
Significance of sediment resuspension and tidal exchange to reduction of polychlorinated biphenyl mass in San Diego Bay, California

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ABSTRACT - Sediments in San Diego Bay (SDB) are known to contain high levels of polychlorinated biphenyls (PCBs), but concentrations are declining. To understand the association of hydrological processes with this trend, we simultaneously measured radioisotopes ²¹⁰Pb, ²¹⁰Po, ²³⁴Th, ¹³⁷Cs, and ²²⁶Ra, as well as PCBs, in samples collected from the sediments and water column of SDB to investigate the resuspension and redistribution of PCBs within SDB. Radioisotope activity and water content in the sediment were highly heterogeneous, indicating an extensively disturbed sedimentation history. Water column distributions of ²¹⁰Pb and ²¹⁰Po suggested strong sediment resuspension, particularly in the northern and southern areas of the bay (North and South Bays, respectively). Particle residence time derived from water column ²³⁴Th activities was about 10 d, deemed sufficient for suspended PCBs to be mobilized to areas where they could be further transported out of SDB via extensive tidal exchange. The observed fractionation with ²¹⁰Pb and ²¹⁰Po near the bay mouth provided further evidence of strong tidal exchange near the bay mouth, where dilution of PCB concentrations was observed. These data suggest that natural hydrological processes, combined with shipping and dredging activities, were at least partially responsible for the reduction of PCB contamination in SDB.

INTRODUCTION

San Diego Bay (SDB) is a narrow mouthed, semi-closed embayment situated at the southern corner of California near the United States-Mexico international border (Figure 1). It can be divided into northern, central, and southern areas (North, Central, and South Bays, respectively), based on the significant difference in geographical settings. The width of the Bay ranges from 0.4 to 5.8 km and the length is

about 24 km. Water depths vary from 1 to 18 m, with an average of 10 m, but are strongly affected by tides. The mean tidal range is 1.7 m but may reach as high as 3 m (Chadwick *et al.* 1999). A model calculation based on a tidal amplitude of 0.8 m yielded 8.1 d for a 50% exchange of water (San Diego Bay Interagency Water Quality Panel 1998). The residence time is not uniform; instead, it increases from 1 d near the bay mouth to 40 d at the southern end of the Bay (Largier 1995).

San Diego Bay is surrounded by a number of cities and is also a host to about 9,000 vessels including 4 U.S. Navy bases with about 80 surface ships and submarines and two aircraft carriers. Because of the heavy commercial and military shipping activities and rapid urbanization in the region, SDB is one of the most contaminated embayments in the United States (Senate Committee on Toxics and Public Safety Management 1988, Fairey *et al.* 1998). Most noticeably, high levels of polychlorinated biphenyls (PCBs) have been found in sediments and biota around SDB (McCain *et al.* 1992, Schroeder 1994, Fairey *et al.* 1998), mainly from discharges of surface runoff prior to the 1970s (Young and Heesen 1974). Although the use of PCBs has been restricted to closed systems since 1977 and no fresh discharge of PCB into SDB has been reported, natural processes and dredging activities within SDB may have greatly influenced the fate of the historically discharged PCBs.

In the last decade, several studies reported a decreasing trend of sediment PCB contamination in SDB (McCain *et al.* 1992; Fairey *et al.* 1998; Chadwick *et al.* 1999). One possible mechanism for this reduction is biodegradation. For example, aerobic microbes could metabolize lightly chlorinated PCBs, particularly ortho-substituted congeners (Bedard *et*

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al. 1987, Fava *et al.* 1991, Harkness *et al.* 1993). However, such a mechanism is nearly impossible to verify because no biodegradation study has been conducted in sediments of SDB. Another possible mechanism responsible for the reduction of sediment PCB concentrations may be natural hydrological and human activities within SDB that are causing contaminants to resuspend and/or diffuse from the sediment bed to the water column and further transport out of the Bay. This mechanism is viable if resuspension is significant and the water column residence time of PCBs is sufficiently long, given the rapid water exchange rate mentioned above.

To understand the association of declining PCB contamination with natural hydrological processes, we simultaneously measured a suite of naturally occurring radioisotopes (^{210}Pb , ^{234}Th , ^{137}Cs , and ^{226}Ra in sediment and ^{210}Pb , ^{210}Po , and ^{234}Th in water) and PCBs in the water column and sediments of SDB. The activities of the radioisotopes with short half-lives were used to elucidate the particle dynamics within the water and sediment columns, the result of which was then extrapolated to the movement of PCBs. ^{210}Pb , ^{210}Po , and ^{234}Th and PCBs are all particle reactive. For example, the distribution coefficients (K_d) of ^{210}Pb and ^{210}Po are about $2\text{-}3 \times 10^5$ (Fisher *et al.* 1988) and the octanol-water partition coefficients (K_{ow}) for individual PCBs range from 10^4 to 10^8 (Hawker and Connell 1988). Although an exact comparison should be made between K_d and K_{oc} ($= C_{oc}/C_{w,e}$, where C_{oc} is the organic carbon normalized concentration of a specific PCB congener in the particulate phase and $C_{w,e}$ is the equilibrium dissolved-phase concentration of the PCB congener), the difference between K_{oc} and K_{ow} is typically small enough so that they can be regarded as identical (K_{ow} is more readily available than K_{oc}). Hence, transport and redistribution of the radioisotopes are expected to mimic those of PCBs. This article reports the findings on the sediment and water column dynamics, while the water quality assessments are presented in a separate article (*In situ measurements of polychlorinated biphenyls in the waters of San Diego Bay, California*; this annual report).

METHODS

Sample Collection

Field sampling was conducted during two seasons, i.e., summer 1999 (from June 15 to July 1) and winter 2000 (from January 31 to February 29) (Table 1). Two sets of stations were sampled across the Bay. The first set of stations comprised Stations 1-9 with Stations 1-3 in the North Bay, Stations 4-7 in the Central Bay, and Stations 8-9 in the South Bay (Figure 1). Water and sediment core samples were collected from these stations for both radioisotope measurements and chemical analysis. The second set of stations, labeled as 1' to 7' (Figure 1), was sampled for water only for additional radioisotope measurements to increase the resolution of spatial distributions across the Bay.

Water samples for radioisotope analysis were collected with 30 L Niskin bottles at pre-designed water depths during the summer 1999 cruises (Table 1). Samples were transferred to 5-gallon plastic bottles that were pre-cleaned with hydrochloric acid and deionized water, acidified to $\text{pH} \approx 1$, and spiked with ^{230}Th , ^{209}Po , and ^{206}Pb . About 50 mg of FeCl_3 were also added to the samples as a co-precipitation agent. Water samples for chemical analysis and total suspended solids (TSS) measurement were collected with an *in situ* pumping and filtering method (Zeng *et al.* 1999) during both the summer 1999 and winter 2000 cruises.

Sediment cores for both chemical and isotope analyses were collected during the summer 1999 season only, because sediment characteristics were not expected to change significantly in less than a year. A 50 x 50 x 50 cm box corer was used to collect little-disturbed sediment cores. Duplicate subcores were taken from each box core using precleaned acrylic plastic cylinders (9.5 cm ID). A small amount of overlying water was kept on each

Table 1. Sedimentation rates (S) estimated based on excess ^{210}Pb profiles with respect to its conservative grandparent ^{226}Ra (Robbins 1978). A linear least-square (r^2) regression analysis was conducted to obtain average S and r^2 values.^a

Station #	1	2	3	4	5	6	8
S (cm/yr)	0.39	NC	1.54	NC	0.34	0.92	NC
r^2	0.52	NC	0.66	NC	0.5	0.33	NC

^a NC = Not computable (due to increasing activity with depth).

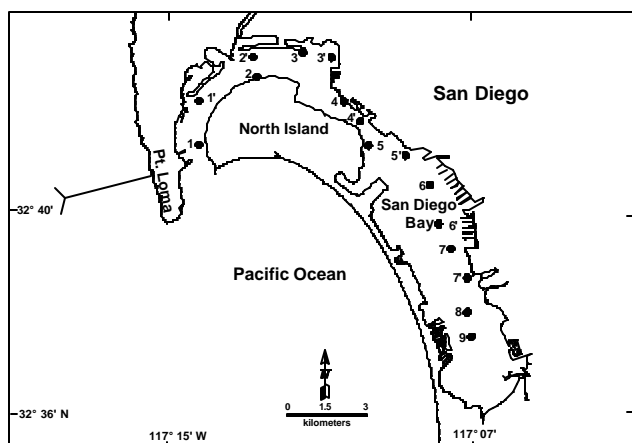


Figure 1. Map showing the study area in San Diego Bay. The first set of stations comprised Stations 1-9 and the second set of stations included Stations 1' to 7'.

subcore. All of the subcores were sealed, preserved in boxes refrigerated with dry ice, and transported to either the University of Southern California (USC) for radioisotope analysis or Southern California Coastal Water Research Project (SCCWRP) for chemical analysis. The subcores for radioisotope analysis were kept at 4°C until analysis, while those for chemical analysis were sliced in 1-cm intervals and stored in clean glass jars at -20°C.

Radioisotope Analysis

The water samples received at USC were immediately treated with $\text{NH}_3\text{H}_2\text{O}$ and stored for at least 12 h for complete precipitation of all metal ions. The samples were vacuum filtered with 0.45 μm Milipore® membrane filters. The precipitates were washed with double deionized water to remove salt and analyzed for ^{210}Pb , ^{210}Po , and ^{234}Th with the methods described previously (Aller and Cochran 1976, Benninger 1976). Sediment cores were sliced into 0.5-cm or 1-cm intervals. Each sample was dried at 60°C and the water content was measured from the weight loss. Dry sediment was pulverized and loaded into plastic tubes for g-counting using high-resolution, well-type intrinsic germanium detectors for determination of ^{210}Pb , ^{226}Ra , ^{234}Th , and ^{137}Cs activities.

Chemical Analysis

Sediment samples spiked with surrogate standards (PCB 65 and PCB 189) were extracted with methylene chloride using a microwave-assisted solvent extractor, MSP 1000 Microwave Sample

Preparation System (CEM Corporation, Matthews, NC), with the following parameters: oven temperature was ramped to 120°C in 15 minutes and held at 120°C for another 15 minutes. After the sample tube was cooled to 35°C or lower (in ~40 min), the organic layer was filtered through a long-stemmed glass funnel containing approximately 10 g of anhydrous sodium sulfate. Each sample was extracted three times with 25 mL of methylene chloride using this procedure. The extracts were combined and concentrated to about 3 mL, solvent exchanged to hexane, and concentrated to about 1 mL using a rotary evaporator at 30°C and 650 mm Hg vacuum pressure, and transferred to a centrifuge tube. One milliliter of concentrated sulfuric acid was added to the tube and the mixture was vigorously mixed using a vortex mixer set at speed 5 for approximately 5 min. After setting, the top organic layer was removed. The acid cleanup was repeated until a clean, cloudless organic layer was obtained. This organic fraction was then transferred to a sample vial and internal standards (PCB 30 and PCB 169) were added. Instrumental analysis was conducted with a procedure described elsewhere (In situ measurements of polychlorinated biphenyls in the waters of San Diego Bay, California; this annual report). Sediment TOC concentrations were measured using the procedure of Zeng and Khan (1994).

RESULTS

Sediment Characterization

The sediments were generally dark and odorous sandy mud or muddy silt. They had more muddy components toward the inner bay. Ubiquitous occurrence of *Siliqua patula* (razor clam) was observed in all of the sediment samples up to the depth of 25 cm, suggesting the possibility of bioturbation. Sediment water content generally ranged from 25 to 50% (wt %) and decreased with depth; but great irregularities were observed (Figure 2), indicating vertical heterogeneity (especially at Stations 2, 4, 6, and 7) and a dynamic sedimentation environment. Sediment heterogeneity was expected because of strong tidal currents in the North Bay, frequent passage of large vessels across the North and Central bays, and regular dredging events.

Sediment total organic carbon (TOC) averaged $0.90 \pm 0.39\%$ and showed no apparent spatial trend across the Bay. The only exception was that sediments collected from Station 1 had particularly low

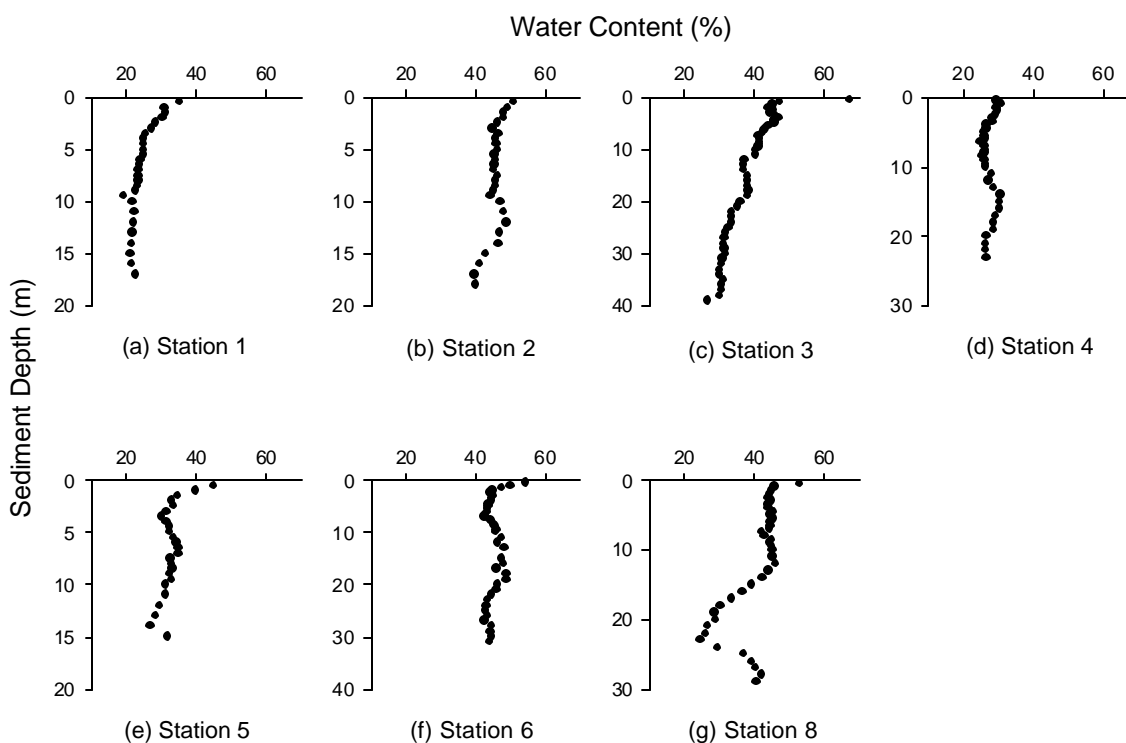


Figure 2. Water content in sediment cores collected from Stations 1-6 and 8. No sediment cores were collected from Stations 7 (because it was a trash dumpsite) and 9 (because it was too shallow for the sampling cruise to access).

TOC concentrations. Similar to water content, TOC profiles in the sediment column also exhibited irregularities that manifested vertical heterogeneity (not shown). A correlation between TOC/total nitrogen (C/N) ratio and TOC (Figure 3) shows that C/N ratios in most samples exceeded the ‘Redfield Ratio’ of ~7 (Broecker and Peng 1982), which defines a narrow range of C/N ratio for organic soft tissues formed by marine plants.

Sediment Profiles of Radioisotopes

The sediment profiles of ^{210}Pb , ^{234}Th , ^{226}Ra , and ^{137}Cs varied spatially (Figure 4). Most of the profiles of ^{210}Pb and ^{234}Th were either homogenized throughout the sediment column or exhibited large spikes at certain depths (Figures 4b and 4e-g). Only the isotopic profiles at Stations 1 and 3 showed an exponentially decreasing trend with sediment depth (Figures 4a and 4c). In addition, bioturbation was evident in all sediment samples, with razor clams being the most predominant organisms. These organisms were found in almost all sediment cores and in some cases 2-3 pieces were present in a single 9.5 cm (ID) subcore. Sedimentation rates (Table 1) calculated using the method described by Robbins (1978) and excess ^{210}Pb were not consistent, due to

processes that have affected the effectiveness of this method (Robbins 1978).

Water Column Profiles of Radioisotopes

The profiles of ^{210}Pb and ^{210}Po activities in water samples collected across SDB showed spatial variability (Figure 5). The stations in the Central Bay (from Station 3 to Station 7') had relatively low ^{210}Pb and ^{210}Po activities with an average of 0.0123 dpm/g, while the stations in the North Bay and South Bay (Stations 1, 1', 2, and 2' in the North Bay; Stations 8 and 9 in the South Bay) had much higher ^{210}Pb and ^{210}Po activities with an average of 0.0262 dpm/g. The ratios of the ^{210}Pb and ^{210}Po activities in the water column samples collected from different depths also varied spatially (Figure 5).

^{234}Th activities in water samples were not measured immediately after sample collection. As a result, large measurement errors were produced from poor recovery and complicated ingrowth correction. Therefore, only averaged ^{234}Th activities across the Bay were used for general assessment. The method proposed by Kaufman *et al.* (1981) and Baskaran *et al.* (1992) was used to calculate the residence time of ^{234}Th in the water column:

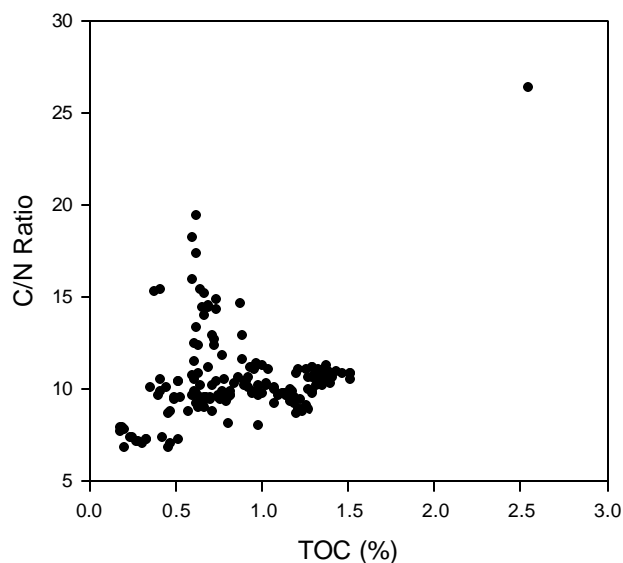


Figure 3. Correlations of C/N ratios versus TOC in the sediments of San Diego Bay. The lone point with a high C/N ratio (~26) occurred at the 16-cm depth of Station 4.

$$\tau = \frac{34.8}{A_{238\text{U}}/A_{234\text{Th}} - 1} \quad (1)$$

where τ is the residence time of ^{234}Th in days and $A_{238\text{U}}$ and $A_{234\text{Th}} - 1$ are activities of ^{238}U and ^{234}Th in dpm/L. The number 34.8 is the mean life of ^{234}Th (half life of ^{234}Th is 22.4 d). Using the ^{238}U activity of 2.45 dpm/L based on the ^{238}U -salinity relationship established by Ku *et al.* (1977), the average residence time of total ^{234}Th was estimated to be 9.8 d. Due to sediment resuspension as described below, ^{234}Th activities in the water column can be apparently higher than when no resuspension was present.

Concentrations of PCBs and Total Suspended Solids

Concentrations of all individual PCBs were below the detectable limit of about 5 ng/g (based on dry sediment weight) in all of the sediment core samples. Water column PCB concentrations and TSS data are reported elsewhere (*In situ measurements of polychlorinated biphenyls in the waters of San Diego Bay, California*; this annual report). In general, water column PCB concentrations were higher in the Central Bay than in the North and South Bays. On the other hand, TSS concentrations appeared to be higher than in the North and South

Bays at the 1-m depth than in the Central Bay, but the distribution patterns were not clear at the 5-m depth.

DISCUSSION

Sediment Heterogeneity and Sedimentation Rate

Sediment heterogeneity as characterized by the irregularities in the profiles of water and radioisotope activities (Figures 2 and 4), as well as TOC contents (not shown), may be attributed to strong tidal currents, heavy shipping traffic, and frequent dredging activities inside SDB. For example, docking of large vessels could stir up as much as 41.7 metric tons surface sediments per day at the Naval Station (located in the Central Bay) alone (Chadwick *et al.* 1999). It is expected that the passage of these large vessels could also cause sediment resuspension in the North Bay in addition to that caused by tidal currents. The substantially higher values of C/N than 7 (Figure 3) probably indicated sediment contamination by petroleum derivatives, which are commonly found in SDB (Chadwick *et al.* 1999). Although the C/N ratio may be altered by denitrification under strictly anoxic conditions, this process is not important in SDB where highly aerobic conditions prevail. As expected, samples from Station 1 had the lowest C/N ratios (< 7) among all the samples, because the location of Station 1 appears to be least contaminated. At about 16 cm depth at Station 4, an extremely high TOC concentration as well as high C/N ratio (Figure 3) was clearly suggestive of organic contamination from an episodic event such as an accidental oil spill.

The irregularities in sediment isotope profiles (Figure 4) undermined the use of ^{210}Pb to estimate sedimentation rates (Table 1). The sedimentation rates estimated from the ^{210}Pb profile range from 0.34 to 1.54 cm/year with low linearities ($r^2 = 0.33 - 0.66$). Sedimentation rates at 3 out of 7 stations could not be calculated by the excess ^{210}Pb method (Robbins 1978) due to the apparently increasing excess ^{210}Pb activities with the sediment depth (Figures 4b, 4d, and 4g). Historically, nuclear weapon tests, which would produce ^{137}Cs residues that may settle with dust onto the ground, were maximized in 1963. The ^{137}Cs profiles in sediment cores (Figure 4) did not indicate any spike throughout the entire sediment column, suggesting that sedimentation rate should be at least 1 cm/yr. Because of the high sedimentation rates, the water channel in SDB has to be dredged regularly to allow the passage of large vessels (Chadwick *et al.* 1999).

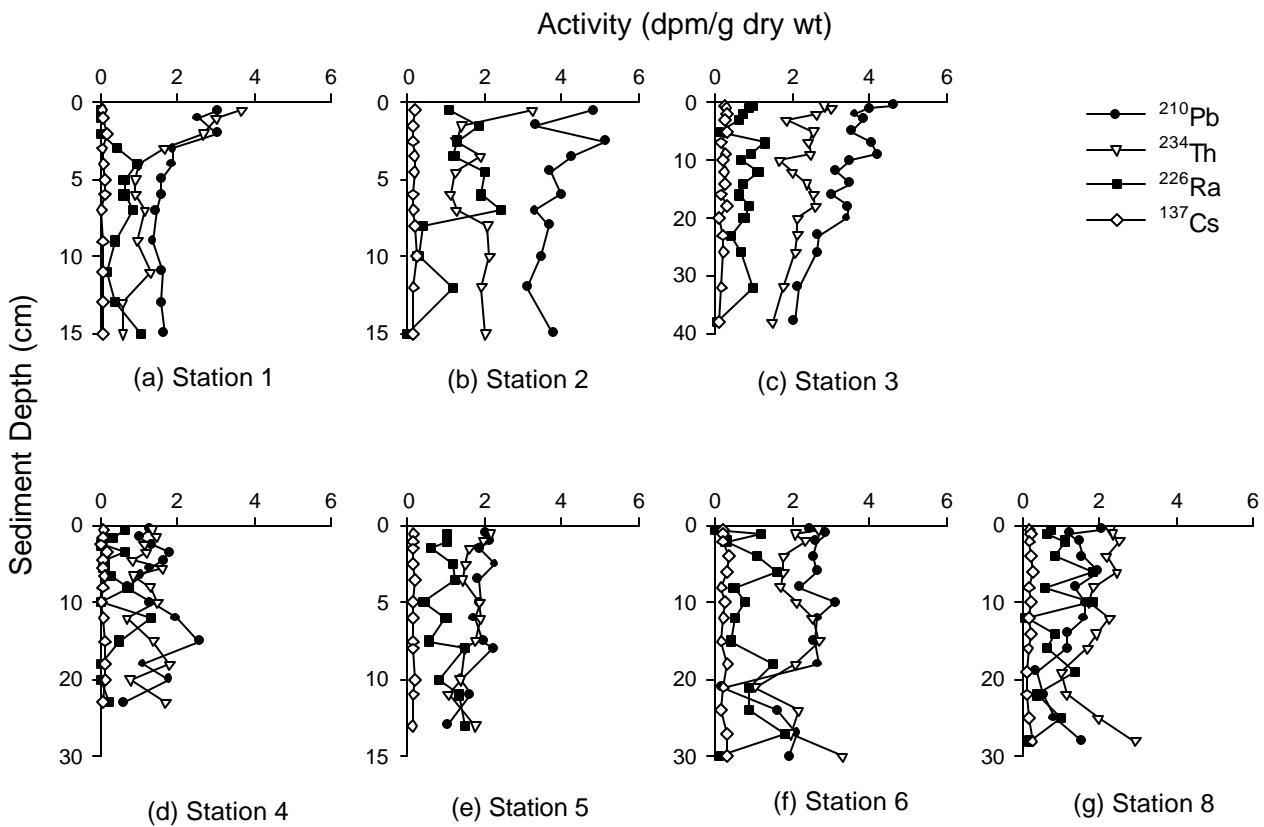


Figure 4. Profiles of ^{210}Pb , ^{234}Th , ^{226}Ra and ^{137}Cs in sediment cores collected from Stations 1-6 and 8 in summer 1999. No sediment cores were collected from Stations 7 (because it was a trash dumpsite) and 9 (because it was too shallow for the sampling cruise to access).

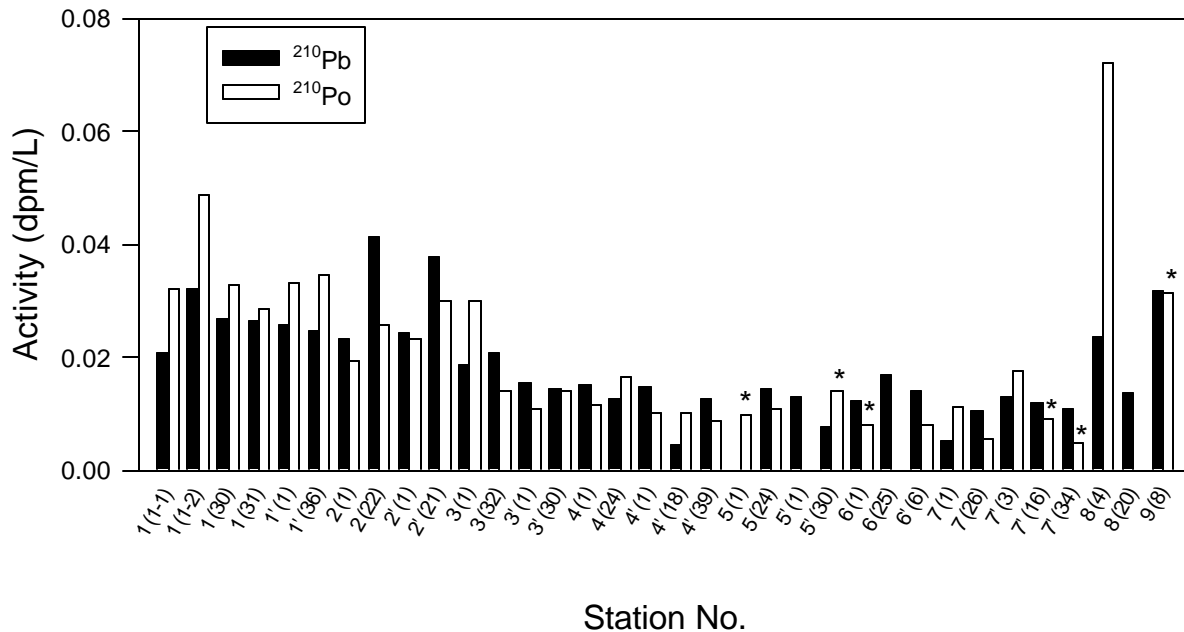


Figure 5. Distribution of ^{210}Pb and ^{210}Po activities in the water column of San Diego Bay. The numbers in the parentheses after station numbers are water depth (ft) from the sediment-water interface. Some data are not presented because of poor recovery. All measurements had error less than 5% except for those marked by asterisks (~30% error).

Evidence of Tidal Exchange in San Diego Bay

A mass balance consideration on the excess ^{210}Pb activities in sediments from Station 3 (Figure 4c) suggested that most of the ^{210}Pb activities in the sediment column ($\sim 45 \text{ dpm/cm}^2$) could not be solely attributed to atmospheric fallout, which accounted for about 4 dpm/cm^2 within the upper 40-cm sediment if we adopted Fuller's (1982) estimate of 0.15 dpm/cm^2 fallout rate. Inputs of ^{210}Pb from river runoff were deemed insignificant in this area (Fuller 1982). Sediment focusing, a process in which abnormally high sedimentation occurs at the expense of erosion in adjacent sediments, should not be a factor here due to strong tidal currents in the North Bay. The ^{210}Pb stripping previously observed by Carpenter *et al.* (1981) in the Washington coastal waters may have been responsible for the large excess ^{210}Pb activities in the North Bay sediments. ^{210}Pb stripping is a process in which higher-than-normal levels of dissolved ^{210}Pb brought into SDB through tidal exchange are scavenged by particles in the bay water and thus are preferentially retained in the SDB. This process is consistent with the relatively high sediment ^{210}Pb activities in Stations 1-3 compared to those in other stations in light of the proximity of these stations to the bay mouth, where strong tidal exchange occurs.

Evidence of Sediment Resuspension

The distributions of ^{210}Pb and ^{210}Po activities in the water column sampled during summer 1999 corresponded with the distance from the bay mouth (Figure 5). The trend of ^{210}Po followed closely with that of its grandparent, ^{210}Pb , so hereafter only ^{210}Pb activities are discussed in details. Stations in the North Bay had ^{210}Pb activities about twice those in the Central Bay (0.0262 versus $\sim 0.0123 \text{ dpm/L}$). ^{210}Pb activities in the South Bay were variable but were generally comparable to those in the North Bay. To determine the sources of ^{210}Pb in the water column, we established the following mass balance equation for each station:

$$T_i = D_i + E_i + [P_{\text{bio}} SS_{\text{bio},i}] + [P_{\text{riv}} SS_{\text{riv},i}] + [P_{\text{sed}} SS_{\text{res},i}] \quad (2)$$

where subscript i indicates station number; T is the total activity of ^{210}Pb in dpm/L ; D is the activity of "dissolved" ^{210}Pb in the water column in dpm/L ; E is the contribution from tidal exchange between SDB and outer sea in dpm/L ; P_{bio} , P_{riv} , and P_{sed} are activities in dpm/g (dry weight) for particles derived from

biological production, river input, and surface sediment, respectively; and SS_{bio} , SS_{riv} and SS_{res} are concentrations of suspended solids in g/L that were derived from biological production, river runoff, and resuspension of surface sediment, respectively.

The activity of "dissolved" ^{210}Pb , D , should be about the same across the Bay because its dominant source (atmospheric fallout) is spatially uniform. This is supported by our measurements of dissolved ^{210}Pb activities across the Bay that showed no spatial gradient (unpublished data). $P_{\text{bio}} SS_{\text{bio}}$ and $P_{\text{riv}} SS_{\text{riv}}$ are also considered invariant across the entire Bay. Biological productivity in the Bay was at the background level in summer seasons (Chadwick *et al.* 1999) and thus could not be responsible for the spatial variation in ^{210}Pb activities. In addition, river inputs should be negligible during this season (Chadwick *et al.* 1999). Therefore, sediment resuspension and tidal exchange should be the processes leading to high ^{210}Pb levels in the North and South bays.

The average TSS was 4.8 mg/L near the bay mouth, 3.2 mg/L in the Central Bay, and 5.8 mg/L in the South Bay, respectively (*In situ measurements of polychlorinated biphenyls in the waters of San Diego Bay, California*; this annual report). Hence, SS_{res} was 1.6 and 2.6 mg/L in the North and South Bays, respectively. Since the average ^{210}Pb activity was 4.2 dpm/g (dry weight) in surface sediments in the North Bay (Figures 4a-4c), the difference between the ^{210}Pb activities near the bay mouth and in the Central Bay attributable to sediment resuspension should be $6.7 \times 10^{-3} \text{ dpm/L}$. Similarly, the difference in ^{210}Pb activities between the South Bay and Central Bay was $5.3 \times 10^{-3} \text{ dpm/L}$, assuming the average ^{210}Pb activity in the surface sediment of the South Bay was 2.05 dpm/g (represented by Station 8). Scarcity of data from the South Bay prevented a solid estimation of the ^{210}Pb mass balance here. For the North Bay, a quantitative estimation is possible. The contribution from sediment resuspension accounts for only 48% of the difference between ^{210}Pb activities in the North and Central Bay (i.e., 0.0139 dpm/L). The rest ($7.23 \times 10^{-3} \text{ dpm/L}$) should have come from tidal exchange with the outer sea, where seawater may have higher ^{210}Pb due to weaker particle scavenging (Robbins 1978). It is intriguing to note that the same tidal exchange may have partially caused abnormally high ^{210}Pb activities in surface sediments of the North Bay through the 'stripping' process as discussed previously, and these two processes are inherently related.

Assessment of PCB Distribution and Transport with Radioisotope Geochemistry

The nondetectable levels of PCBs in sediments may have simply been consistent with the decreasing trend of sediment PCB concentrations reported previously (McCain *et al.* 1992, Fairey *et al.* 1998; Chadwick *et al.* 1999). It is apparent from the above discussions that the decline could have resulted from a combination of natural hydrological processes such as particle resuspension and tidal exchange and human activities such as boating and dredging. Sediment heterogeneity as revealed by widely varying profiles of water content, TOC concentrations, and activities of ^{210}Pb , ^{234}Th , ^{137}Cs , and ^{226}Ra could be best interpreted as results of extensive dredging activities as reported by Chadwick *et al.* (1999). Patterns of ^{210}Pb and ^{210}Po activities in the water column suggested substantial sediment resuspension in the North and South bays, as well as strong tidal exchange between the outer sea and SDB. These processes should have profoundly influenced the magnitude and distribution of PCBs within SDB. While sediment-bound PCBs have been dredged and removed directly from sediments of SDB, they could have also been resuspended from contaminated areas into the water column due to strong tidal events, as well as turbulence caused by the passage of large vessels (Chadwick *et al.* 1999). Strong tidal exchange between the outer sea and SDB could have caused PCBs (in both the particulate and dissolved phases) to be transported out of the Bay. The decreasing trend of water column PCB concentrations toward the bay mouth might be suggestive of dilution effects due to stronger tidal exchange in that area than inside the Bay. It was estimated that about 1 kg of PCBs are transported out of SDB annually (*In situ measurements of polychlorinated biphenyls in the waters of San Diego Bay, California*; this annual report).

This study did not measure radionuclides and PCBs in the colloidal phase, and could not provide data to assess the role of colloids in mediating the redistribution and transport of PCBs within SDB. However, previous studies suggested that colloids could play an important role in sorption, particle scavenging, and transport of colloidal Pb/Th isotopes (Baskaran and Santschi 1993) and PCBs (Baker *et al.* 1986) in aqueous systems. Baker *et al.* (1986) found that the colloid-bound phase contained a significant, if not dominant, fraction of the total hydrophobic contaminants. The higher concentrations

(volume based) of PCBs in the operationally defined dissolved phase relative to the particulate phase in the water column of SDB (*In situ measurements of polychlorinated biphenyls in the waters of San Diego Bay, California*; this annual report) might suggest the presence of colloidal materials in the water column. Colloids could contribute to scavenging of both radioisotopes and PCBs by acting as a “colloidal pump” between the truly dissolved phase and particulate phase (Baskaran and Santschi 1993).

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