Sediment accumulation in central Moreton Bay as determined from sediment core profiles

Report on Project SS Phase 3 - Part A

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Executive Summary

Sediment accumulation rates in the main mud deposition zone of Moreton Bay have been estimated by examining profiles of sediment cores collected in November 1999 from the western (water depth 4 m), central (depth 9 m) and eastern (depth 13 m) regions. Profiles of fallout radionuclides (^{210}Pb, ^{137}Cs and ^{7}Be) and lithogenic radioncuclides (Ra and Th isotopes) were examined to establish sediment chronologies, and to ascertain the depth and rate of mixing in the sediment profile. Measurements of major and trace elements were also made to establish proxy age horizons distinguished by changes to sediment characteristics resulting from recent human activities.

The sediment was mostly comprised of fine-grained clay minerals with no apparent stratification. Profiles of Ra and Th isotopes show that post-depositional mixing is occurring to a depth of at least 35 cm. Be-7 data indicates that mixing is most rapid in the upper 4 cm, occurring on a time scale of weeks to months. Between 4 and 35 cm the time scale of mixing is less than 10-15 years. Although there is no direct evidence, slower mixing (on a time scale of 20 years or more) in sediment below 35 cm cannot be ruled out.

The thickness of the mixed layer has considerably reduced the temporal resolution of ^{210}Pb geochronology, and the time frame over which it can be applied. A simple 2-layer mixing model was applied to the ^{210}Pb profiles, whereby mixing below 35 cm was assumed negligible. This model yielded an apparent mean bulk accumulation rate of 0.62 cm yr^{-1} (equivalent to 0.41 g cm^{-2} yr^{-1} of dry sediment) for the most central site in the main mud lens of the Bay. The apparent bulk accumulation rate at the most easterly site is 1.2 cm yr^{-1} (0.69 g cm^{-2} yr^{-1} of dry sediment). These mean rates pertain to the last 60 years, and are considered upper limits due to the possibility of slow mixing below 35 cm.

Sediment core inventories of ^{210}Pb show that fine sediment is being focussed towards the eastern edge of the mud zone. This trend is consistent with a process of resuspension and transport of sediment from shallow to deeper water. If the ^{210}Pb accumulation rate at the most central site of the mud zone is applied over the entire mud-dominated region, the annual fine-sediment load delivered to central Moreton Bay, averaged over the last 60 years, is equal to or less than 450,000 tonnes of dry sediment.

Attempts to verify ^{210}Pb accumulation rates were made using ^{137}Cs measurements, optically stimulated luminescence (OSL), and major and trace element analysis with limited success. ^{137}Cs profiles were consistent with the ^{210}Pb accumulation rates, but OSL dating was unsuccessful because the quartz was too fine-grain and poorly bleached to be accurately dated. Nor could proxy age markers be established using major and trace element data; analysis indicates very little change in the geochemical composition of the sediment to a depth of 1.8 m. Exceptions were sulfur (S) and arsenic (As), both of which showed an overall increase with depth. Lead decreased by 50%, and zinc by 20% with depth. The higher Pb and Zn concentrations near the surface may reflect anthropogenic activities, but the increase in S and As in deeper sediment is most likely a result of diagenesis (formation of sulphide minerals) rather than anthropogenic input.

Contents

Introduction

This report presents the findings of Part A of Phase 3 of the two-year *Sediment Source Project (Project SS)*. The project was initiated by SEQRWQMS with the broad aim of understanding the nature and origins of sediments and associated nutrients being delivered to Moreton Bay. Work undertaken in the early stages of SEQRWQMS identified sediment as playing a major role in the degradation of numerous habitats within the catchment (WBM Oceanics and Sinclair Knight Merz, 1995). Phases 1 and 2 of our study confirmed the terrestrial origin of fine-grained sediment in the Bay (CSIRO, 2000), and identified potential sources of this sediment using the SedNet model (Prosser et al., 2001) that predicts hillslope and channel erosion, and sediment loads delivered from Southeast Queensland catchments. Phase 3 of the study tests the model predictions by examining the history of sedimentation in the Bay (Part A), and by using spatial tracers to determine catchment sources (Part B).

The main aim of Part A of the study is to determine the rate of accumulation of fine sediments in the central mud-dominated area of Moreton Bay. In particular, the study aims to establish whether the rate of sediment delivery has varied significantly since European settlement, and whether this change has been as associated with changes in the physical and geochemical characteristics of sediment delivered to the Bay. This was done by measuring profiles of fallout and lithogenic radioncuclides, and major and trace elements in sediment cores collected from the main mud zone in the Bay. By establishing a sediment chronology I intended to develop a relationship between sediment delivery to the Bay and the history of catchment land-use.

Methods

Sample sites and collection

Collection of sediment cores occurred on November 11, 1999. Divers collected cores from 3 sites containing the largest mass of fine-grained sediment (mud) in the deposition zone spanning the central and western regions of the Bay (Figure 1). The three sites (Table 1) spanned the width of the main mud zone. Site-1 is the most easterly site in the deepest water (depth 13 m), Site-2 (9 m water depth) is the most central, and Site-3 is a shallow near-shore area (4 m water depth).

Divers either pushed Perspex core tubes into the sediment (short cores up to 75 cm) or hammered in PVC tubes (long cores up to 2 m). Cores were retrieved in an upright position, and placed upright in dry ice until frozen. The cores were kept frozen during transport to the Canberra laboratory, and remained frozen until required for analysis.

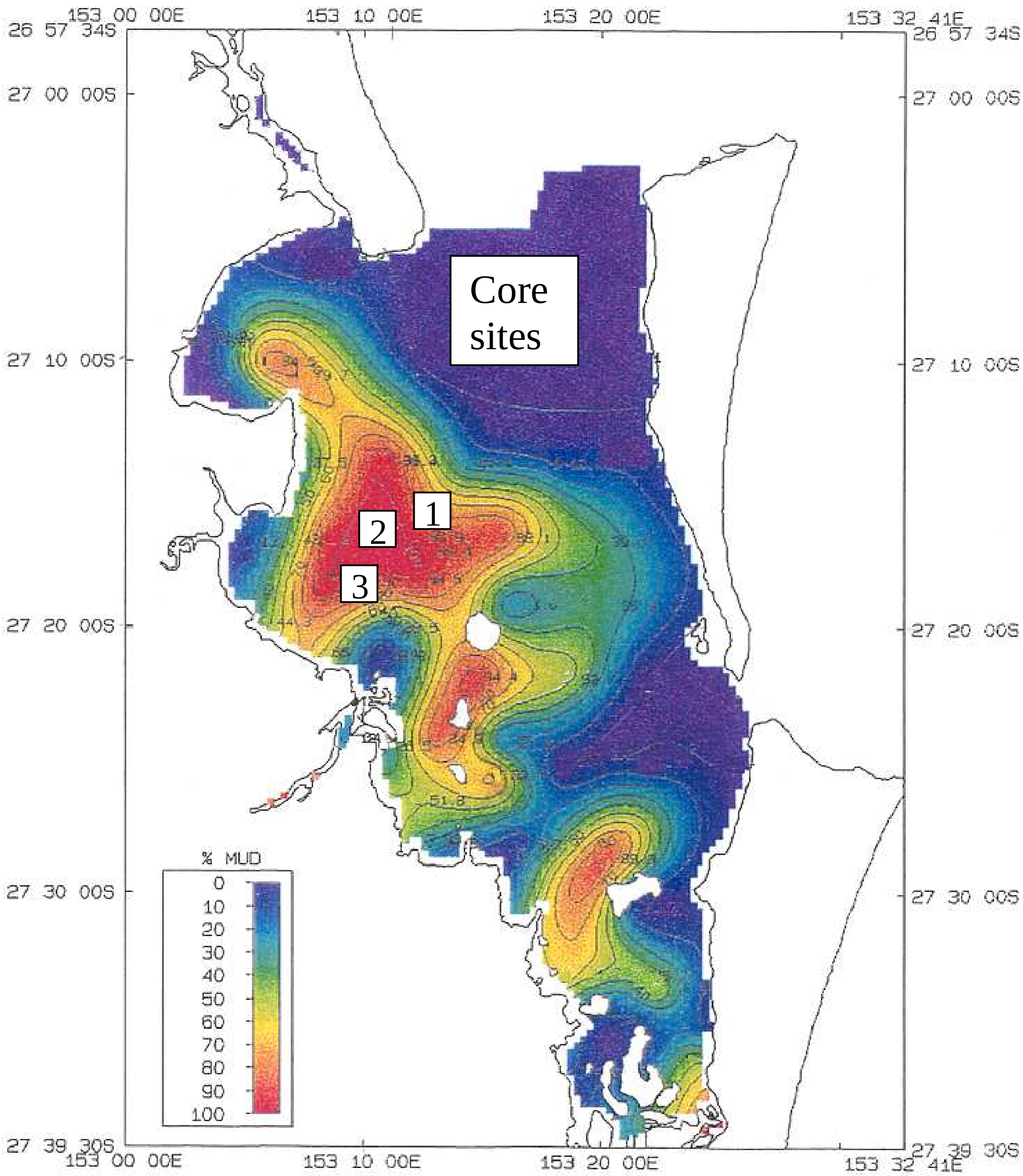

Figure 1. Study sediment core sites shown with the distribution of mud in Moreton Bay (from Heggie et al., 1999).

Table 1. Sediment cores collected.

Site	Location	Core description	Comments
1	S 27° 16.445' E 153° 13.209'	MBSC1 (0.65m long, 10cm diameter) LC1 (1.30m long, 5cm diameter)	Eastern side of mud zone in 13 m water; Brisbane River paleo-channel
2	S 27° 16.921' E 153° 10.539'	MBSC2 (0.55m long,10cm diameter) MBLC2 (1.8m long, 5cm diameter)	Central area of mud zone; 9 m water
3	S 27° 18.549' E 153° 09.521'	SC3 (0.40m, 10cm diameter) LC3 (0.88m long, 5 cm diameter)	Western side of mud zone; Shallow, near-shore; 4 m water

Analysis

After thawing, the cores were sectioned in the laboratory into depth intervals ranging from 1 cm to 6 cm, with near-surface sections sampled at smaller depth intervals. Water content (for porosity) and dry mass was determined for each section. Sediment dry density was also determined.

High-resolution gamma spectrometry (Murray *et al*., 1987) was used for analysis of ^{238}U, ^{226}Ra, ^{210}Pb, ^{228}Th, ^{228}Ra, ^{137}Cs and ^{7}Be in all samples. Samples were cast in resin and counted for 1-2 days using intrinsic germanium gamma detectors. The detectors were calibrated using CANMET uranium ore BL-5, and thorium nitrate refined in 1906 (Amersham International).

Radiochemical separation and alpha spectrometry (Martin and Hancock, 1992) was used to give improved estimates of ^{210}Pb in selected samples (via ^{210}Po analysis) and determine thorium isotopes. This method involved the addition of a tracer isotope of known activity (supplied by Amersham, ±1% uncertainty), followed by radiochemical separation and electroplating. The electroplated discs were counted using high-resolution alpha spectrometry.

Major and trace element concentrations were determined using XRF analysis (Norrish and Hutton, 1969). Major elements were fused in a lithium borate matrix. Tracer elements were determined using the pressed powder method.

Chronometers

The two fallout chronometers used in this study are 'excess' ^{210}Pb, and ^{137}Cs. Both radionuclides accumulate in soils and sediments as a result of atmospheric fallout. Radioactive ^{210}Pb (half-life 22 years) occurs throughout nature, but the 'excess' component found in sediments is usually generated in the atmosphere by radioactive radon gas. Once formed, atmospheric ^{210}Pb rapidly attaches itself to dust particles, and is deposited as dry dust or with rainfall. Fallout ^{210}Pb leads to the accumulation of ^{210}Pb activity over and above that already present in the sediment. The additional ^{210}Pb is termed 'excess' ^{210}Pb, and is determined by the difference between the total

^{210}Pb and ^{226}Ra activities of the sediment. Once isolated by burial, the excess ^{210}Pb activity of sediment decreases due to radioactive decay. Under favourable conditions the rate of sediment accumulation can be determined by the shape of the excess ^{210}Pb depth profile (Appleby and Oldfield, 1992).

Cs-137 (half-life 30 years) is an artificial “man-made” radionuclide originating from the atmospheric testing of nuclear weapons that began in the 1950s. The testing resulted in atmospheric fallout of ^{137}Cs on a global scale, and it is detected in surface soils in all continents. Olley et al. (1990) calculated that the detection of ^{137}Cs in Australian soils indicated that the soil has been exposed to ^{137}Cs fallout during or after 1958. Assuming immobility in the sediment profile, the relationship between fallout history and detection makes ^{137}Cs an important chronological marker in sediment profiles.

Results

Sediment’s physical characteristics

Divers reported the presence of holes ~1cm in diameter in the mud surface at Sites 1 and 2, indicating the presence of burrowing macro-fauna.

All cores from the central region of the mud zone (Sites 1 and 2) contained mainly fine-grained silt and clay (<20 μm particle size). These cores showed no apparent stratification (layering) although the upper 20 cm of sediment at Sites 1 and 2 had light-brownish colouration compared to deeper sediment, indicating oxidation, and by inference, post-depositional mixing. Shell fragments were present in some sections, and at Site-3 the sand and shell content was considerably higher than at the other sites.

Data from four cores are given in Tables 2-6. These include one short core from Site-1 (MBSC1), a short core and a long core from Site-2 (MBSC2 and MBLC2), and a short core from Site-3 (MBSC3). All cores exhibit high porosity, ranging from 0.9 at the surface, decreasing to 0.7 in the deepest sediment.

Radionuclide profiles and core chronologies

The activities of long-lived thorium isotopes (^{232}Th and ^{232}Th) are remarkably constant with depth in all cores, suggesting an approximately constant sediment source, and/or the presence of a post depositional homogenisation process (vertical mixing).

Be-7 (half-life 53 days) is detected to depth of 4 cm in core MBSC1, indicating rapid mixing to this depth at a time-scale of weeks to months. This core was the first core processed in the laboratory, and the detection of ^{7}Be in this core is due to the short delay between collection and measurement by gamma spectrometry. The delay in measurement of the other cores precluded detection of ^{7}Be in these cores.

Table 2. Site-1 short core MBSC1. Radionuclides activity units are Bq kg^{-1}. Values in minor font are measurement uncertainties, and correspond to ±1 SD.

Depth	porosity	^{7}Be		^{137}Cs		^{210}Pb		^{226}Ra		Excess ^{210}Pb		^{232}Th		^{230}Th		^{228}Th		^{228}Ra		$^{228}Ra/^{232}Th$	
0–1	0.878	12.8	4.8	1.7	0.4	52.0	2.6	12.6	0.8	39.4	2.7	33.4	1.7	24.8	1.4	22.6	1.3	19.4	2.0	0.581	0.067
1-2	0.876	20.5	6.1	1.7	0.5	57.0	2.3	15.3	1.1	41.7	2.5							22.4	2.4	0.691	0.088
2-3	0.864	17.7	4.7	1.5	0.4			14.1	0.7			30.1	0.8	24.4	0.7	21.7	0.8	19.6	1.2	0.651	0.043
3-4	0.847	15.7	5.6	1.9	0.4	56.6	2.2	12.7	0.8	43.9	2.3							19.8	1.3	0.611	0.058
4-5	0.844	3.5	6.4	1.7	0.4			13.1	0.8			32.1	1.3	23.9	1.1	23.0	1.0	20.1	1.3	0.626	0.048
5-6	0.837			2.5	0.6	48.6	5.0	13.8	0.8	34.8	5.1	32.4	2.2			22.8	0.7	22.9	1.8	0.707	0.073
6-8	0.820			2.0	0.5	48.7	1.8	13.5	0.9	35.2	2.0	32.4	2.0			24.2	0.7	23.5	1.2	0.725	0.062
8-10	0.813																				
10-12	0.799			2.3	0.5	46.8	2.3	14.2	0.9	32.6	2.5	33.3	1.4	26.0	1.2	26.1	1.2	26.3	0.6	0.790	0.038
12-14	0.784																				
14-16	0.787			2.0	0.4	43.0	1.3	14.0	0.9	29.0	1.6	31.3	2.2	25.4	0.9	24.6	0.9	27.1	0.6	0.866	0.064
16-18	0.785																				
18-20	0.784			2.3	0.4	42.9	1.8	13.1	0.9	29.8	2.0	33.1	1.4	25.3	1.1	25.9	0.5	26.9	1.1	0.813	0.048
20-24	0.769																				
24-28	0.749			1.7	0.5											29.2	0.8	29.6	1.6	0.914	0.079
28-32	0.738																				
32-36	0.761			2.5	0.5	46.9	2.2	15.7	0.7	31.2	2.3	31.2	1.2	27.7	1.1	26.1	1.2	28.1	1.4	0.901	0.057
36-40	0.756																				
40-46	0.703			2.2	0.2	41.1	1.5	15.1	0.3	26.0	1.5	33.4	2.0			33.4	0.6	34.4	0.8	1.030	0.058
46-52	0.720			1.9	0.3			15.4	0.5	*22.6*	*2.9*	33.4	2.0			31.9	0.7	33.7	1.2	1.009	0.063
52-58	0.742			1.7	0.2	33.3	1.6	15.0	0.3	18.3	1.6	33.8	1.5	27.6	1.3	33.5	0.8	34.1	0.5	1.006	0.035
58-65.5	0.743			1.5	0.2	33.6	1.2	14.6	0.3	19.0	1.2	33.4	2.0			35.0	0.6	34.6	0.8	1.036	0.058

Table 3. Site-2 short core MBSC2

Depth (cm)	**Porosity**	**^{137}Cs**	**^{210}Pb**	**^{226}Ra**	**Excess ^{210}Pb**	**^{232}Th**	**^{230}Th**	**^{228}Th**	**^{228}Ra**	**$\frac{^{228}Ra}{^{232}Th}$**
0-1.5	0.838	$2.8_{0.6}$	$44.0_{5.2}$	$12.6_{0.8}$	$31.4_{5.3}$				$19.4_{2.0}$	
1.5-2.5	0.832	$3.3_{0.8}$		$15.3_{1.1}$		$30.7_{1.0}$	$24.7_{0.9}$	$21.5_{0.8}$	$22.4_{2.4}$	$0.730_{0.082}$
2.5-3.8	0.820		$44.5_{1.8}$	$14.7_{0.5}$	$29.8_{1.9}$					
3.8-4.8	0.822	$1.3_{0.7}$	$49.2_{6.6}$	$14.8_{1.1}$	$34.4_{6.7}$				$20.4_{2.3}$	
4.8-6.5	0.810	$2.0_{0.3}$		$14.9_{0.3}$		$32.9_{1.6}$			$22.5_{0.6}$	$0.684_{0.038}$
6.5-8.5	0.793	$2.7_{0.5}$	$45.7_{1.8}$	$13.9_{0.7}$	$31.8_{1.9}$	$30.5_{1.3}$	$25.5_{1.1}$	$21.6_{1.0}$	$20.6_{1.5}$	$0.675_{0.057}$
8.5-10.7	0.788		$41.9_{1.4}$	$14.7_{0.5}$	$27.2_{1.5}$	$31.2_{1.4}$	$26.5_{1.2}$	$20.2_{1.1}$		
10.7-13	0.778	$2.6_{0.5}$		$14.7_{0.5}$					$23.3_{1.3}$	
13-17	0.771	$2.1_{0.5}$	$47.5_{1.8}$	$14.4_{0.7}$	$33.1_{1.9}$	$32.2_{1.2}$	$26.6_{1.1}$	$23.4_{1.0}$	$23.7_{1.5}$	$0.736_{0.054}$
17-21	0.762	$1.9_{0.2}$	$39.7_{1.6}$	$14.3_{0.3}$	$25.4_{1.6}$	$32.3_{1.7}$	$25.2_{1.5}$	$23.0_{1.4}$	$25.0_{0.8}$	$0.737_{0.044}$
21-25	0.749	$2.5_{0.3}$	$46.7_{1.8}$	$14.9_{0.5}$	$31.8_{1.9}$	$32.3_{1.2}$	$26.7_{1.1}$	$24.7_{1.1}$	$24.8_{1.2}$	$0.766_{0.034}$
25-30	0.694	$2.7_{0.2}$	$39.0_{1.3}$	$15.7_{0.3}$	$23.3_{1.3}$	$34.9_{1.4}$	$28.3_{1.2}$	$26.2_{1.2}$	$29.1_{0.7}$	$0.814_{0.037}$
30-35	0.682	$2.1_{0.5}$	$41.8_{1.4}$	$15.7_{0.7}$	$26.1_{1.6}$	$34.4_{1.2}$	$26.1_{1.0}$	$27.0_{1.1}$	$32.0_{1.7}$	$0.829_{0.039}$
35-40	0.706	$2.5_{0.1}$	$33.8_{1.1}$	$14.8_{0.2}$	$19.0_{1.1}$	$34.6_{1.3}$	$26.3_{1.1}$	$27.7_{1.1}$	$30.1_{0.5}$	$0.858_{0.035}$
40-45	0.693	$2.4_{0.4}$	$35.9_{1.1}$	$14.3_{0.7}$	$21.6_{1.3}$	$30.8_{0.8}$	$25.6_{0.9}$	$26.0_{0.9}$	$30.3_{1.6}$	$0.877_{0.035}$
45-50	0.702	$1.3_{0.4}$	$25.3_{0.9}$	$14.9_{0.6}$	$10.4_{1.1}$	$32.9_{1.1}$	$25.8_{0.9}$	$29.7_{1.0}$	$31.4_{0.8}$	$0.933_{0.036}$
50-55	0.699	$0.7_{0.6}$	$24.8_{1.2}$	$14.1_{0.8}$	$10.7_{1.4}$	$34.2_{1.3}$	$26.5_{1.0}$	$30.1_{1.2}$	$33.9_{2.0}$	$0.909_{0.045}$

Table 4. Site-2 long core MBLC2.

Depth (cm)	**Porosity**	^{137}**Cs**	^{210}**Po**	^{226}**Ra**	**Excess** ^{210}**Pb**	^{232}**Th**	^{230}**Th**	^{228}**Th**	^{228}**Ra**	$\frac{^{228}Ra}{^{232}Th}$
0-6	0.824		34.7 1.2	14.6 1.3	20.1 1.8	30.4 1.3	23.4 1.1	20.9 1.0		
6-12										
12-18	0.795		37.1 1.2	14.6 1.3	22.5 1.8					
18-24										
24-30	0.735		34.9 1.2	14.6 1.3	20.3 1.8					
30-36										
36-42	0.770		31.5 1.0	14.6 1.3	16.9 1.6					
42-48	0.744	2.2 0.7	36.5 1.0	13.6 1.1	22.9 1.5	31.9 1.1	24.6 0.9	26.9 1.1	28.9 2.4	0.906 0.081
48-54	0.728	1.8 0.4	30.4 0.9	14.6 1.2	15.8 1.5	33.7 2.4	26.2 2.0	31.5 2.4	31.5 1.5	0.935 0.073
54-60	0.725	1.3 0.5	26.4 4.1	14.1 0.7	12.3 *4.2*	32.0 1.5		31.4 0.8	31.8 1.6	0.994 0.050
60-66	0.724	0.9 0.5	24.4 1.0	14.7 0.6	9.7 1.2	33.1 1.3	25.3 1.1	30.7 1.2	30.7 1.3	0.927 0.054
66-72	0.721	0.7 0.4	22.4 0.8	12.8 0.5	9.6 0.9	32.4 1.3	24.6 1.1	29.4 1.2	32.5 2.0	1.003 0.074
72-78	0.719	0.4 0.4	18.4 0.7	14.1 0.6	4.3 0.9	32.2 1.1	26.4 1.0	34.5 1.2	33.2 2.1	1.031 0.074
78-84	0.723	-0.6 0.6	16.8 0.7	14.1 0.5	2.7 0.9	32.3 1.0	23.6 0.8	32.0 0.7	33.9 2.1	1.050 0.073
84-90	0.729	-0.3 0.6	14.8 0.7	13.6 0.8	1.2 1.1	32.2 1.4	24.3 1.1	32.2 1.4	34.4 2.0	1.068 0.078
90-98	0.704	-0.7 1.0		13.1 1.3		32.6 0.8	25.0 0.7	33.6 0.9	33.1 3.0	1.015 0.095
98-106	0.699	-0.4 0.5		14.8 0.8					36.1 1.8	1.128 0.056
106-114	0.710	-0.1 0.7	15.9 0.8	15.1 0.9	0.8 1.2	32.0 1.5	25.8 1.3	31.2 1.5	35.0 2.2	1.094 0.086
122-130	0.689									
130-138	0.687	-0.2 0.4		15.9 0.7		32.0 1.5		33.7 0.8	33.0 1.6	1.031 0.050
138-146	0.729									
146-154	0.688	-0.7 0.6		17.1 0.9		32.0 1.5		31.8 0.9	34.8 2.0	1.088 0.063
154-164										
164-174	0.693	-0.1 0.3		16.4 0.4		32.1 1.4	25.8 1.2	32.5 1.4	31.3 1.0	0.975 0.053

Table 5 . Site-3 short core MBSC3

Depth (cm)	Porosity	^{137}Cs	^{210}Pb	^{226}Ra	Excess ^{210}Pb	^{232}Th	^{230}Th	^{228}Th	^{228}Ra	^{228}Ra/^{232}Th
0 - 1	0.89	1.5 0.6	31.0 1.1	12.6 0.8	16.9 1.4	25.2 1.1	18.1 0.9	17.9 0.9	19.8 1.9	0.786 0.083
1 - 2	0.87	0.8 0.4	29.5 1.1	14.1 0.6	15.4 1.3				20.8 1.4	
2 - 4	0.90	1.9 0.4	25.3 0.9	11.0 0.6	14.3 1.1	24.3 1.0			18.3 1.0	0.753 0.041
4 - 6	0.90	1.0 0.7	23.5 0.8	10.6 0.9	12.9 1.2				16.8 2.1	
6 - 8	0.88	1.3 0.4	23.7 0.8	11.7 0.7	12.0 1.1	21.8 0.8	17.2 0.7	15.9 0.7	18.0 1.4	0.826 0.071
8 - 10	0.85	1.6 0.6	24.4 1.0	11.6 0.8	12.8 1.3				18.4 1.8	
10 – 12	0.84	1.2 0.5	24.2 0.9	12.8 0.5	11.4 1.0	22.4 1.0	18.3 0.9	17.8 0.9	17.8 0.9	0.794 0.044
12 – 16	0.84	2.0 0.4	26.9 0.9	11.3 0.6	15.6 1.1				19.9 1.4	
16 – 20	0.85	0.9 0.6	25.3 0.9	12.5 0.8	12.8 1.2	26.8 1.1	20.8 0.9	22.1 0.9	22.1 0.9	0.825 0.038
20 – 24	0.83	1.3 0.1	21.2 0.9	12.6 0.5	8.6 1.0	26.1 0.9	23.5 0.9	22.0 0.8	22.6 1.0	0.866 0.049
24 – 28	0.82	1.2 0.4	20.7 0.6	11.4 0.6	9.3 0.8	23.7 0.9	16.7 0.7	21.4 0.8	21.4 0.8	0.906 0.041

Excess ^{210}Pb is determined from the difference between ^{210}Pb and ^{226}Ra activities. At all sites excess ^{210}Pb is highest in the upper portion of the sediment profile. At Sites 1 and 2 excess ^{210}Pb is relatively constant to a depth of about 35 cm, but decreases steadily below 35 cm. At Site-2 excess ^{210}Pb becomes undetectable below 84 cm (detection limit ~2 Bq kg^{-1}). The short core from Site-3 extends to a depth of only 28 cm, and its near-surface excess ^{210}Pb activity is lower than at other sites.

Cs-137 (half-life 30 years) is detected in all cores. It becomes undetectable below about 70 cm depth at Site-2 (detection limit 0.7 Bq kg-1). The interpretation of ^{210}Pb and ^{137}Cs profiles at each site is discussed separately below.

Site-1

Figure 2 (a) shows depth profiles of ^{137}Cs and excess ^{210}Pb for core MBSC1 (depth 65 cm). Note the bottom horizontal axis (excess ^{210}Pb activity) is log scale. Detectable quantities of ^{137}Cs and excess ^{210}Pb are present at the base of the core. Excess ^{210}Pb is highest in the upper 8 cm (about 40 Bq kg^{-1}), decreases slightly over the next few cm to a more or less constant value in the 10-36 cm interval (~30 Bq kg^{-1}), and then decreases linearly to 57 cm depth.

Figure 2 (b) shows a depth profile of the $^{228}Ra/^{232}Th$ activity ratio (AR) for MBSC1. The AR is less than one to a depth of about 40 cm. Below 40 cm the AR is consistent with a value of one. Ra-228 (half-life 5.7 years) is the radioactive decay product of ^{232}Th. In closed systems with no loss or gain of Ra and Th a $^{228}Ra/^{232}Th$ AR equal to one is expected. However, because Ra is much more soluble in salt water than thorium, a $^{228}Ra/^{232}Th$ AR of less than one is often seen in the surface layer of marine sediments. This ^{228}Ra deficiency indicates that Ra is being exported over a time frame equal to or less than about two ^{228}Ra half-lives (10-15 years). Ra-228 export is partly due to molecular diffusion, but it is also aided by biological activity. Bioturbation and bio-irrigation aid Ra loss by flushing water through the sediment, and by rapidly transporting deep sediment upwards towards the sediment-water interface where Ra is more easily lost by diffusion through pore water. In most porous sediments the effects of diffusion on ^{228}Ra deficiency is limited to a depth of just 5-10 cm. The observation of ^{228}Ra deficiency to a depth about 40 cm is almost certainly an indication of sediment mixing, probably to a depth of 30-35 cm. This hypothesis is supported by the relatively constant ^{210}Pb activities in the upper 35 cm of sediment, and by sulphur concentrations (see below).

Using this approach, the bulk accumulation rate (that is for wet sediment) at Site-1 is estimated to be 1.2 ±0.2 cm yr^{-1}, equivalent to about 0.69 g cm^{-2} yr^{-1} of dry sediment. This rate pertains to the last 60 years of sedimentation (about three ^{210}Pb half-lives). The presence of detectable ^{137}Cs at the base of this core (65 cm) adds support to our estimation of the bulk accumulation rate using excess ^{210}Pb. If the upper mixed layer is assumed to extend to 30-35 cm below the surface, then ^{137}Cs has penetrated to a depth of about 30-35 cm below the mixed layer, equivalent to 25-30 years based on the ^{210}Pb accumulation rate. Since detection of ^{137}Cs corresponds to the deposition of sediment within the last 42 years, a bulk accumulation rate of 1.2 cm yr^{-1} would make it detectable to a depth of about 50 cm below the base of the mixed layer (total depth 80-85 cm). This is 15-20 cm below the base of core MBSC1. Since the application of ^{137}Cs chronology requires the determination of the depth at which ^{137}Cs is no longer

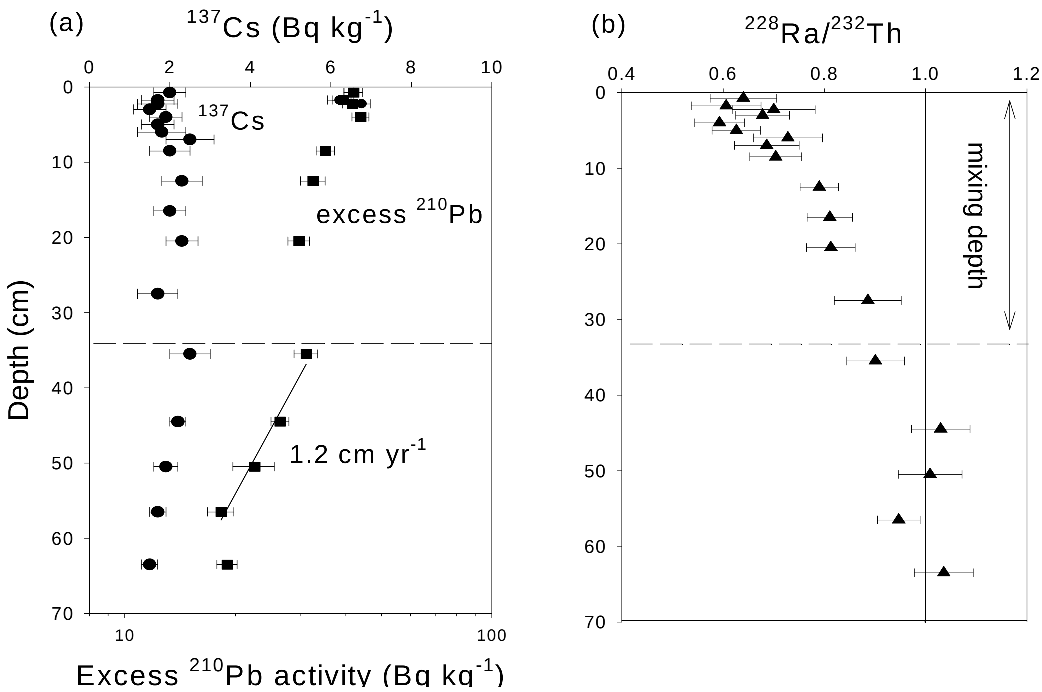

Figure 2. Site-1 radionuclide profiles (MBSC1). ^{137}Cs circles; excess ^{210}Pb squares; ^{228}Ra/^{232}Th triangles

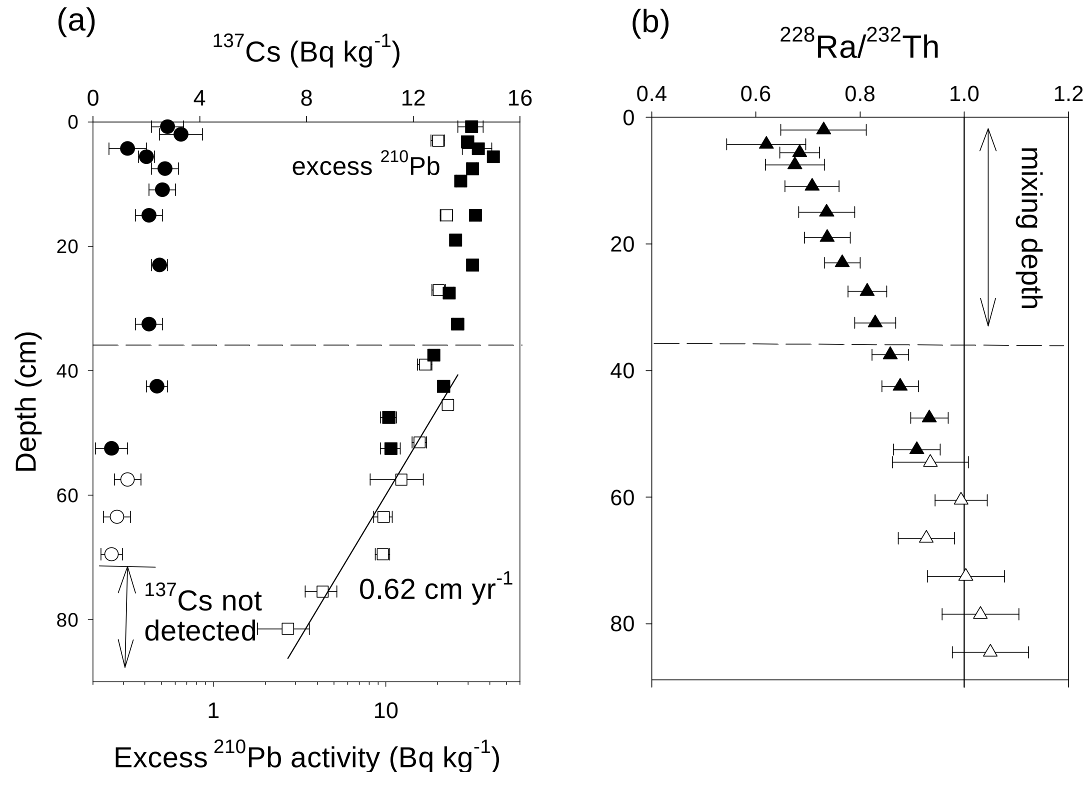

Figure 3. Site-2 radionuclide profiles. Symbols without fill, represent the long core MBLC2; filled symbols represent the short core MBSC2. Circles ^{137}Cs; squares excess ^{210}Pb, triangles ^{228}Ra/^{232}Th AR.

detectable, a proper application of ^{137}Cs chronology requires the analysis of deeper sediment from a longer core taken at this site.

We emphasize that the accumulation rates derived using ^{210}Pb and ^{137}Cs are upper limits. Although the ^{210}Pb and ^{228}Ra/^{232}Th AR profiles indicate that rapid mixing is constrained to the upper 35 cm of sediment, slow mixing on a time-scale of >20 years may be occurring below 35 cm. Slow mixing may not significantly enhance ^{228}Ra export, but it may still produce ^{210}Pb profiles consistent with exponential decrease, even in the absence of net sediment accumulation. In Port Phillip Bay, where burrowing macro-fauna are believed to be abundant, the mixing depth was estimated to be at least 50 cm (Hancock and Hunter, 1999). The presence of burrow openings in sediment at Site-1 and Site-2 suggests these animals are also active in Moreton Bay. If slow mixing is occurring below 35 cm depth, our ^{210}Pb estimates of sediment accumulation will be too high.

Site-2

Figure 3 shows depth profiles of cores MBSC2 and MBLC2. Again, ^{137}Cs and excess ^{210}Pb persist to the base of the short core (MBSC2, 55 cm depth). MBLC2 was the longest core collected, and allowed the examination of sediment well below the upper mixed layer. This core was collected within a few meters of MBSC2, and it can be seen in Figure 2, which superimposes the excess ^{210}Pb profiles of MBSC2 and MBLC2 on the same plot, that he data from the two cores are broadly consistent. As at Site-1, excess ^{210}Pb activity is approximately constant to a depth of 35 cm. On a log scale the excess ^{210}Pb activity then declines in a more or less linear fashion to a depth of 80 cm, below which is it undetectable. Using the approach outlined above, with its accompanying assumptions, the mean bulk accumulation rate of sediment is estimated to be 0.62 ±0.05 cm yr^{-1}, equivalent to 0.41 g cm^{-2} yr^{-1} of dry sediment deposition based on the porosity and dry density of sediment in the Bay. Cs-137 is detected to a depth of about 70 cm, equal to a penetration depth of about 30-35 cm below the upper mixed layer. This yields a mean bulk accumulation rate of between 0.7-0.8 cm yr^{-1}, pertinent to the last 42 years. Given the assumptions inherent in the derivation of the ^{210}Pb rate, and the uncertainty in the exact depth of the base of the upper mixed layer, the rates derived using both chronometers are broadly consistent.

Site-3

Excess ^{210}Pb shows a relatively small change from the surface to the base of the core MBSC3 (depth 28 cm). Cs-137 is present throughout the profile. The ^{228}Ra/^{232}Th AR indicates that mixing likely occurs throughout the length of the core. Apart from excess ^{210}Pb inventory calculations (see below) there is little sedimentation information that can derived from this core.

Fallout radionuclide inventories

Sediment inventories of excess ^{210}Pb can provide information on the extent of deposition occurring within specific areas in the Bay. This information can be used to determine if sediment focusing is occurring in the Bay, as well as providing a check on whether the ^{210}Pb accumulation rates are feasible. The excess ^{210}Pb inventory is found by integrating the excess ^{210}Pb activity in the cores from the surface down to a level where the excess ^{210}Pb activity is considered to be consistent with zero. At Site-2 the excess ^{210}Pb inventory, determined from the profile of MBLC2, is 6700 Bq m^{-2} yr^{-1}. At Site-1 the excess ^{210}Pb inventory at the base of MBSC1 is 8290 Bq m^{-2} yr^{-1}. However, since excess ^{210}Pb is still detectable at the base of this core, its total inventory is likely to somewhat greater. Assuming excess ^{210}Pb continues to decrease exponentially with depth below 65 cm, the expected inventory is estimated to be 10500 Bq m^{-2} yr^{-1}. The inventory at the base of the core taken from Site-3 (MBSC3) is 1450 Bq m^{-2} yr^{-1}. The shape of the ^{210}Pb profile at this site, together with ^{210}Pb data from an adjacent (longer) core indicates that the excess ^{210}Pb inventory at this site is almost certainly <2500 Bq m^{-2} yr^{-1}.

Excess ^{210}Pb inventories and other characteristics of each site are summarized in Table 6. The gradient in the excess ^{210}Pb inventories, from a low value at the shallowest site (Site-3) to the highest value at the deepest site (Site-1) indicates a trend within the mud-dominated zone of greater sediment accumulation with increasing water depth. This in turn suggests that sediment is being preferentially deposited or "focussed" in deeper water, a conclusion consistent with a process of resuspension of sediment in relatively shallow water, and deposition in less turbulent water.

Another potentially significant piece of information can be obtained by comparing the sediment excess ^{210}Pb inventories with the value expected from direct atmospheric fallout (2100 Bq m^{-2} yr^{-1} at Brisbane; Turekian et al., 1977). This comparison can indicate whether the sediment accumulation rates calculated using excess ^{210}Pb and ^{137}Cs are feasible, although the inventories cannot be used as proof that the rates are valid. Delivery of sediment (ie. eroded soil) from the Bay's catchment will bring with it excess ^{210}Pb derived from direct fallout in the catchment. This catchment flux is an additional source excess ^{210}Pb to the Bay, and will lead to sediment inventories higher than that expected solely from direct fallout in the Bay. Knowing the sediment accumulation rate allows an estimate of the catchment input term, which, when added to the fallout value gives an expected inventory value. A measured inventory less than the expected value would indicate that the accumulation rate has been overestimated. Due to the probability of sediment focussing, the converse is not necessarily true.

In calculating catchment ^{210}Pb fluxes, the ^{210}Pb activity of sediment delivered to the Bay is estimated from the activity of three Brisbane River sediment samples collected in the upper estuary (average activity 60 Bq kg^{-1}). The ^{226}Ra activity of sediment in the Bay is about 15 Bq kg^{-1}, and so the excess ^{210}Pb activity of depositing sediment is estimated to be 45 Bq kg^{-1}. If the upper limit of the bulk sediment accumulation at Site-1 is assumed (4.8 kg m^{-2} yr^{-1}), an excess ^{210}Pb flux of 216 Bq $m^{-2}yr^{-1}$ is calculated. When this flux is added to the flux due to direct fallout onto the Bay (66 Bq $m^{-2}yr^{-1}$; Turekian et al., 1977), a total flux of 282 Bq $m^{-2}yr^{-1}$ is obtained. This flux equates to an expected inventory of 9070 Bq m^{-2} (determined from $flux \times half-life/\ln 2$), a value in reasonable agreement with measurement. A similar calculation using Site-2 data yields a catchment input 112 Bq m^{-2} yr^{-1} (assuming an accumulation rate 0.62 cm yr^{-1}), and a total expected inventory of 5700 Bq m^{-2}, again, close to the measured value.

These ^{210}Pb budgets are consistent with the bulk sediment accumulation rates estimated from ^{210}Pb and ^{137}Cs profiles, and indicate that these rates are feasible. However, this consistency cannot be taken as absolute confirmation. It is possible, for example, that the sediment accumulation rate in the Bay is much lower than the apparent ^{210}Pb rate, and that the elevated excess ^{210}Pb inventories seen in the mud-dominated zone are mainly due to sediment focussing.

Table 6. Summary of sedimentation results determined from ^{210}Pb data

Site	Water depth (m)	^{210}Pb inventory [a] (Bq m^{-2})	Apparent sediment accumulation rate	
			(cm yr^{-1})	(kg m^{-2} yr^{-1})
1	13	8,290; (10,500)	1.2	4.8
2	9	6,700	0.62	2.5
3	4	1,450; (<2,500)	n.d.	n.d.

[a] At Site 1 and Site 3 the entire core inventory could not be determined because excess ^{210}Pb was still present at the base of the core. Measured values are given without brackets; values in brackets are inventories estimated from the predicted excess ^{210}Pb profile below the base of the core.
n.d. not determined

Trace element profiles

Major element concentrations were presented in Phase 2 report, and showed little change with depth. Trace element data from MBSC2 and MBLC2 are given in Table 7. Also included are trace element measurements of a Brisbane River sediment sample, fractionated to <10 µm. This sample was collected from a channel bank at Moggill Crossing, and had been deposited during recent high flow.

As was seen in the major element and Th isotope measurements, most trace elements in the core profiles show no significant change with depth. Exceptions are S and As, which show significant increases with depth, and Pb and perhaps Zn, which decrease slightly. Site-2 profiles of these elements are shown in Figure 4. The data from the two cores are overlain, and it is apparent that the profiles of the two cores are broadly similar.

The S concentration at Site-2 (Figure 4(a)) increases rapidly below a depth of about 30 cm. This increase is almost certainly due to *in-situ* sulphide formation in the sediment, rather than a change in the mineralogy of sediment being delivered to the Bay. Due to the low availability of oxygen below the sediment surface, dissolved sulphate in seawater is reduced to solid-phase Fe-sulphide, leading to an increase in the total S content of the sediment. The increase in S below 30 cm provides more evidence for the presence of a rapidly mixed layer in the upper 30-35 cm of sediment

Table 7. Trace element concentrations in cores from Site-2. Units are μg g^{-1}.

Depth (cm)	V	Cr	Co	Ni	Cu	Zn	Ga	As	Rb	Sr	Y	Zr	Nb	Mo	Ag	Cd	Sn	Cs	Ba	La	Ce	Pb
MBSC2																						
13-17					23	114	15	7.7	75	218	31	193	19	2	< 0.5	0.7	5	< 1.5	202	25	45	27
21-25					19	110	15	6.4	77	215	33	196	18	3	< 0.5	< 0.3	3	< 1.5	207	22	51	28
30-35					21	119	17	9.6	78	205	32	198	19	3	< 0.5	0.6	4	< 1.5	229	31	54	28
40-45					23	107	18	7.8	78	198	33	203	18	1	< 0.5	0.4	5	< 1.5	219	29	59	30
50-55					21	121	18	5.8	77	214	34	191	18	5	< 0.5	0.7	4	< 1.5	223	25	51	31
MBLC2																						
24-30	119	106	38	40	20	124	21	8.9	89	211	27	191							202	22	53	32
30-36					23	114	18	8.0	76	197	32	194	20	2	< 0.5	< 0.3	4	< 1.5	224	19	51	27
42-48						115	22	9.7	80	201	34	192			< 0.5	0.4	4	< 1.5	228	30	48	30
48-54	129	108	28	43	26	123	22	8.9	80	204	28	194	15	1	0.3	0.7	3	2.3	213	21	54	30
54-60					32	121	16	8.3	82	196	32	203	19	1	< 0.5	1.4	4	< 1.5	245	29	52	31
60-70					31	105	15	7.6	79	176	31	187	18	4	< 0.5	0.9	5	< 1.5	225	20	53	32
74-78					21	96	20	9.3	75		31	182	18		< 0.5	0.5	3	4.2	208	24	39	27
78-88					22	96	17	13.5	82	164	33	197	18	2	< 0.5	1.0	3	3.3	246	26	51	21
88-96					31	95	19	12.0	86	165	33	198	18	3	< 0.5	1.6	4	< 1.5	244	28	60	20
96-104					28	97	17	9.2	83	173	33	204	18	2	< 0.5	0.4	< 0.5	< 1.5	247	24	49	21
104-112					22	94	15	15.5	81	174	33	204	18	1	< 0.5	1.1	3	< 1.5	249	19	58	15
114-122	129	106	38	39	21	98	22	13.7	83	191	26	200	15	1	0.1	0.4	3	2.0	224	21	54	19
122-130	134	107	29	41	22	99	22	16.8	82	199	26	197	15	1	-0.2	0.3	2	2.5	217	21	51	18
138-146	139	110	37	40	20	96	23	13.8	82	200	26	201	16	1	-0.1	0.3	2	2.2	228	22	54	17
154-164	141	110	36	42	44	106	23	12.6	87	166	27	186	15	1	0.2	-0.1	3	1.9	209	20	56	18
164-174					51		17	13.0			26	215	22	4	< 0.5	1.3	6	< 1.5				17
Brisbane River grab																						
Surface <10μm					44	157	22	7.9	56	135	41	221	20	4	< 0.5	< 0.3	4.4	< 1.5	312	38	52	33

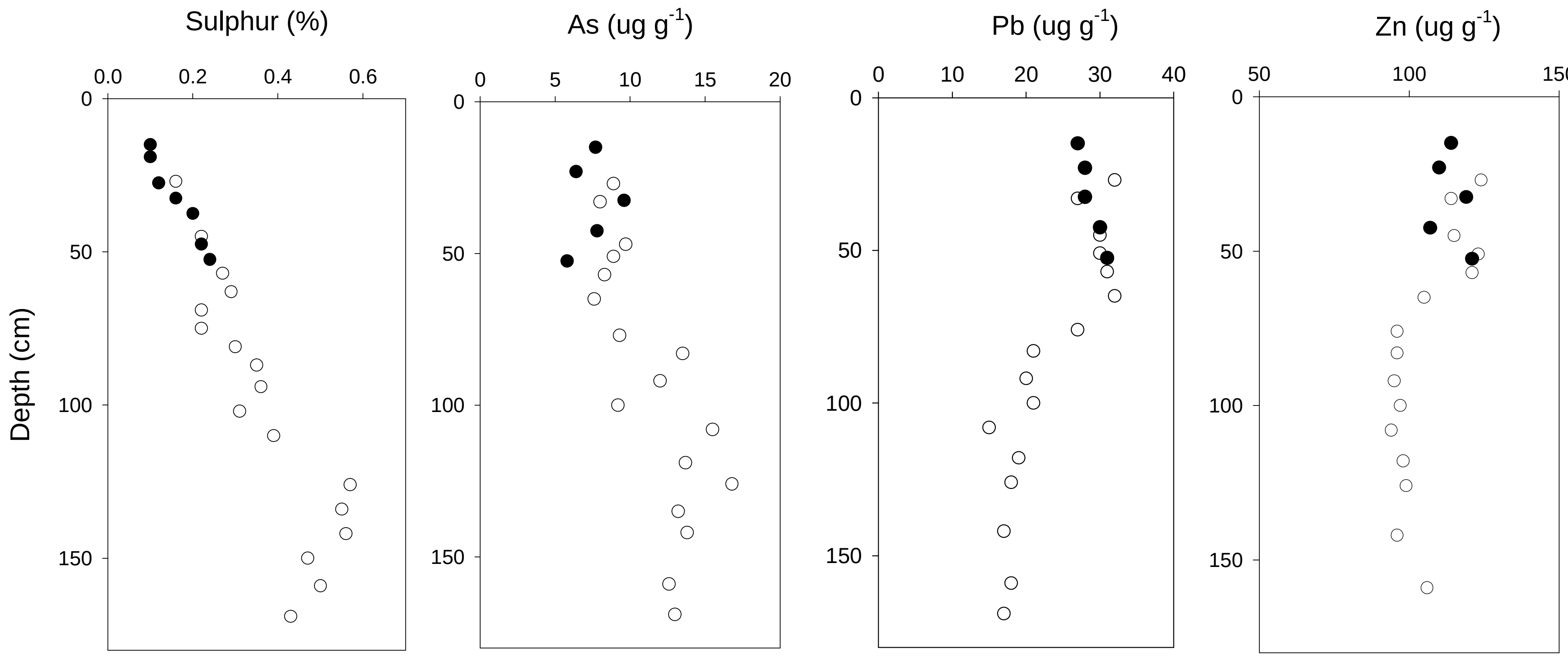

Figure 4. Trace element profiles at site-2; MBLC3 symbols without fill; MBSC3 filled symbols.

(eg. Hancock et al., 2000), and for the use of a 2-layer approach to model the ^{210}Pb profiles.

Although arsenic concentrations (Figure 4(b)) are more variable than S, the increase in As below 80 cm is significant. The mean concentration of As in the upper 80 cm is about 8 μg g^{-1}, similar to the single Brisbane River sample (Table 7). Concentrations below 80 cm are higher by a factor of between 1.5 and 2. The cause of this increase is uncertain, but it is appears to be related to the redox state of the sediment. It is suggested that redox dependent solubility controls the enrichment of As in anoxic sediments (Calvert, 1976), and the correlation of As and S in sediment below 80 cm (r^2 = 0.71) suggests a causal relationship. The incorporation of As into the Fe-sulphide phase is the most likely explanation for the relationship, with the source of the extra As being seawater. A second possible explanation for the higher As concentrations is a change in the source of sediment from the catchment, with a higher proportion of As-rich soils being delivered in the past. A third possibility is anthropogenic sources, such as arsenates used as pesticides and herbicides. The history of its use in the Morton Bay catchment has not been researched by this study, but compounds of As were reputedly popular agricultural chemicals in the US and Australia between 1900 and 1950 (Merry et al; 1983; Haworth et al., 1999).

Pb and Zn both show enhanced concentrations in the upper 70 cm of sediment. The enhancement is about 50% for Pb, and 20% for Zn. The depth of the enhanced concentrations broadly corresponds with the presence of excess ^{210}Pb suggesting increased Pb and Zn input within the last 60 years. The source of the additional metals is not certain, but given the 60 year time frame they might be anthropogenic. Lead isotope measurements currently being made as part of the Phase 3 study may provide a more definite link to human activities. However, even if an anthropogenic link is established it is not certain that these metals will provide time markers for the same reason that ^{210}Pb data is non-definitive; ie. possible mixing below 35 cm.

Discussion

^{210}Pb geochronology

Where the upper layer of sediment is extensively mixed two approaches have commonly been used to estimate sediment accumulation; the two layer mixing model described above, or more complex modelling of sediment transport within the mixed zone involving the determination of mixing rates. In cases where two tracers with suitable half-lives are found within the mixed zone, the effects of mixing and accumulation can sometimes be disentangled. This was the case in central Port Phillip Bay sediment, where excess ^{210}Pb and excess ^{228}Th profiles were used in combination to constrain mixing and sedimentation rates in the upper 20 cm of sediment (Hancock and Hunter, 1999). Due to the more rapid exchange of Moreton Bay water with the ocean, production of ^{228}Th is five times lower in the central Moreton Bay water column compared with Port Phillip Bay, and excess ^{228}Th is not seen in the sediment profile. The half-life of ^{7}Be is too short to be used as an alternative chronometer.

In applying the 2-layer mixing model in conjunction with ^{210}Pb geochronology, constant ^{210}Pb activity in sediment at the base of the mixed layer is assumed. This assumption is reasonable given the apparent thickness of the mixed layer. The activity of excess ^{210}Pb in sediment accumulating at the sediment surface will certainly vary as a result of the sporadic nature of flooding from the Bay's catchment and the highly variable rate at which sediment is delivered to the Bay. However the homogenising effect of bioturbation in the mixed layer and the relatively large depth to which mixing occurs will have the effect of smoothing ^{210}Pb activity variations to the point where constant ^{210}Pb activity at the base of the mixed layer can be reasonably assumed. For example, an estimated 5.4 million tonnes of sediment was transported to the Brisbane River estuary during the 1974 flood (Anon., 1979), reported to be a one in 100 year event. If this sediment load is correct, and the entire load was evenly distributed across the mud-dominated zone, a sediment layer about 7 cm thick would have been deposited. This sediment thickness is a relatively small fraction of the thickness of the mixed layer. Even if the excess ^{210}Pb activity of the 1974 sediment was significantly lower than was normal for depositing sediment, as might be expected during such a large event, mixing within the 35 cm layer would have resulted in a relatively minor change in the excess ^{210}Pb activity of sediment at the base of the mixed layer.

The main effect of a large flood on the ^{210}Pb profile in the mud-dominated zone of the Bay would have been the production of an emergent layer of relatively constant ^{210}Pb activity immediately below the base of the mixed layer. Such a layer might correspond to the layer of approximately constant excess ^{210}Pb activity seen between 50 and 70 cm at Site-2. The ^{210}Pb "age" of sediment at the top of this interval ("age" in this context being the length of time since the sediment emerged from the base of the rapidly mixed layer) is 30 ± 6 years, an age consistent with the hypothesis that the constant activity layer represents, at least in part, deposition that could have occurred in 1974.

The definition of the ^{210}Pb "age" of sediment described above, has implications for the process of relating changes in sediment characteristics to chronology. Due to the homogenising effect of mixing in the upper 35 cm or so, the characteristics of sediment with a ^{210}Pb "age" of (say) 30 years will not necessarily reflect the characteristics of sediment deposited 30 years ago. Rather it represents an average of the characteristics of sediment deposited over the period of time sediment spends in the mixed layer. At Site-2, this length of time, determined from the mixed depth divided by the mean accumulation rate (35 cm/0.62 cm yr^{-1}), is estimated to be at least 50 years.

As noted above, the ^{210}Pb accumulation rates pertain to the last 60 years, meaning that at Site-2 only sediment below 80 cm can be confidently dated as pre-1940. The limited time frame for the ^{210}Pb accumulation rates ages is due to the low excess ^{210}Pb activities at the sediment surface, and throughout the mixed layer. These low activities are almost certainly due to the homogenising effect of mixing, whereby the relatively high activity of excess ^{210}Pb accumulating at the sediment surface is diluted by being mixed with low activity sediment. The restriction of ^{210}Pb dating to post 1940 sediment eliminates, without more chronological information, the prospect of determining the sediment horizon corresponding to pre and post European settlement (ca ~1850). If mixing is mainly responsible for the distribution of sediment in the upper 50 or 60 cm, the characteristics of pre-1850 sediment may be seen at a depth immediately below the deepest sample in which excess ^{210}Pb was detected (~80 cm below the sediment surface). Alternatively, if the post-1940 maximum accumulation rate is applied to the 90 year period from 1850 to 1940, pre-European sediment should be found below 135 cm. However, if accumulation rates prior to 1940 were considerably higher than recent times (>1 cm yr^{-1}) it is conceivable that the 180 cm long core at Site-2 has not penetrated sediment deposited prior to European settlement.

Verification of accumulation rate estimates

Although agreement in our estimates of mean accumulation rates using ^{210}Pb and ^{137}Cs increases confidence in their values, it is emphasised that these rates may still be too high. Slow mixing of sediment, and diffusion of ^{137}Cs through sediment porewater, a process which was found to have occurred to a significant extent in Port Phillip Bay sediments (Hancock and Hunter, 1999), may result in the apparent agreement of ^{210}Pb and ^{137}Cs chronologies in MBLC2 being coincidental. To verify our accumulation rate estimates additional chronological information is required.

The ambiguity of trace element profile interpretations has not provided any proxy age horizons with which to constrain accumulation rates. Optically stimulated luminescence was applied to quartz grains from core MBLC2 in an attempt to independently date discrete sediment layers. However, the method did not yield useful dating information due the fine-grained nature of the quartz in the sediment, and poor bleaching of the quartz.

Other options for validating the ^{210}Pb chronology include radiocarbon dating of shell fragments found in sediment below the mixed layer, and detection of pollen from non-native plant species such as *pinus* pollen. Both these chronometers are theoretically able to date sediment older than the earliest ^{210}Pb age (i.e. pre-1940). If successful, these chronometers would not only help validate ^{210}Pb accumulation rates, but provide a marker delineating sediment associated with periods before and after European settlement. Occasional shell fragments were found at various depths in cores at Site-1, and dating of these fragments might provide validation of the ^{210}Pb chronology, although contamination of sediment with "old" shell fragments is a potential problem. P*inus* pollen is associated with the onset of European settlement, and its first appearance in the core profile would give a time marker corresponding to the period 1850-1900. This chronometer is more likely to yield a useful time horizon than radiocarbon, but collection of additional cores is required.

Comparison with other estimates of sediment accumulation

Long-term accumulation rates

The long-term sedimentation rate in central Moreton Bay can be crudely estimated from the amount of sediment that has accumulated (~5 m; Hekel *et al*. 1979) since the sea-level reached its present level about 6,500 years ago. This long-term bulk accumulation rate (0.08 cm yr^{-1}) is not directly comparable with our ^{210}Pb rate due to increasing compression of the sediment with increasing depth in the sediment column. Nevertheless, even allowing for a factor of two increase in the mass of dry sediment per unit volume in deep sediment compared to sediment in the upper 1 m, it is clear that the equivalent long-term bulk accumulation rate (<0.15 cm yr^{-1}) is much lower (4 to 10 times) than the apparent ^{210}Pb rates at Site-1 and Site-2. Whether this difference is a true reflection of the accelerated delivery of fine-grained sediment to the Bay during the last 60 years or so depends on the extent to which mixing below 35 cm has perturbed the ^{210}Pb profile.

Contemporary estimates of sediment load

The major contributor of terrestrial sediment to Moreton Bay is believed to be the Brisbane River. Recent estimates of mean annual sediment loads delivered to the lower estuary of the Brisbane River have generally been around 300,000 tonnes (Eyre et al., 1998; Moss et al., 1993; Envirotest 1996), although a pre-Wivenhoe Dam estimate of 600,000 tonnes is given by the Port of Brisbane Authority (Anon., 1979) based on a limited period of monitoring. However, estimating the actual load of sediment transported through the mouth of the River into Morton Bay may be more problematic. Using dredging records Eyre et al. (1998) estimated that a mean annual load of just 93,000 tonnes of sediment enters Moreton Bay from Brisbane River.

Other sources of sediment to the main mud deposition zone will include sediment delivered by rivers to the north of the Brisbane River, as well as a contribution from atmospheric fallout. The latter is probably around 35,000 tonnes per year over the entire Bay (based on P data given by Dennison and Abal (1998)).

Estimation of the sediment load into the Bay using ^{210}Pb and ^{137}Cs core profiles is complicated by the variations in the apparent accumulation rate throughout the mud-dominated zone. The most central site within the main zone of mud deposition (Site-2) appears to be a reasonable representation of the average water depth and ^{210}Pb accumulation of the entire zone. If the ^{210}Pb estimate of sediment accumulation at this site (2.5 kg m^{-2} yr^{-1}) is taken as the average for the 183 km^2 zone, the average annual deposition load is 450,000 tonnes. As noted above, this estimate is an upper limit. A better constraint on estimates of the sediment load entering the Bay requires verification of the ^{210}Pb accumulation rate (discussed above), and analysis of more cores from different regions of the mud zone.

Conclusions

- Sediment deposited in the deeper water regions of the mud-dominated zone of the Bay is predominately made up mainly fine-grained clay minerals. Rapid mixing on a time scale of less than about 15 years is occurring in the upper 30-35 cm of the sediment column. Slower mixing may be occurring below this layer.

- Application of a 2-layer mixing model to ^{210}Pb profiles has yielded mean bulk sediment accumulation rates over the last 60 years of 0.6 and 1.2 cm yr^{-1} in the middle and eastern areas of the Bay respectively. Due to the possibility of slow mixing below 35 cm these estimates are considered upper limits. Cs-137 data is consistent with the ^{210}Pb accumulation rates, but it does not conclusively confirm the ^{210}Pb estimates. Additional independent dating evidence is required to validate the ^{210}Pb estimates.

- Mixing has reduced the temporal resolution of the ^{210}Pb geochronology and the time frame over which it can be applied. As a result, it has not been possible to establish the pre and post European settlement horizon (circa 1850) in the sediment profile.

- Major and trace element profiles show little change with depth over the depth range of the longest core (180 cm). Only S, As, Pb and to a lesser extent, Zn, show significant changes. The relationship between S and As (increasing with depth) suggests that sediment diagenesis is the cause of As variation rather than anthropogenic input.

- ^{210}Pb sediment inventories indicate that sediment is being "focussed" in the deep water region of the mud-dominated zone.

- Extrapolation of my estimate of the sediment accumulation rate at the most central core site over the entire central mud zone gives mean annual load of fine sediment deposited in central Moreton Bay of 450,000 t yr^{-1}. Due to the possibility of slow mixing in deep sediment this value is an upper limit. The lower limit cannot be determined with the data that is available. Additional chronological information, such as might be provided by *Pinus* pollen, is required to better constrain the load of fine sediment delivered to central Moreton Bay.

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