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Final Report
September 1, 1976, to December 31, 1977

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THE POLLUTION HISTORY OF THE SAVANNAH RIVER ESTUARY

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ABSTRACT

Records of natural and pollutant fluxes to the Savannah River Estuary are found in some river and marsh deposits into which time frames can be introduced by Pb-210 or plutonium geochronologies. Plutonium releases from the Savannah River Plant are evident in only one deposit and in marsh grass which received the transuranic element from atmospheric transport. The pollution records can be disturbed by bioturbative activities of organisms, by the input of marine solid phases to the estuarine deposits, and by river scour and fill.

INTRODUCTION

The Savannah River Estuary is one of the large salt-marsh estuaries of the world. It has been moderately well studied and, as a consequence, may provide for its counterparts elsewhere a pattern for the behavior of introduced chemical spe[illegible] The [illegible] Estuary has received inputs of transuranic elements (about 0.3 curies of plutonium) from the Savannah River Plant of the U. S. Department of Energy, the movements of which are poorly known (Hayes _et al_., 1976). Previously we have studied the histories of heavy metal inputs to a variety of enrivonments -- the Southern California Bight (Bruland et al., 1974), Narragansett Bay (Goldberg _et al_., 1977) and Chesapeake Bay (Goldberg _et al_., 1978) -- through records in sediments into which a time frame could be introduced. This investigation extends these studies as well as that of Windom (1975) who prepared a preliminary mass balance of heavy metals entering the Savannah River system to consider the processes occurring in a salt-marsh estuary.

SAMPLES

The field work was carried out during the period 17 to 25 October 1976 utilizing the Skidaway Institution of Oceanography (Savannah, Georgia) vessel R/V Blue Fin. The sample locations (Figure 1 and Table 1) were chosen on the basis that no dredging had taken place in the immediate area, that the river bank and channel were relatively stable and not previously subjected to active

TABLE 1: Sample Locations

Date Collected	Number	Latitude	Longitude	Description
October 17, 1976	7610 1715	30° 52' N	81° 23' W	Savannah River, South Carolina slide about 200 km above the mouth. Grab samples a and b. Below Savannah River Plant.
October 17, 1976	7610 1718	33° 29' N	82° 00' W	Savannah River, Augusta, GA. about 320 km above the mouth. Grab sample a and b. Above Savannah River Plant.
October 19, 1976	7610 1912	32° 04' 20" N	81° 00' 30" W	Wilmington River. Box Core 46 cm long. Water depth 3 m.
October 19, 1976	7610 1916	32° 05' 00" N	81° 00' 15" W	Savannah River, South Channel. Box Core 49 cm long. Water depth 4 m. 18 km above the north.
October 20, 1976	7610 2014	32° 01' 30" N	80° 53' 45" W	Marsh adjacent to South Channel of Savannah River 15 cm dia. open barrel core 30 cm long.
October 20, 1976	7610 2014	Same location		Marsh grass Spartina alterniflora. Living plant material.
October 20, 1976	7610 2016	32° 01' 10" N	80° 54' 25" W	Marsh adjacent to Tybee River, 15 cm diameter, open barrel core, 35 cm long.
October 20, 1976	7610 2016	Same location		Marsh grass Spartina alterniflora. Dead plant material.
October 21, 1976	7610 2108	32° 01' 15" N	80° 53' 45" W	Savannah River, South Channel. Box Core 42 cm long. Water depth 4 m. 5 km above the mouth.
October 21, 1976	7610 2110	32° 02' 35" N	80° 58' 35" W	St. Augustine Creek. Box core 54 cm long. Water depth 2 m.
October 25, 1976	7610 2508	31° 59' 20" N	81° 01' 20" W	Spanish Moss.

erosion, that dredge spoil disposal had not taken place and that the sediments appeared to be anoxic (dark grey or black muds). The sediments were retrieved from box cores with the exception of several grab samples. Marsh grass (*Spartina alterniflora*) and [illegible] moss were also collected during this time.

After obtaining the cores, the material and the liner were frozen on board ship with dry ice. After twenty-four hours in the dry ice reefer, the frozen solid cores were extruded from their liners, trimmed and cut into longitudinal sections. One section, about 15 mm thick, was used for x-ray pictures (Figure 2) and two or three 60 mm thick sections were cut for chemical analyses. The sampling schedule for each core was:

Depth in Core	Sampling Inverval
0-20 cm	1 cm
20-40 cm	2 cm
Over 40 cm	4 cm

TECHNIQUES

The analytical techniques used in this investigation have been described in previous publications:

Lead-210	Koide et al., 1973; Koide and Bruland (1975)
Heavy metals	Bruland et al., 1974.
Plutonium	Koide et al., 1975.
Quartz	Rex and Goldberg., 1958.

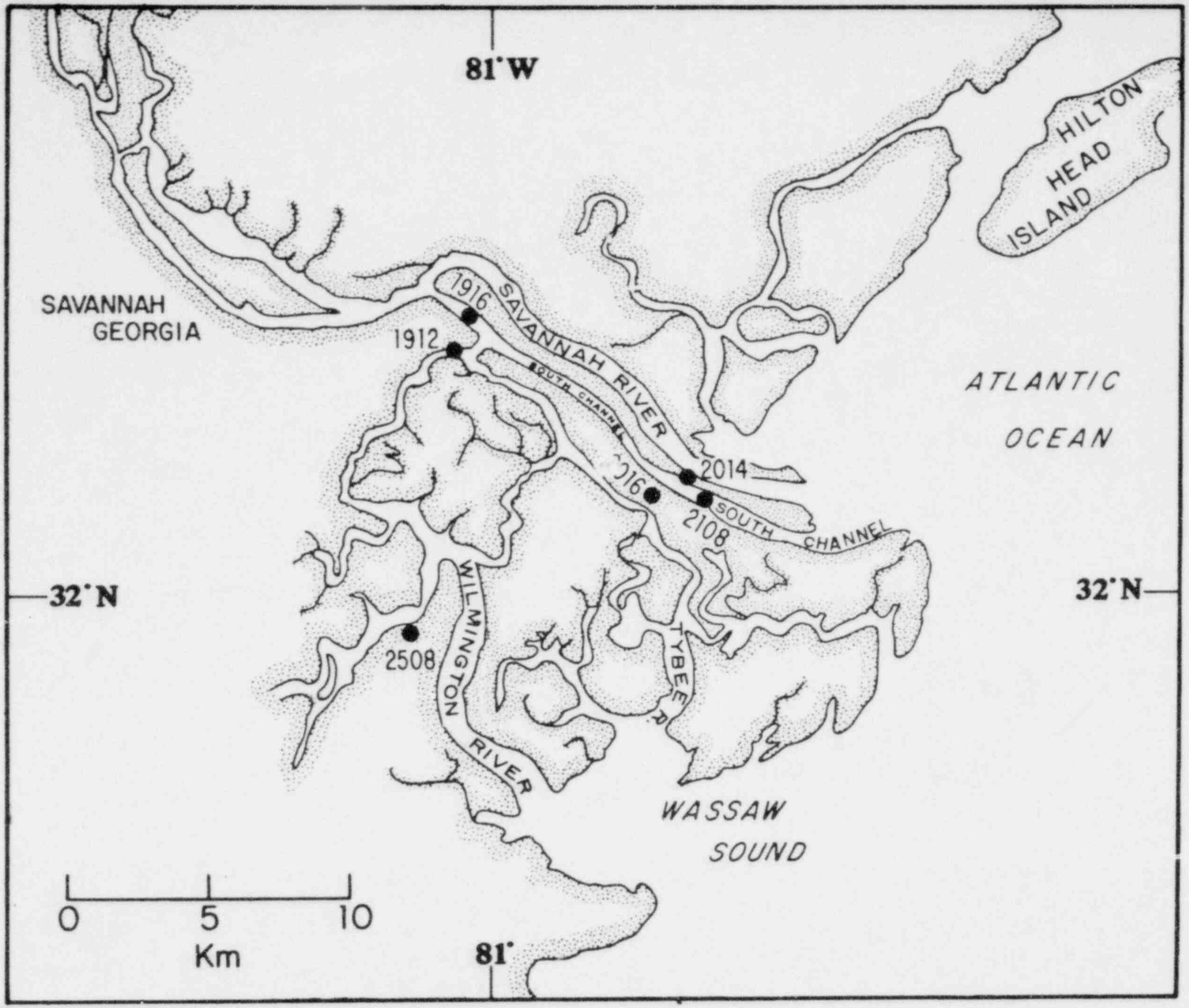

Figure 1. Map of sample locations. Samples 1715 and 1718 are not shown as they are off the map to the north.

FIGURE CAPTION

Figure 2 X-ray pictures of core sections. The marsh cores 2014 and 2016 display dark grey, randomly oriented streaks which are the roots of the marsh grass *Spartina alterniflora*. In River Core 1912 the slight density contrast in the upper 20 cm reflects a high water content. The thin white laminae in the middle and lower sections of the core are fine grained sand. Note the small shell at 16 cm. The upper 15 cm of Core 1916 are mottled without any apparent layering, whereas at depth white laminae composed of fine grained sand are present. The top 7 cm of core 2108 have thin white laminae; below this level, the deposit appears chaotic with randomly sited shells and no indications of lamination. The dark objects at 20 cm are wood fragments.

Figure 2. X-ray picture of Core 2016

Figure 2 (Continued). X-ray picture of Core 2108

Figure 2 (Continued). X-ray Picture of Core 2014

Figure 2 (Continued). X-ray picture of Core 1912

Figure 2 (Continued). X-ray picture of Core 1916

TIME FRAMES FOR THE SEDIMENTS

Sedimentary geochronologies were based upon Pb-210 and artificial radionuclide depth-profiles. Pb-210, with a half life of 22 years, was assumed to be unsupported in the strata sampled which covered a time interval of several decades. The artificial radionuclides are first detectable in coastal marine sediments about 1954 (See Koide et al., 1975 and Goldberg et al., 1977) and this criterion was used also to establish time scales. Only where both methods are in agreement are assigned ages of strata considered reliable. Ideal profiles for a given radionuclide are seldom obtained in estuarine systems inasmuch uniformity in conditions do not prevail over long time periods. However, even modest approximations to ideal systems can yield most useful information.

Marsh Core 7610-2016: The Pb-210 profiles (Figure 3 and Table 2) indicate a sedimentation rate of 1.1 cm/year over the first 15 centimeters and 1.2 cm/year over the second 15 centimeters. Unusual and unexplainable is the break in the profile at 15 cm. If the rate is uniform over the 30 centimeter of core, then the age of the lower strata is computed to be about 1950. Pu-239+240 disappears in the lowest part of the core, the 28-30 cm stratum (Table 2), and this would correspond to about 1954. Thus, for the extent of the core, the two techniques appear to be in agreement within several years for any given stratum. The x-ray picture of the core does not show any stratification or any evidence of a discontinuity at 15 cm. The roots of the marsh grass Spartina are evident throughout the deposit as dark grey, randomly oriented streaks on the X-ray picture (Figure 2).

Table 2. Plutonium and Cesium-137 Contents of Savannah Estuary Sediments

MARSH CORE No. 7610-2014 Adjacent to South Channel Savannah River

Depth in core cm.	Pu-239+240 in dpm/kg	Pu-238/Pu-239+240 (Activity Ratio)	Cs-137 dpm/kg	Pu-239+240/Cs-137 (Activity Ratio)
0-1	49.4 ± 2.2	0.06 ± 0.01		
2-3	27 ± 1.1	---	743 ± 36	0.036
4-5	14.2 ± 0.9	0.02 ± 0.01	542 ± 25	0.026
6-7	16.3 ± 1.2	0.04 ± 0.01		
8-9	17 ± 0.9	0.05 ± 0.01		
10-11	16.2 ± 1.2	0.02		
14-15	8.9 ± 0.8	---		
20-22	8.3 ± 0.7	0.04		
24-26	3.2 ± 0.3	---		

WILMINGTON RIVER CORE NO. 7610-1912

Depth in core cm.	Pu-239+240 in dpm/kg	Pu-238/Pu-239+240 (Activity Ratio)	Cs-137 dpm/kg	Pu-239+240/Cs-137 (Activity Ratio)
0-1	52.3 ± 2.6	0.05 ± 0.01	1251 ± 11	0.042
2-3	54.8 ± 2.3	0.05 ± 0.01		
4-5	54 ± 4	0.05 ± 0.01	---	---
8-9	52 ± 2.6	0.05 ± 0.01	1088 ± 22	0.048
12-13	56.3 ± 4	0.04 ± 0.01	936 ± 21	0.060
16-17	40.3 ± 1.9	0.04 ± 0.01	1985 ± 57	0.020
20-22	7.5 ± 0.7	---	187 ± 8	0.040
28-30	2.3 ± 0.4	---	85 ± 4	0.027
40-44	0.7 ± 0.2	---		

TABLE 2 (Continued)

SAVANNAH RIVER (18 km from mouth) No. 7610-1916

0-1	51.7 ± 1.9	0.09 ± 0.01	4550 ± 190	0.011
4-5	66 ± 2.7	0.08 ± 0.01	---	---
8-9	84.6 ± 5	0.11 ± 0.02	3417 ± 105	0.025
12-13	75.7 ± 4	0.17 ± 0.02	3370 ± 64	0.022
16-17	70 ± 2.4	0.14 ± 0.01	2428 ± 78	0.029
20-22	61 ± 2.4	0.05 ± 0.01	1930 ± 19	0.032
28-30	58 ± 2	0.03 ± 0.01		
34-36	68 ± 2	0.03 ± 0.01		
40-44	13 ± 1	0.04 ± 0.02		

MARSH CORE NO. 7610-2016, Adjacent to Tybee River

0-1	18 ± 2.5	---	590 ± 17	0.031
4-5	26 ± 1.8	0.03 ± 0.01	---	---
6-7	36.5 ± 2.3	0.03 ± 0.01	760 ± 21	0.048
8-9	34.6 ± 1.7	0.03 ± 0.01	770 ± 20	0.045
14-15	10.9 ± 0.9	0.03 ± 0.015	3000 ± 121	0.004
20-22	2.2 ± 0.1		1821 ± 27	0.001
28-30	0.9		77 ± 3	0.012

TABLE 2 (Continued)

SAVANNAH RIVER (5 km from mouth) Core No. 7610-2108

0-1	27 ± 0.9	0.04 ± 0.01	478 ± 14	0.057
2-3	44.7 ± 2	0.05 ± 0.01		
4-5	45 ± 4	0.03		
6-7	24.5 ± 2	0.05 ± 0.02		
8-9	23.2 ± 1.5	0.04 ± 0.01	530 ± 31	0.044
12-13	26.6 ± 1.5	0.03 ± 0.01		
16-17	18.8 ± 2	---		
20-22	22 ± 1.4	0.04 ± 0.02		
28-30	17.6 ± 1	0.06 ± 0.02		
34-36	21.8 ± 1.2	0.03 ± 0.01		

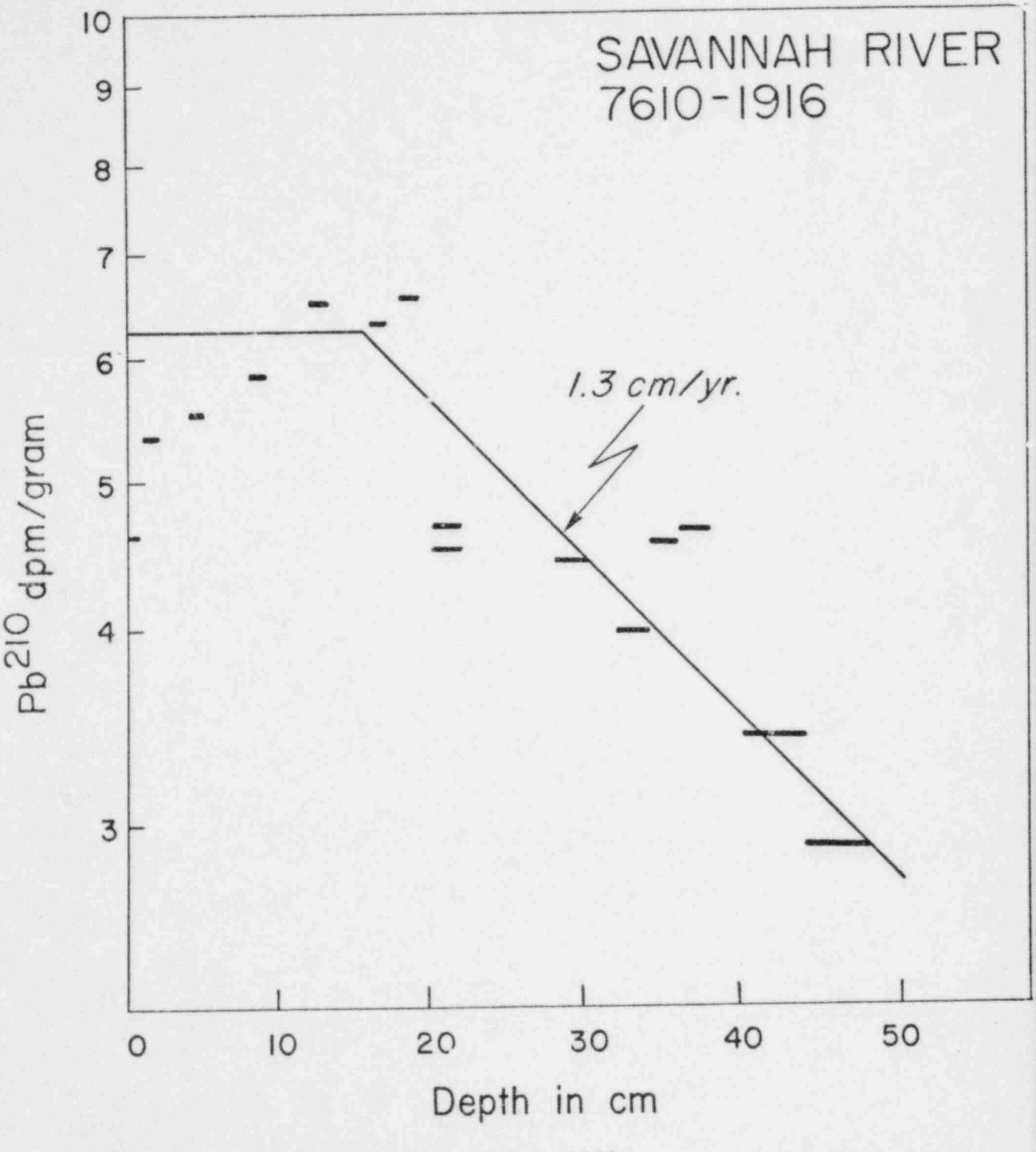

Figure 3. Pb-210 depth profile of Core 1916.

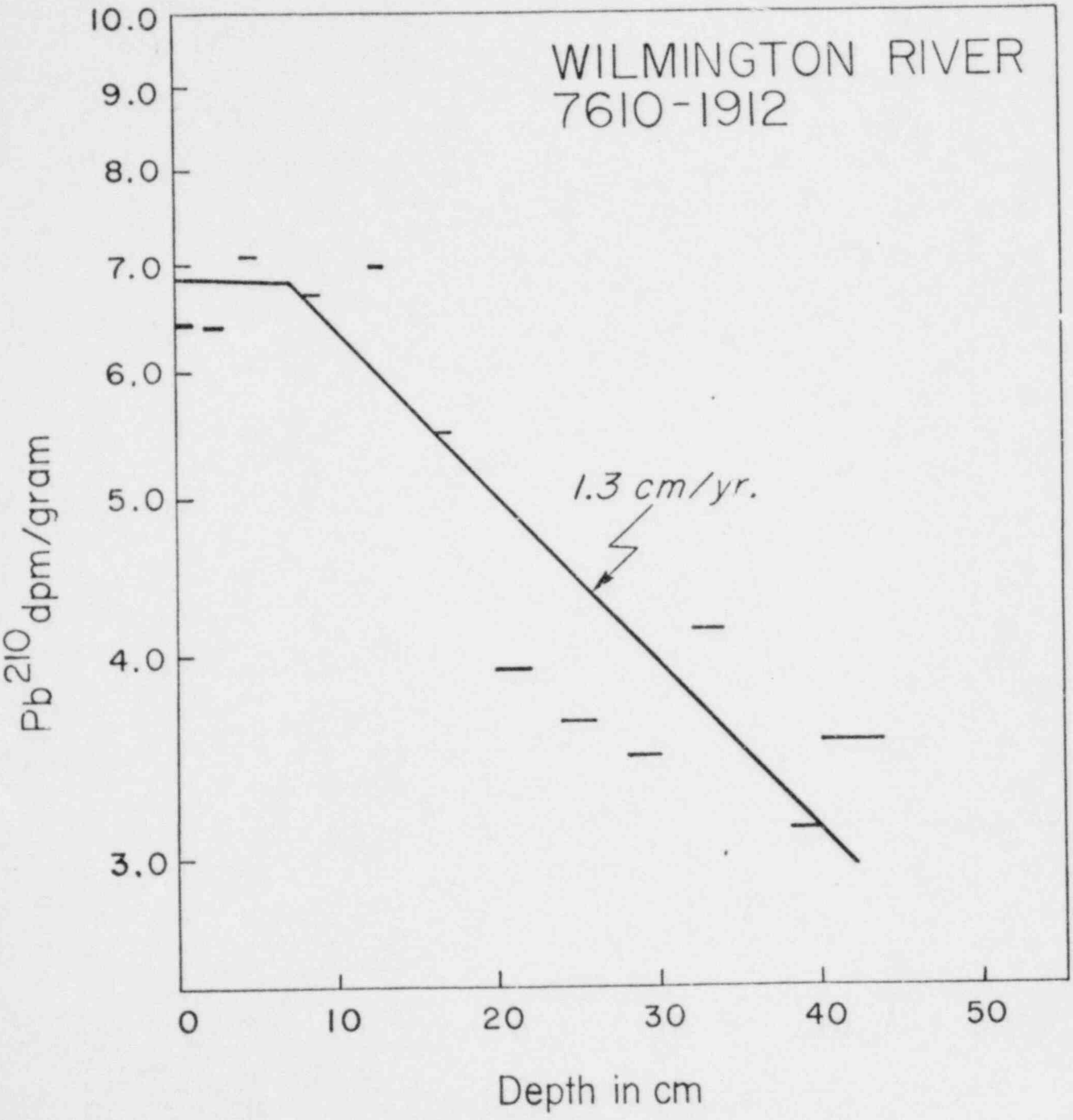

Figure 3 (Continued). Pb-210 depth profile of Core 1912

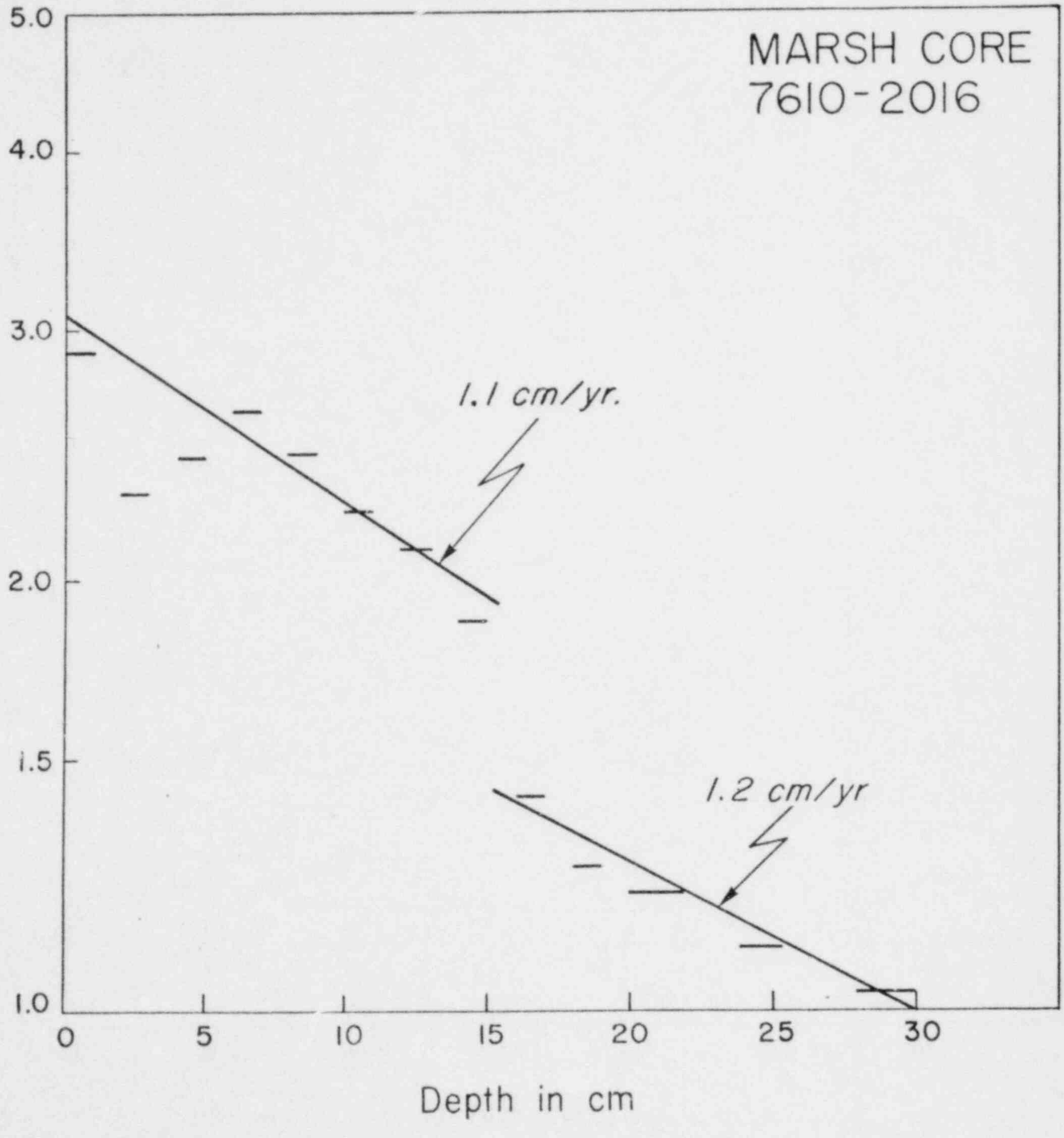

Figure 3 (Continued). Pb-210 depth profile of Core 2016

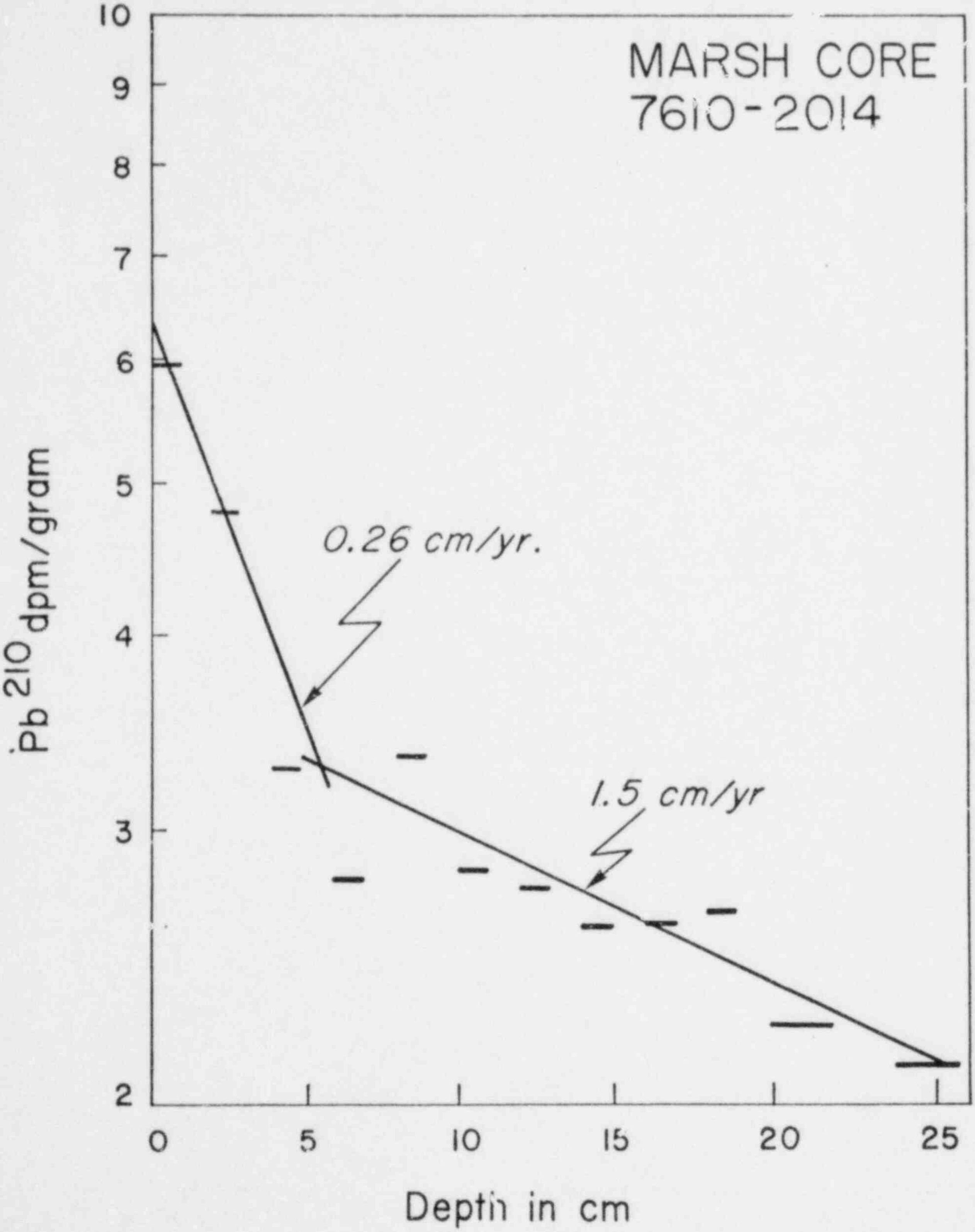

Figure 3 (Continued). Pb-210 depth profile of Core 2014

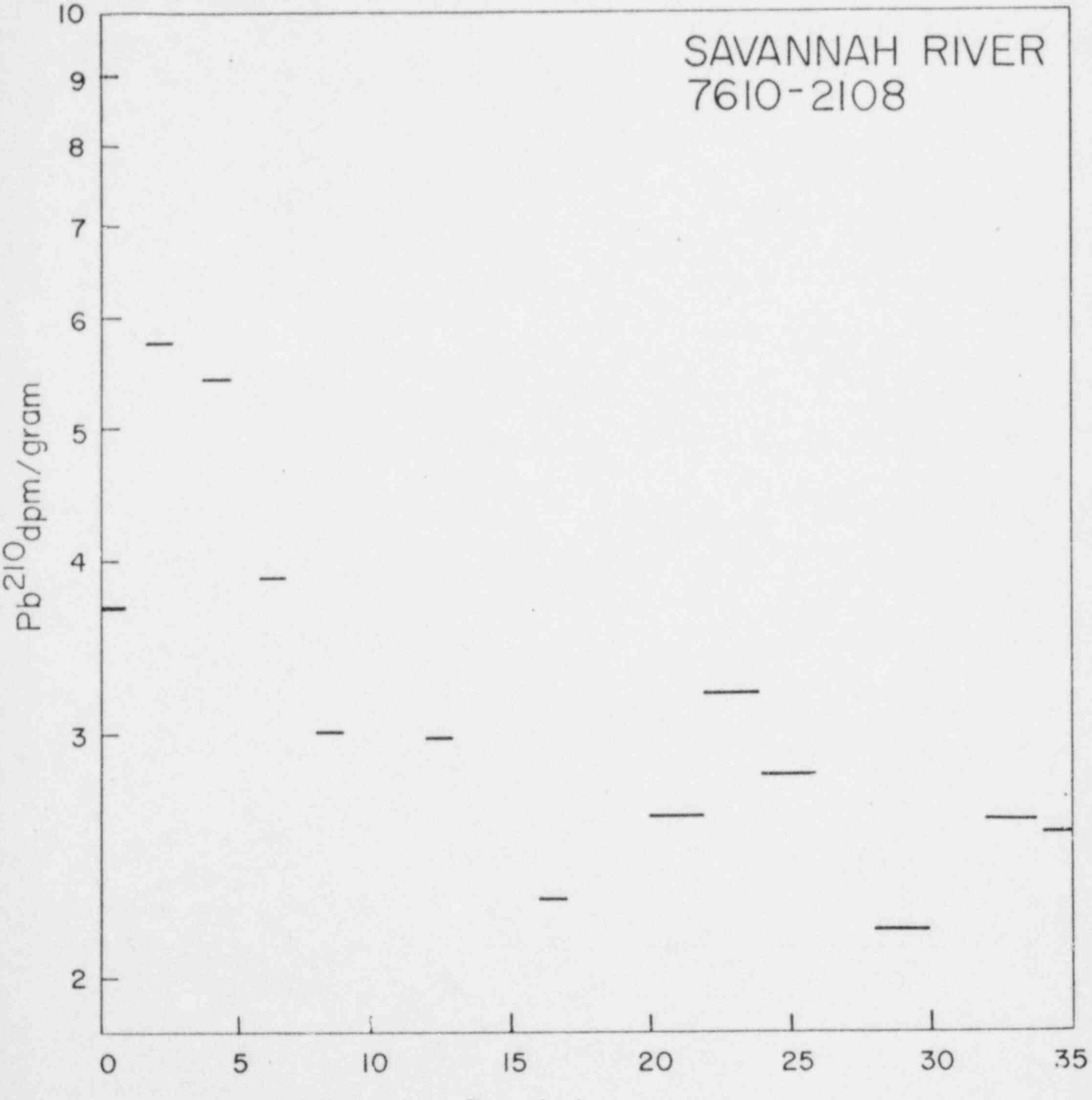

Figure 3 (Continued). Pb-210 depth profile of Core 2108

Willmington River Core 7610-1912: The Pb-210 profiles indicate a sedimentation rate of around 1.3 centimeters per year (Figure 3 and Table 2). The near-uniform values in the upper 13 centimeters may be a consequence of bioturbation. The plutonium-239+240 disappears between the 30 and 44 centimeter levels, the former having a Pb-210 age of 1953 and the latter, 1943. Bioturbation can result in a transfer of plutonium, as well as Pb-210, to deeper levels. Still, there is reasonable agreement between the two geochronologies and the rate of around 1.3 cm/year appears valid. There is evident stratification in the x-ray picture of the core section (Figure 2) and the derivation of a Pb-210 and Pu-239+240 accumulation rate is in agreement with this.

Marsh Core 7610-2014: The two geochronologies are not in accord. The Pb-210 profiles indicate an initial sedimentation rate of 0.26 cm/year to a depth of about 5 cm (Figure 3; Table 2). Then a rate change takes place and the deeper strata accumulate at about 1.5 centimeters per year. According to the former rate, the 5 centimeter level is about 20 years old and in adjacent deeper strata, the Pu-239+240 should disappear. However, the transuranic radionuclides are still detectable at the 24 to 26 centimeter level The x-ray picture of the core section (Figure 2) indicates an intensive intrusion of plant roots. Their growth and movements may have caused displacement of sedimentary phases and may have destroyed the record of sedimentation rates maintained by the lead-210 and plutonium nuclides.

Savannah River Core 7610-2108: The deposit has somewhat uniform concentrations of Pb-210 and Pu-239+240 to the vertical extent of the box-core, 34 - 36 cm (Figure 3; Table 2). Higher levels of the nuclides are evident in the 2-3 and 4-5 cm strata. The distributions may have resulted either from very rapid sedimentation, mixing, or non-uniform rates of accumulation, or perhaps from a combination of these processes. If one neglects the 2-3 and 4-5 cm strata, a Pb-210 sedimentation rate of about 2 cm/year results. The strata would then have deposited over about an 18 year interval which could account for the high Pu-239+240 concentrations at the core bottom. Still, the results clearly do not allow the introduction of a geochronology to the sediments. The x-ray picture (Figure 2) indicates some stratification in the upper layers. At depth in the core, there are numerous clam shells, indicative of sediment and water movements through the activities of the living organisms.

Savannah River Core 7610-1916: There appears to be a good Pb-210 geochronology which yields a sedimentation rate of 1.3 cm/year (Table 2; Figure 3). Bioturbation and/or physical mixing appears to take place to depths of about 13 centimeters. The lowest depth of the box core, 40-44 centimeters would then have been deposited between 31 and 34 years ago. With mixing to 13 centimeters we can account for the presence of plutonium isotopes at these depths. The x-ray picture indicates evident stratification throughout the core below about 13 cm. Above this level, there is a homogenized sediment, in agreement with the results from the radionuclides.

Two aspects of these results appear significant. First of all there is the observation that the riverine deposits have a persistence over decades and thus can reveal sedimentation histories over such time periods. Although the coring sites were chosen with an a priori sense that they would be able to maintain any accumulated solid phases, the particle by particle precipitation mode is established.

Secondly, there appears to be a conflict in the cm/yr sedimentation rates found herein in stratified deposits by plutonium and lead-210 chronologies with that of 1 mm/year based upon eustatic changes of sea level (Rusnak, 1967). There is other evidence that lower rates may prevail in this U. S. southeastern estuarine system. The nine rivers which enter this salt marsh zone carry a suspended load of 8.5×10^{11} grams/year or 42×10^{11} cc/year (assuming a density of 2 grams/cc) (Windom, 1975). If this sediment is uniformly deposited over the salt marsh area of 4×10^{5} hectares, then an accumulation rate of 0.1 mm/year results.

This apparent conflict may be resolved by any of a number of factors. First of all, there may be precipitation of solids from the dissolved or colloidal water phases, a situation which would enhance the sedimentation rates derived solely from the measured particulate load of the rivers. Also, the values determined in this work may be site specific and not truly representative of the entire estuarine system. The coring sites were chosen with the sense that they would be able to maintain precipitated materials more readily than other zones. Finally, there are fluxes of solids of marine origin entering the rivers (See subsequent section) that will increase the accumulation rates based solely upon the river data.

Still, our four measured rates through their consistency appear more reliable than estimated rates based upon regional parameters.

NON-FALLOUT PLUTONIUM

In only one core is there evidence of non-fallout plutonium. The Savannah River Core 1916 displays elevated values of the Pu-238/Pu-239+240 ratios at levels 12-13 cm and 16-17 cm with values of 0.17 and 0.14 respectively (Table 2). About 0.3 Curies of plutonium have been released from the Sanannah River Plant of the U.S. Department of Energy to the estuarine system (D. W. Hayes et al., 1976). At sedimentation rates of 1.3 cm/year, the dates of accumulation of these high values of Pu-238 would be a period around 1966 and 1963 respectively. The plant released both Pu-238 and Pu-239-240 with higher levels of the former. Hayes et al.(1976) calculate that 55 Curies of plutonium have been delivered to the Savannah River watershed by fallout from weapons testing. On the basis of our analyses, there is no extensive plutonium pollution recorded in the sediments other than about double fallout levels in some strata of a deposit located near the plant. On the other hand, living Spartina and dead Spartina from Stations 2014 and 2016 respectively had unusually high values of the ratio, 0.17 and 0.31 (Table 3). The plutonium-238 may have been brought to the plant surfaces from the atmosphere with suspended soil debris from the area adjacent to the plant. Spanish moss, which receives its nourishment from scavenging and from rainout and fallout, had a ratio of 0.17. This observation reinforces the argument of atmospheric, rather than riverine, transport for the Pu-238. These soil particles are known to have elevated levels of this transuranic nuclide (Milham et al., 1976).

METALS

The concentrations of the metals in cores in which geochronologies could be developed and in those which appeared to be mixed provided

TABLE 3. Plutonium and cesium-137 Contents of Plants from Savannah River Estuary System

	Pu-239+240 in dpm/kg	Pu-238 / Pu-239 + 240 (Activity ratio)	Cs-137 dpm/kg	Pu-239 + 240 / Cs-137 (Activity ratio)
Spanish Moss (Living) 7610 2508	7.5 ± 0.5	0.17 ± 0.03	1114 ± 37	0.007
Spartina grass (Detritus) 7610 2016	4.6 ± 0.3	0.17 ± 0.03	201 ± 8	0.023
Spartina grass (Living) 7610 2014	1.7 ± 0.1	0.31 ± 0.03	102 ± 3	0.017

important information (Table 4). In the former case the elemental profiles as a function of depth may be diagnostic both of particle by particle deposition and of processes occurring within the sediment or within the estuarine system. The average concentrations of the metals in mixed sediments again may provide insights into the behaviors of elements in this estuarine zone.

For the three cores in which time frames could be introduced, 7610-1916, 7610-2016 and 7610-1912, the manganese/aluminum ratio appeared to increase with increasing depth (Figure 4). The ratio was used instead of the absolute concentrations inasmuch as there may be various dilutants of the river-borne solid inorganic phases such as organic matter and tidally introduced minerals such as quartz (See subsequent section). The behavior of manganese has been noted before in anoxic cores where the element enters the deposit in an oxidized form as in subsequently reduced to the mobile, divalent state. This latter form then diffuses molecularly out of the deposits to the overlying waters (Lynn and Bonatti, 1965). The other two cores did not display such Mn/Al profiles. The concept that these latter cores were mixed and that the other three were continuously accumulated is strengthened.

In the Wilmington River Core (7610-1912), three metals, lead, chromium and vanadium appeared to decrease with increasing depth, suggesting increased deliveries to the system in recent years (Figure 4). All three of the elements are recognized pollutants, mobilized by man, that often show such behaviors in coastal waters. Cores No. 7610-1916 and Core 7610-2016 appear to have near uniform concentrations of all metals measured except manganese. It is interesting to note that the metal profiles were most evident in those cores with the highest concentrations of metals.

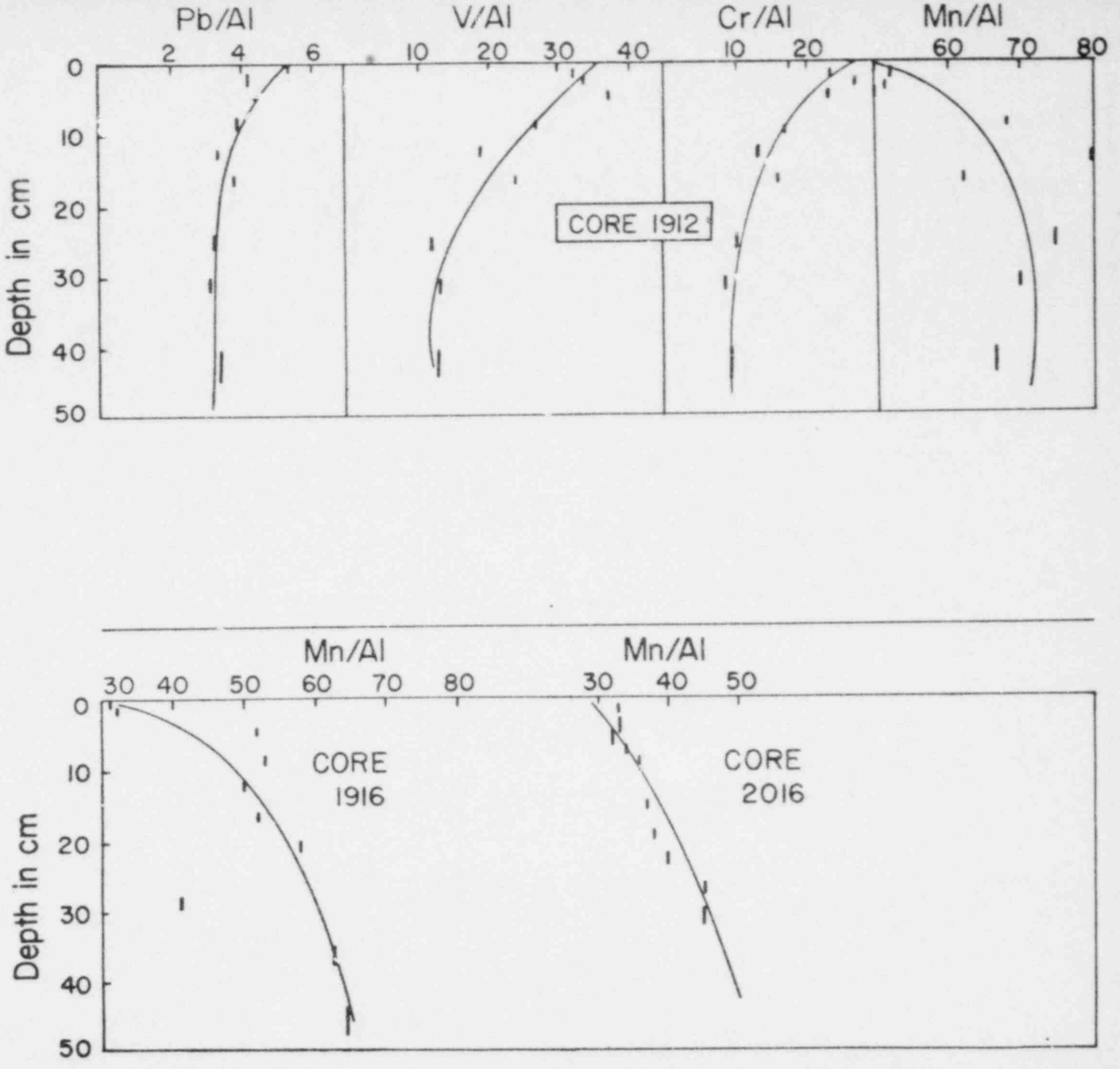

Figure 4. Heavy metal profiles in the Savannah Estuary Cores

TABLE 4. METAL AND QUARTZ CONTENTS OF WILMINGTON RIVER CORE No. 7610-1912(ppm, except quartz, Fe and Mn which are in % dry wt).

Depth	Pb	Zn	Cr	Cu	Co	Ni	Mn	Al	V	Fe	Qu
0-1 cm	60	103	200	53	12	23	560	11.5	350	5.7	9
1-2	58	109	320	57	13	28	700	13.5	430	7.0	
2-3	44	90	280	45	11	19	520	10.3	340	5.1	8
4-5	48	98	250	53	10	20	550	10.9	460	5.4	
8-9	44	78	190	48	11	23	770	11.4	310	5.7	10
12-13	38	96	144	42	12	23	900	11.1	210	4.8	
16-17	41	85	170	47	14	24	680	10.9	260	5.4	
20-22											10
24-26	41	89	132	48	15	26	970	13.0	150	5.8	
30-32	44	102	124	54	16	30	1000	14.2	180	6.6	
38-40											9
40-44	45	95	122	54	16	31	840	12.6	170	5.7	

Table 4 (Continued)

SAVANNAH RIVER CORE No. 7610-1916

Depth	Pb	Zn	Cr	Cu	Co	Ni	Mn	Al	V	Fe	Qu
0-1 cm	4.8	85	150	4.9	12	23	310	10.1	290	4.0	20
1-2	4.2	91	180	49	12	25	330	10.3	300	3.8	
4-5	4.1	99	170	50	13	24	550	10.5	310	5.3	16
8-9	4.2	91	230	52	14	26	570	10.8	310	5.4	
12-13	4.2	105	190	56	14	27	560	11.3	360	5.6	
16-17	4.5	102	260	56	15	25	550	10.5	360	5.1	12
20-22	4.2	83	210	42	14	19	510	8.8	320	5.3	
28-30	4.4	64	160	34	12	18	300	7.4	210	3.8	
36-38	4.0	88	180	41	11	24	620	9.9	230	4.4	21
44-48	4.0	67	110	4.1	11	22	580	9.0	100	4.2	

Table 4 (Continued)

MARSH CORE No. 7610-2014

Depth	Pb	Zn	Cr	Cu	Co	Ni	Mn	Al	V	Fe	Qu
0-1											20
1-2 cm	31	31	130	32	9	16	275	8.1	160	4.1	
3-4	30	40	110	37	12	24	190	9.1	160	4.1	
5-6	31	48	100	38	14	24	220	9.0	144	4.2	
7-8	30	61	120	39	12	25	220	9.7	160	4.5	
8-9											15
9-10	30	58	120	38	14	24	250	9.6	160	4.8	
11-12	30	51	110	42	14	24	260	10.2	160	4.4	
13-14	28	63	100	36	13	24	250	10.0	146	3.9	
15-16	30	58	100	42	14	26	280	9.9	160	4.6	
17-18	29	64	100	41	17	28	315	9.9	160	4.7	
19-20	32	73	120	45	21	28	410	12.5	190	5.9	
20-22											12
22-24	25	50	90	36	14	25	340	8.6	123	4.9	

Table 4 (Continued)

MARSH CORE No. 7610-2016

Depth	Pb	Zn	Cr	Cu	Co	Ni	Mn	Al	V	Fe	Qu
0-1											38
1-2	24	42	56	13	4	11	170	5.2	71	3.2	
3-4	26	47	59	14	5	11	180	5.4	81	3.5	
4-5											39
5-6	27	58	67	15	6	15	210	6.4	99	4.2	
7-8	27	58	68	16	6	16	220	6.5	100	4.2	
9-10	28	64	77	18	6	18	240	6.7	106	4.6	
14-15											39
15-16	24	51	65	16	7	11	230	6.3	94	4.0	
18-19											37
19-20	23	45	56	14	6	15	210	5.5	80	3.6	
22-24	20	50	55	14	7	17	220	5.5	85	3.6	
26-28	18	38	48	12	5	12	210	4.7	68	3.1	
28-30											50
30-32	14	23	33	6	3	6	150	3.3	37	2.0	

Table 4 (Continued)

SAVANNAH RIVER CORE No. 7610-2108

Depth	Pb	Zn	Cr	Cu	Co	Ni	Mn	Al	V	Fe	Qu
0-1	25	58	80	15	7	13	540	4.4	125	4.0	47
2-3	36	89	148	24	9	25	540	7.1	220	5.9	
4-5	26	70	115	18	8	17	470	5.9	160	4.7	33
8-9	24	65	93	16	8	13	470	4.9	160	4.6	
12-13	22	65	92	18	8	13	450	4.6	160	4.4	
16-17	24	67	94	18	7	13	420	4.5	170	4.9	56
22-24	20	53	81	15	5	19	340	4.0	136	3.8	
24-26	23	99	85	16	4	12	360	4.2	138	4.1	
30-32	29	77	88	19	6	14	420	5.4	150	5.1	
34-36	20	42	81	15	5	12	390	5.0	131	4.1	48

The highest concentrations of the metals, exclusive of iron, were found in the two cores furthest from the ocean, Cores 7610-1912 and 7610-1916. In estuarine systems, there is an extensive precipitation of metals in the zones where the salinities reach 10 - 15% (Sholkovitz, 1976). It is precisely in this area that reported salinities achieve such values (Stickney and Miller, 1974). On the other hand, there existed the possibility that ocean introduced solid phases might be diluting the riverborne materials, as has been suggested by Müller and Förstner (1975). These workers noted that Elbe River sediments mixed with North Sea sediments in the estuarine zone. The resulting sediments had heavy metal concentrations intermediate between that of the North Sea and of the Elbe River. Meade (1969) indicates that there is a movement of sand into the Savannah River Estuarine System from the coastal zone. To assess the entry of marine materials into the deposit, we analyzed the sediments for detrital marine minerals using quartz as a representative member (Table 4).

Aluminum was chosen as the metal to test the "dilution hypothesis". Its content in the sediments would be trivially affected through the introduction of aluminum from the quartz which contains only trace amounts of the light metal. The dilution effect of quartz was evident upon the aluminum concentrations. The absolute values of aluminum in the cores varies between 3.3 and 14.2 percent, greater than a factor of four. When the aluminum concentrations are considered on a quartz free basis, their range is reduced by a factor of two, to 6.6 to 14.4%. This dilution of the river-borne materials with the quartz can explain the variations in other metals, whose concentrations vary as does aluminum.

The iron concentrations do not show the marked variations as aluminum does. The reasons for this uniformity are as yet not understood, although we are aware that the American Cyanamid titanium dioxide plant on the Savannah River has discharged large quantities of iron into the river.

Because of the importance of the amount of quartz in the cores in determining the gross compositions of metals in these sediments, comparisons with the results of other workers are somewhat hazardous. Still, we note that the iron, copper and manganese concentrations of our cores and those of Windom (1975) for marsh cores are similar. This suggests that the sediments of Windom contained comparable levels of quartz to those in our marsh cores.

The general sedimentation rate for this area appears to be about 1 cm/year. The quartz levels of Core 2108, at about 50% would double this rate to about 2 cm/year, a value in accord with a calculated one in the previous section.

The plutonium-239+240 levels in the surface sediments of the Savannah system achieve values up to 85 dpm/kg (Level 8-9 cm in Core 1916). This is similar to values reported for the surface sediments of Narragansett Bay (Goldberg et al., 1975) where activities of around 125 dpm/kg were observed and for Chesapeake Bay with the highest value of around 146 dpm/kg was found (Goldberg et al., 1978). The high values in the Savannah deposits are associated with low-quartz containing sediments. Again, the dilution of the river-borne particles bearing plutonium by quartz appears to be the explanation.

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