**Supplementary data S2 Calculation for initial lead isotope ratios**

The decay equations for $^{232}$Th-$^{208}$Pb, $^{235}$U-$^{207}$Pb and $^{238}$U-$^{206}$Pb are as follows:

$$\left(\frac{^{208}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_i = \left(\frac{^{208}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_m - \left(\frac{^{232}\mathrm{Th}}{^{204}\mathrm{Pb}}\right)_m \left(e^{\lambda_1 t} - 1\right) \quad 1$$

$$\left(\frac{^{207}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_i = \left(\frac{^{207}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_m - \left(\frac{^{235}\mathrm{U}}{^{204}\mathrm{Pb}}\right)_m \left(e^{\lambda_2 t} - 1\right) \quad 2$$

$$\left(\frac{^{206}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_i = \left(\frac{^{206}\mathrm{Pb}}{^{204}\mathrm{Pb}}\right)_m - \left(\frac{^{238}\mathrm{U}}{^{204}\mathrm{Pb}}\right)_m \left(e^{\lambda_3 t} - 1\right) \quad 3$$

Where the subscript *i* indicates initial values and *m* indicates measured values.

By dividing Eq. 1 and Eq. 2 by Eq. 3, we have:

$$\left(\frac{^{208}\mathrm{Pb}}{^{206}\mathrm{Pb}}\right)_i = \frac{^{208}\mathrm{Pb}_m - {}^{232}\mathrm{Th}_m \left(e^{\lambda_1 t} - 1\right)}{^{206}\mathrm{Pb}_m - {}^{238}\mathrm{U}_m \left(e^{\lambda_3 t} - 1\right)} \quad 4$$

$$\left(\frac{^{207}\mathrm{Pb}}{^{206}\mathrm{Pb}}\right)_i = \frac{^{207}\mathrm{Pb}_m - {}^{235}\mathrm{U}_m \left(e^{\lambda_2 t} - 1\right)}{^{206}\mathrm{Pb}_m - {}^{238}\mathrm{U}_m \left(e^{\lambda_3 t} - 1\right)} \quad 5$$

By dividing the denominators and numerators on the right-hand side of Eq. 4 and 5 with $^{206}$Pb signal intensity, we obtain:

$$\left(\frac{^{208}\mathrm{Pb}}{^{206}\mathrm{Pb}}\right)_i = \frac{\left(\frac{^{208}\mathrm{Pb}}{^{206}\mathrm{Pb}}\right)_m - \left(\frac{^{232}\mathrm{Th}}{^{206}\mathrm{Pb}}\right)_m \left(e^{\lambda_1 t} - 1\right)}{1 - \left(\frac{^{238}\mathrm{U}}{^{206}\mathrm{Pb}}\right)_m \left(e^{\lambda_3 t} - 1\right)} \quad 6$$

$$\left(\frac{^{207}\mathrm{Pb}}{^{206}\mathrm{Pb}}\right)_i = \frac{\left(\frac{^{207}\mathrm{Pb}}{^{206}\mathrm{Pb}}\right)_m - \left(\frac{^{235}\mathrm{U}}{^{206}\mathrm{Pb}}\right)_m \left(e^{\lambda_2 t} - 1\right)}{1 - \left(\frac{^{238}\mathrm{U}}{^{206}\mathrm{Pb}}\right)_m \left(e^{\lambda_3 t} - 1\right)} \quad 7$$

By replacing $^{235}$U with $^{238}$U/137.88, we have:

$$\left(\frac{^{207}\mathrm{Pb}}{^{206}\mathrm{Pb}}\right)_i = \frac{\left(\frac{^{207}\mathrm{Pb}}{^{206}\mathrm{Pb}}\right)_m - \frac{1}{137.88}\left(\frac{^{238}\mathrm{U}}{^{206}\mathrm{Pb}}\right)_m \left(e^{\lambda_2 t} - 1\right)}{1 - \left(\frac{^{238}\mathrm{U}}{^{206}\mathrm{Pb}}\right)_m \left(e^{\lambda_3 t} - 1\right)} \quad 8$$

All the values with a subscript of *m* in Eq. 6 and 8 are measured by LA-MC-ICPMS

and $t$, which is the sample age, was determined in previous studies. Then with these measured values, the initial $^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$ were obtained.