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090

Analysis of Sediment Data from the Beaufort Sea Shorebase Monitoring Program, 1982–1984

Canada

March 1988

The Environmental Studies Research Funds are financed from special levies on the oil and gas industry and administered by the Canada Oil and Gas Lands Administration for the Minister of Energy, Mines and Resources, and by the Northern Affairs Program for the Minister of Indian Affairs and Northern Development.

Environmental Studies Research Funds
Report No. 090
March, 1988

ANALYSIS OF SEDIMENT DATA FROM THE BEAUFORT SEA SHOREBASE MONITORING PROGRAM 1982 to 1984

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The correct citation for this report is:

Wainwright, P.F., and B. Humphrey. 1988. Analysis of sediment data from the Beaufort Sea Shorebase Monitoring Program, 1982 to 1984. Environmental Studies Research Funds Report No. 090. Ottawa, 147 p.

Published under the auspices
of the Environmental Studies
Research Funds
ISBN 0-920783-89-9

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ACKNOWLEDGEMENTS

Thanks are extended to Gordon Stewart of Indian and Northern Affairs Canada in Yellowknife (the Scientific Adviser) for comments and assistance with the project. Dr. John Hoff of Arctic Laboratories Limited assisted in the selection of methodology and preliminary statistical analyses. Mr. Paul Erickson of Arctic Laboratories Limited acted as manager for this project and provided review and comments for the authors.

SUMMARY

This report presents the analysis and interpretation of data from the chemical analysis of sediments collected from 1982 to 1984 under the Beaufort Sea Shorebase Monitoring Program conducted by Environment Canada and the Department of Indian Affairs and Northern Development. Previous workers had determined that the 1982-83 data were unsuitable for detailed parametric statistical analysis without applying data transformations and other manipulations. For this study, the entire data set was examined to identify an approach or methods that would permit simplification of the analysis. The approach adopted was to assume that the data belonged to a single population. This population was then characterized and examined for deviating observations or outliers. No reasons were found to discount the assumption of a single population when using the Shorebase data and the nearshore data.

The available data sets were examined, the data were standardized and then inappropriate data were rejected. Preliminary analyses demonstrated that the concentrations of contaminants of interest were determined primarily by the grain size of the sediment collected. Therefore, statistical analysis was restricted to observations with concurrent grain size results. Relationships between contaminant concentrations and grain size were then determined and the residual values from the contaminant to grain size regression relations were analysed. It was apparent, by inspection, that the residuals were normally distributed for each laboratory and year analysed, implying that remaining variance was caused by intra- and inter-laboratory analytical variance.

Samples with contaminant concentrations in excess of the value predicted by the grain size relations plus a 99% prediction interval were then identified. Maps of outliers were plotted for each contaminant. Inspection of the resulting maps clearly identifies an association between industrial activity and sites of outliers. Many of the outliers identified are associated with loading docks or sites of dredging activity.

The environmental significance of anthropogenic inputs was assessed by determining an index of contamination, which was mapped in the same way as the contaminant outliers. This index of contamination is the sum of the deviations from the grain size relations for each contaminant. An environmental risk index was not determined at this time. A relatively arbitrary "toxicological factor" would have to be determined for each contaminant. The maps of contaminant deviations and index of contamination were sufficient to identify and interpret areas of risk. The question of what contaminant index should cause concern is not addressed for the same reason.

Outliers were found primarily in Tuktoyaktuk Harbour and McKinley Bay, with some outliers also found in Kugmallit and Hutchison Bays. The outliers in different locations included different contaminants. The sample collection was not representative of the embayments as a whole, therefore, it was impossible to assess the significance of the contamination observed.

It is recommended that the Beaufort Sea Shorebase Monitoring Program be continued provided that the program design is revised to include representative sampling of each embayment, to ensure more consistency in analytical methods, and to include concurrent grain size measurement of all samples.

RÉSUMÉ

Le présent rapport donne les résultats de l'analyse et de l'interprétation des données recueillies de 1982 à 1984, à partir de l'analyse chimique des sédiments, dans le cadre du programme de surveillance du littoral de la mer de Beaufort, une initiative d'Environnement Canada et du ministère des Affaires Indiennes et du Nord Canadien. On avait jugé, lors d'études antérieures, que les données de 1982-83 ne se prêtaient pas à l'analyse statistique détaillé des paramètres sans transformation et manipulation. Aux fins de la présente étude, on s'est penché sur l'ensemble des données pour trouver une méthode permettant de simplifier l'analyse. La procédure retenue se fonde sur la prémisse que les données correspondent à un seul échantillon, lequel a été caractérisé et examiné pour en relever les écarts et les valeurs exceptionnelles. On n'a trouvé aucune raison de rejeter la prémisse d'un seul échantillon dans l'utilisation des données sur le littoral de la mer de Beaufort et d'autres données générales semblables.

Les données disponibles ont été examinées puis normalisées. On a par la suite rejeté celles qui étaient inacceptables. Des analyses préliminaires montrent que la concentration des contaminants à l'étude dépend de la granulométrie des sédiments recueillis. L'analyse statistique a donc été limité aux observations ayant les mêmes résultats granulométriques. Des liens ont ensuite été établis entre la concentration des contaminants et la granulométrie et on a analysé les valeurs résiduelles de la relation de régression entre ces deux éléments. Après examen des résultats, on a pu constater que les valeurs résiduelles étaient normalement distribuées selon le laboratoire et l'année de l'analyse. Ces écarts étaient donc analytiques et s'expliquaient par des facteurs à l'intérieur et à l'extérieur des laboratoires.

On a alors identifié les échantillons ayant une concentration de contaminants supérieure à la valeur prévue dans les relations graulométriques, plus une valeur de prévision de 99%. On a tracé les écarts pour chaque contaminant. L'étude des tracés révele qu'il existe un lien certain entre l'activité industrielle et l'emplacement des écarts. Parmi les écarts relevés, nombre d'entre eux sont associés aux plate-formes de chargement ou aux emplacements de dragage.

L'impact environnemental des activités humaines a été évalué en déterminant un index de contamination qui a été tracé de la même façon que les écarts de contaminants. Cet index de contamination est la somme des écarts relevés dans les relations granulométriques de chaque contaminant. Un index de risque environmental n'a pas été fixé, car il aurait fallu déterminer un facteur toxicologique relativement arbitraire pour chaque contaminant. Les tracés des écarts de contaminants et l'index de contamination étaient suffisants pour identifier et interpréter les endroits de risque. De même, la question de savoir quel index de contamination devrait être cause de consternation n'a pas été étudiée.

Les écarts ont été relevés principalement dans le port de Tuktoyaktuk et la baie de McKinley, ainsi que dans les baies de Kugmallit et de Hutchison. Les écarts ailleurs comprenaient des contaminants différents. La série d'échantillons n'était pas représentative de l'ensemble des baies, donc il était impossible d'évaluer l'impact de la contamination.

Il est recommandé que la programme de surveillance du littoral de la mer de Beaufort se poursuive à condition que la conception du programme soit revue de façon à inclure des échantillons de chaque baie, à assurer l'uniformité des méthodes d'analyse et à inclure des mesures granulométriques concordantes de tous les échantillons.

INTRODUCTION

Oil exploration and production activity in the Canadian Beaufort Sea has an associated risk of causing adverse environmental impacts. The industrial activity associated with the use of shorebases in Tuktoyaktuk Harbour and McKinley Bay to supply offshore drill rigs has greatly increased in recent years. To assess any adverse effects from this industrial activity and to assess the effectiveness and appropriateness of regulatory controls, a detailed understanding of the present conditions of the environment is necessary. A program to monitor sediments from these shorebase areas was initiated in 1982 and continued in a revised form in 1983 and 1984. These programs resulted in the collection of sediment samples at over 100 stations for analysis of metals and hydrocarbons. The four data sets making up the combined data base are Thomas *et al.* (1983), Arctic Laboratories Limited (1984), Nuclear Activation Services Limited (1986) and Can Test Ltd. (1985), hereafter referred to as ALL 82, ALL 83, NAS 84, and Can T 84, respectively. The combined data base is large and has not previously been analysed in detail.

The stated objective of this study is to interpret the 1984 Shorebase Monitoring data in terms of the extent and environmental significance of anthropogenic inputs in the areas sampled compared to background levels in the Beaufort Sea and elsewhere, and to extend the analysis to the entire Shorebase data set.

The determination of the extent of anthropogenic inputs was approached by identifying anthropogenic tracers and mapping their concentrations. These tracers were identified through statistical analysis of the data. A clear relationship between distributions of contaminants and known locations of industrial activity was found.

A previous interpretion of the 1982 and 1983 data (Yunker 1986), showed that the natural variations in contaminant concentrations were large. In recent years, the relationship between contaminant concentrations and sediment grain size has received more attention. Although the precise mechanisms are not known, smaller mineral particles have a greater affinity for metals than do larger particles (e.g., Adams *et al.* 1980; Dossis and Warren 1980). Similarly, clays are often associated with high organic carbon content.

Other recent marine sediment studies in the Beaufort Sea area have shown that many contaminant distributions correlate with sediment grain size distributions (Boehm *et al.* 1985 and 1986; Arctic Laboratories Ltd. and LGL Ltd. 1987). No attempt was made to use these relationships to interpret widely spread data. The present report describes the procedures used to analyse the 1982-1984 data base, and uses the results to identify anomalously high concentrations of contaminants. These outliers were mapped and an index of contamination was determined.

The methods used permit an evaluation of the effect of industrial activity on contaminant levels in the nearshore Beaufort Sea area. This analysis may be updated with collection of additional monitoring data. The method used is robust with regard to sampling and analytical variations, and can detect increases in contaminants at levels below threshold concentrations of concern.

BACKGROUND REVIEW

CANADIAN BEAUFORT SEA

Nearshore Studies

Summary, 1982-1984. The chemical data examined during this study were collected from 124 marine stations between 1982 and 1984 under the auspices of the Beaufort Sea Shorebase Monitoring Program, Beaufort Sea Nearshore Monitoring Program, and other studies (see Figure 1 a to e and Table 1). The combined data consist of 611 analyses of one or more variables of a subsample or replicate from an individual station. For the purposes of this report, these stations have been assigned new station identifiers (referred to in Figure 1 and Table 1) to facilitate discussion.

There were significant differences in the sampling program design between years. In 1982, stratified random sampling was conducted in conjunction with detailed spatial sampling in McKinley Bay, transect sampling following the 3-m depth contour along the coast, and sampling of the shoreline (Thomas *et al.* 1983). In 1983, sampling was conducted at selected stations from the 1982 stratified random stations and at additional stations north of Kugmallit Bay (Arctic Laboratories Ltd. 1984). In 1984, sampling was repeated at the 1983 stations and at additional stations selected on the basis of proximity to sites of local industrial activity (Nuclear Activation Services 1986). Additional sampling was carried out in 1984 at selected stations in the nearshore zone (Can Test 1985). The constraints imposed by sampling design on methods of statistical analyses are discussed in the Statistical Methods section.

Sediment samples were collected by Ekman, Ponar, and Van Veen grabs, and mini-gravity and triple benthos corers. During 1982 and 1983, duplicate subsamples were collected from replicate samples. In 1984, only replicate samples were collected.

Analytical methods and variables observed varied between the data sets. All data sets include analyses of cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), zinc (Zn), n-alkanes, sediment grain size, and total organic carbon (TOC). Barium (Ba) was only measured by Can T 84 and NAS 84; polycyclic aromatic hydrocarbons (PAHs) by ALL 82, Can T 84, and NAS 84; iron (Fe) by ALL 82, ALL 83, and Can T 84; and hexane extractable compounds (HEC) by ALL 82 and ALL 83.

In ALL 82 additional metals, beryllium (Be), vanadium (V), and arsenic (As) were analysed for Tuft Point Stations only. The NAS 84 analyses included major and minor elements (SiO_2, Al_2O_3, CaO, MgO, Na_2O, K_2O, Fe_2O_3, MnO, and P_2O_5) and stratigraphic analysis of the cores. The numbers of observations for each variable are given by data set in Table 2, below.

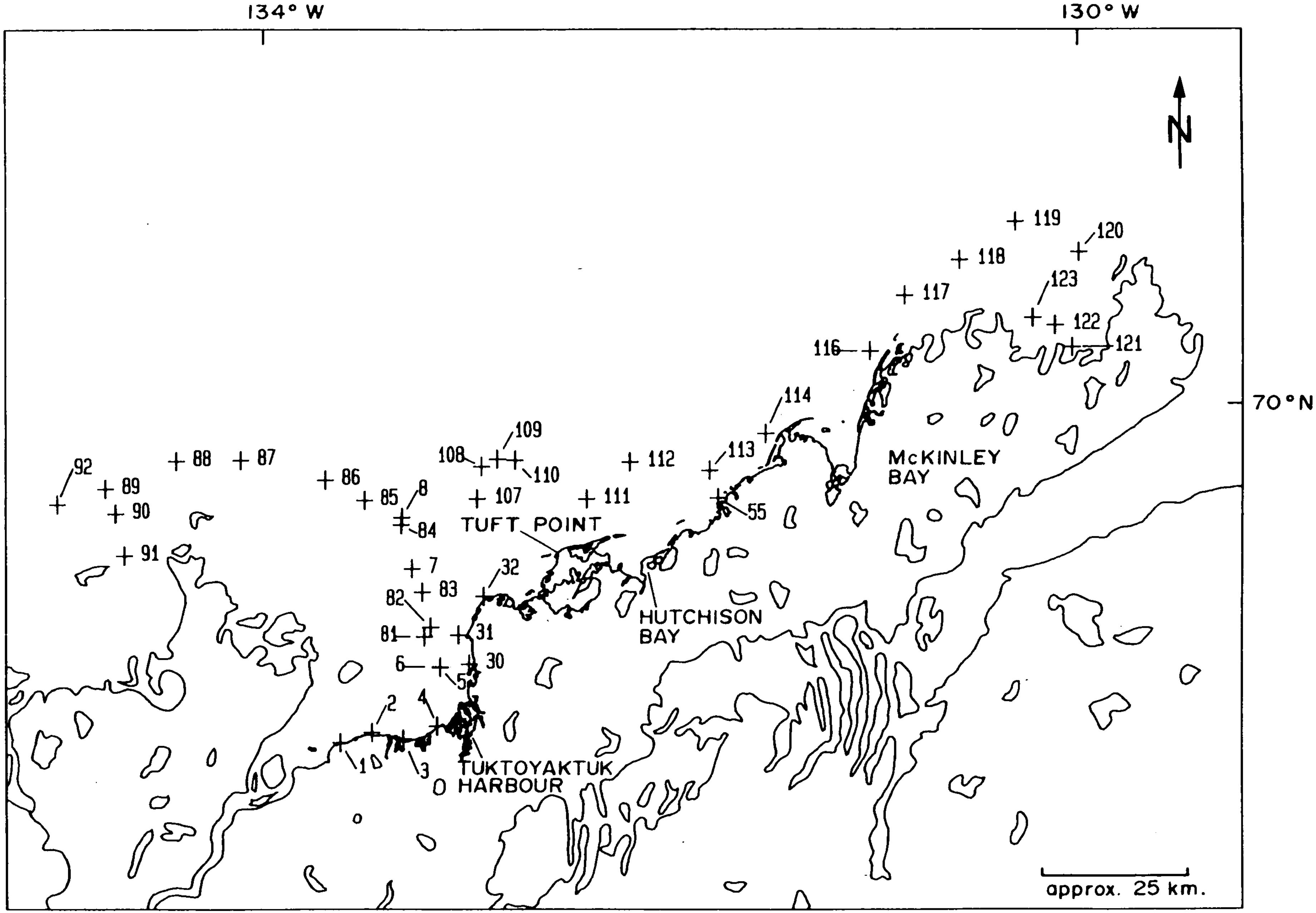

Figure 1a. Locations of 1982 - 1984 stations, Tuktoyaktuk Peninsula nearshore zone.

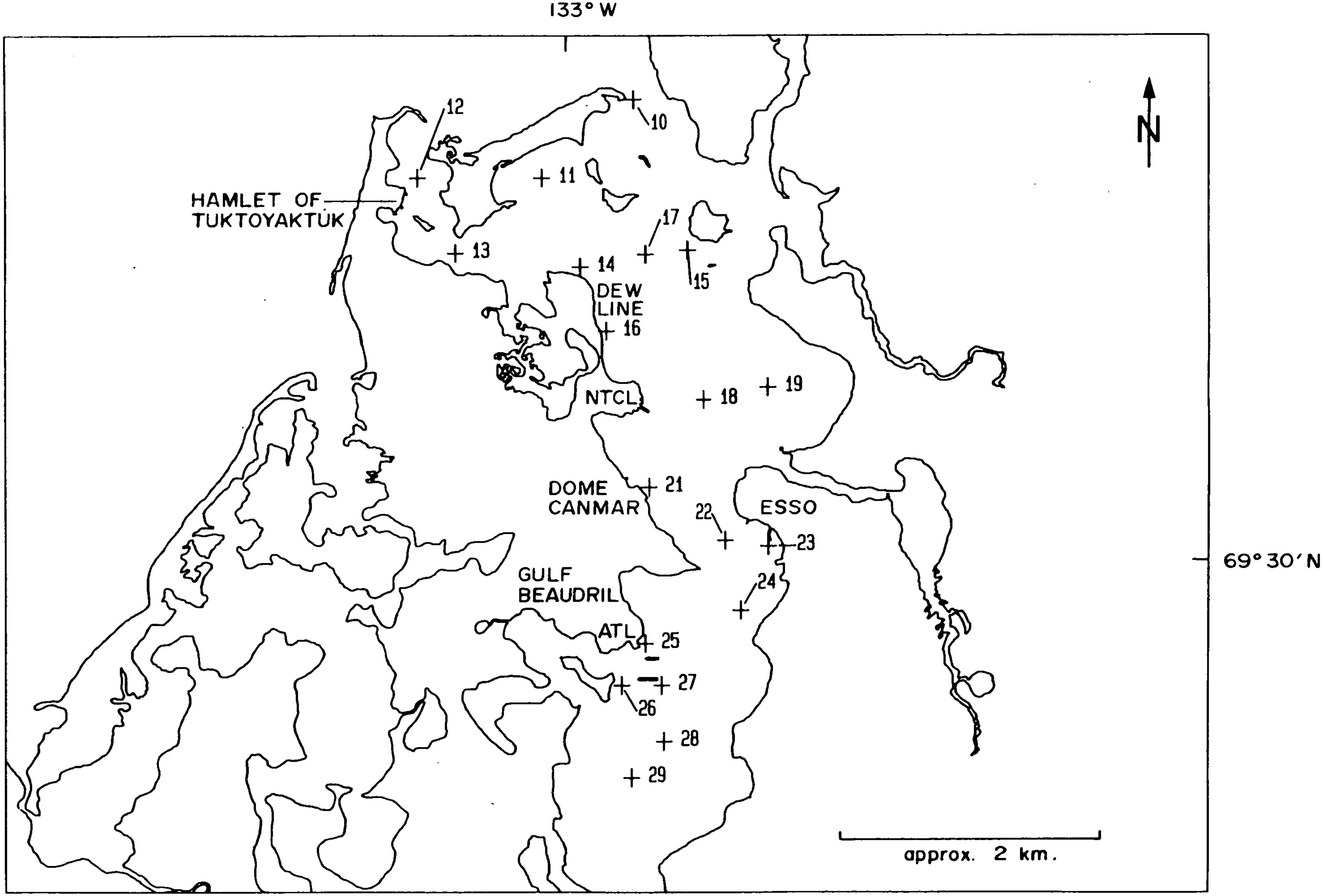

Figure 1b. Locations of 1982 - 1984 stations, Tuktoyaktuk Harbour.

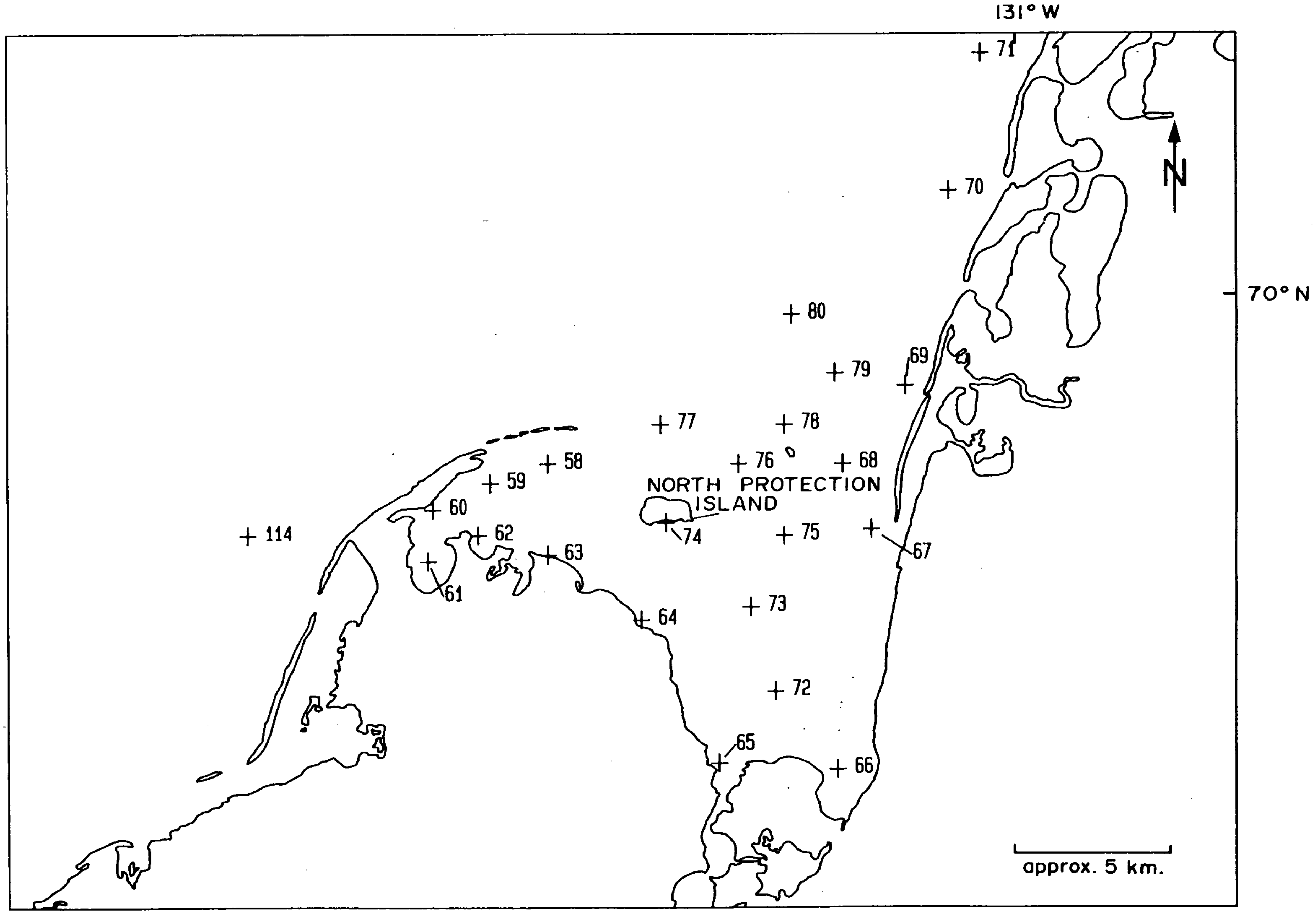

Figure 1c. Locations of 1982 - 1984 stations, McKinley Bay.

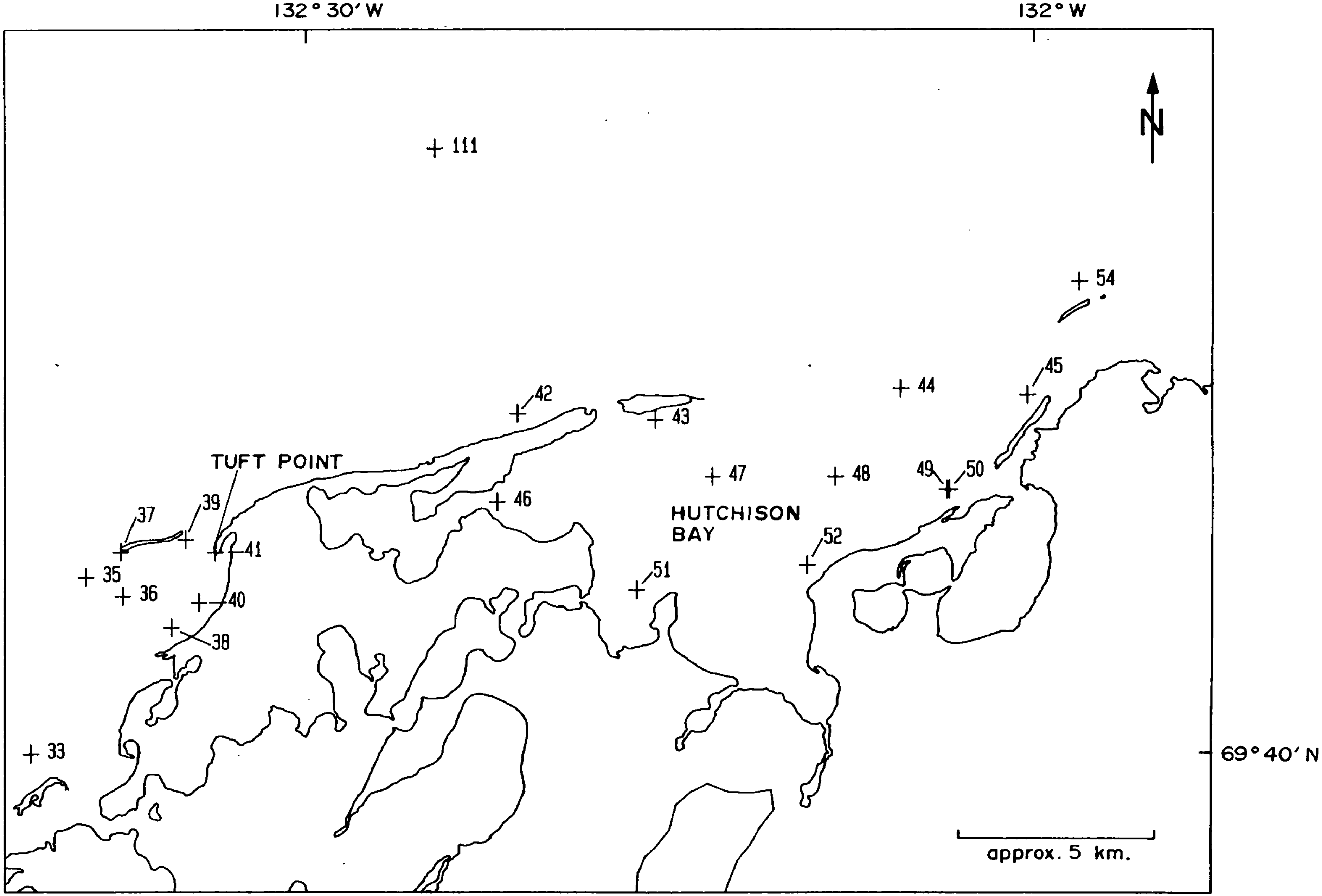

Figure 1d. Locations of 1982 - 1984 stations, Hutchison Bay and Tuft Point.

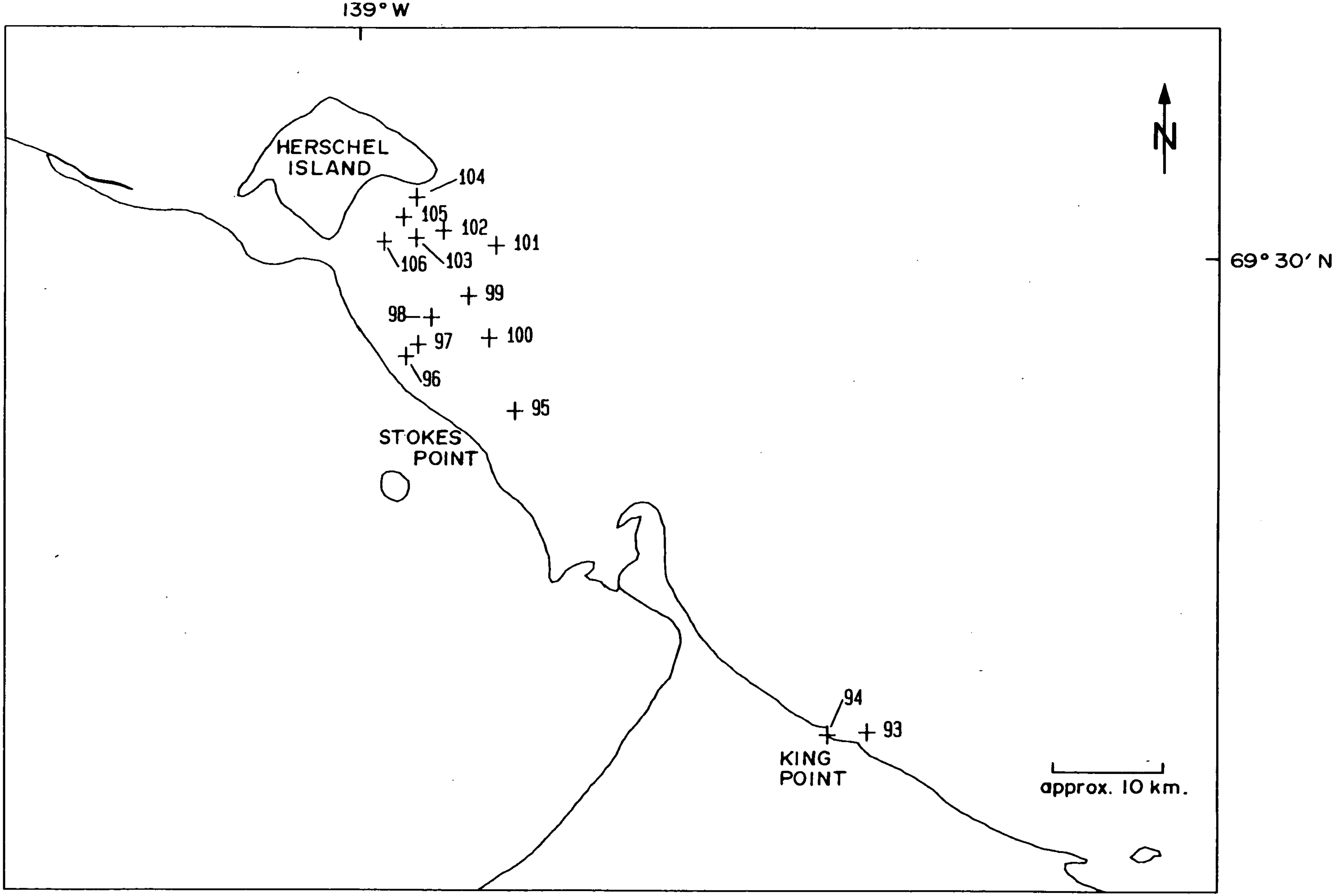

Figure 1e. Locations of 1982 - 1984 stations, Yukon Coast (Herschel Basin and King Point).

TABLE 1

Stations Sampled in 1982 - 1984 Beaufort Sea Monitoring Programs

Revised station number	Original station I.D.	Data set	Subset	Date	Latitude °N	Longitude °W	Depth (m)	Sampler type
1	1	ALL 82	Coast	20/07/82	69° 23.0'	133° 38.2'	2.1	grab
2	2	ALL 82	Coast	20/07/82	69° 24.1'	133° 28.9'	3.3	grab
3	3	ALL 82	Coast	20/07/82	69° 23.4'	133° 19.1'	2.4	grab
4	4	ALL 82	Coast	02/08/82	69° 24.8'	133° 09.0'	2.3	grab
5	SOS 1-1	ALL 83	Coast	12/07/83	69° 31.24'	133° 08.04'	4.3	grab
6	SOS 4-1	ALL 83	Coast	17/07/83	69° 31.31'	133° 08.12'	~4.0	grab
7	SOS 4-3	ALL 83	Coast	17/07/83	69° 42.05'	133° 16.37'	9.0	grab
8	SOS 4-4	ALL 83	Coast	17/07/83	69° 47.69'	133° 19.34'	~10.1	grab
9 [b]	5	ALL 82	Tuk	18/07/82	69° 27.45'	133° 00.38'	2.7	grab
10	16	ALL 82	Tuk	18/07/82	69° 27.47'	132° 59.13'	4.8	grab
11 [c]	6	ALL 82	Tuk	17/07/82	69° 27.13'	133° 00.20'	11.5	grab
11 [de]	TH 2	ALL 83	Tuk	12/07/83	69° 27.13'	133° 00.02'	N/A	grab
11	TH 4	NAS 84	Tuk	22/07/84	69° 27.17'	133° 00.05'	7[a]	core
12	TH 14	NAS 84	Tuk	24/07/84	69° 27.13'	133° 01.64'	10[a]	core
13	7	ALL 82	Tuk	18/07/82	69° 26.81'	133° 01.20'	7.4	grab
13	TH 15	NAS 84	Tuk	24/07/84	69° 26.81'	133° 01.21'	12[a]	core
14	TH 25	NAS 84	Tuk	16/08/84	69° 26.75'	132° 59.75'	5[a]	core
15	15	ALL 82	Tuk	17/07/82	69° 26.82'	132° 58.50'	5.9	grab
15	TH 3	NAS 84	Tuk	22/07/84	69° 26.83'	132° 58.55'	9[a]	core
16	8	ALL 82	Tuk	19/07/82	69° 26.47'	132° 59.45'	2.5	grab
17	TH 16	NAS 84	Tuk	24/07/84	69° 26.80'	132° 58.99'	7[a]	core
18	TH 8	NAS 84	Tuk	24/07/84	69° 26.18'	132° 58.31'	21[a]	core
19 [c]	14	ALL 82	Tuk	17/07/82	69° 26.23'	132° 57.56'	9.3	grab
19	TH 11	ALL 83	Tuk	18/07/83	69° 26.23'	132° 57.56'	N/A	grab
19	TH 7	NAS 84	Tuk	24/07/84	69° 26.23'	132° 57.58'	6[a]	core
20	9	ALL 82	Tuk	19/07/82	69° 25.97'	132° 59.27'	2.8	grab
21	TH 26	NAS 84	Tuk	16/08/84	69° 25.80'	132° 58.95'	6[a]	core
22	13	ALL 82	Tuk	17/07/82	69° 25.57'	132° 58.05'	8.8	grab
22	TH 10	ALL 83	Tuk	18/07/83	69° 25.57'	132° 58.05'	11[a]	grab
22	TH 11	NAS 84	Tuk	24/07/84	69° 25.57'	132° 57.96'	20[a]	core
23	TH 27	NAS 84	Tuk	16/08/84	69° 25.55'	132° 57.55'	10[a]	core
24	12	ALL 82	Tuk	17/07/82	69° 25.27'	132° 57.87'	1.7	grab
25	TH 28	NAS 84	Tuk	16/08/84	69° 25.13'	132° 59.00'	9[a]	core
26	10	ALL 82	Tuk	17/07/82	69° 24.95'	132° 59.27'	2.1	grab
27	TH 19	NAS 84	Tuk	24/07/84	69° 24.95'	132° 58.50'	23[a]	core
28	11	ALL 82	Tuk	17/07/82	69° 24.71'	132° 58.77'	9.3	grab
28	TH 20	NAS 84	Tuk	24/07/84	69° 24.72'	132° 58.80'	5[a]	core
29	TH 22	NAS 84	Tuk	24/07/84	69° 24.55'	132° 59.15'	18[a]	core
30	17	ALL 82	Coast	31/07/82	69° 31.6'	132° 59.4'	2.7	grab
31	18	ALL 82	Coast	31/07/82	69° 34.8'	133° 02.5'	2.7	grab
32	19	ALL 82	Coast	31/07/82	69° 39.0'	132° 55.0'	2.9	grab
33	20	ALL 82	Coast	30/07/82	69° 40.1'	132° 41.9'	3.6	grab

TABLE 1 (continued)

Revised station number	Original station I.D.	Data set	Subset	Date	Latitude °N	Longitude °W	Depth (m)	Sampler type
34[b]	21	ALL 82	Coast	13/08/82	69° 41.9'	132° 39.5'	4.0	grab
35	22	ALL 82	Coast	11/08/82	69° 42.9'	132° 39.5'	10.5	grab
36	23	ALL 82	Coast	13/08/82	69° 42.6'	132° 37.9'	4.4	grab
37	24	ALL 82	Coast	11/08/82	69° 43.3'	132° 38.0'	6.4	grab
38	25	ALL 82	Coast	12/08/82	69° 42.1'	132° 35.8'	3.4	grab
39	26	ALL 82	Coast	13/08/82	69° 43.5'	132° 35.2'	4.6	grab
40	27	ALL 82	Coast	12/08/82	69° 42.5'	132° 34.6'	2.7	grab
41	28	ALL 82	Coast	12/08/82	69° 43.3'	132° 33.9'	1.9	grab
42	29	ALL 82	Coast	30/07/82	69° 45.5'	132° 20.9'	2.9	grab
43	32	ALL 82	Hutch	06/08/82	69° 45.4'	132° 15.0'	2.4[a]	grab
43	HB 1	NAS 84	Hutch	21/07/84	69° 45.40'	132° 15.00'	3[a]	core
44	37	ALL 82	Hutch	07/08/82	69° 45.9'	132° 04.4'	6.5[a]	grab
44	HB 37	ALL 83	Hutch	26/08/83	69° 45.9'	132° 04.4'	~5.0	grab
44	HB 4	NAS 84	Hutch	21/07/84	69° 45.45'	132° 04.00'	6[a]	core
45	40	ALL 82	Hutch	07/08/82	69° 45.8'	131° 59.0'	3.5[a]	grab
46	30	ALL 82	Hutch	06/08/82	69° 44.1'	132° 21.8'	1.0[a]	grab
47	33	ALL 82	Hutch	08/08/82	69° 44.5'	132° 12.5'	4.7[a]	grab
48	36	ALL 82	Hutch	07/08/82	69° 44.5'	132° 07.2'	5.6[a]	grab
48	HB 2	NAS 84	Hutch	21/07/84	69° 44.45'	132° 12.50'	5[a]	core
49	38	ALL 82	Hutch	07/08/82	69° 44.3'	132° 02.4'	3.5[a]	grab
49	HB 38	ALL 83	Hutch	26/08/83	69° 44.3'	132° 02.4'	~2.0	grab
50	39	ALL 82	Hutch	30/07/82	69° 44.3'	132° 02.3'	3.1	grab
51	31	ALL 82	Hutch	06/08/82	69° 42.7'	132° 15.8'	1.0[a]	grab
52	35	ALL 82	Hutch	08/08/82	69° 43.1'	132° 08.4'	2.5	grab
53[b]	34	ALL 82	Hutch	08/08/82	69° 41.2'	132° 10.4'	2.3	grab
54	41	ALL 82	Coast	07/08/82	69° 47.6'	131° 56.8'	3.7[a]	grab
55	42	ALL 82	Coast	30/07/82	69° 49.8'	131° 45.5'	3.1	grab
56[b]	43	ALL 82	Coast	30/07/82	69° 53.0'	131° 33.4'	2.6	grab
57[b]	44	ALL 82	Coast	30/07/82	69° 57.9'	131° 24.0'	3.7	grab
58	51	ALL 82	McKin	24/07/82	69° 57.9'	131° 18.9'	3.9	grab
59	46	ALL 82	McKin	22/08/82	69° 57.6'	131° 21.3'	0.7	grab
60	47	ALL 82	McKin	24/07/82	69° 57.2'	131° 23.7'	0.5	grab
61	48	ALL 82	McKin	18/08/82	69° 56.4'	131° 23.9'	1.2	grab
62	49	ALL 82	McKin	22/08/82	69° 56.8'	131° 21.8'	1.6	grab
63	50	ALL 82	McKin	18/08/82	69° 56.5'	131° 18.9'	1.1	grab
64	52	ALL 82	McKin	18/08/82	69° 55.5'	131° 15.0'	1.1	grab
65	57	ALL 82	McKin	24/07/82	69° 53.3'	131° 11.8'	1.2	grab
66	60	ALL 82	McKin	24/07/82	69° 53.2'	131° 06.9'	2.0	grab
67	63	ALL 82	McKin	26/07/82	69° 56.9'	131° 05.5'	1.3	grab
68	61	ALL 82	McKin	22/08/82	69° 57.9'	131° 06.7'	2.8	grab
69	64	ALL 82	McKin	25/07/82	69° 59.1'	131° 04.1'	3.1	grab
70	66	ALL 82	McKin	25/07/82	70° 02.1'	131° 02.3'	8.9	grab

TABLE 1 (continued)

Revised station number	Original station I.D.	Data set	Subset	Date	Latitude °N	Longitude °W	Depth (m)	Sampler type
71	67	ALL 82	McKin	25/07/82	70° 04.2'	131° 01.0'	1.8	grab
72[b]	56	ALL 82	McKin	22/08/82	69° 54.4'	131° 10.5'	2.2	grab
72	MB 8	NAS 84	McKin	21/07/84	69° 54.40'	131° 09.50'	4[a]	grab
73	59	ALL 82	McKin	24/07/82	69° 55.7'	131° 10.5'	5.5[a]	grab
74	54	ALL 82	McKin	25/07/82	69° 57.0'	131° 14.0'	11.5	grab
74[e]	MB 5	ALL 83	McKin	27/08/83	69° 57.8'	131° 09.8'	11.0	grab
74[d]	MB 12	NAS 84	McKin	21/07/84	69° 57.75'	131° 10.60'	7[a]	core
75	62	ALL 82	McKin	26/07/82	69° 56.8'	131° 09.1'	5.4[a]	grab
75	MB 12	ALL 83	McKin	15/07/83	69° 56.8'	131° 09.1'	N/A	grab
75	MB 6	NAS 84	McKin	21/07/84	69° 57.45'	131° 08.50'	5[a]	grab
76	55	ALL 82	McKin	22/08/82	69° 57.9'	131° 11.0'	10.6	grab
77	53	ALL 82	McKin	23/08/82	69° 58.5'	131° 14.2'	4.4	grab
78	58	ALL 82	McKin	25/07/82	69° 58.5'	131° 09.1'	11.2[a]	grab
78	MB 5	NAS 84	McKin	21/07/84	69° 59.20'	131° 07.00'	7[a]	grab
79	65	ALL 82	McKin	22/08/82	69° 59.3'	131° 07.0'	8.3	grab
80	45	ALL 82	McKin	23/08/82	70° 00.2'	131° 08.8'	10.4	grab
81	1	Can T 84	Coast	09/07/84	69° 34.60'	133° 12.75'	4[a]	core
82	2	Can T 84	Coast	09/07/84	69° 35.64'	133° 10.89'	4[a]	core
83	3	Can T 84	Coast	09/07/84	69° 39.46'	133° 13.31'	5[a]	core
84	4	Can T 84	Coast	09/07/84	69° 46.89'	133° 19.54'	10.8[a]	core
85	5	Can T 84	Coast	09/07/84	69° 49.57'	133° 30.91'	10[a]	core
86	6	Can T 84	Coast	09/07/84	69° 51.80'	133° 42.63'	10.7[a]	core
87	7	Can T 84	Coast	09/07/84	69° 53.94'	134° 07.75'	11[a]	core
88	8	Can T 84	Coast	10/07/84	69° 53.85'	134° 26.93'	10[a]	core
89	9	Can T 84	Coast	10/07/84	69° 50.82'	134° 48.21'	10.3[a]	core
90	10	Can T 84	Coast	10/07/84	69° 48.09'	134° 45.07'	8[a]	grab
91	11	Can T 84	Coast	10/07/84	69° 43.46'	134° 42.44'	6.0[a]	core
92	12	Can T 84	Coast	10/07/84	69° 49.11'	135° 02.51'	6.0[a]	core
93	13	Can T 84	Yukon	12/07/84	69° 06.53'	137° 52.65'	20[a]	core
94	14	Can T 84	Yukon	12/07/84	69° 06.40'	137° 58.08'	10[a]	core
95	15	Can T 84	Yukon	12/07/84	69° 22.97'	138° 41.22'	14-16[a]	core
96	16	Can T 84	Yukon	12/07/84	69° 25.75'	138° 56.33'	11[a]	core
97	17	Can T 84	Yukon	12/07/84	69° 26.35'	138° 54.64'	11.5[a]	core
98	18	Can T 84	Yukon	12/07/84	69° 27.75'	138° 52.78'	51[a]	core
99	19	Can T 84	Yukon	12/07/84	69° 28.85'	138° 47.60'	34[a]	core
100	20	Can T 84	Yukon	12/07/84	69° 26.69'	138° 44.78'	15[a]	core
101	21	Can T 84	Yukon	12/07/84	69° 31.44'	138° 43.85'	15[a]	core
102	22	Can T 84	Yukon	12/07/84	69° 32.21'	138° 51.12'	28[a]	core
103	23	Can T 84	Yukon	12/07/84	69° 31.83'	138° 54.92'	45[a]	core
104	24	Can T 84	Yukon	17/07/84	69° 33.90'	138° 54.85'	10[a]	core
105	25	Can T 84	Yukon	17/07/84	69° 32.90'	138° 56.65'	15[a]	core
106	26	Can T 84	Yukon	17/07/84	69° 31.65'	138° 59.50'	16[a]	core

TABLE 1 (continued)

Revised station number	Original station I.D.	Data set	Subset	Date	Latitude °N	Longitude °W	Depth (m)	Sampler type
107	27	Can T 84	Coast	19/07/84	69° 49.73'	132° 56.90'	10[a]	grab
108	28	Can T 84	Coast	19/07/84	69° 53.25'	132° 55.60'	10[a]	grab
109	29	Can T 84	Coast	19/07/84	69° 54.05'	132° 50.96'	11[a]	core
110	30	Can T 84	Coast	19/07/84	69° 53.95'	132° 45.61'	10[a]	grab
111	31	Can T 84	Coast	19/07/84	69° 49.71'	132° 24.48'	10[a]	core
112	32	Can T 84	Coast	19/07/84	69° 53.75'	132° 11.45'	10.5[a]	core
113	33	Can T 84	Coast	19/07/84	69° 52.80'	131° 48.00'	10[a]	core
114	34	Can T 84	Coast	19/07/84	69° 56.80'	131° 31.50'	10[a]	core
116	36	Can T 84	Coast	19/07/84	70° 05.80'	131° 01.00'	8[a]	grab
117	37	Can T 84	Coast	19/07/84	70° 11.85'	130° 50.80'	10[a]	grab
118	38	Can T 84	Coast	19/07/84	70° 15.85'	130° 34.70'	10.5[a]	grab
119	39	Can T 84	Coast	19/07/84	70° 20.02'	130° 18.40'	10[a]	grab
120	40	Can T 84	Coast	19/07/84	70° 16.70'	130° 00.00'	9.5[a]	core
121	41	Can T 84	Coast	19/07/84	70° 06.25'	130° 02.00'	3[a]	grab
122	42	Can T 84	Coast	19/07/84	70° 08.68'	130° 04.55'	5[a]	core
123	43	Can T 84	Coast	19/07/84	70° 09.50'	130° 13.60'	4[a]	grab
124	MB 4	Can T 84	McKin	21/07/84	70° 00.90'	131° 07.00'	10[a]	N/S

a - indicates depth measured at time of sampling, not corrected for tides.
b - indicates sample washout observed, data not used in analyses.
c - alkane analyses for these samples completed in 1983 (ALL 83).
d - analysis of replicate subsamples for all parameters in 1984 (Can T 84).
e - analysis of replicate subsamples for all parameters in 1984 (NAS 84).

TABLE 2

Summary of number of observations by variable on marine sediment samples

	ALL 82	ALL 83	NAS 84	Can T 84
Alkanes	50	16	75	92
PAHs	43	0	75	50
Grain size	180	74	33	75
Metals	179	69	75	188
TOC	180	69	75	109
HEC	180	69	0	0
Barium	0	0	75	111

Differences in some analytical methods pose problems for statistical analyses (discussed later). For grain size (percentage clay), ALL 82 and ALL 83 reported less than 38 micrometres (<38 μm) as the finest size fraction, whereas Can T 84 reported <2 μm and NAS 84 reported <4 μm. For n-alkane analyses, ALL 82 reported the n-alkanes n-C10 to n-C33 (where n-C10 refers to a normal 10-carbon chain), whereas the other data sets reported n-C12 to n-C36. For PAH analyses, all data sets (except ALL 83) reported naphthalene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzofluoranthenes, benzo(e)pyrene, benzo(a)pyrene, and perylene. ALL 82 also reported benz(b)anthracene. Can T 84 also reported dibenzo(ah)anthracene, benz(ghi)perylene, and indeno(123cd)pyrene. NAS 84 also reported acenaphthene and naphthacene. Can T 84 and NAS 84 reported benzofluoranthenes separately as benzo(b)fluoranthene and benzo(k)fluoranthene. Differences also existed between analytical methods for most other variables. Table 3 summarizes the methodology. A cross-reference to the Arctic Data Compilation and Appraisal Program (ADCAP) and data set identifiers and data quality ratings are also given.

Reconnaissance survey, Arctic Laboratories (ALL 82). Marine sediment samples from the 1982 reconnaissance survey were obtained using a 15 cm x 15 cm brass tall Ekman grab triggered by a messenger. Two subsamples of the top 5 cm of each grab were collected. Beach sediment samples were collected by hand with a nylon scoop. Sixty seven marine stations and 43 beach stations were sampled between 17 July and 4 September, 1982 extending along Tuktoyaktuk Peninsula from the mouth of the East

TABLE 3

Methodology Information

Data Set (ADCAP)	Parameter	Units	Collection	Storage	Analysis	Precision (%)	Accuracy (%)	Data Rating
ALL 82 (82-0103)	Cd	μmol/kg	brass Ekman grab	frozen immediately	aqua regia/HF digestion; GFAAS	± 12.2 ± 13.5	- 1.3 - 10.3	4
	Clay	wt %	brass Ekman grab	frozen immediately	sieved through 38-μm mesh	-	-	2
	Cr	mmol/kg	brass Ekman grab	frozen immediately	aqua regia/HF digestion; FAAS	± 5.2 ± 6.3	- 15.3 - 19.4	4
	Cu	mmol/kg	brass Ekman grab	frozen immediately	aqua regia/HF digestion; FAAS	± 4.9 ± 9.7	+ 2.5 + 6.9	4
	Fe	mol/kg	brass Ekman grab	frozen immediately	aqua regia/HF digestion; FAAS	± 4.3 ± 6.7	- 7.1 - 8.5	4
	HEC	μg/g	brass Ekman grab	frozen immediately	reflux with n-hexane; gravimetry	± 15	-	3
	Hg	μmol/kg	brass Ekman grab	frozen immediately	H_2SO_4/HNO_3 digestion; CVAAS	± 9.4 ± 7.8	+ 10.8 + 9.2	4
	Ni	mmol/kg	brass Ekman grab	frozen immediately	aqua regia/HF digestion; FAAS	± 9.3 ± 5.0	+ 8.0 + 7.4	4
	Pb	mmol/kg	brass Ekman grab	frozen immediately	aqua regia/HF digestion; GFAAS	± 17.8 ± 10.1	- 11.0 - 10.0	4
	Sum Alkanes C10 - C33	ng/g	brass Ekman grab	frozen immediately	Soxhlet extraction; GPAC; GC	± 32	-	3
	Sum PAH	ng/g	brass Ekman grab	frozen immediately	Soxhlet extraction; GPAC; GC/MS	± 11	-	3
	TOC	wt %	brass Ekman grab	frozen immediately	oxidation (acidic $K_2Cr_2O_7$) titration with Fe ammonium sulphate	± 1.3	± 2.9	4
	Zn	mmol/kg	brass Ekman grab	frozen immediately	aqua regia/HF digestion; FAAS	± 3.0 ± 2.9	+ 1.7 - 4.4	4

TABLE 3 (continued)

Data Set (ADCAP)	Parameter	Units	Collection	Storage	Analysis	Precision (%)	Accuracy (%)	Data Rating
ALL 83 (83-0054)	Cd	µg/g	SS Ekman/ Ponar grabs	frozen immediately	aqua regia/HF digestion; GFAAS	± 11.9 ± 23.1	+ 0 + 4.0	4
	Clay	wt %	SS Ekman/ Ponar grabs	frozen immediately	sieved through 38-µm mesh	-	-	2
	Cr	µg/g	SS Ekman/ Ponar grabs	frozen immediately	aqua regia/HF digestion; FAAS	± 9.3 ± 12.5	- 21.1 - 32.5	3
	Cu	µg/g	SS Ekman/ Ponar grabs	frozen immediately	aqua regia/HF digestion; FAAS	± 6.8 ± 10.0	+ 11.6 + 2.7	4
	Fe	wt %	SS Ekman/ Ponar grabs	frozen immediately	aqua regia/HF digestion; FAAS	± 6.5 ± 6.4	+ 1.3 - 4.6	4
	HEC	µg/g	SS Ekman/ Ponar grabs	frozen immediately	reflux with n-hexane; gravimetry	± 15	-	3
	Hg	µg/g	SS Ekman/ Ponar grabs	frozen immediately	hot H_2SO_4/HNO_3 digestion; CVAAS	± 5.9 ± 10.6	- 1.2 + 2.3	4
	Ni	µg/g	SS Ekman/ Ponar grabs	frozen immediately	aqua regia/HF digestion; GFAAS	± 3.0 ± 8.0	+ 11.9 + 19.3	4
	Pb	µg/g	SS Ekman/ Ponar grabs	frozen immediately	aqua regia/HF digestion; GFAAS	± 3.8 ± 10.9	- 51.8 - 51.5	3
	Sum Alkanes C12 - C36	ng/g	SS Ekman/ Ponar grabs	frozen immediately	silica gel elution; GC/FID	-	-	2
	TOC	wt %	SS Ekman/ Ponar grabs	frozen immediately	oxidation (acidic $K_2Cr_2O_7$) titration with Fe ammonium sulphate	± 1.3	± 2.9	4
	Zn	µg/g	SS Ekman/ Ponar grabs	frozen immediately	aqua regia/HF digestion; FAAS	± 3.3 ± 3.3	- 5.2 - 0.8	4

TABLE 3 (continued)

Data Set (ADCAP)	Parameter	Units	Collection	Storage	Analysis	Precision (%)	Accuracy (%)	Data Rating
NAS 84 (83-0034)	Ba	μg/g	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	XRF	± 3 ± 3	- -	3
	Cd	μg/g	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	$HNO_3/HF/ClO_4$ digestion; GFAAS	± 17 ± 13	+ 2 - 4	4
	Clay	wt %	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	sieved through 4-μm mesh	-	-	2
	Cr	μg/g	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	INAA	± 6 ± 6	+ 11 + 1	4
	Cu	μg/g	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	$HNO_3/HF/ClO_4$ digestion; AAS	± 7 ± 10	- 7 - 2	4
	Hg	μg/g	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	HNO_3/H_2SO_4 digestion; $K_2Cr_2O_7/K_2S_2O_8$ oxidation; CVAAS	± 6 ± 7	+ 5 + 2	4
	Ni	μg/g	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	$HNO_3/HF/ClO_4$ digestion; DCP	± 3 ± 5	+ 15 + 19	4
	Pb	μg/g	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	$HNO_3/HF/ClO_4$ digestion; DCP	± 6 ± 8	+ 15 + 19	4
	Sum Alkanes C12 - C36	μg/g	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	3 x 5 acetone/ toluene; GC/MS	- -	- -	2

TABLE 3 (continued)

Data Set (ADCAP)	Parameter	Units	Collection	Storage	Analysis	Precision (%)	Accuracy (%)	Data Rating
NAS 84 (cont'd.)	Sum PAH	µg/g	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	3 x 5 acetone/ toluene; GC/MS	- -	- -	2
	TOC	wt %	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	modified Mebius procedure	± 2 -	+ 12 + 2	4
	Zn	µg/g	gravity corer/ triple benthos corer/Van Veen grab	frozen within 24 h	$HNO_3/HF/ClO_4$ digestion; DCP	± 5 ± 8	- 2 + 3	4
Can T 84 (84-0035A)	Ba	µg/g	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	$HF/HNO_3/HCl$ digestion; ICP	± 2.4 ± 2.4	- -	3
	Cd	µg/g	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	$HNO_3/HClO_4$ digestion; GFAAS	± 15.4 ± 6.7	+ 4 + 1.7	4
	Clay	wt %	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	sieved through 2-µm mesh	-	-	2
	Cr	µg/g	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	$HF/HNO_3/HCl$ digestion; ICP	± 3.1 ± 4	- 21 - 21	4
	Cu	µg/g	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	$HF/HNO_3/HCl$ digestion; ICP	± 9.4 ± 1.4	- 2.7 + 3.6	4
	Fe	wt %	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	$HF/HNO_3/HCl$ digestion; ICP	± 3.2 ± 3.1	- 4.3 - 9.5	4

TABLE 3 (continued)

Data Set (ADCAP)	Parameter	Units	Collection	Storage	Analysis	Precision (%)	Accuracy (%)	Data Rating
Can T 84 (cont'd.)	Hg	μg/g	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	$HNO_3/HClO_4$ digestion; CVAAS	± 9.9 ± 7.7	+ 1.6 - 0.6	4
	Ni	μg/g	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	$HF/HNO_3/HCl$ digestion; ICP	± 3.9 ± 1.9	+ 1.4 - 11.8	4
	Pb	μg/g	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	$HNO_3/HClO_4$ digestion; FAAS	± 7.8 ± 2.4	- 4.4 - 2.4	4
	Sum Alkanes C12 - C36	μg/g	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	dichloromethane extraction; GC/FID	± 12 - 30 (C12-C23) ± 25 - 40 (C24-C36)	- -	3
	Sum PAH	μg/g	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	Soxhlet extraction (dichloromethane); HPLC	± 9 - 22	-	3
	TOC	wt %	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	HCl reflux; Leco induction furnace	-	-	2
	Zn	μg/g	mini-gravity corer/triple benthos corer/ Van Veen grab	frozen within 24 h	$HF/HNO_3/HCl$ digestion; ICP	± 3.9 ± 1.9	+ 1.4 - 11.8	4

Channel to McKinley Bay (see Table 1).

The survey report (Thomas *et al.* 1983) consolidates data from four separate programs:

a) The Shorebase Monitoring Program (a stratified random sampling design with two strata: <6 m and >6 m depth, and 10 stations in four embayments: Tuktoyaktuk Harbour, Tuft Point, Hutchison Bay, and McKinley Bay).

b) Baseline measurements of petroleum hydrocarbons along the shoreline at 10-km intervals.

c) A detailed spatial survey of McKinley Bay (stratified random sampling with two strata: <6 m and >6 m depth).

d) A transect line parallel to Tuktoyaktuk Peninsula following the 3-m contour, extending from the East Channel, sampled every 10 km, to investigate the influence of the Mackenzie River discharge on contaminant concentrations (see Table 1 and Figure 1).

Consistent sampling and analytical methods were used throughout. Yunker (1986) provides a detailed review of sampling design and methodology for both the 1982 and 1983 programs.

Chemical analyses were completed by Arctic Laboratories Limited. (ALL) in 1982, with the exception of alkane analysis of four samples from Tuktoyaktuk Harbour, which were analysed in 1983 by ALL. Analytical methods and numbers of observations are summarized in Tables 2 and 3, respectively. From a statistical perspective, the analytical plan holds two irregularities: the number of hydrocarbon analyses is much smaller than the number of observations of the other variables, and all of the hydrocarbon analyses were performed on one group of subsamples, whereas all analyses of grain size, metals, and other variables were performed on the second group.

Arctic Laboratories (ALL 83). The 1983 survey (ALL 83) was a continuation of the Shorebase Monitoring Program conducted jointly with a program by the Atlantic Geoscience Centre. For the 1983 program, selected stations from the 1982 program were sampled: three in Tuktoyaktuk Harbour, three in Hutchison Bay and two in McKinley Bay. Sampling was also completed at four stations along a transect proceeding northwards from Kugmallit Bay. Logistic problems resulted in the completion of the sampling in three phases with some variance in sampling methods between phases. Also, one of the McKinley Bay stations (station 12) had to be relocated because the Single Steel Drilling Caisson (SSDC) bow section had been placed at that location to serve as a navigational aid (see Table 1 and Figure 1). Some of the stations were sampled with a stainless steel Ekman grab, whereas the remainder were sampled with a Ponar grab. Two subsamples were collected from the top 5 cm of each replicate grab.

Samples were analysed by ALL with some replicate grabs and subsamples analysed in 1984 by Nuclear Activation Services (NAS) and Can Test. No PAH analyses were completed in 1983, only seven samples from Tuktoyaktuk and five from McKinley Bay were analysed for alkanes and only one sample from Hutchison Bay was analysed. Analytical methods and number of observations are given in Tables 2 and 3.

Nuclear Activation Services (NAS 84). The 1984 Shorebase program sampled 22 stations in Tuktoyaktuk Harbour, Hutchison Bay, and McKinley Bay. Selected stations from the 1982 and 1983 programs were sampled and an additional nine stations in Tuktoyaktuk Harbour were selected at locations near sites of industrial activity (see Table 1 and Figure 1). Samples were collected using a triple benthos corer (8-cm diameter) in soft substrate and with a Van Veen grab in sandy substrate. Cores were divided into 5-cm sections and frozen within 24 h of sampling. In most cases, two replicate cores were collected for contaminant analysis and one core for X-ray and photographic analysis. No replicate subsamples were collected.

Samples were analysed by NAS, X-Ray Assay Laboratories Ltd., Diagnostic Research Laboratories, Mann Testing Laboratories Ltd., Indusmin Ltd., and Dr. M. Risk (McMaster University). Analytical methods and numbers of observations are summarized in Tables 2 and 3. Grain size analyses were performed on 44% of the collected samples.

Can Test (Can T 84). The 1984 Nearshore Sediment Monitoring Program (Can T 84) involved the collection of samples at 43 stations ranging from Herschel Island (Yukon Territory) to Russell Inlet at the tip of Tuktoyaktuk Peninsula (see Table 1 and Figure 1). Only one station was located in the Shorebase embayments (station MB4 in McKinley Bay). Samples were collected with either a mini-gravity corer, triple benthos corer, or Van Veen grab. Cores were divided into 5-cm sections. Up to three replicate cores or grabs were collected. Replicate subsamples were not collected.

Analyses were performed by Can Test Ltd. Table 3 summarizes the analytical methods employed. The number of analyses of the variables vary substantially (see Table 2). Greatest emphasis was placed on metal analysis.

Although these data are not specifically part of the monitoring program, they represent sediments from the same general source (the Mackenzie River) at depths similar to the embayments.

Other Studies

Statistical analysis of 1982-83 Shorebase monitoring. In 1986, Yunker (1986) completed a statistical analysis of the 1982 and 1983 data from the Shorebase Monitoring Program as analysed by Arctic Laboratories Limited. The data were rated according to the method of Thomas *et al.* (1982). The variables were then tested for normality and homoscedasticity (equality of variance). In most cases, both tests failed, limiting the use of standard parametric analysis of variance. Attempts to improve the data by transformation failed. Non-parametric tests were therefore applied. Spearman rank correlations were also determined and cluster analysis was performed.

Amongst the conclusions reached were:

a) There was a difference between regions when coastal and embayments were tested together.

b) There was a difference between embayments.

c) There was a difference between sample locations within an embayment in 1982 samples, attributed to difference in grain size distribution.

d) There were no correlations between variables and distance from the Mackenzie Delta.

e) There were good correlations between grain size and metal contaminant concentrations. In 1982, all metals showed these correlations; in 1983, Ni, Cd and Cu did not.

f) Weaknesses in the monitoring program design prevented unequivocal testing of differences between years in the embayments.

g) Total PAH and total alkanes were significantly correlated in the 1982 samples.

Cluster analysis also showed the relationship between metal concentrations and grain size.

Few correlations were found between hydrocarbons and other variables, either in concentration or in character as identified by indices. It was noted that concentrations were high relative to world levels, probably because of input from natural seeps in the Mackenzie River.

Nearshore zone survey. Mudroch (1987) analyzed the nearshore data set (Can T 84) after dividing the data into sub-sets based on location east or west of the Mackenzie River, and depth of sediment. He found that in general, sediment from the 0 - 5 cm depth was not significantly different from that from 10 - 20 cm depth. He also found, when all locations were analyzed together, that the contaminant concentration covaried with percent clay. When data sub-sets were examined, this relationship did not always hold. It was not possible to estimate how the lack of significant relationship between percent clay and contaminant may be due to small sample size, as no indication is given of sample numbers in each sub-set.

Statistical analysis of Beaufort Sea sediments. Hoff and Thomas (1986) did a statistical analysis of Beaufort Sea offshore sediments to provide recommendations for future environmental study designs. They examined available data, determined the types of statistical analysis appropriate for such data, and recommended sampling protocols for future use.

Amongst their conclusions and recommendations were:

a) Grab sampling is preferred to core sampling, as grabs are cost effective, more efficient in some types of sediment, and meet the criteria for sampling.

b) Parametric statistics should be used where possible. Non-parametric statistics refer only to the data sets used, and cannot be generalized.

c) The inclusion of grain size data will permit increased precision in statistics. The grain size effect explains most of the environmental variance for metals, and the identification of secondary factors will not necessarily improve the ability to monitor changes. They conclude that this grain size effect is probably universal in the Beaufort Sea.

d) Hydrocarbon data should be natural logarithm transformed (log base e) before statistical analysis. Although the hydrocarbon distributions were still not normal, the grain size relation was improved. No improvement was found for metals or for hydrocarbon indices.

f) Based on the data of Can Test (1985) (also examined in the present report), a sample size of 11 samples per site (e.g., embayment) is sufficient to identify differences greater than one standard deviation from the expected value at a confidence level of 95%.

g) The magnitude of natural random variations in sediment contaminant concentrations may be used to define a reasonable first-order approximation of a threshold level for ecologically significant concentrations.

Beaufort Sea ocean dumpsite characterization. In a study of two potential ocean dumpsites in the Beaufort Sea based on the recommendations of Hoff and Thomas (1986), Arctic Laboratories analysed 72 samples from each site for metals and hydrocarbons (Arctic Laboratories Ltd. and LGL Ltd. 1987). The samples were collected in a stratified random pattern in two concentric circles at each site. The sample density was high (20 samples at each site). The authors determined that the observed contaminant concentrations were consistent with the contaminant-grain size relationship from Hoff and Thomas (1986) for some contaminants but not for others. Cd, Cr, Ni, Pb, and Sum Alkanes deviated from the values predicted by these relationships, although only Cd and Cr were obviously different. The sediments from the dumpsites were from deeper water than the Can Test samples, and had a consistently high clay content. Differences from the expected values were not large and were assumed to be caused by inter-laboratory differences.

These data were examined as part of this study to identify any similarities or differences between nearshore and embayment sediments and deep water sediments.

Development of a monitoring program for Tuktoyaktuk Harbour. In early 1986, a workshop was held to discuss methods for monitoring the environmental effects of industrial activity in Tuktoyaktuk Harbour. As part of the workshop, examples of programs in the North Sea and Port Valdez, Alaska, were presented. In general, these monitoring programs emphasized biota, not sediments. Also, the focus was on hydrocarbons specifically, with some interest in barium, as a major constituent of barite, and there was less interest in metals. Some consideration was given to grain size, but no results were available.

The recommended Tuktoyaktuk Harbour monitoring program focused on biota exclusively. Although continuing the Shorebase Monitoring Program was not within the scope of the workshop, it was assumed that concurrent sediment monitoring would be continued.

In planning the program, the question of "concentrations of concern" for specific contaminants was addressed. It was proposed that concentrations be "red flagged" when:

a) The concentration of a contaminant in sediment exceeded the background concentration by a predetermined amount, which would depend on the toxicity of the contaminant: (for example, one standard deviation could be used for highly toxic contaminants, but higher levels might be acceptable for less toxic contaminants);

b) Body burdens of contaminants in indicator organisms have increased above background concentrations, as above; and

c) The regulatory limit for a contaminant is exceeded.

Mackenzie River suspended particulate matter. Because the Mackenzie River is the major source of particulates entering the Beaufort Sea, a pilot study to determine the winter flux of contaminants in the river was undertaken in April 1985 and February 1986 (Erickson and Fowler 1987). Suspended particulate matter (SPM) was present at about 5 ppm, with between 65% and 95% less than 6.35 μm in size. Metal concentrations for the SPM were typically 1.5 - 2.5 times higher than mean Beaufort Sea sediment concentrations as determined for the Environmental Protection Service (EPS) Yellowknife sediment data base, using data of quality rating 3 and 4 only (of any grain size).

Hydrocarbons present were associated primarily with the SPM, consistent with partition theory. SPM hydrocarbon concentrations were typically 2000 - 4000 $\text{ng}\cdot\text{g}^{-1}$ (dry weight) total alkanes and 400 - 700 $\text{ng}\cdot\text{g}^{-1}$ total PAH. The distribution of alkanes and aromatics was consistent with the hydrocarbon being of terrigenous origin, with little or no anthropogenic input. Hydrocarbon concentrations for the SPM were typical of concentrations for Beaufort Sea surficial sediments.

ALASKAN BEAUFORT SEA

The opening of Alaskan outer continental shelf areas to oil exploration generated a need to monitor that area for environmental effects. Boehm *et al.* (1985; 1986) have carried out two years of a three-year study to determine baseline concentrations of contaminants before major activity commences. They have measured a number of contaminants over the Alaskan north coast, with particular emphasis on areas where heavy activity is likely.

All analytical data, including metals, were log transformed on the basis of improved within-station variability of log-transforming hydrocarbon data. They also considered normalizing the data by dividing by mud content (silt + clay), but found no improvement.

After log transformation, correlations were found between clay content and Cr, Cu, Zn, and V. Poor correlations were found between clay content and Cd and Ba.

Hydrocarbon concentrations did not correlate well with clay content, but total alkanes, total PAH, and specific aromatics all showed some correlation.

Various hydrocarbon indices were determined. The character of the hydrocarbons in the system was largely terrigenous with some petrogenic input, in particular, near the Colville River which has numerous coal deposits, oil-shale outcrops, and natural oil seeps along its length.

STATISTICAL ANALYSES

METHODS

Statistical Design

Differences in sampling design, and sampling and analytical methods between the data sets limit possible approaches to statistical analysis of these data. The 1982-1984 studies were not carried out according to a consistent design. Problems resulting from the differences in designs include: sources of error are additive (e.g., differences between years are confounded with differences in methods, particularly grain size), there are unequal numbers of observations in experimental treatments (i.e., combinations of data set and location), and sampling was not consistently random nor systematic. In addition, the data sets were examined for normality and homogeneity of variance in preliminary analyses, individually and in combination, and were neither normally distributed nor homogeneous (*cf.* Yunker 1986).

Because of these design problems, it was not appropriate to analyse these data as an experiment (experimental design). However, two approaches to the analysis of these data are suggested:

a) The first approach is based on use of relationships between sediment grain size and contaminant concentrations (Hoff and Thomas 1986; Yunker 1986). The Shorebase data may be analysed in relation to a reference data set, that is, data not contained within the Shorebase embayments. First, it is appropriate to determine whether the Shorebase data set and the reference data set represent the same population (i.e., data ranges and the slopes and intercepts of the contaminant-grain size relations). If suitable, the pooled data may then be examined for outliers (anomalous values) relative to the grain size relation and the residuals examined for the effects of year and location.

b) The second approach would be to analyse only a subset of the data, selected to minimize design problems. Specifically, only data from stations in the embayments which were sampled in all three years would be analysed. This approach would involve excluding the majority of the data from the analysis.

Preliminary results indicated that the second approach would provide less power to detect contamination, and, in addition, would lead to a monitoring program that was sensitive to the location of sampling stations within the embayments. The first approach was preferrable.

A reference data set was then defined including the Can T 84 data, the coastal and Tuft Point data from ALL 82, and data from ALL 83 and NAS 84 which were not from stations in the embayments. Initially data from the 1986 dumpsite survey (Arctic Laboratories Ltd. and LGL Ltd. 1987) were examined, but these data were shown to form dense groupings remote from the other data in scatterplots against grain size. They were not included to avoid biases which could be introduced by the high sampling density used in that program.

Further preliminary tests indicated differences in slope and intercept (for some contaminants) between the reference and Shorebase data, but no significant differences in ranges. These differences were not large and were consistent with differences which might be expected to result from the differing size fractions reported in grain size analysis. Consideration was, therefore, given to the identification of outliers and analysis of residuals on the basis of grain size relations developed only from the Shorebase data.

Limiting the analysis to the Shorebase data would exclude about 30% of the data with grain size observations. Of greater importance, analysis of the combined data (Shorebase and reference data sets) would reduce the power to detect outliers (by broadening the confidence and prediction intervals of the regression relations), but at the same time, would reduce the probability of falsely concluding that an observation is an outlier. As previously discussed, it was desirable that the statistical methods applied to the Shorebase Monitoring Program lead to "robust" conclusions and be relatively insensitive to differences between analytical laboratories. Therefore, analysis of the combined reference and Shorebase data was adopted as the preferred approach.

Method Selection

Graphical analysis (scatterplots and histograms) are useful because they are interpreted easily and may reveal relations between variables, departures from a normal distribution, and problems with data or errors in computations. Graphical analyses were used extensively to examine regression relations, data distributions, and distributions of the residuals (from the regression analyses).

The method of least squares was selected for regression analysis. This method is easily computed by Lotus 1-2-3; it allows easy computation of coefficient of determination, confidence and prediction intervals, and inferences concerning slope of the regression line; and spreadsheet computations can be readily verified against reference data and visually by plotting.

It was proposed to analyse the residuals by analysis-of-variance (ANOVA) and analysis-of-covariance (ANACOVA) to examine the effects of years and locations. However, the residuals did not conform to a normal distribution and problems with unequal numbers of observations and small cell sizes were anticipated. For these reasons, it was preferable to select a non-parametric method for the analysis of the residuals.

The Mann-Whitney U test is a non-parametric method for determination of differences between two populations (of data). It is related to Wilcoxon's rank sum.

The Mann-Whitney statistic, **U**, is obtained by ordering the pooled observations from the two test populations according to magnitude and counting the number of observations in population A that precede each observation in population B. The **U** statistic is the sum of these counts. Very large or very small values of **U** imply a separation of the ordered A and B observations and provides evidence to indicate a difference between the population distributions. Where the number of observations in either population is less than 10, the significance of the Mann-Whitney statistic, **U**, is determined against critical values given by the distribution function of U. Where the number of observations in both populations is greater than or equal to 10, the significance of the **U** statistic is determined against critical values of the **z** statistic (standardized normal curve areas).

This method was selected for the evaluation of the differences between groups of data because it is insensitive to departures from a normal distribution and allows the significance of differences between population distributions to be assessed.

Data Processing

All data processing was performed on IBM PC-compatible microcomputers using dBASE III Plus, 1-2-3, and a custom mapping software package (ESLMap by ESL Environmental Sciences Limited). Data were acquired in a machine-readable form from a sediment chemistry database (maintained by EPS Yellowknife; McDonald *et al.* 1986) and 1-2-3 spreadsheets (NAS 84). Extensive editing and some additional data entry were required.

Format and unit conversions. 1-2-3 files of PAH and alkane data were edited to remove page headings, footings, and box and line characters. Following this initial clean-up, the Lotus files were exported to dBASE. A program was then executed to transpose the data from columns to rows. The 1-2-3 files of the metals data contained no information. Missing metal data together with grain size, moisture, and total organic carbon (TOC) data from NAS 84 were entered.

Data from the EPS sediment database were converted from PASCAL data to delimited ASCII and imported to dBASE. Fields not required for our analyses were then deleted (e.g., UTM co-ordinates and body burdens). A program was then executed to reduce the multiple records (individual sample data represented by up to three records, one for each quality rating) to a single record appropriate for statistical analysis.

Individual alkane data for the 1982 analyses were obtained from ALL files (file: 82-015) and entered. Data from alkane analysis of five 1982 samples reported in ALL 83 were entered. Data from replicate metals and hydrocarbons analyses by Can Test (which were not included in the EPS sediment database) were entered.

Different methods of analysis were used in grain size determinations. For statistical analyses a variable representing percentage clay was required. A percentage clay variable was therefore created from the data sets as follows:

- ALL 82 data, <38 μm fraction for percentage clay
- ALL 83 data, <38 μm fraction for percentage clay
- Can T 84 data, <2 μm fraction for percentage clay
- NAS 84 data, <4 μm fraction for percentage clay.

Hydrocarbon data recalculations. Different methods were employed by ALL, NAS, and Can Test for PAH and alkane analyses. For alkane analyses, in 1982 the alkanes n-C10 to n-C33 were determined, whereas in 1983 and 1984 the alkanes n-C12 to n-C36 were determined. To ensure a true comparison, the data for Total Alkanes were discarded and replaced with the variable Sum Alkanes, which was calculated as the sum of n-C12 to n-C33.

Similarly, data for Total PAH were discarded and replaced with the variable Sum PAH, which was calculated as the sum of naphthalene, fluorene, phenanthrene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzofluoranthenes, benzo(e)pyrene, benzo(a)pyrene, and perylene. When required, benzo(b)fluoranthene and benzo(k)fluoranthene were summed to give benzofluoranthenes.

Various indices that are considered to be indicative of petroleum origin and weathering were calculated (where possible). These indices were the following:

- n-C17:pristane ratio
- n-C18:phytane ratio
- pristane:phytane ratio
- carbon predominance index (CPI)
- saturated hydrocarbon weathering ratio (SHWR) (Owens *et al.* 1986).

Lastly, the Sum Alkane and Sum PAH data were log transformed (natural logarithm) as is commonly required for analyses of hydrocarbon data (Hoff and Thomas 1986).

Data verification. The composite data file was then examined and verified. Several data errors were identified and corrected. Moisture data for the Can Test data set and lead data from the 1982 data set required recalculation. Data from 1982 stations where "wash-out" had been reported were removed from the data set. Problems with misclassification of subsamples and replicates were also resolved. One mercury value (0.322 μg/g) from the 1983 data set (ALL 83) was discarded. This observation was one of a series of 10 replicate grabs, where the other values were in the range 0.061 to 0.081 μg/g, so the high value was considered to be an artifact.

Assignment of categories. Data for core fractions deeper than the top 5 cm were separated from data for surficial sediments (to a separate file). Data from beach samples (in 1982) also were separated. Classification variables representing data set (i.e., collection year and analytical laboratory) and sub-set (sampling location), and unique observation identifiers, and core fraction (where appropriate) were then assigned to the data.

Descriptive statistics. Means, standard deviations, maximums, minimums, and 95% and 99% confidence intervals (about the means) were calculated on the combined data (1982 to 1984). Histograms of frequency distributions were plotted and examined visually for normality.

Regression analyses. Initially, scattergrams against percentage clay were plotted to examine groupings visually within the data and their relation with grain size. Regression analyses were then performed of contaminants against percentage clay, percentage silt, and TOC; and also the hydrocarbon indices and Sum Alkanes and Sum PAH in various combinations and against hexane extractable compounds (HEC).

Regression analyses were performed in accordance with a simple linear probabilistic model using the method of least squares. Coefficients of determination (r^2), Student's **t** statistics, and 95% and 99% prediction intervals for **y** (the dependent variable) were calculated with a 1-2-3 spreadsheet. The accuracy of the spreadsheet calculation was confirmed against a reference data set given by Mendenhall (1979). All regression results were graphed and inspected visually.

The coefficient of determination indicates the reduction in the sum of squares of deviations obtained by using the linear model to the total sum of squares of deviations about the sample mean (which would be the predictor of **y** if the independent variable, **x**, were ignored). The **t** statistic indicates the significance of the linear relation (i.e., the hypothesis that the slope of the regression line is not equal to zero).

Some data were excluded from the regression analysis, specifically:

a) The NAS 84 alkane data were excluded because of concerns related to data quality (see subsection on Quality Analysis in Results and Table 3).

b) Two observations of barium at station 21 (Tuktoyaktuk Harbour) were excluded because they were clearly outliers - the quality of the analyses of these two samples was good and these values are not considered to be artifacts, however, their inclusion would bias the regression analysis.

c) All cadmium observations from McKinley Bay were excluded from the regression analysis because values for McKinley Bay were frequently high relative to the grain size relation predictions and it was concluded that McKinley Bay cadmium data were unsuitable for the definition of a reference or baseline cadmium to grain size relation.

All data, including those noted above, were included in the calculation of residuals and detection of outliers.

Residual analysis. Residuals were calculated by subtraction of the values predicted by the grain size relation (percentage clay). Histograms of the frequency distribution of the residuals were plotted and visually examined for normality and differences between data sets. Mann-Whitney **U** statistics, Wilcoxon's rank sum (**T**) and **z** statistics were computed to test for significant differences between the data sets.

RESULTS

Results are presented in four parts:

- A quality analysis of the 1982 - 1984 program design and methodology;
- Statistical analysis of the 1982 - 1984 data set;
- Examination of the core data; and
- Additional consideration of the hydrocarbon data.

Quality Analysis

Experimental design. The 1982-1984 data set is actually a composite of several experimental designs, which individually may have been adequate if carried out consistently from year to year. However, the experimental design is not balanced (i.e., unequal allocation of sampling stations, replicates, and analyses between embayments and years) and frequently lacks critical grain size observations. Deviations from a consistent experimental design have limited the ability to interpret the data collected.

Sampling methods. Differences in sample collection and handling may influence the power of statistical methods because such differences introduce a source of non-random error, which in this case is confounded with the potential variation between years. Although there is no direct evidence for systematic differences between core and grab samples, use of different samplers may have introduced error.

Samples for hydrocarbon analysis (alkanes and PAHs) were stored in plastic (i.e., Whirlpak bags) in all years, which is an undesirable but adequate practice. In 1982, a brass grab was used for collection of samples for metal analysis, which is also undesirable but in this case may be considered adequate given that care was taken to discard sediment near the walls of the grab.

Positioning accuracy during sample collection is not an influence on data quality for the method of analysis employed herein, however, position accuracy would be of concern if analysis of individual stations over time were to be attempted.

Analytical methods. Analytical methods have not been consistent throughout the program (1982-1984). Except in two cases, this inconsistency does not affect the data, as adequate quality control and quality assurance (QC/QA) programs were included. The two exceptions were the grain size determinations by all laboratories, and the determination of alkanes by NAS for the 1984 data.

The use of standard reference materials (SRMs) in metal analysis increases the confidence in the data. All laboratories gave similar results for the analysis of MESS-1, an SRM provided by the National Research Council of Canada (NRCC) for the analysis of trace metals in marine sediments, with minor exceptions: ALL 83 had poor recovery of Pb, and ALL 82, ALL 83 and Can T 84 had poor recoveries of Cr. All other elements were reported accurate to within 10% of the reference value. The distribution of residuals after percentage clay regression reflect these differences. The distribution maximum for Pb residuals by ALL 83 was lower than the maxima for the other laboratories (Figure 2), whereas the higher recoveries reported by NAS 84 are reflected in the residual maxima for that laboratory being higher than the other laboratories (Figures 2 and 3). No SRMs for hydrocarbons in sediments are available.

The three laboratories each used a different size threshold for the determination of percentage clay. Some of the observed differences in the residuals after grain size regression may be caused by these differences. Although the statistical analyses employed here do not appear to suffer from the variability introduced by these differences, a consistent procedure should be used in future. Most (70%) of the Shorebase data are based on a clay fraction of <38 μm. Therefore, 38 μm would

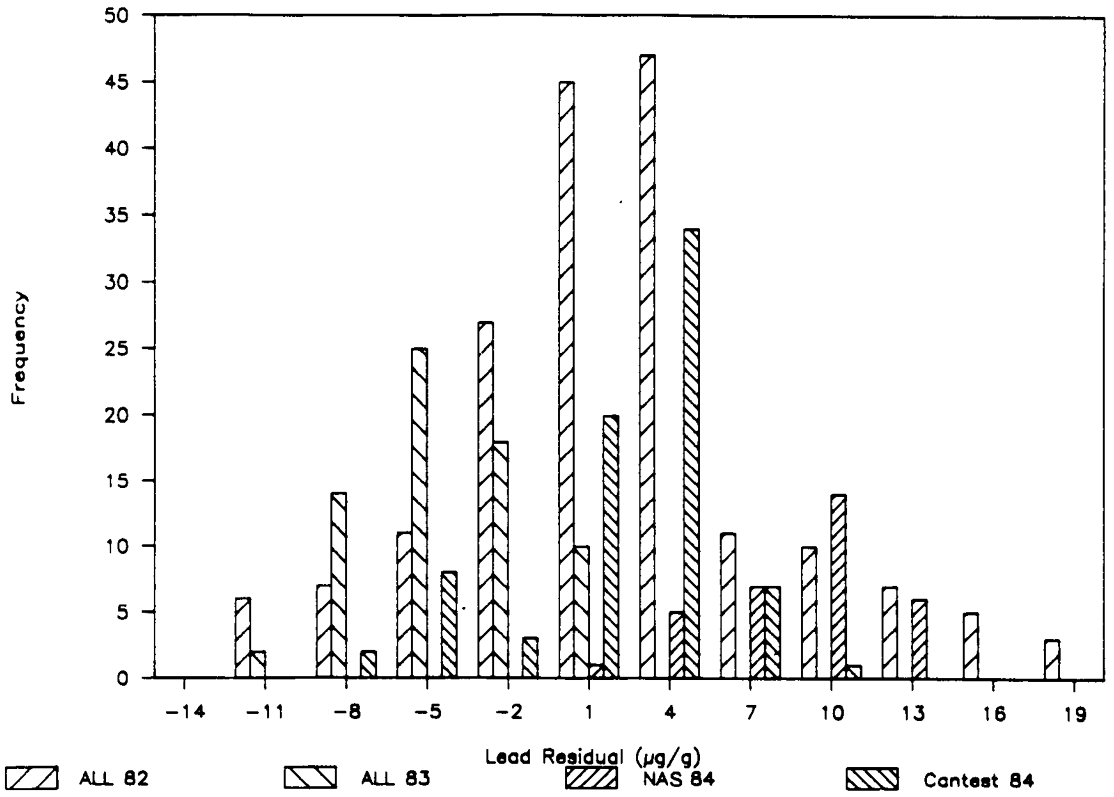

Figure 2. Frequency distribution of residuals for lead (Pb).

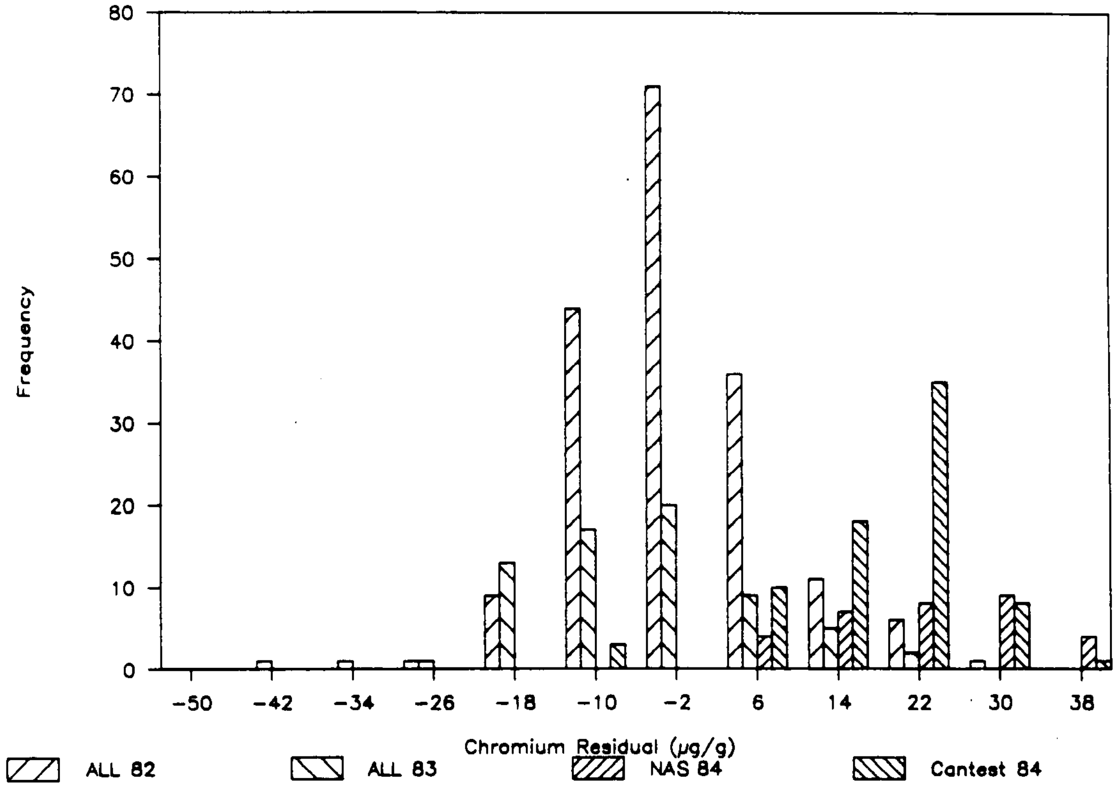

Figure 3. Frequency distribution of residuals for chromium (Cr).

appear to be the appropriate threshold for future analysis, even though it includes a contribution from the silt fraction.

The alkane determination by NAS 84 is not a generally recognized procedure for sediment. The NAS 84 procedure did not use internal standards similar to the compounds of interest, and therefore the recoveries may be suspect. Reported problems with analytical replication led to the low quality rating applied to these data.

The PAH analyses in Can T 84 were done by a liquid chromatographic method, rather than a gas chromatographic method. In the absense of SRMs for PAH, no distinction can be made.

Descriptive Statistics

Appendix 1 presents histograms of the distributions of the variables of interest (and iron, which was considered as a reference compound) together with their means, standard deviation, and number of observations. It is apparent from the histograms that the variables of interest are not normally distributed. In several cases (e.g., cadmium and mercury, Figures 4 and 5), the departure from normality is large. Therefore, confidence intervals based on the mean and standard deviation are not valid and parametric methods should not be employed to interpret these data.

Grain Size Relation

Regression results. A relation between grain size (percentage clay) and contaminant concentration was demonstrated for all variables of interest. Appendix 2 presents plots of the derived contaminant to grain size relations and gives 95% and 99% prediction intervals, the estimated equation of the regression line, the coefficient of determination, and the number of observations on which each regression is based. To assist in identifying groupings in the data, a letter symbol was assigned to represent combinations of location, collection date, and analytical laboratory as outlined in Table 4.

The effect of grain size accounts for 25.8% to 82.5% of the observed variance in contaminant concentrations, see Table 5. Figure 6 presents a plot of the regression for chromium with prediction intervals; note the presence of values in excess of the upper boundary of the 99% prediction interval with symbol L (Tuktoyaktuk, NAS 84).

The variances of the contaminant data for any region depend on the dispersion of clay within the region and, because each region is heterogeneous in grain size distribution, the specific locations where samples were collected. Note that the frequency distributions of percent clay are markedly different between the shorebase

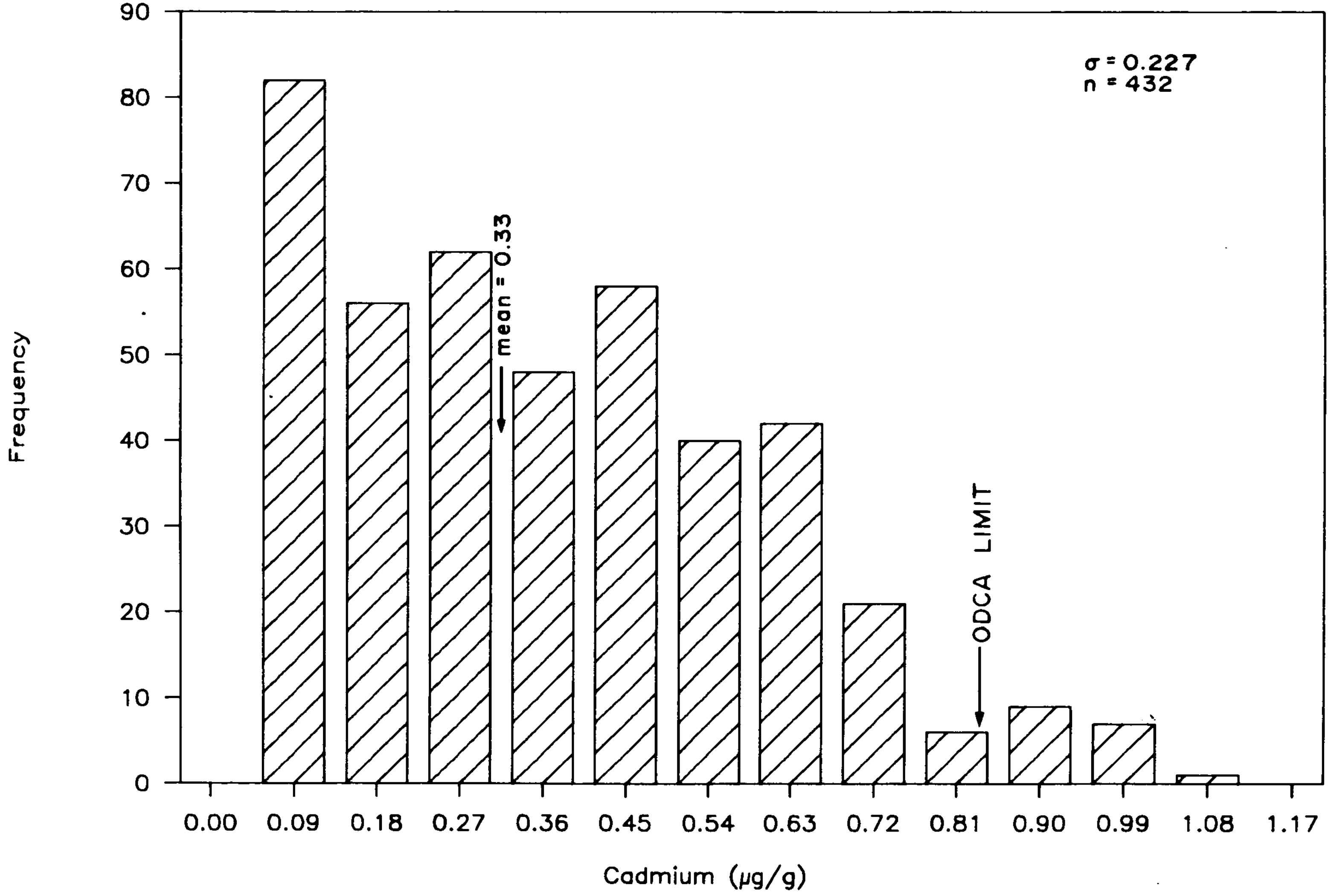

Figure 4. Frequency distribution and descriptive statistics for cadmium (Cd).

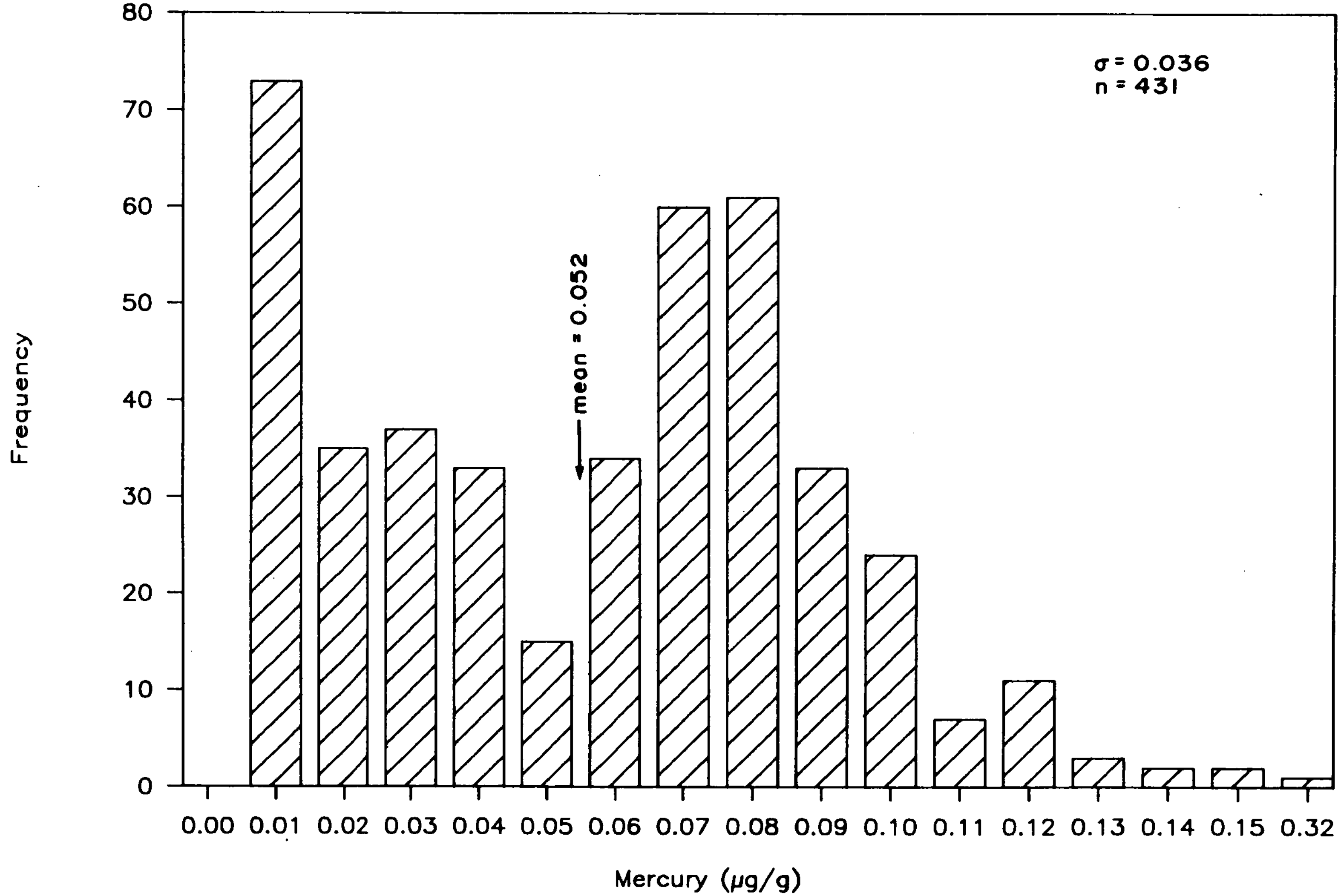

Figure 5. Frequency distribution and descriptive statistics for mercury (Hg).

TABLE 4

Symbols used in plots of regression analyses to identify groupings of data

Symbol	Data Group	Collection Date	Analysis	No. Stations
A	Coastal	1982	ALL (1982)	60
B	Tuktoyaktuk	1982	ALL (1982)	30
C	Tuktoyaktuk	1982	ALL (1983)	2
D	Hutchison Bay	1982	ALL (1982)	37
E	McKinley Bay	1982	ALL (1982)	93
F	McKinley Bay	1982	ALL (1983)	2
G	Tuktoyaktuk	1983	ALL (1983)	30
H	Hutchison Bay	1983	ALL (1983)	2
I	McKinley Bay	1983	ALL (1983)	30
J	McKinley Bay	1983	NAS (1984)	3
K	Tuktoyaktuk	1983	NAS (1984)	3
L	Tuktoyaktuk	1984	NAS (1984)	63
M	Hutchison Bay	1984	NAS (1984)	12
N	McKinley Bay	1984	NAS (1984)	11
O	Tuktoyaktuk	1983	Can Test (1984)	3
P	McKinley Bay	1983	Can Test (1984)	3
Q	Coastal	1984	Can Test (1984)	71
R	Yukon	1984	Can Test (1984)	144
T	Coastal	1983	ALL (1983)	8
U	McKinley Bay	1984	Can Test (1984)	3

TABLE 5

Coefficients of determination from least squares regression analysis against percentage clay

Contaminant	Coefficient of determination (r^2)
Barium	60.3
Cadmium	60.9
Chromium	78.7
Copper	76.8
Lead	25.8
Mercury	74.6
Nickel	73.4
Sum Alkanes	31.7
Sum PAHs	32.8
Zinc	82.5

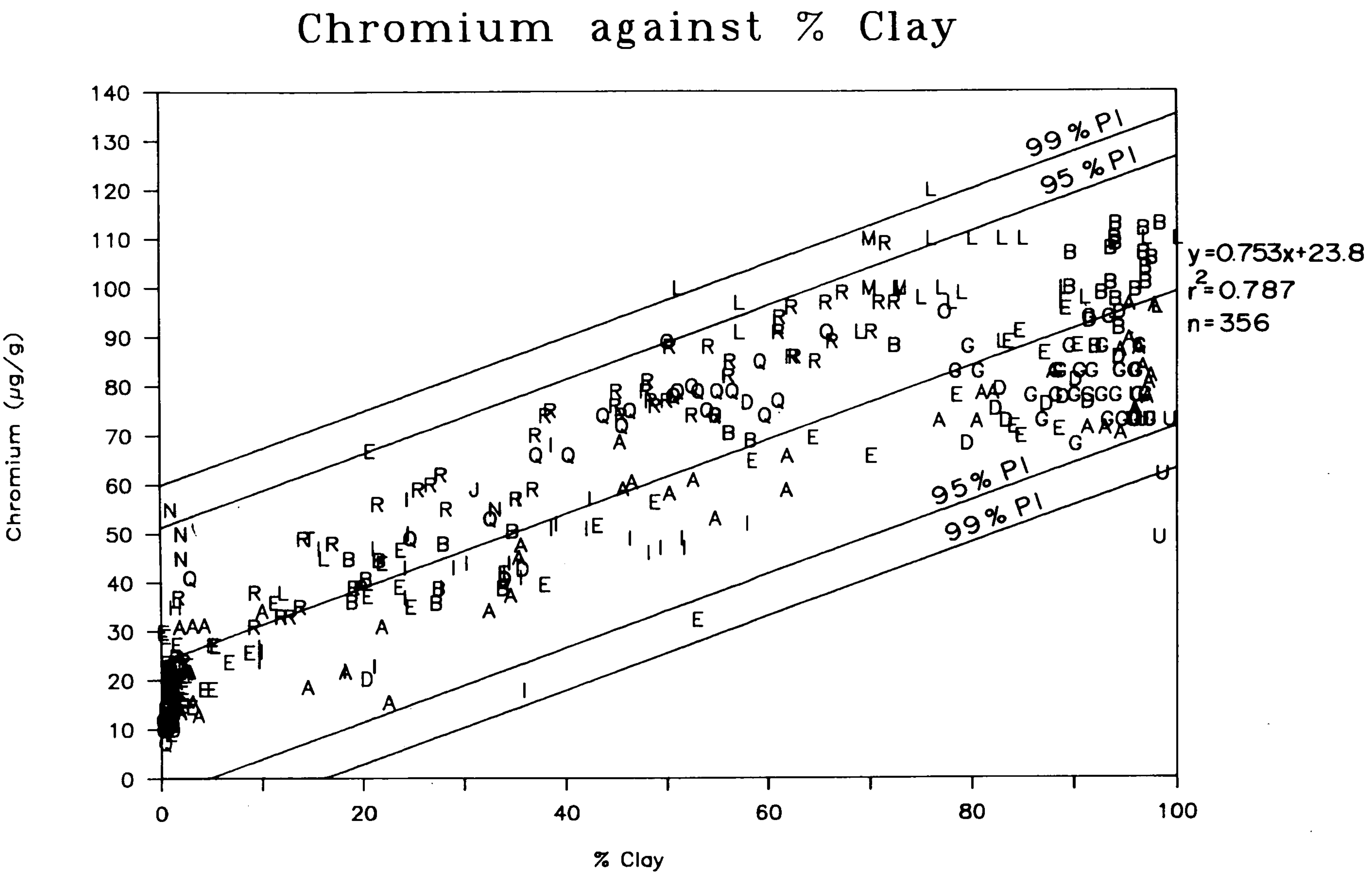

Figure 6. Regression analysis of chromium (Cr) against % clay.

embayments and also between the combined Shorebase data set and the reference data set (Figures 7 to 12). It is essential that grain size be taken into account in the analyses of sediment contaminant data.

Of interest, differences in the grain size categories used by the different laboratories are apparent in these frequency distributions. For example, in Figure 7 the NAS 84 data do not include any observations above the 80th percentile, whereas the ALL 82 and ALL 83 data show a high proportion of observations in the 90th and 100th percentiles and the Can T 84 data fall somewhere between these two frequencies.

Also of note, the distributions of percentage clay in the embayments, in the reference data and in the combined data set, are not normal. Therefore, the distributions of contaminant data are expected not to be normal, as has been demonstrated (Yunker 1986 and see Appendix 1).

Residuals. Histograms of the frequency distributions of the residuals from the grain size regressions are given in Appendix 2. These histograms indicate that the distributions of the residuals are not normal (see Figures 2 and 3). However, if the residuals of the data from a single analytical laboratory are examined, the residuals conform to a normal distribution. The histogram for chromium (see Figure 3) illustrates this most clearly. In this figure, the distributions of residuals from the Can T 84 and NAS 84 data are clearly shifted relative to those of ALL 82 and ALL 83.

Table 6 presents results of Mann-Whitney U tests on the residuals for significant differences between the analytical laboratories. Absolute values of the z statistic greater than 1.96 (where $n \geq 30$) indicate significant differences. Initially, tests were performed between ALL and the other laboratories (NAS and Can Test). For all variables, except nickel and Sum PAH (and barium, for which ALL performed no analyses), significant differences were found at this level. For both nickel, Sum PAH, and barium significant differences between the laboratories were found when data from individual data sets were compared (Table 7).

These differences between the laboratory data sets prevent further investigation of the effects of years and locations. For example, Mann-Whitney U tests are presented in Table 8 comparing concentrations of chromium in Tuktoyaktuk Harbour and McKinley Bay, first based on the combined data set and then, only for the ALL data sets. Note that the result of the Mann-Whitney U test using the combined data indicates that McKinley Bay has significantly higher concentrations of chromium. However, if only the ALL data are considered, there is no significant difference. Additional statistical analyses were not attempted beyond this level.

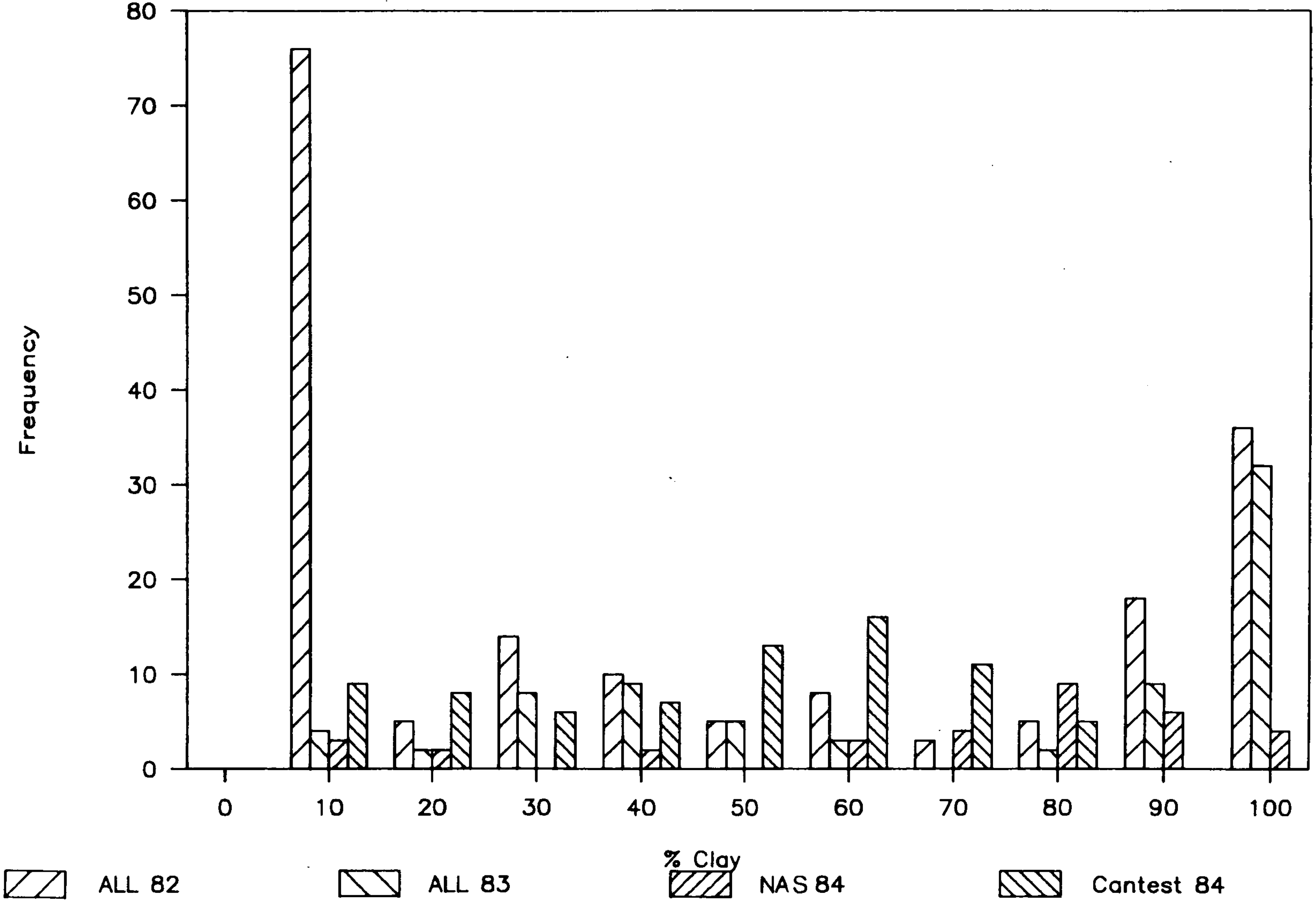

Figure 7. Frequency distribution of clay in the combined 1982 - 1984 data.

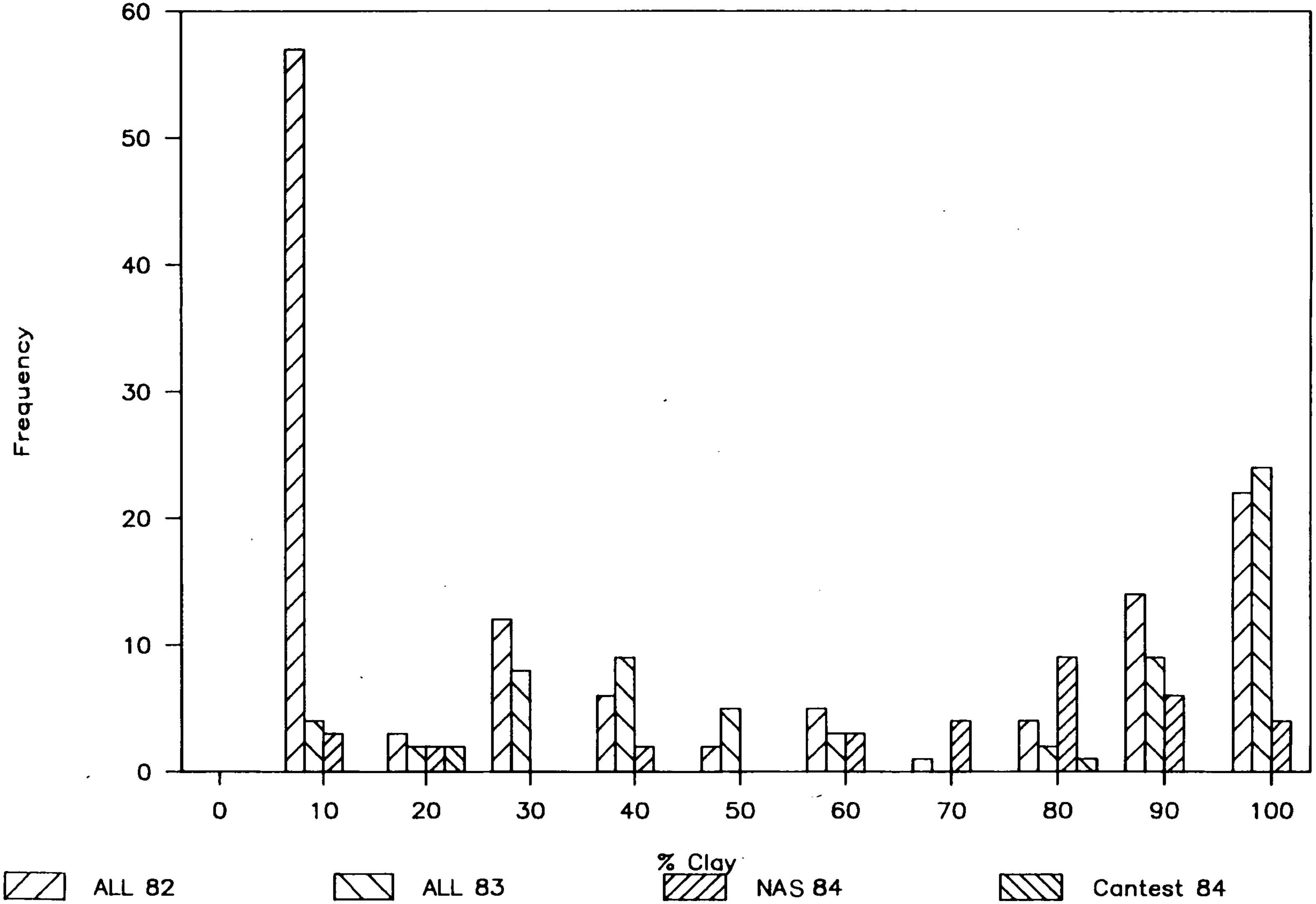

Figure 8. Frequency distribution of clay in the 1982 - 1984 shorebase data (embayments only).

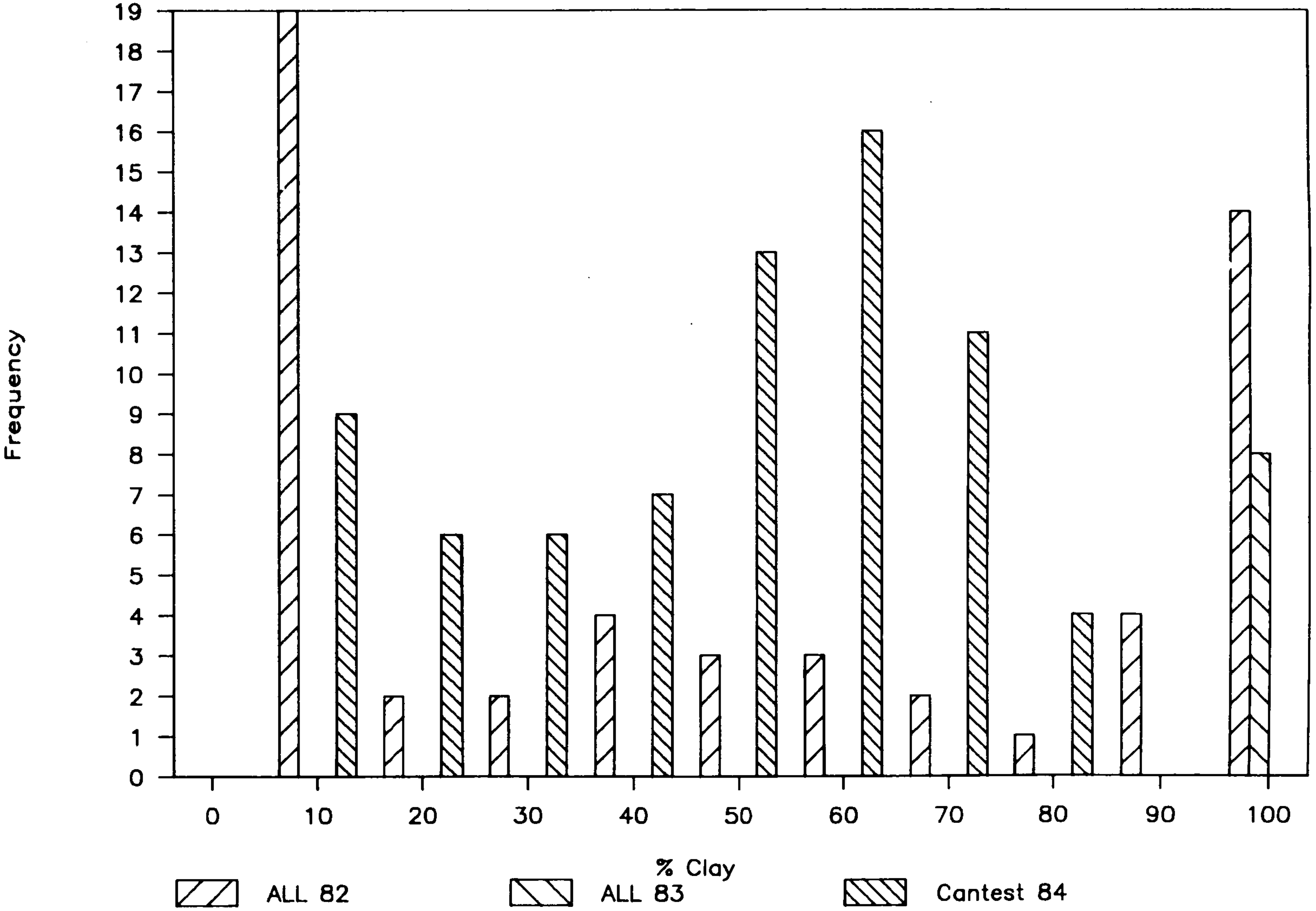

Figure 9. Frequency distribution of clay in the 1982 - 1984 reference data (other than embayments).

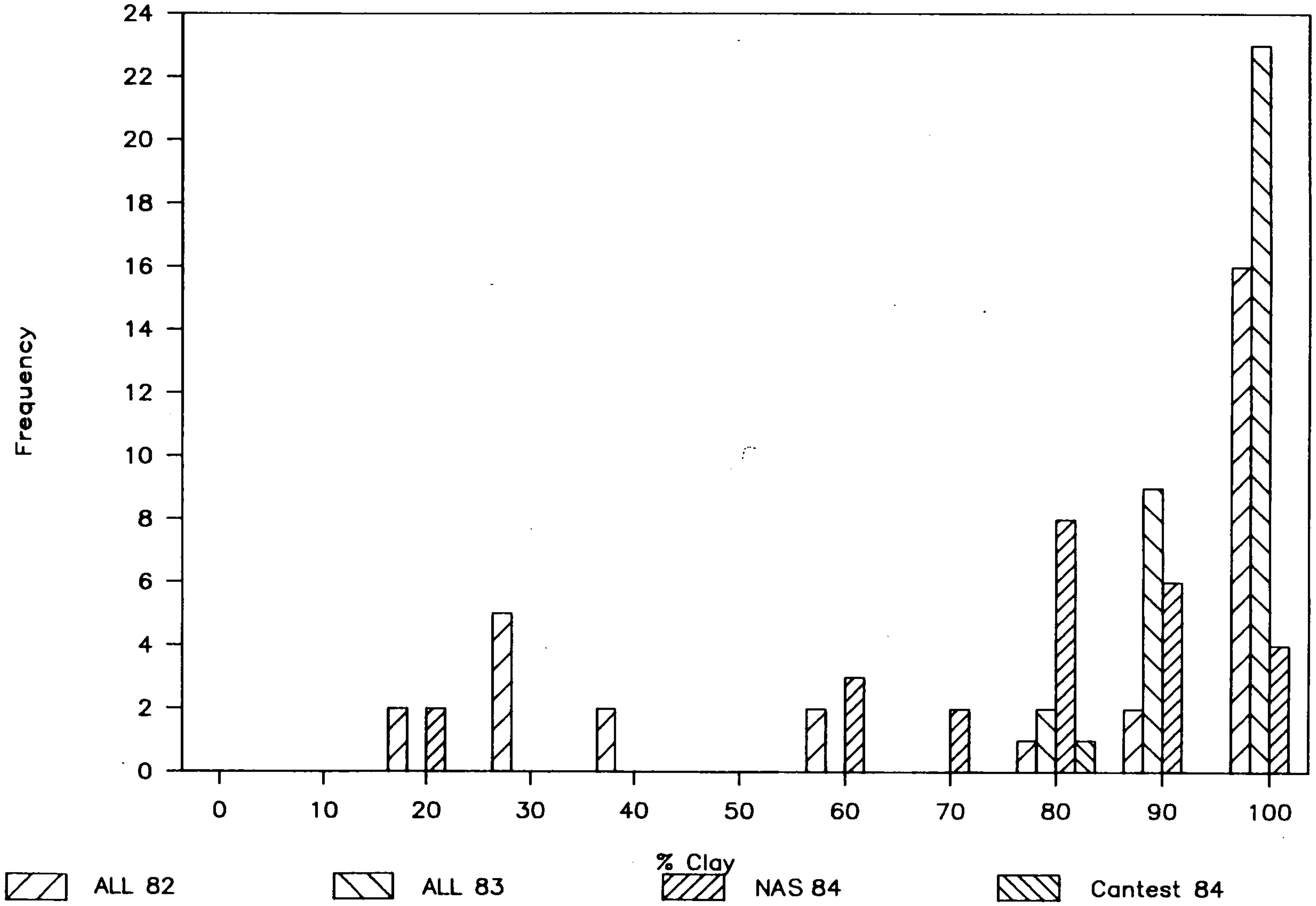

Figure 10. Frequency distribution of clay in the 1982 - 1984 Tuktoyaktuk data subset.

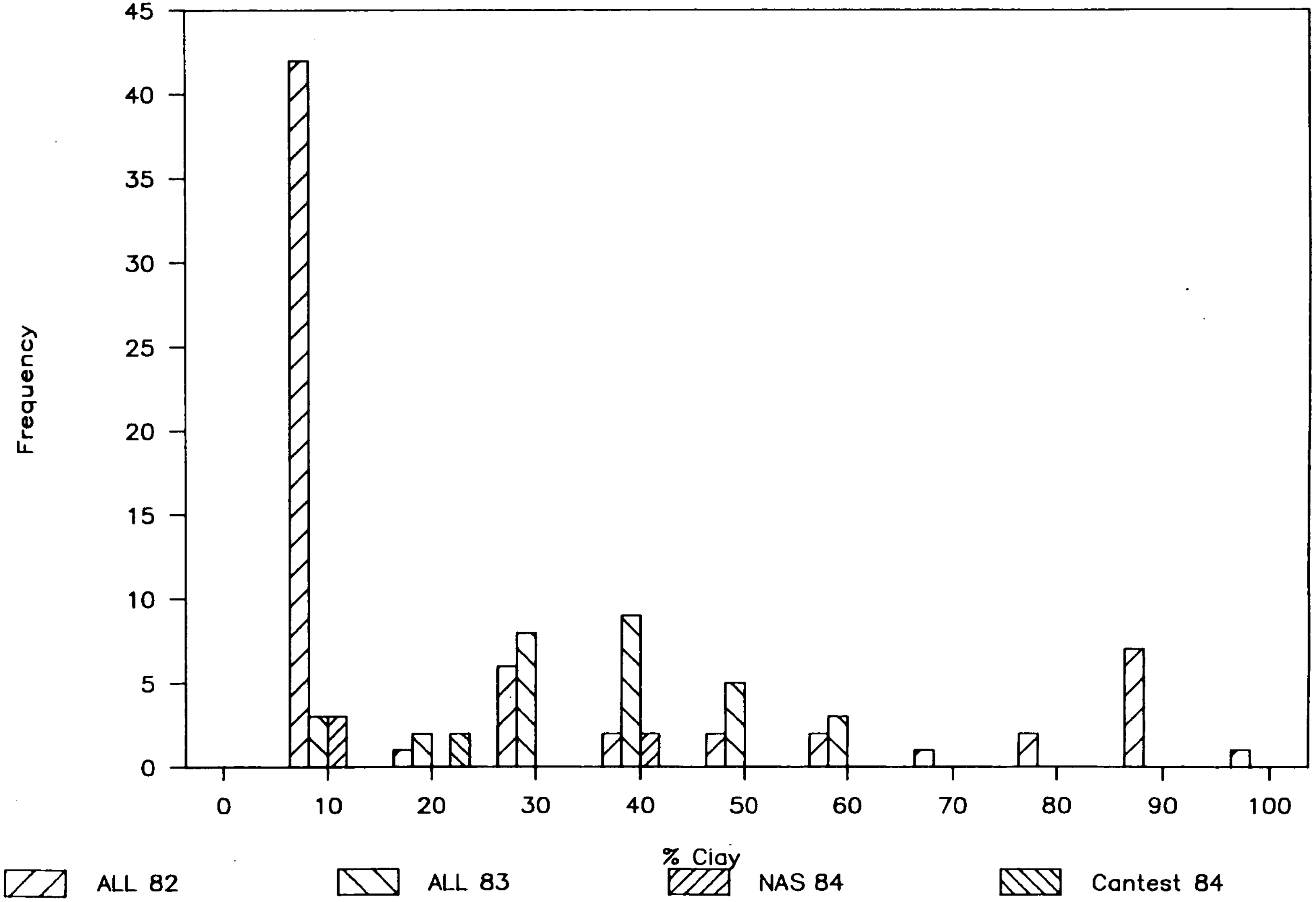

Figure 11. Frequency distribution of clay in the 1982 - 1984 McKinley Bay data subset.

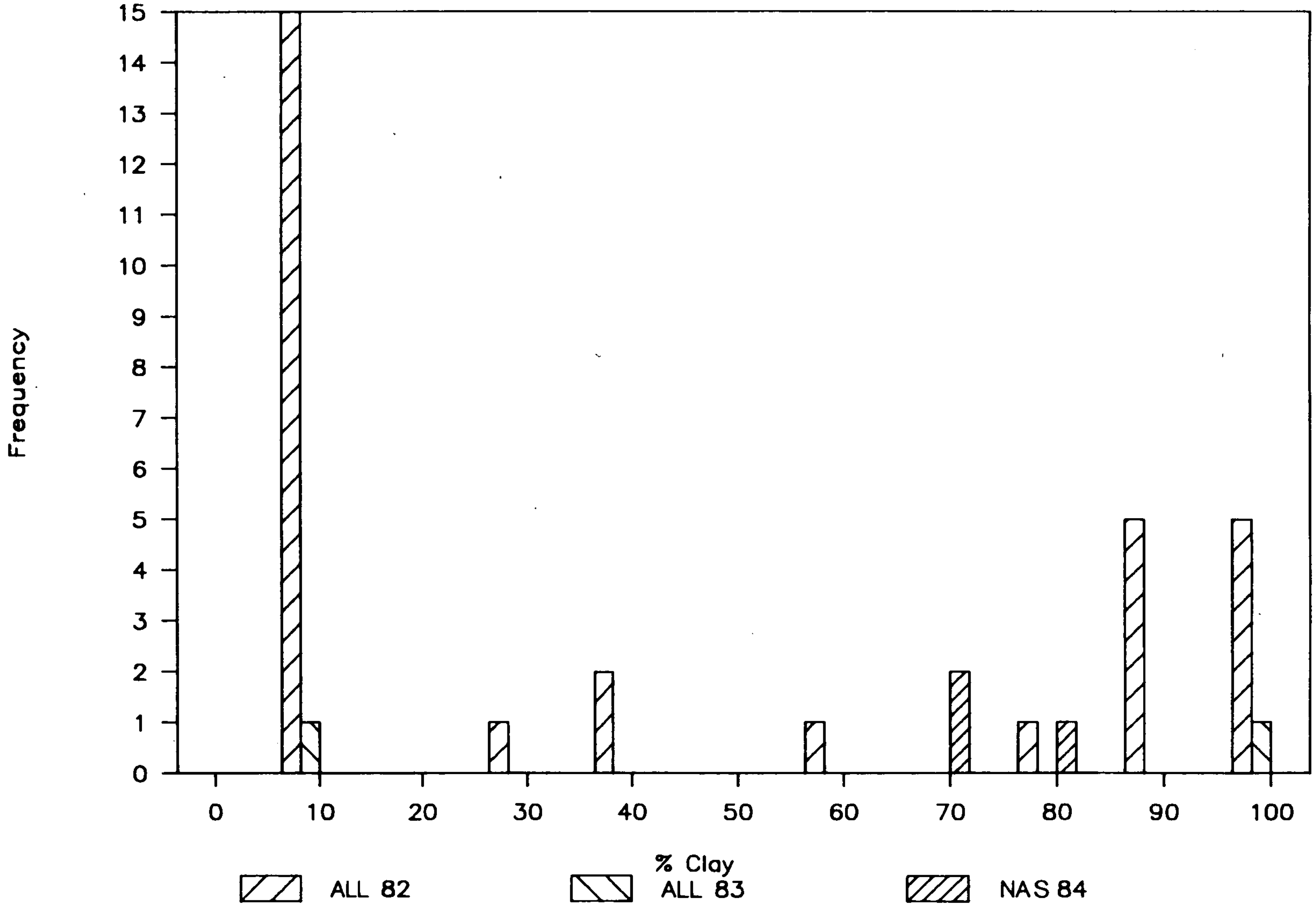

Figure 12. Frequency distribution of clay in the 1982 - 1984 Hutchison Bay data subset.

TABLE 6

Mann-Whitney U tests of differences between ALL 82 and ALL 83 data sets and NAS 84 and Can T 84 data sets

	No. of observ. (n)	Wilcoxon's Rank Sum (T)	Mann-Whitney U statistic (U)	z statistic (z)
Cadmium (Cd)				
ALL 82 and 83	248	46045.5	11614.5	-1.99
NAS 84/Can T 84	108	17500.5	15169.5	
Chromium (Cr)				
ALL 82 and 83	248	32659	25001	13.01
NAS 84/Can T 84	108	30887	1783	
Copper (Cu)				
ALL 82 and 83	248	37674.5	19629.5	7.07
NAS 84/Can T 84	108	25515.5	7046.5	
Mercury (Hg)				
ALL 82 and 83	247	37564	19740	7.20
NAS 84/Can T 84	108	25626	6936	
Nickel (Ni)				
ALL 82 and 83	248	44507	13153	-0.27
NAS 84/Can T 84	108	19039	13631	
Lead (Pb)				
ALL 82 and 83	248	38842	18818	6.08
NAS 84/Can T 84	108	24704	7966	
Zinc (Zn)				
ALL 82 and 83	248	36788	20872	8.38
NAS 84/Can T 84	108	26758	5912	
Log (Sum Alkanes) [Ln(ΣAlk)]				
ALL 82 and 83	58	5557	2244	-2.78
NAS 84/Can T 84	105	7809	3846	

TABLE 6 (continued)

	No. of observ. (n)	Wilcoxon's Rank Sum (T)	Mann-Whitney U statistic (U)	z statistic (z)
Log (Sum PAH) [Ln(ΣPAH)]				
ALL 82 and 83	37	2125	1279	-0.45
NAS 84/Can T 84	73	3980	1422	
Iron (Fe)				
ALL 82 and 83	248	32784	16692	10.43
NAS 84/Can T 84	75	19542	1908	

TABLE 7

Mann-Whitney U test of differences between individual data sets

	No. of observ. (n)	Wilcoxon's Rank Sum (T)	Mann-Whitney U statistic (U)	z statistic (z)
Barium (Ba)				
NAS 84	33	2404	632	-4.04
Can T 84	75	3482	1843	
Nickel (Ni)				
ALL 82	179	24405	5130	-2.97
Can T 84	75	7980	8295	
Log (Sum PAH) [Ln(ΣPAH)]				
NAS 84	30	703	1052	4.57
Can T 84	43	1998	238	

TABLE 8

Comparison of chromium concentrations in Tuktoyaktuk Harbour and McKinley Bay

	No. of observ. (n)	Wilcoxon's Rank Sum (T)	Mann-Whitney U statistic (U)	z statistic (z)
Chromium (combined data set)				
Tuktoyaktuk Hbr.	86	9501	3098	-3.55
McKinley Bay	103	8454	5760	
Chromium (ALL 82 and ALL 83)				
Tuktoyaktuk Hbr.	60	5035	2555	-1.18
McKinley Bay	96	7211	3205	

Cores

Core data were available only from the NAS 84 and Can T 84 data sets. Grain size measurements were available for about 30% of these data. Most of the core data with grain size observations were from either the 0-to-5-cm sections or the 15-to-20-cm sections. One-way ANOVA of the residuals from contaminant to grain size regressions showed no significant difference between these two horizons. Surface enrichment was observed in some cores; these samples were also identified as outliers using the departure from prediction interval method described above.

Analysis of the core data provided no more information than analysis of the data from grab samples. (Data from the analysis of surficial sections were included with the data from the analysis of grab samples in the preceding analysis).

Hydrocarbons

Hydrocarbon concentrations. The grain size relationships for hydrocarbons are not as significant as those found for most metals; only 30% of the variance may be explained by regression of Sum Alkanes or Sum PAH against percentage clay (see Appendix 2, Figures 2-17 and 2-19). A similar but no better relationship (i.e., no more explaining power) was found by regression of Sum Alkanes against total organic carbon, and no relationship was found by regression of Sum Alkanes against HEC (see Appendix 3).

Some of the values found (up to 24 ppm) for Sum Alkanes were above the Ocean Dumping Control Act (ODCA) limits for HEC. The HEC values themselves were usually well above the ODCA limits, but it is not clear which compounds were contributing to the observed HEC; the alkanes and PAH determined in these programs did not contribute significantly to the high values observed.

Hydrocarbon indices. Specific indices have been developed to infer origin to hydrocarbons found in the environment, and to monitor the degradation of anthropogenic hydrocarbons. Those indices in current use were examined:

a) **Carbon Predominance Index (CPI)**: the ratio of odd-numbered carbon chain alkanes to even-numbered carbon chain alkanes. Biogenic hydrocarbon mixtures contain much higher concentrations of the odd-numbered carbon chains (CPI > 1), whereas petroleum hydrocarbons have an equal distribution of odd- and even-numbered carbon chains (CPI = 1). No grain size relation was found with CPI, and no relation between CPI and Sum Alkanes was found. For most samples, including those with the highest concentrations, the CPI indicated biogenic origin.

b) **Pristane:Phytane Ratio**: Pristane is a biogenic isoprenoid while phytane is a common petrogenic isoprenoid. The ratio of pristane to phytane has been used as an indicator of hydrocarbon origin. A high ratio (> 1) indicates biogenic origin, while ratios near 1 indicate petrogenic origin. At low concentrations in the environment, some phytane typically is present and this indicator loses its significance. No relationship was found between the pristane:phytane ratio and Sum Alkanes, implying that most of the concentrations found were biogenic.

c) **Saturated Hydrocarbon Weathering Ratio (SHWR)**: the ratio of low molecular weight alkanes (n-C12 - n-C25) to higher molecular weight alkanes (n-C17 - n-C25) is used as an indicator of petroleum hydrocarbon weathering. Freshly spilled oil would have a high SHWR, whereas the index for weathered oil approaches 1. This index is not useful for background hydrocarbon concentrations, but should be used to monitor known spills of hydrocarbon.

d) **n-C17:Pristane and n-C18:Phytane Ratios**: as biodegradation of petroleum hydrocarbons proceeds, the straight chain (normal) alkanes are preferentially degraded. A petroleum product or crude oil has a high ratio for both of these indices, whereas they approach 1 or less for a weathered oil. Again, these indices are not applicable to background hydrocarbon concentrations, and should be restricted to monitoring known spills.

None of the weathering ratios examined showed any relationship to percentage clay or to Sum Alkanes (see Appendix 3). This result is to be expected as none of the hydrocarbons measured were shown to be clearly petrogenic. It is difficult to distinguish between background hydrocarbons and heavily weathered petroleum hydrocarbon.

DETERMINATION OF ANTHROPOGENIC INPUT

Athropogenic inputs of contaminants were investigated by identification of outliers (i.e., anomalously high concentrations of contaminants) using statistical techniques and then mapping the distribution of these outliers. A quantitative index of the degree of contamination was developed (described below) and this index of contamination was then mapped to examine the distribution and significance of anthropogenic inputs. Mapping was performed using a software mapping package developed by ESL Environmental Sciences Limited. This software allows the data and results of statistical analysis to be displayed interactively on detailed maps of variable scale, with symbol sizes and types determined on the basis of criteria defined by the operator. Detailed maps of the embayments and reference areas were produced using this software, in which the type and size of symbols represent the magnitude of the index of contamination.

OUTLIERS BY CONTAMINANT

Outliers were defined as observations with a magnitude either higher or lower than the range of magnitudes which statistically characterized the distribution of the data. The range of magnitudes which characterized the data distribution may be calculated as a confidence interval or prediction interval (depending on statistical method).

As described previously (see the subsection on Descriptive Statistics in Results) a confidence interval based on the mean and variance is not valid because of significant departures from normality. Alternatively confidence intervals may be developed using non-parametric methods, however, such an approach is computation-intensive and impractical for a data set of this size. Further, it is necessary to take into consideration the grain size of the sediment when screening the observations for outliers, because grain size explains from 25.8% to 82.5% of the variance in concentrations observed (see the subsection on Grain Size Relation in Results). An index of contamination was developed based on the observed departure from the concentration range predicted by the grain size relation.

CALCULATION OF INDEX

For each contaminant, the degree of contamination was calculated as:

$$D_i = (C_o - C_u) / C_m$$

where:

D_i = degree of contamination for contaminant **i**;
C_o = concentration observed;
C_m = mean concentration of contaminant **i** from the data used to determine the grain size relation; and
C_u = upper boundary of the prediction interval from the grain size relation calculated as follows:

$$C_u = C_p + t_{\alpha/2} \cdot s \left[1 + 1/n + (\%clay - \%clay_m)^2 / SS_{\%clay} \right]^{1/2}$$

$$s^2 = (SS_C - \beta_1 \cdot SS_{C\%clay}) / (n - 2)$$

and

$$C_p = \beta_0 + (\beta_1 \cdot \%clay)$$

where:

β_0 and β_1 are the regression coefficients;
$\%clay$ = percentage clay observed;
$\%clay_m$ = mean percentage clay from the data used to determine the grain size relation;
n = the number of observations on which the grain size relation is based;
s^2 = estimated variance of the random error;
$SS_{\%clay}$ = sum of squares for percentage clay;
SS_C = sum of squares for the contaminant;
$SS_{C\%clay}$ = sum of squares of the cross-product: contaminant x percentage clay;
$t_{\alpha/2}$ = critical value of **t** for probability α; and
C_p = concentration of contaminant predicted by the regression relation.

All values of D_i less than zero are considered to be zero, as a negative value for D_i requires that the concentration observed is less than that predicted by the grain size relation. The index of contamination is then calculated by summing the values of D_i for all contaminants measured for that sample:

$$I = (\sum_i D_i)$$

The resulting index, I, will be zero if the concentrations of all contaminants observed are less than, or equal to, the prediction interval for probability α.

Two values of α were considered and evaluated, 5% and 1%, which correspond to 95% and 99% prediction intervals. Figures 13 and 14 present maps of the index of contamination derived from 95% and 99% prediction intervals, respectively. The 99% prediction interval is preferable because it gives results which are consistent with expectations (that the foci of contamination are the active shorebase areas), because falsely concluding that a station is contaminated is undesirable by itself, and because departure from the prediction interval does not imply environmental impact. It is preferable to adopt the more conservative value.

INDEX OF CONTAMINATION

The geographic distribution of the index of contamination (I) (based on the 99% prediction interval) is presented in map form (Figures 15 to 18). In these maps a circle presents a value of $I > 0$, where the size of the circle is related to the magnitude of I, and crosses indicate values of $I = 0$. Stations are labelled with the contaminants considered as outliers.

Appendix 4 presents maps of the distribution of individual contaminants, labelled with the value of **D**, the degree of contamination, for that contaminant.

The maps demonstrate that the majority of the observed outliers were found in Tuktoyaktuk Harbour and McKinley Bay. There were also some outliers in Kugmallit Bay (cadmium) and Hutchison Bay (copper and mercury). Also note that the pattern of outliers for McKinley Bay and Tuktoyaktuk Harbour were different.

HYDROCARBON CONTAMINATION

It is important to note that simple deviation from expected values does not imply anthropogenic input of hydrocarbons. When an outlier is identified, the patterns of specific compounds must be examined. If the CPI is high, it is likely that the source was biogenic, not anthropogenic. The pattern of the alkanes and PAHs (e.g., chromatograms) and the CPI were examined for all hydrocarbon outliers.

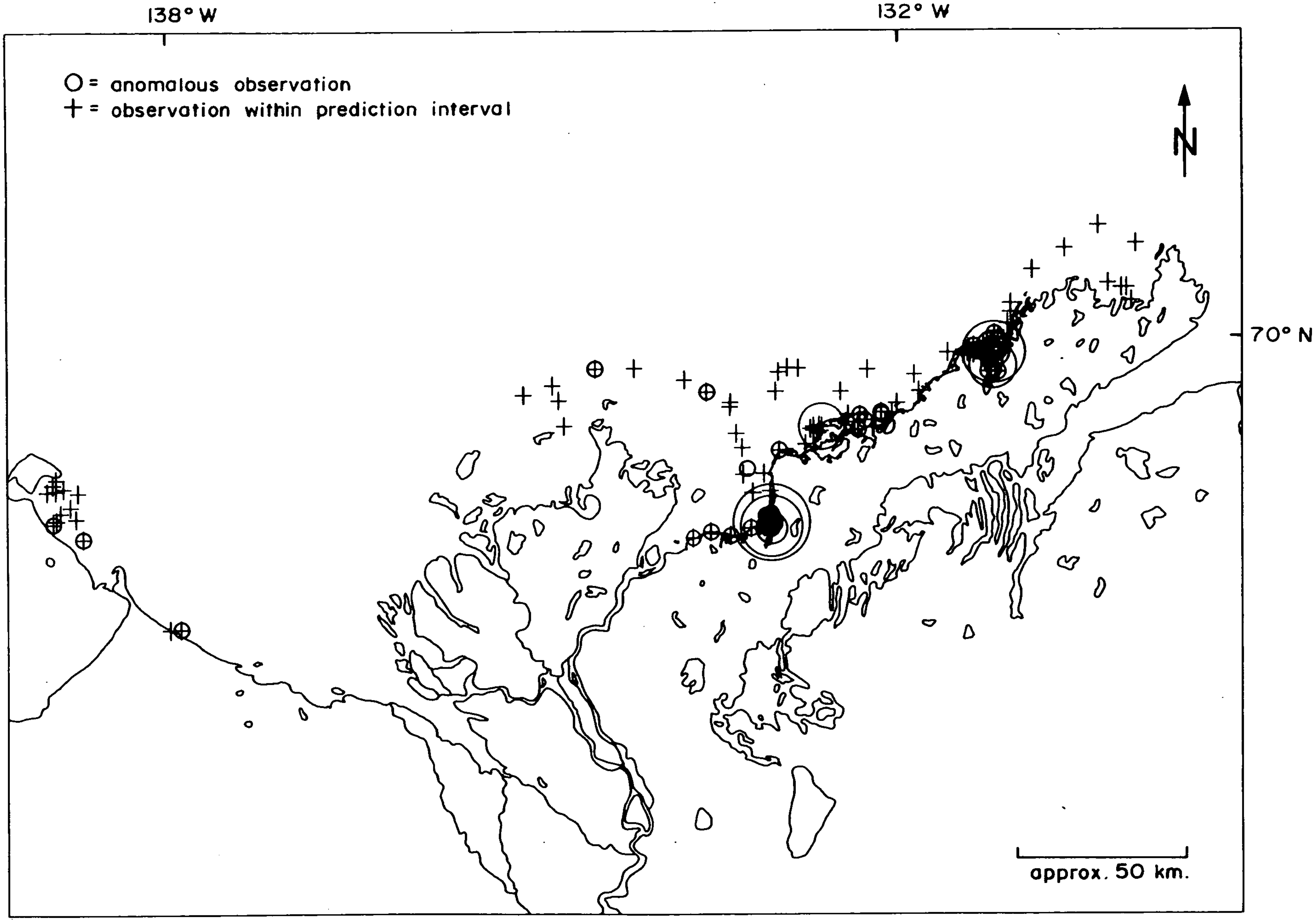

Figure 13. Map of distribution of index of contamination (I) based on 95% prediction interval.

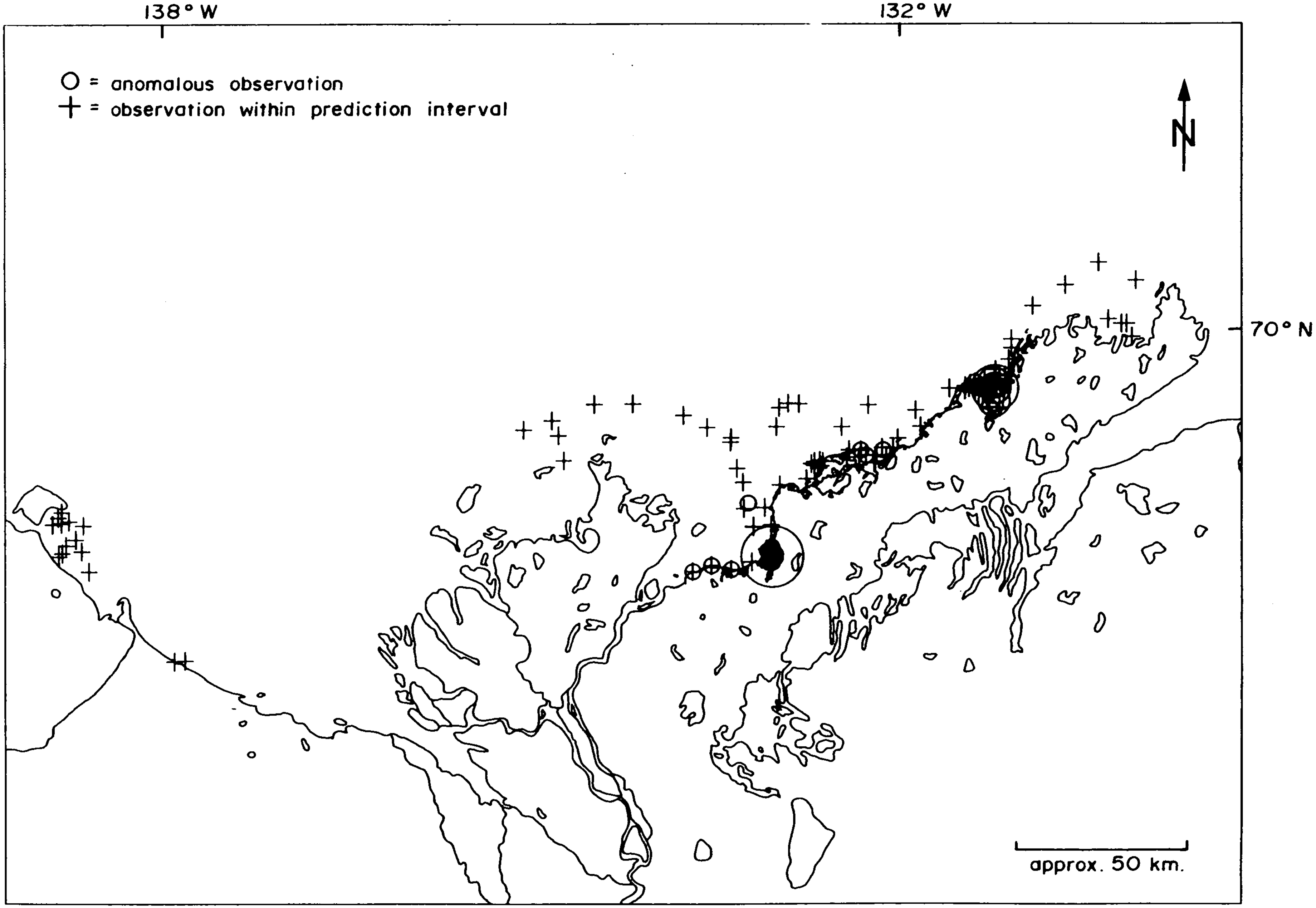

Figure 14. Map of distribution of index of contamination (I) based on 99% prediction interval.

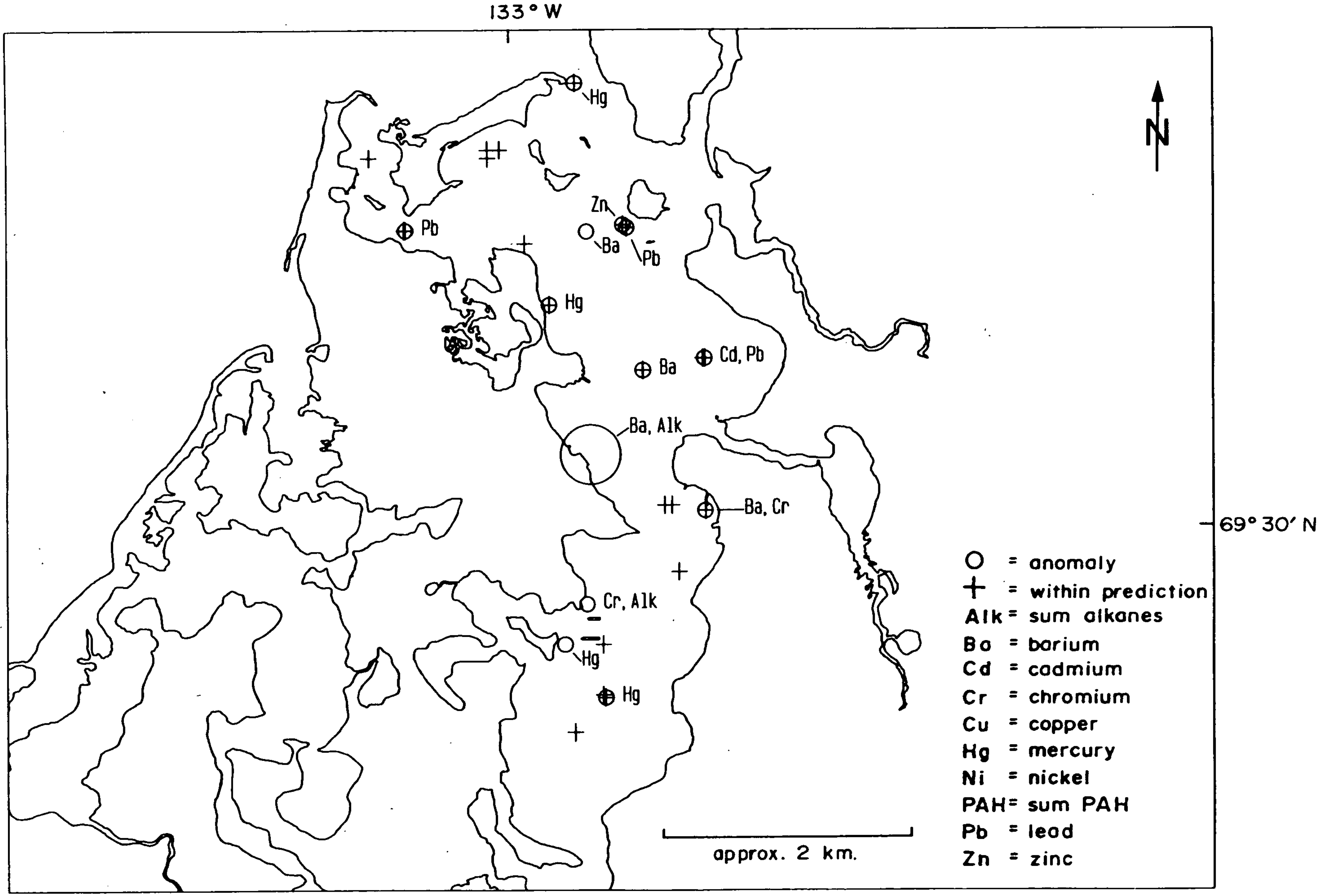

Figure 15. Map of distribution of index of contamination (I) for Tuktoyaktuk Harbour.

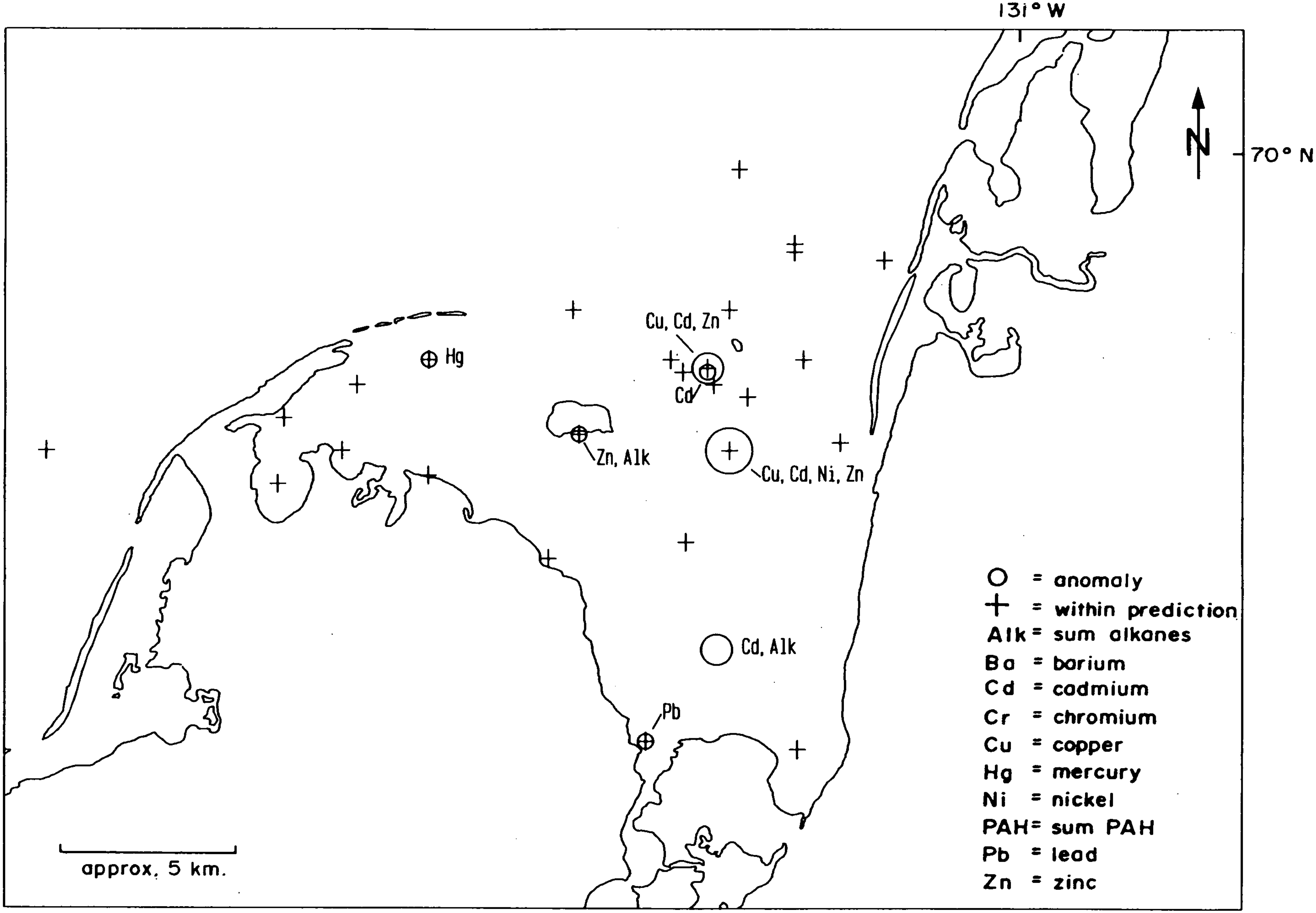

Figure 16. Map of distribution of index of contamination (I) for McKinley Bay.

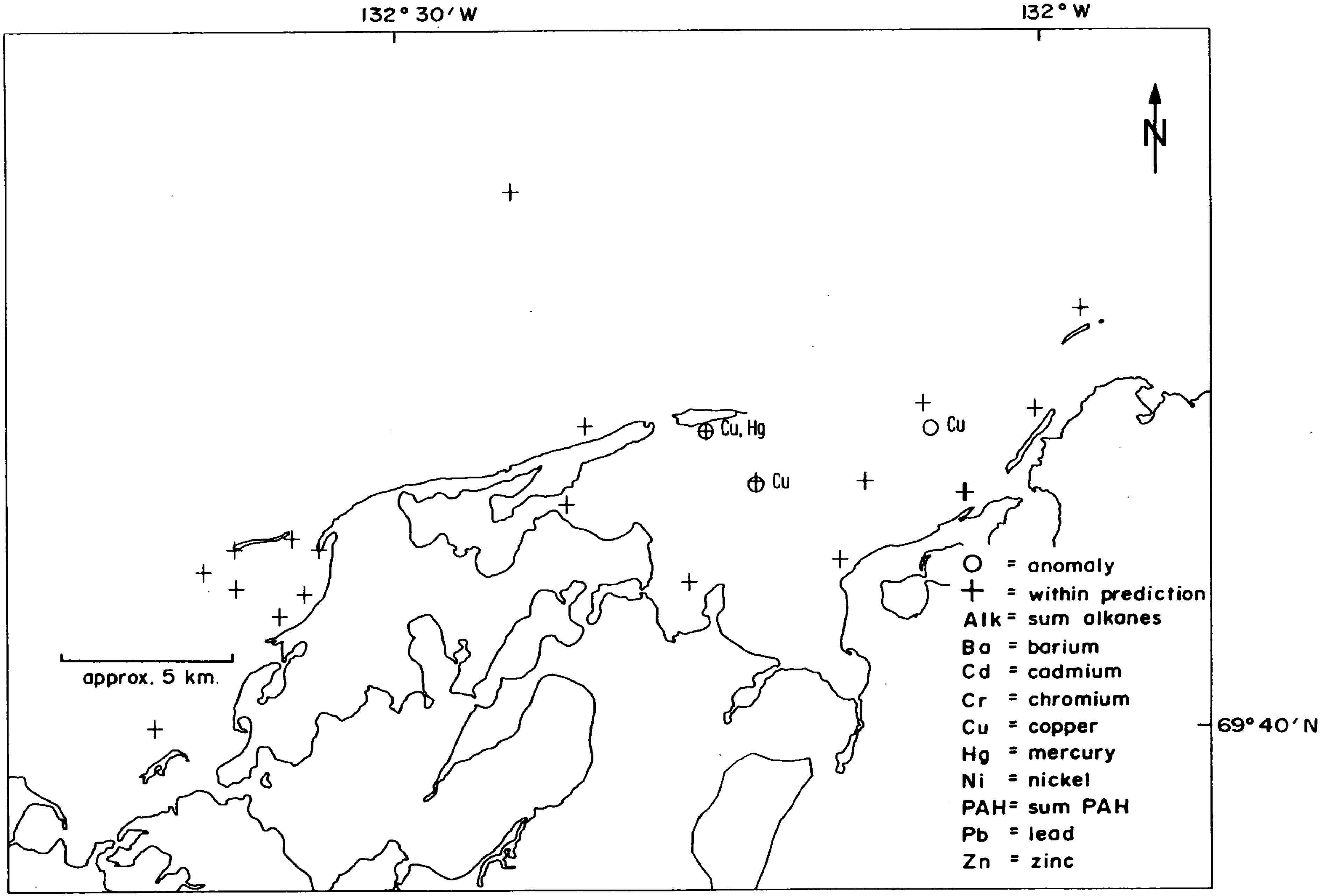

Figure 17. Map of distribution of index of contamination (I) for Hutchison Bay.

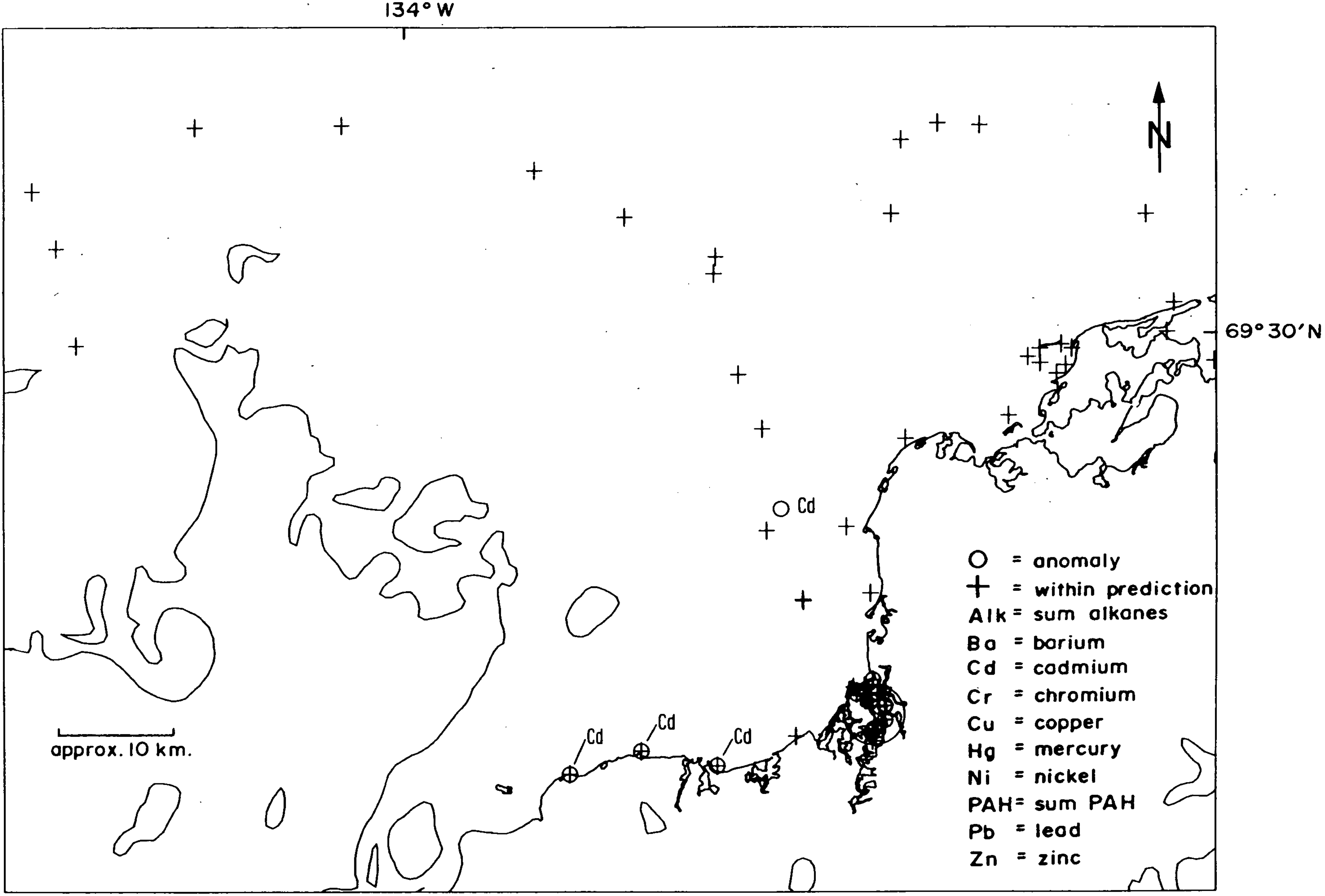

Figure 18. Map of distribution of index of contamination (**I**) for Kugmallit Bay.

ENVIRONMENTAL SIGNIFICANCE

The degree of contamination (**D**) and index of contamination (**I**) values greater than zero (see Figures 15 to 18) indicate that observed concentrations were in excess of those predicted on the basis of sediment grain size. It cannot be assumed that values greater than zero result in adverse effects on the environment, but rather that values of **I** greater than zero imply some risk of environmental effects.

RISK INDEX

It was proposed originally to develop an ecological risk index similar to that of Hakanson (1980). This index would extend the index of contamination by incorporating a toxic response factor and an ecological sensitivity factor to provide a ranking of the stations in terms of relative ecological risk. Such an index cannot be developed objectively for the Beaufort Sea nearshore zone. A toxic response factor potentially could be established from the magnitudes of aquatic LC_{50}-96h (the concentration of a substance which is lethal to 50% of a target species within 96 h under defined exposure conditions) data, as sediment toxicity data are limited. Data are not available to assign ecological sensitivity factors for specific areas of the nearshore zone.

The benefits of a risk index are the result of the reduction of a complex matrix of contaminant data to a single numerical value which may be more easily interpreted. The mapping approach adopted here provides the same benefits by identifying potentially significant concentrations which may then be examined specifically. The development of a risk index was not pursued, because a method of establishing toxic response factors objectively could not be identified.

CONCENTRATIONS OF CONCERN

Thomas *et al.* (1986) reviewed information on ecological effects of contaminants and concentrations of concern. Concentrations of concern are generally available for water column exposure but are limited for sediments. The only criteria identified were from the ODCA applicable to "bulk wastes" and thus to sediments when disposed pursuant to the Act. The ODCA specifies limits for mercury, cadmium and petroleum-related compounds as:

- Cadmium - 0.6 ppm,
- Mercury - 0.75 ppm,
- Petroleum-related compounds - 10 ppm of hexane soluble substances.

No concentrations of mercury in the Shorebase data approached the ODCA limit. Sixty-one observations of cadmium exceeded the ODCA limit with a maximum observed concentration of 1.01 ppm at station 75 (McKinley Bay). Note that from the regression analysis, the upper boundary of the 95% prediction interval exceeded the ODCA limit of 0.6 ppm at a value of about 38% clay. It is expected that cadmium concentrations will exceed the ODCA limit where the sediments are of fine texture. With respect to the limit for petroleum-related compounds, 244 of 249 observations of hexane-extractable compounds exceeded the ODCA limit of 10 ppm. One hundred and four of 233 values of Sum Alkanes (n-C12 to n-C33) also exceed a value of 10 ppm, with a maximum concentration of 107 ppm at station 12 (Tuktoyaktuk Harbour).

DISCUSSION

UTILITY OF APPROACH

The method developed in this project is easy to use and easy to maintain over time. The data are held in a dBASE database, and the calculations are performed using a spread-sheet program such as 1-2-3. The method clearly indicates deviations from expected contaminant concentrations in Beaufort Sea nearshore sediments. Any future determinations can be added to the database and, if they do not represent outliers, can be included in the baseline set of data. Any new data which deviate significantly will be flagged by a value of the index of contamination greater than zero.

SENSITIVITY AND ROBUSTNESS

The method is sensitive, in that it can detect small deviations from expected values. The regression of grain size provides this sensitivity by reducing the variance of the residuals significantly compared to the untreated data. At the same time, the method appears to be sufficiently robust to accommodate differences in analytical and sampling methodology and differences between laboratories. Any improvement in consistency between methods will be seen as increased sensitivity, but the present results appear to be sufficiently sensitive to detect the influence of anthropogenic activity and to identify areas of contamination.

The differences between laboratories have precluded the identification of between-year differences. Improved analytical consistency may permit between-year comparisons.

ENVIRONMENTAL SIGNIFICANCE

The results show that Tuktoyaktuk Harbour and McKinley Bay, the two major shorebase sites, had a greater number of contaminant outliers than the surrounding areas. The distribution of outliers is not limited, however, to the major industrial shore base sites and the distribution of contaminant outliers is not consistent with sites of industrial activity as the only contaminant sources. Some specific sites of contamination are discussed below.

Alkane contamination. Alkane concentrations are elevated at specific sites in both locations. In Tuktoyaktuk Harbour, three sites (all near docks) had high concentrations (see Figure 15), and in McKinley Bay, two sites had elevated alkane concentrations, one of which was also near a dock (see Figure 16). There were no corresponding PAH outliers at these sites, which may possibly be caused by the scatter in the PAH to grain size relation or by the poor relationship observed between Sum Alkanes and Sum PAH. All outliers in Tuktoyaktuk Harbour and the largest outlier in McKinley Bay were part of the NAS 84 data set; these analyses were of low quality which may contribute to their classification as outliers.

Examination of the alkane distribution of these results indicates a high CPI and a pattern (n-C25 to n-C31 envelope, high CPI) commonly considered to represent terrigenous wax material, often the result of surface drainage or coastal erosion. The remaining outlier near the McKinley Bay dock site has an alkane pattern similar to a weathered petroleum product or crude oil.

Cadmium contamination. Cadmium outliers were common in McKinley Bay and Kugmallit Bay. In addition, the grain size relation indicates that fine sediments naturally will exceed the ODCA limit of 0.6 ppm for cadmium. This result suggests either that there may be an environmental risk associated with fine sediments in the Beaufort Sea or that the ODCA limit for cadmium is not applicable (i.e., is too low).

Barium contamination. Barium concentrations were elevated at some Tuktoyaktuk Harbour sites. The greatest deviations were found near docks. These deviations may represent a spill of barite. Barium is not considered very toxic.

Copper, cadmium, and zinc contamination. Two sites in McKinley Bay were noteworthy as having elevated concentrations of copper, cadmium and zinc. One of these sites was in the turning basin, and the other was just south of the turning basin.

Mercury contamination. Mercury concentrations were elevated at some sites in Tuktoyaktuk Harbour, although one mercury outlier was also found in each of McKinley and Hutchison Bays. No association with specific industrial sites was apparent.

Copper contamination. Three of eight Hutchison Bay sites showed copper outliers. McKinley Bay also demonstrated two sites with elevated copper concentrations, however, none were apparent in Tuktoyaktuk Harbour.

The metal deviations may be natural anomalies (as appears to be the case with the association between fine sediment and high cadmium concentrations and for four out of five alkane outliers) or may be anthropogenic. The environmental significance of these contaminant deviations is not clear. It is not clear that sample collection was representative of the embayments, which limits the conclusions that may be drawn, but the distribution of deviations from predictions is sufficient cause to indicate that the two shorebase embayments are sites of concern.

The analysis of the monitoring results from 1982 to 1984 does not indicate that environmentally significant changes to the sediments have occurred, but that some detectable changes were occurring in the two major shorebase embayments.

DESIGN PROBLEMS

The central hypothesis for testing in the Beaufort Shorebase Monitoring Program as proposed by Yunker (1986) is the following:

H_0 "The difference between Impact and Control locations, averaged over several times in the After condition, does not change from the difference between Impact and Control locations, averaged over several times in the Before condition."

where Impact location refers to Tuktoyaktuk Harbour and McKinley Bay, and Control location refers to Hutchison Bay. An experimental design to test this hypothesis would allocate an equal number of samples to the Control location(s) and the Impact location(s). Chemical analyses of the samples should also be allocated uniformly. Further, because of the importance of the grain size effect demonstrated by Yunker (1986) and in this study, analysis of sediment grain size must be performed on all samples.

The adequacy of any sampling design is dependent on the objectives of the monitoring study, that is, the hypothesis to be tested. A formal statement of the objectives of the Shorebase Monitoring Program was not available, however, some general comments may still be made concerning the design. Although inconsistencies in methodology limited the analysis to some extent, design inadequacies also limited the ability to analyse the data (e.g., it was not possible to test which embayment was more contaminated).

The sampling design was inadequate because a significant proportion of the data (40%) were excluded from analysis because of lack of critical grain size data. Also, control samples were collected at various locations that were inconsistent between years. The influence of the location of control samples could be significant in assessment of differences between years, which was not possible in this case because of inter-laboratory methodology differences. The suitability of Hutchison Bay as a control embayment in future monitoring should be reconsidered, given the frequency of contaminant outliers observed. Lastly, the number and location of samples collected could not be considered to be representative of the specific embayments. Representative sampling could, in future, be conducted at no incremental cost and would extend the ability to analyse the data. Representative sampling could be achieved through stratified random sampling, as systematic sampling is more sensitive to positioning error and inability to resample specific locations year to year.

TESTS OF SPECIFIC HYPOTHESES

Specific hypotheses tested for the 1984 data, (identified in the Statement of Work) and the results are:

a) $\mathbf{H_0}$: No differences exist between embayments.

Differences in station grain size within the embayments explain the differences in most contaminant concentrations. The data sets do not permit rigorous testing of the embayments as a whole because the suites of samples were not representative of the whole embayments. Different contaminants are elevated in the different embayments. This confirms Yunker's (1986) conclusion that embayments were different in 1982 and 1983.

b) $\mathbf{H_0}$: No differences exist between sample locations within embayments.

Some sample locations showed elevated concentrations of some contaminants. Differences between locations clearly existed, however, most concentration differences can be explained by grain size differences.

c) $\mathbf{H_0}$: No differences exist between depth horizons of cores at sample locations.

The available data did not permit adequate testing of this hypothesis.

d) $\mathbf{H_0}$: No differences exist between replicate samples within single stations.

Replicate grabs were often different.

e) $\mathbf{H_0}$: No correlation exists between physical and chemical variables with distance from the Mackenzie Delta.

In the 1984 data, no observed differences could be explained by distance from the delta.

f) H_0: No correlation exists between and among contaminant concentrations, total organic carbon (TOC), water depth, and sediment grain size.

Contaminant concentrations were shown to be correlated with grain size. TOC is related to grain size, therefore some correlations appear between TOC and contaminant concentration. Any correlations between contaminants and water depths were not testable.

Specific hypotheses tested on the complete data set and the results are:

a) H_0: No differences exist between embayments.

Tuktoyaktuk Harbour and McKinley Bay were found to have different contaminant concentrations, most of which can be explained by grain size differences between the embayments. The contaminant distributions and anthropogenic inputs identified by this method were different in the two embayments.

b) H_0: No differences exist between years for all embayments.

Any differences between years for the embayments were indistinguishable from intra- and inter-laboratory analytical differences.

c) H_0: No differences exist between years for individual embayments.

Intra- and inter-laboratory analytical differences masked any such differences.

d) H_0: No correlation exists between physical and chemical variables with distance from the Mackenzie Delta.

There were a group of cadmium outliers at nearshore sites in Kugmallit Bay, near the mouth of the East Channel of the Mackenzie River. Because of lack of data, it was not possible to determine whether this was a local anomaly or the influence of the Mackenzie River.

e) H_0: No correlation exists between and among contaminant concentrations, TOC, water depth, and sediment grain size.

Sediment grain size explains between 25% and 82% of the contaminant concentrations. TOC is related to sediment grain size, and therefore shows similar relationships. Correlations with water depth were not testable using the data available.

RECOMMENDATIONS

FUTURE MONITORING

The continuation of sediment contaminant monitoring of the shorebase embayments is recommended because the 1982-1984 data demonstrate evidence of environmental contamination. Previous sampling design and methods have been inconsistent, which has been detrimental to the monitoring program. Consistent methods should be adopted and a revised sampling design should be employed.

Sampling Design

The sampling design should incorporate random sampling that is representative of the embayments. Replicate samples are not beneficial. Instead, attempts to compare locations within embayments should be discontinued, and the design should include single samples at a greater number of locations and only analytical replication for QC/QA purposes. Sampling locations with coarse substrate or shallow water should be avoided. The number of samples collected in the shorebase embayments and control locations should be equally allocated. Sampling should include the accumulation basins in each embayment, but need not be limited to them. A stratified random sampling design based on depth appears appropriate, however, other designs may be equally suitable depending on monitoring objectives.

Grain size measurements must be obtained for all samples and the influence of grain size must be considered in the interpretation and analysis of all data.

The mapping of contaminant outliers has identified several potential contaminant sources. Where specific sites are considered to be of concern, a systematic sampling program along transects radiating from the suspected source(s) is recommended to assess the spatial contamination and the zone of influence of the potential source(s).

Sampling Methods

A grab sampler is recommended because the focus of the Shorebase Monitoring Program is on surficial sediments and grabs typically yield a larger sample size. Samples for hydrocarbon analysis should not be stored in plastic containers (other than Teflon).

Analytical Methods

Consistency must be maintained in sampling and analytical methods, particularly the size thresholds used in grain size determination.

A hierarchical approach to hydrocarbon analyses should be adopted. Analyses should be performed initially on all samples using an inexpensive technique such as infra-red spectroscopy for alkanes <u>and</u> ultra-violet excitation-emission spectroscopy (UV/FL) for PAHs. Although the UV/FL method often exhibits high natural background, the monitoring program is only interested in deviations from that natural background. When these analyses indicate elevated concentrations, detailed analysis should be performed using gas chromatography/flame ionization detection (GC/FID) or gas chromatography/mass spectrometry (GC/MS) techniques as appropriate. The present GC/FID alkane determination is adequate. The alkane patterns are useful in evaluating origin. The GC/MS alkane method should not be used without specific alkane internal standards and improved replication. The GC/MS procedure for PAH is not adequate to evaluate origin. A procedural change would be necessary; data regarding substitution patterns on the aromatic rings are required, which would increase the cost, and is of limited value. These additional analyses should be used sparingly.

QC/QA Procedures

An intercalibration program should be undertaken to establish the extent of inter-data set bias. This procedure would involve blind reanalysis of control samples and, possibly, intercalibration of sampling methods. Analysis of standard reference materials are not considered sufficient for this purpose.

Standard reference materials should continue to be used whenever possible. It is recommended that a Beaufort Sea standard reference sediment be prepared for all contaminants, including hydrocarbons.

Where QC/QA programs indicate problems (e.g., lead analyses by ALL in 1983 and alkane analyses by NAS in 1984) the analyses should be redone.

ENVIRONMENTAL RISK

Where the grain size relationship predicts contaminant concentrations higher than regulatory limits (as is the case with cadmium for Beaufort Sea nearshore sediments), the specific sediments should be investigated to confirm the applicability of the regulatory limit.

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APPENDIX 1

Frequency Distributions and Descriptive Statistics for Specific Contaminants

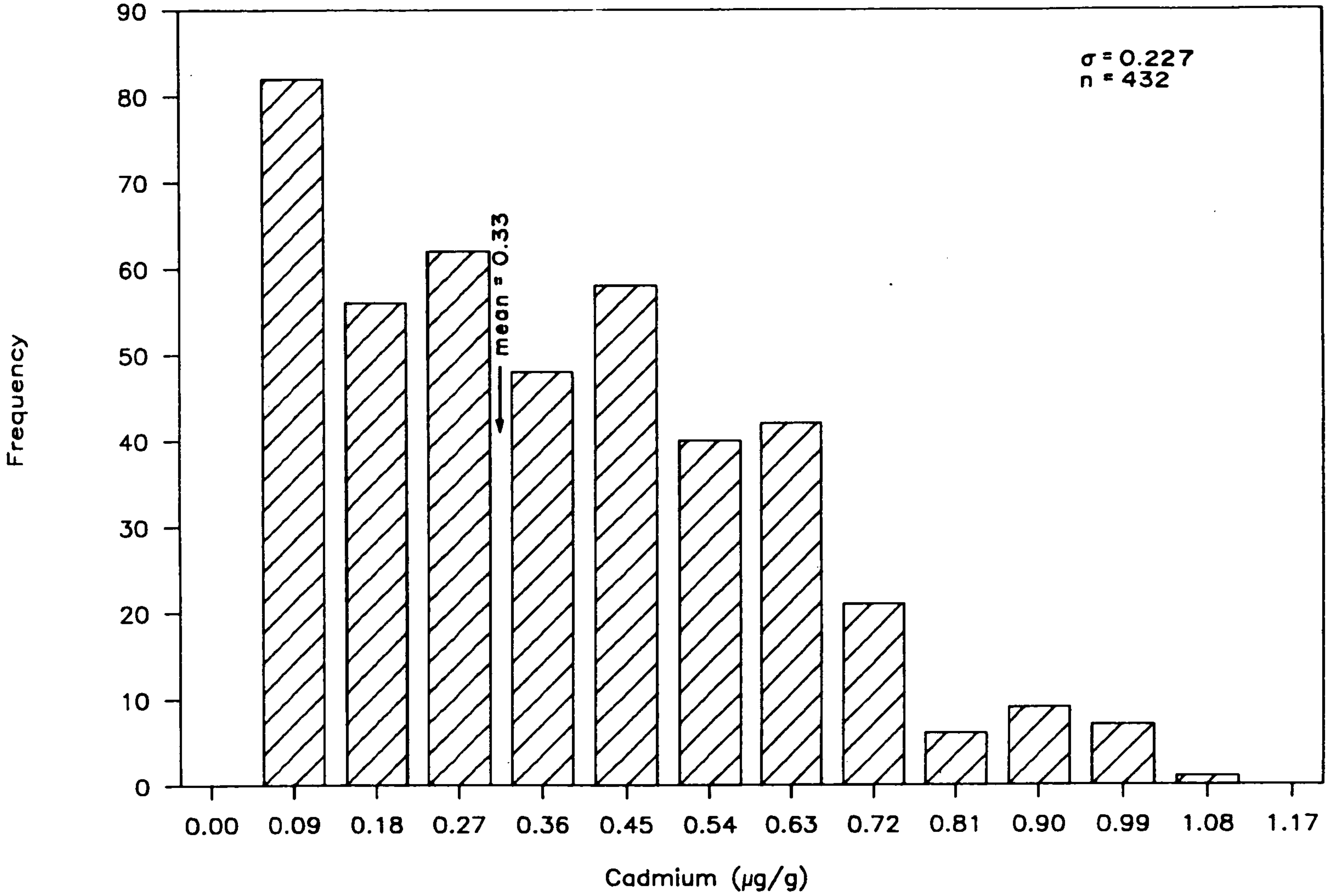

Figure 1 - 1. Frequency distribution and descriptive statistics for cadmium (Cd).

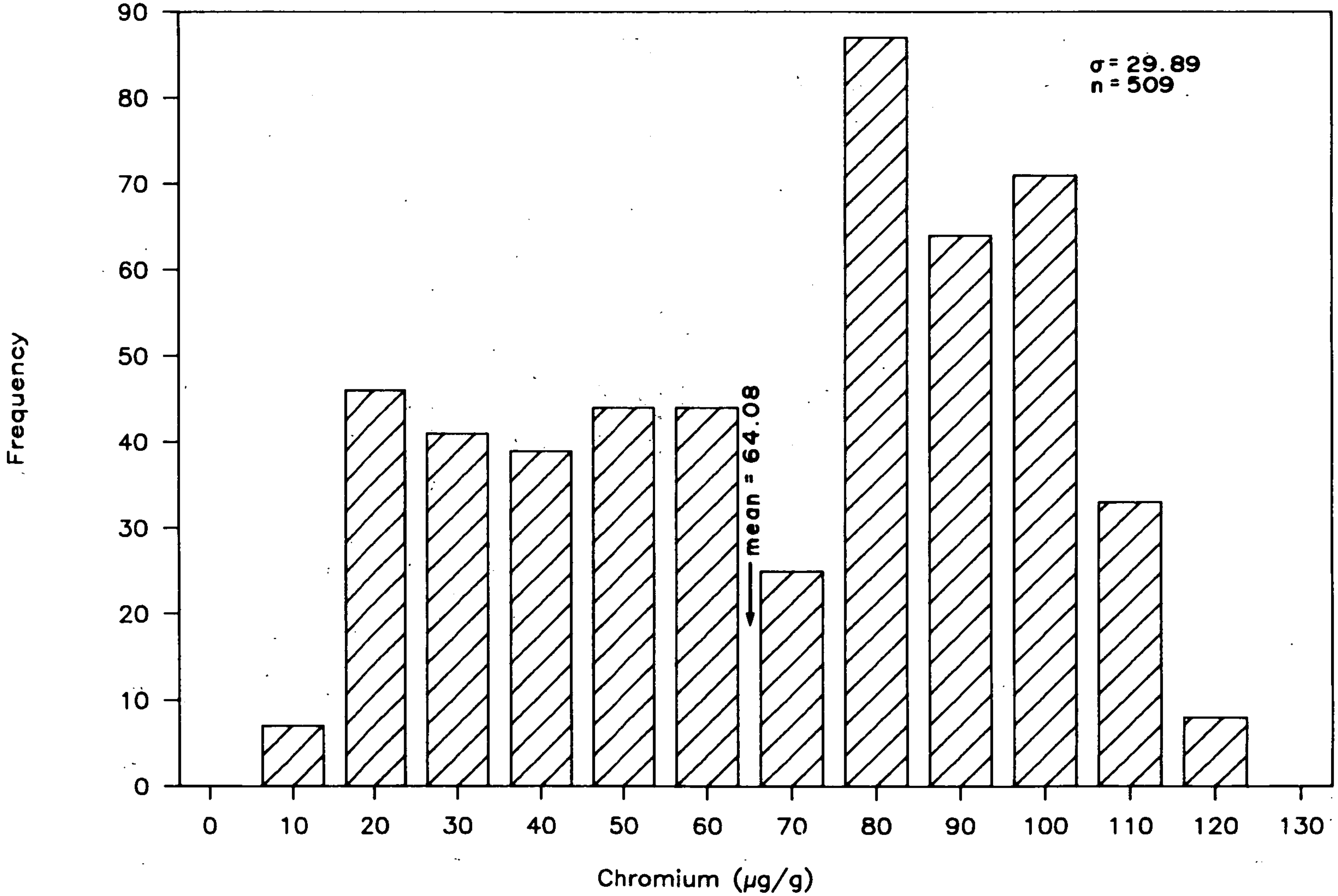

Figure 1 - 2. Frequency distribution and descriptive statistics for chromium (Cr).

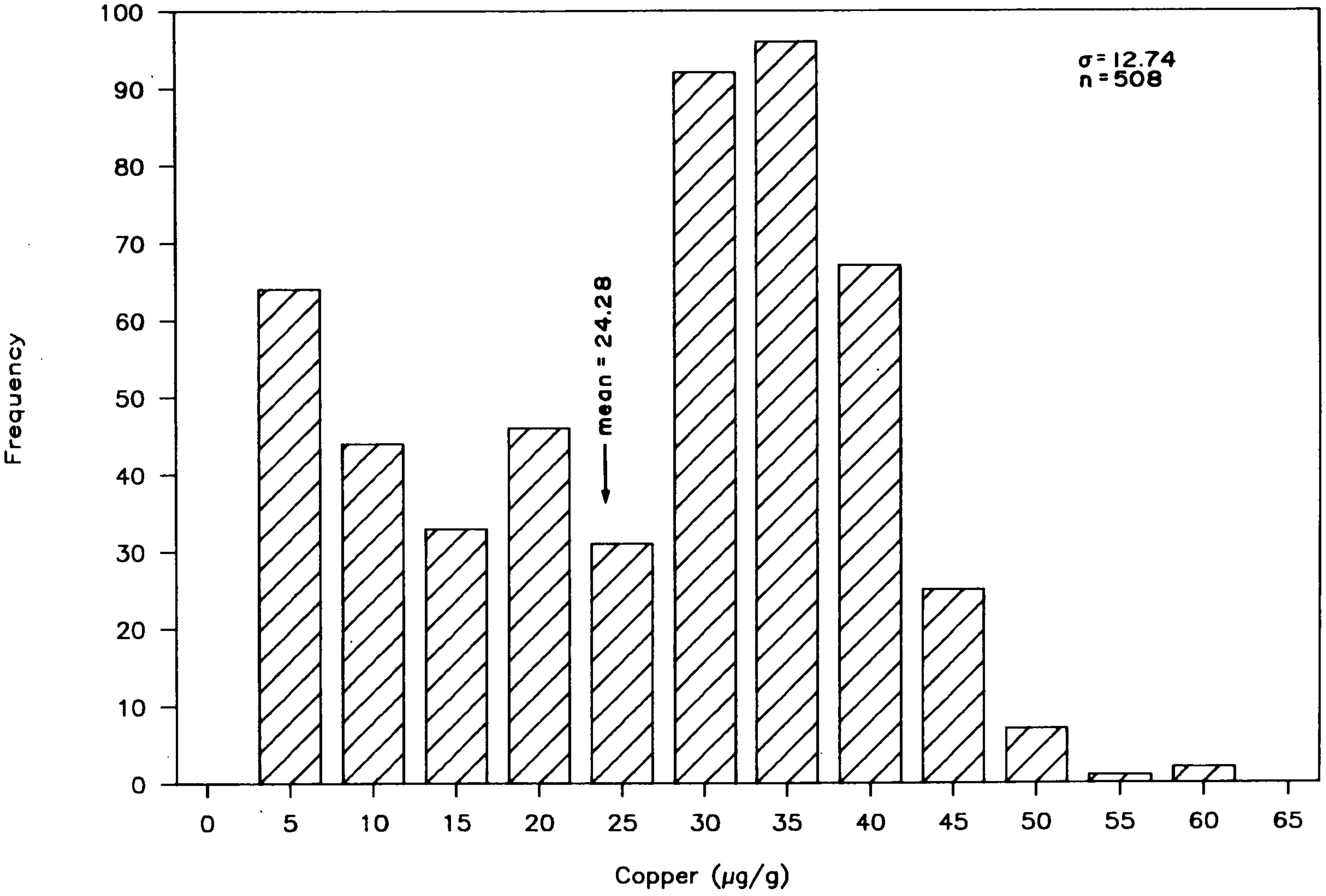

Figure 1 - 3. Frequency distribution and descriptive statistics for copper (Cu).

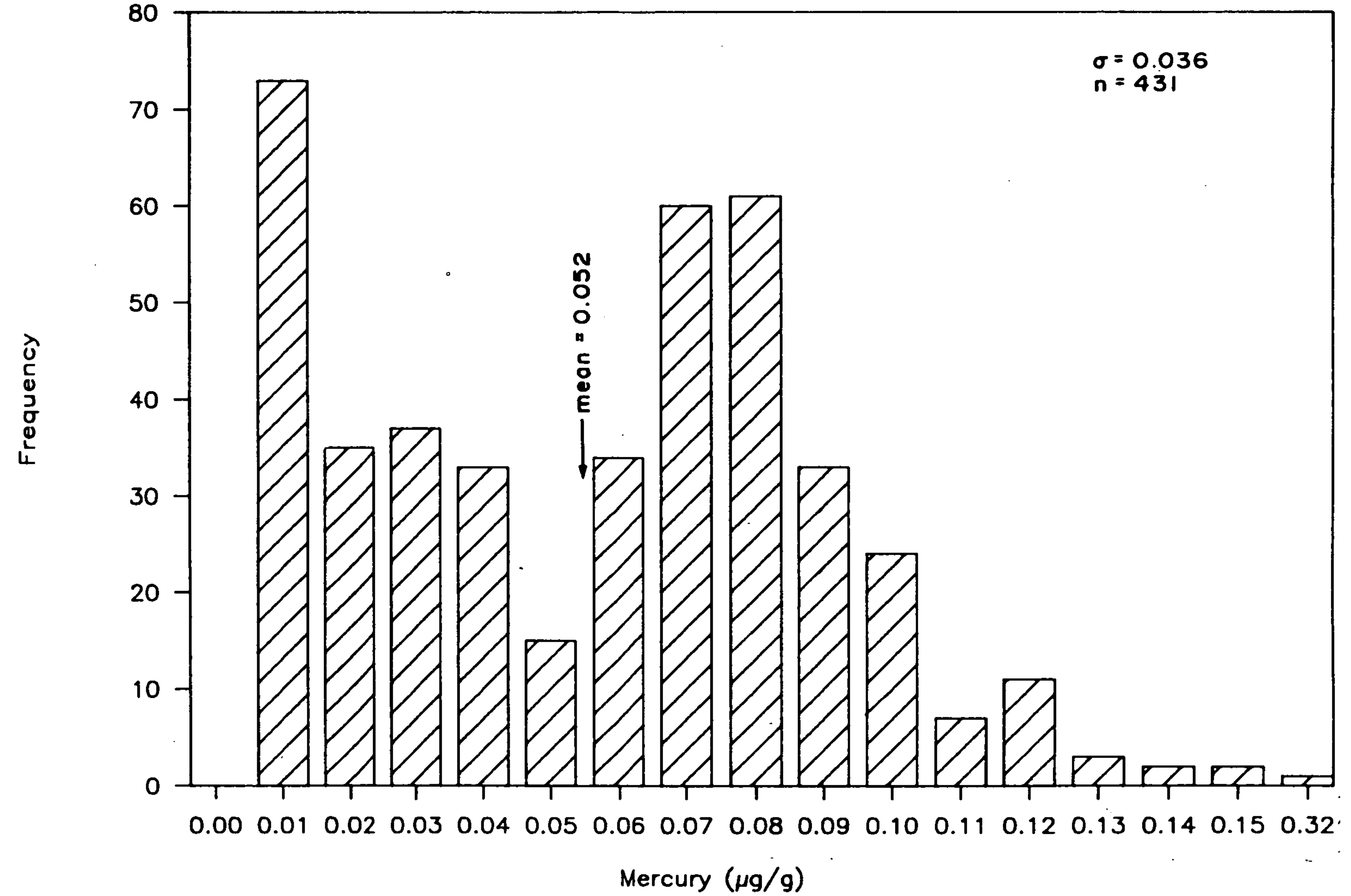

Figure 1 - 4. Frequency distribution and descriptive statistics for mercury (Hg).

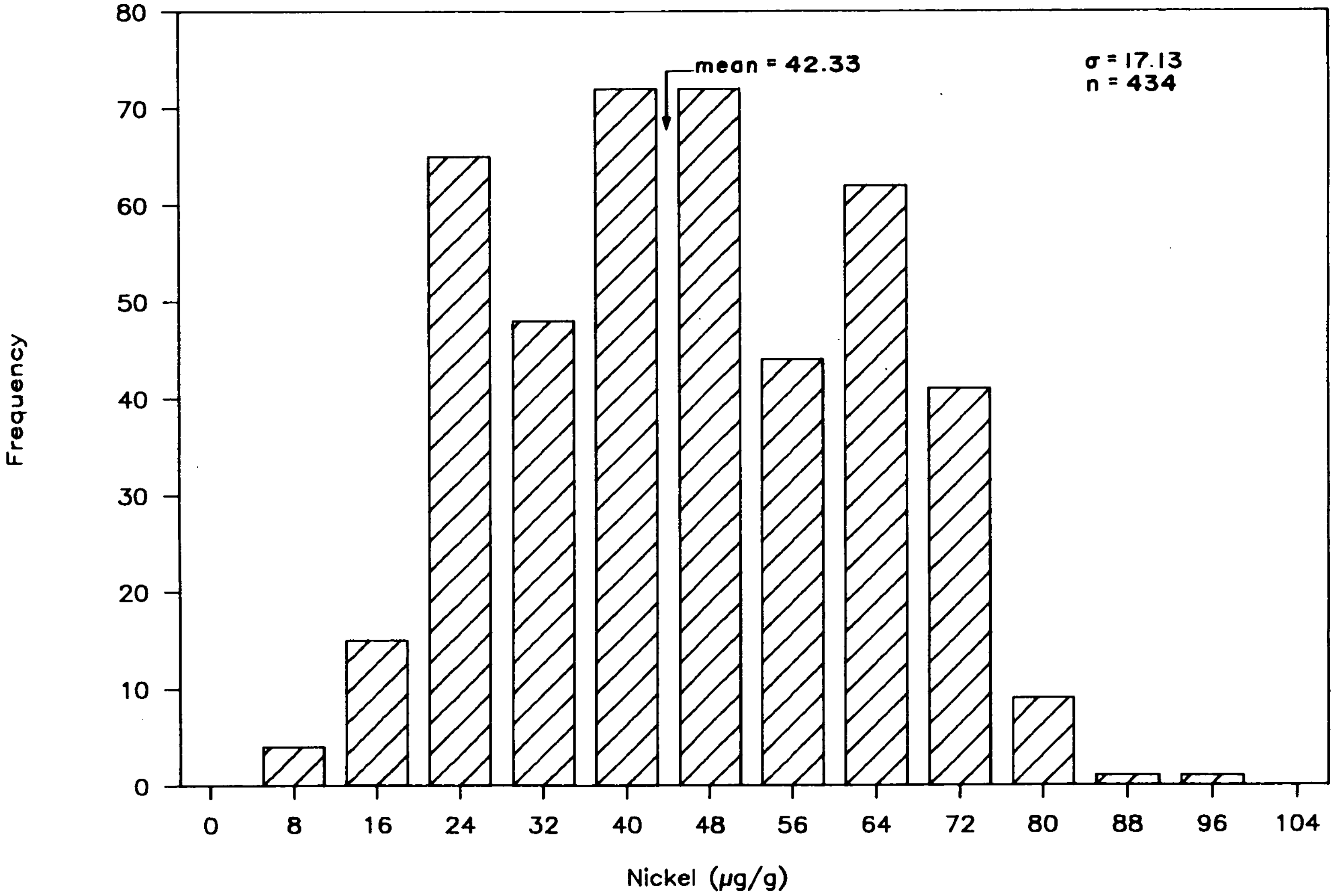

Figure 1 - 5. Frequency distribution and descriptive statistics for nickel (Ni).

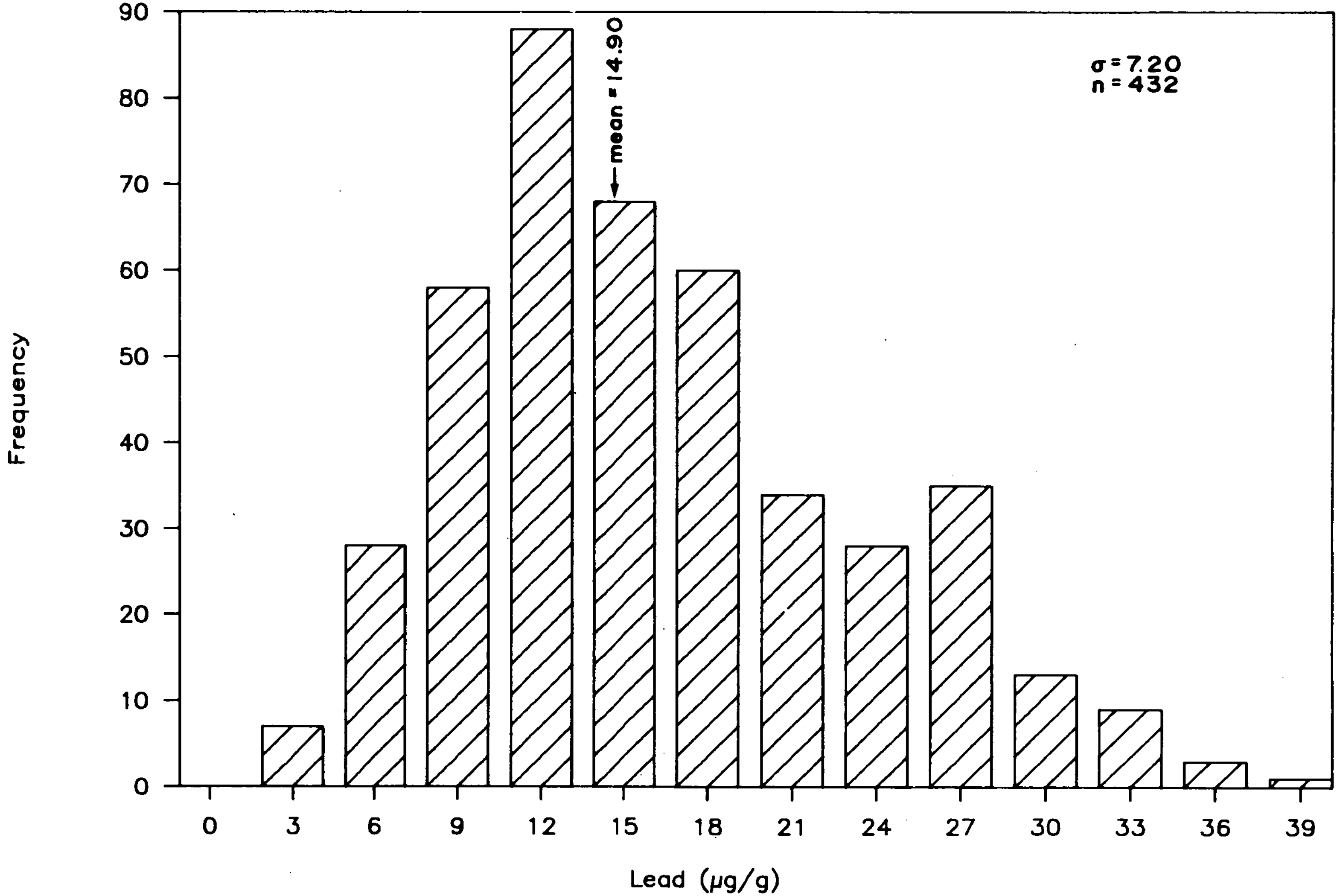

Figure 1 - 6. Frequency distribution and descriptive statistics for lead (Pb).

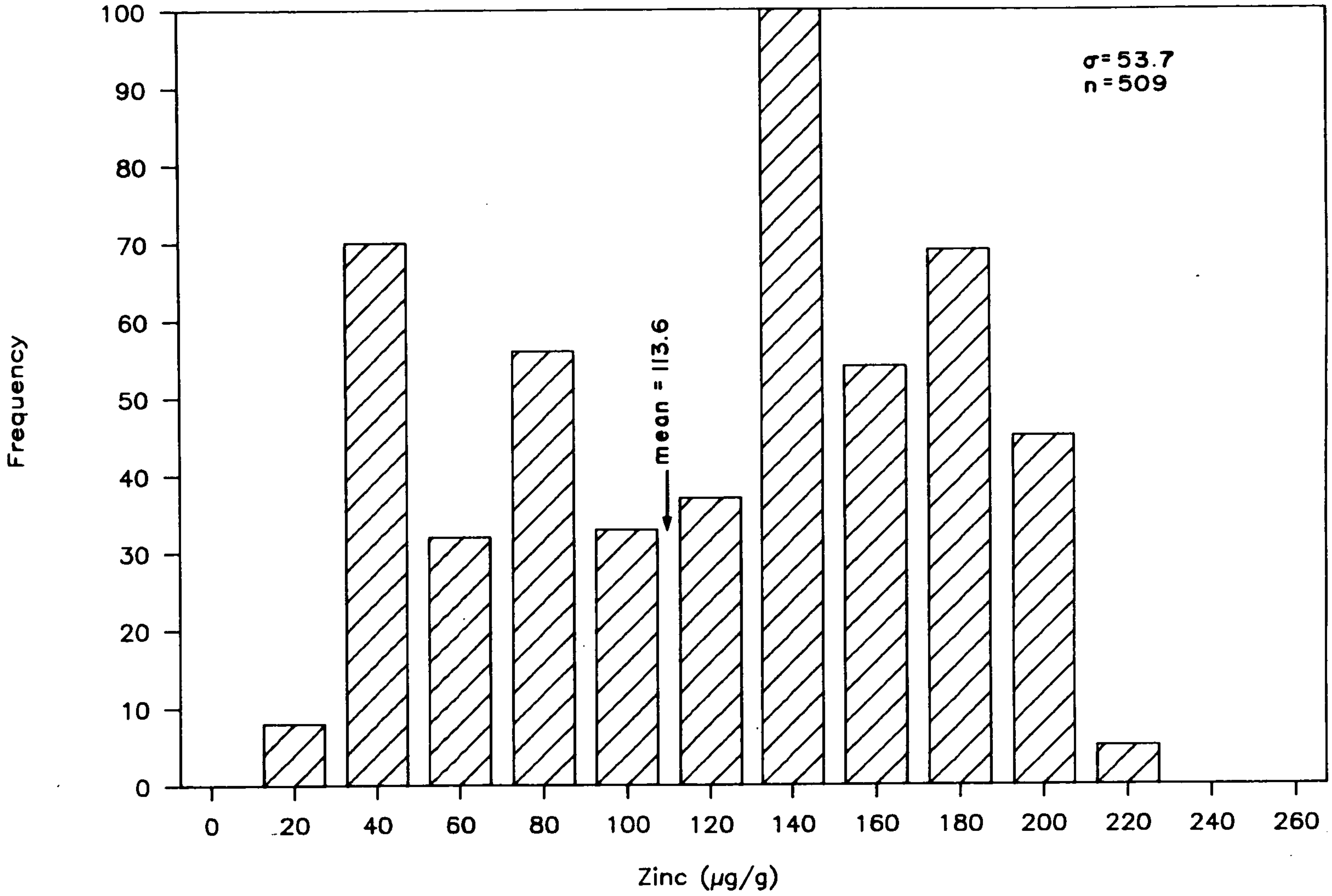

Figure 1 - 7. Frequency distribution and descriptive statistics for zinc (Zn).

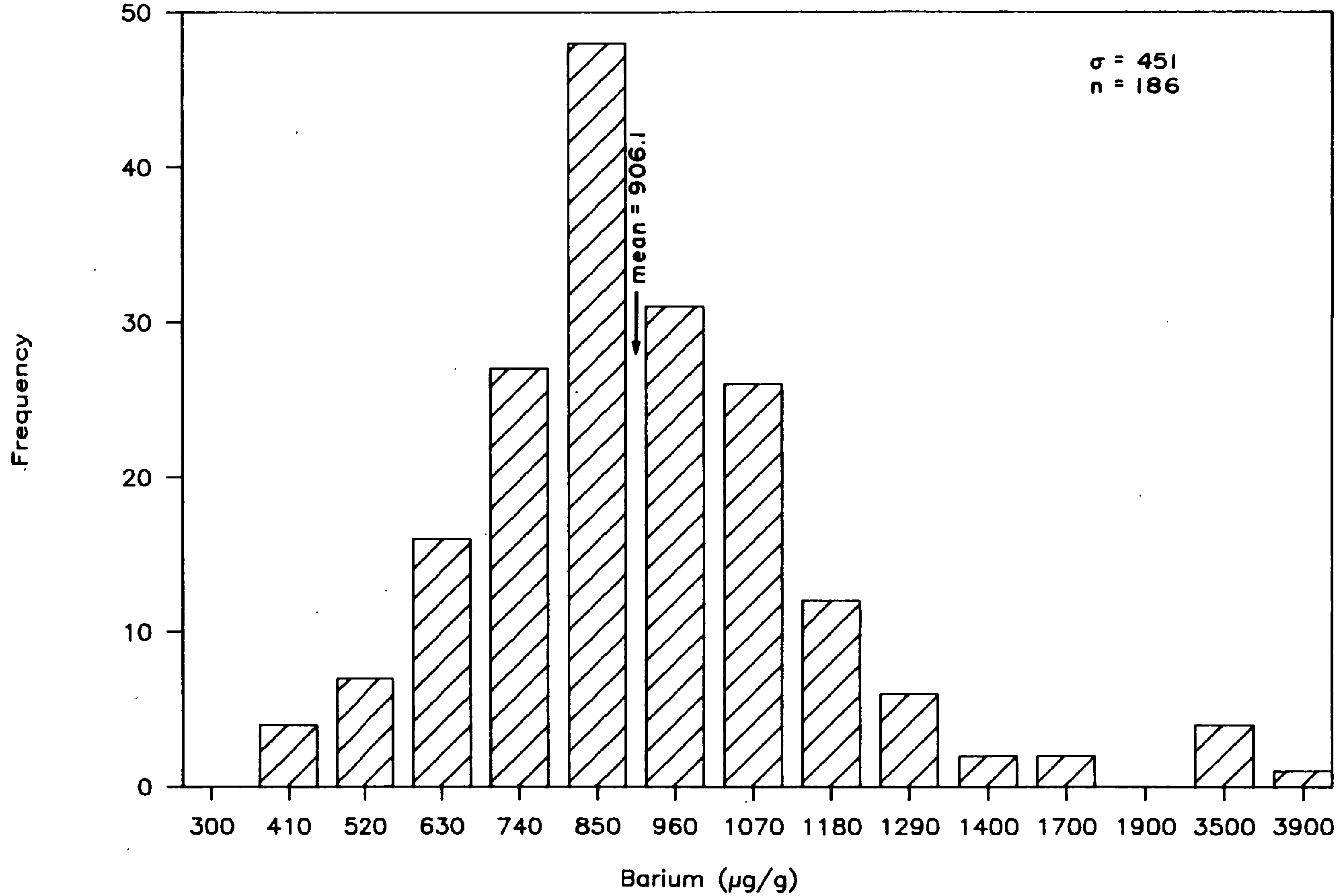

Figure 1 - 8. Frequency distribution and descriptive statistics for barium (Ba).

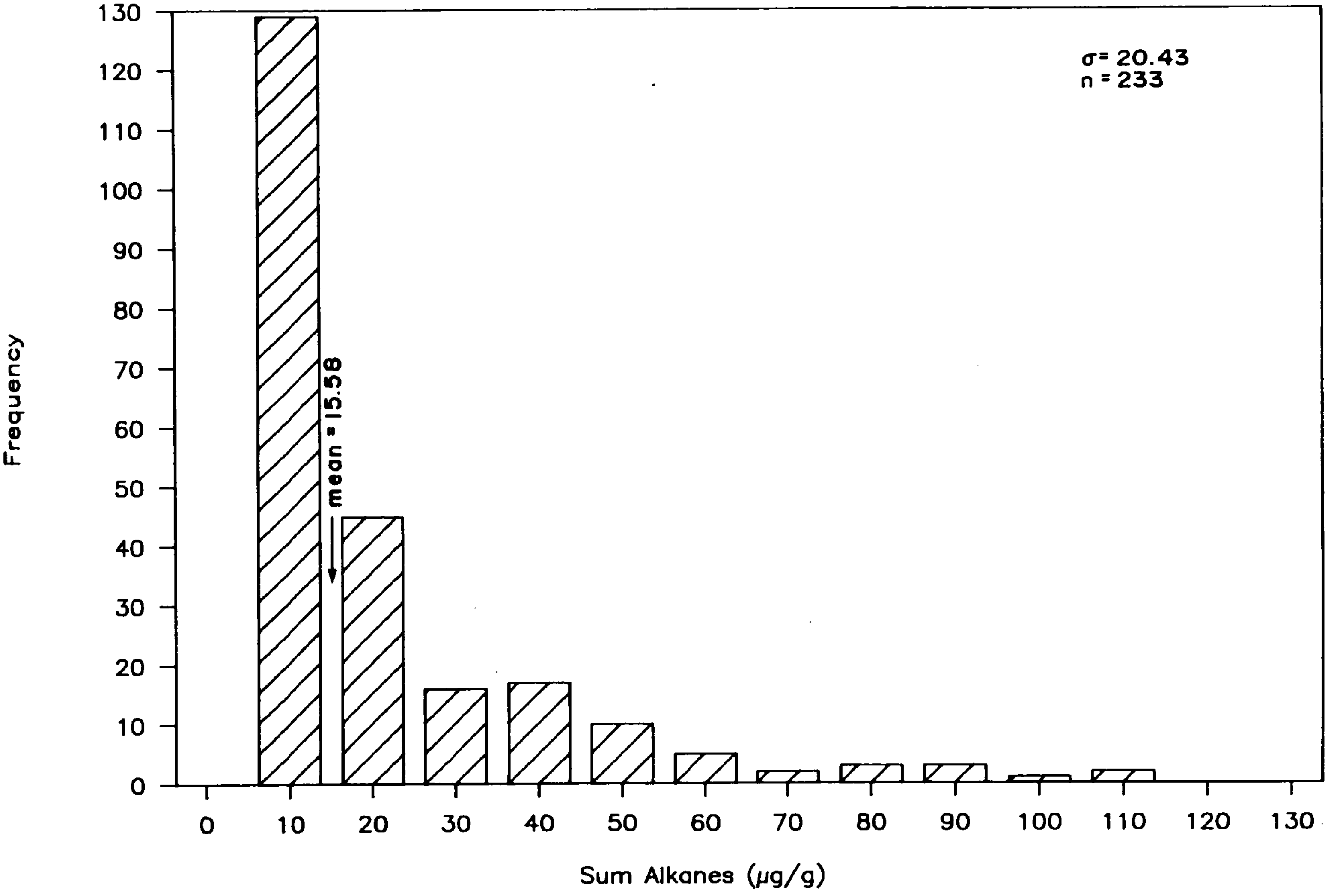

Figure 1 - 9. Frequency distribution and discriptive statistics for Sum Alkanes (ΣAlk) (nC12 - nC33).

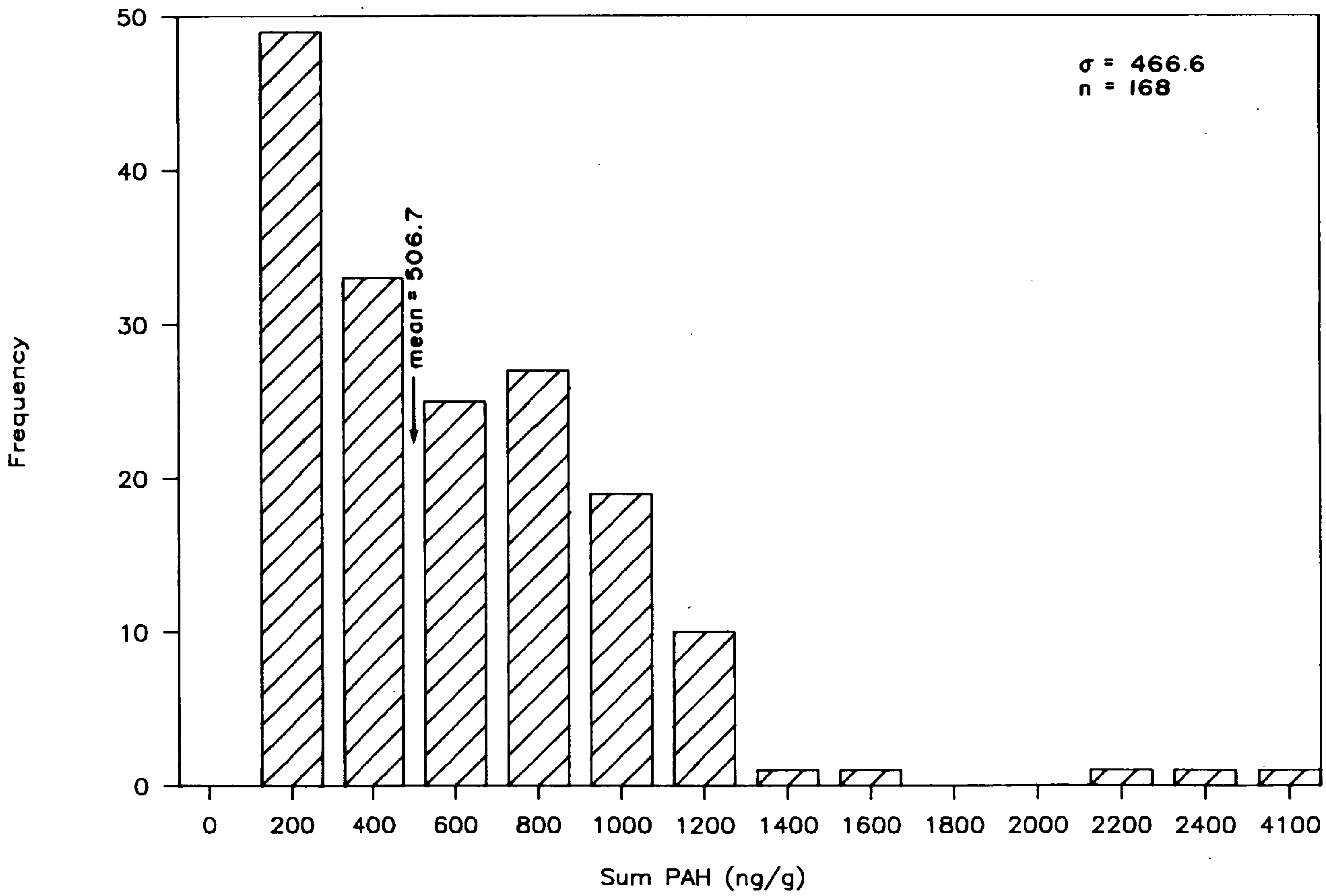

Figure 1 - 10. Frequency distribution and descriptive statistics for Sum PAH (ΣPAH).

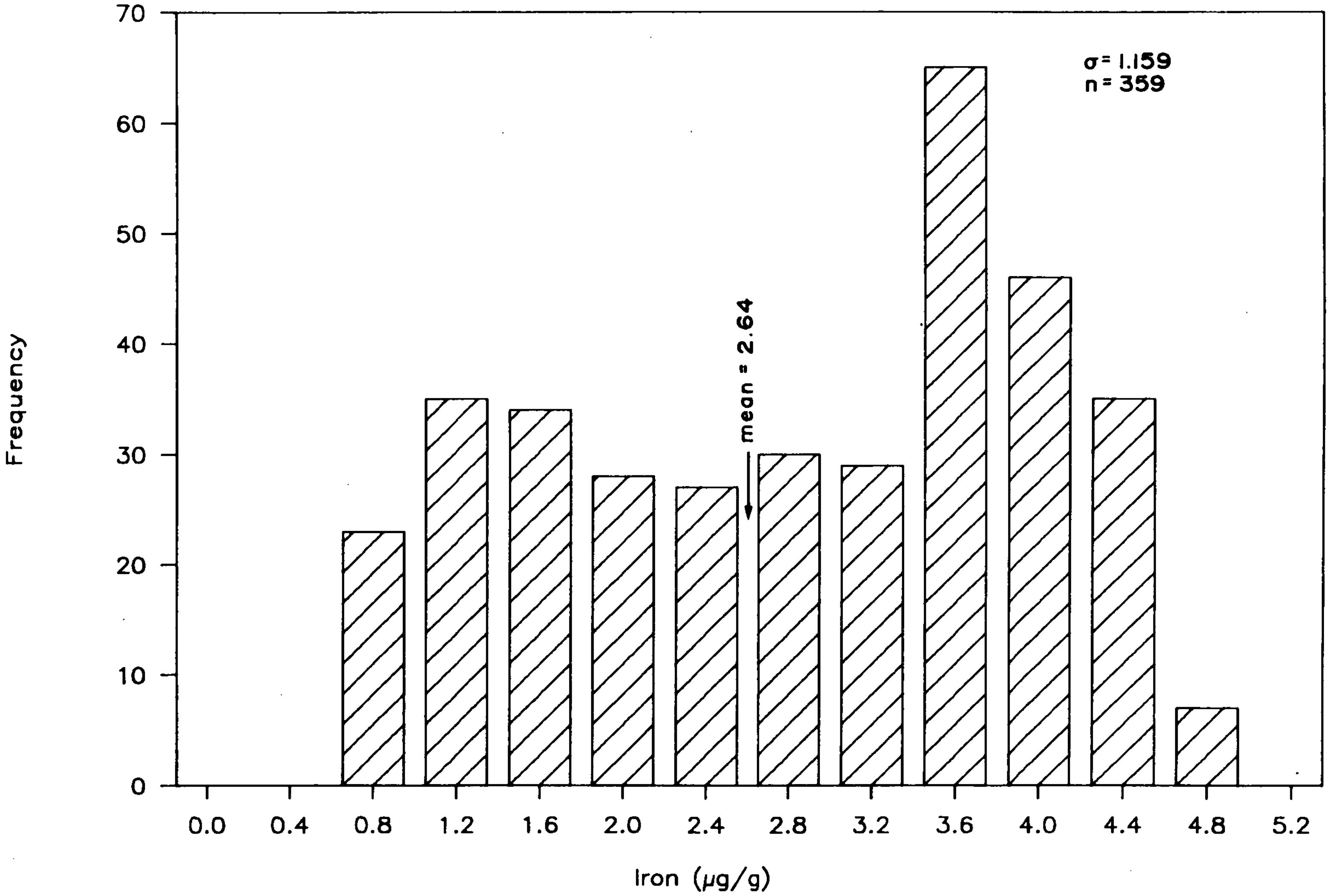

Figure 1 - 11. Frequency distribution and descriptive statistics for iron (Fe).

APPENDIX 2

Regression Analyses and Frequency Distribution of Residuals for Specific Contaminants

See Table 4 (page 41) for a listing of meanings of letters used to identify groupings of data.

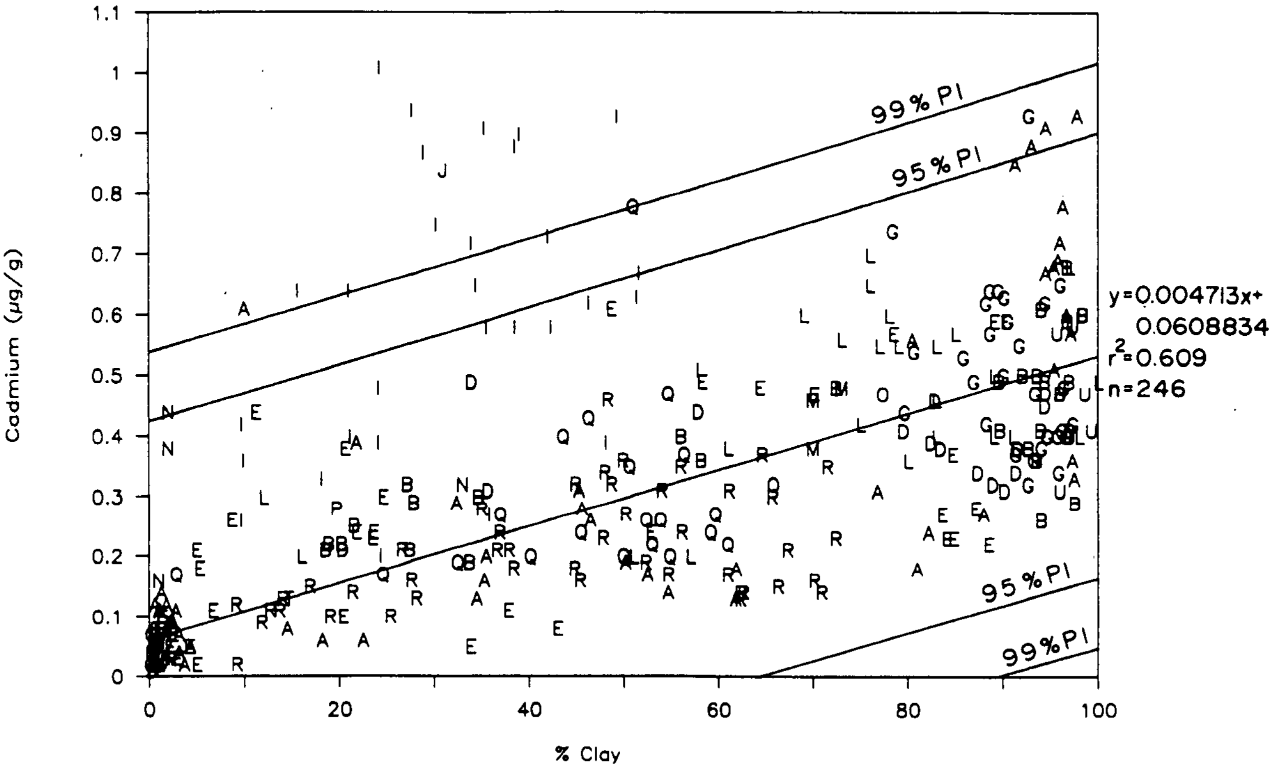

Figure 2 - 1. Regression analysis of cadmium (Cd) against % clay (McKinley Bay excluded from regression).

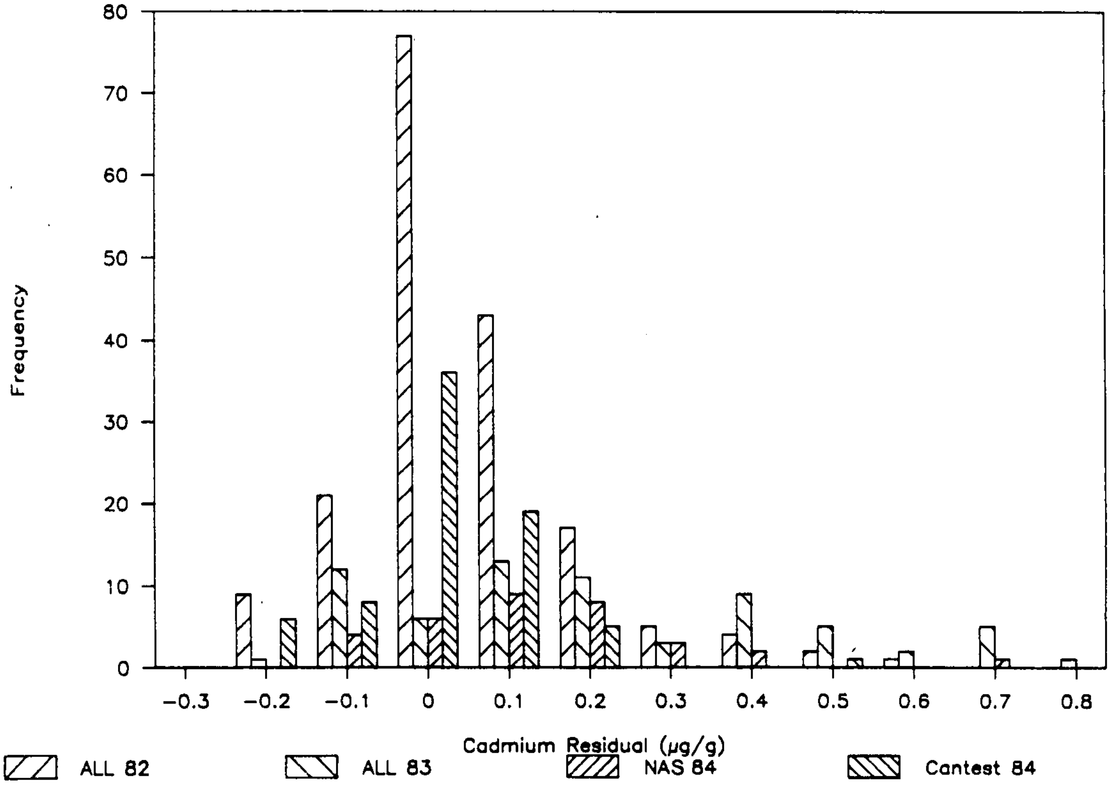

Figure 2 - 2. Frequency distribution of cadmium (Cd) residuals.

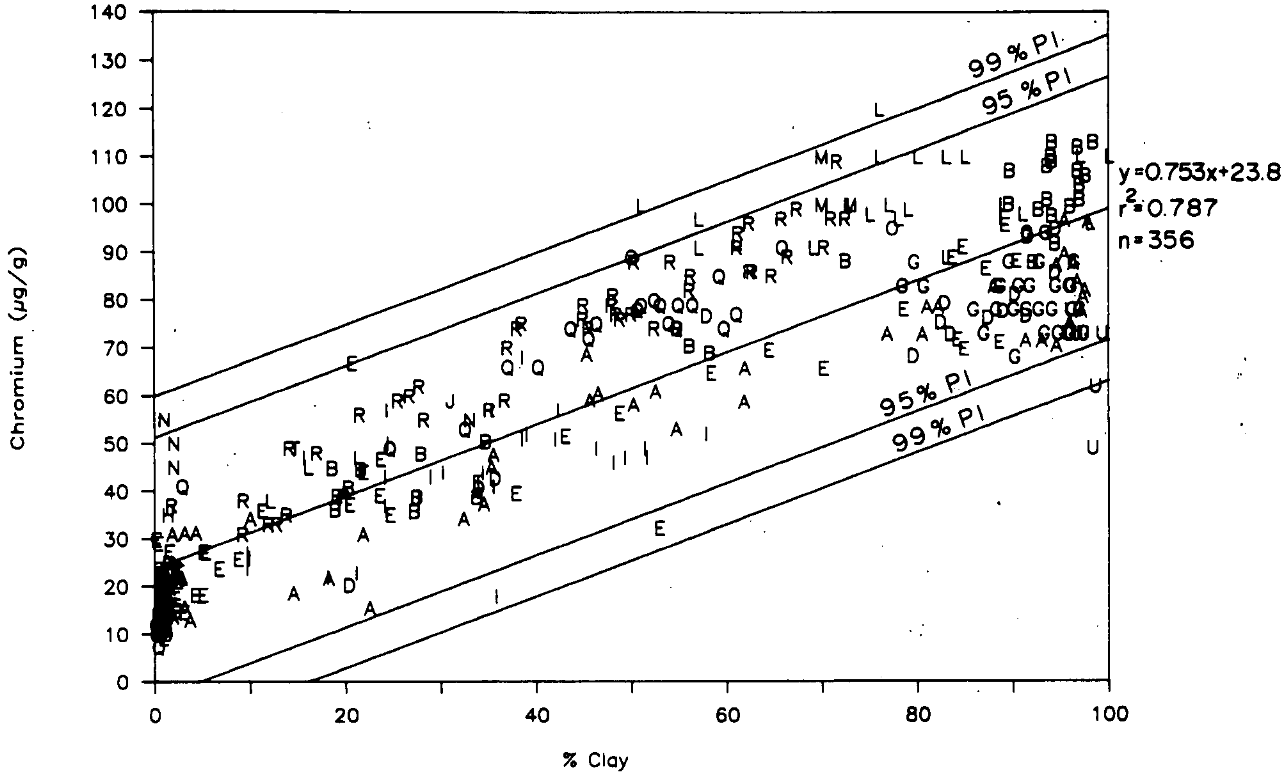

Figure 2 - 3. Regression analysis of chromium (Cr) against % clay.

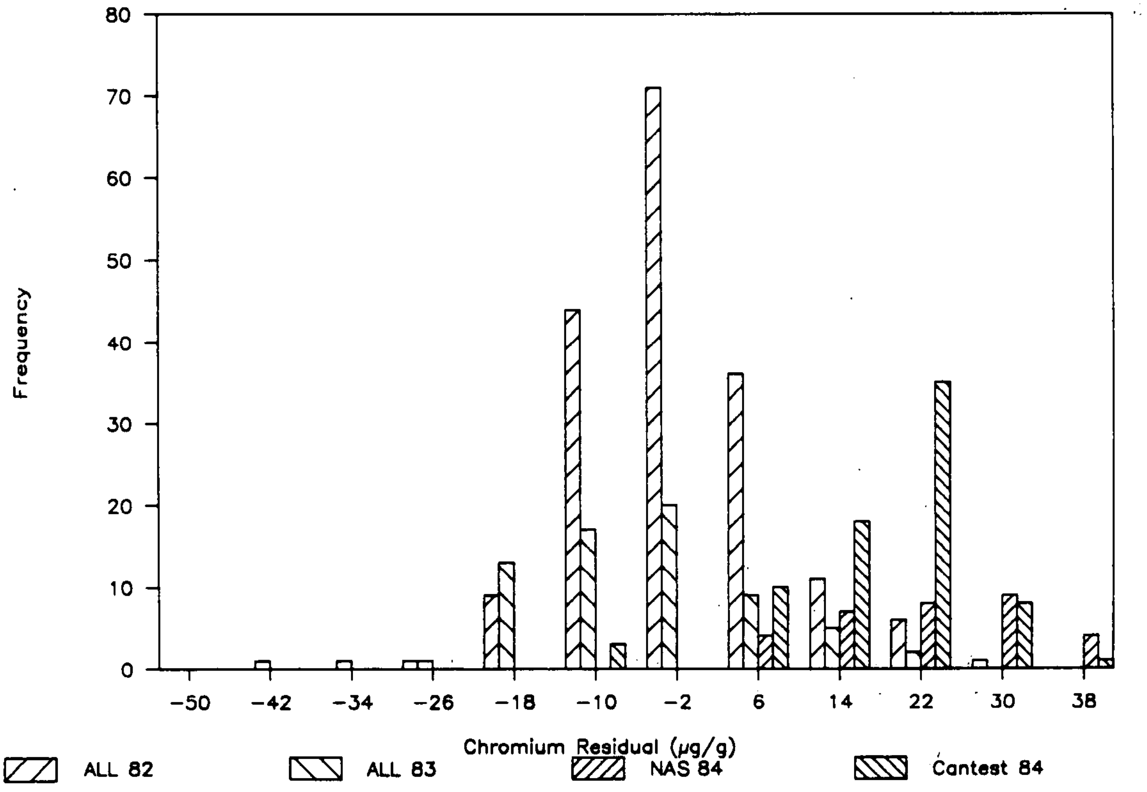

Figure 2 - 4. Frequency distribution of chromium (Cr) residuals.

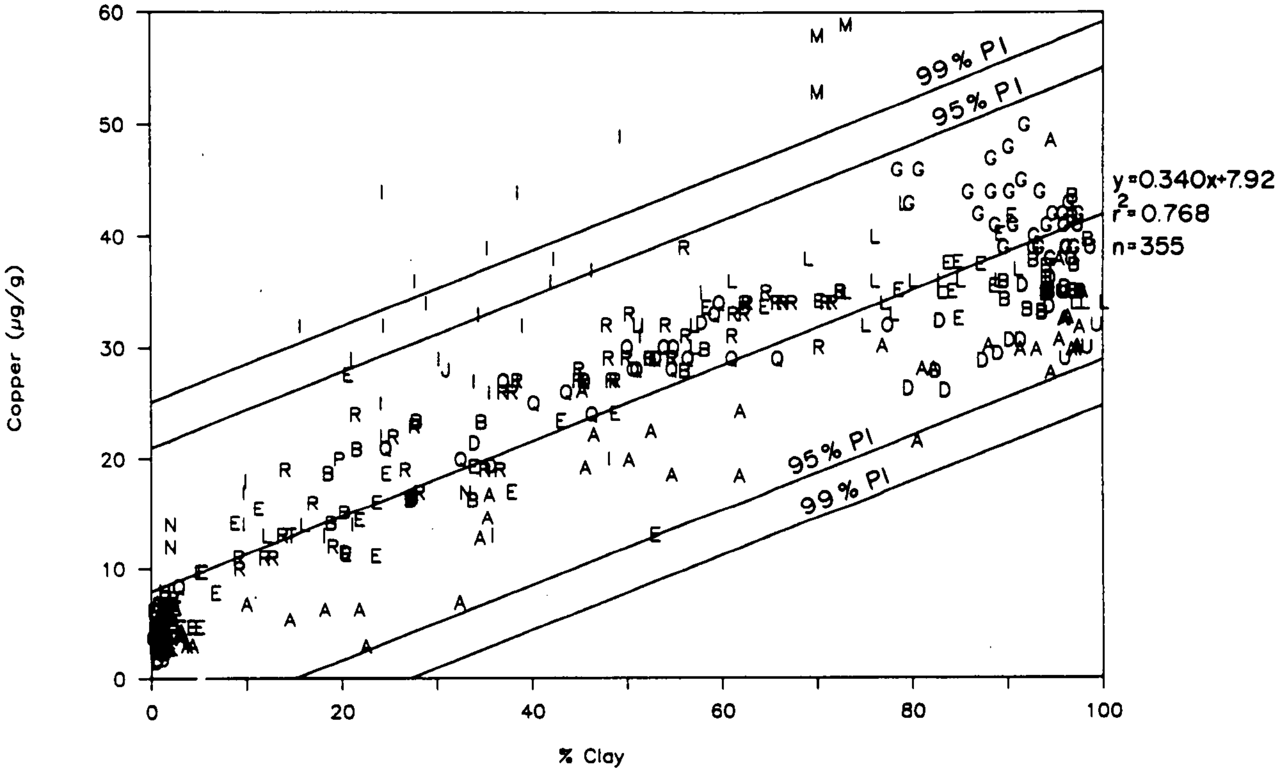

Figure 2 - 5. Regression analysis of copper (Cu) against % clay.

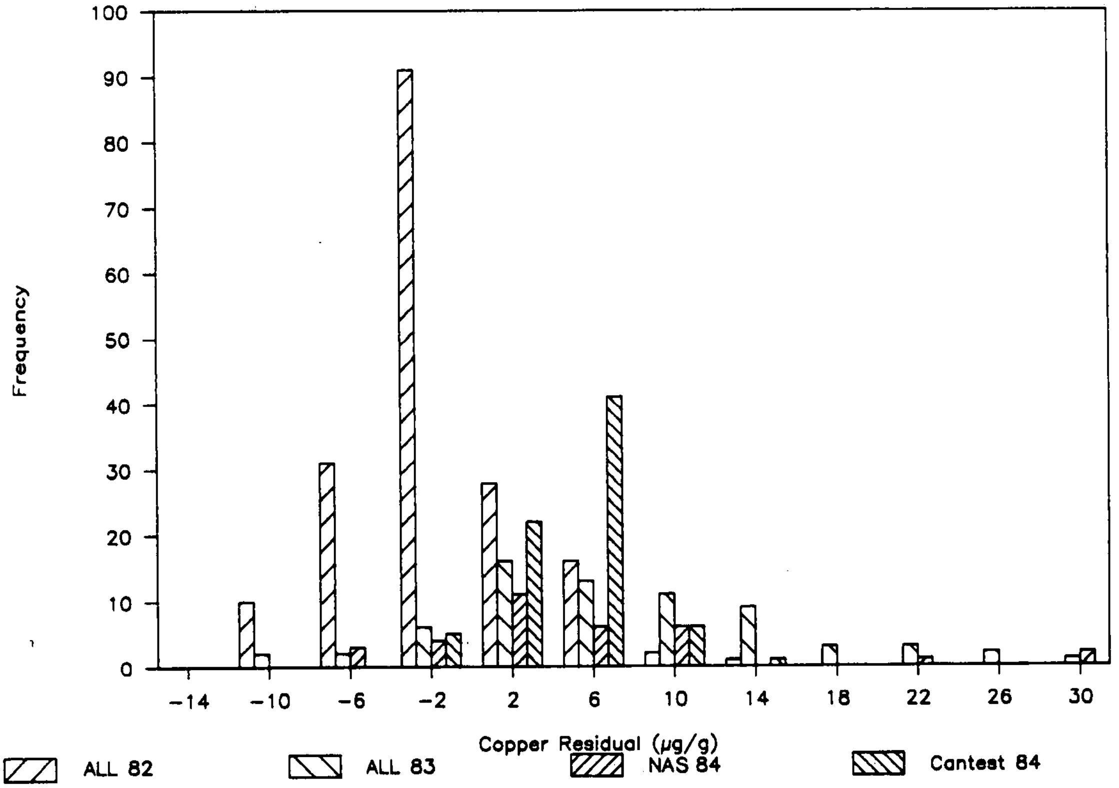

Figure 2 - 6. Frequency distribution of copper (Cu) residuals.

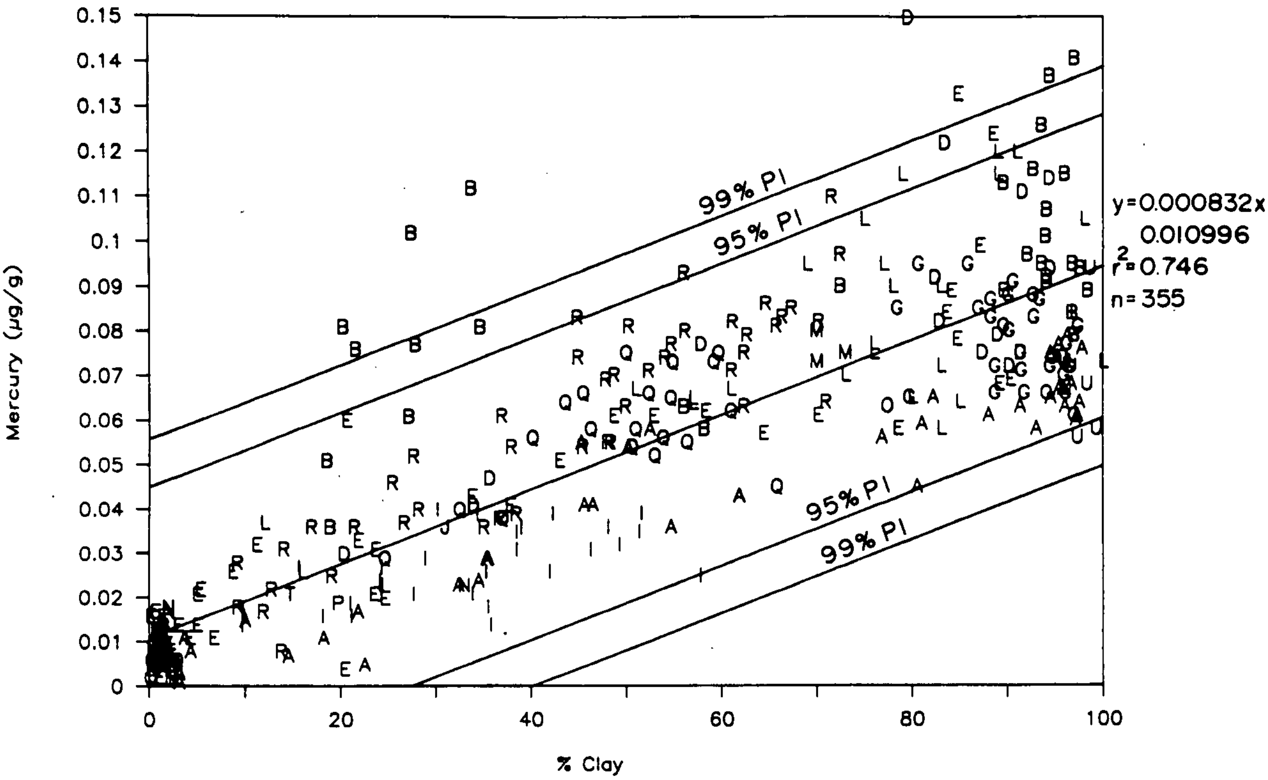

Figure 2 - 7. Regression analysis of mercury (Hg) against % clay.

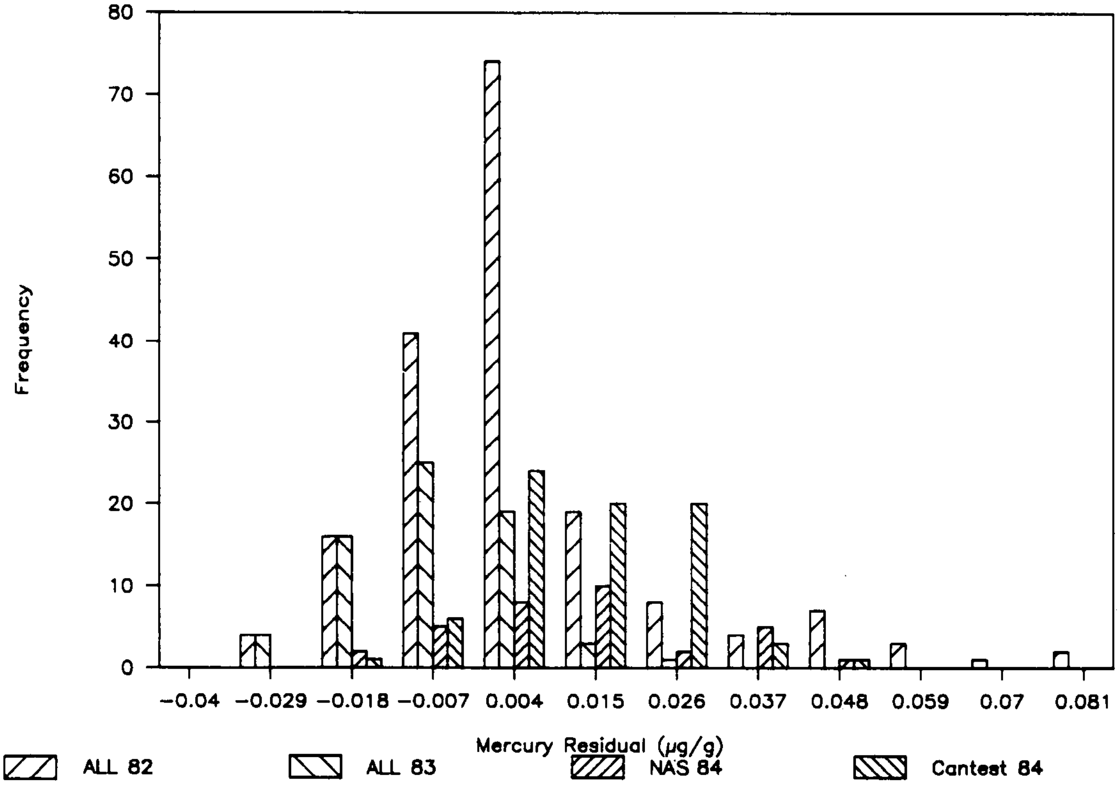

Figure 2 - 8. Frequency distribution of mercury (Hg) residuals.

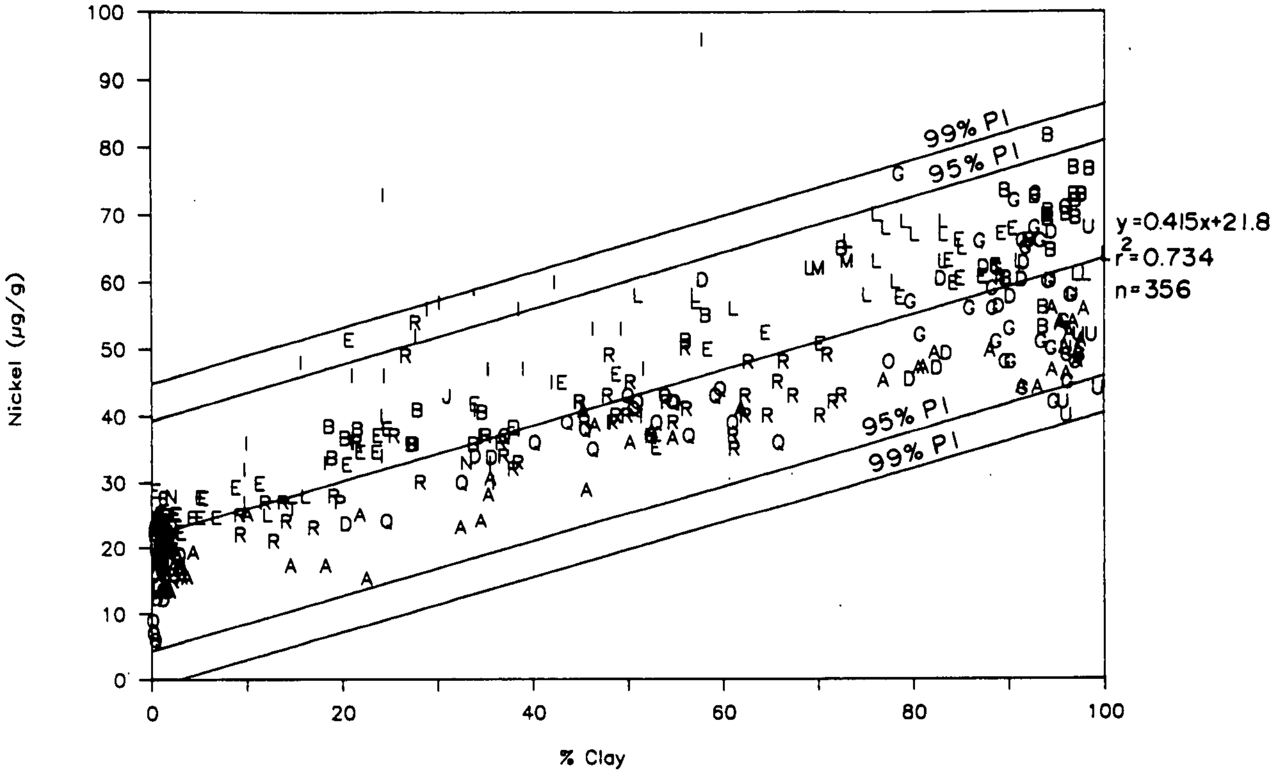

Figure 2 - 9. Regression analysis of nickel (Ni) against % clay.

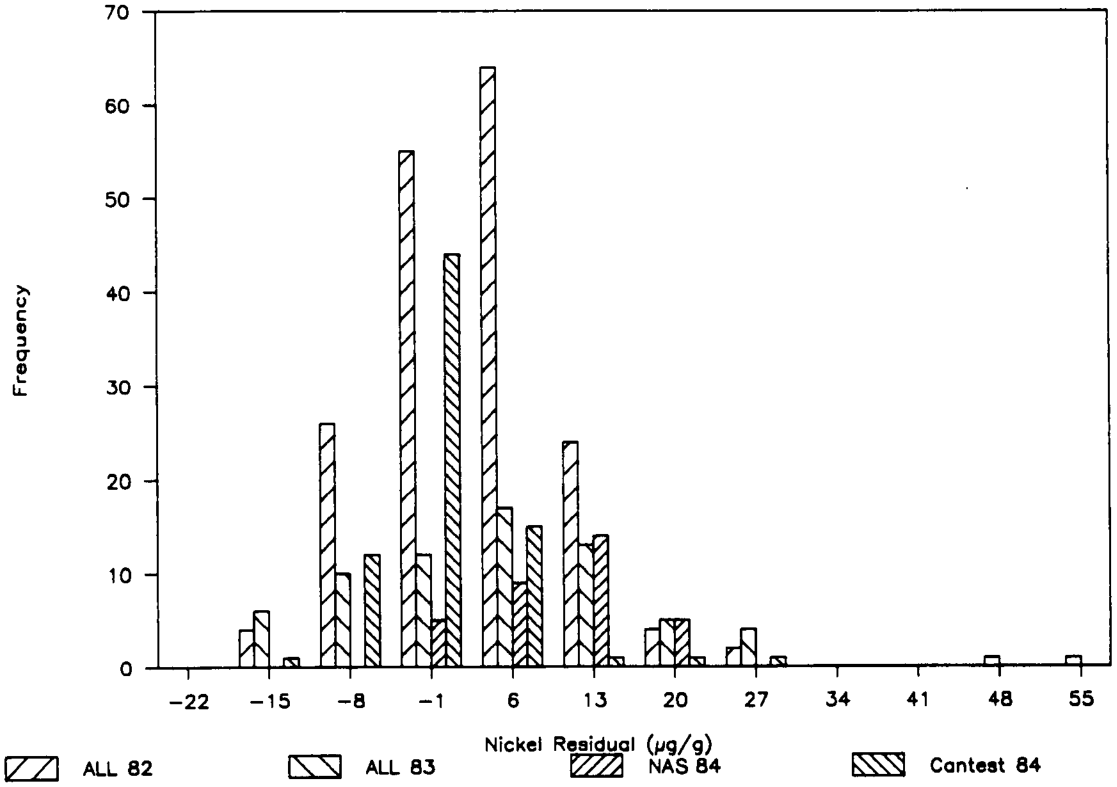

Figure 2 - 10. Frequency distribution of nickel (Ni) residuals.

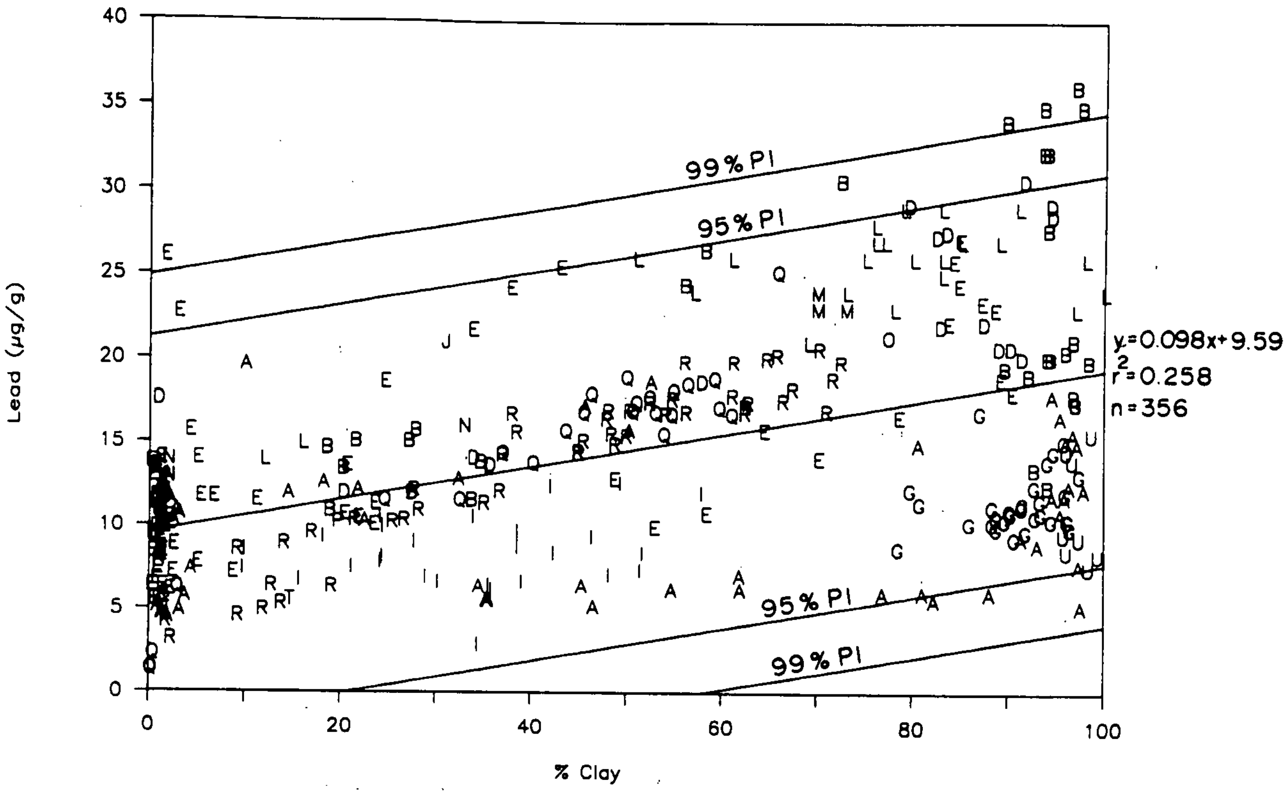

Figure 2 - 11. Regression analysis of lead (Pb) against % clay.

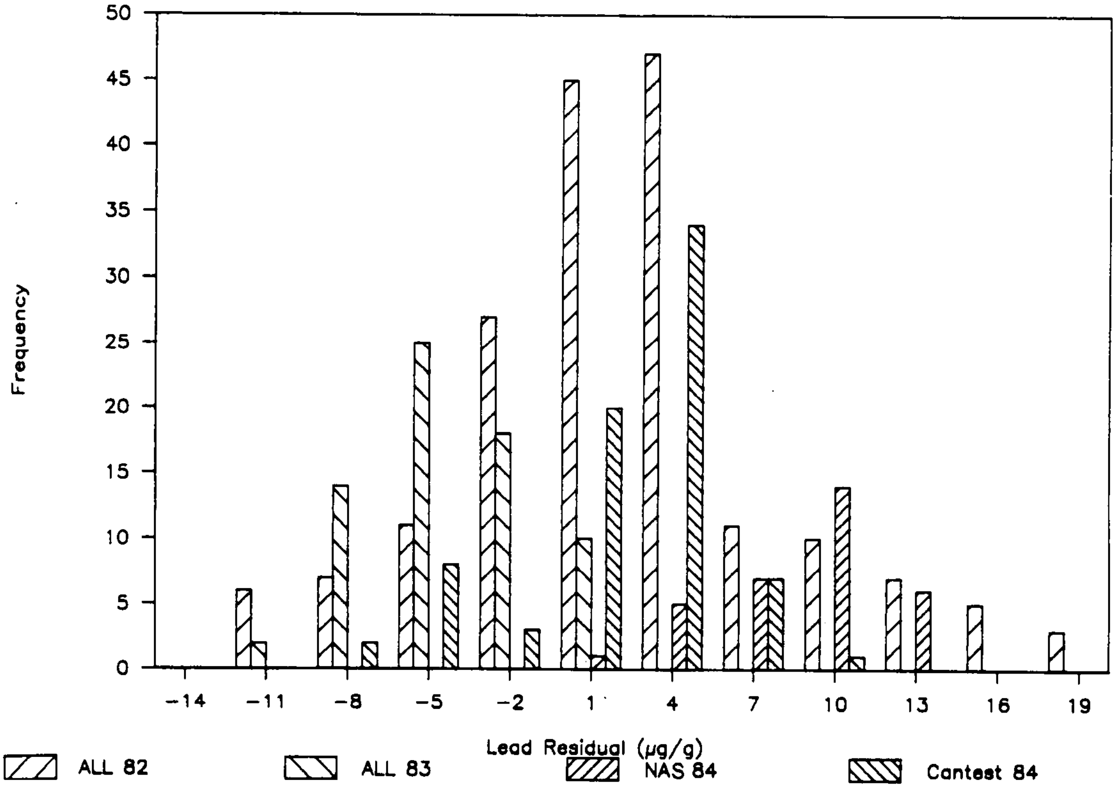

Figure 2 - 12. Frequency distribution of lead (Pb) residuals.

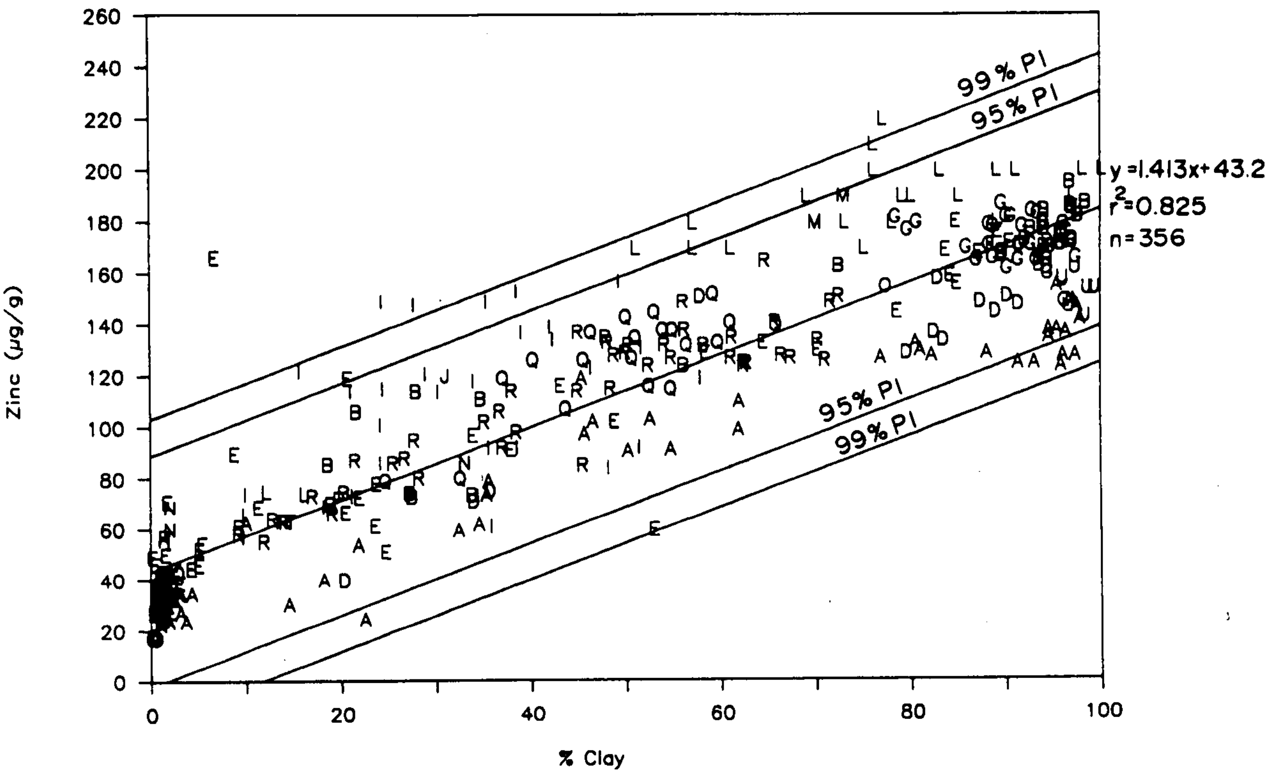

Figure 2 - 13. Regression analysis of zinc (Zn) against % clay.

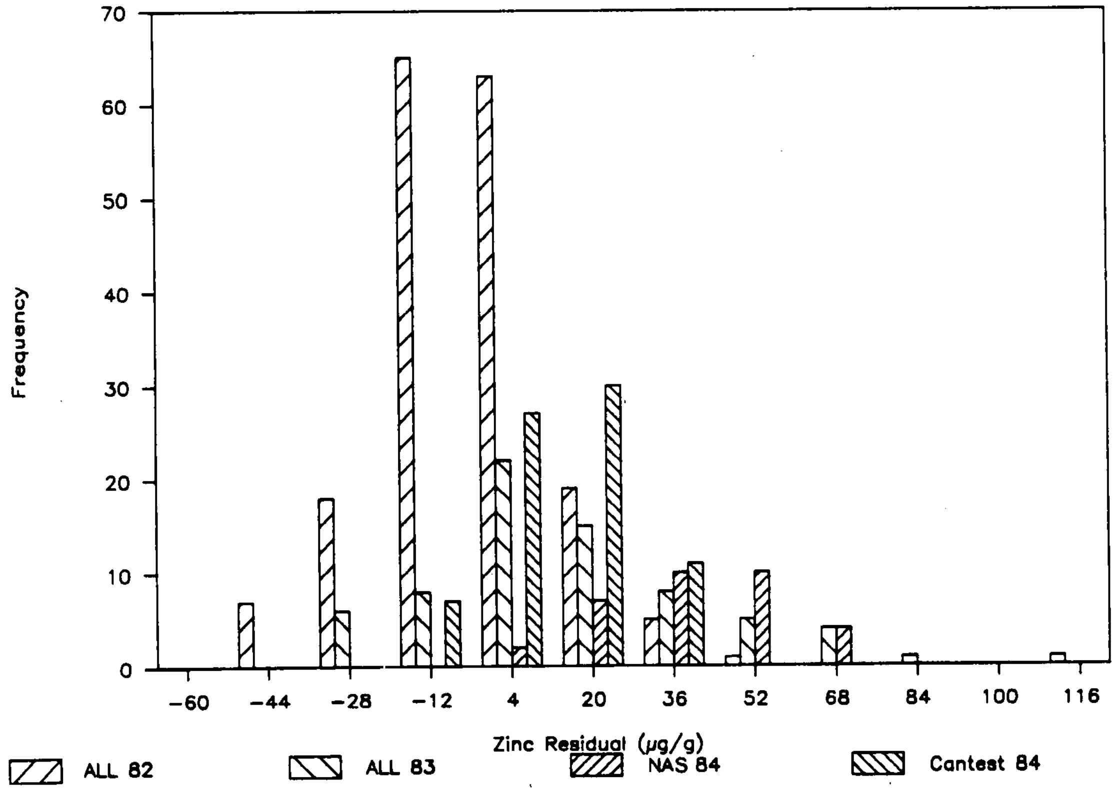

Figure 2 - 14. Frequency distribution of zinc (Zn) residuals.

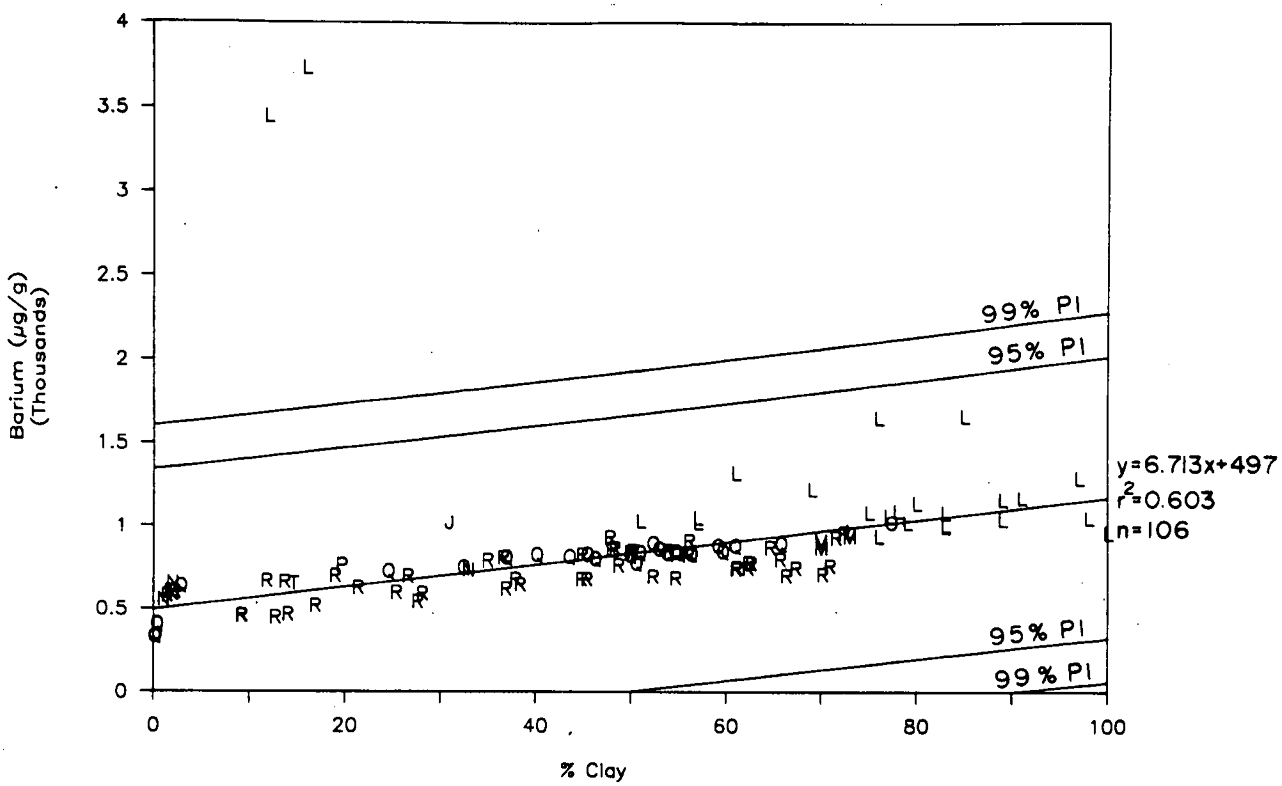

Figure 2 - 15. Regression analysis of barium (Ba) against % clay. (Station 21 excluded from regression).

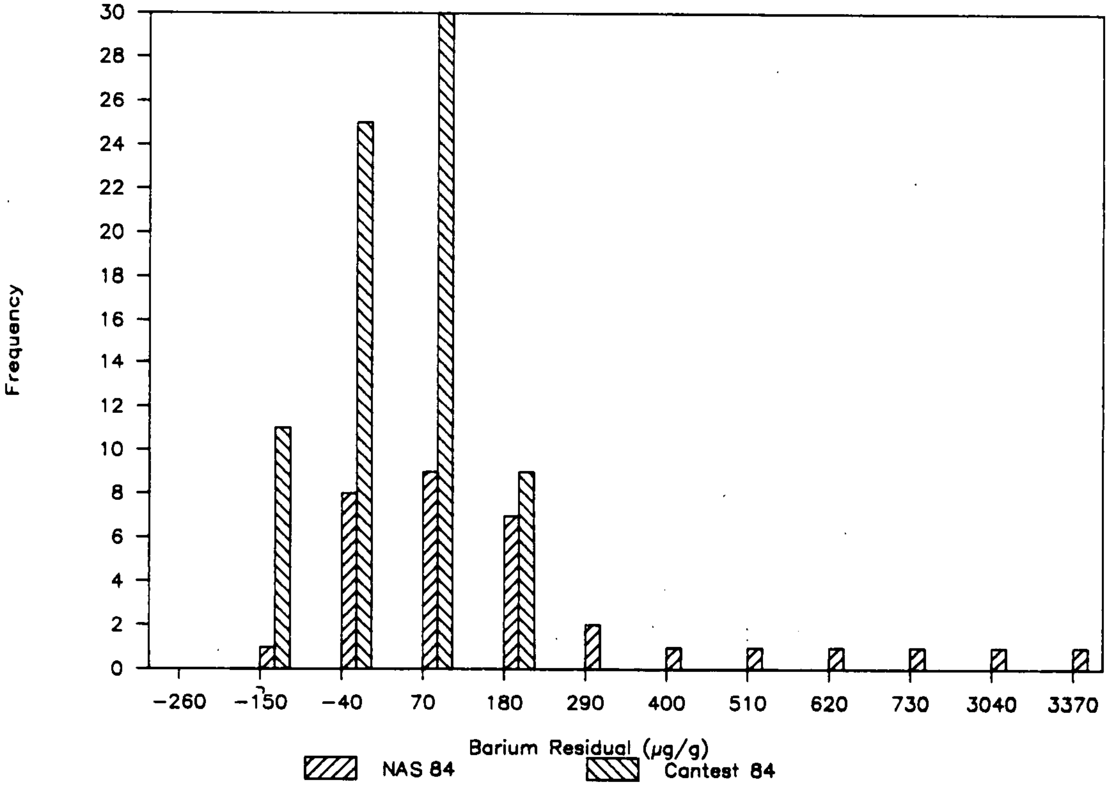

Figure 2 - 16. Frequency distribution of barium (Ba) residuals.

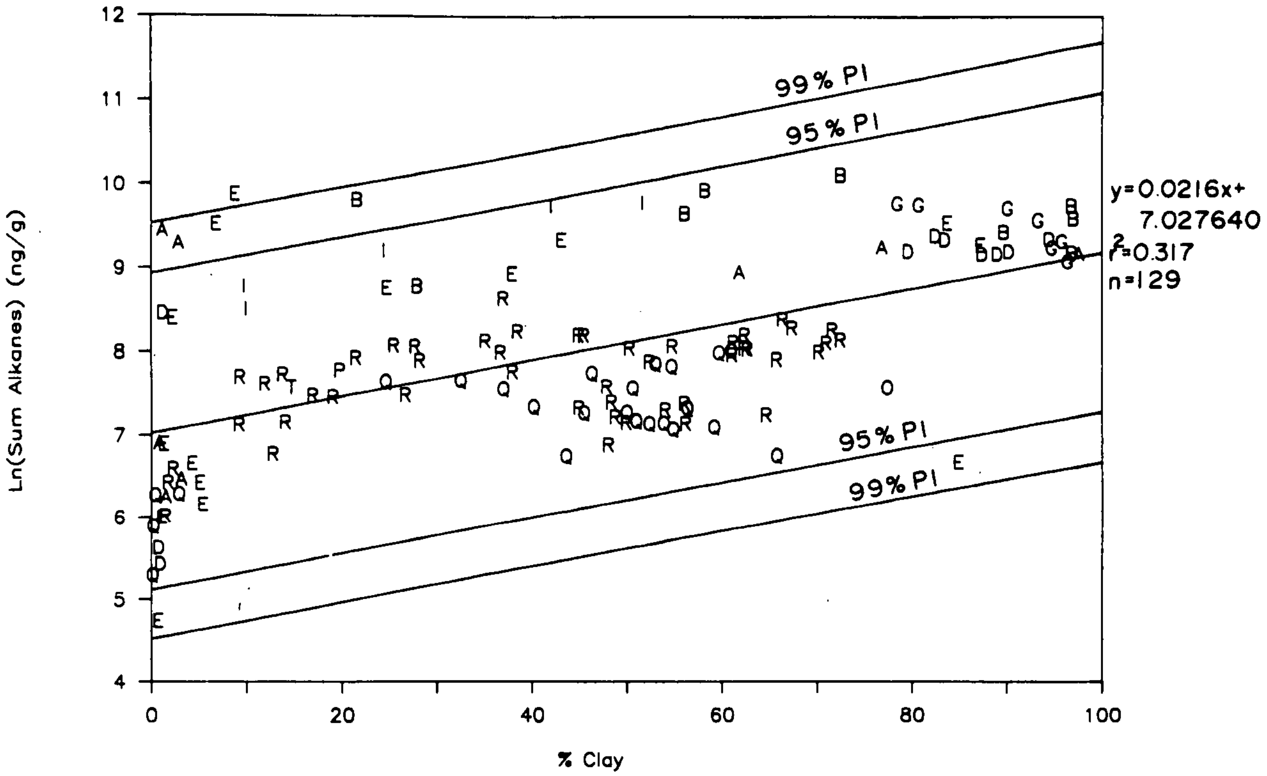

Figure 2 - 17. Regression analysis of Sum Alkanes (ΣAlk) against % clay (nC12 - nC33).

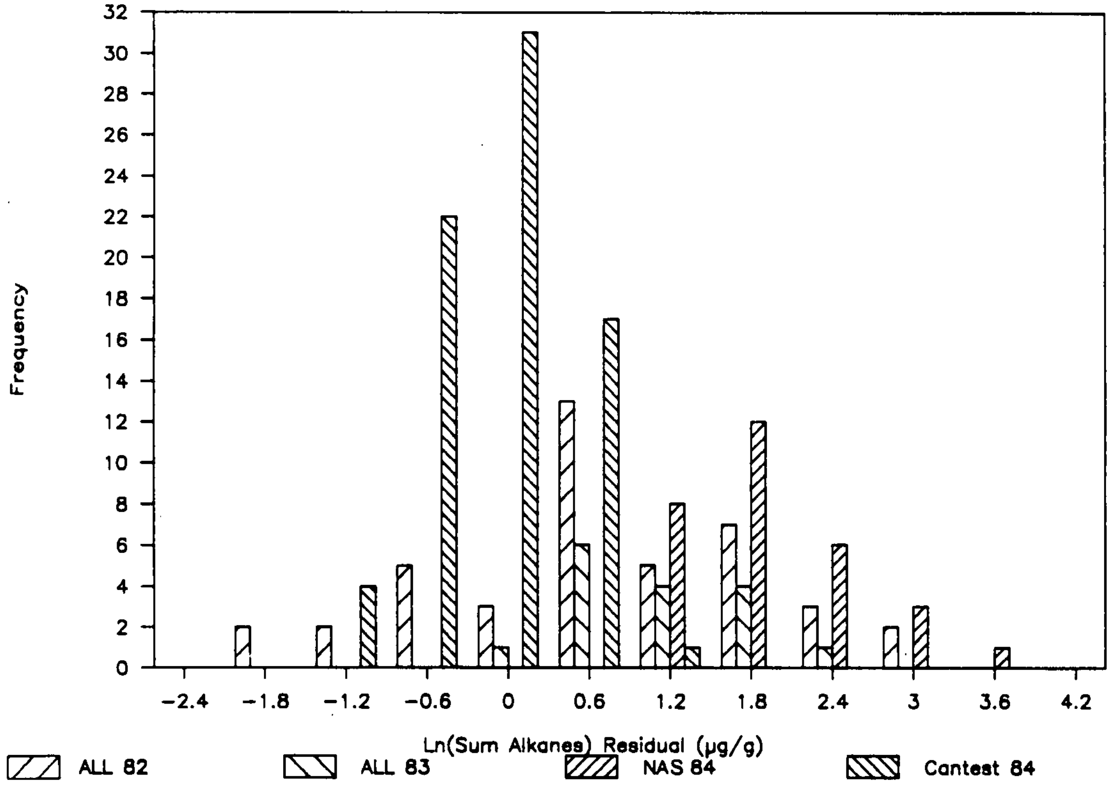

Figure 2 - 18. Frequency distribution of Sum Alkanes (ΣAlk) residuals.

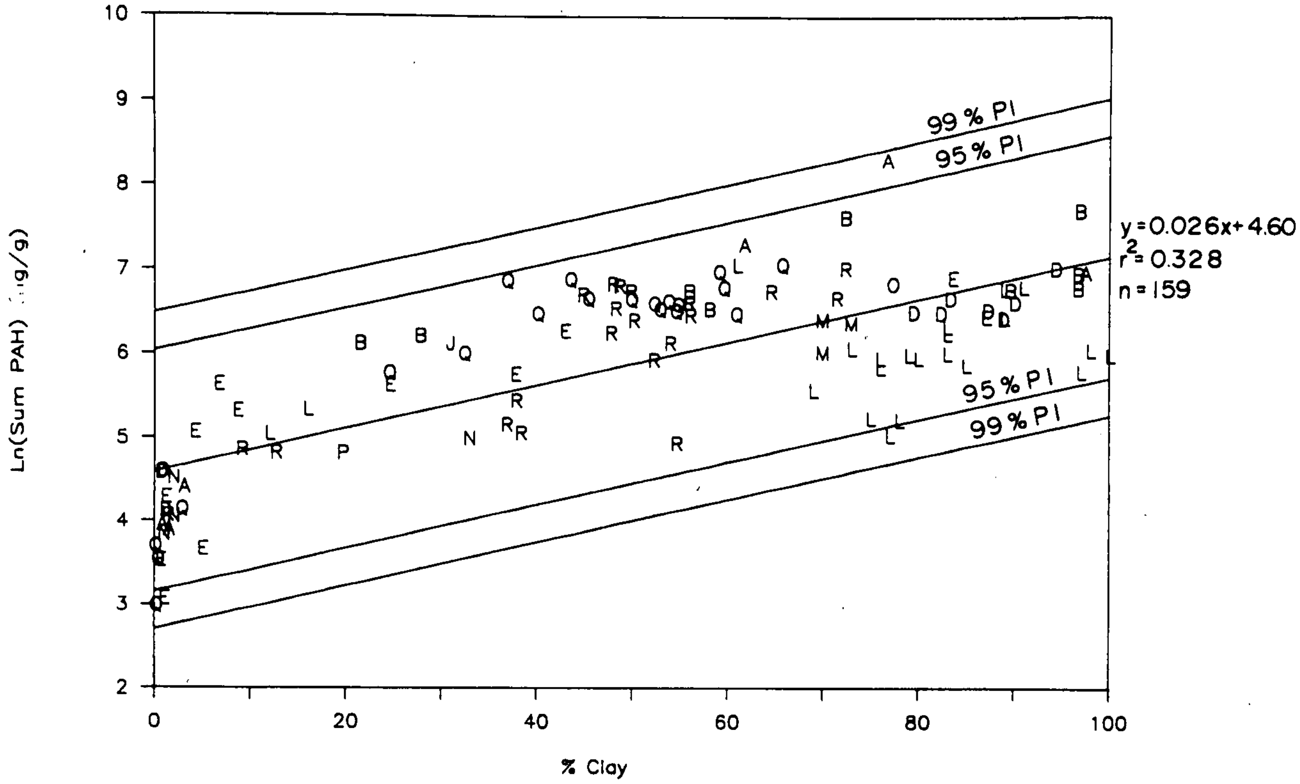

Figure 2 - 19. Regression analysis of Sum PAH (ΣPAH) against % clay.

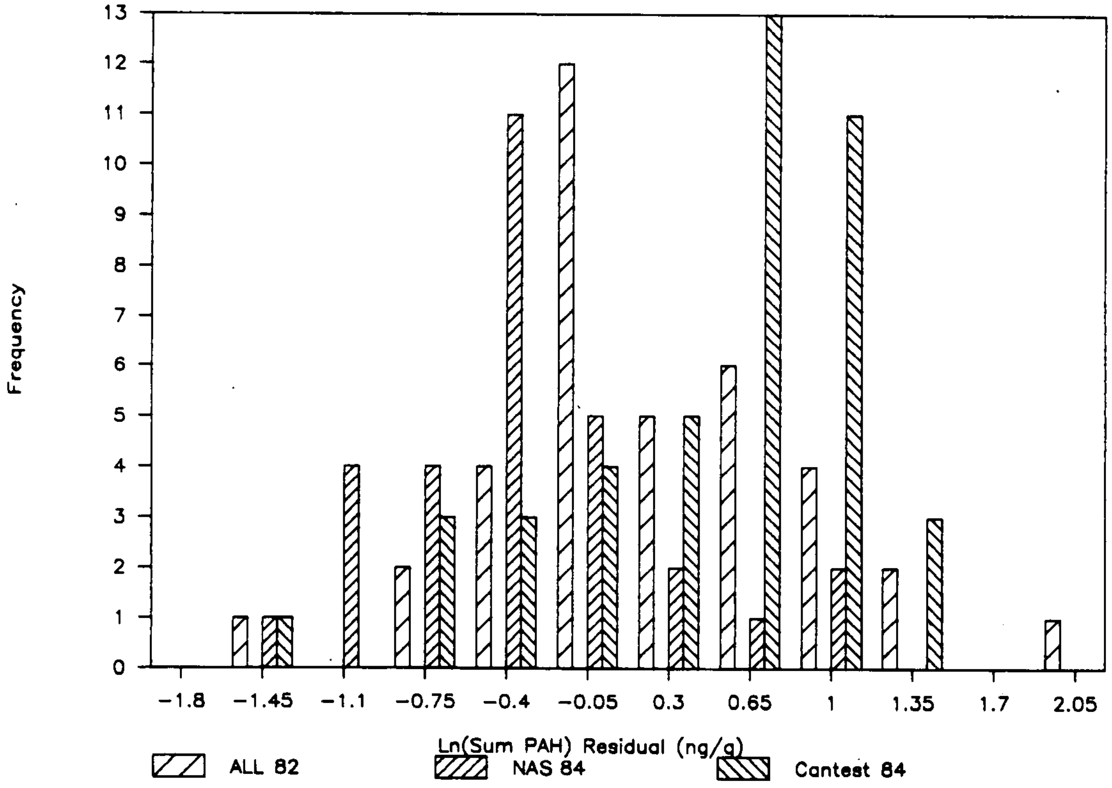

Figure 2 - 20. Frequency distribution of Sum PAH (ΣPAH) residuals.

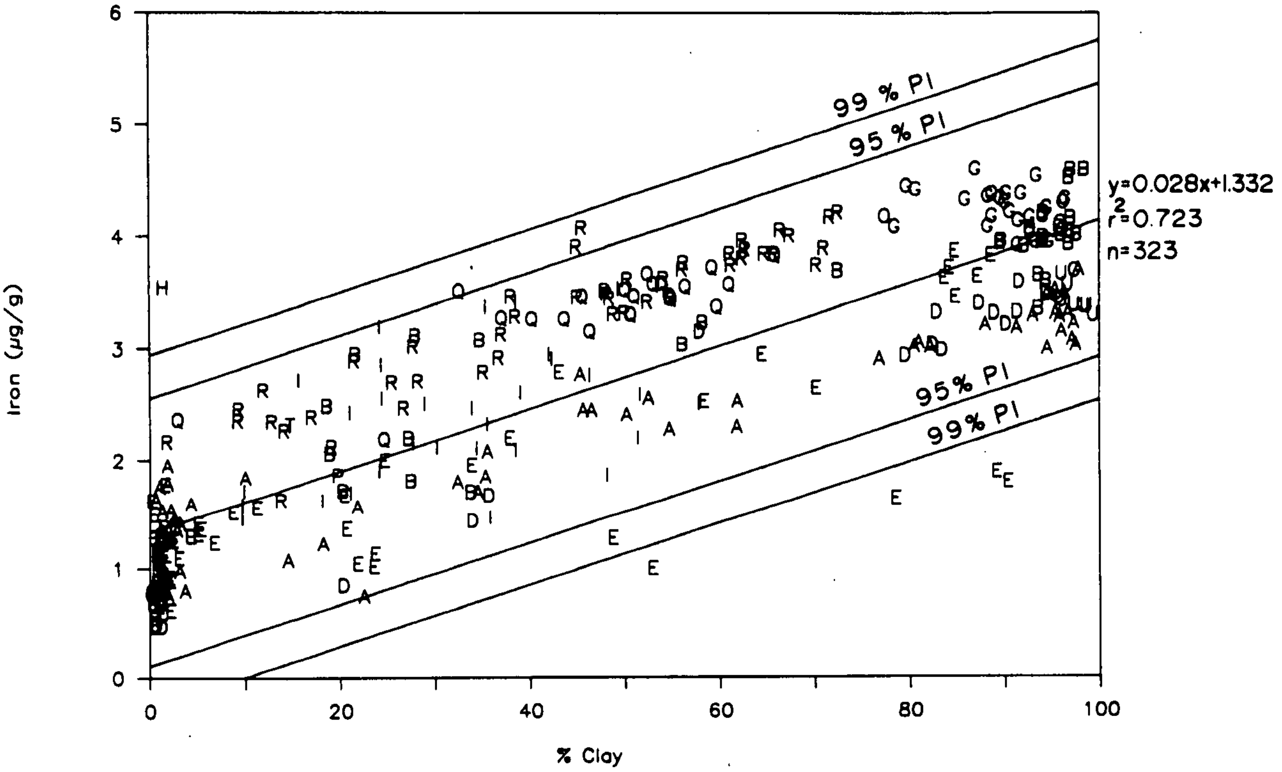

Figure 2 - 21. Regression analysis of iron (Fe) against % clay.

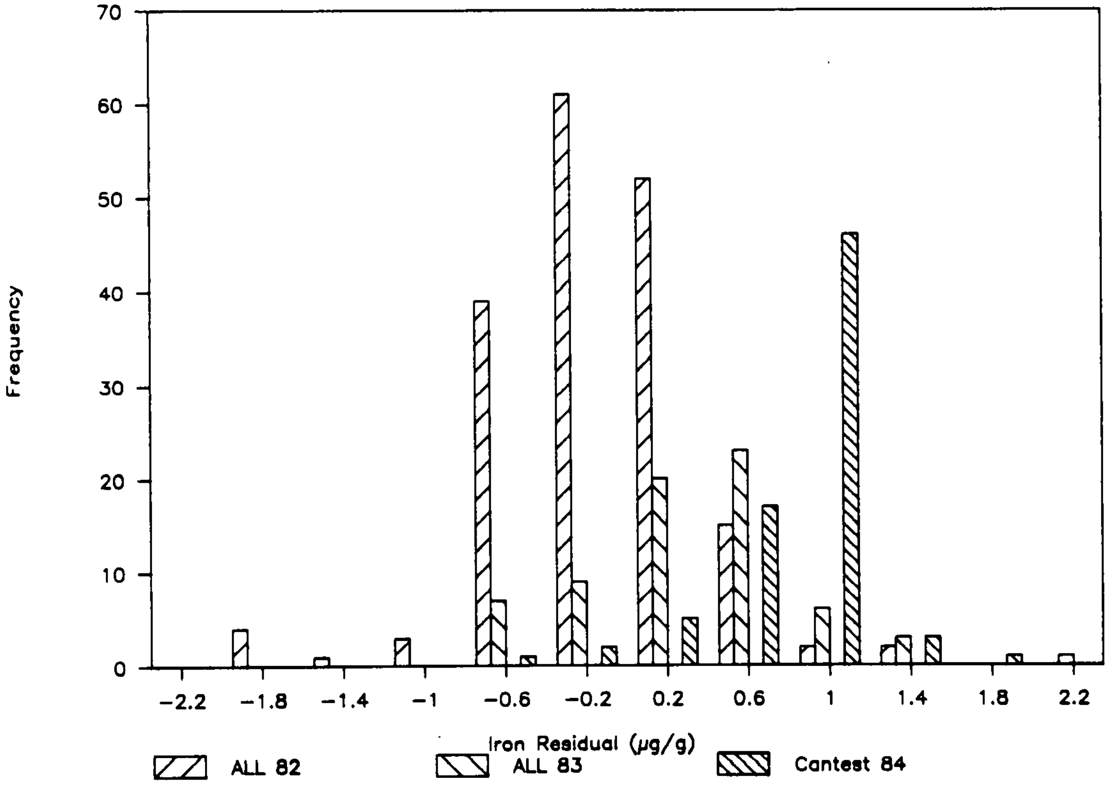

Figure 2 - 22. Frequency distribution of iron (Fe) residuals.

APPENDIX 3

Hydrocarbon Regression Analyses

See Table 4 (page 41) for a listing of meanings of letters used to identify groupings of data.

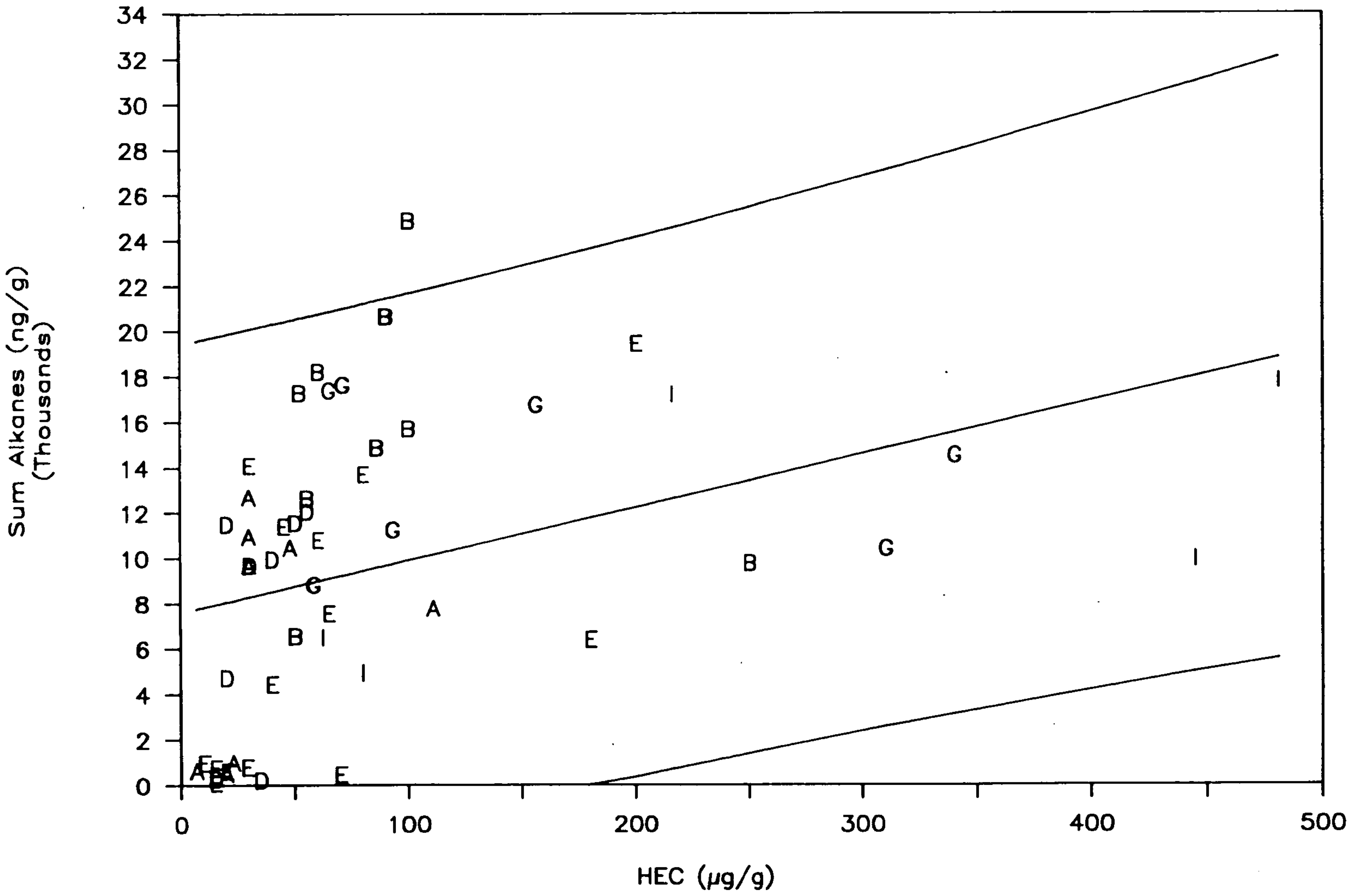

Figure 3 - 1. Regression analysis of Sum Alkanes (ΣAlk) against hexane extractable compounds (HEC) (nC12 - nC33).

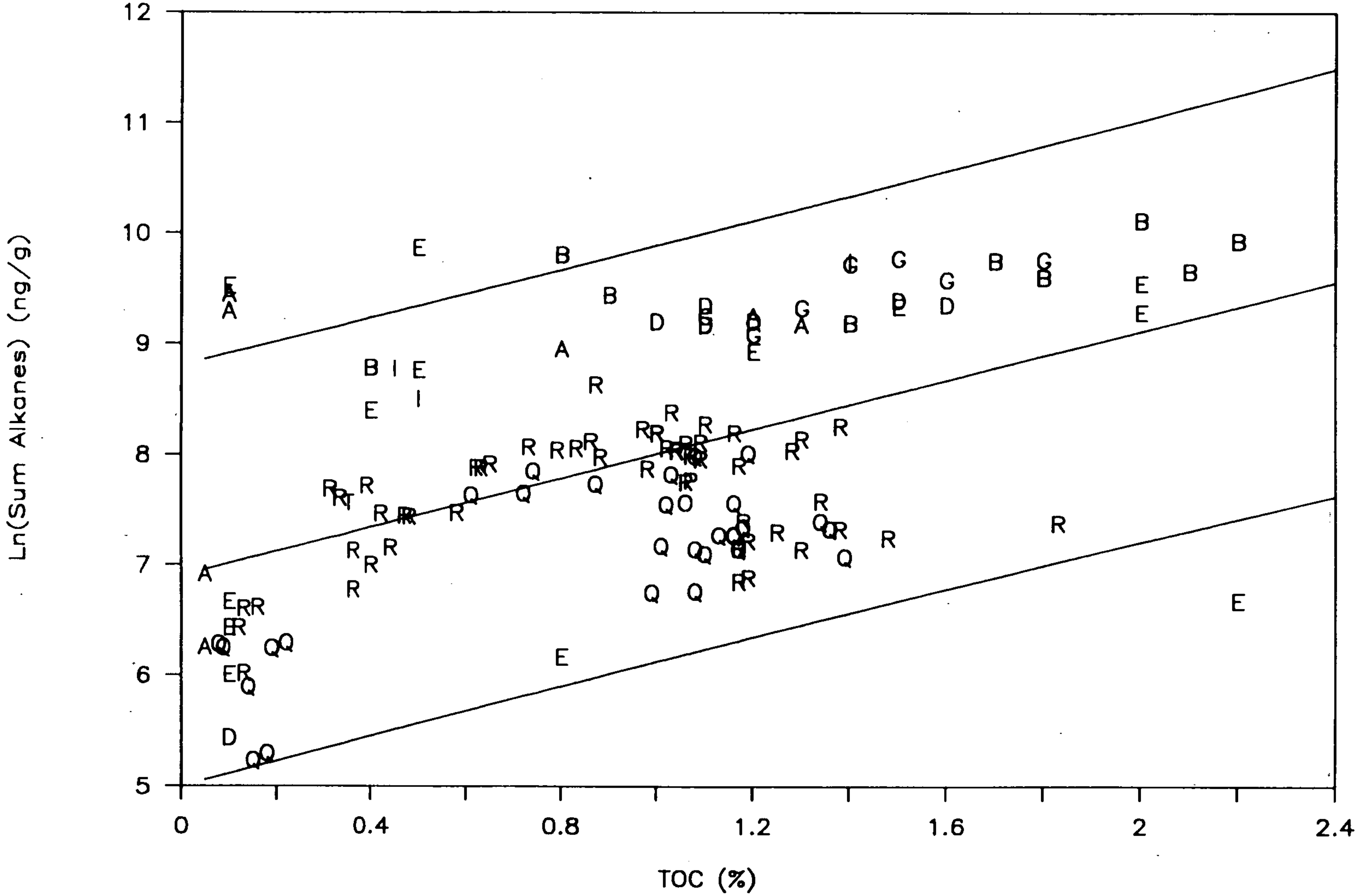

Figure 3 - 2. Regression analysis of Sum Alkanes (ΣAlk) against total organic carbon (TOC) (nC12 - nC33).

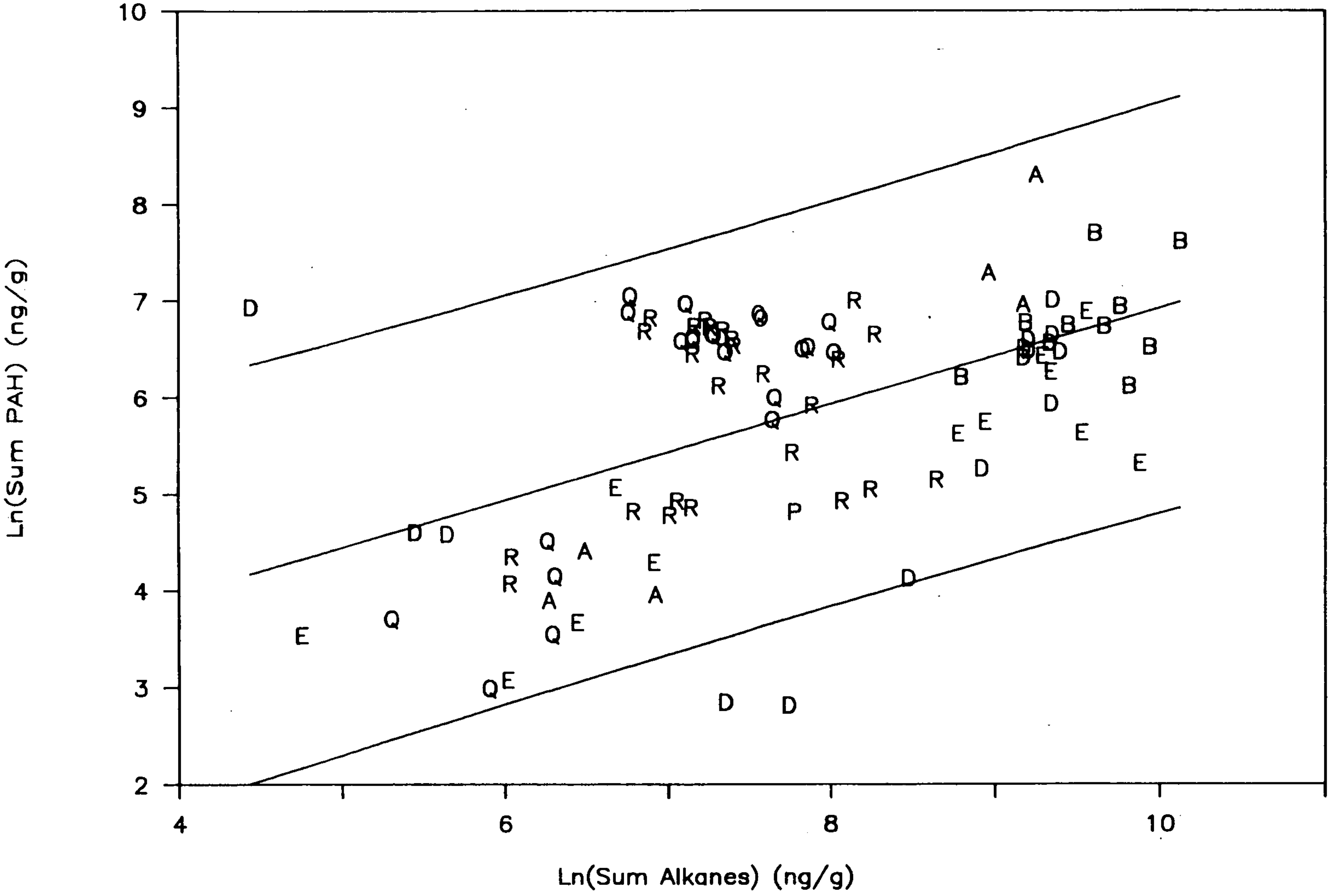

Figure 3 - 3. Regression analysis of Sum PAH (ΣPAH) against Sum Alkanes (ΣAlk).

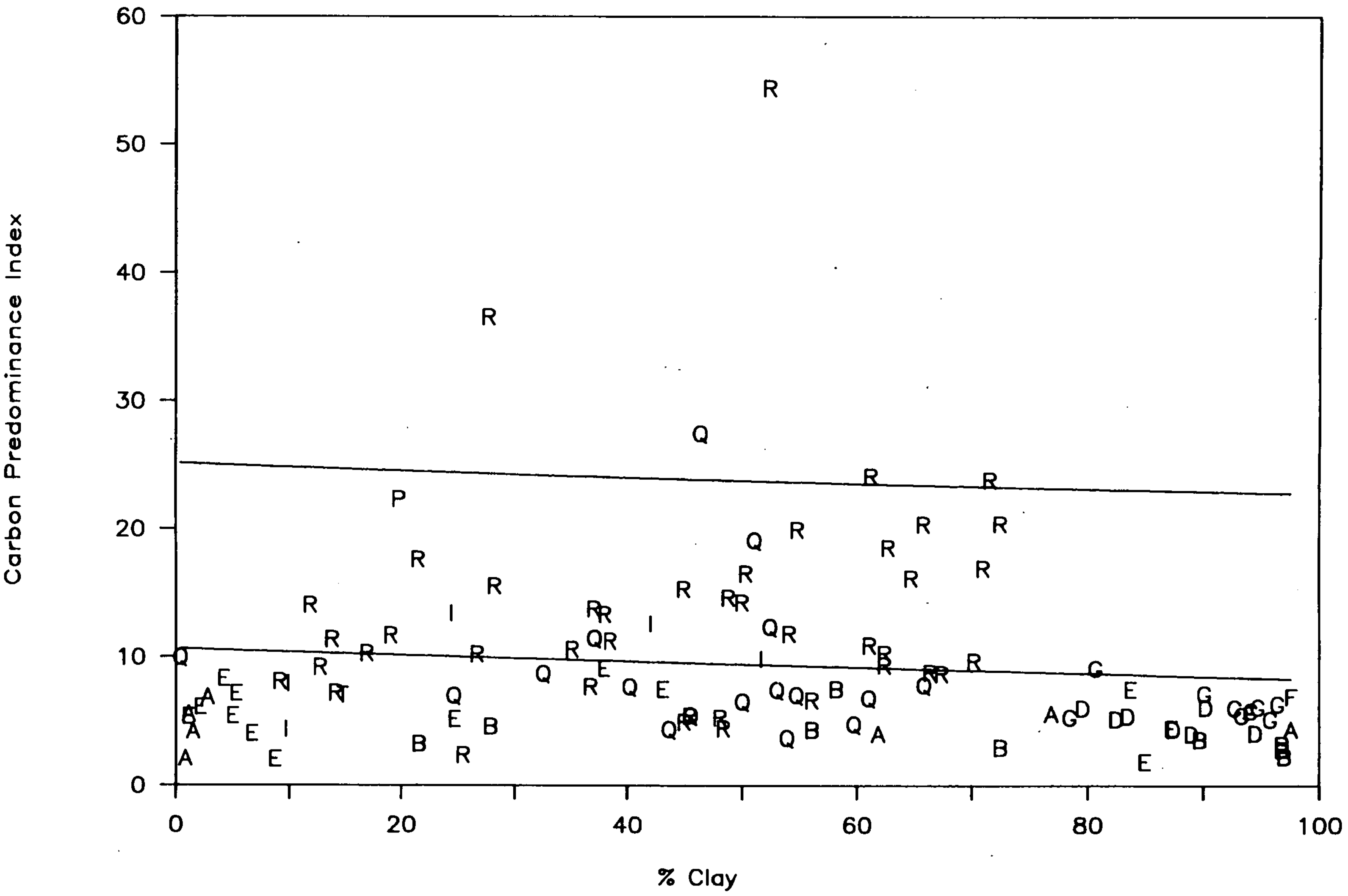

Figure 3 - 4. Regression analysis of carbon predominance index (CPI) against % clay.

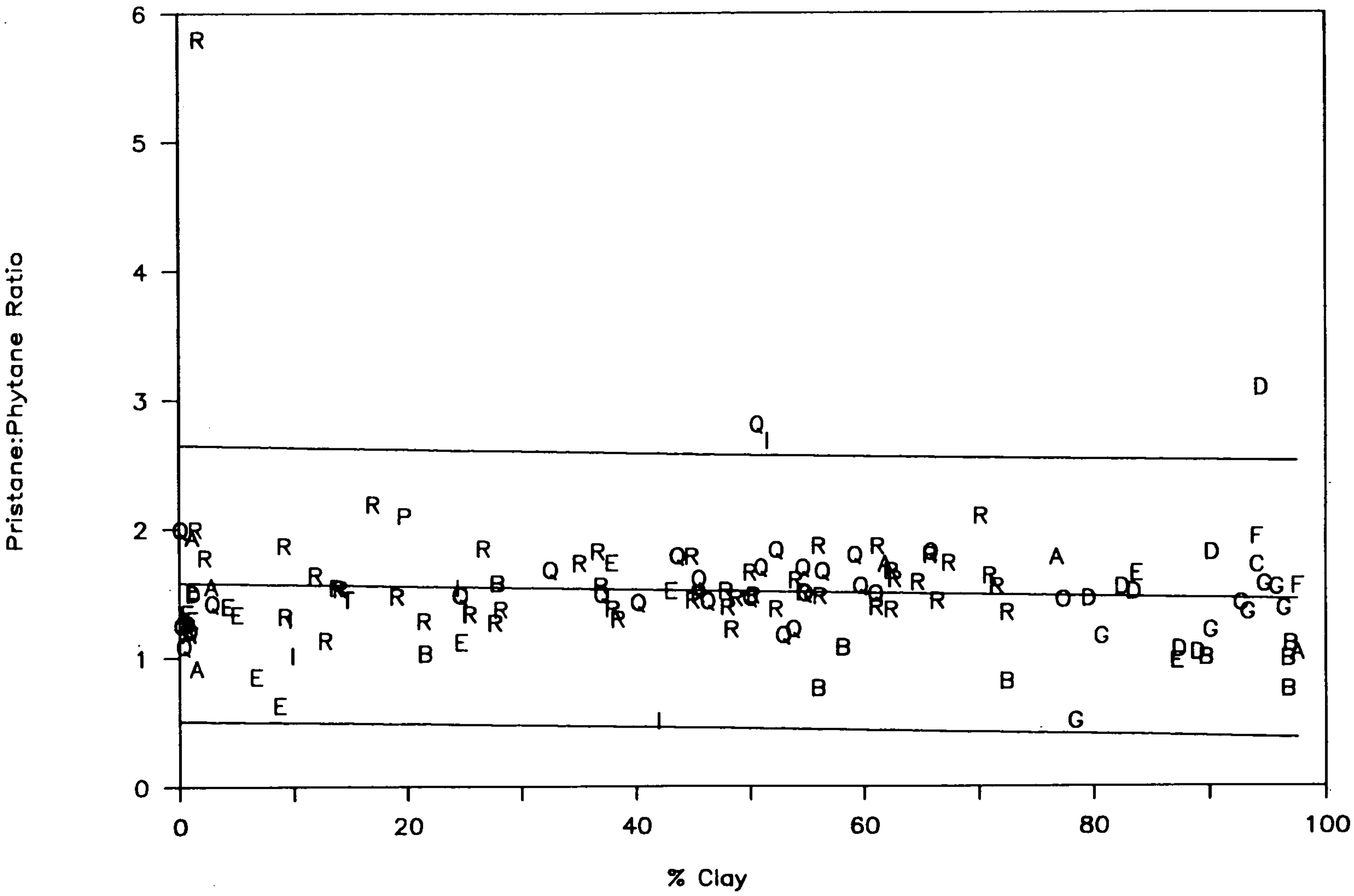

Figure 3 - 5. Regression analysis of pristane:phytane ratio against % clay.

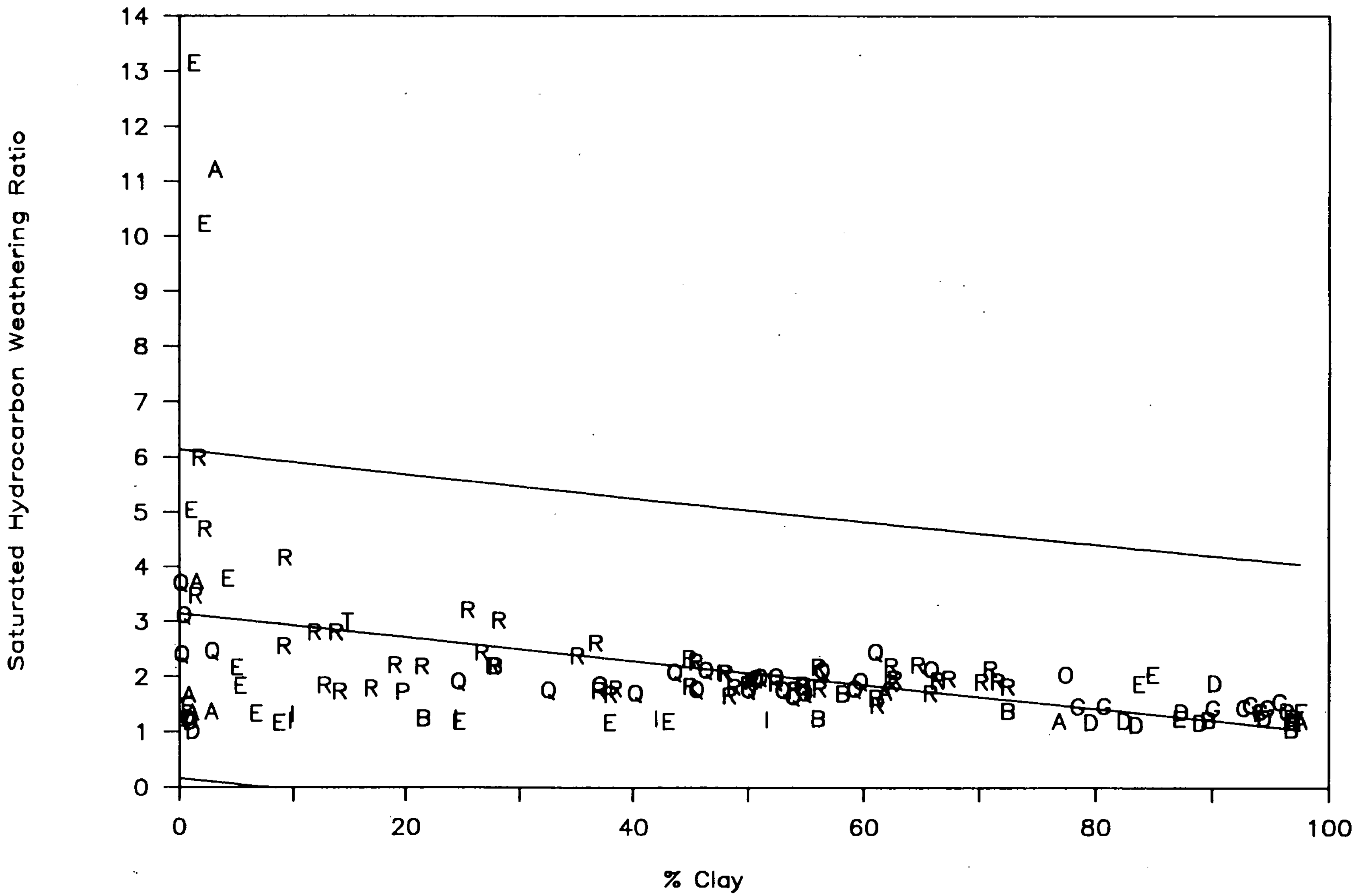

Figure 3 - 6. Regression analysis of saturated hydrocarbon weathering ratio (SHWR) against % clay.

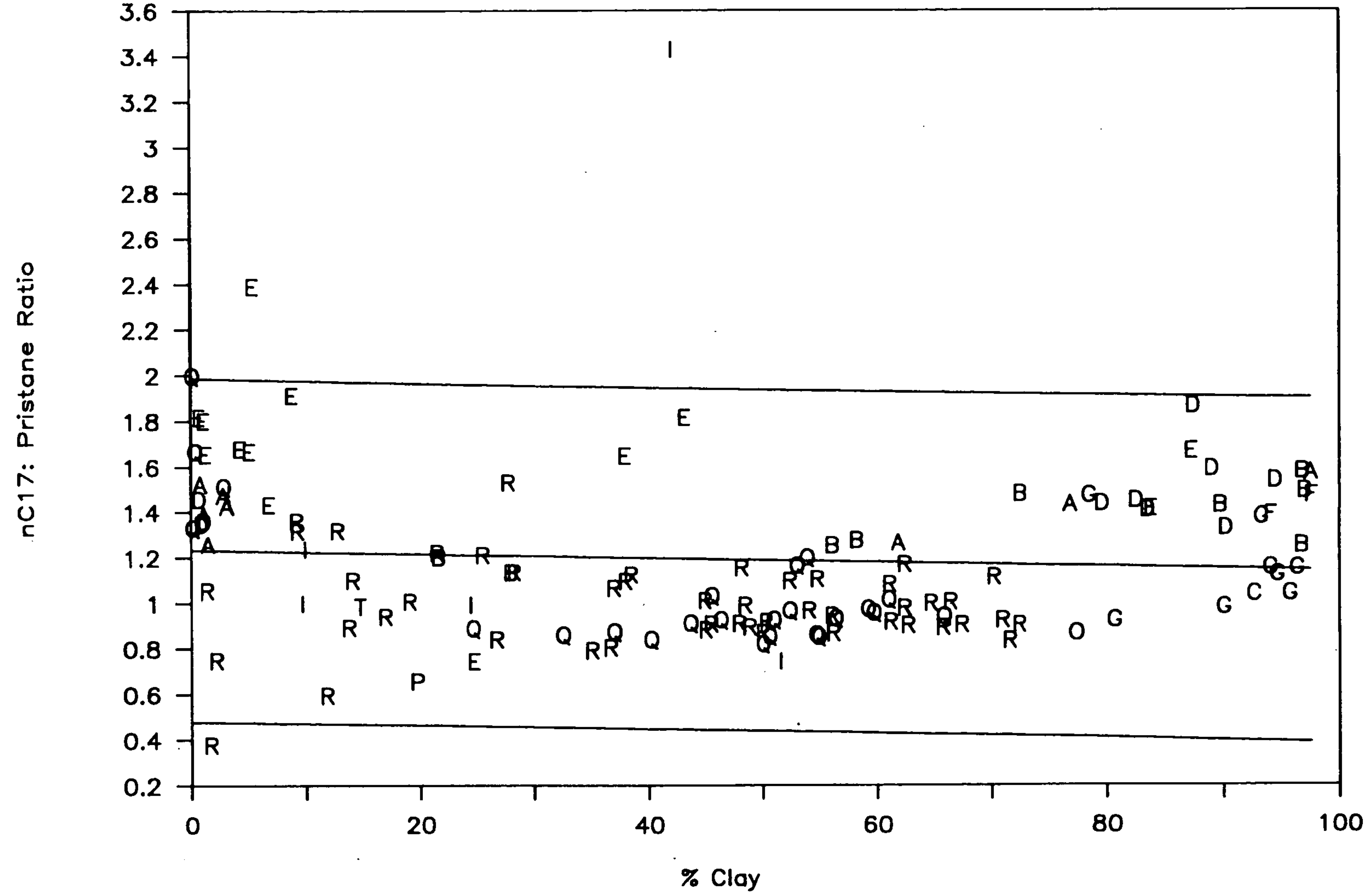

Figure 3 - 7. Regression analysis of n-C17:pristane ratio against % clay.

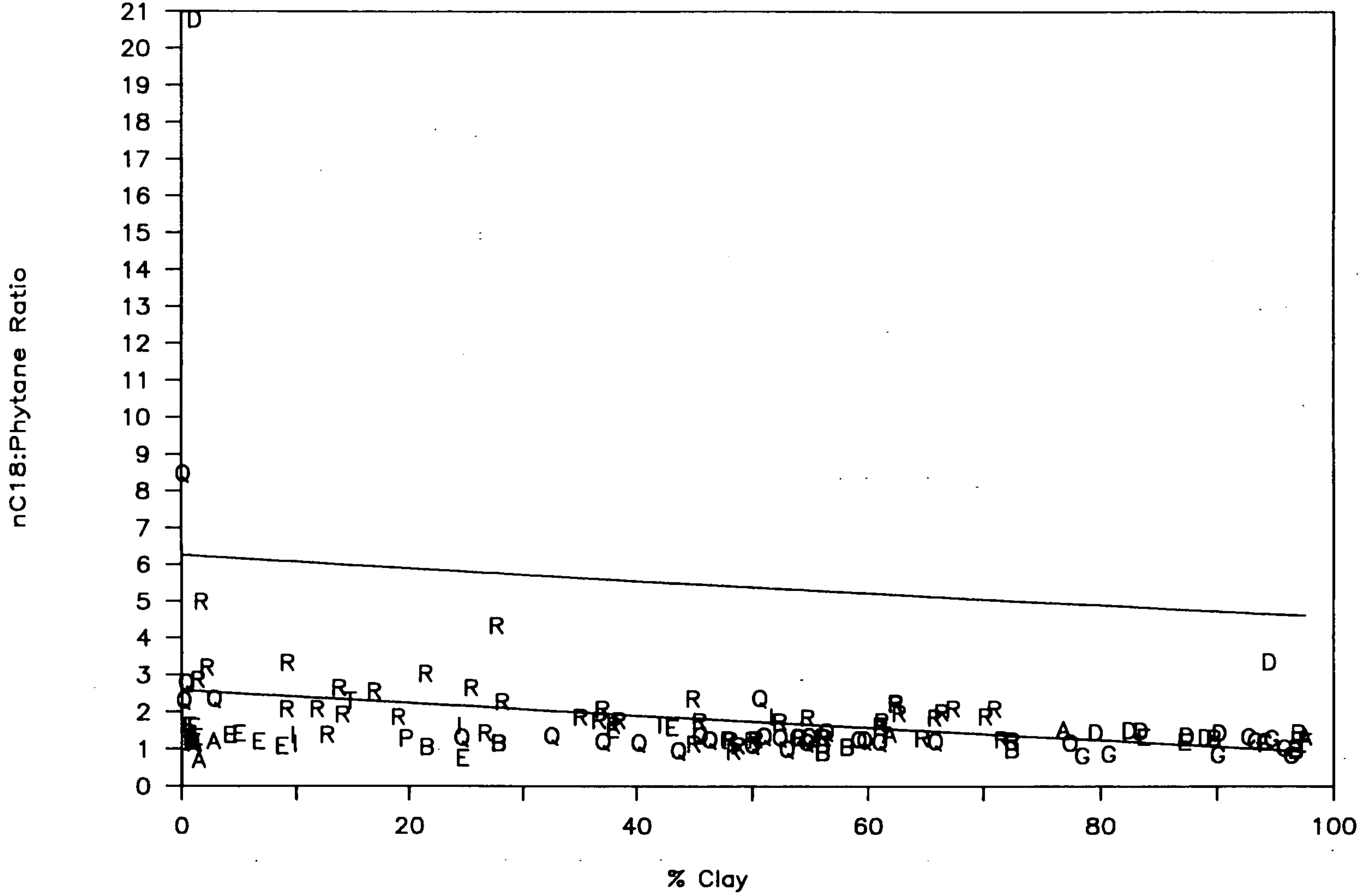

Figure 3 - 8. Regression analysis of n-C18:phytane ratio against % clay.

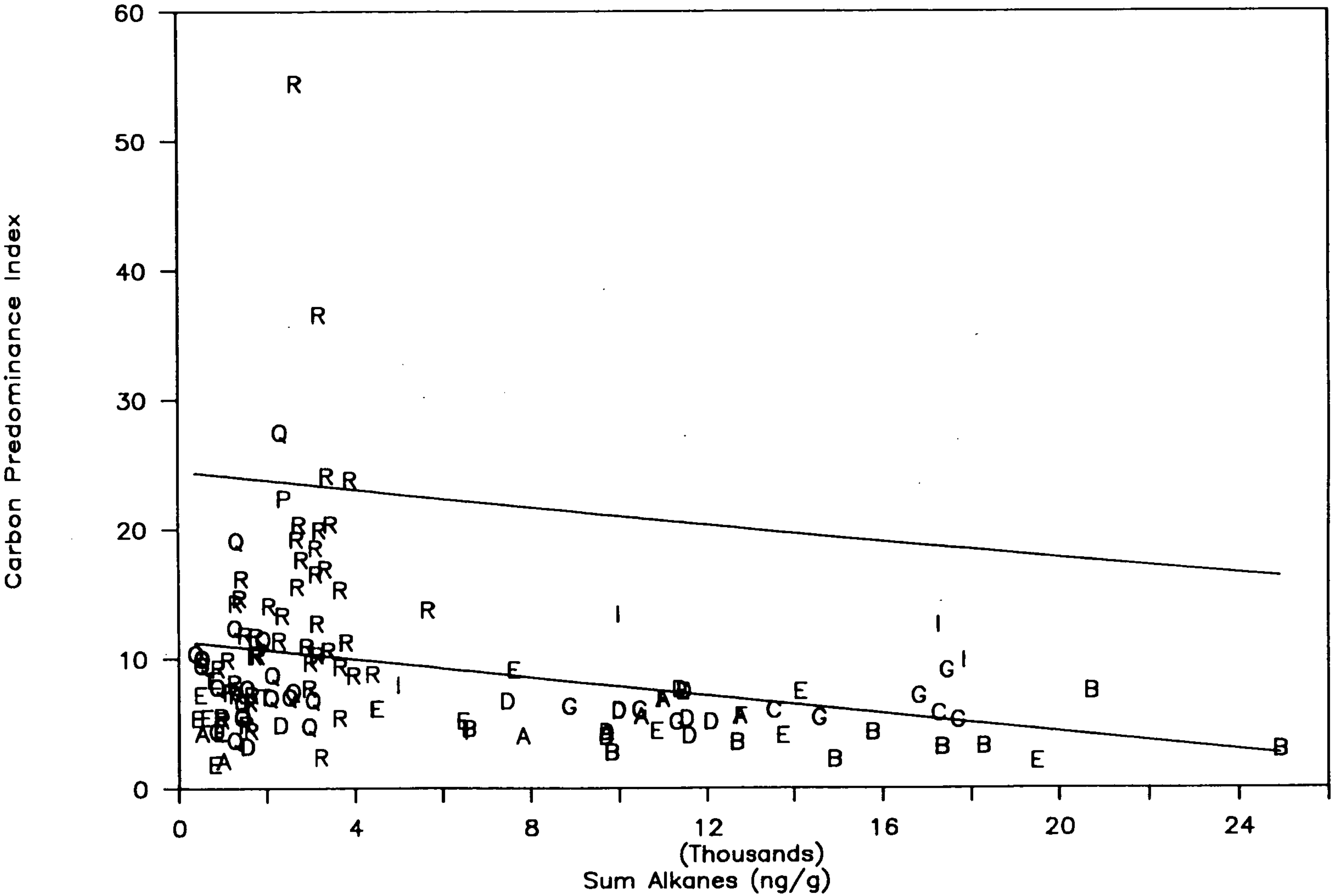

Figure 3 - 9. Regression analysis of carbon predominance index (CPI) against Sum Alkanes (ΣAlk) (nC12 - nC33).

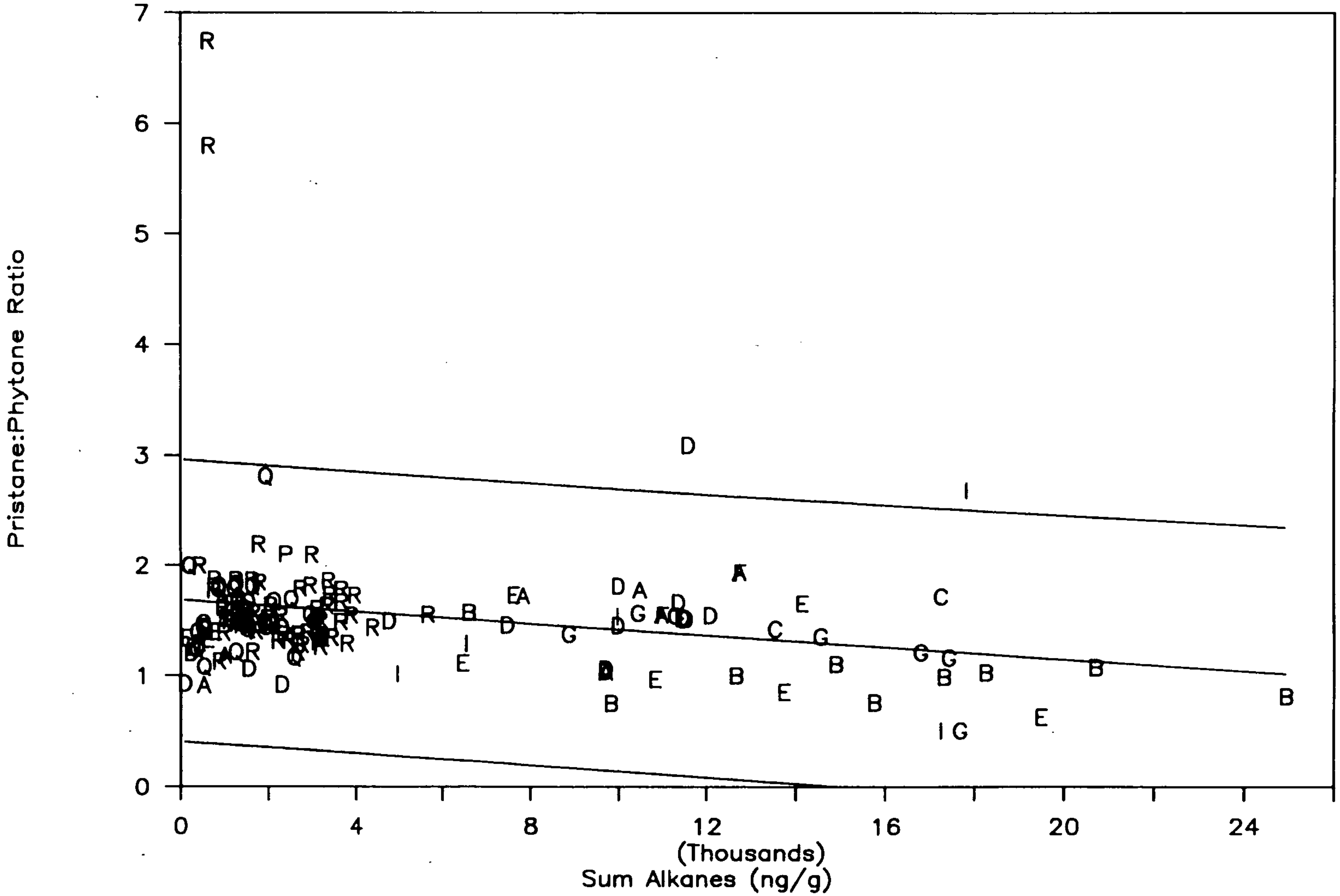

Figure 3 - 10. Regression analysis of pristane:phytane ratio against Sum Alkanes (ΣAlk) (nC12 - nC33).

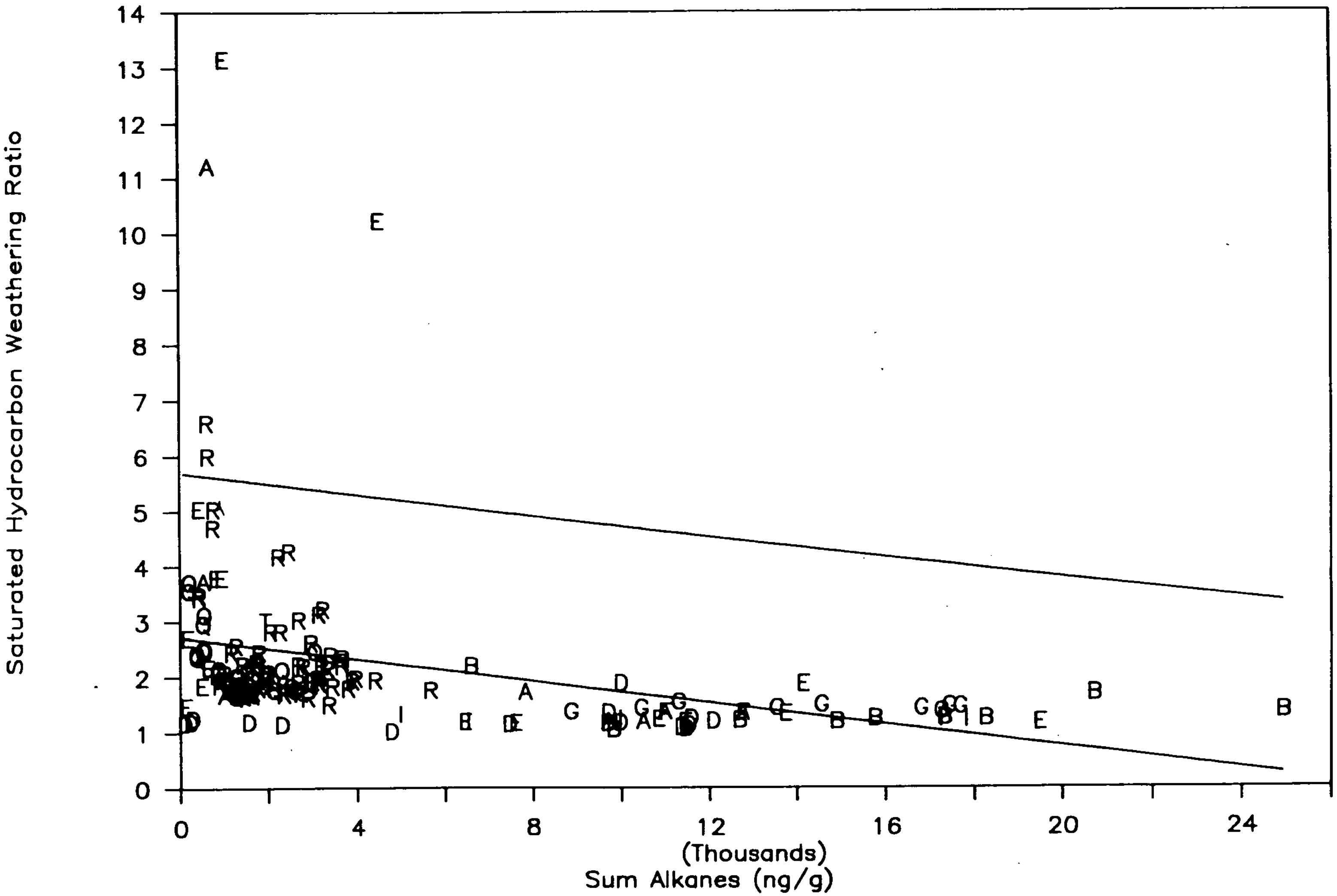

Figure 3 - 11. Regression analysis of saturated hydrocarbon weathering ratio (SHWR) against Sum Alkanes (ΣAlk) (nC12 - nC33).

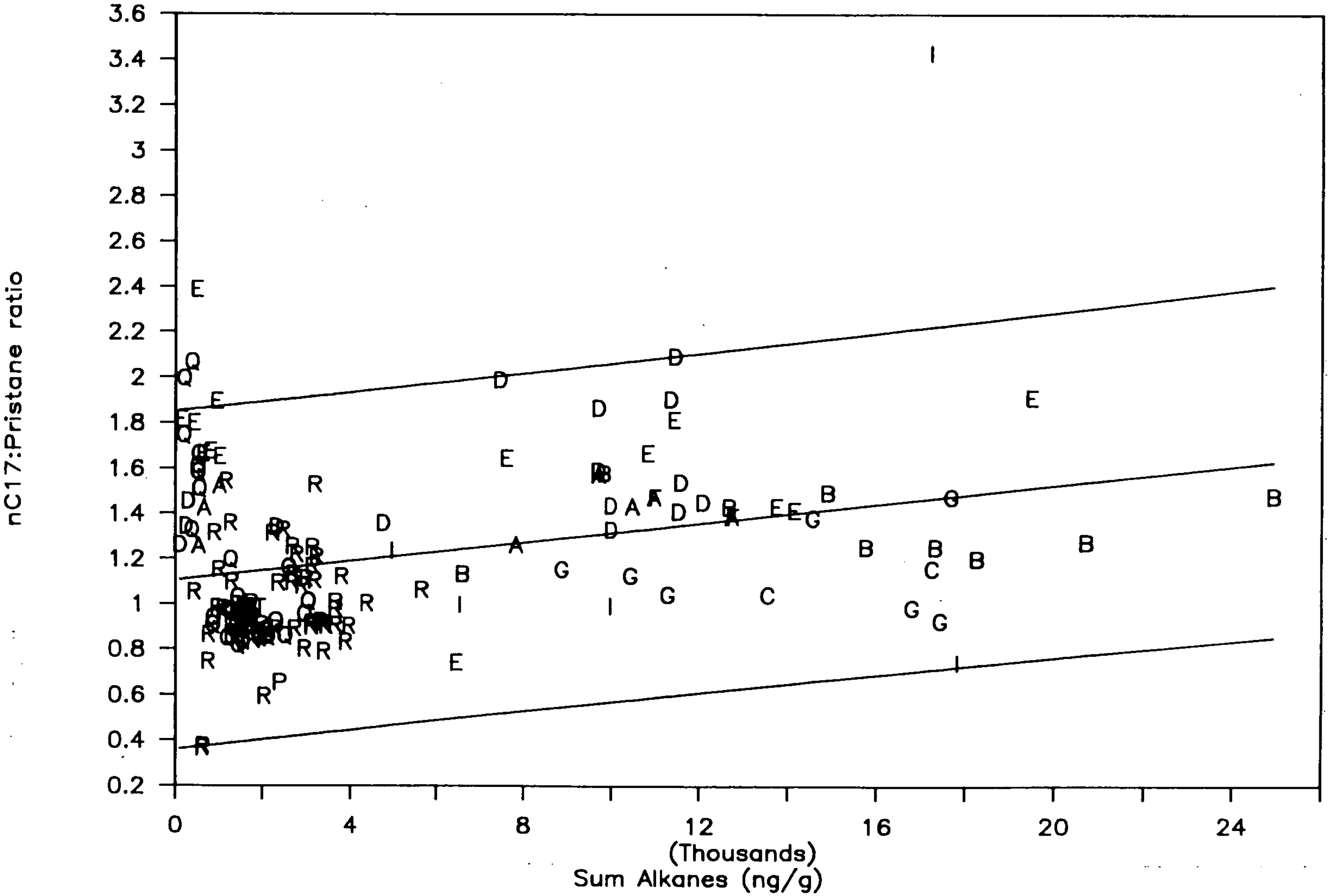

Figure 3 - 12. Regression analysis of n-C17:pristane ratio against Sum Alkanes (ΣAlk) (nC12 - nC33).

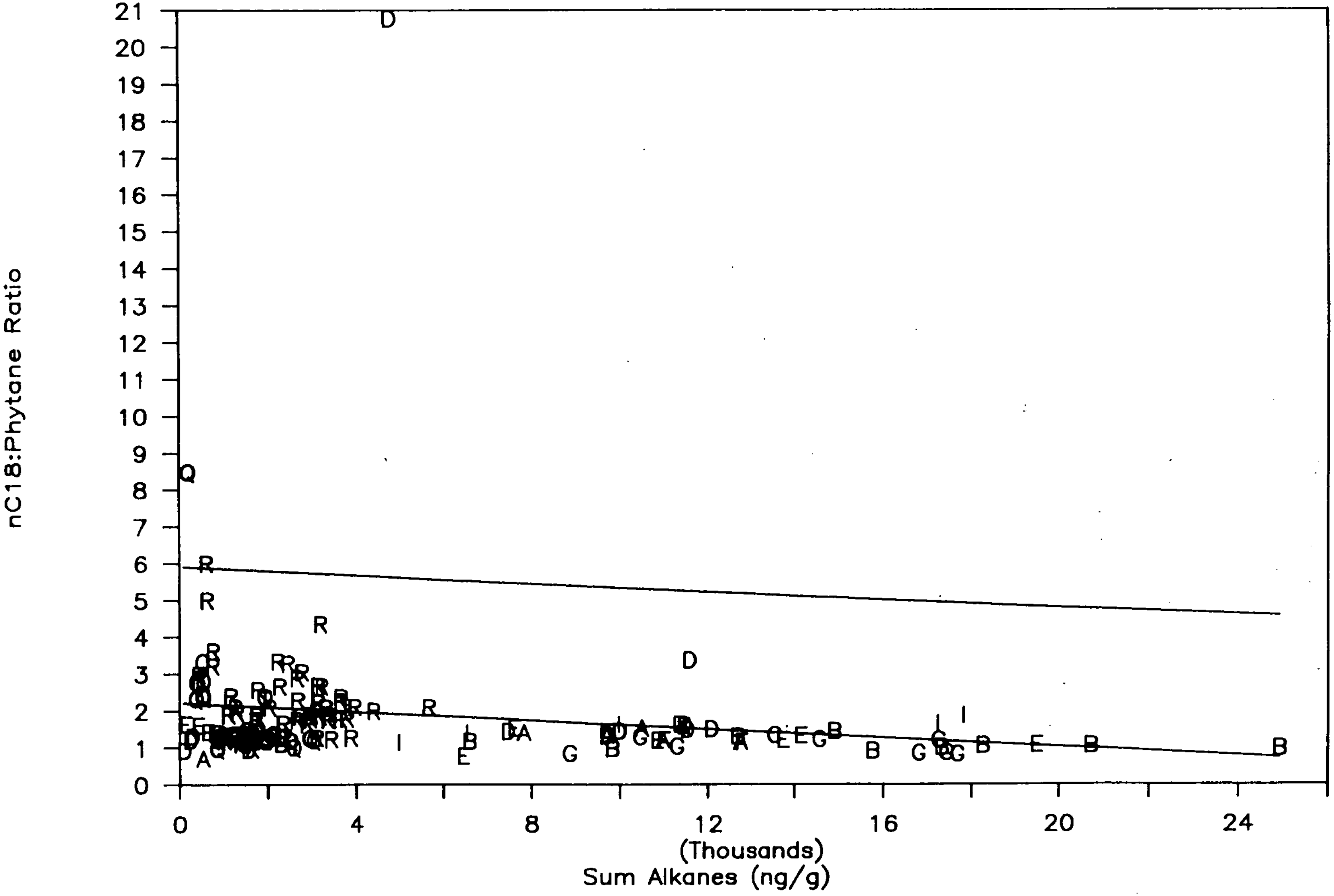

Figure 3 - 13. Regression analysis of n-C18:phytane ratio against Sum Alkanes (ΣAlk) (nC12 - nC33).

APPENDIX 4

Maps of Degree of Contamination for Specific Contaminants

The maps in Appendix 4 are described in the section: Determination of Anthropogenic Input. Each map shows the distribution of the calculated Degree of Contamination Index (D) for a specific contaminant. "Circles" indicate stations at which the index is greater than zero and are labelled with the value of the index. "Pluses" indicate stations at which the value of D is zero.

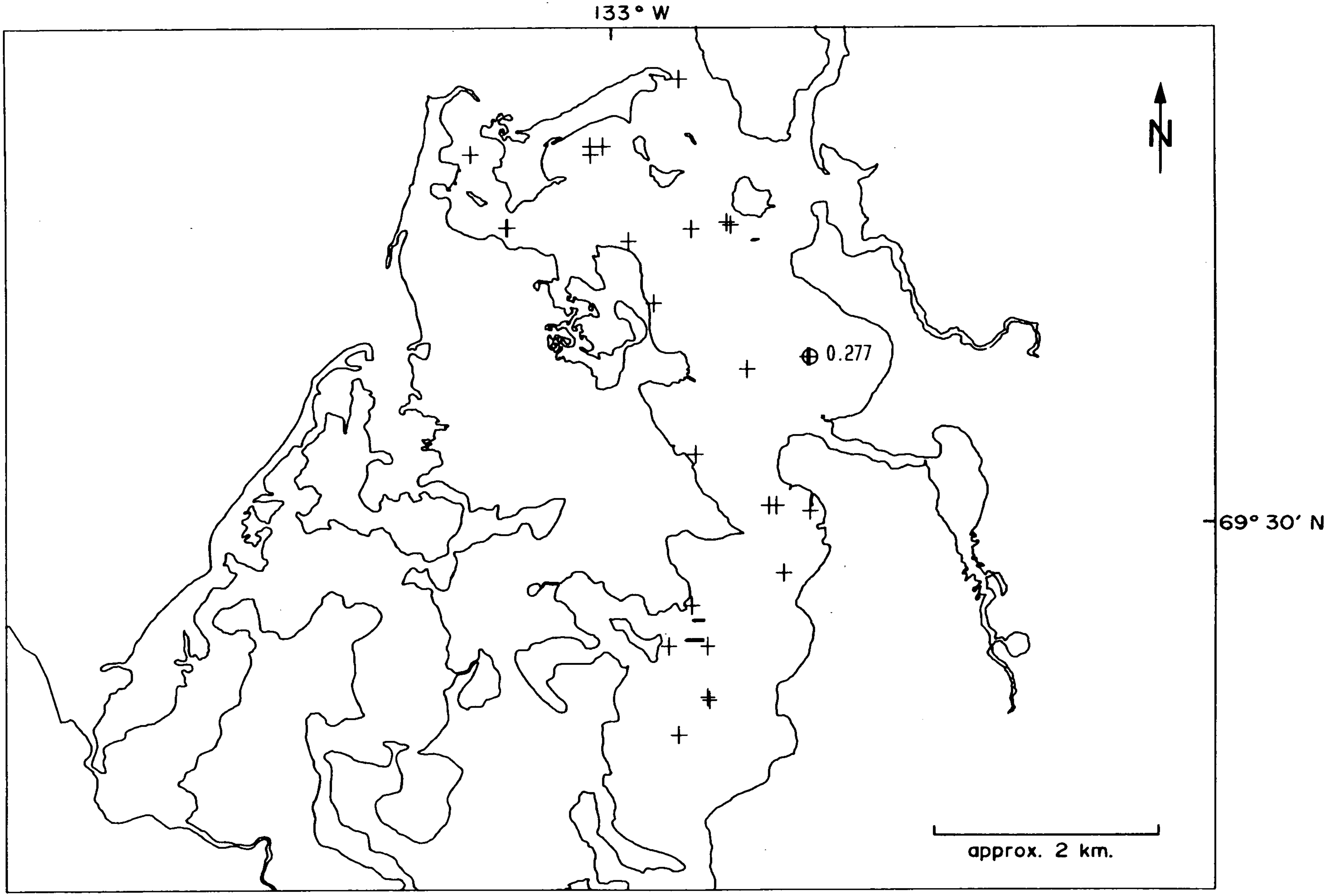

Figure 4 - 1. Distribution of degree of contamination index (D) for cadmium in Tuktoyaktuk Harbour.

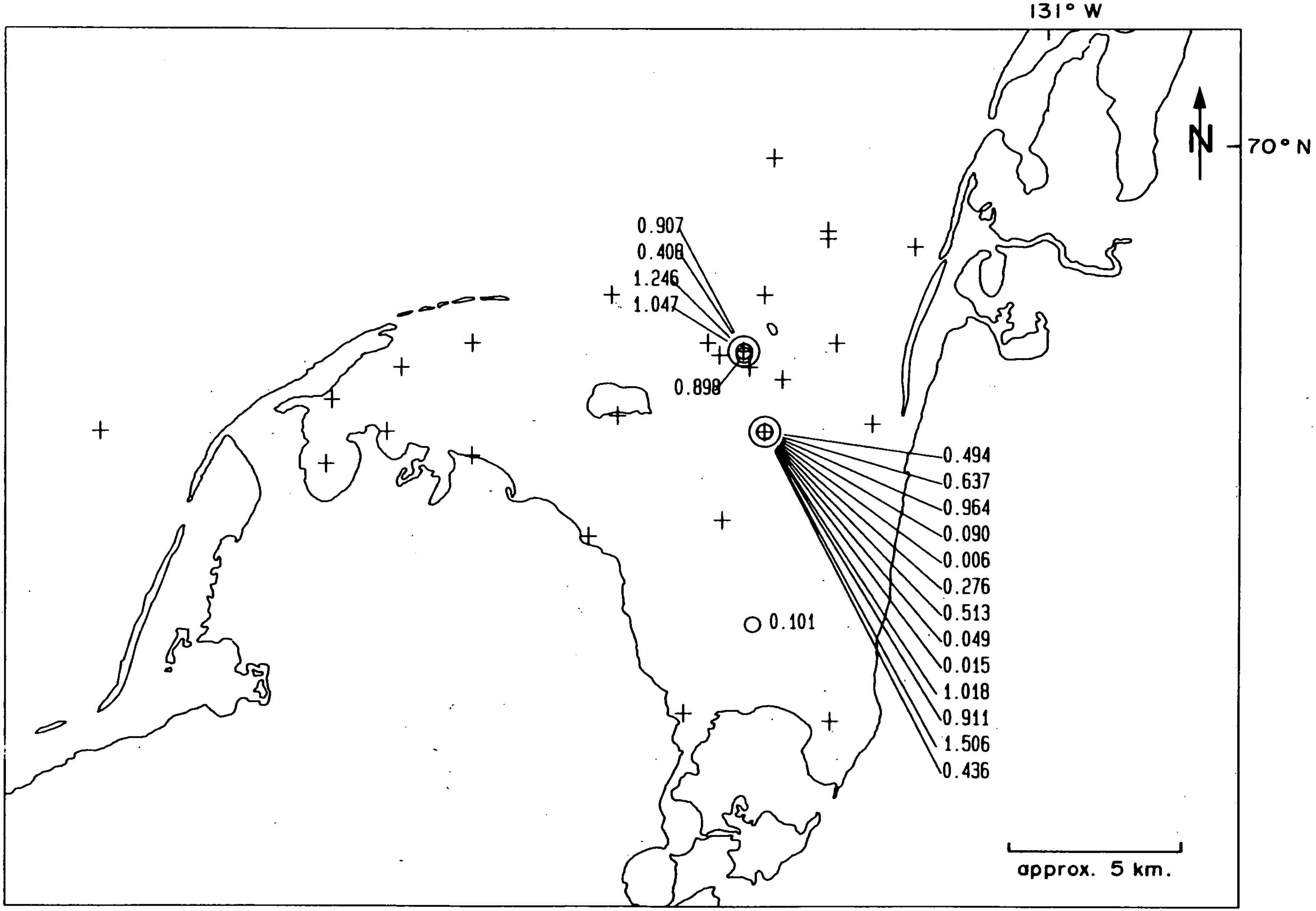

Figure 4 - 2. Distribution of degree of contamination index (D) for cadmium in McKinley Bay.

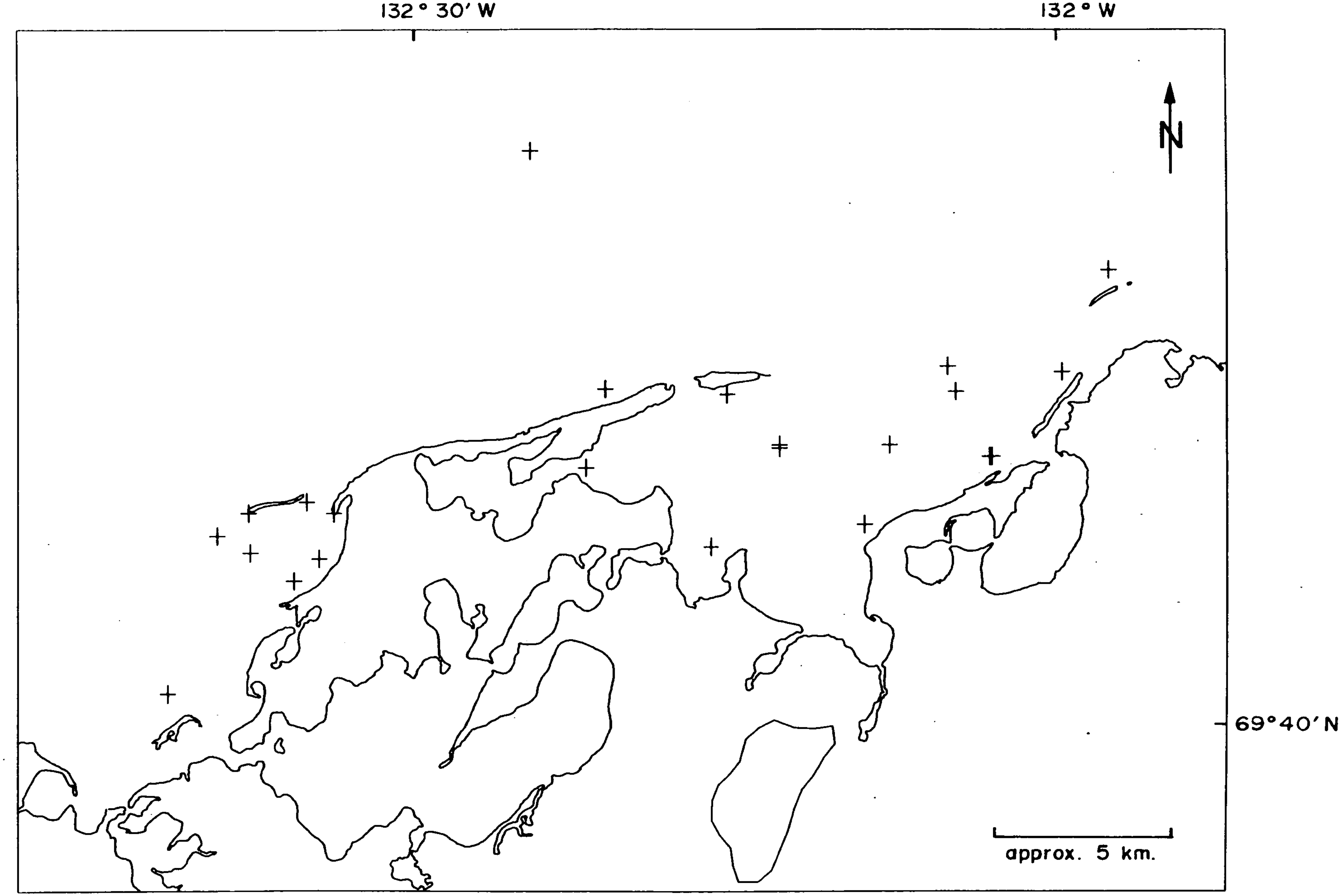

Figure 4 - 3. Distribution of degree of contamination index (D) for cadmium in Hutchison Bay.

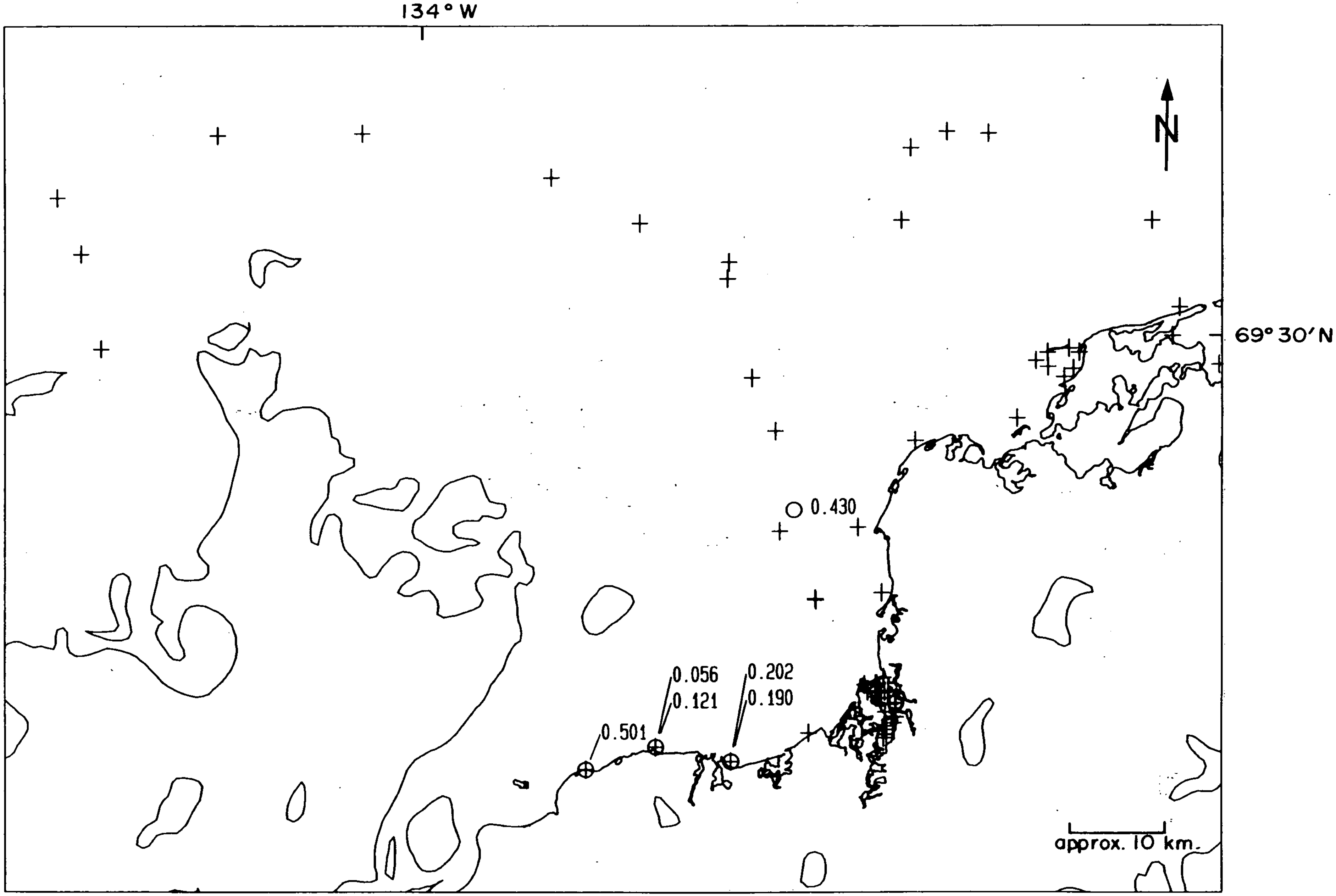

Figure 4 - 4. Distribution of degree of contamination index (D) for cadmium in Kugmallit Bay.

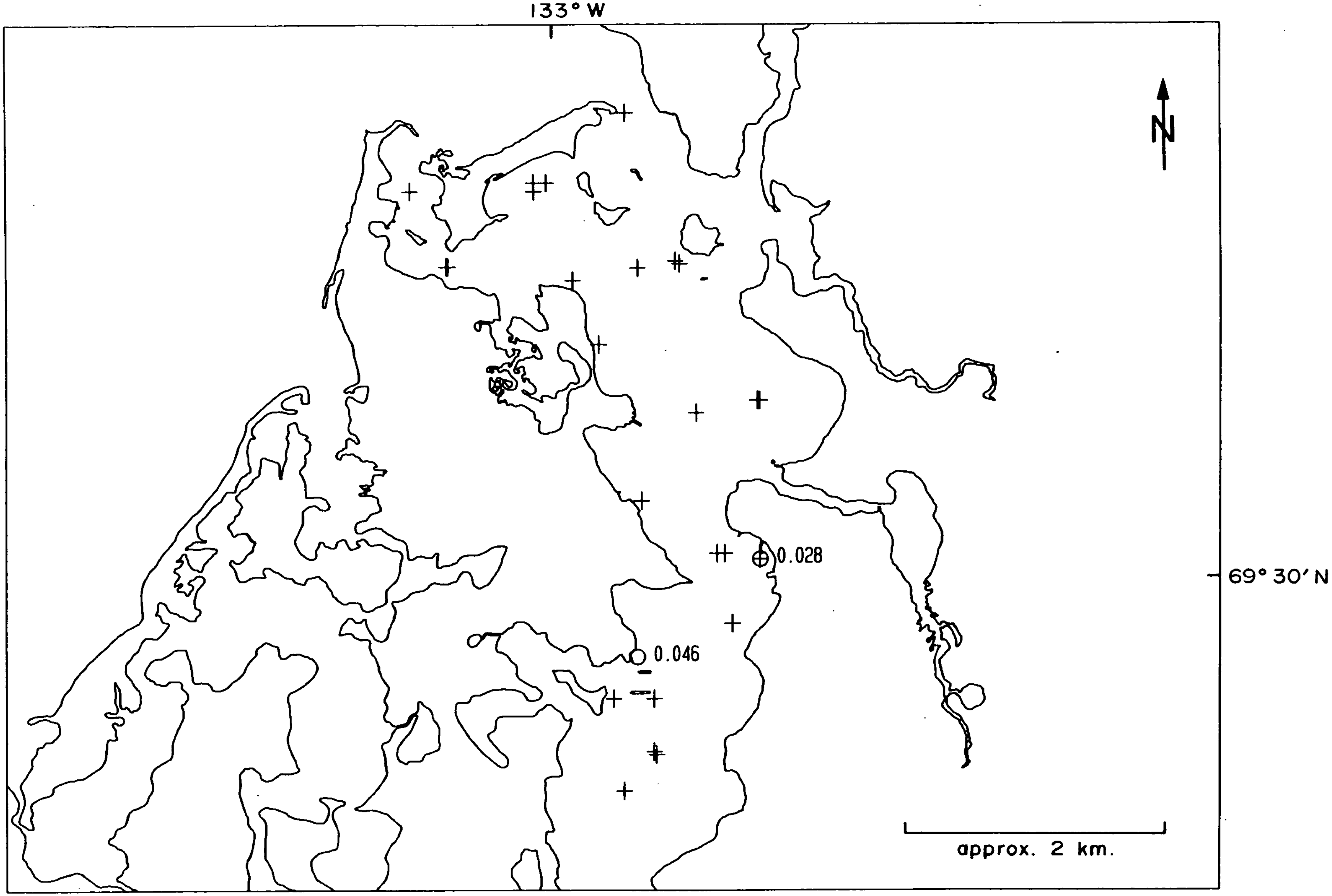

Figure 4 - 5. Distribution of degree of contamination index (D) for chromium in Tuktoyaktuk Harbour.

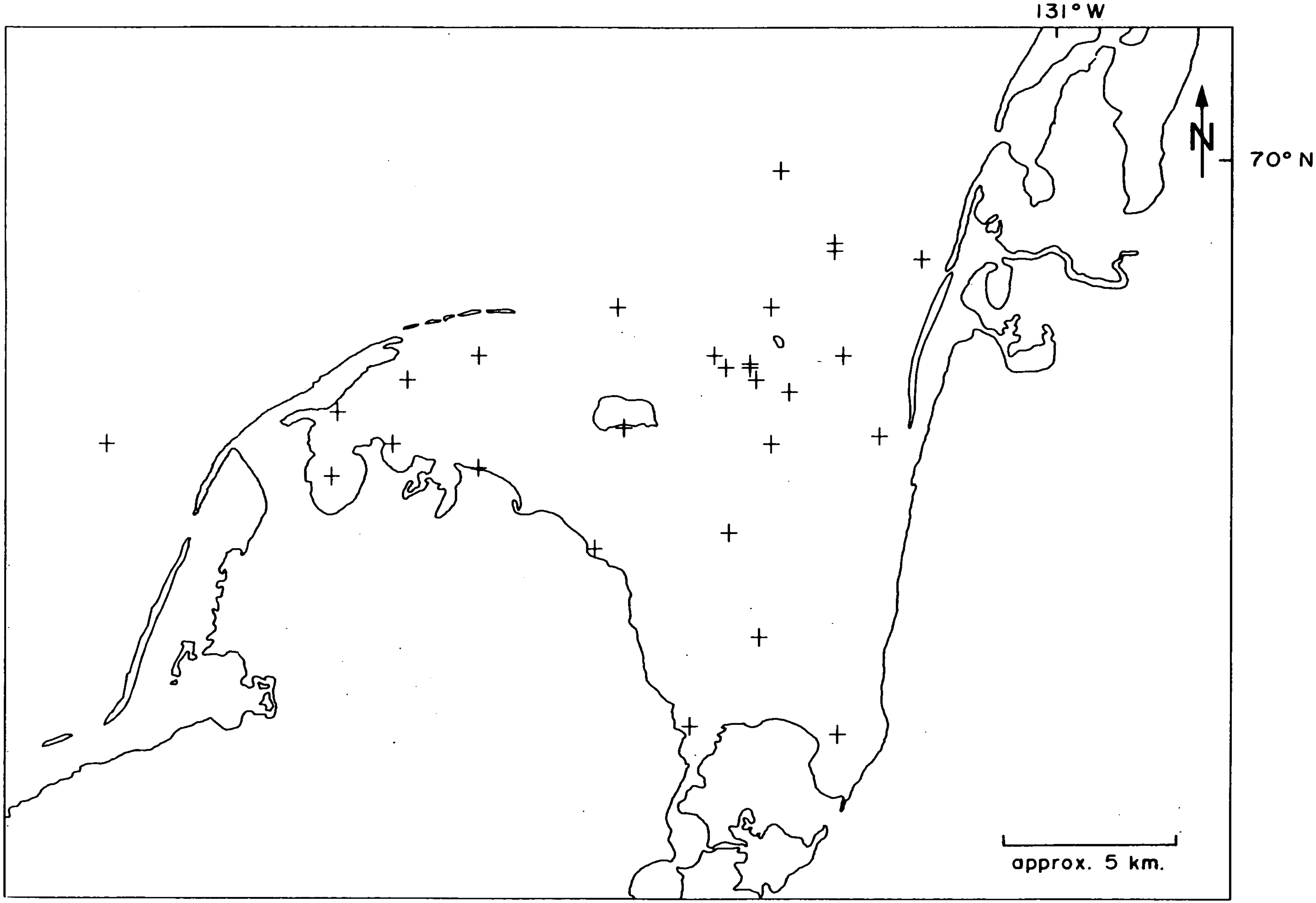

Figure 4 - 6. Distribution of degree of contamination index (D) for chromium in McKinley Bay.

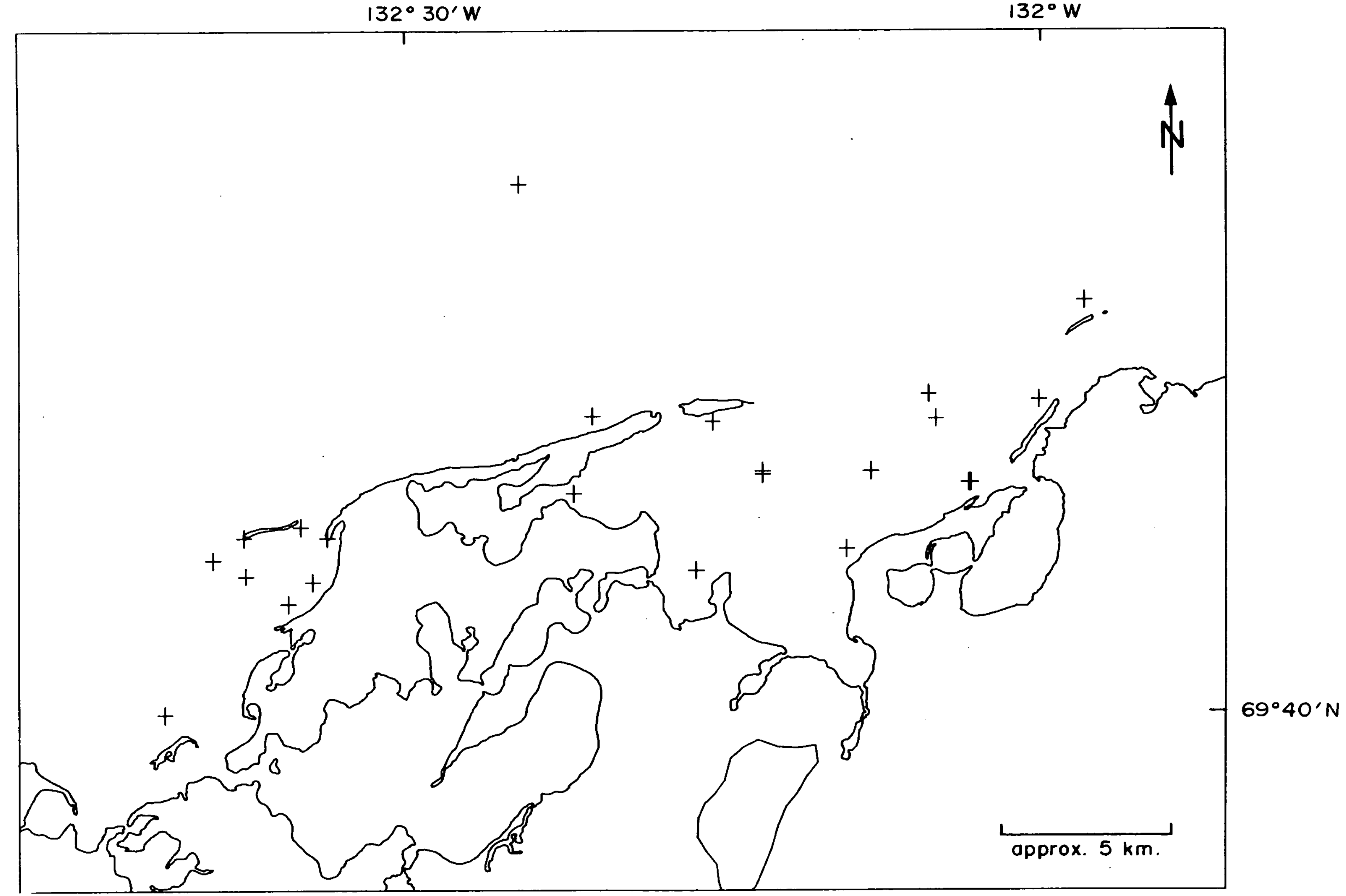

Figure 4 - 7. Distribution of degree of contamination index (D) for chromium in Hutchison Bay.

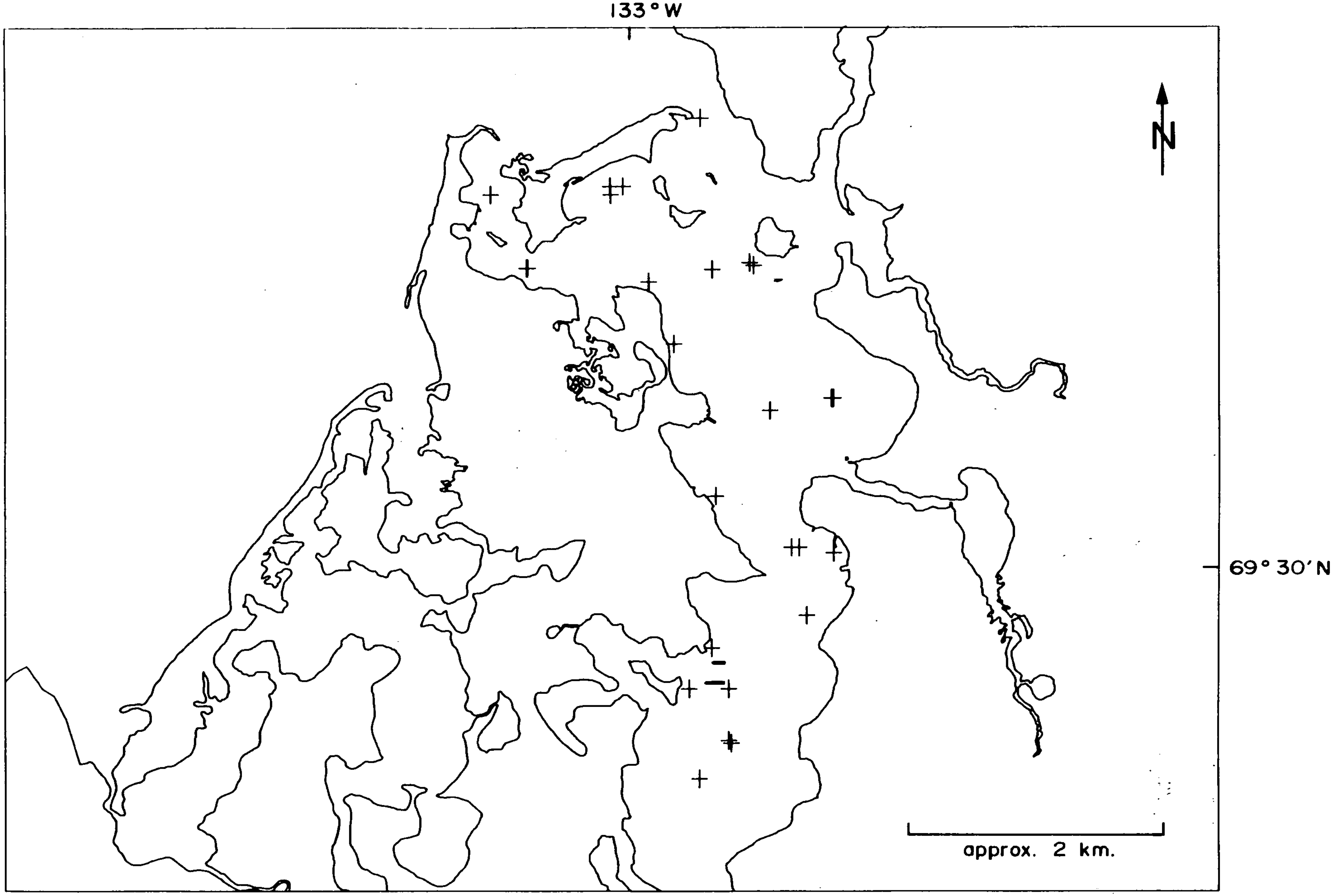

Figure 4 - 8. Distribution of degree of contamination index (D) for copper in Tuktoyaktuk Harbour.

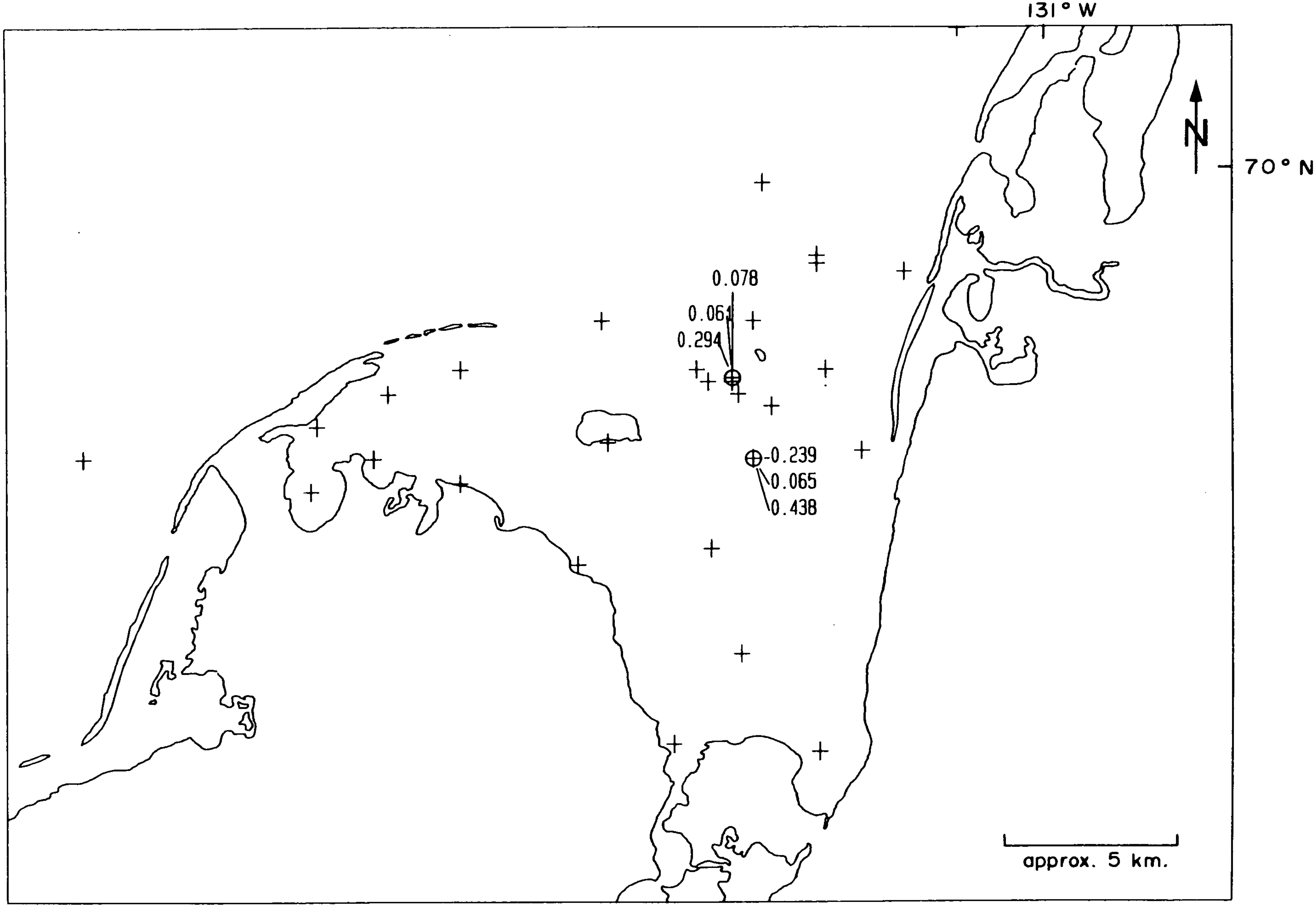

Figure 4 - 9. Distribution of degree of contamination index (D) for copper in McKinley Bay.

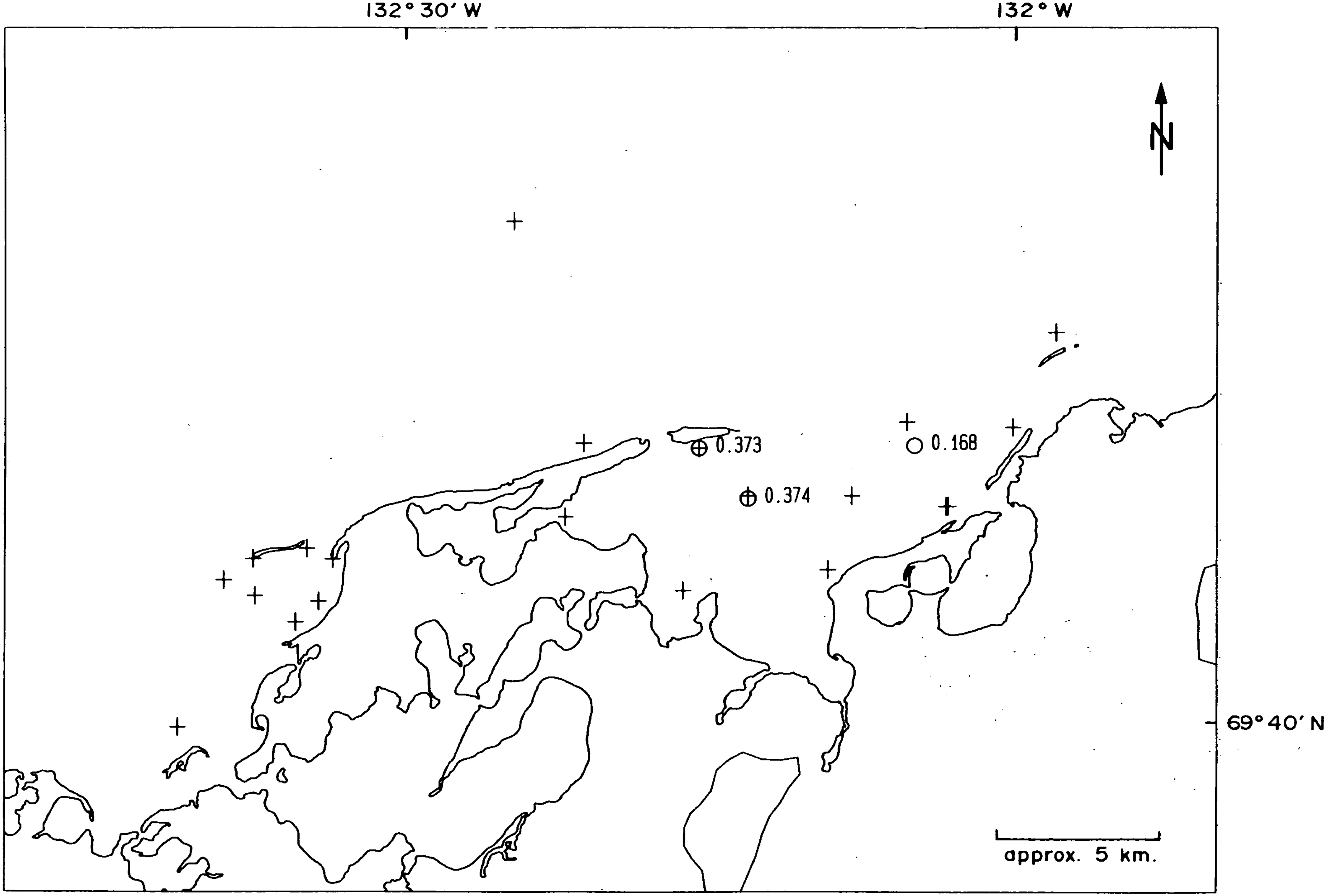

Figure 4 - 10. Distribution of degree of contamination index (D) for copper in Hutchison Bay.

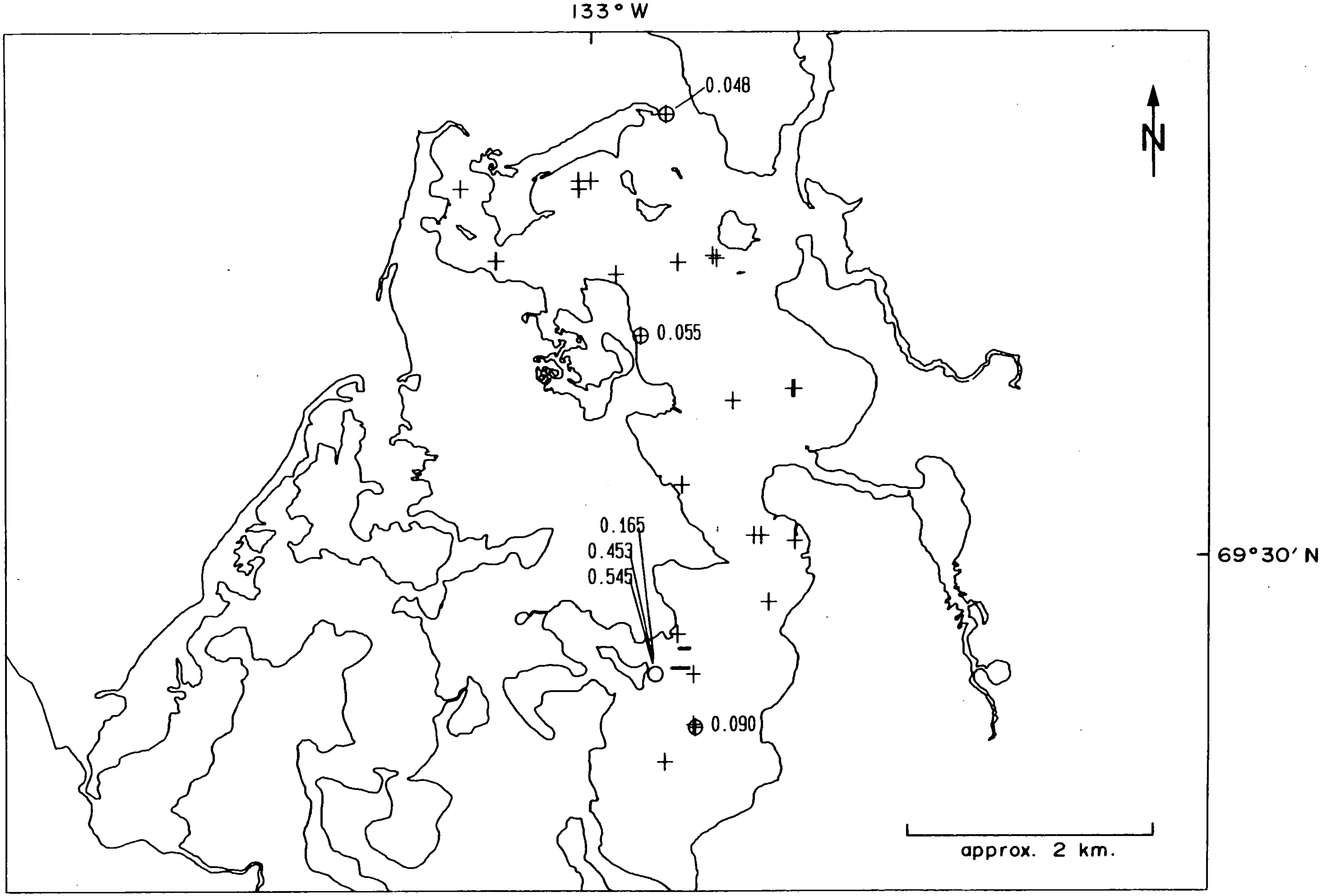

Figure 4 - 11. Distribution of degree of contamination index (D) for mercury in Tuktoyaktuk Harbour.

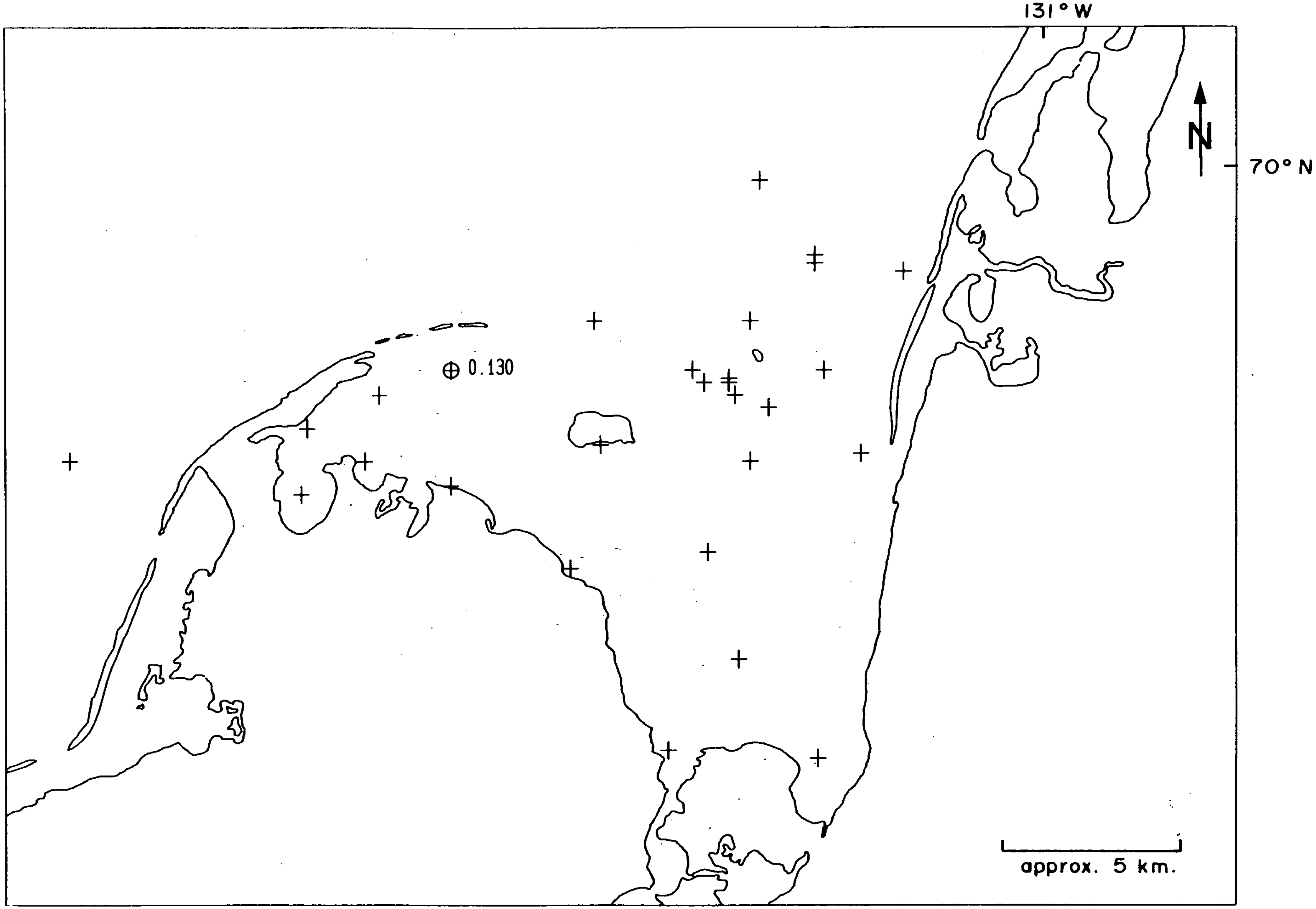

Figure 4 - 12. Distribution of degree of contamination index (D) for mercury in McKinley Bay.

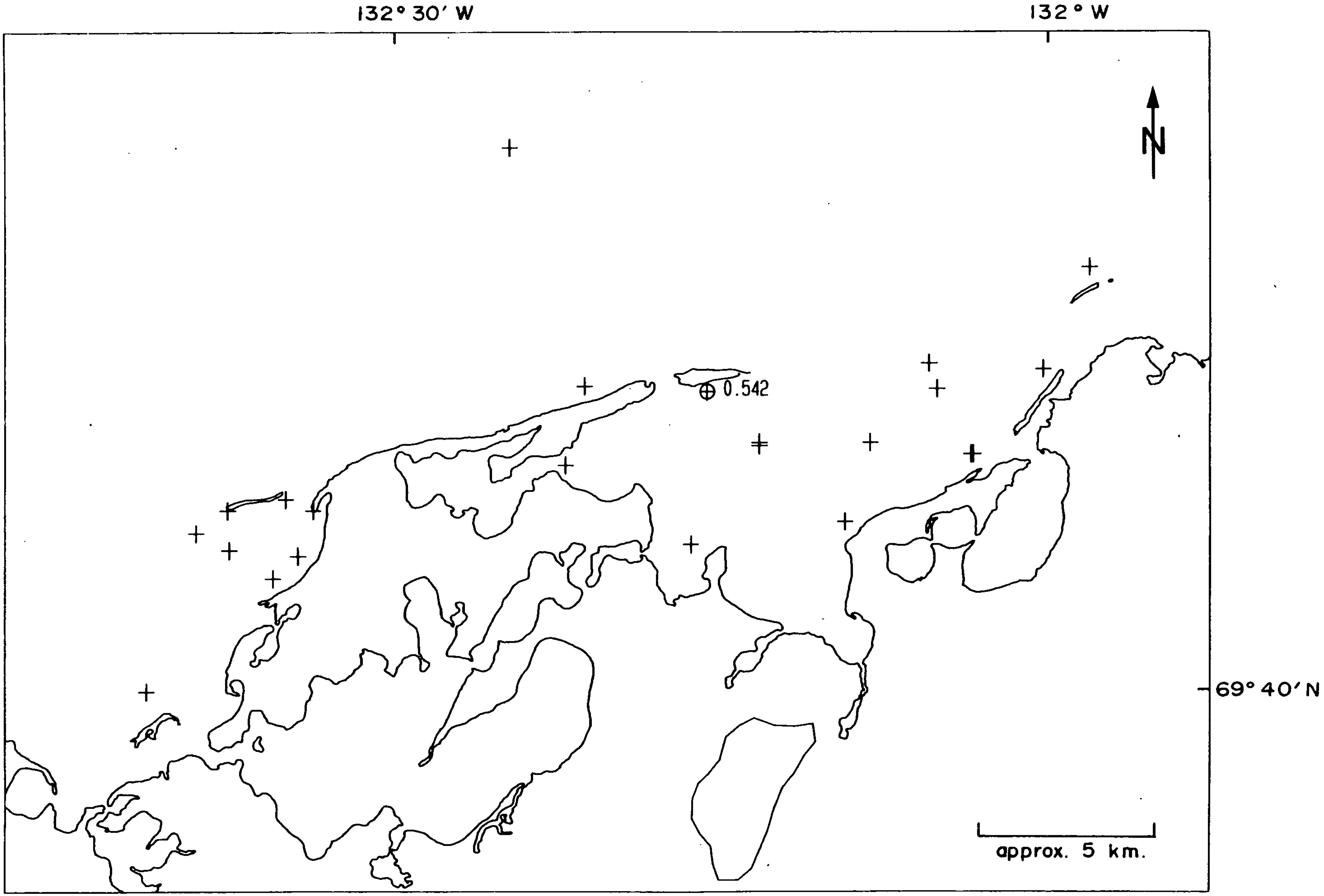

Figure 4 - 13. Distribution of degree of contamination index (D) for mercury in Hutchison Bay.

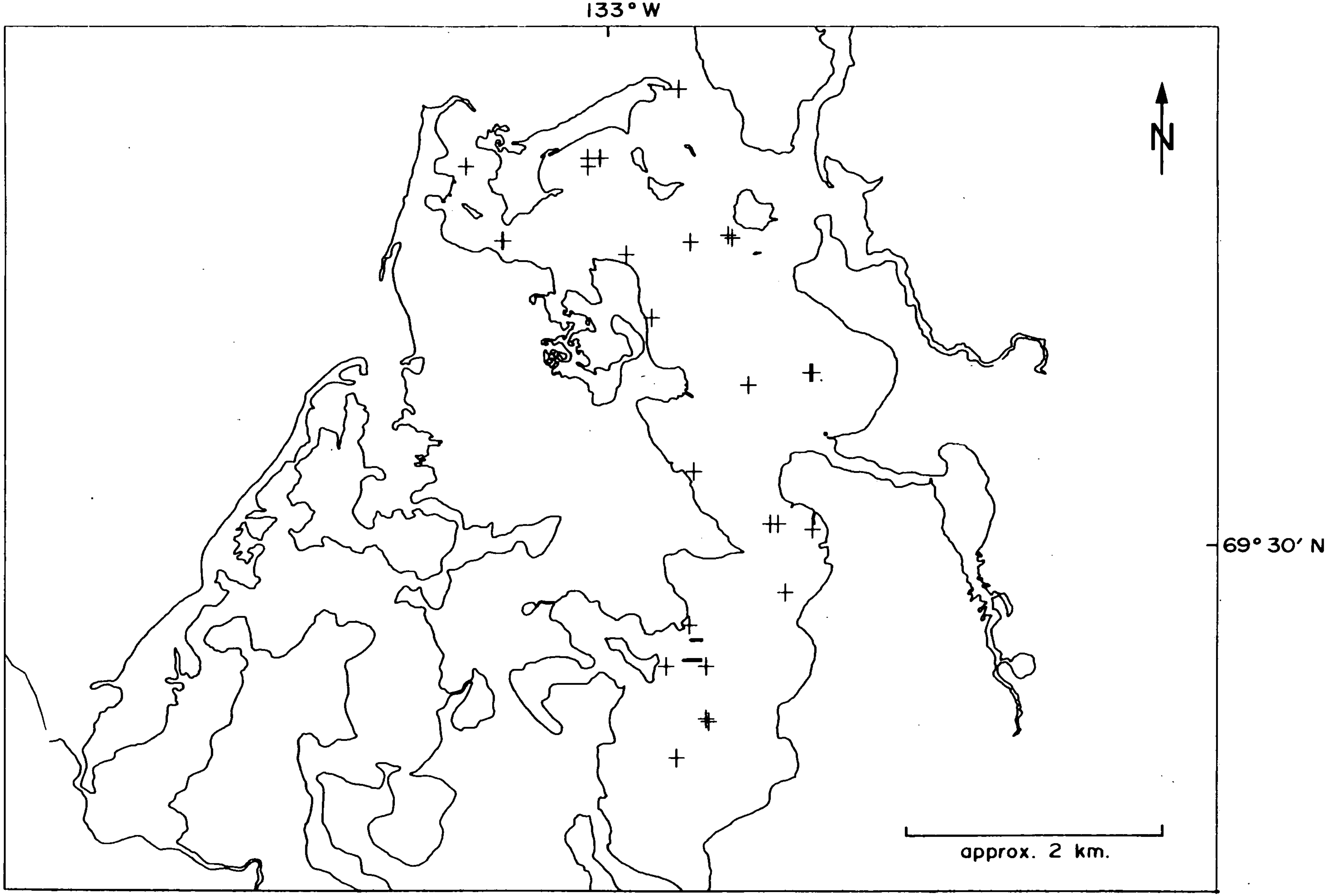

Figure 4 - 14. Distribution of degree of contamination index (D) for nickel in Tuktoyaktuk Harbour.

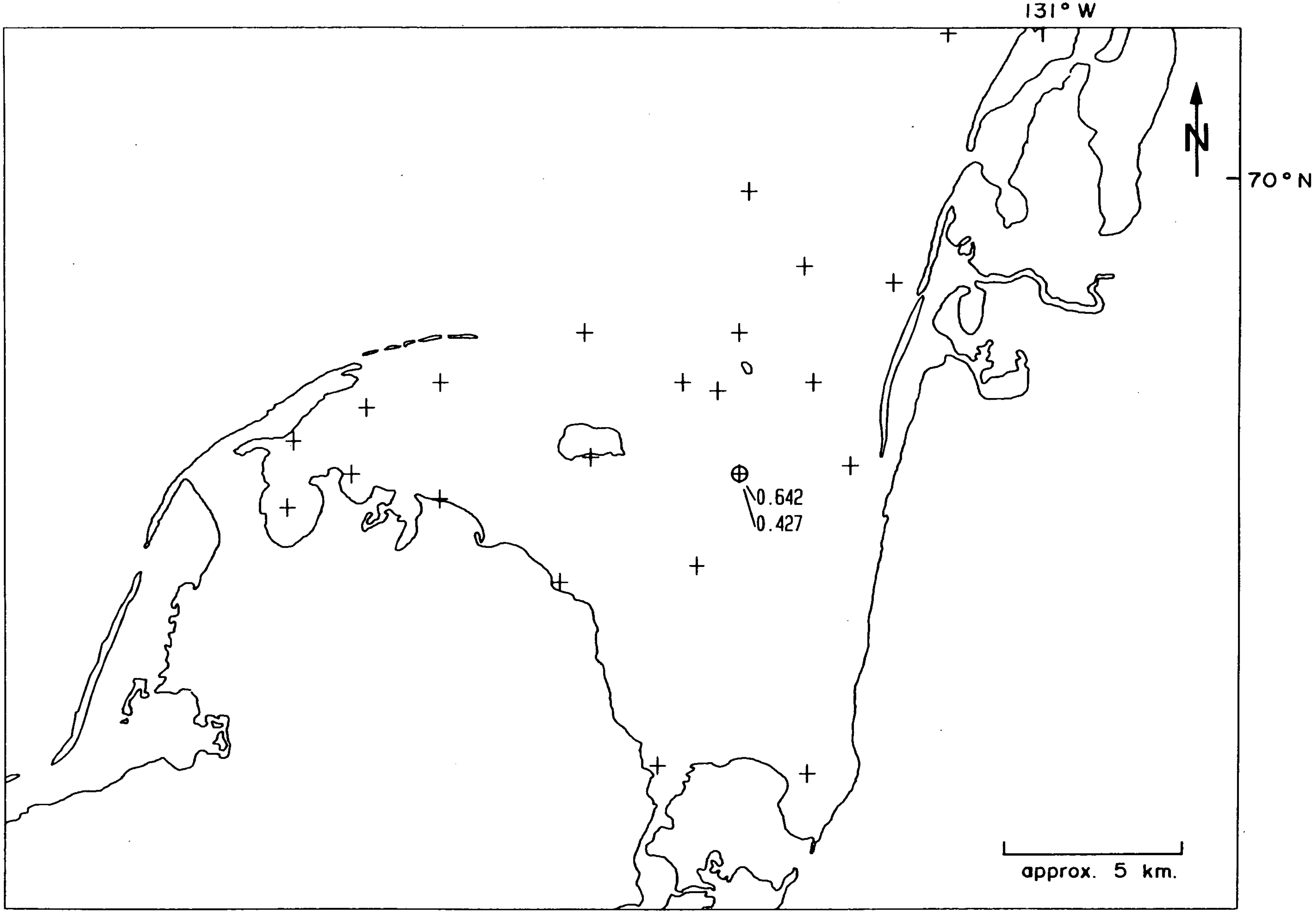

Figure 4 - 15. Distribution of degree of contamination index (D) for nickel in McKinley Bay.

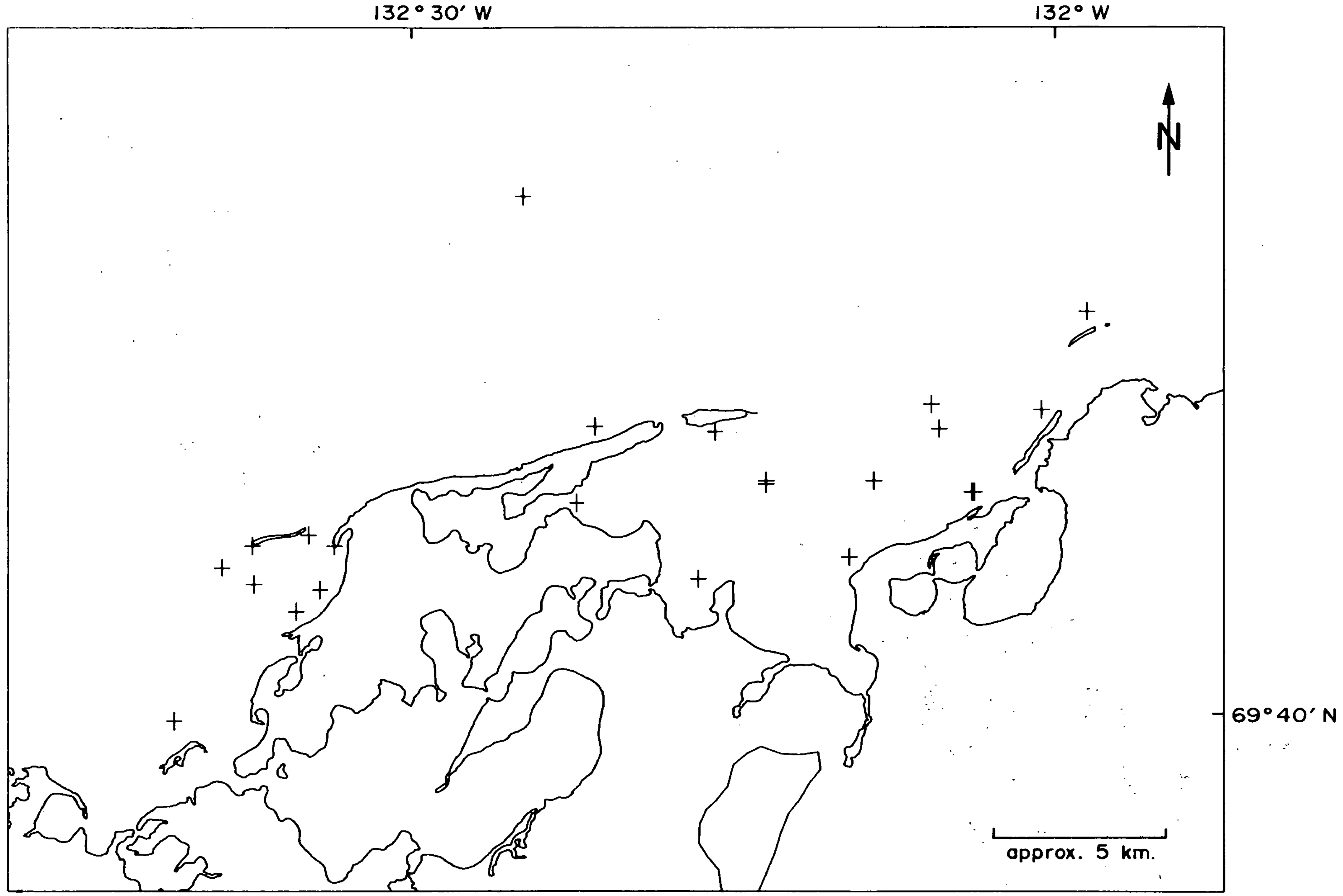

Figure 4 - 16. Distribution of degree of contamination index (D) for nickel in Hutchison Bay.

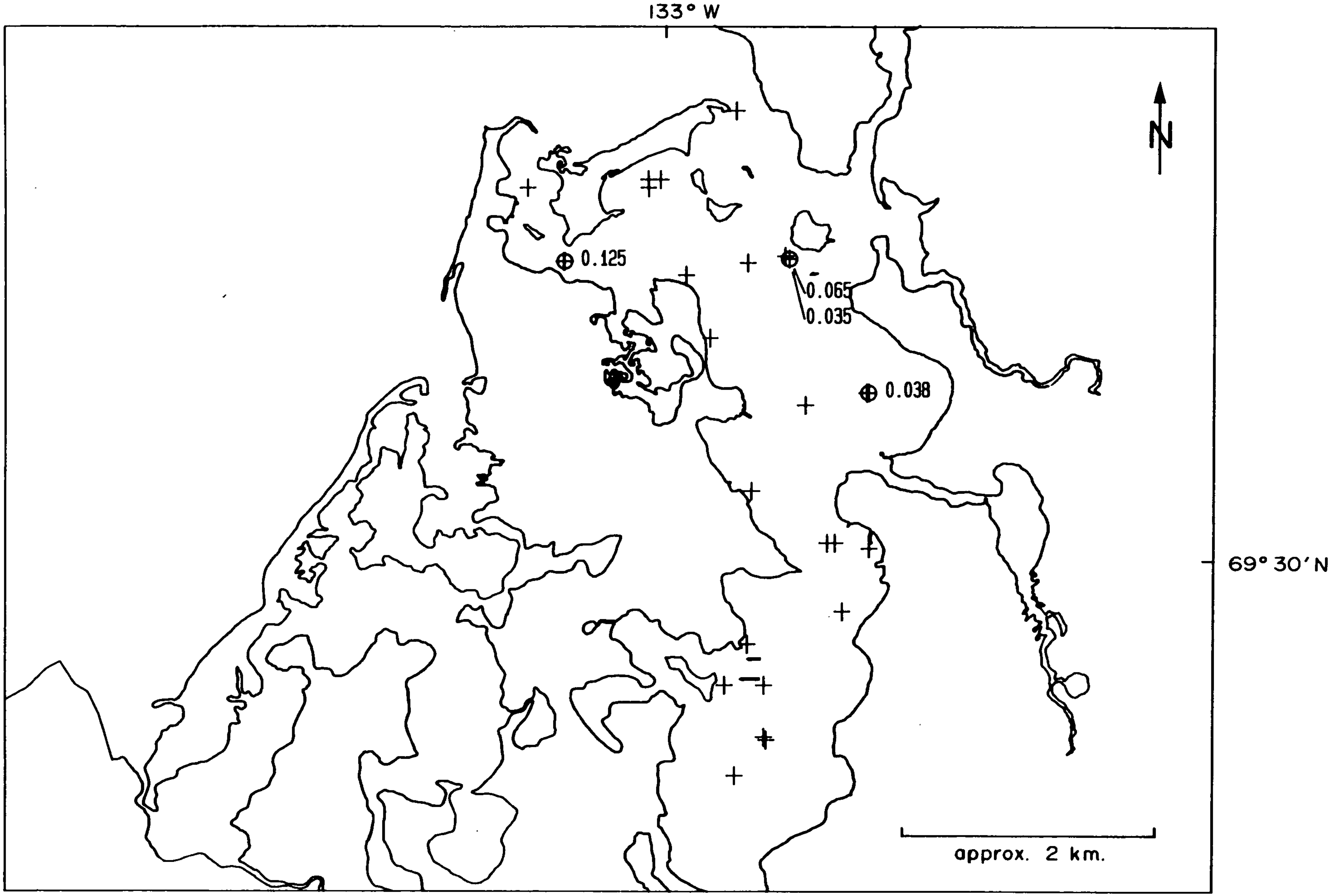

Figure 4 - 17. Distribution of degree of contamination index (D) for lead in Tuktoyaktuk Harbour.

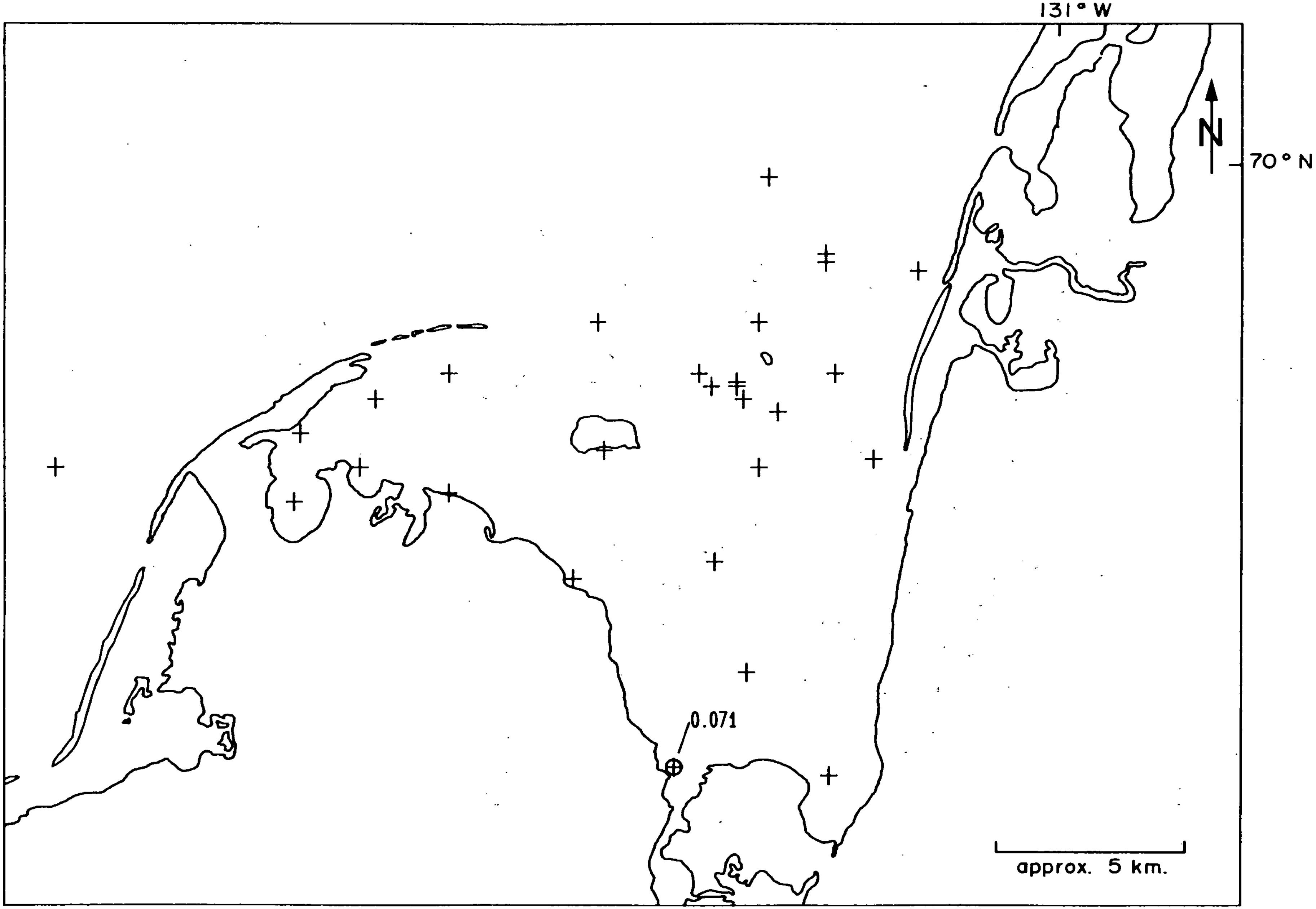

Figure 4 - 18. Distribution of degree of contamination index (D) for lead in McKinley Bay.

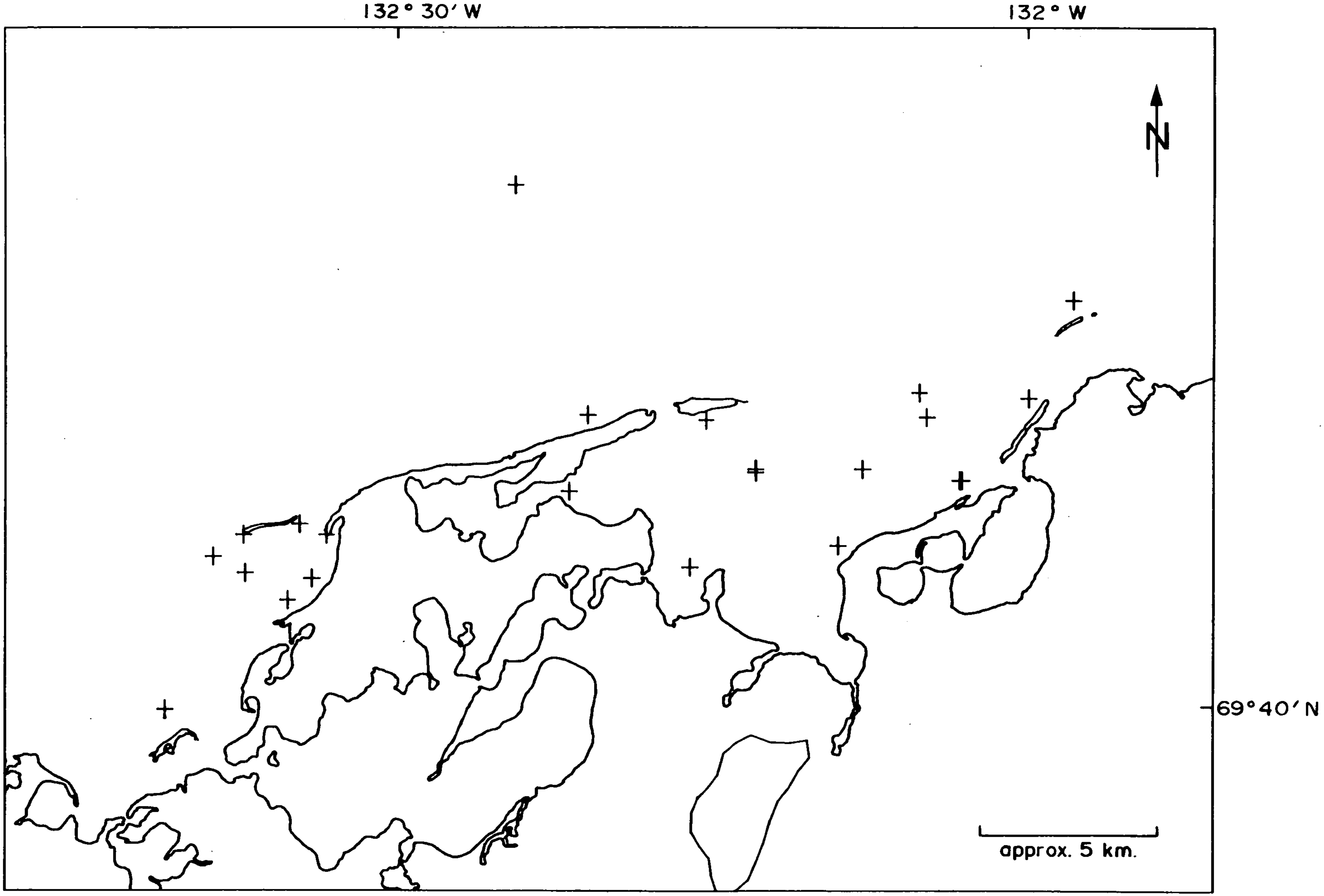

Figure 4 - 19. Distribution of degree of contamination index (D) for lead in Hutchison Bay.

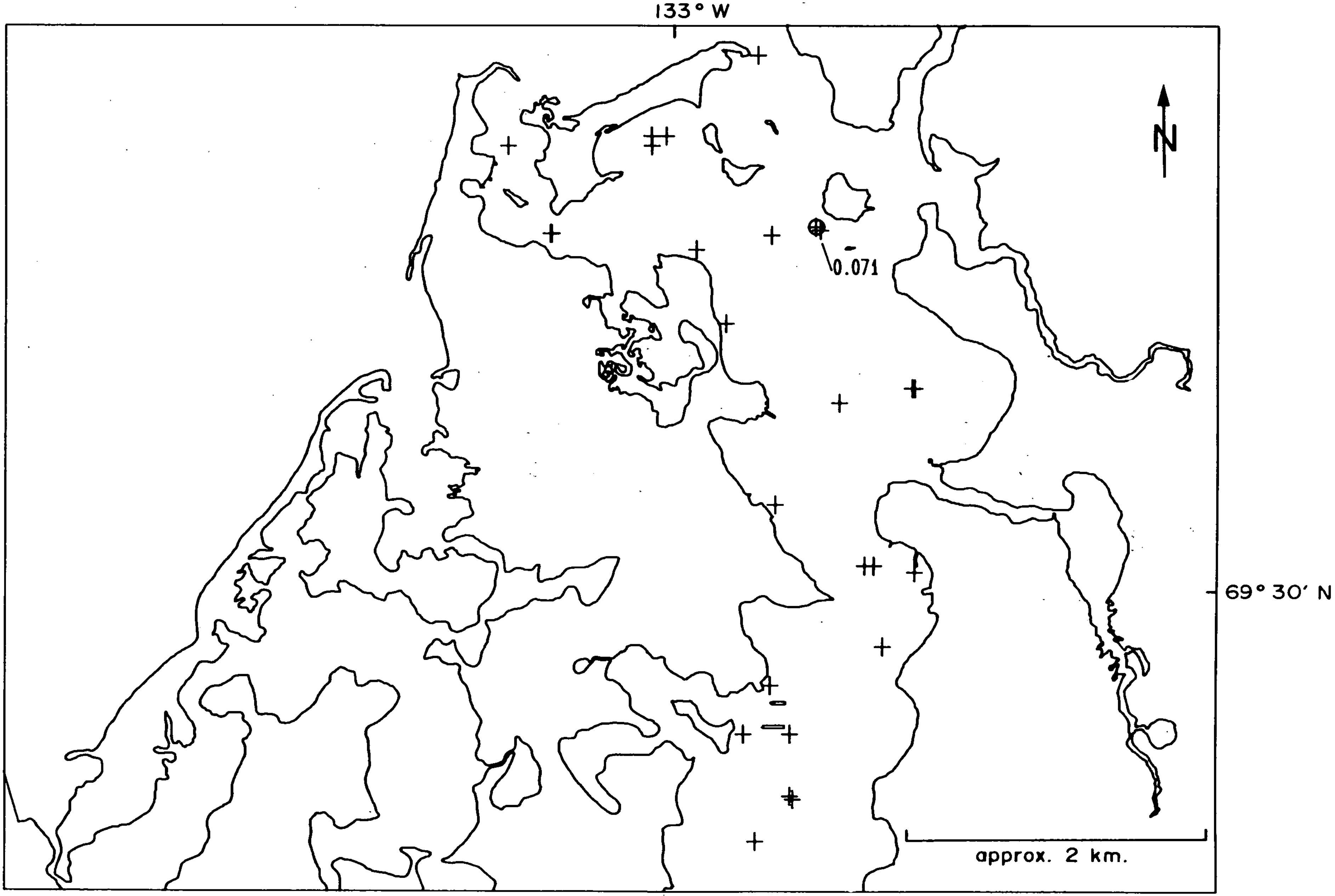

Figure 4 - 20. Distribution of degree of contamination index (D) for zinc in Tuktoyaktuk Harbour.

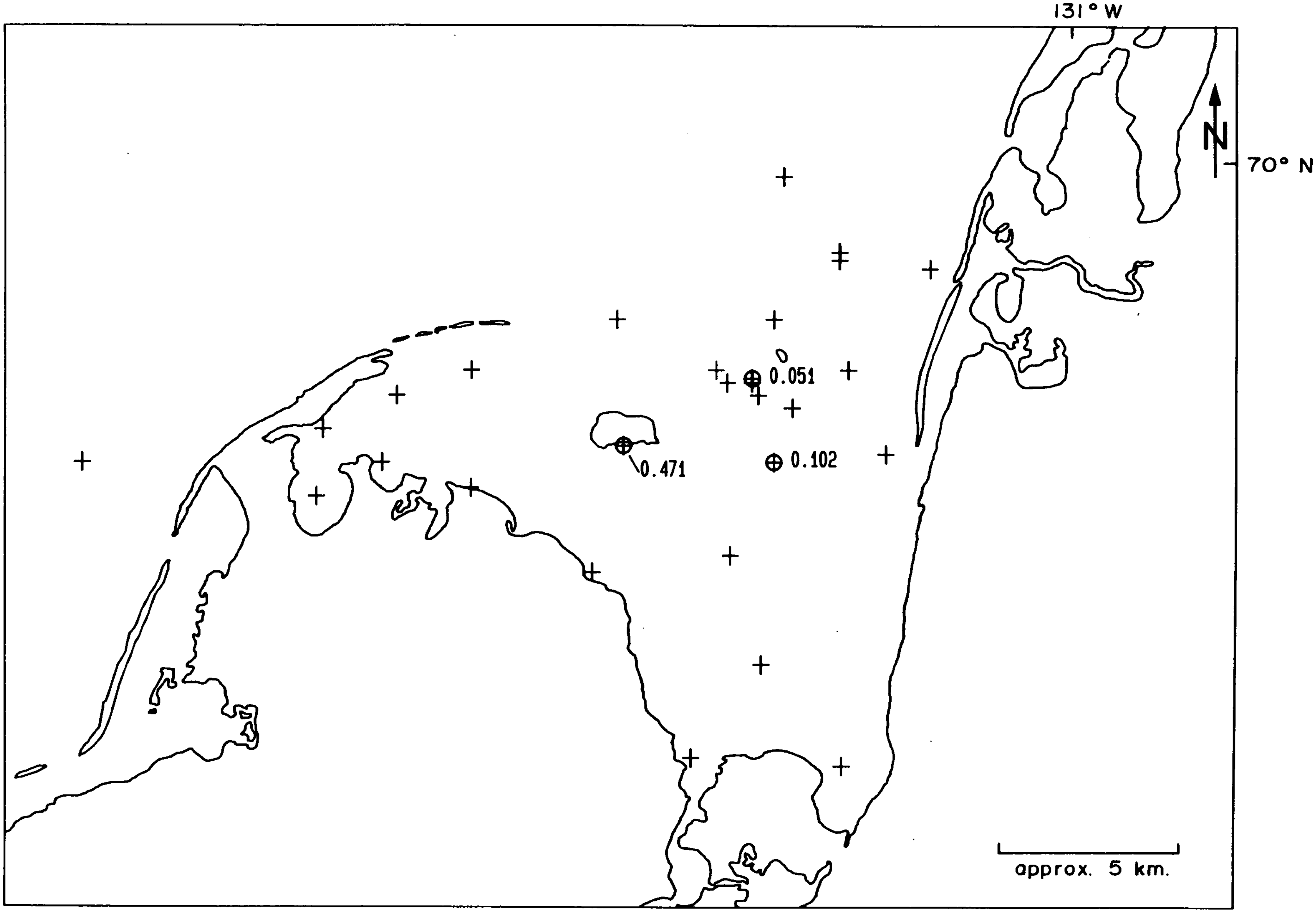

Figure 4 - 21. Distribution of degree of contamination index (D) for zinc in McKinley Bay.

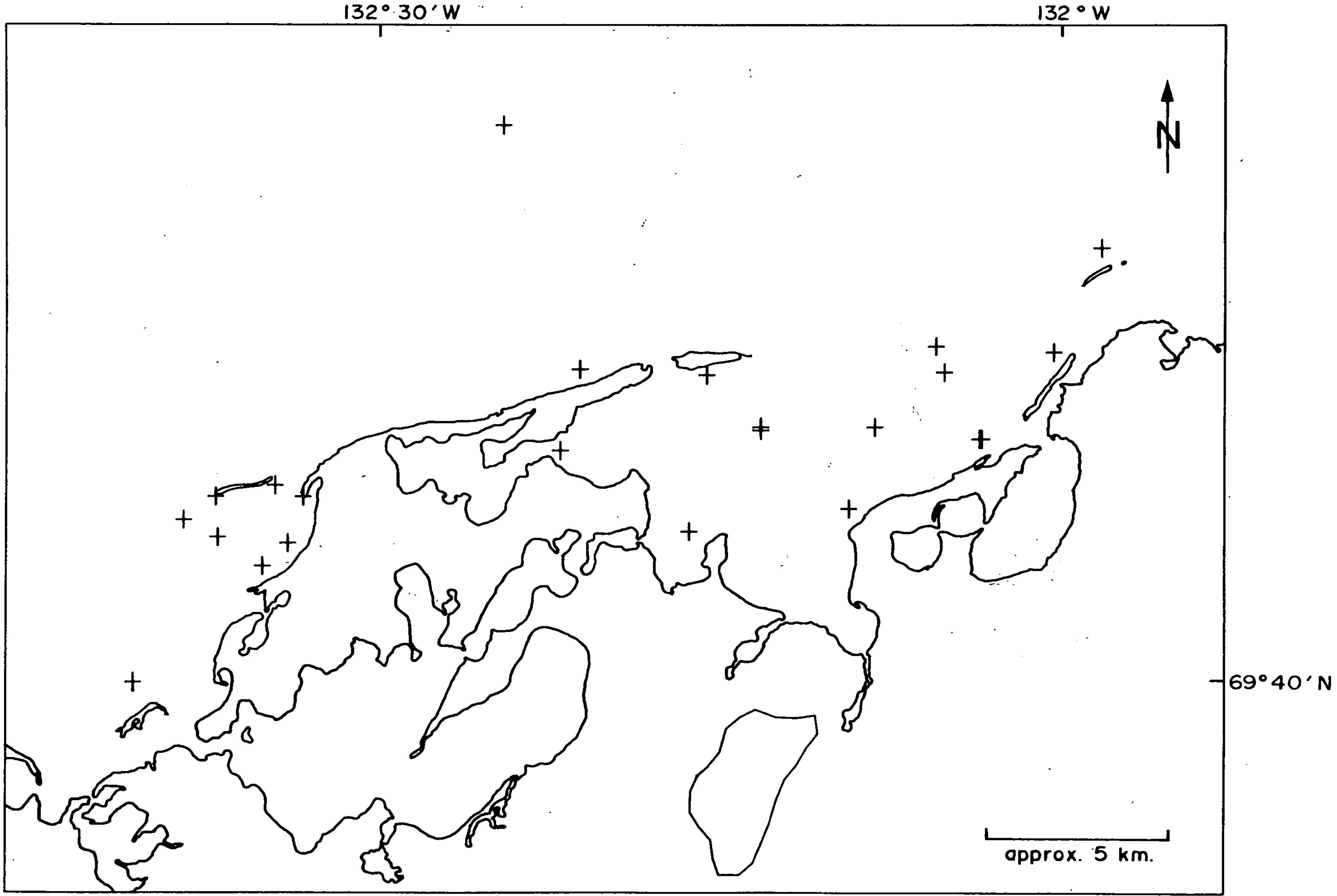

Figure 4 - 22. Distribution of degree of contamination index (D) for zinc in Hutchison Bay.

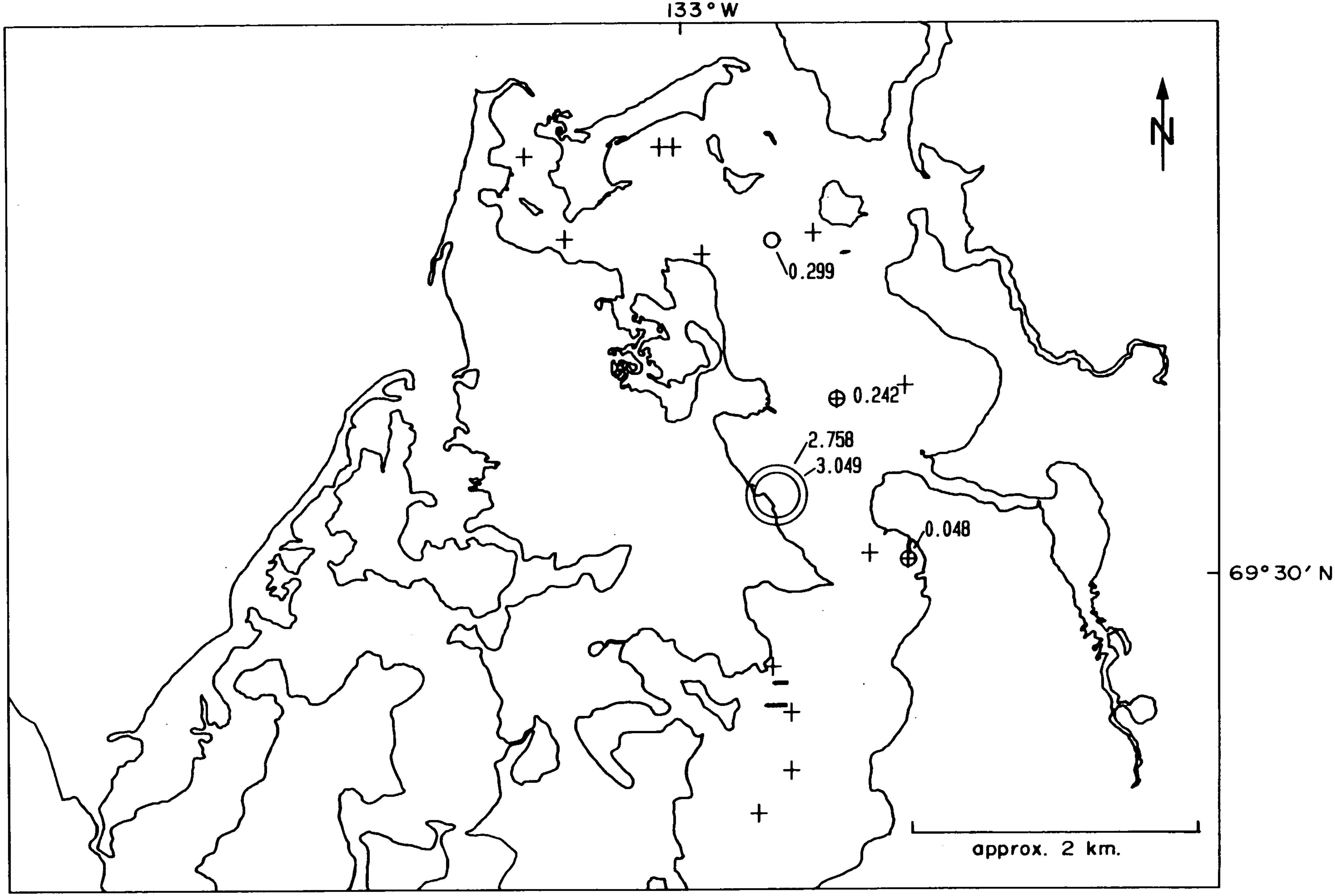

Figure 4 - 23. Distribution of degree of contamination index (D) for barium in Tuktoyaktuk Harbour.

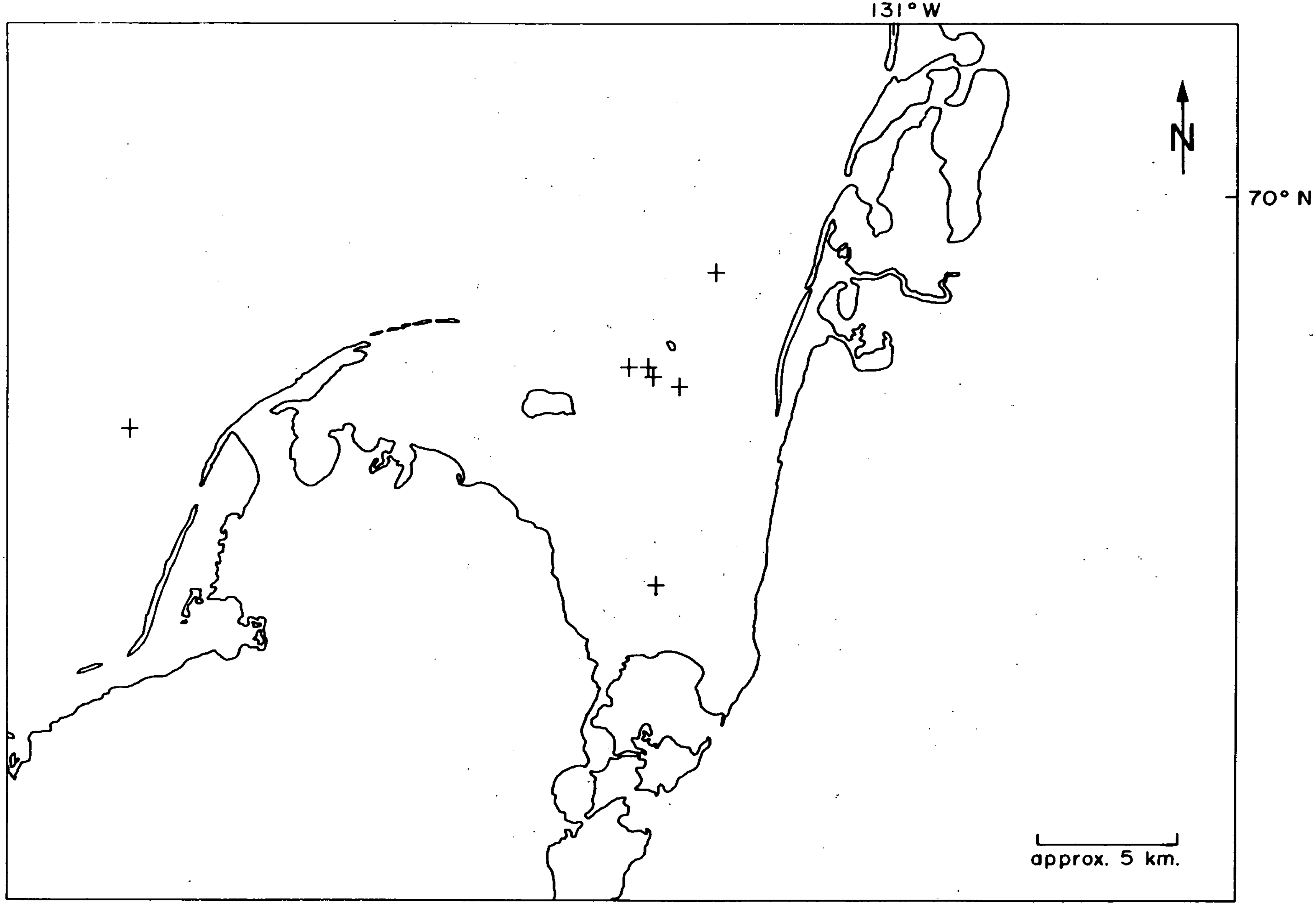

Figure 4 - 24. Distribution of degree of contamination index (D) for barium in McKinley Bay.

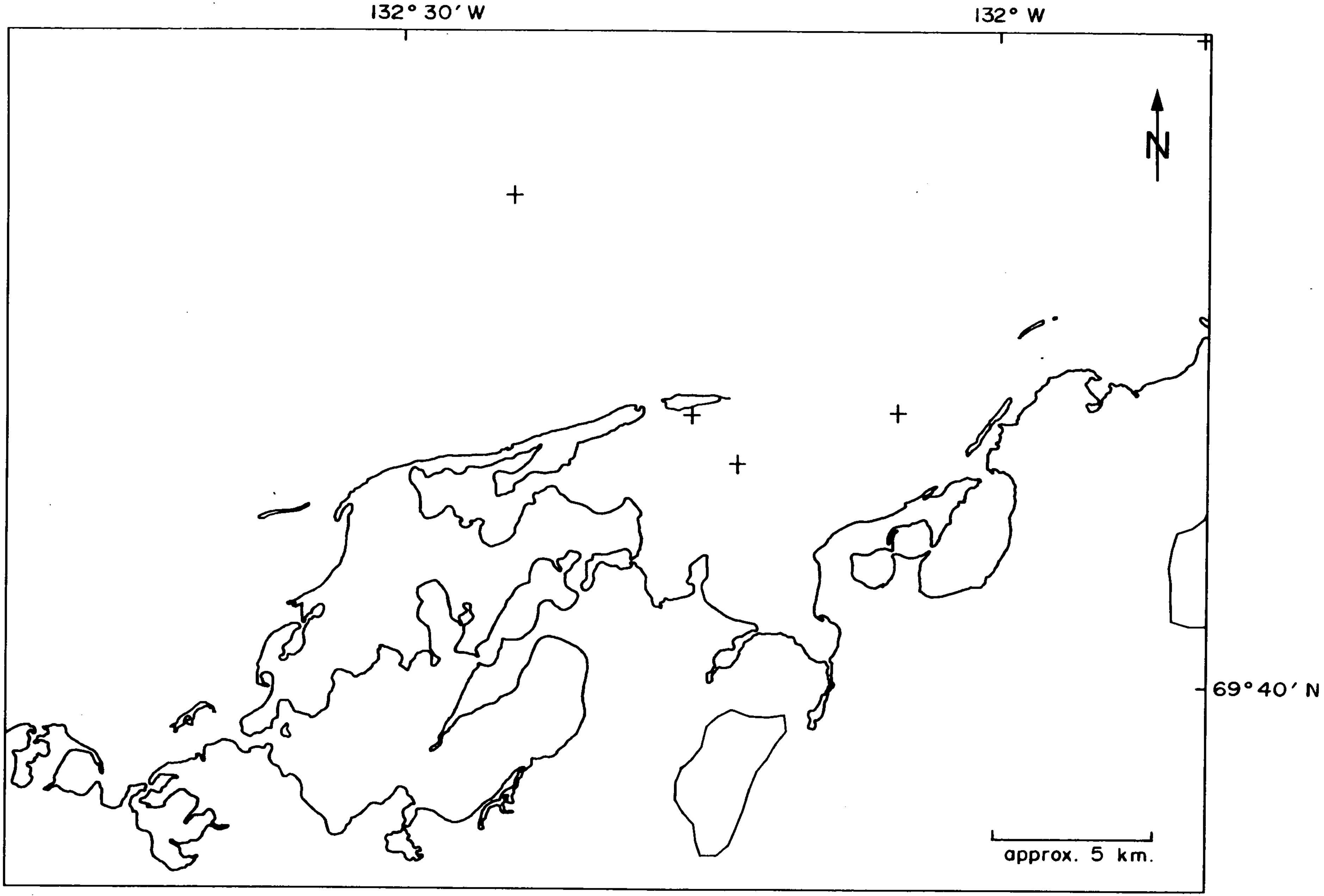

Figure 4 - 25. Distribution of degree of contamination index (D) for barium in Hutchison Bay.

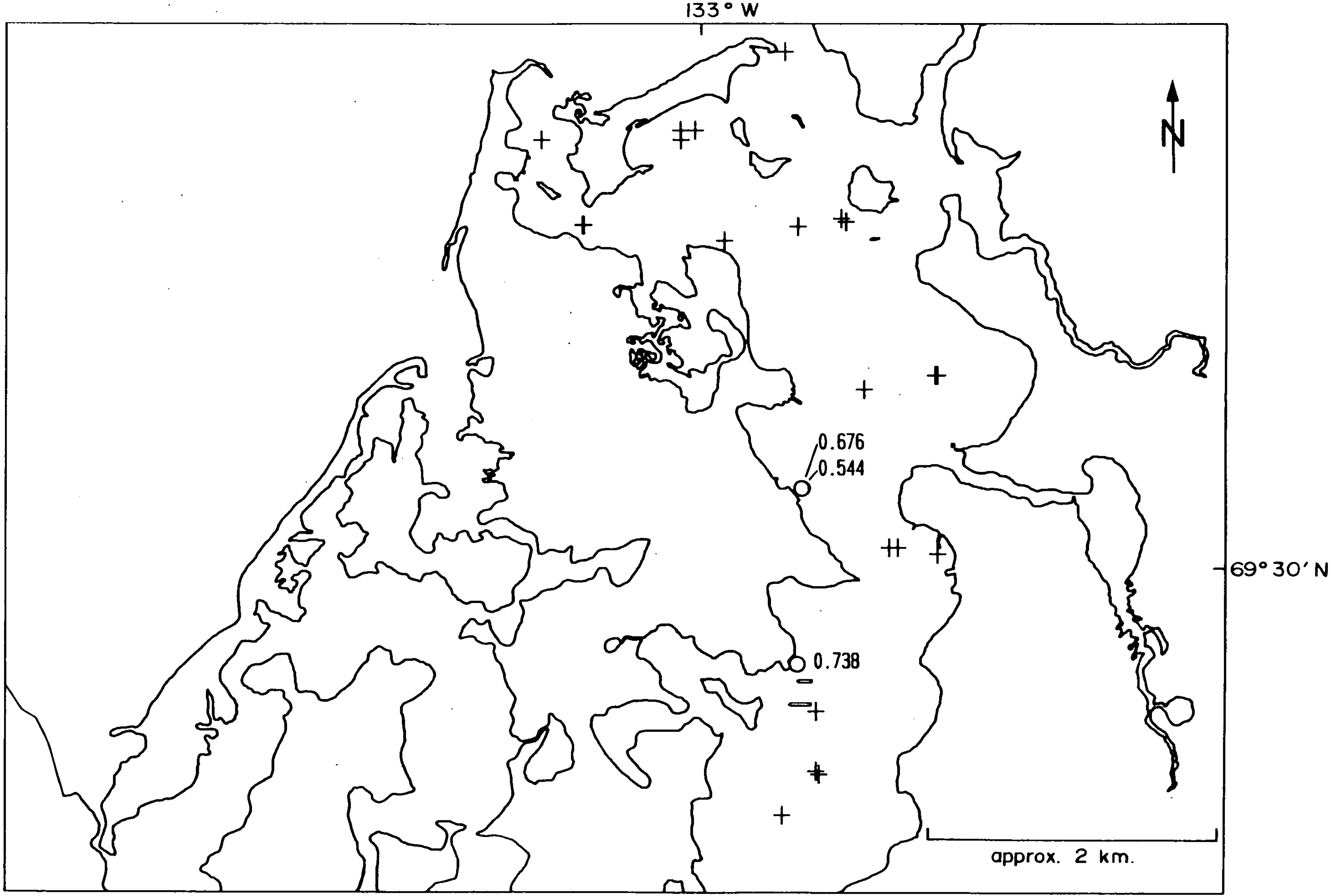

Figure 4 - 26. Distribution of degree of contamination index (D) for Sum Alkanes in Tuktoyaktuk Harbour.

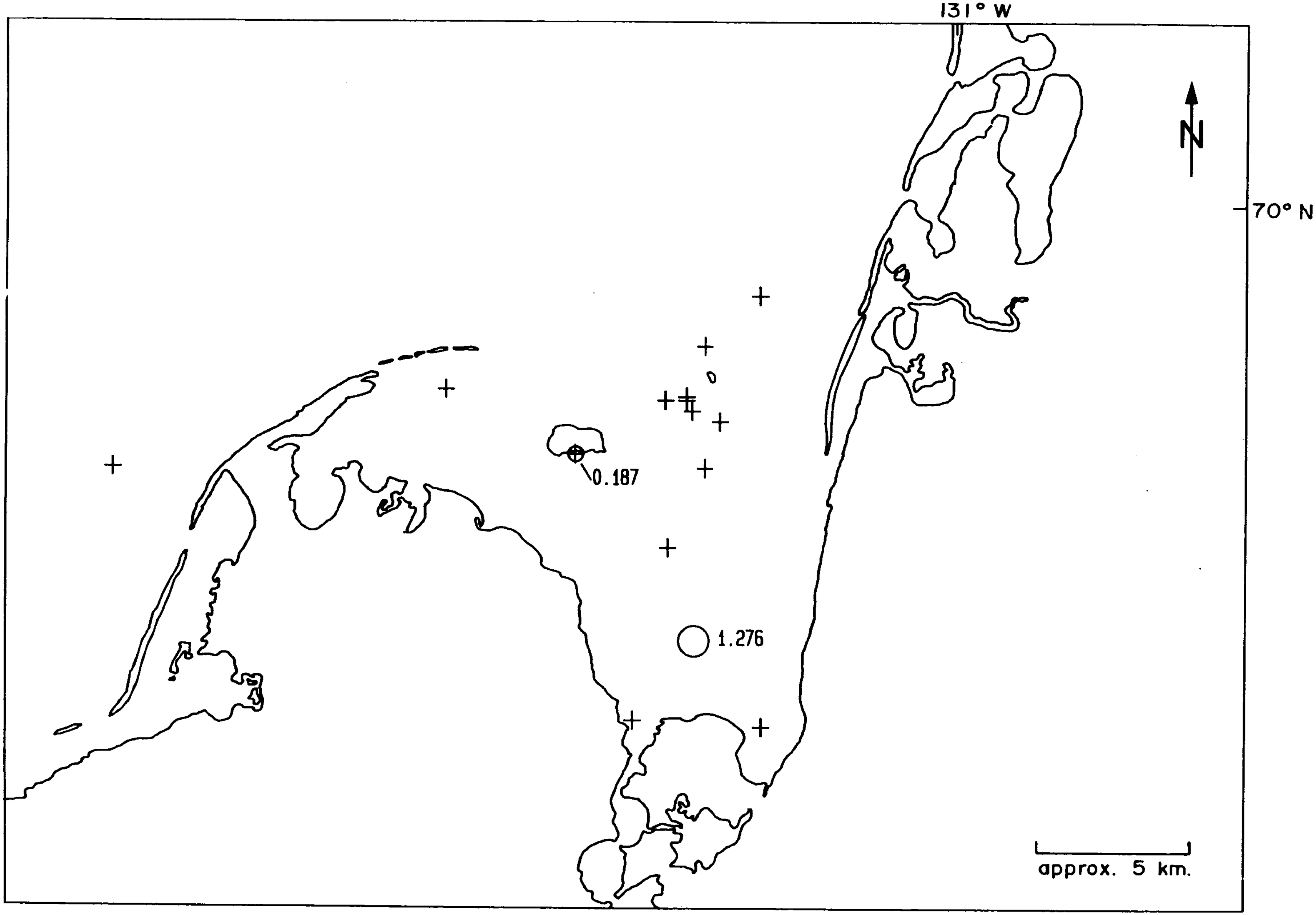

Figure 4 - 27. Distribution of degree of contamination index (D) for Sum Alkanes in McKinley Bay.

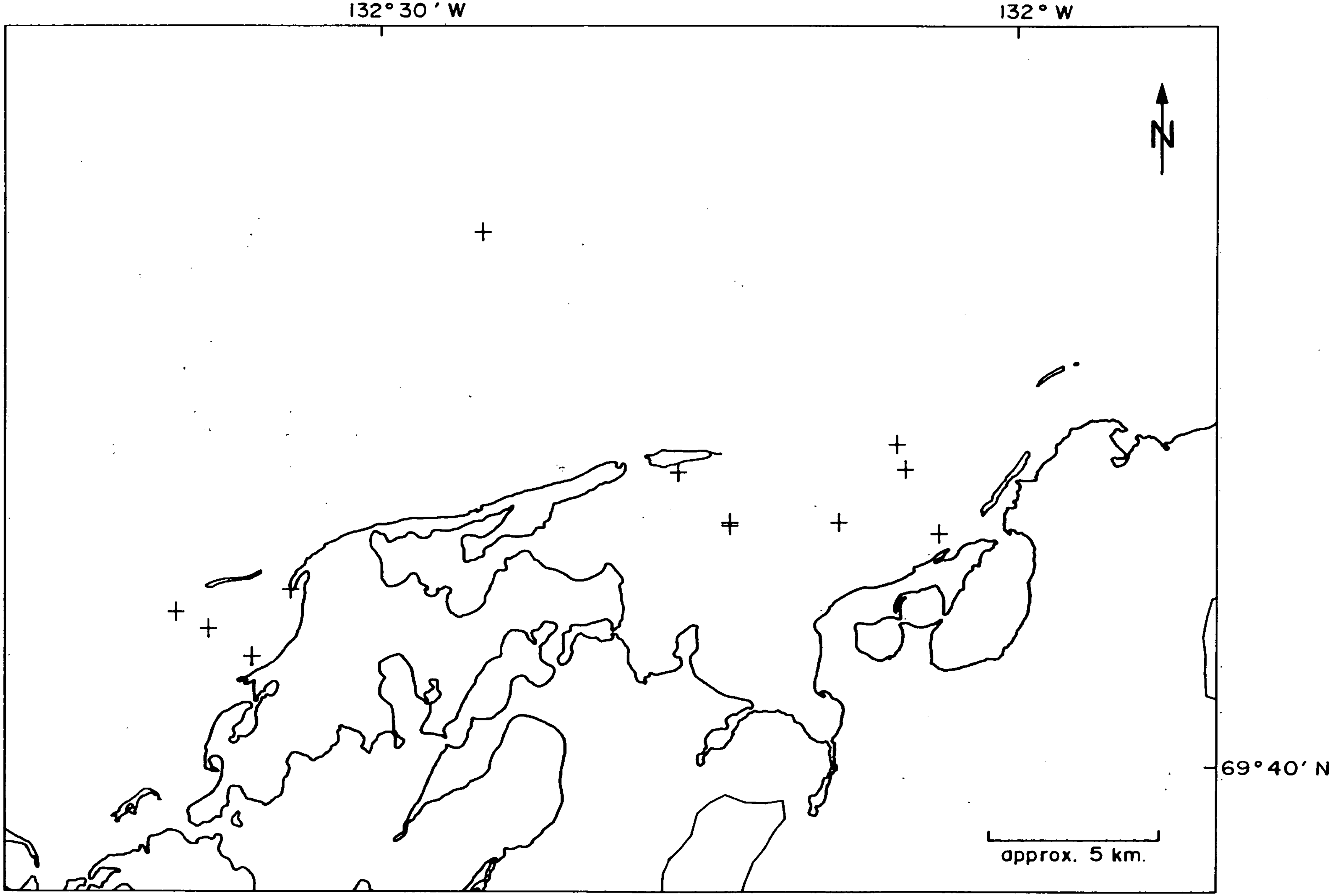

Figure 4 - 28. Distribution of degree of contamination index (D) for Sum Alkanes in Hutchison Bay.

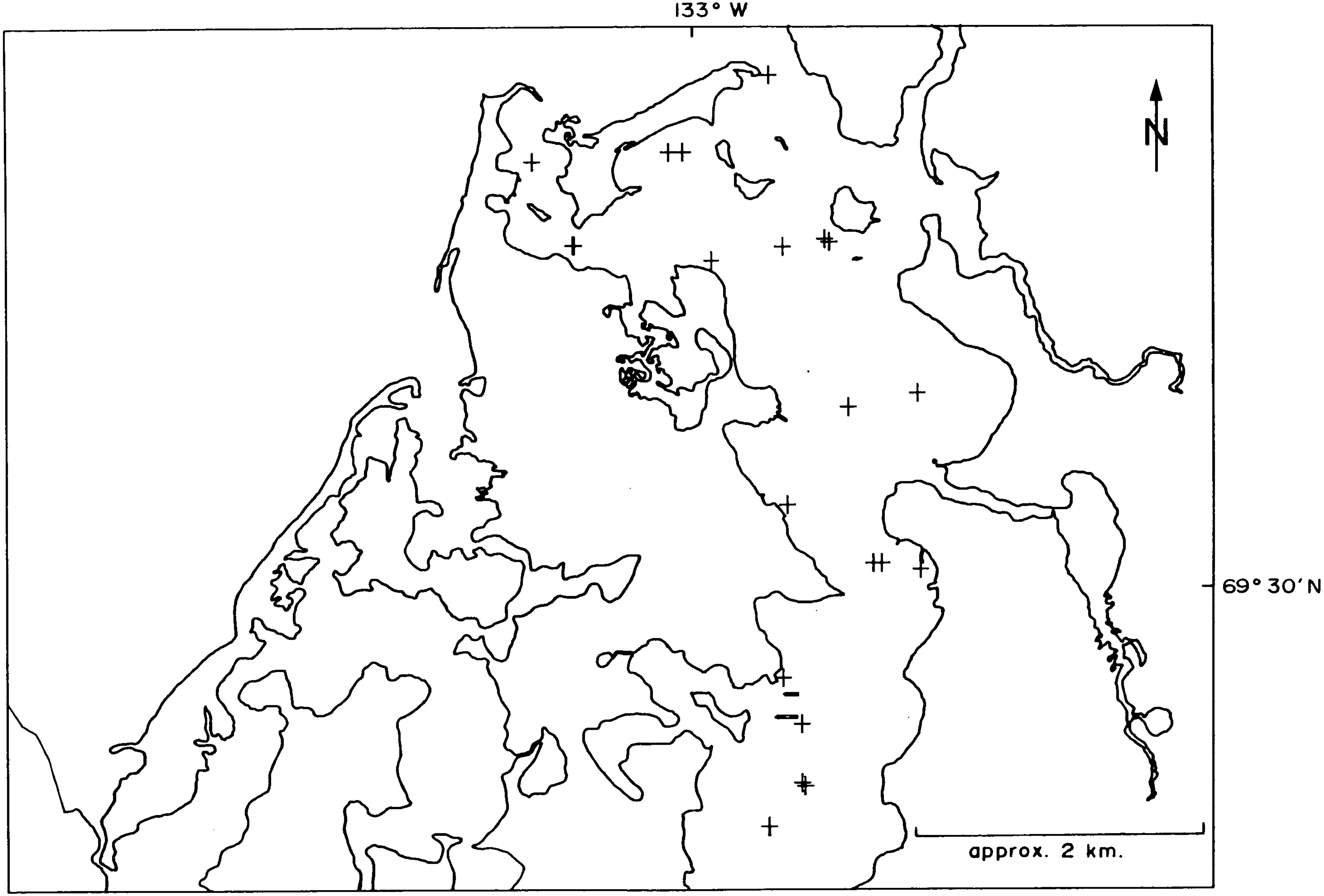

Figure 4 - 29. Distribution of degree of contamination index (D) for Sum PAH in Tuktoyaktuk Harbour.

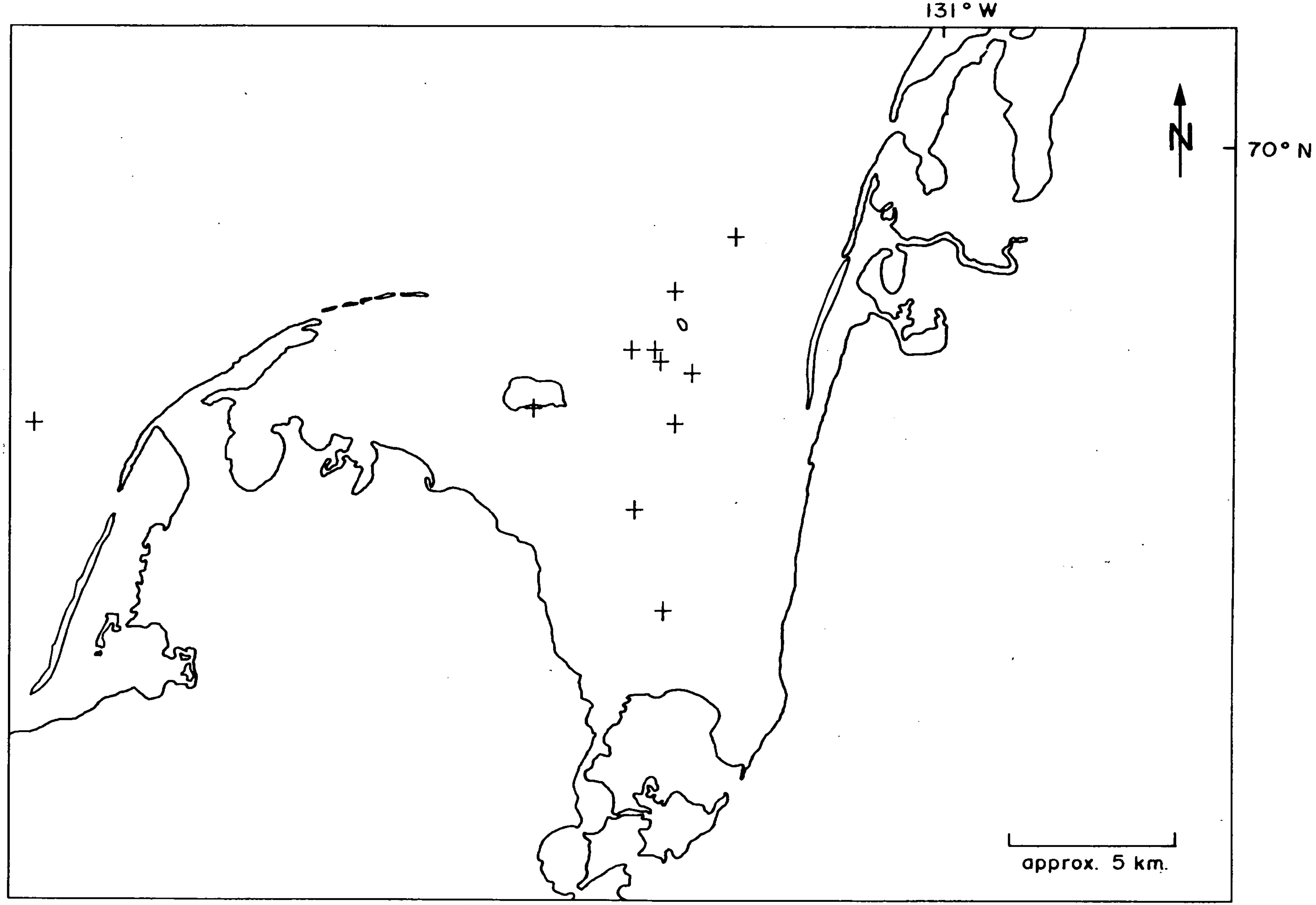

Figure 4 - 30. Distribution of degree of contamination index (D) for Sum PAH in McKinley Bay.

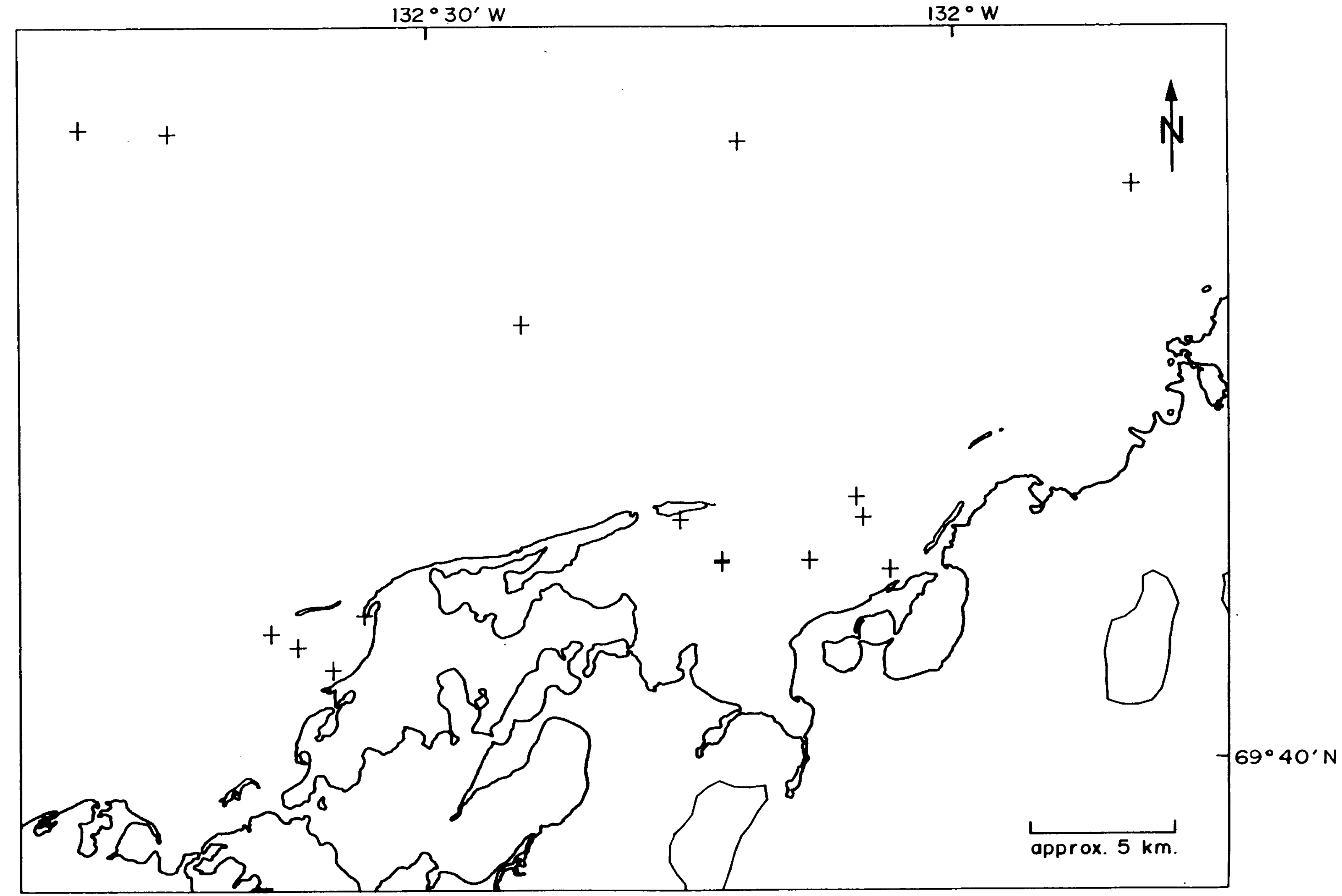

Figure 4 - 31. Distribution of degree of contamination index (D) for Sum PAH in Hutchison Bay.