt–felsic rock ratio of 20:69:11 (Table S1) is representative of the total range as defined by their calculated errors, showing densities correlating more or less with the 50th percentile of the randomized set in each case. The calculated ‘point of no return’ for minimally hydrated Archean UCC discussed in the main manuscript, which occurs at ~2.3 GPa (Fig. 3), is reproduced by this sensitivity analysis (cf. Fig. S5). At slightly lower pressure, between 0% and 28% of all randomized bulk compositions exhibit negative buoyancy, although above 2.4 GPa, between 73% and 92% are denser than surrounding mantle pyrolite. For anhydrous equivalents, very few randomized examples retain positive buoyancy compared to mantle pyrolite: from 22% to 33% below the quartz–coesite transition, and less than 19% above the transition. These data suggest that some highly felsic crust may have the potential to be exhumed from Archean subduction zones without the help of external forcing, although this is not expected to be the norm.

FIGURES

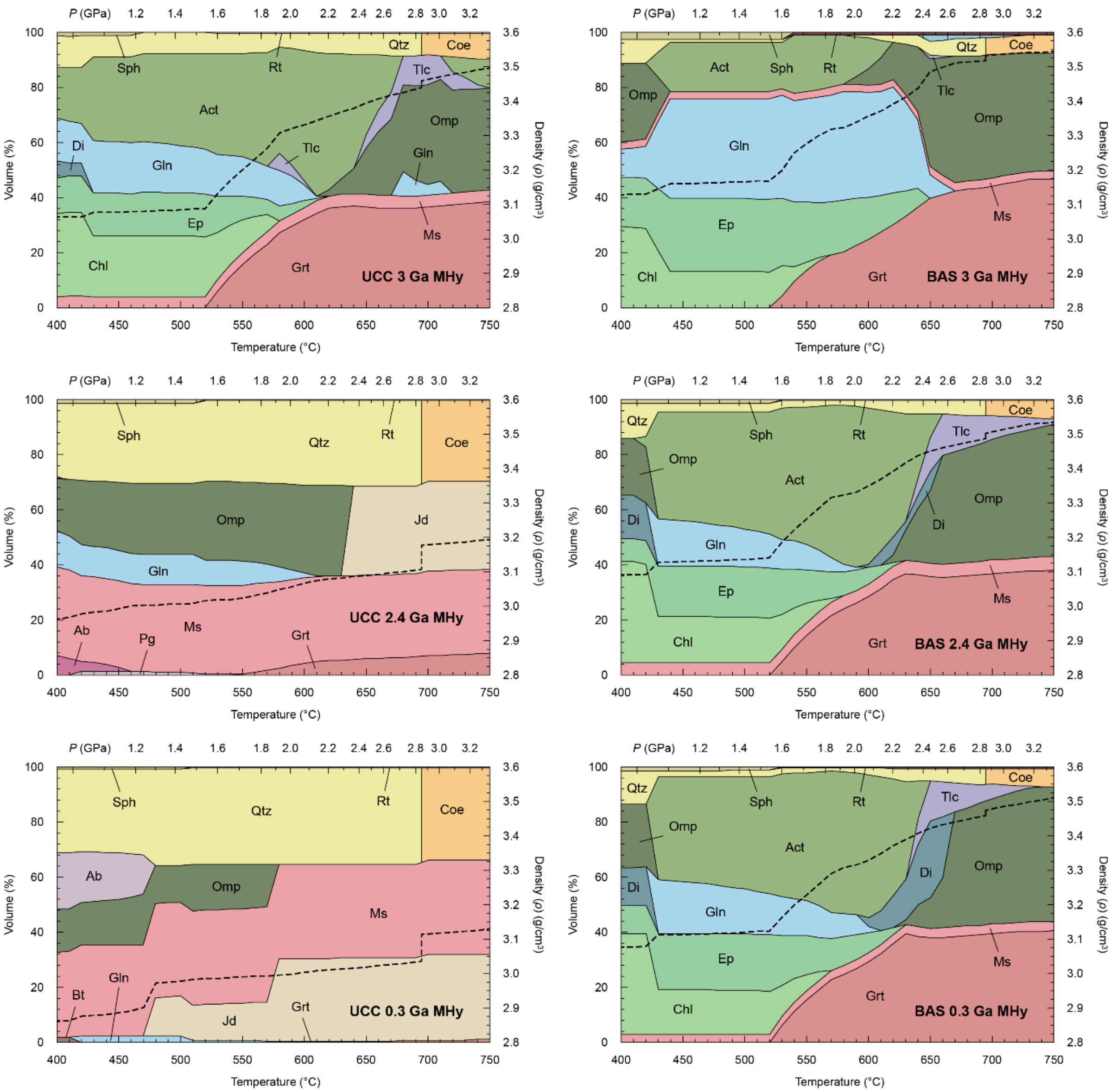

Figure S1. Modeboxes for minimally hydrated (MHy) crustal lithologies at 0.3, 2.4, and 3 Ga showing equilibrium volume proportions of solid phases stable along the modeled geotherm. Free aqueous fluid content is not shown, as it does not affect bulk-rock density. UCC = Upper continental crust and BAS = continental basalt. See Table 3 for bulk compositions. Bold dashed line shows bulk-rock density and mineral abbreviations are after Whitney and Evans (2010).

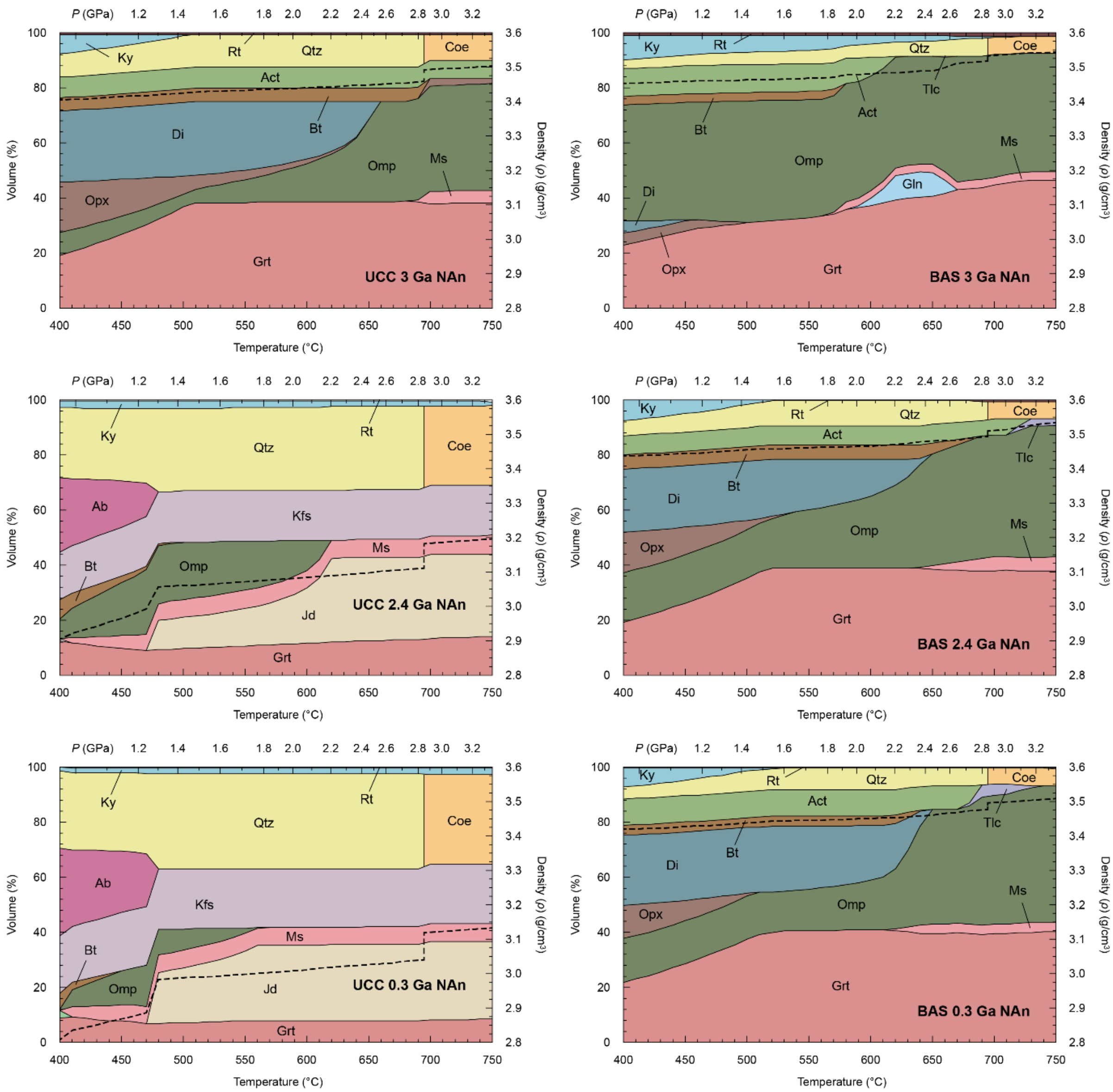

Figure S2. Modeboxes for nominally anhydrous (NAn) crustal lithologies at 0.3, 2.4, and 3 Ga showing equilibrium volume proportions of solid phases stable along the modeled geotherm. Free aqueous fluid content is not shown, as it does not affect bulk-rock density. UCC = Upper continental crust and BAS = continental basalt. See Table 3 for bulk compositions. Bold dashed line shows bulk-rock density and mineral abbreviations are after Whitney and Evans (2010).

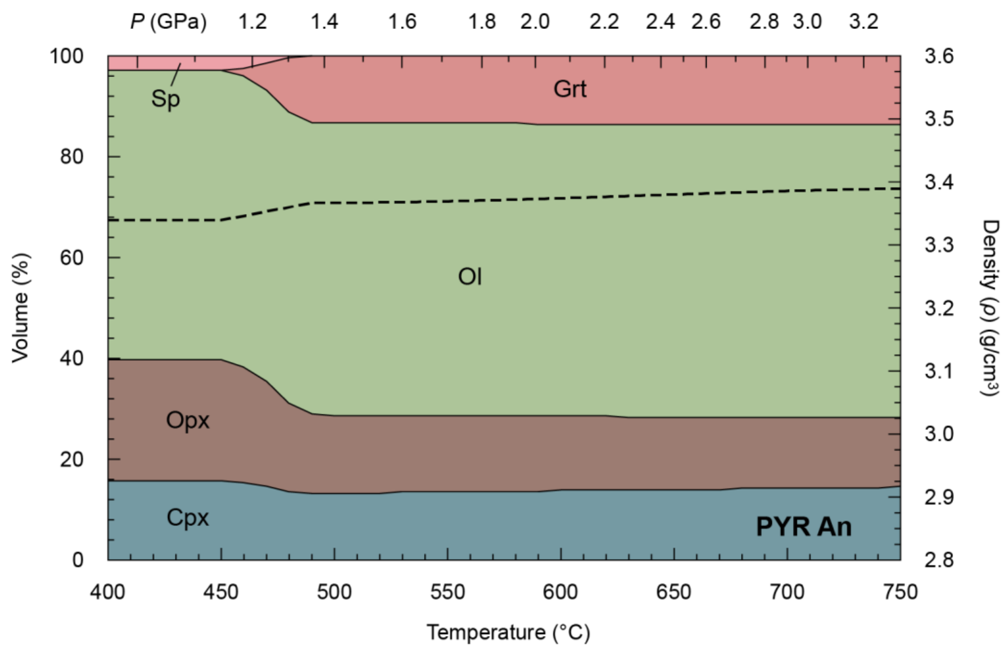

Figure S3. Modebox for anhydrous pyrolite (PYR An) showing equilibrium volume proportions of phases stable along the modeled geotherm. Bold dashed line shows bulk-rock density and mineral abbreviations are after Whitney and Evans (2010).

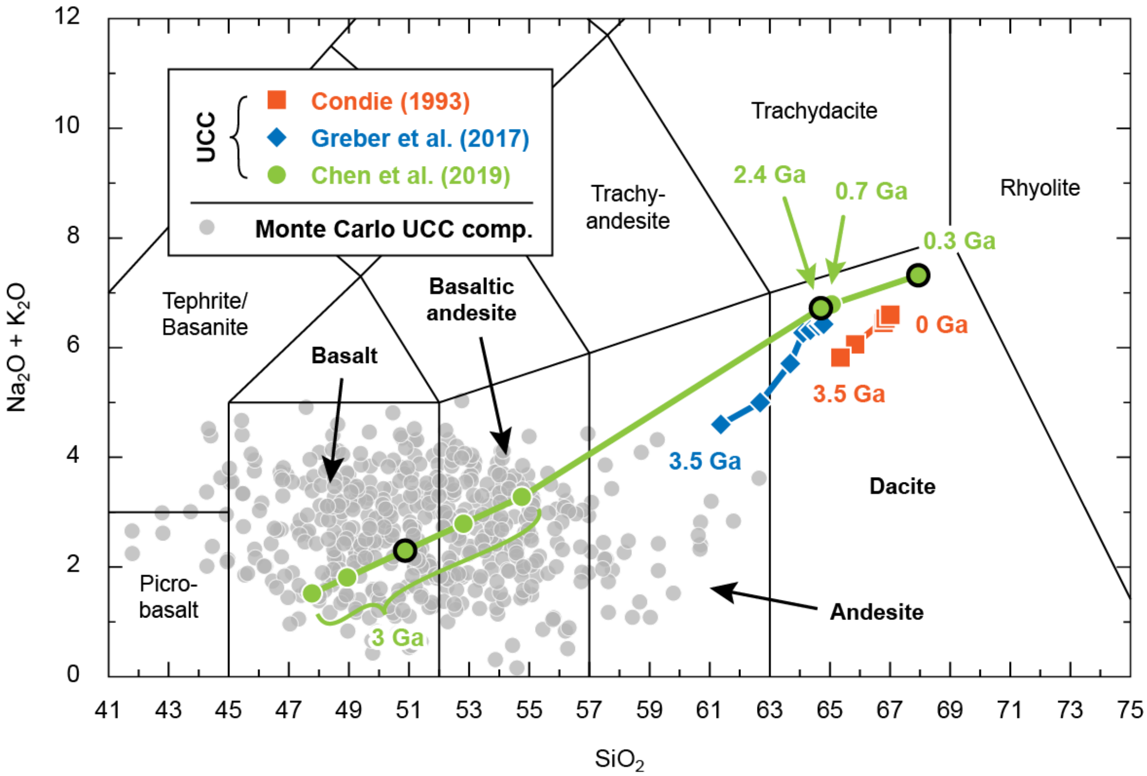

Figure S4. **Total alkali–silica (TAS) diagram showing calculated distribution of randomized Archean (3 Ga) UCC bulk compositions used for sensitivity analysis.** The Monte Carlo procedure (cf. Palin et al., 2016) produced 500 new compositions for Archean UCC (grey circles) by considering errors reported by Chen et al. (2020) for all three major lithological components: komatiite, greenstone (basalt), and felsic crust (TTG). These data mostly occupy the basalt and basaltic andesite fields on the TAS diagram. These 500 data points were used to generate the density distributions at each pressure–temperature condition shown in Fig. S5.

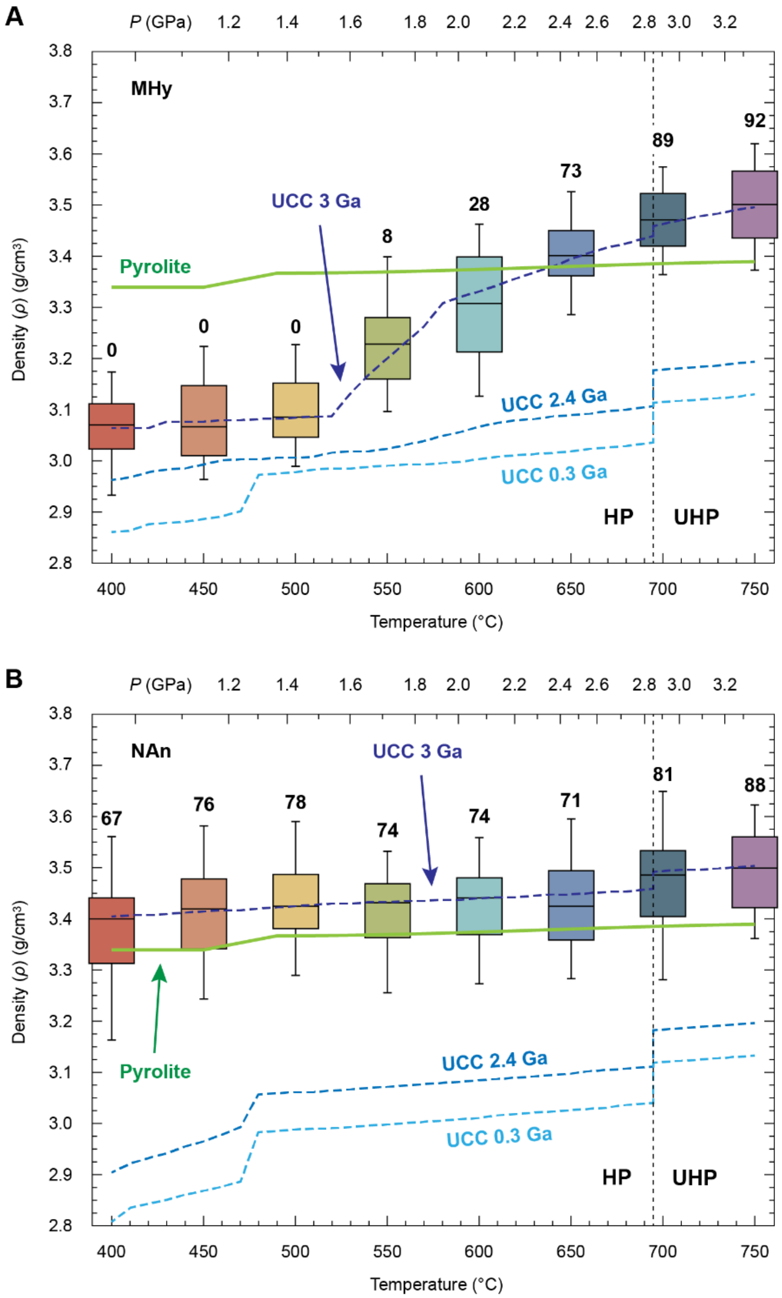

Figure S5. Results of sensitivity analysis for the density of Archean (3 Ga) UCC during subduction. Density distributions are shown as box and whisker plots and consider 500 randomized bulk compositions determined at eight pressure–temperature (*P*–*T*) conditions (see Supplementary Information text). The upper and lower limits of each box are the 75^{th} and 25^{th} percentiles, respectively, the 50^{th} percentile is the line within the box, and the whiskers represent the 5^{th} and 95^{th} percentiles. Numbers above each box show the percentage of data points for that *P*–*T* condition that have a density greater than surrounding pyrolite. All other annotations are taken from Fig. 3 in the main text.

TABLES

Table S1. Upper continental crust (UCC) compositions (weight % oxide) reconstructed by Chen et al. (2020), reported on an anhydrous basis with all iron as Fe^{2+}. The Archean UCC composition considered here is for a komatiite–basalt–felsic rock ratio of 20:69:11. Interpreted juvenile continental crust thickness is from Dhuime et al. (2015). The UCC is taken to represent the top third of the entire crustal column.

Age (Ga)	Thickness (km)	SiO_2	TiO_2	Al_2O_3	FeO^{tot}	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
Archean (3)	18	50.87	0.69	12.19	11.47	0.18	11.14	8.14	1.86	0.44	0.07
Paleo-Proterozoic (2.4)	25	64.70	0.69	14.84	5.33	0.08	2.26	3.86	3.48	3.24	0.17
Phanerozoic (0.3)	32	67.94	0.50	14.66	4.04	0.07	1.34	2.70	3.59	3.72	0.14

Table S2. Bulk-rock compositions used for petrological modeling (mol. %). Upper continental crust (UCC) compositions after Chen et al. (2020) (cf. Table 1), basalt/greenstone compositions after Condie et al. (2016), and pyrolite composition after Ringwood (1975). MHy = minimally hydrated; NAn = nominally anhydrous.

Age (Ga)	Petrological component	H_2O	SiO_2	Al_2O_3	CaO	MgO	FeO	K_2O	Na_2O	TiO_2	O
Archean (3)	UCC (NAn)	1.00	52.44	7.41	8.99	17.11	9.89	0.29	1.86	0.54	0.49
	UCC (MHy)	13.01	46.07	6.51	7.90	15.03	8.69	0.25	1.64	0.47	0.43
	Basalt/greenstone (NAn)	1.00	51.07	9.76	11.27	14.11	8.27	0.18	2.90	1.04	0.41
	Basalt/greenstone (MHy)	13.76	44.48	8.50	9.82	12.29	7.20	0.16	2.53	0.90	0.36
Paleo-Proterozoic (2.4)	UCC (NAn)	1.00	69.94	9.45	4.47	3.65	4.82	2.23	3.65	0.56	0.24
	UCC (MHy)	12.27	61.97	8.38	3.96	3.23	4.27	1.98	3.23	0.50	0.21
	Basalt/greenstone (NAn)	1.00	51.12	7.41	10.70	17.31	9.33	0.31	1.81	0.54	0.48
	Basalt/greenstone (MHy)	13.75	44.53	6.46	9.32	15.08	8.13	0.27	1.57	0.47	0.42
Phanerozoic (0.3)	UCC (NAn)	1.00	73.73	9.37	3.13	2.17	3.66	2.58	3.78	0.40	0.18
	UCC (MHy)	9.91	67.09	8.53	2.85	1.97	3.33	2.35	3.44	0.37	0.16
	Basalt (NAn)	1.00	50.86	7.72	11.11	16.75	9.47	0.22	1.94	0.47	0.49
	Basalt (MHy)	13.75	44.30	6.72	9.68	14.59	8.24	0.19	1.69	0.41	0.43

Table S3. Parameters used for isostatic balance calculations.

Symbol	Parameter	Archean	Proterozoic
ρ_w	Density of seawater	1030 kg m^{-3}	1030 kg m^{-3}
ρ_o	Density of continental crust	2865 kg m^{-3}	2800 kg m^{-3}
ρ_c	Density of oceanic crust	2900 kg m^{-3}	2900 kg m^{-3}
ρ_m	Density of mantle	3330 kg m^{-3}	3330 kg m^{-3}
h_o	Ocean depth above Proterozoic oceanic crust	–	4 km
T_o	Thickness of oceanic crust	7 km	7 km
T_c	Thickness of continental crust	18 km	30 km
λ	Fraction of basalt in Archean continental crust	0.65	–

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