

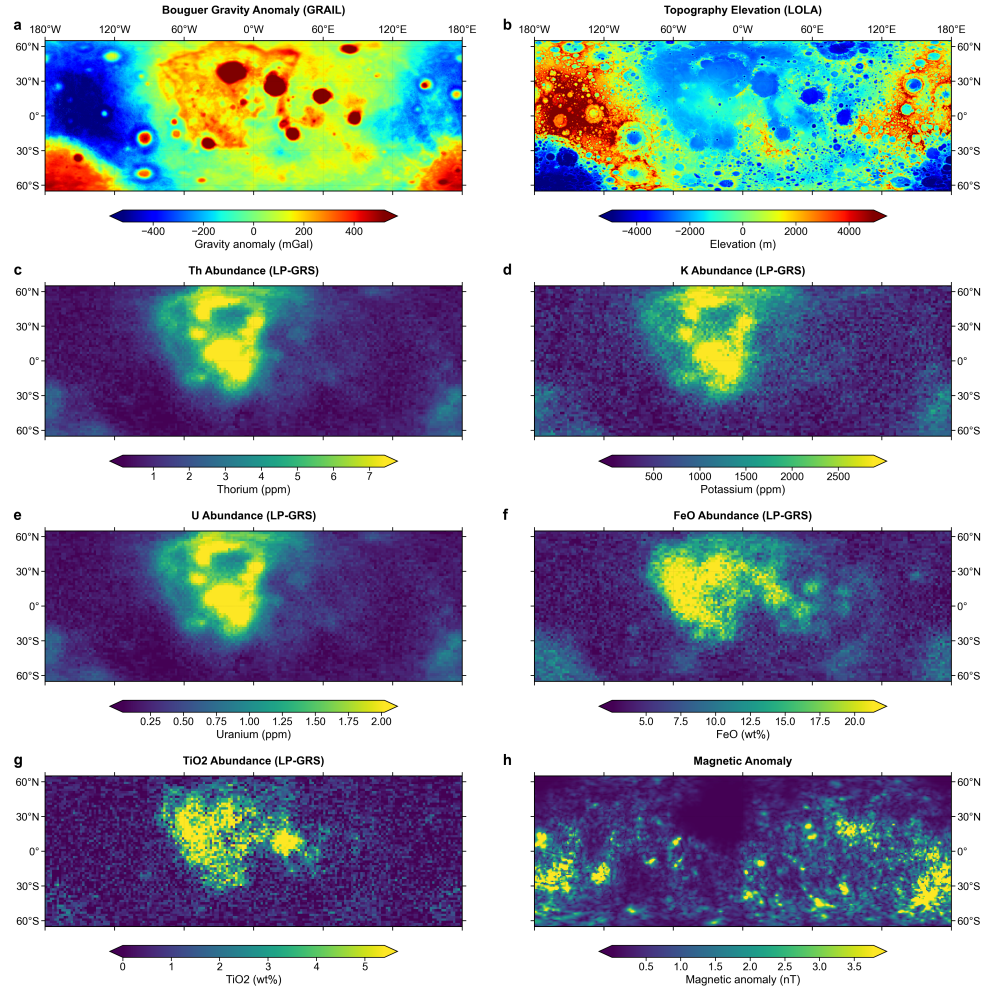
Supplementary Information for “Multisource constraints on lunar crater-to-basin transitions and implications for the evolution of the lunar hemispheric dichotomy”

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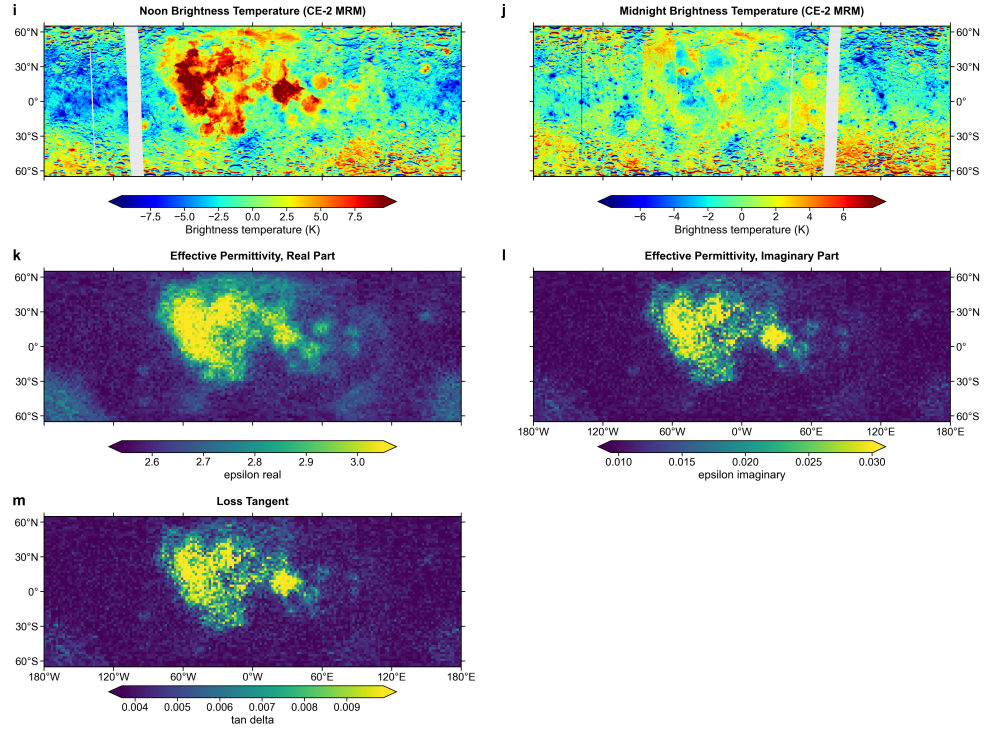
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1. Supplementary Figures

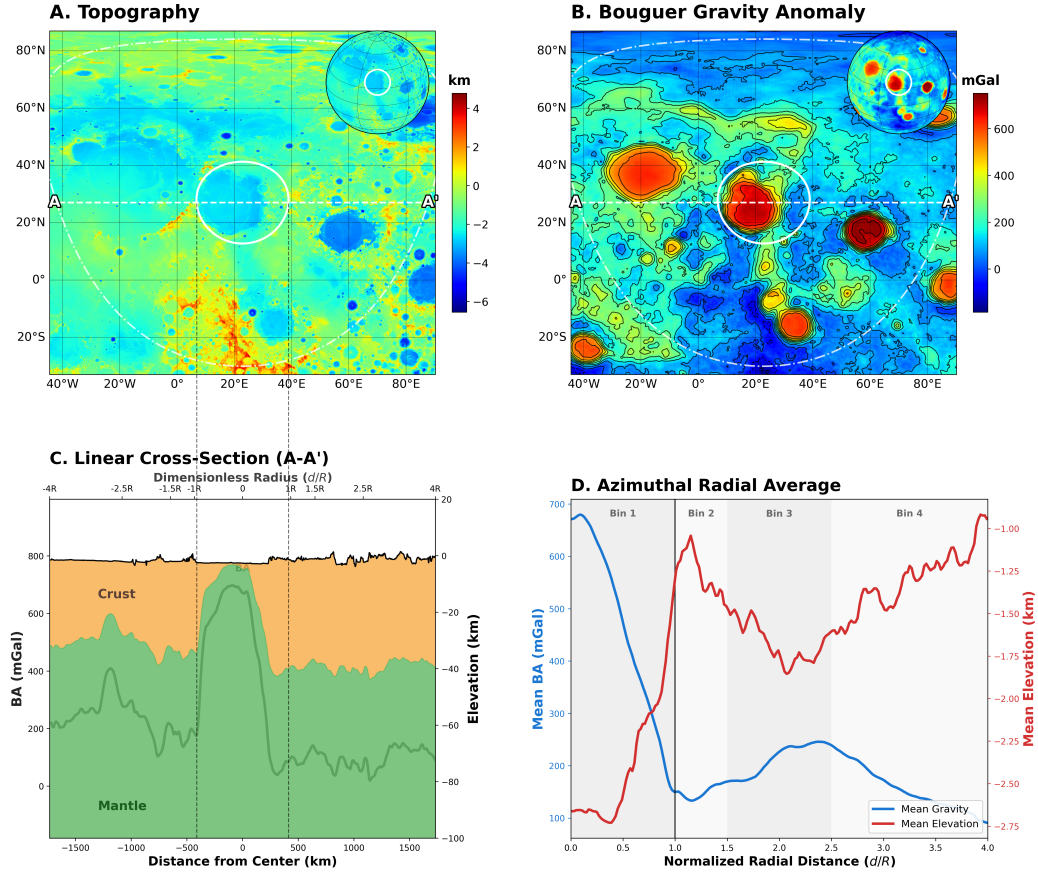
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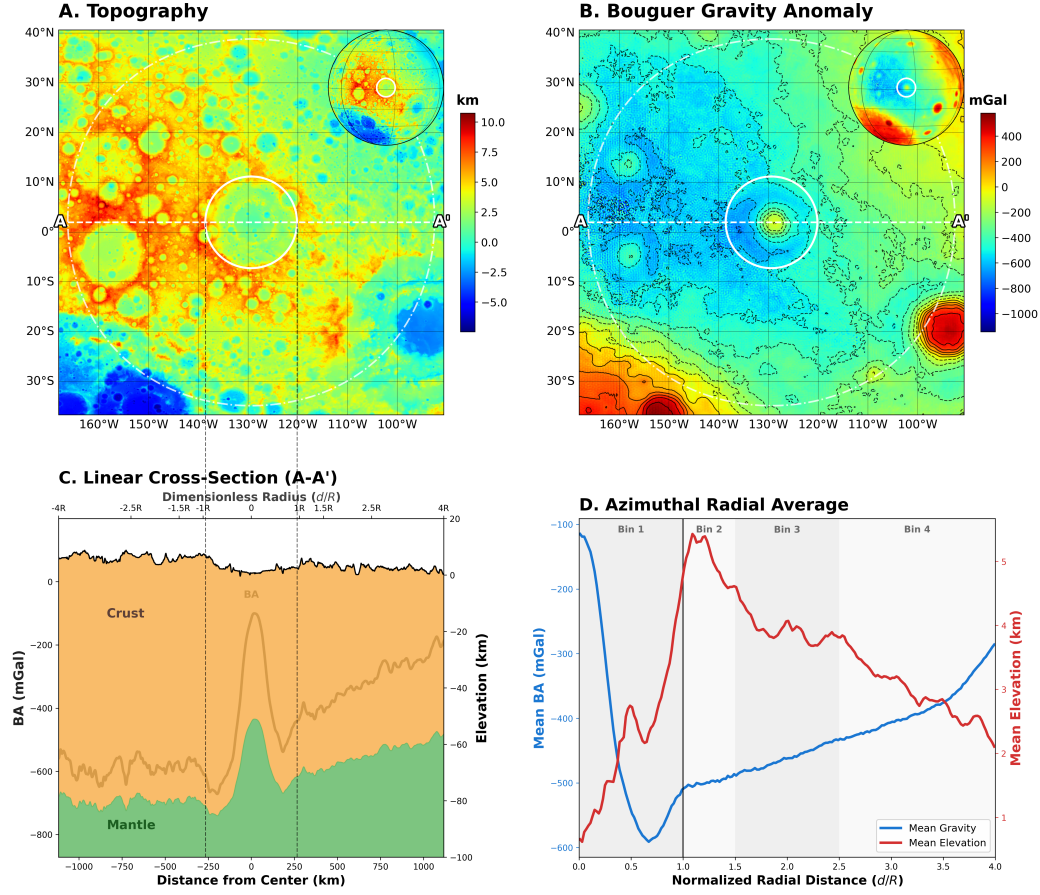
Supplementary Fig. 1: Global lunar physical-property datasets at 32 ppd. (a) Bouguer gravity anomaly; (b) topographic elevation; (c) Th abundance; (d) K abundance; (e) U abundance; (f) FeO abundance; (g) TiO₂ abundance; and (h) magnetic anomaly.



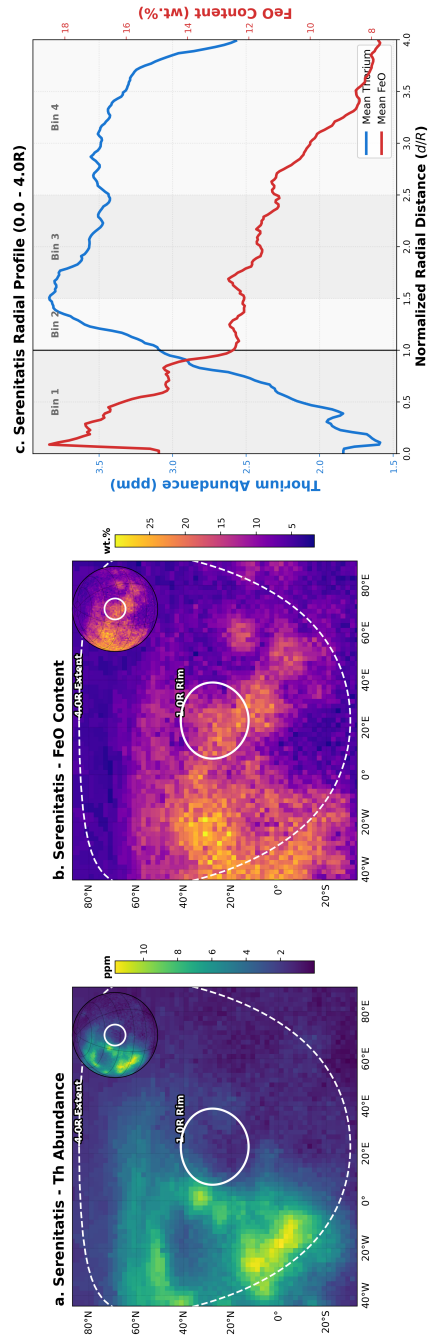
Supplementary Fig. 1: Global lunar physical-property datasets at 32 ppd (continued). (i) Latitude-corrected noon brightness temperature; (j) latitude-corrected midnight brightness temperature; (k) real part of the effective complex permittivity; (l) imaginary part of the effective complex permittivity; and (m) dielectric loss tangent.



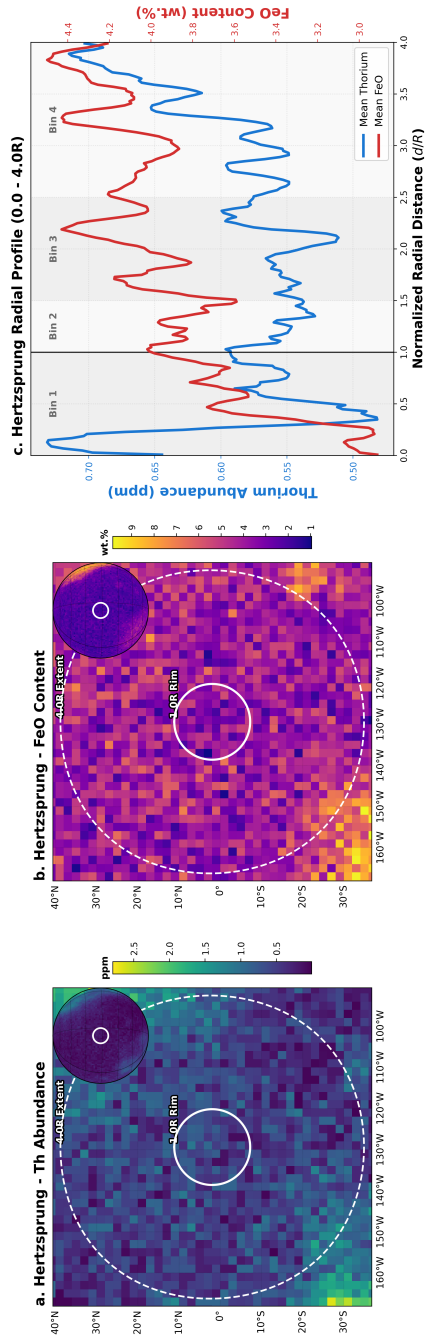
Supplementary Fig. 2: Serenitatis basin. (A) LOLA topography, where the solid white line denotes the $1.0R$ crater rim, the dashed white line denotes the $4.0R$ boundary, and A–A' is the profile trace. (B) Bouguer gravity anomaly, with contours divided into 14 intervals between the anomaly minimum and maximum and smoothed using a Gaussian low-pass filter. (C) Topography, Bouguer gravity anomaly (BA), and crustal structure along A–A', with a vertical exaggeration (VE) of 6:1. (D) Normalized radial profiles; the vertical line marks $1.0R$, and blue and red curves denote Bouguer gravity anomaly (mGal) and elevation (m), respectively.



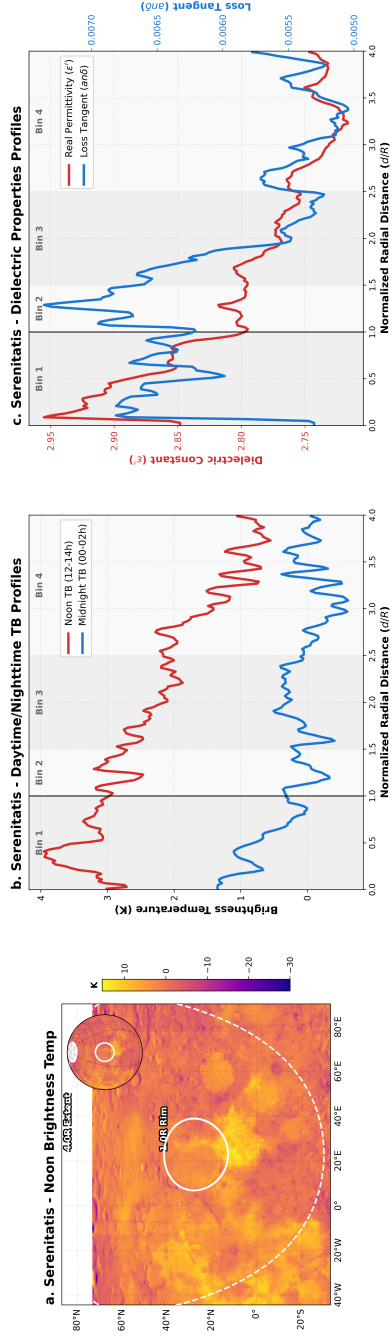
Supplementary Fig. 3: Hertzsprung basin. (A) LOLA topography, where the solid white line denotes the $1.0R$ crater rim, the dashed white line denotes the $4.0R$ boundary, and A–A' is the profile trace. (B) Bouguer gravity anomaly, with contours divided into 14 intervals between the anomaly minimum and maximum and smoothed using a Gaussian low-pass filter. (C) Topography, Bouguer gravity anomaly (BA), and crustal structure along A–A', with a vertical exaggeration (VE) of 6:1. (D) Normalized radial profiles; the vertical line marks $1.0R$, and blue and red curves denote Bouguer gravity anomaly (mGal) and elevation (m), respectively.



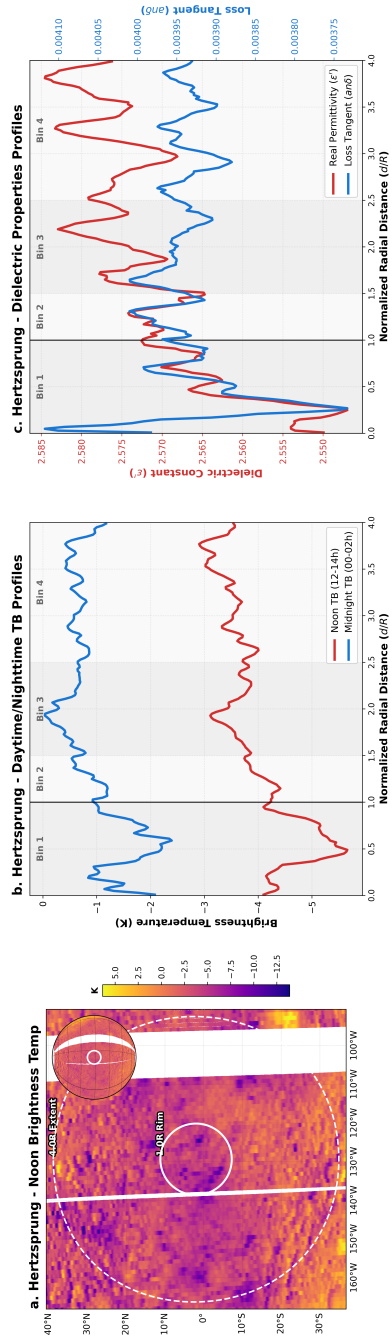
Supplementary Fig. 4: Serenitatis basin. (a) Th abundance; (b) FeO abundance; and (c) azimuthally averaged normalized radial profiles. In the maps, solid and dashed white lines denote the main basin rim ($1.0R$) and outer boundary ($4.0R$), respectively. An equirectangular projection is used, with increasing distortion at middle and high latitudes. In the profile, blue and red curves denote mean Th and FeO abundances, respectively; the vertical black line marks the $1.0R$ main boundary; and the shaded backgrounds (Bin 1 to Bin 4) denote the four geochemical intervals.



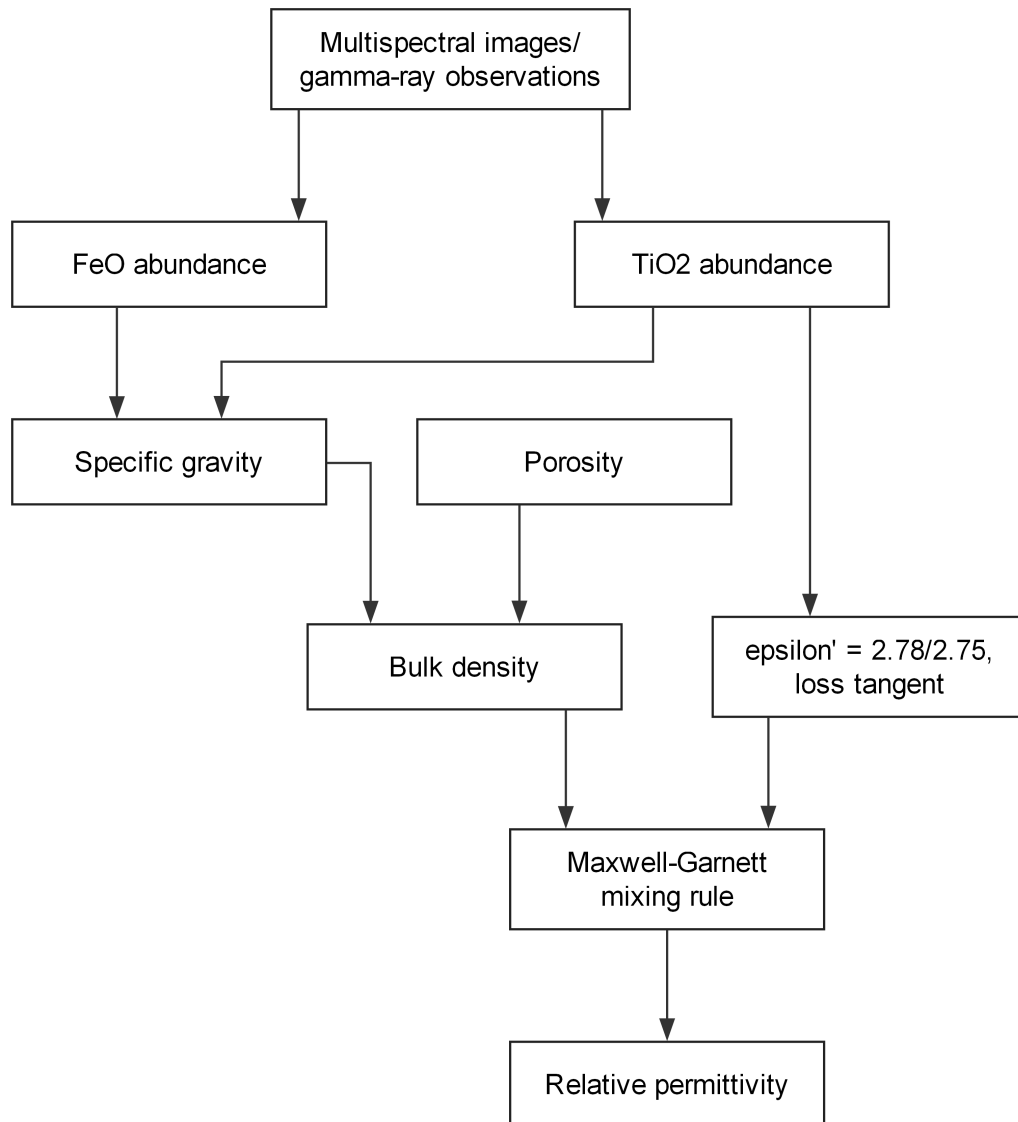
Supplementary Fig. 5: Hertzsprung basin. (a) Th abundance; (b) FeO abundance; and (c) azimuthally averaged normalized radial profiles. In the maps, solid and dashed white lines denote the main basin rim (1.0R) and outer boundary (4.0R), respectively. An equirectangular projection is used. In the profile, blue and red curves denote mean Th and FeO abundances, respectively; the vertical black line marks the 1.0R main boundary, and the shaded backgrounds (Bin 1 to Bin 4) denote the four geochemical intervals.



Supplementary Fig. 6: Thermal and dielectric properties of Serenitatis basin. (a) Spatial distribution of noon brightness temperature; (b) normalized radial profiles of noon and midnight brightness temperatures; and (c) normalized radial profiles of real permittivity and dielectric loss tangent. Noon brightness temperature exceeds midnight brightness temperature, with a day-night phase reversal near the reference main hinge-fault radius.



Supplementary Fig. 7: Thermal and dielectric properties of Hertzsprung basin. (a) Spatial distribution of noon brightness temperature; (b) normalized radial profiles of noon and midnight brightness temperatures; and (c) normalized radial profiles of real permittivity and dielectric loss tangent. Midnight brightness temperature exceeds noon brightness temperature, and no pronounced phase reversal occurs near the main hinge-fault zone.



Supplementary Fig. 8: Workflow for inverting the effective complex permittivity of the lunar regolith using the Maxwell-Garnett mixing model.

2. Supplementary Tables

Supplementary Table 1: Sample sizes in the standard diameter bins for the global lunar crater population

Bin	D range (km)	Global n	Nearside n	Farside n
B1	$5 \leq D < 10$	58,649	19,307	39,342
B2	$10 \leq D < 20$	17,439	5,356	12,083
B3	$20 \leq D < 30$	3,299	1,333	1,966
B4	$30 \leq D < 40$	1,345	567	778
B5	$40 \leq D < 50$	767	327	440
B6	$50 \leq D < 60$	478	187	291
B7	$60 \leq D < 70$	317	116	201
B8	$70 \leq D < 80$	184	61	123
B9	$80 \leq D < 90$	149	59	90
B10	$90 \leq D < 100$	120	39	81
B11	$100 \leq D < 110$	65	25	40
B12	$110 \leq D < 120$	44	18	26
B13	$120 \leq D < 130$	39	15	24
B14	$130 \leq D < 140$	28	14	14
B15	$140 \leq D < 150$	24	9	15
B16	$150 \leq D < 160$	17	8	9
B17	$160 \leq D < 170$	11	5	6
B18	$170 \leq D < 180$	9	1	8
B19	$180 \leq D < 190$	14	5	9
B20	$190 \leq D < 200$	2	1	1
B21	$200 \leq D < 210$	7	3	4
B22	$210 \leq D < 220$	4	1	3
B23	$220 \leq D < 230$	4	1	3
B24	$230 \leq D < 240$	5	1	4
B25	$240 \leq D < 300$	8	2	6
B26	$300 \leq D < 400$	9	1	8
B27	$400 \leq D < 500$	6	3	3
B28	$500 \leq D < 700$	9	3	6
B29	$700 \leq D < 1000$	6	5	1
B30	$1000 \leq D < 1500$	2	2	0
B31	$1500 \leq D < 2600$	1	0	1

Supplementary Table 2: Sensitivity of PCA-weighted changepoints to bin shifts and replacement of missing standard errors

Region	Rightward shift (km)	Min			Median			Max		
		Midpoint	Support probability	95% CI	Midpoint	Support probability	95% CI	Midpoint	Support probability	95% CI
Global	0	195	0.826	165–205	195	0.826	165–205	195	0.826	165–205
Global	1	196	0.764	166–206	196	0.764	166–206	196	0.764	166–206
Global	2	197	0.671	87–207	197	0.693	87–207	197	0.795	167–207
Global	3	198	0.507	128–208	198	0.507	128–208	198	0.507	128–208
Global	4	189	0.488	139–209	189	0.488	139–209	189	0.488	139–209
Global	5	190	0.406	170–210	190	0.406	170–210	190	0.406	170–210
Nearside	0	185	0.345	55–205	185	0.235	55–205	205	0.325	155–205
Nearside	1	186	0.414	56–206	186	0.354	56–206	196	0.391	166–206
Nearside	2	197	0.338	57–197	197	0.473	67–197	197	0.682	157–197
Nearside	3	188	0.570	158–198	188	0.597	158–198	188	0.604	168–198
Nearside	4	189	0.594	149–199	189	0.604	149–199	189	0.645	169–199
Nearside	5	190	0.639	140–200	190	0.618	150–200	190	0.656	170–200
Farside	0	195	0.913	185–195	195	0.913	185–195	195	0.900	185–195
Farside	1	196	0.820	186–196	196	0.818	186–196	196	0.806	186–196
Farside	2	207	0.364	57–207	207	0.364	57–207	207	0.364	57–207
Farside	3	188	0.633	188–208	188	0.638	188–208	188	0.620	188–208
Farside	4	189	0.798	189–209	189	0.797	189–209	189	0.779	189–209
Farside	5	190	0.810	190–210	190	0.801	190–210	190	0.782	190–210

Only the joint PCA-weighted results from segmented regression and Fisher optimal partitioning are listed. The original search range is $D < 240$ km. After shifting the bins by s km, the upper search limit is adjusted to $D < 240 + s$ km. Midpoint denotes the midpoint of the dominant bin, and all values are in km. Min, Median, and Max indicate that a missing standard error was replaced by the minimum, median, or maximum standard error, respectively, among valid $D \geq 240$ km bins in the corresponding spatial domain. Each configuration uses 1000 Monte Carlo realizations.

Supplementary Table 3: PCA-weighted Monte Carlo changepoint results for different upper search limits

Region	Upper limit (km)	Bin range (km)	Midpoint (km)	Support probability	95% CI (km)
Global	240	$190 \leq D < 200$	195	0.826	165–205
	300	$190 \leq D < 200$	195	0.557	185–215
	400	$190 \leq D < 200$	195	0.562	185–225
	500	$190 \leq D < 200$	195	0.603	165–235
	700	$190 \leq D < 200$	195	0.461	185–270
	1000	$190 \leq D < 200$	195	0.237	185–350
	1500	$400 \leq D < 500$	450	0.651	195–450
	2600	$500 \leq D < 700$	600	0.885	195–600
Nearside	245	$185 \leq D < 195$	190	0.618	150–200
	305	$185 \leq D < 195$	190	0.391	160–210
	405	$215 \leq D < 225$	220	0.311	150–220
	505	$225 \leq D < 235$	230	0.454	150–230
	705	$245 \leq D < 305$	275	0.379	150–275
	1005	$245 \leq D < 305$	275	0.304	150–355
	1505	$405 \leq D < 505$	455	0.356	150–455
	2605	$405 \leq D < 505$	455	0.373	150–455
Farside	240	$190 \leq D < 200$	195	0.913	185–195
	300	$190 \leq D < 200$	195	0.651	185–215
	400	$190 \leq D < 200$	195	0.595	185–215
	500	$190 \leq D < 200$	195	0.735	185–215
	700	$190 \leq D < 200$	195	0.655	185–215
	1000	$190 \leq D < 200$	195	0.596	165–215
	1500	$190 \leq D < 200$	195	0.587	165–215
	2600	$190 \leq D < 200$	195	0.438	185–450

Supplementary Table 4: Basin-level Neumann 60% quantile calibrations for nearside and farside large impact basins

Basin	D (km)	R_{60}/R	$R_{50}-R_{70}$ (R)	R_{60} (km)	Status
Nearside: 17/23 valid; equal-weight mean $0.491R$ (bootstrap 95% CI: $0.429R-0.541R$)					
Serenitatis Basin	866.2	0.57	0.39–0.73	246.9	Valid
Imbrium Basin	1198.4	0.65	0.59–0.67	389.5	Valid
Crisium Basin	1114.5	0.45	0.43–0.47	250.8	Valid
Smythii Basin	954.7	0.49	0.43–0.53	233.9	Valid
Tranquillitatis Basin	907.1	–	–	–	Not detected
Nectaris Basin	872.0	0.47	0.43–0.53	204.9	Valid
Humorum Basin	796.4	0.47	0.43–0.51	187.1	Valid
Nubium Basin	659.2	–	–	–	Not detected
Fecunditatis Basin	652.9	0.57	0.45–0.67	186.1	Valid
Humboldtianum Basin	599.8	0.53	0.49–0.55	158.9	Valid
Grimaldi Basin	463.8	0.47	0.43–0.51	109.0	Valid
Mutus–Vlacq Basin	444.3	0.49	0.41–0.59	108.8	Valid
Crüger–Sirsalis Basin	438.1	0.63	0.47–0.73	138.0	Valid
Schiller–Zucchi Basin	354.1	0.55	0.51–0.59	97.4	Valid
Bailly	295.5	0.37	0.33–0.41	54.7	Valid
Iridum	249.8	–	–	–	Not detected
Deslandres	234.2	0.51	0.47–0.57	59.7	Valid
Clavius	221.2	0.11	0.05–0.17	12.2	Valid
Rupes Recta basin candidate	214.1	–	–	–	Not detected
Schickard	207.6	0.45	0.39–0.57	46.7	Valid
Humboldt	204.2	0.57	0.47–0.65	58.2	Valid
Janssen	203.4	–	–	–	Not detected
Gerard Q Outer	198.5	–	–	–	Not detected
Farside: 37/39 valid; equal-weight mean $0.458R$ (bootstrap 95% CI: $0.433R-0.485R$)					
Hertzprung Basin	558.8	0.43	0.39–0.47	120.1	Valid
South Pole–Aitken Basin	2491.9	0.65	0.51–0.77	809.9	Valid
Oriental Basin	941.0	0.45	0.43–0.47	211.7	Valid
Coulomb–Sarton Basin	659.6	0.47	0.43–0.49	155.0	Valid
Mendel–Rydberg Basin	654.3	0.49	0.47–0.51	160.3	Valid
Moscoviense North	634.7	0.51	0.49–0.53	161.9	Valid
Freundlich–Sharonov Basin	613.9	0.49	0.47–0.53	150.4	Valid
Apollo Basin	505.3	0.43	0.41–0.47	108.6	Valid
Dirichlet–Jackson Basin	429.9	0.49	0.43–0.53	105.3	Valid
Korolev Basin	429.7	0.45	0.39–0.51	96.7	Valid
Moscoviense Basin	423.9	0.59	0.47–0.69	125.0	Valid
Amundsen–Ganswindt Basin	365.9	0.43	0.39–0.49	78.7	Valid
Lorentz	353.3	0.39	0.35–0.47	68.9	Valid
Ingenii Basin	333.9	0.39	0.35–0.45	65.1	Valid
Poincaré	327.8	0.49	0.45–0.53	80.3	Valid
Mendeleev	327.5	0.49	0.41–0.53	80.2	Valid
Birkhoff	322.3	0.37	0.33–0.43	59.6	Valid
Schrödinger	321.5	0.41	0.37–0.49	65.9	Valid
Planck	318.4	0.39	0.35–0.43	62.1	Valid
Sikorsky–Rittenhouse Basin	296.9	0.29	0.19–0.39	43.1	Valid
TOPO-13	271.3	0.37	0.31–0.43	50.2	Valid
Von Kármán M	270.0	0.49	0.43–0.55	66.1	Valid
Harkhebi	266.7	0.55	0.47–0.59	73.3	Valid
Gagarin	260.4	0.33	0.15–0.39	43.0	Valid

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Supplementary Table 4 continued

Basin	D (km)	R_{60}/R	$R_{50}-R_{70}$ (R)	R_{60} (km)	Status
Milne	253.9	0.47	0.43–0.51	59.7	Valid
Fermi	238.5	0.43	0.33–0.59	51.3	Valid
Pasteur	237.2	0.51	0.41–0.57	60.5	Valid
Leibnitz	233.6	0.33	0.27–0.39	38.5	Valid
d’Alembert	232.4	0.53	0.39–0.59	61.6	Valid
Campbell	229.4	0.37	0.31–0.53	42.4	Valid
Keeler West	228.6	–	–	–	Not detected
Landau	228.4	0.51	0.39–0.59	58.3	Valid
Galois	218.5	–	–	–	Not detected
Schwarzschild	216.5	0.43	0.33–0.59	46.5	Valid
Bel’kovich	213.6	0.63	–	67.3	Valid
Poczobutt	209.4	0.57	0.45–0.61	59.7	Valid
Wegener–Winlock Basin	209.3	0.43	–	45.0	Valid
Szilard North	208.9	0.49	0.37–0.67	51.2	Valid
Oppenheimer	202.3	0.41	0.29–0.57	41.5	Valid

For each basin, the 60% quantile of the Bouguer-anomaly distribution within the basin interior was used as the baseline. R_{60} was defined by the first outward decrease of the azimuthally averaged Bouguer anomaly to this baseline and assigned to the final radial sample above the baseline before the crossing, at a sampling interval of $0.02R$. The procedure was repeated with 50% and 70% quantile baselines; the resulting $R_{50}-R_{70}$ interval denotes the calibration range. All valid basins were assigned equal weight in the hemispheric means, and 95% confidence intervals were obtained from 10 000 bootstrap resamples of complete basins. “Not detected” indicates that the central annulus was below the 60% quantile baseline or that no downward crossing occurred within $1.5R$. R_{60} could be determined for Wegener–Winlock Basin and Bel’kovich, but the 50% or 70% baseline did not yield a complete crossing range.

Supplementary Table 5: Topographic elevation and first derivative near $0.61R$ for nearside and farside large impact basins

Normalized radius d/R	Farside mean elevation (m)	Nearside mean elevation (m)	Nearside local slope k_{near}
0.51	-789.7	-1741.9	2.355
0.53	-761.0	-1694.8	0.055
0.55	-757.2	-1693.7	0.090
0.57	-805.7	-1691.9	0.160
0.59	-826.3	-1688.7	0.915
0.61	-843.3	-1670.4	1.315
0.63	-823.7	-1644.1	1.305
0.65	-790.2	-1618.0	1.415
0.67	-758.8	-1589.7	0.060
0.69	-740.4	-1588.5	-0.175

Supplementary Table 6: Bouguer anomaly, topographic elevation, and first and second derivatives near the $0.89R$ - $0.95R$ main hinge-fault zone calibrated from farside large impact basins

Radius d/R	g (mGal)	dg/dR	d^2g/dR^2	H (m)	dH/dR	d^2H/dR^2
0.85	-143.6	+232.9	+1129	-155	+7365	+38000
0.87	-139.0	+255.5	+251393	-8	+8125	-976000
0.89	-133.9	+5283.4	-235887	155	-11395	-451750
0.91	-28.2	+565.6	-59993	-73	-20430	+1729500
0.93	-16.9	-634.2	-11341	-482	+14160	-244500
0.95	-29.6	-861.0	+16312	-199	+9270	+591250
0.97	-46.8	-534.8	+13149	-13	+21095	+42000
0.99	-57.5	-271.8	+4834	409	+21935	-1165750
1.01	-62.9	-175.2	-2043	847	-1380	-383000