Section 9: The Effects of Bioturbation on Sedimentary Contaminants Inferred from Modeling Radionuclide Profiles in

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Sediment reworking (or mixing) by biological and physical processes can make the sedimentary record of environmental change difficult to interpret. Because of the reworking, sediments do not remain permanently in the same stratigraphic position. Rather, the feeding habits of sediment-dwelling organisms can move freshly deposited sediment to different depths below the sediment surface, a process called bioturbation. This activity results in sediment horizons that contain material of a variety of ages. This phenomenon is observed and interpreted in Massachusetts Bay sediments by using radionuclide profiles from sediment cores.

The radionuclides ^{210}Pb, $^{239+240}$Pu, and ^{234}Th can be used to interpret processes of sediment reworking, because each of these isotopes is strongly adsorbed to particles. The different source functions and half lives of each isotope ensure that unique insight about sediment reworking processes can be gleaned from the sedimentary records. ^{210}Pb and ^{234}Th are both naturally occurring uranium-series radionuclides with relatively constant inputs to the sediments. ^{210}Pb originates primarily (in shallow waters) from decay of atmospheric ^{222}Rn, whereas ^{234}Th is a decay product of uranium in seawater. Each isotope reveals information about particle reworking spanning a time scale somewhat greater than its half life (22.3 years for ^{210}Pb, 24 days for ^{234}Th). The longer-lived $^{239+240}$Pu (with a half life greater than 6,500 years) is derived from atmospheric testing of nuclear weapons. If sediments are not reworked, the earliest detection of $^{239+240}$Pu in sediments corresponds to its first significant production in the 1950s, and the peak activity corresponds to the fallout peak in 1963.

In slowly accumulating sediments typical of the continental shelf, bioturbation is the primary process driving vertical transport of these radionuclides, rather than sedimentation. Under these conditions, the depths of penetration of $^{239+240}$Pu, and of excess ^{210}Pb (that derived from atmospheric ^{222}Rn that is present in excess of its U-series parent isotopes) are strongly dependent on the depth of sediment mixing. The shapes of the nuclide profiles can also be used to infer rates of bioturbation. In some cases, mixing can be interpreted as a simple diffusive process. However, in a number of sediment cores from Massachusetts Bay, subsurface maxima in radionuclide profiles provide evidence of rapid removal of sediments from the sediment surface (ingestion) followed by injection of this material (defecation) a few centimeters below the sediment surface. This process has significant implications for the age of surficial sediment and for discerning changes in sediment contaminant concentrations following changes in contaminant inputs.

The primary evidence for ingestion of surficial sediment by organisms, followed by defecation at a depth of a few centimeters, stems from the profiles of excess ^{210}Pb. In the absence of such a process, the maximum excess ^{210}Pb activity would be expected to be observed at the sediment surface, which typically is thought of as the youngest sediment. However, in roughly half of the cores collected from eight locations in Massachusetts Bay, there is a clear ^{210}Pb maximum present at a depth of about 3 cm (Crusius and others, 2004; fig. 9.1B).

This subsurface maximum is most readily explained if surficial sedimentary material is being consumed by organisms in the sediment and deposited at depth. This process has been identified during previous work in Massachusetts Bay and elsewhere (Wheatcroft and others. 1994; Shull and Yasuda, 2001). The organisms thus far identified in Massachusetts Bay and (or) Boston Harbor sediments that carry out this sort of mixing are cirratulid polychaetes, including *Tharyx acutus* (Myers, 1977) and *Cirriformia grandis* (Shull and Yasuda, 2001).

With the aid of a sediment-mixing model, we sought to quantify the rate of this sediment-reworking process. A mathematical description of this mixing process is presented in Crusius and others (2004) and will not be repeated here; however, some model simulations of this process are presented. When the ingestion-rate constant is on the order of 0.5 turnover per year or greater, a well-defined subsurface maximum is observed in the ^{210}Pb profile (fig. 9.2A). In other words, the surficial sediment must be fully ingested and subsequently defecated at least once every 2 years to reproduce this feature in the sediment. The $^{239+240}$Pu data also reveal a subsurface maximum in many cases (fig. 9.1D). Because this feature could conceivably be caused by the fallout maximum of $^{239+240}$Pu, however, the Pu data were de-emphasized in the interpretation. The ^{234}Th data that are available show well-defined maxima at the surface, which is most likely due to the much shorter half life of ^{234}Th. Over the time scale recorded by this isotope (a few months), there is little downward transport of sediment. However, there is one thing that must be borne in mind when evaluating the ^{234}Th data. Samples from a few centimeters below the surface and deeper were analyzed many months after collection, after "excess" ^{234}Th would have decayed, which means that we cannot be certain there was not significant downward transport of ^{234}Th. Taken together, however, the ^{210}Pb and ^{234}Th data suggest that downward transport by this process of subsurface defecation occurs on a time scale of a few months to a couple of years. Note that an ingestion rate constant of roughly 12 turnovers per year or greater would be required to produce a significant subsurface ^{234}Th maximum (fig. 9.2C).

The interpretations of the radiochemical profiles contribute two main points to our understanding of new contaminant additions to coastal sediments. First, any new sediment-bound contaminant that settles to the sea floor can be rapidly diluted within the upper sediment column at a rate and to a depth that depends on the abundances and kinds of sediment-dwelling organisms present. For some low-toxicity contaminants, the natural dilution process can be an environmental benefit. However, for contaminants that can be dangerous at extremely low concentrations, mixing downward can be a disadvantage because the contaminant is less likely to be resuspended and flushed from the nearshore environment. Second, a consequence of this mixing process is that surficial sediments may not accurately or sensitively record recent changes in contaminant deposition. These results thus indicate that, in slowly accumulating sediments affected by this sort of bioturbation, newly deposited contaminants may be interspersed at a range of depths in the sediment, and thus it may be difficult to infer the temporal history of contamination.

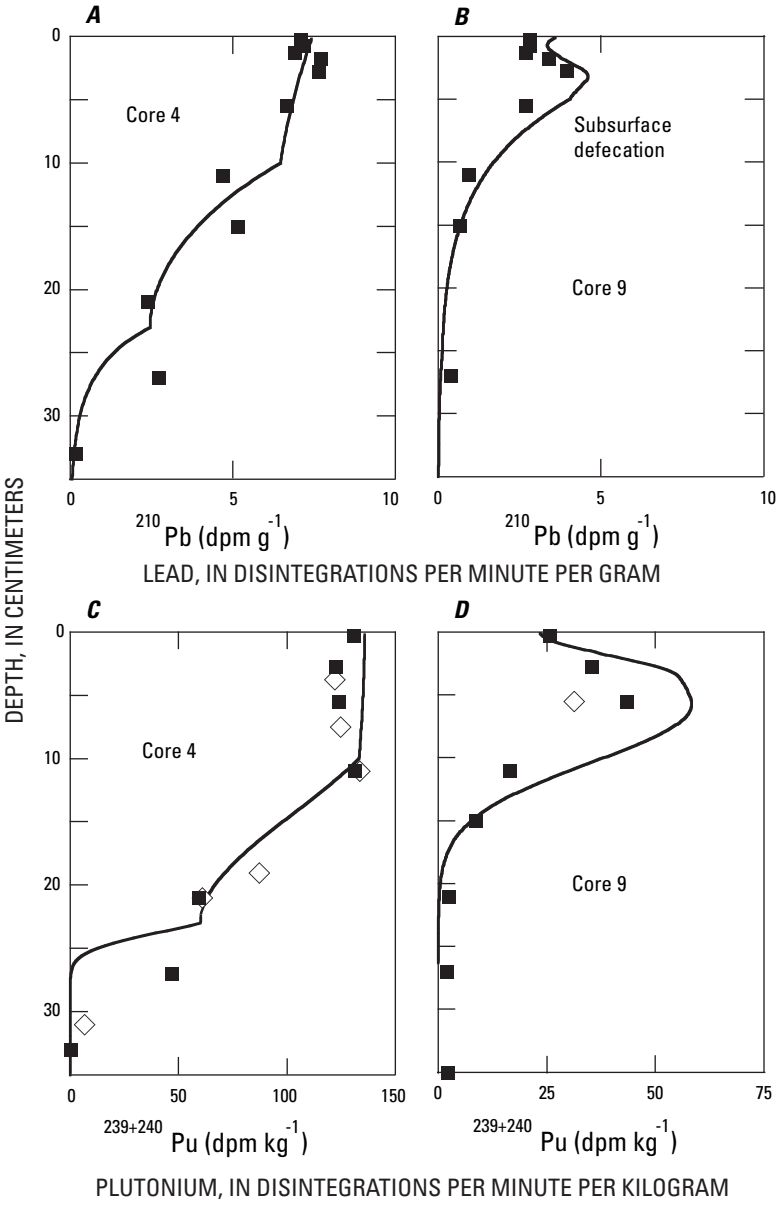

Figure 9.1. Results of mixing-model simulations of the ^{210}Pb and $^{239+240}$Pu profiles for core 4 *(A)* and *(C)* and core 9 *(B)* and *(D)*. All ^{210}Pb data represent excess ^{210}Pb (see text). $^{239+240}$Pu data were generated both by alpha counting (solid squares) and by inductively coupled plasma-mass spectrometry (open diamonds). Core 4 model runs invoked only biodiffusive mixing, whereas the core 9 model runs invoked surface ingestion followed by subsurface defecation. Model parameters are presented in Crusius and others (2004).

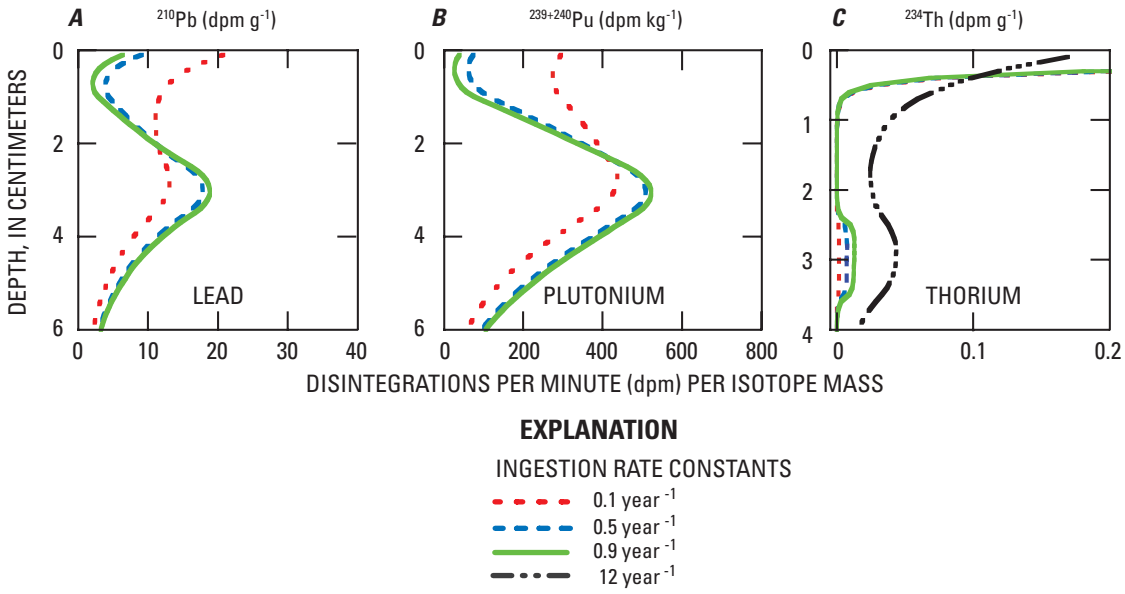

Figure 9.2. Sensitivity of the surface ingestion and subsurface defecation model to the ingestion-rate constant, yr^{-1}. ^{210}Pb data represent excess ^{210}Pb. Note a surface maximum of ^{234}Th in all model runs. Model equations and parameters are presented in Crusius and others (2004).