SURFICIAL GEOLOGY AND DRIFT EXPLORATION:

MAHATTA CREEK MAP AREA (92L/5)

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INTRODUCTION

In 1993, detailed drift exploration and surficial mapping was undertaken in NTS sheets 92L/6 (Alice Lake) and 92L/11 (Port McNeill) as part of an integrated resource assessment program defining the mineral potential of northern Vancouver Island (Panteleyev *et al.*, 1994; Bobrowsky and Meldrum, 1994). A similar, but independent study covering NTS sheet 92L/12 (Quatsino), was completed in 1991 (Kerr 1992; Kerr and Sibbick, 1992). This year, surficial mapping and till geochemistry sampling was extended into NTS 92L/5 (Mahatta Creek; Figure 1); an area supporting a number of mineral occurrences (Figure 2) and recent detailed bedrock mapping information (Nixon *et al.*, 1993a, 1993b).

- Surficial geology fieldwork in the Mahatta Creek map area represents the final stage of a drift program on the northern part of Vancouver Island. The objectives in this area are the same as those established in the surrounding sheets and include:
- Mapping surficial sediments and documenting the Quaternary geologic history.
- Completing a regional drift-exploration project focused on till geochemistry.
- Developing interpretive drift exploration models and products.

This paper reviews the mapping and till sampling procedures used in 92L/5, provides summary statistics regarding the drift sampling program and offers an interpretation of the Quaternary geologic history of the area based on airphoto analysis and ground truthing observations. Results of the till geochemistry sampling program will appear in a publication covering all four map sheets examined on northern Vancouver Island.

PHYSICAL SETTING

The study area lies on the west side of Vancouver Island and is surrounded on three sides by ocean waters: Brooks Bay to the southwest, Quatsino Sound to the northwest and Neroutsos Inlet to the

northeast. Coastal lowlands are dominated by glacially smoothed, joint and fault-faceted bedrock hillocks, ranging in height from 10 to 100 metres. Inland from coastal margins, much of the central and southeastern land area is a glaciated montane landscape with highly variable relief: the highest peak in the map area, Mount Wolfenden (1273 metres above sea level), lies only 3 kilometres from the shore of Neroutsos Inlet (Figure 2). Montane and lowland areas are incised by U-shaped valleys that drain to fjords such as Quatsino Sound, Neroutsos, Klaskino and Klaskish inlets. Valleys and fjords exploit regional northwest and northeast-striking faults.

Subaerial tuffs, basaltic to rhyolitic lavas and clastic sediments and limestones of the Lower Jurassic Bonanza Group cover much of the study area. These rocks are the principal host for local copper, molybdenum, lead, zinc and gold mineralization (Nixon *et al.*, 1993b). Up to three-quarters of the map area is presently mantled by a Quaternary drift of variable thickness.
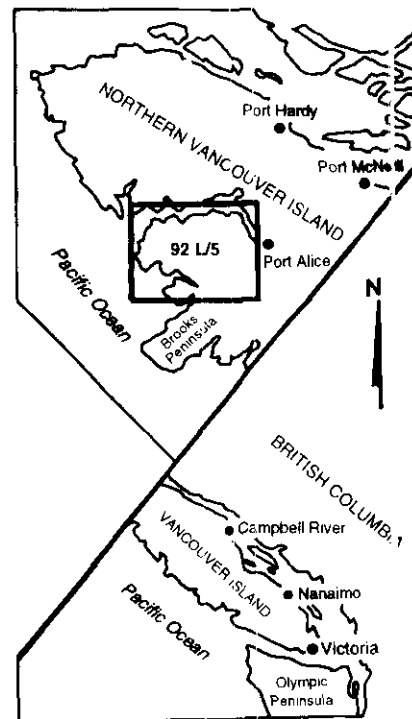

Figure 1. Location of the Mahatta Creek map area.

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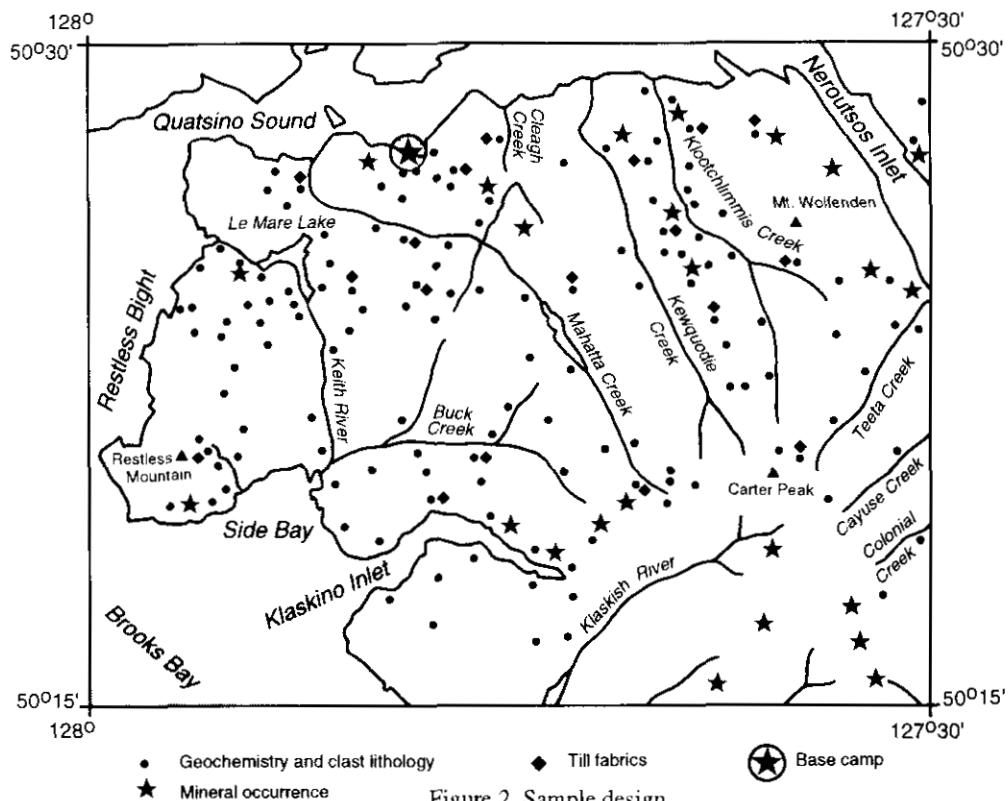| Symbol	Legend
●	Geochemistry and clast lithology
★	Mineral occurrence
◆	Till fabrics
⊛	Base camp

Figure 2. Sample design

METHODS

Fieldwork was based out of a camp established at the Mahatta River log sort, 65 kilometres west of Port Alice on the south shore of Quatsino Sound (Figure 2). Much of the map area was reached by logging roads using a four wheel-drive vehicle. Off-road access was gained by mountain bikes or on foot. Natural and culturally derived exposures such as road cuts provided the primary sampling source for surface and subsurface sediments. Where exposure was poor or lacking, shovel excavations were used to create new exposures.

Preliminary 1:50 000-scale surficial geological mapping and airphoto interpretation of the landforms was completed in the office before fieldwork commenced, using photo suites BC7711 and BC7714. Terrain units were classified as polygons according to the type of surficial material and surface expression. These criteria were coded using mapping standards detailed in Howes and Kenk (1988).

Verification of airphoto interpretation consisted of ground truthing observations at 143 field stations (Figure 2), which were located (UTM coordinates) with the aid a Trimble Navigation global positioning system (accuracy as good as ±30 metres). Elevations were determined using a Thommen altimeter, benchmarked to daily mean sea level at base camp (accuracy ±5 metres).

At each station, exposures were logged in detail using traditional Quaternary geology mapping techniques to document the nature, type and extent of the overburden cover (Figure 3). Observations included general exposure attributes such as depth to bedrock, depth of oxidation, surface expression, section height, length and number and type of facies. Specific characteristics of the various facies was also recorded and included information on the type of basal contact, texture, percentage of clasts and fines, clast shape, roundness and size, presence of striae, faceting and fabric, and presence of sedimentary and deformational structures (Table 1). Paleocurrent directions were determined in waterborne sediments from orientations of relict channels, cross-bedding and clast imbrication.

Undisturbed basal (lodgement) till matrix samples (1 to 5 kilograms per sample) were collected at 86 sites for geochemical analysis. Additional samples of ablation till, colluvium and glaciofluvial sediments were taken from 34 locations (Table 2). Sampling was restricted to the unweathered C-horizon which ranged from 0.5 to 9 metres below surface. Sediment samples were stored in heavy-mil plastic bags. In the laboratory, sediment samples were air-dried at 25-30°C for a minimum of 48 hours, then crushed and sieved to obtain a -230-mesh fraction. Seven duplicate field and ten laboratory split samples were integrated into the sample suite. Representative splits have been submitted for aqua regia inductively coupled plasma emission spectroscopy (ICP-ES) and instrumental neutron activation (INA) analysis.

Former ice-accumulation areas and limits of glaciation were identified from the distribution of cirques, glacial troughs and landforms such as moraines, and glaciofluvial deposits. Regional and local paleo-iceflow patterns were established by plotting the distribution of glacial troughs, roches moutonées and striae on the preliminary 1:50 000-scale surficial geology map. Additional paleo-iceflow data were derived from pebble fabrics measured in exposures of lodgement till.

At 18 locations, the trend and plunge of 50 prolate shaped clasts (at least 2 centimetres in length) was recorded. Two and three-dimensional statistics were generated from the measurements using Rosy™ and Stereo™ stereographic projection programs. Glacial transport paths will be further defined by the examination of clast provenance for 59 locations. Approximately 100 clasts were obtained from lodgement till exposures at these locations. Variations in pebble lithology frequency will then be integrated with facies analyses and inferred ice-flow directions to generate ice-transport and depositional models.

LITHOFACIES DESCRIPTIONS

The Quaternary cover ranges in thickness from less than a metre in upland areas and montane valleys to greater than ten metres in lowlands (Figure 3). Within this cover, eight lithofacies are distinguished, including four diamictons, and subordinate glaciofluvial, glaciolacustrine, fluvial and marine facies. Certain diamictons are primary indicator facies as they represent first derivatives of erosion and deposition (Shilts, 1993, 1994). As such, they can be confidently used in exploration for buried mineral occurrences (Bobrowsky and Meldrum, 1994). Other lithofacies have undergone secondary or tertiary resedimentation and are less reliable

indicators (Shilts, 1993). Quantitative data were collected mainly for diamicton and glaciofluvial facies and are summarized in Tables 1 and 2. Other subordinate facies descriptions are supplemented with qualitative observations.

FACIES A

Facies A comprises grey to olive-brown massive diamictons veneering or blanketing lowlands and montane valley sides between 600 to 880 metres above sea level. In these areas, facies A usually overlies striated or glacially streamlined bedrock (Figure 3, logs 2, 4, 5 and 6; Photo 1). Observed thickness for this facies ranges from 0.5 to 6.0 metres, with a mean of 2.4 metres based on 86 observations (Table 2). The facies is matrix supported, composed mainly of homogeneous, compact silt and clay (70% based on 86 samples); bedding-parallel fissility is found in 30% of samples. Clast content varies from 10 to 30%, and consists of subrounded, locally derived lithologies with occasional rounded exotic clasts (Table 1). Mean clast size generally ranges from 3 to 20 centimetres, but boulders up to 3 metres are found. Clast shapes range from prolate to equant, with a mean shape being bladed (Table 1). Approximately 95% of facies A deposits contain striated
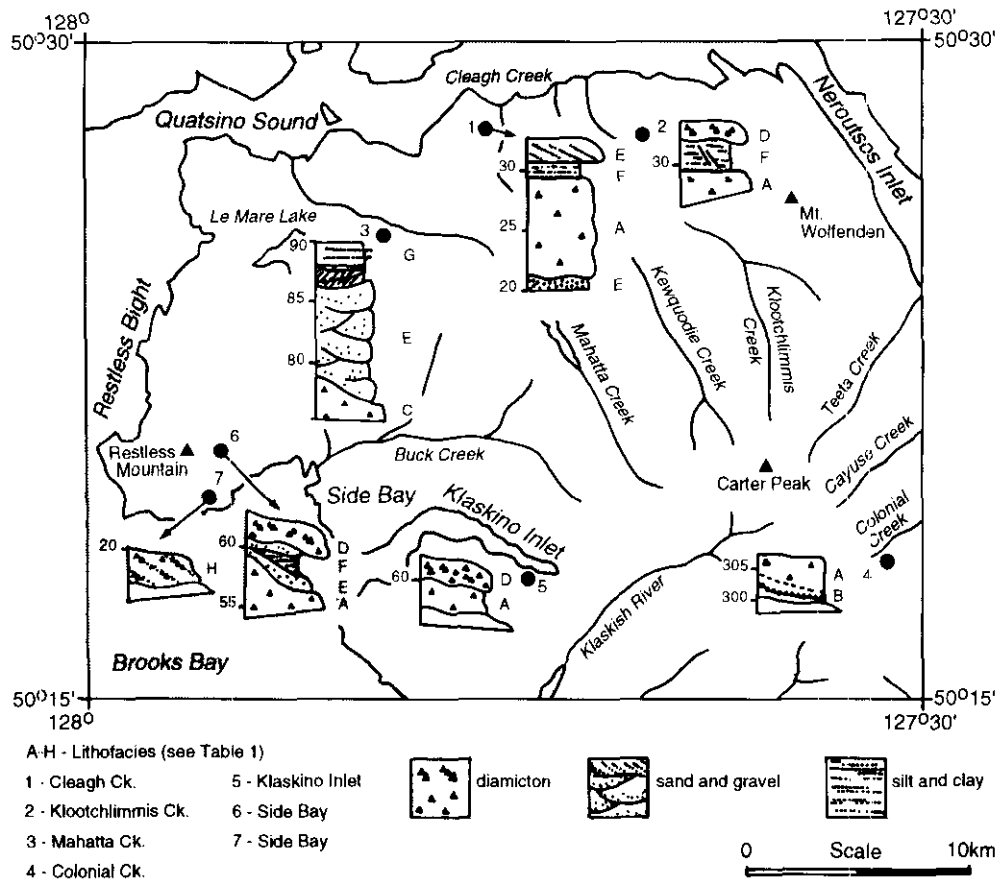

Figure 3.Simplified and selected stratigraphy (section elevations in metres above sea level)

TABLE 1: DRIFT SEDIMENTOLOGY AND GENETIC INTERPRETATION

Facies	Matrix Texture[a]	Matrix Structure[b]	Clast Content[c]	Clast Size[d]	Clast Roundness[e]	Clast Shape[f]	Genesis[g]
FACIES A	Matrix-supported	Massive	17	3	Subround	Blade	Lodgement till
FACIES B	Matrix-supported	Stratified	≈ 20	≈3	Subround	Blade	Basal melt-out till
FACIES C	Matrix-supported	Stratified	38	4	Subangular	Oblate	Supraglacial, or ablation till
FACIES D	Clast-supported	Massive	61	3	Subangular	Blade	Colluvium
FACIES E	Gravel and sand	Stratified	22	3	Round	Oblate	Glaciofluvial sediments
FACIES F	Silt and clay	Laminated	<1	<1	-	-	Glaciolacustrine sediments
FACIES G	Gravel and sand	Stratified	≈ 30	≈3	Round	Oblate	Fluvial sediments
FACIES H	Matrix-supported	Massive	≈ 40	≈3	Subangular	Blade	Marine sediments

a   Mean observed grain sizes and arrangement of clasts
b   Mean observed three-dimensional arrangement of contacts or internal discontinuities
c   Mean percentage clast content
d   Mean clast size in centimetres
e   Mean sharpness or degree of rounding of edge of clasts
f   Mean shape of clasts
g   Interpreted origin of facies

TABLE 2: DRIFT SAMPLE MEDIA AND STATISTICS

Facies Type	Bulk Sample[a]	Pebble Sample[b]	Drift Depth[c]	Oxidation Depth[d]	Sample Depth[e]
FACIES A	86	59	2.45	0.80	2.01
FACIES C	11	10	3.11	0.76	2.53
FACIES D	13	12	2.38	0.80	2.13
FACIES E	10	0	5.03	1.29	2.30
	Total = 120	Total = 81	Mean = 3.24	Mean = 0.91	Mean = 2.74

a   Number of geochemical samples collected
b   Number of pebble samples collected
c   Mean depth of sampled drift medium in metres
d   Mean depth of oxidation in metres
e   Mean depth of collection for geochemical sample

and/or faceted clasts. Prolate clasts display a moderate to strong preferred fabric in the direction of local paleoiceflow (see section on paleo-iceflow, below). Basal contacts are gradational where they overlie facies B, and erosional and sharp over all other deposits. Facies A deposits are interpreted to represent lodgement tills deposited at the base of active glacier ice (cf. Muller, 1983; Dreimanis, 1976; 1988).

FACIES B

Facies B are grey to olive-brown diamictons, locally preserved as veneers in leeside bedrock cavities found along montane valleys between 600 and 880 metres above sea level (Figure 3, log 4). This facies is found at three sites and is consistently overlain sharply by facies A (Photo 1). Observed thickness does not exceed 0.5 metre. Facies B diamictons are stratified and matrix supported. Matrices are composed predominantly of silt and clay (Table 1). Quantitative assessment of clast content and shape is lacking, as this facies was not included in the geochemical drift sampling program. However, general field observations suggest roundness and shape values similar to those observed in facies A, and clast provenance appears to be primarily of local origin. Diamictons comprising facies B are interpreted to represent basal melt-out tills (cf. Shaw, 1985), deposited through basal melting of stationary or stagnant glacier ice.

FACIES C

Grey to reddish brown, partly weathered diamictons, blanketing valley floors and overlying facies A or bedrock, characterize facies C (Figure 3, log 3; Photo 2). Basal contacts range from erosional (11 of 19 observations) to gradational (43%). Facies thickness averages 3.1 metres and ranges from 0.7 to 10.0 metres. Matrices are deficient in silt and clay, and display a wide textural and structural range, including massive matrix supported (42%) and stratified matrix supported (58%). Clast content varies from 35 to 65%, and consists predominantly of distally derived subangular to subrounded pebbles. Observed clasts range from 1 to 10 centimetres, with an average size of 4 centimetres (based on 11 samples; Table 1). Approximately 40% of the deposits observed contain striated or faceted clasts. Facies C diamictons are interpreted as supraglacial or ablation tills (cf. Dreimanis, 1988) accumulated by surface melting of ice in areas dominated by downwasting of stagnant ice (cf. Boulton and Eyles, 1979).

FACIES D

Facies D consists of weathered, olive to reddish brown diamictons found along steep valley margins, where they form blanket or fan-shaped deposits overlying bedrock and other sediments (Figure 3, logs 2, 5 and 6; Photo 3). Basal contacts are primarily erosional (8 of 13
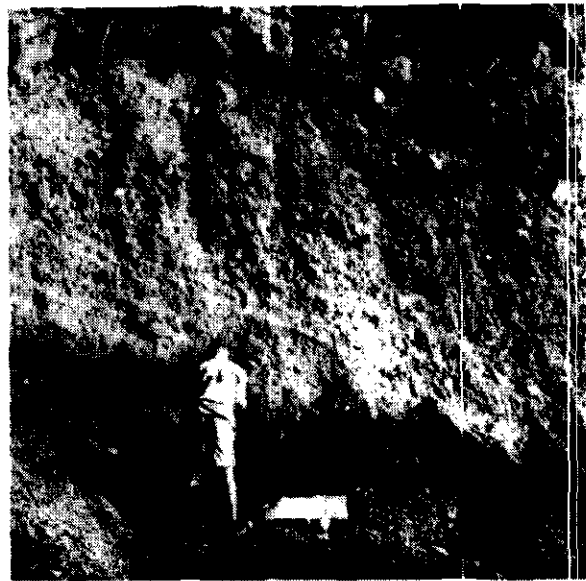

Photo 1. Stratified matrix supported diamictons typical of facies B (basal melt-out till) overlain by massive matrix supported diamicton characterizing facies A

observations), although gradational contacts are observed. Deposit thickness averages 2.4 metres for 13 samples, and ranges from 2.0 to 3.5 metres (Table 2). Diamicton matrices are deficient in fines, and have textures and structures ranging from stratified clast supported (14 %) to massive clast supported (86%). Relict structures (fissility, fabric, bedding) are locally preserved. Clast contents vary from 50% (stratified clast supported) to 80% (massive clast supported), with a mean content of 61% (Table 1). Mean clast size ranges from 2 to 5 centimetres, with a maximum of 80 centimetres. Facies D diamictons are interpreted as mass movement deposits derived from mechanically weathered bedrock, solifluction (cf. Eyles and Paul, 1983), and tills that have undergone direct, gravity-induced mass movement (cf. Lawson, 1988).

FACIES E

Facies E consists of gently undulating blankets of yellow to red-stained sand and gravel, confined to anomalous settings above or adjacent to contemporary valley floors (Photo 4). Deposit thickness exceed 10 metres (Figure 3, log 3). This facies may onlap or incise diamicton facies A, C or D (Figure 3, logs 1, 2 and 3). Where evident, basal contacts are predominantly erosional (8 of 10 observations) and channelized. Gravels are polymictic, with rounded clasts ranging from 1 to 6 centimetres in diameter. Sands are well sorted and often normally graded. Foreset, trough-cross, ripple-drift and laminar bedding are preserved in this facies and often indicate paleoflows counter to the present drainage direction. Normal faults are common along exposed flanks of deposits. Gravel and sand deposits of facies E are interpreted as ice-proximal glaciofluvial sediment (cf. Miall, 1977; Rust and Koster, 1984).

Photo 2. Massive matrix supported diamicton typical of facies C (ablation till).

Photo 3. Couplets of stratified and massive diamictons characterizing facies D (colluvium).

Photo 4. Exposed section of normally graded gravel and sand typical of facies E (glaciofluvial sediments). Sequence forms a terrace graded to 30 m above sea level along Mahatta Creek.

Photo 5. Rhythmically interbedded fine sand, silt and clay characterizing facies F (glaciolacustrine sediments). Facies F is truncated by late or postglacial debris-flow diamictons (facies D).

FACIES F

Facies F consists of grey to olive-green, rhythmically interbedded fine sand, silt and clay with dispersed clasts which are occasionally faceted and/or striated (Photo 5). Facies F deposits are confined to lower reaches of valleys where they disconformably overlie facies A. Upper contacts may be erosional or gradational, whereas lower contacts are always gradational At Klootchlimmis Creek (Figure 3, log 2), facies F is cross-cut by normal faults with displacements that rarelyexceed 10 centimetres. Fault planes are oriented parallel to valley sides, and indicate extension into valleys. Facies

F sediments are unconformably overlain by ice-contact sediment gravity-flow deposits (facies D; Photo 5). At Cleagh Creek (Figure 3, log 1) and Side Bay (Figure 3, log 6) profiles coarsen upwards through facies E into facies F. Maximum thickness does not exceed 3 metres. Dispersed clasts with penetrative structures are interpreted to represent dropstones in an ice-proximal setting (Brodzikowski and van Loon, 1991). Rhythmic bedding and other characteristics of facies F lend support to the interpretation that it was deposited in a glaciolacustrine environment (cf. Shaw, 1975; Catto, 1987).

FACIES G

Facies G comprises undulating blanket deposits of yellow-stained clast and matrix-supported sand and gravel, confined primarily to contemporary valley floors (Figure 3, log 3). The intercalated beds of sand and gravel occur in channel features incised into other types of deposits (such as facies E) or bedrock and do not exceed 5 metres in thickness. Interbed contacts range from sharp, erosional to gradational, whereas the basal contact of the facies is erosive. Clasts in the gravel component are rounded to well rounded with a mean diameter of approximately 3 centimetres; provenance is highly variable, which indicates derivation from a number of sources. The gravels are moderately to well sorted. The sand component is well sorted and normally graded. Foreset, trough-cross, ripple-drift and laminar bedding indicate flow direction similar to the present-day drainage (contrast with facies E). Facies G is interpreted as fluvial sediments deposited by braided or anastomosing streams (cf. Miall, 1977; Collinson, 1978).

FACIES H

Facies H consists of veneers or blankets of reddish stained, poorly sorted, matrix supported sand and gravel overlying bedrock platforms below 20 metres above sea level (Figure 3, log 7). The sediments are typically massive, but occasionally display crude coastward-dipping stratification. Clast content averages 40% and pebble lithologies are highly variable (Table 1). Facies H is interpreted as wave-reworked deposits (cf. Elliot, 1978).

GEOMORPHIC DESCRIPTIONS

LIMITS TO GLACIATION

Evidence of glaciation is absent or not preserved above 600 to 880 metres above sea level along interfluves in several parts of the study area (Figure 4). Characteristically, exposed bedrock appears to have undergone frost shattering rather than glacial streamlining or deposition. Features resembling gendarmes and tors are preserved along some ridges, for example between Carter Peak and Mount Wolfenden. On gentle slopes, bedrock is frequently draped by sediment gravity-flow deposits, resembling solifluction deposits or thin soils; glacial sediments are absent.

These observations suggest a stable surface elevation for ice cap development over the study area prior to deglaciation, and a minimum limit to glaciation (cf. Huntley and Broster, 1994). This limit probably varied from about 880 metres above sea level in the east and southeast to 600 metres elevation along the western seaboard (Figure 4), resulting in an ice surface gradient of approximately 2.3° (between Restless Mountain and Carter Peak). Ice thicknesses greater than 900 metres were attained by major ice streams occupying Neroutsos

Inlet and Quatsino Sound. Elsewhere, ice thickness averaged in the order of 670 metres in the eastern montane valleys to 520 metres in western coastal areas. During full glacial times, approximately 22 square kilometres (2% of the map area) may have been ice-free, 32% of which was the land area surrounding Mount Wolfenden.

GLACIAL LANDFORMS AND PALEO-ICEFLOW PATTERNS

Below 660 to 880 metres above sea level, all drainage basins show significant derangement through glacial erosion. Ice accumulation and erosion focused in the headwaters of all major valleys resulted in the formation of cirques, horns and arêtes. Cirque floors range from 300 metres above sea level near Restless Bight to 610 metres above sea level in the southeast part of the map area. This suggests that interior areas were primary ice-accumulation zones and coastal areas functioned as low-elevation tributary ice sources at later stages of glaciation. Most cirques are oriented north to northwest, although southeast of Klaskish and Teeta rivers, cirques face southwest or northeast (Figure 4).

All major valleys have a prominent U-shaped morphology, suggesting they accommodated glaciers at sometime in their past. Although pre-late Wisconsinan sediments were not observed, the well developed nature of the valleys argues for repeated glacial erosion focused along structural features such as faults. Regional paleo-iceflow was directed along northwest and northeast-oriented fault-controlled valleys (Figure 4). South of latitude 50°21' N, ice generally flowed to the southwest toward Brooks Bay, whereas north of this latitude, ice flowed into Quatsino Sound. Roches moutoneés and striae are ubiquitous and consistently indicate down-valley ice flow along montane reaches of valleys. Paleo-iceflow along Klaskino Inlet and Klaskish River was west and southwest, respectively. In contrast, ice flowed northeast along Teeta, Cayuse and Colonial creeks. Northwesterly ice flow was restricted to Mahatta, Kewquodie and Klootchlimmis creeks. An exception to this pattern occurs near Le Mare Lake, where paleo-iceflow was directed southward along Keith River into Side Bay. In summary, directional landforms indicate that early ice-flow was controlled by valley orientation, but as ice thickened, glaciers were no longer confined and spilled out over coastal lowlands and valley divides.

Clast fabric and striae orientation data (Table 3) provide other paleo-iceflow information. Mean vectors for two-dimensional and three-dimensional fabric data predominantly cluster in an up-ice direction (Table 3). This is consistent with expected fabrics in lodgement tills as clasts become aligned parallel to upward-directed ice-flow lines below the equilibrium line altitude (cf. Dowdeswell and Sharp, 1986). Exceptions to this rule occur in tills deposited in cirque basins (field stations 9 and 43; Table 3). Here, clast fabrics cluster subparallel to
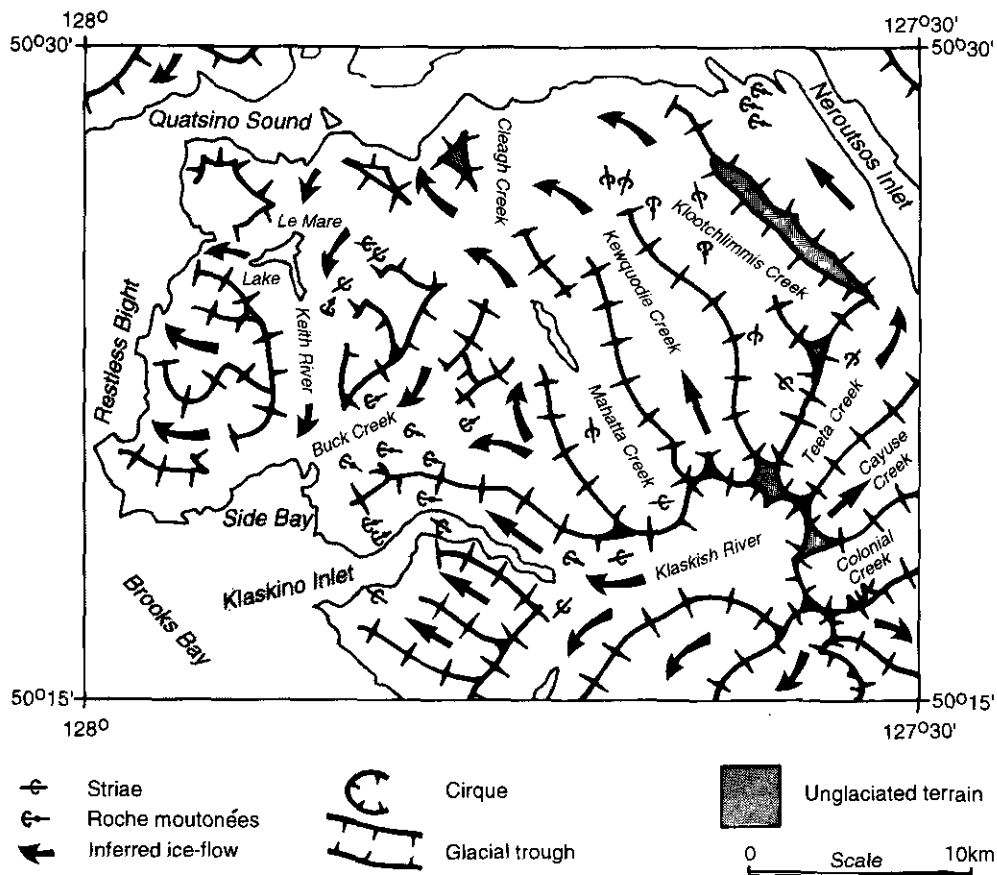
Figure 4. Paleo-iceflow patterns

the direction of ice flow and presumably reflect clast alignment with respect to downward-directed ice-flow lines. In areas of expected divergent flow (field stations 49, 53, 65 and 76; Table 3), fabrics tend toward a girdle distribution.

MORAINES

Gently undulating ground moraine was deposited ubiquitously over lowland areas and valley sides. The morainal sediments consist of lodgement (facies A) and melt-out till (facies B). In areas of high to moderate relief, and on steep slopes, morainal blankets are rare or extensively reworked by deglacial and postglacial mass-movement processes (facies D). Along valley floors, ablation till (facies C) and ice-contact sediments (facies E) form isolated patches of hummocky ground moraine and glaciofluvial deposits. These landform assemblages are indicative of an ice-retreat history characterized by stagnant ice conditions, with dead ice confined to valley floors (cf. Fulton, 1991).

Approximately 1 kilometre upstream from the mouth of Klootchlimmis Creek, a ridge 30 metres high forms a barrier between the coastal lowland along Quatsino Sound and higher ground to the south. Postglacial fluvial incision has revealed a complex interior, composed of lodgement till and ablation till that moraine for a glacier lobe that occupied Klootchlimmis is partly draped down-valley by colluvium and glaciofluvial sediments. Ridge morphology, position and facies

association suggest that it may represent a terminal valley, or an interlobate moraine formed between ice in Quatsino Sound and Klootchlimmis Creek.

GLACIOFLUVIAL AND GLACIOLACUSTRINE LANDFORMS

Relict glaciofluvial landforms are graded to local paleo-baselevels at 210, 152, 90, 60 and 30 metres above sea level. In upland reaches of valleys, deglacial kame terraces, till and bedrock-walled meltwater channels have profiles graded to 210 and 152 metres above sea level (Figure 5A). Kames and channels locally form landform assemblages with eskers and hummocky ground moraine and are implicitly deglacial ice-contact forms. The above observations suggest two early stages of stable ice margins in upland areas during deglaciation.

Incised remnants of broad, gently undulating plains form paired terraces in lower valley reaches. Terraces have steep, long profiles ranging from 0.6° (Mahatta Creek) to 3.2° (Teeta Creek), and are interpreted as portions of a relict network of glacial spillways graded to a relative base level 90 metres above sea level. Foresets, ripples and clast imbrication in glaciofluvial sediments indicate paleoflows directed to outlets at Side Bay, Klaskino Inlet, Klootchlimmis and Cleagh creeks. Terraces are absent along Quatsino Sound and Side Bay, suggesting that meltwater drainage was facilitated by supraglacial channels formed on remnant glacier lobes in these areas. The 90-metre base level was

TABLE 3: PALEO-ICEFLOW DATA

| Field Station	Easting	Northing	Facies[a]	Data Type[b]	Mean Vector[c]	E1[d]	E2[d]	E3[d]	Inferred Paleoflow[e]
2	595400	5585600	A	3D	160 / 12	0.70	0.22	0.08	NW
9	602500	5580250	A	3D	278 / 01	0.61	0.31	0.08	NW
18	593250	5590630	A	3D	161 / 04	0.55	0.32	0.12	NNW
29	595570	5575730	A	3D	065 / 09	0.56	0.30	0.14	WNW
39	586190	5575520	A	3D	097 / 08	0.65	0.30	0.04	WNW
43	601370	5579220	A	3D	100 / 08	0.56	0.34	0.09	NE
49	584790	5583560	A	3D	020 / 12	0.48	0.42	0.10	SW
53	583670	5588390	A	3D	030 / 06	0.50	0.41	0.08	W / HW
65	589300	5589090	A	3D	154 / 06	0.50	0.43	0.06	W / SE
76	579930	5583540	A	3D	104 / 00	0.52	0.41	0.07	S
98	580350	5588640	A	3D	002 / 09	0.55	0.36	0.09	SW
114	576450	5577390	A	3D	055 / 18	0.63	0.31	0.06	S
126	588710	5577600	A	3D	047 / 13	0.62	0.27	0.11	WSW
131	581220	5584800	A	3D	058 / 16	0.76	0.17	0.07	SSW
137	593520	5587710	A	3D	142 / 03	0.69	0.23	0.08	NW
141	585510	5589110	A	3D	146 / 14	0.68	0.26	0.05	NNW
15	596550	5591540	A	2D	090	-	-	-	NW
33	589110	5586650	A	2D	114	-	-	-	NW
3	593770	5586560	R	Striae	232	-	-	-	SW
23	596730	5586520	R	Striae	314	-	-	-	NW
76	579930	5583540	R	Striae	126	-	-	-	SE
131	581220	5584800	R	Striae	202	-	-	-	SSW
137	593520	5587710	R	Striae	320	-	-	-	NW

a   Facies sampled: A - lodgement till; R - bedrock

b   Type of data collected at site: 3D - equal-area lower-hemisphere plot of dip direction and plunge   of prolate clast long axes (n = 50); 2D - directional circular-frequency plot of prolate :last long axis (n = 50); Striae - glacially striated bedrock surface

c   Mean trend and plunge of data set (n = 50)

d   Eigenvectors E1 - E3: E1 > E2 > E3- single area of point concentration on the sphere;   E1=E2>E3 - girdle distribution where points lie on a great circle trace; E1=E2=E3 - uniform distribution.

e   Paleoice-flow determined from directional glacial landform (U-shaped trough, roche moutonée)

possibly controlled by ice confined to Quatsino Sound and Side Bay, as well as the lowest reaches of Mahatta, Koskimo and Cleagh creeks, and suggests a third stable elevation for the ice surface during deglaciation (Figure 5B). Below 90 metres elevation, glaciofluvial sediments and colluvium prograde over, or truncate locally deformed glaciolacustrine sequences (Photo 5). In the southeast, incised glaciofluvial and lake deposits are graded to 60 metres elevation, whereas in the northeast, including Cleagh and Klootchlimmis valleys, sequences are graded to 30 metres above sea level. Sediments are interpreted as being deposited in lakes dammed by remnant ice and morainal deposits at valley confluences (Figure 5C). Deformation is implicitly related to postglacial incision of deglacial sediments and slumping into contemporary valley axes. The 60 and 30-metre base

levels represent two final stable ice-retreat surfaces prior to full deglaciation (Figure 5D).

POSTGLACIAL LANDFORMS

At Restless Bight, Side Bay and Quatsino Inlet, distinctive plains are formed at about 20 metres above sea level. Here, glacial sediments have been extensively reworked and locally display crude coastward-dipping stratification. The plains are interpreted as wave-cut platforms and indicate a maximum postglacial incursion to 20 metres above sea level in this area. Inland, glacial deposits have been extensively remobilized, and postglacial fan aprons and debris flows are ubiquitous Although some remobilization implicitly occurred during the paraglacial stage of deglaciation (cf. Church and
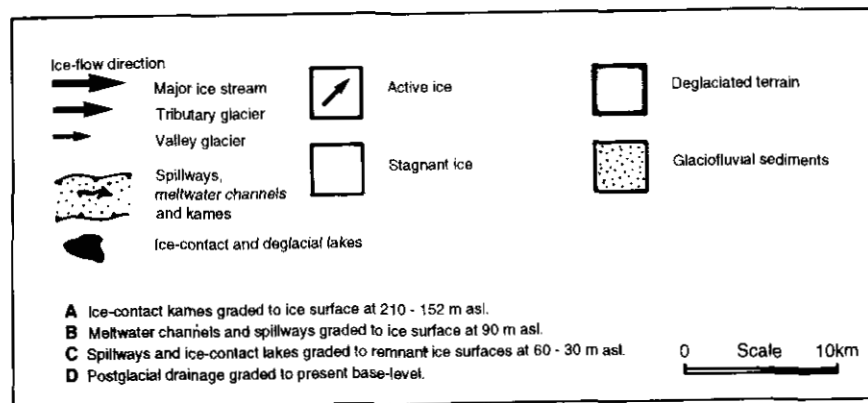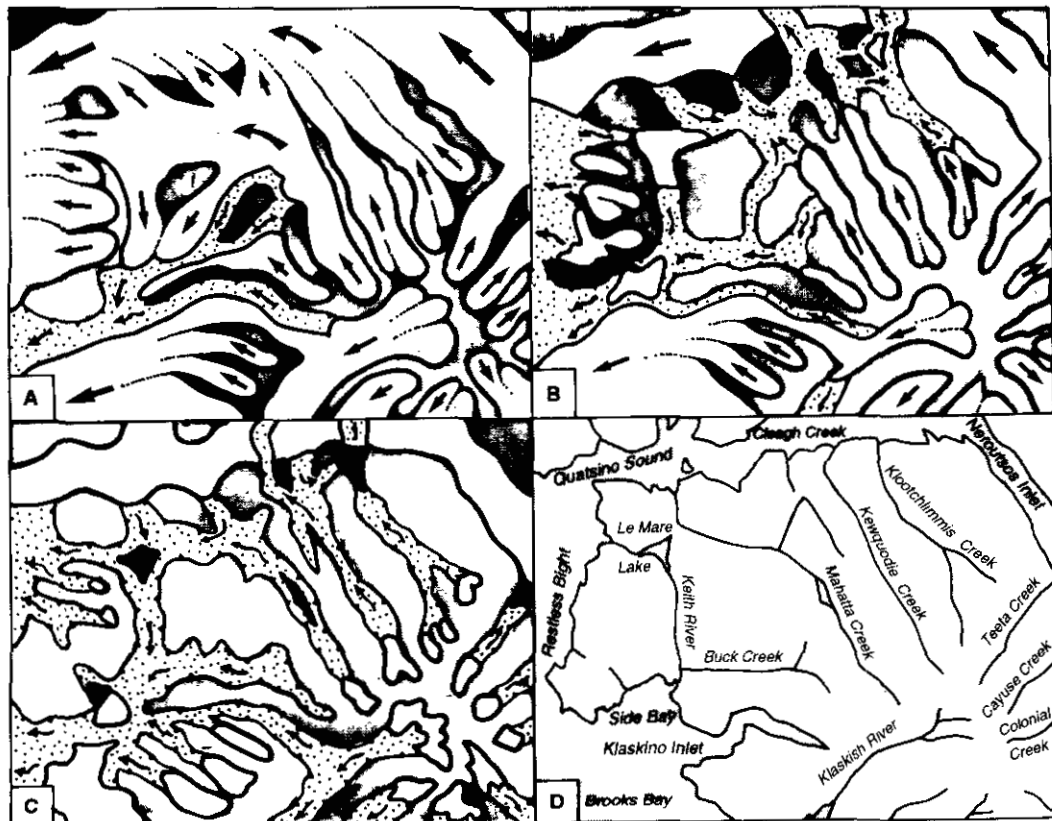
Model of deglaciation for the Mahatta Creek map area.

Ryder, 1972), recent slides are attributed to local farming practices

REGIONAL GLACIAL HISTORY

Howes (1983) recognized two tills separated by glaciomarine silt, ^{14}C dated at 20 600±330 years BP (GSC-2505) on northern Vancouver Island. The tills indicate two glaciations probably correlative to the early Wisconsinan Muchalat River drift (Howes 1981) or Dashwood drift (Alley, 1979) and a later advance (Port McNeill till) correlated with the Fraser Glaciation. Olympia nonglacial interval sediments are not found in the area, suggesting that materials were deposited in transient sedimentary environments (Howes, 1983).

With the onset of climatic deterioration at the end of the Olympia nonglacial interval, ice accumulated in the Coast Mountains and montane areas of northern Vancouver Island. Westward-flowing glaciers from the Coast Mountains entered the Strait of Georgia and Queen Charlotte Strait, reaching a maximum thickness of about 2000 metres (Clague, 1983). Over northern Vancouver Island, mountain ice caps fed a system of glaciers confined to major valleys (cf. Davis and Mathews, 1944) and ice thickness probably did not exceed 750 metres (Howes, 1983). Glacier advance was also marked by glacio-eustatic lowering of sea level up to 100 metres near Port Hardy (Clague et al., 1982; Howes, 1983) and glacio-isostatic depression of land surfaces of up to 100 metres north of Cape Scott (Luternauer et al., 1989). By

20 600±330 years BP, glaciomarine silts were deposited in front of advancing ice margins. These sediments are probably contemporaneous with the ubiquitous Quadra sand exposed throughout much of the Strait of Georgia. At about 15 000 years BP, Vancouver Island glaciers coalesced with Coast Mountain ice; an event marked by the widespread truncation of glacier advance sequences and deposition of Port McNeill till.

Climate warming began around 13 630±310 years BP (WAT-721), and resulted in ice stagnation as glaciers were cut off from source areas (cf. Fulton, 1991). Thus, the Fraser Glaciation maximum lasted for approximately 7000 years. Supraglacial (ablation) till and glaciofluvial sediments were deposited during ice retreat. At this time, terrestrial deglacial sediments were deposited as much as 95 metres below present sea level (Luternauer et al., 1989). Raised deltas, beach deposits and strand lines at 90 and 20 metres above sea level suggest a marine transgression as part of the postglacial cycle (Howes, 1983). The latter deposits were eventually exposed through rapid crustal rebound during the early Holocene (Luternauer et al., 1989).

LOCAL GLACIAL HISTORY

Geomorphic and lithostratigraphic evidence accumulated in this study suggests that sediments and landforms in the Mahatta Creek map area are products of the late Wisconsinan Fraser Glaciation. This does not preclude the existence of older deposits; rather, pre-Fraser Glaciation landforms and sediments were probably modified or eroded during the final glaciation.

The advance stage of the Fraser Glaciation was marked by ice accumulation in cirques and the formation of isolated mountain ice caps on major peaks in the east-central part of the map area. South of latitude 50°21' N, glaciers flowed west to southwest, whereas north of this latitude, paleo-iceflow was north to northwest (Figure 4, Figure 5). Exceptions to the regional flow directions occurred along Teeta, Cayuse and Colonial creeks where northeast flow occurred, and around Le Mare Lake where ice flow was to the south (Figure 4). Divergent flow occurred as montane valley glaciers entered lowland and coastal regions. By the glacial maximum (circa 15 000 years BP), valley glaciers were confluent with large west-flowing ice streams occupying Quatsino Sound and Klaskino Inlet. These glaciers probably formed a large piedmont apron as they flowed over Brooks Bay (cf. Luternauer et al., 1989). At this time, a stable surface elevation for ice cap development varied from 880 metres above sea level in the east to 600 metres above sea level along the western seaboard. Ice thickness greater than 900 metres was attained by major glaciers occupying Neroutsos Inlet and Quatsino Sound. Elsewhere, ice thickness ranged from 670 metres in eastern montane valleys to 520 metres in western coastal areas. During full glacial conditions, approximately 2% of the map area was ice-free.

In front of advancing ice margins, glaciofluvial sediments were deposited along valley floors. Much of the evidence for these deposits has been removed by subsequent glaciation. However, observed deposits at Cleagh Creek, for example, are presumed to be correlative with Port McNeill advance sediments (cf Howes, 1983). In most areas, glacially streamlined bedrock is directly overlain by Fraser Glaciation lodgment or basal melt-out till. The tills form extensive ground moraine cover over much of the study area Above the glacial limit, bedrock was subject to frost shatter, producing localized solifluction deposits and talus.

At the start of deglaciation, the altitude of the local equilibrium line rose above the maximum elevation of the area (cf. Fulton, 1991). In coastal areas and lower valley reaches, glaciers were isolated from source areas and downwasted in situ. This resulted in deposition of hummocky ground moraine comprising ablation till. Kames, eskers, terraced spillways and meltwater channels formed near to these moraines and indicate a complex pattern of ice retreat. Meltwater drained first to outlets at Side Bay, Klaskino Inlet, Klootclimmis and Cleagh creeks, and then by supraglacial channels formed on remnant glacier lobes in Quatsino Sound and Side Bay to ice-free areas of the continental shelf. Glaciofluvial and glaciolacustrine deposits were graded to local base levels at 210, 152, 90, 60 and 30 metres elevation. Base levels relate to five progressively lower, stable ice-surface elevations during retreat (Figure 5A-D), and not marine incursion limits attributed to glacio-isostatic depression (cf. Howes, 1983; Luternauer et al., 1989).

In coastal regions, glacio-isostatically depressed areas were inundated to a maximum depth of 20 metres above sea level. In these areas, glacial and deglacial units were locally reworked and subsequently exposed by rebound during the Holocene. Terrestial glacial sediments on slopes were extensively remobilized and redeposited. Elsewhere, glacial deposits were modified in situ through pedogenesis. Where underlying geology is dominated by acidic Bonanza Group volcanics, podzols with distinctive aluminum and iron-rich B-horizon hardpans developed (Bobrowsky and Meldrum, 1994). Fluvial deposits of variable thickness were deposited along most valley floors, and overlie most older units. Organic deposits are rare and restricted to poorly drained depressions along valley floors.

CONCLUDING REMARKS

Fieldwork and findings in this paper present the final field component of a drift exploration program on northern Vancouver Island. Although detailed geochemical and lithological sampling was undertaken, data interpretation remains outstanding. Combining information from detailed logging, mapping of sediments, and paleoice-flow patterns will provide a powerful interpretative tool for these data.

To facilitate future drift exploration, we have ranked Quaternary deposits described in this paper according to their potential utility for geochemical and lithological sampling (cf. Bobrowsky et al., 1994; Proudfoot et al., 1994; Table 4). Lodgement till (facies A), basal melt-out till (facies B) and some colluvium

TABLE 4: DRIFT SAMPLING MATRIX

Drift Sampling Category[a]	I	II	III	IV	V
Terrain Unit[b]	R Mv Cv	Mb Cb Cv/M	Mx Cx Mh/M	FG F	LG W
Facies Unit	A B D	A B D	A B D C/A	E G	F H
Drift Thickness	< 1 m	> 1 m	< 10 m	< 10 m	< 10 m
Transport Distance	10s of metres	10s to 100s of metres	10s to 100s of metres	10s to 1000s of metres	10s to 1000s of metres
Derivative Phase	1st	1st	1st 2nd	2nd 3rd	3rd 4th
Genetic Interpretation	Very Easy	Easy	Moderate	Difficult	Very Difficult
Geochemical and Pebble Sampling Interpretation	Very Easy	Easy	Moderate	Difficult	Very Difficult

a Drift Sampling Category. I - very high; II - high; III - moderate; IV - low ; V - very low.
Categories refer to their potential utility, or favourablity for drift sampling based on: the
type of facies and terrain unit; drift thickness and proximity of units to parent material or
bedrock; transport distance and transport direction; derivative phase (cf. Shilts, 1993); and
ease of interpretation of data (cf. Bobrowsky et al., 1994; Proudfoot et al., 1994).

b Terrain units (after Howes and Kenk, 1988). C - colluvium; M - till; FG - glaciofluvial sediment; LG
- glaciolacustrine sediments; F - fluvial sediment; W - marine sediment. v - veneer (< 1 m); b -
blanket (> 1 m); x - complex or combined units; h - hummocky. Mh/M - upper unit (Mh)
stratigraphically overlies lower unit (M) ; C/A - upper facies (C) stratigraphically overlies lower
facies (A)

(facies D) represent first derivative products of erosion and deposition with relatively simple and short transport histories (cf. Shilts, 1993). Where these deposits form thin veneers over bedrock (Mv, Cv), they rank as highly favourable deposits for drift sampling (category I; Table 4). The second category of favourable deposits (category II; Table 4) includes blanket deposits of lodgement and melt-out till (Mb), colluvium (Cb), and colluvial veneers overlying till (Cv/M). Moderately favourable deposits for sampling (category III) include complex sedimentary units (e.g. Mx, Cx, Mh/M), comprising basal tills, colluvium and ablation till (facies C). Less favourable deposits (category IV; Table 4) include glaciofluvial (facies E) and fluvial sediments (facies G). These deposits form thick sedimentary units (FGb, Fb) with transport distances ranging from tens to thousands of metres (Table 4). Third and fourth derivative products

are represented by glaciolacustrine (facies F) and marine sediments (facies H). They form simple sedimentary units (LGb, Wb), but because of complex histories and potentially long transport distances, they are the least favourable sampling media (category V; Table 4). We recommend that future exploration in the map area focus on drift sample categories I and II.

ACKNOWLEDGMENTS

REFERENCES

Alley, N.F. (1979): Middle Wisconsin Stratigraphy and Climate Reconstruction, Southern Vancouver Island, British Columbia; *Quaternary Research*, Volume 11, pages 213-237.

Bobrowsky, P.T. and Meldrum, D. (1994): Preliminary Drift Exploration Studies, Northern Vancouver Island; *in* Geological Fieldwork 1993, Grant, B. and Newell, J.M., *B.C. Ministry of Energy, Mines and Petroleum Resource*, Paper 1994-1, pages 87-99.

Bobrowsky, P.T., Huntley, D.H. and Proudfoot, D.N. (1994): Drift Exploration Potential Map (DEP): Derivative Interpretative Map for Mineral Exploration Generated from Surficial Geology Data, *in* Abstracts and Program, *Geological Society of America*, Volume 26, A500.

Boulton, G.S. and Eyles, N. (1979): Sedimentation by Valley Gaciers; a Model and Genetic Classification; *in* Moraines and Varves, Schlüchter, Ch., Editor, *Balkema*, pages 11-24.

Brodzikowski, K and van Loon, A.J. (1991): Glacigenic Sediments, *Elsevier*, 674 pages.

Catto, N.R. (1987): Lacustrine Sedimentation in a Proglacial Environment, Caribou River Valley, Yukon, Canada; *Boreas*, Volume 16, pages 197-206.

Church, M. and Ryder, J.M. (1972): Paraglacial Sedimentation: a Consideration of Fluvial Processes Conditioned by Glaciation; *Geological Society of America*, Bulletin, Volume 83, pages 3059-3072.

Clague, J.J. (1983): Glacio-isostatic Effects of the Cordilleran Ice Sheet, British Columbia, Canada; *in* Shorelines and Isostasy, Smith, D.E., Editor, *Academic Press*, pages 321-343.

Clague, J.J., Harper, J.R., Hebda, R.J. and Howes, D.E. (1982): Late Quaternary Sea Level and Crustal Movements, Coastal British Columbia; *Canadian Journal of Earth Sciences*, Volume 19, pages 597-618.

Collinson, J.D. (1978): Alluvial Sediments; *in* Sedimentary Environments and Facies (Chapter 3), Reading, H.G., Editor, *Elsevier*, pages 15-60.

Davis, N.F.G. and Mathews, W.H. (1944): Four Phases of Glaciation with Illustrations from Southwestern British Columbia; *Journal of Geology*, Volume 52, pages 403-413.

Dowdeswell, J.A. and Sharpe, M.J. (1986): Characterization of Pebble Fabrics in Modern Terrestrial Glacigenic Sediments; *Sedimentology*, Volume 33, pages 699-710.

Dreimanis, A. (1976): Tills: Their Origin and Properties; *in* Glacial Till, Legget, L.F., Editor, *Royal Society of Canada*, Special Publication 12, pages 11-49

Dreimanis, A. (1988): Tills: Their Genetic Terminology and Classification; *in* Genetic Classification of Glacigenic Deposits, Goldthwait, R.P. and Matsch, C.L., Editors, *Balkema*, pages 17-67.

Elliot, T. (1978): Clastic Shorelines; *in* Sedimentary Environments and Facies (Chaper 7), Reading, H.G., Editor, *Elsevier*, pages 143-175.

Eyles, N and Paul, M.A. (1983): Landforms and Sediments Resulting from Former Periglacial Climates; *in* Glacial Geology, Eyles, N., Editor, *Pernagon Press*, pages 111-139.

Fulton, R.J. (1991): A Conceptual Model for Growth and Decay of the Cordilleran Ice Sheet; *Géographie Physique et Quaternaire*, Volume 45, pages 281-286.

Howes, D.E. (1981): Terrain Inventory and Geological Hazards: Northern Vancouver Island; *B.C. Ministry of Environment, Lands and Parks*, MOE Manual 10.

Howes, D.E. (1983): Late Quaternary Sediments and Geomorphic History of Northern Vancouver Island, British Columbia; *Canadian Journal of Earth Sciences*, Volume 20, pages 57-65.

Howes, D.E. and Kenk, E, (1988): Terrain Classification System for British Columbia (Revised Edition); *B.C. Ministry of Environment, Lands and Parks. Surveys and Resource Mapping Branch*, MOE Manual 0, 90 pages.

Huntley, D.H. and Broster, B.E. (1994): Glacial Lake Camelsfoot: A Late Wisconsinan Advance Stage Proglacial Lake in the Fraser River Valley Gang Ranch Area, British Columbia; *Canadian Journal of Earth Sciences*, Volume 31, pages 798-807.

Kerr, D.E. (1992): Surficial Geology of the Quatsino Area, NTS 92 L/12, scale 1:50 000; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1992-6.

Kerr, D.E. and Sibbick, S.J. (1992): Preliminary Results of Drift Exploration in the Quatsino (92 L/12) and the Mount Milligan (93 N/1E, 93 O/4W) Areas; *in* Geological Fieldwork 1991, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resource*, Paper 1992-1, pages 341-347.

Lawson, D.E. (1988): Glacigenic Resedimentation: Classification Concepts and Applications to Mass-movement Processes and Deposits; *in* Genetic Classification of Glacigenic Deposits, Goldthwait, R.P. and Matsch, C.L., Editors, *Balkema*, pages 47-169.

Luternauer, J.J., Clague, J.J., Conway, K.W., Barrie, J.V, Blaise, B and Mathewes, R.W. (1989): Late Pleistocene Terrestrial Deposits on the Continental Shelf of Western Canada: Evidence for Rapid Sea-level Change at the End of the Last Glaciation; *Geology*, Volume 17, pages 357-360.

Miall, A.D. (1977): A Review of the Braided River Depositional Environment; *Earth Science Reviews*, Volume 13, pages 1-62.

Muller, E.M. (1983): Till Genesis and the Glacier Sole. *in* Tills and Related Deposits, Evenson, E.B., Schlüchter, Ch. and Rabassa, J., Editors, *Balkema*, pages 19-22.

Nixon, G.T., Hammack, J.L., Hamilton, J.V. and Jennings, H. (1993a): Preliminary Geology of the Manatta Creek Area, Northern Vancouver Island; *in* Geological Fieldwork 1992, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 17-35.

Nixon, G.T., Hammack, J.L., Hamilton, J.V. and Jennings, H (1993b): Geology of the Mahatta Creek Map Area, NTS 92 L/5, Scale 1:50 000; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1993-10.

Panteleyev, A., Bobrowsky, P.T., Nixon, G.T. and Sibbick, S. (1994): Northern Vancouver Island Integrated Project; *in* Geological Fieldwork 1993, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 59-62. Rust, B.R. and Koster, E.H. (1984): Coarse Alluvial Deposits; *in* Facies Models, Walker, R.G., Editor, *Geological Association of Canada*, Geoscience of Canada Reprint Series, pages 53-70.

Proudfoot, D.N., Bobrowsky, P.T. and Meldrum, D.G. (1994): Drift Exploration Potential Maps Derived from Terrain Geology Maps; *in* Drift Exploration in Glaciated and Mountainous Terrain, Brobrowsky, P.T., Sibbick, S.J. and Matysek, P.F., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, in press.

Rust, B.R. and Koster, E.H. (1984): Coarse Alluvial Deposits; *in* Facies Models, Walker, R.G., Editor, *Geological Association of Canada*, Geoscience of Canada Reprint Series, pages 53-70.

Shaw, J. (1975): Sedimentary Successions in Pleistocene Ice-Marginal Lakes; *in* Glaciofluvial and Glaciolacustrine Sedimentation, Jopling, A.V and McDonald, B.C., Editors, *Society of Economic Palaeontologists and Mineralogists*, Special Publication No. 23, pages 281-303.

Shaw, J. (1985): Subglacial and Ice Marginal Environments; *in* Glacial Sedimentary Environments, Ashley, G.M., Shaw, J. and Smith, N.D., Editors, *Society of Economic Palaeontologists and Mineralogists*, Short Course No. 16, pages 7-84.

Shilts, W.W. (1993): Geological Survey of Canada's Contributions to Understanding the Composition of Glacial Sediments; *Canadian Journal of Earth Sciences*, Volume 30, pages 333-353.