10.1071/EN04011_AC ©CSIRO 2004 Accessory Publication: Environmental Chem., 2004, 1(1), 49–54. Appendix 1 - Data and interpretation of ²¹⁰Pb dating of a 2.8 m core from Tamar Estuary taken March 2001

Table 1 – Radiochemica	al data for Tamar Estuary	v core taken March 2001.
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(Area of the core 8.814 cm^2)

Depth			Slice	Slice	Wt. %	Activity of Po-210				Activity of Ra-226				Activity of Excess Pb-210				
			Wet Wt.	Dry Wt.	H_2O													
(cm)		(cm)	(g)	(g)		(dpm/g)		(dpm/g)	(%)	(dpm/g)		(dpm/g)	(%)	(dpm/g)		(dpm/g)	(%)	
5	+/-	5	110.0	34.9	68.3	5.73	+/-	0.20	3.4	0.68	+/-	0.04	5.3	5.05	+/-	0.20	4.0	
15	+/-	5	116.3	39.5	66.0	5.14	+/-	0.20	3.8	0.90	+/-	0.05	5.2	4.25	+/-	0.20	4.8	
25	+/-	5	111.9	39.3	64.9	5.59	+/-	0.23	4.2	0.89	+/-	0.04	5.0	4.71	+/-	0.24	5.1	
35	+/-	5	113.3	40.1	64.6	4.27	+/-	0.11	2.7	0.92	+/-	0.04	4.7	3.35	+/-	0.12	3.6	
45	+/-	5	110.9	37.3	66.4	4.24	+/-	0.16	3.8	0.81	+/-	0.04	4.4	3.44	+/-	0.17	4.8	
55	+/-	5	110.5	38.1	65.5	3.11	+/-	0.13	4.1	0.91	+/-	0.04	4.3	2.20	+/-	0.13	6.1	
65	+/-	5	116.3	38.8	66.6	4.83	+/-	0.14	2.9	0.56	+/-	0.03	4.9	4.28	+/-	0.14	3.3	
75	+/-	5	120.5	41.2	65.8	4.45	+/-	0.18	4.1	0.67	+/-	0.04	5.9	3.78	+/-	0.19	4.9	
85	+/-	5	119.2	37.7	68.4	2.14	+/-	0.08	3.9	0.82	+/-	0.04	5.1	1.31	+/-	0.09	7.1	
95	+/-	5	124.0	49.7	59.9	1.56	+/-	0.06	3.6	0.73	+/-	0.04	4.8	0.83	+/-	0.07	8.0	
105	+/-	5	117.3	44.6	62.0	1.60	+/-	0.07	4.4	0.78	+/-	0.04	5.6	0.82	+/-	0.08	10.1	
115	+/-	5	121.8	45.7	62.5	1.39	+/-	0.07	5.0	0.76	+/-	0.04	5.4	0.63	+/-	0.08	12.8	
125	+/-	5	112.1	42	62.5	1.25	+/-	0.07	5.7	0.87	+/-	0.05	6.1	0.38	+/-	0.09	23.3	
135	+/-	5	108.6	37.8	65.2	3.73	+/-	0.12	3.2	0.77	+/-	0.04	5.7	2.96	+/-	0.13	4.3	
145	+/-	5	108.8	39.1	64.1	5.23	+/-	0.16	3.1	0.47	+/-	0.03	5.9	4.76	+/-	0.16	3.4	
155	+/-	5	117.0	42.1	64.0	3.92	+/-	0.13	3.2	0.59	+/-	0.03	5.0	3.32	+/-	0.13	3.9	
165	+/-	5	120.0	40.9	65.9	1.18	+/-	0.06	4.7	0.80	+/-	0.05	5.8	0.38	+/-	0.07	19.1	
175	+/-	5	122.5	43.3	64.7	1.13	+/-	0.04	3.4	0.83	+/-	0.04	5.2	0.30	+/-	0.06	19.4	
185	+/-	5	114.9	38.7	66.3	1.03	+/-	0.04	3.6	0.78	+/-	0.04	5.0	0.25	+/-	0.05	21.2	
195	+/-	5	91.7	31.9	65.2	2.04	+/-	0.07	3.5	0.51	+/-	0.03	5.6	1.53	+/-	0.08	5.1	
205	+/-	5	134.4	42.2	68.6	4.99	+/-	0.13	2.6	0.75	+/-	0.03	4.5	4.25	+/-	0.13	3.2	
215	+/-	5	131.5	47	64.3	2.78	+/-	0.10	3.6	0.89	+/-	0.04	4.9	1.89	+/-	0.11	5.8	
225	+/-	5	114.0	37.2	67.4	1.05	+/-	0.03	2.9	0.67	+/-	0.04	6.7	0.39	+/-	0.05	14.0	
235	+/-	5	113.6	41	63.9	1.05	+/-	0.03	3.1	0.75	+/-	0.04	5.6	0.30	+/-	0.05	17.9	
245	+/-	5	117.9	49.2	58.3	0.97	+/-	0.03	3.4	0.63	+/-	0.04	6.5	0.34	+/-	0.05	15.7	
255	+/-	5	126.2	51	59.6	1.19	+/-	0.04	3.7	0.77	+/-	0.05	7.0	0.42	+/-	0.07	16.5	
265	+/-	5	124.1	56.8	54.2	1.53	+/-	0.05	3.0	0.95	+/-	0.06	6.2	0.58	+/-	0.07	12.8	
275	+/-	5	107.0	49.7	53.6	1.60	+/-	0.04	2.5	0.81	+/-	0.05	5.9	0.79	+/-	0.06	7.8	

Interpretation 1

Determination of sedimentation rate limited to top 60cm due to discontinuities - average sedimentation rate of 2.12 ± 0.52 cmy⁻¹ for top 60 cm.



Interpretation 2





Appendix 2 – Report on ²¹⁰Pb dating of 60 cm core from Tamar Estuary taken July 2000 (Analyses and interpretation by Australian Institute of Marine Science)

The sediment core (60 cm long, core ID = 10 cm) was collected off Valley Street, Home Reach, Launceston, by staff and students from the University of Tasmania. The core was sliced into 2 and 4 cm sections and measurements of wet and dry weight for each sediment core slice were made. The dried sediment core slices were sent to the Australian Institute of Marine Science for radiochemical measurements and sedimentation model interpretation.

²¹⁰Pb analyses

Gamma spectrometric measurements of ²¹⁰Pb, ²²⁶Ra, ¹³⁷Cs, and other isotopes were made on 50-150 grams of dried and ground bulk sediment core slices packed (with a 10 tonne hydraulic press) into a custom designed gas-tight Perspex container. Direct estimation of ²¹⁰Pb was obtained from the 46.5 keV gamma emission. After storage for 3-4 weeks, radon daughter in-growth allowed estimation of ²²⁶Ra from the gamma photopeaks of ²¹⁴Pb at 295 and 351 keV, and ²¹⁴Bi at 609 keV. Thermonuclear bomb fallout nuclide ¹³⁷Cs was estimated from the 661.6 keV gamma emission of ^{137m}Ba. One well and four planar germanium detectors, each housed inside 10 cm thick walled lead castles with steel liners, were used for these analyses. The energy spectra of the gamma spectrometers were calibrated with Amersham and CANMET standards, of known low activity spikes of suitable nuclides, in cleaned silica sand of geometry and mass similar to the sediment samples. IAEA marine sediment reference material IAEA-315 was used to check the calibrations. Counting errors of the sample measurements were less than 10%, except for some very low activity ¹³⁷Cs samples which had errors of 30%.

Interpretations of radiochemical tracer sedimentation history were done with several submodels described by Robbins (1978, 1986, and personal communications), which utilise a sediment mixed layer thickness, a decadal-century scale average input of ²¹⁰Pb, Tasmanian measurements of thermonuclear bomb fallout ⁹⁰Sr (¹³⁷Cs) over 1950-1990 (about 312 Bq ¹³⁷Cs m⁻²), and diffusion coefficients for ²¹⁰Pb and ¹³⁷Cs in marine sediments (Li & Gregory, 1974).

Sediment mixed layer thickness was determined by the relatively homogeneous excess ²¹⁰Pb and ¹³⁷Cs activities of the core top slices. Mass accumulation rate (MAR) was estimated from linear regression of the log of excess ²¹⁰Pb activities for each sediment core slice below the mixed layer, against linear accumulated sediment mass/area (g cm⁻² = sediment core depth), being the mass of sediment accumulated over several half lives (22.6 yr) of ²¹⁰Pb. This MAR (in kg m⁻²yr⁻¹) allowed the calculation of average age (accounting for mixed layer depth) of each sediment core slice. The ²¹⁰Pb chronology was compared to the independently known history of bomb fallout ¹³⁷Cs in the core profile (accounting for more porewater diffusion of ¹³⁷Cs, compared to ²¹⁰Pb). MAR can be converted to a linear accumulation rate in cm yr⁻¹ by multiplication by bulk density of the sediment (which varies between 1.5 and 2 g cm⁻³).

Interpretation and discussion

The radiochemical data from gamma spectrometric counting of the sediment core slices are given in Table 1, and are presented in graphical form in Figure 1. Excess ²¹⁰Pb is the result of subtraction of parent ²²⁶Ra from granddaughter total ²¹⁰Pb. In addition, ⁷Be was detected in the top slice only.

Simple regression of the log/linear decline in excess ²¹⁰Pb with core depth (below the sediment mixed layer) gives an estimate of accumulation rate of 10.6 kg m⁻² yr⁻¹. The inventory of ²¹⁰Pb in excess of its parent ²²⁶Ra is very large (Fig. 1), and this inventory requires an annual flux of 698 Bq ²¹⁰Pb m⁻² yr⁻¹ to the sediment surface, approximately 14 times the likely supply rate from the atmosphere. This implies that a large amount of fine sediment has been focussed into this depositional site from adjacent non-depositional regions. The sediment mixed layer thickness is

about 21 cm, which is approximately equivalent to 9 years of deposition. From this information, it is concluded that any derived average age assignment to sediment slices should have a minimum error of \pm 10 years, on the time scale of excess ²¹⁰Pb decay usually detectable, which is typically 4 half lives, or about 100 years. From the mass accumulation rate, the average time of deposition of the core bottom slice is calculated to be approximately 1976 \pm 10 years.

At the core bottom slices, there is about 65 Bq kg⁻¹ of excess ²¹⁰Pb, which can generally be detected to <5 Bq kg⁻¹. The complete excess ²¹⁰Pb profile would require another metre of sediment core depth, and this data would confirm the interpretation. The interpretation of MAR for this core is based on less than one half-life decay of ²¹⁰Pb, and 3-4 half-lives of decay can normally be detected in a complete profile.

⁷Be was detected in the 0-2 cm slice only, at relatively high activity (41.0 Bq kg⁻¹ ± 9.6). This cosmogenic isotope has a half life of 54 days, and this high activity suggests that this core site has not been rapidly mixed for approximately 100 days before the date of sampling. There is also a small excess of ²²⁸Th ($t_{1/2}$ =1.91yrs) over its parent ²²⁸Ra in the top 4 surface layers (0-8cms), which lends support to the suggestion of rapid rates of deposition and slow mixing rates. Excess ²²⁸Th is derived from the water column where dissolved ²²⁸Ra decays to ²²⁸Th (via ²²⁸Ac). The ²²⁸Th, being highly particle re-active, attaches to particles which settle on the sediment surface, in the same manner as excess ²¹⁰Pb labelled particles settle and accumulate at the top of the sediment profile.

Bomb fallout ¹³⁷Cs was supplied to land and water surfaces in Tasmania from 1952-1980, with maximal fallout in 1965, and submaximal peaks in 1958 and 1972. The total inventory in Tasmania is probably in the range 300-400 Bq ¹³⁷Cs m⁻². EML ⁹⁰Sr data indicate a value of 312 Bq ¹³⁷Cs m⁻² for Hobart, decay corrected to 2000. The ¹³⁷Cs inventory in this core is very high, 1554 Bq m⁻², or about 5 times the supply from atmospheric fallout, and the core depth sampled only the top third of the complete profile. The presence of high activities of ¹³⁷Cs at the core top suggests that fine clayrich sediment labelled with 1958-1975 ¹³⁷Cs is now being accumulated at this coring site. Atmospheric fallout of ¹³⁷Cs has been negligible since 1980, which suggests that most of this core is being supplied with resuspended sediment from the land or sea that has a strong 1958-1975 label. The ¹³⁷Cs in the top 35 cm of this core. It is expected that even higher activities of ¹³⁷Cs should occur at sediment core depths of 0.6-1.3 meters.

References

EML data from the following website: http://www.eml.doe.gov/databases/

Li, Y.-H. & Gregory, S. 1974 Diffusion of ions in seawater and in deep-sea sediments. Geochimica et Cosmochimica Acta 38, 703-714.

Robbins, J.A. 1978 Geochemical and geophysical applications of radioactive lead. In Biogeochemistry of Lead in the Environment (ed. J. O. Nriagu). Elsevier Scientific Publishers, volume 1A, pp. 285-393.

Robbins, J.A. 1986 A model for particle-selective transport of tracers in sediments with conveyor belt deposit feeders. Journal of Geophysical Research 96, 17081-17104.

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are Bq kg ⁻ dry weight.																
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	SLICE															
DEPTH	DRY WT	MASS	RA226	RA226	PB210	PB210	CS137	CS137	U238	U238	RA228	RA228	TH228	TH228	K40	K40
cms	g	g/cm2		err		err		err		err		err		err		err
0-2	55.06	0.70	24.99	0.85	135.24	6.67	6.27	0.71	93.47	11.36	31.17	1.98	36.62	1.32	252.44	14.22
2-4	71.58	1.61	25.91	0.90	129.48	10.00	6.28	0.82	74.17	10.53	30.51	1.98	35.19	1.23	256.95	16.77
4-6	85.30	2.70	24.65	0.85	127.82	6.36	4.40	0.69	73.61	11.44	28.74	1.91	34.45	1.12	238.74	15.80
6-8	65.23	3.52	29.06	1.31	129.75	8.25	5.73	0.75	78.85	11.54	31.97	1.85	36.50	1.14	240.20	16.49
8-10	63.26	4.33	24.84	1.18	126.05	7.74	5.46	0.72	76.92	10.93	32.30	1.77	34.28	1.06	248.87	16.09
10-12	56.97	5.06	26.58	0.99	134.83	9.77	6.54	0.92	77.53	11.67	40.40	2.34	37.83	1.34	264.92	18.39
12-14	74.36	6.00	25.69	0.70	137.14	5.10	5.24	0.54	76.31	8.92	36.21	1.69	35.23	1.15	230.26	10.92
14-16	72.78	6.93	27.51	0.83	122.35	5.96	5.23	0.67	58.56	10.56	33.97	1.90	35.33	1.10	213.75	14.42
16-18	70.90	7.83	23.85	0.82	120.05	9.09	6.42	0.77	60.78	9.49	35.97	1.94	35.58	1.18	249.12	15.56
18-20	75.49	8.79	23.81	1.08	127.25	6.91	5.57	0.64	64.75	9.57	34.62	1.65	35.06	1.03	219.32	14.15
20-22	68.82	9.66	25.73	0.69	129.17	4.95	5.14	0.53	78.66	8.82	36.92	1.69	35.73	1.15	223.85	10.65
22-24	53.29	10.34	26.32	0.95	126.64	6.97	5.73	0.81	71.28	12.83	37.38	2.28	39.43	1.28	228.61	17.10
24-28	121.22	11.88	25.19	0.73	123.49	5.49	5.61	0.60	66.21	9.76	34.98	1.75	35.91	1.04	224.64	12.96
28-32	154.91	13.86	25.99	1.05	112.89	6.12	5.42	0.59	74.33	9.51	37.73	1.59	39.01	1.07	247.37	13.71
32-36	139.67	15.63	27.50	0.65	119.83	4.24	5.56	0.49	81.35	8.26	39.81	1.61	40.61	1.20	236.34	9.72
36-40	143.94	17.46	25.55	0.75	103.92	7.82	7.02	0.68	61.26	8.72	39.24	1.80	40.94	1.22	253.10	14.19
40-44	147.40	19.33	27.59	0.53	109.48	2.97	6.55	0.40	69.43	6.32	41.19	1.39	41.56	1.12	227.56	7.48
44-48	140.22	21.12	26.16	0.67	93.74	4.39	7.22	0.57	83.60	9.62	43.71	1.74	42.31	1.11	231.17	11.57
48-52	146.30	22.98	25.15	0.65	95.29	6.93	8.28	0.59	86.26	8.36	42.47	1.63	42.78	1.19	238.61	12.22
52-56	148.76	24.87	25.91	0.96	96.79	5.16	7.77	0.54	70.42	8.49	41.48	1.46	42.63	1.07	240.06	12.34
56-60	123.04	26.44	25.34	0.55	108.68	3.48	7.72	0.46	68.61	6.84	41.98	1.49	43.48	1.18	205.62	7.95

Table 1. Radiochemical data for sediment core AIMS 1234, Tamar Estuary, Valley Street Home Reach, July 6 2000. The "depth" column gives the slice thickness and depth in the sediment core. The column labelled "mass" is the accumulated dry weight divided by the area of the core (80.12 cm^2) . "err" is the uncertainty estimate for each nuclide, and is a 1 sigma error estimate from the accumulative errors of our standard calibrations, background counts, and sample counting error. The units of measurement for each nuclide are Bq kg⁻¹ dry weight.



Core 1234 Tamar Estuary, Valley Street Home Reach

MAR = 10.6 kg m ⁻² y ⁻¹	Inventory Excess ²¹⁰ Pb = 22334 ± 1549 Bq m
Mixed Layer Thickness = 9 g cm ⁻² or 20 cms	Flux Excess 210 Pb = 698 ± 48 Bq m ⁻² y ⁻¹
= 9 yis	Inventory 137 Cs = 1554 ± 154 Ba m ⁻²

Figure 1. A. Sediment core profiles of excess ²¹⁰Pb and ¹³⁷Cs in Tamar Estuary Core 1234. The vertical axis of the graph is accumulated dry weight (g cm⁻²), a surrogate parameter for sediment core depth. The middle vertical axis in the figure is labelled with core depth in cm. One sigma error bars are given for each datum. MAR = mass accumulation rate. The mixed layer thickness is the surface sediment zone of relatively uniform ²¹⁰Pb and ¹³⁷Cs activity which appears to be mixed on a decadal time scale, in units of accumulated sediment weight, centimeters, and the time equivalent of this thickness. Excess ²¹⁰Pb is the isotope activity in excess of its grandparent ²²⁶Ra isotope. The inventory is the depth integrated activity per unit area of the stated isotopes. The Flux Excess ²¹⁰Pb item is the average annual supply of excess ²¹⁰Pb necessary to maintain the measured inventory of this isotope over a century.