Coastal Circulation and Sediment Dynamics in Hanalei Bay, Kaua'i, Hawaii

PART II:

Tracking Recent Fluvial Sedimentation: Isotope Stratigraphy Obtained in Summer 2005

U.S. Department of the Interior
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ADDITIONAL DIGITAL INFORMATION

This report contains material related to the following Infobank Activity ID numbers: A-1-05-KA (for June 2005 field work;) and S-1-05-KA (for August 2005 field work):

http://walrus.wr.usgs.gov/infobank/a/a105ka/html/a-1-05-ka.meta.html
http://walrus.wr.usgs.gov/infobank/s/s105ka/html/s-1-05-ka.meta.html

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ABSTRACT

Delivery and dispersal of fluvial sediment in Hanalei Bay, Kaua'i, Hawai'i, have important implications for the health of local coral reefs. The reef community in Hanalei Bay represents a relatively healthy ecosystem. However, the reefs are periodically stressed by storm waves, and increases in sediment and dissolved substances from the Hanalei River have the potential to cause additional stress. Increased turbidity and sedimentation on corals during Hanalei River floods that occur in seasons of low wave energy, when sediment would not be readily remobilized and advected out of the bay, could affect the health and sustainability of coral reefs and the many associated species.

Measurements of short-lived isotopes ^{7}Be and ^{137}Cs in sediment cores have been used to trace the thickness and distribution of terrestrial sediment in Hanalei Bay, in order to assess spatial and temporal patterns of sediment deposition and remobilization relative to coral-reef locations. A third isotope, ^{210}Pb, derived primarily from seawater, provides additional information about recent sedimentary history. Isotope profiles and observations of sedimentary facies from cores collected at multiple locations in June 2005, and again in August 2005, indicate the presence of recent fluvial sediment and organic debris in the east part of the bay near the mouth of the Hanalei River. Away from the immediate vicinity of the river mouth, sediment in the uppermost 1 m below the sea floor had not retained a significant quantity of fluvial sediment within the eight months prior to either sampling effort. During the study interval in summer 2005 the Hanalei River had no major floods and there was relatively little sediment input to the bay. Sediment away from the river mouth was dominated by carbonate sand, although some terrestrial sediment was present in sub-sea-floor horizons. Sedimentary facies and isotope inventories throughout the bay showed substantial spatial heterogeneity.

Sediment cores will be collected again at the same sites discussed here during early and late summer 2006. If possible, additional sites will be sampled in the Black Hole depocenter near the river mouth. Major floods in winter and spring 2006 are expected to leave a significant new sediment signal in the bay that should be detected in summer 2006.

INTRODUCTION

Analyses of terrestrial sediment delivery to the coral-reef community of Hanalei Bay on the island of Kaua'i, Hawai'i, USA, were conducted as part of the U.S. Geological Survey (USGS) Coastal and Marine Geology Program's Coral Reef Project. The field studies discussed in this report occurred concurrently with measurements of waves, currents, temperature, salinity, and turbidity in Hanalei Bay by (Storlazzi and others, 2006). Together, these studies are intended to provide a detailed understanding of the oceanic and sedimentary processes that directly affect the development and health of coral-reef communities and their many associated species in the bay. The ultimate goal of the USGS Coral Reef Project, which is actively involved in similar research in other areas of the Hawaiian Islands, is to understand better the transport mechanisms of sediment, larvae, pollutants, and other water-borne substances in coral-reef environments. Assessing the oceanic and sedimentary processes that affect coral-reef communities, such as those in Hanalei Bay, is a necessary step in identifying potential threats to these reefs, which constitute an integral part of the Hawaiian Islands' ecosystem.

Delivery of fluvial sediment to Hanalei Bay has particularly important implications for the health of the local coral-reef ecosystem. Deposition on and burial of corals by fluvial sediment during floods of the Hanalei River in seasons of low wave energy, when sediment would not be readily remobilized by waves and removed by currents, could have substantial negative effects on the health of coral reefs and the many other species associated with them. In addition to the physiological stress imposed by sediment, the coral-reef and near-shore ecosystems may potentially be affected by substances such as fertilizers and other contaminants discharged into the bay during river floods.

Sediment cores were collected at seven locations within Hanalei Bay during two sampling surveys in the summer of 2005. Observations of sedimentary facies were then used together with measurements of short-lived isotopes ^{7}Be, ^{137}Cs, and ^{210}Pb in these cores to trace the thickness and distribution of terrestrial sediment in the bay, and thus to assess spatial and temporal patterns of sediment deposition and remobilization.

Project Objectives:

The goal of this component of the USGS Coral Reef Project is to identify the spatial and temporal distribution of terrestrial sediment in and around the near-shore coral-reef community of Hanalei Bay, Kaua'i, Hawai'i. Isotope and sedimentary-facies data obtained from sediment cores will provide insight into the potential effects of terrestrial sediment delivery patterns around the Hanalei Bay coral reefs. These data are relevant to future watershed-restoration projects proposed by the U.S. Coral Reef Task Force's (USCRTF) Hawaiian Local Action Strategy (LAS) to address land-based-pollution threats to coral reefs in the Hanalei linked watershed-reef system. The work was conducted with the collaboration of the Hanalei Watershed Hui, a local organization dedicated to monitoring environmental quality in the Hanalei Bay watershed (http://www.hanaleiwatershedhui.org/).

Study Area:

Sediment cores were collected in Hanalei Bay, on the north shore of the island of Kaua'i, Hawai'i (figs. 1, 2). Hanalei Bay covers an area of approximately 4.4 km^2. The 25-km-long Hanalei River, a designated American Heritage River, is one of the largest rivers in the Hawaiian Islands in terms of water discharge. It drains an area of 54.4 km^2 before debouching into the bay. Its north-facing drainage basin consists of steep-walled, heavily vegetated volcanic ridges and fluvial gorges that drain the area of the island's 1,500-m-high central mountains. These mountains receive the highest recorded rainfall on Earth (>10 m yr^{-1}). The lowermost 12 km of the river channel pass through a broad floodplain consisting of middle to late Holocene marine sands overlain by fluvial deposits (Calhoun and Fletcher, 1996) that have now been developed for extensive agricultural use. The potential for runoff of sediment and contaminants to affect coral-reef ecology in the bay in the lower river basin is considered a subject of great concern by the Hanalei Watershed Hui; agricultural development and soil erosion in the drainage basin can increase the sediment load in the river. The steep topography of the drainage basin is subject to landslides that deliver variable amounts of sediment to the river, for an estimated total sediment yield of 140 ± 55 Mg km^{-2} yr^{-1} (Calhoun and Fletcher, 1999). Calhoun and Fletcher (1999) estimated that approximately 30 percent of the annual fluvial sediment load is deposited on the coastal floodplain, while 70 percent (1.76×10^4 Mg) is delivered to Hanalei Bay.

The Hanalei River enters Hanalei Bay from the east (fig. 1); the smaller Waioli and Waipa Rivers and several small freshwater streams also discharge intermittently into the bay's south and west sides, and likely deliver submarine groundwater discharge to the bay even in the absence of surface stream flow (Storlazzi and others, 2006). The physical environment of the bay in summer is dominated by northeast to easterly trade winds accompanied by low wave energy. From June through August 2005 significant wave heights were <1 m within the bay itself with periods 2.5–5.9 seconds, driven dominantly by northeast trade winds (Storlazzi and others, 2006). Winter conditions, typically beginning in October, are characterized by a North Pacific swell regime that produces wave heights of 2–5 m with periods of 12–20 seconds (Moberly and Chamberlain, 1964) that approach the bay typically from the northwest. Occasional low-pressure systems, including hurricanes, approach Kaua'i but usually make landfall on the south coast, away from Hanalei Bay.

Current meters deployed during the summer of 2005 (Storlazzi and others, 2006) indicated weak currents in the bay from early June through late August, with net near-surface flow entering the bay in the east and flowing out of the bay in the west. Near-bed current velocities indicated opposite, cyclonic (counter-clockwise) flow. Waves and currents in the western part of the bay were more energetic than in the east. Currents of 0.05 m s^{-1} were measured near the surface at the CRAMP (Coral Reef Assessment and Monitoring Project, a study site established by the University of Hawai'i) site compared to 0.02 m s^{-1} near the surface at the offshore wall site; Storlazzi and others, 2006, see fig. 2), a difference attributed to more direct exposure to trade winds at the western side of the bay.

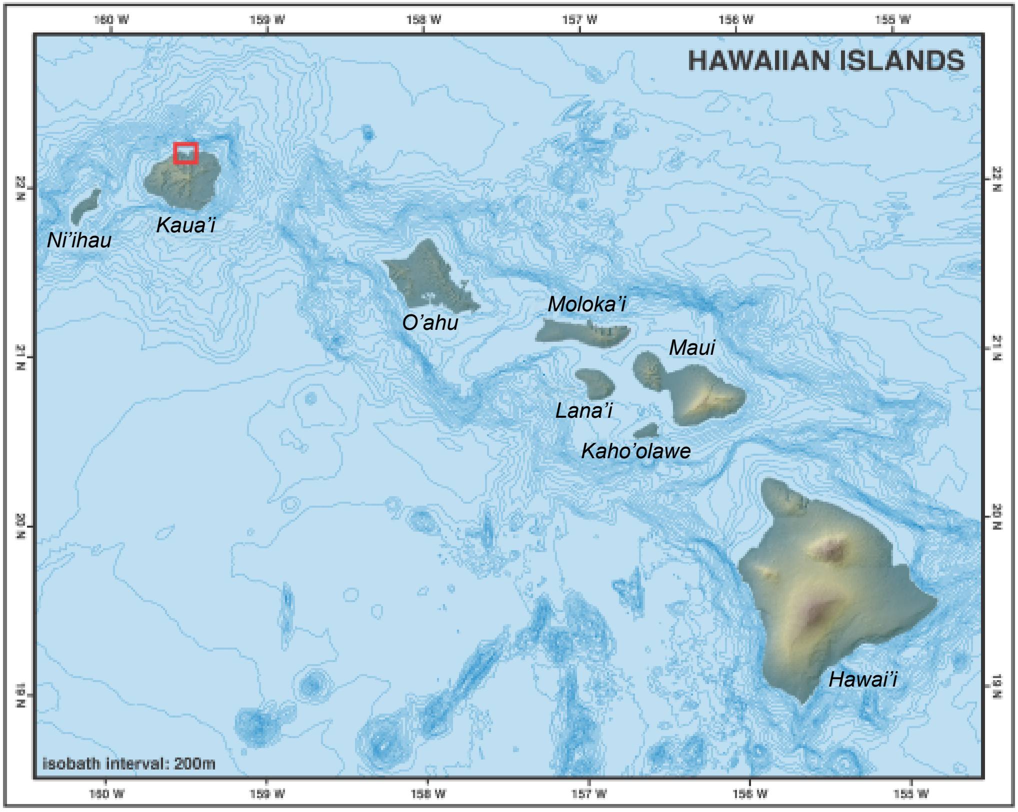

Figure 1. *Location map showing the major Hawaiian Islands. Hanalei Bay, on the north shore of Kaua'i, is shown in the red box.*

The sea floor of Hanalei Bay consists of marine carbonate sediment and terrigenous siliciclastic material derived from the basaltic highlands of the Hanalei River basin (Calhoun and others, 2002). The center of the bay is largely free of indurated coral-reef substrate, with a flat sea floor at typically 10–18 m water depth. At the east side of the bay, 500 m offshore of the river mouth, is a broad depression ~15 m deep known as the Black Hole because terrestrial sediment and dark organic matter obscures visibility in the water column (fig. 2). The fringing reef inside Hanalei Bay hosts ecological communities that were, in recent studies of the bay's marine biological diversity, considered to be relatively healthy. Hanalei Bay is unusual among Hawaiian coral communities in having increased its live coral cover since the mid-1990s (Friedlander and others, 1997, 2005).

Isotopes Used as Sediment Tracers:

This study utilizes three radioisotopes: ^{7}Be, ^{137}Cs, and ^{210}Pb. These isotopes have been used in previous studies of near-shore and inner-shelf sedimentation to assess accumulation rates and sources. All are particle-reactive and adsorb readily onto the surfaces of sediment grains. Beryllium-7 has been shown to be especially useful for identifying episodic seasonal flood deposits near shore (Allison and others, 2000). Lead-210 and ^{137}Cs have been used together in numerous coastal and lacustrine settings to estimate accumulation rates and deposition age of sediment (Duursma and Gross, 1971; Nittrouer and others, 1979; Smith and Ellis, 1982; Buesseler and Benitez, 1994; Allison and others, 1998, 2000; Jaeger and Nittrouer, 1995; Kuehl and others, 1995; Goodbred and Kuehl, 1998; Draut and others, 2005).

The first tracer, ^{7}Be, is a naturally occurring isotope with a 53-day half-life that forms in the atmosphere by cosmic-ray spallation of nitrogen and oxygen. The production of cosmogenic ^{7}Be is controlled by insolation, and so the flux of ^{7}Be from the atmosphere to the earth's surface has a latitudinal and seasonal dependence (Olsen and others, 1986; Baskaran and others, 1993). After it becomes associated with airborne particles and is deposited on land, ^{7}Be rapidly becomes incorporated into vegetation and soil. In contrast to the slow rate at which ^{7}Be can be delivered to the sea floor via settling of particles through the marine water column (which may take longer than its activity remains measurable), ^{7}Be is concentrated in terrestrial sediment carried to the coastal ocean by river discharge. An appreciable inventory of this isotope can therefore accumulate in fluvial deposits near shore (Canuel and others, 1990; Allison and others, 2000). The presence of ^{7}Be in near-shore sediment indicates that sediment had been exposed to the atmosphere within the past eight months, or approximately five half-lives; it is therefore particularly useful for detecting recently deposited fluvial sediment.

Cesium-137 is an isotope with a 30-year half-life and a non-constant source function: it was first introduced to the environment during nuclear-weapon testing that began in the 1950s and peaked in 1963, then ceased to be added

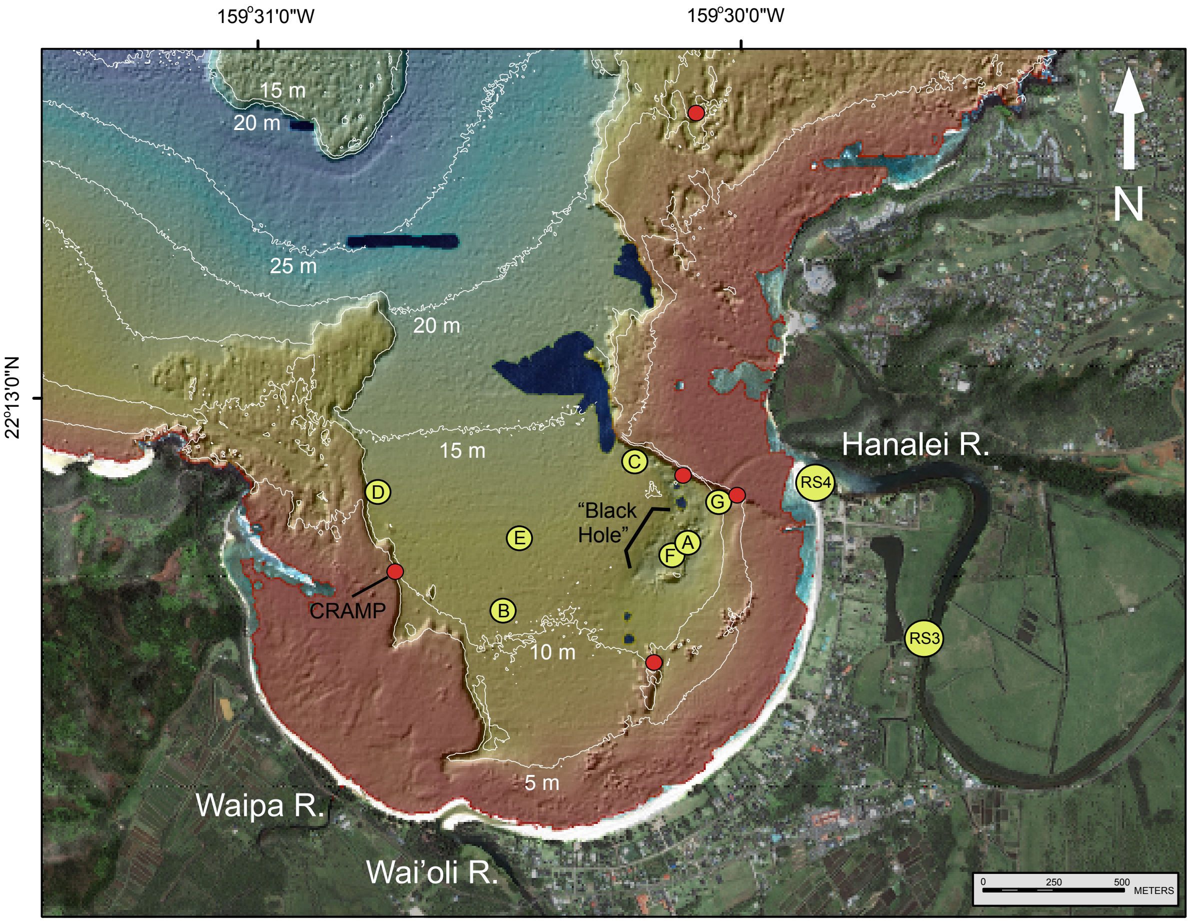

***Figure 2**. Locations of sediment-core sites in Hanalei Bay. Stations occupied in June and August 2005 for this study (yellow circles) identified by station letter (A–G). River Sites 3 and 4 (RS3 and RS4) are also marked; River Sites 1 and 2 are located out of this map area, ~4 km and ~2.5 km upstream of the river mouth, respectively (locations listed in tab. 1). Red circles indicate the locations of oceanographic instrument packages deployed during summer 2005 (Storlazzi and others, 2006). Bathymetry in this image has been interpolated from SHOALS lidar data; dark-blue areas indicate no bathymetric data. The isobath interval is 5 m.*

after the 1972 atmospheric nuclear testing ban with the exception of additions caused by the 1979 and 1986 nuclear accidents at Three Mile Island and Chernobyl, respectively. Because ^{137}Cs has been almost entirely removed from the atmosphere by rainfall, it is now introduced to the marine environment primarily via sediment that has been eroded from land and discharged by rivers into the ocean (for example, Smith and Ellis, 1982). As with ^{7}Be, the supply of ^{137}Cs to shallow marine settings is controlled largely by fluvial sedimentation. Measurable activity of ^{137}Cs indicates that some component of the sediment has been in contact with an atmospheric or fluvial source more recently than the 1950s, when this isotope was first introduced to the environment. If sediment has accumulated undisturbed since that time, ^{137}Cs profile with sediment depth may mirror the history of atmospheric fallout, and so can be used to infer accumulation rates (Livingston and Bowen, 1979; Miller and Heit, 1986).

The third isotope, ^{210}Pb, is a naturally occurring daughter product of ^{238}U with a half-life of 22.3 years. Excess ^{210}Pb is defined as the ^{210}Pb activity above (in excess of) the equilibrium activity supported by concentrations of parent and grandparent isotopes in the ^{238}U decay series in the same sediment sample. The excess ^{210}Pb activity is the difference between the total ^{210}Pb and the supported ^{210}Pb. Supported ^{210}Pb, that amount of ^{210}Pb in sediment produced *in situ* by continuous ^{226}Ra decay (via ^{222}Rn, with a 3.8-day half-life), is identified by measurement of ^{214}Pb (half-life 26.8 minutes), an intermediate daughter product between ^{222}Rn and ^{210}Pb that is assumed to be in secular equilibrium with ^{210}Pb. Because the half-life of ^{226}Ra is long (1,622 years), supported ^{210}Pb is produced in marine sediment by ^{226}Ra decay for thousands of years after its deposition and isolation from other ^{210}Pb sources. In the coastal marine environment of the Hawaiian Islands, adjacent to clear Pacific Ocean water, the primary source of excess ^{210}Pb is the decay of ^{226}Ra dissolved in seawater. Other sources include fallout to surface water following its production in the atmosphere from the decay of ^{222}Rn gas, and input by fluvial discharge. The presence of excess ^{210}Pb characterizes sediment deposited within the past ~100 years, or five half-lives. In undisturbed sediment, the excess ^{210}Pb-activity profile can be used to model rates of sediment accumulation and mixing (for example, Nittrouer and others, 1979; Crusius and others, 2004).

METHODS

Sediment Collection and Sub-Sampling:

Sediment cores were collected with a diver-operated hand-held coring unit at seven sites in Hanalei Bay (fig. 2). Core collection occurred in June and August 2005, coincident with the times chosen by Storlazzi and others (2006) to deploy and recover oceanographic instruments. Core sites were chosen to provide representative spatial coverage around the bay; two of seven sites were located in the Black Hole (Stations A and F), two along the coral wall at the east side of the bay near the Hanalei River mouth (Stations C and G), two in the central part of the bay (Stations B and E), and one along the coral wall at the northwest side of the bay (Station D; fig. 2). The diver-operated corer uses a slide hammer to drive a 10.7-cm-diameter polycarbonate core barrel into the sea floor, and can collect cores up to ~0.8 m long depending on the consolidation of the sediment. A check valve within the slide hammer-core barrel adapter provides suction to retain sediment while the barrel is pulled out of the sediment. The bottom of the core barrel is sealed as soon as possible by inserting a piston. Core lengths recovered during this study typically ranged from 20–50 cm (tab. 1). At sites of uniform unconsolidated sand, core recovery was often complicated by the movement of water through the sediment during insertion of the piston.

After core collection, sediment was extruded from the core barrel using a jack to push the piston and sediment through the barrel. Sedimentary facies and textures were described qualitatively and sampled during extrusion. The top 22 cm of each core was sampled in 2-cm intervals; below 22 cm, sample thicknesses alternated between 2 cm and 8 cm. Additional samples were collected from any horizons with unusual facies variation. Sediment from the edges of each sample was discarded to avoid sampling material that had been smeared, obscuring its original depth, as the core barrel was driven into the sea floor or extruded from the barrel.

In addition to sediment cores collected within Hanalei Bay, four sediment grab samples (0–5 cm deep) were obtained from the river bottom in August 2005 (fig. 2). Facies at these four river sites were described, and, along with the core samples, these were later analyzed on gamma counters to allow comparison of isotope activity in the river sediment with that in the bay.

Isotope Analysis by Gamma Counting:

Gamma-ray activity provides a straightforward and efficient means to measure the radioactive isotope content in sediment (Gäggler and others, 1976). Each isotope emits gamma radiation at a characteristic frequency associated with its decay. Because detection by this method allows detection of multiple frequencies simultaneously, the activities of all desired isotopes are assessed in one counting session.

Laboratory analyses were performed at the USGS laboratory in Woods Hole, MA. The wet sediment samples were homogenized and sub-sampled. Aliquots weighing approximately 100 g were freeze-dried and then disaggregated. Samples were analyzed on planar germanium detectors (Canberra Industries, Inc., model GS2020S) for 48–96 hours (until the ^{210}Pb standard error was within 3%). Activity levels of ^{7}Be, ^{137}Cs, and ^{210}Pb were measured using net counts of the 478, 661.6, and 46.3 keV peaks respectively. Excess ^{210}Pb activity was calculated from independent measurement of ^{214}Pb at 352 keV (Livingston and Bowen, 1979; Joshi, 1987). The efficiency of the detectors over the energy range 46.3–665 keV was calibrated using EPA

Site	Latitude	Longitude	Core	Date	Water Depth	Core Length	Comments
A	22° 12.739'	159° 30.083'	K0605-1	6/7/05	15.3 m	58 cm	Black Hole
			K0805-7	8/27/05	15.3 m	53 cm	
B	22° 12.595'	159° 30.506	K0605-2	6/7/05	11.0 m	34 cm	South-central bay
			K0805-1	8/24/05	11.3 m	38.5 cm	
C	22° 12.889	159° 30.196	K0605-3	6/7/05	13.1 m	52 cm	NE side of bay
			K0805-3	8/25/05	13.4 m	23 cm	
D	22° 12.840	159° 30.764	K0605-4	6/8/05	13.4 m	21 cm	NW side of bay
			K0805-4	8/26/05	13.4 m	34 cm	
E	22° 12.743	159° 30.474	K0605-5	6/8/05	12.2 m	21 cm	Middle of bay
			K0805-6	8/26/05	12.2 m	39 cm	
F	22° 12.725	159° 30.087	K0605-6	6/8/05	14.6 m	4 cm	Black Hole
			K0805-2	8/25/05	15.6 m	58.5 cm	
G	22° 12.807	159° 30.039	K0605-7	6/8/05	10.7 m	15 cm	Reef wall near river mouth
			K0805-5	8/26/05	8.5 m	28 cm	
River Site 1			grab sample	8/28/05	1.2 m	n/a	30 m upstream of stream gage
River Site 2	22° 12.649'	159° 28.547'	grab sample	8/28/05	0.8 m	n/a	Under traffic bridge
River Site 3	22° 12.799	159° 29.489	grab sample	8/28/05	0.9 m	n/a	0.8 km above river mouth
River Site 4	22° 12.825	159° 29.731	grab sample	8/28/05	0.5 m	n/a	Beach park at river mouth

Table 1. *Locations, lengths, and dates of sediment cores collected in June and August 2005, and river-bed grab samples collected in August 2005.*

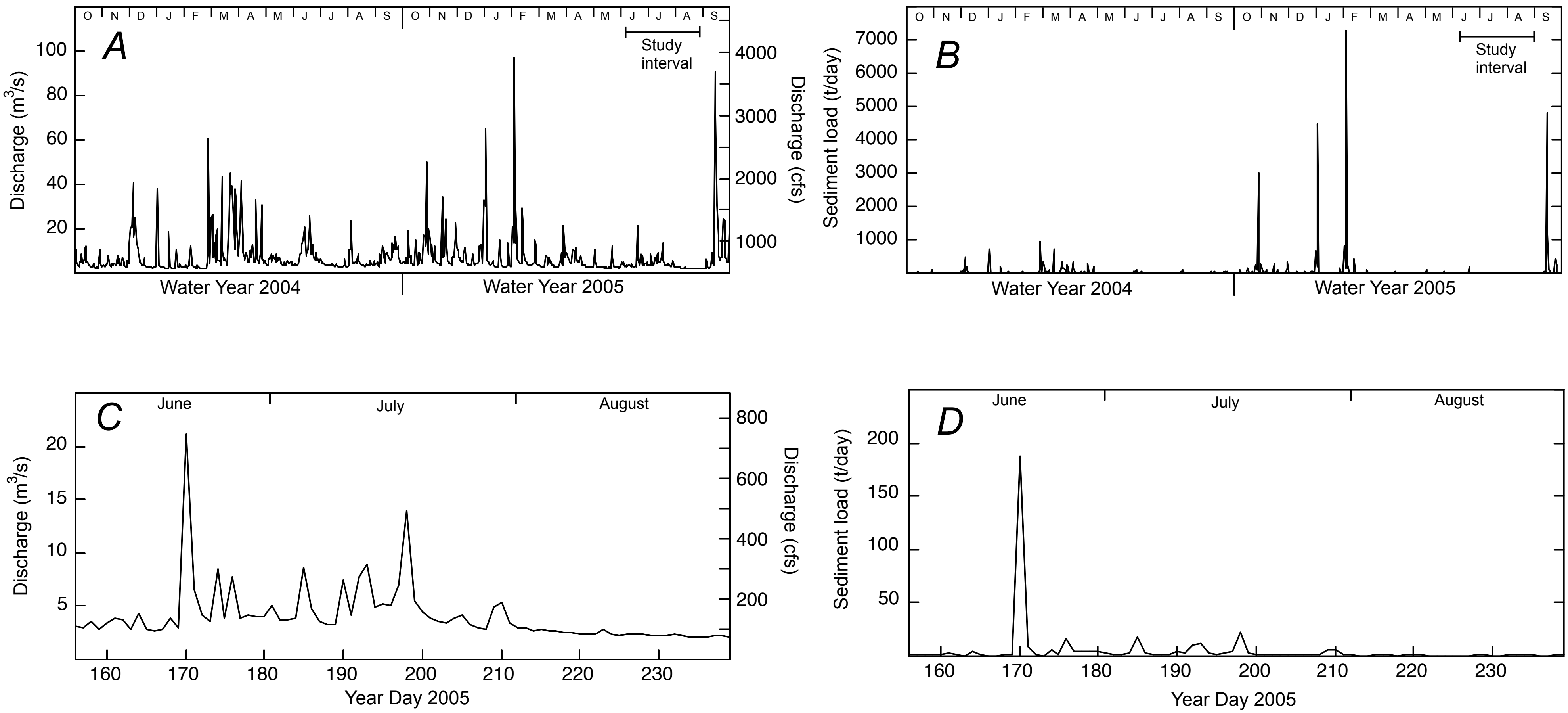

Figure 3. *Water and sediment discharge from the Hanalei River. Data were measured at USGS gaging station number 16103000 ("Hanalei River near Hanalei", located 9.2 km upstream from the river mouth) and were provided by the USGS Pacific Islands Water Science Center in Honolulu, Hawai'i (http://hi.water.usgs.gov/). A. Hydrograph for water years 2004 and 2005 (10/1/03 through 9/30/05) with the study interval (June–August 2005) indicated. B. Fluvial sediment load (in metric tons per day) for water years 2004 and 2005 based on a rating curve and suspended-sediment samples analyzed by the Water Resources Division of the USGS. C. Hydrograph during the study interval in summer 2005, beginning with the start of the June coring work (6/5/05; Year Day 156) and ending with the final day of August field work (8/27/05; Year Day 239). D. Fluvial sediment load during the summer 2005 study interval.*

standard pitchblende ore in the same range of geometry as the samples. Calibration of the detectors specifically for ^{137}Cs (661.6 keV) was carried out with a standard solution from Isotope Products Laboratory. The activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb were decay-corrected to the date of core collection. A correction for self-absorption on all of the isotopes was made using the method of Cutshall and others (1983). The accuracy of these results was confirmed by analyses of standard reference materials, which yielded excellent agreement with certified results.

Isotope inventories (total activity beneath 1 cm^2 of sea-floor area at the core site) were calculated for the cores by multiplying the measured activity (in disintegrations per minute per dry gram of salt-free sediment) in each depth interval by the estimated bulk density (g cm^{-3}) and by the core section thickness (cm). The products were summed over the entire core length. Sediment bulk density was estimated using a measured weight per unit volume of disaggregated, freeze-dried sediment. This procedure assumes that the unconsolidated sandy sediment was not compacted appreciably.

RESULTS

The hydrograph and sediment load for the Hanalei River during the study interval, and for the two most recent complete water years, are shown in figure 3. The Hanalei River flood event that most recently preceded the June core collection occurred on 2/2/05, with a peak discharge of 95 m^3 s^{-1} (3,370 cfs; fig. 3). The time between June and August core collection was a time of low fluvial sediment input to Hanalei Bay when no major floods occurred.

Locations, dates, lengths, and sediment-sample depths for each core and river grab sample are listed in table 1. Inventories of ^{7}Be, ^{137}Cs, and excess ^{210}Pb for each core site are reported in table 2. Complete descriptions of sediment from all 14 cores (seven each in June and August 2005) are listed in appendices 1 and 2. Figures 4–17, ordered by core site name (locations shown in fig. 2), show activity profiles for ^{7}Be, ^{137}Cs, and excess ^{210}Pb in the 14 cores, as well as sedimentary-facies diagrams. Isotope activities have been decay-corrected to the time of sample collection, and are reported as disintegrations per minute per dry gram of salt-free sediment. Facies showed substantial spatial heterogeneity within the bay; examples of different sediment types observed are shown in the photographs in figure 18.

Cores collected in the Black Hole (at Stations A and F; figs. 4, 5, 14, and 15) contained a thin layer of unconsolidated very fine-grained sediment and organic debris at the surface, underlain by a mixture of carbonate sand and dark mud. Rounded siliciclastic pebbles were found in the upper parts (within 15 cm of the sea floor) of two of the Black Hole cores (Core K0605-1 from Station A in June, and Core K0805-2 from Station F in August). Three of the four Black Hole cores (From Stations A and F; cores K0605-1, K0805-2, and K0805-2) contained dark, consolidated mud with wood and leaf debris that extended from a depth of

Station	Core	Excess 210Pb dpm/cm^2	Complete inventory recovered?	137Cs dpm/cm^2	Complete inventory recovered?	7Be dpm/cm^2	Complete inventory recovered?
A	K0605-1	208	y, 56 cm	2.34	y	9.46	y
	K0805-7	205	y, 40 cm	1.66	y	0.07	y
B	K0605-2	243	n, but almost	0.33	y	0.00	y
	K0805-1	262	n, but almost	2.38	probably	0.58	y
C	K0605-3	293	n, but almost, 53 cm	0.09	y	0.09	y
	K0805-3	53	n. only 20 cm	0.03	y	0.00	y
D	K0605-4	107	n. only 20 cm	0.02	y	0.05	y
	K0805-4	135	n, 30 cm	0.00	y	0.34	y
E	K0605-5	163	n. only 20 cm	0.01	y	0.32	y
	K0805-6	168	n, 18 cm	0.00	y	0.00	y
F	K0605-6	28	n, only 4 cm	0.40	n	0.31	n
	K0805-2	128	y, 40 cm	1.33	y	0.79	y
G	K0605-7	56	n. only15 cm	1.39	n. only15 cm	1.55	n
	K0805-5	88	n, 18 cm	2.51	n	2.18	n? only 18 cm

Table 2. *Inventory of ^{7}Be, ^{137}Cs, and excess ^{210}Pb in the sediment at all core sites. Inventories were calculated from gamma-counted activity. Units are disintegrations per minute (dpm) per cm^{2} of sea-floor surface area.*

15–20 cm below the sea floor down to the base of each core. The fourth Black Hole core (Core K0605-6) was too short (4 cm) to allow much comparison between its facies and that of the other three, although its consolidated mud and sparse sand were similar to the upper 4 cm of the other three.

The June and August cores from Black Hole Station A contained facies and isotope-activity profiles that differed somewhat (figs. 4 and 5). In June, Core K0605-1 at this station contained appreciable ^{7}Be activity down to a depth of ~20 cm below the sea floor, measurable ^{137}Cs in the upper ~25 cm, and excess ^{210}Pb that ranged from 5–10 dpm g^{-1} in the upper ~25 cm. In contrast, at this same site in August (Core K0805-7), only one sample (centered at a depth of 7 cm beneath the sea floor) had any measurable ^{7}Be. Measurable ^{137}Cs was present in the upper ~20 cm but displayed a very different profile from that of the June core, and excess ^{210}Pb in the upper 20 cm was higher than in June (up to 12 dpm g^{-1}). In both the June and August cores from Station A, the dark, consolidated mud layer between ~20 cm and the cores' bases was almost entirely inactive with respect to the three isotopes analyzed. At Black Hole Station F, both cores contained some ^{7}Be in the upper 5 cm but the June core (K0605-6) was too short to calculate inventory accurately for any of the three isotopes measured. In the August core from Station F (K0805-2), low activity levels of ^{137}Cs were detected in the upper 10 cm (~0.1 dpm g^{-1}) and excess ^{210}Pb was a fairly constant 6–8 dpm g^{-1} in the upper 12 cm.

The cores from Station G, at the east side of the bay near the river mouth, both contained carbonate sand immediately beneath the sea floor, underlain by a horizon of mixed carbonate sand and dark mud 5–8 cm thick, which in turn was underlain by more carbonate sand. Core K0605-7 (Station G in June) stopped at a depth of 15 cm beneath the sea floor; below that depth, Core K0805-5 (from the same Station G in August) contained unstratified sand, coral rubble, and siliciclastic gravel. Beryllium-7 profiles from these two cores at Station G were similar, within the analytical and sampling error, with both cores showing ^{7}Be activity in the upper 5 cm. Both cores displayed ^{137}Cs peaks between 5 and 13 cm, allowing for sampling error. However, activity levels in the August core (K0805-5) were more than twice as high as those in the June core (K0605-7). Excess ^{210}Pb in both cores was at or below 5 dpm g^{-1}.

The remaining core site, Station C, located along the coral wall at the northeast side of the bay, was dominated by carbonate sand in both the June (K0605-3) and August (K0805-3) cores, although some silicilastic heavy-mineral grains were visible in both. The longer of those two cores (K0605-3) contained dark sand below a depth of 36 cm that was finer-grained than the overlying dominantly carbonate layer. Both ^{7}Be and ^{137}Cs were not detectable in both cores collected at Station C, with the exception of one sample from the June core (K0605-3) that had very low activity (~0.03 dpm g^{-1}) and a large error. Excess ^{210}Pb in the June core decreased down-core from ~8 dpm g^{-1} to below 5 dpm g^{-1}, and was almost not detectable (<2 dpm g^{-1}) at this site in August.

Cores from Station B, in the south-central part of the bay, were dominated by carbonate sand although the core collected in August (K0805-1) had three distinct horizons of darker sand with isolated clay patches. This August core had

Station A, June 2005 (Core K0605-1)

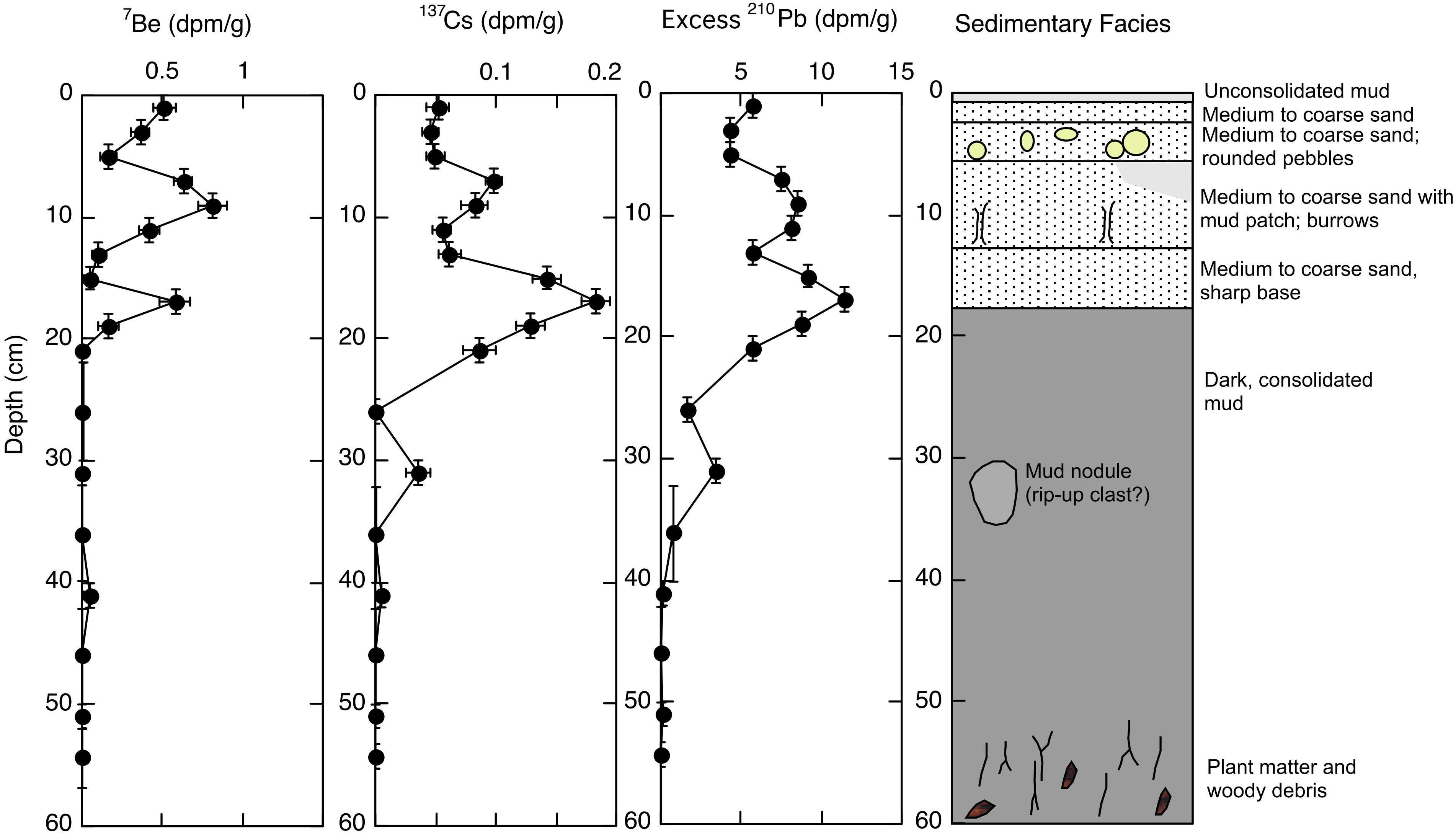

Figure 4. *Sedimentary facies and isotope activity at Station A in June 2005 (Core K0605-1). Activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located in the Black Hole, at the east side of Hanalei Bay, near the mouth of the Hanalei River.*

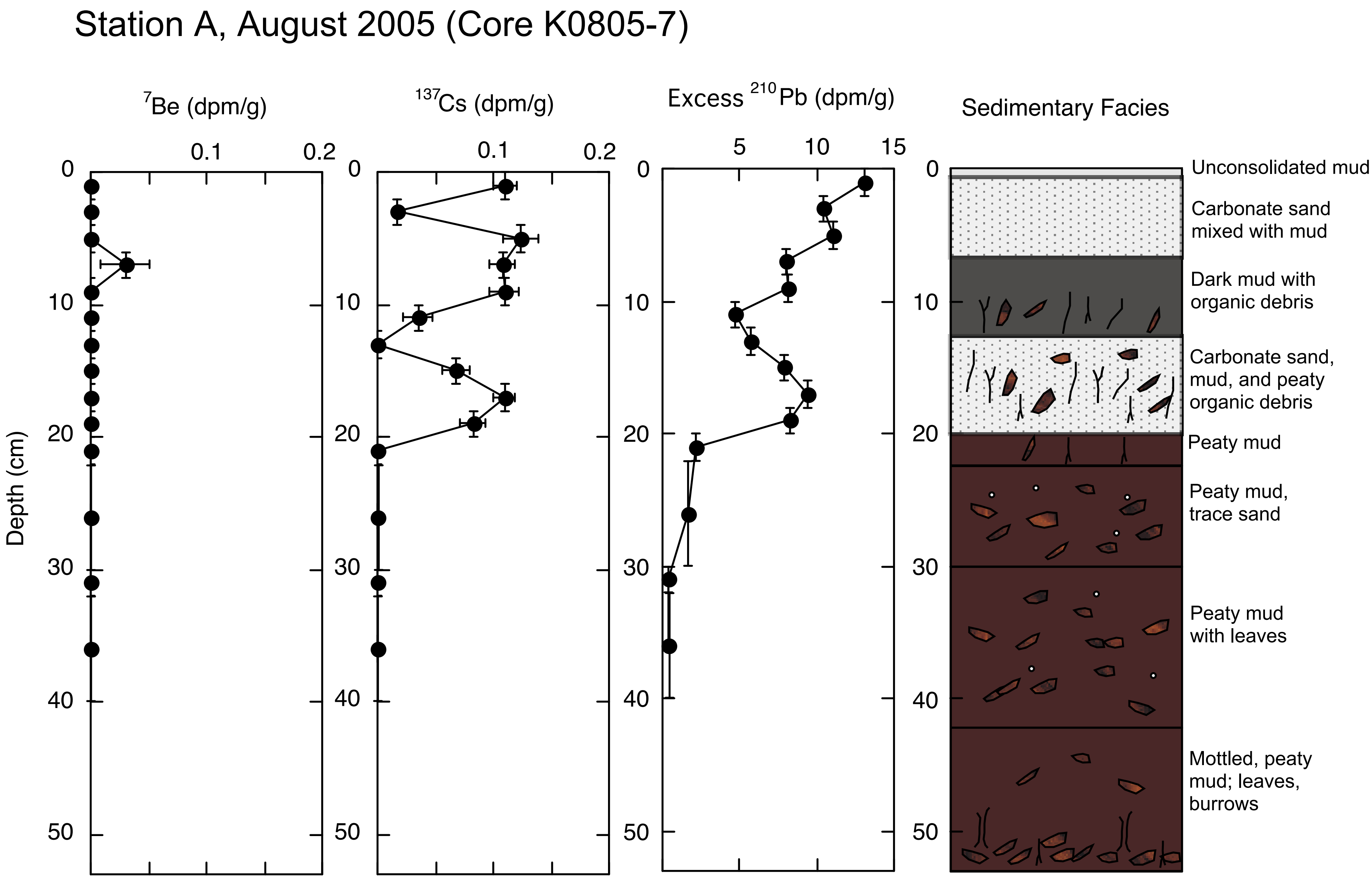

Figure 5. *Sedimentary facies and isotope activity at Station A in August 2005 (Core K0805-7). Activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located in the Black Hole, at the east side of the bay, near the river mouth.*

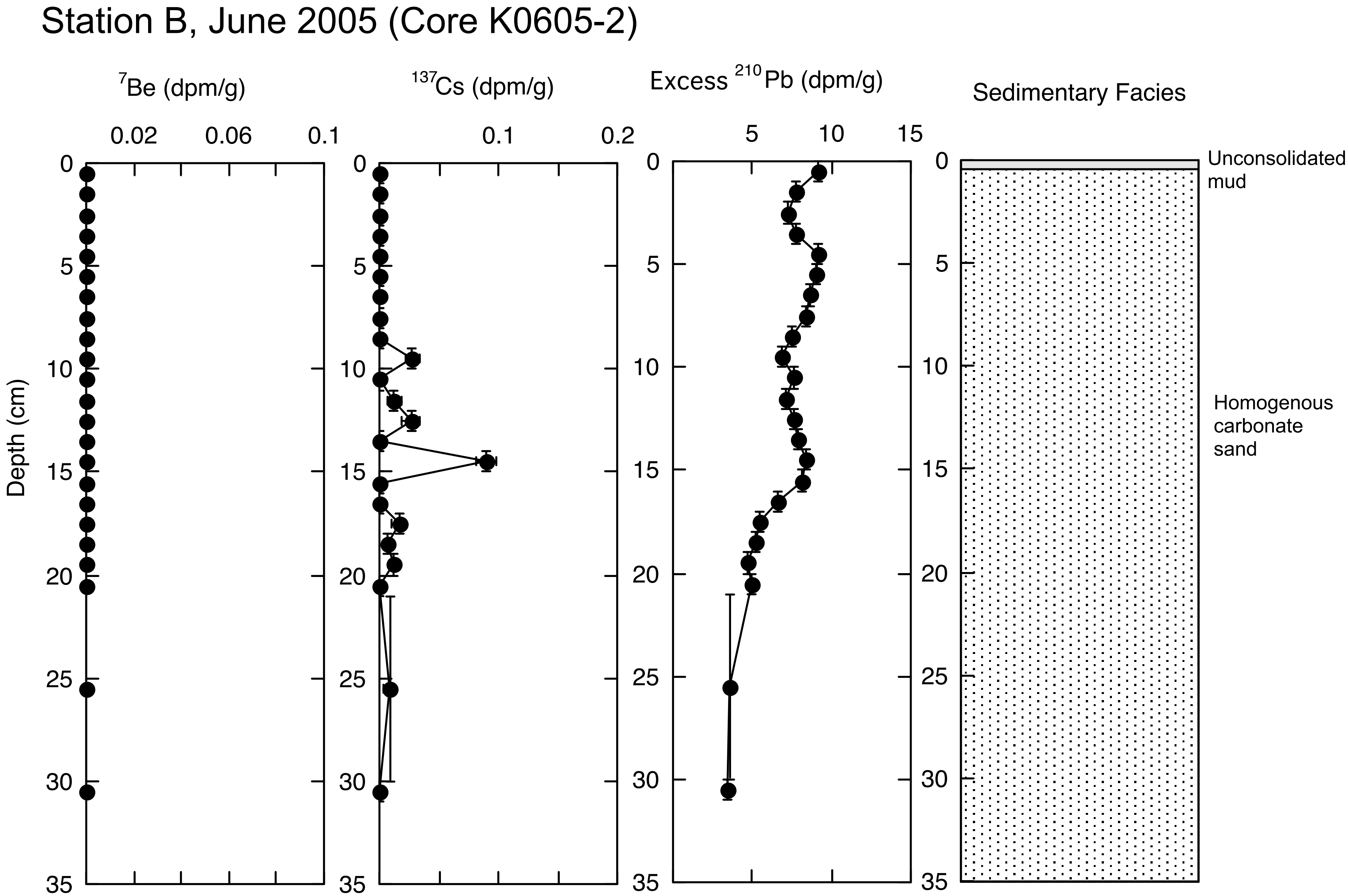

Figure 6. *Sedimentary facies and isotope activity at Station B in June 2005 (Core K0605-2). Activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located in the south-central part of the bay.*

Station B, August 2005 (Core K0805-1)

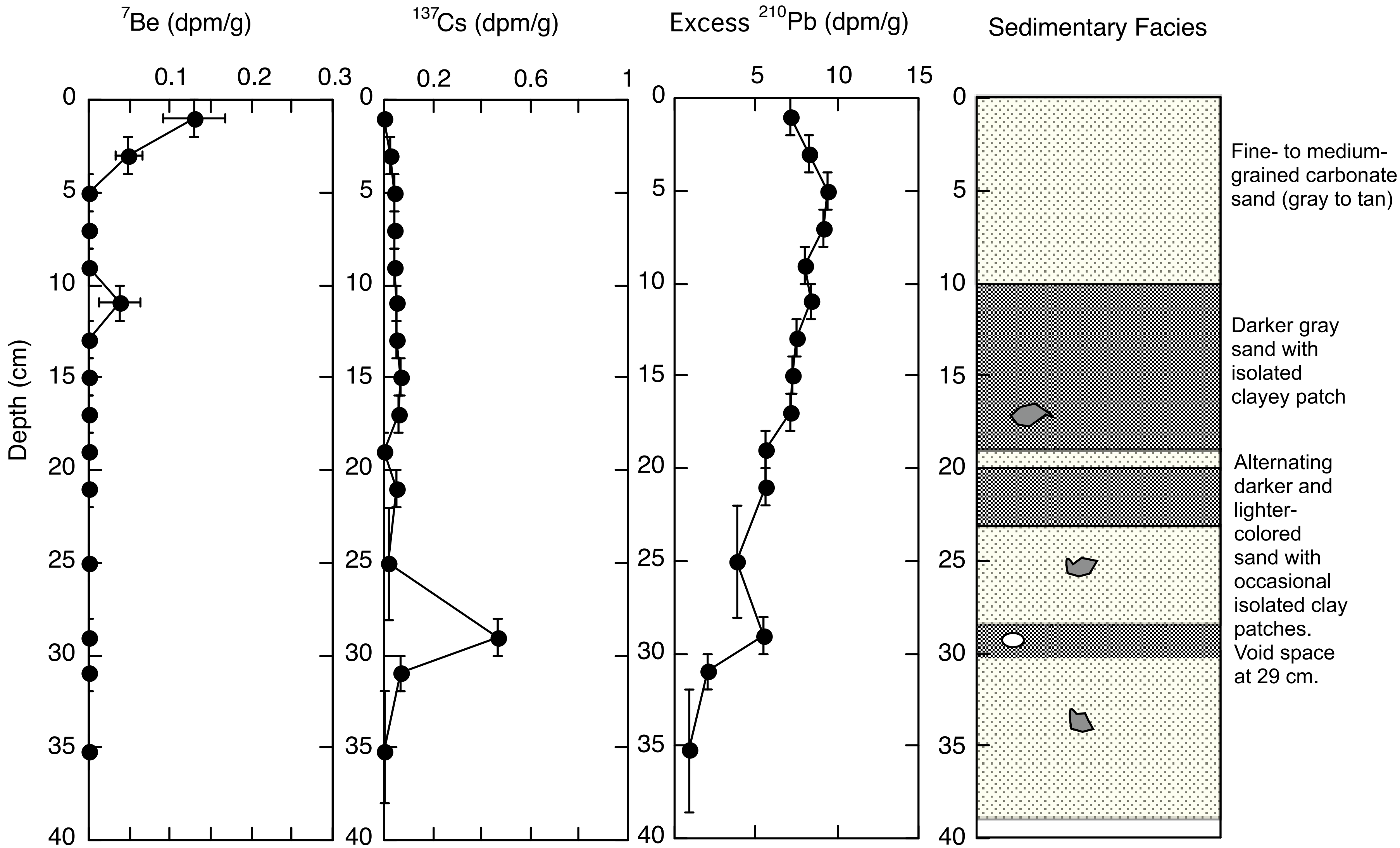

Figure 7. *Sedimentary facies and isotope activity at Station B in August 2005 (Core K0805-1). Activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located in the south-central part of the bay.*

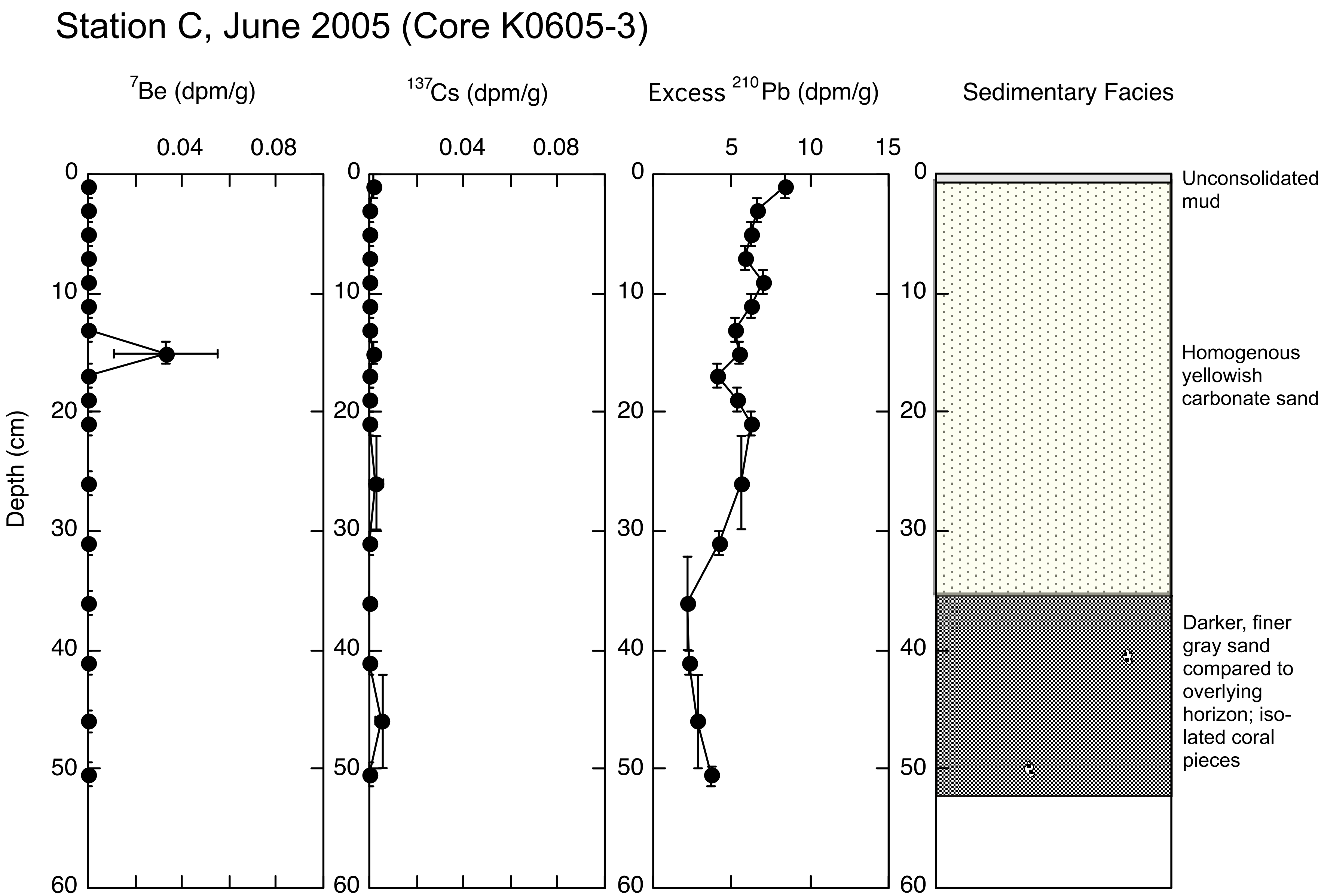

Figure 8. *Sedimentary facies and isotope activity at Station C in June 2005 (Core K0605-3). Activities of* ^{7}Be*,* ^{137}Cs*, and excess* ^{210}Pb*, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located on the northeast side of the bay, ~8 m away from the coral wall near the river mouth.*

Station C, August 2005 (Core K0805-3)

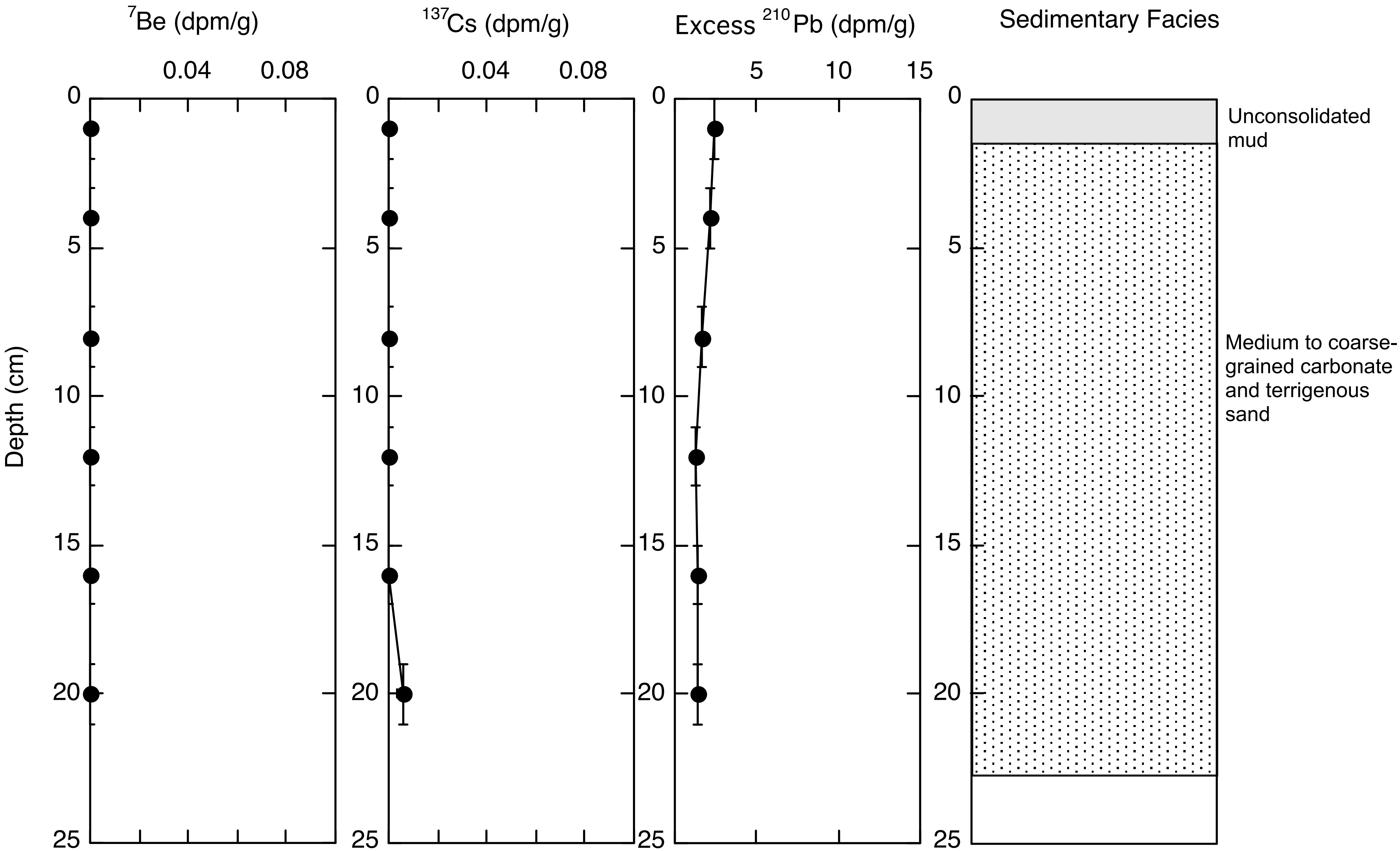

Figure 9. *Sedimentary facies and isotope activity at Station C in August 2005 (Core K0805-3). Activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located on the northeast side of the bay, ~8 m away from the coral wall near the river mouth.*

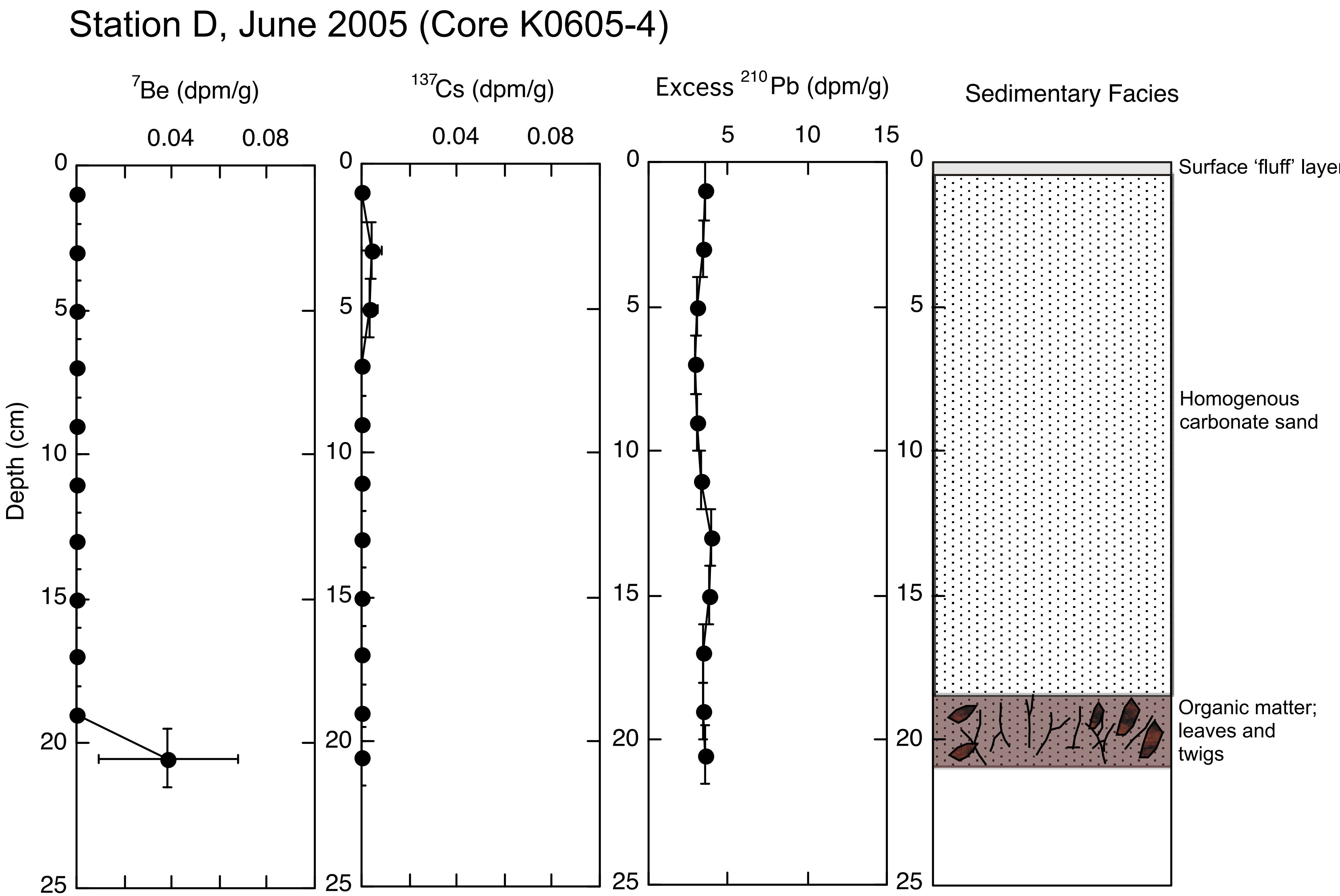

Figure 10. *Sedimentary facies and isotope activity at Station D in June 2005 (Core K0605-4). Activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located on the northwest side of the bay, ~5 m away from a coral wall near the location of the CRAMP (Coral Reef Assessment and Monitoring Project)-site instrument package discussed by Storlazzi and others (2006).*

Station D, August 2005 (Core K0805-4)

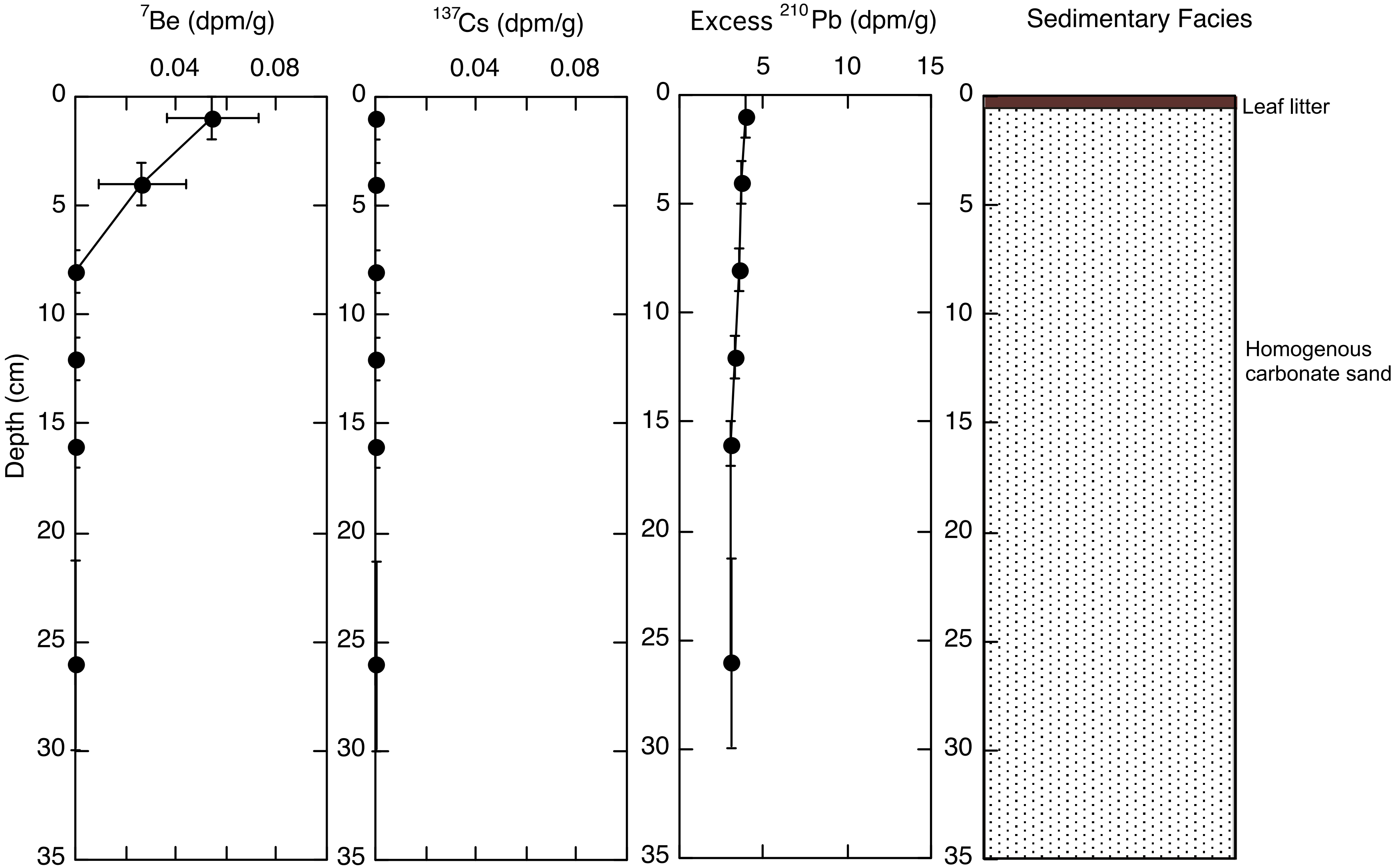

***Figure 11**. Sedimentary facies and isotope activity at Station D in August 2005 (Core K0805-4). Activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located on the northwest side of the bay, ~5 m away from a coral wall near the location of the CRAMP (Coral Reef Assessment and Monitoring Project)-site instrument package discussed by Storlazzi and others (2006).*

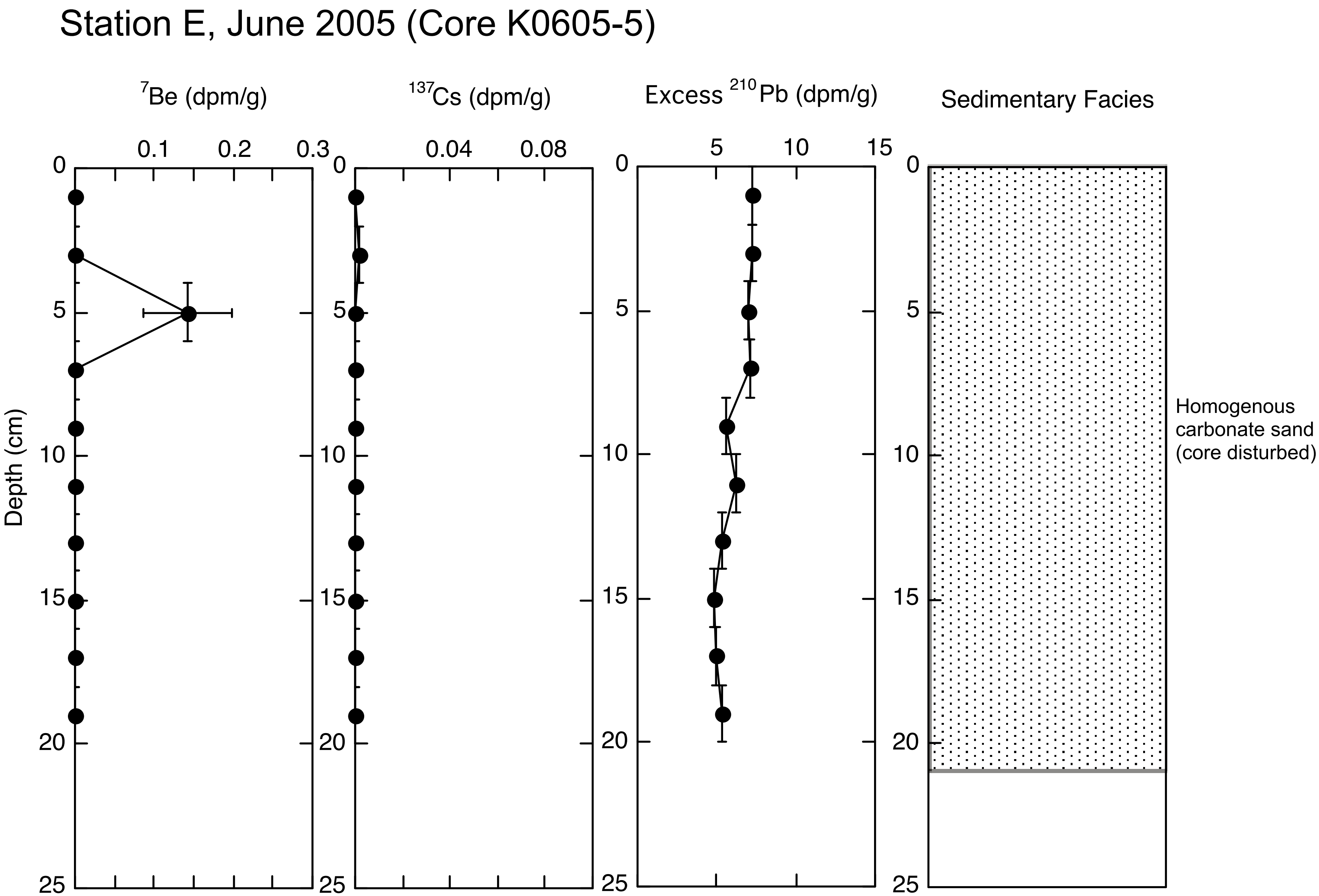

Figure 12. *Sedimentary facies and isotope activity at Station E in June 2005 (Core K0605-5). Activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located in the middle of the bay.*

Station E, August 2005 (Core K0805-6)

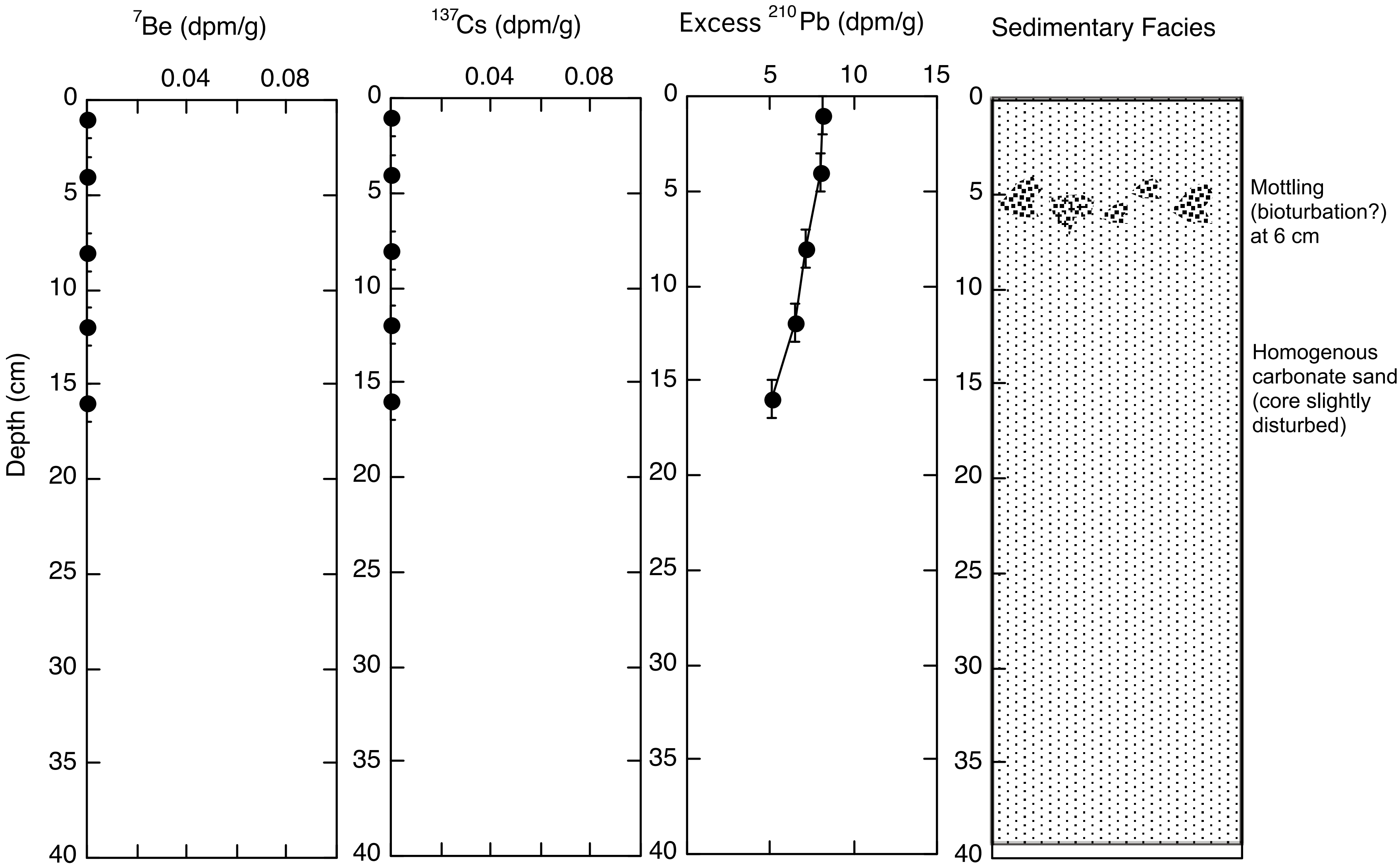

Figure 13. *Sedimentary facies and isotope activity at Station E in August 2005 (Core K0805-6). Activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located in the middle of the bay.*

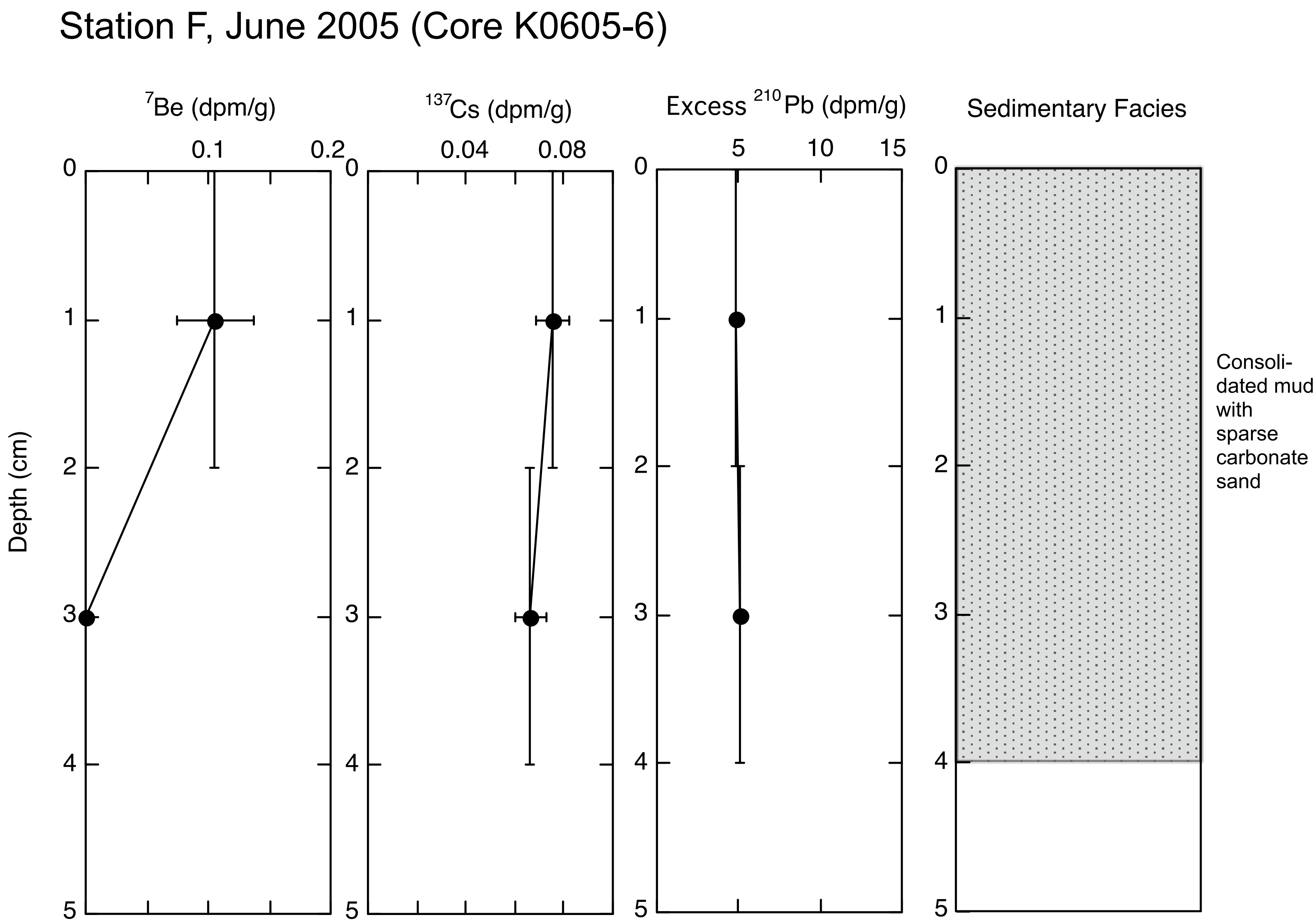

Figure 14. *Sedimentary facies and isotope activity at Station F in June 2005 (Core K0605-6). Activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located in the Black Hole.*

Station F, August 2005 (Core K0805-2)

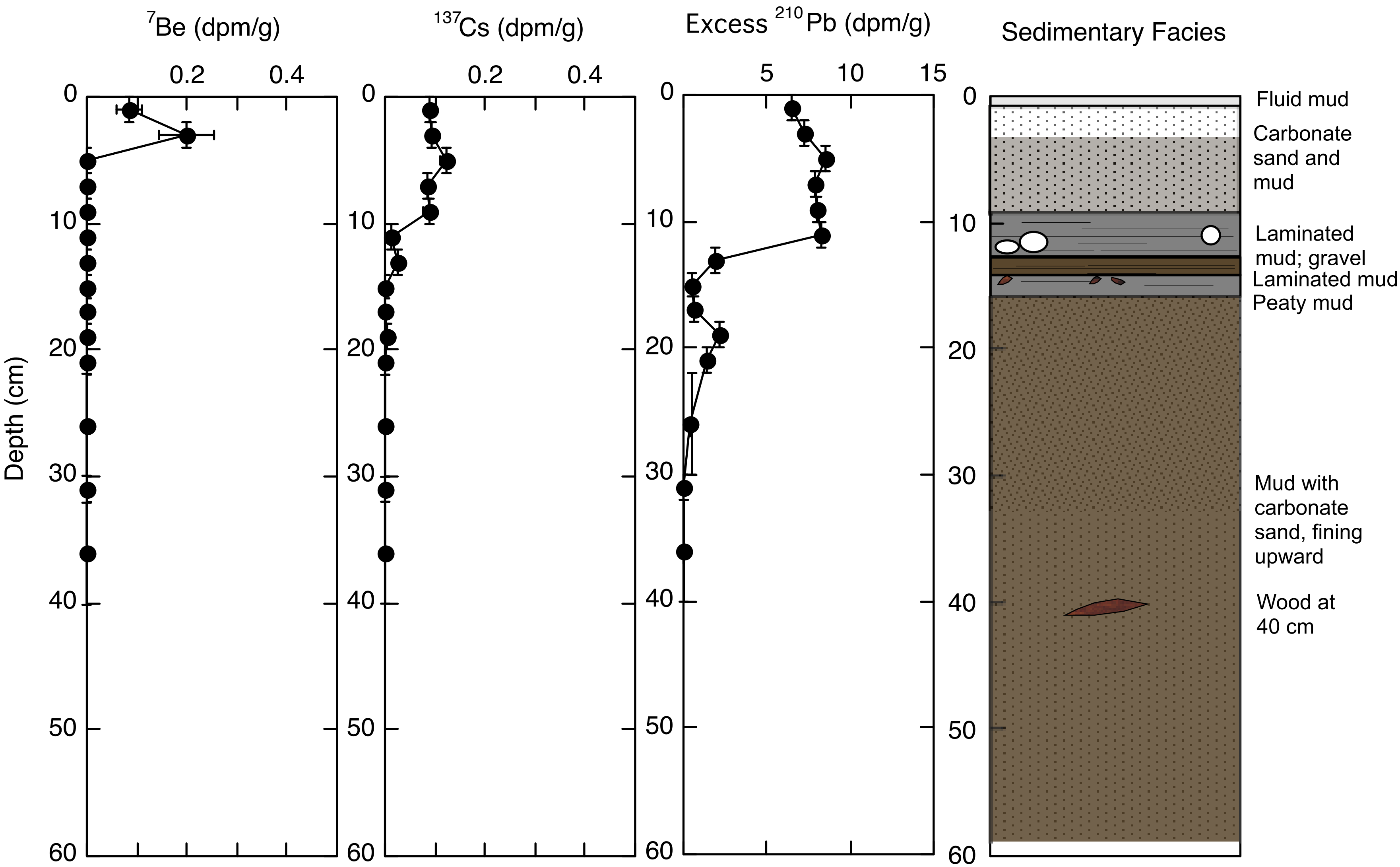

Figure 15. *Sedimentary facies and isotope activity at Station F in August 2005 (Core K0805-2). Activities of ^{7}Be, ^{137}Cs, and excess ^{210}Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located in the Black Hole.*

Station G, June 2005 (Core K0605-7)

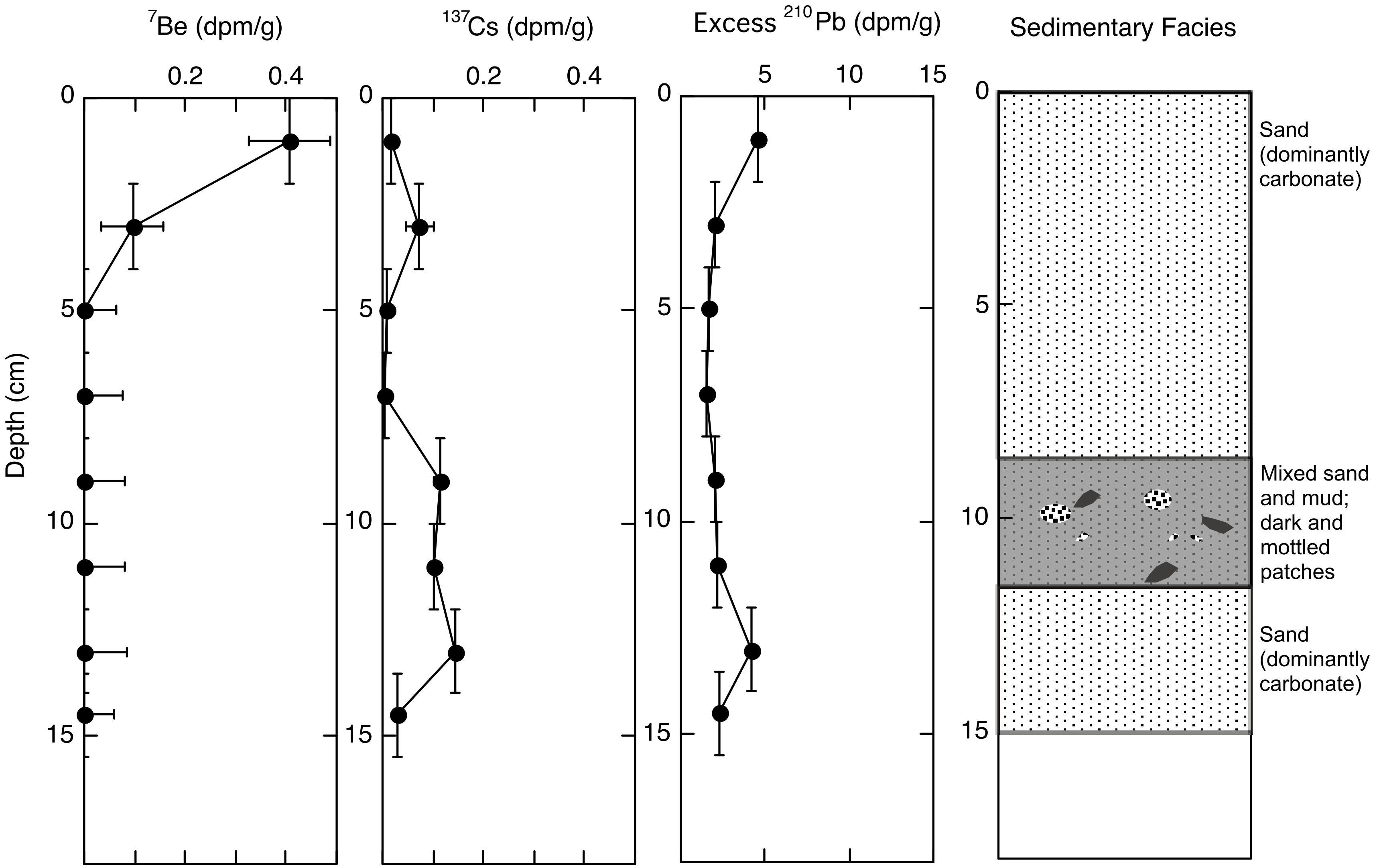

Figure 16. *Sedimentary facies and isotope activity at Station G in June 2005 (Core K0605-7). Activities of* ^{7}*Be,* ^{137}*Cs, and excess* ^{210}*Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located next to the reef wall on the east side of the bay, near the river mouth.*

Station G, August 2005 (Core K0805-5)

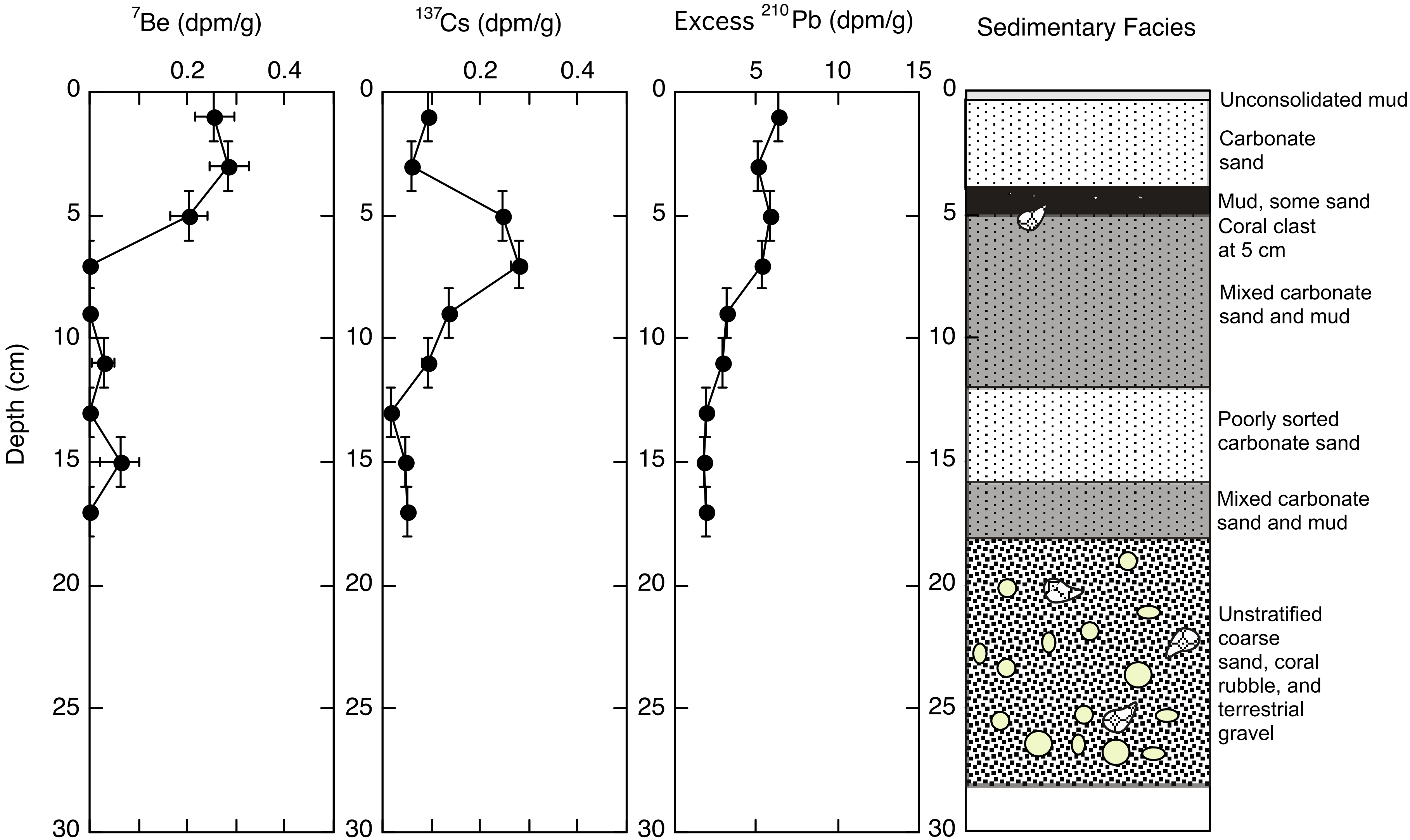

Figure 17. *Sedimentary facies and isotope activity at Station G in August 2005 (Core K0805-5). Activities of* ^{7}*Be,* ^{137}*Cs, and excess* ^{210}*Pb, all decay-corrected to the date of sample collection, are shown in disintegrations per minute (dpm) per dry gram of salt-free sediment. This site is located next to the reef wall on the east side of the bay, near the river mouth.*

measurable ^{7}Be activity in its upper 4 cm, while the June core (K0605-2) had none. Both exhibited a single-point peak in ^{137}Cs, which was otherwise absent, at 14 cm in June (K0605-2) and at 29 cm in August (K0805-1), the latter accompanied by a finer grain size than in the overlying and underlying horizons. Both cores from Station B had excess ^{210}Pb profiles that decreased steadily from ~8 dpm g^{-1} to below 5 dpm g^{-1}.

At Station E, in the middle of the bay, both the June and August cores consisted entirely of homogenous carbonate sand. The June core (K0605-5) was disturbed by the motion of water through the sand during core recovery. Beryllium-7 and ^{137}Cs were not detectable in the cores collected at Station E except for one sample in the June core (K0605-5) that contained ^{7}Be activity on the order of 0.1 dpm g^{-1} at a depth of 5 cm. Both cores exhibited excess ^{210}Pb profiles that decreased slightly down-core from ~7 dpm g^{-1} at the sea floor to ~5 dpm g^{-1} below 10 cm.

Cores from Station D, on the northwest side of the bay approximately 5 m away from a coral wall, were dominated by a homogenous carbonate-sand facies throughout much of the core in both June and August. During both sampling visits, a surface fluff layer that contained leaf litter and other organic debris was present. Divers observed that this material was readily mobilized by surge at the sea floor, and may have been resuspended during core collection. The June core at this location (K0605-4) contained a basal horizon of leaves and woody debris with its upper contact ~18 cm beneath the sea floor. No similar horizon was present in the August core at Station D (K0805-4) even though it extended 35 cm below the sea floor. The August core contained ^{7}Be in its upper ~5 cm, while there was no detectable ^{7}Be in the June core except for a very low activity with a large counting error that occurred in the basal organic layer. Neither core contained ^{137}Cs; both cores from Station D contained excess ^{210}Pb profiles that remained constant at ~4 dpm g^{-1} throughout the core.

Isotope activities in the four sediment grab samples collected from the surface of the Hanalei River bed in August 2005 provide a basis for comparison of the August cores collected within the bay. The four samples spanned approximately the lowermost 4 km of the river channel. The sample collected farthest upstream is referred to as River Site #1 in table 1, and is located ~4 km from the mouth and above most of the agricultural runoff in the Hanalei Valley. Sediment from River Site #1 consisted of mud and organic debris; this sample had ^{7}Be activity of 0.22 ± 0.06 dpm g^{-1}, ^{137}Cs activity of 0.39 ± 0.02 dpm g^{-1}, and excess ^{210}Pb activity of 0.09 ± 0.05 dpm g^{-1}. Sediment at River Site #2, located ~2.5 km above the river mouth, consisted of mud and organic material with ^{7}Be activity of 0.06 ± 0.03 dpm g^{-1}, ^{137}Cs activity of 0.39 ± 0.02 dpm g^{-1}, and excess ^{210}Pb activity of 1.44 ± 0.09 dpm g^{-1}. River Site #3 was located ~0.8 km above the river mouth, in an area dominated by coarse sand; this sample had no measurable ^{7}Be, ^{137}Cs activity of 0.15 ± 0.01 dpm g^{-1}, and no measurable excess ^{210}Pb. River Site #4 was located at the river mouth, where fine sand and mud were collected on the left (southern) bank of the river by the Hanalei beach park. Sediment from River Site #4 contained ^{7}Be activity of 0.06 ± 0.03 dpm g^{-1}, ^{137}Cs activity of 0.003 ± 0.002 dpm g^{-1}, and excess ^{210}Pb activity of 2.11 ± 0.08 dpm g^{-}

[1]. Because the river-sediment samples were grab samples from the bed surface only, isotope inventories in the river bed beneath those sampling sites cannot be measured.

DISCUSSION

Sedimentary Facies and Isotopic Signatures:

Carbonate sand was the dominant sediment type at many of the sampled sites. Most cores also contained some material derived from a terrestrial source: siliciclastic pebbles and gravel, heavy-mineral sand grains, and organic debris such as leaves and wood. Terrestrial material was especially prevalent in cores taken from the east side of the bay near the river mouth, and in the Black Hole bathymetric depression. The thickest accumulation of recent fluvial sediment was sampled at Station A in the Black Hole (Core K0605-1), where, in June 2005, the ^{7}Be profile showed that sediment that had been deposited within the past eight months was present to a depth of 22 cm. This recent accumulation of terrestrial sediment is inferred to have occurred during the Hanalei River flood event that most recently preceded the June core collection: a flood on 2/2/05 with a peak discharge of 95 m^3 s^{-1} (3,370 cfs; fig. 3). Suspended-sediment concentrations measured during that flood were sufficient to deliver a total sediment load that exceeded 7,000 t d^{-1} (http://hi.water.usgs.gov/; fig. 3), making that the largest flood, in terms of both water and sediment discharge, that occurred during combined Water Years 2004 and 2005. Although this February 2005 event was a substantial flood, traces of its sediment were scarce by the time we collected sediment cores four months later.

The paucity of detectable terrestrial sediment in June 2005 is attributed to energetic wave conditions that presumably dominated Hanalei Bay during late winter and spring. Wave heights and currents were not measured within the bay during that time (the USGS oceanographic instruments were deployed in June 2005; Storlazzi and others, 2006). The nearest buoy operated by the National Oceanic and Atmospheric Administration, 270 km WNW of Kaua'i, recorded conditions between February and June 2005 that could account for remobilization and removal of substantial fluvial sediment from Hanalei Bay if similar conditions prevailed within the bay itself. Data from that buoy indicate a storm in mid-March 2005 with significant wave heights (H_{sig}) greater than 7 m (http://www.ndbc.noaa.gov/station_page.php?station=51001). Such energetic oceanographic conditions, common on Kaua'i's north shore in winter months, apparently removed most of the sediment delivered by the 2/2/05 flood from Hanalei Bay.

At several core sites, sediment collected in August 2005 was markedly different in composition from that collected in June. At Station A in the Black Hole, the facies sampled in June and August were broadly similar (both exhibiting the dark, consolidated mud with sparse sand and terrestrial-vegetation debris below ~20 cm) but the June (Core K0605-1) and August (K0805-7) isotopic profiles were substantially different. These differences in sediment content and isotopic profiles are likely a result of having sampled slightly different locations in August than in June, although attempts were made to return to the very same stations using previously recorded GPS waypoints. It is not possible otherwise to explain the disappearance, by late August, of all of the ^{7}Be that had been present at Station A in June. Too little time had elapsed between collection of the June and August cores (83 days, or 1.6 half-lives) for all of the June ^{7}Be inventory to have been lost by radioactive decay. Wave and current gages in the bay recorded no resuspension events between June and August that could have removed the upper ~20 cm of ^{7}Be-rich sediment (Storlazzi and others, 2006).

The variety of sediment, and the variable thickness of recently delivered fluvial material (as identified by the presence of ^{7}Be) implies a spatially heterogeneous sea floor, particularly at the east side of the bay near the river mouth. It is likely that bioturbation disturbed most or all of the cored sediment and isotopic profiles, altering their appearance in August from what it had been in June; evidence for bioturbation was frequently observed, including burrows, mottled texture (fig. 19), and the presence of live worms, small shrimp, and, in Core K0805-7 from Station A in the Black Hole, a live 1-cm-diameter crab. Bioturbation would be expected to mix the sediment and its associated particle-reactive isotopes and to blur peaks in isotope activity, but would have little or no effect on the total inventory of a particular isotope beneath the sea floor at a given site.

Grab samples of sediment collected from the Hanalei River bed in August 2005 indicated a general pattern of river-bed ^{7}Be activity that decreased by an order of magnitude downstream (with the exception of the sample taken at River Site #3, in which ^{7}Be was absent; this is probably attributable to the coarse grain size at that location). River Site #1, the farthest upstream of the four river samples, contained ^{7}Be activity of 0.22 ± 0.06 dpm g^{-1}, almost the highest of any marine or fluvial samples collected in August. This value is similar to the ^{7}Be activity measured in August 2005 at marine Stations F and G, both of which were very near the river mouth. Activity of ^{137}Cs decreased downstream by two orders of magnitude along the lowermost 4 km of the river channel, from 0.39 (a value much higher than was found in all but one of the marine sediment samples) to 0.003 dpm g^{-1}. These down-channel decreases in ^{7}Be and ^{137}Cs activity are consistent with the expected behavior of these isotopes, which tend to be concentrated in terrestrial runoff. Excess ^{210}Pb in the river-bed samples increased by more than an order of magnitude down-channel from River Site #1 to the mouth, likely due to the availability of excess ^{210}Pb in the marine water column (the basaltic Hawaiian Islands, which are poor in the parent ^{238}U compared with granitic continental source rocks, correspondingly produce little terrestrial ^{210}Pb). It is noteworthy, though, that sediment samples from the lower Hanalei River probably do not record a purely terrestrial sediment signal, especially during summer low discharge. Calhoun and Fletcher (1999) recorded, on three-fourths of their sampling days, a wedge of sea water under the traffic

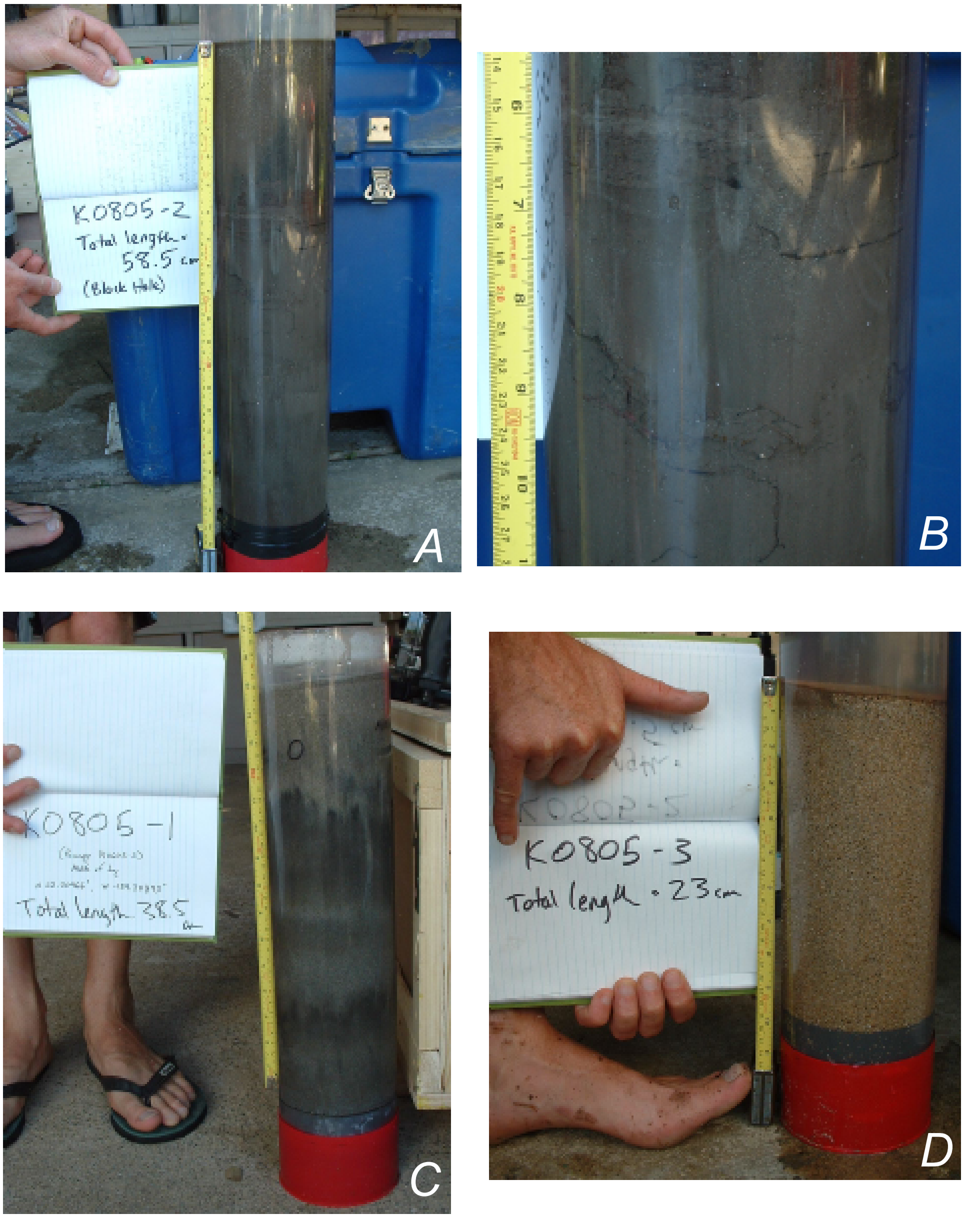

Figure 18. *Photographs of sediment cores from Hanalei Bay.* A. *Mixed mud and sand overlie consolidated mud in sediment from the Black Hole (Core K0805-2, collected in August 2005 from Station F).* B. *Close-up view of the same core as in A, showing detail of mud with carbonate sand that grades upward into laminated mud containing peat and rare sand. A contact occurs at 15.5 cm, above which laminated mud was present (see appendix 2 for a complete facies description).* C. *Alternating sandy (lighter) and muddy (darker) horizons in Core K0805-1, collected at Station B in the south-central part of Hanalei Bay.* D. *Example of the uniform, unconsolidated sand that occurs in many of the cores, with a fine-grained surface 'fluff' layer (Core K0805-3, from Station C on the northeast side of the bay).*

Figure 19*. Photograph of mottled texture attributed to bioturbation in sandy sediment. This example is from Station B in the south-central part of Hanalei Bay, Core K0805-1. The internal core diameter is 10.8 cm.*

bridge (our River Site #2) with a thickness that typically occupied the lower half of the river's water column. With this saltwater wedge underlying fresh water in the lower river channel, ocean-sourced ^{210}Pb and suspended sediment of marine origin could affect the terrestrial isotopic signal sampled at River Sites #2, 3, and 4.

The total inventory of ^{7}Be, ^{137}Cs, and excess ^{210}Pb at each core site varied slightly between the June and August 2005 sampling visits (figs. 20–22). It is clear from the ^{7}Be inventory calculations that the greatest accumulation of recent fluvial sediment (that which had been delivered within the past ~8 months, likely dominated by the 2/2/05 flood) is near the Hanalei River mouth on the east side of the bay (fig. 20) and in the Black Hole. Cesium-137, which, like ^{7}Be, is concentrated primarily in terrestrial sediment, shows a similar pattern, with the highest total inventories in the Black Hole and at Station G, although in August 2005 the south-central part of the bay (Station B) had a ^{137}Cs inventory nearly as high as that on the east side of the bay, at 2.38 dpm cm^{-2} (though based on a single-point peak; fig. 21).

Excess ^{210}Pb inventory in the marine sediment cores did not show patterns as clear as those of ^{7}Be and ^{137}Cs (fig. 22). This is partially because cores were not always long enough to include all of the down-core extent of excess ^{210}Pb (see tab. 1; for this reason, excess ^{210}Pb inventory for several sites have been omitted from fig. 22 and others are reported as minimum values). High excess ^{210}Pb inventory at core sites away from the river mouth (such as Station B) suggests that a major source of excess ^{210}Pb is scavenging from seawater. It is probable that grain-size variation has affected some of the isotopic profiles in the cores collected for this study (as substances that adsorb to particle surfaces, all three isotopes will be present in higher activity levels in finer sediment compared to the same mass of coarse-grained sediment). However, none of the cores exhibited a 'standard' excess ^{210}Pb profile (one with a well defined surface mixed layer underlain by gradually decreasing activity and finally by background or 'supported' activity) that would have represented undisturbed sediment (Nittrouer and others, 1979). This is not surprising given the energetic wave climate that prevails in Hanalei Bay during the fall and winter, which would be expected to resuspend sediment frequently; resuspension events would disturb any established ^{210}Pb profile while also providing an opportunity for sediment to scavenge additional ^{210}Pb from the water column. Given the irregular ^{210}Pb-activity profiles in these cores, it is not practical to try to estimate accumulation rate by either the Constant Initial Concentration or the Constant Rate of Supply geochemical models often applied for such purposes (Bentley and Nittrouer, 1999; Noller, 2000; Draut and others, 2005).

Accumulation and Transport Patterns:

The summer of 2005 was an interval during which no major Hanalei River floods occurred. Although this study interval was quiescent with respect to fluvial sediment delivery to the bay (the most recent substantial flood having occurred on 2/2/05), summer floods can and do happen on this river that are an order of magnitude higher than the discharge during summer 2005. Recent examples include a 27 $m^3 s^{-1}$ (962 cfs) event on July 12, 2000, and a 56 $m^3 s^{-1}$ (1,960 cfs) event on July 26, 2003. Floods of these magnitudes have the potential to deposit large quantities of sediment in the bay, by the combination of a large sediment input with low summer wave and current energy. The weak, cyclonic, near-bottom currents, weak anticyclonic surface currents (0.02–0.05 m s^{-1}), and low wave heights (H_{sig} 0.2–0.8 m) measured in the bay by Storlazzi and others (2006) during the summer of 2005 would likely not be efficient enough to flush a major fluvial sediment input out of the bay quickly. A large summer flood could therefore create substantial turbidity in the photic zone while quiescent conditions would allow sediment to settle on reefs and the sea floor within the bay.

Based on the oceanographic data collected by Storlazzi and others (2006), it is likely that the anticyclonic surface summer currents redistribute sediment from the hypopycnal fluvial surface plume in a clockwise pattern around the bay. This is supported by the low proportion of mud and organic terrigenous material at Station C on the northeast side of the bay, which would be up-current from the river mouth and Black Hole depocenter during the summer. It is inferred that these fine-grained and low-density materials would have been winnowed out of fluvial material while in suspension near that site and transported to the south, leaving the coarser siliciclastic sand to settle downward where it would encounter cyclonic near-bottom currents (Storlazzi and others, 2006). Siliciclastic sand, but little to no terrigenous mud or organic debris, was found on the northeast side of the bay within the sea floor at Station C (Core K0605-3). Terrestrial materials may be transported south with the river plume by anticyclonic surface currents toward the Black Hole. Sediment that settles to the sea floor in the Black Hole is likely to remain there at least temporarily, because this bathymetric depression forms a natural sediment trap.

Current patterns measured by Storlazzi and others (2006) are consistent with the lack of terrigenous material in the middle of the bay (Station E). The anticyclonic surface current may also have been responsible for transporting terrestrial leaf litter from the Hanalei River mouth to the northwest side of the bay (Station D). Alternatively, the organic matter on the sea floor and ~20 cm deep at Station D (Core K0605-4) could have been delivered by the lesser flow of the Waipa or Wai’oli Rivers and then transported north to that site by the current. It is not known how winter sediment-transport pathways may differ from those inferred from the summer data sets collected by this study and by Storlazzi and other (2006). Additional oceanographic and sedimentologic studies planned for the summer of 2006 will likely clarify patterns of sediment motion around the bay.

The core sites discussed in this report, and several planned new sites in the Black Hole, which seems to act as an important sediment trap, will be sampled again in June and August, 2006. The 2006 sampling plan is intended to capture a record of several major river floods that have occurred during winter and spring 2006, and to document the sedimentary signal of any floods that may occur in spring and summer 2006. New core stations around the bay, in addition to four new core sites currently planned for the Black Hole area, may be sampled

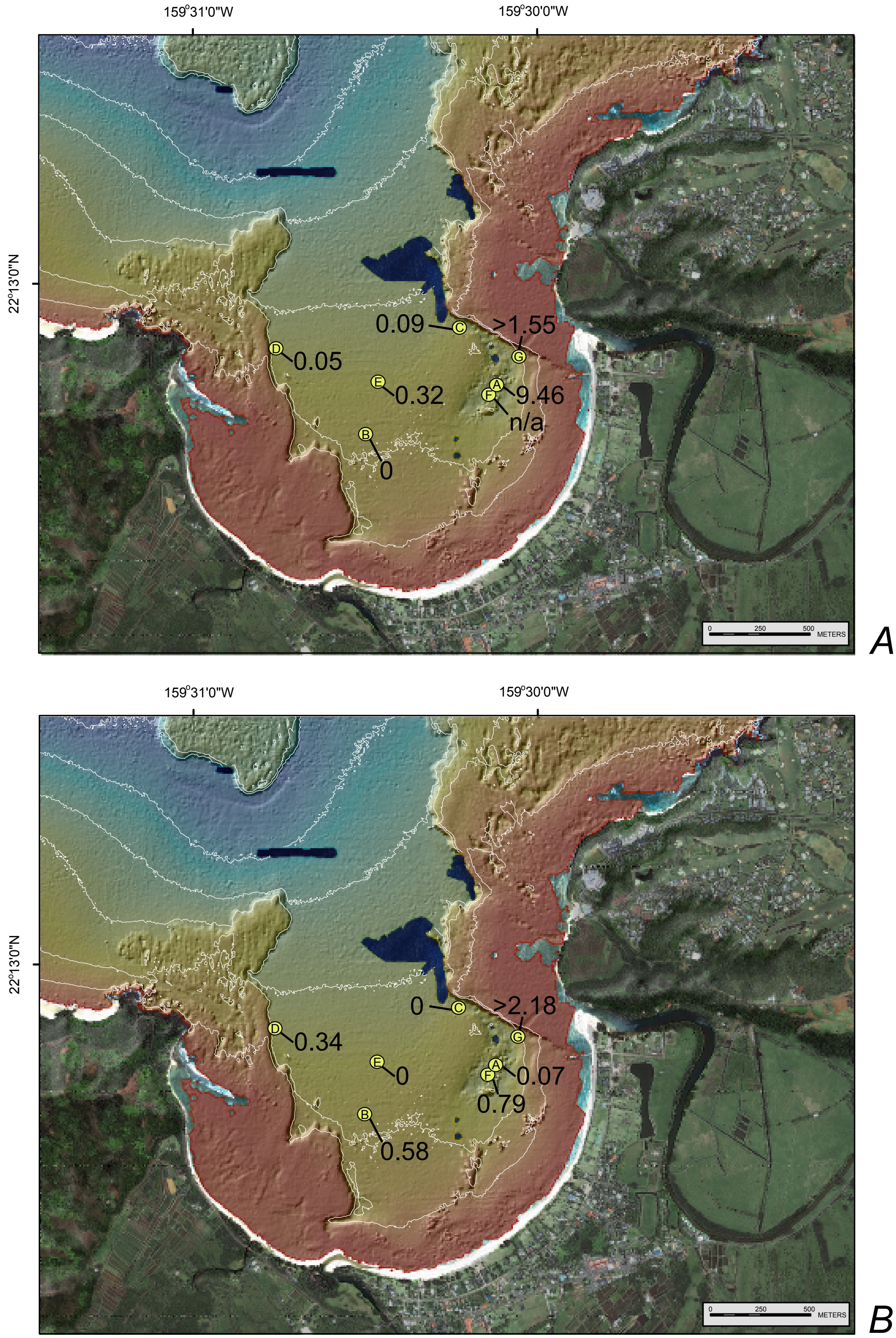

Figure 20. *Inventory of ^{7}Be, in dpm cm^{-2}, at core sites in June* (A) *and August* (B) *2005. Where minimum values are given, cores were not long enough to capture all of the inventory of this isotope (see tab. 2).*

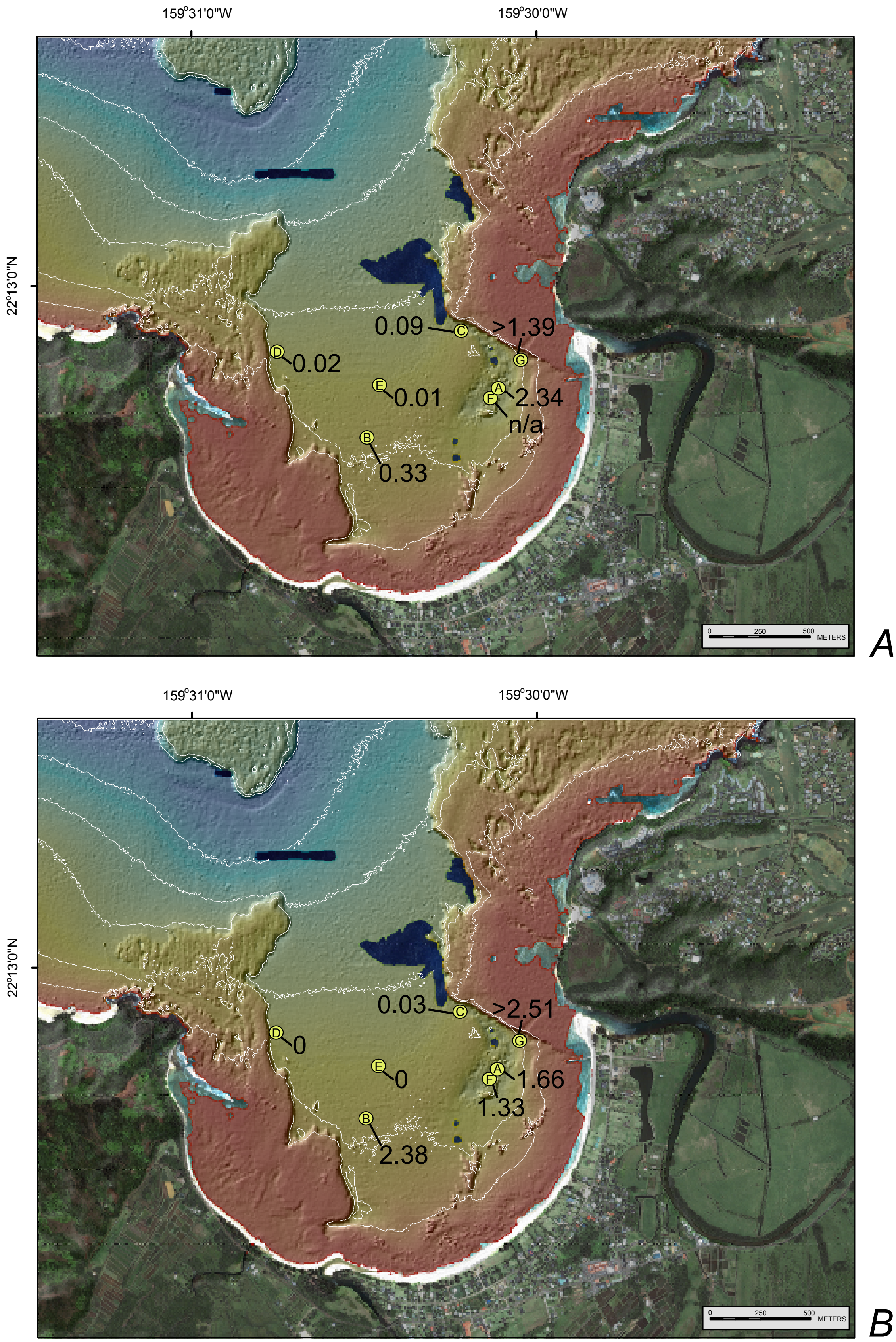

Figure 21. *Inventory of* ^{137}*Cs, in dpm cm*$^{-2}$*, at core sites in June* (A) *and August* (B) *2005. Where minimum values are given, cores were not long enough to capture all of the inventory of this isotope (see tab. 2).*

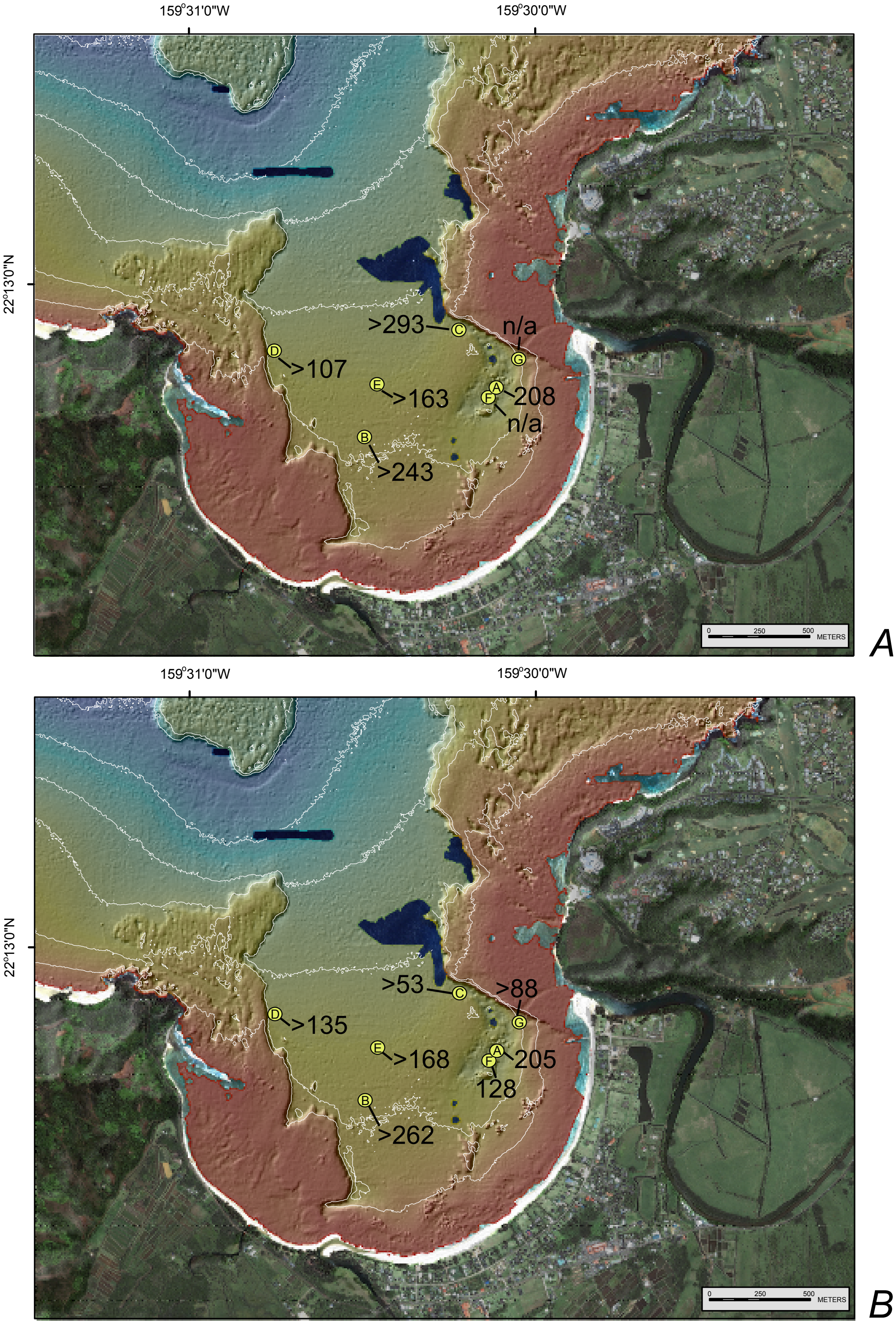

Figure 22. *Excess ^{210}Pb inventory in dpm cm^{-2} at core sites in June* (A) *and August* (B) *2005. Where minimum values are given, cores were not long enough to capture all of the inventory of this isotope (see tab. 2). Because excess ^{210}Pb activity typically penetrates deeper beneath the sea floor than that of ^{7}Be or ^{137}Cs, excess ^{210}Pb inventory relies on collection of longer cores. Values are not given ("n/a") for sites at which cores were too short to estimate the excess ^{210}Pb inventory.*

if the initial sampling efforts in June 2006 suggest that studying more sites would be warranted. If the distribution of recent fluvial sediment can be quantified shortly after a flood and again several months later, these isotope-geochemical techniques can thus be used to compile a more complete picture of the sediment dynamics in Hanalei Bay that affect local coral-reef communities.

CONCLUSIONS

Sedimentary facies and short-lived isotopes have been used to map the distribution of recent fluvial sediment delivered to Hanalei Bay, Kaua'i. The youngest and thickest terrigenous sediment is located on the east side of the bay near the Hanalei River mouth and in the Black Hole bathymetric depression, which apparently acts as a sediment trap. The thickest accumulation of recent fluvial sediment was sampled in the Black Hole, where as much as 22 cm of predominantly terrestrial sediment may have accumulated within the previous eight months based on a ^{7}Be-activity profile. Recent terrestrial sediment detected in June 2005 may have been the remnant of a much more substantial flood deposit from a Hanalei River flood in early February 2005. Core sites farther from the river mouth, in the middle and western part of the bay, did not contain a significant quantity of recent fluvial sediment during the spring and summer of 2005.

The coral-reef community in Hanalei Bay has the potential to be adversely affected by the delivery of fluvial sediment. Deposition on and burial of corals by sediment during summer floods, when wave and current energy are low and sediment would not be readily remobilized, could have significant effects on the reef ecosystem. Additional study in 2006 may clarify the spatial and temporal patterns of sediment redistribution in the bay following substantial spring and summer input of fluvial sediment. Sediment cores will be collected again at the same sites discussed here during early and late summer 2006. If possible, up to six sites will be sampled in the Black Hole depocenter near the river mouth (Stations A, F, and four new sites). Major floods of the Hanalei River have occurred in winter and spring 2006, some of which occurred late enough that they are expected to have left a significant new sediment signal in the bay.

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APPENDIX 1: Sediment log for cores collected in June 2005

Station A (Core K0605-1; Black Hole):
0–0.5 cm: Fine-grained 'fluff' layer of surface sediment.
0.5–2 cm: Medium to coarse sand.
2–6 cm: Rounded pebbles up to 2.5 cm in diameter, in medium-coarse sand matrix.
6–13 cm: Dominantly medium to coarse sand but with some fine, dark mud along one side of the core. Several 1–2 mm-wide burrows occur from 10–13 cm.
13–17 cm: Medium to coarse sand with sharp base.
17–58 cm: Dark, very fine mud that is more consolidated than the overlying horizon. Sediment is gray, black, or brown mud with some small plant rootlets and pieces of wood in the lower part of this unit. A rounded clump of mud was found that spanned from 30–35 cm depth, speculated to have been a possible mud rip-up clast. Similar objects were observed on the sea floor in this area of this core site at the time of its collection.

Station B (Core K0605-2; Middle-south part of bay):
0–0.5 cm: Thin surface fluff layer that is easily mobilized by surge on sea floor.
0.5–34 cm: Homogenous carbonate sand.

Station C (Core K0605-3; Northeast side of bay along coral wall):
This core was disturbed by water flowing through the unconsolidated sand during collection.
0–0.5 cm: Thin surface fluff layer (organics and very fine sediment) that is easily mobilized by surge on sea floor.
0.5–36 cm: Homogenous carbonate sand.
36–52 cm: Sand appears finer and has a grayer color than the overlying more yellow sand. This is attributed to a higher heavy-mineral content in this lower unit. Two coral fragments >1 cm across were present, at 40 cm and at 50 cm.

Station D (Core K0605-4; Northwest side of bay near CRAMP site):
0–0.5 cm: Thin surface fluff layer that is easily mobilized by surge on sea floor.
0.5–18 cm: Homogenous carbonate sand.
18–21 cm: Dark organic matter including leaves and twigs up to 5 cm long.

Station E (Core K0605-5; Middle of bay):
This core was disturbed by water flowing through the unconsolidated sand during collection.
0–21 cm: Homogenous fine- to medium-grained carbonate sand.

Station F (Core K0605-6; Black Hole):
Only 4 cm of core recovery. Fluff / fluid-mud layer was present on the sea floor initially but was lost or disturbed by core collection.

Station G (Core K0605-7; Along reef wall near Hanalei River mouth):
0–8.5 cm: Sand.
8.5–12 cm: Mixed sand and mud, mottled coloring, with some dark gray to black patches.
12–15 cm: Sand.

APPENDIX 2: Sediment log for cores and river-bed samples collected in August 2005

Station A (Core K0805-7; Black Hole):
0–0.5 cm: Fine-grained brown ‘fluff’ layer of surface sediment.
0.5–7 cm: Carbonate sand mixed with mud.
7–13 cm: Dark brown to black mud. Within that horizon is (from 10–12 cm) fresh woody debris, other organics, worms, and less sand than the overlying horizon.
13–20 cm: Mixed carbonate sand, mud, and peaty organic debris.
20–22 cm: Brown, peaty mud with well preserved leaves and trace amounts of wood.
22–30 cm: Brown peaty mud with well preserved leaves. Small amount of sand but dominantly mud with leaves.
30–42 cm: Brown peaty mud with well preserved leaves.
42–49 cm: Brown peaty mud with well preserved leaves; mottled texture, no real bedding. Sparse sand.
48 cm: Burrows visible; wood and plant debris within brown peaty mud.
49–53 cm: Plant matter.

Station B (Core K0805-1; Middle-south part of bay):
0–10 cm: Fine to medium-grained gray to tan-colored sand.
10–19 cm: Slightly darker gray sand compared to the overlying horizon. An isolated clayey patch (1–2 cm wide) is present at 17 cm.
19–20 cm: Lighter-colored sand compared to the overlying horizon.
20–23 cm: Darker gray sand compared to the overlying horizon.
23–28 cm: Lighter-colored sand compared to the overlying unit; this horizon has a sharp basal contact. An isolated clayey patch (1–2 cm wide) is present at 25 cm.
28–30 cm: Darker sand with void space ~1 cm wide.
30–38.5 cm: Grades gradually downward to lighter colored sand. An isolated clayey patch (1–2 cm wide) is present at 33 cm.

Station C (Core K0805-3; Northeast side of bay along coral wall):
0–2 cm: Surface fluff / fluid-mud layer, mixing downward into fine carbonate sand.
2–23 cm: Unconsolidated, homogenous mixture of medium- to coarse-grained carbonate and terrigenous sand.

Station D (Core K0805-4; Northwest side of bay near CRAMP site):
0–0.5 cm: Small amount of leaf litter on sea floor but no real fluff layer.
0.5–34 cm: Homogenous, unconsolidated carbonate sand.

Station E (Core K0805-6; Middle of bay):

0–39 cm: Homogenous, unconsolidated carbonate sand; small amount of mixing when core was collected. Mottled coloration was observed at a depth of 6 cm, attributed to bioturbation.

Station F (Core K0805-2; Black Hole):
Several worms were present in this core.
0–0.5 cm: Surface fluff / fluid-mud layer, very fine sediment.
0.5–9.5 cm: Coarser sediment (unit coarsens upward) including carbonate sand and mud.
9.5–12 cm: Laminated mud with occasional gravel-sized clasts. Dark brown to black sand and mud. At 12 cm is a sharp basal contact.
12–14 cm: Laminated gray to brown mud.
14–15.5 cm: Gray laminated mud layer with an abrupt lower contact. This unit is peaty.
15.5–32 cm: Brown to black mud with occasional carbonate sand grains. The lower contact is gradational as this horizon grades down into sandier facies.
32–58.5 cm: Brown to black mud with some carbonate sand. At 40 cm was a piece of wood that measured 4 cm long and 1 cm wide.

Station G (Core K0805-5; Along reef wall near Hanalei River mouth):
0–0.5 cm: Surface fluff / fluid-mud layer, dark brown.
0.5–4 cm: Medium to coarse-grained carbonate sand.
4–5 cm: Fine black mud mixed with carbonate sand.
5–12 cm: Mixed carbonate sand and black mud. A 2-cm-wide clast of coral rubble occurs at a depth of 5 cm.
12–16 cm: Poorly sorted carbonate sand.
16–18 cm: Mixed carbonate sand and black mud.
18–28 cm: Unsorted, unstratified mixture of coarse-grained sand, coral rubble, and terrestrial gravel.

River Site #1 (~4 km upstream of river mouth, near USGS gaging station 16103000): Sediment at this site consisted of mud and abundant organic debris, including leaves and stems. Logs and branches are present underwater in the river channel in the immediate area surrounding this sample location.

River Site #2 (under the traffic bridge where the access road between the towns of Hanalei and Princeville crosses the Hanalei River, ~2.5 km above the river mouth): Sediment at this site is dominantly mud with abundant organic debris.

River Site #3 (approximately 0.5 km above the river mouth): Sediment at this location is mixed sand and mud, dominated by dark, heavy-mineral, siliciclastic grains.

River Site #4 (on river left at the mouth, adjacent to the Hanalei beach park): Sediment at this site is fine sand and mud that forms a sandbar 5–15 m wide.