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Radiochemistry and sedimentology of surficial mud-dominated deposits, Hillborough Bay, Florida

Gregg R. Brooks

Hepsi D. Zsoldos

Robert H. Byrne

Larry J. Doyle

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- Phase II Report -

by
Gregg R. Brooks
Hepsi D. Zsoldos
Robert H. Byrne
Larry J. Doyle

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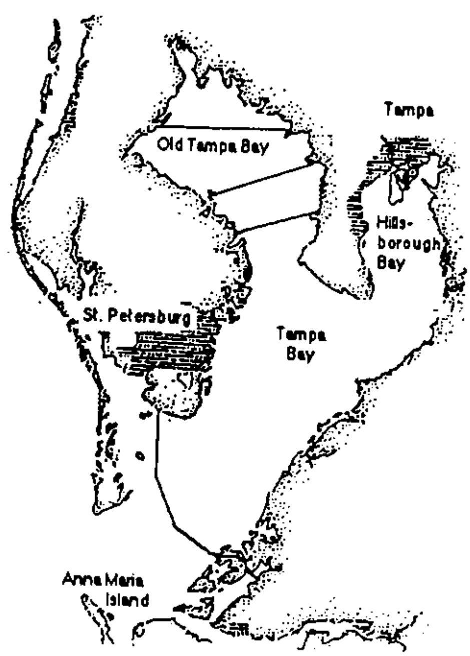

THE CENTER FOR NEARSHORE MARINE SCIENCE
OF THE
UNIVERSITY OF SOUTH FLORIDA
Dr. Larry J. Doyle, Director

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Executive Summary

Fine-grained sediments, because of their characteristics and association with contaminants, have been identified as a potential threat to Hillsborough Bay. Mapping of mud-size surface sediments by the Bay Study Group (BSG) showed that they occupy approximately 24% of Hillsborough Bay bottom with a large concentration in west central Hillsborough Bay. A study of the geologic history of these fine-grained deposits, the initial phase of this project, showed that muds have been accumulating in bathymetric depressions within the Bay for several thousand years at relatively low rates averaging between 30-60 cm/1,000 years.

The objectives of this project were to investigate depositional patterns and accumulation rates of sediments deposited during the period when man's influence on the Bay has been the greatest; compare results with historic patterns identified during Phase I; and, evaluate the extent to which man's activities may have impacted Bay sedimentation patterns and accumulation rates.

Four large-diameter push cores were collected, three in Hillsborough Bay and one in Old Tampa Bay, and analyzed for sedimentology and radiochemistry in order to determine the extent and timing of alterations in geologically recent (within approximately the past 100 years) sedimentation patterns.

Radiochemical analyses show that ^{210}Pb dating is questionable as a geochronological indicator for Tampa Bay sediments. Nevertheless, tentative rates based upon ^{210}Pb and ^{137}Cs values range from 0.18 ± 0.07 - 0.72 ± 0.35 cm/year, which is consistent with values calculated for many other estuaries. Vertical distributions of core samples show that surficial sediments of west central Old Tampa Bay are distinctly different than Hillsborough Bay with

larger mean grain sizes and lower calcium carbonate and TOC percentages. Weak tendancies toward a decrease in grain size and increase in TOC (and to some extent calcium carbonate content) in the upper 20-30 cm of some Hillsborough Bay cores suggest sedimentation patterns may have been altered in the recent geologic past. The lack of such a pattern in Hillsborough Bay core 10-20 indicates that this alteration was not experienced Bay wide. Lead-210 and ^{137}Cs data suggest that alterations began between approximately 35 and 140 years ago, which would be consistent with the most active development of the Bay area. Accumulation rates appear to have increased by up to one order of magnitude over average rates calculated for approximately the last 5,000 years, which may also correlate with early Bay area development.

Introduction

Hillsborough Bay is the northeast lobe of Tampa Bay, the largest open water estuary on Florida's west coast (Fig. 1). For a complete description of the setting and previous works, the reader is referred to Doyle, et al. (1989). The Phase I study of fine-grained (<63μ) sediments in Hillsborough Bay (Brooks and Doyle, 1989) established distribution patterns and average accumulation rates of mud-dominated sediments at selected sites within the Bay over the past several thousand years. Phase II of the study, the focus of this investigation concentrates on the uppermost 50-100 cm of the sediment column, or those sediments believed to have been deposited within approximately the past 100 years.

Objectives of this study were to investigate depositional patterns and accumulation rates of sediments deposited during the period of man's presence in the Bay area; compare results with historic patterns identified during Phase I; and, evaluate the extent to which man's activities have impacted Bay sediment distribution patterns and accumulation rates. Since sedimentary deposits record the recent development and activities affecting the Bay, results will be important for determining the overall impact that man's activities have had on the Hillsborough Bay ecosystem, which should prove useful for more effective Bay management.

Sediment accumulation rates can be assessed from observation of the distribution of ^{210}Pb in a sediment column. At any depth in a sediment column, the total ^{210}Pb can be partitioned into an excess term and a component which is attributable to in-situ production (decay of ^{226}Ra). Thus,

$$^{210}Pb\ (\text{total}) = {}^{210}Pb\ (\text{excess}) + {}^{210}Pb\ (\text{in-situ production});$$

and it is the excess ^{210}Pb term which is of interest in assessing sediment accumulation rates. Although atmospheric input is generally thought to be the dominant source of ^{210}Pb, Benninger (1978) has also argued that the interpretation of excess ^{210}Pb levels can be complicated by riverine and groundwater sources as well.

In order to accurately determine sedimentation rates with ^{210}Pb, a number of physical criteria must be satisfied (Robbins and Eddington, 1975):

1) The flux of ^{210}Pb into sediments has remained constant through time.

2) The sedimentation rate has been constant during the period of time to be determined.

3) There has been little or no post-depositional migration of ^{210}Pb in the sedimentary column.

4) The activity of ^{226}Ra does not change along the length of the core in question.

Martin and Rice (1981) have additionally made the following suggestions about ^{210}Pb dating. They stated that ^{210}Pb dating should not be done when:

a) The grain size of the sediment varies significantly throughout its length.

b) The ratio of maximum (surface) activity of the excess ^{210}Pb to the ^{226}Ra supported ^{210}Pb in the sediment column is 5:1 or less.

c) The area being investigated has a very low sedimentation rate (<0.1cm/yr) and cannot be sampled in intervals small enough to provide a decay profile.

d) The sediment column is deeply mixed by bioturbation or by other physical or chemical processes. Bioturbated cores include those that appear in the field to be undisturbed but for which X-radiographs show an intense network of worm burrows.

e) The study environment has a history of dredging and/or spoil dumping.

Methods

Four sediment cores were collected at predetermined sites deemed most appropriate for project objectives. Three of the cores (3-30, 3-13 and 10-20) were collected at sites previously occupied by the Bay Study Group (Johansson and Squires, 1988), and during phase I (Brooks and Doyle, 1989) in Hillsborough Bay (Fig. 1). Core OTB3 was collected from adjacent Old Tampa Bay (Fig. 1) for comparison purposes.

As a result of the large amount of sediment required for radiochemical analyses an 8" diameter "push corer" was developed by the BSG specifically for this project. The corer is approximately 1m in length and constructed such that it can be operated by a single diver with relative ease. Once on board ship, each core was extruded into a trough for subsampling. The presence of amphipods <u>Ampelisca</u> <u>sp</u>. on the surface, as well as overall appearance, indicates that cores were relatively undisturbed by the sampling procedure. Each core was subsampled at 2cm intervals and transported back to the laboratory for individual analyses.

Sedimentological analyses were performed on all samples by the same methods as those performed during Phase I in order to maintain consistency. Analyses were performed on the same samples that underwent radiochemical analyses. All samples were analyzed for texture at whole phi(ϕ) intervals using standard seive and pipette methods (Folk, 1965). Phi mean and standard deviation were computed for each sample by the method of moments (Folk, 1965). Calcium carbonate content (%CO_3) was determined for all samples by the acid leaching method (Milliman, 1974). Total Organic Content (TOC) was determined for all samples by loss on ignition at 550°C (Dean, 1974).

All samples for radiochemical analyses were weighed, measured for bulk-density (g/cm^3) and dried at 95 degrees (C) to determine water content.

Samples were then powdered, sieved through a 500 um screen to ensure uniformity of size, sealed in 160 ml aluminum cans and allowed to equilibrate for 17-21 days (5-6 half lives of ^{222}Rn) so that the daughter products of ^{222}Rn could come into equilibrium with ^{226}Ra.

Because there are variations in bulk density throughout the core, compaction corrections were used when analyzing lead and cesium profiles. Lynch et al. (1989) used the following equation to normalize each section of the core to the bottom five sections of the core:

$$CI_x = (BD_x/BD_5)(I) \tag{1}$$

where CI_x is the compacted interval length in centimeters of section x, BD_x is the bulk density of section x in g/cm^3, BD_5 is the average bulk density in the bottom five sections of the core (g/cm^3) and I is the original section length (2 cm in this case). The resulting "new" sections are stacked atop each other to determine the new sample positions within the core.

Samples were analyzed for radionuclide content using an extended range intrinsic germanium (Ge(I)) detector (Canberra Model GX 1518). Custom standards of ^{210}Pb and ^{226}Ra having the same geometry as the sample were obtained from Isotope Products, Inc. The concentrations of ^{210}Pb, ^{214}Pb and ^{214}Bi were determined from their peaks at 46.5, 352 and 609 keV respectively. Because standard and sample are generally not identical, self absorption corrections were performed and activities were obtained by direct comparison to our standards. Lead-214 and ^{214}Bi activities were used to determine the activity of ^{226}Ra.

Cesium-137 and ^{40}K activities were determined by calibrating the detector against the ^{226}Ra standard and integrating the number of counts under the peaks at 661.6 and 1480 keV respectively.

Accumulation rates were calculated by combining the radioactive decay law with the relation t=x/S giving:

$$A_{ex} = A_o \, e^{-(x/S)\lambda} \qquad \text{and} \qquad (2)$$

$$\ln A_{ex} = -x(\lambda/S) + \ln A_o \qquad (3)$$

where A_{ex} is equal to the activity (dpm/g) of the excess ^{210}Pb, A_o is the activity of ^{210}Pb at the surface (x=0), lambda (λ)is the decay constant of ^{210}Pb (0.0311/yr), x is depth (cm) measured from the sediment surface, and S is the sedimentation rate (cm/yr) (Ku, 1976).

Plotting the natural log (ln) of excess ^{210}Pb against depth should yield a straight line such that:

$$\text{Slope} = -\lambda/S \qquad \text{or} \qquad (4)$$

$$\text{Sedimentation rate (S)} = -\lambda/\text{slope} \qquad (5)$$

Cesium-137 accumulation rates were determined by plotting the activity (dpm/g) against depth:

$$S = X/t \qquad (6)$$

where S is the sedimentation rate (cm/yr) and X is the depth of the 1963 peak. An assumption is made that the depth of ^{137}Cs particles in the 1963 peak are due solely to accumulation and not to any other processes such as bioturbation, mobilization, or diffusion (Lynch et al., 1989).

Results and Discussion

Recovery from the coring procedure appeared to be good with generally 50-70 cm of undisturbed core recovered after compaction from dewatering. Based upon visual observation, the fluid content of the sediments appeared to be relatively high with an increase in approximately the upper 20cm. No downcore trends are evident as all cores consisted principally of medium to dark gray muds. Quartz sand is present as a minor component in Hillsborough Bay cores and a substantial component of the Old Tampa Bay core. Layers of small mollusc shell fragments occur sporadically, as do isolated whole gastropod shells.

Sedimentology

Results of textural analysis show relatively large variations both within each core and between cores (Figs. 2 and 3). No strong trends are evident. Cores 3-30 and 3-13 exhibit the smallest grain sizes and show similar patterns of distribution (Figs. 2 and 3). Both have mean sizes in the 7-8ϕ range (Fig. 2), and consist of 70-100% mud-size material. Both show a weak tendency toward becoming finer upcore (Figs. 2 and 3). Core 10-20 consists of coarser-grained material (Figs. 2 and 3) with a range from almost 4ϕ to a little over 7ϕ mean size. Mud content ranges from 65-100%. Old Tampa Bay core OTB3 contains the coarsest sediments with a mean size range of 3-5ϕ and a mud content of 50-60% (Figs. 2 and 3). Downcore values are variable, but show no trends.

Hillsborough Bay cores 3-30, 3-13 and 10-20 show the same general patterns as the upper portions of corresponding vibracores from the Phase I project (Brooks and Doyle, 1989). Core 10-20 appears to be coarser grained but exhibits a similar pattern. Core 3-13 on the other hand, consists of finer-grained material but exhibits a similar pattern.

Calcium carbonate content of core samples range from less than 5% to approximately 35% of the total sediment. Hillsborough Bay cores 3-30, 3-13 and 10-20 have much higher percentages (10-35%) than Old Tampa Bay core OTB3 (<6%) and also show more variation (Fig. 4). Cores 3-30 and 10-20 have similar percentages (10-30%) and a similar tendency toward declining from the core base at 50-70cm and then increasing from approximately 20cm to the surface (Fig. 4). Core 3-13 exhibits the highest percentages ranging from approximately 10 to 35% with a weak tendency toward increasing upcore. Old Tampa Bay core OTB3 consists of less than 6% calcium carbonate. Percentages show little vertical variation and no trends are evident. In comparison to the upper sections of vibracores from Phase I (Brooks and Doyle, 1989), patterns are generally similar. Cores 3-13 and 3-30 are very similar to Phase I patterns, and core 3-30 exhibits some similarity but values are a bit higher than those reported in Phase I.

Total Organic Content (TOC) percentages range from less than 1 to over 18% (Fig. 5). Cores 3-30 and 3-13 have highest percentages ranging from almost 10 to over 18% and both show a weak tendency toward increasing upcore (Fig. 5). Core 10-20 TOC percentages range from <1 to almost 10%, although all but one sample contains greater than 6%. Core 10-20 samples show a weak tendency toward decreasing upcore (Fig. 5). Old Tampa Bay core OTB3 percentages range from 2% to a little over 5% TOC. Little variation exists and there is a slight tendency toward increasing from approximately 20cm to the surface (Fig. 5). In comparison with Phase I data (Brooks and Doyle, 1989), TOC percentages for core 10-20 are very similar, with values mostly in the 5-10% range and showing a slight tendency toward decreasing upcore. Cores

3-30 and 3-13 both appear to have higher percentages than reported in Phase I and also exhibit a weak tendency toward increasing upward where none was evident in Phase I data.

Radiochemistry

The activities of ^{210}Pb, ^{226}Ra, ^{137}Cs, and ^{40}K for all sediments are given in Tables 1 and 2 and Figures 6-21. Sediment water content is also shown in Table 1. Errors quoted on all activities depict counting errors. Potassium-40 (Figures 18-21) was measured as a potentially useful parameter for characterizing the amount of illitic clay found in the sediments (Sharma et al., 1987). Berylium-7 is not given as it was not found in sufficient activities to be detectable, probably due to too large a sampling interval.

Compaction corrections (Table 3) were necessary for the interpretation of cores with high organic content. Compaction corrections seemed especially important for Stations 3-13 and 3-30 due to their high organic content, higher water content and lower bulk density. This correction normalized the upper portions of the core to the lower sections. Due to water content in the upper part of cores, compaction causes sediment sections to shrink (Lynch et al., 1989). Using Hillsborough Bay station 3-13 as an example, one can see that the first two centimeters of the core compacted to 1.24 cm, while in the lower part of the core (50-52 cm), which was highly dewatered, compaction corrections were not necessary. Failure to account for compaction can result in an overestimation of the accumulation rate (Lynch et al., 1989).

^{210}Pb profiles - Station 3-13 (Figure 6) shows a somewhat disturbed profile in the upper 8 cm. Both ^{210}Pb and ^{226}Ra (determined from ^{214}Pb and ^{214}Bi) vary significantly within this section. Radium-226 activities range from a low of 3.4 dpm/g at the bottom of the core and increase to a high of

Hillsborough Bay Station 3-13

depth	compact depth	Pb-210	error	Ra-226	error	Excess Pb-210	error
0	0.62	7.478	0.567	5.531	0.121	1.947	0.58
2	1.89	11.153	0.793	6.967	0.157	4.186	0.808
4	3.26	10.43	0.65	6.418	0.136	4.012	0.664
6	4.66	9.378	0.664	5.775	0.129	3.603	0.676
8	6.13	10.272	0.805	8.68	0.176	1.592	0.824
14	10.7	9.255	0.74	6.638	0.153	2.618	0.755
18	14.1	7.046	0.737	6.878	0.173	0.169	0.757
22	17.4	4.77	0.572	4.856	0.142	-0.086	0.59
28	22.47	4.232	0.548	5.612	0.143	-1.379	0.566
32	26.14	4.562	0.544	4.643	0.138	-0.081	0.561
38	32.06	2.674	0.426	4.105	0.12	-1.431	0.442
54	47.61	2.949	0.392	3.403	0.117	-0.454	0.409

Hillsborough Bay Station 3-30

depth	compact depth	Pb-210	error	Ra-226	error	Excess Pb-210	error
0	0.665	10.744	0.800	6.112	0.149	4.632	0.814
2	2.025	9.395	0.722	6.352	0.154	3.043	0.739
4	3.530	8.743	0.754	6.227	0.151	2.516	0.769
6	5.110	9.769	0.706	6.189	0.144	3.580	0.721
8	6.710	11.260	0.763	6.367	0.155	4.892	0.779
12	9.990	9.769	0.773	6.073	0.156	3.697	0.788
16	13.060	8.563	0.729	7.403	0.157	1.161	0.745
22	14.560	6.452	0.634	6.531	0.147	-0.079	0.650
24	19.720	6.556	0.605	5.161	0.131	1.395	0.619
28	23.470	6.386	0.593	5.541	0.136	0.845	0.608
32	27.670	6.268	0.614	6.228	0.147	0.040	0.631

Hillsborough Bay Station 10-20

depth	compact depth	Pb-210	error	Ra-226	error	Excess Pb-210	error
0	2.64	7.029	0.564	4.07	0.116	2.959	0.576
2	4.46	6.275	0.52	4.926	0.123	1.349	0.534
4	6.34	7.939	0.637	5.127	0.136	2.812	0.651
6	8.31	6.328	0.548	4.964	0.129	1.364	0.563
10	10.3	5.622	0.488	3.604	0.116	2.018	0.502
14	14.39	4.087	0.44	4.38	0.118	-0.293	0.456
18	18.54	3.951	0.438	3.939	0.114	0.012	0.452
24	24.14	3.767	0.439	4.263	0.116	-0.496	0.454
30	29.02	3.712	0.46	3.698	0.122	0.015	0.476
38	35.98	2.705	0.372	3.683	0.11	-0.977	0.388
44	42.32	2.555	0.326	3.045	0.102	-0.49	0.341
52	52.1	3.224	0.398	3.233	0.113	-0.009	0.414
64	63.87	5.938	0.546	5.745	0.148	0.193	0.566

Old Tampa Bay Station 3

depth	compact depth	Pb-210	error	Ra-226	error	Excess Pb-210	error
0	0.605	4.277	0.587	2.413	0.128	1.864	0.600
2	1.815	4.040	0.392	2.644	0.097	1.396	0.404
4	3.040	3.716	0.428	2.687	0.096	1.029	0.439
6	4.340	3.738	0.608	2.640	0.140	1.099	0.624
8	5.760	3.814	0.399	2.353	0.093	1.461	0.410
10	7.290	4.282	0.460	2.590	0.107	1.692	0.473
12	8.910	3.673	0.375	2.544	0.091	1.129	0.386
18	14.250	2.686	0.336	1.928	0.084	0.759	0.346
24	19.980	2.061	0.297	1.881	0.088	0.180	0.310
36	32.200	1.831	0.267	1.992	0.082	-0.161	0.279
44	40.070	1.248	0.235	1.965	0.086	-0.717	0.251
54	50.530	1.664	0.270	2.005	0.089	-0.341	0.285

Table 1 - U-238 series in Tampa Bay Cores

Hillsborough Bay Station 3-13

depth	Cs-137	error	K-40	error
0	0.224	0.038	8.685	0.791
2	0.318	0.058	11.413	1.059
4	0.300	0.049	11.864	0.869
6	0.320	0.045	11.728	0.924
8	0.149	0.054	13.219	1.050
14	0.055	0.049	11.840	1.022
18	0.035	0.057	9.800	0.930
22	0.009	0.048	9.298	1.026
28	0.016	0.046	8.990	0.994
32	0.073	0.047	10.785	0.989
38	0.003	0.045	11.545	0.909

Hillsborough Bay Station 3-30

depth	Cs-137	error	K-40	error
0	0.256	0.053	10.048	1.000
2	0.224	0.062	10.802	1.066
4	0.247	0.059	11.010	1.092
6	0.308	0.052	9.965	0.939
8	0.263	0.058	11.836	1.094
12	0.206	0.058	9.712	1.086
16	0.181	0.053	10.169	1.099
22	0.147	0.051	10.360	0.911
24	0.140	0.043	9.275	0.843
28	0.082	0.047	6.810	0.842
32	ND	ND	8.778	0.774

Hillsborough Bay Station 10-20

depth	Cs-137	error	K-40	error
0	0.142	0.051	5.708	0.993
2	0.065	0.051	9.445	0.820
4	0.015	0.060	9.797	0.982
6	0.024	0.056	8.490	0.719
10	0.083	0.048	10.162	0.861
14	0.032	0.044	9.064	0.829
18	0.055	0.047	9.402	0.848
24	0.000	0.000	11.463	0.993
30	0.000	0.000	13.217	1.114
38	0.000	0.000	7.951	0.768
44	0.000	0.000	4.968	0.727
52	0.058	0.048	7.592	0.884
66	0.000	0.000	10.673	1.103

Old Tampa Bay Station 3

depth	Cs-137	error	K-40	error
0	0.176	0.059	8.596	0.959
2	0.166	0.041	6.208	0.692
4	0.134	0.046	6.394	0.639
6	0.143	0.069	6.575	1.065
8	0.111	0.000	6.886	0.660
10	0.134	0.049	4.915	0.794
12	0.138	0.040	5.466	0.614
18	0.049	0.043	4.047	0.624
24	0.061	0.039	3.617	0.608
36	0.013	0.038	3.815	0.058
44	0.000	0.000	3.960	0.568
54	0.000	0.000	4.128	0.571

Table 2: Cs-137 and K-40 activities in Tampa Bay Cores.

section interval (cm)	bulk density (g/cm^3)	compacted interval (cm)	new section interval (cm)	Midpoint (cm)
Hillsborough Bay Station 3-13				
0-2	0.321	1.24	0.00-1.24	0.62
2-4	0.336	1.30	1.24-2.54	1.89
4-6	0.373	1.44	2.54-3.98	3.26
6-8	0.349	1.35	3.98-5.33	4.66
8-10	0.411	1.59	5.33-6.95	6.13
10-12	0.383	1.48	6.92-8.40	7.66
12-14	0.406	1.57	8.40-9.97	9.19
14-16	0.427	1.65	9.97-11.62	10.70
16-18	0.427	1.65	11.62-13.27	12.45
18-20	0.427	1.65	13.27-14.92	14.10
20-22	0.411	1.59	14.92-16.51	15.72
22-24	0.458	1.77	16.51-18.28	17.4
24-26	0.417	1.61	18.28-19.89	19.09
26-28	0.437	1.69	19.89-21.58	20.74
28-30	0.458	1.77	21.58-23.35	22.47
30-32	0.476	1.84	23.35-25.19	24.27
32-34	0.492	1.90	25.19-27.10	26.14
34-36	0.505	1.95	27.10-29.05	28.08
36-38	0.515	1.99	29.05-31.04	30.05
38-40	0.525	2.03	31.04-33.07	32.06
40-42	0.512	1.98	33.07-35.05	34.06
42-44	0.497	1.92	35.05-36.97	36.01
44-46	0.466	1.80	36.97-38.77	37.87
46-48	0.435	1.68	38.77-40.45	39.61
48-50	0.476	1.84	40.45-42.29	41.37
50-52	0.518	2.00	42.29-44.29	43.29
52-54	0.559	2.16	44.29-46.45	45.37
54-56	0.600	2.32	46.45-48.77	47.61

Table 3. Compacted depth data.

section interval (cm)	bulk density (g/cm3)	compacted interval (cm)	new section interval (cm)	Midpoint (cm)
Hillsborough Bay Station 3-30				
0-2	0.307	1.33	0.00-1.33	0.67
2-4	0.321	1.39	1.33-2.72	2.03
4-6	0.374	1.62	2.72-4.35	3.53
6-8	0.351	1.52	4.35-5.87	5.11
8-10	0.388	1.68	5.87-7.55	6.71
10-12	0.379	1.64	7.55-9.19	8.37
12-14	0.369	1.60	9.19-10.79	9.99
14-16	0.351	1.52	10.79-12.30	11.55
16-18	0.351	1.52	12.30-13.82	13.06
18-20	0.372	1.61	13.82-15.43	14.63
20-22	0.390	1.69	15.43-17.13	16.28
22-24	0.393	1.70	17.13-18.83	14.56
24-26	0.411	1.78	18.83-20.61	19.72
26-28	0.423	1.83	20.61-22.44	21.53
28-30	0.473	2.05	22.44-24.49	23.47
30-32	0.485	2.10	24.49-26.59	25.54
32-34	0.496	2.15	26.59-28.75	27.67
34-36	0.508	2.20	28.75-31.06	29.96
36-38	0.483	2.09	31.06-33.14	32.10
38-40	0.519	2.25	33.14-35.47	34.35

Hillsborough Bay Station 10-20

0-2	0.466	1.75	0.00-1.75	0.88
2-4	0.474	1.78	1.75-3.56	2.64
4-6	0.479	1.80	3.26-5.36	4.46
6-8	0.522	1.96	5.36-7.32	6.34
8-10	0.527	1.98	7.32-9.30	8.31
10-12	0.533	2.00	9.30-11.30	10.30
12-14	0.533	2.00	11.30-13.50	12.40
14-16	0.471	1.77	13.5-15.27	14.39
16-18	0.602	2.26	15.27-17.53	16.40
18-20	0.535	2.01	17.53-19.54	18.54
20-22	0.511	1.92	19.54-21.46	20.50
22-24	0.487	1.83	21.46-23.29	22.38
24-26	0.450	1.69	23.29-24.98	24.14
26-28	0.442	1.66	24.98-26.64	25.81
28-30	0.431	1.62	26.64-28.26	27.45
30-32	0.405	1.52	28.26-29.78	29.02
32-34	0.453	1.70	29.78-31.48	30.63
34-36	0.458	1.72	31.48-33.20	32.34
36-38	0.479	1.80	33.20-35.00	34.1

Table 3 continued

section interval (cm)	bulk density (g/cm^3)	compacted interval (cm)	new section interval (cm)	Midpoint (cm)
H.B. 10-20 (continued)				
38-40	0.522	1.96	35.00-36.96	35.98
40-42	0.522	1.96	36.96-38.92	37.94
42-44	0.596	2.24	38.92-41.96	40.04
44-46	0.618	2.32	41.16-43.48	42.32
46-48	0.791	2.97	43.48-46.45	44.97
48-50	0.663	2.49	46.45-48.94	47.70
50-52	0.562	2.11	48.94-51.05	50.00
52-54	0.557	2.09	51.05-53.14	52.10
54-56	0.525	1.97	53.14-55.11	54.13
56-58	0.546	2.05	55.11-57.16	56.14
58-60	0.573	2.15	57.16-59.31	58.24
60-62	0.605	2.27	59.31-61.58	60.45
62-64	0.421	1.58	61.58-63.16	62.37
64-66	0.378	1.42	63.16-34.58	63.87
Old Tampa Bay Station 3				
0-2	0.652	1.21	0.00-1.21	0.61
2-4	0.652	1.21	1.21-2.42	1.82
4-6	0.668	1.24	2.42-3.66	3.04
6-8	0.728	1.35	3.66-5.01	4.34
8-10	0.803	1.49	5.01-6.5	5.76
10-12	0.852	1.58	6.50-8.08	7.29
12-14	0.895	1.66	8.08-9.74	8.91
14-16	1.051	1.95	9.74-11.69	10.72
16-18	0.862	1.60	11.69-13.29	12.49
18-20	1.035	1.92	13.29-15.21	14.25
20-22	0.981	1.82	15.21-17.03	16.12
22-24	1.051	1.95	17.03-18.98	18.01
24-26	1.078	2.00	18.98-20.98	19.98
26-28	1.035	1.92	20.98-22.90	21.94
28-30	1.067	1.98	22.90-24.88	23.89
30-32	1.127	2.09	24.88-26.97	25.93
32-34	1.067	1.98	26.97-28.95	27.96
34-36	1.148	2.13	28.95-31.08	30.02
36-38	1.094	2.03	31.08-33.11	32.30
38-40	1.159	2.15	33.11-35.26	34.19
40-42	1.024	1.90	35.26-37.26	36.21
42-44	0.986	1.83	37.26-39.09	38.18
44-46	1.056	1.96	39.09-41.05	40.07
46-48	1.223	2.27	41.05-43.30	42.19
48-50	1.040	1.93	43.30-45.23	44.27
50-52	1.164	2.16	45.23-47.39	46.31
52-54	1.110	2.06	47.39-49.45	48.42
54-56	1.159	2.15	49.45-51.61	50.53

Table 3 continued

8.68 dpm/g at 8 cm before decreasing again to 5.53 dpm/g at the surface. The (ln) excess ^{210}Pb profile shows some signs of exponential decay with depth. A least squares fit of the profile yields a sediment accumulation rate of 0.18$\pm$0.07 cm/yr.

Station 3-30 (Figure 7) has a more stable ^{226}Ra profile with the exception of a high ^{226}Ra activity at approximately 16 cm. The excess ^{210}Pb profile is smoother than for Station 3-13. A least squares fit of the profile (Figure 11) yields a sediment accumulation rate of 0.25$\pm$0.058 cm/yr.

The upper portion of Station 10-20 (Figure 8) was found to be quite disturbed. The excess ^{210}Pb varies between 1-3 dpm/g from 0-10 cm. The value below this point drops off to zero and is assumed to be in secular equilibrium with ^{226}Ra throughout the remainder of the core. The excess ^{210}Pb profile (Figure 12) at this station is the most poorly defined of the four stations.

Old Tampa Bay Station 3 (OTB 3) has the best radiochemical profiles (Figure 9) of all four stations. The ^{226}Ra varies only slightly in the top portion of the core (0-14 cm). From 14 cm to the bottom, the ^{226}Ra is very constant. The ^{210}Pb excess profile is variable between 0-7 cm but shows an exponential decrease with depth below this. A regression line drawn through the profile (Figure 13) yields an accumulation rate of 0.32$\pm$0.07 cm/yr.

It is possible to construct an entirely different pattern of sediment accumulation rates in Tampa Bay by using profiles whose excess ^{210}Pb values are larger than their associated error bars. For example, at Station 3-13 (Figure 10), the lowest point on the plot is a very small number (0.20$\pm$0.76 dpm/g - see Table 1). This number has such a large error associated with it that it can and probably should be ignored. The resultant plot of (ln) excess ^{210}Pb versus depth (Figure 22) is quite different from Figure 10. This new plot is effectively useless for the purposes of dating.

Station 3-30 (Figure 11) has an excess ^{210}Pb value of 0.076$\pm$0.634 dpm/g at a depth of 32 cm. Eliminating this value and re-plotting the profile yields an accumulation rate of 0.46$\pm$0.11 cm/yr (Figure 23). This is almost twice the rate calculated from Figure 11 (0.25$\pm$0.058 cm/yr).

The most dramatic difference is found when comparing Old Tampa Bay Station 3 (OTB3) (Figure 14) with the profile that results after eliminating the excess ^{210}Pb value at the depth of 24 cm (0.19$\pm$0.31 dpm/g - Table 1). The new profile (Figure 24) yields a rate of 0.72$\pm$0.35 cm/yr. This is more than twice that calculated from Figure 14 (0.32$\pm$0.07 cm/yr).

Cesium-137 profiles - It is important to emphasize at the outset that the ^{210}Pb dating method gives average accumulation rates for the past 100 years while the ^{137}Cs yields estimates accumulation only for the past 25-30 years and that ^{137}Cs dating of sediments is best done in areas where the accumulation rate is rapid (about 1 cm/yr) (Sharma et al., 1987). Even though our calculated rates are not ideal, two out of four Tampa Bay stations have ^{137}Cs profiles that are potentially useful for dating very recent sediments.

Station 3-13 (Figure 14) has a peak that falls between 1.9 and 4.9 cm. The accumulation rate was determined by taking the mid-point of the two depths and dividing by 27 years. This gives an accumulation estimate of 0.13 cm/yr.

Cesium-137 activity is highest at 5.1 cm at Station 3-30 (Figure 15). This maximum is assumed to be the 1963 peak and yields an accumulation rate of 0.19 cm/yr. However, ^{137}Cs was detected throughout the core. This could be the result of either mobilization of ^{137}Cs downcore or extensive bioturbation.

The Station 10-20 core (Figure 16) had very little activity at the top, and none to speak of at depths greater than 2.5 cm. There is 2-3 times less ^{137}Cs activity present than the other stations. Given the proximity of this station to other Hillsborough Bay stations, there is no reason to suspect that

^{137}Cs fallout would be different at this location. Based on this very low ^{137}Cs activity and the erratic ^{210}Pb profile, it is possible that this station has undergone recent erosion, and that the top 10-15 cm of the core may actually be missing.

There was no ^{137}Cs peak evident in Old Tampa Bay Station 3 (Figure 17), possibly due to vertical mixing as a result of bioturbation.

Based on available data, we feel that ^{210}Pb dating is a questionable geochronological indicator for the Tampa Bay area for the following reasons:

1) Calculated accumulation rates in Tampa Bay (Figures 10-14) have a range of 0.18±0.07 - 0.32±0.07 cm/yr. Rates calculated from Figures 22-24 are in the range of 0.46±0.11 - 0.72±0.35 cm/yr. These two differing rates result from the elimination of only <u>one</u> point from each profile. By dropping this point, accumulation rates in Tampa Bay more than double making it evident that there are serious problems with placing too heavy an emphasis on rates determined by ^{210}Pb geochronology.

Additionally, it must be pointed out that accumulation rates between Hillsborough Bay and Old Tampa Bay cannot be compared with one another as sedimentation processes may be very different in each bay (see following section).

Therefore, accumulation rates in Hillsborough Bay using the first scenario (calculated using all data points) range from 0.18±0.07 - 0.25±0.058 cm/yr (Station 3-30). Station 10-20 has no excess ^{210}Pb profile to speak of, possibly due to localized erosion as previously pointed out.

Accumulation rates are estimated in the second excess ^{210}Pb scenario (calculated by using only those excess ^{210}Pb values that are larger than their error bars) by Station 3-30 only. Rates at this station are estimated to be 0.46±0.11 cm/yr. The excess ^{210}Pb profile of Station 3-13 is not usable for dating purposes.

Accumulation rates in Old Tampa Bay vary from 0.32$\pm$0.07 cm/yr using the first excess ^{210}Pb profile (Figure 14) to 0.72$\pm$0.35 cm/yr using the second scenario of excess ^{210}Pb (Figure 24).

2) ^{226}Ra activity does not stay constant with depth. Stations 3-13 and 3-30 show a general increase in ^{226}Ra upcore. Station 3-13 has a factor of two increase from the bottom to the center of the core. Station 10-20 has a ^{226}Ra maximum at the bottom of the core. ^{226}Ra values decrease upcore, but are not steady. Of the four stations, OTB3 is very constant with depth, but even this core shows an increase of ^{226}Ra toward the top. This violates the Robbins and Eddington (1975) requirement that ^{226}Ra remains constant throughout the length of the core.

3) Sediments appear to be vertically mixed, sometimes deeply, as in the case of Station 10-20. All ^{210}Pb profiles show a near surface zone of disturbance. It is unlikely that the coring and sampling process could cause this degree of disturbance, especially as Ampelisca sp. tubes were found undisturbed on the top of two out of three Hillsborough Bay cores. Martin and Rice (1981) stated that there should be no deep mixing of the sediments by bioturbation or other physical or chemical mixing process.

4) The initial activity ratio of excess ^{210}Pb to ^{226}Ra never reaches 5:1 (Martin and Rice, 1981). Station 3-13 has a ratio of 0.35 at the surface, Station 3-30 has a ratio of excess ^{210}Pb to ^{226}Ra of 0.77, Station 10-20 has a ratio of 0.73 and OTB3 yields a ratio of 0.77. The low activity ratios are probably due to locally elevated radium levels, especially in Hillsborough Bay.

5) Hillsborough Bay has a history of dredging and spoil dumping. There are several spoil islands located in Hillsborough Bay from recent dredging episodes, and dredging activities tend to disrupt natural sediment deposition.

6) The average depth of Tampa Bay (approximately 3 meters) makes it very easy for other physical processes to disturb sediments. Storms which bring high winds can stir the surface sediments. Prop wash from recreational boating as well as shrimping activities also mix surface sediments.

Summary - Keeping in mind the above concerns, all available evidence suggests that tentative accumulation rates using ^{210}Pb are in the range of 0.18±0.07 - 0.46±0.11 cm/yr in Hillsborough Bay and 0.32±0.07 - 0.72±0.35 cm/yr in Old Tampa Bay. Cesium 137 rates are on the order of 0.13 - 0.19 cm/yr.

Recent Depositional History

Fine-grained sediments in west central Hillsborough Bay show the same general vertical distribution patterns as was found for corresponding depths reported in Phase I. The similarity of values and trends for closely spaced samples in the upper 70cm of Phase II push cores to those for the Phase I vibracores, helps to independently verify data validity and allows for a more complete comparison with historical (approximately last 5ka) data. Although no strong vertical trends exist, weak tendencies for a variety of cores and parameters were noticed with the vast majority beginning in the 20-30cm range (Figs. 2-5). Hillsborough Bay cores 3-30 and 3-13 show the greatest tendency toward changes in the upper 20-30cm with increases in TOC and calcium carbonate content and a corresponding decrease in grain size. These tendencies appear different when compared to historical patterns (Brooks and Doyle, 1989), thereby signifying a change in sedimentation patterns at some time in the past few thousand years. The upper 20cm (approximate) of fine-grained sediments in west central Hillsborough Bay contain an increased amount of fine-grained material rich in organics and calcium carbonate. Core

10-20 does not show this tendency indicating that the Hillsborough Bay basin as a whole may not have experienced this alteration in sediment distribution patterns.

Old Tampa Bay core OTB3 is considerably different from Hillsborough Bay cores. Distinctly larger mean grain sizes, lower TOC and calcium carbonate content percentages indicate Old Tampa Bay (at least the portion where OTB3 was collected), is under different influences and possibly an entirely different sedimentologic regime. A distinct increase in TOC over the upper 10-20cm of core, however, indicates that there has been an increased input or preservation of organics, which is consistent with what was found for Hillsborough Bay cores 3-30 and 3-13.

Lead-210 and ^{137}Cs data (see radiochemical section) suggest sediment accumulation rates in the 0.13-0.72 cm/yr range. Based upon these rates observed trends in cores beginning in the 20-30 cm (downcore depth) range would have begun between about 35 and 140 years ago. Hence, the tendencies noticed toward decreasing grain size, increasing TOC, and to some extent an increase in calcium carbonate content, signify a change in sedimentation patterns, which would be coincidental with the time period of most active development of the Tampa Bay area.

Comparing sediment accumulation rates of the upper 50-100 cm of sediment calculated from this study, to average rates over approximately the last 5,000 years reported in the Phase I study, suggest an increase by approximately one order of magnitude over the recent geologic past. Accumulation rates determined by ^{210}Pb and ^{137}Cs methods yield an average rate of approximately 0.3 cm/yr for Hillsborough Bay over the past 100 or so years. Note that the OTB3 data are thrown out, because comparisons are being made within Hillsborough Bay. Average rates calculated using radiocarbon methods for the same Hillsborough Bay deposits ranged from approximately 30-60 cm/1,000 yrs over the past 5,000 (approximate) years (Brooks and Doyle, 1989). Such an increase may represent a substantial increase in the input of fine-grained sediments into the Bay that is coincidental with and possibly attributable to Bay area development.

It must be pointed out, however, that this increase may be an artifact of the different time scales involved. For example, the rates calculated over approximately the last 5,000 years are average rates that may include periods of rapid deposition and periods of no deposition, or possibly even erosion. The result is that there may have been periods since the last 5,000 years where accumulation rates have been as high or maybe even surpassed those calculated for the last 100 years. Hence, the recent rate increase may be a result of a natural increase in sediment input and not a response to Bay area development. The fact that data from different depths in cores yield consistently similar rates over approximately the past 5,000 years, however, suggest that there has been at least some increase in accumulation rate during this time interval. Although rates may have increased at any time in the past few thousand years (there are no data points between approximately 4,000 years ago and 100 years ago), an increase accompanying the observed alteration of sedimentation patterns at 20-30 cm downcore depths would be a reasonable interpretation.

An alternate scenario, based upon the low rate of 0.13 cm/yr, shows an increase in accumulation rate over the past few thousand years of only a factor of two, which, when considering the errors potentially involved, may be insignificant. These data, therefore, give us a general idea of accumulation rates in the Bay area and it would be unwise to place too much emphasis on their absolute value.

Accumulation rates calculated in this study are lower than the 0.4-2.0 cm/yr rates calculated by the same general method (Trefry, Trocine, and Metz, 1988) for the lower Hillsborough River. This may reflect a greater input of river transported sediments, or be an artifact of the different techniques used. Our rates are consistent, however, with those reported for upper Chesapeake Bay (Schubel, in Davis, 1978) and Delaware Bay (Ootsdam, in Davis, 1978). Accumulation rates calculated for approximately the upper 50 cm of mud-dominated sediments in Hillsborough and Old Tampa Bays, therefore, may be more consistent with those reported for other U.S. east coast estuaries than previously believed.

Summary & Conclusions

1) Lead-210 dating is a questionable geochronological indicator for the Tampa Bay area for the following reasons:

   a) Two different ranges of accumulation rates can be calculated by omitting one point from the data set. The difference between the ranges is more than a factor of two.

   b) ^{226}Ra activity does <u>not</u> stay constant with depth.

   c) Sediment columns appear to be disturbed.

   d) The initial activity ratio of ^{210}Pb to ^{226}Ra never comes close to reaching the recommended 5:1.

   e) Hillsborough Bay has a history of dredging and spoil dumping that tend to disrupt sediment deposition.

   f) The average depth of Tampa Bay (approximately 3 meters) makes it very easy for other physical processes to disturb sediments.

2) Keeping in mind the above concerns, tentative sediment accumulation rates using ^{210}Pb are in the range of 0.18 ± 0.07 - 0.25 ± 0.058 cm/yr in Hillsborough Bay and 0.32 ± 0.07 - 0.72 ± 0.35 cm/yr for Old Tampa Bay. Cesium-137 rates are on the order of 0.13-0.19 cm/yr.

3) Surficial (approximately the upper 50 cm) sediments from mud-dominated deposits in west central Old Tampa Bay appear to be distinctly different from those in Hillsborough Bay with larger mean grain sizes and consistently lower percentages of calcium carbonate and TOC.

4) Weak tendencies toward increasing TOC and calcium carbonate content, and an accompanying decrease in grain size in the upper 20-30 cm of some cores, may represent an alteration of sedimentation patterns. Lead-210 and Cesium-137 data indicate these alterations may have occurred

between 35 and 140 years ago, which would be consistent with most active Bay area development.

5) Distinct differences between sediments in core 10-20, and cores 3-30 and 3-13, suggest that alterations in net sediment accumulation patterns may not have been experienced throughout all of Hillsborough Bay.

6) Despite the problems shown with ^{210}Pb dating in Tampa Bay, data indicate accumulation rates are consistent with those reported for other estuaries, and up to one order of magnitude greater than average net rates for approximately the past 5,000 years.

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FIGURES

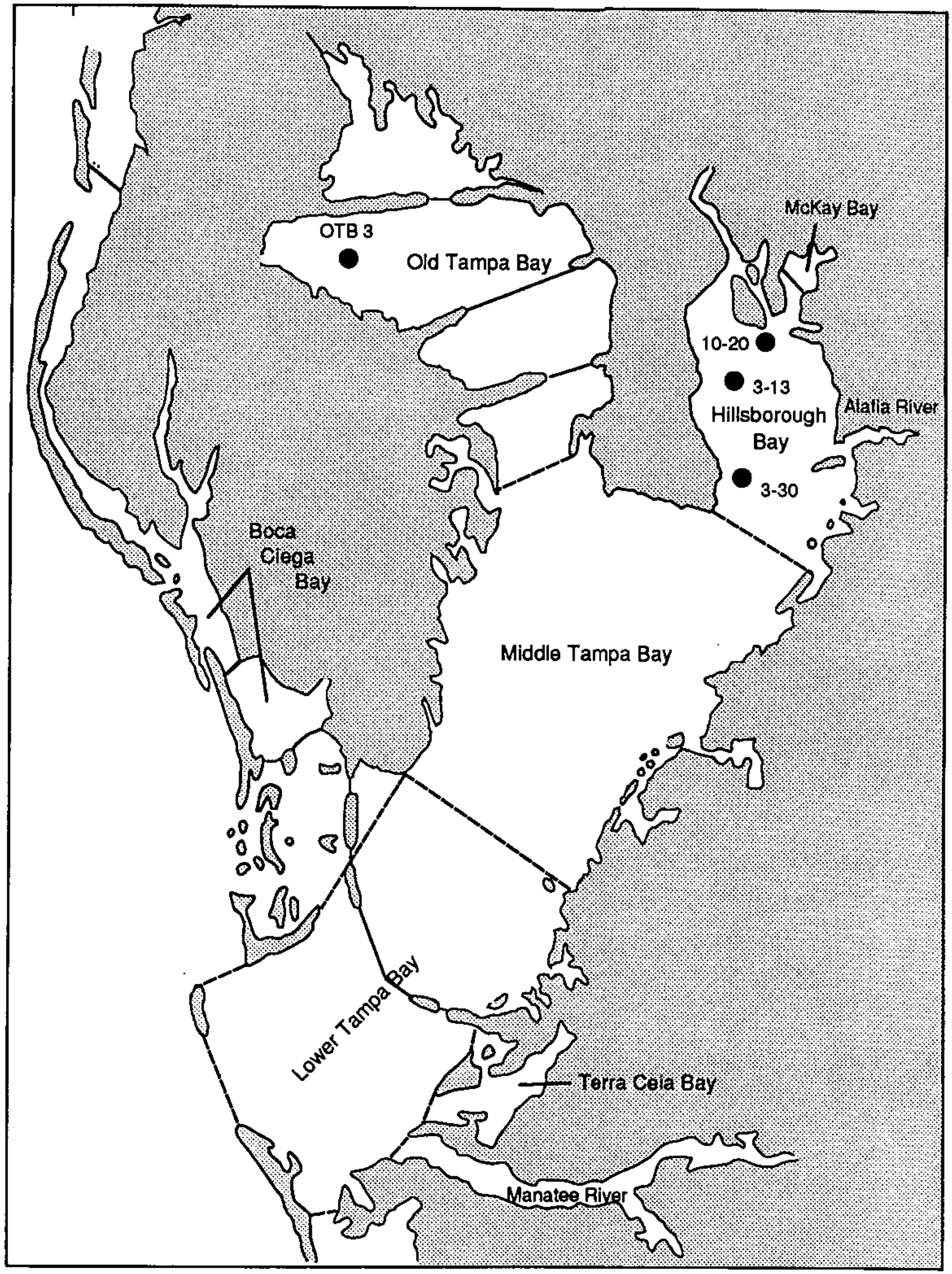

Figure 1: Location of Tampa Bay study sites.

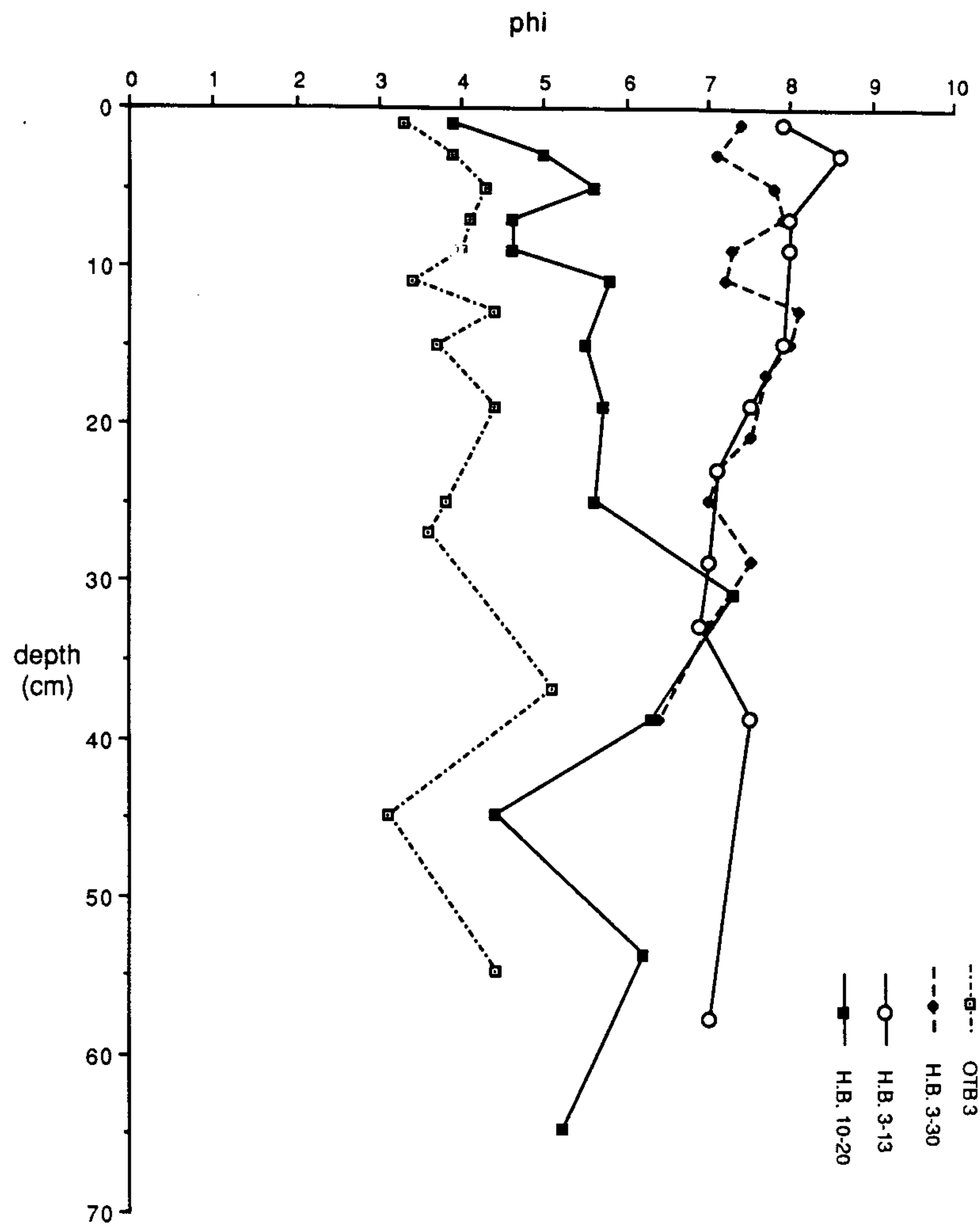

Figure 2: Mean Grain Size from Tampa Bay Stations

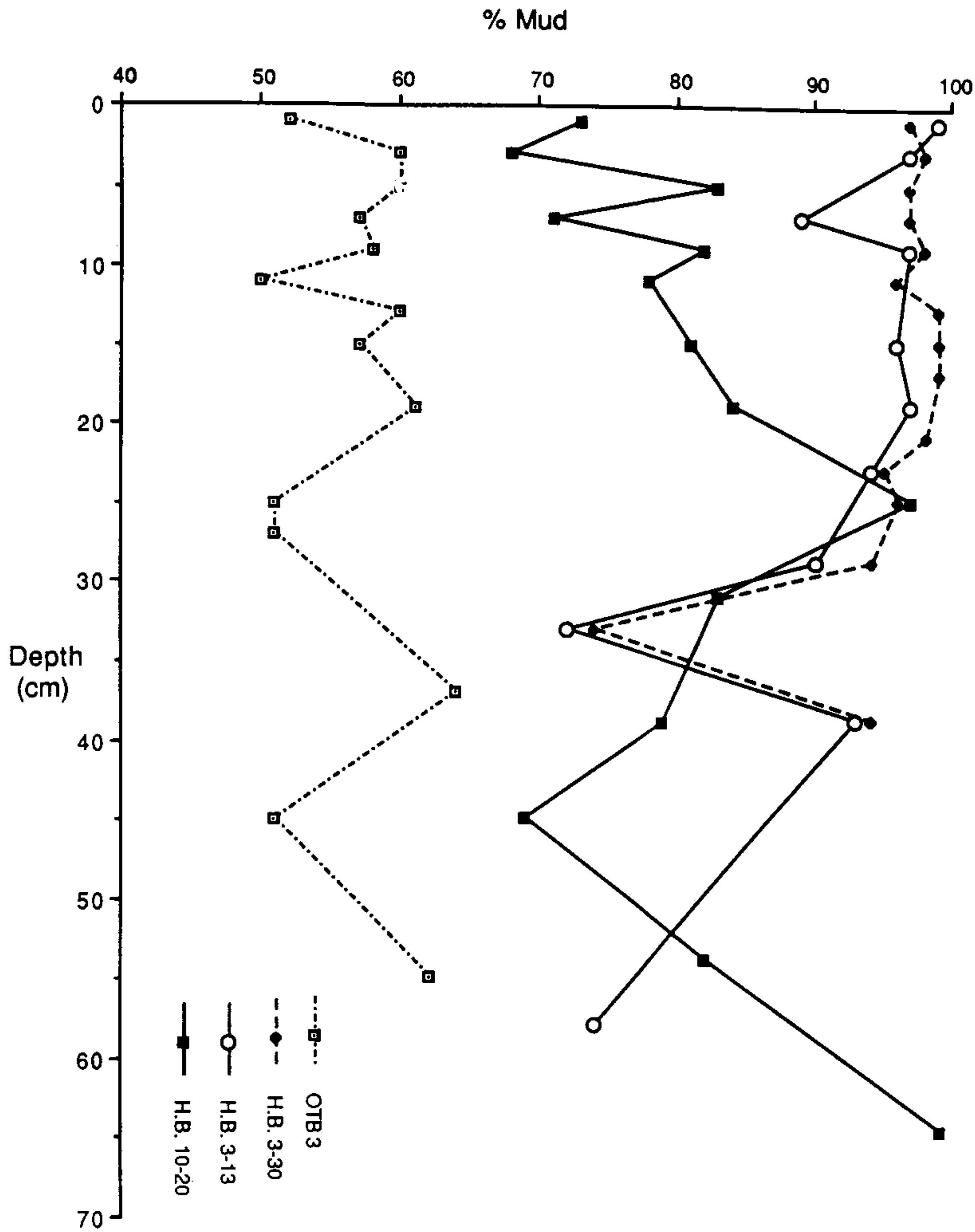

Figure 3: % Mud from Tampa Bay Stations

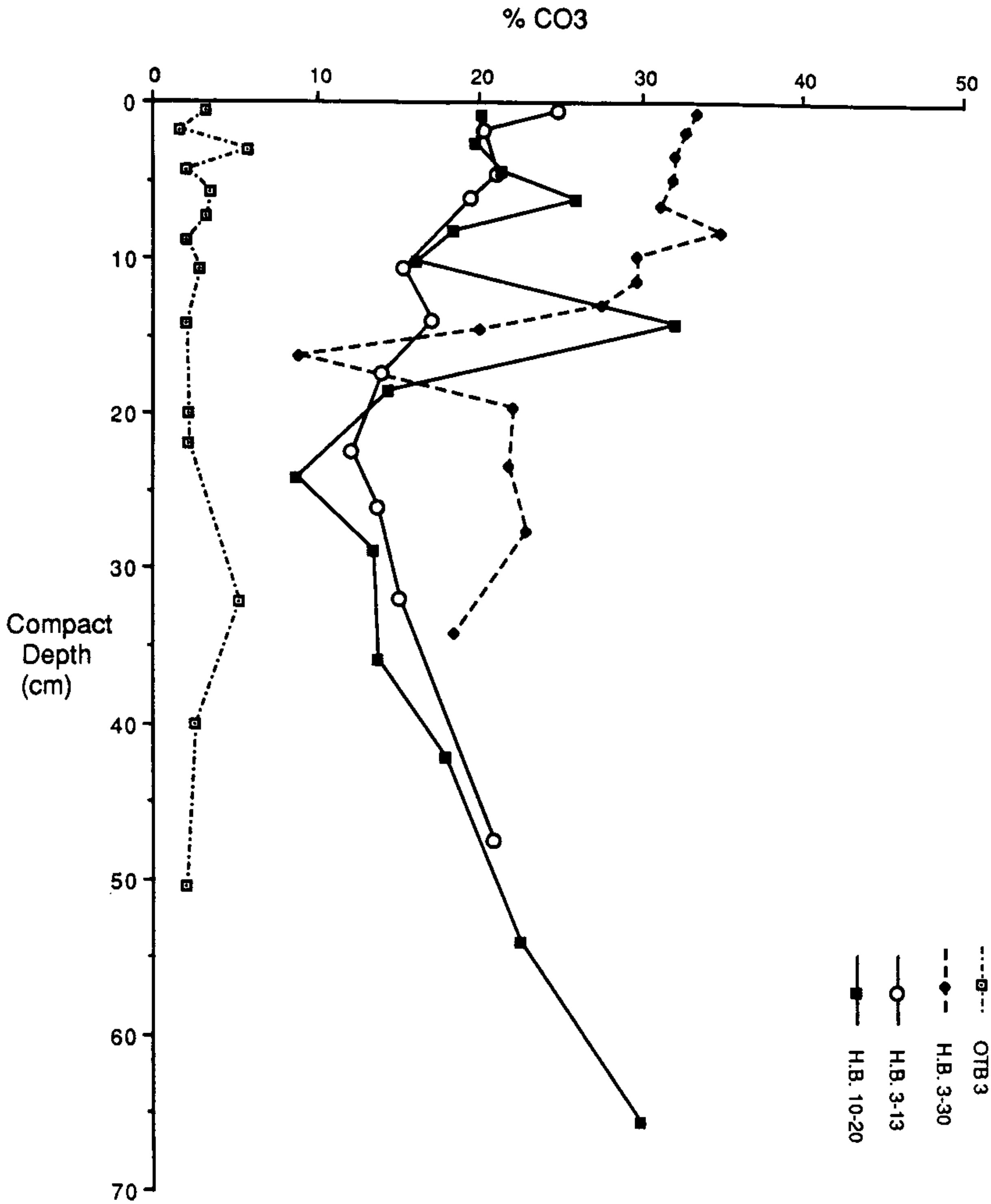

Figure 4: % CO3 from Tampa Bay Stations

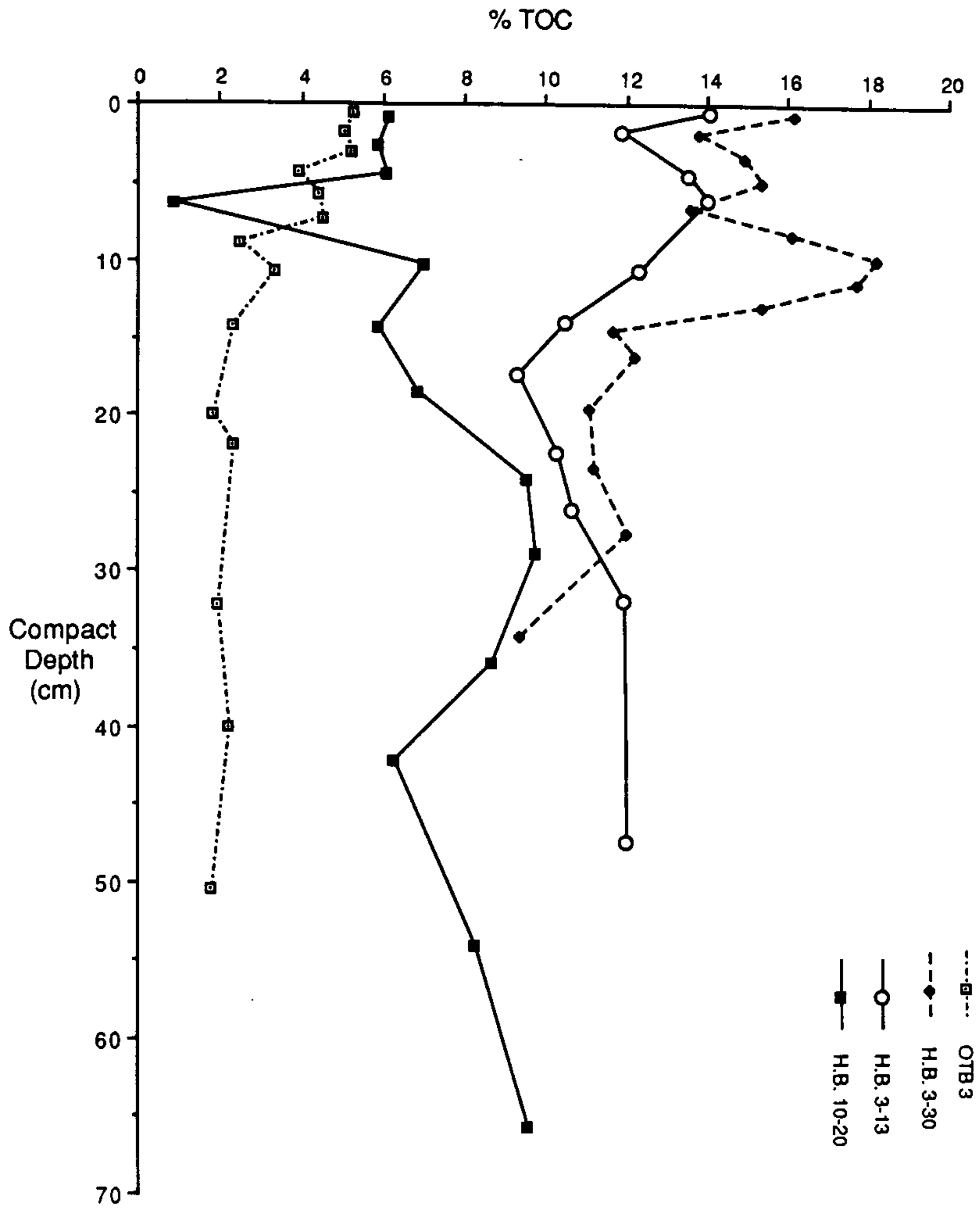

Figure 5: Total Organic Content from Tampa Bay Stations

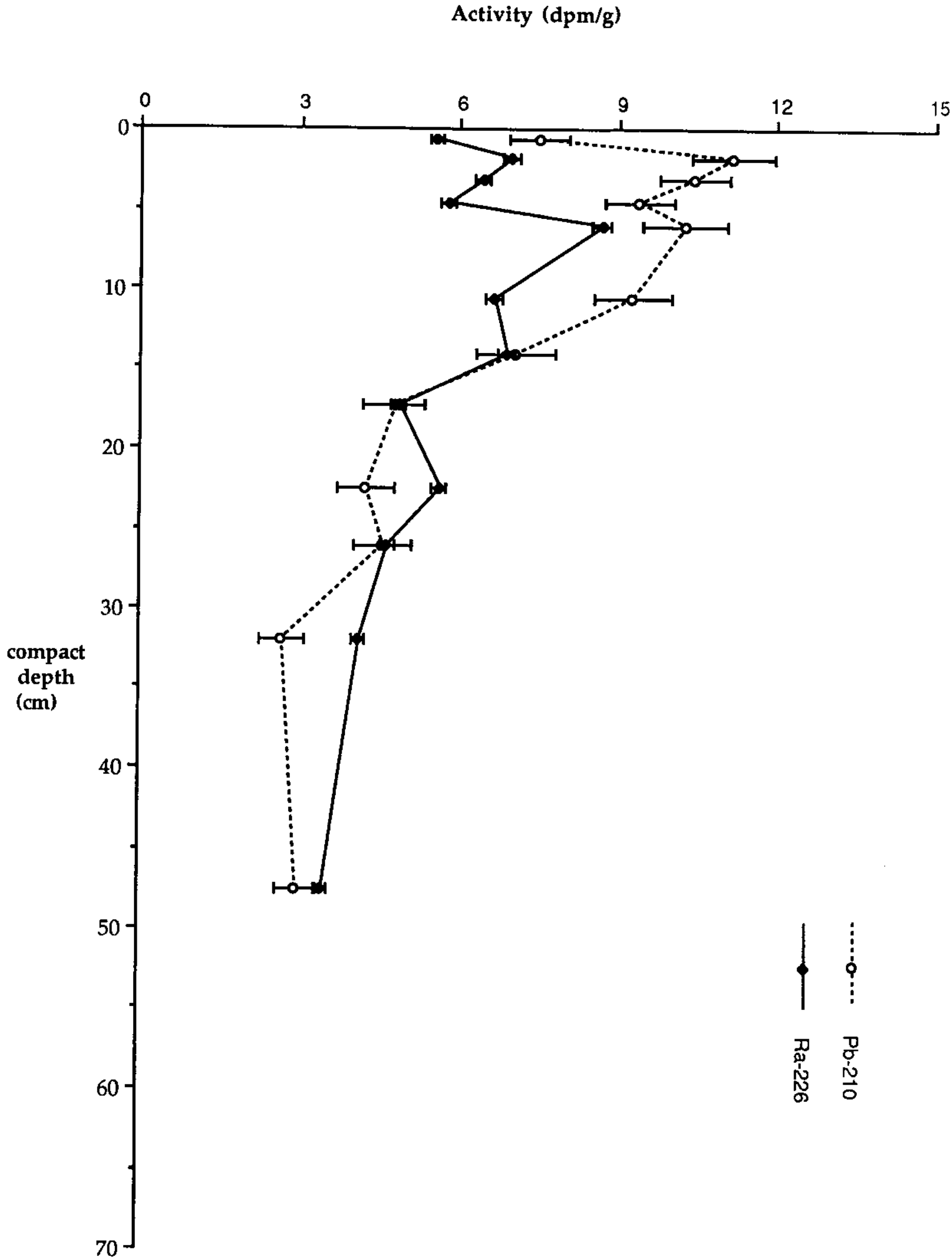

Figure 6: Hillsborough Bay Station 3-13

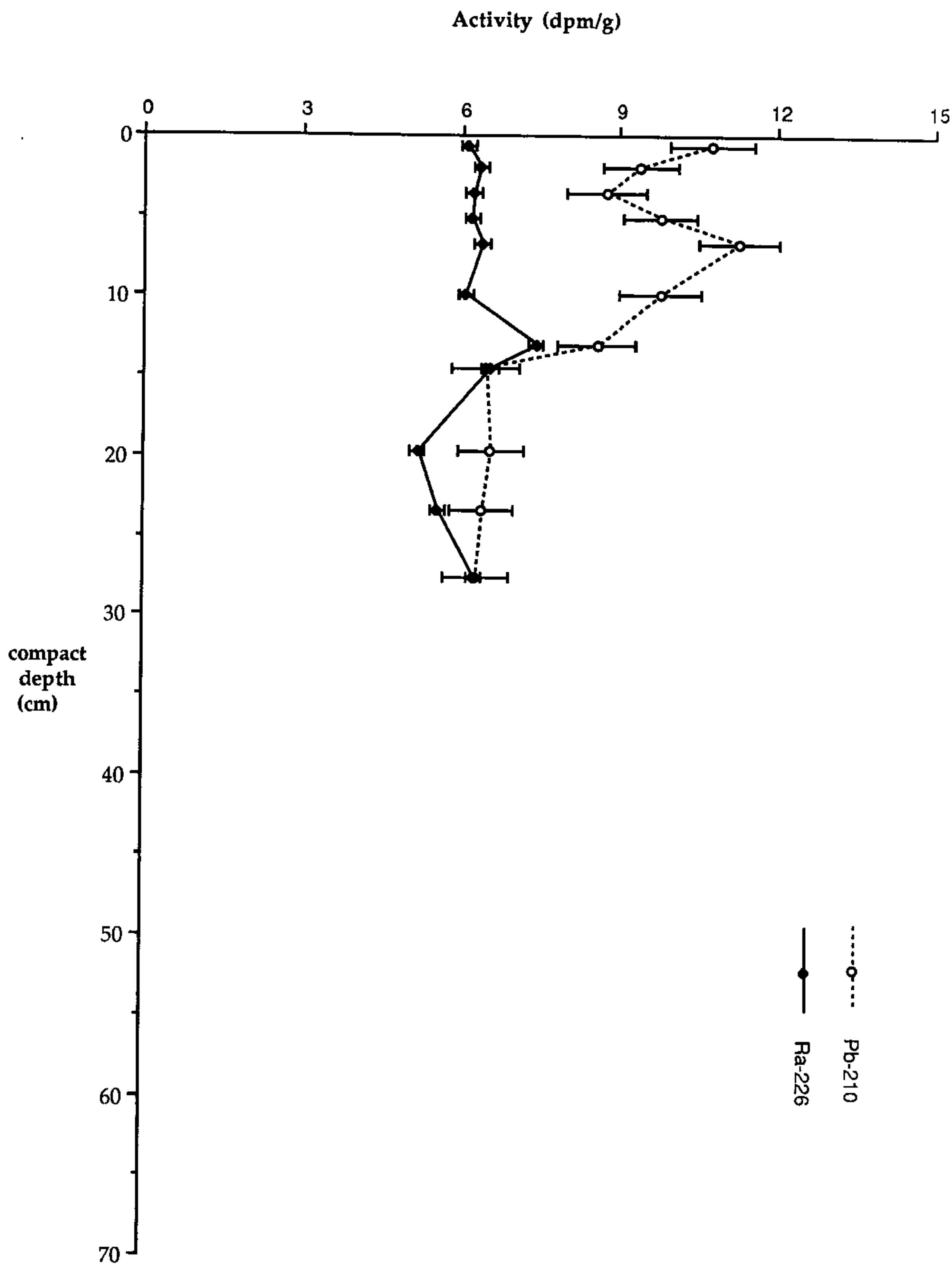

Figure 7: Hillsborough Bay Station 3-30

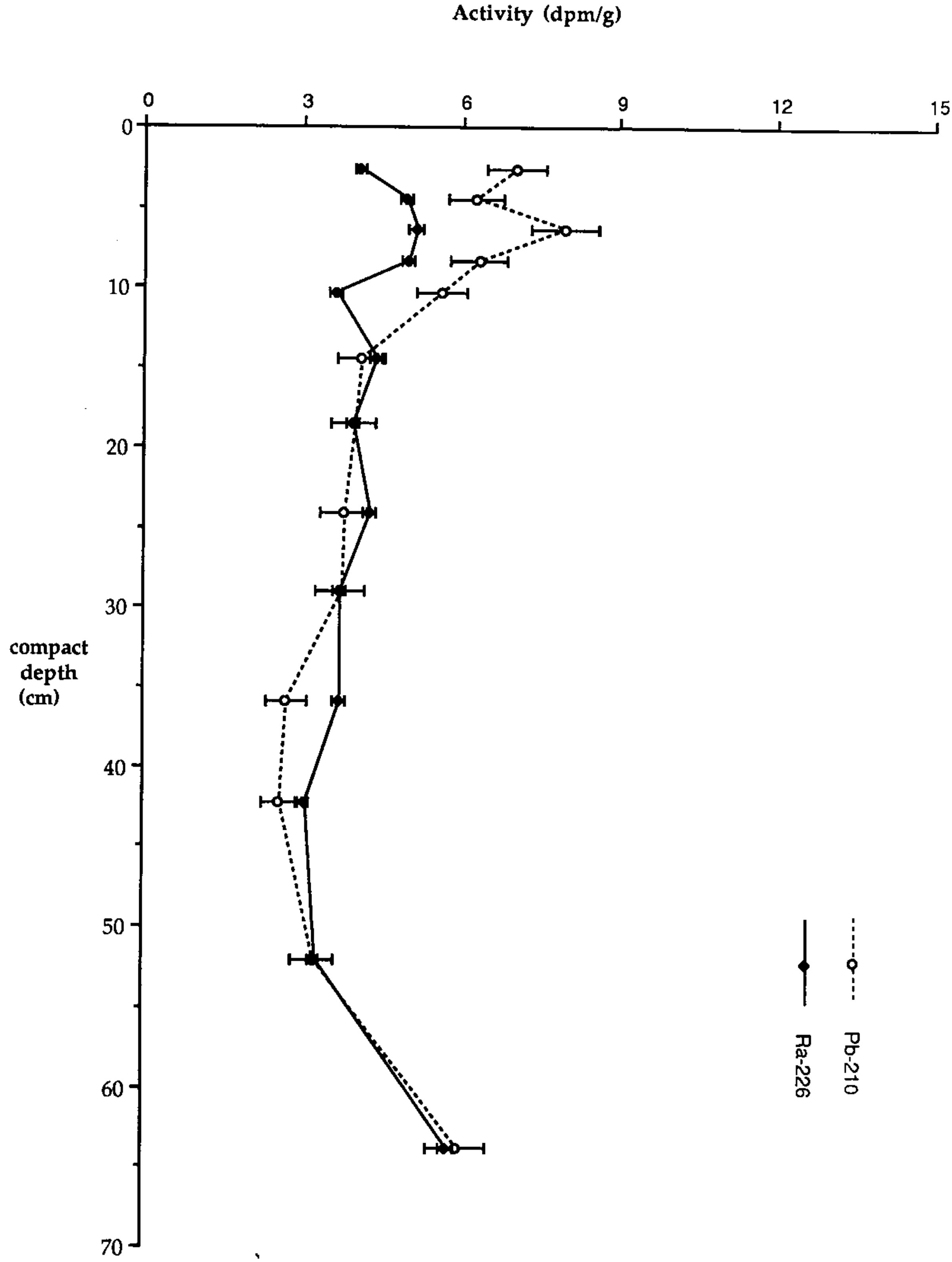

Figure 8: Hillsborough Bay Station 10-20

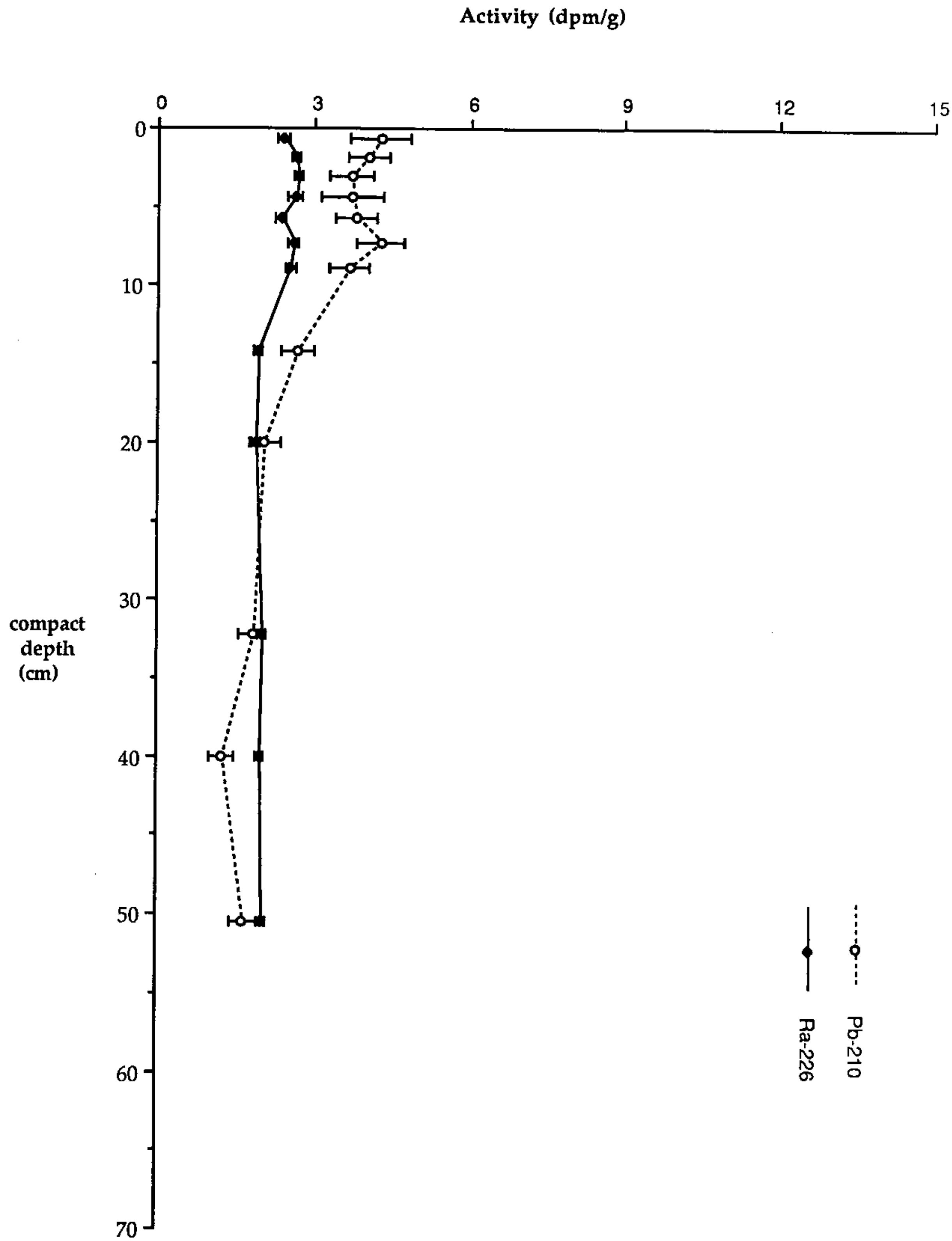

Figure 9: Old Tampa Bay Station 3

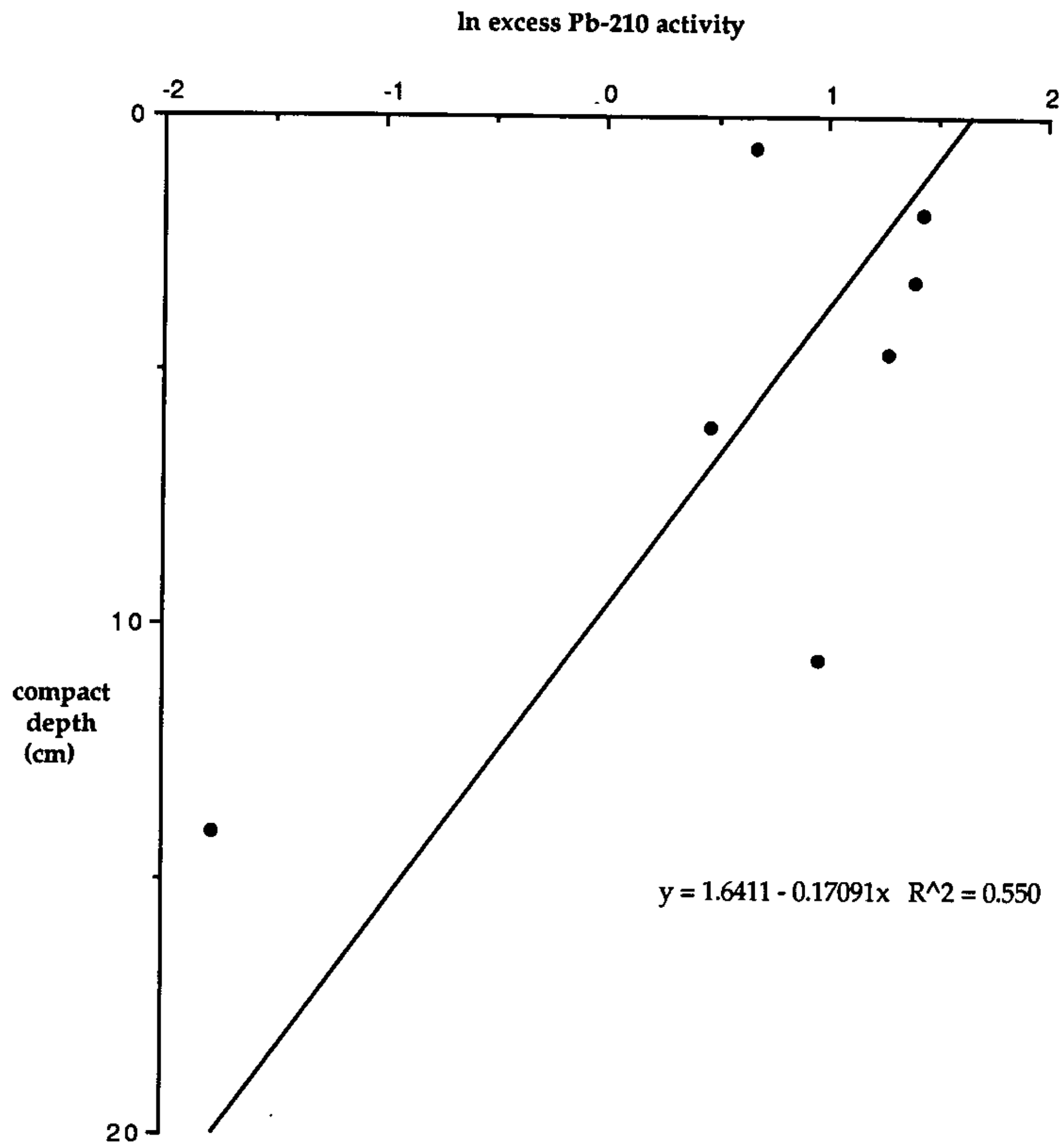

Figure 10: Hillsborough Bay Station 3-13 - ln excess Pb-210 vs depth

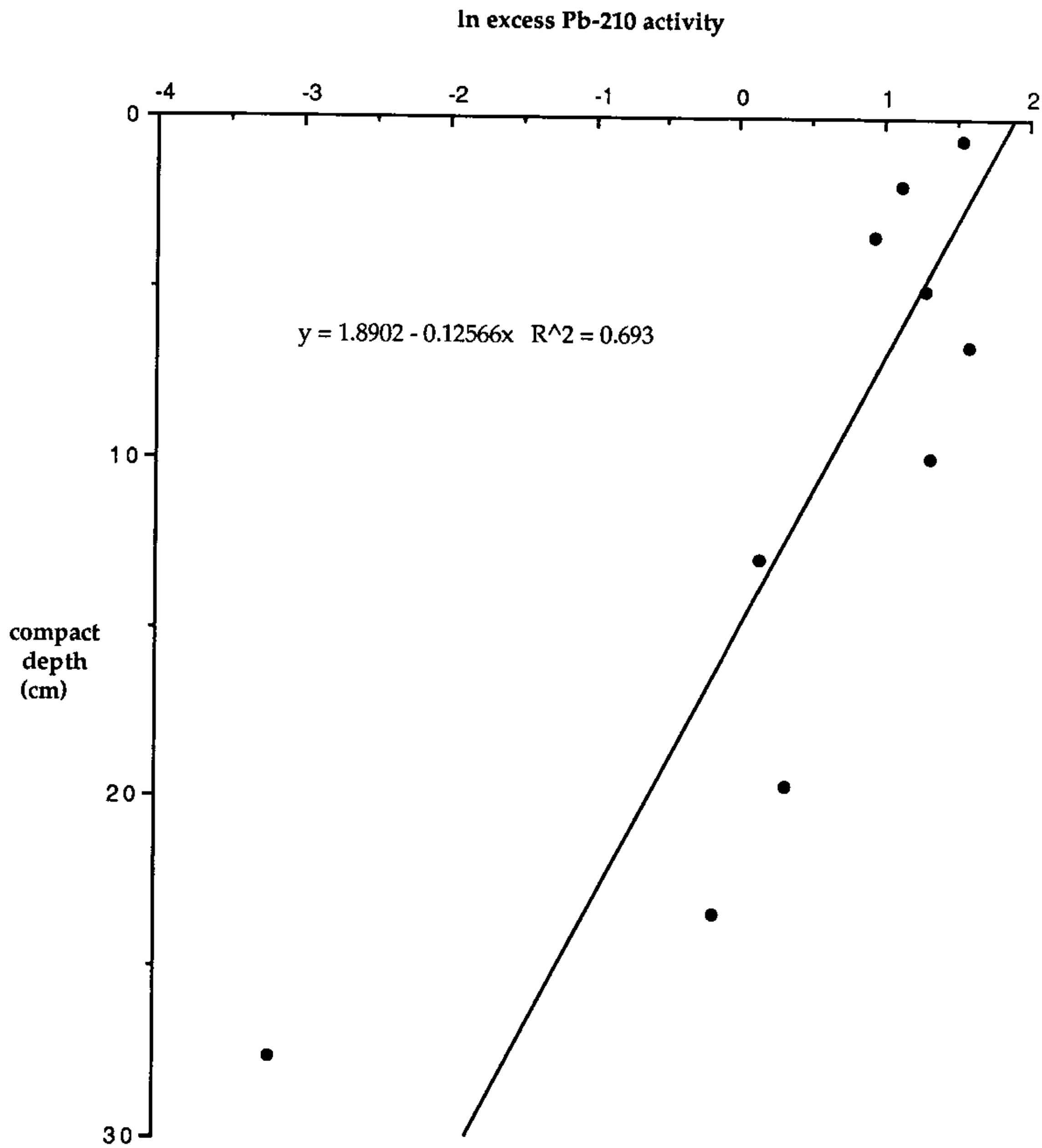

Figure 11: Hillsborough Bay Station 3-30 - ln excess Pb-210 vs depth

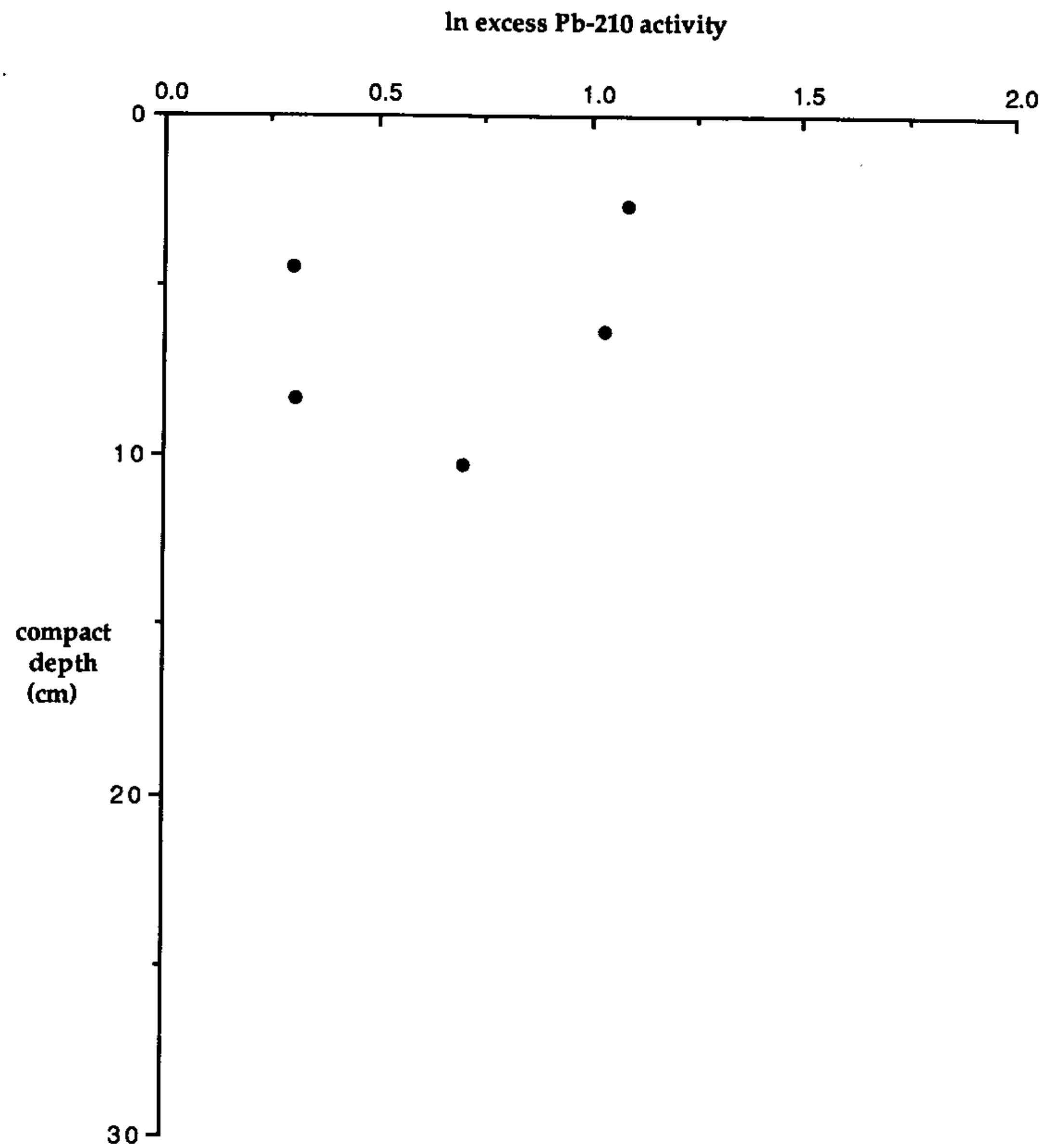

Figure 12: Hillsborough Bay Station 10-20 - ln excess Pb-210 vs depth

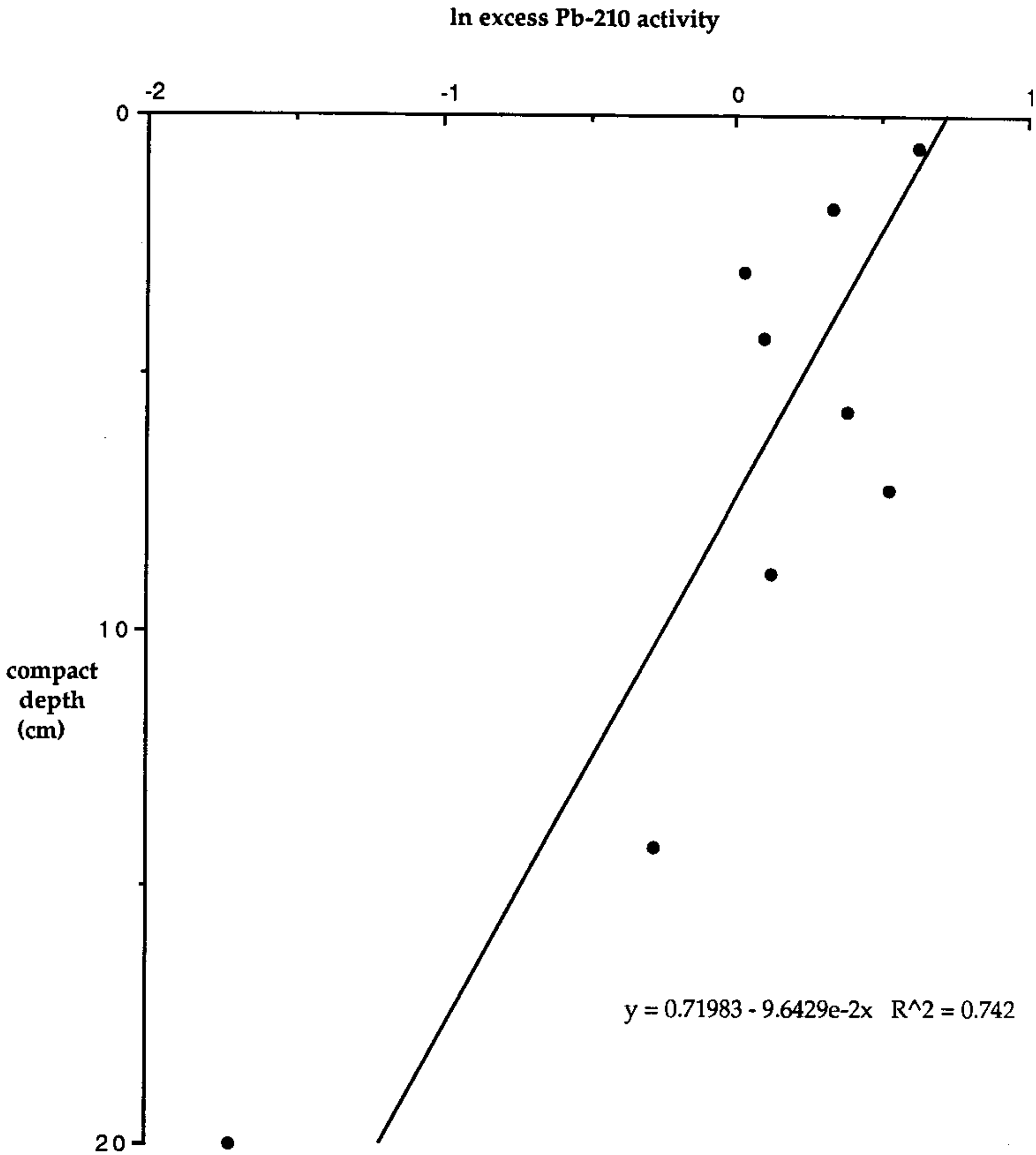

Figure 13: Old Tampa Bay Station 3 - ln excess Pb-210 vs depth

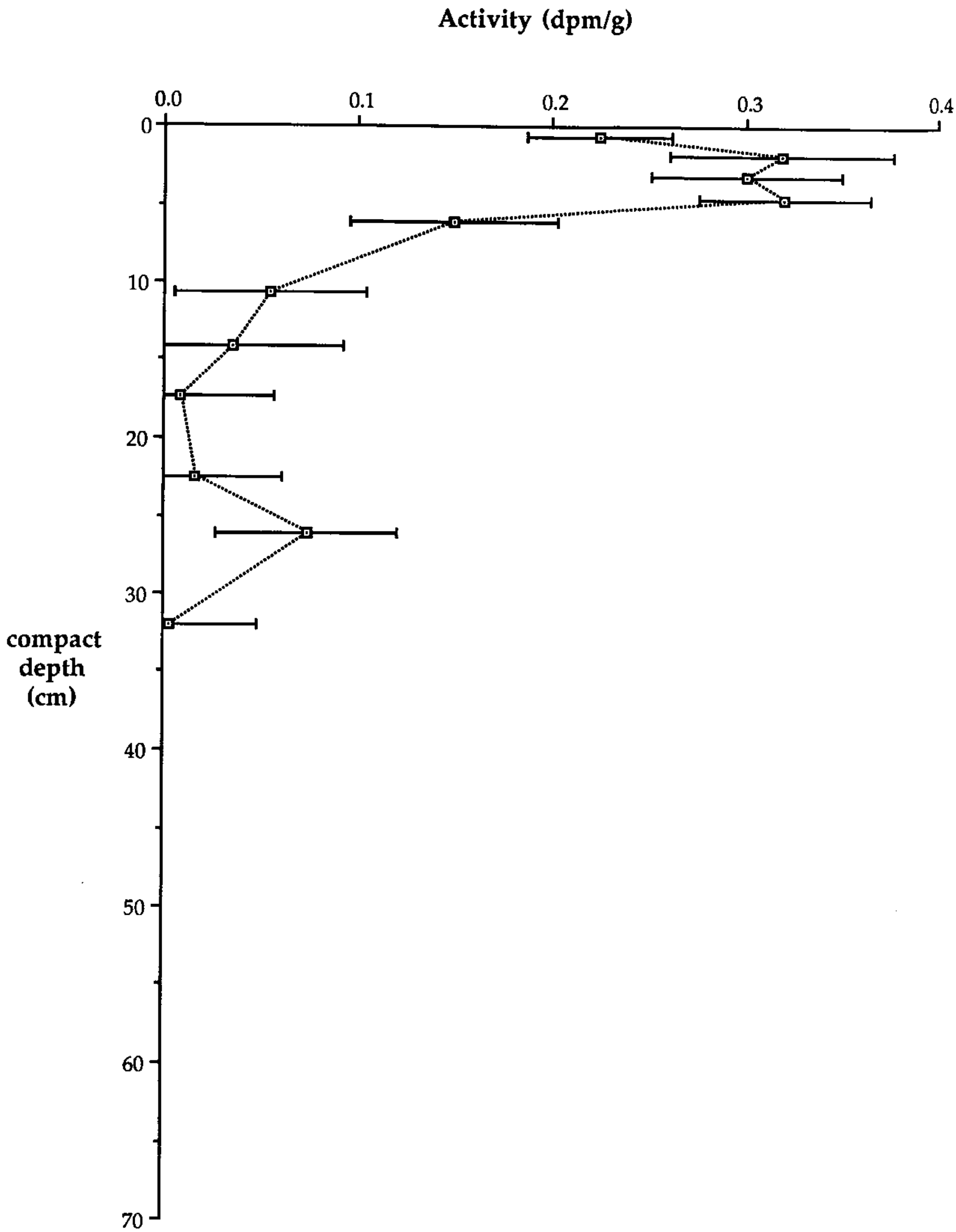

Figure 14: Hillsborough Bay Station 3-13 - Cs-137

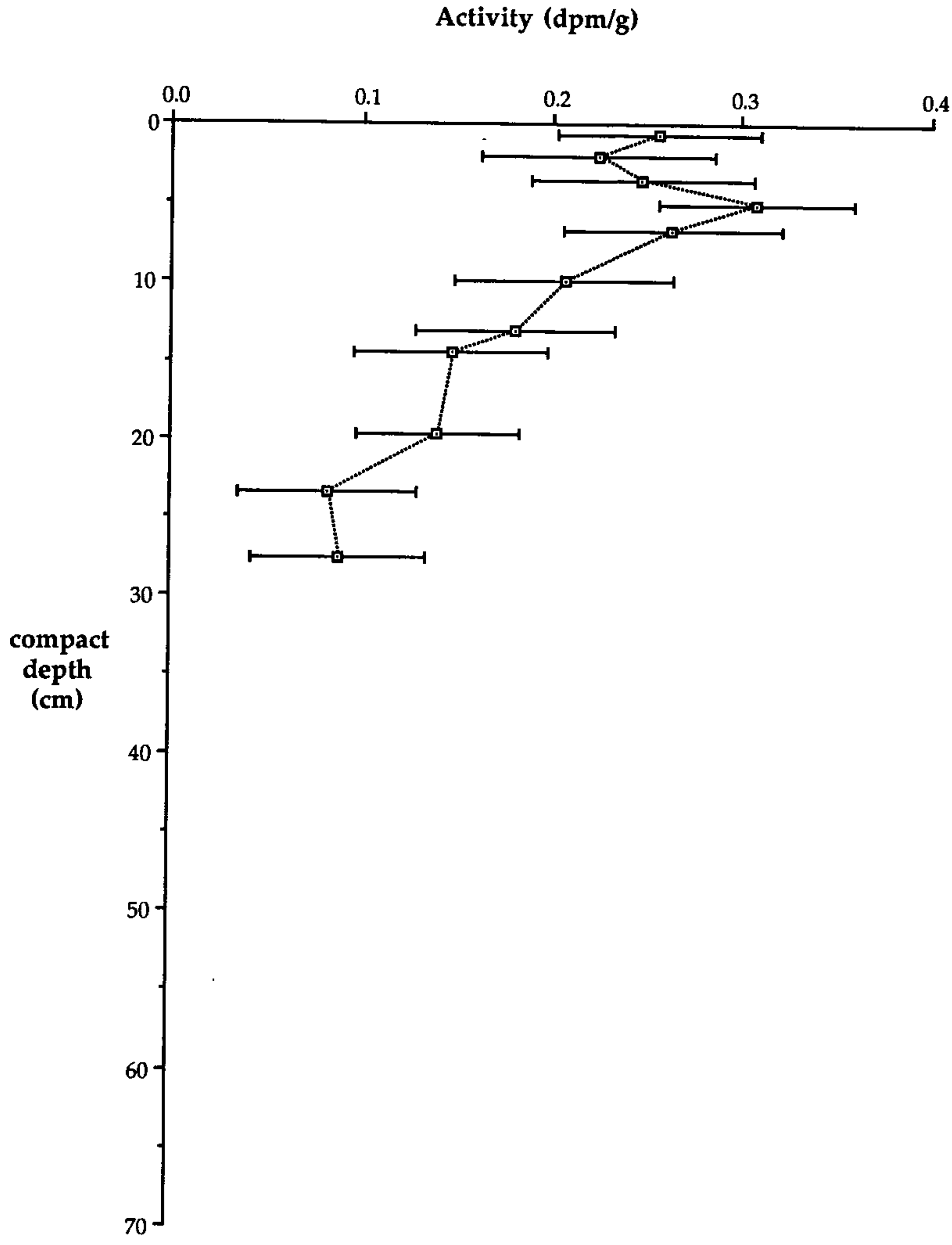

Figure 15: Hillsborough Bay Station 3-30 - Cs-137

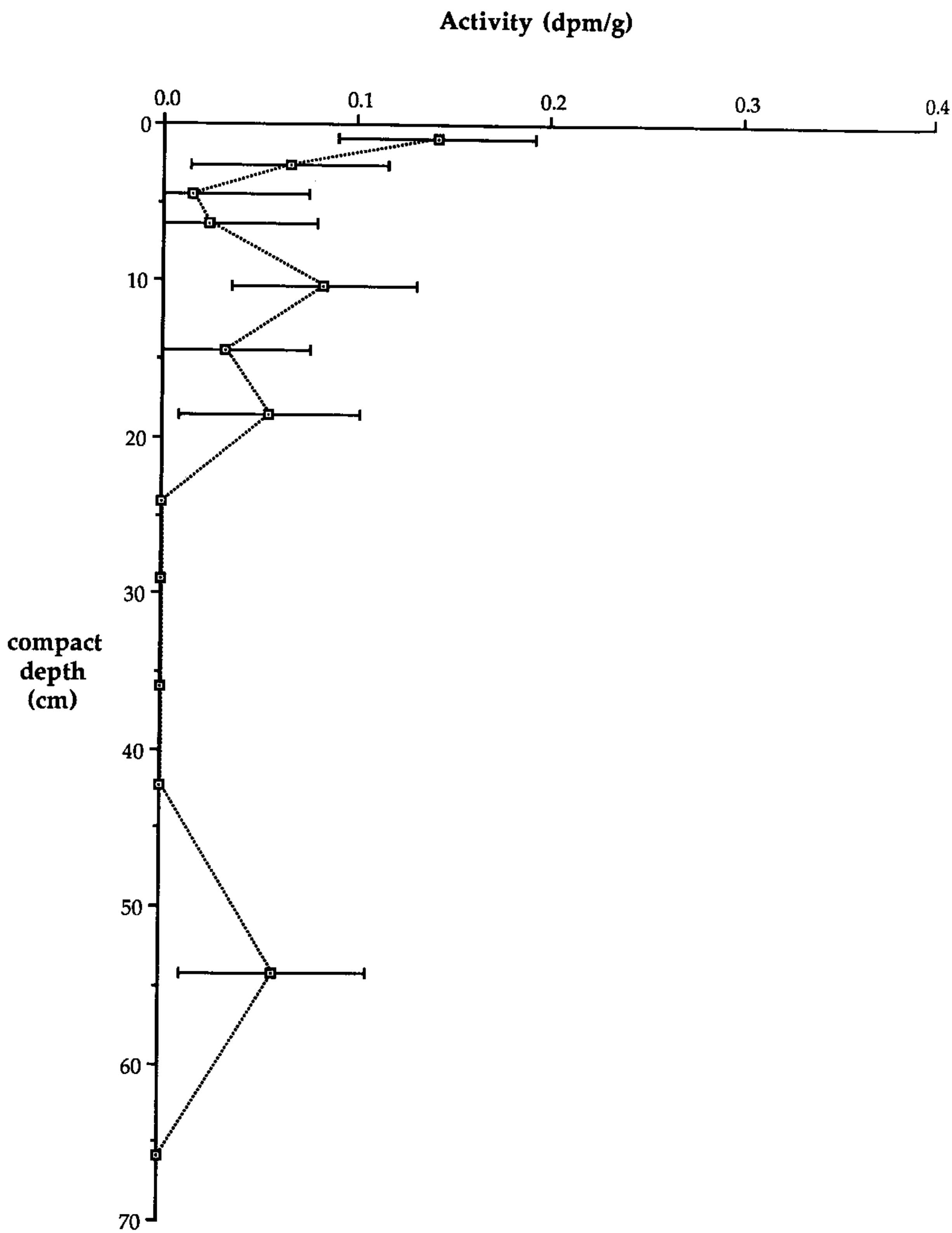

Figure 16: Hillsborough Bay Station 10-20 - Cs-137

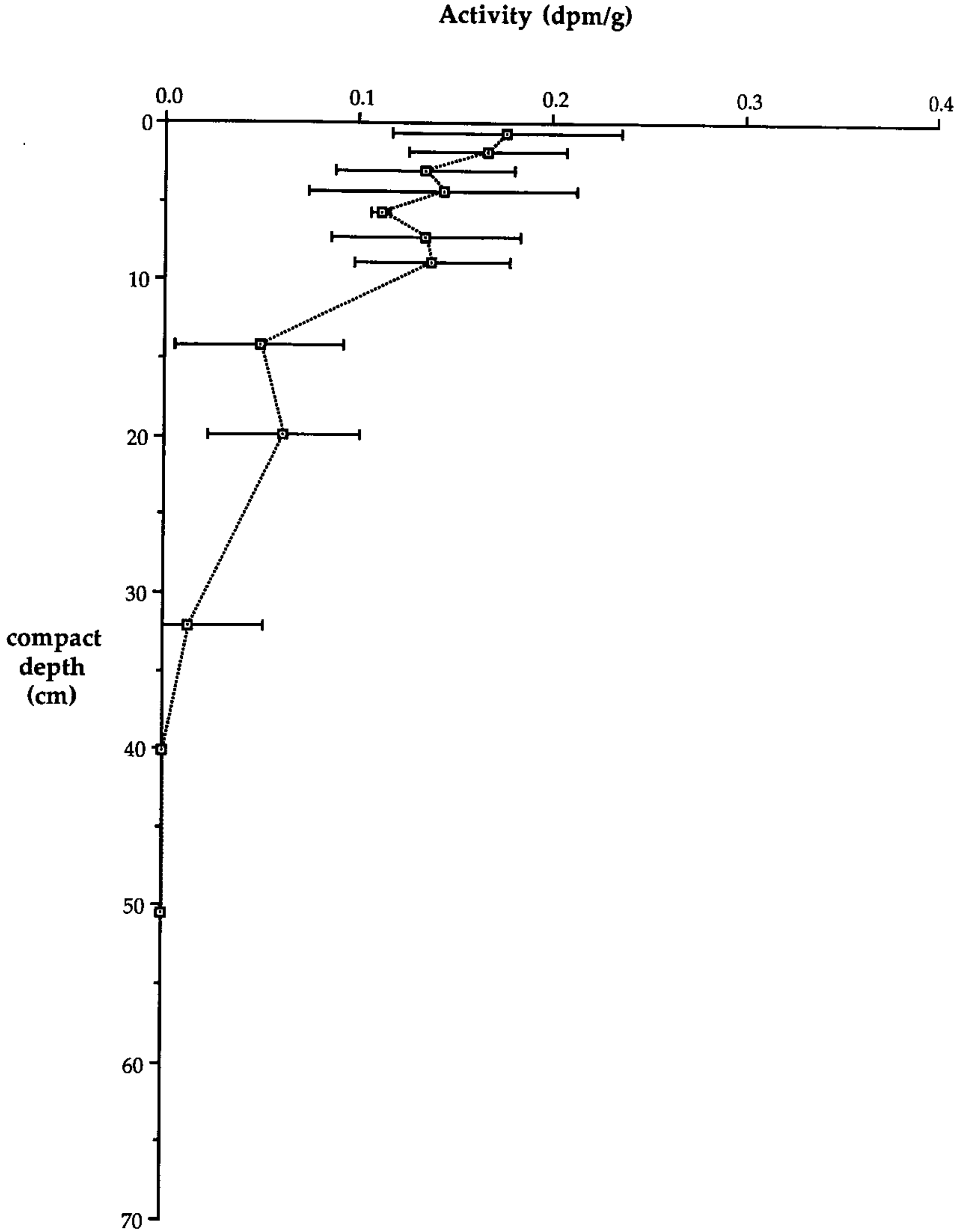

Figure 17: Old Tampa Bay Station 3- Cs-137

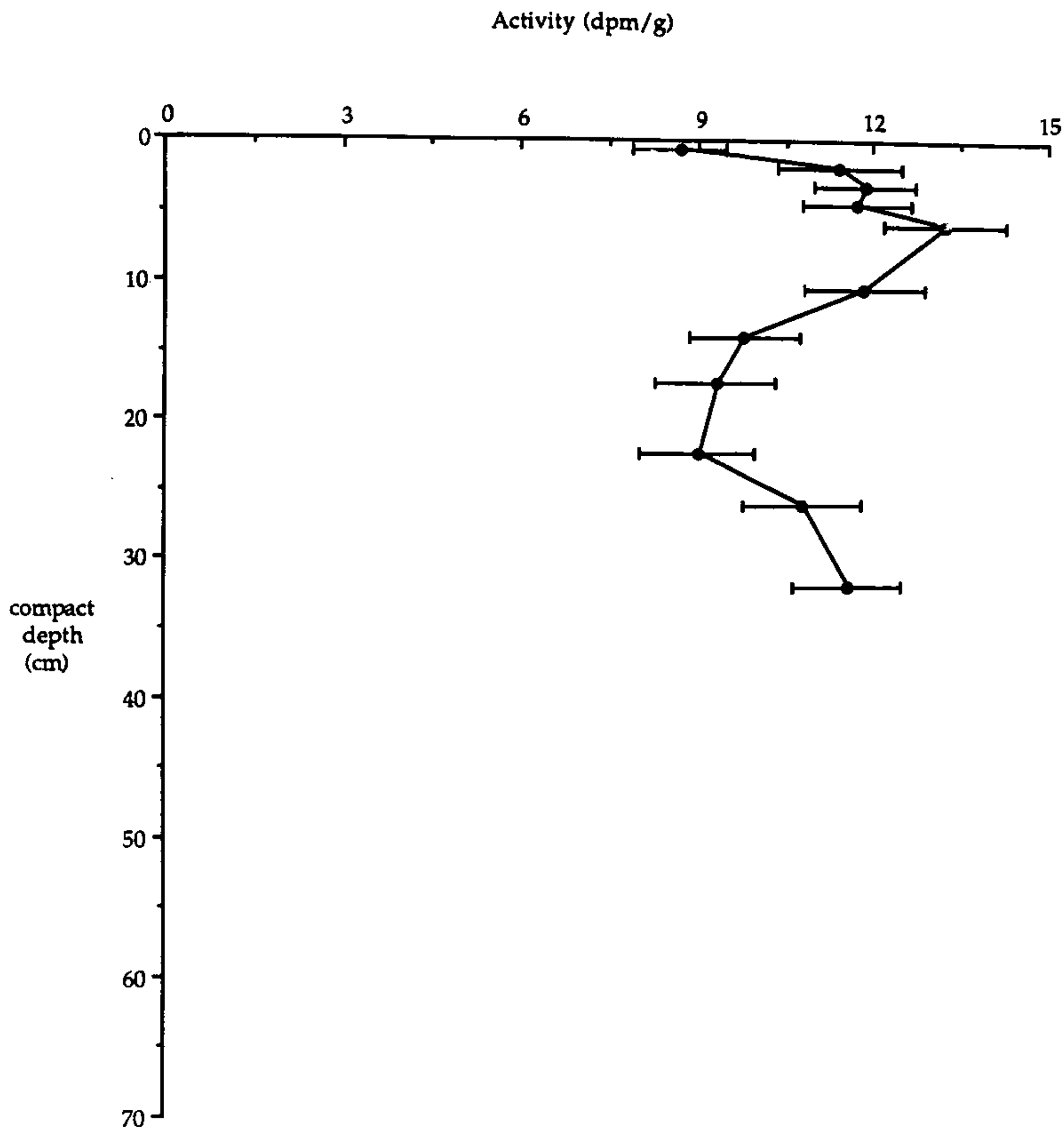

Figure 18: Hillsborough Bay Station 3-13 - K-40

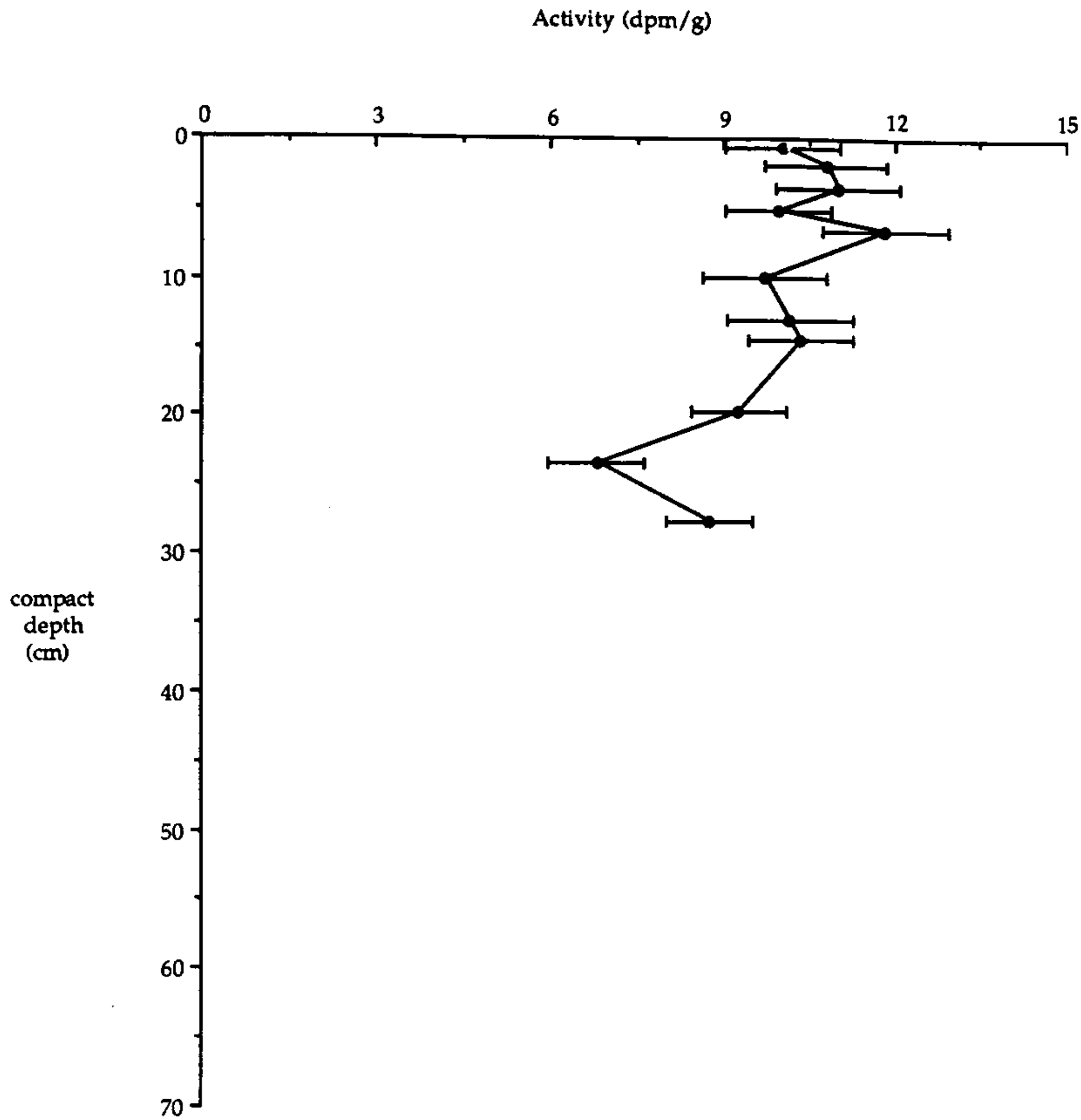

Figure 19: Hillsborough Bay Station 3-30 - K-40

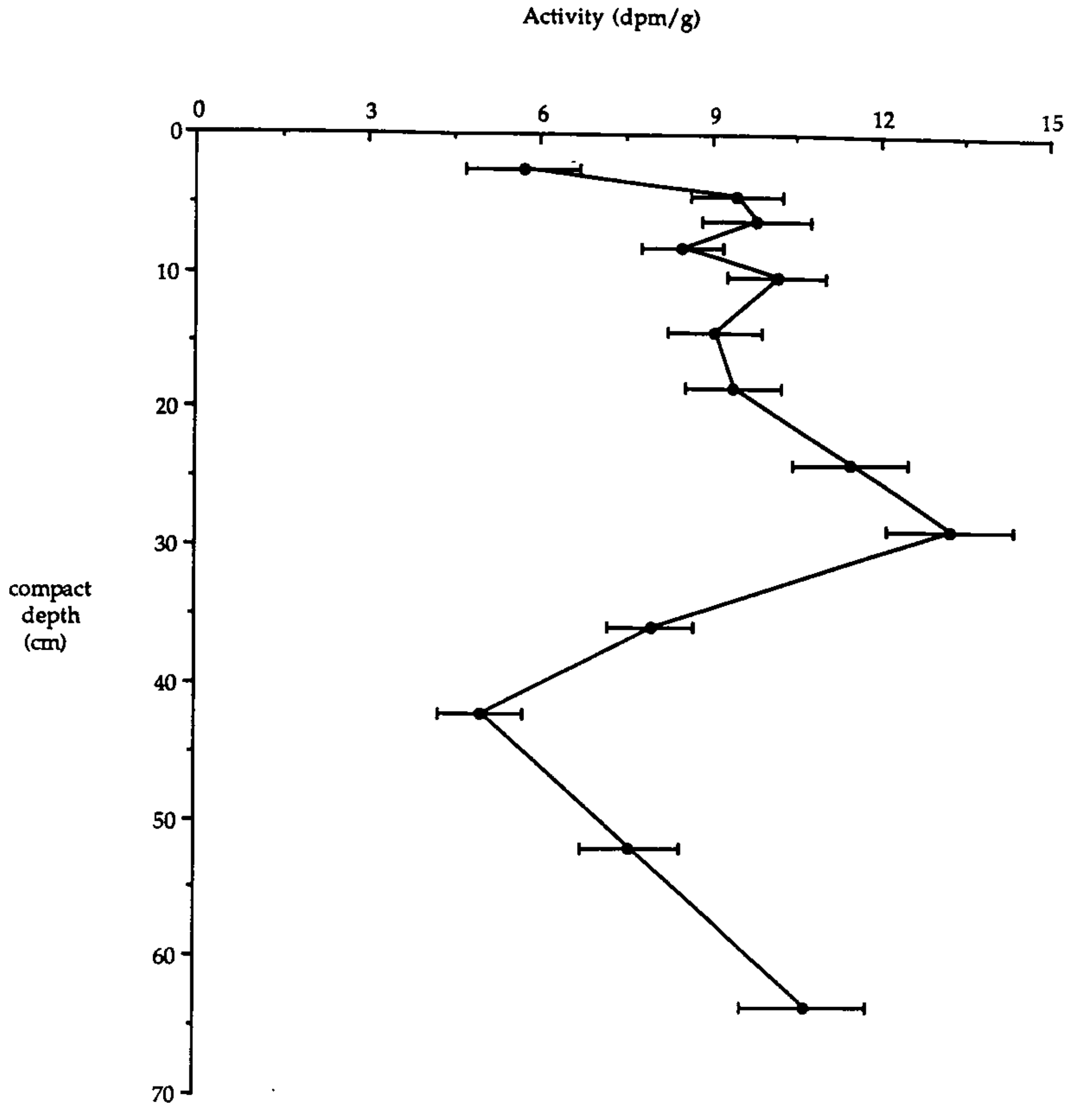

Figure 20: Hillsborough Bay Station 10-20 - K-40

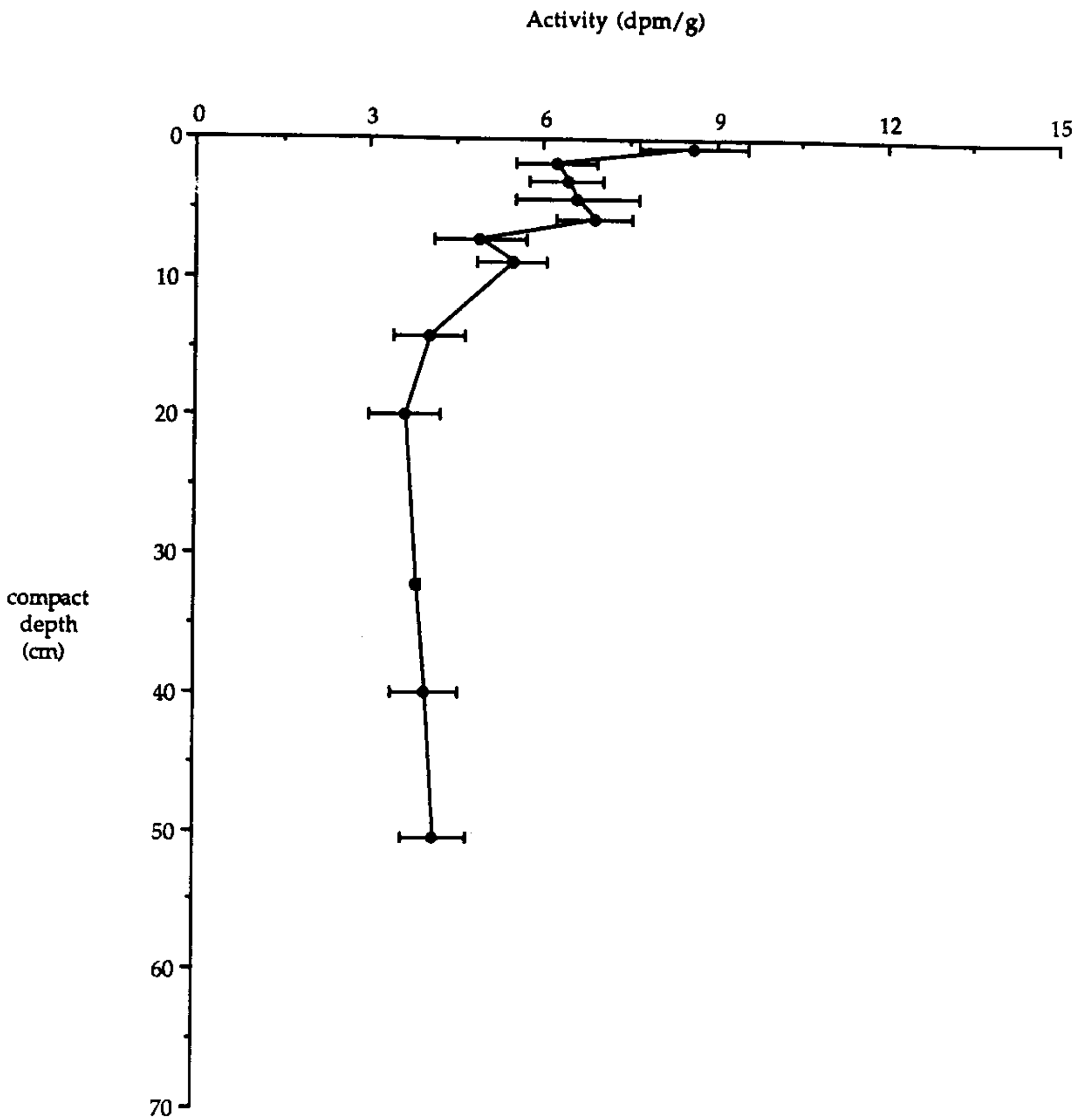

Figure 21: Old Tampa Bay Station 3 - K-40

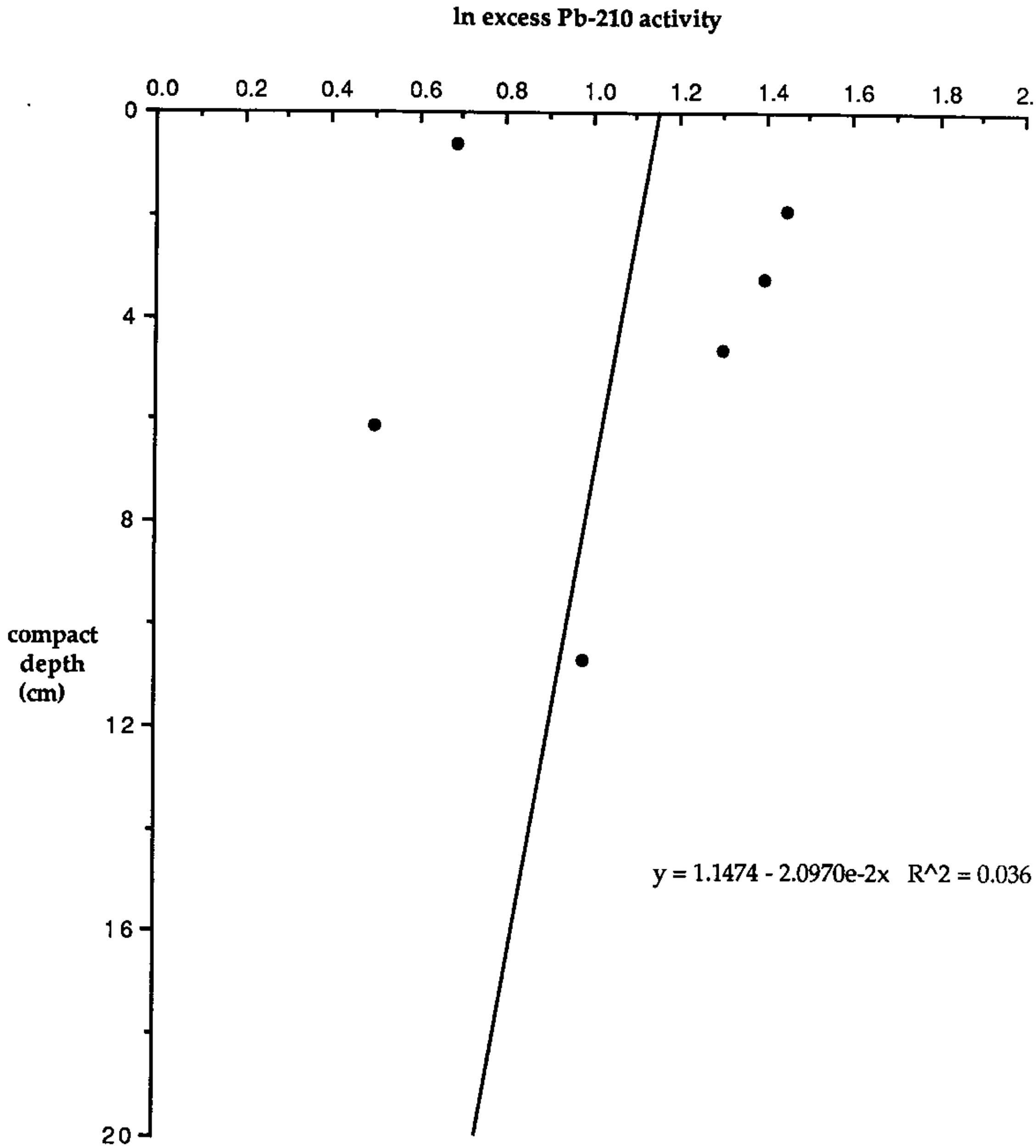

Figure 22: Hillsborough Bay Station 3-13 - ln excess Pb-210 vs depth

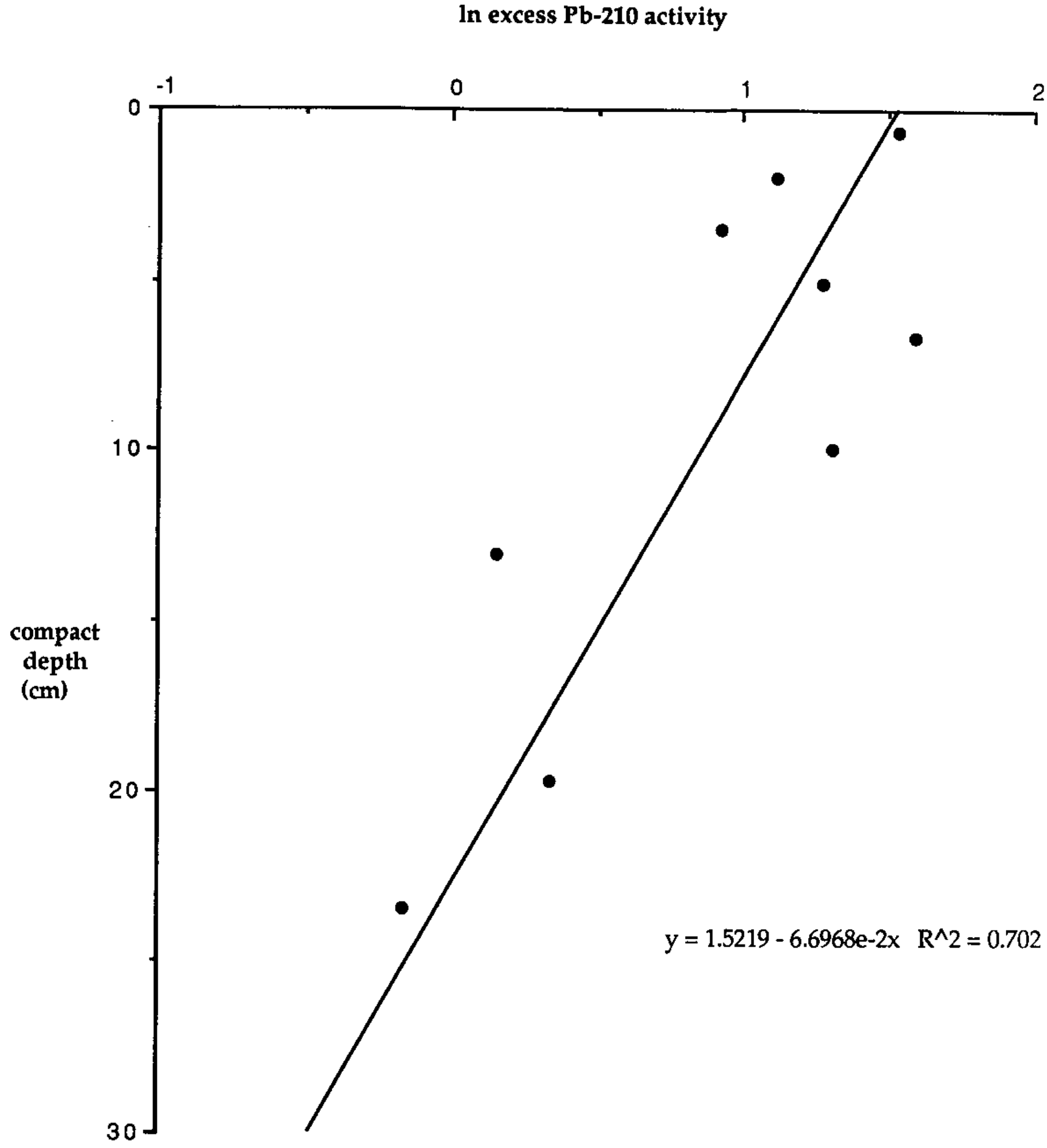

Figure 23: Hillsborough Bay Station 3-30 - ln excess Pb-210 vs depth

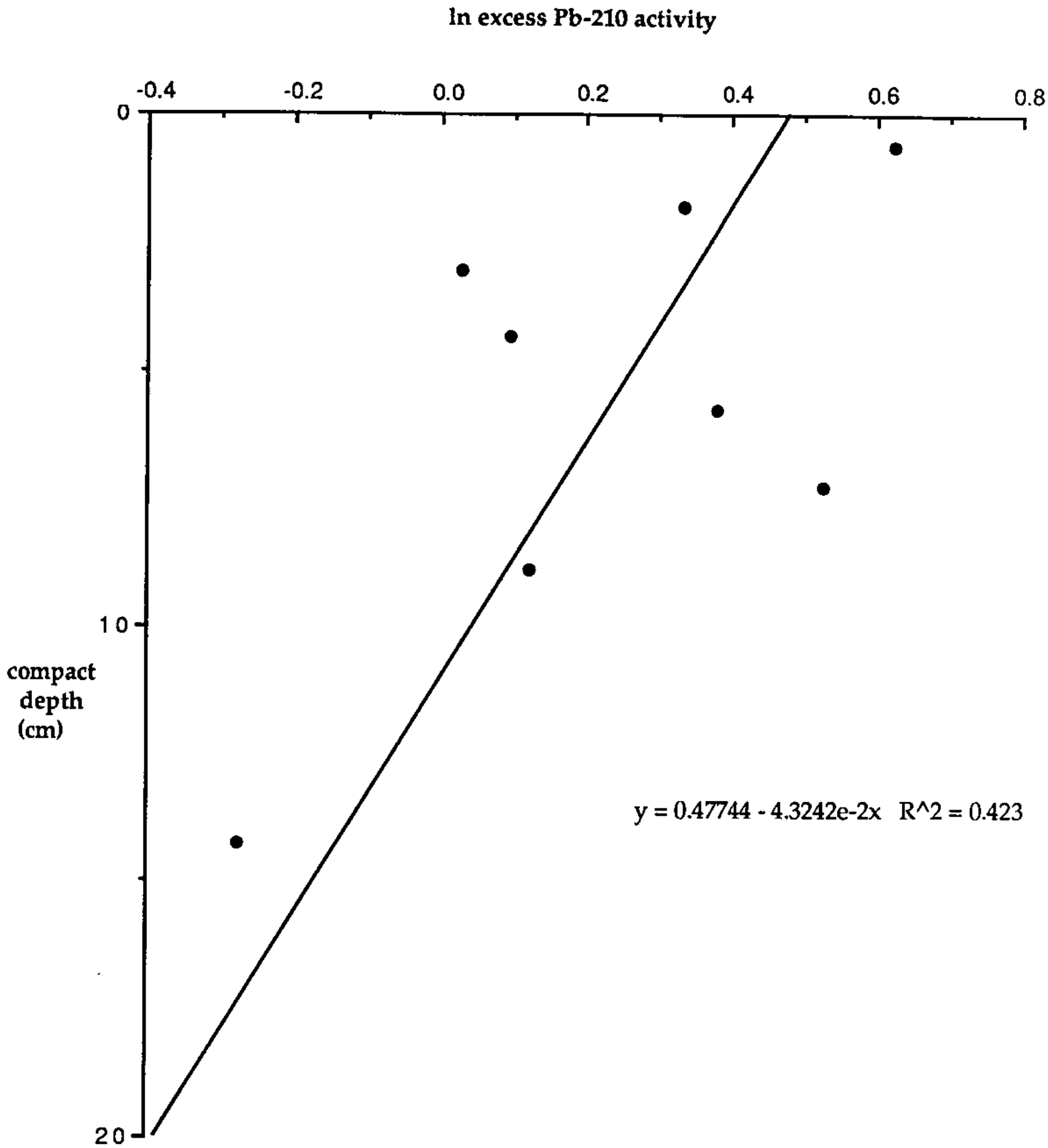

Figure 24: Old Tampa Bay Station 3 - ln excess Pb-210 vs depth