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Rise of major subaerial landmasses about 3.0 to 2.7 billion years ago

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Supplementary Information

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Materials and Methods

Data compilation and filtering

Mesozoic basalts with or without low-temperature hydrothermal alteration (Fig. 1) were from Deep Sea Drilling Program (DSDP) and Ocean Drilling Program (ODP) (Emmermann and Puchelt, 1980; Joron *et al.*, 1980; King *et al.*, 1993; Fisk *et al.*, 2002; Kelley *et al.*, 2003) with glass compiled from Bergmanis *et al.* (2007). Data is compiled in Table S-2. Modern seafloor hydrothermal alteration studies reveal that low-temperature hydrothermally altered oceanic basalts can strongly enrich in some elements (*e.g.*, K, Rb, Li, Cs) probably due to the formation of secondary clay minerals (*e.g.*, smectite) during alteration (Emmermann and Puchelt, 1980; Jeffrey and Jose, 1984). However, elements Rb, especially for Li and Cs are relatively scarce in the complied igneous databases. Further tests can be made when the global igneous databases grow and more samples with combined Rb-Li-Cs contents are reported.

Global continental igneous (comprising mafic volcanic and plutonic rocks) database here (for Fig. 2a) were compiled from Keller and Schoene (2012) and the EarthChem repository (http://www.earthchem.org/, accessed 19 February 2020). To overcome the bias of unintendedly erroneous data, we have checked original publications of all the pre-Archean data and corrected some statistical mistakes, *e.g.*, values of K_2O erroneously replaced as Na_2O in igneous database (Keller and Schoene, 2012) according to Polat and Hofmann (2003). All these volcanic and plutonic data for calculation are compiled in Tables S-3 and S-4, respectively.

Note that those data (~2.1 Ga) from Stepanova *et al.* (2014) were not considered in our compiled mafic plutonic dataset (Table S-5). These MORB-type tholeiitic dikes (dolerite, intrusive rock) formed in an extensional setting (the Karelian Craton, in Finland) associated with opening of the Lapland-Kola and Svecofennian oceans, where they may undergo low-temperature hydrothermal alteration resulting in elevated mean K/La (1867 ± 503, 1 s.e.m.; Table S-5). Given the scarcity of magmatic records during 2.1-2.2 Ga, incorporation of these data into our calculation yields higher K/La that may reflect hydrothermal alteration of hypabyssal rocks at the regional scale (*e.g.*, the Karelian Craton).

In order to include mantle-derived magmas to the utmost, following Keller and Schoene (2012), firstly we filtered the data set with SiO_2 contents from 43 to 51 wt. % (including komatiites). Fractional crystallization or accumulates of some minerals, *e.g.*, plagioclase, alkali feldspar, apatite etc., may influence K/La of mafic rocks, the data set was further filtered by P_2O_5 (≥0.1 wt. %), Al_2O_3 (≤20 wt. %), and MgO (≥6 wt. %) to minimise the effect of fractional crystallization of apatite and feldspar as well as feldspar cumulation. Igneous rocks older than 3.6 Ga were not taken into consideration because such rock records are too rare to be representative.

Statistical methods

We employed the weighted bootstrap resampling method to minimise spatiotemporal preservation bias and to obtain systematic trends of geochemical averages of global igneous rocks (Keller and Schoene, 2012). Every geochemical variable in the database was implemented by following steps: (1) Each sample in a dataset is attached a weight that is inverse to sample's spatiotemporal density. (2) Every data point for a variable is assumed to follow a Gaussian distribution with a mean equal to the value and the standard deviation estimated from its 1σ (usually assumed 2 % as 1σ error). Each geochemical data was used to be randomly (with Monte Carlo simulations) selected proportional to its sample weight to get resampling dataset. (3) According to each sample's age with its uncertainty, the resampling dataset was divided into 100-million-year bins and then a mean value was calculated for every bin. (4) step (1) to (3) were run 10,000 times. (5) A total mean and one standard error of the mean (1 s.e.m.) were calculated for each bin based on results of 10,000 times simulations. Given the worldwide sample distribution (Fig. S-1), this statistical method provides a robust way to optimise, particularly in the pre-Archean era, heterogeneously spatiotemporal sample distribution (15). Note that when it comes to mean value of a ratio (*e.g.*, K/La), elements K and La were resampled by Monte Carol method respectively, and then converted to a ratio for mean and error calculation.

Compilation of elevation data and data processing

We compiled open-source SRTM 90-m Digital Elevation Data (Fig. 3c,d) from http://srtm.csi.cgiar.org/ and conducted Gaussian Fitting via MATLAB's Curve Fitting Tool to smooth the data. Inserted Background maps of Figure 3c,d were downloaded from GeoMapAPP (http://www.geomapapp.org/).

Data availability

Data analysed for this work is available within the paper and its supplementary materials.

Code availability

MATLAB codes for Figure 2a are available at https://github.com/chuntaoL/secular-K-La-variations.

Supplementary Tables

Table S-1 Mean K/La values of continental mafic volcanic and plutonic rocks were calculated by the weighted bootstrap resampling method (10,000 times) for 100-Ma bins with error bars showing 1 s.e.m. uncertainties.

	Volcanic rocks		Plutonic rocks	
Age (Ma)	Mean K/La	Error (1 s.e.m.)	Mean K/La	Error (1 s.e.m.)
100	390	19	533	37
200	500	58	596	47
300	531	41	538	48
400	835	72	538	73
500	661	56	544	59
600	476	39	604	94
700	523	90	514	135
800	1008	111	444	36
900	702	50	494	62
1000	420	37	498	80
1100	477	29	453	31
1200	605	77	681	144
1300	527	48	649	69
1400	574	68	513	40
1500	546	55	653	100
1600	531	58	635	96
1700	504	47	599	111
1800	572	36	744	108
1900	618	30	411	59
2000	468	36	571	95
2100	446	40	567	92
2200	495	61	531	83
2300	521	81	542	77
2400	561	91	542	77
2500	625	63	625	68
2600	853	149	530	77
2700	584	83	599	74
2800	1039	149	475	61
2900	1168	219	469	77
3000	1684	317	570	114
3100	2028	339	622	136
3200	2190	352	688	160
3300	1624	237	732	183
3400	2209	336	748	194
3500	2580	426	753	223
3600	2117	436	742	258

Table S-2 Geochemical data of basalts with or without low-temperature hydrothermal alteration with seawater.

The data table is available for download (Excel file) at https://www.geochemicalperspectivesletters.org/article2115.

Table S-3 Geochemical data of continental mafic volcanic samples (with filtering of SiO_2 = 43–51 wt. %, MgO ≥ 6 wt. %, Al_2O_3 ≤ 20 wt. %, and P_2O_5 ≥ 0.1 wt. %).

The data table is available for download (Excel file) at https://www.geochemicalperspectivesletters.org/article2115.

Table S-4 Geochemical data of continental mafic plutonic samples (with filtering of SiO_2 = 43–51 wt. %, MgO ≥ 6 wt. %, Al_2O_3 ≤ 20 wt. %, and P_2O_5 ≥ 0.1 wt. %).

The data table is available for download (Excel file) at https://www.geochemicalperspectivesletters.org/article2115.

Table S-5 Geochemical raw data of tholeiitic dikes at the Karelian Craton and mean K/La calculated by the bootstrap method.

The data table is available for download (Excel file) at https://www.geochemicalperspectivesletters.org/article2115.

Supplementary Figures

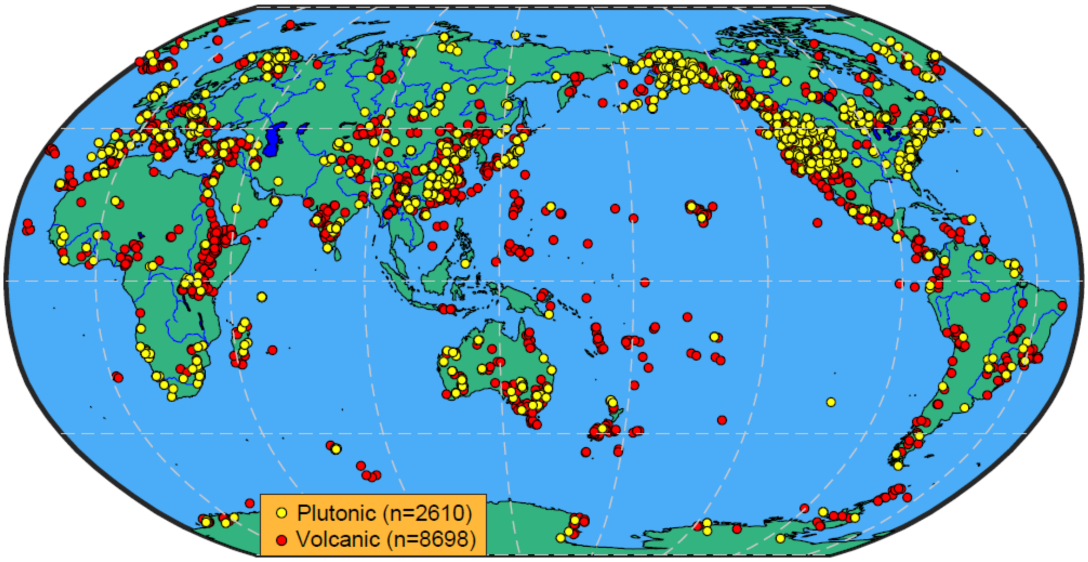

Figure S-1 Global distribution of continental igneous raw samples (listed in Tables S-2 and S-3; with filtering of SiO_2 = 43–51 wt. %, $MgO \geq 6$ wt. %, $Al_2O_3 \leq 20$ wt. %, and $P_2O_5 \geq 0.1$ wt. %).

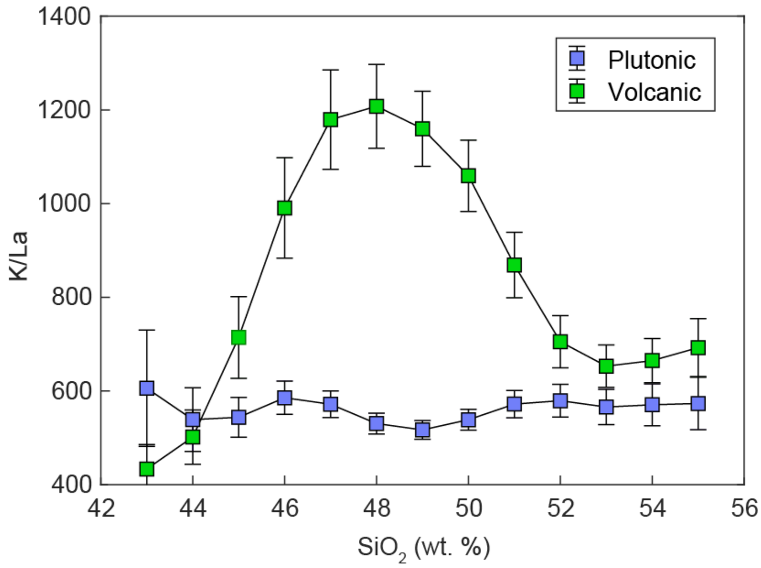

Figure S-2 Diagram of K/La versus SiO_2 for continental mafic volcanic and plutonic rocks. Mean K/La values of mafic volcanic and plutonic rocks were calculated by the weighted bootstrap resampling method (10,000 times) for 1 wt. % SiO_2 intervals with error bars showing 1 s.e.m. uncertainties. Mean K/La of mafic plutonic rocks keeps nearly constant with SiO_2 varying from 43 to 55 wt. %, suggesting that K/La cannot be significantly fractionated during mantle partial melting and differentiation of mafic magmas. While mafic volcanic rocks yield elevated mean K/La values for a given $SiO_2 \geq 45$ wt. %, which most likely reflects that submarine mafic volcanic magmas have more chance to experience low-temperature hydrothermal alteration with seawater. Mafic plutonic rocks were emplaced at depths, thus being least affected by post superficial seawater-rock interaction.

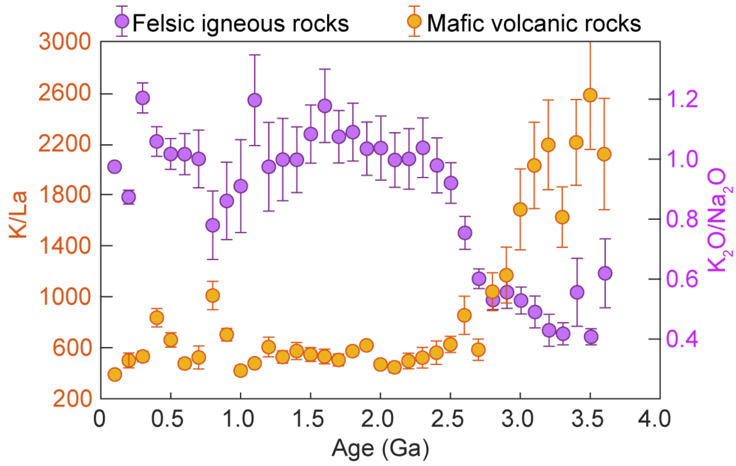

Figure S-3 Secular compositional variations of K/La of mafic volcanic rocks (the same as Fig. 2a in the main text) and K_2O/Na_2O of felsic igneous rocks (modified from Keller and Schoene, 2012). Mean K_2O/Na_2O of felsic igneous rocks increase from ~3.0 to ~2.5 Ga, of which contamination cannot interpret the nearly contemporaneous reduction in mean K/La of mafic volcanic rocks.

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