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SPATIAL ANALYSIS IN MARINE PLACER EXPLORATION: PRELIMINARY RESULTS FROM ST. GEORGE'S AND PORT AU PORT BAYS, NEWFOUNDLAND

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ABSTRACT

Exploration for marine mineral-placer deposits on the Newfoundland continental shelf requires integration of geochemical, geophysical, geological and oceanographic data. This project develops a method for the spatial analysis of data using a geographical information system (GIS). Specifically, methods of database structure, data encoding, data interpolation and data interpretation will be examined with reference to chromite occurrences in Port au Port Bay, and ilmenite–magnetite occurrences in St. George's Bay.

In an attempt to identify possible sources and dispersal paths of detrital grains and to locate any anomalies that might be of economic interest, surface grab samples will be analyzed for major- and selected-trace elements. Textural analyses will be undertaken in order to examine the genesis of individual sediment facies and the overall degree of sediment reworking. The shallow seismic reflection data will be interpreted on the basis of amplitude of reflection, acoustic coherence or incoherence, form, relief and boundary and stratigraphic relationships.

Data integration will include the creation of digital files for all variables and their importation into SPANS™ GIS software. Interpolation of the irregular spaced data, presents a particular problem that will be addressed when processing this data. Following interpolation, thematic maps for each variable will be created and overlaid to find spatial relationships between the themes, or to use previously derived relationships to identify areas that meet specific criteria. The present study is designed to identify the combination of themes that appear to be most diagnostic of placer formation, for the sites of interest.

Geochemical analyses appear to confirm that chromite and other heavy minerals of ophiolitic derivation are, locally, being concentrated in Port au Port Bay bottom sediments. The analyses also show that some geochemical values are sporadic and do not show any relationships to elements of probable ophiolitic derivation.

It is too early in the study to present any of the spatial analysis techniques or findings. The completed dataset and application of the GIS study will be reported at a later date.

INTRODUCTION

Although the continued success of high-latitude offshore-placer mining operations (e.g., Alaska; Mining Journal, 1986) has heightened exploration activities in both the United States and Canada, deposit models and specific geological constraints are, in many instances, poorly defined. Given that several claims have been staked in offshore Newfoundland and that an exploration program, for placer chromite, is presently underway in Port au Port Bay, it is becoming apparent that improved methods of data interpretation must be developed.

This report focuses on the development of a method for the spatial analysis of relevant geological and oceanographic data, using a geographical information system (GIS). Specifically, methods of database structure, data encoding, data interpolation and data interpretation will be examined with reference to chromite occurrences in Port au Port Bay, and ilmenite–magnetite occurrences in St. George's Bay. The types of data used include those most readily acquired in an offshore program, namely sediment texture and sediment geochemistry, heavy minerals and geophysical profiles. It is anticipated that the method will aid the placer explorationist

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in target delineation and preliminary resource evaluation.

The following discussion is limited to a brief description of the methods of sample collection and sample analysis and a preliminary examination of the analytical results.

DATA COLLECTION

In August/September, 1988, the Atlantic Geoscience Centre (AGC) undertook a nearshore study, off the southwest coast of Newfoundland (Forbes and Shaw, 1989). Geophysical surveys, surface grab samples and gravity cores were collected along the south coast from LaPoile Bay to Barasway Bay, and off western Newfoundland in St. George's and Port au Port bays. Twenty-two grab samples and 6 cores (one empty) were taken in Port au Port Bay (Figure 1); twenty grab samples and 2 cores were taken in St. George's Bay (Figure 2). A Van Veen grab sampler was used for all the grab samples and an Alpine gravity corer for the cores. Sample descriptions and details of sample collections have been summarized in Forbes and Shaw (1989).

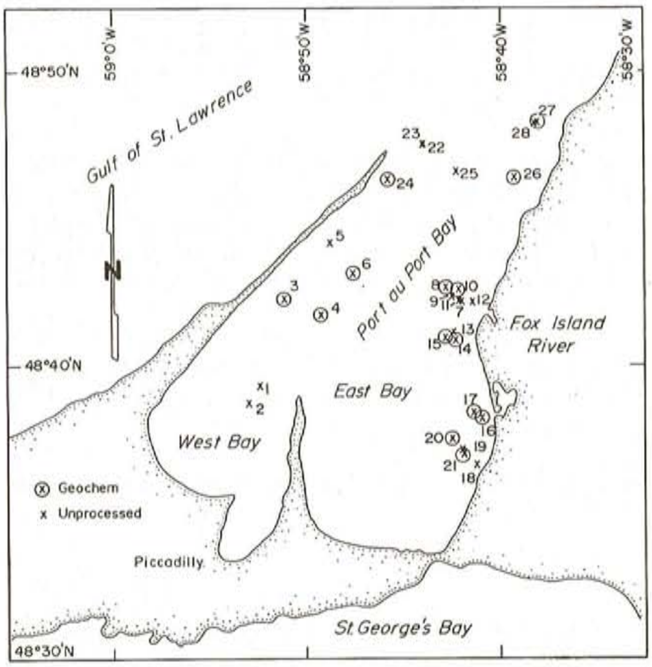

Figure 1. *Location of samples in Port au Port Bay.*

Geophysical equipment included a Klein 100 kHz sidescan sonar system, a Datasonics bubble pulser, a Huntec Sealion sound source with an ORE Geopulse 5210A receiver and LT06 NSRFC streamer, and a 280 joule 20-tip surface tow sparker having a Geopulse receiver and the NSRFC streamer. The sparker system was the primary source of high-resolution data (approximately 2- to 8-m resolution). A Barringer magnetometer was towed on all survey lines.

DATA ANALYSIS

All samples are being analyzed for major- and selected-trace elements, in an attempt to identify possible sources and

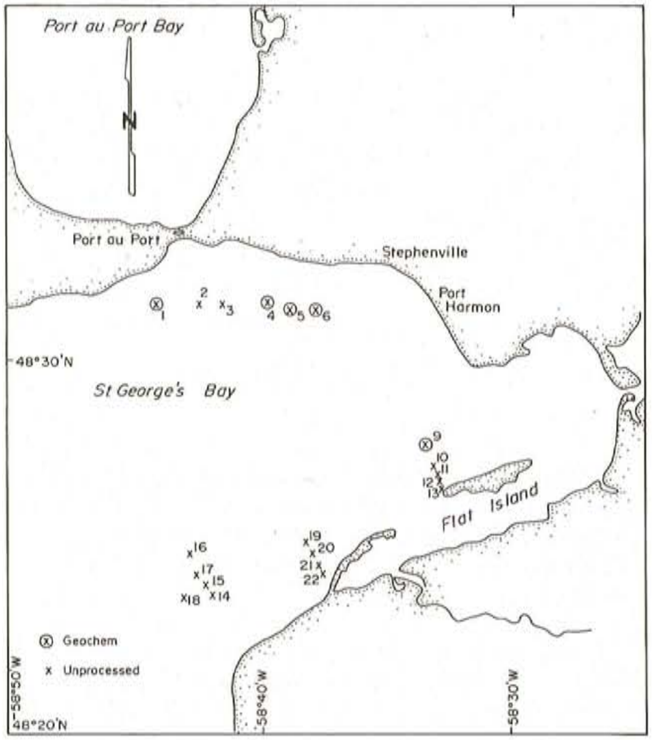

Figure 2. *Location of samples in St. George's Bay.*

dispersal paths of detrital grains and to locate any anomalies that might be of economic interest. To date, 18 samples from Port au Port Bay, 5 from St. George's Bay and 5 blind duplicates have been analyzed by the Department of Mines and Energy. Sample locations are shown on Figures 1 and 2, and a partial listing of analytical results is presented in Table 1. Details of sample preparation, analytical methods, and a complete data listing can be found in Swinden and Forbes (1989).

Textural analyses will be performed on all samples. Sediment texture is an important criteria in establishing the genesis of individual sediment facies and the overall degree of sediment reworking. The sediment samples from St. George's Bay are being analyzed by the Atlantic Geoscience Centre, using a settling tube. The Port au Port Bay samples are being analyzed at C-CORE, using a standard mechanical sieving technique.

Heavy minerals will be separated using a Magstream separator having a density cut-off of 2.8 g/cm^3. Energy dispersive X-ray analysis will be used to determine the elemental ratios of the heavy-mineral suite; this is particularly important in the case of chromite, in which the ratio of chrome to iron has a direct bearing on its economic potential.

Shallow-seismic and sidescan-data interpretation in Port au Port Bay was undertaken by an independent contractor to the Geological Survey of Canada (Earth and Ocean Research Limited, 1989). The shallow-seismic reflection data were interpreted on the basis of amplitude of reflection, acoustic coherence or incoherence, form, relief and boundary and

Table 1. Representative analyses of bottom sediments from Port au Port and St. George's bays

spl. no. lab. no.	NO8003 2140855	NO8010 2140860	NO8015 2140862	NO8016 2140863	NO8024 2140871	NO8026 2140872	NO9001 2140875	NO9009 2140879
SiO_2	66.65	60.35	57.95	59.4	75.8	72.9	68.1	64.1
Al_2O_3	10.42	8.49	10.25	6.12	5.7	8.03	11.63	11.09
Fe_2O_3	0.21	0.74	0.13	4.15	3.84	1.15	1.62	1.41
FeO	3.32	5.01	4.79	2.55	0.99	1.92	1.66	2.49
FeO_{tot}	3.51	5.68	4.91	6.29	4.45	2.96	3.12	3.76
MgO	3.55	10.18	7.84	14.62	1.94	3.08	1.81	2.88
CaO	1.21	3.27	2.35	2.16	2.98	3.33	4.93	4.19
Na_2O	2.62	2.02	2.47	1.35	1.44	2.21	3.08	2.54
K_2O	2.33	1.24	2.12	0.97	1.28	1.53	1.53	2.11
TiO_2	0.61	0.51	0.57	0.38	1.57	0.62	0.6	0.72
MnO	0.05	0.09	0.07	0.09	0.12	0.07	0.07	0.08
P_2O_5	0.17	0.18	0.18	0.14	0.09	0.12	0.08	0.18
LOI	8.39	7.55	10.3	7.15	3.14	4.25	2.91	7.46
Total	99.53	99.63	99.02	99.08	98.89	99.21	98.02	99.25
Sb	0.39	1.1	0.42	0.29	0.37	0.2	0.21	0.48
As	11	17	14	30	4.6	4.6	2.8	4.9
Au	<2	<2	<2	<2	4.9	3.5	2.3	<2
Pd	<4	<4	<4	<4	<4	<4	<4	<4
Pt	<10	<10	<10	<10	<10	<10	<10	<10
Cu	18	22	22	15	9	10	10	18
Zn	68	70	75	58	36	38	31	52
Pb	17	37	19	3	8	8	8	16
Mo	2.8	<1	2.1	<1	<1	<1	<1	1.2
Ag	<2	<2	<2	<2	<2	<2	<2	<2
Sn	<100	<100	<100	<100	<100	<100	<100	<100
W	<1	<1	<1	<1	<1	<1	<1	<1
U	3.2	1.6	2.6	1.4	1.7	1.9	0.8	2.1
Ba	460	290	360	260	380	460	440	590
Cd	<5	<5	<5	<5	<5	<5	<5	<5
Cr	300	2320	1000	5540	3070	1800	110	110
Co	12	38	22	53	16	11	11	10
Ni	51	280	190	520	58	56	12	42
Rb	61	35	68	29	30	37	34	48
Sc	11	17	14	14	13	11	12	13
V	89	105	103	96	105	68	76	80
Sr	121	109	123	70	126	152	308	208
Th	7.1	4.1	7.2	4	7.1	5.9	2.9	7.1
Zr	251	40	210	76	486	910	62	397
Hf	6.3	3.8	5.3	5.8	30	22	3.7	10
La	30	18	27	14	33	24	14	27
Ta	0.65	<0.5	0.73	<0.5	1.9	0.61	<0.5	1
Nb	7	2	7	0	24	7	8	7
Y	17	15	17	10	18	16	11	18

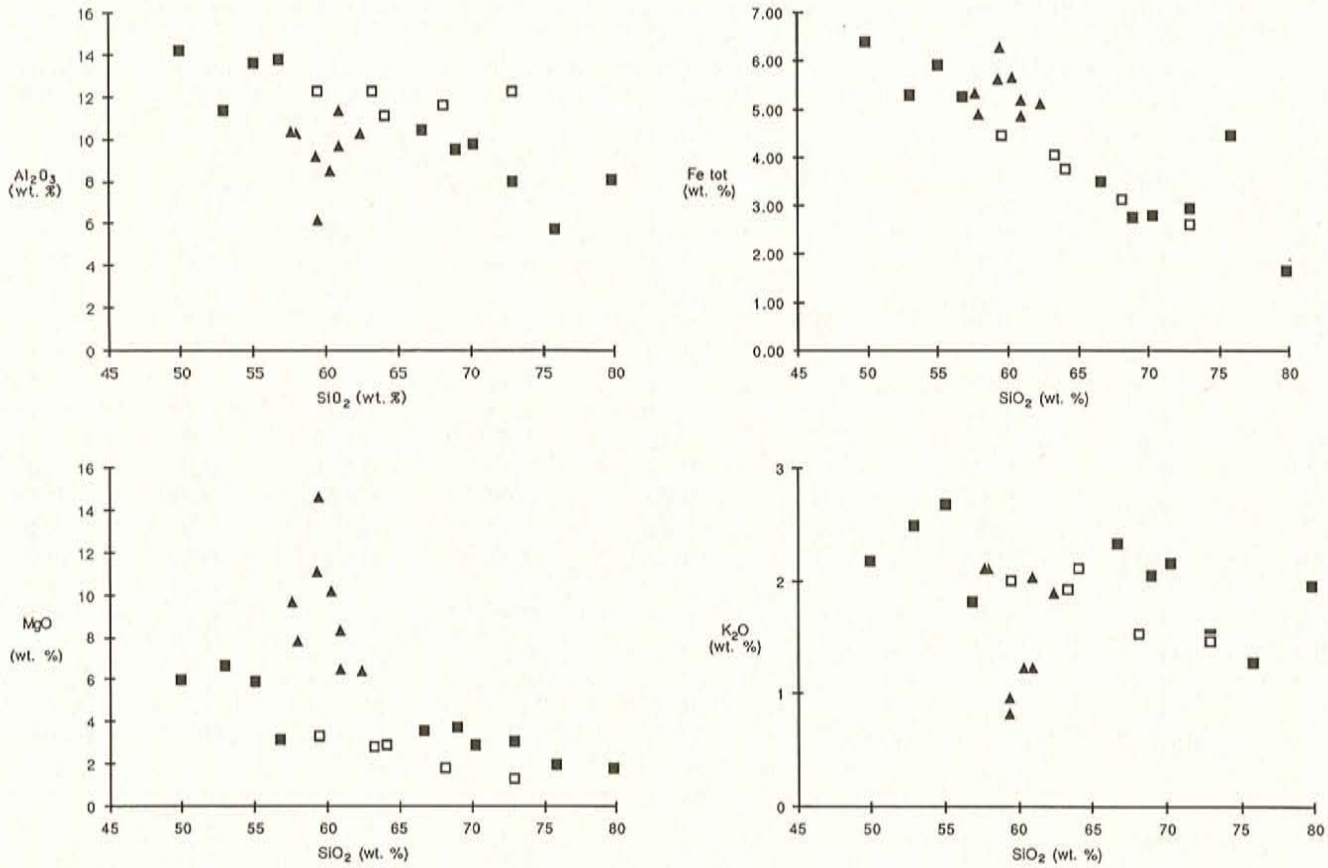

Figure 3. *Covariation of selected major-element oxides with silica. Open symbols are St. George's Bay samples. Closed symbols are Port au Port Bay samples; squares are samples on the 'normal detrital trend'; triangles are samples that define the 'ophiolite provenance anomaly' (see text).*

stratigraphic relationships. Preliminary interpretation of the St. George's Bay geophysical data will be undertaken by C-CORE.

PRELIMINARY ANALYTICAL RESULTS

Geochemistry

Examination of blind duplicates show that the precision of the analysis is generally very good and that the results are reproducible. Whereas data compilation is incomplete and neither grain-size analyses nor mineralogical studies have been carried out on these samples, the observations discussed below are tentative and preliminary in nature.

Most major-element oxides show a strong negative correlation with silica (Figure 3), apparently recording dilution of alumina and the various cations by silica. This trend may reflect the range of composition of detritus from a heterogeneous source region or it may be partly a function of grain size, and reflect clays being diluted by detrital quartz in the silt or sand fraction. For ease of discussion, the trend will be referred to as the 'normal detrital trend'.

There is an anomaly superimposed on the normal detrital trend, which is best displayed as a diffuse peak of MgO enrichment (MgO generally 0.7 percent) at between 55 and 65 percent SiO_2 (Figure 3). These samples show no MgO$-SiO_2$ correlation. The anomalous samples are also enriched, with respect to the normal detrital trend, in the transition elements (e.g., Fe, Cr, Ni) and depleted in Al_2O_3 and the alkali and alkaline earth elements (represented by K_2O on Figure 3). This geochemical anomaly probably results from concentration of olivine (hence the excellent MgO−Ni correlation, Figure 4), pyroxene (which may contain some of the Cr) and probably chromite (at least in the most Cr-rich samples). Depletion in alumina, alkali and alkaline earth elements is probably a dilution effect, as these elements are not found in olivine, pyroxene or chrome spinel. The strong Cr−MgO correlation in Figure 4 may partially reflect Cr in pyroxene, but also indicates simultaneous accumulation of chromite, pyroxene and olivine from the same source (presumably the ophiolites in the Lewis Hills to the east).

Two samples plot well above the Cr−MgO trend at low MgO contents on Figure 4. These most probably contain detrital chromite. Most other elements that might reflect accumulation of heavy minerals (e.g., TiO_2 for iron−itanium oxides, Zr, Jf, Ta, Th for zircon or monazite) show little consistent covariation with silica (e.g., Figure 5). However, there are isolated high values that may reflect local accumulation of heavy minerals. One of the low MgO−high

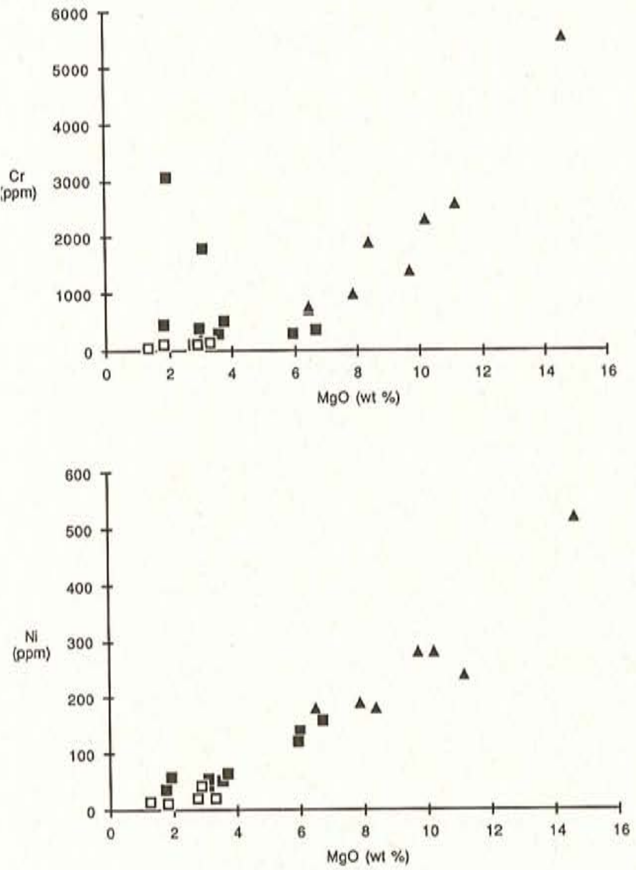

Figure 4. *Covariation of Ni and Cr with MgO. Open symbols are St. George's Bay samples. Closed symbols are Port au Port samples; squares are samples on the 'normal detrital trend'; triangles are samples that define the 'ophiolite provenance anomaly'. Note that two samples from the normal detrital trend are enriched in Cr but not in Ni or MgO, probably indicating accumulation of chromite.*

Cr samples (NO8024) contains anomalous TiO_2 (Figure 5; Table 1). This sample is also relatively enriched in Fe (Figure 3) and V, suggesting that the high TiO_2 reflects either simultaneous accumulation of Cr-rich and Fe–Ti-rich spinel or local accumulation of a Cr–Fe spinel. Anomalous Zr in sample NO8026 (Figure 5; Table 1) may reflect local accumulation of zircon. There is no geochemical evidence of enrichment of base metals in any of the sediments. Copper, Zn and Pb all show a strong negative correlation (e.g., Zn, Figure 5), which is interpreted to reflect the normal detrital trend.

All St. George's Bay samples plot in the normal detrital trend. Within Port au Port Bay, many of the Cr-rich samples were taken near the outflow of the Fox Island River, which may support earlier conclusions of Emory-Moore *et al.* (1988) that this river is transporting ophiolite-derived chromite to the bay. Anomalous concentrations of chromite are also locally present in the sediment at a considerable distance form the Fox Island River (e.g., NO8024, NO8026; Table 1), suggesting that either chromite is being delivered to the bay at more than one site or that there is a complex system of redistribution of heavy minerals within the bay.

About 60 percent of samples analyzed contain less than the detection limit of 2 ppb gold and the maximum concentration of gold was 9.1 ppb (at 60 cm depth). Gold shows no obvious correlation with the detrital trend or with other elements. The highest gold values in these samples could represent minor accumulation of free gold. Both platinum and palladium are at or below detection limits in all samples.

Texture

Based on visual descriptions of surface grabs and sieve-size analyses from a previous investigation by Shearer (1970), sediment texture in Port au Port Bay appears to be mainly controlled by bathymetry. A general trend of coarsening shoreward can be seen with the fine grained ($<63\mu m$) sediment, restricted to water depths of greater than 25 m, and a gradual shoreward transition to sands and then to gravels. Local exceptions to this trend appear to be the result of differing sources of sediment supply. As an example, the nearshore region off the mouth of Fox Island River is dominated by relict gravels created through the reworking of a major subflow fan complex, whereas the nearshore sediment package off the Two Guts Pond area is the product of coastal erosion of raised marine terraces and thus dominanted by sand.

Sample distribution in St. George's Bay is irregular. Visual observations indicate that sand or sand and gravel are present along the shoreline to about 40- to 50-m water depth, where the sediments grade into mud.

Geophysics

Geophysical interpretation by Earth and Ocean Resources Limited (1989) of the data collected in Port au Port Bay, define five distinct acoustical units interpreted to record a complex series of Late Quaternary events. A geophysical profile, recorded off the mouth of Fox Island River (Figure 6) illustrates the considerable thickness of sediment in the nearshore regions (up to 100 m) with sediment facies ranging from a lowermost till to a surficial cover of reworked sand and gravel. Interpretation of the St. George's Bay geophysics data is presently underway.

SPATIAL ANALYSIS OF DATA

The results of the data and sample analyses will be integrated with existing geological, topographic, and oceanographic data using a geographic information system (GIS). Digital files will be created for all variables and these imported into SPANS™ software. Where sample density allows, point data will be interpolated using a triangulated irregular network. The very irregular grid, over which the samples were collected, presents a particular problem that will have to be addressed when the data is processed. Following interpolation, thematic maps for each variable will be created. Of particular interest to the present study, is the ability of SPANS to overlay two or more thematic layers in a database and find spatial relationships between the themes,

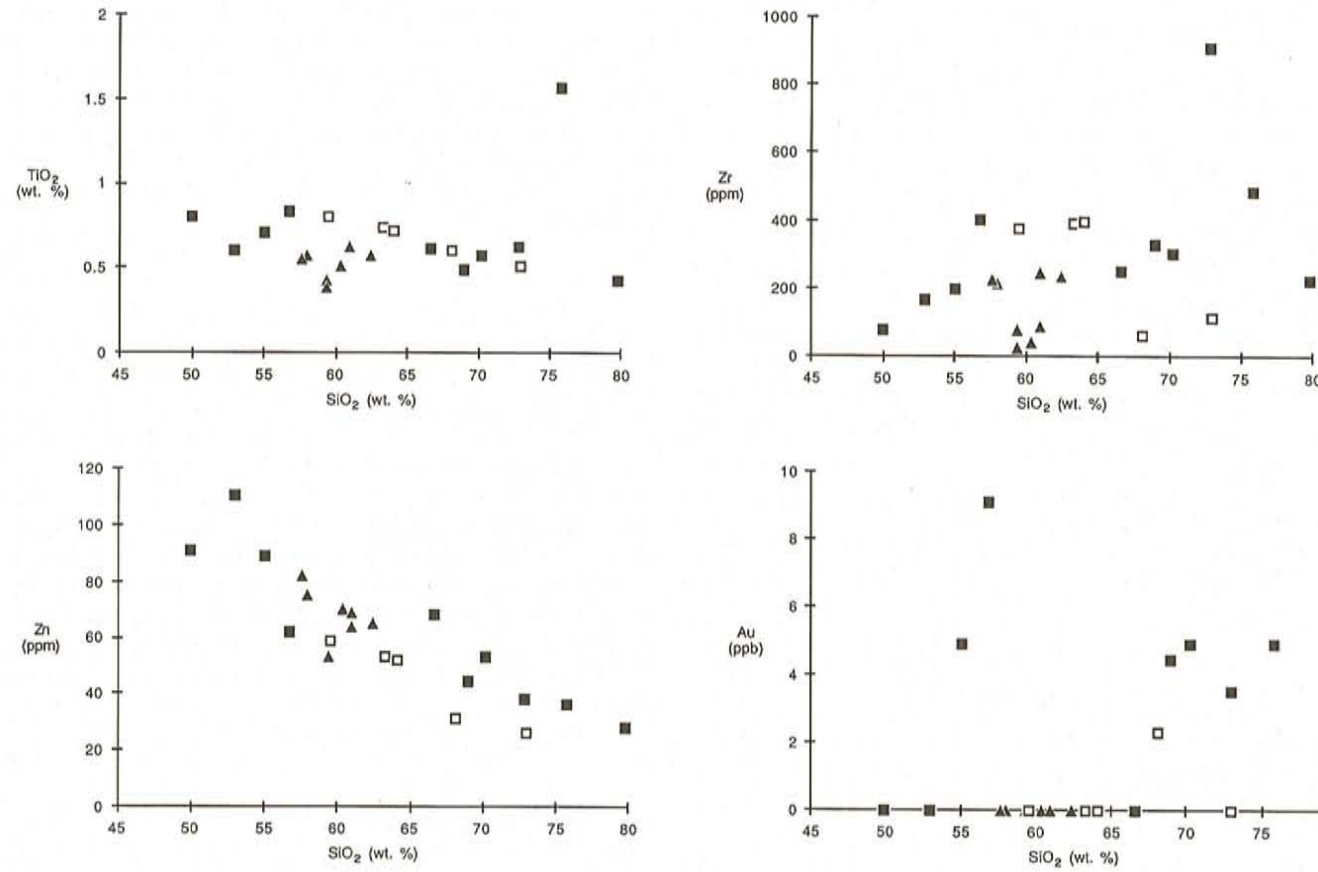

Figure 5. *Covariation of minor and trace elements with silica. Open symbols are St. George's Bay samples. Closed symbols are Port au Port Bay samples; squares are samples on the 'normal detrital trend'; triangles are samples that define the 'ophiolite provenance anomaly'.*

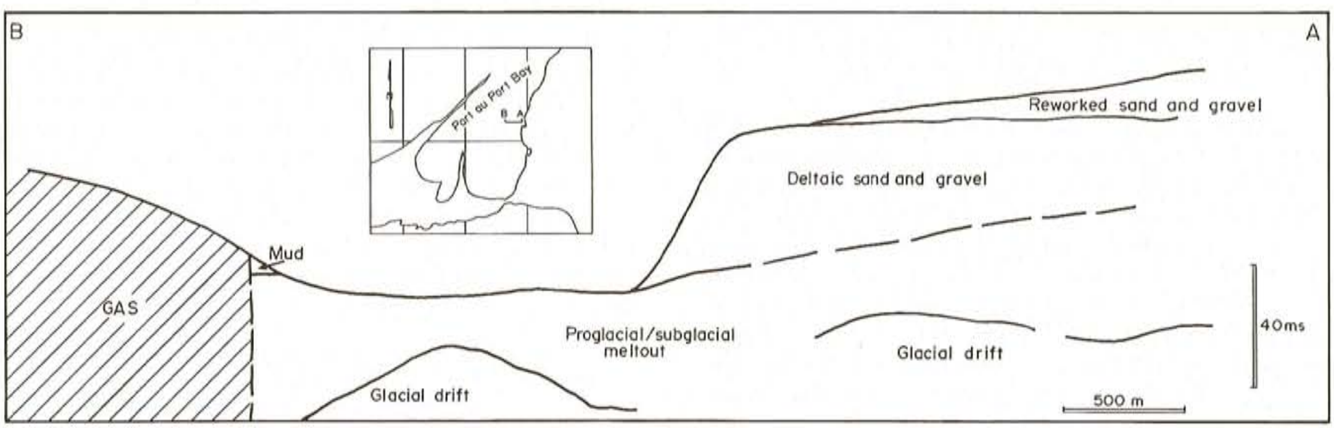

Figure 6. *Subbottom sediment profile taken off of the Fox Island River mouth. Vertical scale 1 ms = 1.5 m, assuming a velocity of 1500 m/sec (see Earth and Ocean Research Limited, 1989).*

or to use previously derived relationships, which can be used to identify areas that meet specific criteria. The present study is designed to identify the combination of themes that appear to be most diagnostic of placer formation for the sites of interest. Given these and a defined methodology for GIS applications, the placer explorationist can enter new data as it becomes available and create maps that will highlight the areas of the greatest potential.

The relatively sparse database available detracts from the statistical validity of data interpolation, thereby making the identification of thematic controls on placer formation problematic. Compatible data from previous studies will be integrated, but the database is still weak and this limitation must be realized. Although the control parameters will be specific to the sites of interest, they will be designed using known principles of allocthonous placer formation and thus applicable to light–heavy-mineral placer formation elsewhere. Finally, it should be stressed that the scientific principles used in, and the methods developed for, this study are adaptable to both regional and localized studies.

DISCUSSION

Without textural and mineralogical data, the significance of the geochemical results are speculative. The geochemical data appear to confirm that chromite and other heavy minerals of ophiolitic derivation are locally being concentrated in Port au Port Bay bottom sediments, and indicate geochemical parameters by which anomalous concentrations of ophiolite-derived detritus may be recognized. Gold values are highly variable and do not show any relationships to elements of probable ophiolitic derivation.

It is too early in the investigation to present any of the spatial analysis techniques or findings. The completed dataset and application of the GIS study will be reported at a later date.

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