Additional description and age data

Stable isotope analyses: $\delta^{18}O$ and $\delta^{13}C$ analyses were performed in two batches. The first batch was performed on a Finnigan MAT 252 stable isotope mass spectrometer at Monash University. CO_2 from was liberated by acidification using H_3PO_4 in a He atmosphere in a Finnigan MAT Gas Bench and analysed by continuous flow. Precision (1σ) based on replicate analyses is: $\delta^{18}O$ = ±0.1‰ and $\delta^{13}C$ = ±0.1‰. The second batch of samples was run on VG Isocarb automated device attached to a VG Prism2 mass spectrometer a the Scottish Universities Environmental Research Centre (East Kilbride, Scotland). Precision (1σ) based on replicate analyses is $\delta^{18}O$ = ±0.1‰ and $\delta^{13}C$ = ±0.1‰.

[Mg:Ca] analyses: Subsamples of 0.1-0.2 mg were digested in Specpure concentrated HNO_3 then diluted to 1:20 with MQ double-deionised water. The solutions were analysed at the University of Newcastle using a Varian Liberty 4000 inductively coupled plasma atomic emission spectrometer. The coefficient of variation on replicate analyses was better than 0.6% for Mg and 0.9% for Ca.

Fluorescence analyses: Fluorescence measurements were made directly on the polished slab of RL4 using a fibre-optic probe coupled to a Varian Cary Eclipse Fluorescence Spectrophotometer. Measurements were made along a traverse parallel and 5 mm from where the stable isotope/trace element samples were drilled. For each sample point, ultra-violet excitation energy in the 300-400 nm wavelength (λ) range (supplied from a xenon flash lamp) was applied to the sample in 1 nm steps via the fibre-optic probe, which has a spot size of 4 mm. The resulting emission intensity was detected at 1 nm steps between 380 and 480 nm. The excitation and emission slits were set at 5 nm and the lamp energy fixed at 700 PMT voltage. The fluorescence measurements were interfaced with a moving stage, which advanced the sample beneath the fibre-optic probe at 1 mm increments after each analysis. This produced a 153-point time-series, which represents a 4-point moving average of calcite fluorescence due to the probe's 4 mm spot size. The first two and last two analyses were disregarded due to edge effects.

Fluorescence data for each sample point are represented by an excitation-emission matrix (EEM), which shows emission intensity (z) for each excitation λ (y) - emission λ (x) pair (see McGarry and Baker 2000). In the first step, a 3 × 3 smoothing routine is performed on each EEM to remove random fluorescence noise, which occasionally produces spurious peak intensity values unrepresentative of the true fluorescence center. The fluorescence center, i.e. the excitation λ and emission λ coordinate of the highest fluorescence intensity, was identified on the smoothed EEM using a computer program called FLUORO written by Matthew Pickett. A time-series of peak emission λ was compiled from these data.

The spectrophotometer was calibrated prior to and immediately after analysis using the standard Varian instrument calibration routine. Repeat analyses using precisely the same settings as above were conducted at three randomly selected positions along the growth axis of RL4 in order to quantify repeatability. Ten repeats were carried out at each of these points. These yielded coefficients of variation of less than 1% for peak excitation wavelength, peak emission wavelength and peak fluorescence intensity.

Detrital Th correction for U-series ages: Ages are corrected for the effects of non-radiogenic ^{230}Th using an assumed initial $^{230}Th/^{232}Th$ activity ratio of 0.155 ± 0.045, the uncertainty on which is propagated into the final age uncertainty. This value is unusually low for stalagmites, but is well constrained in being the range of values over which the corrected ages remain in their correct sequence within error. Even after removal of the

badly contaminated sample RL 4-2 from consideration, the maximum possible value for $^{230}Th/^{232}Th_{(initial)}$ is constrained to 0.4 by the remaining samples.

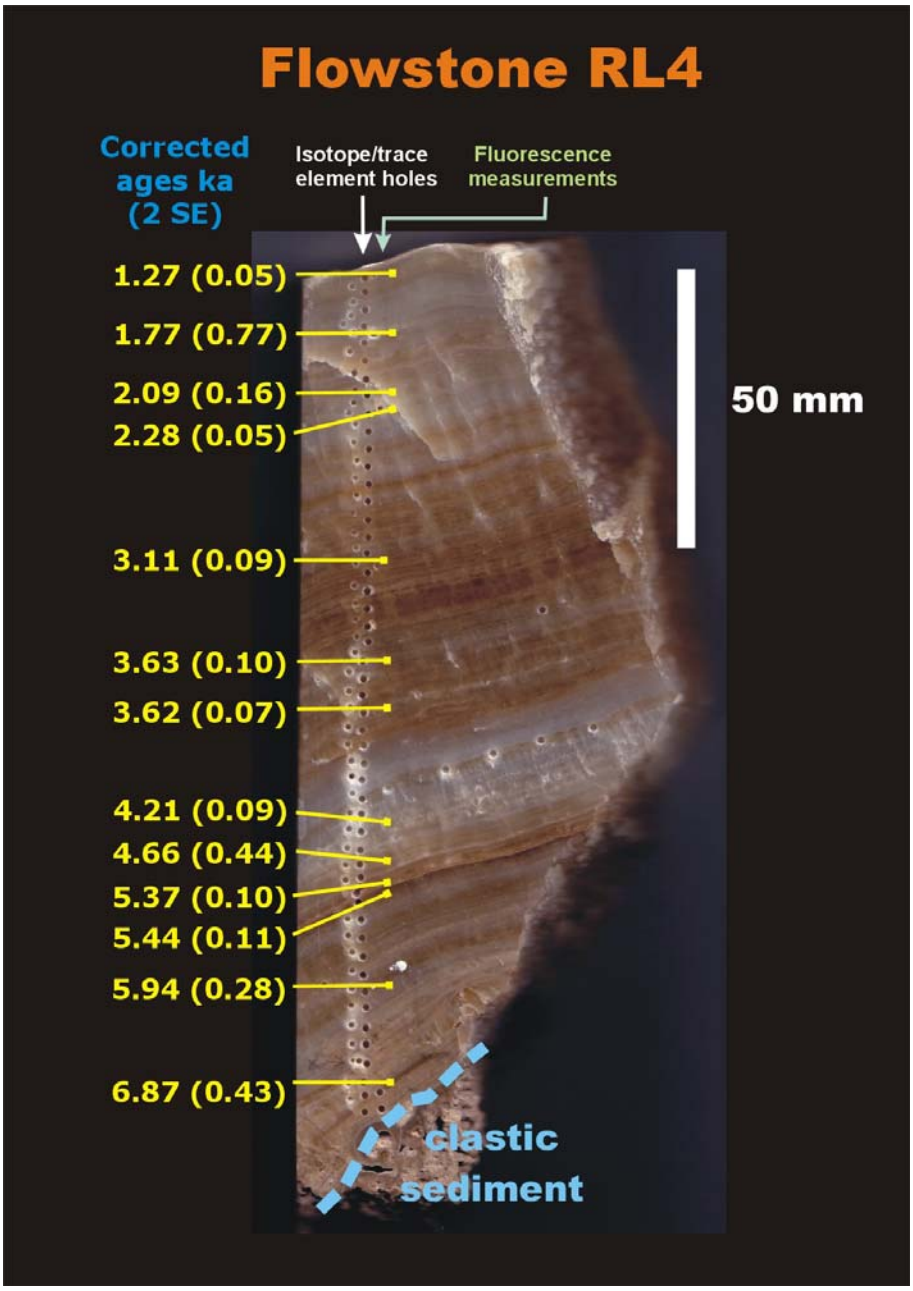


Figure DR1: Polished section of RL4 showing the position of the isotope/trace element and U/Th dating samples.

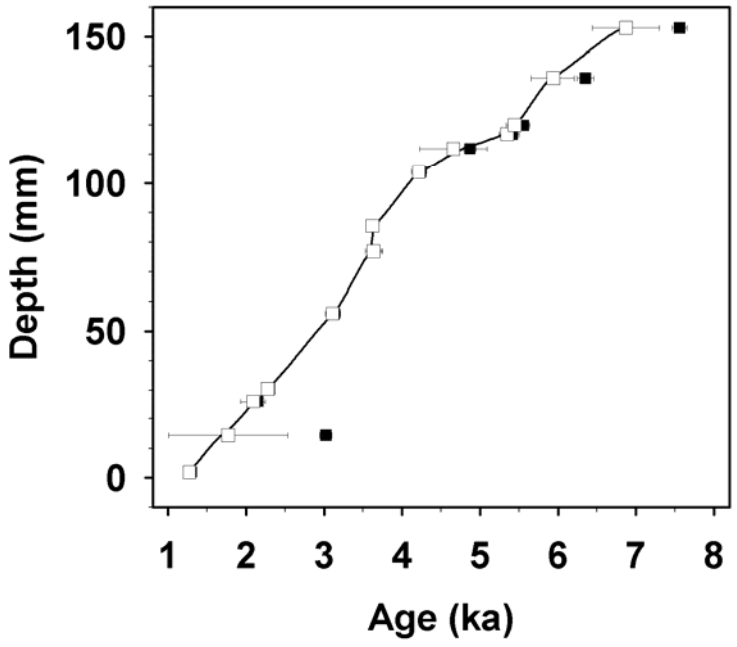


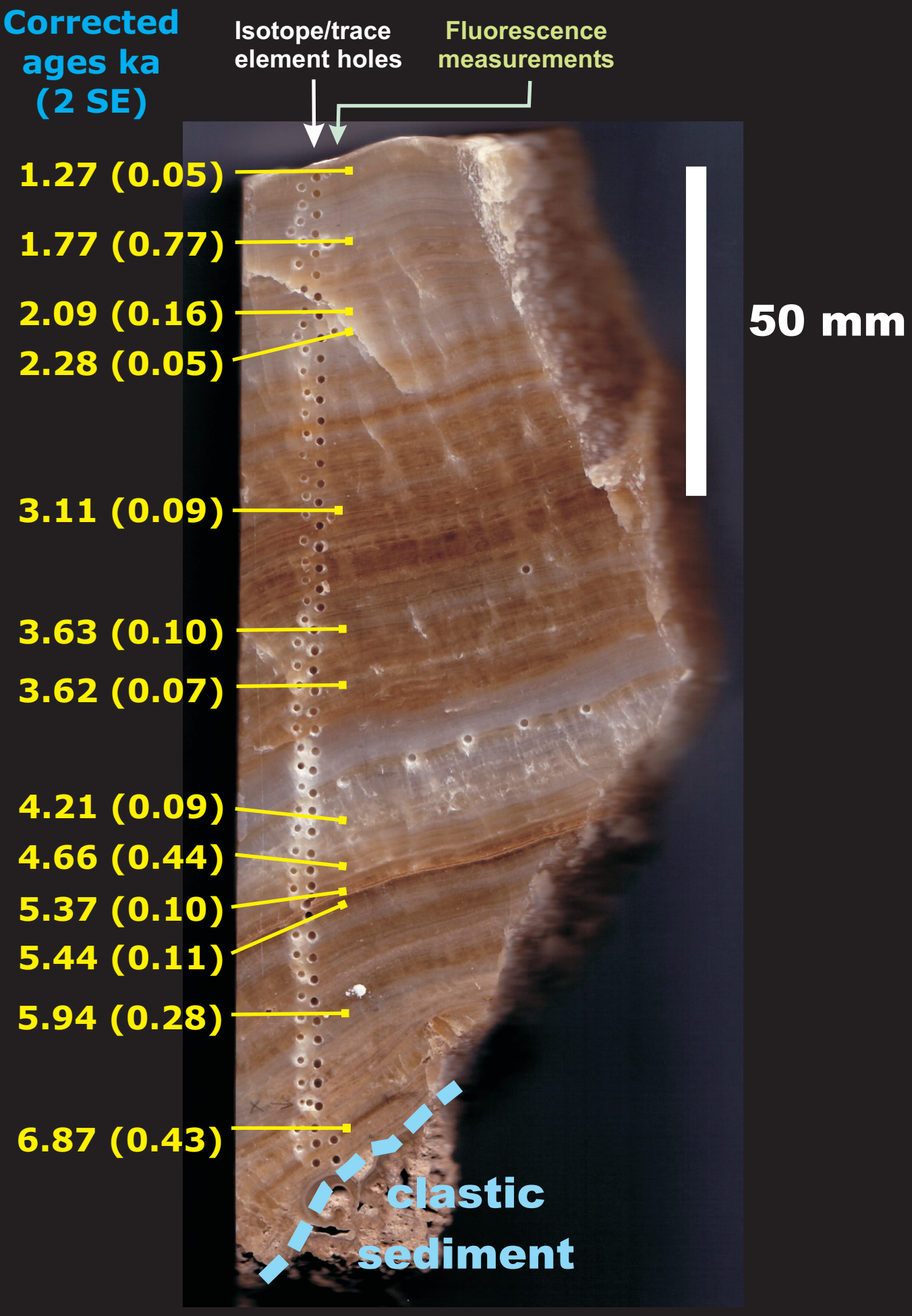
Figure DR2: Age-depth plot of raw (solid symbols) and corrected (open symbols) uranium-series ages. The error bars for each set represent 95% age uncertainties. The line joining the corrected ages, which represents the median age-depth model derived from Bayesian-Monte Carlo simulations (Drysdale et al. 2004), was used to develop the time series in this study.

TABLE DR1. SAMPLE DEPTH AND AGE DATA FOR FLOWSTONE RL4.

Sample	Depth (mm)		U (ppb)		$[^{230}Th/^{238}U]$		$[^{234}U/^{238}U]$		$[^{232}Th/^{238}U] \times 10^3$		Uncorrected age (ka)		$[^{234}U/^{238}U]_{init}$		Corrected age (ka)	
RL4-1	2.0	(0.75)	335	(6)	0.00837	(29)	0.7088	(13)	1.0496	(0.0036)	**1.29**	**(0.04)**	0.7077	(13)	**1.27**	**(0.05)**
RL4-2	14.5	(0.75)	484	(9)	0.01940	(50)	0.7095	(12)	53.5195	(0.1850)	**3.02**	**(0.08)**	0.7070	(12)	**1.77**	**(0.77)**
RL4-9	26.0	(0.525)	440	(5)	0.01396	(61)	0.7135	(18)	1.0356	(0.0577)	**2.15**	**(0.09)**	0.7118	(18)	**2.09**	**(0.16)**
RL4-3	30.5	(0.75)	527	(10)	0.01507	(33)	0.7235	(13)	0.7078	(0.0026)	**2.29**	**(0.05)**	0.7217	(13)	**2.28**	**(0.05)**
RL4-10	56.0	(0.525)	669	(5)	0.02028	(47)	0.7153	(13)	0.4284	(0.0136)	**3.13**	**(0.07)**	0.7127	(13)	**3.11**	**(0.09)**
RL4-11	77.0	(0.525)	911	(7)	0.02315	(62)	0.7038	(16)	0.2403	(0.0106)	**3.67**	**(0.10)**	0.7008	(16)	**3.63**	**(0.10)**
RL 4-4	85.5	(0.75)	690	(13)	0.02287	(44)	0.6999	(13)	0.1493	(0.0009)	**3.62**	**(0.07)**	0.6968	(13)	**3.62**	**(0.07)**
RL4-12	104.0	(0.525)	675	(6)	0.02652	(50)	0.6961	(18)	0.3361	(0.0115)	**4.24**	**(0.08)**	0.6924	(18)	**4.21**	**(0.09)**
RL4-13	112.0	(0.525)	592	(4)	0.03118	(50)	0.7141	(28)	3.4737	(0.1466)	**4.87**	**(0.08)**	0.7101	(29)	**4.66**	**(0.44)**
RL4-5	117.0	(0.75)	640	(12)	0.03472	(59)	0.7177	(13)	2.7140	(0.0154)	**5.41**	**(0.09)**	0.7133	(13)	**5.35**	**(0.10)**
Rl4-6	120.0	(0.75)	649	(14)	0.03487	(51)	0.7030	(15)	4.5595	(0.0245)	**5.55**	**(0.08)**	0.6983	(15)	**5.44**	**(0.11)**
RL4-7	136.0	(0.75)	569	(11)	0.03998	(66)	0.7074	(14)	17.6856	(0.0837)	**6.35**	**(0.11)**	0.7021	(14)	**5.94**	**(0.28)**
RL4-8	153.0	(0.75)	705	(13)	0.04677	(58)	0.6998	(12)	28.8352	(0.1321)	**7.56**	**(0.10)**	0.6933	(13)	**6.87**	**(0.43)**

Notes: The numbers in round brackets are 95% uncertainties. Isotope data are expressed as activity ratios, the 95% uncertainties for which include allowances for external standard reproducibility and spike calibration uncertainty, although uncertainty in decay constants is not propagated. $[^{230}Th/^{238}U]$ is determined using a mixed spike calibrated against a solution of HU-1 - see Hellstrom (2003) for a detailed description of the method and results of standard analyses. Age is calculated using the standard U-Th age equation, using decay constants of 9.195×10^{-6} and 2.835×10^{-6} for ^{230}Th and ^{234}U respectively. Corrected age is calculated allowing for an initial $[^{230}Th/^{232}Th]$ of 0.155 ± 0.045 (see text above), included as an additional term in the standard U-Th age equation. $[^{234}U/^{238}U]_{initial}$ is calculated using $[^{234}U/^{238}U]$ and the corrected age.

Flowstone RL4



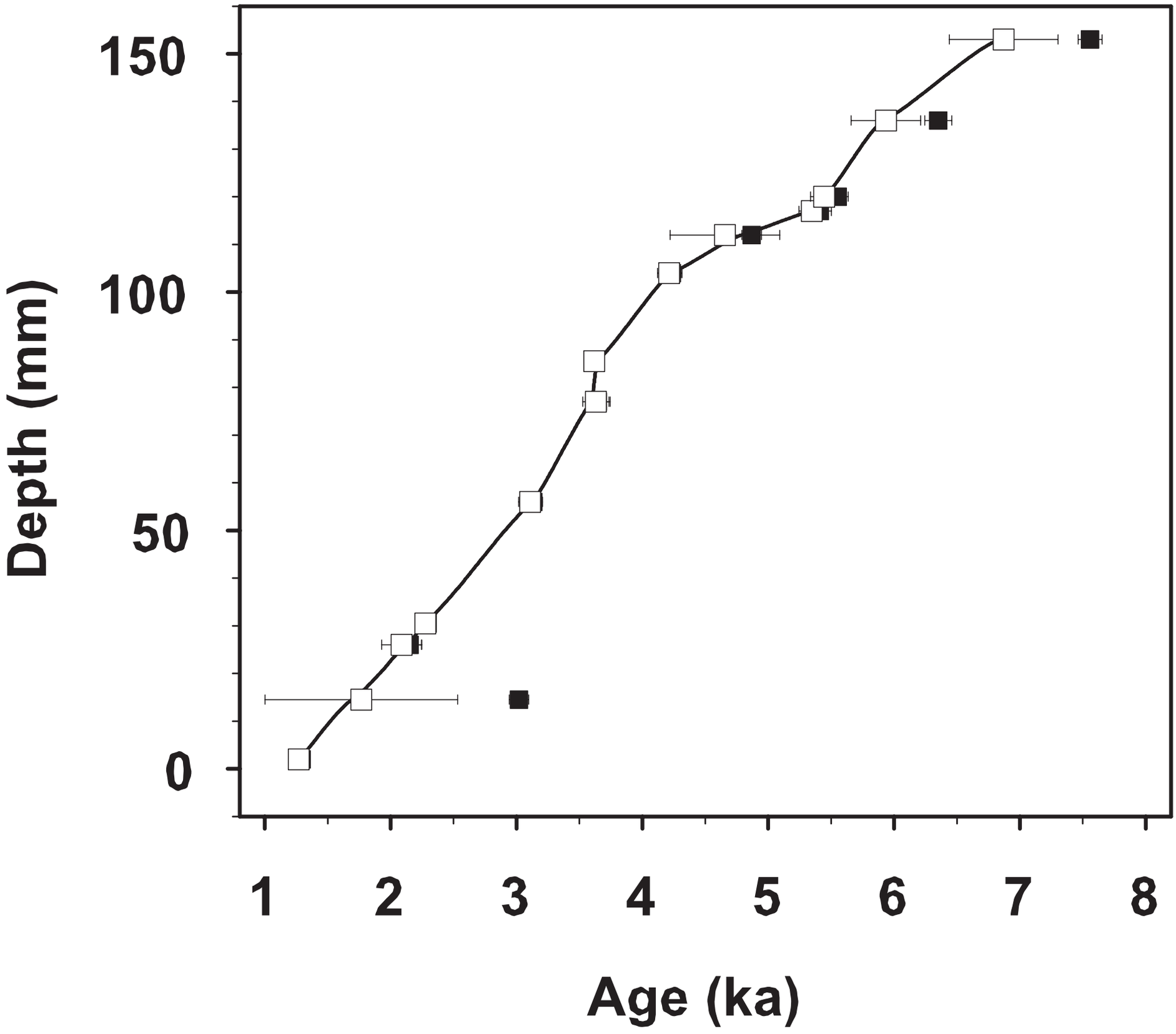

150
100
50
0
Depth (mm)
1
2
3
4
5
6
7
8
Age (ka)

Table DR1. Sample depth and age data for flowstone RL4.

Sample	Depth (mm)		U (ppb)		[230Th/238U]		[234U/238U]		[232Th/238
RL4-1	2	-0.75	335	(6)	0.00837	-29	0.7088	-13	1.0496
RL4-2	14.5	-0.75	484	(9)	0.0194	-50	0.7095	-12	53.5195
RL4-9	26	-0.525	440	(5)	0.01396	-61	0.7135	-18	1.0356
RL4-3	30.5	-0.75	527	(10)	0.01507	-33	0.7235	-13	0.7078
RL4-10	56	-0.525	669	(5)	0.02028	-47	0.7153	-13	0.4284
RL4-11	77	-0.525	911	(7)	0.02315	-62	0.7038	-16	0.2403
RL 4-4	85.5	-0.75	690	(13)	0.02287	-44	0.6999	-13	0.1493
RL4-12	104	-0.525	675	(6)	0.02652	-50	0.6961	-18	0.3361
RL4-13	112	-0.525	592	(4)	0.03118	-50	0.7141	-28	3.4737
RL4-5	117	-0.75	640	(12)	0.03472	-59	0.7177	-13	2.714
Rl4-6	120	-0.75	649	(14)	0.03487	-51	0.703	-15	4.5595

Notes: The numbers in round brackets are 95% uncertainties. Isotope data are expressed as activity ra
the 95% uncertainties for which include allowances for external standard reproducibility and spike calib
is not propagated. [230Th/238U] is determined using a mixed spike calibrated against a solution of HU-
and results of standard analyses. Age is calculated using the standard U-Th age equation, using decay
Corrected age is calculated allowing for an initial [230Th/232Th] of 0.155 ± 0.045 (see text above), inclu
[234U/238U]initial is calculated using [234U/238U] and the corrected age.

3U] × 103	Uncorrected age (ka)		[234U/238U]init		Corrected age (ka)	
-0.0036	1.29	-0.04	0.7077	-13	1.27	-0.05
-0.185	3.02	-0.08	0.707	-12	1.77	-0.77
-0.0577	2.15	-0.09	0.7118	-18	2.09	-0.16
-0.0026	2.29	-0.05	0.7217	-13	2.28	-0.05
-0.0136	3.13	-0.07	0.7127	-13	3.11	-0.09
-0.0106	3.67	-0.1	0.7008	-16	3.63	-0.1
-0.0009	3.62	-0.07	0.6968	-13	3.62	-0.07
-0.0115	4.24	-0.08	0.6924	-18	4.21	-0.09
-0.1466	4.87	-0.08	0.7101	-29	4.66	-0.44
-0.0154	5.41	-0.09	0.7133	-13	5.35	-0.1
-0.0245	5.55	-0.08	0.6983	-15	5.44	-0.11

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ration uncertainty, although uncertainty in decay constants
1 - see Hellstrom (2003) for a detailed description of the method
constants of 9.195 ´ 10-6 and 2.835 ´ 10-6 for 230Th and 234U respectively.
uded as an additional term in the standard U-Th age equation.