Lower Duwamish Waterway Group

Port of Seattle / City of Seattle / King County / The Boeing Company

Lower Duwamish Waterway Remedial Investigation

DATA REPORT:
SEDIMENT TRANSPORT CHARACTERIZATION
FINAL

For submittal to

The US Environmental Protection Agency
Region 10
Seattle, WA

The Washington State Department of Ecology
Northwest Regional Office
Bellevue, WA

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Acronyms

Acronym	Definition
ARI	Analytical Resources, Inc.
COC	chain-of-custody
CSM	conceptual site model
DQI	data quality indicator
dw	dry weight
Ecology	Washington Department of Ecology
EDS	Environmental Data Services, Ltd.
EPA	US Environmental Protection Agency
FS	feasibility study
LCS	laboratory control standard
LDW	Lower Duwamish Waterway
MLLW	mean lower low water
MS/MSD	matrix spike/matrix spike duplicate
Pa	pascal
pCi/g dw	picocuries/gram dry weight
PVC	polyvinyl chloride
PSEP	Puget Sound Estuary Program
PST	Pacific Standard Time
PTL	Particle Technology Labs, Ltd.
QAPP	Quality Assurance Project Plan
QEA	Quantitative Environmental Analysis, LLC
RI	remedial investigation
RPD	relative percent difference
RSD	relative standard deviation
SEI	Sea Engineering, Inc.
SRM	standard reference material
TOC	total organic carbon
Windward	Windward Environmental, LLC
ww	wet weight

1.0 Introduction

This data report presents the results of analyses of geochronology and erosion property sediment samples collected as part of the Phase 2 Remedial Investigation (RI) for the Lower Duwamish Waterway (LDW). As described in the Phase 2 RI work plan (Windward 2004b), the results of these analyses will aid in designing the subsurface sediment sampling program and will refine the preliminary conceptual site model (CSM) for sediment transport initially presented in the Phase 1 RI report (Windward 2003) and refined in the sediment transport characterization quality assurance project plan (QAPP) (Windward 2004a). In addition, these results will be used in the feasibility study (FS) to evaluate remedial alternatives. Collection and analysis of these samples was conducted in accordance with the QAPP (Windward 2004a).

The geochronology study was designed to partially fulfill Task 1 of the sediment transport characterization by addressing issues related to the depositional environment within the LDW. The primary objectives of Task 1 are:

- collect and analyze sedimentation data from bench areas
- develop an improved understanding of the depositional environment within the LDW by combining bench-area data with existing navigation channel data/information and other bathymetric analyses

The erosion property study was designed to partially fulfill Task 2 of the sediment transport characterization by evaluating the potential for sediment bed scour within the LDW resulting from both natural and anthropogenic hydrodynamic forces. The objectives of Task 2 are:

- collect and analyze data on the potential for sediment bed erosion
- quantify the effects of hydrodynamics on the spatial distribution of bottom shear stress in the LDW for various flow conditions
- determine areas of potential sediment bed scour during rare high-flow events
- quantify the impacts of anthropogenic forces (e.g., ship propeller scour) on sediment bed erosion

The first objectives listed above for Tasks 1 and 2 were met by conducting two field events. Sediment cores for the geochronology study were collected on December 16 and 17, 2004, and sediment cores for the erosion property field study were collected on December 6 to 9, 2004. For both tasks, Section 2.0 summarizes the sample collection and processing methods, sample identification, and field deviations from the QAPP. Section 3.0 summarizes the laboratory methods and deviations from the QAPP, and Section 4.0 summarizes the laboratory and data validation results. Section 5.0 provides reference citations. Additional non-laboratory analyses will be conducted, as described in the QAPP and the above bullets. The results of these additional analyses will be described in the sediment transport data analysis report, which will be submitted to EPA and Ecology on July 8, 2005.

The text of this report is supported by the following appendices:

- Appendix A – data tables
- Appendix B – data management
- Appendix C – data validation reports
- Appendix D – raw analytical laboratory data
- Appendix E – field notes, laboratory notes, sediment collection forms, and sample alteration forms
- Appendix F – chain-of-custody forms

2.0 Geochronology and Erosion Property Sample Collection and Processing Methods

This section briefly describes sediment core collection and sample processing methods. The field procedures are described in more detail in the QAPP (Windward 2004a). Field deviations from the QAPP are also presented in this section. Photocopies of field and laboratory forms, notebooks, and sample alteration laboratory forms are presented in Appendix E. Photocopies of completed chain-of-custody (COC) forms used to track sample custody are presented in Appendix F.

2.1 GEOCHRONOLOGY FIELD STUDY

2.1.1 Geochronology core collection

QEA and Windward collected sediment cores from fourteen locations (Table 2-1, Figure 2-1) using a gravity corer with a 4-inch (outer diameter) polyvinyl chloride (PVC) core tube. Because inertia was utilized as the primary driving force to achieve the desired penetration depth, the degree of penetration was altered by either adjusting the number of weights at the top of the tube or by changing the vertical distance from which the core tube was allowed to free-fall. The corer was advanced into the sediment to refusal using enough weight to achieve the minimum target penetration depth of 80 cm. At each sample location, total water depth and total sediment recovered was measured and recorded in the field log book (Table 2-2). Time and date of core collection were also recorded.

Table 2-1. Geochronology sediment core sampling locations in the LDW

Location	Target Location				Actual Location			
	Latitude	Longitude	X	Y	Latitude	Longitude	X	Y
LDW-Sg1a	47 33.9888	122 20.9617	1266172	210321	47 33.9891	122 20.9605	1266177	210323
LDW-Sg2	47 33.5523	122 20.9733	1266072	207669	47 33.5580	122 20.9707	1266083	207703
LDW-Sg3	47 33.2353	122 20.4620	1268138	205701	47 33.2358	122 20.4607	1268143	205704
LDW-Sg4	47 33.0290	122 20.3632	1268520	204439	47 33.0316	122 20.3681	1268500	204455
LDW-Sg5a	47 32.5858	122 20.2131	1269085	201733	47 32.5916	122 20.2080	1269107	201768
LDW-Sg6	47 32.3628	122 19.8570	1270524	200349	47 32.3628	122 19.8574	1270523	200349
LDW-Sg7	47 32.1007	122 19.4613	1272122	198724	47 32.1006	122 19.4630	1272115	198724
LDW-Sg8	47 31.6785	122 18.6658	1275347	196095	47 31.6783	122 18.6665	1275344	196094
LDW-Sg9	47 31.5925	122 18.6275	1275495	195569	47 31.5921	122 18.6278	1275494	195567
LDW-Sg10	47 31.5880	122 18.5438	1275839	195535	47 31.5876	122 18.5447	1275835	195533
LDW-Sg11b	47 31.3714	122 18.4395	1276243	194210	47 31.3713	122 18.4425	1276231	194210
LDW-Sg11c	47 31.4298	122 18.4582	1276173	194567	47 31.4300	122 18.4582	1276173	194568
LDW-Sg12	47 31.0366	122 18.3723	1276481	192170	47 31.0369	122 18.3720	1276482	192172
LDW-Sg13	47 30.9432	122 18.2900	1276809	191596	47 30.9434	122 18.2905	1276807	191597

Coordinates given in NAD83 horizontal datum; latitude and longitude expressed in degrees and minutes; X-Y coordinates in Washington State Plane N (US feet).

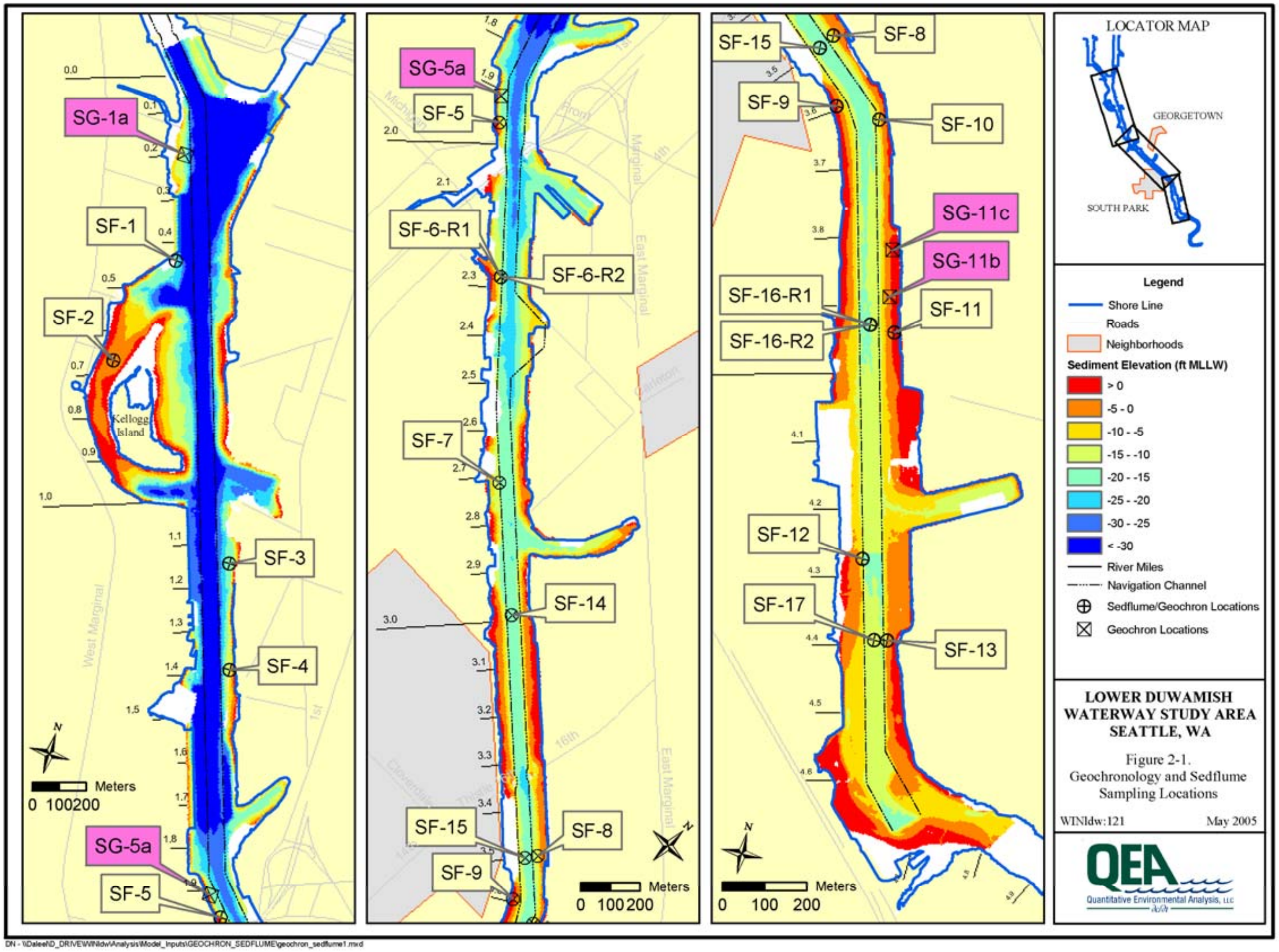

Figure 2-1. Geochronology and sedflume sampling locations

Table 2-2. Sample collection information for geochronology sediment cores in the LDW

Location	Collection Date	Time (PST)	Elevation (ft MLLW)	Penetration Depth[a] (cm)	Core Recovery[b] (cm)	Percent Recovery[c]
LDW-Sg1a	12.17.2004	1512	-17.7	165	127	77
LDW-Sg2	12.17.2004	1424	-3.5	122	87	71
LDW-Sg3	12.16.2004	1406	-21.4	175	136	78
LDW-Sg4	12.16.2004	1225	-12.8	170	117	69
LDW-Sg5a	12.17.2004	0954	-16.5	162	138	85
LDW-Sg6	12.16.2004	1147	-17.9	205	140	68
LDW-Sg7	12.16.2004	0802	-16.1	150	118	79
LDW-Sg8	12.16.2004	1043	-10.3	165	133	81
LDW-Sg9	12.16.2004	1027	+0.4	165	96	58
LDW-Sg10	12.16.2004	0934	-11.0	132	101	78
LDW-Sg11b	12.17.2004	1244	-1.3	83	43	52
LDW-Sg11c	12.17.2004	1157	+0.6	116	36	31
LDW-Sg12	12.16.2004	0854	-11.1	182	123	68
LDW-Sg13	12.16.2004	0834	-8.3	180	130	72

[a] penetration depth estimated in the field by measuring the distance from the top of the core catcher insert (estimated from outside the gravity corer) to the highest level sediment reached along the outside of the gravity corer

[b] core recovery was measured in the field by measuring from the top of core catcher insert (estimated from outside the gravity corer) to the top of the core tube, and subtracting the distance from the top of the core tube to the sediment surface layer inside the tube

[c] percent recovery was calculated as core recovery/penetration depth x 100

MLLW – mean lower low water

PST – Pacific Standard Time

2.1.2 Geochronology core processing

Following core collection, each sediment core was extruded in 1-cm increments using a hydraulic extruder jack. The outer layer (0.25 to 0.5 cm) of each 1-cm core section was scraped away using a stainless steel straight edge to exclude any sediment that came in contact with the wall of the core tube. Each 1-cm sediment section was removed using the stainless steel straight edge and placed in a stainless steel bowl. This process was repeated for each sediment sample interval, including those that were archived. Each sample interval was visually inspected and physical characteristics were recorded. These characteristics include general sediment type and approximate grain size (i.e., fine, medium, coarse) (see Appendix E-3). The sample was then thoroughly homogenized with a stainless steel spoon, split, placed into two labeled sample containers, and stored at 4°C. All stainless steel straightedges, bowls, and spoons were thoroughly decontaminated between samples by cleaning them with an Alconox® detergent solution, rinsing with tap water, and rinsing with deionized water. The equipment was then wrapped in aluminum foil to prevent contamination between uses.

Every fifth segment of the sediment core (e.g., 0-1 cm, 5-6 cm, 10-11 cm) was submitted for laboratory analysis for ^{210}Pb, ^{137}Cs, total solids, and total organic carbon (TOC). Samples (1-cm thick) that were not submitted for laboratory analysis were archived in jars prepared in the same way as those used for samples that were submitted for laboratory analyses. The number of segments submitted for laboratory analysis per core varied because of differences in total sediment core lengths collected. A maximum of 17 segments per core (not including field duplicate and matrix spike/matrix spike duplicate [MS/MSD] samples) were selected for laboratory analysis, which represents a maximum segment depth of 80-81 cm. In order to obtain enough mass for chemical analyses, 2-cm increments were sometimes collected to be split following homogenization between the field duplicate or MS/MSD sample and its parent sample. All remaining 1-cm segments beyond the 81-cm depth were archived for potential later analysis.

2.2 EROSION PROPERTY FIELD STUDY

2.2.1 Erosion property core collection

Sediment cores with a 30-cm minimum length for testing in a sediment flume apparatus (Sedflume) were collected by Sea Engineering, Inc. (SEI) from seventeen locations (Table 2-3, Figure 2-1) using the following procedure. A 10-cm x 15-cm rectangular corer was used during this study. Lexan corers were inserted into a thin stainless steel sleeve. The neck of the sleeve is a rectangular tube, so that the main body of the box corer fits snugly inside.

Table 2-3. Erosion property sediment core sampling locations in the LDW

LOCATION	TARGET LOCATION				ACTUAL LOCATION			
	LATITUDE	LONGITUDE	X	Y	LATITUDE	LONGITUDE	X	Y
LDW-Sf1	47 33.7803	122 20.8854	1266461	209048	47 33.7807	122 20.8900	1266442	209051
LDW-Sf2	47 33.5523	122 20.9733	1266072	207669	47 33.5520	122 20.9732	1266072	207667
LDW-Sf3	47 33.2353	122 20.4620	1268138	205701	47 33.2358	122 20.4607	1268143	205704
LDW-Sf4	47 33.0290	122 20.3632	1268520	204439	47 33.0326	122 20.3612	1268529	204461
LDW-Sf5	47 32.5621	122 20.1764	1269233	201586	47 32.5555	122 20.1594	1269302	201545
LDW-Sf6	47 32.3628	122 19.8570	1270524	200349	47 32.3625	122 19.8569	1270525	200347
LDW-Sf7	47 32.1007	122 19.4613	1272122	198724	47 32.1008	122 19.4610	1272123	198725
LDW-Sf8	47 31.6785	122 18.6658	1275347	196095	47 31.6787	122 18.6657	1275348	196096
LDW-Sf9	47 31.5925	122 18.6275	1275495	195569	47 31.5919	122 18.6279	1275493	195565
LDW-Sf10	47 31.5880	122 18.5438	1275839	195535	47 31.5881	122 18.5433	1275841	195536
LDW-Sf11	47 31.3279	122 18.4169	1276331	193944	47 31.3280	122 18.4174	1276329	193945
LDW-Sf12	47 31.0366	122 18.3723	1276481	192170	47 31.0365	122 18.3712	1276485	192169
LDW-Sf13	47 30.9432	122 18.2900	1276809	191596	47 30.9432	122 18.2886	1276815	191596

Location	Target Location				Actual Location			
	Latitude	Longitude	X	Y	Latitude	Longitude	X	Y
LDW-Sf14	47 31.9495	122 19.1803	1273261	197783	47 31.9495	122 19.1803	1273261	197783
LDW-Sf15	47 31.6600	122 18.6850	1275266	195984	47 31.6594	122 18.6854	1275264	195980
LDW-Sf16	47 31.3307	122 18.4651	1276133	193965	47 31.3307	122 18.4652	1276133	193965
LDW-Sf17	47 30.9396	122 18.3129	1276714	191576	47 30.9394	122 18.3128	1276715	191574

Coordinates given in NAD83 horizontal datum; latitude and longitude expressed in degrees and minutes; X-Y coordinates in Washington State Plane N (US feet).

The assembled coring sleeve was lowered to the sediment bed using a pole. Pressure was applied to the top of the sleeve, causing the sleeve to penetrate into the sediment bed. The coring sleeve was pushed into the sediment bed until refusal; penetration varied depending on the softness of the sediment. The objective was to obtain a relatively undisturbed core.

After retrieving the coring unit and bringing it onboard the sampling boat, the barrel was lifted off of the core tube and a plug was inserted into the core tube from the bottom to act as a piston for later use in Sedflume. The top of the core was then capped, and sediment cores were transported and stored thereafter in an upright position. After capping, cores were visually inspected for length and quality. If a sediment core appeared to have been disturbed during coring (e.g., surface layer washed out from draining water or debris obstructing sediment penetration), it was discarded and another core taken from that sampling location. Acceptable cores were capped and stored on deck until returned to the onshore processing site. Collection information for accepted cores is provided in Table 2-4.

Table 2-4. Collection information for erosion property sediment cores in the LDW

Location	Collection Date	Time (PST)	Elevation (ft, MLLW)	Core Recovery[a] (cm)
LDW-Sf1	12.09.2004	1540	-19.2	35.6
LDW-Sf2	12.09.2004	1316	-4.9	43.2
LDW-Sf3	12.09.2004	1406	-21.4	32.7
LDW-Sf4	12.09.2004	1140	-11.7	45.7
LDW-Sf5	12.09.2004	1035	-4.1	36.8
LDW-Sf6 [b]	12.07.2004	1439	-18.4	36.0
		1500	-18.7	41.0
LDW-Sf7	12.07.2004	1304	-16.6	38.0
LDW-Sf8	12.07.2004	1030	-11.7	37.0
LDW-Sf9	12.06.2004	1453	-2.0	48.0
LDW-Sf10	12.06.2004	1538	-10.7	40.6
LDW-Sf11	12.07.2004	1103	-0.9	39.0
LDW-Sf12	12.06.2004	1340	-13.5	54.5

LOCATION	COLLECTION DATE	TIME (PST)	ELEVATION (ft, MLLW)	CORE RECOVERY[a] (cm)
LDW-Sf13	12.06.2004	1044	-7.3	48.0
LDW-Sf14	12.09.2004	0927	-20.2	35.5
LDW-Sf15	12.09.2004	0853	-19.6	54.6
LDW-Sf16 [b]	12.07.2004	0905	-17.6	44.5
		1150	-16.8	41.0
LDW-Sf17	12.06.2004	1129	-18.1	46.0

[a] field estimate

[b] a field duplicate sample was taken at this location

MLLW – mean lower low water

PST – Pacific Standard Time

2.2.2 Erosion property core processing

At the onshore processing site, samples for bulk property analysis were taken from the core, placed in appropriate containers, labeled, sealed, and preserved for delivery to the laboratory. The sampling procedure for the bulk property samples is briefly described below. Sampling procedures are described in detail in Section 3.2.4 of the QAAP (Windward 2004a).

All sediment cores were tested using a Sedflume at the onshore processing site located at Terminal 117. Prior to testing a core in Sedflume, a visual description of sediment in the core was recorded. A qualitative description of sediment type (e.g., clay, silt, medium sand) for each sample interval tested was recorded on field forms (see Appendix D-3). Bulk property subsamples for each core were obtained from within the core; subsamples were collected at the surface (prior to starting the first shear stress cycle) and at the newly exposed surface after each shear stress cycle. Two 5-g subsamples of sediment were collected from the surface of the sediment core near the downstream edge of the test section. These subsamples were obtained while the core was in the Sedflume by stopping flow within the device, opening up the Sedflume, and manually collecting the samples.[1] The samples were analyzed for particle size distribution using a laser particle size analyzer, and for bulk density. Gas content was not determined for bulk density measurements; all samples for particle size were sonicated to disaggregate the sediments before they were analyzed for grain size.

At the start of each test, the core tube was inserted into the bottom of the test section. An operator moved the sediment upward through the core tube using a hydraulic piston that moved inside the core, pushing upward on the plug inserted earlier. By these means, the sediment in the core was raised and the sediment surface was positioned so that it was level with the bottom of the test section in Sedflume. Water

[1] Six erosion cycles were applied to each core. Subsamples for bulk density and particle size were collected during the first five (all but the deepest) erosion cycles.

collected from the LDW was forced through the duct and the test section over the surface of the sediments. As the sediment in the core eroded, the sediment core was moved upwards so that the sediment-water interface remained level with the bottom of the test section. The erosion rate was determined by measuring the amount of erosion (i.e., the distance the sediment core was moved upward within the core tube) in a specific amount of time.

Erosion rates at different shear stresses on the same core were measured by running Sedflume sequentially on the same core, starting at a low shear stress and doubling shear stress with each succeeding iteration.[2] Generally, about four iterations were run sequentially during a particular shear stress cycle. Each shear stress, measured in units of Pascals (Pa), was applied until at least 1-3 mm, but no more than 2 cm, of sediment was eroded, with each shear stress being applied for a minimum of 20 seconds and a maximum of 10 minutes.

The amount of erosion (i.e., the distance the sediment core was moved upward within the core tube) and time were recorded for each shear stress. This procedure defined the minimum erosion rate for LDW sediment as 1.67×10^{-4} cm/s, and the maximum erosion rate as 0.1 cm/s. The time interval was recorded for each cycle with a stopwatch. The flow was then increased to the next higher shear stress until the highest shear stress in the cycle was applied. This cycle was repeated until the top 30 cm of sediment in the core was eroded. Often, the Sedflume analysis could not be conducted on the lower 5-10 cm of the collected core due to a number of factors. Therefore, recoveries of greater than 30 cm may be listed where less than 30 cm of the core could be analyzed. If, after three shear stress cycles, an erosion rate of less than approximately 1.7×10^{-4} cm/s was measured for a particular shear stress, that shear stress value was dropped from the cycle; if, after multiple cycles, the erosion rates decreased significantly, a higher shear stress was included in the cycle. The method for converting flow rate to shear stress is described by McNeil et al. (1996).

2.3 Sample Identification Scheme

Each sampling location was assigned a unique alphanumeric location identification (ID) number. The first three characters of the location ID are "LDW" to identify the Lower Duwamish Waterway project area. The next characters indicate the type of samples to be collected (i.e., Sg for sediment cores for geochronology analysis and Sf for sediment cores for Sedflume analysis), followed by a consecutive number

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[2] Although linear increases in shear stress levels would help increase the accuracy of the critical shear stress interpolation, Sedflume operating procedures specify that shear stress levels are doubled starting at 0.1 Pa in order to accurately develop the relationship between erosion rate and shear stress. The risk of skewing data based on assumed critical shear stresses outweighs the potential loss of accuracy by using specified shear stress intervals.

identifying the specific location within the LDW area. The 13 geochronology locations and 17 Sedflume locations were numbered independently.

Sample ID numbers are similar to location ID numbers, but also indicate the depth interval included in the sample. For example, the 0 to 1 cm section of the sediment core collected at location LDW-Sg2 would be called LDW-Sg2-0-1. Field duplicate and MS/MSD samples were collected in 2-cm sections and identified with the sample ID number followed by FD or MS,MSD (e.g., LDW-Sg2-5-7-FD or LDW-Sg2-5-7-MS,MSD), respectively.

Sedflume cores were analyzed as a continuous unit (i.e., no discrete sampling intervals), so the sample ID number is the same as the location ID number for these cores. Field replicates of Sedflume cores were identified with the parent ID number followed by "DUP" (e.g., LDW-Sf6-DUP). However, bulk sediment samples from Sedflume cores were only identified by "SF" and followed by a two-digit station number (01-17), and sub-sample number (1-5) (e.g., SF-02-1, SF-02-2, etc.). Field replicates of bulk sediment samples were additionally identified with either "R1" or "R2" (replicate 1 or 2, respectively) between the station number and sub-sample number (e.g., SF-06-R1-1, SF-06-R2-1, etc.)

2.4 Field Deviations from the QAPP

Field deviations from the QAPP (Windward 2004a) included modifications to collection dates, methods, and locations. These field deviations did not affect the data quality and are discussed in detail below. EPA and Ecology were consulted on deviations that had a significant effect on study design.

- The QAPP specified that geochronology field work would be conducted December 6-17, 2004. The sampling was completed by December 17, but sample processing was not completed until December 29, 2004 because sediment core processing took longer than anticipated.
- A 3-inch (outer diameter) gravity corer specified in the QAPP was not used to collect sediment cores because it failed to provide enough sediment mass for the required chemistry analyses. A 4-inch (outer diameter) gravity corer was used instead. Photographs could not be taken through the 4-inch core tube, as specified in Section 3.2.3 of the QAPP, because it was opaque. The 3-inch corer utilized a clear core tube liner, through which photographs were to be taken, but the 4-inch corer did not require a core tube liner.
- The Unified Soil Classification System described in Section 3.2.3 of the QAPP was not used to describe the sediment type of each sample interval collected from the geochronology cores. Instead, a qualitative description of sediment type (e.g., clay, silt, medium sand) was recorded on the sediment collection forms (see Appendix E-3).

- Geochronology stations Sg1, Sg5, and Sg11 were relocated because of low recovery resulting from obstructions to the gravity corer by hard-packed native sediments. Cores were taken from alternate stations Sg1a, Sg5a, and Sg11b and c, respectively, in order to obtain higher recoveries. Both cores from Sg11b and c were retained for analysis despite continued low recoveries because no better recoveries could be obtained in the vicinity of Sg11. Thus, 14 geochronology cores were collected, instead of the 13 specified in the QAPP. Additionally, except for Sg5a, depths for the relocated locations met the target ranges specified in the QAPP. The targeted depth range of location Sg5 was >-5 ft and the actual depth of Sg5a was -16.5 ft.

3.0 Laboratory Methods

The methods and procedures used to analyze the sediment samples are described briefly in this section and in more detail in the QAPP (Windward 2004a).

Analytical Resources, Inc. (ARI) analyzed each homogenized sample collected from the geochronology cores for total organic carbon and total solids. Mass Spec Services conducted the radionuclide analyses for ^{210}Pb and ^{137}Cs. Particle Technology Labs, Ltd. (PTL) conducted the grain size analysis for Sedflume samples.

3.1 Sediment Analytical Methods

Sediment samples were analyzed by methods described in the QAPP (Windward 2004a) and in Table 3-1.

Table 3-1. Analytical methods for sediment analyses

Parameter	Unit	Method
^{210}Pb	pCi/g dw	radiochemical isolation/beta assay of Bi-210 daughter product
^{137}Cs	pCi/g dw	direct gamma spectral analysis
TOC	% dw	combustion (Plumb 1981)
Total solids	% ww	gravimetry (PSEP 1986)
Sediment grain size	% dw	laser diffraction (Malvern Mastersizer 2000)

dw – dry weight ww – wet weight pCi/g dw – picocuries/gram dry weight

3.2 Laboratory Deviations from the QAPP

The QAPP specified that percent moisture was to be analyzed for the geochronology samples, but ARI analyzed for total (percent) solids instead. Percent moisture can be calculated from the difference between 100 and percent solids.

Radionuclide analyses for matrix replicates for sediment cores Sg9, Sg11b, Sg11c, and Sg12 were not conducted because there was insufficient sample matrix from each core.

The QAPP indicated that dry density for Sedflume and geochronology samples would be calculated using Equation 3-2:

$$\rho_b = \frac{\rho_w \rho_s}{\rho_w + (\rho_s - \rho_w)W}$$

where

ρ_b = dry density (g/cm^3)

ρ_w = density of water (g/cm^3)

ρ_s = density of sediment particles (assumed 2.65 g/cm^3)

W = water content (i.e., percent moisture expressed as a unitless fraction)

However, the equation given was for bulk (or wet) density, which was actually the intended parameter to measure. The bulk density data presented in this report were calculated for both Sedflume and geochronology samples using Equation 3-2 from the QAPP.

These deviations did not affect the data quality.

4.0 Results

Results of the sediment analyses are summarized in this section. A detailed discussion of the approach used in averaging field duplicates and laboratory replicates is presented in Appendix B. The number of significant figures shown for each concentration in all tables in this section was specified by the analytical laboratory. There was no additional manipulation of significant figures.

Quality assurance review of the results was conducted in accordance with the QAPP (Windward 2004a). Environmental Data Services, Ltd. (EDS) conducted full validation for radionuclides on 20% of the total samples. Summary validation was conducted on all of the remaining samples, and for the conventional sediment analytes (grain size, TOC, and total solids). The results of the data validation are discussed in this section, and presented in full in Appendix C; raw laboratory data are presented in Appendix D.

4.1 Geochronology Study Results

Sediment core sections were analyzed for TOC and total solids by ARI and for ^{210}Pb and ^{137}Cs by Mass Spec Services. The results of these analyses are summarized in Table 4-1 and presented in full in Appendix A, Attachment A-1. The chemistry and radionuclide data are plotted as a function of core depth in Figures 4-1 through 4-14 (located at the end of this document).

Table 4-1. Summary of geochronology chemistry results

Station ID	TOC (%) Range	Total Solids (%) Range	^{210}Pb (pCi/g dw)			^{137}Cs (pCi/g dw)		
			Detection Frequency	Range of Detected Concs.	Range of Detection Limits	Detection Frequency	Range of Detected Concs.	Range of Detection Limits
LDW-Sg1a	1.42-3.12	47.00-55.00	17/17	0.27-0.94	na	13/17	0.093-0.431	0.055-0.093
LDW-Sg2	0.740-3.48	50.55-70.90	17/17	0.14-0.59	na	6/17	0.071-0.169	0.032-0.083
LDW-Sg3	1.43-2.60	46.80-55.05	17/17	0.50-1.00	na	15/17	0.100-0.357	0.081-0.089
LDW-Sg4	0.885-2.73	45.20-64.30	17/17	0.26-0.75	na	17/17	0.085-0.455	na
LDW-Sg5a	1.78-3.27	40.70-54.47	17/17	0.38-1.08	na	16/17	0.110-0.302	0.071
LDW-Sg6	1.16-2.32	51.10-72.60	17/17	0.22-1.02	na	17/17	0.072-0.224	na
LDW-Sg7	1.30-2.51	50.30-68.60	17/17	0.24-0.80	na	17/17	0.080-0.382	na
LDW-Sg8	1.11-2.73	54.60-71.60	17/17	0.22-0.51	na	0/17	na	0.028-0.065
LDW-Sg9	0.651-2.99	52.20-73.50	15/17	0.20-0.65	0.21-0.24	7/17	0.083-0.355	0.036-0.111
LDW-Sg10	1.23-2.23	48.30-61.60	17/17	0.21-1.04	na	17/17	0.102-0.290	na
LDW-Sg11b	0.847-2.85	57.50-83.90	9/9	0.18-0.43	na	6/9	0.096-0.161	0.032-0.057
LDW-Sg11c	0.581-1.96	59.93-77.60	7/7	0.19-0.36	na	5/7	0.097-0.241	0.034-0.050
LDW-Sg12	1.63-4.68	39.20-66.20	17/17	0.43-1.40	na	10/17	0.074-0.191	0.052-0.106
LDW-Sg13	1.43-2.97	44.70-61.70	17/17	0.37-1.04	na	10/17	0.070-0.129	0.049-0.122

na – not applicable
pCi/g dw – picocuries/gram dry weight

4.2 EROSION PROPERTY STUDY RESULTS

Results of the erosion property study are presented in Appendix A and in Figures 4-15 through 4-33 (located at the end of this document). Two field replicates (i.e., separate cores) were collected at Sf-6 and Sf-16. The results for these replicates are presented separately. Specifically, details of the Sedflume testing, including the magnitude and duration of the applied shear stresses and the measured erosion rates for each test cycle, are provided in Appendix A, Attachment A-2. Bulk density and particle size information for the sediment subsamples collected from the surface of the sediment core before each test cycle are presented in Appendix A, Attachment A-3. Bulk density and erosion rate data are plotted as a function of core depth in Figures 4-15 through 4-33. Sediments collected during the erosion potential study are composed primarily of sandy silt, and exhibit relatively uniform bulk sediment properties, both vertically throughout the sediment column as well as spatially throughout the LDW. For example, about 90% of the D_{50} (median particle size) values for individual samples vary between 10 and 50 μm, with this size range classified as silt. No gravel was detected in the cores and the maximum particle diameter is approximately 2,000 μm (coarse sand).

4.3 DATA VALIDATION RESULTS

TOC and total solids results were validated by Windward. The data quality indicator (DQI) for accuracy for laboratory control standards (LCS), standard reference materials (SRM), and MS recoveries is 75-125% for TOC. All LCS, SRM, and MS recoveries were within these limits. The DQI for precision for laboratory triplicate relative standard deviations (RSDs) for TOC is 30% and for moisture is 20%. Duplicate relative percent differences (RPDs) and triplicate RSDs were acceptable. The QAPP criteria for field duplicate RPDs are 30% for TOC and 20% for moisture. The RPD values met the QAPP criteria. All data are valid and acceptable for use. None of the results were qualified.

Radionuclide results were validated by EDS. All samples collected during the course of this project were validated according to level A requirements of US Department of Energy TPR-80 – SOP-12.1.2 (Radiological Data Validation), which includes, but is not limited to, the elements specified in the list below:

- holding times
- blank contamination
- initial and continuing calibration for gamma spectrometry and beta assay gas flow proportional detection systems
- beta spectrometry recovery standard (i.e., analytical yield evaluation)
- matrix spike/matrix spike duplicates
- laboratory control samples

- field duplicates

In addition, a minimum of one sample from each sample delivery group, for each analysis type, was evaluated based on raw data and bench records to verify the accuracy of the analytical results reported. No errors were identified during this process. Each of the sample delivery groups evaluated was found to be complete initially, or was completed after resubmittal of additional information at the request of the data validator. The detection limits obtainable by means of mass spectrometry for cesium-137, which was undetected in at least some of the samples from 10 of 14 cores, were much lower than the target MDL of 0.2 pCi/g dw specified in the QAPP. All data are valid and acceptable for use. None of the results were qualified by the validator. The data validation conducted on the entire set of radionuclide results exceeded the requirements specified in the QAPP, which indicated that full validation would be conducted on at least 10% of the samples or on a single sample delivery group. Summary validation was not conducted for any of the samples.

Laboratory instruments used in the Sedflume study included an Ohaus TS200S and an Omega FP6500 in the SEI mobile laboratory and a Malvern Mastersizer 2000 in the PTL laboratory. The Ohaus TS200S was calibrated using a 200-g weight once a month in the SEI laboratory during use. This exceeded the manufacturer's recommendations for calibration frequency. The Omega FP6500 paddlewheel flow center was calibrated prior to use for each core and realigned within the 5% error rate recommended by the manufacturer. The Malvern Mastersizer 2000 was operated and calibrated regularly in accordance with PTL standard operating procedure PTL-10-200. These procedures for calibration matched or exceeded the manufacturer's recommendations for calibration frequency.

5.0 References

McNeil J, Taylor C, Lick W. 1996. Measurements of erosion of undisturbed bottom sediments with depth. J Hydraul Eng 122(6):316-324.

Windward. 2003. Lower Duwamish Waterway remedial investigation. Phase 1 remedial investigation report. Prepared for Lower Duwamish Waterway Group. Windward Environmental LLC, Seattle, WA.

Windward. 2004a. Lower Duwamish Waterway remedial investigation. Quality assurance project plan: Sediment transport characterization. Draft. Prepared for Lower Duwamish Waterway Group. Windward Environmental LLC, Seattle, WA.

Windward. 2004b. Lower Duwamish Waterway remedial investigation. Task 8: Phase 2 RI work plan. Prepared for Lower Duwamish Waterway Group. Windward Environmental LLC, Seattle, WA.

Geochronology and Erosion Property Results Figures

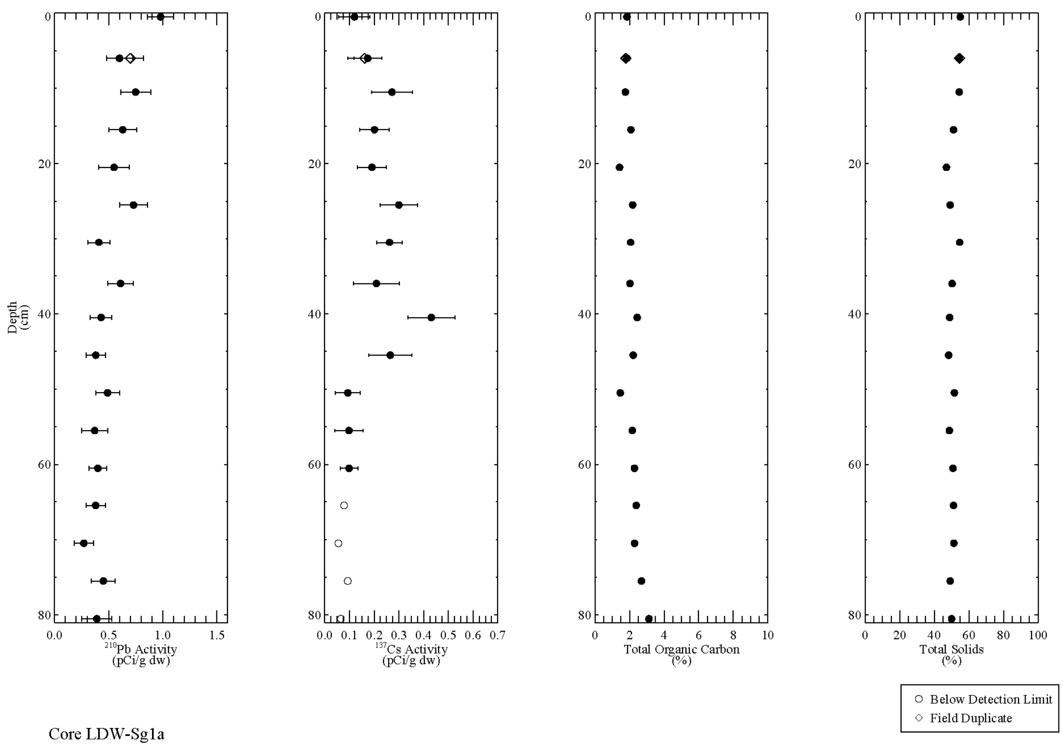


Figure 4-1. Geochronology sediment core Sg1a

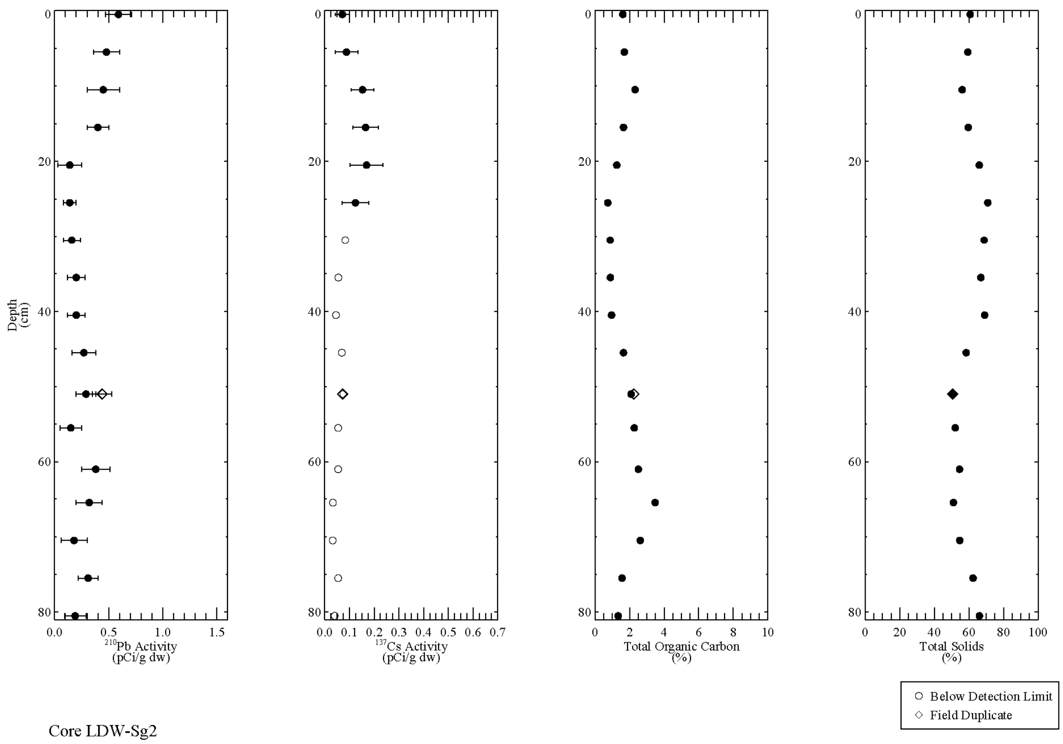


Figure 4-2. Geochronology sediment core Sg2

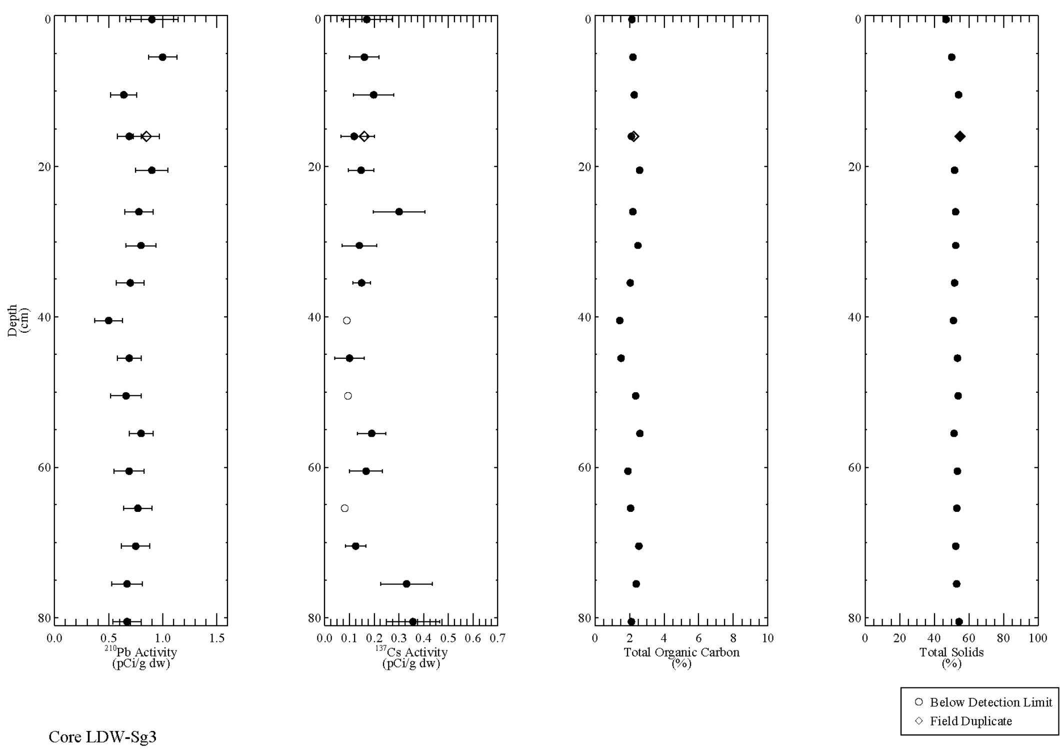


Figure 4-3. Geochronology sediment core Sg3

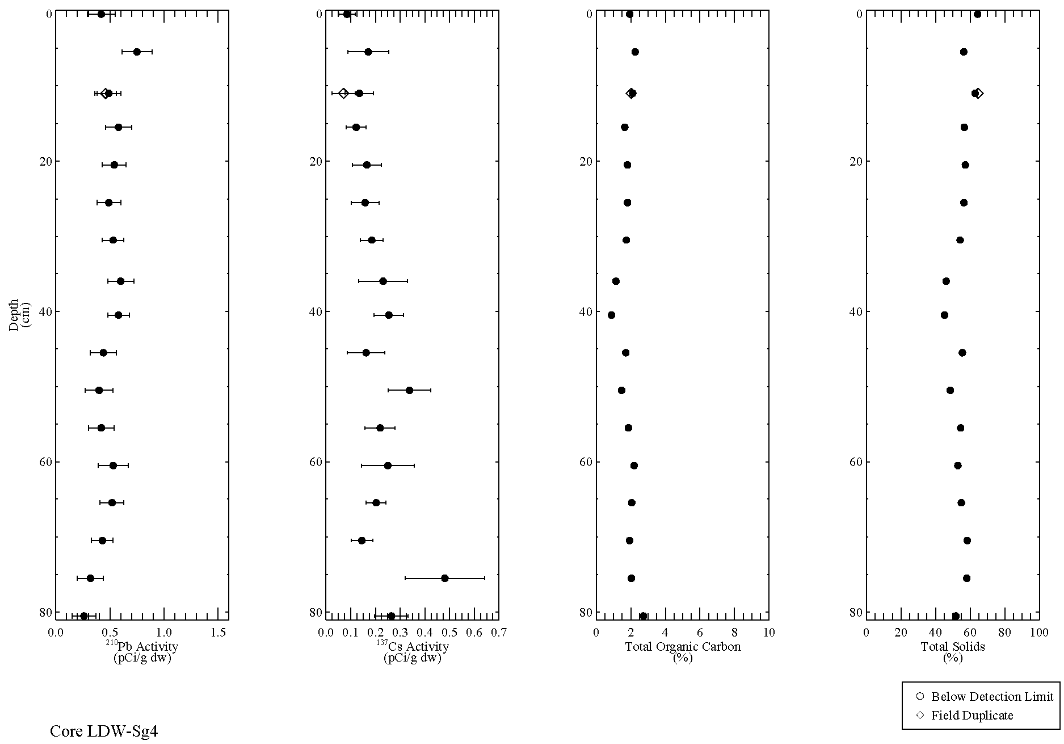
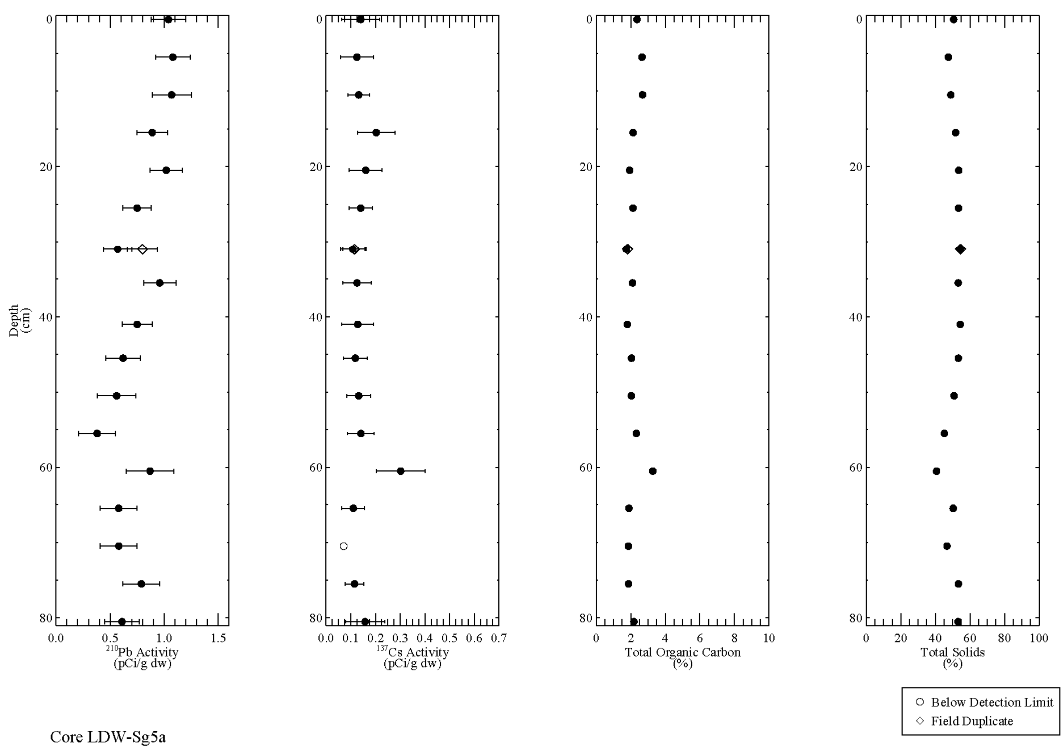


Figure 4-4. Geochronology sediment core Sg4



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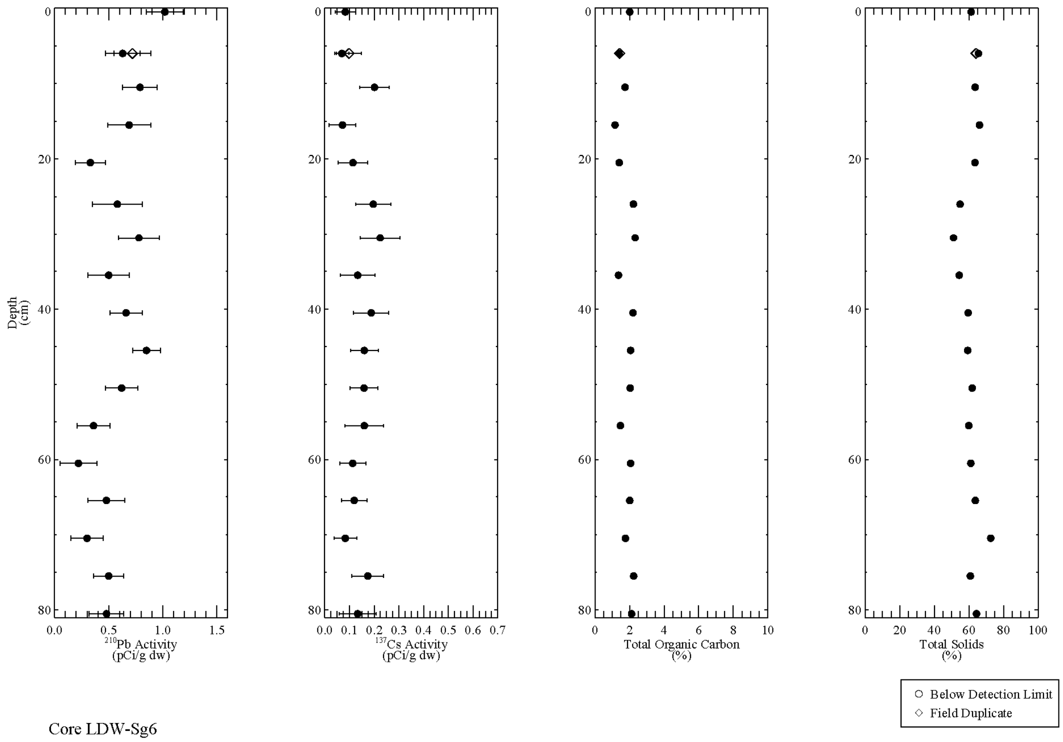
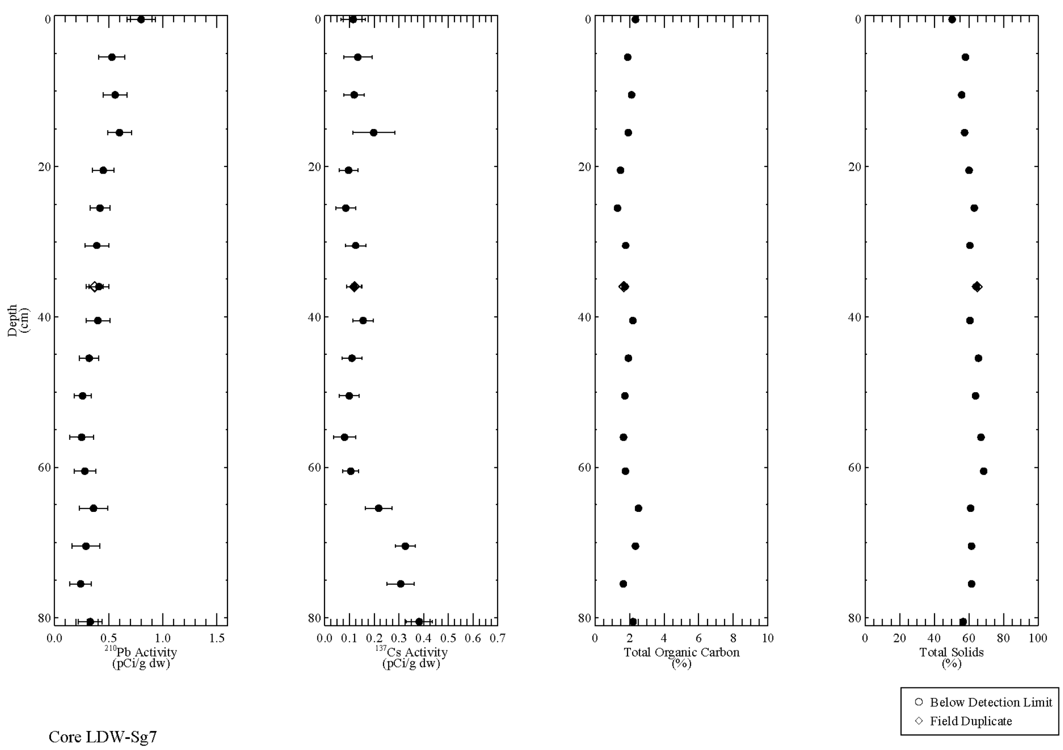


Figure 4-6. Geochronology sediment core Sg6



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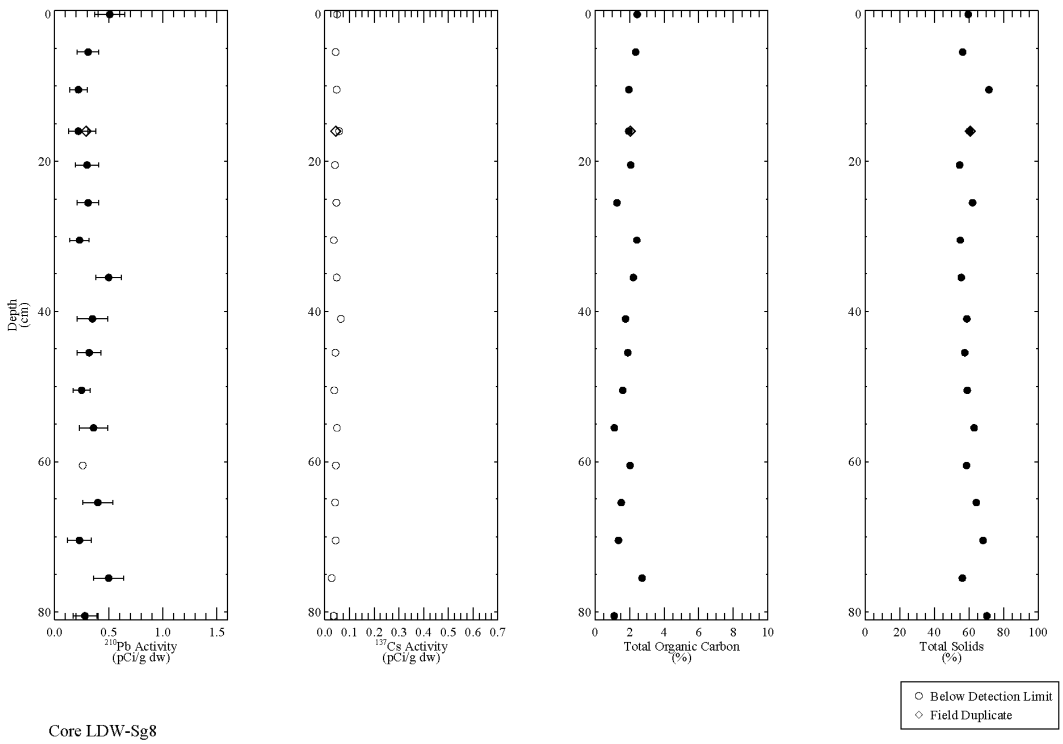


Figure 4-8. Geochronology sediment core Sg8

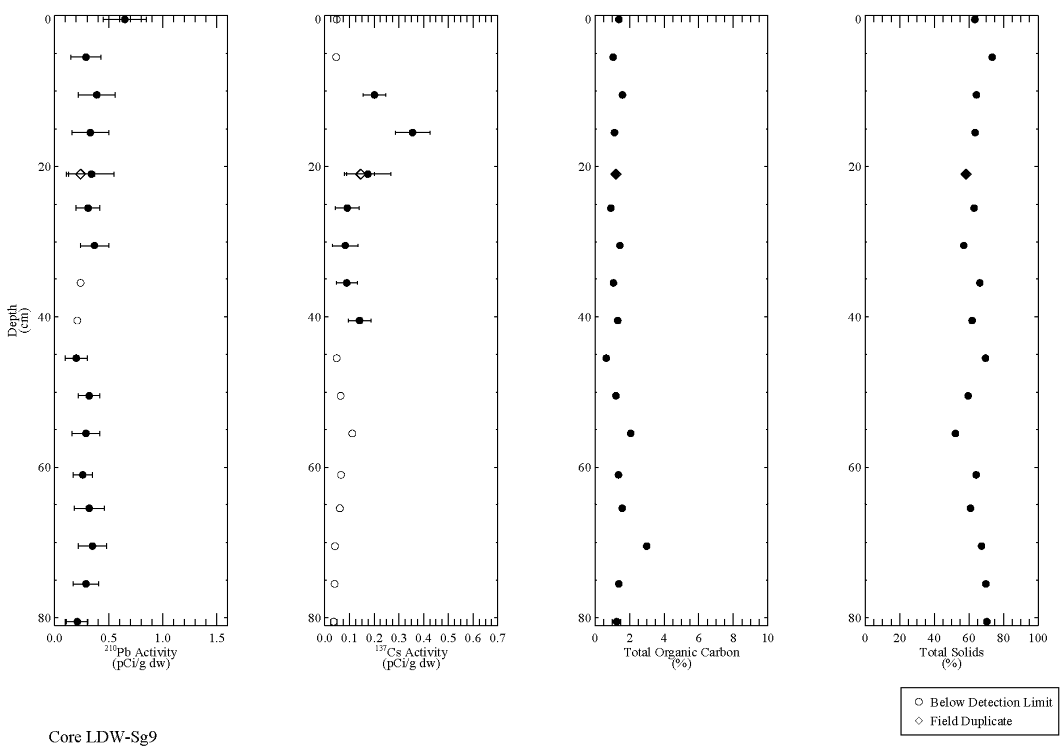


Figure 4-9. Geochronology sediment core Sg9

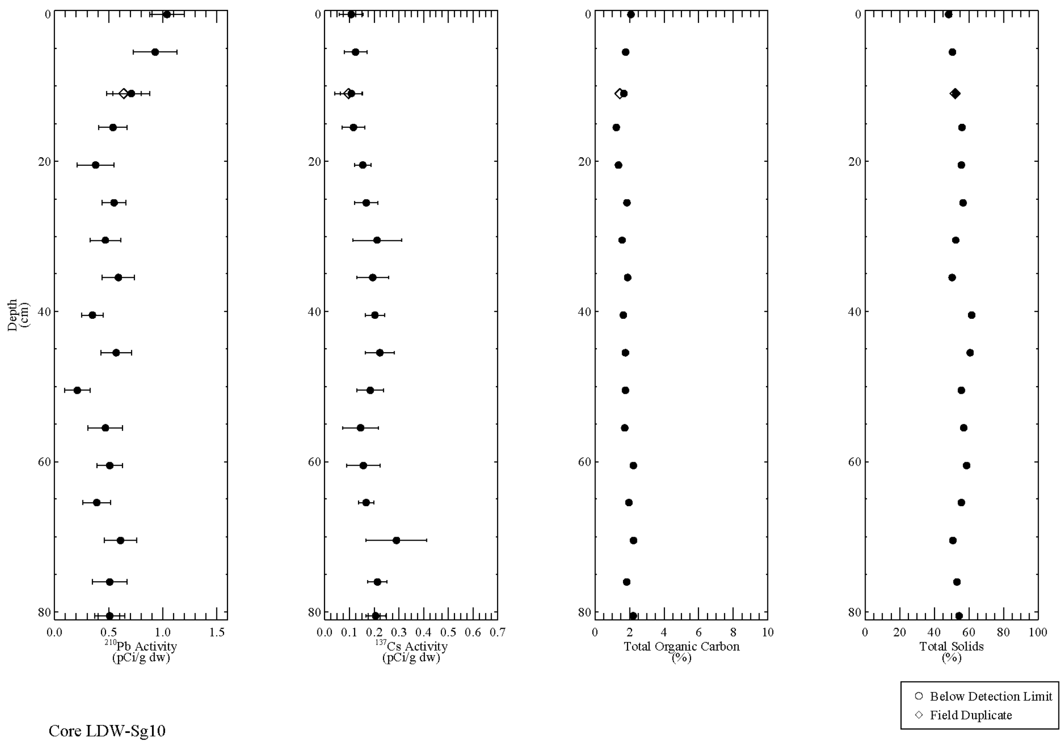


Figure 4-10. Geochronology sediment core Sg10

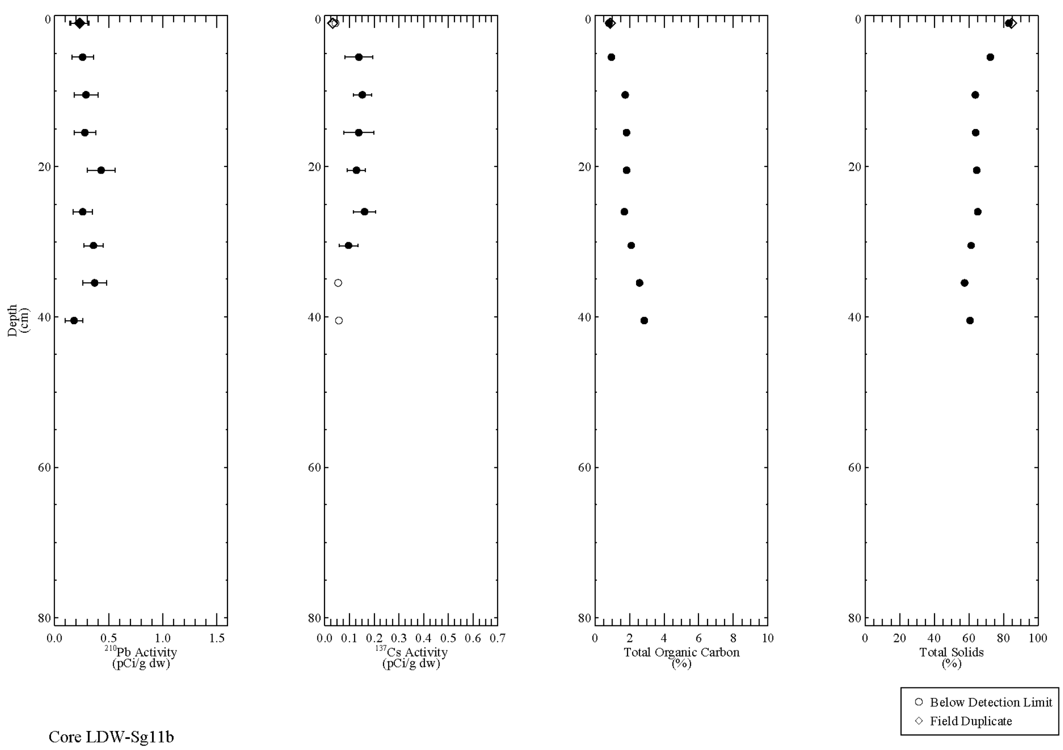


Figure 4-11. Geochronology sediment core Sg11b

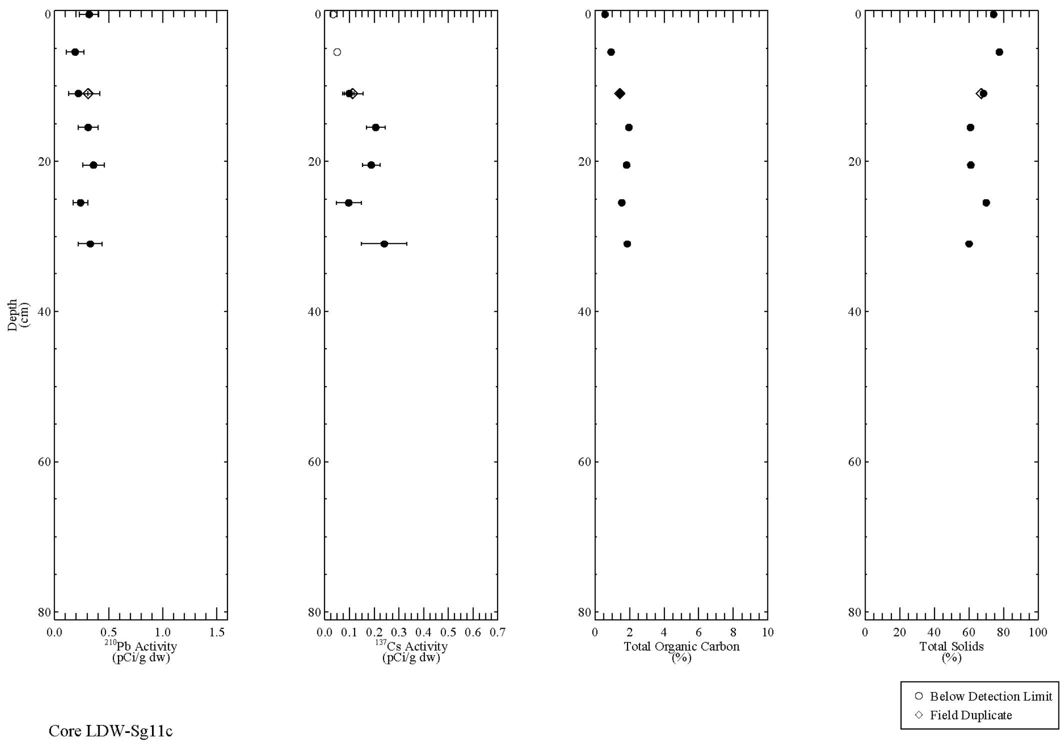


Figure 4-12. Geochronology sediment core Sg11c

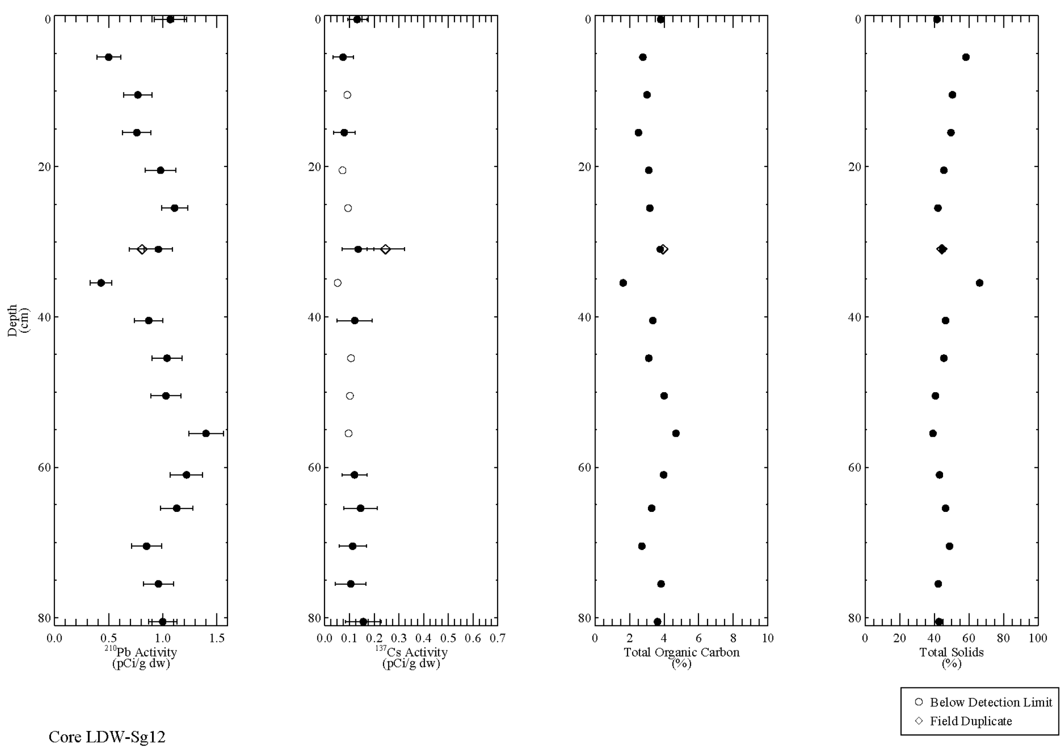


Figure 4-13. Geochronology sediment core Sg12

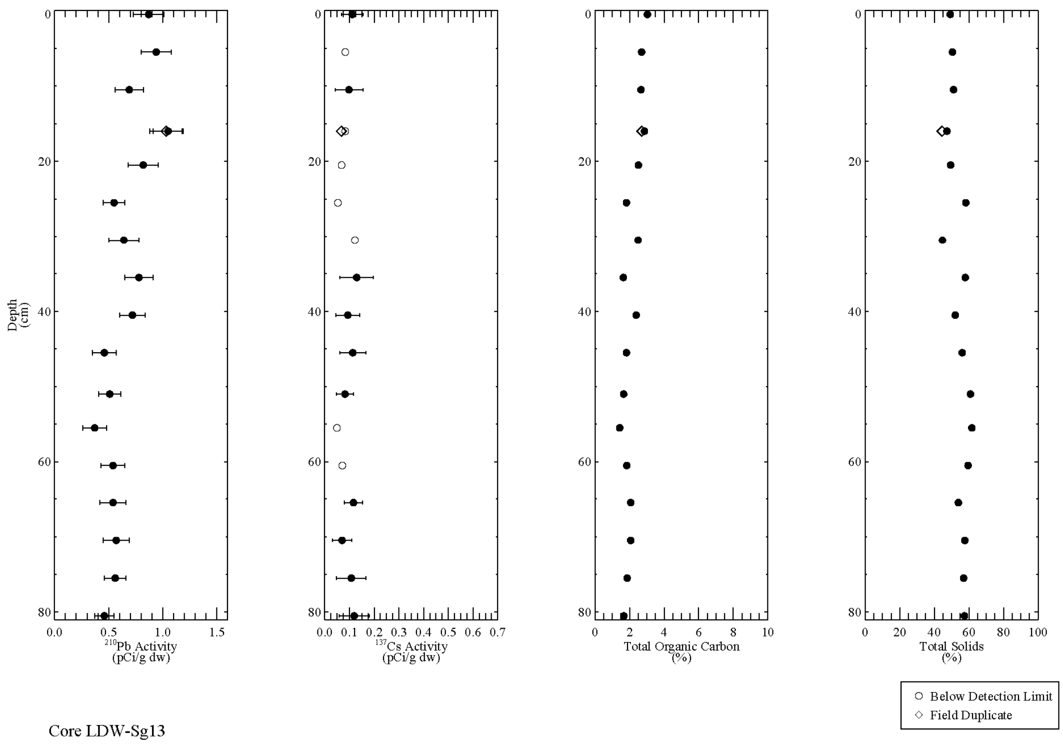


Figure 4-14. Geochronology sediment core Sg13

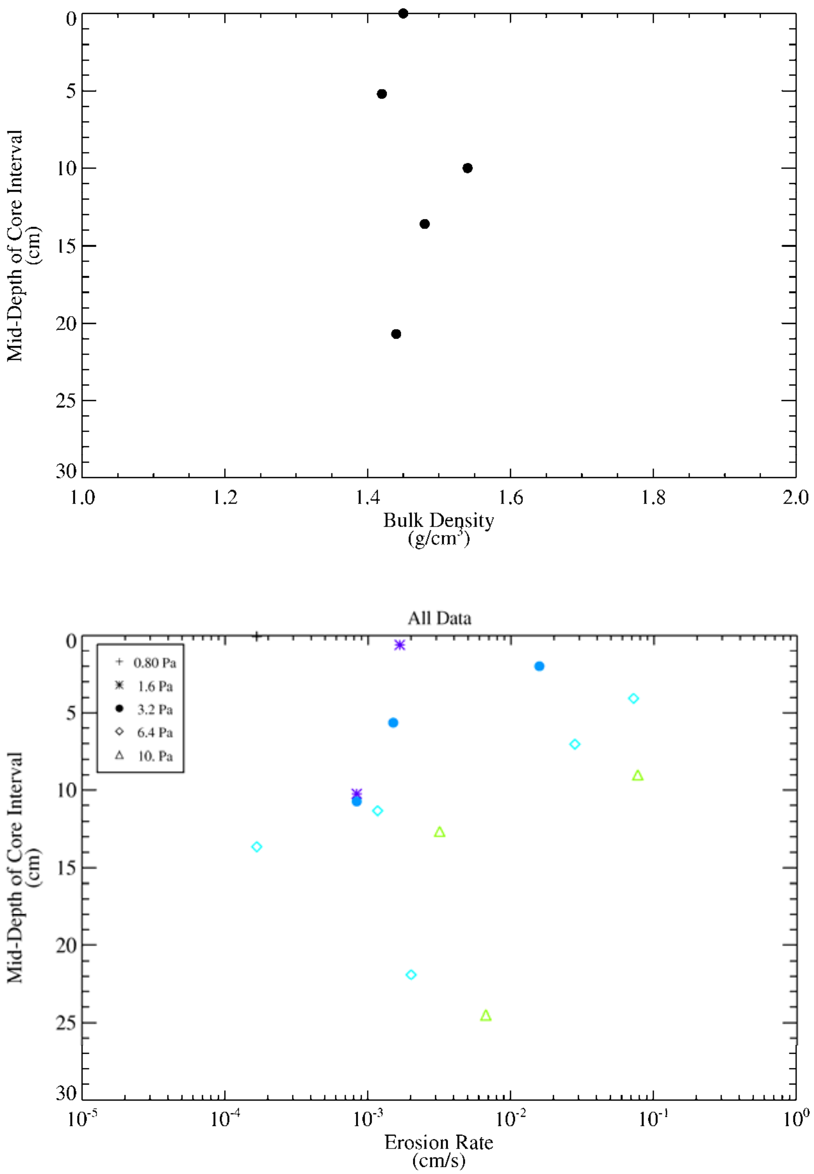
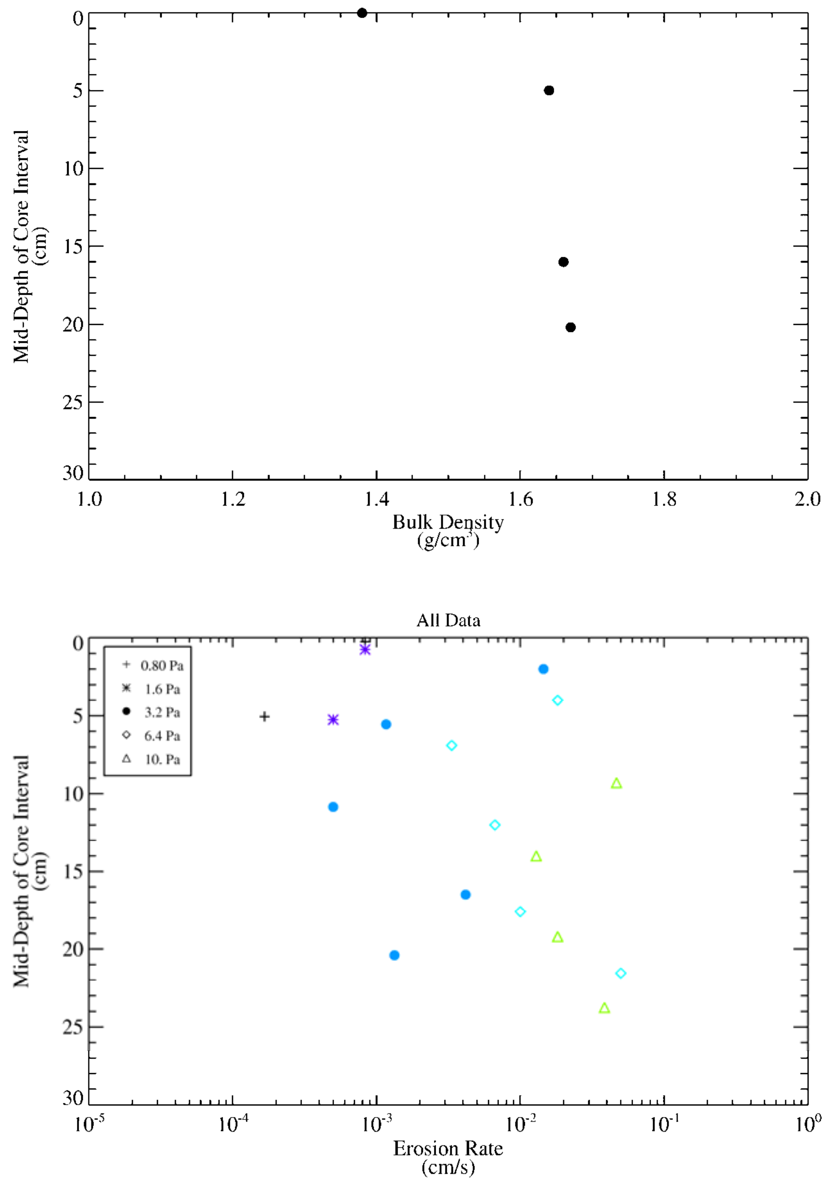


Figure 4-15. Erosion property sediment core Sf1



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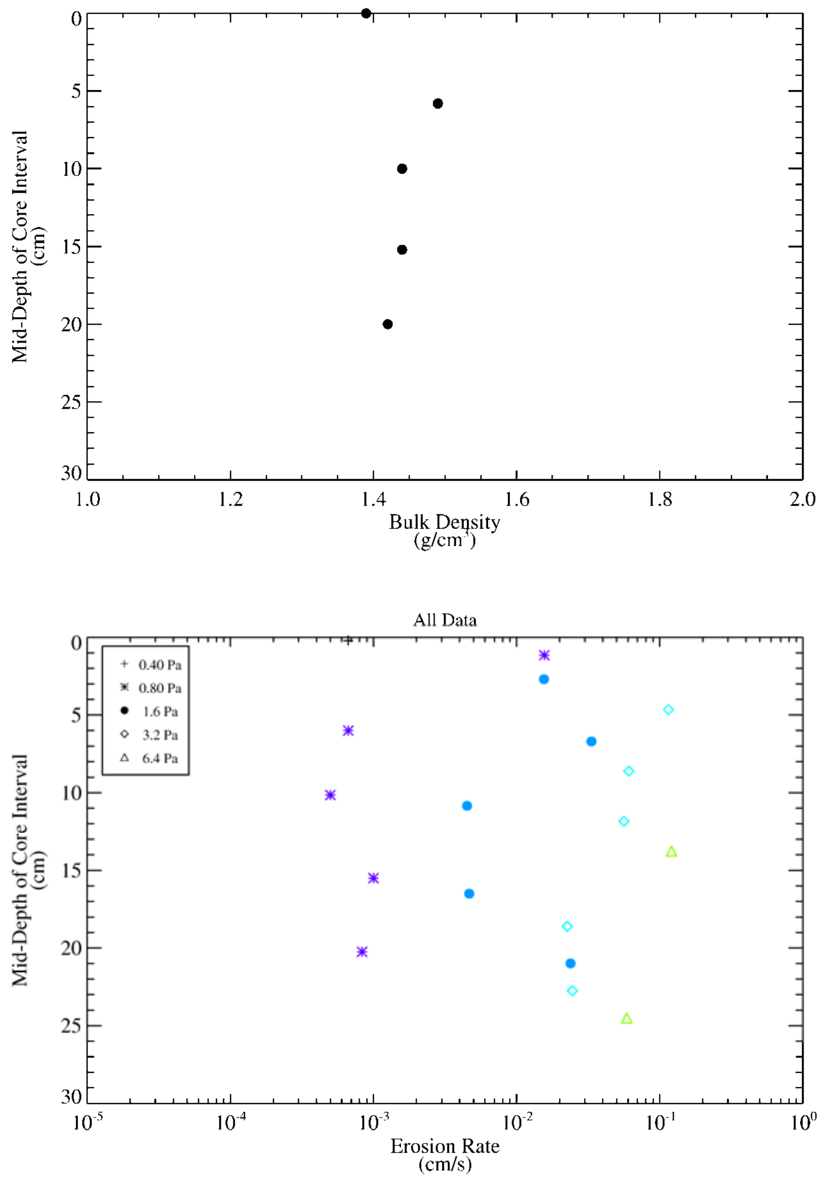

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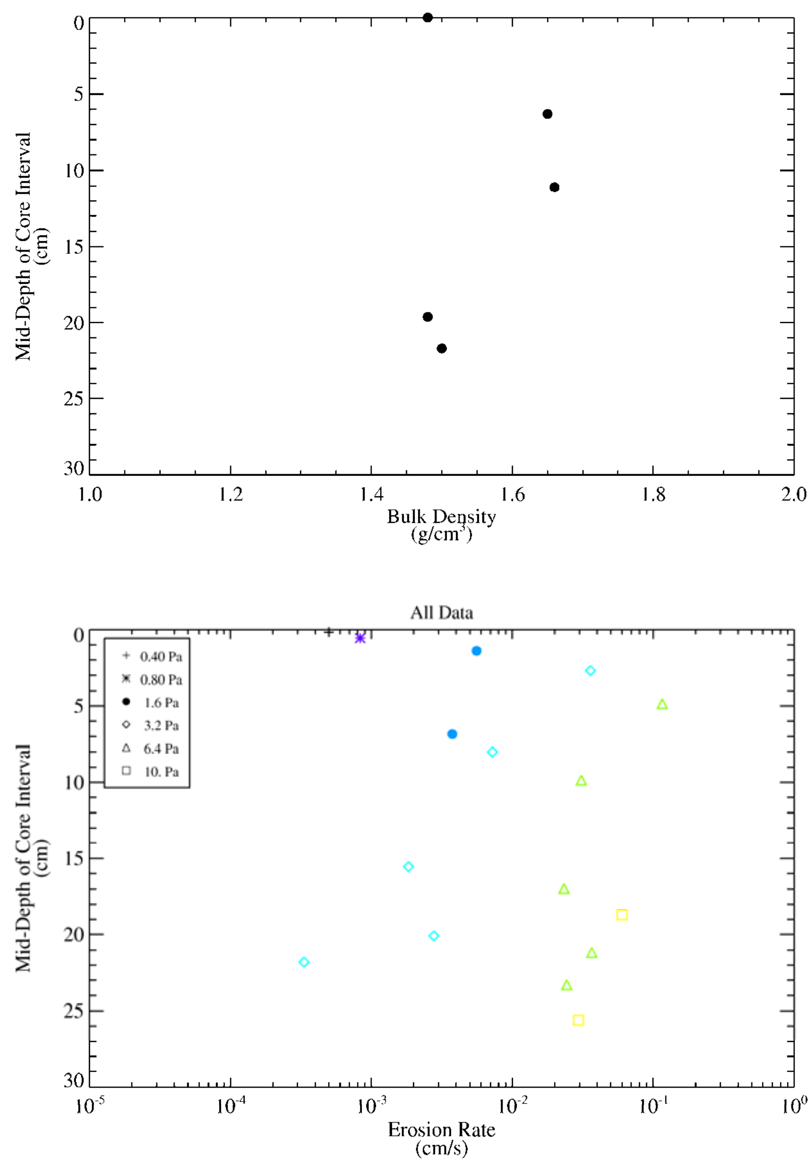


Figure 4-18. Erosion property sediment core Sf4

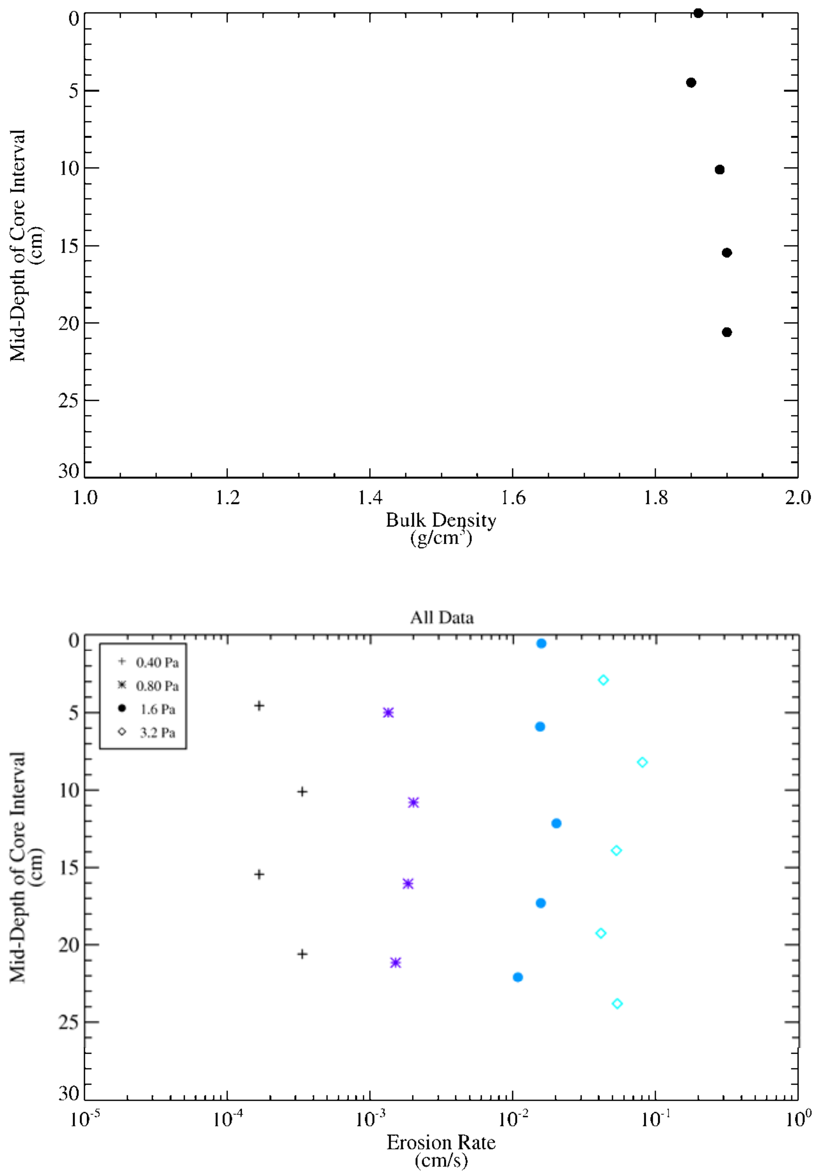


Figure 4-19. Erosion property sediment core Sf5

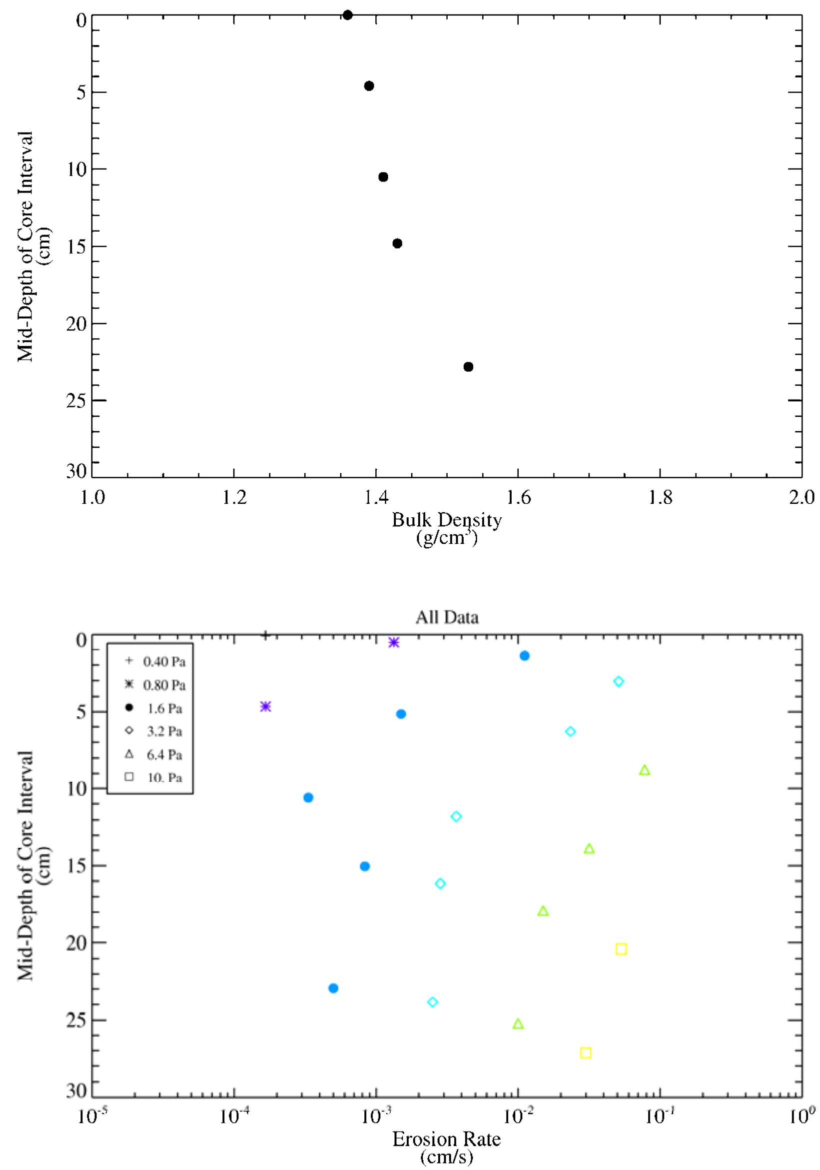


Figure 4-20. Erosion property sediment core Sf6

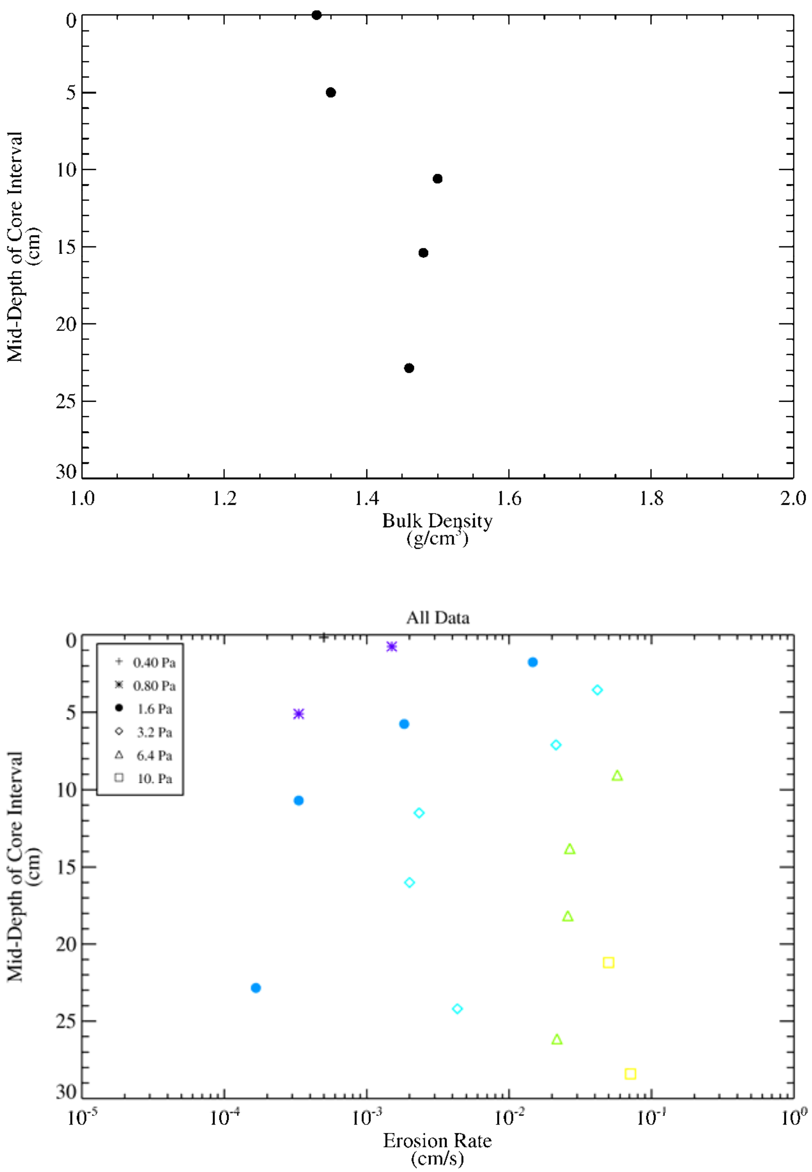


Figure 4-21. Erosion property sediment core Sf6-DUP

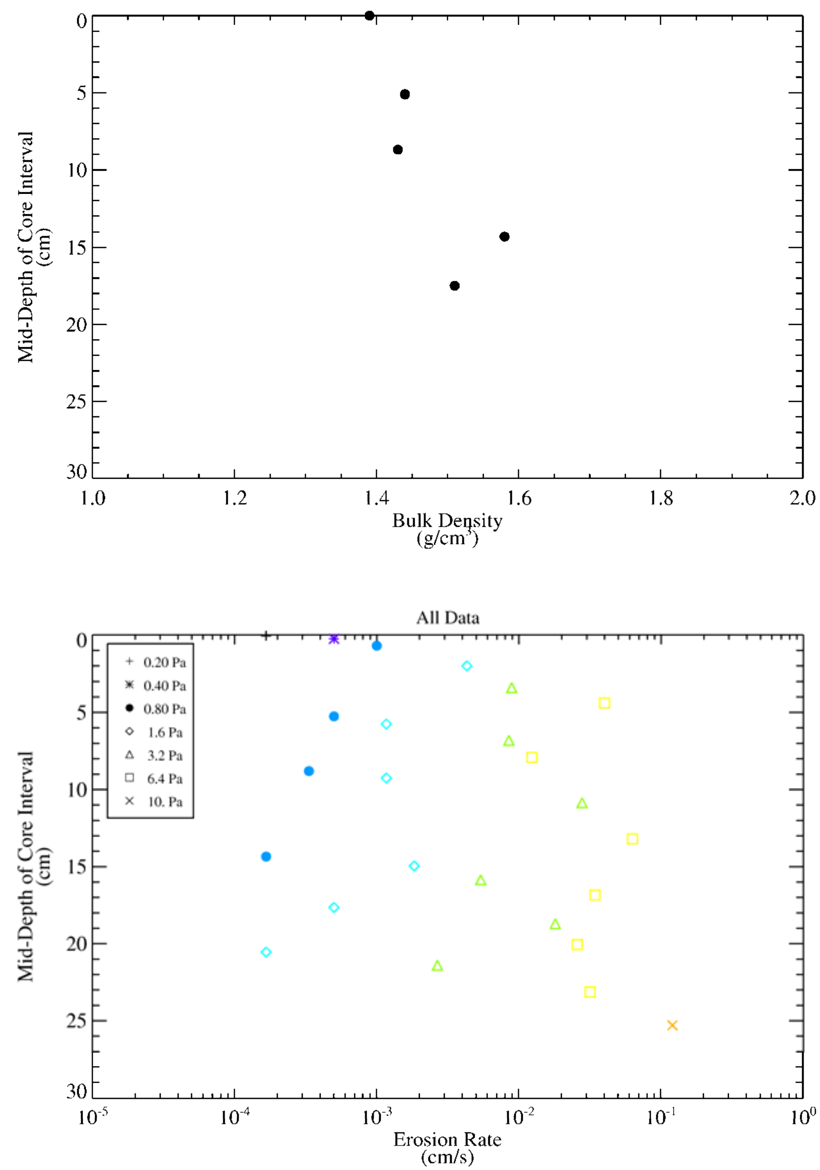


Figure 4-22. Erosion property sediment core Sf7

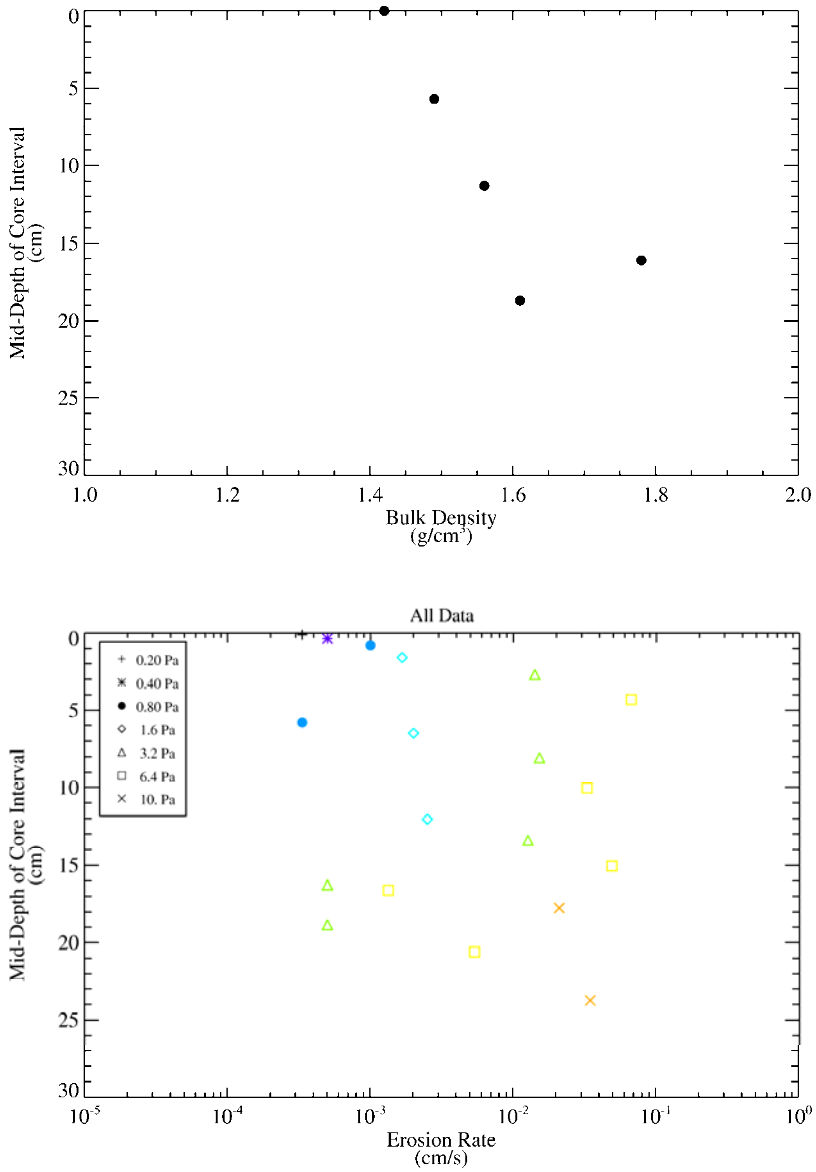


Figure 4-23. Erosion property sediment core Sf8

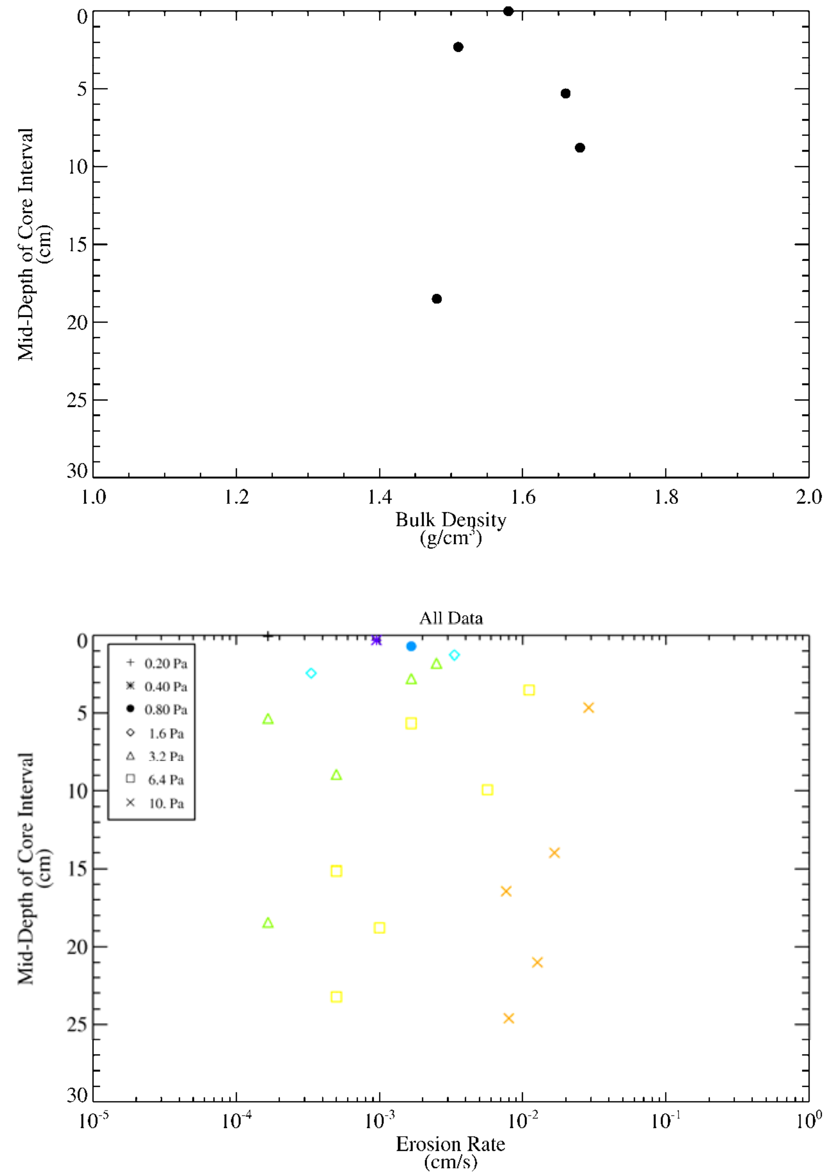


Figure 4-24. Erosion property sediment core Sf9

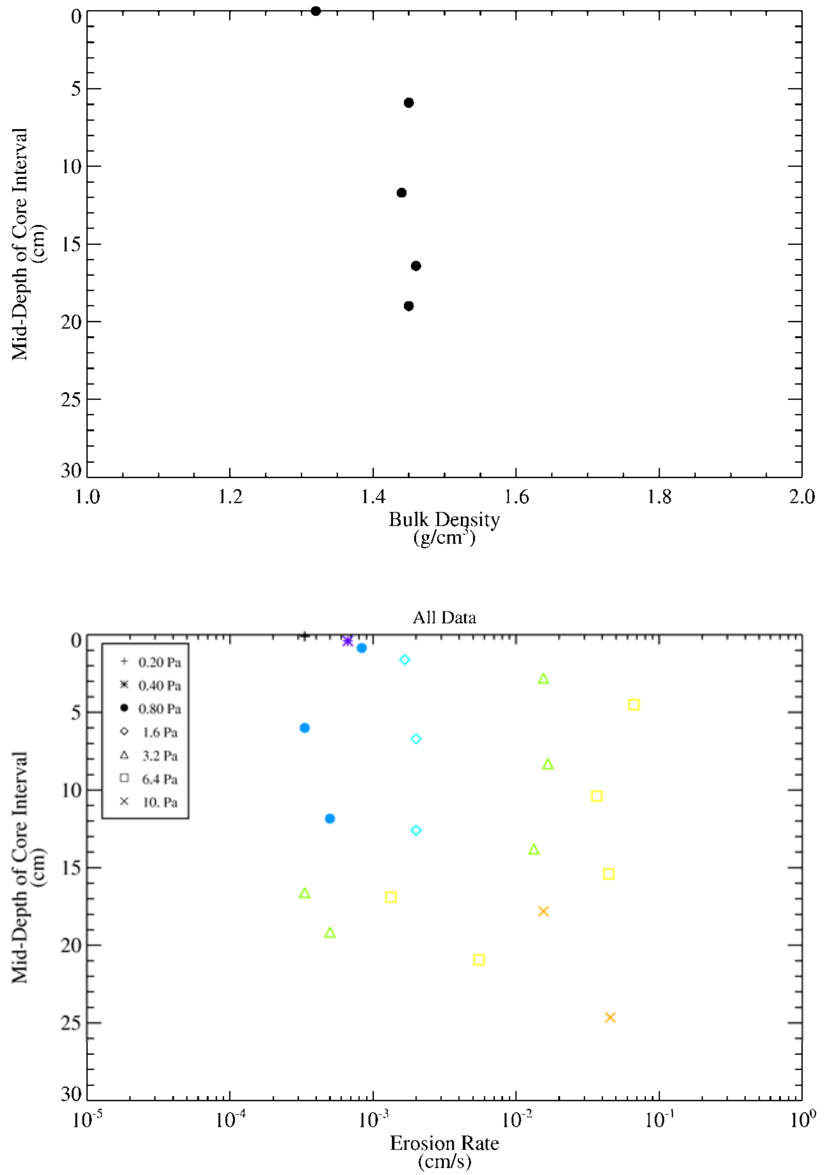


Figure 4-25. Erosion property sediment core Sf10

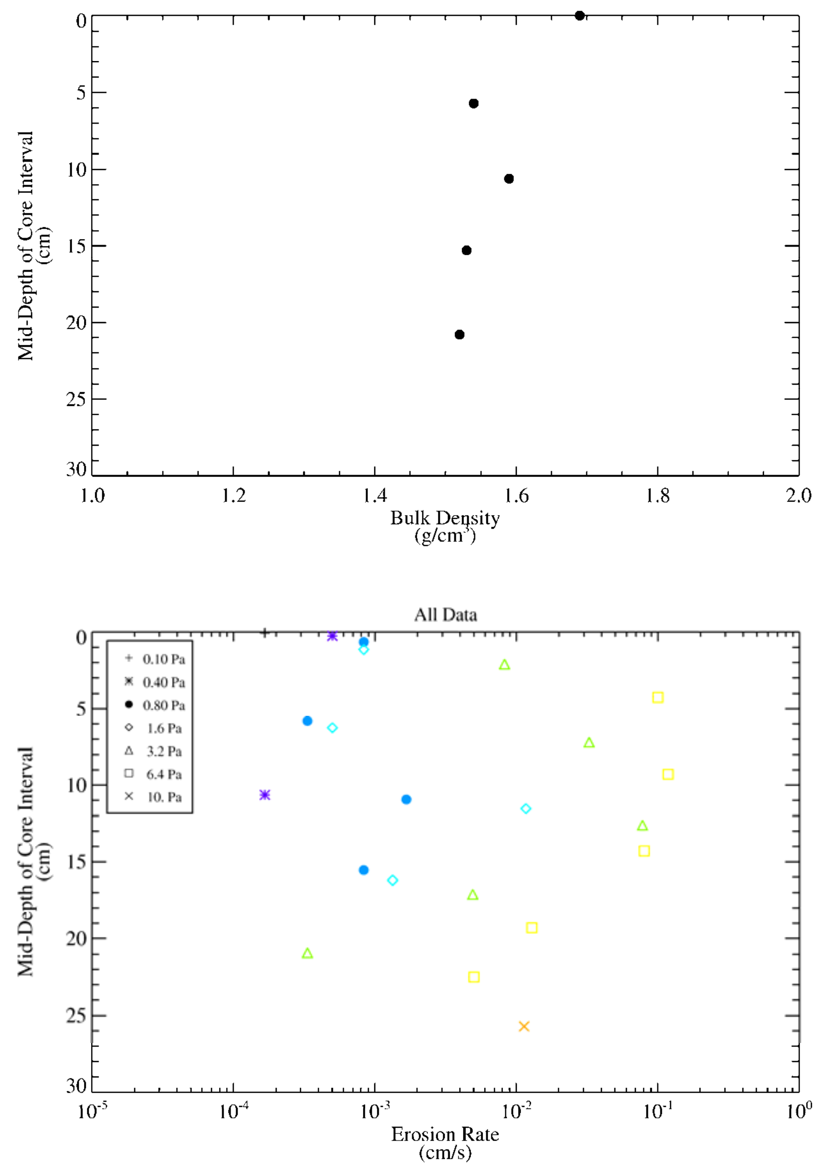


Figure 4-26. Erosion property sediment core Sf11

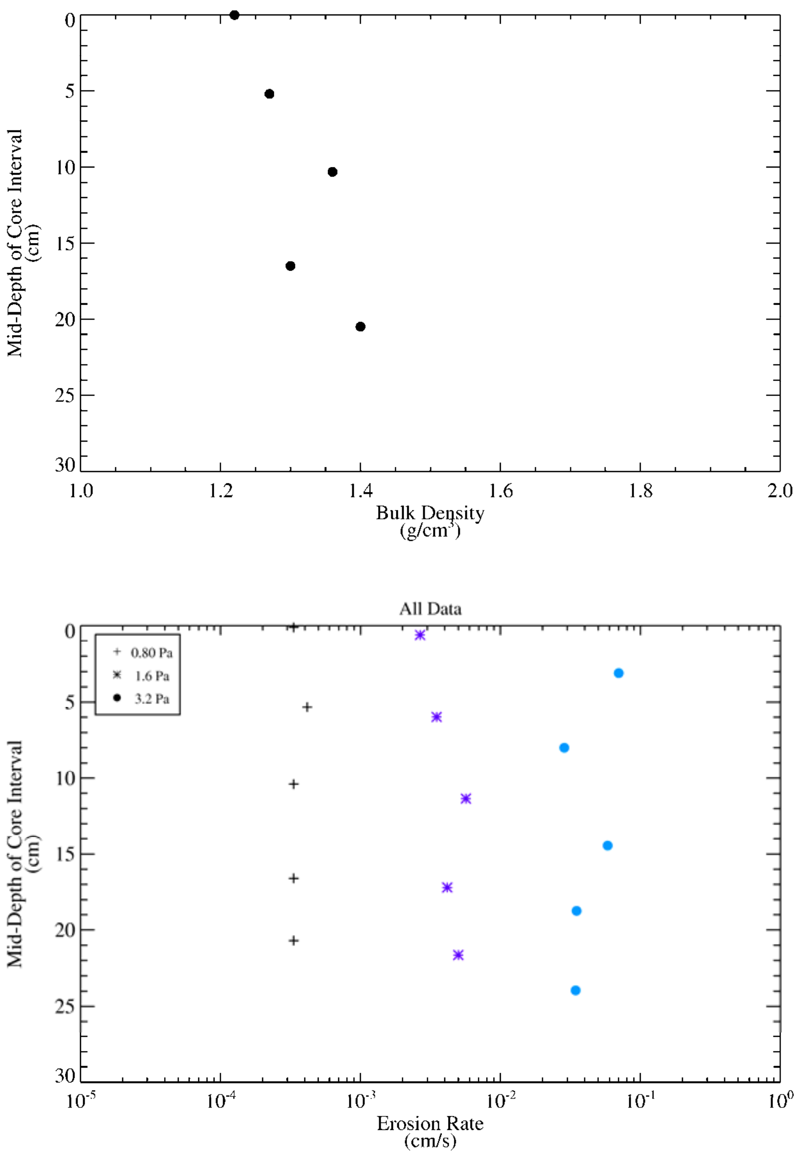


Figure 4-27. Erosion property sediment core Sf12

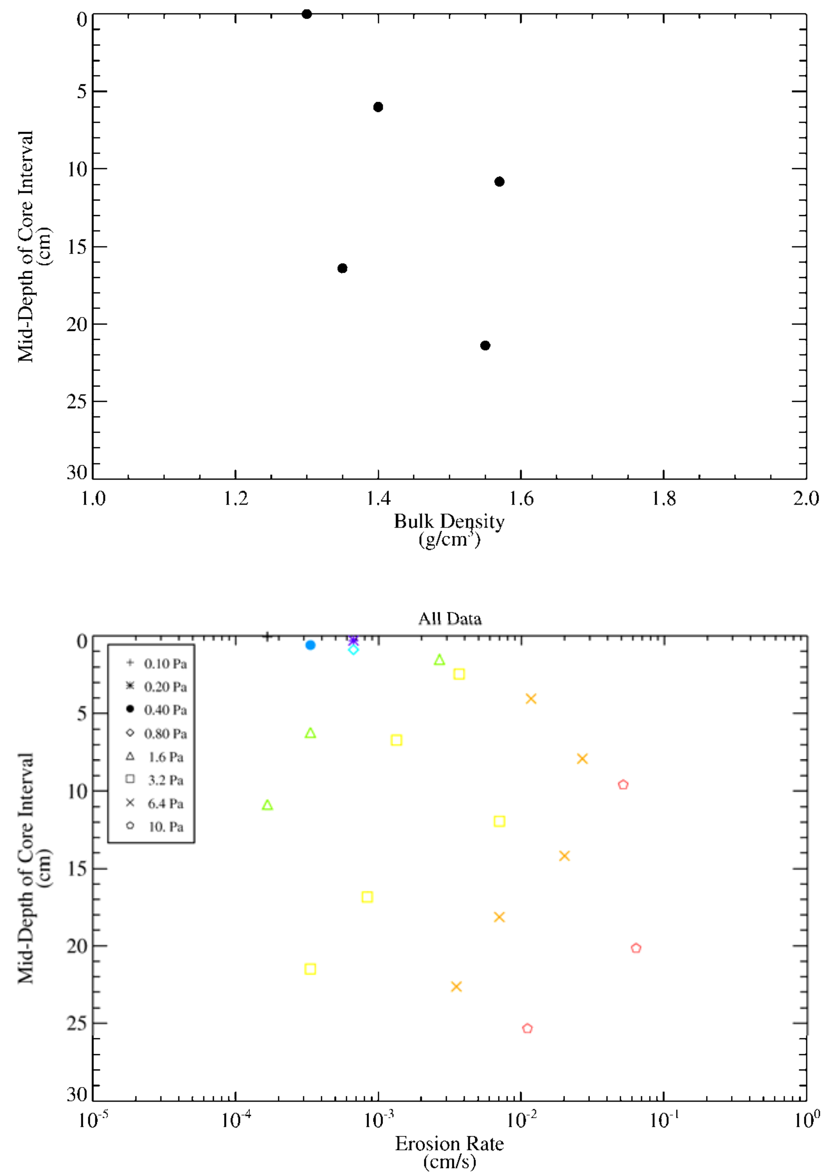


Figure 4-28. Erosion property sediment core Sf13

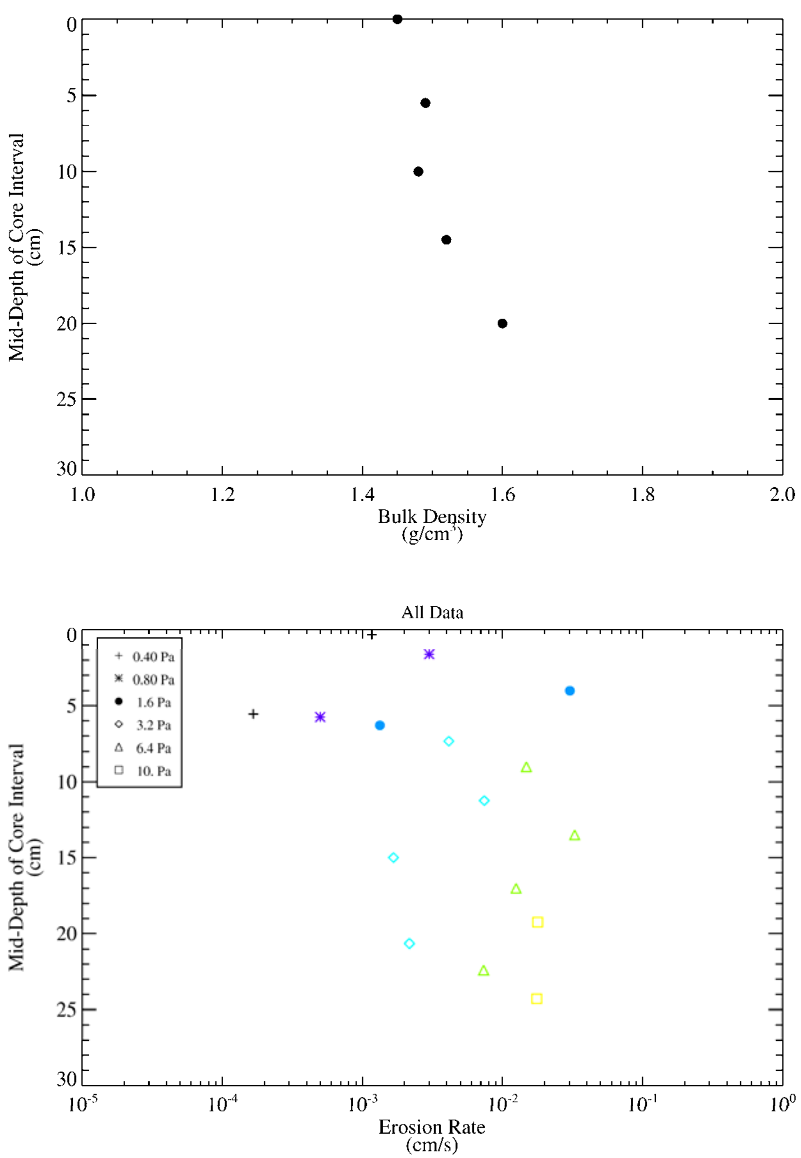
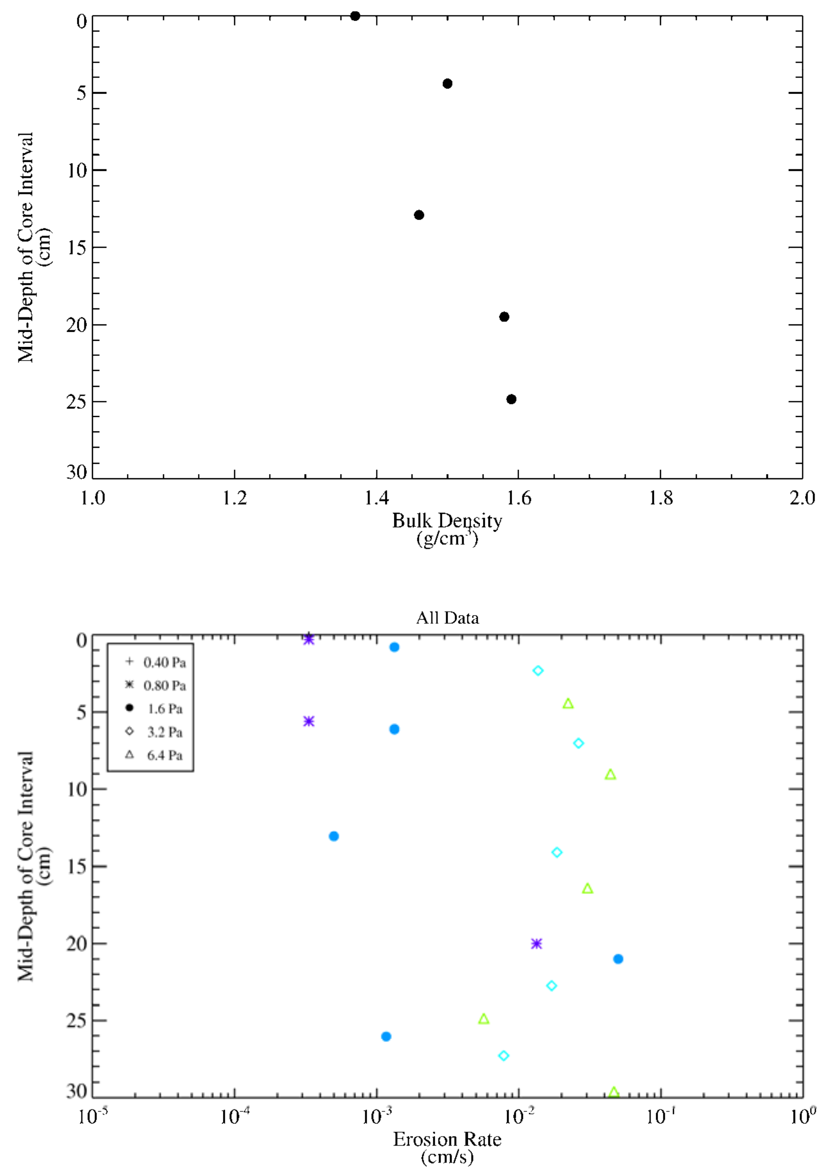


Figure 4-29. Erosion property sediment core Sf14



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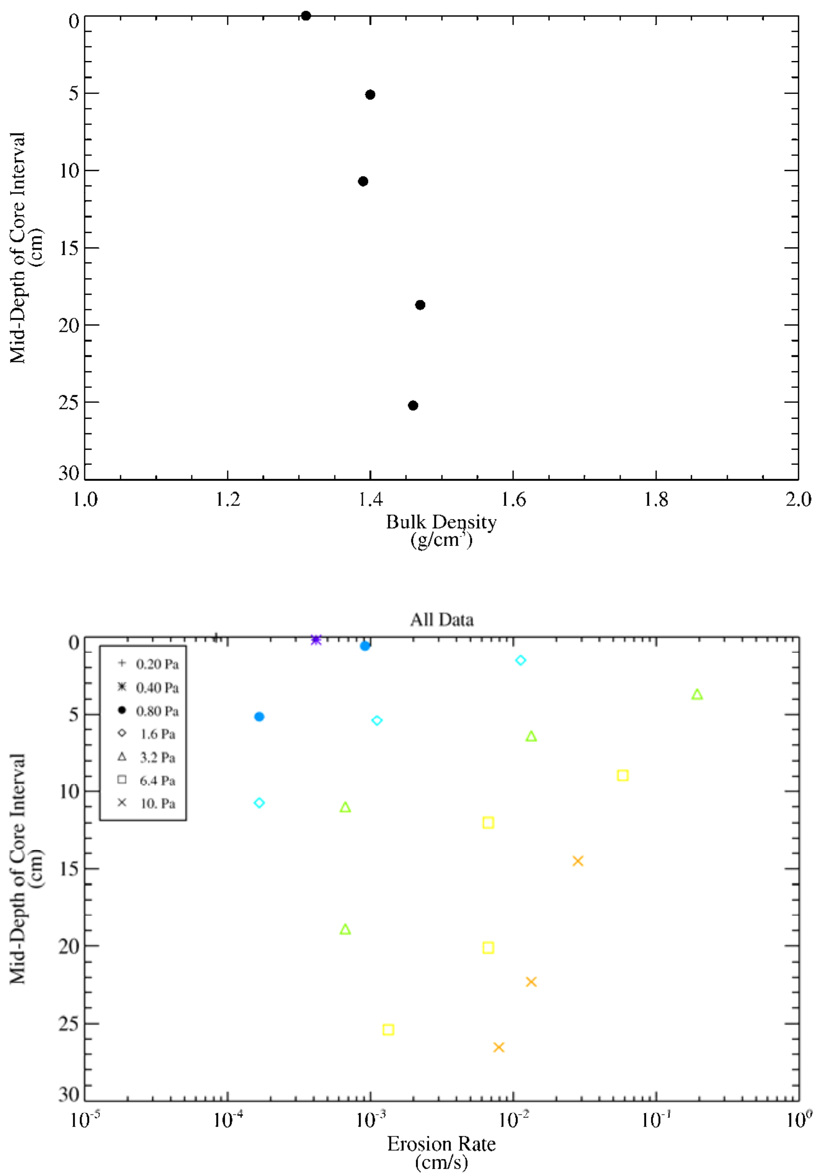

Figure 4-31. Erosion property sediment core Sf16

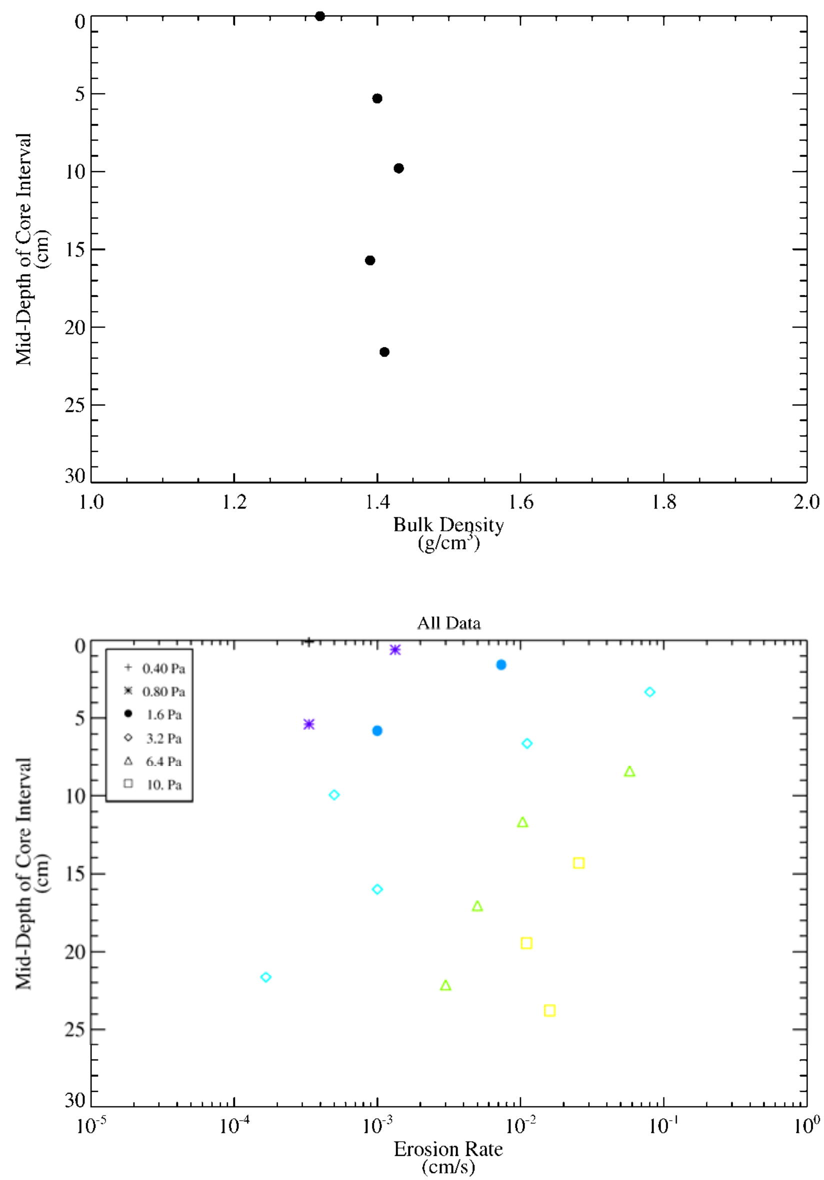

Figure 4-32. Erosion property sediment core Sf16-DUP

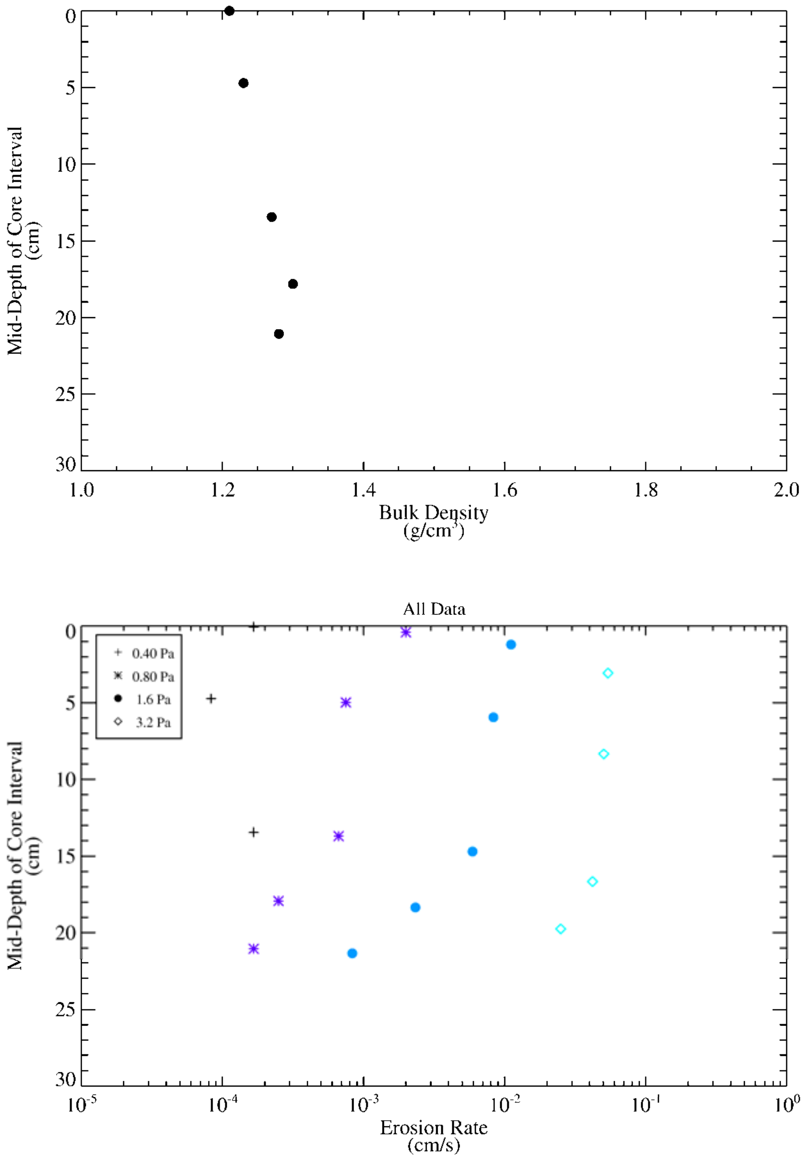

Figure 4-33. Erosion property sediment core Sf17