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Supplement of

Iterative outlier identification for robust cosmogenic $^{26}\mathrm{Al}/^{10}\mathrm{Be}$ burial dating of fluvial terraces: a case study from the Danube River (Vienna Basin, Austria)

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1) Model setup

Table S1: Production rates used for the modelling

Production rate at sample location	Surface	5.5 m depth	11.7 m depth
^{10}Be spallation[atoms/g_{qtz}/y]	4.819	0.005	0.000
^{10}Be slow muons [atoms/g_{qtz}/y]	0.042	0.020	0.009
^{10}Be fast muons [atoms/g_{qtz}/y]	0.039	0.030	0.023
^{26}Al spallation[atoms/g_{qtz}/y]	32.288	0.033	0.000
^{26}Al slow muons [atoms/g_{qtz}/y]	0.475	0.228	0.098
^{26}Al fast muons [atoms/g_{qtz}/y]	0.269	0.208	0.156

2) Results of the bootstrapping and Post-burial production test

Table S2. Burial age and denudation rate modelling results using ISO and INV for the two sampled depth levels treated independently. *: averaged values and standard deviation of the bootstrapped runs. Rχ^2: reduced χ^2 values.

			ISO				INV						
			Burial age [Ma]			Rχ^2	Burial age [Ma]			Sink denudation rate [m/Ma]			Rχ^2
Complete dataset		All samples	2.23	±	0.49	3.0	2.23	±	0.40	9.7	±	1.5	1.8
	Bootstrap	w/o #10	2.67	±	0.71	2.9	2.25	±	0.40	9.1	±	1.4	2.2
		w/o #11	1.93	±	0.51	3.0	1.90	±	0.34	12.7	±	2.0	2.1
		w/o #12	2.35	±	0.54	3.0	2.34	±	0.42	9.7	±	1.5	2.1
		w/o #13	2.39	±	0.55	2.5	2.38	±	0.43	9.6	±	1.4	1.5
		w/o #15	1.21	±	0.35	2.0	1.22	±	0.22	12.1	±	1.9	1.1
		mean*	2.11	±	0.79	2.7	2.02	±	0.61	10.7	±	2.3	1.2
w/o #15		All samples	1.21	±	0.35	2.0	1.22	±	0.22	12.1	±	1.9	1.1
	Bootstrap	w/o #10	1.46	±	0.44	1.3	1.44	±	0.27	7.3	±	1.2	0.3
		w/o #11	0.90	±	0.36	1.1	0.88	±	0.16	32.6	±	5.3	0.2
		w/o #12	1.06	±	0.41	3.0	1.04	±	0.19	13.8	±	2.2	2.1
		w/o #13	1.47	±	0.53	2.8	1.48	±	0.26	10.8	±	1.6	1.8
		mean*	1.22	±	0.53	2.1	1.21	±	0.37	16.1	±	11.7	0.6
Complete dataset		All samples	0.78	±	0.14	4.0	0.82	±	0.15	66.1	±	12.4	2.9
	Bootstrap	w/o #20	0.68	±	0.13	3.8	0.72	±	0.14	4.1E+5	±	7.9E+4	2.7
		w/o #21	0.44	±	0.15	2.7	0.58	±	0.11	2.9E+8	±	5.4E+7	1.8
		w/o #22	0.79	±	0.17	4.8	0.83	±	0.16	63.15	±	12.04	3.8
		w/o #23	0.89	±	0.16	3.6	0.92	±	0.17	60.86	±	11.68	2.7
		w/o #24	1.22	±	0.23	2.4	1.27	±	0.24	4.68	±	0.83	1.3
		w/o #25	0.78	±	0.14	4.8	0.82	±	0.15	73.17	±	13.81	3.8
		mean*	0.80	±	0.30	3.6	0.86	±	0.29	-		-	2.0
w/o #24		All samples	1.22	±	0.23	2.4	1.27	±	0.22	4.7	±	0.8	1.3
	Bootstrap	w/o #20	1.20	±	0.29	3.1	1.22	±	0.21	6.0	±	1.0	1.9
		w/o #21	0.85	±	0.25	1.8	0.91	±	0.16	11.7	±	2.1	0.8
		w/o #22	1.28	±	0.26	2.9	1.32	±	0.23	4.5	±	0.8	1.8
		w/o #23	1.28	±	0.23	1.8	1.32	±	0.24	7.1	±	1.3	0.8
		w/o #25	1.42	±	0.27	2.2	1.34	±	0.23	2.4	±	0.4	1.1
		mean*	1.20	±	0.34	2.4	1.22	±	0.28	6.3	±	3.7	0.8

Table S3. Burial age and denudation rate modelling results for the merged dataset using INV on the complete and bootstrapped datasets. *: averaged values and standard deviation of the bootstrapped runs. $R\chi^2$: reduced χ^2 values.

			INV						
			Burial age [Ma]			**Sink denudation rate [m/Ma]**			**$R\chi^2$**
Complete dataset	All samples		1.13	±	0.21	22.3	±	4.1	3.4
	Bootstrap	w/o #10	1.12	±	0.21	23.4	±	4.3	3.8
		w/o #11	0.98	±	0.18	49.7	±	9.2	3.1
		w/o #12	1.13	±	0.21	22.4	±	4.1	3.8
		w/o #13	1.14	±	0.21	22.3	±	4.1	3.8
		w/o #15	0.97	±	0.18	19.8	±	3.7	1.9
		w/o #20	1.11	±	0.20	25.3	±	4.7	3.6
		w/o #21	1.06	±	0.20	25.5	±	4.7	3.8
		w/o #22	1.20	±	0.22	20.0	±	3.7	3.7
		w/o #23	1.20	±	0.22	19.2	±	3.6	3.0
		w/o #24	1.28	±	0.24	14.7	±	2.6	2.9
		w/o #25	1.27	±	0.23	22.5	±	4.1	3.8
		mean*	1.13	±	0.23	24.1	±	10.2	3.0
w/o #15 and #24	All samples		1.10	±	0.20	11.9	±	2.2	1.0
	Bootstrap	w/o #10	1.21	±	0.22	7.1	±	1.3	0.8
		w/o #11	1.02	±	0.18	17.3	±	3.3	1.0
		w/o #12	1.09	±	0.20	11.6	±	2.2	1.1
		w/o #13	1.10	±	0.20	11.9	±	2.2	1.2
		w/o #20	1.09	±	0.19	12.9	±	2.4	1.1
		w/o #21	0.89	±	0.16	17.0	±	3.2	0.7
		w/o #22	1.14	±	0.20	11.4	±	2.1	1.1
		w/o #23	1.22	±	0.22	11.3	±	2.1	0.7
		w/o #25	1.10	±	0.20	11.4	±	2.0	1.1
		mean*	1.10	±	0.22	12.4	±	3.9	0.8

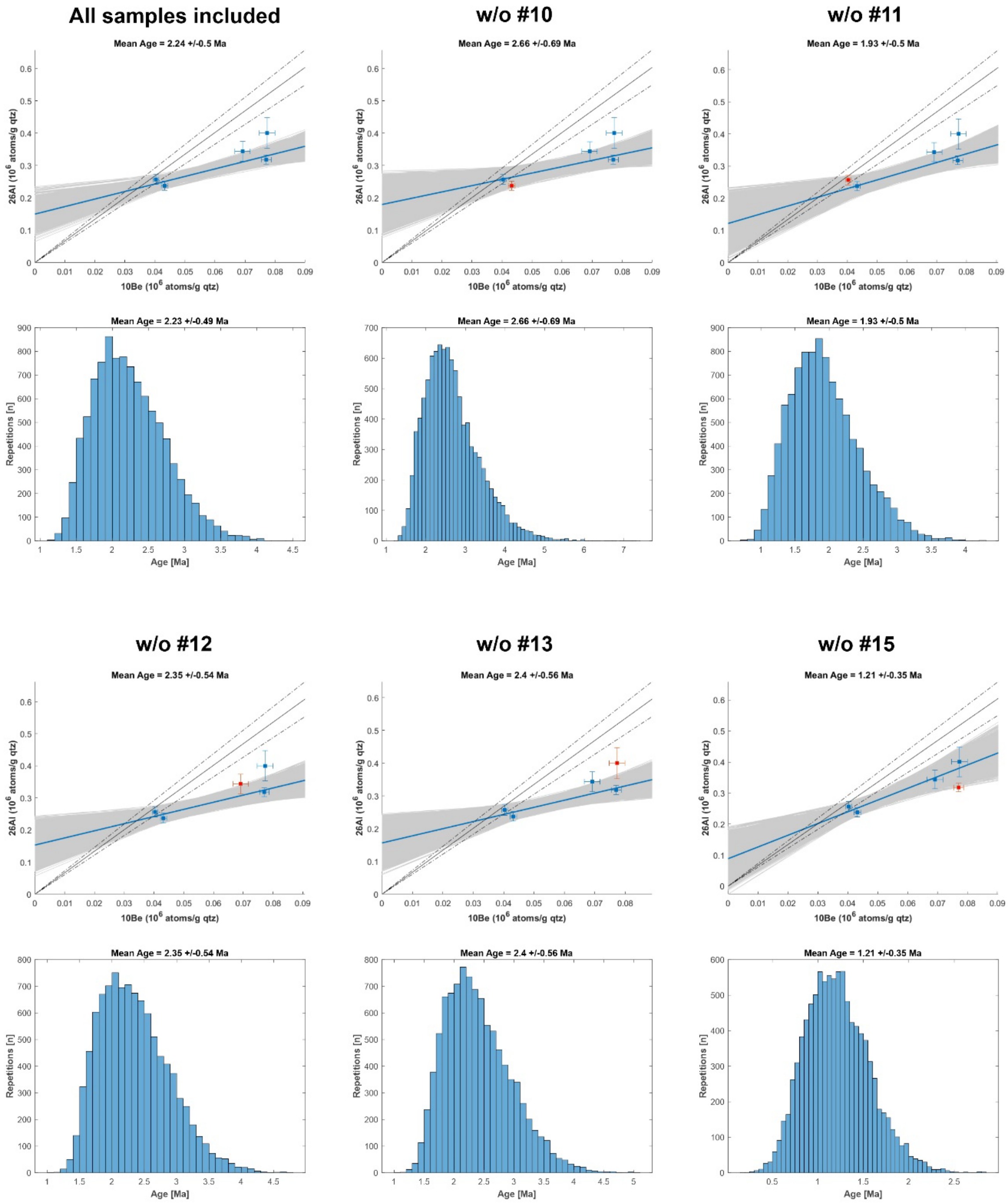


Fig. S1. Isochron plots and histograms for the 5.5 m level.

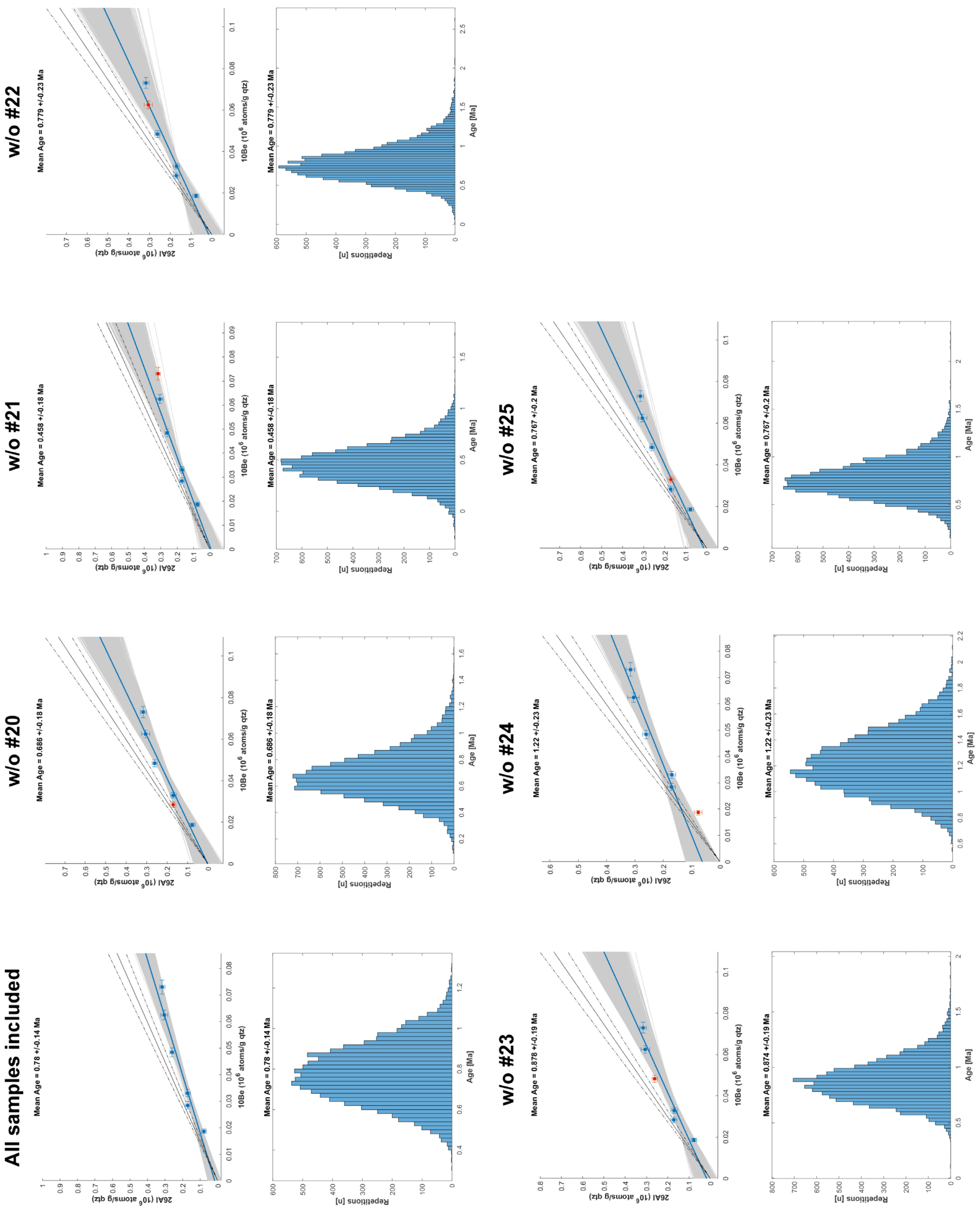
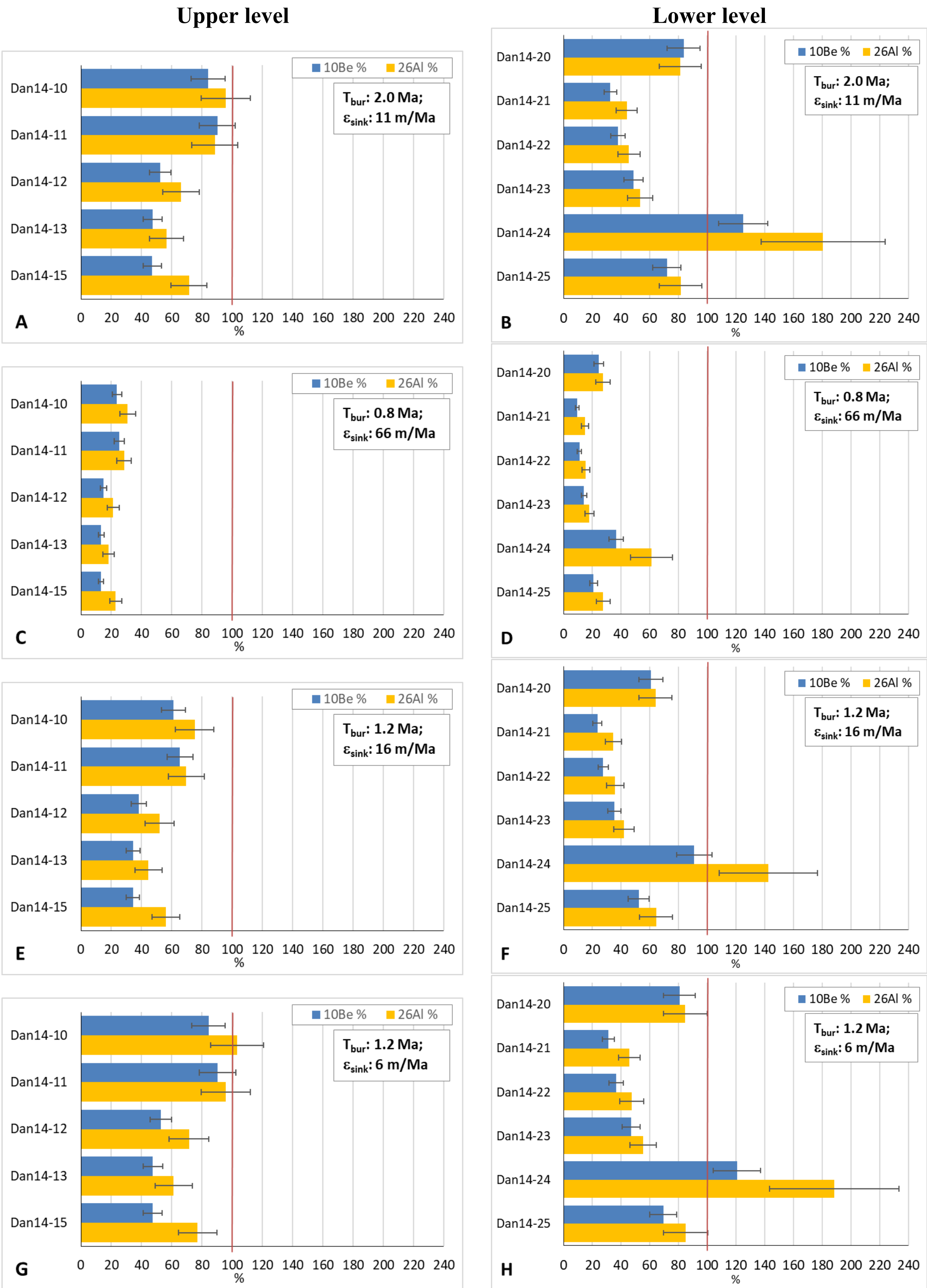


Fig. S2 Isochron plots and histograms for the 11.8 m level


Upper level
Lower level
10Be %
26Al %
A
Tbur: 2.0 Ma; εsink: 11 m/Ma
B
Tbur: 2.0 Ma; εsink: 11 m/Ma
C
Tbur: 0.8 Ma; εsink: 66 m/Ma
D
Tbur: 0.8 Ma; εsink: 66 m/Ma
E
Tbur: 1.2 Ma; εsink: 16 m/Ma
F
Tbur: 1.2 Ma; εsink: 16 m/Ma
G
Tbur: 1.2 Ma; εsink: 6 m/Ma
H
Tbur: 1.2 Ma; εsink: 6 m/Ma
Dan14-10
Dan14-11
Dan14-12
Dan14-13
Dan14-15
Dan14-20
Dan14-21
Dan14-22
Dan14-23
Dan14-24
Dan14-25
0 20 40 60 80 100 120 140 160 180 200 220 240
%

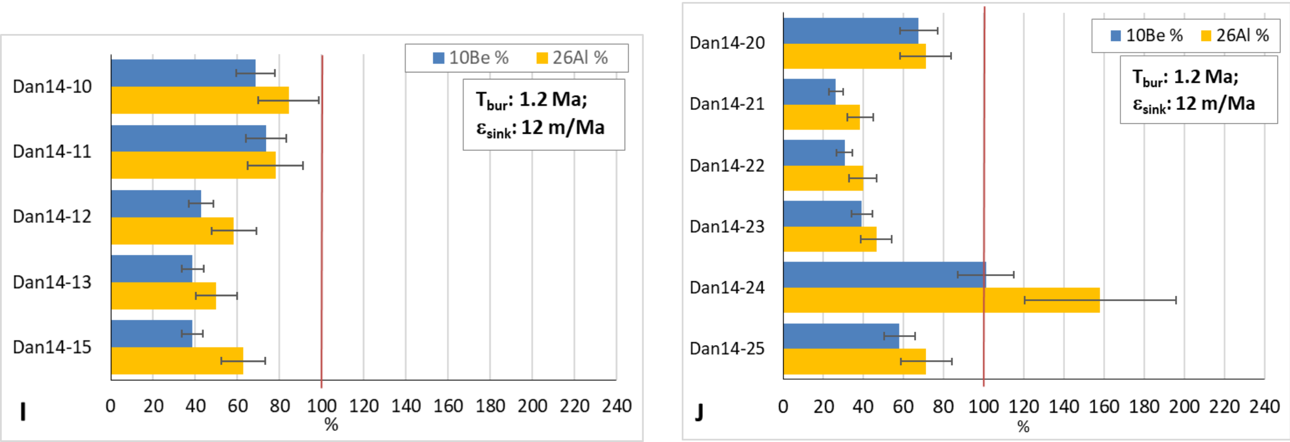


Fig. S3. Post-burial ^{10}Be and ^{26}Al concentrations in percentage of the measured CRN concentrations for different modelled scenarios for the upper (A, C, E, G, I, left column) and the lower (B, D, F, H, J, right column) levels. The red line marks 100%, where the measured CRN and modelled post-burial CRN inventories are equal. Samples below 100% contain CRN from previous exposure and can provide information on the age. Samples above 100% accumulated all CRN during the depositional period. For the most probable scenario (I, J) of ~1.2 Ma burial age (T_{bur}) and 12 m/Ma sink denudation rate (ε_{sink}) the only sample failing this test is #24. Note that during a longer burial duration of 2 Ma (A, B) or at a slower denudation rate of 6 m/Ma (G, H) the ^{26}Al inherited inventories of sample #10 and #11 would have also been decayed. The error bars include the uncertainties of the measured nuclide concentrations, the surface production rates and half-lives of ^{10}Be and ^{26}Al. The observed higher proportion of ^{26}Al is a result of higher ^{26}Al/^{10}Be production rate ratios at 5-12 m depth compared to the surface values, which makes the post-burial ^{26}Al inventory larger. Note that a longer burial time and/or the slower denudation rate results in larger ratio of the post-burial ^{10}Be and ^{26}Al inventories.

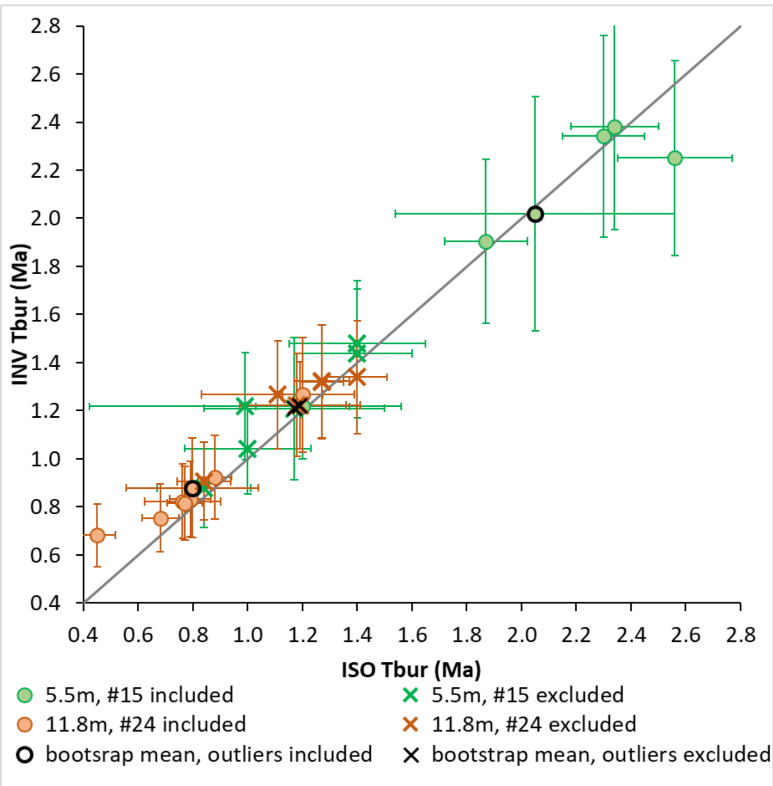


Fig. S4. Comparison plot of bootstrapping using ISO and INV. Note that i) burial ages provided by the two methods are consistent and ii) burial ages of the upper level are much older than those of the lower level when the outliers are included, leading to a stratigraphically impossible situation. Ages are much more clustered when outliers are excluded from both sample sets, and the burial ages of the two levels are consistent.

3) **Apparent source denudation rates**

Source denudation rates are termed apparent, as this is the only variable to modulate the parameters of the source area that define the CRN amounts and ratio (R_0) the samples are buried with. For small catchments, with no significant variability of the latitude and elevation of the catchment area, the source production rates can be considered constant. In such cases, the modelled source denudation rates can provide a good estimate of the true natural value. However, in the case of large rivers, like the Danube, the variability in altitude and latitude throughout the catchment is considerable, leading to large variability of the production rates throughout the source area. In this situation, the denudation rate cannot be regarded as the only or the most deterministic parameter for the amounts of CRN accumulated during exposure and subsequent erosion. This is why in cases like the present study, the INV modelled source denudation rates scatter widely (Tables S4, S5) and do not reflect the actual true source denudation rates and have to be regarded as apparent.

Table S4. Minimum and maximum values of the apparent source denudation rates for the two sampled levels of the bootstrap runs using INV.

				Source denudation rate [m/Ma]		
				min	**-**	**max**
Upper level (5.5 m depth)	Complete dataset	All samples		47	-	1 810
		Bootstrap	w/o #10	48	-	287 110
			w/o #11	48	-	222
			w/o #12	45	-	2 249
			w/o #13	45	-	5 570
			w/o #15	63	-	279
			mean*	50	-	59 086
	w/o #15	All samples		63	-	279
		Bootstrap	w/o #10	68	-	1 058
			w/o #11	58	-	134
			w/o #12	65	-	235
			w/o #13	73	-	376
			mean	66	-	451
Lower level (11.6 m depth)	Complete dataset	All samples		57	-	316
		Bootstrap	w/o # 20	10	-	207
			w/o # 21	10	-	223
			w/o # 22	57	-	321
			w/o #23	54	-	314
			w/o # 24	62	-	771
			w/o #25	57	-	303
			mean	42	-	357
	w/o #25	All samples		62	-	771
		Bootstrap	w/o #20	61	-	318
			w/o #21	76	-	296
			w/o # 22	61	-	938
			w/o #23	57	-	533
			w/o #24	64	-	4 000
			mean*	64	-	1 217

Table S5. Minimum and maximum values of the apparent source denudation rates for the merged dataset of the bootstrap runs using INV.

			Source denudation rate [m/Ma]		
			min	**-**	**max**
Complete dataset	All samples		54	-	801
	Bootstrap	w/o #10	56	-	734
		w/o #11	52	-	346
		w/o #12	53	-	794
		w/o #13	53	-	803
		w/o #15	60	-	875
		w/o #20	53	-	646
		w/o #21	59	-	633
		w/o #22	52	-	1 058
		w/o #23	50	-	1 309
		w/o #24	53	-	273
		w/o #25	53	-	786
		mean*	54	-	755
w/o #15 and #24	All samples		60	-	310
	Bootstrap	w/o #10	60	-	579
		w/o #11	59	-	251
		w/o #12	60	-	314
		w/o #13	59	-	309
		w/o #20	59	-	251
		w/o #21	65	-	254
		w/o #22	59	-	320
		w/o #23	56	-	329
		w/o #25	60	-	317
		mean*	60	-	325