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PLACER POTENTIAL OF FOX ISLAND RIVER AND EAST-CENTRAL PORT AU PORT BAY: A PRELIMINARY ASSESSMENT

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ABSTRACT

Surficial-sediment texture, mineralogy and geochemistry are used to assess the potential for chromitiferous placers in Fox Island River and east-central Port au Port Bay, western Newfoundland. The geological setting of the study area constitutes a glaciated region which is characterized by the four criteria necessary for heavy-mineral placer formation: a source (Lewis Hills ophiolite), liberation mechanism (Pleistocene glaciation), conduit (Fox Island River), and sink (Port au Port Bay). Heavy-mineral distribution in the river, the coastal beaches and in the offshore reflect varying hydraulic regimes and the character of primary- and secondary-sediment sources. The highest heavy-mineral concentrations are found in beach sediments as discrete laminae and in modern marine sands; the lowest concentrations are found in the aggrading portions of the river mouth.

Conceptual models are formulated to trace the dispersal path of chromite and associated heavy minerals in both the fluvial- and coastal-offshore zones. Proglacial outwash bars, raised beaches and raised marine terraces warrant further investigation.

INTRODUCTION

A placer deposit is a concentration of economically valuable detrital mineral grains which are formed by surface or near-surface mechanical processes (most commonly running water). Placer minerals include 'heavy heavy minerals' (specific gravity 6.8-21), such as native gold, native platinum and cassiterite; the 'light heavy minerals' (specific gravity 4.2-5.3), chromite, rutile, ilmenite, zircon and monazite; and the gem minerals (specific gravity 2.9-4.1), diamonds, rubies and sapphires (Emery and Noakes, 1968). Placer deposits have historically provided a major share of the world's gold, platinum, diamond, ilmenite, rutile, zircon, and tin.

Despite their economic importance, there has been little sedimentary research in placer genesis (Slingerland and Smith, 1986). This is particularly true in glaciated terrains where the effects of glacial and glacially influenced sedimentary processes on placer formation are poorly understood. The site chosen for the present research (i.e., Fox Island River—Port au Port Bay, western Newfoundland; Figure 1) was extensively glaciated during the Quaternary, and is characterized by the four geological criteria necessary for placer formation:

1) source—ophiolitic rocks containing chromite and platinum-group elements (PGE),

2) liberation mechanism—glacial, periglacial, and postglacial processes resulting in the mechanical attrition of bedrock and contemporaneous dispersal and deposition of large volumes of sediment,

3) conduit (transport pathway)—Fox Island River and associated tributaries, and

4) depositional sink—Port au Port Bay.

The objective of the present study is to assess the placer potential of Fox Island River and Port au Port Bay. Longer term research objectives are:

1) the development of a preliminary genetic model for fluvial and marine placer formation in a glaciated terrain, and

2) delineation of favourable sites for further work.

GEOLOGY OF THE SOURCE ROCKS

The suite of rocks represented in the Fox Island River drainage basin include (Williams, 1975):

1) inliers of Precambrian basement

2) an autochthonous Cambro-Ordovician carbonate succession

3) a Middle Ordovician allocthonous clastic shelf succession and ophiolitic suite, and

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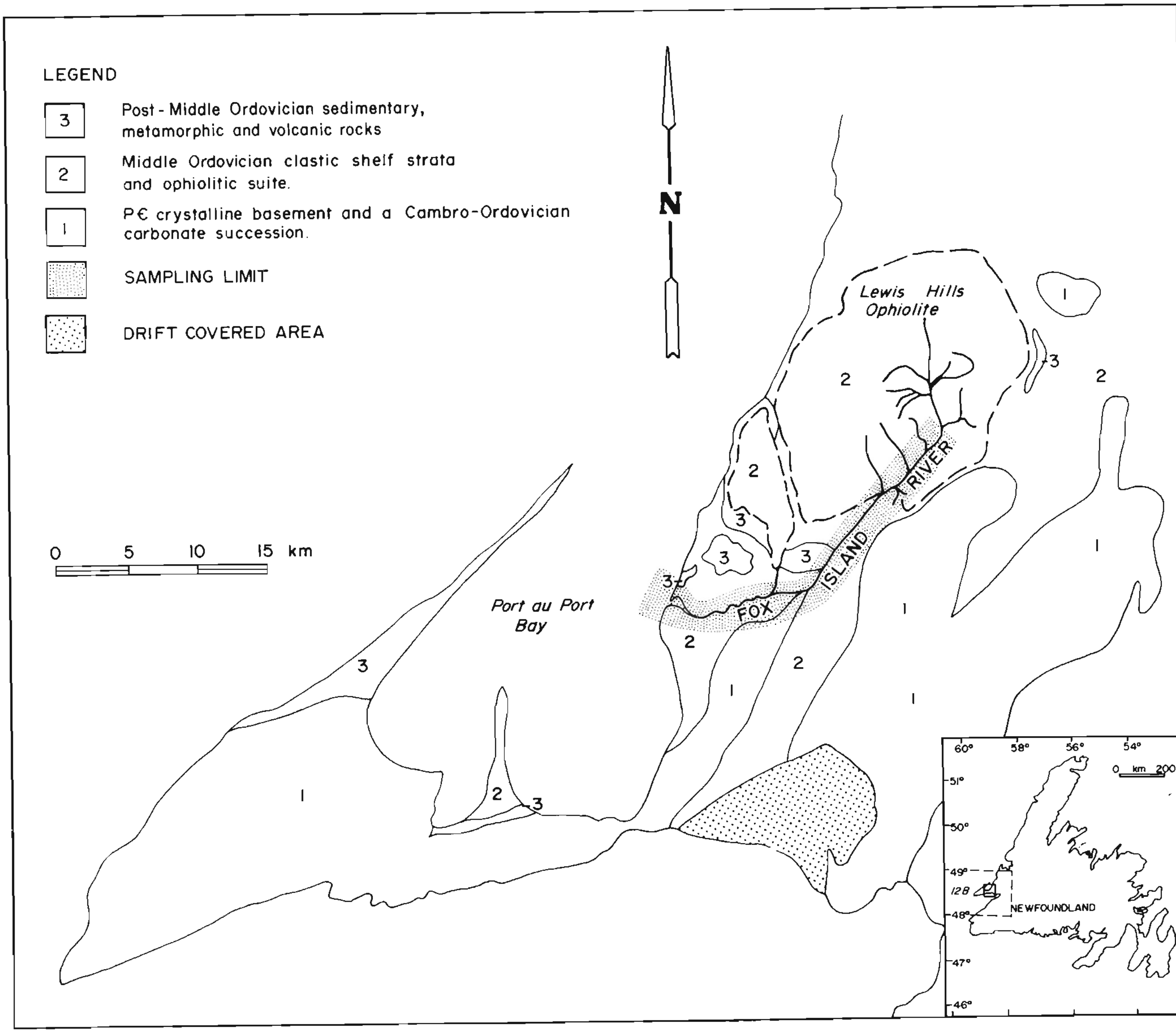

Figure 1. *Location and geological setting of the study area.*

4) neoautocthonous schists, volcanic rocks and Carboniferous cover rocks.

Within the present study area, the Lewis Hills ophiolitic rock suite forms the highest structural slice in a series of stacked thrust sheets, which are interpreted to record the evolution and destruction of the ancient continental margin of North America (Williams, 1975). Discrete lithologic assemblages (e.g., harzburgite and wehrlite) within the ophiolite are characterized by numerous discontinuous layers of disseminated and massive chromite. Chromite grains are generally euhedral to subhedral, <2 mm in diameter, and grade at approximately 36–52 weight percent Cr_2O_3 in the richest sections (Snelgrove, 1934; Dunsworth *et al.*, 1984).

The geological significance and economic potential of platinum-group elements (PGE) in ophiolitic complexes have recently received considerable attention (e.g., Legendre and Auge, 1986). Although no economic lode deposits have been discovered, platiniferous placer deposits are known to occur in association with ophiolitic suites (Ford, 1981). Given the known, albeit very low-grade occurrences of PGE in the Lewis Hills ophiolite (Page and Talkington, 1984), there exists a potential for associated PGE-bearing placer deposits within the study area.

QUATERNARY GEOLOGY: LIBERATION MECHANISM AND SECONDARY SOURCE

Glacial, periglacial and postglacial processes are of considerable importance to the liberation of placer minerals due to their effects on bedrock attrition and overall sediment availability. Glaciated terrains are generally characterized by a regolith of mechanically weathered debris, which is the product of subglacial quarrying and abrasion, erosion by running water, and freeze–thaw activity. These processes release large volumes of sediment ranging in size from <63 micrometres to house-sized boulders.

Within the study area, maximum ice extent during the late Wisconsin was very near present coastal limits (Grant, 1977). Of the three glacial rock-stratigraphic units recognized in southwestern Newfoundland, only the Robinson's Head Drift occurs in the study area (Brookes, 1974). This unit is considered to be a product of a local ice readvance (12,600 ± 140 yrs. B.P.), and is characterized by a sheet of coarse till (Brookes, 1974).

Sediments exposed in the incised river banks of Fox Island River and in wave-cut terraces along coastal sections reveal a complex sequence of Quaternary events. Facies types identified include (no chronological ordering): diamictons (basal till and/or resedimented morainal material), pro- and postglacial colluvial, fluvial and deltaic sands and gravels, and raised marine silts and clays.

Isostatic readjustment subsequent to the late Wisconsin recession resulted in a 60 m drop in relative sea level dating from 14,000 to 6,000 yrs. B.P. Relative sea level has risen about 14 m from 6,000 yrs. B.P. to present (Brookes *et al.*, 1985).

A CHARACTERIZATION OF THE CONDUIT AND SINK

Given the source (Lewis Hills ophiolite and glacial sediments) and a liberation mechanism (glacial- and postglacial-mechanical weathering), an attempt was made to further characterize the transport corridor (Fox Island River) and depositional sink (Port au Port Bay). To this end, a detailed surficial mapping and sampling program with select geophysical profiling was undertaken; a description of field and analytical procedures and preliminary results follow.

Methodologies

Mapping and Sampling Program. Surficial sediments from the bed of Fox Island River, the beaches adjacent to the river and in the offshore zone (<20m water depth) fronting the river mouth were mapped and sampled for textural and mineralogical analyses. A total of 312 surficial samples (average weight of 1 kg) were collected: 35 in Port au Port Bay, 25 from the coastal beach and 252 from Fox Island River. Representative samples from major glacial sequences were collected from incised river banks and wave-cut terraces. Finally, three bulk samples (weighing about 30 kg) from the beach sediment, glacial outwash and diamicton were collected for analyses of noble metals.

All river samples were collected on a coarse line grid of 250 m with sample intervals of 100 m. The samples were restricted to the <4 mm size fraction as the very coarse cobble—boulder lag that characterizes the river bed precluded any form of bulk sampling for textural analysis. The potential loss of fines resulting from subaqueous sampling in the river was minimal due to low water conditions, which allowed sampling of exposed riverbed sediments.

Offshore surficial grab samples were collected by scuba divers on a coarse line grid of 1 km with sample intervals of 250 m. Sample positioning, accurate to within ± 50 m, was determined by fin and compass. A hand trowel was used for collection of offshore samples. Depth limitations on scuba divers restricted sample collection to <20 m water depth.

Two graduated marker posts were inserted in the seabed and will be used to monitor net sediment erosion and/or deposition. A washer, placed over the marker rod, will drop to the depth of deepest erosion (this is important given that diver observation of the rods is not possible during storms, when deepest erosion is expected to occur). The rods will be examined every six months to coincide with induced seasonal variations.

Geophysical Program. The geophysical program consisted of VLF—resistivity, hammer refraction, seismic and sonic subbottom profiling surveys. The total VLF—resistivity coverage was 1.9 km using 10 m stations (Figure 2). A dual channel Huntec system with a source-receiver station of 2 m was used in the collection of 0.5 km of seismic data (Figure 2). Each of the two geophones were used separately over the same area and then both used simultaneously in a reverse profile; this repetition was required for the detection of dipping or ghost layers in the subsurface.

A Raytheon 1000X dual frequency subbottom profiler was used in the nearshore area off the mouth of Fox Island River. Approximately 5 km of line were surveyed. The quality of the data was poor because the acoustically hard seabed in the area (coarse sands and gravels) caused considerable scattering of the signal and a generally incoherent response.

Laboratory Analysis. Analyses of samples were selective and based on the criteria of uniform geographic spacing and inferred geomorphic controls (i.e., where flow velocity variations occur within the river). Twenty riverbed, three beach, and thirty-three offshore samples were chosen for textural analyses. Samples were dried, split and sieved through a bank of seven sieves measuring 0.063 mm, 0.106 mm, 0.25 mm, 0.5 mm, 1.0 mm, 2.0 mm and 4.0 mm.

Heavy-mineral separation of both the 0.063 mm to <0.25 mm and >0.25 mm to <1.0 mm size fractions were carried out on 19 offshore samples, 2 beach samples, and 44 river samples using a combination of gravity and centrifuge techniques. In addition, the 0.063 mm to <0.106, the 0.106 mm to <0.250 mm, and the 0.250 mm to <0.500 mm size fractions of one offshore, one beach, and one riverbed sample were individually separated in order to identify any mineralogical partioning by size. Polytungstate, a nontoxic, water-soluble heavy liquid (specific gravity of about 2.8), was used in all heavy-mineral analyses.

Petrographic examination of selected heavy residues was complimented by energy dispersive X-ray analyses of constituent mineral species. DCP emission spectrometry (performed on a contractual basis by Nuclear Activation Services Limited) was used for total metal analyses of the

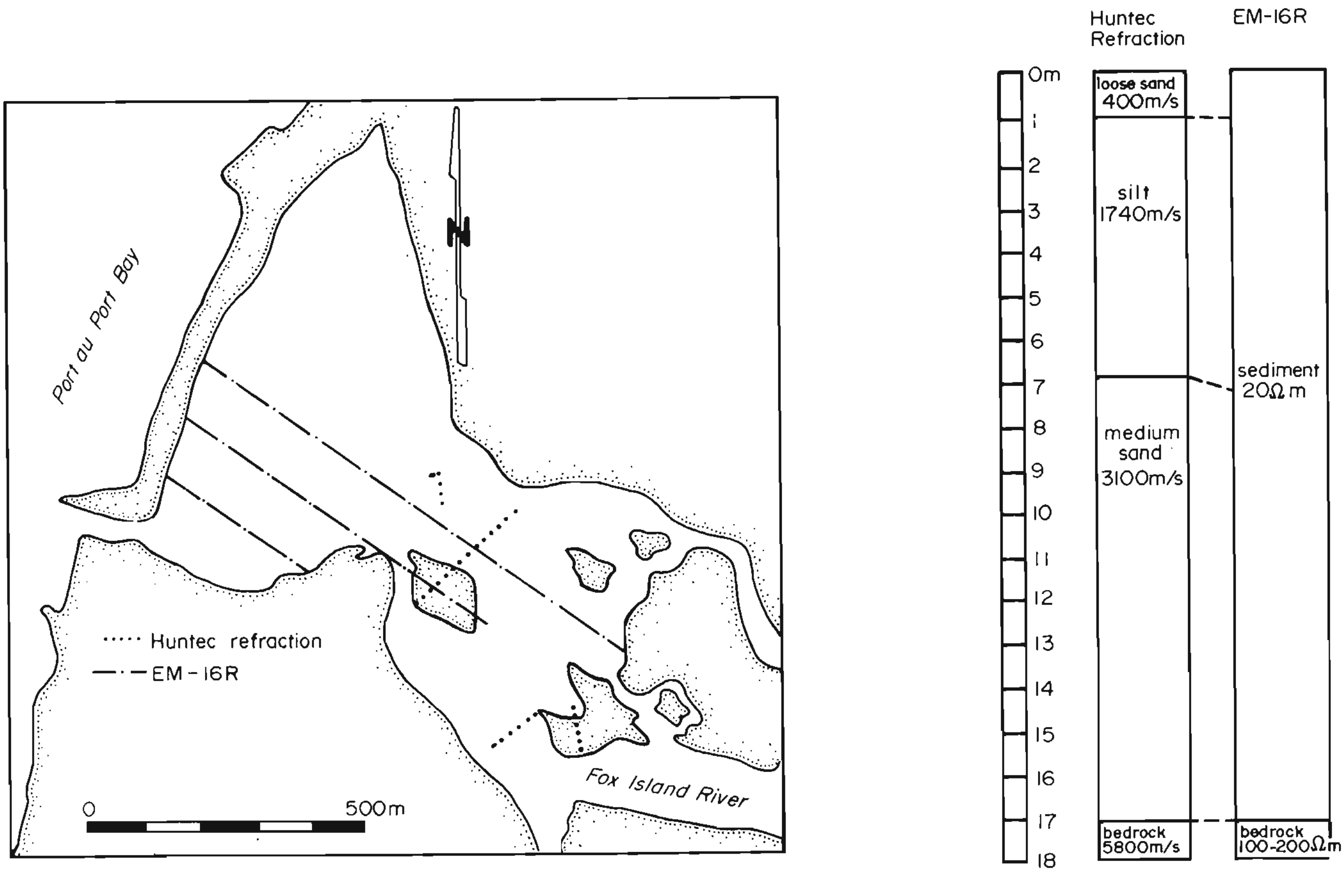

Figure 2. *Location and interpreted stratigraphy of the geophysical profiles; m/s is metres per second; Ω m is ohm-metres.*

sand (0.063 mm to 1.0 mm) fraction of 30 samples. Analyses of noble metals by ICP mass spectrometry is underway.

Results and Interpretation

Geophysics. Four stratigraphic horizons, as determined through graphic velocity calculations of seismic traces, were identified near the mouth of Fox Island River. An interpretation of sediment lithology (Figure 2), is based on velocity ranges for known sediment types. The resistivity data did not provide the necessary differentiation of sedimentary horizons, but did confirm the depth to bedrock.

Facies Characterization. The Fox Island River–Port au Port Bay system consists of three general depositional environments: offshore, beach, and river. Each environment is characterized by discrete facies types of which six have been delineated on the basis of textural character, *in situ* visual descriptions and spatial distribution; facies O1, O2, and O3 are found in the offshore zone; facies B1 and B2 characterize the beach deposits; and facies R1 characterizes Fox Island River sediments.

Facies O1 occurs in water depths >10 m (Figure 3). It consists of well-sorted, medium sand with <3 weight percent gravel and no clay or silt. Ephemeral current ripples and abundant sand dollars are present. Facies O1 is interpreted to represent modern marine sands undergoing active transport through the influence of waves and tidal currents.

Facies O2 is a poorly sorted, sandy gravel found in water depths ranging from <15 m to the intertidal zone (Figure 3). The sand component of this facies, ranging in content from 18 weight percent to 67 weight percent is generally entrapped within gravel–cobble interstices. Cobbles range up to 8 cm in diameter and are generally well-rounded. The gravel bed is inhabited by a variety of flora and fauna, suggesting overall gravel immobility. On this basis, facies O2 may be interpreted to represent a wave-reworked, lag deposit derived from glacial sediments.

Facies O3 is a well-sorted, medium sand which blankets gravel and cobbles (Figure 3). This facies is found in water depths of <3 m, and is restricted in occurrence to the lee side of a protruding subaqueous sand spit. This suggests deposition by longshore currents.

Facies R1 is found within the confines of the Fox Island River and is characterized by a surficial pebble–cobble lag armour with interstitial sands and isolated sand lenses. A general trend of decreasing boulder–cobble size downriver is observed with many local variations related to changes in

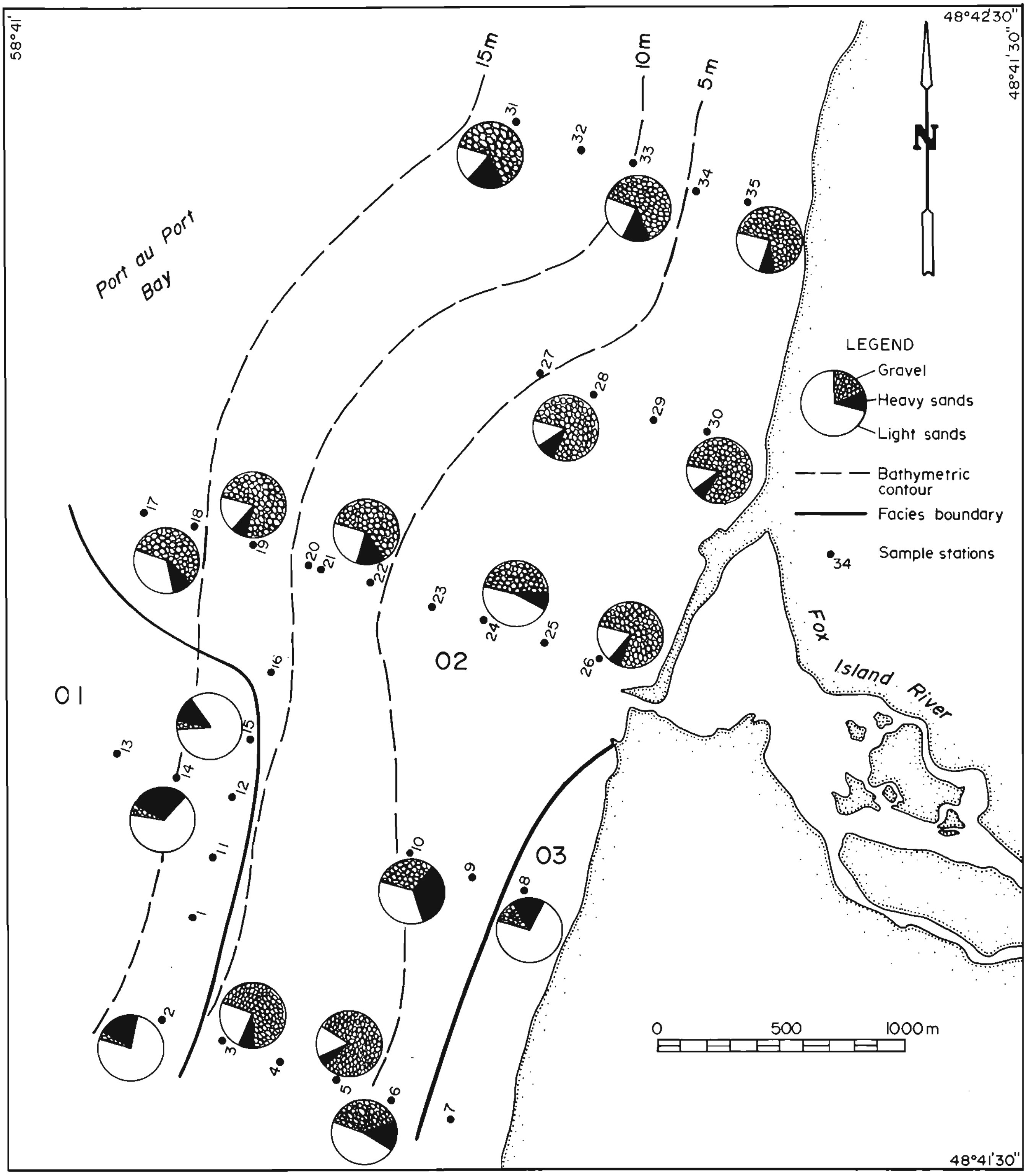

Figure 3. *Textural facies distribution and heavy-mineral abundances in east-central Port au Port Bay.*

bedrock lithology, presence of talus slopes and character of the incised glacial sediments. Grain-size distributions of the <4 mm size fraction vary unsystematically downriver. Near the mouth of the river, facies R1 is dominated by sands and gravels that form elongate bars with superimposed current ripples.

Facies B1 is characterized by unimodal, well-sorted supratidal sands. Facies B2 is defined by a moderately sorted, intertidal pebble armour.

Heavy Minerals. The heavy-mineral suite within the study area is mineralogically immature, consisting of, in order of decreasing abundance: opaques, garnet, pyroxene, amphibole, olivine, rutile, zircon, staurolite and epidote. Textural constraints on mineralogy include:

1) an increase in total heavy-mineral content with decreasing grain size,

2) an increase in the abundance of zircon and opaques with a decrease in grain size and,

3) a decrease in the abundance of olivine with a decrease in grain size.

Preliminary examination of the opaque minerals (through energy dispersive X-ray analysis) reveals an abundance of chromite (20-40 weight percent of the opaque minerals) followed by magnetite, ilmenite and minor sulphide phases. Cr_2O_3 content of the chromite varies between 35-55 weight percent.

The spatial variation of heavy-mineral concentrates within the sand fraction (0.063 mm to 1.00 mm) of the offshore, beach, and river facies is illustrated in Figures 3 and 4. Within facies R1 sediments, heavy-mineral abundances decrease downriver, probably reflecting both distance from source (Lewis Hills ophiolite) and increased dilutional effects of aggradational processes in the lower reaches of the river. In contrast, the upper river is dominated by erosional processes which serve to enhance heavy-mineral enrichment through entrapment of grains in gravel interstices (Figure 4).

The supratidal beach sediments (facies B1) are characterized by discrete heavy-mineral laminae with concentrations reaching 98 total weight percent (Figure 4). Heavy-mineral-rich laminae range in thickness from 2 mm to 10 mm and are separated by 10 mm to 100 mm of clean quartzofeldspathic sand. These heavy-mineral occurrences are typical of beach placers, and generally result from grain segregation within bedflow during wave backwash, and in this case, during storm events. Heavy-mineral concentrations within the intertidal zone (facies B2) are much less, averaging 18 weight percent.

The concentration of heavy minerals detected in one analyzed sample of facies O3 (see Figure 3) was 18 total weight percent. This concentration may have formed through either differential entrainment (i.e., selective transport of light grains resulting in a residual lag of heavy minerals) or selective grain settling. Facies O3 sands are present only as a very thin surface veneer.

Facies O2 sediments exhibit a large variation in heavy-mineral content, ranging from 4 total weight percent to 32 total weight percent. Anomalous concentrations of heavy minerals probably formed as a result of lag entrapment within gravel interstices. The cause of the unsystematic heavy-mineral distribution may be attributed to local variations in cobble–boulder size coupled with spatial variabilty in sediment supply.

Facies O1 exhibits the highest overall heavy-mineral content (excepting the supratidal beach) ranging up to 32 total weight percent. The operative enrichment process is probably differential entrainment through wave and tidal reworking.

Geochemistry. The relative concentrations of Cr, Fe, Mg and Ti in the sand fraction (0.063 mm to 1.00 mm) of select offshore and river sediments are listed in Table 1; normalized plots illustrating the spatial distribution of these elements are provided in Figures 5a and 5b. Several observations can be made:

1) Mg and Ti content in the river sediments reflect local changes in bedrock lithology; Mg decreases away from the Lewis Hills ophiolite, Ti increases downriver where volcanic and metasedimentary rocks predominate;

2) Cr content of the river and offshore sediments varies unsystematically and is spatially correlative with Fe, reflecting the high Fe and Cr content of spinels;

3) within the offshore sediments, all element concentrations are less variable (Table 1), reflecting more uniform enrichment processes and minimal primary source-related biases.

An analysis of a discrete heavy-mineral laminae within the supratidal beach zone (facies B1) assayed 67,000 ppm Cr, 130,000 ppm Fe, 40,000 ppm Mg and 5,200 ppm Ti. In contrast, a bulk sample from the intertidal sediment (facies B2) assayed 310 ppm Cr, 41,0000 ppm Fe, 45,000 ppm Mg and 1,600 ppm Ti.

DISCUSSION: A GENETIC MODEL FOR PLACER DEVELOPMENT

The distribution and preservation of heavy-mineral placer deposits is dependent on temporal variations in depositional environments and overall sediment availability. Exploration strategies for heavy-mineral placers in the present study area, and in glaciated terrains as a whole, require that genetic models be formulated to trace the dispersal path of placer minerals. For the purpose of the present study, a sequence of simplified conceptual models are presented in an attempt to trace the contemporaneous dispersal of chromite and

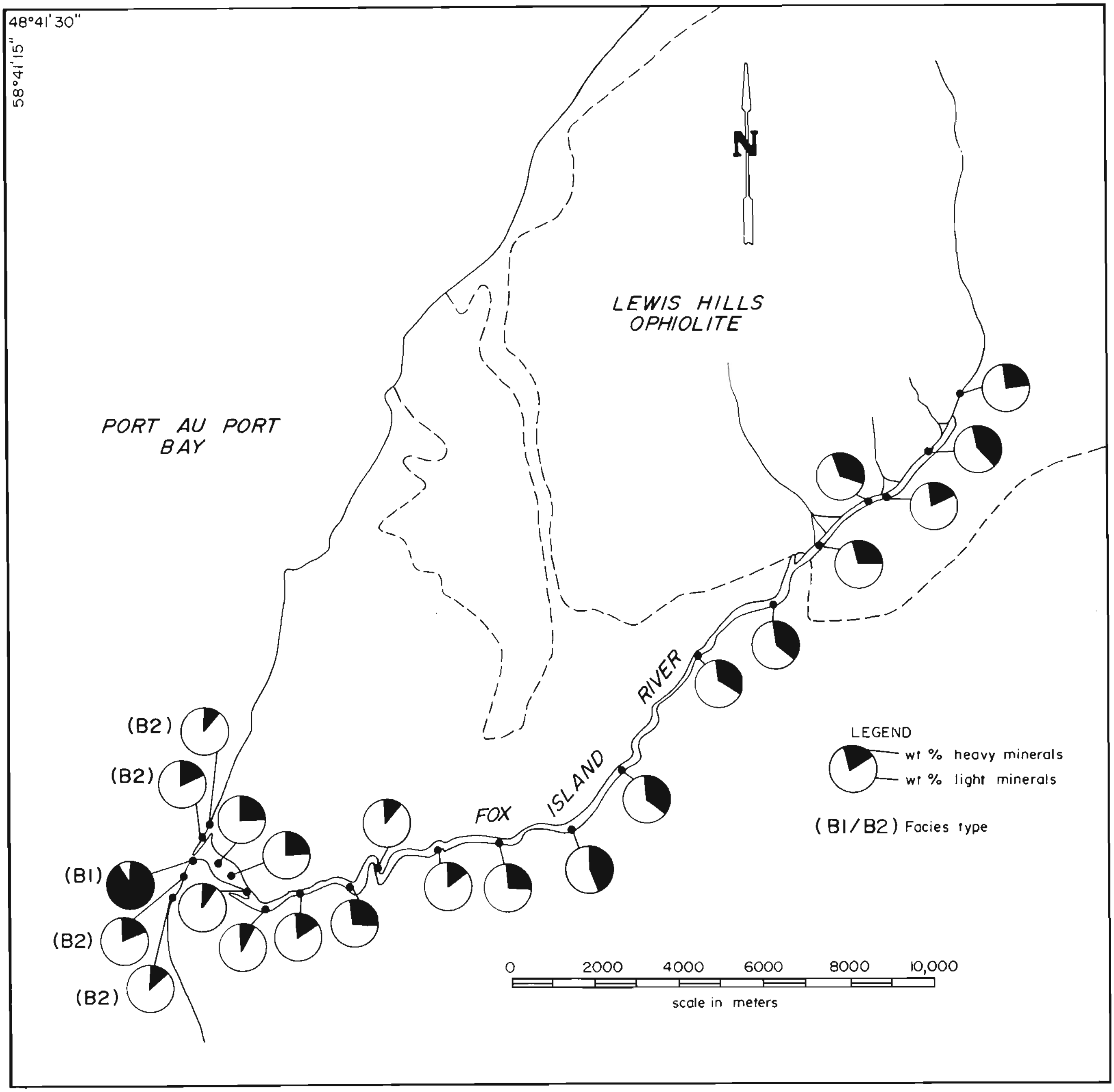

Figure 4. *Heavy-mineral abundances (0.065 mm to 1.00 mm sand fraction) in Fox Island River and the adjacent coastal beach.*

Table 1. Sediment geochemistry

	Cr		Fe		Mg		Ti	
	river	offshore	river	offshore	river	offshore	river	offshore
minimum (ppm)	750	1,800	48,000	44,000	62,000	52,000	30	1,000
maximum (ppm)	18,000	6,500	83,000	55,000	210,000	83,000	1,200	1,500
average (ppm)	5,000	3,583	59,867	49,500	139,733	67,917	481	1,266
C. V. (%)	87	38	16	6	40	15	96	16

C. V. – coefficient of variation

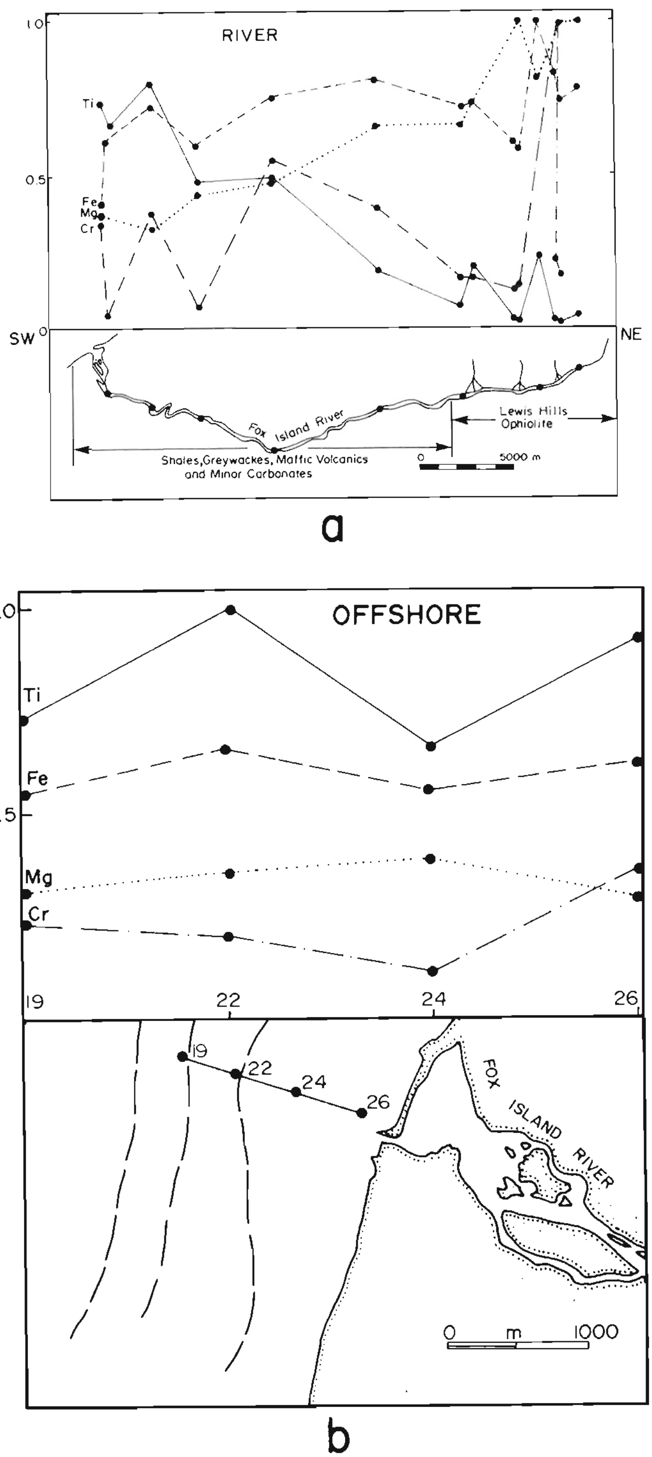

Figure 5. *Normalized plots of the spatial distribution of Ti, Cr, Fe and Mg, in Fox Island River (a) and in east-central Port au Port Bay (b).*

associated heavy minerals in both the fluvial (Figures 6 to 8) and coastal–marine (Figures 9 to 11) environments. The models are based primarily on reported glacial style (Brookes, 1974; Grant, 1977), sea-level history (Brookes *et al.*, 1985), observed field relations and initial sediment analysis as presented in this report. Model assumptions include:

1. the study area was characterized by alpine-style glaciation that was confined to the major trunk valley (as supported by the observed local dipsersal of pebbles and by the model proposed by Grant, 1977),

2. the maximum areal extent of late Wisconsin ice was near present coastal limits and occurred at approximately 14,000 yrs. B.P. (Grant, 1977),

3. the late Wisconsin relative sea-level maximum occurred at approximately 14,000 yrs. B.P. (Brookes *et al.*, 1985), and

4. relative sea-level minimum occurred at approximately 6,000 yrs. B.P. (Brookes *et al.*, 1985).

The conceptual models, presented in Figures 6 to 11, illustrate and describe the effects of deglaciation and isostatic rebound on the stratigraphy and placer potential of fluvial and marine deposits within the present study area.

CONCLUSIONS

The textural, mineralogical and geochemical character of the surficial sediments within Fox Island River and east-central Port au Port Bay reflect the spatial variability inherent in differing depositional environments and in the type and relative contribution of sediment sources (e.g., glacial, fluvioglacial, marine). An accurate assessment of the placer potential in the study area cannot yet be made due to limited sample coverage, incomplete sample analysis (particularly with respect to PGE) and the lack of information upon which estimates of grades and tonnages can be based. Mineral commodities of interest include chromite, platinum, aggregate and heavy-mineral byproducts (e.g., zircon, rutile). Based on the available data, the strongest heavy-mineral potential appears to be in the modern supratidal beach sediments where concentrations reach 98 total weight percent including approximately 7 total weight percent chromic oxide. Of further interest is facies O1 marine sands where modern concentrating mechanisms are operative and thick sand accumulations are likely to occur.

Potential zones of placer development and targets for further work may also include proglacial outwash bars, raised beach deposits and raised marine terraces. Modern fluvial placers are unlikely to occur in the upper river due to high-energy flooding and removal of most sand-sized sediment from the major trunk valley. Sediment in the lower river may contain isolated zones of placer enrichment, although none were identified in the present study.

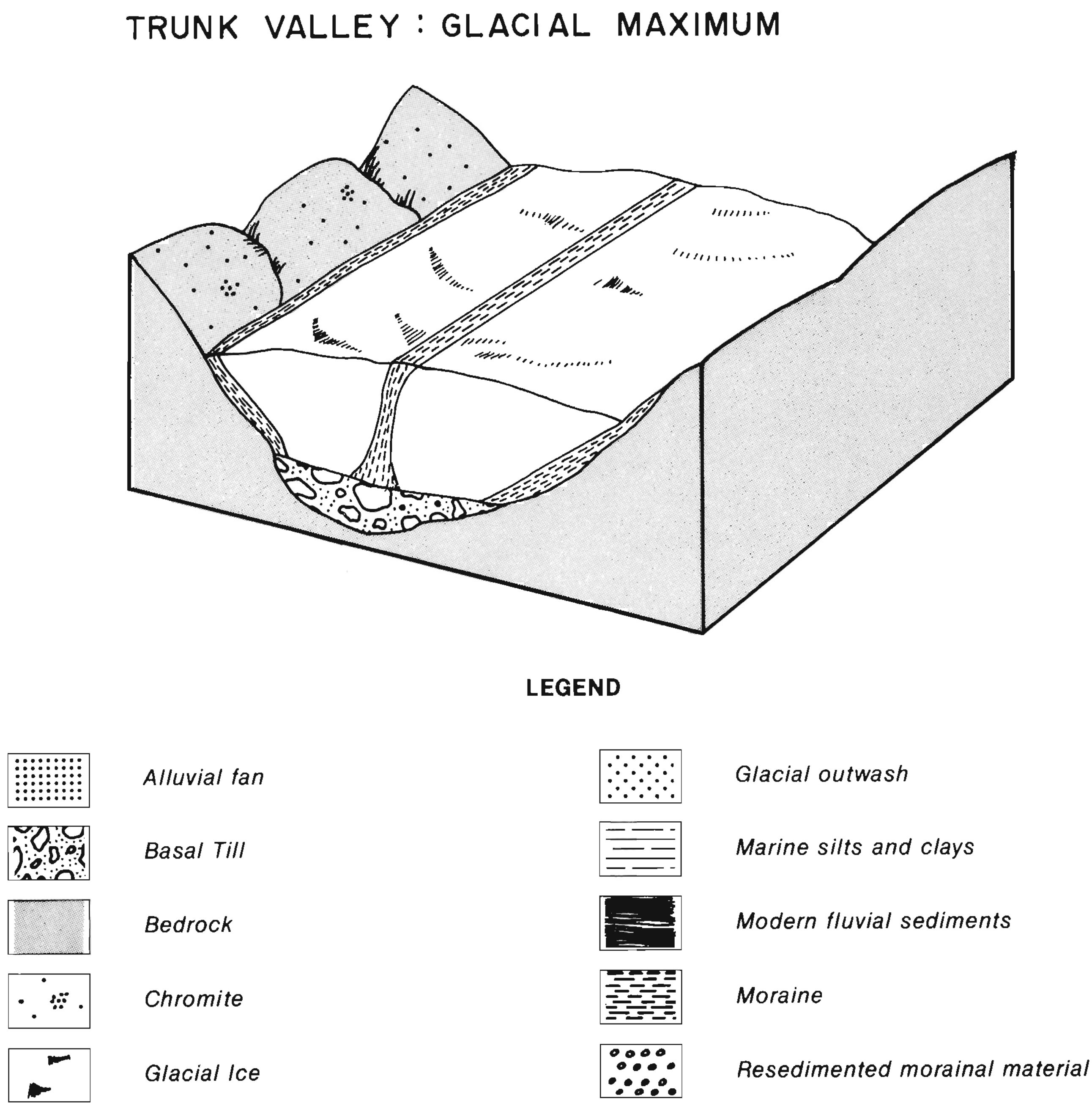

Figure 6. *Valley glaciation during the late Wisconsin (14,000 yrs. B.P.) characterized by ice scouring and dispersal of chromitiferous bedrock (i.e., the Lewis Hills ophiolite) and pre-existing sediment. Tills and morainal deposits formed. Placer deposits, if present, confined to basal tills and lateral moraines (where mutual attrition of particles is high) and occur close to source (e.g., New Zealand; Henley and Adams, 1979). Glacial tills and moraines commonly act as intermediate collectors providing ample low-grade material for postglacial reworking.*

TRUNK VALLEY: IMMEDIATE POST-GLACIAL

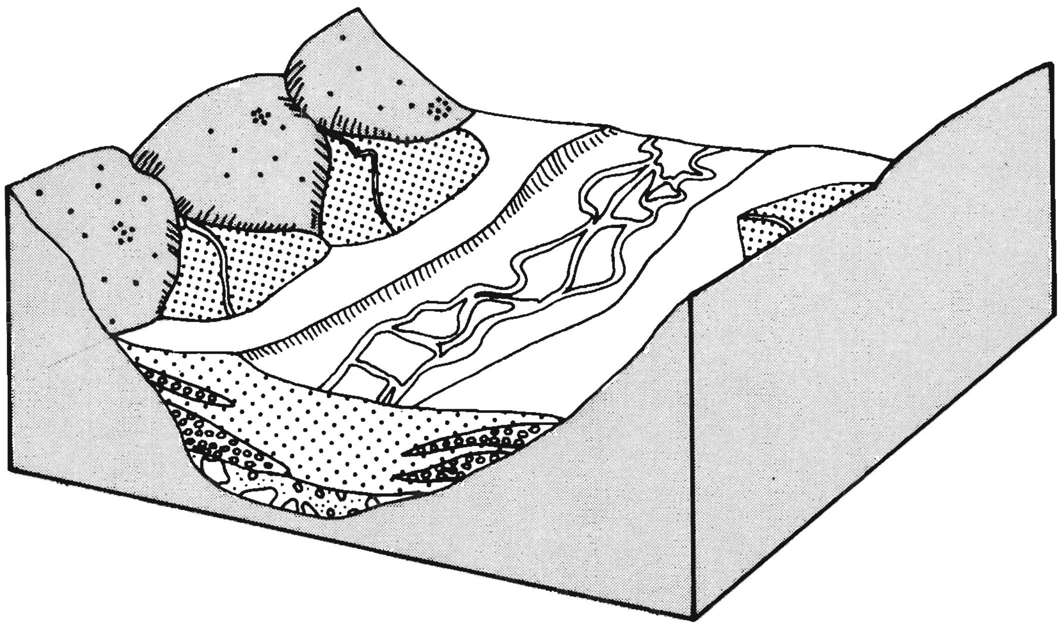

Figure 7. *Contemporaneous deposition of resedimented morainal material and glaciofluvial outwash as glacier recedes upvalley (about 14,000 yrs. B.P.). Sediment is rapidly aggraded with localized and probably very minimal sediment reworking. Placers are unlikely. (See Figure 6 for legend.)*

TRUNK VALLEY: PRESENT DAY

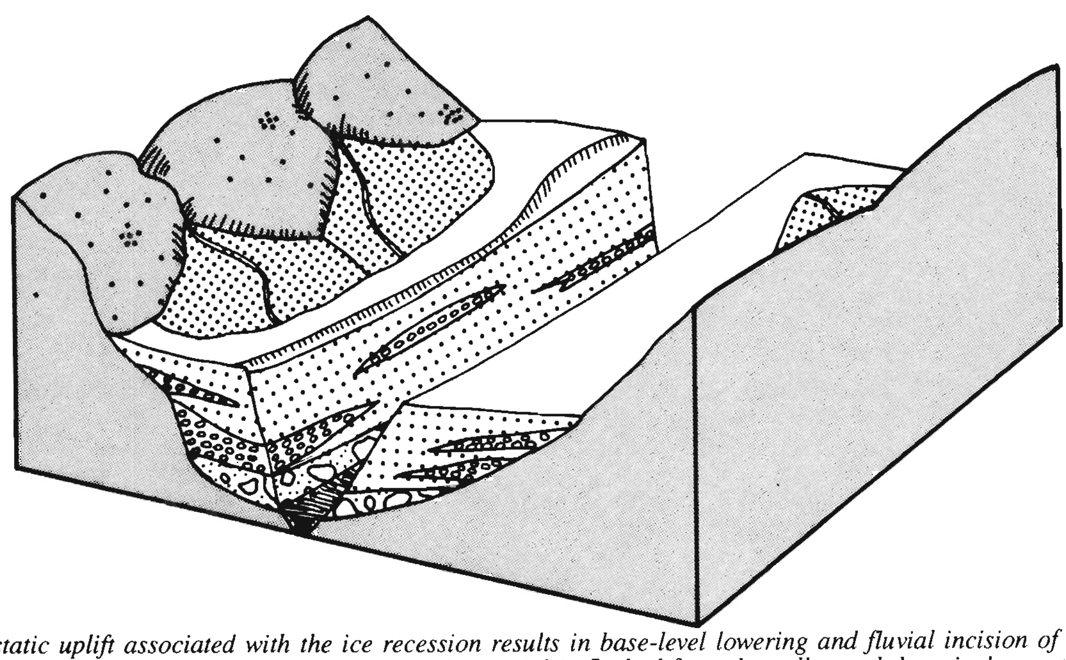

Figure 8. *Isostatic uplift associated with the ice recession results in base-level lowering and fluvial incision of aggraded glacial sediments (6,000 yrs. B.P.). Fluvially transported material is flushed from the valley and deposited near the mouth of the Fox Island River and in Port au Port Bay. Placer accumulations, if present, are localized and the product of either lag entrapment within gravel interstices, or selective grain settling in response to a marked decrease in flow velocity (e.g., pockets behind boulders). Large placer deposits are unlikely due to the overall paucity of sand-sized material. (See Figure 6 for legend.)*

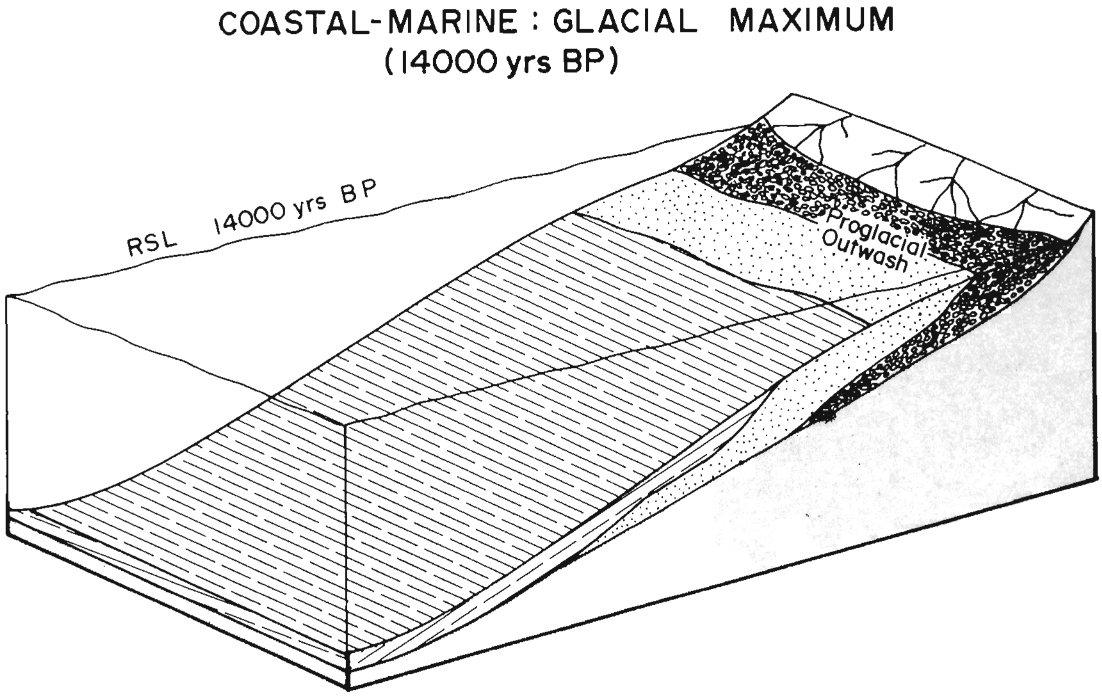

Figure 9. *Proglacial deposition and braid delta construction during the sea-level highstand (about 14,000 yrs. B.P.). Deposits generally fine downslope and fine upsection (as a result of a retreating glacial source) (cf. Miall, 1983). Some lateral variation (not illustrated) is expected as distributary channels migrate across the outwash front. Heavy-mineral enrichment within discrete sand facies may occur in submarine channels, in zones of wave reworking, and in subaerial outwash on the sandur face (e.g., Baffin Island; Emory-Moore, 1986). In general, sediments aggrade rapidly with limited opportunity for reworking. Placers will thus be low grade and not a prime exploration target. (See Figure 6 for legend.)*

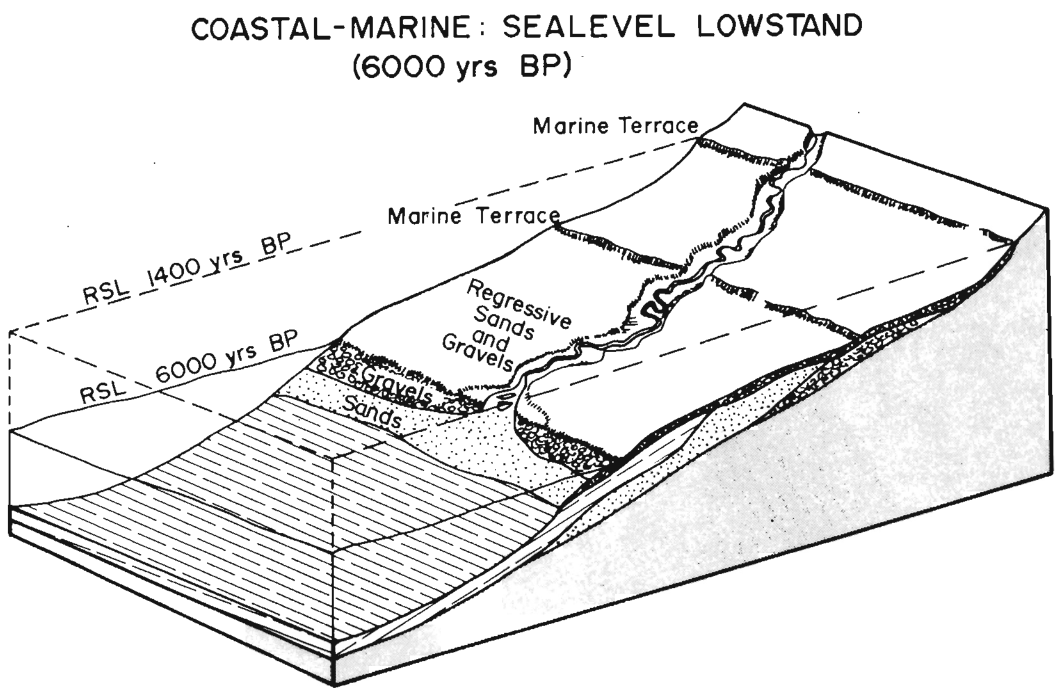

Figure 10. *Sea-level regression from about 14,000 yrs. B.P. to 6,000 yrs. B.P. with a lowstand at approximately 15 m below present sea level. Outwash deposits reworked to form a residual sand and gravel lag. Marine stillstands are marked by wave-cut terraces where heavy minerals may be locally enriched (e.g., Oregon, U.S.A.; Griggs, 1945). The relatively rapid rate of sea-level regression in the study area (approximately 0.75 mm per yr.) may have precluded the development of mature planation surfaces and associated placer deposits. (See Figure 6 for legend.)*

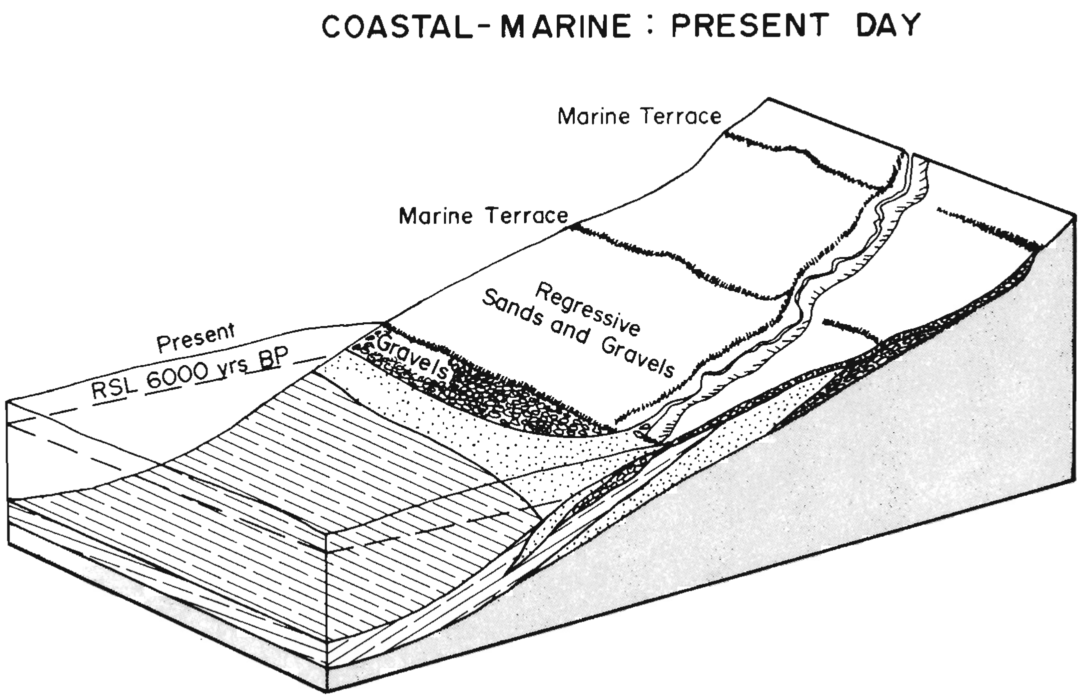

Figure 11. *A marine transgression from 6,000 yrs. B.P. to present with onlap of beach and offshore sands and gravels. Sediment sources include reworked proglacial outwash units and modern discharge from the Fox Island River. Wave and tidal reworking may selectively concentrate heavy minerals in the beach and offshore zones (e.g., Oregon, U.S.A.; Griggs, 1945 and northern British Columbia, Canada; Barrie* et al., in preparation). *(See Figure 6 for legend.)*

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