

Supporting Information

Isotopic Imaging using fs-LA single collector ICP-SFMS for direct U/Th dating of small archaeological carbonates

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Formula S-1: Age equation of the U/Th dating method

The age of carbonate formation is determined by solving the decay equation, usually assuming that the carbonate behaves as a closed system for uranium and thorium once it is formed. It is also usually assumed that the ^{230}Th content is null at the time of the carbonate formation and consequently, that the ^{230}Th measured today comes only from the radioactive decay of the uranium trapped in the carbonate during its formation. The measurement of the $^{230}\text{Th}/^{234}\text{U}$ activity ratio is often preferred to the $^{230}\text{Th}/^{238}\text{U}$ ratio because the ^{230}Th and ^{234}U contents are usually closer to each other than the ^{230}Th with ^{238}U contents, what allow easier and often more accurate measurements. It is also noticeable that the $^{234}\text{U}/^{238}\text{U}$ activity ratio usually presents a small natural disequilibrium in natural water, what is taken in account in the second member of the age equation. When possible, corrections of the $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ ratios are made for taking in account the contribution resulting from the incorporation in the carbonate of small detrital particles.

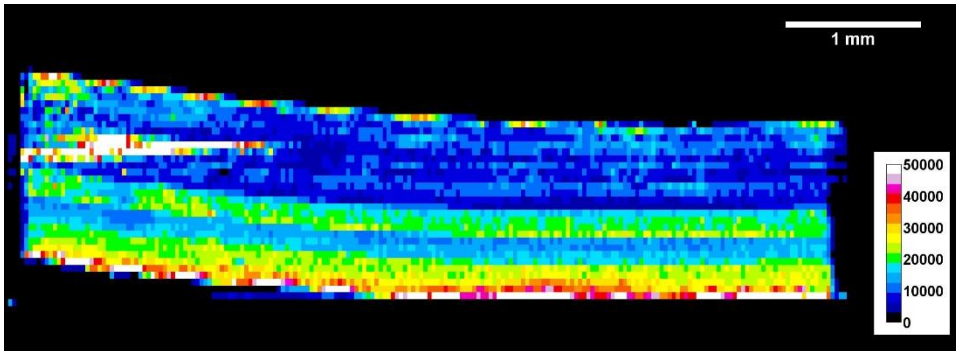
$$1 - \left(\frac{^{230}\text{Th}}{^{238}\text{U}}\right) = e^{-\lambda_{230}T} - \left(\frac{^{234}\text{U}}{^{238}\text{U}} - 1\right) \left(\frac{\lambda_{230}}{\lambda_{230} - \lambda_{234}}\right) (1 - e^{(\lambda_{234} - \lambda_{230})T})$$

Where the radioelement ratios are given as activity ratios, T is the age of formation of the carbonate and λ_{230} and λ_{234} are the decay constants of the respective radioelements.

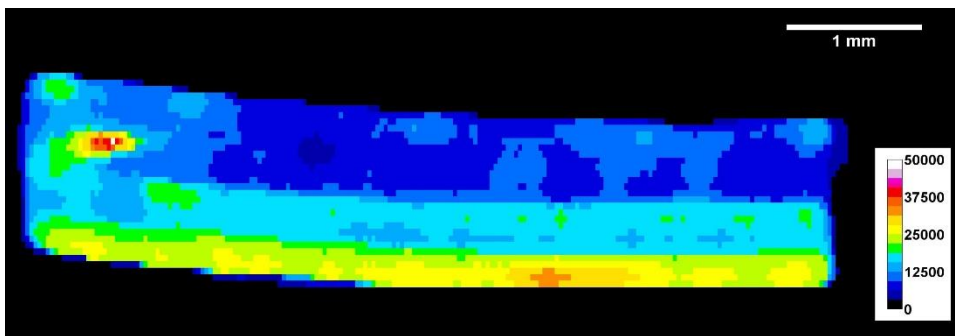
Figure S-1: Construction of ^{238}U based ROIs for sample BRSA9

ROIs based on the U signal measurement (Figure S-1c) are defined by considering the ^{238}U mapping (Figure S-1a), and using a combination of a median filter (Figure S-1b). A threshold value is also considered in order to highlight different areas of stable ^{238}U signal. In this example, these areas correspond to 3 peaks observable on the histogram of the signal distribution (Figure S-3). The limit threshold between different areas is defined using both the local minima identifiable on the histogram and morphological criteria such as the apparent layered pattern on BRSA9. These ROIs were used for the research of potential uranium leached areas in this sample.

a - ^{238}U mapping of a BRSA9 analysis



b - ^{238}U mapping of a BRSA9 analysis with median filter applied



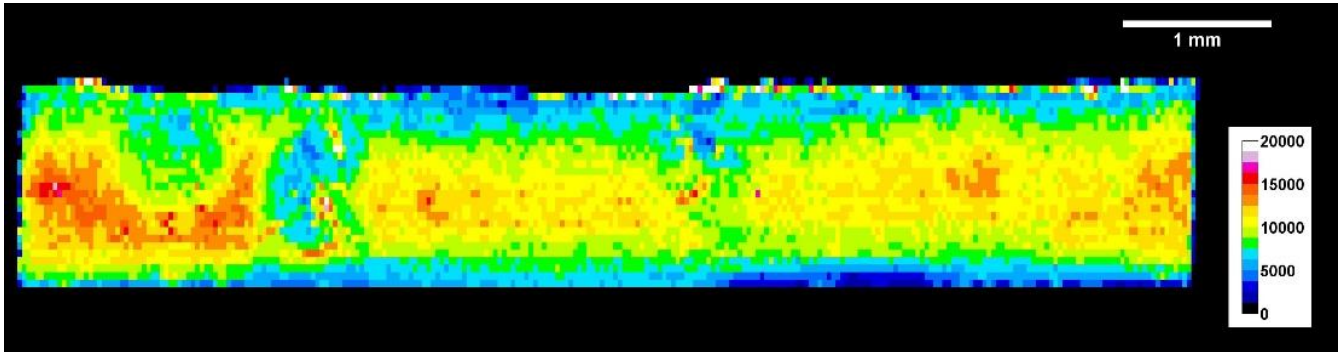
c - ROI defined on the BRSA9 analysis from the filtered ^{238}U mapping



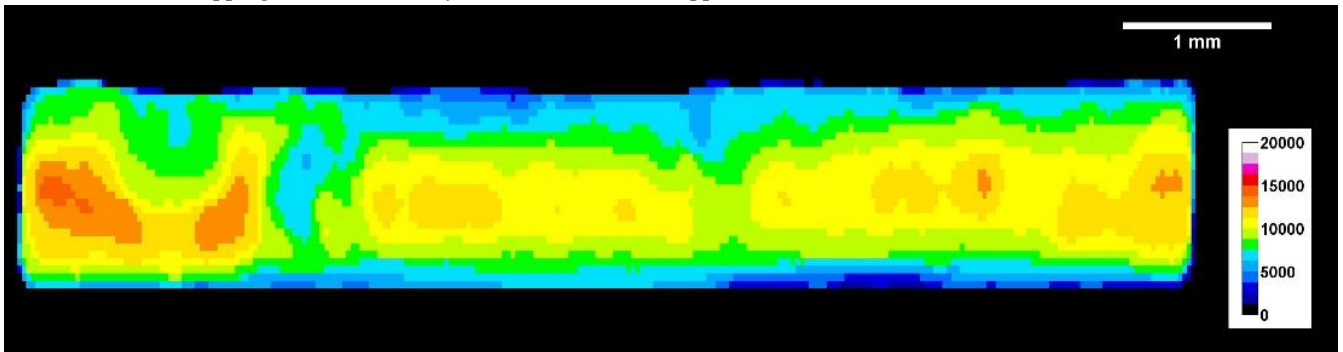
Figure S-2: Construction of ^{238}U based ROIs for sample DRS10

ROIs based on the U signal measurement (Figure S-2c) are defined by considering the ^{238}U mapping (Figure S-2a), using a combination of a median filter (Figure S-2b). A threshold value is also considered in order to highlight different areas of stable ^{238}U signal. In this example as in the previous one, these areas correspond to 3 peaks observable on the histograms of the signal distribution (Figure S-3) . The limit threshold between the different areas is defined using both the local minima identifiable on the histogram and morphological criteria. These ROIs were used for the research of potential uranium leached areas in this sample.

a - ^{238}U mapping of a DRS10 analysis



b - ^{238}U mapping of a DRS10 analysis with median filter applied



c - ROI defined on the DRS10 analysis from the filtered ^{238}U mapping

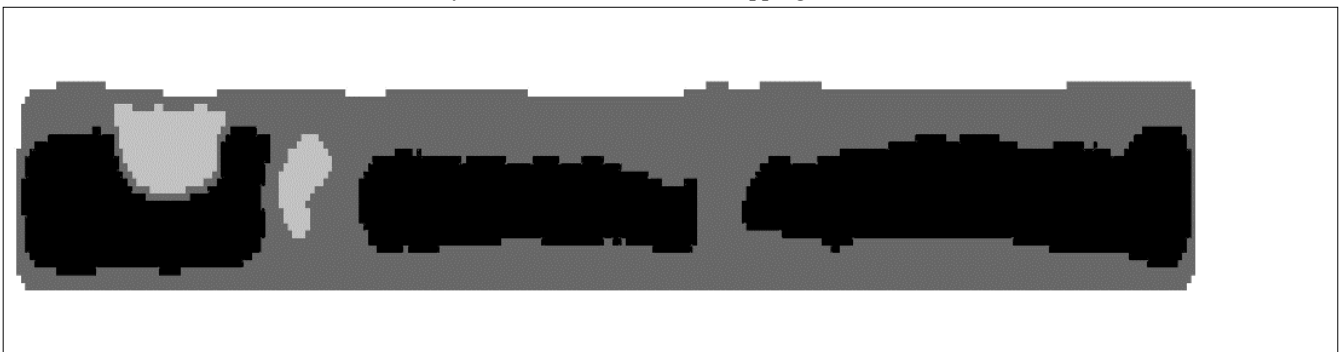


Figure S-3: Histogram of ^{238}U signal intensity for the BRSA9 and DRS10 samples

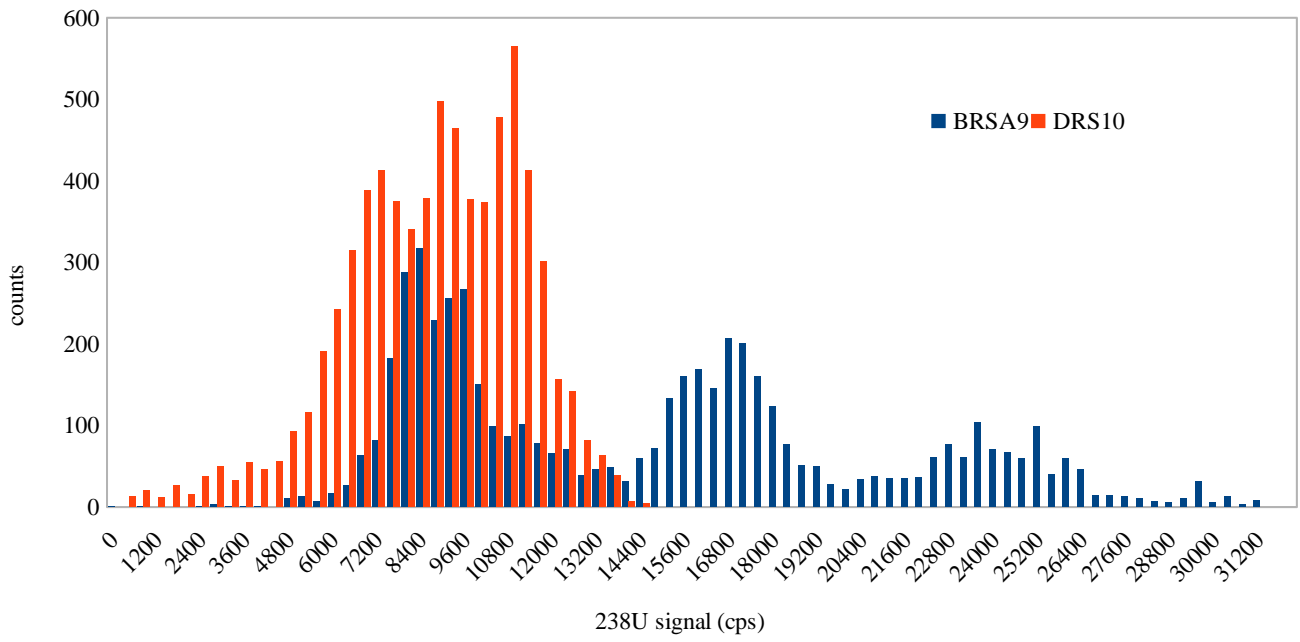


Figure S-4: Results of an analysis of DRS10 with suspected uranium leaching

This graph represents the $^{234}\text{U}/^{238}\text{U}$ and $^{230}\text{Th}/^{234}\text{U}$ activity ratio of the ^{238}U based ROIs of a DRS10 slice analysis. The values reported are the average values per ROI. We can observe a slight increase of the $^{234}\text{U}/^{238}\text{U}$ activity ratio with the increase of ^{238}U content, even if the values remain compatible within the uncertainties at 95% CL. Combined with $^{230}\text{Th}/^{234}\text{U}$ activity ratios that are higher than 1 for most of the ROIs, this indicates a leaching of uranium that increased the $^{230}\text{Th}/^{234}\text{U}$ activity ratio while decreasing the $^{234}\text{U}/^{238}\text{U}$ activity ratio (as ^{234}U is more easily leached than ^{238}U). The ROI with $8.8 \cdot 10^3$ cps of ^{238}U is noticeable because despite of being one of the richest in uranium, it presents the highest $^{230}\text{Th}/^{234}\text{U}$ activity ratio associated with the lowest $^{234}\text{U}/^{238}\text{U}$ activity ratio. This is the evidence that this ROI underwent the more intense leaching, but despite of this, it is still one of the richest in uranium. That suggests that this ROI had, before leaching, the highest uranium content and still has one of the highest contents at the issue of the leaching. This is possible considering the high heterogeneity of the uranium content, that can vary by a factor 10 within this sample. A few ROIs with high uranium contents still present plausible $^{230}\text{Th}/^{234}\text{U}$ activity ratios and similar $^{234}\text{U}/^{238}\text{U}$ activity ratios, what indicates that they could be exempt of leaching. Nevertheless, considering the risk that this whole part of the sample may have undergone uranium leaching, all the ROIs of this analysis were removed from the DRS10 age calculation. It is also noticeable that this slice represents alone 80% of the ROIs of DRS10 showing evidence of uranium leaching, leading to the hypothesis that this leaching might have occurred during the preparation of this slice. Further investigations on leaching induced during sample preparation are in progress.

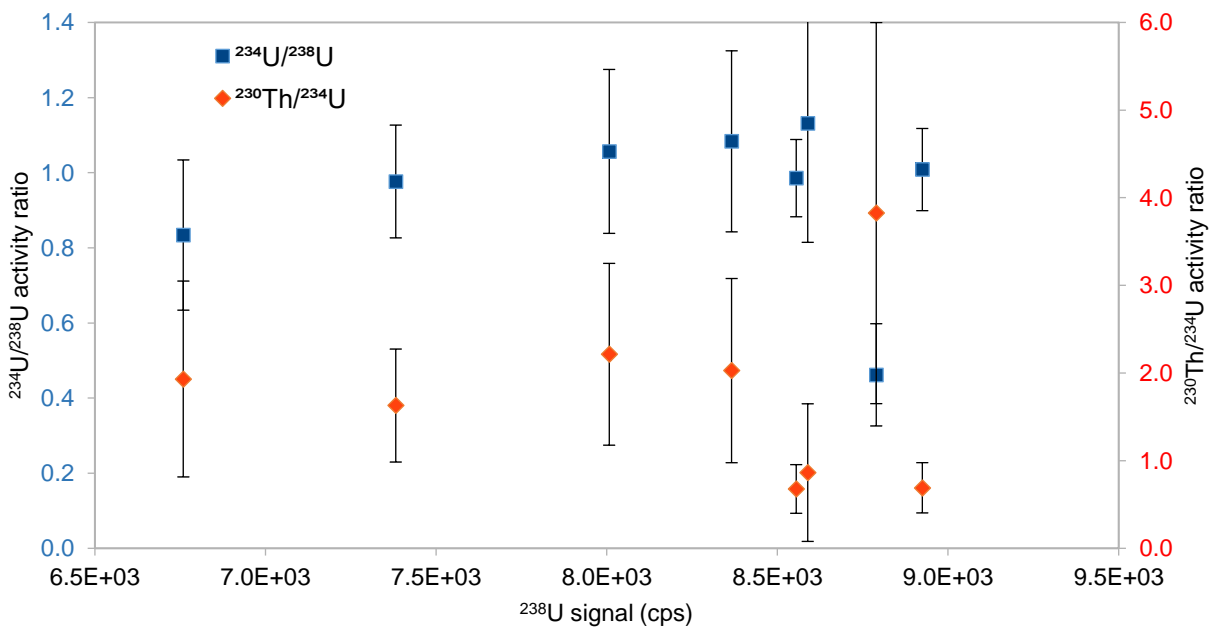
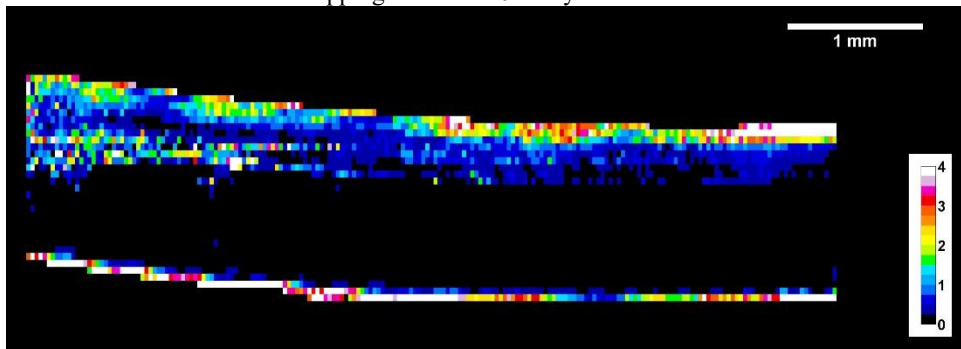


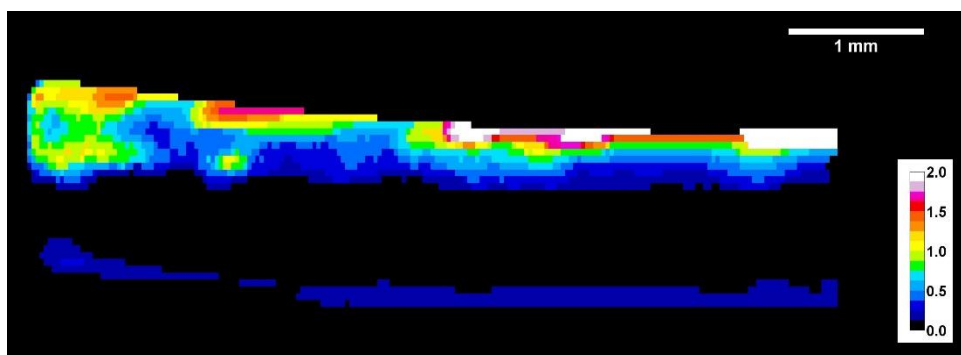
Figure S-5: Construction of $^{232}\text{Th}/^{238}\text{U}$ based ROIs for sample BRSA9

ROIs based on the $^{232}\text{Th}/^{238}\text{U}$ ratio (Figure S-5c) are defined from the ratio mapping (Figure S-5a), using a combination of a median filter (Figure S-5b) and a threshold in order to highlight different areas of stable ratio. The limit thresholds between the different areas are defined using both the local minima identifiable on the histogram (Figure S-7) and morphological criteria such as the apparent layered pattern on BRSA9 (Figure S-5). These ROIs were used to construct the isochrone curves in order to correct the activity ratios from the detrital contribution.

a - $^{232}\text{Th}/^{238}\text{U}$ ratio mapping of a BRSA9 analysis



b - $^{232}\text{Th}/^{238}\text{U}$ ratio mapping of a BRSA9 analysis with median filter applied



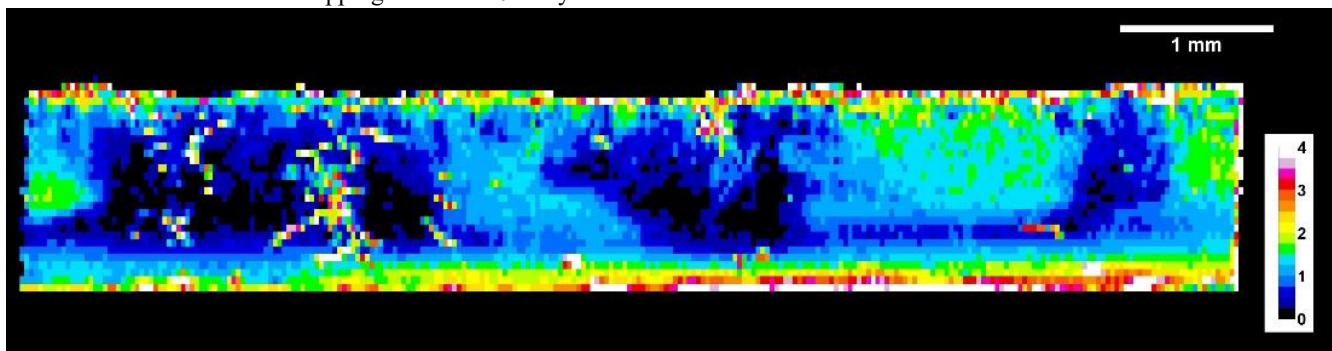
c - ROI defined on the BRSA9 analysis from the filtered $^{232}\text{Th}/^{238}\text{U}$ ratio mapping



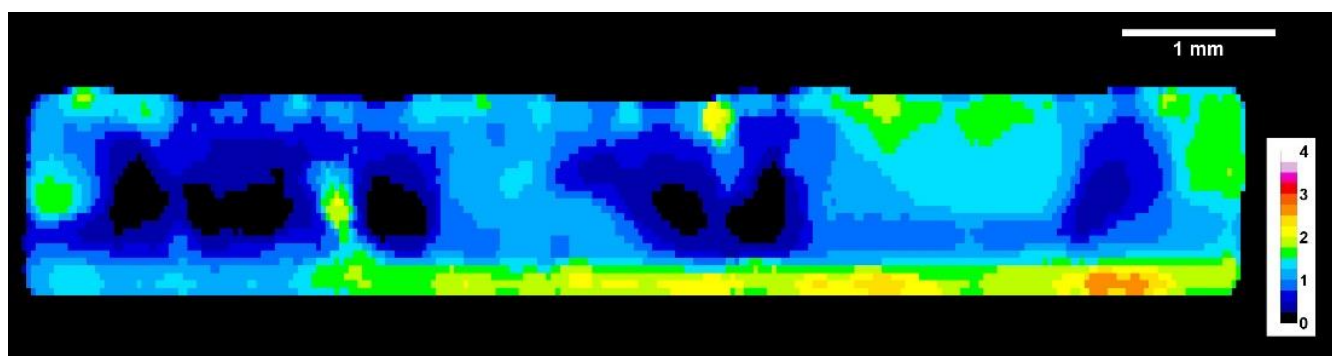
Figure S-6: Construction of $^{232}\text{Th}/^{238}\text{U}$ based ROIs for sample DRS10

ROIs based on the $^{232}\text{Th}/^{238}\text{U}$ ratio (Figure S-6c) are defined from the ratio mapping (Figure S-6a), using a combination of a median filter (Figure S-6b) and a threshold in order to highlight different areas of stable ratio. The limit thresholds between the different areas are defined using the local minima identifiable on the histogram (Figure S-7)). These ROIs were used to construct the isochrone curves in order to correct the activity ratios from the detrital contribution.

a - $^{232}\text{Th}/^{238}\text{U}$ ratio mapping of a DRS10 analysis



b - $^{232}\text{Th}/^{238}\text{U}$ ratio mapping of a DRS10 analysis with median filter applied



c - ROI defined on the DRS10 analysis from the filtered $^{232}\text{Th}/^{238}\text{U}$ ratio mapping



Figure S-7: Histogram of $^{232}\text{Th}/^{238}\text{U}$ signal intensity on the BRSA9 and DRS10 analysis

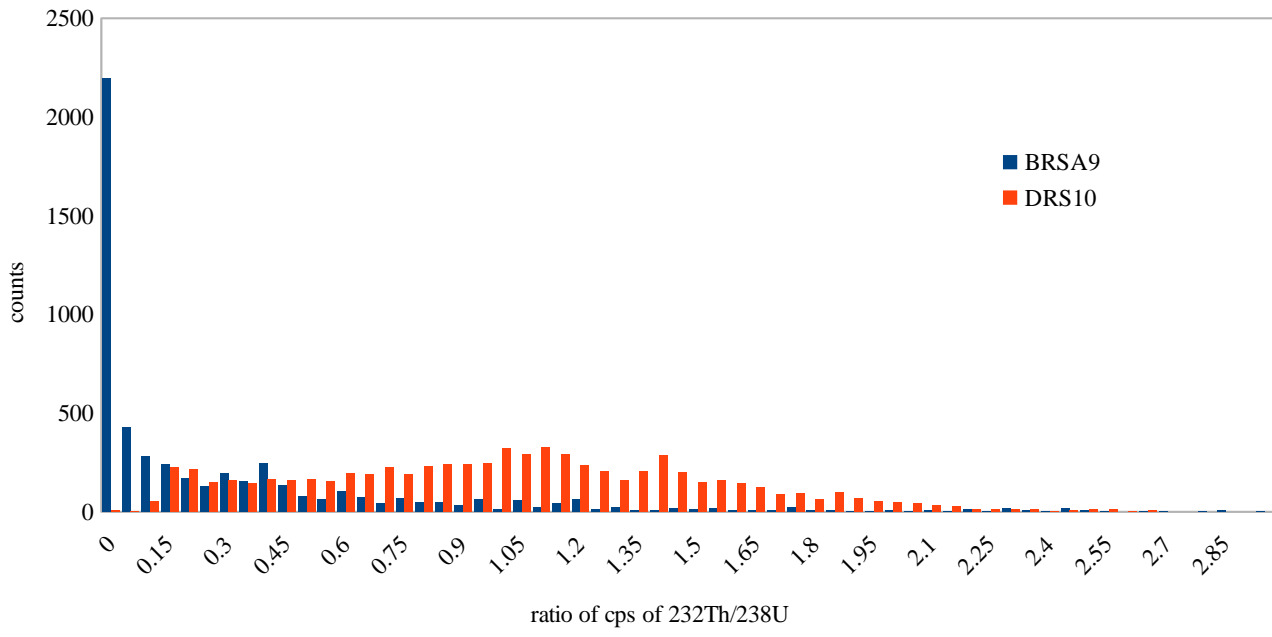


Figure S-8: Monte Carlo calculated Graphics of age distributions of four different samples

Distributions of U-Th ages for speleothem and shell samples whose $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ ratios were not corrected and corrected for the detrital part. These distributions were obtained using the Monte Carlo code (Code S-1) with 10^6 samplings and a 0.1 ka of time resolution. An improvement of the uncertainties of the calculated ages with detrital correction is observed for 3 samples (b, c and d), while sample BCO1H (a) displays an increase of uncertainty with the detrital correction. In addition, Salam12 shows a corrected age older than the uncorrected one, discussed in the main text.

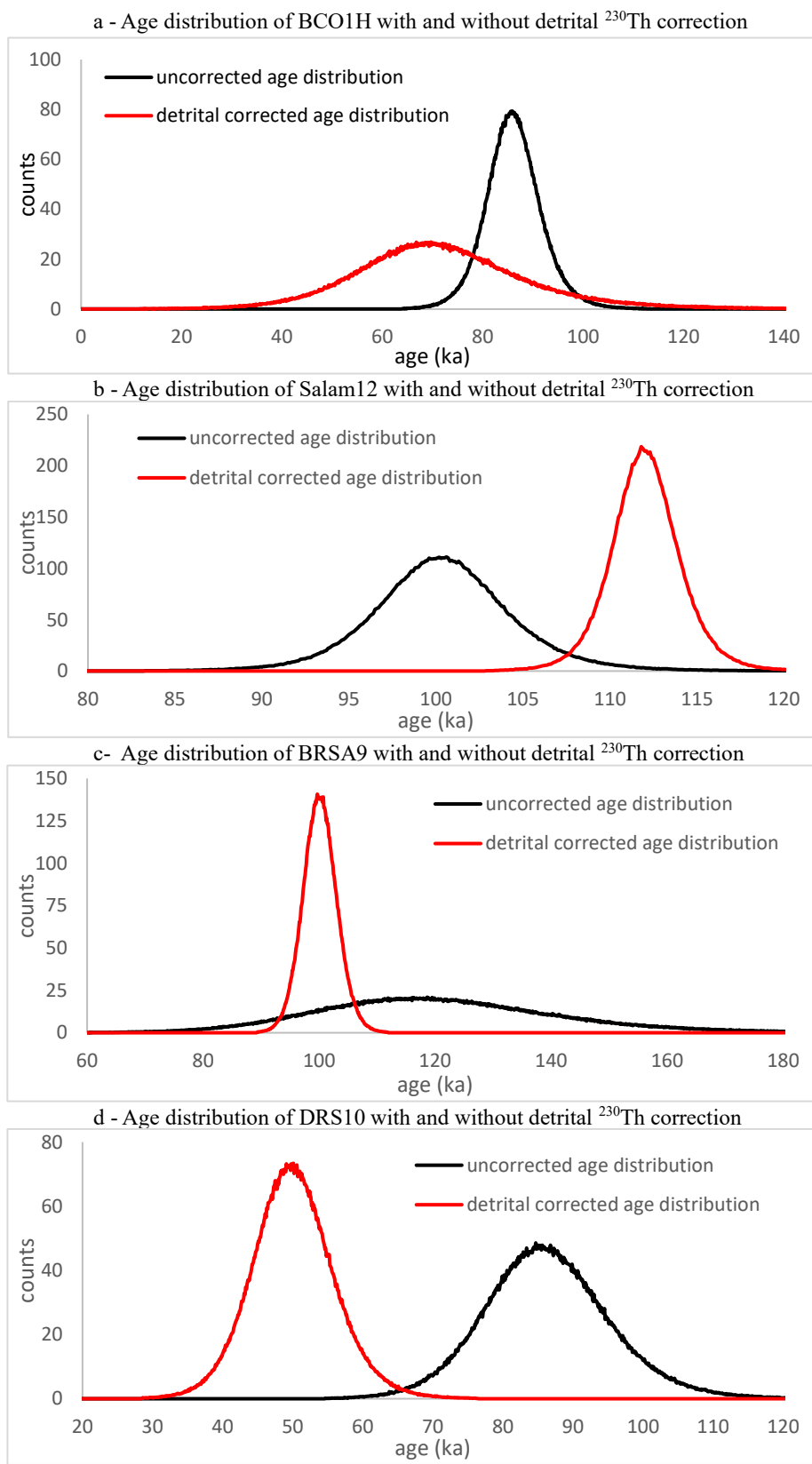
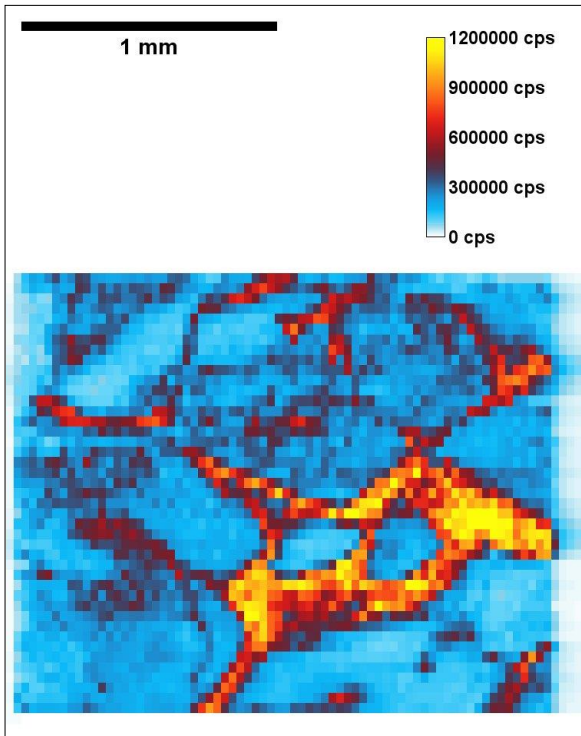


Figure S-9: ^{238}U and ^{232}Th mappings of speleothem sample Salam12

Examples of ^{238}U and ^{232}Th images obtained by fsLA-ICPMS on speleothem sample Salam12 (resolution of $50\mu\text{m}$).

a - ^{238}U image



b - ^{232}Th image

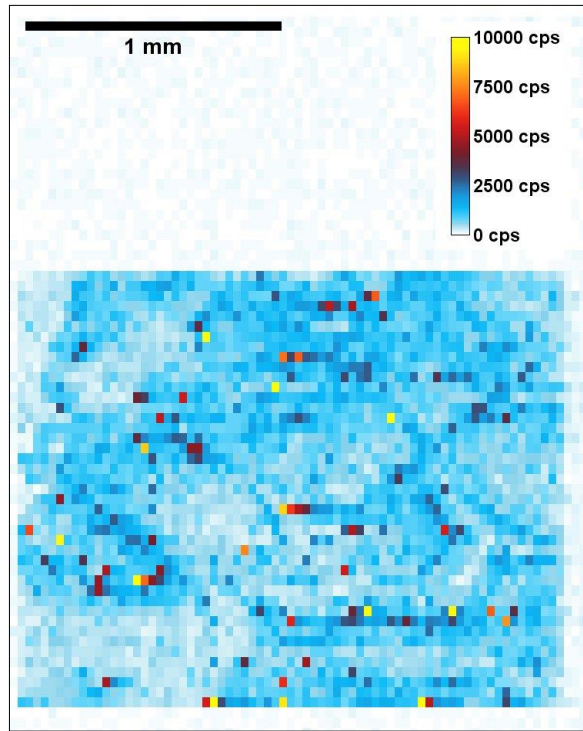
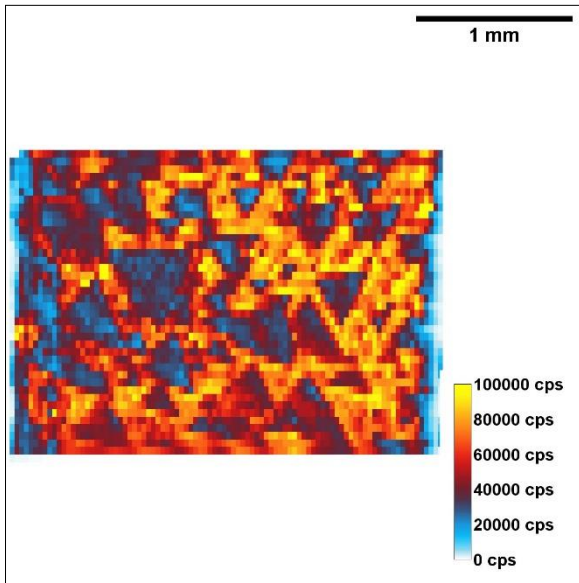


Figure S-10: ^{238}U and ^{232}Th mappings of speleothem sample BCO1H

Examples of ^{238}U and ^{232}Th images obtained by fsLA-ICPMS on speleothem sample BCO1H (resolution of $50\mu\text{m}$).

a - ^{238}U image



b - ^{232}Th image

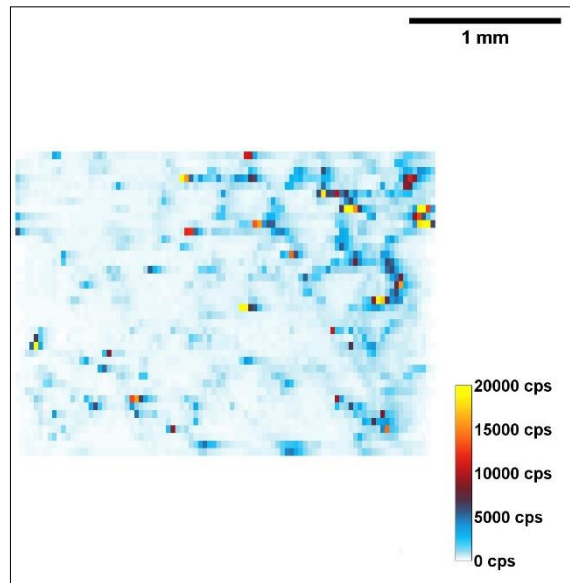


Figure S-11: Isochrone plots for the speleothem sample Salam12

Plots representing the ROIs data points and the best fitting used for calculating the detrital corrected $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ ratios. The slope of the $^{230}\text{Th}/^{232}\text{Th} = f(^{234}\text{U}/^{232}\text{Th})$ plot gives the $^{230}\text{Th}/^{234}\text{U}$ activity ratio corrected for detrital ^{230}Th , while the intercept gives the detrital $^{230}\text{Th}/^{232}\text{Th}$ value. Similarly, the slope of the $^{234}\text{U}/^{232}\text{Th} = f(^{238}\text{U}/^{232}\text{Th})$ plot gives the $^{234}\text{U}/^{238}\text{U}$ activity ratio corrected for detrital ^{234}U , while the intercept gives the detrital $^{234}\text{U}/^{232}\text{Th}$ value.

The fitting was obtained by iteratively reweighted a least squares regression using the Tukey's bisquare function.

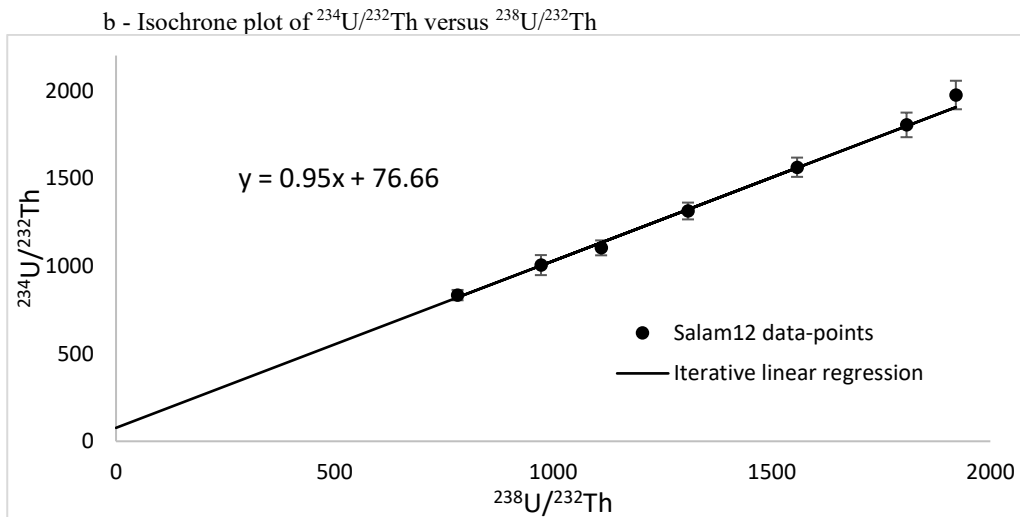
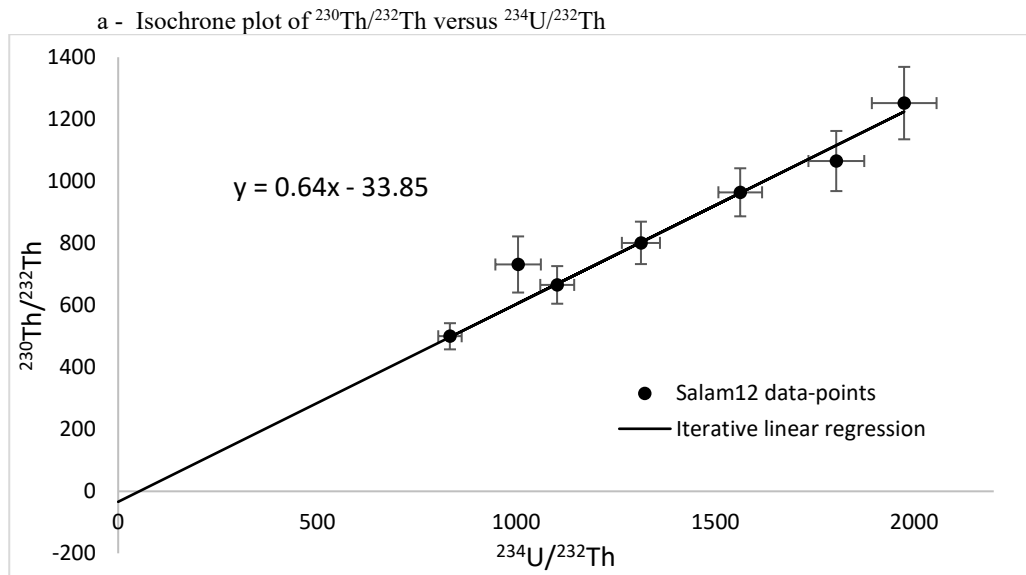


Figure S-12: Isochrone plots for the speleothem sample BCO1H

Plots representing the ROIs data points and the best fitting used for calculating detrital corrected $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ ratios. The slope of the $^{230}\text{Th}/^{232}\text{Th} = f(^{234}\text{U}/^{232}\text{Th})$ plot gives the $^{230}\text{Th}/^{234}\text{U}$ activity ratio corrected for detrital ^{230}Th , while the intercept gives the detrital $^{230}\text{Th}/^{232}\text{Th}$ value. Similarly, the slope of the $^{234}\text{U}/^{232}\text{Th} = f(^{238}\text{U}/^{232}\text{Th})$ plot gives the $^{234}\text{U}/^{238}\text{U}$ activity ratio corrected for detrital ^{234}U while the intercept gives the detrital $^{234}\text{U}/^{232}\text{Th}$ value.

The fitting was obtained by iteratively reweighted least squares regression using the Tukey's bisquare function.

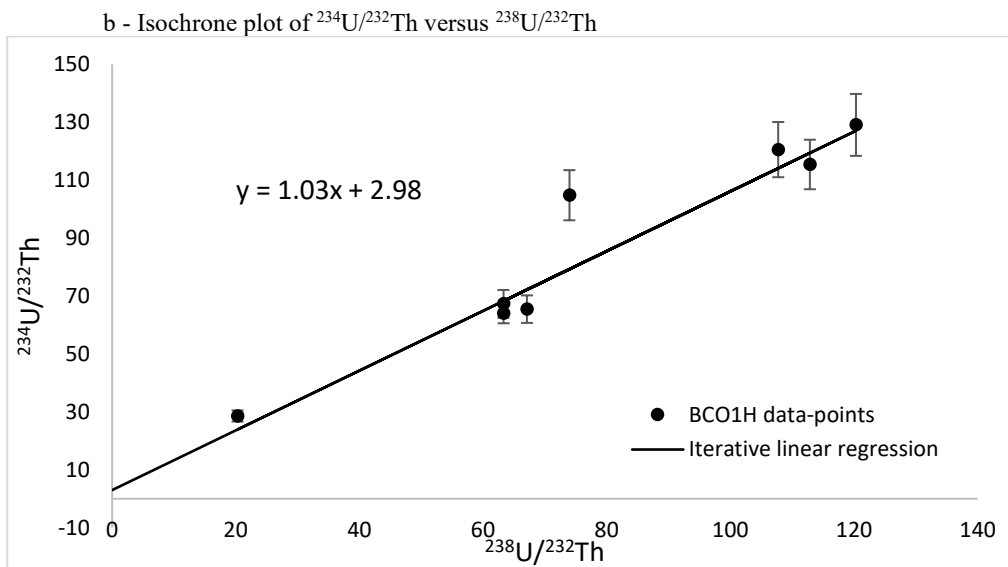
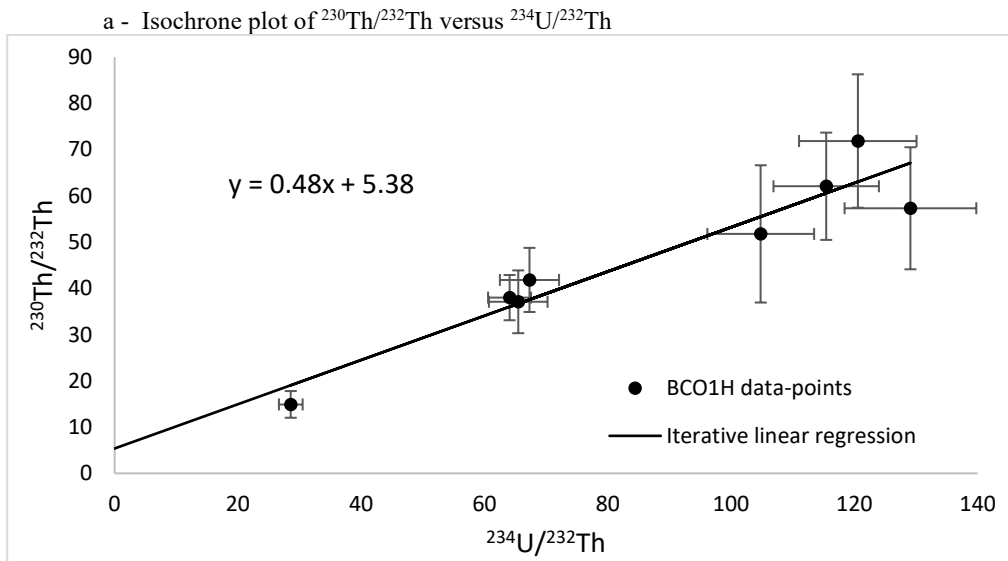


Table S-1: Details of the ICPMS measurement results for each ROI of each sample, including isotopic ratios

Summary of measurements in cps and activity ratios in Bq.Bq⁻¹ on each ROI of the speleothem samples and of the archaeological shell samples. Std indicates the standard deviation of the measure on the left expressed in the same unit.

Samples	Surface (mm ²)	Back-ground noise on 230 mass (cps)	Std	²³⁰ Th (cps)	Std	²³⁰ Th/ ²³² Th*	Std	²³⁰ Th/ ²³⁴ U*	Std	²³⁴ U/ ²³⁸ U*	Std
Salam12	2342	0.274	0.029	2.44	0.10	500	21	0.61	0.03	1.07	0.02
	668	0.078	0.008	6.79	0.30	1,065	48	0.60	0.03	1.00	0.02
	623	0.073	0.008	6.93	0.32	1,252	58	0.61	0.03	1.03	0.02
	1493	0.175	0.018	3.58	0.15	801	34	0.59	0.03	1.00	0.02
	1148	0.134	0.014	2.29	0.13	732	45	0.70	0.05	1.03	0.03
	1052	0.123	0.010	5.56	0.22	964	39	0.59	0.03	1.00	0.02
	2042	0.239	0.019	2.35	0.10	666	30	0.57	0.03	0.99	0.02
BCOIH	1.64	0.186	0.025	0.96	0.07	14.9	1.4	0.52	0.05	1.41	0.05
	0.82	0.186	0.025	0.52	0.04	51.8	7.4	0.49	0.07	1.42	0.06
	0.31	0.013	0.006	1.19	0.08	38.0	2.4	0.58	0.04	1.01	0.03
	1.91	0.013	0.006	0.52	0.05	62.1	5.8	0.53	0.05	1.02	0.04
	0.68	0.008	0.004	0.81	0.07	41.8	3.5	0.62	0.06	1.06	0.04
	0.18	0.008	0.004	0.31	0.03	57.3	6.6	0.45	0.05	1.07	0.04
	0.83	0.043	0.010	0.76	0.06	37.1	3.4	0.59	0.06	0.98	0.04
0.73	0.043	0.010	0.47	0.04	71.9	7.2	0.62	0.07	1.12	0.04	
BRS A9	1.43	0.038	0.012	0.19	0.04	91.7	24.6	0.59	0.17	1.60	0.16
	2.79	0.038	0.012	0.42	0.04	192.3	21.8	0.69	0.08	1.68	0.08
	3.65	0.038	0.012	0.18	0.02	2.6	0.5	0.48	0.09	1.85	0.10
	1.54	0.038	0.012	0.75	0.07	14.9	1.6	0.73	0.08	1.81	0.09
	0.98	0.034	0.010	0.22	0.05	206.7	57.2	0.86	0.26	1.50	0.19
	2.28	0.034	0.010	0.36	0.04	164.2	21.8	0.56	0.08	2.05	0.10
	0.57	0.034	0.010	0.53	0.10	83.0	17.1	0.72	0.16	1.77	0.16
	1.70	0.034	0.010	0.27	0.04	8.8	1.6	0.73	0.15	1.98	0.16
	0.61	0.034	0.010	0.61	0.11	8.2	1.5	0.65	0.13	1.72	0.14
	0.53	0.034	0.010	0.49	0.10	3.6	0.8	1.00	0.25	1.89	0.23
	2.51	0.039	0.011	0.21	0.03	167.0	31.9	0.71	0.15	1.55	0.12
	0.34	0.039	0.011	0.37	0.11	15.5	5.3	1.14	0.45	1.67	0.32
	0.39	0.039	0.011	0.74	0.15	14.1	2.9	1.28	0.31	1.56	0.20
	0.78	0.039	0.011	0.20	0.05	4.2	1.4	1.08	0.41	1.39	0.24
	0.26	0.039	0.011	0.13	0.08	1.8	1.5	0.31	0.27	1.98	0.42
	1.21	0.046	0.012	0.32	0.05	214.8	44.4	0.61	0.14	2.35	0.19
2.21	0.046	0.012	0.42	0.05	273.7	35.3	0.62	0.09	1.61	0.08	
0.95	0.046	0.012	0.76	0.09	67.1	9.0	0.66	0.10	1.96	0.11	
0.04	0.046	0.012	1.34	0.60	4.8	2.2	2.73	1.71	0.93	0.39	
0.20	0.046	0.012	1.16	0.25	4.5	1.0	3.47	1.13	1.21	0.28	
DRS10	1.00	0.062	0.008	0.15	0.03	3.4	1.7	0.45	0.23	1.45	0.20
	1.21	0.062	0.008	0.13	0.03	1.1	0.6	0.38	0.21	1.32	0.17
	1.02	0.062	0.008	0.13	0.03	0.9	0.5	0.53	0.31	1.03	0.17
	0.98	0.062	0.008	0.17	0.03	1.7	0.7	0.70	0.31	1.98	0.31
	1.54	0.063	0.009	0.25	0.03	2.4	0.6	0.64	0.16	1.34	0.12
	2.04	0.063	0.009	0.24	0.03	1.7	0.4	0.62	0.14	1.42	0.11
	1.34	0.063	0.009	0.18	0.03	1.3	0.4	0.81	0.31	1.24	0.17
	1.42	0.037	0.008	0.17	0.03	5.4	1.5	0.48	0.14	1.51	0.14
	1.84	0.037	0.008	0.21	0.03	2.8	0.6	0.80	0.18	1.30	0.12
	0.76	0.037	0.008	0.16	0.04	1.4	0.5	0.53	0.23	1.54	0.21
	1.08	0.012	0.004	0.16	0.03	1.7	0.5	0.65	0.20	1.32	0.16
	0.54	0.012	0.004	0.13	0.04	1.8	0.8	0.48	0.23	1.50	0.24
3.25	0.012	0.004	0.10	0.02	5.8	2.0	0.39	0.14	1.27	0.14	

* activity ratios in Bq.Bq⁻¹

Code S-1: Monte Carlo code of the ImageJ macro for calculation of U/Th ages with uncertainties

This code written in Java is an ImageJ macro and allows calculating using a Monte Carlo method a distribution of U-Th ages based on the averaged $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ ratios and their associated standard deviations. A series of random samplings of the $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ values is realized in a Student's t-distribution of the uncertainties based on the degree of freedom of the model. Above a degree of freedom of 100 (what is never the case in this study), the distribution is assumed normal and the sampling is done assuming a normal distribution. An age is calculated for each sampling, the iteration of samplings creating the age distribution. The most likely age is then calculated as the mean of that distribution and the uncertainties on the age (at the 95% confidence level) are estimated by the limit age values representing 2.5% and 97.5% of the cumulated distribution of the age probabilities.

```
// Macro for U/Th age calculation and error using MC sampling of uncertainty in a Student's t-distribution
// Written by Loic MARTIN (loic.martin@u-bordeaux-montaigne.fr) - October 2021
```

```
// parameters
var Cst_230Th = 0.00000917055435753526; // 230Th decay constante (per year)
var Cst_234U = 0.00000282203070010563; // 234U decay constante (per year)
var age_res = 100; // resolution of the age integration in year
var Tdist_res = 0.00001; // resolution of the t-distribution calculated
var CL = 0.95; // confidence level for uncertainty calculation
it = 1000; // number of random samplings in isotopic ratio distribution
mean_Th0_U4 = 0.50; // mean value of the 230Th/234U activity ratio
SD_Th0_U4 = 0.010; // standard deviation of the 230Th/234U activity ratio
mean_U4_U8 = 1.00; // mean value of the 234U/238U activity ratio
SD_U4_U8 = 0.010; // standard deviation of the 234U/238U activity ratio
FDom=20; // Degrees of freedom of the model

do {
Dialog.create("MC_UTh_age");// creation of an dialogue box
Dialog.addMessage("Isotopic ratios and standard Errors:");
Dialog.addMessage(" ");
Dialog.addNumber("230Th/234U", mean_Th0_U4);
Dialog.addNumber(" + -", SD_Th0_U4);
Dialog.addNumber("234U/238U", mean_U4_U8);
Dialog.addNumber(" + -", SD_U4_U8);
Dialog.addNumber("Degrees of freedom of dataset :", FDom);
Dialog.addNumber("Nb. Of iterations :", it);
Dialog.show();

mean_Th0_U4=Dialog.getNumber(); // retrieving the value from the dialogue box
SD_Th0_U4=Dialog.getNumber();
mean_U4_U8=Dialog.getNumber();
SD_U4_U8=Dialog.getNumber();
FDom=Dialog.getNumber();
it=Dialog.getNumber();

MC_age(it,mean_Th0_U4,SD_Th0_U4,mean_U4_U8,SD_U4_U8,FDom);
// calculating the age distribution
} while (1)
exit()

function MC_age(it,mean_Th0_U4,SD_Th0_U4,mean_U4_U8,SD_U4_U8,FDom) {
random("seed",getTime());// initiating the pseudo-random engine
/** creating the t-distribution **/
t=0;
G1= Gamma((1.*(FDom+1.)/2.));
G2= Gamma(1.*(FDom/2.));
f= G1/(G2*pow(FDom*3.1415, 0.5))*pow(1+t*t/FDom,-(FDom+1)/2);
while(f>0.001){
t += Tdist_res;
f= G1/(G2*pow(FDom*3.1415, 0.5))*pow(1+t*t/FDom,-(FDom+1)/2);
}
t_max=t; // calculating the 99.9% limit of the t-distribution
Ncat=2*t_max/Tdist_res;
Tdist = newArray(Ncat);
Tsum=0;
for (i = 0; i < Ncat; i++){ // calculating the values of the t-distribution on the interval
```



```

        t=(i-Ncat/2)*Tdist_res;
        f = G1/(G2*pow(FDom*3.1415, 0.5))*pow(1+t*t/FDom,-(FDom+1)/2);
        Tdist[i] = f;
        Tsum += f;
    }
    Tdist_cum = newArray(Ncat+1);
    Tdist_cum[0]=0.;
    for (i = 0; i < Ncat; i++){ // calculating the cumulated probabilities of the t-distribution
        Tdist[i] /= Tsum*Tdist_res;
        Tdist_cum[i+1]=Tdist_cum[i]+Tdist[i]*Tdist_res;
    }
    // creating arrays for activity ratios and age distributions
    dist_Th0_U4 = newArray(it); for(i=0; i<it; i++)dist_Th0_U4[i]=0.;
    dist_U4_U8 = newArray(it); for(i=0; i<it; i++)dist_U4_U8[i]=0.;
    dist_age = newArray(it); for(i=0; i<it; i++)dist_age[i]=0.;
    max_age=0;
    title = "[Progress]";
    run("Text Window...", "name="+ title +" width=40 height=1 monospaced");

    for(i=0; i<it; i++){ // age distribution Monte Carlo sampling
        // display calculation progress
        if (floor((i+1)/it * 100) / 100 == (i+1)/it) print(title, "\\Update:"+(i+1)+" "+ it +" ("+(i+1)*100) / it +"%") /*\n"+getBar(i,
        100)*);
        if (i ==0) print(title, "\\Update:"+(i)+" "+ it +" ("+(i)*100) / it +"%") /*\n"+getBar(i, 100)*);

        ThU_ageMoy = mean_Th0_U4* mean_U4_U8; // calculation of the most probable age
        ageMoy=0.;
        ThU_test=0.;
        while(ThU_test<ThU_ageMoy){
            ageMoy += age_res;
            ThU_test= (1.-exp(-Cst_230Th*ageMoy)) +
            Cst_230Th/(Cst_230Th-Cst_234U)*(mean_U4_U8-1.)*(1.-exp((Cst_234U-Cst_230Th)*ageMoy));
        }

        TRand = 0;
        if(FDom>100) TRand = random("gaussian"); // random sampling in a Normal distribution if degrees of freedom >100
        else {
            URand = random(); // uniform random sampling of a probability on 0-1 interval
            jmin =0;
            jmax = Ncat+1;
            while(jmax-jmin>1){ // dichotomic determination of the t-distribution value corresponding to the probability
                if(URand<Tdist_cum[Math.floor((jmax+jmin)/2)])jmax=Math.floor((jmax+jmin)/2);
                else jmin=Math.floor((jmax+jmin)/2);
            }
            TRand=1.*(jmin-Ncat/2.)*Tdist_res;
        }
        ThU_Tdist = TRand*SD_Th0_U4+mean_Th0_U4; // calculating the 230Th/234U ratio corresponding to the sampling
        dist_Th0_U4[i]= ThU_Tdist; // recording the 230Th/234U ratio sampling in a array

        TRand = 0;
        if(FDom>100) TRand = random("gaussian"); // random sampling in a Normal distribution if degrees of freedom >100
        else {
            URand = random(); // uniform random sampling of a probability on 0-1 interval
            jmin =0;
            jmax = Ncat+1;
            while(jmax-jmin>1){ // dichotomic determination of the t-distribution value corresponding to the probability
                if(URand<Tdist_cum[Math.floor((jmax+jmin)/2)])jmax=Math.floor((jmax+jmin)/2);
                else jmin=Math.floor((jmax+jmin)/2);
            }
            TRand=1.*(jmin-Ncat/2.)*Tdist_res;
        }
        U4U8_Tdist = TRand*SD_U4_U8 + mean_U4_U8; // calculating the 234U/238U ratio corresponding to the sampling
        dist_U4_U8[i]= U4U8_Tdist; // recording the 234U/238U ratio sampling in a array

        Th0_U8 = dist_Th0_U4[i]*dist_U4_U8[i]; // calculating the 230Th/238U ratio corresponding to the sampling

```

```

age = 0.;
it_age = 0;
ThU_age=0.;
while(ThU_age<Th0_U8){ // determination of the age corresponding to the sampling
    age += age_res;
    ThU_age=(1.-exp(-Cst_230Th*age)) + Cst_230Th/(Cst_230Th-Cst_234U)*(dist_U4_U8[i]-1.)*(1.-exp((Cst_234U-
Cst_230Th)*age));
    if(dist_Th0_U4[i]>1.){age=1000000; break;}
    if(age>1000000){ break;}
}
dist_age[i]=age;
// recording the age sampling in a array
if(age > max_age)max_age=age; // determining the maximum age of the sampling
} // end of the Monte Carlo sampling

histo_size = max_age/age_res+1;
// construction of the age distribution histogram
histo_age = newArray(histo_size);
ages = newArray(histo_size);
for(i=0; i<histo_size; i++){histo_age[i] = 0.;ages[i] = i*age_res;}
for( i=0; i<it; i++)histo_age[dist_age[i]/age_res] += 1;

age_min = 0.; // calculation of the minimum and maximum age corresponding to confidence level CL
age_max = 0.;
histo_cum = newArray(histo_size);
histo_cum[0]=histo_age[0]/it;
for(i=1; i<histo_size; i++)histo_cum[i]=0.;
for(i=1; i<histo_size; i++) {
    histo_cum[i]= histo_cum[i-1]+histo_age[i]/it;
    if((histo_cum[i-1]<=(1.-CL)/2.)&&(histo_cum[i]>(1.-CL)/2.))age_min = (i-1)*age_res;
    if((histo_cum[i-1]<(1.+CL)/2.)&&(histo_cum[i]>=(1.+CL)/2.))age_max = (i)*age_res;
}

/** displaying the results */
run("Close");
print("age(ka): " + ageMoy/1000., "+" + (age_max-ageMoy)/1000., "-" + (ageMoy-age_min)/1000.);
Plot.create("Histogram of U/Th age", "age (ka)", "Counts",ages,histo_age);
Plot.addText("age(ka):", 0.05, 0.1); Plot.addText(ageMoy/1000., 0.15, 0.1);
Plot.addText("+", 0.20, 0.1); Plot.addText((age_max-ageMoy)/1000., 0.22, 0.1);
Plot.addText("-", 0.27, 0.1); Plot.addText((ageMoy-age_min)/1000., 0.29, 0.1);
Plot.show();// creating histogram plot of the age distribution
}

function Gamma(n){ // gamma function for integer and half-integer value
nint = Math.floor(n);
G=1.;
for( i = 0; i < nint; i++) G *= n-i;
if(nint<n) G *= pow(3.1415,0.5)/2.;
return(G);}

```