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TRACE METALS IN SURFACE SEDIMENTS OF THE MID-ATLANTIC CONTINENTAL SHELF

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This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

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ABSTRACT

The concentrations of 9 trace metals (Fe, Pb, Zn, Ba, Cu, Ni, V, Cr, and Cd) in surficial Continental Shelf sediments are low compared to the concentrations reported for average crustal rocks. No evidence for the accumulation of anthropogenic trace metals was found at the 51 locations sampled in this study. Trace metal concentrations generally correlate with the concentration of fine-grained sediment. No seasonal variability in trace metals was observed. This study provides baseline data for trace metals in an area of the Continental Shelf where potential petroleum resource development is expected and where the impact of trace metal additions related to resource development will need evaluation.

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INTRODUCTION

The purpose of this study was to determine the present concentrations and aerial distribution of nine trace metals in surficial bottom sediments. The elements chosen for analysis include Fe, Pb, Zn, Ba, Cu, Ni, V, Cr, and Cd. With the exception of Fe which is important as an indicator of authigenic processes, the trace metals analyzed are either present in crude oils (Ni and V) or are used during drilling operations related to offshore resource development. An additional goal was to determine the magnitude and seasonal changes in the trace metal concentrations.

This data provides a basis to determine the magnitude of future changes in trace metal concentrations in an area where potential petroleum resource development is expected. There is very little published data on the concentration of trace metals in continental shelf sediments off the eastern United States. A few samples from this study area were analyzed by Manheim (1971). A complementary trace metal analysis program on the same samples was performed by the Virginia Institute of Marine Science (VIMS). (Harris et al, 1977).

METHODS

The samples analyzed for trace metals were collected with stainless steel grab samplers by scientists from the Virginia Institute of Marine Science.

Six separate grab samples were taken at each station and subsamples from each grab were combined and homogenized at the VIMS laboratory to provide a blended sample representative of that station. Twenty-four stations were sampled during each of the four seasons. Twenty-seven additional stations were sampled during the winter and summer. The seasonal spacing of sampling intervals makes it possible to test for seasonal changes in trace metal concentrations which may be due to the collective effects of seasonal changes in sediment transport due to storms, primary production and resulting flux of material to the bottom, and the activity of benthic organisms.

A total of 150 homogenized samples were prepared and frozen until analysis. Approximately 40 grams of material were later dried to a constant weight in glass beakers. Large particles (> 3 mm) were removed. The remaining material was ground in an agate disk mill until small aliquots would pass a 100-mesh sieve. All glass and plastic ware used in the analysis were cleaned with 8N HNO_3 and rinsed thoroughly with distilled-deionized water. All reagents were checked for contamination and were found to contain undetectable quantities of the nine elements analyzed.

Sediment was dissolved by heating samples weighing 1 g on a hotplate at 150° C for 16 hours (overnight) with 5 ml $HClO_4$, 5 ml HNO_3, and 15 ml HF in covered teflon beakers. The beakers were then uncovered and solutions were evaporated to dryness. The salts were dissolved in HCl and diluted to 50 ml (final HCl concentration about 1N). The resulting solutions were analyzed for trace metals by flame and flameless atomic absorption spectrophotometry. Background correction was used to correct for non-atomic absorption. Instrumental methods and sensitivities are reported in Table 1A, 1B and 1C.

Analytical precision was determined by analyzing 5 aliquots from each of 2 samples for the 9 elements of interest (Table 2). Calculated coefficients of variation are generally less than 10% except for those elements present at concentrations near the detection limit of the technique (Cd and Cu).

Accuracy of the methods was determined by the analysis of a number of USGS standard rocks and standard plastic clay from the National Bureau of Standards. A set of these standards was analyzed with the samples from each seasonal cruise. The mean values (plus 2 standard deviations) reported in Table 3 are in agreement with published recommended values (Table 4; Flanagan, 1973) for GSP-1, AGV-1, and G2 with the exception of nickel which is somewhat lower. The nickel values obtained for these rocks, however, and all elements listed for BCR-1 are within the range of values determined by other investigators (Flanagan, 1969). The mean values (plus 2 standard deviations) obtained (Table 3) for the marine mud standard (MAG-1) are in agreement with the values reported by Manheim et al., 1976. Our values for Fe, Ba, and Cr in the N.B.S. plastic clay standard are more than two standard deviations from N.B.S. values. However, the plastic-clay standard did not dissolve completely, suggesting a different matrix than the other standards which were completely dissolved. This could account for the lower Cr concentrations obtained by our method, but it does not explain the higher Ba and Fe values. The plastic-clay material for each analysis came from the same bottle which, perhaps, was not representative or was contaminated. The good agreement between the

Table 1A. Flame Atomic Absorption with Background Correction (P.E. 603).

Element	Wave Length	Slit	Flame
Zn	213.9	3	air-C_2H_2
Fe	248.3	4	air-C_2H_2
Ba[1]	553.6	4	N_2O-C_2H_2

[1] Sample and standard solutions made to contain 1000 ppm NaCl.

Table 1B. Flameless AAS with Background Correction (P.E. 503 and HGA 2100).

Element	Wave Length	Slit	Temperature		
			Dry	Char	Atomize
Cu[1]	324.7	4	110	600	2500
Ni[1]	232.0	3	110	600	2500
Cr	357.9	4	110	800	2600
V [2]	318.4	3	110	1000	2700
Cd	228.8	3	110	250	2100
Pb[1,3]	283.3	3	110	400	2300

[1] Interrupt cycle.

[2] Memory effect apparent -- requires second high temperature burn prior to introduction of next sample and a preliminary screening to separate high and low samples.

[3] Method of additions required.

Table 1C. Detection Limits and Analytical Sensitivity of Atomic Absorption on Total Sediment Digestates.

Element	Detection Limit ppm dry weight	Sensitivity Flame AA[1] ppm/1% absorption	Sensitivity Graphite Furnace[2] picograms/1% absorption
Fe	20	0.12	
Pb	4		20
Zn	2	0.18	
Ba	50	0.4	
Cu	2	.09	30
Ni	2		100
V	2		380
Cr	2		20
Cd	0.1		1.5

[1] Perkin Elmer Model 603.

[2] Perkin Elmer 503 with HGS 2100 Graphite Furnace.

Table 2. Precision of trace metal analysis.

Sample	$\%Fe_2O_3$	Metals (ppm) Pb	Zn	Ba	Cu	Ni	V	Cr	Cd
A1 Fall Cruise	1.9	11	26	250	6	6	25	7*	0.35
	1.9	10	27	250	4	7	25	19	0.45
	1.9	10	27	200	5	7	22	21	0.42
	1.9	10	28	250	4	7	26	21	0.25
	1.9	9	28	250	5	7	25	20	0.25
Mean	1.9	10	27.2	240	4.8	6.8	24.6	20.3	0.34
Std. Dev.	0	0.7	0.8	22.4	0.8	0.4	1.5	1.0	0.09
Coef. of Var. %	0	7	2.9	9.3	16.6	5.9	6.1	4.9	26.5
A4 Fall Cruise	4.0	12	36	250	3	8	26	24	<0.1
	4.1	10	40	250	3	9	26	23	<0.06
	4.2	10	40	250	2	9	27	24	<0.06
	4.1	9	41	280	3	9	29	24	<0.06
	4.1	10	40	250	2	8	27	24	<0.06
Mean	4.1	10.2	39.4	256	2.6	8.6	27	23.8	<0.1
Std. Dev.	0.1	1.1	1.9	13.4	0.5	0.5	1.2	0.4	-
Coef. of Var. %	1.7	10.8	4.8	5.2	19.2	5.8	4.4	1.7	-

*This value not used in the calculation of statistics.

Table 3. Trace metal concentrations in standard rock materials.
(Page 1 of 2.)

Sample	$\%Fe_2O_3$	Metals (ppm) Pb	Zn	Ba	Cu	Ni	V	Cr	Cd
BCR-1	13.0	14	130	850	22	8	400	14	<0.1
	12.7	13	120	680	18	8	400	11	<0.1
	13.5	13	120	690	13	7	380	10	
	13.7	13	125	750	16	7	330	9	<0.1
Mean	13.23	13.3	126.3	742.5	17.3	7.5	377.5	11	<0.1
Std. Dev.	0.46	0.5	4.8	78.0	3.8	0.6	33.0	2.2	
Coef. of Var. %	3.48	3.8	3.8	10.5	22.0	8.0	8.7	20	
GSP-1	4.2	59	100	1600	30	7	55	9	<0.1
	4.2	50	98	1400	36	7	55	14	<0.1
	4.6	51	100	1480	32	7	50	12	
	4.5	50	99	1400	27	6	45	9	<0.1
Mean	4.38	52.5	99.3	1470	31.3	6.8	51.3	11	<0.1
Std. Dev.	0.21	4.4	1.0	94.5	3.8	0.5	4.8	2.4	
Coef. of Var. %	4.79	8.4	1.0	6.4	12.1	7.4	9.4	21.8	
AGV-1	6.5	39	92	1500	62	17	130	7	<0.1
	6.6	36	86	1300	66	13	120	11	<0.1
	6.8	34	86	1300	59	13	120	10	
	6.8	32	86	1500	59	13	110	8	<0.1
Mean	6.68	35.3	87.5	1400	61.5	14	120	9	<0.1
Std. Dev.	0.15	3.0	3	115.5	3.3	2	8.2	1.8	
Coef. of Var. %	2.25	8.5	3.4	8.25	5.4	14.3	6.8	20	
G-2	2.5	33	87	2400	8	<2	30	3	<0.1
	2.6	31	84	2000	11	<2	37	7	<0.1
	2.5	30	83	2080	8	2	37	8	
	2.6	28	83	2100	7	2	29	6	<0.1
Mean	2.55	30.5	84.3	2145	8.5		33.3	6	<0.1
Std. Dev.	0.06	2.1	1.9	175.4	1.7		4.3	2.2	
Coef. of Var. %	2.35	6.9	2.3	8.2	20		12.9	36.7	
BHVO-1	12.2	3	100	150	180	120	340	260	<0.1
	11.7	<4	100	150	150	110	280	260	<0.1
	12.5	4	100	140	150	120	320	290	
	12.5	4	100	140	150	110	280	260	<0.1
Mean	12.2		100	145	157.5	115	305	267.5	<0.1
Std. Dev.	0.4		0	5.8	15	5.8	30	15	
Coef. of Var. %	3.3			4	9.5	5	9.8	5.6	
MAG-1	6.9	35	130	620	40	57	150	94	0.15
	6.9		130	510	35	52	130	110	0.18
	6.8	28	130	550	30	59	120	130	
	6.8	24	120	480	27	55	150	90	0.10
Mean	6.85	29	127.5	540	33	55.8	137.5	106	0.14
Std. Dev.	0.06	5.6	5	60.6	5.7	3.0	15	18.2	0.04
Coef. of Var. %	0.88	19.3	3.92	11.2	17.3	5.4	10.9	17.2	28.57

Table 3. (Continued; page 2 of 2).

Sample	%Fe_2O_3	Metals (ppm) Pb	Zn	Ba	Cu	Ni	V	Cr	Cd
P-CLAY	1.7	45	100	470	80	51	250	120	<0.1
	1.9		100	380	60	51	250	130	<0.1
	1.9	43	95	440	55		170	110	
	2.0	41	96	370	64	51	190	120	<0.1
Mean	1.88	43	97.8	415	64.8	51	215	120	<0.1
Std. Dev.	0.13	2.0	2.6	48.0	10.8	0	41.2	8.2	
Coef. of Var. %	6.91	4.7	2.7	11.6	16.7		19.2	6.8	

Table 4. Best values for trace metals in USGS rock standards (Flannagan 1973).

Sample	%Fe_2O_3	Metals (ppm) Pb	Zn	Ba	Cu	Ni	V	Cr	Cd
BCR-1	13.40	17.6	120	675	18.4	15.8	399	17.6	0.12
GSP-1	4.33	51.3	98	1300	33.3	12.5	52.9	12.5	0.06
AGV-1	6.76	35.1	84	1208	59.7	18.5	125	12.2	0.09
G-2	2.65	31.2	85	1870	11.7	5.1	35.4	7	0.04

Table 5. Pearson correlation coefficients.[1]

	Fe	Pb	Zn	Ba	Cu	Ni	V	Cr	Carbon
Fe									
Pb	.63								
Zn	.83	.83							
Ba	.44	.74	.64						
Cu	.49	.56	.75	.45					
Ni	.69	.70	.86	.57	.82				
V	.79	.70	.89	.62	.71	.85			
Cr	.76	.76	.90	.64	.79	.92	.89		
Carbon	.41	.34	.51	.17	.29	.50	.41	.42	
Mud	.49	.49	.69	.29	.71	.70	.58	.62	.52

[1]All correlation coefficients significant at 0.001 level. Calculations based on 150 samples for trace metals and 141 samples for organic carbon and mud.

Cr, Fe, and Ba of other standards analyzed in this study and published results on standards suggests that our values on standards and samples are valid within the error limits indicated.

The precision of the analyses of standards is in all but 4 cases within 20% of the mean values. The coefficients of variation for the analyses of all standards is 11%. This includes all the data and reflects the variability of chemical and instrumental setup on four different occasions during the year.

To support the interpretation of trace metal data, the percent carbon and the percent mud for most of the samples is included in this report. Total organic carbon was determined on a LECO carbon analyzer after the carbonate fraction had been removed. Carbon data was provided by Robert Miller and David Schultz, U. S. Geological Survey, Reston, Va. Size analysis on these samples was performed with standard sieving and pipetting techniques (Johnson and Wood, 1977).

RESULTS AND DISCUSSION

The seasonal trace metal values for each station are given in the Appendix, Tables 1-4. Values for percent organic carbon and percent mud are presented in the Appendix, Table 5. Station locations are listed in Appendix Table 6.

A first step in the analysis of these data was to determine the strength of correlation between the variables measured and to determine if any seasonal trends could be defined. Cadmium was not treated in this analysis because most samples contained less than the detection limit of the analytical method. The Pearson correlation coefficient matrix (Table 5) shows a number of strong covariant relationships among elements and between elements and the variables carbon and mud. For example, a correlation coefficient equal to or greater than 0.7, significant at the 0.001 level, exists between Zn and each of the following variables: Fe, Pb, Cu, Ni, V, Cr, and mud. Although covariant relationships do not confirm chemical associations, this assemblage of variables suggests that the clay mineral fraction in these sediments may control the variability in trace metals. As discussed in a later section, the clay mineral fraction diluted by various amounts of quartz-rich sandy sediments which are low in trace metals could explain the covariability observed.

To determine seasonal trends in the trace metals, organic carbon, and sediment size, the data were analyzed with multiple regression techniques. In the first stage of the circulation, the variability in each trace metal that could be explained by carbon and mud was removed. In the second stage, the percentage of the remaining variability that could be explained by seasonal differences was evaluated with a method similar to covariant analysis (Kim and Kohout, 1975). The results of this analysis technique (Table 6) indicates that the independent variables mud and carbon explain a significant amount of the variability in all the metals except Ba. The influence of seasons explains less than 9% of the variability of Ba and 4% or less of the variability of the other metals, carbon, and mud. This calculation indicates that no clear seasonal relationships exist in this set of data.

Because no seasonal trends were observed in the statistical analysis of metals, carbon, or mud, averages of seasonal values at each station were calculated and plotted. The resulting distributions (Figs. 1-10) are quite similar, reflecting the same covariant relationships indicated between many variables in the table of Pearson correlation

Table 6. Results of multiple regression analysis.

Metal	% of Metal Variability Explained		
	Carbon	Mud	Seasons
Fe	16.6	10.3	1.3
Pb	11.7	13.7	1.3
Zn	26.3	24.9	0.3
Ba	2.9	5.4	8.9
Cu	9.6	42.2	0.1
Ni	24.8	26.4	0.6
V	17.1	18.5	4.0
Cr	17.7	22.3	0.9
Cd	Most values below metal detection limit		
Carbon		27.4	2.8
Mud	27.4		3.2

coefficients. Cd values were not plotted since all averages were below analytical detection limits. Trace metal concentrations determined in this study are in general agreement with less sensitive measurements of a previous investigation of the same general area (Table 7A; Manheim, 1971).

In general, the concentrations of carbon, mud, and metals increase with water depth. The major contours are generally subparallel to the shoreline and the continental shelf edge. The distribution of the trace metals observed in the sediment appears to be dependent on the natural distribution of grain size (Schlee, 1973; Hathaway, 1971) and does not show anomalies which might be expected from local sources. However, the areas of waste disposal on the shelf were not sampled. The concentrations of metals at the 51 sample locations are low compared to levels in average crustal materials (Table 7B and 7C). In addition, the range of values for a particular element is narrow, generally less than a factor of 30 between the lowest and highest concentrations.

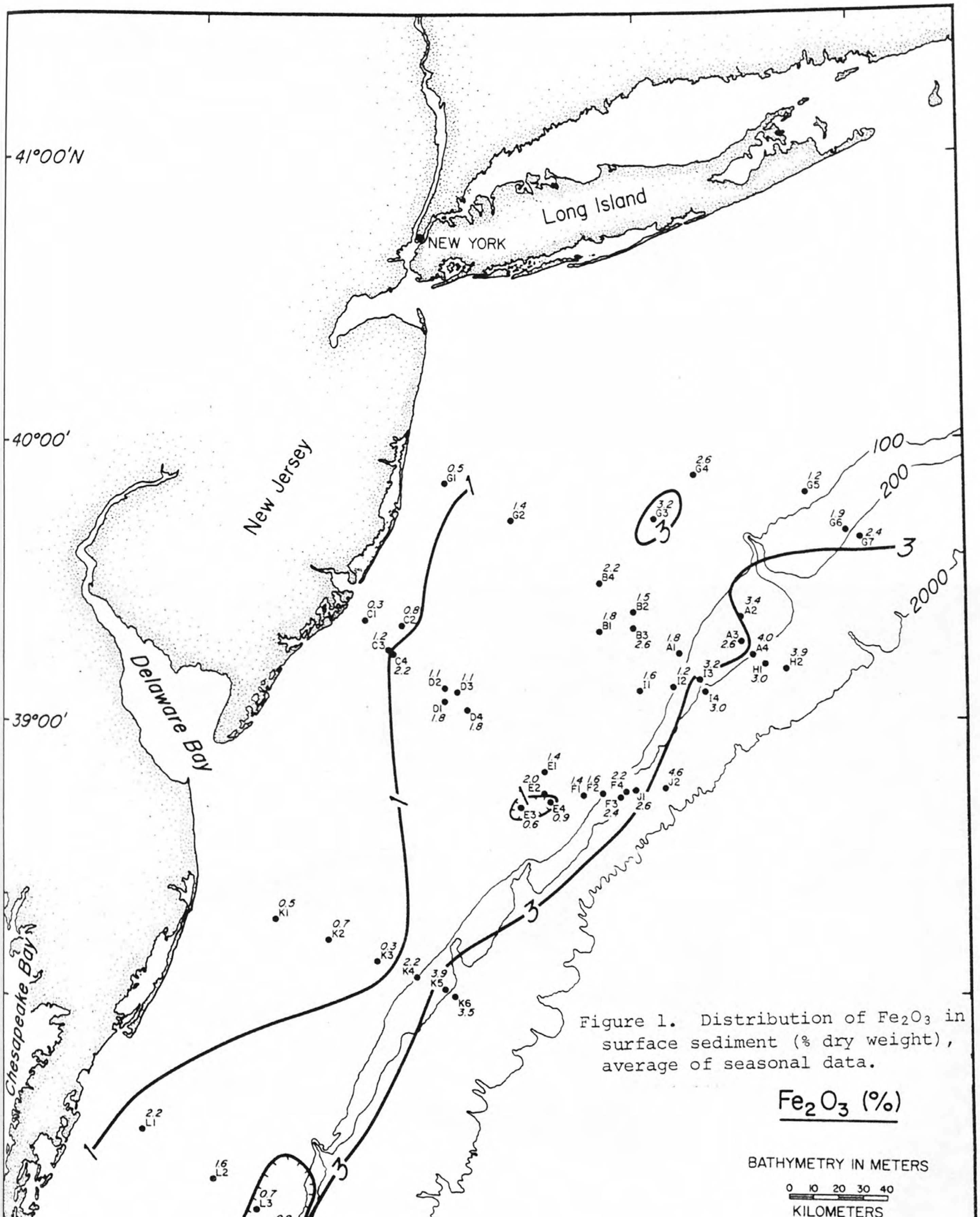

Figure 1. Distribution of Fe_2O_3 in surface sediment (% dry weight), average of seasonal data.

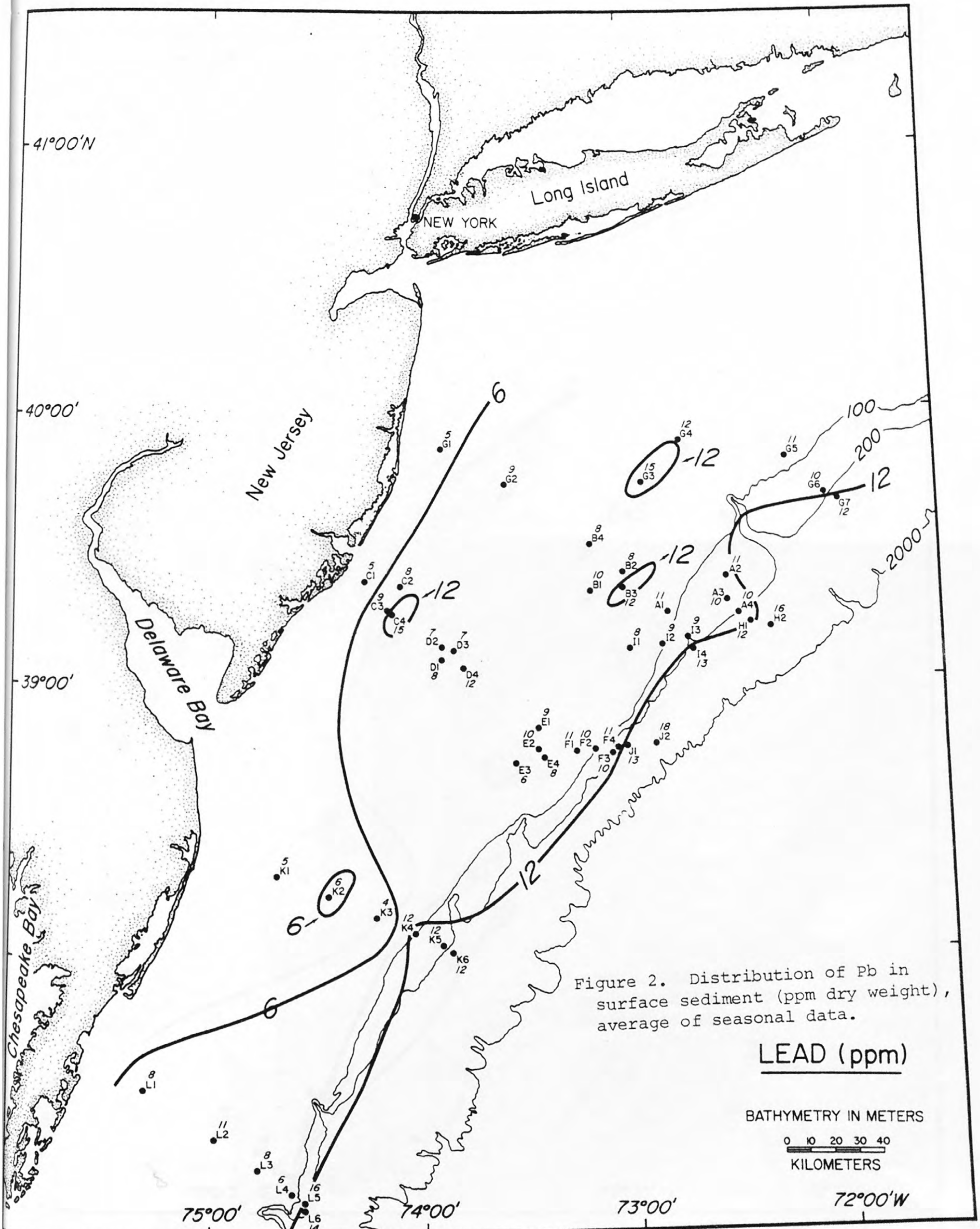

Figure 2. Distribution of Pb in surface sediment (ppm dry weight), average of seasonal data.

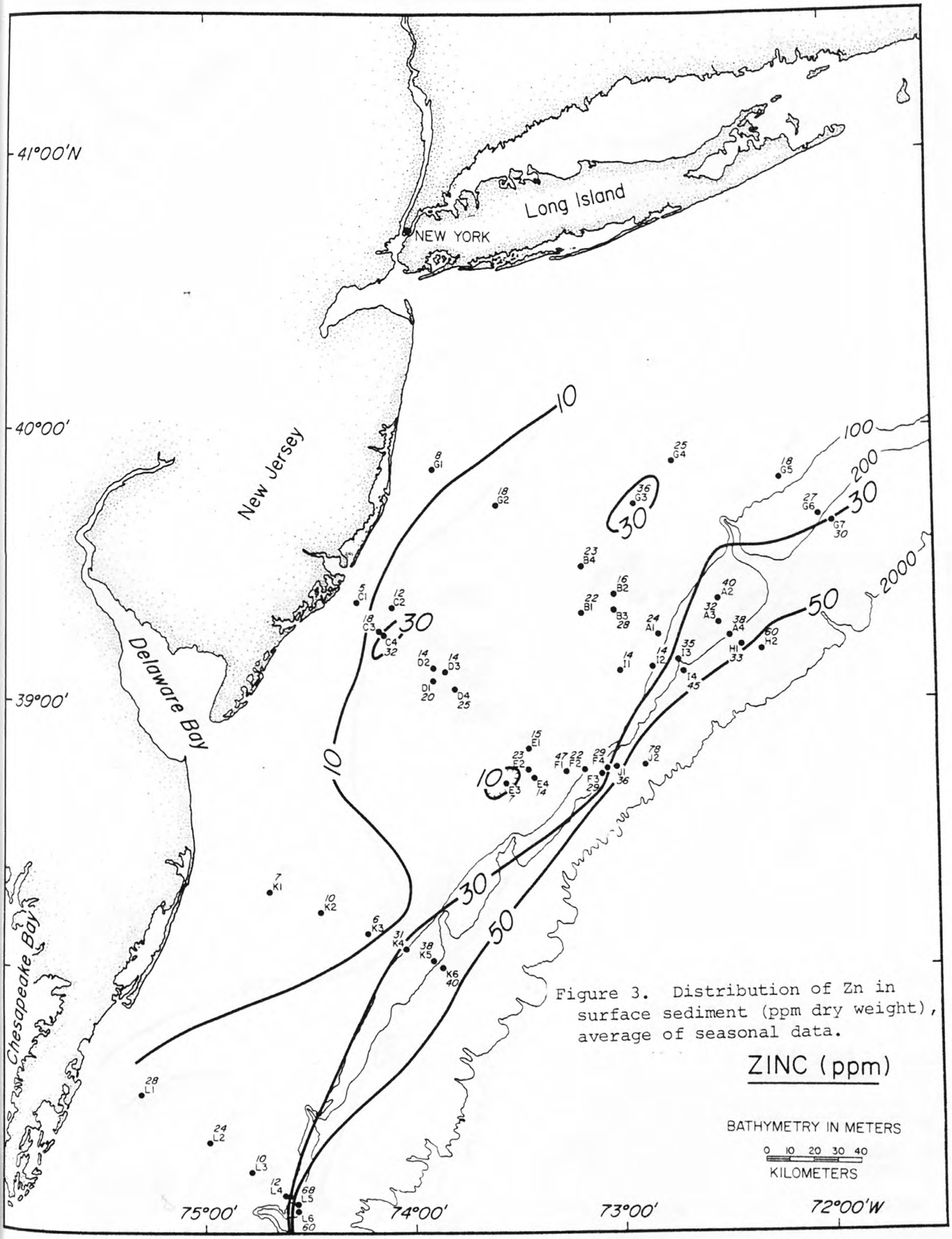

Figure 3. Distribution of Zn in surface sediment (ppm dry weight), average of seasonal data.

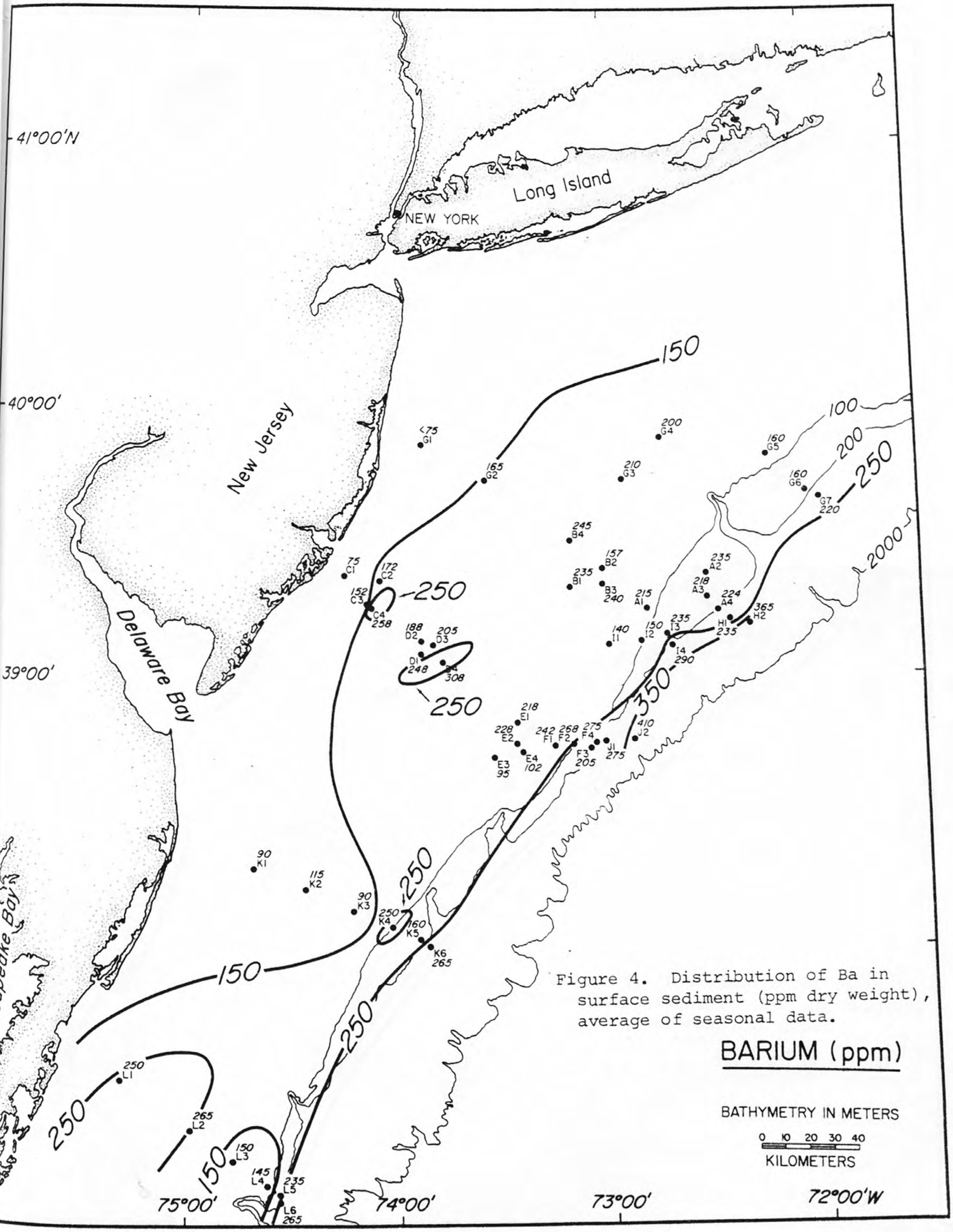

Figure 4. Distribution of Ba in surface sediment (ppm dry weight), average of seasonal data.

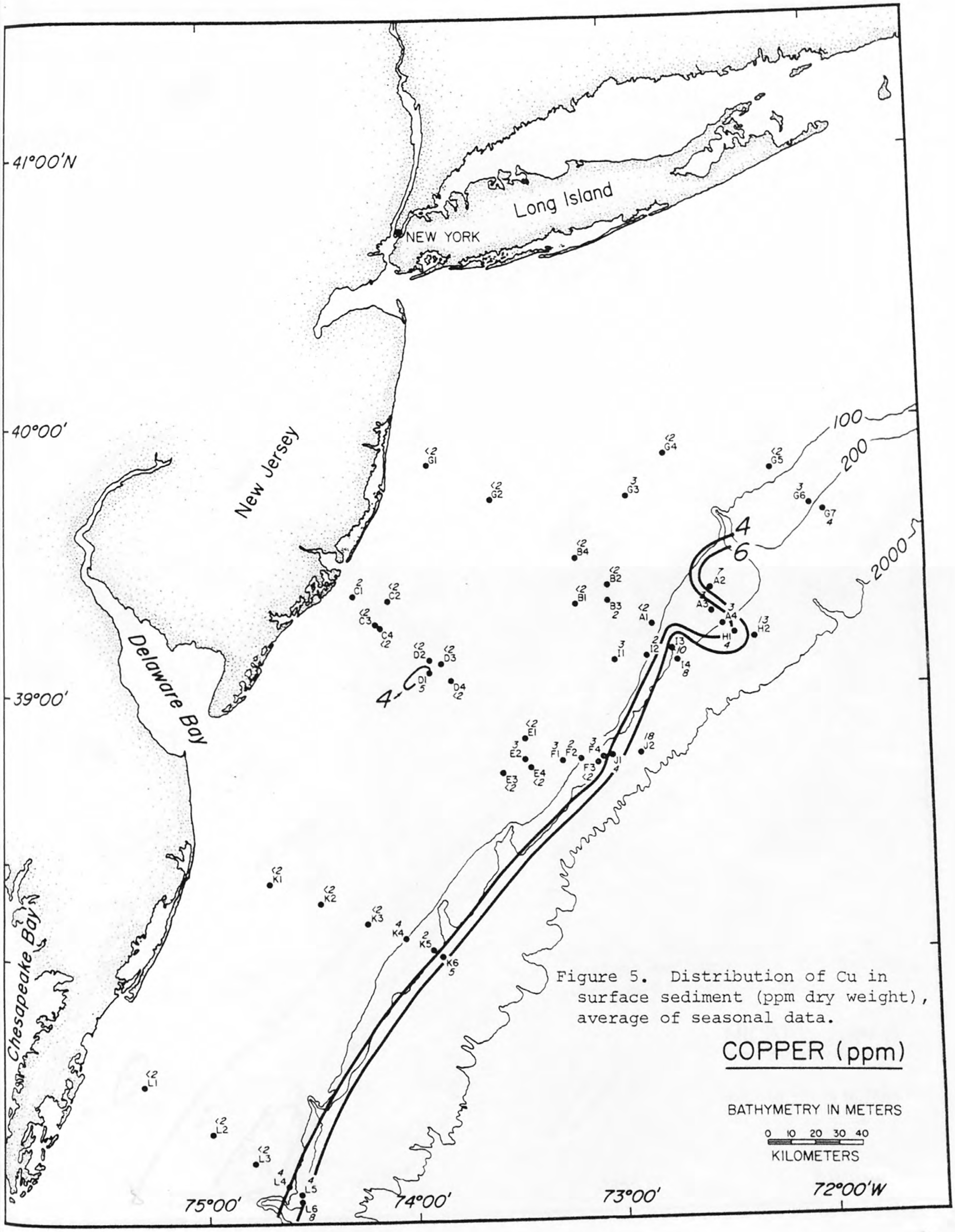

Figure 5. Distribution of Cu in surface sediment (ppm dry weight), average of seasonal data.

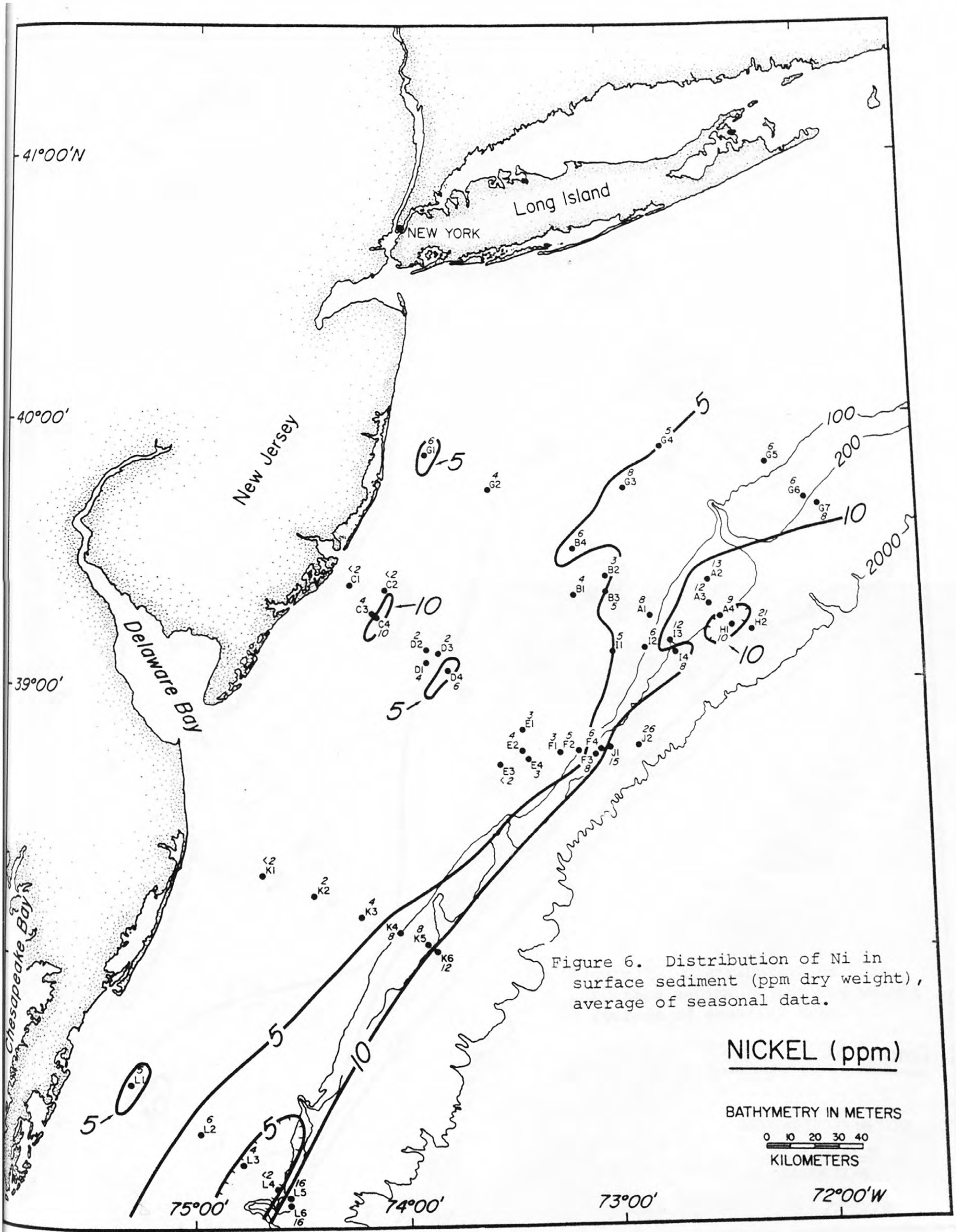

Figure 6. Distribution of Ni in surface sediment (ppm dry weight), average of seasonal data.

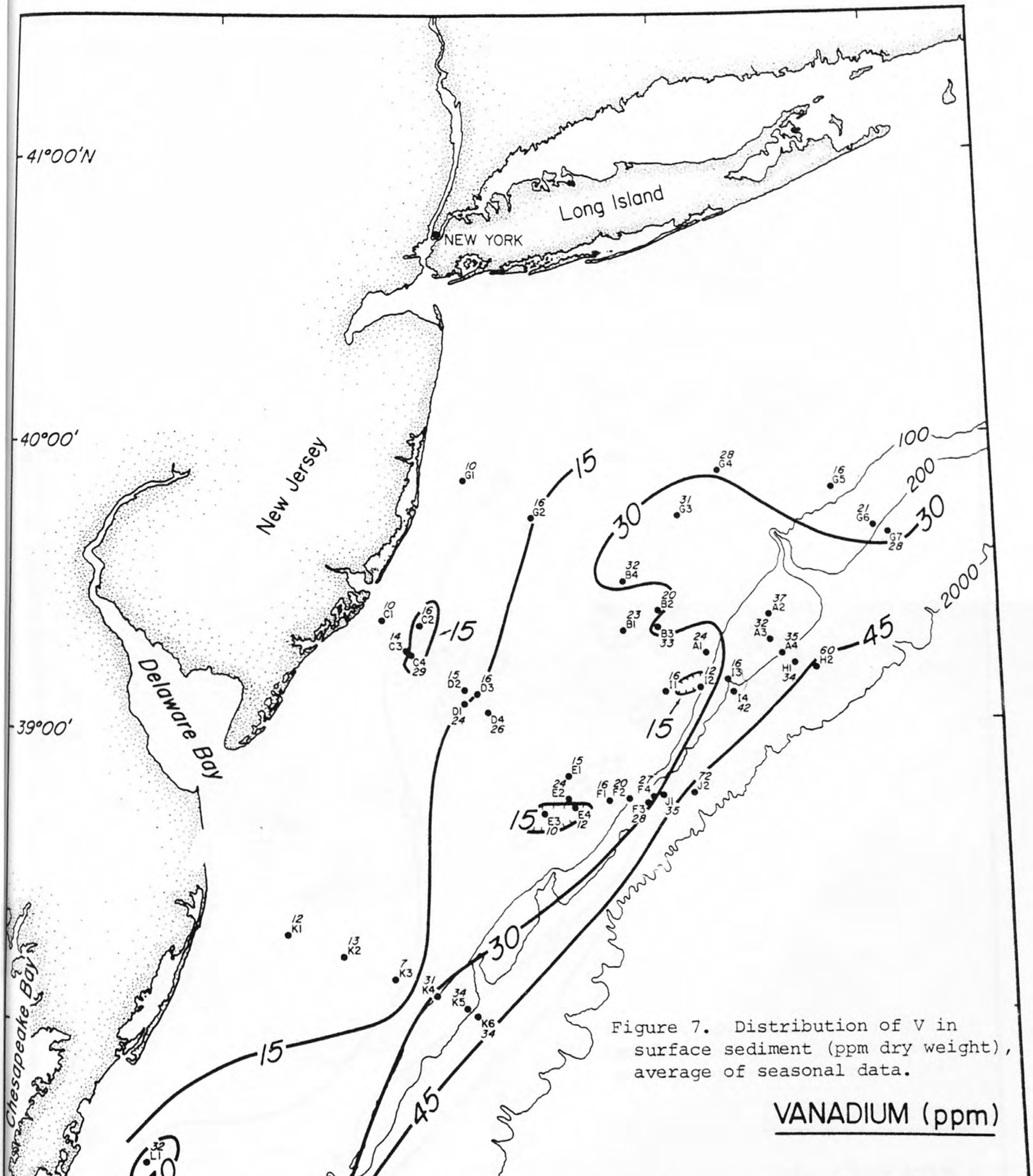

Figure 7. Distribution of V in surface sediment (ppm dry weight), average of seasonal data.

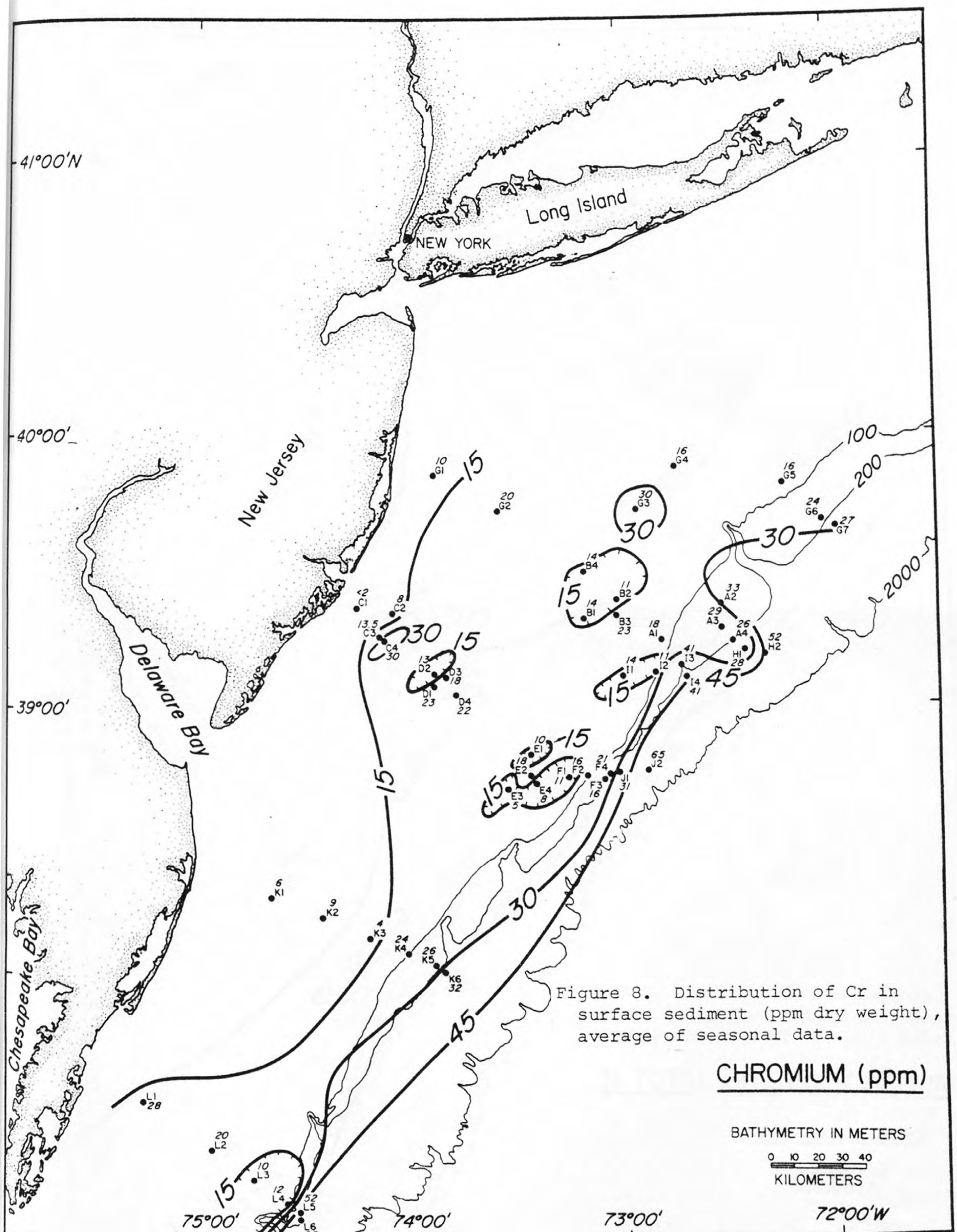

Figure 8. Distribution of Cr in surface sediment (ppm dry weight), average of seasonal data.

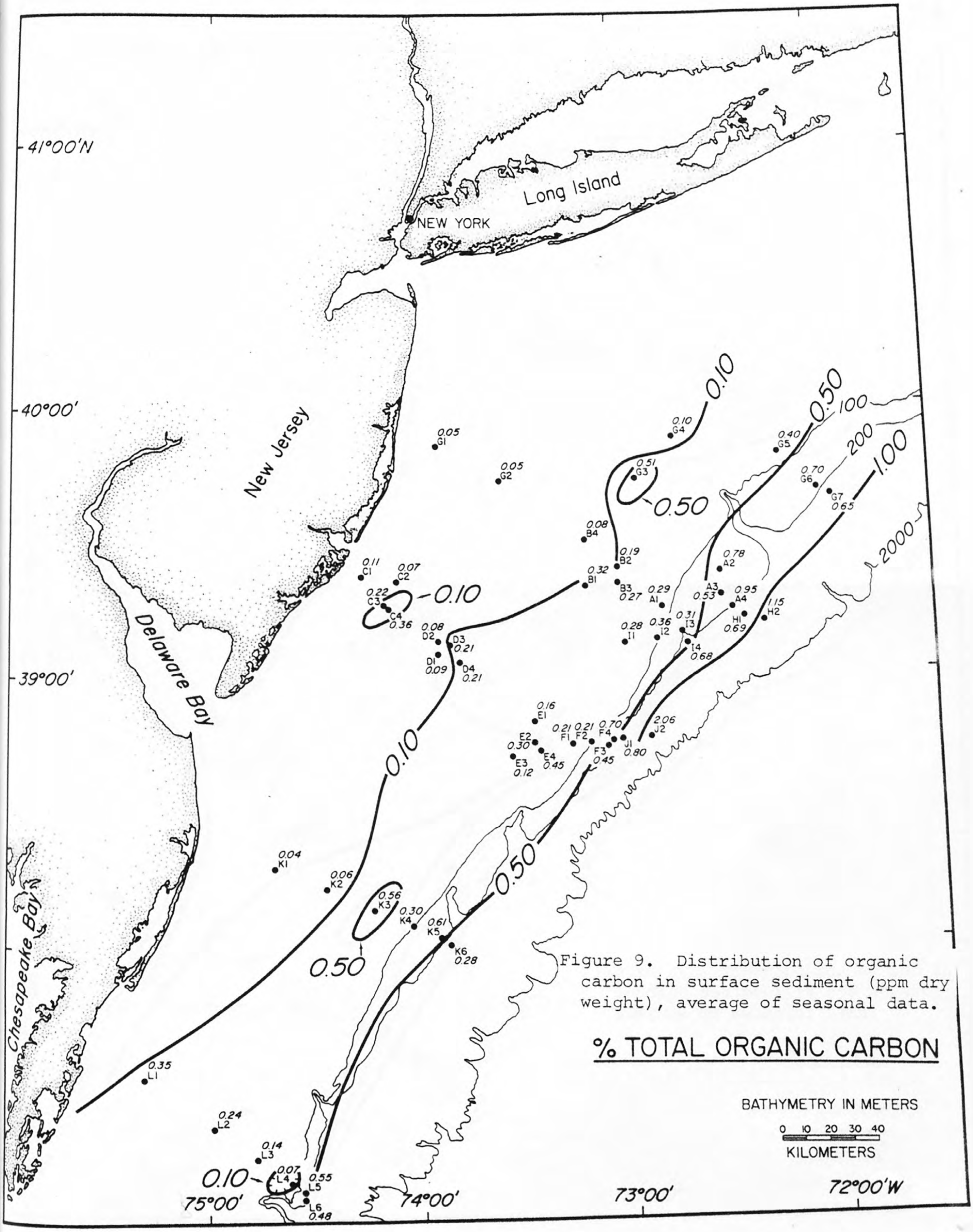

Figure 9. Distribution of organic carbon in surface sediment (ppm dry weight), average of seasonal data.

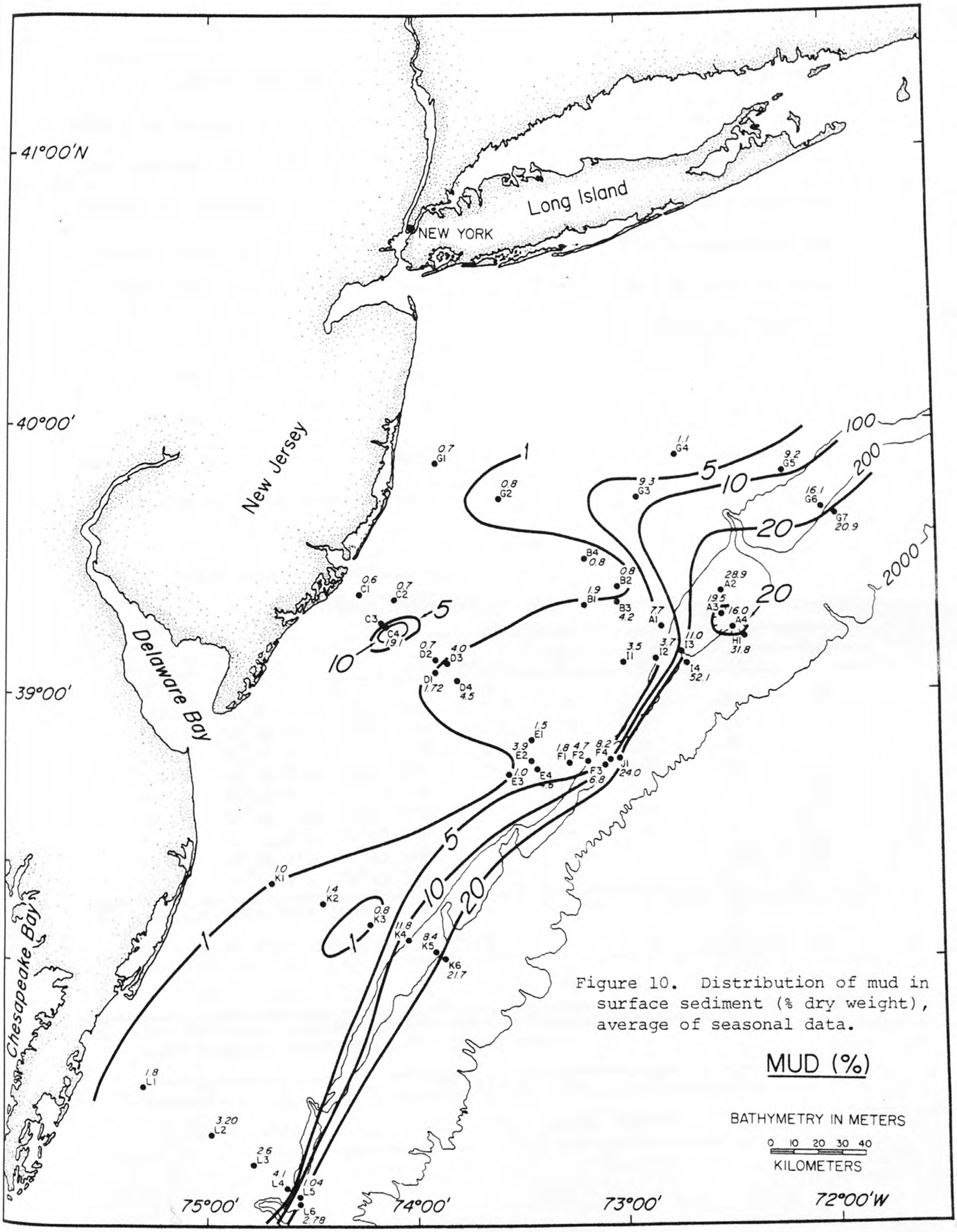

Figure 10. Distribution of mud in surface sediment (% dry weight), average of seasonal data.

Because the quartz-rich coarse fraction of the total sediment sample is typically poor in trace metals and serves to dilute any recently added contaminants, the analysis of totally decomposed sediment samples may not be the most sensitive approach to identify trace metal contamination. Analysis of the isolated fine fraction of sediment or of a chemically leached fraction of the total sediment might be more sensitive. In spite of its comparatively lower sensitivity, the total dissolution technique would identify sampled areas having anomalously high trace metal concentrations.

Natural processes of sediment sorting probably are the most important control of the trace metal distribution. The fine-grained sediments which contain higher concentrations of trace metals and organic

Table 7. Trace metal concentrations.

A. Trace Metals in Surface Sediments of Middle Atlantic Continental Shelf (Hathaway 1971):

Station			$\%Fe_2O_3$	Zn (ppm)	Ba (ppm)	Cu (ppm)	Ni (ppm)
1890	38°00.0'N	74°15.5'W	0.9	16	200	<20	18
1891	38°00.0'N	73°59.4'W	2.1	16	200	<20	36
2027A	38°29.9'N	74°45.2'W	2.0	<16	100	<30	<30
2027B	38°39.9'N	74°45.2'W	2.9	<16	100	<30	27
2032	38°19.8'N	74°30.0'W	0.8	<16	<100	<30	<30
2054	36°39.4'N	75°30.7'W	0.6	16	<100	<20	<20
2057	36°48.5'N	75°45.0'W	1.1	16	100	<20	<20
2080A	36°35.4'N	74°43.5'W	2.5	16	200	<20	<20
2080B	36°35.4'N	74°43.5'W	2.4	24	100	<20	<20

B. Average Abundance (ppm) of Element in the Earth's Crust (Krauskoph 1967):

Pb	V	Cr	Cd	$\%Fe_2O_3$	Zn	Ba	Cu	Ni
13	135	100	0.2	8	70	425	55	75

C. Average Metal Concentrations and One Standard Deviation of 150 Sediment Samples Analyzed in This Study (ppm):

Pb	V	Cr	Cd	$\%Fe_2O_3$	Zn	Ba	Cu	Ni
10±3	25±13	20±13	<0.1	2±2	25±15	207±77	3±3	6±5

carbon have accumulated on the continental slope. In contrast, the higher currents and wave-induced turbulence on the continental shelf prevent the accumulation of fine-grained sediments by continually winnowing away the fine material.

The processes which control the distribution of natural trace metals will also influence the fate of trace metals which may be added by man's activities. The present data suggest that added trace metals associated with fine-grained sediments may not be permanently deposited on the continental shelf. There are two general sinks for fine-grained material present in continental shelf waters off the Middle Atlantic States. The first is the continental slope where surface sediment is classified as silt and clay (Schlee, 1973; Hathaway, 1971). Estuaries along the east coast make up the second sink. Estuarine circulation is thought to bring material landward from the continental shelf (Meade, 1969). Little is known about the rates of sediment transport or rates of deposition in either area.

The present data show that any major accumulation of trace metals which might result from a point source on the continental shelf would stand out against the low background values presently found in the surface sediment.

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Appendix: Table 1. Trace Element Concentrations in the Sediments VIMS Fall 1975 Cruise

STATION	% FE_2O_3	PPM PB	ZN	BA	CU	NI	V	CR	CD
A01	1.9	10	27	240	5	7	25	20	0.34
A02	3.2	10	38	250	5	11	33	26	<.1
A03	2.4	10	29	250	3	20	29	45	<.1
A04	4.1	10	39	256	2.6	9	27	24	<.1
B01	1.8	11	18	250	<2	3	18	12	<.1
B02	1.6	8	15	150	<2	<2	18	9	<.1
B03	2.3	14	26	250	<2	4	25	19	<.1
B04	1.8	8	21	250	2	5	23	6	<.1
C01	0.25	4	5	<50	<2	<2	7	<2	<.1
C02	0.67	8	14	150	<2	<2	14	10	<.1
C03	1.1	6	12	80	<2	<2	15	7	<.1
C04	1.4	14	58	180	5	6	18	18	<.1
D01	1.9	6	19	250	<2	2	25	22	<.1
D02	.95	7	12	200	<2	<2	12	10	<.1
D03	1.0	9	13	250	<2	<2	12	7	.12
D04	1.9	15	25	380	<2	4	25	27	<.1
E01	1.2	11	17	250	<2	3	12	12	<.1
E02	1.5	9	17	250	4	3	18	17	<.1
E03	0.57	6	7	100	2	<2	10	4	<.1
E04	0.75	6	11	80	<2	<2	9	4	<.1
F01	1.3	12	16	250	<2	2	13	8	<.1
F02	1.5	12	24	250	3	5	17	16	<.1
F03	2.5	11	29	220	2	16	22	40	<.1
F04	2.0	11	29	220	<2	6	26	20	<.1

Appendix: Table 2. Trace Metal Concentrations in the Sediments VIMS Winter 1976 Cruise

STATION	% FE_2O_3	PPM PB	ZN	BA	CU	NI	V	CR	CD
A01	1.6	11	20	200	<2	5	19	12	<0.1
A02	3.7	13	47	250	8	18	43	45	<0.1
A03	2.5	10	31	200	4	9	37	25	<0.1
A04	3.3	11	35	200	3	9	39	25	<0.1
B01	1.8	11	21	220	<2	5	26	15	<0.1
B02	1.4	8	16	180	<2	3	19	9	<0.1
B03	2.6	12	30	230	4	5	36	25	<0.1
B04	1.9	8	24	230	<2	6	26	17	<0.1
C01	0.24	<4	50	<50	4	<2	8	<2	<0.1
C02	0.84	6	12	200	<2	<2	13	5	<0.1
C03	0.71	6	10	80	<2	<2	10	7	<0.1
C04	1.3	8	18	200	<2	3	22	15	<0.1
D01	1.9	10	26	300	<2	5	24	36	<0.1
D02	1.1	6	14	180	<2	<2	12	21	<0.1
D03	1.1	7	15	230	<2	3	16	8	<0.1
D04	1.8	12	25	300	<2	5	26	21	<0.1
E01	1.0	6	13	180	<2	<2	12	8	<0.1
E02	2.5	12	32	250	3	6	29	26	<0.1
E03	0.54	6	90	80	<2	<2	9	3	<0.1
E04	0.80	8	14	80	<2	2	10	6	<0.1
F01	1.3	10	17	250	<2	3	15	9	<0.1
F02	1.5	11	22	300	2	4	17	15	<0.1
F03	2.4	10	30	200	<2	6	31	21	<0.1
F04	2.1	11	30	250	3	5	29	24	<0.1
G01	0.54	4	10	<50	<2	<2	10	6	<0.1
G02	1.3	7	18	150	<2	<2	17	23	<0.1

Appendix: Table 2. (con't)

STATION	% FE_2O_3	PB	ZN	BA	CU	NI	V	CR	CD
		PPM							
G03	3.1	16	37	220	3	9	37	36	<0.1
G04	2.4	12	27	220	<2	4	30	17	<0.1
G05	1.1	12	20	200	<2	4	17	18	<0.1
G06	1.9	12	30	200	3	7	24	29	<0.1
G07	2.3	13	32	220	3	7	30	28	<0.1
H01	3.0	12	34	220	5	11	41	32	<0.1
H02	3.8	16	60	350	13	24	72	58	<0.1
I01	1.4	9	17	180	3	4	16	15	<0.1
I02	1.2	9	16	180	<2	3	13	8	<0.1
I03	2.5	9	31	250	3	7	31	24	<0.1
I04	2.9	13	46	300	8	18	48	47	<0.1
J01	2.5	13	37	300	5	14	37	33	<0.1
J02	4.5	17	79	400	19	29	86	72	<0.1
K01	0.52	4	80	80	<2	<2	8	5	<0.1
K02	0.73	6	12	130	<2	2	13	8	<0.1
K03	0.35	4	80	80	<2	3	8	3	<0.1
K04	2.2	13	33	250	3	9	31	26	<0.1
K05	3.2	12	39	200	2	8	34	27	<0.1
K06	3.4	12	42	280	6	11	41	35	<0.1
L01	2.0	7	29	280	<2	7	34	30	<0.1
L02	1.7	11	26	280	<2	6	27	18	<0.1
L03	0.76	8	13	180	<2	4	13	12	<0.1
L04	0.77	7	15	180	4	< 2	8	15	<0.1
L05	10.4	17	70	250	4	19	74	57	<0.1
L06	6.0	16	64	280	12	18	77	69	<0.1

Appendix: Table 3. Trace Element Concentrations in the Sediments VIMS Spring 1976 Cruise

STATION	% FE_2O_3	PPM PB	ZN	BA	CU	NI	V	CR	CD
A01	1.9	12	24	220	2	7	29	19	<0.1
A02	3.7	11	39	220	10	12	43	31	<0.1
A03	2.9	11	38	220	3	10	38	26	<0.1
A04	3.3	11	33	220	3	9	38	27	<0.1
B01	1.8	11	29	250	<2	5	25	15	<0.1
B02	1.4	8	15	180	<2	3	20	12	<0.1
B03	2.6	12	26	260	2	6	40	24	<0.1
B04	2.5	9	24	250	<2	7	42	16	<0.1
C01	0.36	6	6	<100	<2	<2	13	5	<0.1
C02	0.90	9	12	220	<2	2	19	10	<0.1
C03	1.9	18	36	350	3	8	16	27	<0.1
C04	1.9	18	36	350	3	8	16	27	<0.1
D01	1.5	8	15	220	<2	4	22	15	<0.1
D02	1.4	6	13	150	<2	2	18	12	<0.1
D03	1.2	7	13	220	<2	2	18	11	<0.1
D04	1.9	12	25	270	2	7	31	21	<0.1
E01	1.6	8	10	220	<2	3	17	12	<0.1
E02	1.6	10	17	210	<2	3	22	14	<0.1
E03	0.53	6	5	<100	<2	<2	10	6	<0.1
E04	1.1	9	14	150	2	4	16	13	<0.1
F01	1.2	10	13	250	<2	3	16	11	<0.1
F02	1.4	10	18	300	<2	5	23	16	<0.1
F03	2.4	9	27	220	2	5	34	23	<0.1
F04	2.1	10	25	450	3	6	31	20	<0.1

Appendix: Table 4. Trace element Concentrations in the Sediments VIMS Summer 1976 Cruise

STATION	% FE_2O_3	PPM PB	ZN	BA	CU	NI	V	CR	CD
A01	2.0	10	25	200	2	6	23	21	<0.1
A02	3.2	11	38	220	4	10	30	29	<0.1
A03	2.5	9	32	200	3	7	26	21	<0.1
A04	5.4	10	44	220	3	10	37	29	<0.1
B01	1.7	9	18	220	< 2	3	23	13	<0.1
B02	1.7	7	17	120	< 2	3	21	14	<0.1
B03	2.7	12	29	220	< 2	5	31	23	<0.1
B04	2.4	8	26	250	< 2	8	35	19	<0.1
C01	0.27	5	5	100	< 2	< 2	12	4	<0.1
C02	0.94	8	12	120	< 2	< 2	18	9	<0.1
C03	1.1	7	15	100	< 2	< 2	17	13	<0.1
C04	4.1	21	77	300	15	21	59	58	.16
D01	1.9	8	22	220	< 2	5	27	20	<0.1
D02	1.1	8	16	220	< 2	3	17	10	<0.1
D03	1.0	6	13	120	< 2	3	17	8	<0.1
D04	1.7	11	26	280	< 2	6	23	18	.11
E01	1.7	10	21	220	< 2	3	20	16	<0.1
E02	2.3	11	26	200	< 2	4	25	17	<0.1
E03	0.68	8	8	100	< 2	< 2	11	6	<0.1
E04	1.1	8	15	100	< 2	3	12	9	<0.1
F01	1.7	10	20	220	5	3	20	15	<0.1
F02	1.9	9	23	220	< 2	5	24	18	<0.1
F03	2.3	10	29	180	< 2	4	26	19	<0.1
F04	2.4	11	33	180	3	8	22	20	<0.1
G01	0.50	6	6	100	3	10	9	13	<0.1
G02	1.4	11	19	180	2	7	15	17	<0.1

Appendix: Table 4. (con't)

STATION	% FE_2O_3	PPM PB	ZN	BA	CU	NI	V	CR	CD
G03	3.4	14	34	200	3	7	25	24	< 0.1
G04	2.7	11	23	180	< 2	6	25	14	< 0.1
G05	1.4	10	17	120	2	8	15	15	< 0.1
G06	1.9	9	24	120	3	6	18	20	< 0.1
G07	2.4	12	29	220	4	9	26	26	< 0.1
H01	3.1	11	32	250	4	9	28	25	< 0.1
H02	4.1	15	59	380	13	18	47	46	< 0.1
I01	1.8	8	12	100	3	6	15	14	< 0.1
I02	1.3	8	12	120	3	8	12	14	< 0.1
I03	4.0	9	39	220	17	18	40	58	< 0.1
I04	3.1	13	44	280	8	13	37	35	< 0.1
J01	2.6	13	35	250	4	16	33	29	< 0.1
J02	4.8	20	78	420	17	23	58	58	< 0.1
K01	0.52	6	6	100	< 2	< 2	15	7	< 0.1
K02	0.65	7	7	100	< 2	3	13	10	< 0.1
K03	0.34	5	3	100	< 2	4	6	5	< 0.1
K04	2.3	12	29	250	4	7	31	23	< 0.1
K05	4.6	11	36	120	2	7	34	24	< 0.1
K06	3.6	12	37	250	4	12	28	28	< 0.1
L01	2.3	10	27	220	< 2	9	30	25	< 0.1
L02	1.6	11	21	250	< 2	5	22	21	< 0.1
L03	0.71	7	8	120	< 2	3	10	9	< 0.1
L04	0.86	6	9	100	4	3	7	9	< 0.1
L05	11.4	15	67	220	3	13	44	46	< 0.1
L06	8.1	12	56	250	5	13	50	37	< 0.1

Appendix:Table 5 Concentrations of Organic Carbon, Mud and Water Content of Surface Sediments Collected on VIMS Cruises

Sta.	FALL[1]		WINTER			SPRING			SUMMER		
	Org. C %	Mud %	Org. C %	Mud %	Water Content %	Org. C %	Mud %	Water Content %	Org. C %	Mud %	Water Content %
A-1	0.39	6.91	0.25	4.2	19.31	0.19	10.5	21.64	0.34	9.0	24.09
A-2	1.11	24.10	0.84	29.2	30.14	0.28	35.5	26.48	0.90	26.7	27.55
A-3	0.611	14.55	0.34	22.1	26.55	0.46	23.4	27.61	0.69	18.0	24.44
A-4	1.64	14.51	0.60	12.7	24.55	0.43	15.4	24.92	1.11	21.5	29.98
B-1	0.37	1.91	0.43	3.1	21.19	0.32	1.5	19.71	0.15	1.1	21.28
B-2	0.324	0.08	0.22	1.2	16.84	0.097	1.0	18.14	0.13	0.8	19.10
B-3	0.11	3.93	0.46	5.3	21.73	0.205	0.5	22.95	0.30	7.1	24.60
B-4	0.056	0.68	0.09	1.3	18.31	0.091	0.5	15.66	0.09	0.8	18.79
C-1	0.28	0.66	0.04	0.7	17.22	0.047	0.5	16.80	0.06	0.6	11.65
C-2	0.052	0.53	0.08	0.7	17.39	0.032	0.7	16.76	0.10	0.9	18.12
C-3	0.080	1.17	0.27	-	11.35	0.07	0.4	15.16	0.45	0.6	14.36
C-4	0.393	20.93	0.06	1.0	18.94	0.32	6.2	25.12	0.67	48.2	34.93
D-1	0.031	1.87	0.14	3.5	22.50	0.077	0.7	18.57	0.10	0.8	20.35
D-2	0.060	0.69	0.06	0.7	18.40	0.14	0.6	16.10	0.06	0.8	20.63
D-3	0.061	12.99	0.56	1.3	19.99	0.15	0.8	18.77	0.07	0.8	20.15
D-4	0.161	3.34	0.24	4.3	22.41	0.27	7.2	22.20	0.17	3.1	26.07

[1]Water content determinations were requested after fall samples had been processed.

Appendix;Table 5 cont.

Sta.	FALL Org. C %	FALL Mud %	WINTER Org. C %	WINTER Mud %	WINTER Water Content %	SPRING Org. C %	SPRING Mud %	SPRING Water Content %	SUMMER Org. C %	SUMMER Mud %	SUMMER Water Content %
E-1	0.140	1.74	0.06	1.2	17.64	0.21	0.9	20.39	0.23	2.3	23.78
E-2	0.256	1.34	0.35	7.0	18.36	0.25	1.8	18.48	0.33	5.5	21.70
E-3	0.218	1.05	0.05	1.0	16.39	0.14	1.1	17.91	0.07	1.0	18.49
E-4	0.615	4.41	0.42	4.3	18.19	0.51	4.5	19.78	0.25	5.1	17.33
F-1	0.112	1.59	0.08	1.6	19.27	0.21	1.3	19.36	0.43	2.7	24.54
F-2	0.271	3.96	0.17	5.2	23.36	0.2	3.4	23.13	0.42	6.4	30.18
F-3	0.506	4.94	0.35	5.7	22.61	0.55	8.6	24.69	0.41	8.1	27.54
F-4	1.123	1.67	0.44	6.7	24.26	0.36	10.7	25.36	0.88	13.6	32.75
G-1			0.03	0.7	11.50				0.05	0.7	12.73
G-2			0.06	0.8	18.10				0.05	2.4	23.84
G-3			0.41	9.3	21.89				0.51	9.2	23.19
G-4			0.18	1.1	16.58				0.10	1.1	19.81
G-5			0.43	9.2	20.23				0.36	10.1	20.83
G-6			0.63	13.7	25.76				0.76	18.5	28.68
G-7			0.46	20.9	24.28				0.84	-	28.34
H-1			0.76	25.2	27.09				0.62	38.3	24.74
H-2			1.13	-	40.35				1.17	-	41.86

Appendix:Table 5 cont.

Sta.	FALL Org. C %	FALL Mud %	WINTER Org. C %	WINTER Mud %	WINTER Water Content %	SPRING Org. C %	SPRING Mud %	SPRING Water Content %	SUMMER Org. C %	SUMMER Mud %	SUMMER Water Content %
I-1			0.46	4.7	18.54				0.09	2.3	18.55
I-2			0.27	4.2	13.69				0.44	3.2	18.13
I-3			0.50	8.0	21.07				0.12	14.0	22.48
I-4			0.73	-	38.07				0.62	52.1	35.60
J-1			0.77	24.6	29.73				0.83	23.3	32.38
J-2			1.77	-	54.25				2.34	-	53.12
K-1			0.04	1.2	10.26				0.04	0.7	19.85
K-2			0.09	1.8	17.55				0.02	0.9	22.67
K-3			1.07	0.6	12.90				0.04	0.9	20.54
K-4			0.04	12.4	25.61				0.56	11.3	28.68
K-5			0.53	7.5	22.34				0.69	9.2	25.04
K-6			0.48	-	24.30				0.08	21.7	27.18
L-1			0.12	1.6	20.49				0.58	1.8	20.96
L-2			0.33	2.8	22.09				0.14	3.6	22.47
L-3			0.21	1.5	19.03				0.07	3.6	19.57
L-4			0.07	2.4	16.20				0.07	5.8	17.89
L-5			0.78	9.7	22.15				0.32	11.1	22.17
L-6			0.71	-	29.00				0.25	27.8	26.14

Appendix: Table 6a. Station locations of Grab Samples VIMS FALL CRUISE

Station #	Date	Lat.	Long.	Water Depth (m)
A-1	11/3/75	39°15.0'N	72°47.0'W	91
A-2	"	39°22.0'N	72°31.1'W	128
A-3	"	39°17.0'N	72°29.7'W	136
A-4	"	39°14.3'N	72°27.4'W	195
B-1	11/4/75	39°20.0'N	73°10.5'W	63
B-2	"	39°23.2'N	73°00.7'W	58
B-3	"	39°20.0'N	73°01.0'W	72
B-4	"	39°30.4'N	73°10.6'W	40
C-1	11/5/75	39°22.1'N	74°15.3'W	14
C-2	"	39°22.1'N	74°06.4'W	22
C-3	"	39°15.8'N	74°08.8'W	25
C-4	"	39°15.2'N	74°08.0'W	33
D-1	10/20/75	39°06.5'N	73°55.2'W	31
D-2	"	39°07.7'N	73°51.2'W	33
D-3	10/29/75	39°06.9'N	73°46.0'W	33
D-4	"	39°03.5'N	73°46.5'W	49
E-1	"	38°49.0'N	73°26.0'W	60
E-2	10/30/75	38°43.0'N	73°25.0'W	76
E-3	10/31/75	36°42.4'N	73°32.7'W	63
E-4	"	38°42.8'N	73°24.3'W	76
F-1	"	38°44.2'N	73°14.9'W	83
F-2	11/1/75	38°44.4'N	73°09.1'W	110
F-3	"	38°44.3'N	73°04.6'W	146
F-4	11/2/75	38°44.2'N	73°03.6'W	183

Appendix: Table 6b Station Locations of Grab Samples VIMS WINTER CRUISE

Station #	Date	Lat.	Long.	Water Depth (m)
A-1	3/4/76	39°14.7'N	72°47.4'W	90
2	3/5/76	39°22.2'N	72°31.0'W	127
A-3	3/15/76	39°16.6'N	72°30.0'W	136
A-4	"	39°14.3'N	72°26.7'W	196
B-1	3/4/76	39°19.3'N	73°10.1'W	63
B-2	"	39°23.3'N	73°00.6'W	61
B-3	"	39°19.7'N	73°00.3'W	72
B-4	"	39°29.9'N	73°10.0'W	41
C-1	2/20/76	39°21.8'N	74°15.8'W	15
C-2	"	39°21.0'N	74°05.3'W	25
C-4	2/21/76	39°15.2'N	74°08.0'W	34
D-1	"	39°04.6'N	73°53.5'W	39-40
D-2	"	39°07.5'N	73°53.5'W	32
D-3	"	39°06.7'N	73°50.0'W	35
D-4	"	39°02.9'N	73°47.2'W	49
E-1	3/3/76	38°49.1'N	73°25.6'W	66
E-2	"	38°44.3'N	73°25.5'W	73
E-3	3/2/76	38°41.3'N	73°32.3'W	64
E-4	3/3/76	38°42.8'N	73°24.3'W	77
F-1	3/18/76	38°44.1'N	73°14.7'W	84
F-2	"	38°44.2'N	73°09.1'W	110
F-3	"	38°43.8'N	73°04.3'W	150
F-4	"	38°44.6'N	73°03.1'W	183
G-1	3/8/76	39°51.4'N	73°53.1'W	27
G-2	"	39°43.6'N	73°34.8'W	37
G-3	"	39°43.7'N	72°54.7'W	73-74
G-4	"	39°53.4'N	72°43.2'W	55
G-5	3/9/76	39°48.9'N	72°12.3'W	90
G-6	"	39°40.6'N	72°00.8'W	167
G-7		39°39.2'N	71°57.4'W	295-300
H-1	3/16/76	39°12.2'N	72°23.6'W	350-400
I-1	3/14/76	39°06.6'N	72°59.0'W	80
I-2	3/14/76	39°07.5'N	72°49.1'W	94
I-3	3/15/76	39°08.9'N	72°42.0'W	180
J-1	3/20/76	38°45.0'N	73°00.8'W	365
K-1	3/2/76	38°17.5'N	74°41.0'W	29
K-2	3/12/76	38°12.7'N	74°26.6'W	41
K-3	"	38°08.0'N	74°13.0'W	53
K-4	"	38°04.6'N	74°01.7'W	105
K-5	"	38°01.6'N	73°53.8'W	151
L-1	3/22/76	37°31.2'N	75°18.6'W	26
L-2	"	37°20.2'N	74°58.7'W	41
L-3	"	37°13.6'N	74°40.6'W	58
L-4	"	37°08.2'N	74°37.0'W	94
L-5	"	37°05.1'N	74°33.4'W	180-200

Appendix: Table 6c Station Locations of Grab Samples VIMS SPRING CRUISE

#	Date	Lat.	Long.	Water Depth (m)
A-1	6/22/76	39°14.7'N	72°47.2'W	91
A-2	"	39°21.6'N	72°31.0'W	128
A-3	"	39°16.5'N	72°29.9'W	136
A-4	6/23/76	39°14.3'N	72°26.8'W	196
B-1	6/21/76	39°19.4'N	73°10.3'W	64
B-2	"	39°23.4'N	73°00.6'W	60
B-3	"	39°19.8'N	73°00.4'W	72
B-4	6/22/76	39°30.0'N	73°10.0'W	40
C-1	6/15/76	39°22.1'N	74°15.7'W	17
C-2	"	39°21.0'N	74°05.2'W	21
C-3	6/16/76	39°15.2'N	74°09.1'W	24
C-4	"	39°15.6'N	74°07.6'W	34
D-1	"	39°04.6'N	73°51.2'W	31
D-2	"	39°07.5'N	73°50.1'W	33
D-3	6/17/76	39°06.6'N	73°45.9'W	39
D-4	"	39°04.9'N	73°47.1'W	49
E-1	6/17/76	38°47.1'N	73°27.4'W	67
(	6/18/76	38°44.1'N	73°25.0'W	64
E-3	"	38°41.4'N	73°32.5'W	63
E-4	6/17/76	38°42.8'N	73°24.3'W	77
F-1	6/19/76	38°44.3'N	73°14.7'W	85
F-2	"	38°44.3'N	73°09.4'W	113
F-3	"	38°43.6'N	73°04.7'W	152
F-4	6/20/76	38°44.3'N	73°03.1'W	184

Appendix: Table 6d Station Locations of Grab Samples VIMS SUMMER CRUISE

Station #	Date	Lat.	Long.	Water Depth (m)
VIMS A-1	8/21/76	39°34.3'N	72°46.8'W	90
A-2	8/22/76	39°31.6'N	72°30.7'W	127
A-3	8/22/76	39°36.5'N	72°29.6'W	136
A-4	8/22/76	39°34.2'N	72°26.5'W	198
B-1	8/20/76	39°19.3'N	73°10.1'W	63
B-2	8/21/76	39°23.3'N	73°00.5'W	61
B-3	8/21/76	39°15.8'N	73°00.4'W	72
B-4	8/21/76	39°29.9'N	73°10.1'W	41
C-1	8/16/76	39°22.1'N	74°15.6'W	16
C-2	8/16/76	39°20.9'N	74°04.2'W	25
C-3	8/15/76	39°15.4'N	74°09.4'W	24
C-4	8/15/76	39°14.9'N	74°07.5'W	34
D-1	8/17/76	39°04.7'N	73°51.2'W	31
D-2	8/17/76	39°07.1'N	73°49.6'W	33
D-3	8/17/76	39°06.6'N	73°45.4'W	34
D-4	8/17/76	39°02.9'N	73°47.1'W	48
E-1	8/17/76	38°47.3'N	73°23.8'W	68
E-2	8/18/76	38°44.2'N	73°25.6'W	70
E-3	8/18/76	38°41.3'N	73°32.0'W	63
E-4	8/18/76	38°42.6'N	73°24.3'W	75
F-1	8/20/76	38°43.5'N	73°13.9'W	84
F-2	8/20/76	38°43.7'N	73°08.5'W	113
F-3	8/20/76	38°43.6'N	73°04.0'W	153
F-4	8/20/76	38°44.2'N	73°02.8'W	183
G-1	8/26/76	39°51.5'N	73°53.1'W	24
G-2	8/26/76	39°43.7'N	73°34.9'W	37
G-3	8/27/76	39°43.1'N	72°54.2'W	73
G-4	8/27/76	39°53.4'N	72°43.2'W	56
G-5	8/27/76	39°48.9'N	72°12.4'W	92
G-6	8/27/76	39°40.7'N	72°00.7'W	167
H-1	8/28/76	39°12.1'N	72°23.6'W	390
I-1	8/23/76	39°06.6'N	72°59.0'W	77
I-2	8/22/76	39°07.5'N	72°49.0'W	93
I-3	8/22/76	39°08.8'N	72°41.8'W	179
I-4	8/29/76	39°06.1'N	72°40.3'W	460
J-1	8/29/76	38°45.2'N	73°01.0'W	350
K-1	8/23/76	38°17.5'N	74°41.0'W	29
K-2	8/23/76	38°12.6'N	74°26.5'W	42
K-3	8/23/76	38°08.0'N	74°13.0'W	53
K-4	8/31/76	38°04.6'N	74°01.9'W	102
K-5	8/31/76	38°01.6'N	73°53.9'W	145
K-6	8/31/76	38°00.6'N	73°51.9'W	355
L-1	9/1/76	37°13.2'N	75°18.6'W	24
L-2	9/1/76	37°20.2'N	74°58.7'W	48
L-3	9/1/76	37°13.6'N	74°46.6'W	66
L-4	9/1/76	37°08.1'N	74°36.9'W	91
L-5	9/1/76	37°06.1'N	74°33.4'W	190
L-6	9/1/76	37°04.6'N	74°33.2'W	332