



GEOLOGICAL SURVEY OF CANADA

OPEN FILE 3052

**Geochemistry of marine sediments
from the Strait of Georgia,
British Columbia**

C.E. Dunn, R.G. Balma, and W.A. Spirito

1996



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GEOCHEMISTRY OF MARINE SEDIMENTS FROM THE STRAIT OF GEORGIA, BRITISH COLUMBIA

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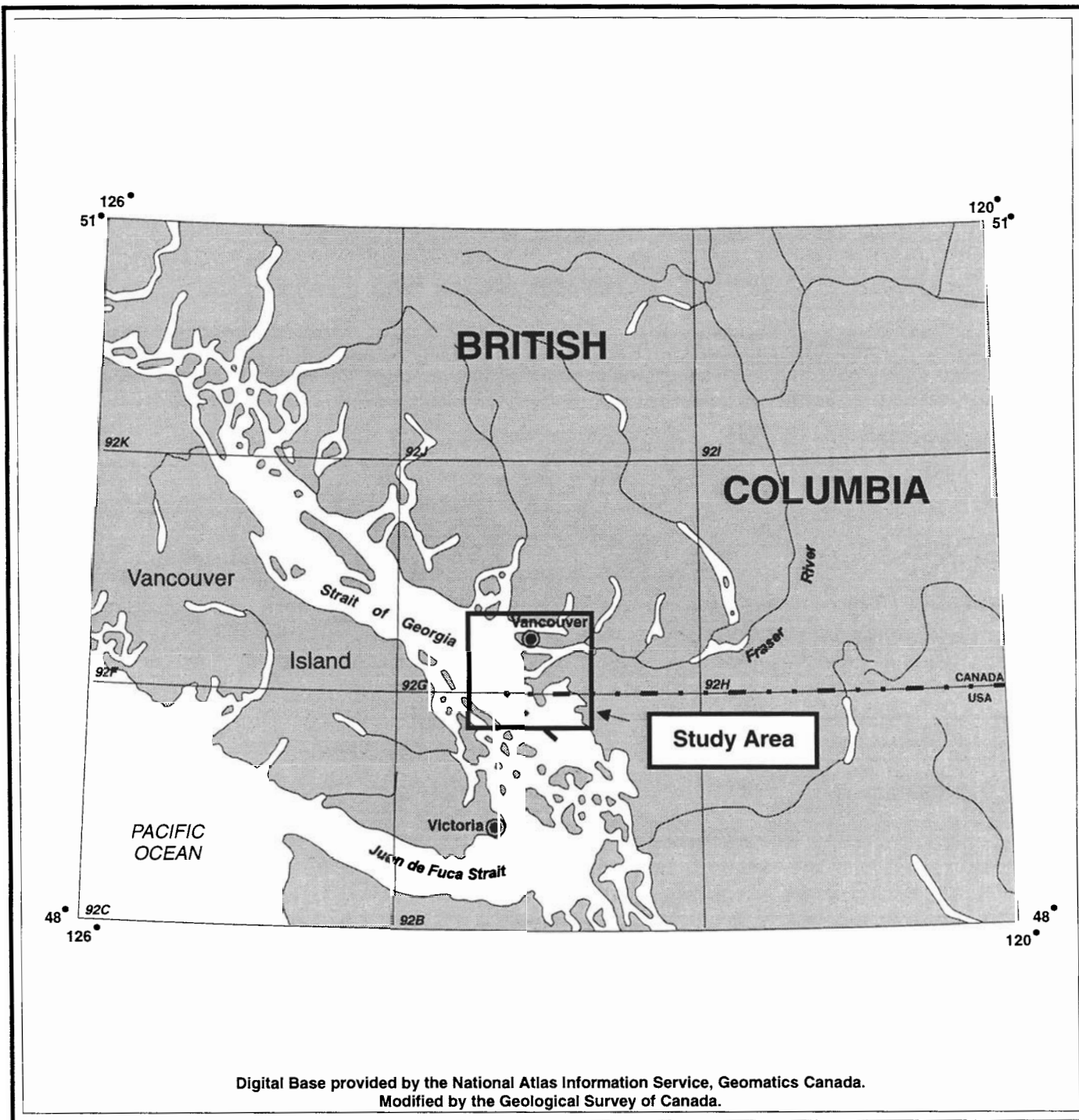


Fig. 1: Survey area with respect to National Topographic System (NTS) map sheets

GEOCHEMISTRY OF MARINE SEDIMENTS FROM THE STRAIT OF GEORGIA, BRITISH COLUMBIA

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INTRODUCTION

This Open File Report contains data from a geochemical study of surface marine sediments from the Strait of Georgia, and a few fluvial deposits from the Fraser River. Figure 1 shows a general outline of the area sampled, and Fig. 2 shows locations of all samples for which analytical data were obtained. This compilation has been prepared to provide baseline information on the distribution of a wide range of chemical elements in muds and sands from the survey area. Studies have been published on the content of a few metals in sediments from the Fraser River delta (e.g. Grieve and Fletcher, 1976), but no comprehensive regional geochemical studies have been undertaken on sediments from the Strait of Georgia. Delaney and Turner (1994) have provided a useful directory of element databases for the Vancouver area. Concern about the level of anthropogenic input of heavy metals and other elements into the sediments of the Fraser River system and the Strait of Georgia requires that present concentrations of elements be ascertained to provide a yardstick for future environmental evaluations.

The first section of this report deals with the methodology and highlights some of the element associations within the survey area. This is followed by maps with dots proportional to the relative concentration of each element accompanied by transparent overlay maps with sample numbers and bathymetry. A complete listing of the analytical data and summary statistics of each element are given in the appendices.

METHODS

Sample Collection and Preparation

A total of 172 surface grab samples of mud, sandy mud or sand were collected from the survey area during a scientific cruise on CSS Tully in November, 1992 (code-named TUL 92A). A Shipek grab sampler was lowered to the sea floor to scoop up approximately 200 - 500 g of the top 10 cm of sediment. Evoy *et al.* (1993) estimated that at an 'offshore background' site, west of Sturgeon Bank (Lulu Island, close to site #12 on Fig. 2), at a water depth of 200 m, the sedimentation rate is 0.76 cm/yr. From that location southward for 20 km, sediments from several cored sections were estimated to have accumulated at rates varying from 0.49 - >2.92 cm/yr (Evoy *et al.*, 1993). Assuming that similar rates occur throughout much of the Strait of Georgia, the top 10 cm of material collected for the present study comprises sediments that accumulated within the past 20 years, and perhaps less.

All sediment samples were freeze-dried. One portion was retained for sedimentological studies (the original purpose for collecting the samples), and a second was set aside as a reference sample for any future studies. Sufficient material (5 - 10 g) remained for geochemical

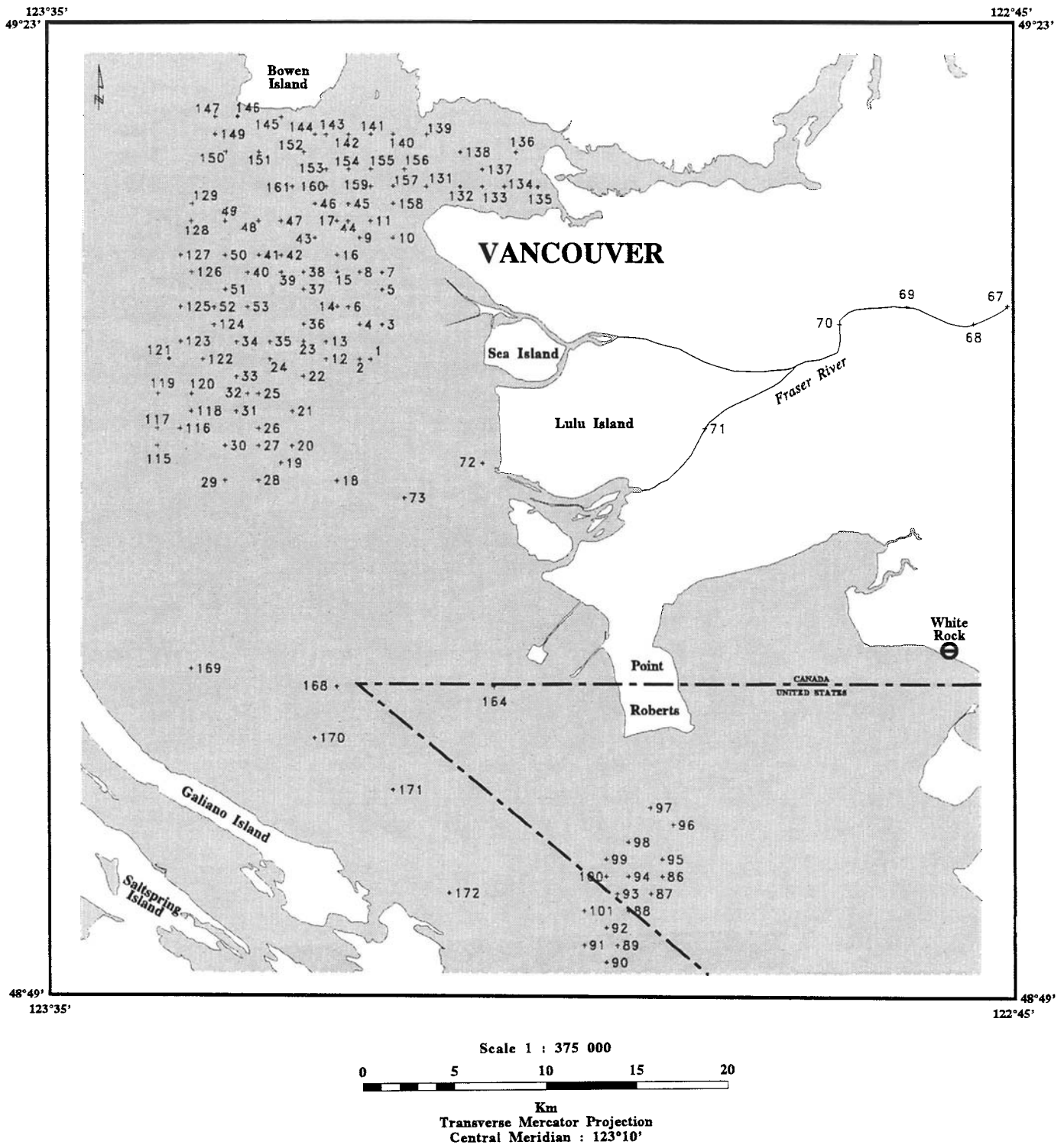


Fig. 2 - Locations of Samples (with sample numbers)

analysis of each of 127 samples from the reference set. This material was forwarded to the authors in Ottawa by Drs. V. Barrie and J. Luternauer.

Samples were gently disaggregated with an agate mortar and pestle, and any shell fragments or pebbles were removed with plastic tweezers. Clay-rich samples were ground to a fine powder in the agate mortar, and the sandy samples were ground in a ceramic ball mill. Although the maximum grain size was 50μ , the great majority of the grains were $<2\mu$ in diameter because most samples comprised clay-size particles.

Analysis

The analytical program used the following techniques:

- X-Ray Fluorescence (XRF) analysis for major oxides and some trace elements;
- Instrumental neutron activation analysis (INAA), mostly for trace elements;
- Inductively-coupled plasma emission spectrometry (ICP-ES) following an aqua regia digestion, mostly for trace elements;
- Ion chromatography for F, Cl, and S;
- Cold-vapour atomic absorption (AA) spectrometry for Hg.

There are several conventional methods of expressing and grouping analytical data. Because of the large number of determinations, in this report the data have been grouped by analytical method, and within each group they have been listed in alphabetical order of chemical symbol. The conventional method of expressing concentrations of major elements analyzed by XRF is by their oxides. Analyses by INAA and ICP-ES are normally expressed as elemental concentrations. The rare earth elements (REE) are commonly grouped together, but in this study the seven REE determined by INAA are arranged in alphabetical order with other determinations by this method. For ease of recognition of analytical method, data obtained by the three main techniques are listed on paper of different colours - white for XRF, blue for INAA, and yellow for ICP-ES. Determinations by miscellaneous analytical methods are listed on white paper,

a) XRF

Prior to XRF analysis, approximately 1.5 g of powder was ignited in a muffle furnace to determine loss-on-ignition at 900°C . During this procedure, traces of volatile elements (e.g. F, Cl, Br, Hg), water (moisture $[\text{H}_2\text{O}]$ and structurally bound $[\text{H}_2\text{O}^{2-}]$) and CO_2 were lost. This prepared each sample for fusion of a 1 g aliquot with lithium metaborate (LiBO_2) for analysis in a Philips wavelength dispersive spectrometer (Model PW1404) in the analytical laboratories at the Geological Survey of Canada in Ottawa. The XRF work was completed under the direction of Richard Rousseau, and element concentrations were determined by the methods of Rousseau (1984a, 1984b). The XRF method provides total content of each element, regardless of chemical bonding within the minerals comprising the sample. The list of major elements (expressed as their oxides, arranged in alphabetical order) and trace elements, with their determination levels obtained by this method, is given in Table 1.

Table 1: Determination Limits for Elements Analyzed by XRF

Element	Expressed as:	Units of Measure	Determination Limit*
Aluminum	Al ₂ O ₃	%	0.2
Calcium	CaO	%	0.01
Iron	Fe ₂ O ₃	%	0.06
Potassium	K ₂ O	%	0.05
Magnesium	MgO	%	0.01
Manganese	MnO	%	0.01
Phosphorus	P ₂ O ₅	%	0.01
Silicon	SiO ₂	%	0.5
Titanium	TiO ₂	%	0.02
Sodium	Na ₂ O	%	0.03
Barium	Ba	ppm	30
Niobium	Nb	ppm	10
Rubidium	Rb	ppm	10
Strontium	Sr	ppm	20
Zirconium	Zr	ppm	10

* values for all elements above the determination limit except for a few Nb analyses

b) INAA (blue sheets)

Approximately 0.5 g of the dry powder (not ignited) was weighed accurately into a polyethylene vial and sent to Activation Laboratories Ltd. (Ancaster, Ontario) for analysis by instrumental neutron activation. As for determinations by XRF, INAA is non-destructive and provides total content of each element, regardless of bonding within the samples. Table 2 lists the elements determined by this method and their determination levels. Several elements for which the analytical laboratory reported values have been excluded from this table where all, or almost all, were below determination limits (i.e. Ag 1 ppm; Hg 1 ppm; Ir 2 ppb; Ni 50 ppm; Se 2 ppm; Sn 100 ppm; Ta 0.5 ppm; W 1 ppm). Good precision was obtained on data for Rb, but it was not as good as for determinations by XRF, and there was a bias toward lower values by INAA. Consequently, Rb determinations by INAA have been omitted.

Table 2: Determination Limits for Elements Analyzed by INAA

Element		Units of Measure	Determination Limit
Arsenic	As	ppm	0.5
Gold	Au	ppb	2
Barium	Ba	ppm	10
Bromine	Br	ppm	1
Calcium	Ca	%	0.5
Cobalt	Co	ppm	1
Chromium	Cr	ppm	1
Cesium	Cs	ppm	0.5
Iron	Fe	%	0.05
Hafnium	Hf	ppm	0.5
Sodium	Na	ppm	10
Antimony	Sb	ppm	0.1
Scandium	Sc	ppm	0.1
Thorium	Th	ppm	0.1
Uranium	U	ppm	0.1
Zinc	Zn	ppm	20
Rare Earth Elements:			
Lanthanum	La	ppm	0.1
Cerium	Ce	ppm	3
Neodymium	Nd	ppm	5
Samarium	Sm	ppm	0.1
Europium	Eu	ppm	0.01
Terbium	Tb	ppm	0.5
Ytterbium	Yb	ppm	0.05
Lutetium	Lu	ppm	0.05

All values above the determination limit except for some analyses for Au, Ca, and Cs

c) **ICP-ES (yellow sheets)**

Dry powders (not ignited) were analyzed by Acme Analytical Laboratories Limited (Vancouver, B.C.). A 0.500 g split of each sample was digested with 3 ml of a 3:1:2 mixture of HCl-HNO₃-H₂O (i.e. aqua regia) at 95°C for one hour, then diluted to 10 ml with distilled water. Acme reports that for some materials the leach is partial for Mn, Fe, Sr, P, La, Cr, Mg, Ba, Ti, B, W, and limited for Na, K, and Al. The analytical listings provided by the laboratory include data for some elements for which precision is poor at the low concentrations present in the sample media. These data have been excluded from consideration and are not reported here.

The partial leach occurs when the aqua regia digestion fails to release into solution some elements that are structurally bound within tight crystal lattices. Although aqua regia provides a strong acid attack, the partial release of elements provides an indication of their relative stability in the sediments. Therefore, if data are available for elements determined by more than one analytical method, and there is relevant additional information, both data sets have been included for comparative purposes.

Table 3 lists the elements determined by ICP-ES for which adequate precision and accuracy were obtained, and their determination limits. An estimate is given of the percentage of each element released into solution during the aqua regia digestion.

d) **Other Methods**

Fluorine, Cl and S, were determined on 100 mg aliquots of the dry powders, at the GSC Ottawa laboratories by the method of Hall *et al.* (1986). Pyrohydrolysis is used to separate the elements from their matrix, and concentrations are determined by ion chromatography (Dionex). Determination limits (in ppm) are F (50), Cl, (100), and S (50).

Carbon dioxide was determined by acid evolution. Content of organic C was estimated by calculating the difference between total C (determined by combustion) and carbonate C determined by acid evolution.

Mercury, although not determined by ICP-ES, is included in Table 3 because it was determined from the same acid digestion. The 'cold vapour' method that was used reduces mercury ions to metallic mercury which is then flushed with H₂ into an atomic absorption spectrometer for determination of concentrations.

Table 3: Elements Analyzed by ICP-ES: Units of measurement, determination limits and approximate percentage of elements released into solution during the aqua regia digestion (determined by comparison with Standard BCSS-1 and/or total concentrations obtained from XRF or INAA - see section on 'Analytical Precision and Accuracy')

Element		Units of Measure	Determination Limit	Approx. % of element leached by acid digest
Silver	Ag	ppm	0.1	100% (?)
Aluminum	Al	%	0.01	25 - 30%
Boron	B	ppm	2	<25%
Barium	Ba	ppm	1	10-20%
Beryllium	Be	ppm	0.2	most?
Calcium	Ca	%	0.01	50%
Cadmium	Cd	ppm	0.2	100% (?)
Cobalt	Co	ppm	1	90-100%
Chromium	Cr	ppm	1	40%
Copper	Cu	ppm	1	100%
Iron	Fe	%	0.01	80-90%
Mercury*	Hg	ppb	10	100% (?)
Potassium	K	%	0.01	20-25%
Lanthanum	La	ppm	1	80%
Lithium	Li	ppm	2	100% (?)
Magnesium	Mg	%	0.01	70-80%
Manganese	Mn	ppm	1	100%
Molybdenum	Mo	ppm	2	100% (?)
Sodium	Na	%	0.01	45-60%
Nickel	Ni	ppm	1	90-100%
Phosphorus	P	%	0.001	60-70%
Lead	Pb	ppm	2	80-100%
Strontium	Sr	ppm	1	20-25%
Titanium	Ti	%	0.02	30%
Vanadium	V	ppm	1	30%
Zinc	Zn	ppm	1	70-90%

All values above the determination limit except some analyses for Ag, B, Be and Mo.

*Determined by cold-vapour AA.

Analytical Precision and Accuracy

Data quality was monitored throughout all analytical programs by inserting within each batch of 20 samples, two sub-samples of a single sample selected at random (i.e. a duplicate sample for determining analytical precision and sample homogeneity), and one sample of the National Research Council (NRC) standard marine mud #BCSS-1 (for determining the accuracy of the analytical procedures). Table 4 lists the data obtained on the duplicate pairs.

Table 5 lists data for BCSS-1 obtained during this study and those provided on the leaflet supplied with each bottle of BCSS-1 (NRC, Institute for National Measurement Standards, Chemical Metrology). Values from this leaflet are classified according to the level of assurance that can be applied to the analyses. The highest level of assurance is a 'certified value' which is based on the results of determinations by at least two independent methods of analysis. The confidence limits for certified values are defined as any individual sub-sample for which '95% of samples from any bottle would be expected to have concentrations within the specified range 95% of the time'. Secondly there are a few 'information values' that are considered less reliable because they are not based on the results of at least two independent methods, or there were insufficient analyses performed. Finally, there are some semi-quantitative 'guideline' values which are 'probably within a factor of three of the true values': these are based upon a single mass spectrographic analytical report and 'care should be exercised not to attribute more reliability to these numbers than they warrant'. In the present study, data from the semi-quantitative analysis were consulted, but not listed here because of the high level of uncertainty ascribed to these data by the NRC. Data presented here for BCSS-1 are from highly qualified commercial and government laboratories which have provided analyses that are more reliable than the semi-quantitative scan. Determinations by several analytical methods, with strict quality control, have provided data for which there is a high level of confidence.

In Table 3 the right-hand column lists the approximate percentage of each element that was leached from the sample powder by the acid (aqua regia) digestion. The amount of an element that will be released from its chemical bonding within a sample will depend on the mineralogy and the strength of the structural bond holding that element in a crystal lattice. In this study, the large majority of samples were similar in composition (clay minerals) and therefore it can be assumed that a similar proportion of an element was released from each sample. Additional control on this leach is provided by using a standard sample of similar composition to the samples being analyzed. The percentage of an element leached for ICP-ES determinations (Table 3) has been estimated by comparing maximum, percentile, and especially median concentrations of an element in the entire sample population (see Appendix C) with the same statistical parameters for the total concentration of that element as determined by XRF or INAA. The accuracy of the XRF and INAA data were first verified from comparison with certified values for BCSS-1. Certified data are not available for all elements, therefore some estimates are followed by (?) indicating that some geochemical assumptions have been made on the most likely sites for these elements to reside and therefore their probable degree of bonding in crystal structures.

Table 4: Replication of analytical data on two sub-samples of several samples: 4.1 Determinations by XRF; 4.2 Determinations by INAA; 4.3 Determinations by ICP-ES on an aqua regia digestion; 4.4 Determinations by miscellaneous chemical methods

4.1 XRF

Site	Al ₂ O ₃ %	Ba ppm	CaO %	Fe ₂ O ₃ %	K ₂ O %	MgO %	MnO %	Na ₂ O %	Nb ppm	P ₂ O ₅ %	Rb ppm	SiO ₂ %	Sr ppm	TiO ₂ %	Zr ppm
5	14.3	590	2.49	6.4	2.19	3.09	0.07	3.2	<10	0.23	80	58.4	290	0.79	150
5	14.4	580	2.48	6.4	2.22	3.08	0.07	3.2	13	0.23	75	58.7	270	0.78	150
23	14.0	530	2.32	6.5	2.06	3.03	0.07	3.7	10	0.26	74	56.6	260	0.76	130
23	13.9	560	2.33	6.5	2.10	3.03	0.07	3.9	13	0.25	71	55.9	260	0.76	130
44	13.9	550	2.63	5.7	1.95	2.60	0.07	3.2	<10	0.20	66	60.9	290	0.67	120
44	14.4	590	2.67	5.9	2.00	2.78	0.07	3.2	<10	0.20	68	61.0	270	0.69	120
72	10.2	490	2.23	3.6	1.34	1.94	0.06	2.6	<10	0.13	38	74.6	290	0.50	94
72	10.3	560	2.28	3.8	1.34	2.01	0.06	2.7	<10	0.13	42	73.7	300	0.53	110
95	12.6	450	3.78	4.6	1.45	2.00	0.06	3.6	10	0.16	52	65.5	390	0.59	190
95	12.8	480	3.77	4.6	1.44	2.01	0.05	3.4	<10	0.17	46	65.4	400	0.59	180
123	14.0	580	2.24	6.4	2.07	2.95	0.07	3.7	12	0.22	76	56.6	250	0.76	130
123	13.9	540	2.24	6.4	2.08	2.95	0.07	3.8	10	0.22	77	55.9	260	0.75	130
138	14.5	600	2.8	6.4	2.21	3.00	0.07	3.3	17	0.23	79	60.1	240	0.76	150
138	14.6	610	2.84	6.5	2.24	3.09	0.07	3.3	20	0.22	76	59.4	250	0.79	150
154	14.8	610	2.42	6.7	2.34	3.07	0.07	3.6	20	0.24	85	57.5	210	0.76	120
154	14.8	600	2.4	6.7	2.32	3.11	0.07	3.6	15	0.24	82	57.7	220	0.76	120
170	14.0	480	2.73	5.9	1.91	2.53	0.06	3.6	18	0.20	68	61.6	230	0.77	160
170	14.1	430	2.74	5.8	1.90	2.52	0.06	3.5	18	0.20	69	61.3	240	0.79	160

4.2 INAA

Site	As ppm	Au ppb	Ba ppm	Br ppm	Ca %	Ce ppm	Co ppm	Cr ppm	Cs ppm	Eu ppm	Fe %	Hf ppm	La ppm
5	7.3	18	610	55	1.7	44	15	93	2.4	1.04	4.12	3.3	22.9
5	7.6	15	510	55	<0.5	44	15	93	3.3	1.15	3.82	3.2	22.7
23	8.4	<1	540	100	<0.5	36	15	77	2.3	1.05	3.82	2.8	19.7
23	10.0	10	480	100	1.7	40	14	76	2.5	1.01	3.81	3.3	19.4
44	7.3	4	500	65	2.2	39	13	75	2.5	0.96	3.46	3.0	18.8
44	8.6	<1	560	65	1.2	39	12	70	2.2	1.01	3.45	3.6	19.1
72	4.2	<1	530	16	1.7	27	9	75	0.9	0.74	2.27	2.2	13.6
72	3.7	2	510	17	1.8	29	10	100	1.0	0.76	2.56	3.0	14.8
95	5.3	3	300	39	1.9	33	10	83	1.6	0.83	2.90	4.9	16.5
95	5.1	<1	360	41	2.8	34	11	87	1.5	0.91	2.96	4.6	17.4
123	7.2	4	530	120	2.6	38	18	86	2.6	1.05	3.98	3.8	20.3
123	6.6	5	420	120	2.7	46	17	90	3.1	0.94	4.14	3.2	21.1
138	8.8	6	490	64	1.8	48	16	96	3.0	1.13	3.87	3.6	22.9
138	8.0	5	470	58	2.3	40	15	80	2.2	0.90	3.51	3.1	20.9
154	11.0	9	480	100	2.2	45	18	95	2.9	1.05	4.27	3.0	22.8
154	9.1	6	530	100	1.8	46	18	94	3.3	1.10	4.36	3.0	22.9
170	6.4	2	460	94	1.1	50	14	92	2.7	0.96	3.72	4.4	21.4
170	7.3	1	480	96	2.6	49	14	90	2.6	1.01	3.90	4.4	21.0
Site	Lu ppm	Mo ppm	Na ppm	Nd ppm	Sb ppm	Sc ppm	Sm ppm	Ta ppm	Tb ppm	Th ppm	U ppm	Yb ppm	Zn ppm
5	0.28	<2	21300	20	0.8	14.0	5	3.9	<0.5	6.0	1.8	1.77	73
5	0.33	<2	21000	22	0.6	14.0	5	4.0	<0.5	6.2	1.9	1.77	110
23	0.27	<2	23900	21	0.7	14.0	23	3.6	<0.5	5.6	1.2	1.81	110
23	0.29	<2	23900	16	0.7	14.0	23	3.5	0.7	5.3	1.4	1.68	130
44	0.24	<2	21400	14	1.0	13.0	44	3.5	<0.5	5.4	1.2	1.68	150
44	0.28	<2	21500	17	1.1	13.0	44	3.5	<0.5	4.8	1.6	1.78	100
72	0.24	<2	17500	12	0.5	9.0	72	2.5	<0.5	2.8	0.7	1.36	77
72	0.22	<2	17100	14	0.5	9.4	72	2.6	<0.5	3.1	0.9	1.60	80
95	0.24	<2	23700	13	0.3	11.0	95	3.1	0.6	3.9	1.1	1.58	50
95	0.25	<2	24200	16	0.4	11.0	95	3.3	<0.5	4.1	1.3	1.46	61
123	0.25	<2	26400	18	0.8	15.0	123	4.1	<0.5	6.1	1.7	1.81	180
123	0.20	<2	27300	16	1.0	15.0	123	4.2	<0.5	5.9	2.3	1.89	210
138	0.32	<2	22900	22	1.1	14.0	138	4.3	<0.5	6.6	1.9	1.84	170
138	0.28	<2	20700	19	0.8	13.0	138	3.8	0.6	5.5	1.7	1.68	160
154	0.23	<2	26200	22	0.9	15.0	154	4.3	<0.5	6.3	1.4	2.02	130
154	0.21	2	26700	24	0.8	15.0	154	4.3	0.5	6.3	1.9	1.94	130
170	0.33	<2	27800	19	0.7	13.0	170	4.0	<0.5	5.4	2.0	2.01	100
170	0.30	<2	27700	22	0.6	13.0	170	4.0	0.8	5.2	1.7	1.99	85

4.3 ICP-ES

Site	Ag ppm	Al %	B ppm	Ba ppm	Be ppm	Ca %	Cd ppm	Co ppm	Cr ppm	Cu ppm	Fe %	K %	La ppm
5	0.8	1.95	21	59	0.3	0.81	0.3	13	52	53	3.64	0.27	14
5	0.7	1.85	19	55	0.4	0.78	0.3	12	48	50	3.47	0.25	13
23	0.2	2.06	25	57	0.3	0.78	0.3	11	46	41	3.64	0.35	12
23	0.3	2.03	26	55	0.3	0.77	0.3	11	45	38	3.50	0.33	12
44	0.2	2.02	21	74	<0.2	0.86	0.2	11	47	44	3.63	0.34	13
44	0.2	1.83	17	52	0.2	0.90	0.2	11	43	40	3.23	0.27	11
72	0.2	1.07	6	58	0.3	0.61	<0.2	8	33	17	2.33	0.12	8
72	0.4	1.01	6	57	<0.2	0.58	<0.2	8	32	19	4.35	0.11	8
95	0.2	1.40	20	58	<0.2	1.23	0.3	7	34	17	3.81	0.23	9
95	0.2	1.53	21	64	<0.2	1.45	0.2	8	34	19	3.30	0.24	9
123	0.4	1.92	31	53	0.3	0.72	0.3	11	47	41	3.42	0.33	12
123	0.2	2.05	28	56	0.4	0.76	0.2	12	47	42	3.67	0.37	12
138	0.7	1.79	24	56	<0.2	0.74	<0.2	11	46	120	3.37	0.26	13
138	0.7	1.87	23	64	0.2	0.77	0.3	11	51	96	3.54	0.27	13
154	0.5	2.03	29	58	0.2	0.72	0.3	11	49	56	3.58	0.35	13
154	1.0	1.97	33	57	0.2	0.70	0.3	11	48	55	3.49	0.34	13
170	0.1	1.83	24	45	0.3	0.70	<0.2	8	39	27	3.11	0.26	10
170	0.3	1.88	27	49	0.2	0.72	<0.2	9	38	28	3.23	0.28	11

Site	Li ppm	Mg %	Mn ppm	Mo ppm	Na %	Ni ppm	P %	Pb ppm	Sr ppm	Ti %	V ppm	Zn ppm
5	26	1.37	403	2	1.00	45	0.062	14	59	0.14	51	91
5	25	1.33	389	<1	0.96	43	0.060	11	56	0.14	48	88
23	27	1.32	422	1	1.38	39	0.064	10	65	0.13	51	82
23	24	1.30	411	1	1.29	39	0.062	12	63	0.13	49	82
44	31	1.25	410	1	1.17	37	0.056	12	79	0.13	50	82
44	25	1.16	378	1	1.02	36	0.050	12	65	0.11	46	77
72	9	0.87	359	<1	0.38	35	0.033	3	42	0.10	36	41
72	8	0.79	565	2	0.33	45	0.031	4	39	0.10	33	38
95	21	0.76	398	1	0.62	30	0.040	4	75	0.13	42	48
95	17	0.79	353	1	0.62	28	0.042	6	85	0.13	43	49
123	29	1.24	402	<1	1.52	37	0.054	11	62	0.11	50	82
123	31	1.34	426	1	1.60	40	0.058	11	64	0.11	53	89
138	28	1.25	361	1	1.06	39	0.061	23	60	0.12	47	91
138	28	1.29	379	1	1.09	40	0.070	29	64	0.12	48	97
154	31	1.31	396	1	1.38	39	0.060	17	63	0.11	49	86
154	26	1.27	401	1	1.35	38	0.058	18	62	0.11	48	85
170	30	1.05	288	<1	1.03	30	0.051	9	53	0.13	44	74
170	30	1.07	300	1	1.09	30	0.053	9	56	0.14	45	73

4.4 MISCELLANEOUS METHODS

Site	C _{ORG} %	CO ₂ %	Cl ppm	F ppm	Hg ppb	LOI %	S ppm
5	1.2	0.4	>1%	581	105	7.7	1859
5	1.2	0.4	>1%	611	100	7.8	1686
23	1.6	0.3	>1%	609	85	10.2	1784
23	1.7	0.1	>1%	548	90	10.6	1793
44	1.2	0.4	>1%	538	100	8.1	1629
44	1.4	0.2	>1%	450	90	8.0	1515
72	<0.2	<0.1	4967	329	20	2.3	352
72	<0.2	<0.1	4649	339	20	2.3	321
95	0.5	0.5	6418	358	30	4.2	1256
95	0.5	0.6	5870	513	35	4.2	1211
123	1.6	0.4	>1%	542	90	9.8	2081
123	1.7	<0.1	>1%	523	100	10.0	2102
138	1.3	0.3		706	170	8.0	1722
138	1.3	<0.1		711	165	7.9	1816
154	1.5	<0.1		622	85	9.7	1829
154	1.5	0.1		616	90	9.7	1857
170	1.4	<0.1		594	60	8.1	1823
170	1.4	<0.1		571	60	8.2	1859

Table 5: Analysis of National Research Council standard marine mud #BCSS-1: 5.1 Determinations by XRF; 5.2 Determinations by INAA; 5.3 Determinations by ICP-ES on an aqua regia digestion; 5.4 Determinations by miscellaneous chemical methods

5.1 XRF

	Al ₂ O ₃ %	Ba ppm	CaO %	Fe ₂ O ₃ %	K ₂ O %	MgO %	MnO %	Na ₂ O %	Nb ppm	P ₂ O ₅ %	Rb ppm	SiO ₂ %	Sr ppm	TiO ₂ %	Zr ppm
	11.8	310	0.73	4.8	2.18	2.41	0.03	2.4	14	0.17	92	65.1	110	0.71	250
	11.7	340	0.74	4.8	2.17	2.43	0.03	2.4	14	0.17	89	64.9	110	0.71	240
	11.8	320	0.74	4.8	2.16	2.40	0.03	2.5	15	0.17	91	65.2	110	0.70	230
	11.7	340	0.73	4.8	2.14	2.39	0.03	2.4	16	0.18	87	64.6	120	0.69	240
	11.7	340	0.72	4.8	2.14	2.39	0.03	2.4	14	0.17	92	65.0	110	0.71	240
	11.9	330	0.74	4.8	2.16	2.41	0.03	2.4	18	0.17	85	65.7	110	0.70	240
	12.0	280	0.79	4.7	2.24	2.37	0.03	2.4	24	0.16	90	66.5	88	0.73	260
	11.9	310	0.77	4.8	2.22	2.35	0.03	2.4	24	0.16	94	66.8	94	0.73	240
Mean	11.81	321.25	0.75	4.79	2.18	2.39	0.03	2.41	17.38	0.17	90.00	65.48	106.50	0.71	242.50
Standard Deviation	0.11	21.00	0.02	0.04	0.04	0.03	0.00	0.04	4.31	0.01	2.93	0.79	10.30	0.01	8.86
95% Confidence Limit	0.078	14.553	0.016	0.024	0.025	0.017		0.024	2.985	0.004	2.029	0.549	7.134	0.010	6.142
Values Certified by NRC	11.83		0.76	4.7	2.17	2.44		2.72		0.154		66.1	96	0.73	

5.2 INAA

	As ppm	Au ppb	Ba ppm	Br ppm	Ca %	Ce ppm	Co ppm	Cr ppm	Cs ppm	Eu ppm	Fe %	Hf ppm	La ppm
	11.0	4.0	310	70	0.25	57	12	110	3.4	1.10	3.04	5.4	29.3
	11.0	5.0	310	71	0.25	57	11	110	3.3	1.19	3.06	5.9	29.8
	12.0	4.0	300	68	1.00	57	11	110	3.5	1.14	2.93	5.8	28.7
	11.0	0.5	270	74	1.70	54	12	110	3.6	1.11	2.88	4.9	29.3
	9.9	0.5	330	78	1.10	58	13	110	3.7	1.19	3.13	5.2	31.3
	10.0	3.0	300	76	1.40	57	13	110	4.7	1.13	3.05	5.7	30.0
	9.6	4.0	260	73	0.70	56	12	110	3.4	1.13	2.87	5.4	29.4
	11.0	0.5	320	73	0.90	69	13	140	3.5	1.24	3.32	6.7	32.7
Mean	10.69	2.69	300.00	72.88	0.91	58.13	12.13	113.75	3.64	1.15	3.04	5.63	30.06
Standard Deviation	0.79	1.89	23.90	3.23	0.51	4.55	0.83	10.61	0.45	0.05	0.15	0.54	1.31
95% Confidence Limit	0.549	1.309	16.565	2.236	0.354	3.152	0.578	7.350	0.310	0.033	0.103	0.377	0.908
Values Certified by NRC	11.1						11.4	123	4 ¹				

	Lu ppm	Mo ppm	Na ppm	Nd ppm	Sb ppm	Sc ppm	Sm ppm	Ta ppm	Tb ppm	Th ppm	U ppm	Yb ppm	Zn ppm
	0.31	3	17200	21	0.6	11	4.9	1.40	0.25	7.0	1.2	2.04	76
	0.32	3	17000	26	0.6	11	5.0	1.30	0.70	7.0	1.7	2.24	140
	0.32	3	16300	25	0.7	10	4.8	0.60	0.90	7.4	2.0	2.16	130
	0.26	1	17400	30	0.7	11	5.5	0.25	0.25	7.3	2.4	1.98	140
	0.34	1	17900	28	0.6	11	5.5	0.25	0.70	7.4	2.4	2.27	130
	0.34	1	17200	27	0.6	11	5.4	0.25	0.80	7.0	1.7	2.02	170
	0.28	1	17400	27	0.6	11	5.2	0.25	0.25	7.0	1.8	1.99	170
	0.40	1	20100	29	0.7	11	5.7	0.25	0.25	7.4	2.4	2.40	80
Mean	0.32	1.75	17562.50	26.63	0.64	10.88	5.25	0.57	0.51	7.19	1.95	2.14	129.50
Standard Deviation	0.04	1.04	1119.87	2.77	0.05	0.35	0.33	0.50	0.29	0.20	0.43	0.15	35.48
95% Confidence Limit	0.029	0.717	776.014	1.922	0.036	0.245	0.225	0.345	0.199	0.141	0.301	0.107	24.589
Values Certified by NRC		1.9 ¹			0.6	20							119

¹ information value

5.3 ICP-ES

	Ag ppm	Al %	B ppm	Ba ppm	Be ppm	Ca %	Cd ppm	Co ppm	Cr ppm	Cu ppm	Fe %	K %	La ppm
	0.1	1.62	27	31	0.6	0.43	0.3	10	46	17	2.82	0.21	20
	0.1	1.49	25	30	0.5	0.39	0.3	9	44	15	2.64	0.20	19
	0.2	1.55	27	32	0.4	0.41	0.3	10	48	16	2.80	0.22	21
	0.4	1.67	31	32	0.6	0.45	0.2	11	51	17	2.99	0.23	22
	0.3	1.98	36	75	0.6	0.71	0.3	10	56	22	3.74	0.43	20
	0.5	1.61	33	32	0.6	0.46	0.3	11	53	18	2.90	0.20	22
	0.6	1.60	34	31	0.5	0.42	0.3	10	50	16	2.87	0.22	22
	0.5	1.53	35	30	0.5	0.40	0.3	9	49	15	2.70	0.21	20
Mean	0.34	1.63	31.00	36.63	0.54	0.46	0.29	10.00	49.63	17.00	2.93	0.24	20.75
Standard Deviation	0.19	0.15	4.17	15.53	0.07	0.10	0.04	0.76	3.81	2.27	0.34	0.08	1.16
95% Confidence Limit	0.133	0.105	2.893	10.760	0.052	0.072	0.024	0.524	2.644	1.571	0.239	0.054	0.807
Values Certified by NRC					1.3		0.25	11.4	123	18.5			

	Li ppm	Mg %	Mn ppm	Mo ppm	Na %	Ni ppm	P %	Pb ppm	Sr ppm	Ti %	V ppm	Zn ppm
	33	1.18	203	2	0.79	47	0.046	21	37	0.02	31	97
	30	1.07	190	1	0.74	43	0.042	17	35	0.02	28	88
	37	1.13	205	1	0.80	46	0.044	21	37	0.02	30	93
	41	1.24	211	3	0.87	50	0.049	17	39	0.02	32	102
	33	1.09	317	2	0.87	47	0.042	14	59	0.06	40	84
	35	1.21	212	2	0.88	49	0.047	19	40	0.02	32	102
	37	1.17	205	1	0.82	47	0.046	17	38	0.02	30	94
	35	1.08	198	1	0.78	43	0.042	17	36	0.02	29	88
Mean	35.13	1.15	217.63	1.63	0.82	46.50	0.04	17.88	40.13	0.03	31.50	93.50
Standard Deviation	3.31	0.06	40.76	0.74	0.05	2.51	0.00	2.36	7.79	0.01	3.70	6.63
95% Confidence Limit	2.296	0.044	28.247	0.516	0.035	1.737	0.002	1.633	5.399	0.010	2.566	4.597
Values Certified by NRC			229	1.9 ¹		55.3		22.7	96 ¹		93.4	119

¹ information value

5.4 MISCELLANEOUS METHODS

	C_{ORG} %	CO₂ %	Cl ppm	F ppm	Hg ppb	LOI %	S ppm
	2.1	0.05	>1%	642	130	8.7	3205
	2.1	0.20	>1%	604	125	8.6	3208
	2.1	0.05	>1%	640	150	8.6	3174
	2.1	0.05	>1%	672	145	8.7	3260
	2.1	0.05	>1%	614	135	8.7	3318
	2.2	0.05	>1%	686	175	8.5	3111
	2.1	0.05	>1%	690	150	8.6	3379
	2.1	0.05	>1%	702	130	8.5	3202
Mean	2.11	0.07		656.25	142.50	8.61	3232.13
Standard Deviation	0.04	0.05		36.54	16.26	0.08	84.51
95% Confidence Limit	0.024	0.037		25.322	11.265	0.058	58.564
Values Certified by NRC	2.19						3600

MAP PRODUCTION AND DATA HANDLING

Maps were drawn using the Transverse Mercator projection, with a central meridian of $123^{\circ} 10'$. The coastline and drainage were digitized from Canadian Hydrographic Service Map L/C-3463, Strait of Georgia, Southern Portion, at a scale of 1:80,000. Digital bathymetry from the Canadian Hydrographic Service's Natural Resource Maps (NRM) 15792 and 15783 (1:250,000) was also integrated within the spatial database. The digital base for the index map (Fig. 1) is a GSC modified 1:750,000 National Atlas Information Service Map provided by Geomatics Canada.

Data for the study area were compiled using Microsoft Access relational database software. Separate tables for the various analytical and location data sets were created. These tables were linked through a primary site-id key. Data listings for all samples are presented in Appendix A.

Statistics were generated for each element using SPSS software (Statistical Package for the Social Sciences). Statistical summaries provided in Appendix C were generated using software developed in the Applied Geochemistry and Geophysics Subdivision of the Geological Survey of Canada. For computing purposes, analytical results less than detection were assigned a value of half the determination limit. For samples with duplicate analyses, the analysis from the first of each duplicate pair was plotted.

The element distribution and sample site maps were created using ArcInfo software. Site specific location and analytical point data were transferred from the relational database into ArcInfo point attribute tables. In order to partially automate the mapping process an ArcInfo macro was written, prompting users to enter all variables necessary to create the element distribution maps. The maps show percentile values of the data, and dots of increasing size that correspond to relative concentrations of elements according to an exponential function. Different functions were used (as shown beneath the percentile values on the right hand of each map) in order to provide an appropriate visual impact. For output, ArcInfo map compositions were first converted into graphics files and then converted to PostScript files. These were subsequently printed at 600 dots per inch on a laser printer.

RESULTS

Appendix A shows distribution patterns of the elements. They are arranged in groups by analytical method, and within each group the elements are arranged alphabetically by chemical symbol. Details of all the analytical results are presented in Appendix B arranged in the same order as elements in Appendix A. Appendix C provides basic statistical analysis of each element, arranged in the same order as elements in Appendices A and B.

To assist the reader in locating each sample a transparent overlay with sample numbers is provided as a loose sheet at the back of this report. By overlaying this sheet on any of the element distribution maps any site of interest can be precisely located, and the data pertaining to that sample can be found by referring to Appendix B. In Appendix B each sample has data extending over four pages: the first has data determined by XRF, the second by INAA, the third by ICP-ES, and the fourth by miscellaneous analytical methods. At the beginning of each page of XRF data the latitude and longitude of each sample location is provided in decimal degrees. A second loose transparent overlay is provided that shows the bathymetry of the Strait of Georgia. This map includes small crosses identifying the locations of the samples.

It is important to note that the varying sizes of dots on each element distribution map (Appendix A) represent *relative* element accumulations, and do not necessarily reflect unusual enrichments. The dots are proportional in size to the concentration of a particular element for the entire data set of 126 samples (127 samples determined by INAA). For example the data for Pb (shown also on Fig. 4, p.25) show that the spread between the median and maximum concentrations is a narrow range from 12 - 28 ppm Pb. However, there is a distinct *relative* enrichment in the north of the survey area. By referring to Table 6 it is evident that Pb levels in the Strait of Georgia are mostly lower than average concentrations in marine muds from elsewhere. This method of data presentation is of value in displaying geographic trends of enrichment and depletion - care should be taken to appreciate the absolute range of concentrations before assessing whether or not unusually high concentrations are present. Table 6 provides data to assist in such evaluations.

From Table 6 it can be seen that the median concentrations of elements in the sediments of the Strait of Georgia are very similar to concentrations in the National Research Council standard marine muds (PACS-1, BCSS-1, and MESS-2) from locations around Canada. Mud from Esquimalt Harbour (PACS-1) is unusually enriched in a number of trace elements. Therefore for most trace elements, concentrations in the other standards have been cited as comparative values. In order to provide a broader comparison of the composition of muds from the Strait of Georgia with those from elsewhere, a review has been made of data compiled by Wedepohl in the Handbook of Geochemistry (Wedepohl, 1969 - 1978). These data are presented in the right-hand half of Table 6. For many elements no data were cited for near-shore muds, and so many of the comparisons are of data from deep-sea muds. Typically, the deep-sea muds are considerably more enriched in Fe and Mn than those from shallower waters. For those elements where data for marine muds could not be found, concentrations in shales (derived from

marine muds) are quoted. In general, trace element concentrations are similar to, or less than those in marine muds from around the world.

In order to assist the reader in synthesizing the many maps presented in this report in Appendix A, several maps showing similar element distribution patterns have been photographically reduced and presented as figures 3 - 8. The full page maps are reproduced in Appendix A. Brief comments are provided alongside each of these figures in the following pages.

	Median in Strait of Georgia (this study)	NRC Marine Sediments	Average quoted in the literature**	Type of sediment or sedimentary rock
<i>Determinations by XRF (Major Oxides)</i>				
Al ₂ O ₃ %	14.0	12.23 ¹	15.47	Shales
CaO %	2.44	2.92 ¹	3 - 5	Marine muds and shales
Fe ₂ O ₃ %	6.40	6.96 ¹	9.3	Deep sea muds
K ₂ O %	2.06	1.50 ¹	2.81	Marine muds
MgO %	2.96	2.41 ¹	2.50	Shales
MnO %	0.07	0.07 ¹	4.9	North Pacific deep sea muds
Na ₂ O %	3.50	4.40 ¹	4.0	Marine muds
P ₂ O ₅ %	0.23	0.23 ¹	0.15	Shelf clays (0.28% in deep sea muds)
SiO ₂ %	58.0	55.7 ¹	54.0	Clays derived from rocks of intermediate composition
TiO ₂ %	0.75	0.70 ¹	0.71	Deep sea sediments
<i>Determinations by XRF (Trace elements)</i>				
Ba ppm	550	---	546	Shales
Nb ppm	10	---	10	Shales
Rb ppm	74	---	128	Shales
Sr ppm	260	277 ¹	130-280	Marine sediments
Zr ppm	130	---	180	North Pacific deep sea muds
<i>Determinations by INAA</i>				
As ppm	8.3	11.1 ²	9 - 11	Marine muds
Au ppb	4	---	1.6 - 4.2	Near-shore clay-rich silts - Canadian Arctic
Br ppm	85	---	111	Barents Sea muds (top 1 cm)
Ce ppm	42	---	73	North American shales
Co ppm	15	17.5 ¹	12	Atlantic deep sea muds
Cr ppm	84	113 ¹	84-110	North Pacific deep sea muds
Cs ppm	2.5	4 ²	6	Modern sediments
Eu ppm	1.01	---	1.2	North American shales
Hf ppm	3.3	---	4.6	Deep sea muds
La ppm	20.3	---	37	North American shales
Lu ppm	0.26	---	0.4	North American shales

Nd ppm	18	---	33	North American shales
Sb ppm	0.7	0.59 ²	1 - 2	Marine muds
Sc ppm	14	---	19	North Pacific deep sea muds
Sm ppm	3.8	---	5.7	North American shales
Th ppm	5.7	---	4.8	Marine muds
U ppm	1.7	---	2.3	Marine muds
Yb ppm	1.81	---	3.1	North American shales
Zn ppm	120	119 ²	85	North Pacific deep sea muds
Determinations by ICP-ES				
Ag ppm	0.4	0.18 ³	0.1 - 0.3	Clay-rich sediments
B ppm	25*	---	230 - 2500	Saline clays
Be ppm	0.2	1.3 ²	2.5	Deep sea muds
Cd ppm	0.2	0.25 ²	0.24	Marine muds
Cu ppm	42	39 ³	300	North Pacific deep sea muds
Li ppm	27	74 ³	49 - 70	Pacific Ocean deep sea muds
Mo ppm		1.9 ²	4 - 18	Pacific Ocean deep sea muds
Ni ppm	39	44 ¹	39	Near-shore marine muds (world-wide)
Pb ppm	12	22 ³	51	North Pacific muds
V ppm	50	127 ¹	120	Deep sea sediments
Determinations by Miscellaneous Chemical Methods				
C _{org} %	1.4	2.1 ³	---	Highly variable
Hg ppb	95	92 ³	400	Shales
F ppm	579	---	200 - 400	Marine muds
S ppm	1724	1800 ³	1100	Marine muds (wide range in concentrations)

* Partial extraction

** Extracted from comprehensive summary of world literature published by Wedepohl (1969-1978)

¹ NRC marine sediment reference material 'PACS-1' - mud from Esquimalt Harbour

² NRC marine sediment reference material 'BCSS-1' - mud from Baie des Chaleurs (Gulf of St. Lawrence)

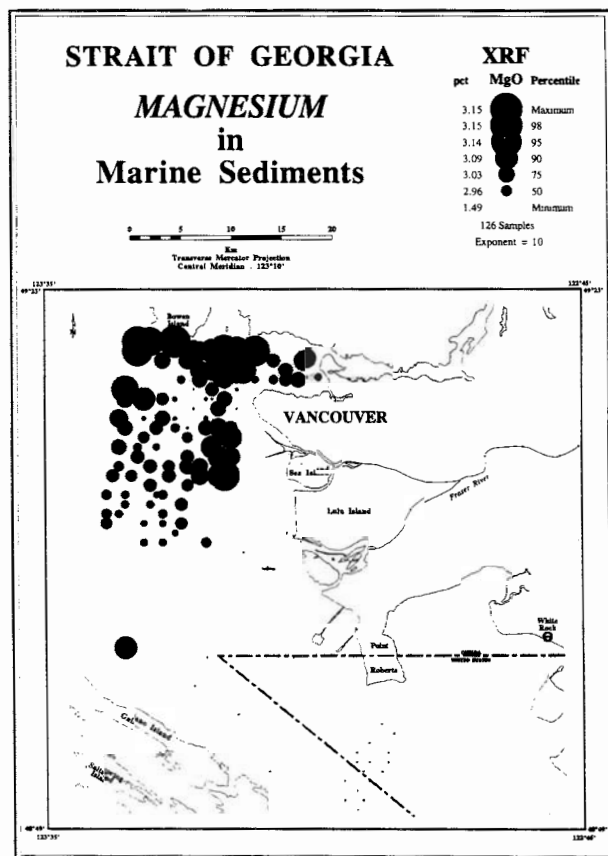
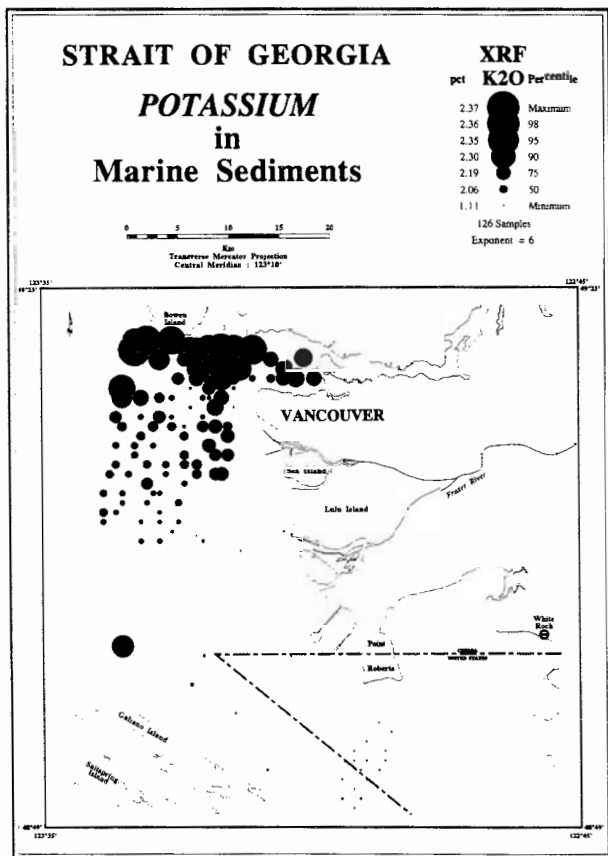
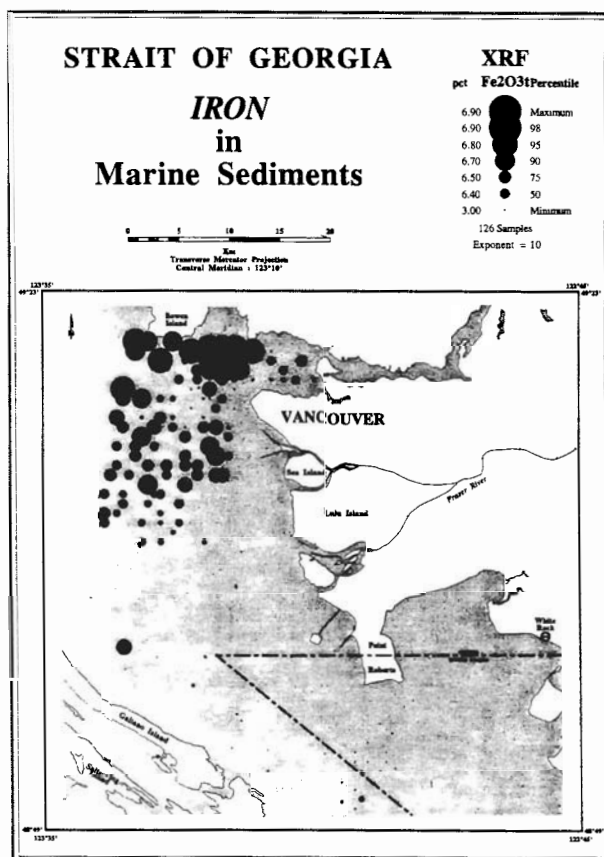
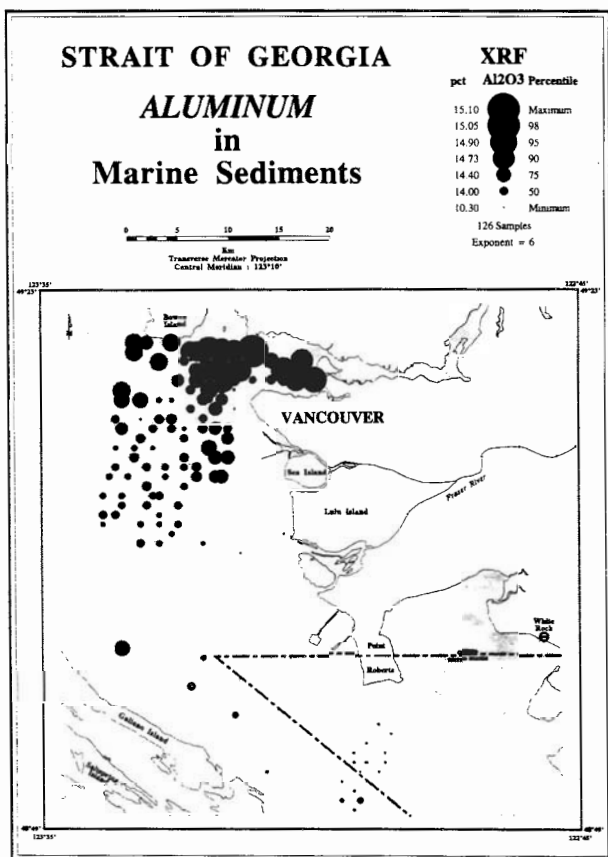
³ NRC marine sediment reference material 'MESS-2' - mud from the Beaufort Sea

Table 6: Comparison of median concentrations in muds from the Strait of Georgia with muds from elsewhere in Canada (NRC Standard Reference Muds - column 3) and marine muds from around the world

Major Elements - 'Clay Factor'

Figure 3 shows that there are relatively high concentrations of Al, K, Fe, and Mg in the northern part of the survey area. The range in concentrations is moderate to low, with no site unusually enriched in any of these elements. Water depth at these sites ranges from approximately 25 - 200 m (see transparent overlay of bathymetry). Tidal vectors in the Strait are mostly northward, suggesting therefore that fine-grained potassium-rich alumino-silicates (e.g. clay minerals such as illite) and ferro-magnesian rich minerals (e.g. smectites) are preferentially concentrating in the northern area. A possible contributory factor could be the southward flux of waters and sediments from Howe Sound (north of Bowen Island). Mixing of waters from these two source areas could promote flocculation and precipitation of the fine grained clay mineral particles. Waters moving westward into the area from Burrard Inlet and Vancouver Harbour (i.e. east of Vancouver) could also be transporting clay minerals into the northern part of the survey area. Trace elements associated with these major elements are shown on Fig. 4.

Fig. 3 Distribution patterns of major elements in sediments from the Strait of Georgia: enrichments related to alumino-silicates and ferro-magnesian clay minerals.



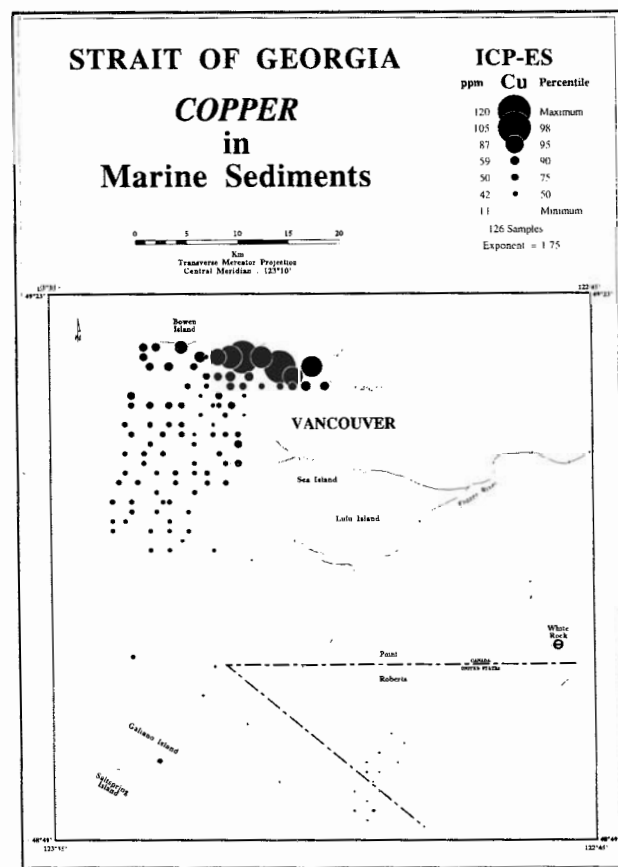
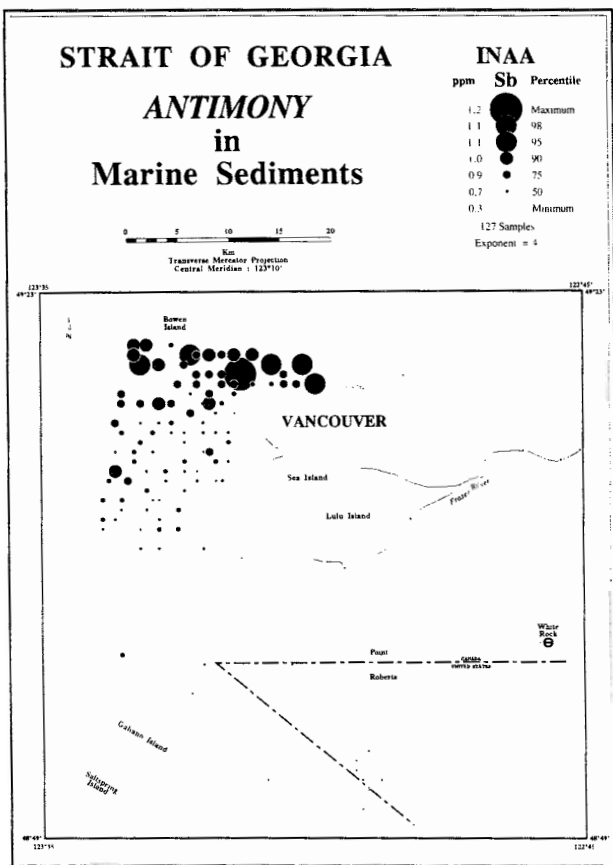
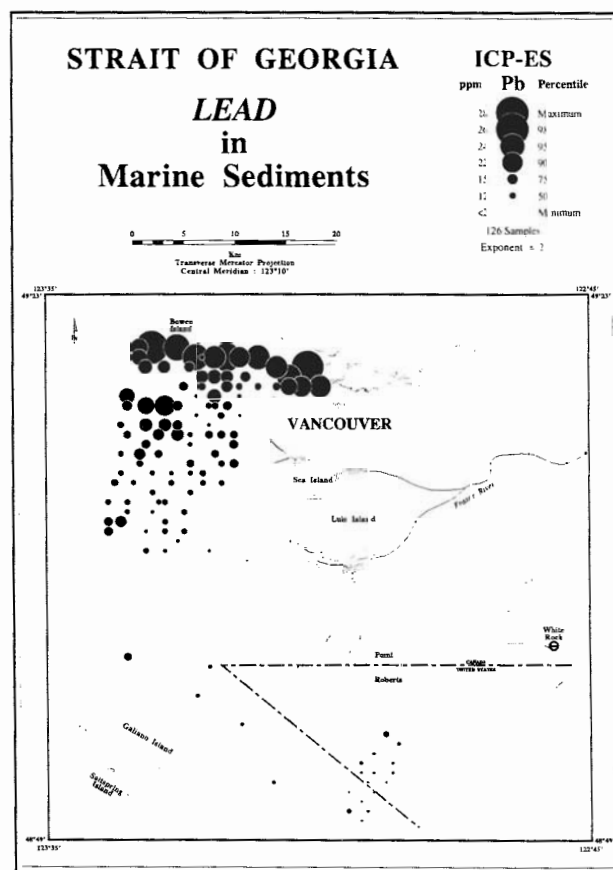
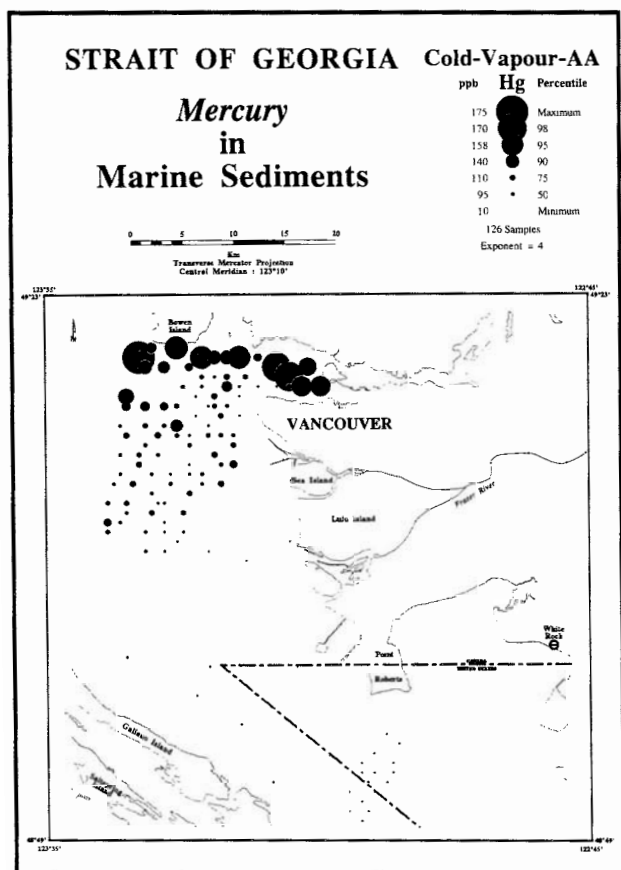
Trace Elements - 'Clay Factor'

Several trace elements show similar patterns of relative concentration to those of the major elements depicted in Fig. 3. The inference is that these elements either travel with the clay mineral particles and precipitate with them or that the clay minerals scavenge the metals by adsorbing them on the fine-grained particles.

Figure 4 shows examples of the four metals Hg, Pb, Sb, and Cu. Concentrations of these metals are not unusually high. The range of mercury is from below the determination level of 10 ppb Hg to a maximum of 175 ppb Hg, all far below the 400 ppb Hg quoted as an average level for shales (Table 6). At the northern end of the survey area mercury levels are mostly in excess of 100 ppb. Similarly, lead concentrations (Fig. 4) are low in all samples, ranging from 15 - 28 ppm Pb in the north, but mostly less than 15 ppm Pb in the south. The analytical data obtained for antimony by INAA are extremely precise and accurate, therefore the subtle differences in concentrations are real, and not attributable to analytical errors. The maximum concentration of 1.2 Sb is in accord with the expected level for marine muds (Table 6). Copper concentrations are highest in the northeast, reaching a maximum of 120 ppm Cu. Fluorine, niobium and rubidium also exhibit very similar distribution patterns to the four elements shown on Fig. 4.

Many other elements are relatively enriched in the north, but also show enrichment elsewhere in the survey area, most commonly in the deeper waters toward the east. They include thorium, the rare-earth elements, cesium, cobalt, scandium, lithium and zinc.

Fig. 4 Distribution patterns of trace element sediments from the Strait of Georgia: enrichments associated mostly with fine-grained alumino-silicates.

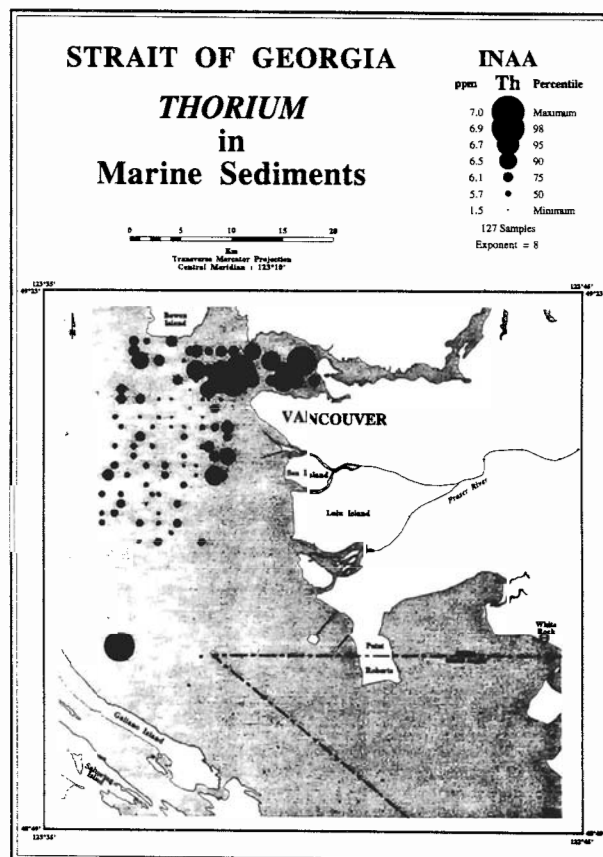
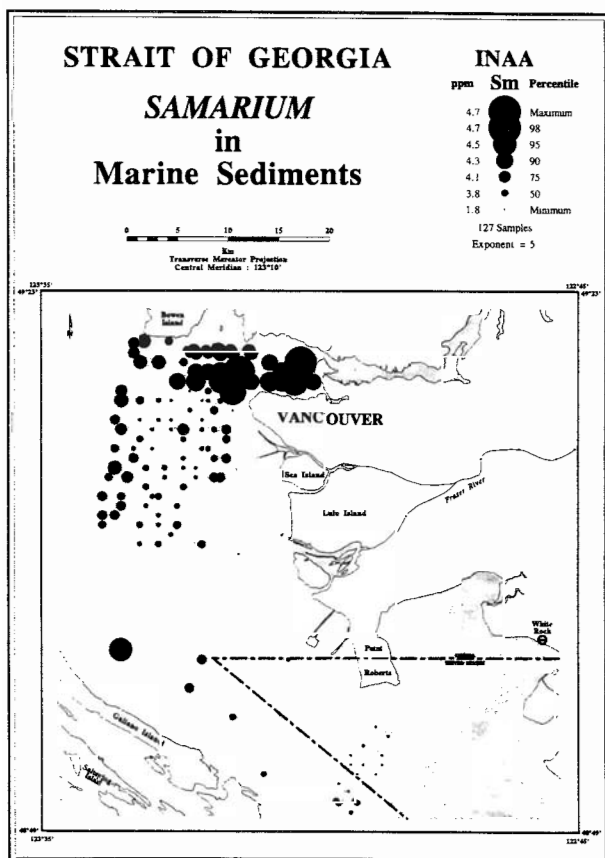
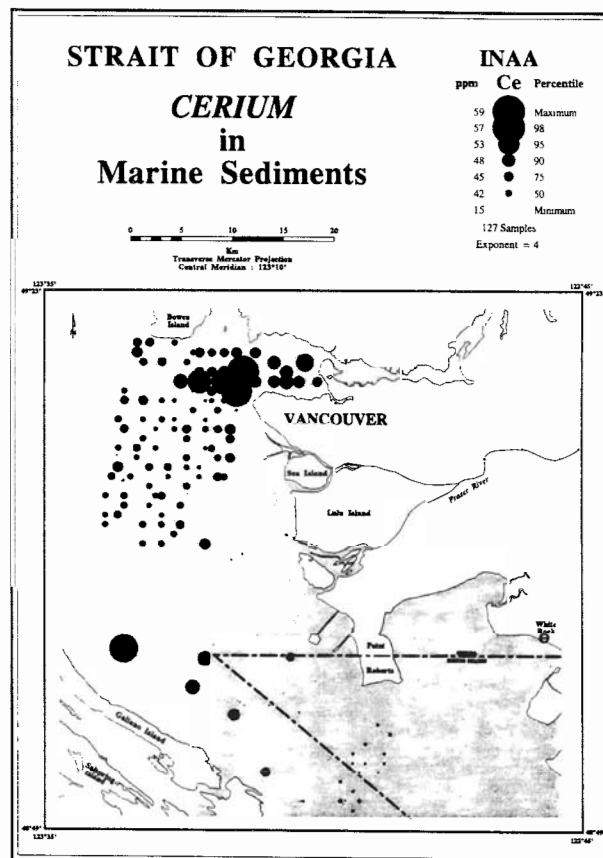
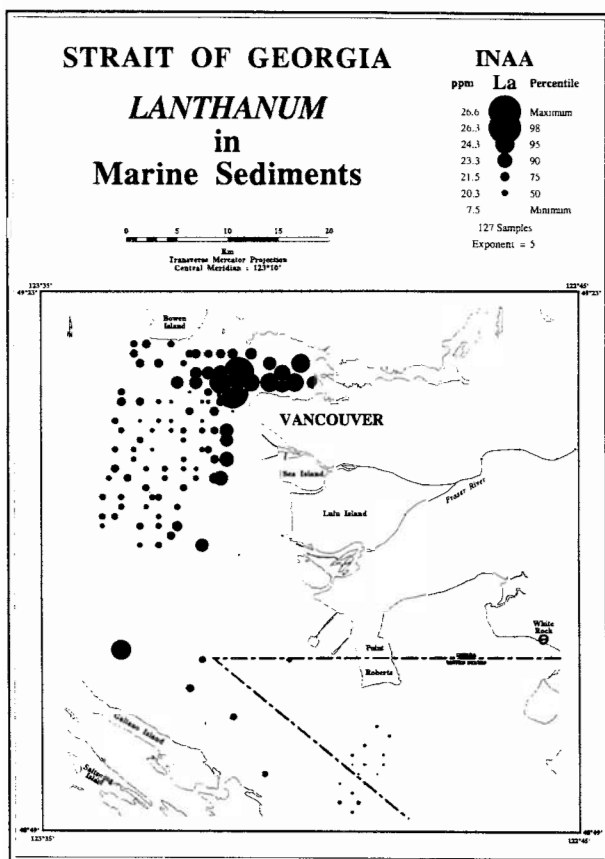


Trace Elements - 'Resistate' Fraction

Several elements are relatively enriched in sediments deposited in waters that are 50 - 200 m deep, along the slope from Sturgeon Bank (west of Lulu and Sea Islands) toward deeper waters of the Strait of Georgia. Elements in this suite include those that, characteristically are enriched in resistate fractions of sediments (e.g. monazite, ilmenite, rutile), notably thorium and the rare-earth elements (REE). Figure 5 shows examples of three of the REE (lanthanum, cerium and samarium) and thorium. The other REE that were determined (neodymium, europium, ytterbium, and lutetium) all have similar distribution patterns.

There is moderate enrichment of uranium, beryllium, and gold at these sites. At several locations, gold concentrations are unusually high for marine sediments, attaining a maximum concentration of 35 ppb Au. Typically, levels would be less than 4 ppb Au. Of note, also, are the patterns of titanium enrichment (see Appendix A, XRF) trending northward along the slope.

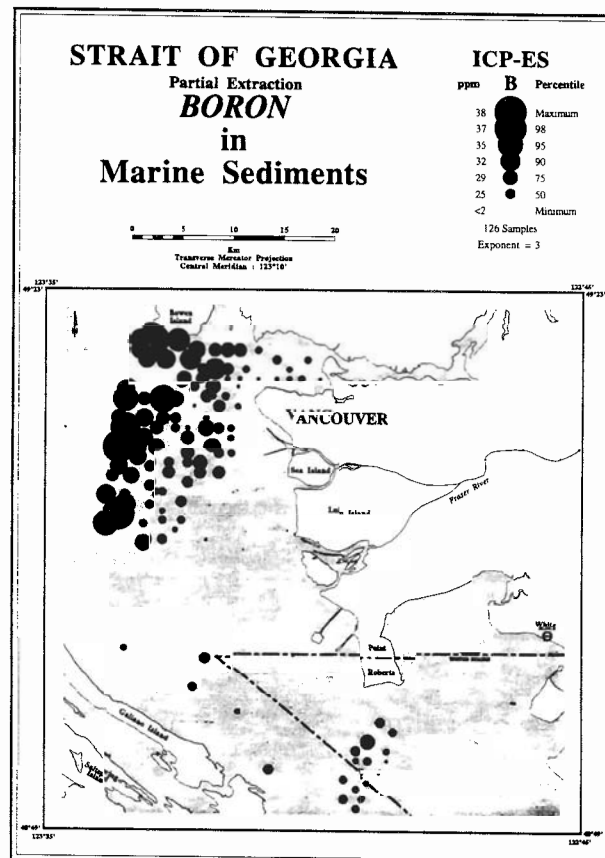
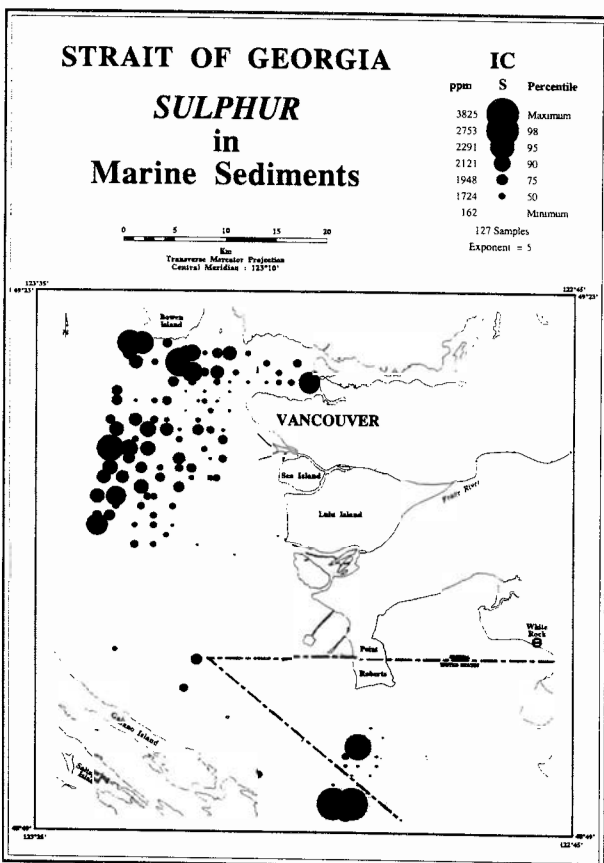
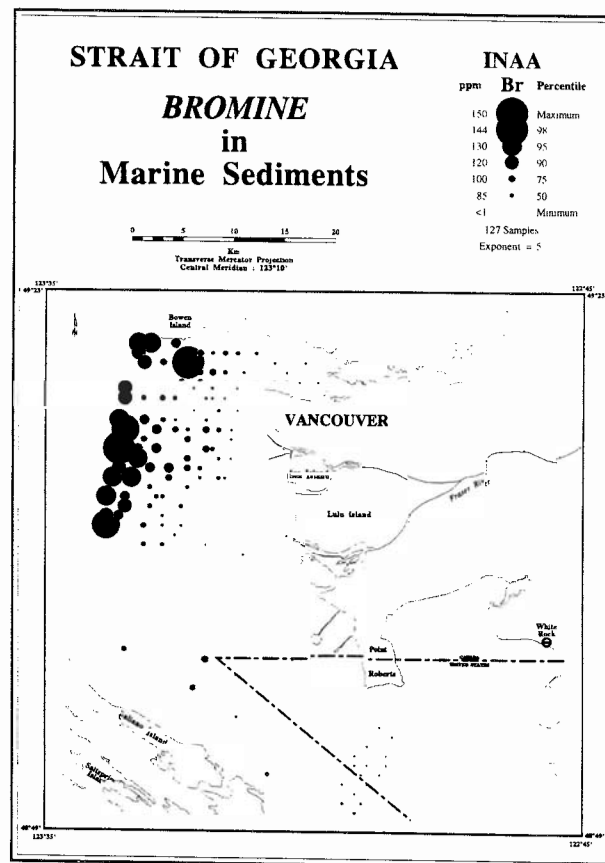
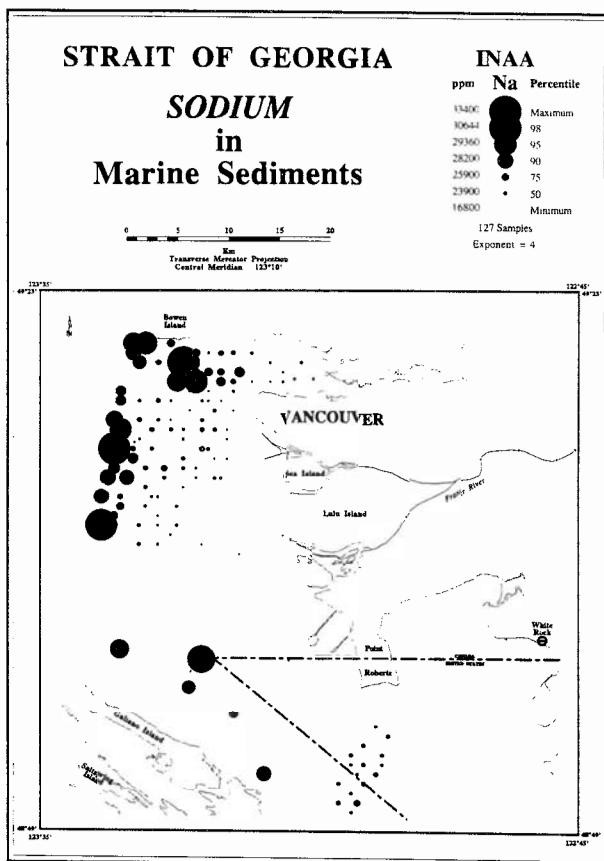
Fig. 5 Distribution patterns of rare-earth elements (REE) and thorium in sediments from the Strait of Georgia: enrichments related in part to relatively coarse grained deposits.



'Deep Water' Elements

Figure 6 shows distribution patterns of several elements that are relatively enriched in sediments retrieved from the deepest waters, namely the northerly trending trench in the western part of the survey area where water depth exceeds 300 m. Sodium, bromine, sulphur and the aqua-regia extractable boron (less than 25% of the total - see Table 3) are associated at many sites. Sulphur enrichment occurs also in the far south of the survey area. In addition, there is relative enrichment of manganese and cobalt, and some iron, scandium, cesium, vanadium and zinc.

Fig. 6 Distribution patterns of elements in sediments from the Strait of Georgia: enrichments in fine-grained sediments from deep waters.

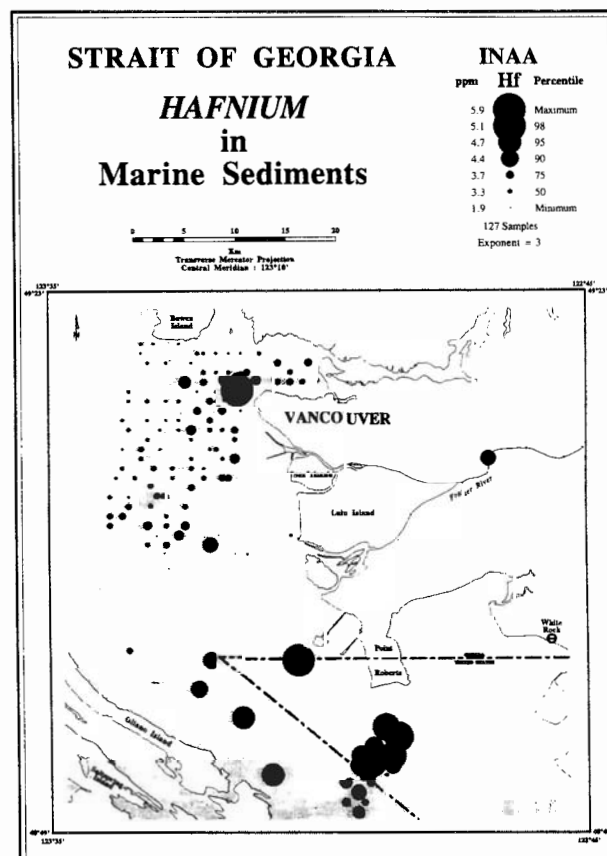
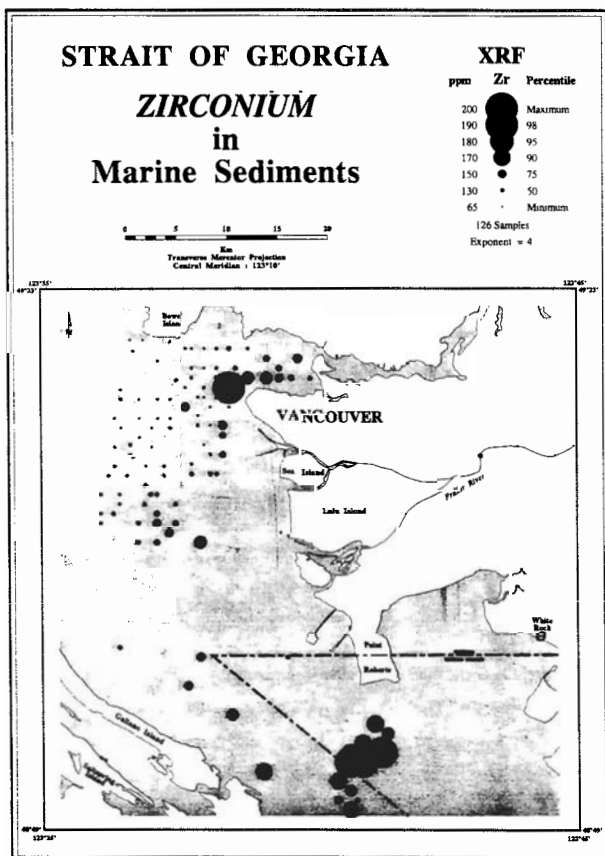
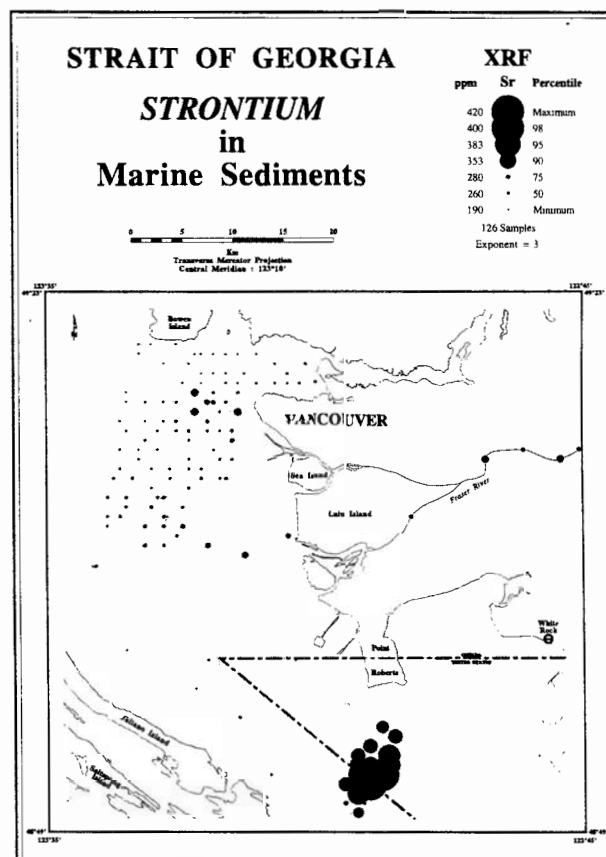
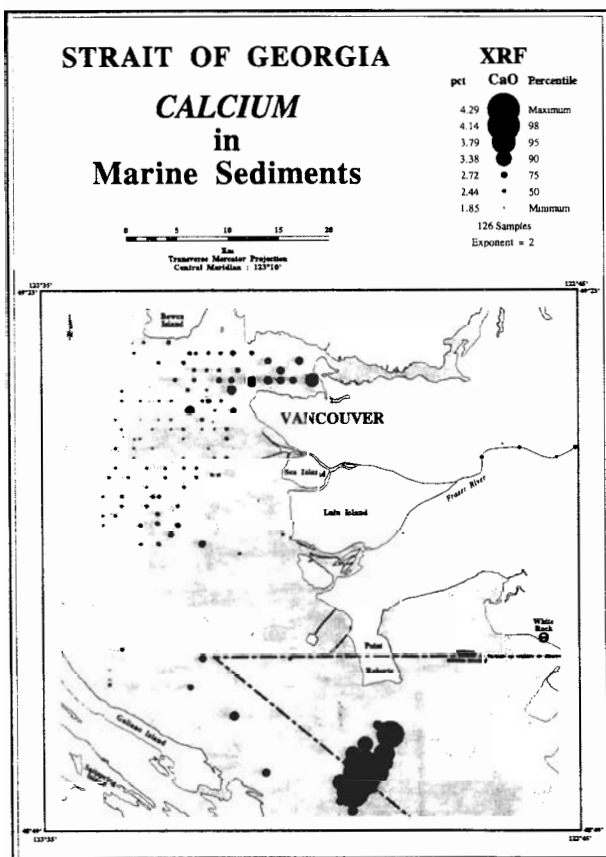


Carbonate Fraction

Figure 7 shows that on Roberts Bank (south of Point Roberts) the sediments are enriched in calcium and strontium. The map of carbon dioxide content of the sediments (Appendix A, Miscellaneous Methods) shows a similar distribution pattern, demonstrating that these elements are associated with carbonates, and that the carbonate content of the sediments is at its highest (locally over 5% CaCO_3) in this southern area that straddles the border between territorial waters belonging to Canada and the United States.

Similar patterns of element enrichment are exhibited by zirconium and hafnium. These elements have a close geochemical affinity, but are not usually enriched in carbonate-rich sediments. It is likely that the Zr and Hf occur in zircon, and that the slightly elevated levels reflect a very subtle enrichment of this heavy mineral - perhaps because of a low sedimentation rate or winnowing of the sediments (J. Luternauer, personal communication). As noted above (Fig. 6) levels of sulphur, too, are relatively high in this area.

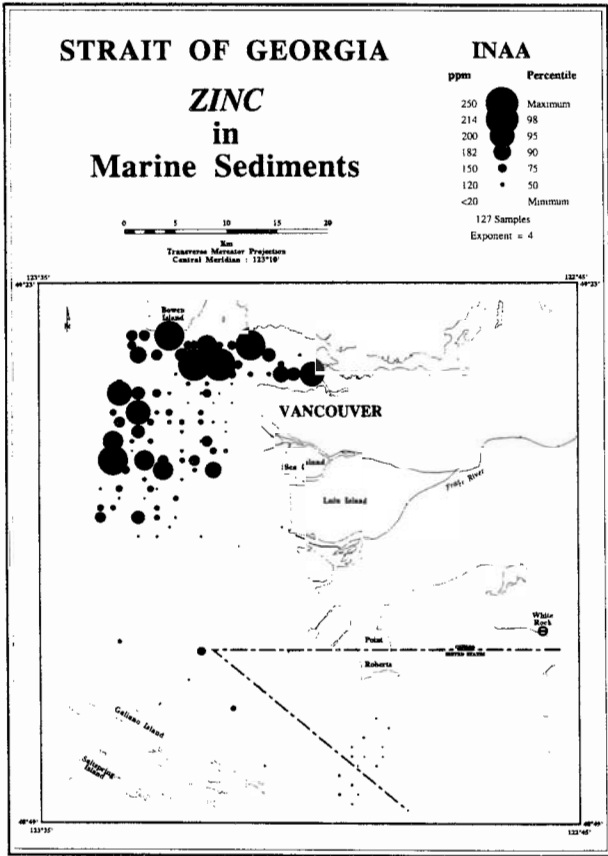
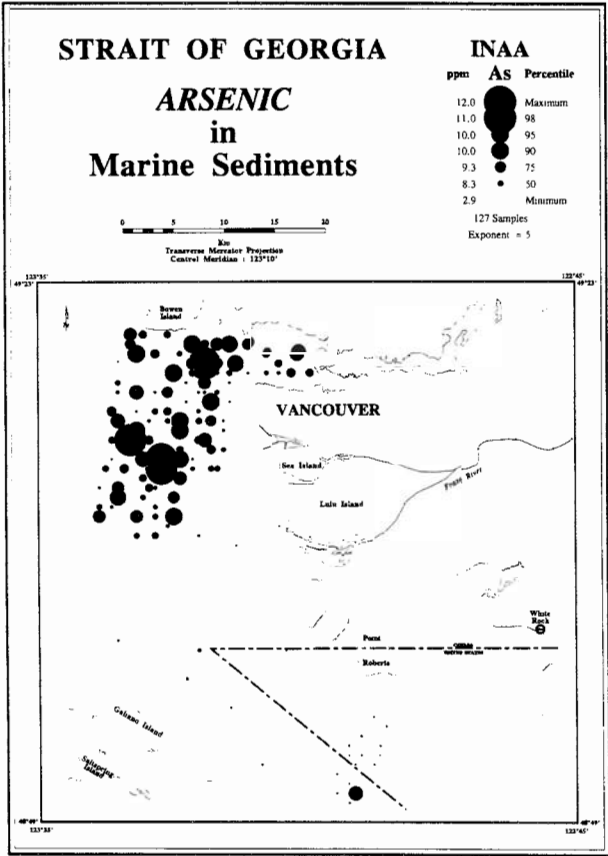
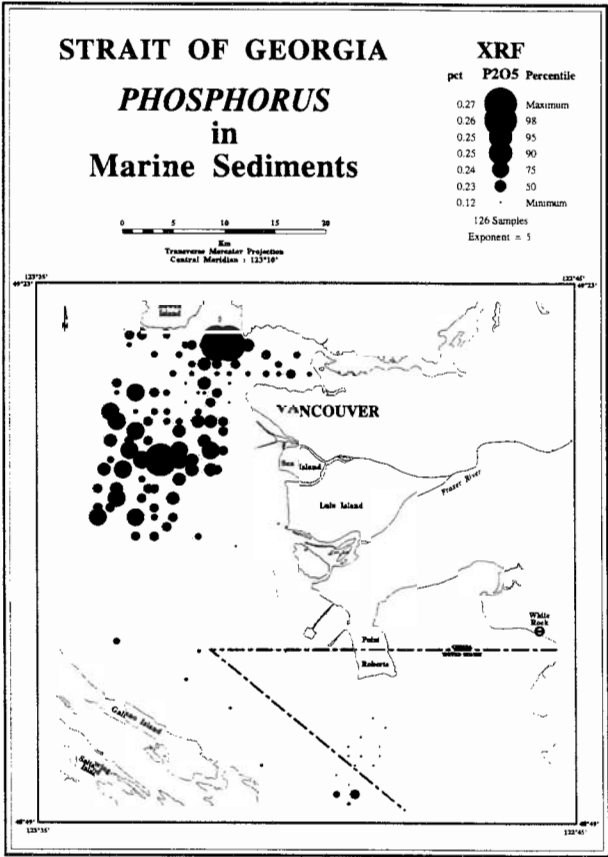
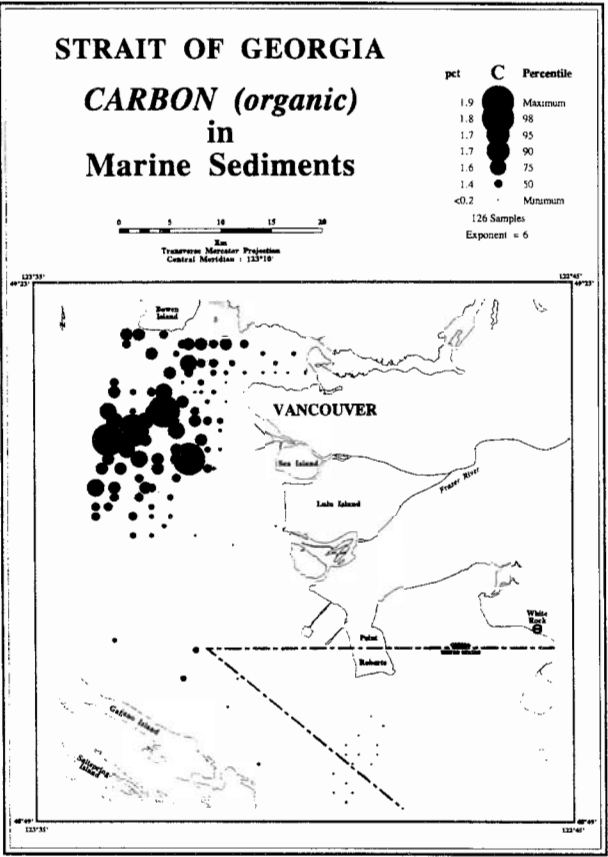
Fig. 7 Distribution patterns of elements in sediments from the Strait of Georgia: enrichments indicating an association of carbonates (Ca, Sr) and a slight increase in zircon content (Zr, Hf).



'Organic' Fraction

Figure 8 shows several elements that have, in part, somewhat similar distribution patterns. By overlaying the bathymetry map on that of organic carbon (Appendix A, Miscellaneous Methods) it is apparent that most of the sediments with highest content of organic carbon were retrieved from a northwesterly-trending trench where waters are deep. Although concentrations of phosphorus, arsenic and zinc are all low, they appear to have a weak association with organic carbon. No doubt other elements are associated with the organic fraction, but their associations with other fractions of the sediments obscures this relationship. A factor analysis of the data set would be of value in clarifying such relationships.

Fig. 8 Distribution patterns of elements in sediments from the Strait of Georgia: enrichments related in part to organic-rich fine-grained sediments.



CONCLUDING REMARKS

This report outlines the methods used, quality control, and major observations on the large, multi-element data set acquired from the chemical analysis of marine sediments from the Strait of Georgia. Discussion of the results is not exhaustive, but highlights some of the element patterns and offers some simple interpretations. It provides basic, tightly controlled data and information which can be used for more in-depth studies. This baseline data set is a 'snapshot' account of the chemical environment present in the Strait of Georgia at the end of 1992. As such, it can be used as a yardstick by which to measure and monitor future changes in the Strait of Georgia.

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