Supplemental information for:

Testing the applicability of optically stimulated luminescence dating to Ocean Drilling Program cores.

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Section S1. Authigenic uranium content and ^{230}Th ingrowth calculations

The environmental dose rate for MIS 6-5e samples from core 658B was calculated using a version of the $Marine_{xs+auth}$ model described in Armitage (2015). Briefly, ^{238}U and ^{232}Th and bulk K concentrations were measured using ICP-MS. Authigenic uranium (U_{auth}) activity was calculated using Equation S1:

$$U_{auth} = {}^{238}U_m - 0.8 * {}^{232}Th_m \qquad \text{(Eq. S1)}$$

where $^{238}U_m$ and $^{232}Th_m$ are the measured activities of ^{238}U and ^{232}Th respectively (Yu et al., 1999). The remaining uranium ($^{238}U_m$-U_{auth}) is assumed to be detrital (U_{det}) and in secular equilibrium with all its decay products.

Armitage (2015) approximated the dose rate due to U_{auth} by assuming secular equilibrium from $^{238}U_{auth}$-$^{234}U_{auth}$, and no dose from the decay products of $^{234}U_{auth}$. This approximation was valid since limited ingrowth of ^{230}Th ($^{230}Th_{in}$) from $^{234}U_{auth}$ would have occurred for the relatively young (0-50 ka) samples presented in that study. Conversely, for MIS 6-5e samples presented here, appreciable ^{230}Th ingrowth will have occurred during burial. Since ^{230}Th has no long-lived decay products, $^{230}Th_{in}$ may be assumed to be in secular equilibrium with those decay products for the purposes of calculating a dose rate. In addition, since $^{234}U_{auth}$ is itself in secular equilibrium with $^{238}U_{auth}$ (half-life ~4.5 Ga), $^{230}Th_{in}$ is in secular equilibrium with the entire ^{238}U decay series. Consequently, the dose rate per unit activity due to $^{230}Th_{in}$ is identical to that for $^{238}U_{det}$.

$^{230}Th_{in}$ activity as a proportion of U_{auth} activity (A) at time t may be calculated using Equation S2:

$$A = 1 - e^{-\lambda t} \qquad \text{(Eq. S2)}$$

where λ is the ^{230}Th decay constant. Consequently, for a sample with an unknown age, ^{230}Th ingrowth would require a time dependant dose rate calculation. However, for a known age sample, the mean $^{230}Th_{in}$ content may be calculated, and incorporated into the dose rate calculation as a time independent dose rate contribution. This may be done by repeatedly calculating A for a relatively small time step (in this case 250 years) from t = 0 to the known age of the sample, and taking the mean value ($\bar{A}$). Since A is the $^{230}Th_{in}$ activity as a proportion of U_{auth} activity, and the dose rate per unit activity due to $^{230}Th_{in}$ is identical to that for $^{238}U_{det}$, the effects of ^{230}Th ingrowth upon dose rate may be accounted for reducing U_{auth} activity by the mean $^{230}Th_{in}$ activity i.e. $\bar{A}$. Consequently, for the purposes of the $Marine_{xs+auth}$ model described by Armitage (2015), a corrected value of U_{auth} may be calculated using Equation S3:

$$\text{Corrected } U_{auth} = U_{auth} * (1-\bar{A}) \qquad \text{(Eq. S3)}$$

For the samples presented in Section 5, values of $\bar{A}$ range from 0.40 at 123 ka to 0.44 at 140 ka. Dose rate data are presented in Tables S1 and S2.

Table S1: Water and radioisotope concentrations for MIS6-5e samples from Core 658B. In addition, all samples were assumed to have $^{230}Th_{xs}$ and $^{231}Pa_{xs}$ activities of 36.6±9.3 Bq/kg and 3.38±0.87 Bq/kg at burial. These data are used to generate the dose rates presented in Table S2.

Sample	Core depth (m)	Water (%)	^{238}U (ppm)	^{232}Th (ppm)	K (%)
69B	19.39	47.0±5.0	10.76±0.07	3.88±0.05	0.91±0.03
71A	19.90	46.6±5.0	9.00±0.09	3.77±0.06	0.97±0.04
71B	19.90	46.6±5.0	9.00±0.09	3.77±0.06	0.97±0.04
73B	20.40	46.2±5.0	6.83±0.14	4.54±0.04	1.08±0.05
74B	20.65	46.1±5.0	5.60±0.09	4.65±0.05	1.02±0.03
75B	20.90	45.9±5.0	5.39±0.05	4.52±0.03	1.20±0.04
76B	21.17	45.8±5.0	5.35±0.07	4.89±0.06	1.10±0.04
77A	21.39	45.7±5.0	4.28±0.03	5.91±0.09	1.21±0.05

Table S2: Equivalent dose, dose rate and age data for MIS6-5e samples from Core 658B. OSL ages were calculated using the Marine$_{xs+auth}$ dose rate model described in Section S1 (Armitage, 2015). Uncertainties are based on the propagation, in quadrature, of errors associated with individual errors for all measured quantities. In addition to uncertainties calculated from counting statistics, errors due to 1) beta source calibration (3%) Armitage and Bailey, 2005, 2) ICP-MS/Gamma spectrometer calibration (3%), 3) dose rate conversion factors (3%) and 4) attenuation factors (3%) have been included Murray and Olley, 2002. $D_{r(sup\text{-}auth)}$ is the dose rate due to $^{238}U_{auth}$ in equilibrium to ^{234}U and the $^{238}U_{detrital}$ and ^{232}Th decay series in equilibrium plus the ^{40}K dose rate. For the purposes of calculating $Dr_{(sup\text{-}auth)}$, $^{238}U_{auth}$ activities were corrected for ^{230}Th ingrowth during burial using Equation S3. $\overline{A}$ is the mean ingrown ^{230}Th activity during the burial period for each sample as a proportion of U_{auth} activity. $D_{tot(xs)}$ is the total dose due to $^{230}Th_{xs}$ and $^{231}Pa_{xs}$ since burial.

Sample	D_e (Gy)	$D_{r(sup\text{-}auth)}$ (Gy/ka)	$\overline{A}$	$D_{tot(xs)}$ (Gy, total)	Age (ka) OSL	Age (ka) $\delta^{18}O$	Ratio (OSL/$\delta^{18}O$)
69B	242±9	1.88±0.15	0.40	28.2±5.2	113±10	123±4	0.92±0.08
71A	230±12	1.76±0.13	0.41	28.4±5.3	114±10	127±4	0.90±0.08
71B	235±9	1.76±0.13	0.41	28.8±5.3	117±9	127±4	0.92±0.08
73B	226±16	1.70±0.11	0.42	28.8±5.3	116±11	132±4	0.88±0.09
74B	224±10	1.55±0.09	0.43	30.0±5.6	125±9	134±4	0.94±0.07
75B	241±9	1.65±0.09	0.43	30.4±5.6	128±8	136±4	0.94±0.07
76B	246±11	1.61±0.09	0.44	31.1±5.8	134±9	138±4	0.97±0.07
77A	262±10	1.65±0.08	0.44	31.8±5.9	139±9	140±4	0.99±0.07

Table S3: Energy emission per unit decay and dose rates for the ^{232}Th decay series.

Isotope	Half-life (a)	Energy Release (MeV)			Dry dose rate (Gy/ka per Bq/kg)		
		α	β	γ	α	β	γ
^{232}Th	1.4050E+10	4.00	0.011	0.001	0.02024	0.00006	0.00001
^{228}Ra	5.7500E+00	-	0.009	0.000	-	0.00005	0.00000
^{228}Ac	7.0157E-04	-	0.417	0.860	-	0.00211	0.00435
^{228}Th	1.9120E+00	5.41	0.019	0.003	0.02733	0.00010	0.00002
^{224}Ra	1.0021E-02	5.67	0.002	0.010	0.02868	0.00001	0.00005
^{220}Rn	1.7619E-06	6.29	-	0.001	0.03179	-	0.00000
^{216}Po	4.5948E-09	6.78	-	0.000	0.03427	-	0.00000
^{212}Pb	1.2138E-03	-	0.172	0.144	-	0.00087	0.00073
^{212}Bi	1.1512E-04	2.18	0.503	0.104	0.01100	0.00255	0.00053
^{212}Po (0.641)	9.4747E-12	5.63	-	-	0.02847	-	-
^{208}Tl (0.359)	5.8046E-06	-	0.214	1.214	-	0.00108	0.00614
Full ^{232}Th series		35.95	1.349	2.337	0.18177	0.00682	0.01181

Table S4: Energy emission per unit decay and dose rates for the ^{238}U decay series.

Isotope	Half-life (a)	Energy Release (MeV)			Dry dose rate (Gy/ka per Bq/kg)		
		α	β	γ	α	β	γ
^{238}U	4.4680E+09	4.19	0.007	0.001	0.02120	0.00004	0.00001
^{234}Th	6.5911E-02	-	0.059	0.008	-	0.00030	0.00004
$^{234}Pa_m$	2.2023E-06	-	0.810	0.016	-	0.00410	0.00008
$^{234}Pa_{(0.0016)}$	7.6368E-04	-	0.001	0.001	-	0.00001	0.00001
^{234}U	2.4558E+05	4.76	0.012	0.001	0.02406	0.00006	0.00001
^{230}Th	7.5418E+04	4.66	0.013	0.001	0.02358	0.00007	0.00001
^{226}Ra	1.6002E+03	4.77	0.004	0.007	0.02414	0.00002	0.00004
^{222}Rn	1.0457E-02	5.49	-	0.000	0.02775	-	0.00000
^{218}Po	5.8940E-06	6.00	-	-	0.03034	-	-
^{214}Pb	5.1018E-05	-	0.291	0.239	-	0.00147	0.00121
^{214}Bi	3.7709E-05	0.00	0.654	1.475	0.00001	0.00331	0.00746
^{214}Po	5.1968E-12	7.69	-	0.000	0.03886	-	0.00000
^{210}Pb	2.2213E+01	-	0.033	0.005	-	0.00017	0.00002
^{210}Bi	1.3721E-02	-	0.389	-	-	0.00197	-
^{210}Po	3.8026E-01	5.30	0.000	0.000	0.02682	0.00000	0.00000
Full ^{238}U series		42.87	2.273	1.755	0.21675	0.01149	0.00887
Total incl. & post ^{234}U		38.68	1.396	1.730	0.19555	0.00706	0.00874
Total incl. & post ^{230}Th		33.92	1.384	1.728	0.17149	0.00700	0.00874
Total pre-^{234}U		4.19	0.878	0.026	0.02120	0.00444	0.00013

Table S5: Energy emission per unit decay and dose rates for the ^{235}U decay series.

Isotope	Half-life (a)	Energy Release (MeV)			Dry dose rate (Gy/ka per Bq/kg)		
		α	β	γ	α	β	γ
^{235}U	7.0400E+08	4.11	0.029	0.164	0.02080	0.00015	0.00083
^{231}Th	6.9870E-02	-	0.146	0.023	-	0.00074	0.00012
^{231}Pa	3.2760E+04	4.92	0.032	0.040	0.02489	0.00016	0.00020
^{227}Ac	2.1770E+01	0.07	0.012	0.001	0.00036	0.00006	0.00000
$^{227}Th_{(0.986)}$	5.1143E-02	5.81	0.050	0.154	0.02936	0.00025	0.00078
$^{223}Fr_{(0.014)}$	4.1828E-05	0.00	0.000	0.001	0.00002	0.00000	0.00000
^{223}Ra	3.1294E-02	5.66	0.068	0.135	0.02863	0.00034	0.00068
^{219}Rn	1.2548E-07	6.75	0.007	0.058	0.03414	0.00003	0.00029
^{215}Po	5.6436E-11	7.39	-	-	0.03737	-	-
^{211}Pb	6.8636E-05	-	0.450	0.064	-	0.00227	0.00032
^{211}Bi	4.0688E-06	6.55	0.013	0.047	0.03311	0.00007	0.00024
^{211}Po	1.6351E-08	0.02	-	-	0.00010	-	-
^{207}Tl	9.0691E-06	-	0.495	0.002	-	0.00250	0.00001
Full ^{235}U series		41.30	1.303	0.689	0.20879	0.00659	0.00348
Total incl. & post ^{231}Pa		37.19	1.128	0.501	0.18799	0.00570	0.00253

Table S6: Energy emission per unit decay and dose rates for ^{40}K and ^{87}Rb.

Isotope	Half-life (a)	Energy Release (MeV)			Dry dose rate (Gy/ka per 1% nat. K or 50 ppm nat. Rb)		
		α	β	γ	α	β	γ
^{40}K	1.248E+09	-	0.499	0.156	-	0.799	0.249
^{87}Rb	4.810E+10	-	0.082	-	-	0.018	-
Total		-	0.581	0.156	-	0.817	0.249

References

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