Areas of non-deposition (or erosion), denoted by patterns of strong backscatter intensity continuous on scales of 10's of meters or more, are characterized by cobble bottoms or bedrock exposures. These bottoms lack evidence of sustained bedload transport and (or) net accumulation of sediment. The channel bottom adjacent to Chester Island is an example of the non-deposition sedimentary environment (Figures 26).

Note that the sedimentary environments maps presented herein are subject to refinement, perhaps reinterpretation, as new data become available. Moreover, the spatial distributions as mapped are representative for the survey period and reflect time-averaged sedimentation conditions. Temporal changes in hydrodynamics, not to mention human disturbances, are liable to modify the bottom to some extent, perhaps rendering these maps inaccurate in places. Also note that the boundaries drawn to set apart the various environment types are, in reality, more gradational than depicted in the maps.

5.5. Subbottom Observations

5.5.1. Features of Note

Because the chirp sonar dataset is extensive and difficult to generalize, only those results salient to the understanding of sediment transport and deposition in the upper estuary are elaborated. Details regarding the full dataset are available from the authors at request.

Sonar Line 103, collected in the northernmost part of the study area, illustrates the coarse-grained bedload environment (Figure 34). Though bedload transport occurs to some extent throughout the estuary, well-developed trains of ripples and waves are best developed in Zones 2–3, where copious sand and sandy gravel is available for transport. Line 103 reveals that coarse-grained material is derived locally from erosion of subbottom strata and packaged into asymmetric sand waves with an orientation (lee side upriver) indicative of transport during flood tides (Figure 34).

Sonar Line 39 depicts an example of a fine-grained deposition environment (Figure 35). Deposition of fine-grained suspended sediments generally increases down-estuary of Philadelphia and is initially apparent near Marcus Hook. There, a massive quantity of fluidized mud (soupy, silty clay) was present during the geophysical survey,

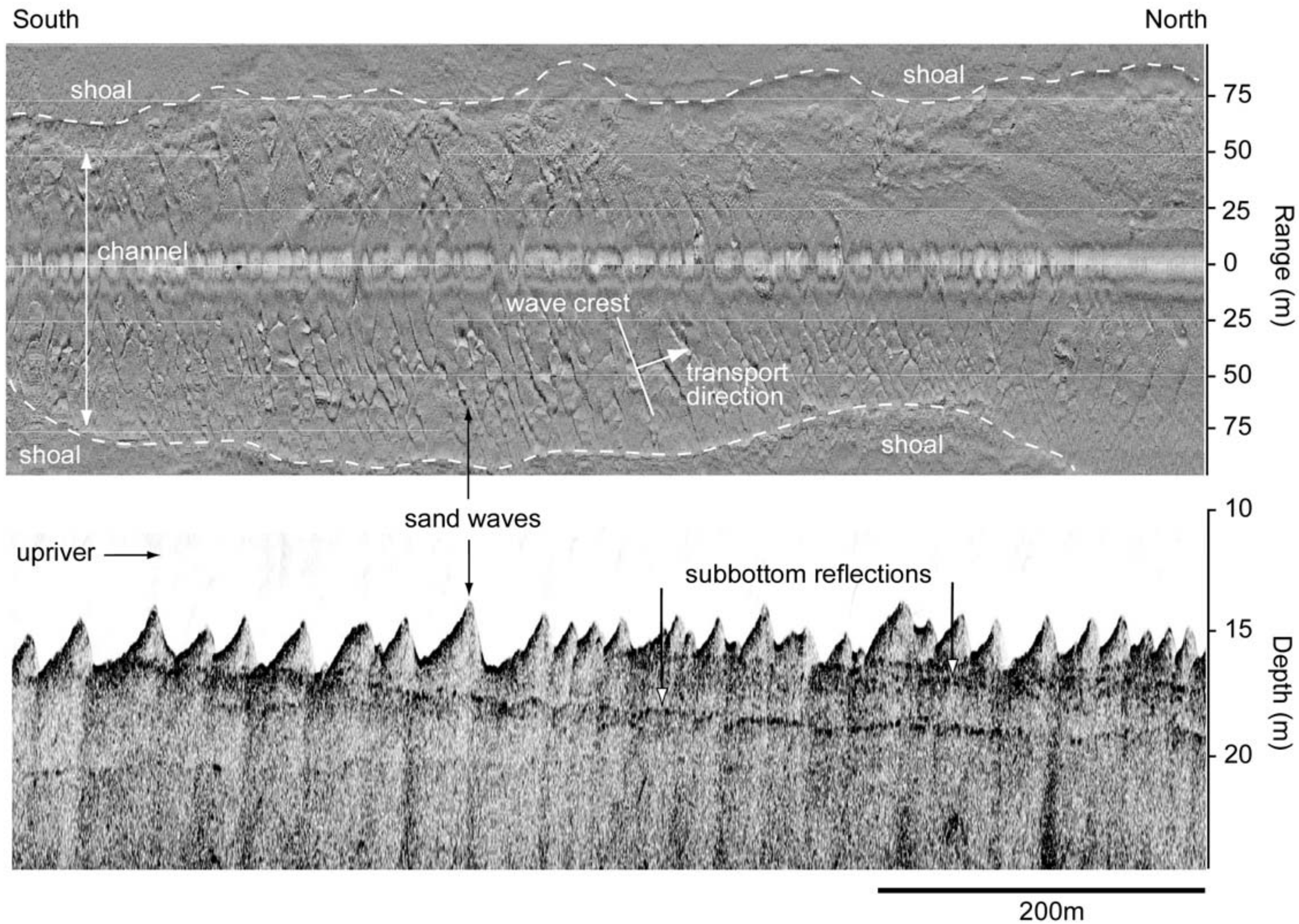

Figure 34. Sonar Line 103 (partial). Shown are the chirp profile (bottom) and corresponding sidescan image (see Figure 14 for location). Survey line trends along the channel of the tidal Delaware River, and the dashed line denotes the channel–shoal boundary. Bedload transport is indicated by a train of 2–3 meter amplitude sand waves oriented in the direction of flood-tidal currents. Note the truncation of subbottom strata, an indication of erosional reworking of the bottom.

particularly within the shipping channel, and later confirmed by coring in April and November of 2001. Though small patches of fluid mud were observed elsewhere down-estuary, the largest accumulations were present off Marcus Hook at the time of survey. Otherwise, normally consolidated silty clay and sandy, silty clay characterize the bottom in this area. In the shipping channel, fluid muds are underlain by gas-charged deposits (biogenic methane gas) that produce a "turbid" acoustic signature (Figure 35). Voids and bubbles observed in cores collected in channel confirm the presence of gas. Fortuitously, the fluid-mud layers were sufficiently thick to be resolved by the chirp sonar and therefore were mapped (Figure 36). Based on their spatial extent and porosity (see Core 15b in Appendix D), the fluid mud deposits had a cumulative dry mass estimated at $\sim 3.5 \times 10^5$ tons, a mass equivalent to ~25 % of the annual fluvial sediment load delivered to the estuary. This observation suggests that material sequestered in isolated depocenters may collectively comprise a substantial fraction of the total sediment mass stored within the subtidal estuary.

Another example of a fine-grained depositional environment is illustrated by sonar Line 122. Most prominently south of the Delaware Memorial Bridge, mud deposition is relatively uniform across the natural channel as indicated by a ≤1-m thick acoustically transparent layer atop more reflective strata (Figure 37). Bottom sediments in the channel are normally consolidated clays with variable amounts of sand and silt. Within the shipping channel, however, bottom sediments are far more variable across-channel with fine-grained, weakly reflective muds present on the western side, strongly reflective sandier muds on the eastern. On the eastern flank, coarse-grained sediments were commonly packaged into discontinuous ribbons and lineations plainly visible atop a muddy substrate (Figure 37). This pattern reveals a complex combination of suspended-load deposition and bedload transport within the shipping channel, a consequence of cross-channel variations in current velocity and sediment availability.

Previous work has shown that the sedimentary cover is thin to non-existent in places where bedrock is exposed at, or just below, the riverbed (Duran, 1986; USACE, 1973). This is exemplified by the Line 34 chirp profile, which shows a 1−2 m thick deposit of acoustically transparent strata resting on a strongly reflective surface with a distinct, undulating contact (Figure 38). From its acoustic properties the reflector is

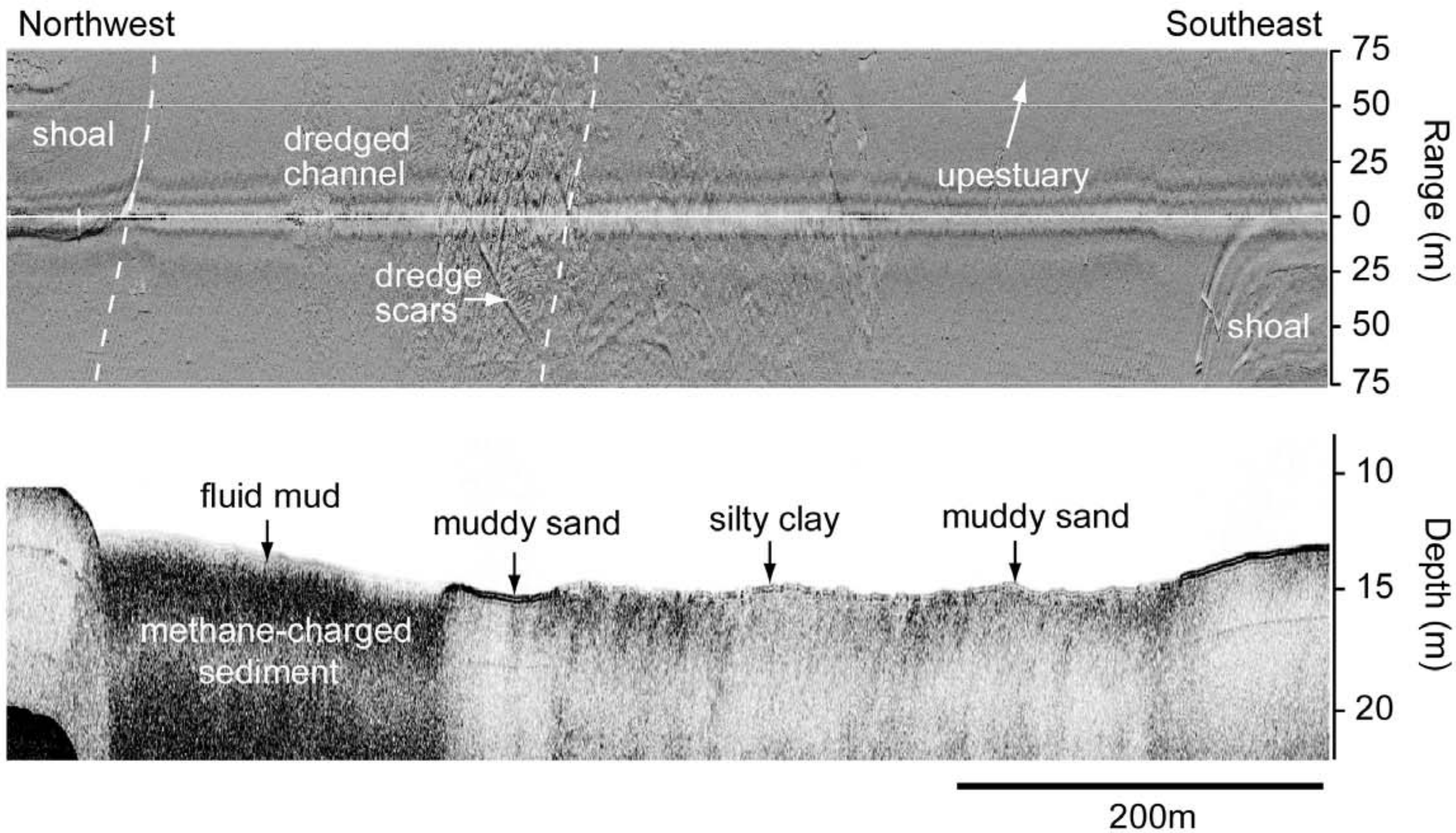

Figure 35. Sonar Line 39 (partial). Chirp profile (bottom) and sidescan image trend perpendicular to the estuarine channel. Bottom types noted are based on analysis of grab samples. The muddy bottom is morphologically smooth with a weak backscatter signature. Position of the dredged channel is depicted by dashed lines. Note the 2–3 m thick layer of fluid muds atop methane-charged sediment. Also note the dredge-cutter scars at the channel edge.

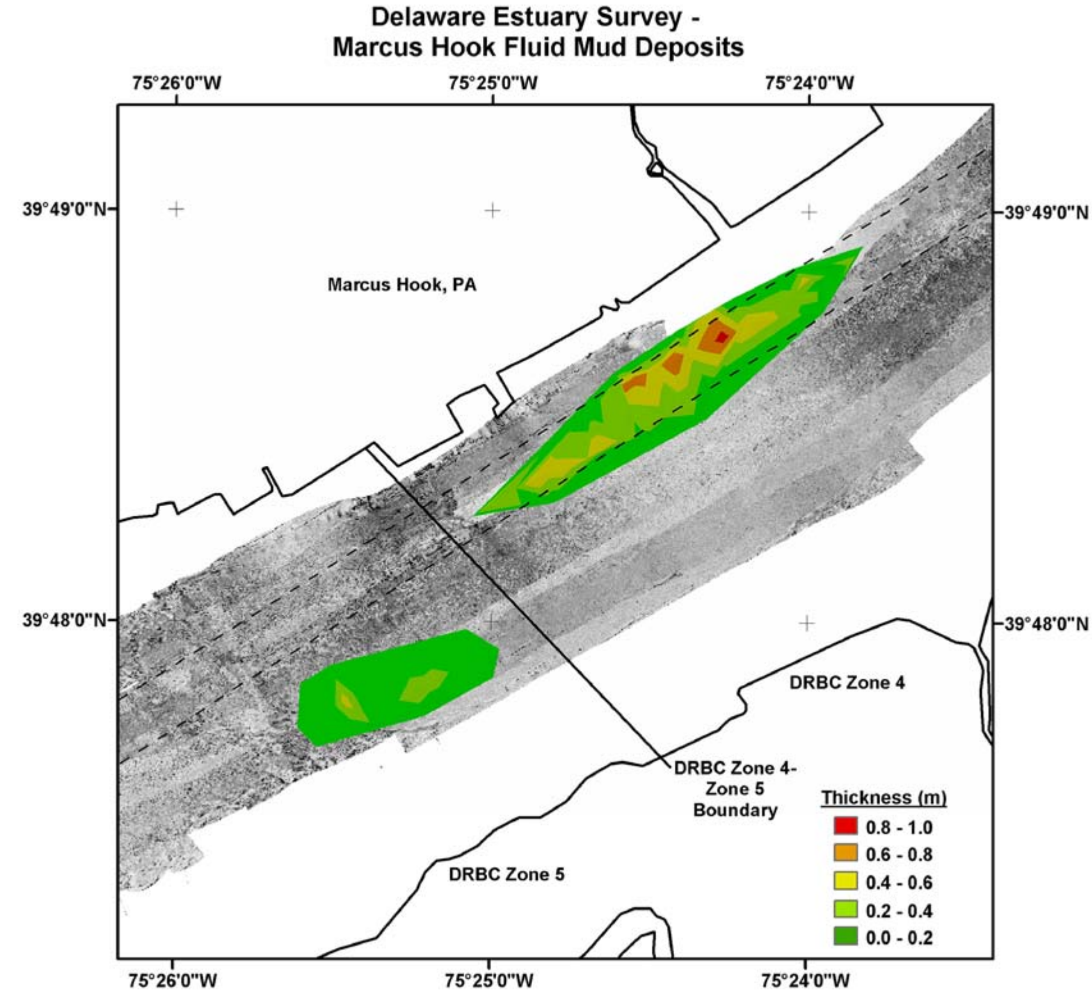

Figure 36. Fluid-mud distribution map. Shown is the contoured thickness of fluid mud deposits as mapped via chirp sonar in August 2001.

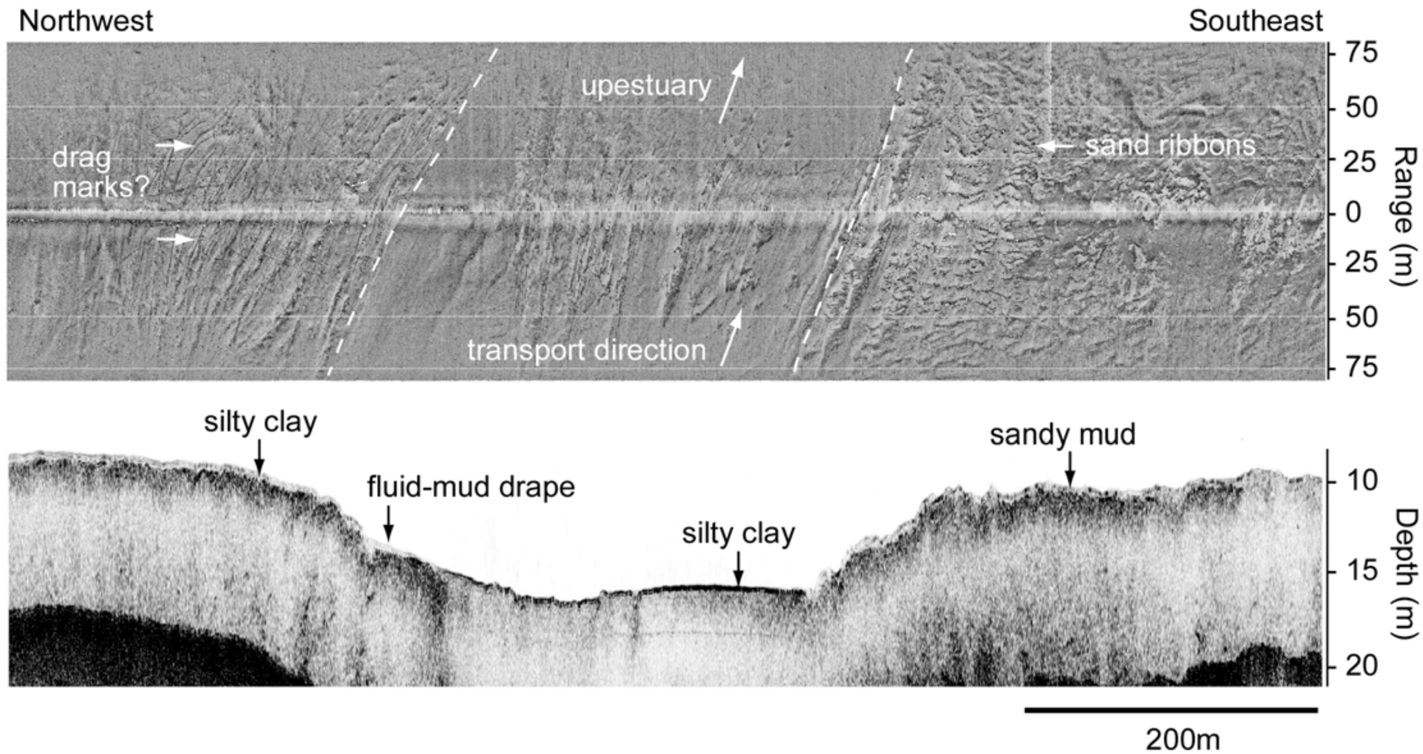

Figure 37. Sonar Line 122. The chirp profile (bottom) and sidescan sonograph trend perpendicular to the estuarine channel (see Figure 5 for location). Bottom types are based on analyses of grab samples. Moderate backscatter intensity is created by bedforms oriented both parallel and perpendicular to along-channel flow. Dredged channel bounds are denoted by dashed line on sonograph. Note that fluid mud preferentially accumulates on the western channel edge. Also note lineations that are interpreted to be drag marks.

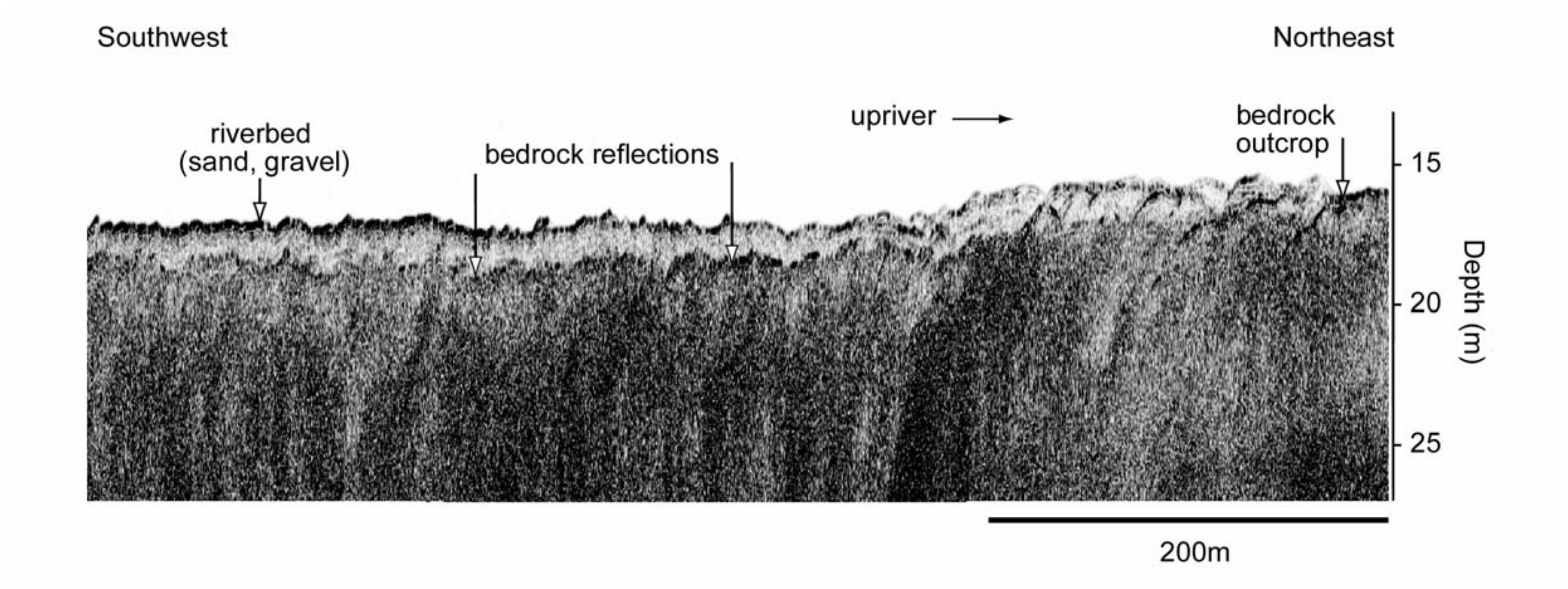

Figure 38. Sonar Line 34 (partial). Chirp profile trends along the dredged channel in the upper estuary (see Figure 8 for location). Note that bedrock is merely 1–2 m beneath the river bottom at this location and outcrops in places. See Figure 36 for contour map of bedrock occurrence.

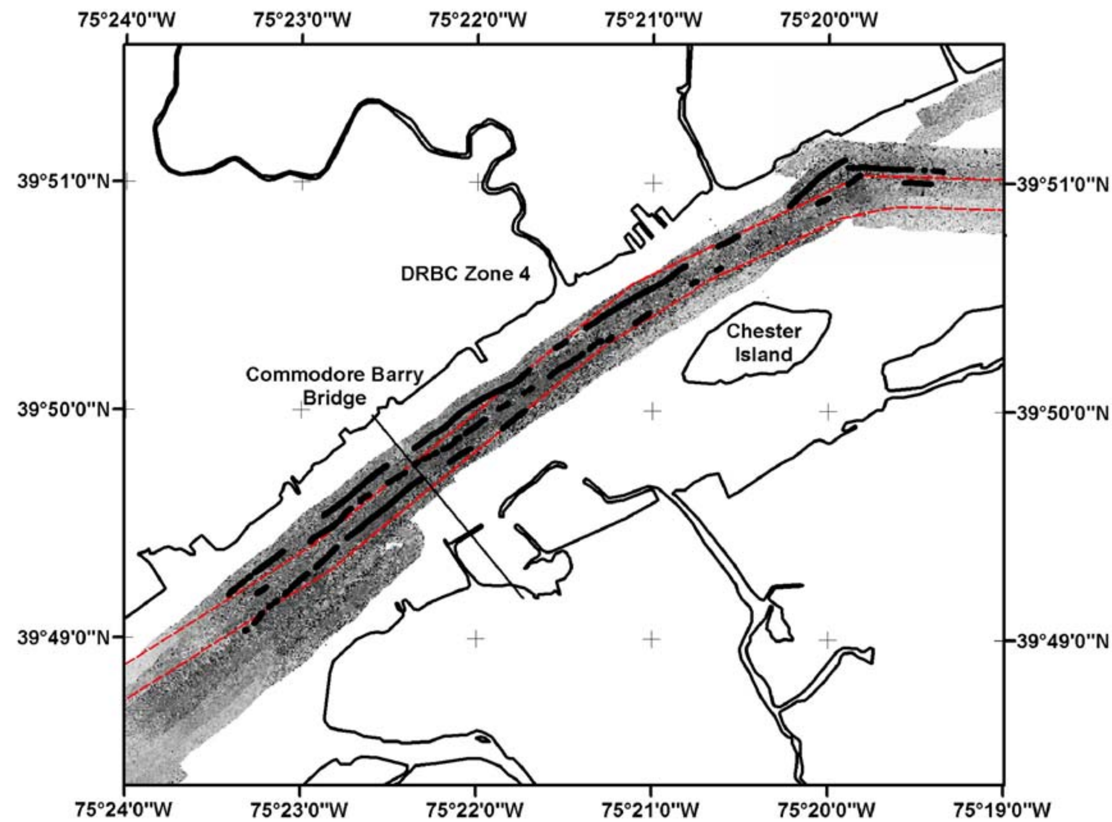

Figure 39. Bedrock occurrence map. Bold (black) lines denote areas surveyed where bedrock is exposed at, or within 50 cm of, the riverbed. The shipping channel is shown by the thin dotted line.

interpreted to be crystalline bedrock, perhaps the Wissahickon Schist mapped locally (Lyttle and Epstein, 1987; Schenck et al., 2000). Nearby grab samples confirmed the presence of a rocky bottom characterized by angular fragments and rounded cobbles, though the actual bedrock geology is unknown. Bedrock exposures at or within 50 cm of the bottom are particularly numerous between Tinicum Island and Chester. The mapped distribution of these exposures is shown in Figure 39.

The paucity of sedimentary cover in Zone 4 reveals that sediment accumulation is negligible on the long term, though there are clear exceptions. Where the bottom has been deepened through dredging, fine-grained sediments trapped within the channel can accumulate to form localized depocenters. Sediment accumulations within the shipping channel are not trivial; indeed, independent estimates (Biggs and Beasley, 1988; USACE, 1973) suggest that the mass of sediment dredged annually from the channel (~$3x10^6$ tons) exceeds that supplied to the estuary by rivers on an annual basis ($1–2x10^6$ tons). Clearly, not only does channel maintenance create a bathymetric trap for sediments, it permanently removes material that would otherwise disperse throughout the open estuary and hydraulically contiguous environments. In this manner dredging constitutes a net sink for sediment in the river–estuary system.

5.6. Radioisotope Profiles and Sedimentation Rates

5.6.1. Reconnaissance Cs-137 Measurements

A total of 25 HDC samples from the subtidal estuary were collected early in this study to evaluate the potential of Cs-137 as a sediment chronometer. Of these, 13 cores from muddy depositional sites were selected for reconnaissance Cs-137 measurements (Figure 40; Table 4). Core subsamples were first counted at low resolution (top, middle, and bottom) as gross measure of sediment "age", because the mere presence/absence of Cs-137 in sediments is an indication of deposition after or before 1954, respectively. Only at three sites, Tinicum Island shoal (C-14b), Marcus Hook East (MHE), and Smyrna River mouth (C-16A), were Cs-137 activities high enough to warrant more detailed measurements. Elsewhere the activities were at or below detection limits (Appendix C), suggesting that net accumulation of mud was locally negligible and (or) the bottom erosional, since 1954. In sum, the reconnaissance measurements revealed that the rates of fine-sediment accumulation between Burlington and New Castle are by and large too