QUATERNARY GEOLOGY: COQUITLAM-PORT MOODY AREA, BRITISH COLUMBIA

by

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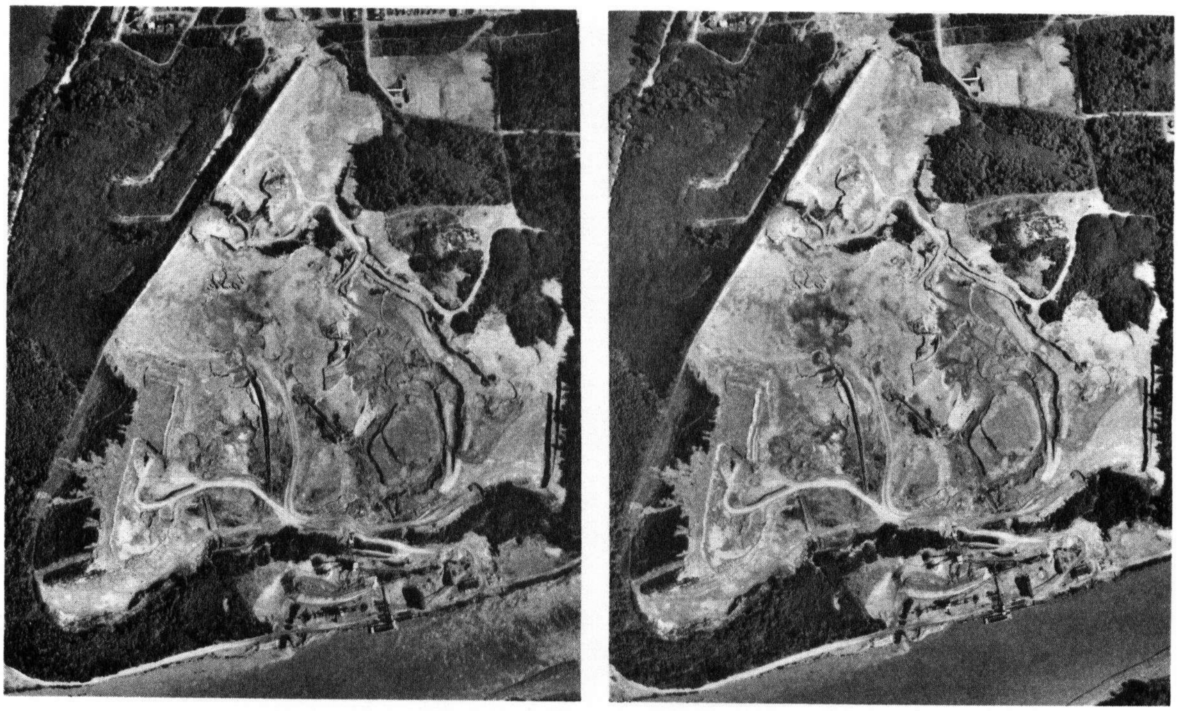

Frontspiece: Stereo pair of Mary Hill Gravel Pit, Port Coquitlam, B.C. as it appeared in March, 1974.

ABSTRACT

During Quaternary time the Coquitlam-Port Moody area underwent two and possibly three major glaciations separated by nonglacial intervals. Each glaciation was accompanied by eustatic and isostatic sea-level changes of up to 230 m, relative to present sea level, and probably some tectonic adjustment. Associated with each major ice advance were two or three local ice advances represented by tills separated by outwash deposits. During the last major glaciation (Fraser), two stades occurred (Vashon and Coquitlam), possibly separated by an interstade (Quadra). The Coquitlam Stade was the earliest and is represented by the Coquitlam Drift (between 25,000 and 21,600 radiocarbon yr. B.P.) which has not been recognized before on the B. C. mainland; it may correlate with the Evans Creek Stade discovered in northwestern Washington. Nine formational lithostratigraphic units are mapped and described for the area, each probably representing a geologic-climatic unit. The units are separated by unconformities representing three-dimensional irregular buried landscapes which were reshaped and replaced by new ones. Consequently, the Quaternary stratigraphy is extremely complex and sediment units occur sporadically. Correlations based on other than a three-dimensional study are at best tentative and must be supported by radiocarbon dates. The topography of the area was developed before Semiahmoo? time (>62,000 radiocarbon yr. B.P.) and has remained basically the same since then.

Large gravel reserves occur in the area, many of them buried in uplands and in the sediment fill occupying the lower Coquitlam River valley. Outwash gravels are the most extensive of the four types found in the area and Vashon outwash is the most commonly mined. Buried landscapes make pit run reserve estimation very difficult, and municipal zoning regulations are phasing out gravel operations and covering valuable reserves with urban and industrial subdivisions.

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DEDICATION

Dedicated to Fran

whose patience and understanding

in realizing the completion of this work

was surpassed only by her encouragement.

CHAPTER ONE: INTRODUCTION

A. General

The Coquitlam-Port Moody area is located 20 km east of the city of Vancouver and is bounded approximately by latitudes 49°13' and 49°20'N, and longitudes 122°45' and 122°53'W (Fig. 1). It lies at the southern end of the B.C. Coast Mountains and contains the glacier-carved Coquitlam valley which opens onto a flat-lying area underlain by sediments deposited by the Fraser, Pitt, and Coquitlam Rivers. This area surrounds Mary Hill and is bordered by uplands to the north and west.

During the time of field work, 1974-76, the writer was employed with J. E. Armstrong of the Geological Survey of Canada (G.S.C.) to assist him in the revaluation of terrain inventory maps and in Quaternary stratigraphic studies of the Fraser Lowland, B.C. For this thesis the writer undertook the problem of working out in detail the stratigraphy and Quaternary history of the Coquitlam-Port Moody area, where pre-Vashon Pleistocene sediments are best exposed in the Fraser Lowland. Soon after work on the thesis began, it was realized that the Coquitlam-Port Moody area contains some of the most stratigraphically complex Quaternary deposits in the world, whose history involved repeated glaciations, sea-level changes, and the formation of nonglacial organic sediments.

This study is based on detailed investigations of eight gravel pits in the area in which stratigraphic sections of Pleistocene sediments are well exposed and is an attempt to correlate these sections and gain an understanding of the

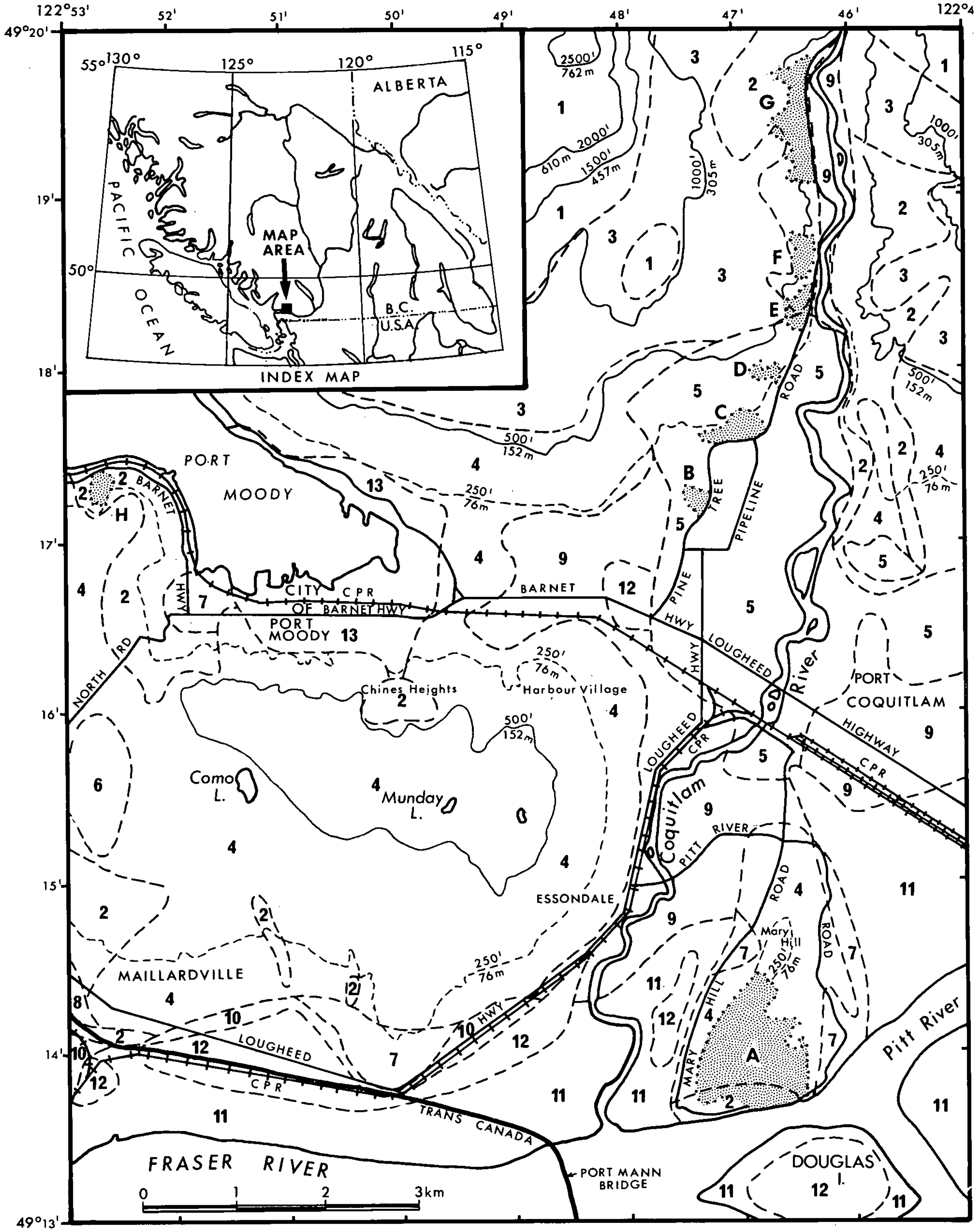


Figure 1 INDEX AND GRAVEL PIT LOCATION MAPS WITH GEOLOGICAL CONTACTS (based on Armstrong, in prep.).

LEGEND for Figure 1

Quaternary Deposits

Holocene

Holocene Sediments

13 Slopewash

12 Peat--bog, swamp, and shallow lake deposits.

11 Fraser River sediments--floodplain, channel, and estuarine silt, clay, and minor sand.

10 Lowland stream deposits-- channel and floodplain silt, clay, fine sand and minor gravel; may in part be deltaic deposits.

9 Mountain stream deposits--channel and deltaic sand and gravel with minor silt and clay.

Holocene and Pleisocene

8 Sand--floodplain, channel, and slopewash sand (Holocene); may in part be reworked marine littoral and beach sand (Pleistocene).

Pleistocene

Capilano Sediments

7 Raised marine beach, spit, bar, and lag veneer sand and gravel.

6 Raised intertidal and beach sand.

5 Raised deltaic and channel fill sand and gravel.

Vashon Drift and Capilano Sediments

4 Glaciomarine stony silt loam and glacial deposits including till, stony laminated silts, and substratified glaciofluvial sand and gravel.

Vashon Drift

3 Till, stony laminated silts and substratified glaciofluvial sand and gravel.

Pre-Vashon Sediments

2 Sand, gravel, silt, clay, and till underlying Vashon Drift.

Mesozoic

1 Bedrock--granitic and associated rock types at or near the surface. Commonly overlain by till, silt, and outwash sand and gravel.

— — — Geological contact

Gravel Pit studied

Gravel pits studied:

A Mary Hill

B Greater Vancouver Sewerage and Drainage District

C Allard

D Kask Bros.

E Johnson

F S and S and Columbia Bitulithic

G Jack Cewe Ltd.

H Port Moody sanitary landfill

depositional processes and mechanisms operating in the area during Quaternary time. This should help in the geological interpretation of adjacent areas and perhaps in discovering more sources of granular aggregate in the Greater Vancouver area.

Investigations by the writer and associates have included: radiocarbon dating or organic materials collected from the sediments; determination of directions of paleostream flow in the sand and gravel units from cross-bedding, foreset bedding, and imbrication; stone fabric studies of glacial diamictons to determine directions of ice flow in the area; grain size and basic mineralogical analyses of the sediments; and insect studies of some organic-bearing sediments. Analyses of pebble samples and calculations of provenance are given in Appendix 2. Paleocurrent directions based on small scale cross-beds (paleochannel widths up to 5 cm) were determined by digging into a sediment face and scraping out a horizontal surface to form a step. Paleochannel axes were then measured in plan view, in the concave direction of the troughs (Fig. 25). Large scale cross-beds (paleochannel widths 5 cm to 5 m; Fig. 24) were measured where cross sections normal to paleochannel axes could be seen. Pebble fabric analyses were done by measuring the direction and plunge of pebble long axes as they occurred in undisturbed exposures of glacial diamictons.

Individual stratigraphic sections in each gravel pit are described and then correlated and graphically illustrated by diagrammatic cross sections for each pit. Finally the stratigraphy of the pits are correlated with one another and cross sections constructed through the whole map area. Reconstruction of the Quaternary history of the area is based on section descriptions and conclusions drawn from them. Photographs of the sediment units are included in Chapter Five but are referred to throughout the thesis.

The south slope of Mary Hill on the Fraser River was the site of the first gravel pit in the area in 1928, and it was the only pit until Deeks Sand and Gravel Co. opened a pit north of Lougheed Highway (No. 7) in the early 1940's. The general public removed aggregate for their own use from other excavations in Crown Land in that area until the District of Coquitlam took control of the land use in the valley in the mid 1960's. Since then companies and the municipality have opened and extended gravel pits in the Coquitlam valley, mainly for the sale of granular aggregate, under strict by-laws imposed by the District. Excavations at the Port Moody sanitary landfill site were begun by Scott Bros. in 1963 for sand sales and in the mid 1960's by the City of Port Moody for garbage disposal.

B. Previous Work

The earliest work on surficial geology done in the area was by Burwash (1918) who mapped the surficial and bedrock geology of the Greater Vancouver area (east to Haney) and Howe Sound. Johnston (1921, 1923) published the first map of surficial deposits in the Vancouver area while studying the sedimentation of the Fraser River delta.

No further geological studies were published on the Coquitlam-Port Moody area until Armstrong (1953) wrote a paper on the geology of sand and gravel deposits in the Lower Fraser Valley, and Armstrong and Brown (1954) published a paper on the glaciomarine deposits found in the same area. Roddick and Armstrong (1956) produced a preliminary bedrock map of the Vancouver area (east half) showing the distribution of Quaternary deposits in general. This was later replaced by a revised map and report (Roddick, 1965). Armstrong (1957) completed a preliminary report and map (1:63,360 scale) on the surficial geology of the New Westminster area, and in 1961 Armstrong wrote a paper on the soils of the coastal area of southwest British Columbia from a geological viewpoint. In a field trip guidebook Armstrong (1965) described the exposure at Mary Hill, and in a classic joint paper, he documented the Pleistocene stratigraphy and chronology in southwestern B.C. and northwestern Washington (Armstrong, et al., 1965). Leaming (1968) generally described the operations and deposits on the gravel pits studied in this thesis in a report on the sand and gravel in the Strait of Georgia area.

Recently Armstrong (1975) reported on stratigraphic studies and revaluation of his preliminary surficial geology map sheets in the Fraser Lowland and in that year briefly described the Quaternary geology of the Fraser Lowland for a field trip guidebook, Armstrong and Hicock (1975) investigated buried landscapes in Mary Hill, and Rowe (1975) wrote an unpublished B.Sc. thesis on the Mary Hill gravel pit. Armstrong and Hicock (1976) described Quaternary-multiple valley development in the lower Coquitlam valley and Armstrong and Clague (in press) have redefined the Quadra sediments, using Mary Hill as a parastratotype section.

CHAPTER TWO: MARY HILL

A. Introduction

Mary Hill gravel pit was in 1975 the largest in British Columbia. It was excavated into the southern slope of Mary Hill, City of Port Coquitlam, a small rounded upland surrounded by the wide, flat-bottomed valleys of the Fraser, Pitt, and Coquitlam Rivers (Fig. 1). Mary Hill was approximately 3 km long, 1.5 km wide, and 95 m in elevation. When field work was done for this thesis, the pit extended 1200 m north of the Fraser River with an average width of 750 m and contained some of the best exposed Pleistocene stratigraphic sections, commonly in three dimensions, in the Fraser Lowland (Frontspiece). Much of the pit had been filled in but remaining exposures revealed the complex nature of the sediment contacts. This complex stratigraphy probably occurs in Pleistocene uplands throughout the Fraser Lowland and is exemplified by buried landscapes in composite hills.

Gravel excavation was started at Mary Hill in 1928 by the Freshwater Sand and Gravel Co. (Gilley Bros.) which hydraulically mined the southern slope by pumping Fraser River water through six-inch pipelines suspended from a derrick on a barge. Later a steam-driven immobile dredge, mounted on pilings, used clam buckets to scoop up gravel that was monitored from the hillside and caught behind a gate at the river level. As the monitored face was excavated further into the hill, the gravel had to be transported to the buckets by carts on tracks. The buckets then dumped the gravel into hoppers feeding the sorting apparatus on the barge. Gilley Bros. operated this way until 1930 when a wooden separating plant was constructed on shore. In 1946 a road was constructed along the base of the hill and by 1950 trucks were used to haul the monitored gravel to a hopper which fed a conveyor belt carrying material to the separating plant. A new steel separating plant and concrete storage silos were built at the base of the hill in 1952, and soon after hydraulic mining was replaced by large diesel shovels and trucks. Gilley Bros. amalgamated with Evans, Coleman, and Evans in 1955 and soon after sold all their interest in the pit, making the latter company sole owners. In 1958 Ocean Cement Ltd. (now controlled by Genstar) bought the pit and operated it through various subsidiary companies. The last of these was Construction Aggregates Ltd. which operated the pit from 1970 until 1975 when it was required to close because of zoning regulations imposed by the City of Port Coquitlam. The city plans to have engineered homes built on the site.

Until 1960 the separating plant could process only sand and gravel, but in that year a new steel separating tower with scrubbers and washers was installed to process till (Leaming, 1968). For many years only deep holes in small areas within the pit were mined, often making gravel removal difficult, and the pit extended only 200 metres north of Fraser River in 1965. Since then much greater areas have been uncovered and the pit greatly expanded to the dimensions at the time of closure in 1975. Since 1928 the pit has supplied over 20 million m^3 of sand, gravel, and crushed rock at a present-day value of at least $20 million (pit run material only, at the site) to the construction industry in the Greater Vancouver area.

B. Measured Sections

The best exposed sections in the pit which were measured with a Wallace and Tiernan altimeter are shown in Fig. 2. The measured sections lie along four cross section lines chosen to best illustrate the stratigraphic relationships between the sediment units (Index Map, Fig. 2). A diagrammatic fence diagram incorporating the measured sections is shown later in Fig. 3. Field data are plotted on each section where the work was done and are coded in the legend to save space in the text. Data are also recorded on separate maps under "Quaternary History and Conclusions" in this chapter or in the appendices.

C. Diagrammatic Composite Sections

Fig. 3 is a diagrammatic fence diagram of the southern half of Mary Hill as it probably appeared before excavation. The measured sections of Fig. 2 and topographic surface at the time of mapping are plotted on each cross section. Geological contacts shown by solid lines indicate where information is known from other, less well exposed sections, and broken contacts indicate where information was extrapolated.

Descriptions of the sediment units in Fig. 3 are given in the legend; however, additional information is given below, commencing with the oldest unit.

Unit 1, an undifferentiated glacial complex, comprised of lodgement till, glaciofluvial, glaciomarine, and glaciolacustrine phases, was found in measured sections B, D, M, and P,

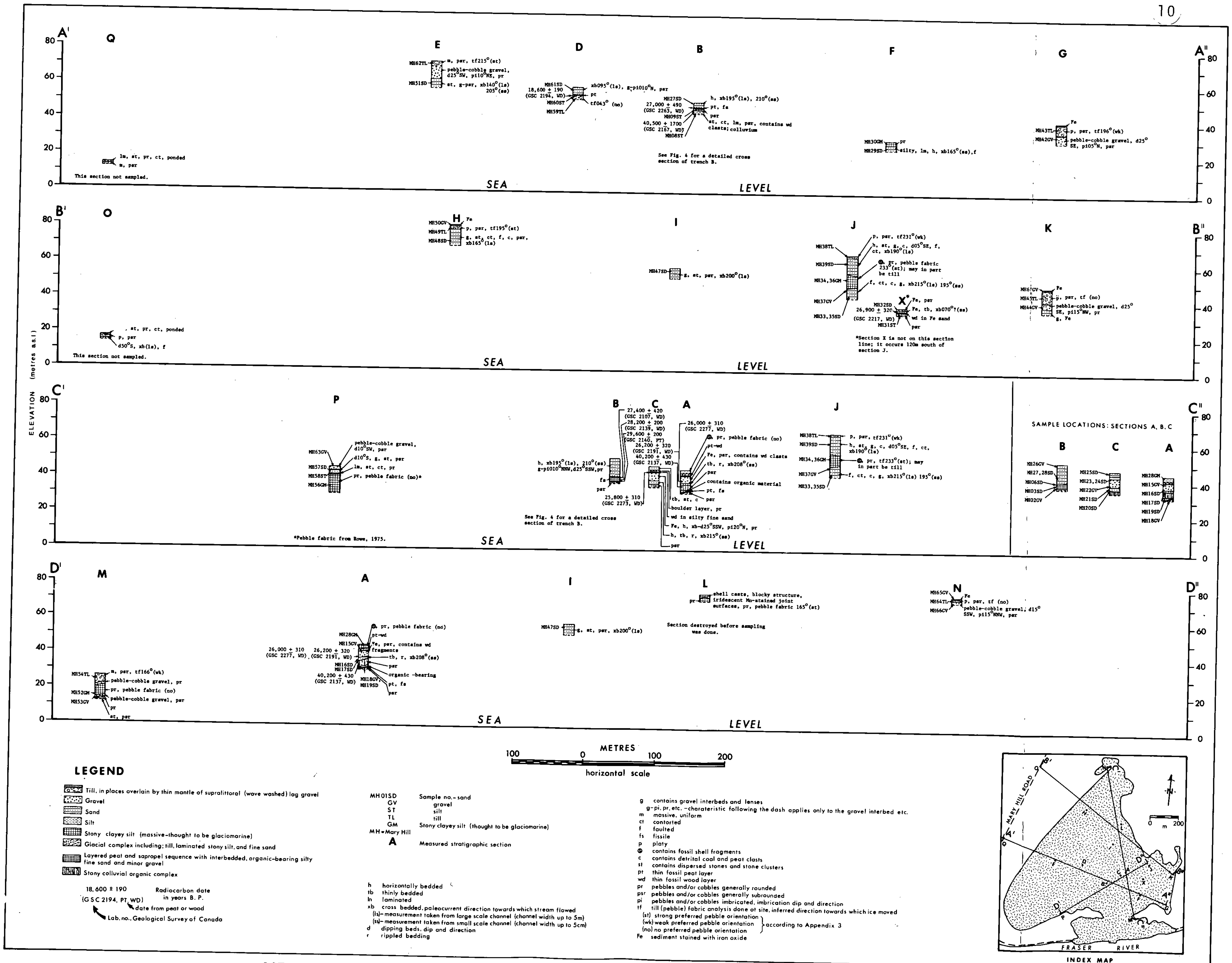


Figure 2 MEASURED STRATIGRAPHIC SECTIONS, MARY HILL GRAVEL PIT, PORT COQUITLAM, B.C.

and in other limited exposures on the south flank of Mary Hill. Because of limited exposure, the stratigraphic succession of these phases in unit 1 is not certain, but is thought to be (youngest to oldest): glaciolacustrine, glaciomarine, glaciofluvial, till.

Armstrong (1965) described a massive stony clayey silt unit exposed on the south flank of the hill and mapped it as Semiahmoo Drift (?). Further excavation into the hill since then has revealed that this blue-grey stony clayey silt is only one phase of the glacial complex in unit 1. The writer found this phase exposed in measured sections M and P. It is probably glaciomarine as it is massive (but weathers to a blocky structure) and poorly compacted, contains few scattered stones (up to 2 m dia. observed), has a finer matrix than the till phase, and has no preferred pebble orientation (shown later in Fig. 5A); however, no shells or shell impressions were found in it.

The till phase includes ponded glaciolacustrine stony laminated silt containing till clasts and was observed only in the gullies at measured sections B and D. In these gullies the till is pale greenish-brown, very stony and has a sandy to silty matrix.

The glaciolacustrine laminated silt and fine sand phase was exposed at measured section P, and on the south flank of the hill 70 m west of measured section M, where it overlies the glaciomarine phase (Fig. 39). The glaciolacustrine phase was probably formed by stones dropping from drifting ice into mud on the bottom of a glacial lake. Silt and fine sand laminae are commonly bent under or draped over stones in this phase. Wood from this phase were dated as >62,000 radiocarbon yr. B.P. (M. Stuiver, University of Washington - pers. comm.) and as >48,000 and >44,000 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.). L. D. Wilson (G.S.C. Quaternary Paleocology Laboratory, Ottawa) reported on the latter sample as follows: "Sample is highly distorted, compressed and lignified. Visible features appear to be those found in Abies sp. (Western Fir). Condition of the wood does not permit positive identification."

Glaciofluvial gravel and sand underlie the massive glaciomarine phase at measured section M and are probably outwash deposits.

At measured section B (shown later in detail in Fig. 4) interbedded stony silts and well sorted fine to medium sand are contorted and faulted and underlie the till phase of unit 1. These sediments may be glaciolacustrine and proglacial outwash deposits which developed faults when overridden by the glacier that deposited the overlying till. Due to lack of exposures, the stratigraphic position of these sediments can only be described as sub-till in unit 1.

Unit 2, stony organic colluvium, was exposed only in the gullies at measured sections A and B and in a small exposure at the base of measured section C. As stated in the legend, this complex has two crudely interlayered phases: a dense, detrital organic-rich diamicton (exposed at sections A (Fig. 32), B, and C) containing an assortment of organic debris (looks like till from a distance); and a poorly compacted, silt-rich diamicton (exposed only at section B) containing wood, and clasts of glacial sediments. The writer suggests that both phases are reworked organic and glacial deposits formed by mass wasting processes on a buried landscape. Wood from the organic-rich phase at measured section A dated as 40,200±430 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.) and was identified by L. D. Wilson (pers. comm.): "Coniferous wood, strongly compressed and lignified probably Picea sp. (spruce)." From the silt-rich phase at measured section B, a root dated as 40,500±1700 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.) and was identified by R. J. Mott (pers. comm.): "Coniferous wood somewhat decayed. Features resemble those of Tsuga heterophylla (western hemlock)." M. Stuiver (University of Washington) analyzed another wood chunk from the organic-rich phase at measured section A and commented on it as follows: "...the third sample appears to have even a younger age than determined previously for this strata (G.S.C. 2137-40,200±430)."

J. V. Matthews (G.S.C., Ottawa) examined a sample of the organic-rich phase and reported:

> "The following beetles were identified in this sample:
>
> Coleoptera
> Carabidae "ground beetles"
> Agonum consimile Gyllenhal — Pronotum
>
> Staphylinidae "rove beetles"
> Olophrum boreale (Payk.) — Pronota, elytra, heads
>
> "The species in this sample are northern and cannot be collected at Vancouver today. A relict population of A. consimile apparently occurs today at Duncan on Vancouver Island, but otherwise all collecting records are from localities in northern B.C. In other parts of

Canada it is also primarily northern, occurring from Edmonton north in Alberta; Churchill and The Pas in Manitoba; Fort Severn, Ontario; Ungava region of Quebec; Cape Breton Island, Nova Scotia; and in Newfoundland and southern Labrador. A. consimile lives near standing water where substrate is soaked and vegetation is abundant. The distribution of O. boreale is less perfectly known, but it would be entirely unexpected at Vancouver today. In the north (Northwest Territories and Alaska) it may be collected in the same biotypes that A. consimile occupies. Hatch in his monograph on the beetles of the Pacific Northwest (including British Columbia) does not list O. boreale, but I strongly suspect that it does occur in northernmost B.C. since I have collected it in the southern part of the Yukon Territory. It seems quite likely in view of these fossils that the peat from which they come was deposited during a period of climate colder than at present."

Unit 3, organic bog and swamp deposits, occurred only at measured section B where three thin fibrous and fissile peat layers (10-40 cm thick) and a lower diatomaceous sapropel layer (5-10 cm thick; identified by S. Federovich, pers. comm.) are separated by organic-bearing silty fine sand and minor gravel (See also Fig. 4). A sample from the sapropel layer dated as 29,600$\pm$200 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.) and was described by S. Federovich (pers. comm.) as follows:

"Due to excessive fragmentation, critical identification was at times difficult and uncertain, allowing only a partial listing of the diatom taxa present in the assemblage. It also precludes a detailed ecological interpretation. However, the dominance of species comprising the genera Eunotia and Pinnularia suggests an oligotrophic, calcium-poor bog environment."

The fresh-water diatom assemblage includes the following species: "Cyclotella comta, Cymbella cistula, Eunotia arcus, Eunotia exigua, Eunotia alpina?, Eunotia lunaris, var. Subarcuata, Eunotia praerupta, Eunotia robusta, Eunotia robusta var. diadema, Melosira distans, Eunotia valida?, Pinnularia interrupta, Pinnularia maior, Pinnularia viridis, var. sudetica?, Pinnularia viridis, Rhopalodia gibba, Tabellaria flocculosa."

M. Kuc (G.S.C., Ottawa) also made this comment on the sapropel sample:

> "This is a most typical diatomaceous sapropel, rather oligotrophic, on which developed vascular plant (sedgy) growth. If there is any time interval between these two components it is short. The sample is very uniform, is free of introduced macrofossils, and is thus suitable for radiocarbon dating."

Wood from the lowest peat layer dated as 28,200±200 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.) and L. D. Wilson (pers. comm.) reported: "Identified as Picea sp. (spruce)." Dr. J. V. Matthews examined the lowest peat layer for fossil beetles and reported as follows:

"Fossils:

Coleoptera	
Carabidae "ground beetles"	
Scaphinotus angusticollis Mann.	Elytra
S. marginatus Fisch.	Elytra
Patrobus fossifrons Eschz.	Pronotum
Scarabaeidae "scarab beetles"	
Genus?	Pronota, elytra
Chrysomelidae	
Donacia sp.	Elytra

"All three of the identified species can be found in the Vancouver area today. The first two are for the most part deep forest species (Scaphinotus individuals are snail eaters) while the third occurs near ponds." A fossil stump (30 cm diameter) from the second peat layer (Fig. 35) dated 27,400±420 radiocarbon Yr. B.P. (W. A. Blake, Jr., pers. comm.) and R. J. Mott (pers. comm.) stated: "Wood is somewhat decayed and therefore hard to section. Identified as Picea sp. (spruce) probably P. sitchensis."

Wood from the highest peat layer dated as 27,000±490 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.) and R. J. Mott (pers. comm.) reported: "Identified as Picea sp. (cf. P. sitchensis) (sitka spruce)." Unit 3 unconformably overlies unit 2, as is shown later in Figs. 4 and 34.

Unit 4, rusty sandy gravel, was exposed in the middle of the pit at measured sections A, C (Fig. 31), F, J, and X. This unit contains wood-bearing organic silt layers and grades downward into fine sand and silt at the base. At measured section J cross-bedded and faulted gravelly sand containing dispersal coal and wood clasts underlies stony clayey silt of unit 5 (Fig. 30) and has been mapped with unit 4; however it may belong to the sand of unit 6. Wood from section A dated 26,200±320 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.) but was not identified. From section X a fossil log (3 m long, 30 cm dia.) dated 26,900 ±320 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.) and L. D. Wilson (pers. comm.) reported: "Identified as Abies sp. (western fir)." Wood from rusty fluvial gravel, 30 cm above the paleoslope on unit 2 (and 1 m south of the 26,200 date) at measured section A, was dated as 26,000±310 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.) and R. J. Mott (pers. comm.) identified it: "...as Picea sp. (spruce)." Wood from a thin organic silt layer at the top of unit 4 at measured section C dated as 25,800±310 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.); R. J. Mott (pers. comm.) identified it: "...as Picea sp. (spruce)."

Unit 5, stony clayey silt, was observed at sections A, C, J (Fig. 29, 30) and L. Fossil shells and shell fragments were found in this unit, which strongly suggests a glaciomarine origin. This unit is generally massive but varies in compactness, stoniness, and matrix proportions of sand, silt, and clay; it may in part be till. Boulders up to 1 m dia. were observed in this unit. Between measured sections A and C unit 5 pinches out to the west and is represented only by a boulder layer at section C.

Unit 6, sand (Figs. 24, 25), is exposed in several sections in the middle and towards the back of the pit. It is described adequately in the legend of Fig. 3 and is thought to be proglacial channel and flood plain deposits, which grade upward into unit 7 gravel and sand. Paleochannels are shallow (0.1 to 1 m deep) and wide (1 to 10 m wide). Isolated stones and stone clusters were probably dropped from floating ice or tree parts carried by the meltwater streams. Armstrong and Clague (in press) reported the polynomorph assemblage (identified by J. Terasmae) from peaty silt in Quadra Sand at Mary Hill as follows: *Picea* (88% of aboreal pollen), *Pinus* (6%), *Salix* (6%) *Artemisa*, *Compositae*, and *Lycopodium*. At measured section D wood from a thin peat layer at the very base of unit 6 (Fig. 26--directly overlying unit 1) dated as 18,600$\pm$190 radiocarbon yr. B,P, (W. A. Blake, Jr., pers. comm.) and L. D. Wilson (pers. comm.) reported: "Identified as *Picea sp*. (spruce)."

Unit 7 occurred as southward-dipping foreset gravel and sand beds on the flanks of Mary Hill (Fig. 22). It was probably deposited by voluminous meltwater discharges as proglacial deltas between tills and close to advancing ice margins.

Paleochannels are deeper and narrower than those in unit 6.

Unit 8, till (Figs. 20, 21) was exposed at several sections over the entire area of the pit and occurs in at least three southward-dipping layers on the southern slope of Mary Hill (Armstrong and Hicock, 1975); each layer is truncated by the next youngest layer and separated by outwash gravels (unit 7). This unit varies from compact, platy, and stony lodgement tills, deposited at the base of glacier ice, to poorly compacted, massive (or contorted), and less stony flow tills which were probably deposited as mud slides at the edges of wasting ice margins. Till colour varies from dark grey to dull reddish-orange, depending on the degree of oxidation. Stones up to 5 m dia. were observed in it (Fig. 21).

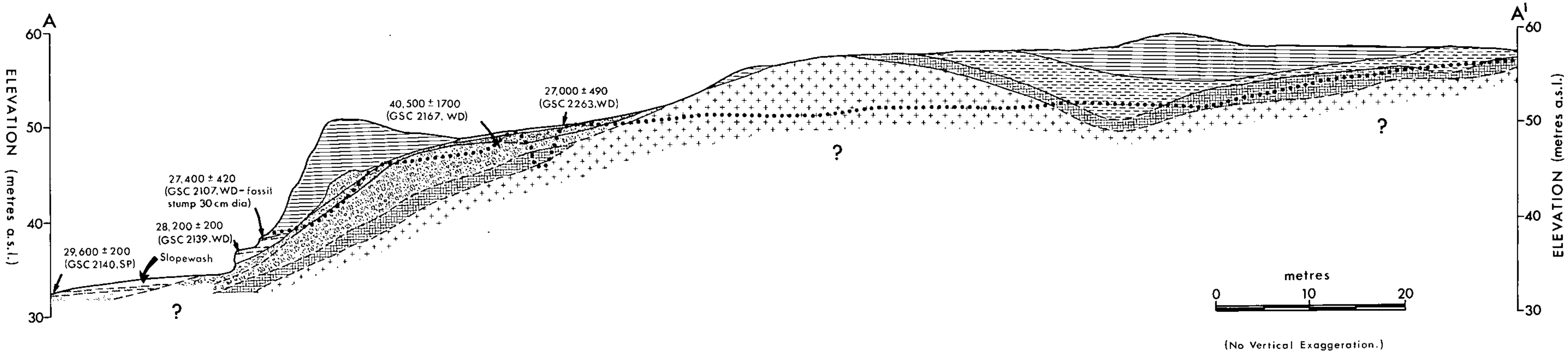
Unit 9, glaciomarine sediments (Fig. 19), was seen only at measured section L (and in contact with unit 5) at the time of mapping but was observed elsewhere in the pit by previous workers (Armstrong, 1953, 1965; Leaming, 1968; Rowe, 1975; Armstrong and Hicock, 1975). As stated in the legend of Fig. 3, the characteristic features of this unit are: blocky structure, manganese staining on joint surfaces, the presence of marine shells and fragments, and scattered stones. Stones up to 10 cm dia. were observed in this unit at section L. In 1962 J. E. Armstrong collected a fossil shell assemblage from this unit on the south flank of Mary Hill and the fauna were identified by F. J. E. Wagner (pers. comm.) as follows: Pelecypoda: *Nucula tenuis* (Montagu), *Nuculana fossa* (Baird), *Chlamys hindsii* (Carpenter), *Clinocardium blandum* (Gould), *Clinocardium ciliatum*

(Fabricius), Serripes groenlandicus (Brugière), Macoma calcarea (Gmelin), Macoma inconspicua (Broderip and Sowerby), Macoma planiuscula (Grant and Gale), Mya truncata (Linné), Hiatella arctica (Linné); Gastropoda: Trichotropia cancellata (Hinds), Natica clausa (Broderip and Sowerby); Annelida: Serpula vermicularis (Linné); Cirripedia: Balanus sp. Dr. Wagner also remarked:

> "Except for Macoma planiuscula, which has not previously been identified from this area, all of these species are common in the Newton stony clay. M. planiuscula is a cold-water form, ranging at present from the Arctic Ocean to Puget Sound."

Unit 10, supralittoral lag gravel, forms a thin (less than one meter) cover over units 8 and 9 and was probably formed by ocean waves and spray pounding against and washing over these sediments, when they formed the upper slopes of a beach at one time. The beach concept for the formation of these gravels was first conceived by Burwash (1918) and Johnston (1923). A complete transition may be found (Fig. 15) between well washed, oxidized, almost clean pebble-cobble gravel to a slightly reworked, slightly oxidized diamicton containing a silty matrix. Generally unit 10 occurs as a dull reddish-orange sandy gravel containing a few shell casts, and stones in the same size range that occurs in units 8 and 9.

Fig. 4 is a more detailed diagrammatic section (with no vertical exaggeration) of the drainage trench at measured section B, the only site where units 1, 2, and 3 of Fig. 3 occurred together, and represents one site where various phases of these units could be differentiated. Here an unconformity (Fig. 34,35) was uncovered between two organic units: the "Fossil Bog and



LEGEND

SAND

Sand with gravel interbeds.

FOSSIL BOG and GYTTJA DEPOSITS

Thin fissile peat and sapropel layers containing fossil tree stumps (up to 30 cm dia.), roots, logs, (up to 3m long), and insects.

Fine sand and silty fine sand containing finely disseminated organic matter and fossil insects; and minor iron stained, well sorted fine gravel.

STONY COLLUVIAL ORGANIC COMPLEX

Dense, stony and gritty, detrital organic-rich diamicton (weathered surface resembles till) containing fossil twigs, leaves, wood pieces, and insects; stones up to 10 cm dia. observed at this site.

Moderately to poorly compacted, contorted, stony, silt-rich diamicton containing fossil wood pieces and roots, clasts of laminated stony silt, and gravel and sand pockets and lenses.

"UNDIFFERENTIATED" GLACIAL COMPLEX

Laminated stony silts; compact, slightly contorted, containing clasts of till; probably ponded.

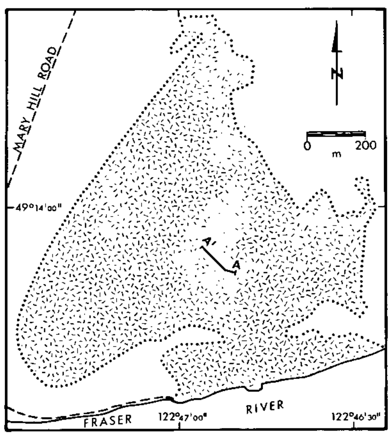
Till; massive, moderately to well compacted; pale brownish green colour.

Contorted and faulted stony silts interbedded with well sorted fine to medium stony sand; faults probably caused by the load of overriding ice.

Section not exposed below this line ••••••

Geological contact; observed, inferred —— - - -

27,400 ± 420 (GSC 2107, SP, WD) — Radiocarbon date in years B. P.; SP, WD: date on sapropel or wood; GSC 2107: Lab. no., Geological Survey of Canada



INDEX MAP

DETAILED DIAGRAMMATIC CROSS-SECTION IN GULLY AT MEASURED SECTION B

Figure 4

Gyttja Deposits," and the "Colluvial Organic Complex." The importance of this surface is uncertain as the "Fossil Bog and Gyttja Deposits" may have older, buried, organic layers that would narrow the hiatus between the two units; and the "Colluvial Organic Complex" may contain organic material younger than what has been dated from it so far. The base of the "Sand" unit is an unconformity and the top of the "'Undifferentiated' Glacial Complex" represents a buried landscape. On the right side of the figure these two surfaces merge. The legend adequately describes the various phases of the sediment units, and radiocarbon dates, where obtained, are plotted on the diagram.

A geological map was not drawn for the pit as exposures occurred in only near-vertical faces and gullies, which continuously changed as gravel excavation proceeded. Soon the pit will be infilled and graded and a geological map would be meaningless. Rowe (1975) drew a geological map of the pit as it appeared one day in the spring of 1975.

D. Quaternary History and Conclusions

Mary Hill has been subjected to at least two glaciations separated by at least one nonglacial interval. During the last glaciation two stades (minor glacial intervals within the glaciation) occurred, possibly separated by an interstade (a warmer interval between the stades, during which peat formed). Three glaciomarine layers suggest that ocean waters covered the hill at least three times during the Pleistocene epoch.

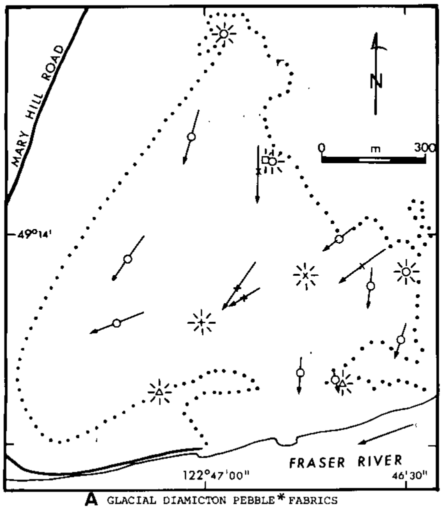
The hill itself is not a recent geonorphological form (and not bedrock-cored (Armstrong, 1957)) but probably existed more than 62,000 years ago (QL-194), although in a different shape, during glacial conditions when unit 1 (Fig. 3), the undifferentiated glacial complex, was being deposited.

The earliest phase of unit 1 to be laid down was the sub-till contorted silt and fine sand in measured section B (Fig. 4). They appear to be glaciolacustrine or proglacial deposits. Glacier ice advanced southward (Fig. 5A) over these sediments and reshaped them. Lodgement till was laid down and the sub-till deposits failed and became contorted under the weight of glacier ice. Meltwater filled hollows on the till surface and floating ice dropped stones and till clasts into the ponded muds.

The glacier then retreated as the climate warmed and Coast Mountains-derived outwash gravel and sand (Figs.5C, D, Appendix 2) were deposited, probably into the sea, which apparently followed the glacier's retreat and eventually drowned Mary Hill.

During this time glaciomarine sediments were probably deposited up to at least 40 m above present sea level. Drifting ice randomly (Fig. 5A) dropped stones mainly of northern provenance (Figs.5C, D, Appendix 2) into sea-floor muds.

The land then isostatically rebounded faster than the eustatically rising sea and the ocean floor became exposed. Meltwater from the retreating ice sheet filled depressions in the raised sea floor which may have been formed by the scouring and/or percussion of drifting ice keels. Rhythmically laminated glaciolacustrine silts containing widely scattered, Coast Mountains-derived (Figs. 5C, D, Appendix 2), dropstones were laid down in these depressions in a similar manner described for the glaciomarine phase of unit 1. Scattered wood fragments were



A GLACIAL DIAMICTON PEBBLE* FABRICS

Inferred direction of ice movement: based on strong, weak, and no preferred pebble (long axis) orientations (Appendix 3)

□ Glaciomarine Stony Clayey Silt (unit 9, Fig. 3)

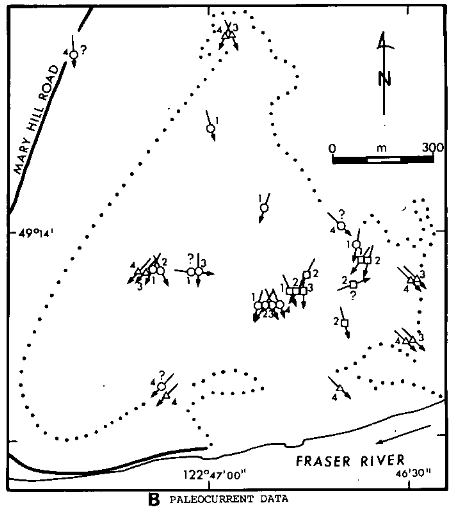
O Till (unit 8)

x Stony Clayey Silt (unit 5)

+ Till phase of Undifferentiated Glacial Complex (unit 1)

Δ Massive Stony Silt phase of Undifferentiated Glacial Complex (unit 1)

*The ratio of long axis length/intermediate axis length for most pebbles measured was 1.5 to 2.0. 95% of all pebble long axis measured in this pit dipped less than 25°, and 60% dipped less than 10°; 55% dipped Northward (against direction of ice movement).



B PALEOCURRENT DATA

Δ Pebble-Cobble Sandy Gravel (unit 7, Fig. 3)

O Sand (unit 7)

□ Sandy Gravel (unit 4)

Measurements done on:

1 Cross-bedding; paleochannel widths 5cm to 5m (large scale)

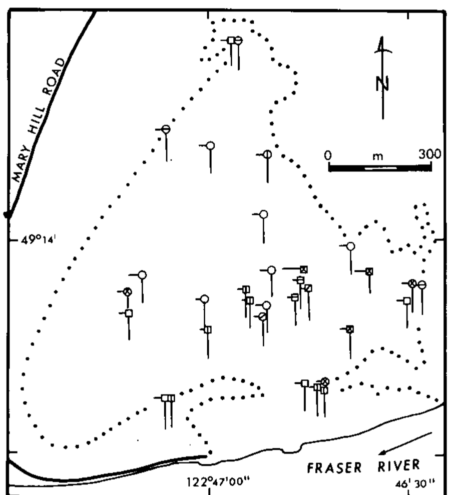
2 Cross-bedding; paleochannel widths up to 5cm (small scale)

3 Pebble imbrication

4 Foreset bedding

/ Inferred direction of stream flow

4O1 More than one measurement taken at same site (eg. Foreset bedding in unit 7, and large scale paleochannels in unit 6 were both analysed at same site)



C PEBBLE* PROVENANCE (see Fig. D for source areas)

Samples taken from:

ϴ Supralittoral Lag Gravel (unit 10, Fig. 3)

⊗ Till (unit 8)

□ Pebble-Cobble Gravel (unit 7)

O Sand (unit 6)

⊠ Stony Clayey Silt (unit 5)

⊟ Sandy Gravel (unit 4)

⊘ Fossil Bog and Gyttja Deposits (unit 3).

⧄ Colluvial Organic Complex (unit 2)

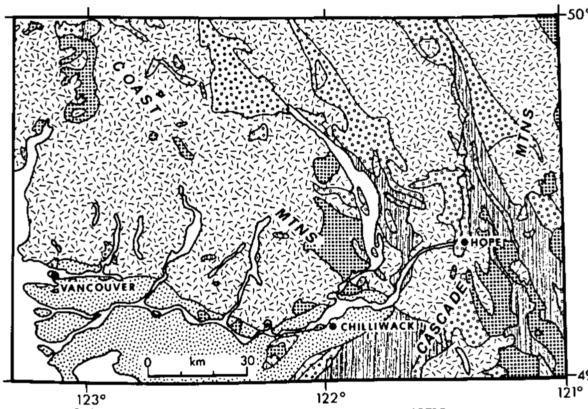
⧈ Undifferentiated Glacial Complex (unit 1)

% pebbles having Cascade Mtns. source (Eastern provenance)

100 0 0 — 100: % pebbles having Coast Mtns. source (Northern provenance)

Sand (unit 6, Fig. 3) pebble sample in which 80% of the pebbles have a Coast Mtns. source (Northern provenance) and 20% have a Cascade Mtns. source (Eastern provenance)

*Pebbles ranging from 1 to 8 cm. dia. were analyzed.



D GENERALIZED REGIONAL GEOLOGY: PEBBLE SOURCE AREAS.

(modified after Roddick et. al., 1973: G.S.C. Open File Geological Map #165)

GRANITIC AND ASSOCIATED ROCK TYPES (including low grade metaplutonics, metavolcanics)

VOLCANIC ROCK TYPES (including flows, tuffs, and breccias)

QUARTZITE, CHERT, PELITE, AND ARGILLITE

OTHER ROCK TYPES (including medium to high grade metamorphics, sedimentary, and ultramafics)

UNCONSOLIDATED (QUATERNARY) SEDIMENTS

Fig. 5 RESULTS OF SOME FIELD WORK DONE IN MARY HILL GRAVEL PIT: A, GLACIAL DIAMICTON PEBBLE FABRICS; B, PALEOCURRENT DATA; C, PEBBLE PROVENANCE, D; GENERALIZED REGIONAL GEOLOGY SHOWING SOURCE AREAS FOR PEBBLES IN C.

deposited in the glaciolacustrine silts and may represent trees growing along the prehistoric lake shore; however, they are well rounded clasts and were probably reworked from an older non-glacial sediment unit. A landscape was developed on unit 1.

The geologic history of Mary Hill immediatley after this glaciation has not been unravelled. About 40,000 years ago a stony organic colluvium (unit 2, Fig. 3) was deposited. It formed on a slope at the edge of a depression, probably during a nonglacial interval, by mass wasting processes mixing organic deposits (containing spruce and western hemlock trees) and glacial sediments. Pebbles from unit 2 have a dominant northern provenance (Figs. 5C, D, Appendix 2). A landscape was developed on unit 2.

A large time gap seems to exist between 40,000 and 30,000 yr. B.P. at Mary Hill, unless the "Fossil Bog and Gyttja Deposits" (unit 3, Fig. 3) have buried organic layers older than 30,000 yr. B.P. that would narrow the hiatus; or the "Colluvial Organic Complex" (unit 2) contains organic material younger than 40,000 yr. B.P. Armstrong (in prep.) has evidence elsewhere in the Fraser Lowland suggesting that organic deposits were formed between 30,000 and 40,000 yr. B.P. Presumably the warm non-glacial interval also persisted through this apparent time gap at Mary Hill. Layered bog and gyttja deposits containing spruce trees formed between 30,000 and 27,000 years ago, against a slope developed on the organic colluvium at measured section B (Fig. 4). Pebbles from a gravel interbed in unit 3 have a dominantly northern provenance (Figs. 5C, D. Appendix 2). A landscape was formed on unit 3.

Fluvial silt, sand, and gravel containing detrital wood clasts (unit 4, Fig. 3) were then deposited against the slope on the organic colluvium about 26,000 years ago. At least one wood-bearing organic silt layer containing buried logs up to 4 m long and 30 cm dia. occurs in unit 4, indicating the existence of a buried forest, including western fir. Streams flowed southward (Fig. 5B) and pebbles were mainly derived from the Coast Mountains (Figs. 5C, D, Appendix 2) during deposition of this unit. At measured section J cross-bedded and faulted sand occurs below stony clayey silt (unit 5) and has been mapped with unit 4. However, it is texturally similar to sand of unit 6 and may represent an early phase of proglacial outwash during the last glaciation, which was interrupted by a local ice advance from the east and northeast. A landscape was developed on unit 4.

Fossiliferous stony clayey silt (unit 5, Fig. 3) was laid down up to at least 75 m above present sea level less than 26,000 years ago when the ocean probably covered Mary Hill as the land was isostatically depressed by a piedmont ice lobe and melting icebergs and rafts dropped stones into sea-bottom muds. Pebbles from this unit have a substantial eastern component in their provenance (Figs. 5C, D, Appendix 2). Pebble fabrics (Fig. 5A) are inconclusive for this unit as two of the three fabrics are strongly oriented and a south to southwest ice advance over the glaciomarine deposits probably occurred, thereby disturbing the glaciomarine sediments and mixing them with till. Faults were probably developed in the underlying sand by the weight of glacier ice during this time. A landscape was formed on unit 5.

By about 18,600 years ago, when the climate had warmed, the ice margin had retreated from Mary Hill and a thin wood (spruce)-bearing peat layer formed at the base of the sand of unit 6. After formation of the peat layer fine to medium proglacial sand was deposited by distal meltwater streams of low discharges flowing southward (Fig 5B), in wide (1 to 10 m), shallow (0.1 to 1 m deep) and probably braided channels. During this time an ice sheet was probably advancing southward in the Coast Mountains. Eventually the small streams became greater meltwater discharges with increasing competence, flowing in larger, deeper channels and carrying increasing amounts of Coast Mountains-derived (Figs. 5C, D, Appendix 2) gravel. Isolated stones and stone clusters were probably dropped from melting ice blocks and/or tree parts carried by meltwater streams.

As the ice sheet approached the immediate area of Mary Hill large southward-flowing meltwater discharges (Fig. 5B) deposited Coast Mountains-derived (Figs. 5C, D, Appendix 2) gravel and sand of unit 7, into the sea as deltaic foreset beds dipping away from the hill while the land was being isostatically depressed.

The ice sheet eventually advanced into the area and till, unit 8, was deposited. Presumably the ice margin retreated briefly; more deltaic outwash (unit 7) was deposited; the ice margin advanced again, depositing a second till which truncated the first; and this procedure was repeated once more to form a third till truncating the previous two. Outwash gravel was deposited below, between, and above the tills (Fig. 3). Pebbles from unit 8 also have a dominant northern provenance as do those from unit 7 (Figs. 5C, D, Appendix 2). Some eastern-derived pebbles were probably reworked from older sediments in the area. During each ice advance the glacier overrode and incorporated its own rounded outwash and redeposited it in the tills. During each depositional episode of units 6, 7, and 8, Mary Hill was reshaped again and new landscapes were formed, burying and truncating the previous landscapes.

In summary, the last ice advance at Mary Hill was probably the major one during the last glaciation. The last glaciation may have started with a cooling climate about 26,000 years ago while the upper sand of unit 4 (at measured section J) was being deposited by distal outwash streams in wide, shallow channels. Perhaps a local ice lobe advanced from the east and northeast during the deposition of unit 5, then retreated rapidly while the main, distant, ice sheet continued to advance from the north. With the local ice sheet gone from Mary Hill and the main sheet yet to come, perhaps interstadial conditions existed there while a thin peat layer formed and distal, braided low-charge meltwater streams continued to deposit sand of unit 6 in wide, shallow channels. Eventually the main ice sheet reached Mary Hill and deposited units 7 and 8.

The ice later retreated as the climate became warmer and the sea covered the hill once more before the land could isostatically rebound fast enough, and fossiliferous "Glaciomarine Stony Clayey Silt" (unit 9, Fig. 3) was laid down up to at least 76 m above present sea level. As the land continued to rise, now faster than the eustatically rising sea level, the surface of Mary Hill (underlain mainly by units 8 and 9) experienced the pounding of waves and surf during storms, which partially to completely disaggregated units 8 and 9 and left a thin cover of unit 10, "Supralittoral Lag Gravel."

Armstrong (in press) has shown that other ice advances (Fort Langley, Sumas) occurred to the east of the Coquitlam-Port Moody area after the last retreat of ice from Mary Hill.

During post-glacial (Holocene) time sediments have been deposited around Mary Hill by the Fraser, Pitt, and Coquitlam Rivers; and on the hill by creeks, mass wasting, and man.

Mary Hill was reshaped during each glacial and nonglacial interval and finally by marine action. Thus the hill is a composite one, made up of many buried landscapes, each masking and/or truncating the ones constructed before it.

CHAPTER THREE: LOWER COQUITLAM VALLEY

A. Introduction

Coquitlam valley, which commences in the extreme southern part of the Coast Mountains of British Columbia, emerges onto the Fraser Lowland 20 km east of Vancouver. It is a glacier-carved bedrock valley (Armstrong and Brown, 1954), the bottom of which is filled with Quaternary sediments that are deeply incised by Coquitlam River.

Quaternary sediments are well exposed along Pipeline Road in gravel pits in the west bank of the lower part of the Coquitlam River valley below Coquitlam Lake and the Greater Vancouver Watershed. In these pits several buried landscapes have been exposed.

Lower Coquitlam valley has the highest concentration of gravel pits in the Fraser Lowland. Deeks Sand and Gravel Co. opened the first pit before 1942, which was located in the area between Pipeline Road and pits B and C (Fig. 1). Jack Cewe Ltd. started test pits 4 km to the north up the valley in 1958. Other small pits in the valley were located in Crown Land and were freely excavated by the public for their personal use until the District of Coquitlam imposed land-use by-laws for the area in the mid 1960's. Since then several companies have opened and enlarged gravel pits in the west bank of the river valley (Fig. 1).

Table I summarizes gravel pit ownership and operations that have occurred over the years on the west side of the valley.

TABLE I: GRAVEL PIT OPERATIONS ON THE WEST BANK OF THE LOWER COQUITLAM RIVER VALLEY*

Pit (Fig. 1)	OWNER	OPERATOR	DATES	Removal of Sand and Gravel from 1 April 75 to 31 March 76 (m^3)**	TYPE OF OPERATION IN 1976
B	Greater Vancouver Sewerage and Drainage District	C and C Trucking	? to 1975	278,042	front end loaders, dump trucks, sorting equipment.
	as above	West-Lin Gravel Supplies	1975 to present		
C	J. J. Allard, C. J. Smithers, R. B. Selkirk, D. Keenan, A. G. Terry	Allard Contractors Ltd.	1960's to present	6,000	as above
D	Kiewit & Sons of Canada Ltd.	same	early 1960's to ?	27,627	front end loaders, dump trucks; pit run operation with portable sorting equipment in reserve
	Kask Bros. Ready Mix Ltd.	same	? to early 1976		
	as above	C and C Trucking	early 1976 to present		
E	D and R Sand and Gravel Ltd.	same	early 1960's to ?	232,166	as above
	Allan Johnson	Johnson Trucking Ltd.	? to present		
F (north end)	C. B. Scott and E. A. Graves	S and S Sand and Gravel Ltd. until early 1970's	early 1960's to 1975	----	dormant since at least 1972
	Jack Cewe Ltd.	none	1975 to present		
F (south end)	Kiewit & Sons of Canada Ltd.	same	? to 1960's	----	as above
	Columbia Bitulithic Ltd.	same from 1960's to ?	1960's to present		
G (main pit)	Jack Cewe Ltd.	same	late 1950's to present	688,463	front end loaders, dump trucks, sorting equipment, asphalt plant.
G (extreme north end)	A. M. amd K. M. Fulawka	same	? to 1975	17,158	front end loaders, dump trucks; pit run operation
	Allard Contractors Ltd.	same	1975 to present		

* Information provided by Burt Thomas, P. Eng. District of Coquitlam
** Value of pit run material ranges from 80¢ to $1.00 per cubic yard ($0.76m^3$). Screened gravel and crushed rock is sold up to $4.25 per cubic yard.

The Deeks Sand and Gravel Co. became Deeks-McBride Ltd. by 1960 (Leaming, 1968) and they and G. H. Phillips Contracting Ltd. operated two pits in the area between Pipeline Road and pits B and C. In the late 1960's Lafarge Concrete Ltd. became the owner-operators of that area, and in 1974 they closed down the pit and the property was consigned to the Coquitlam Parks Branch. During field work very few exposures remained in this area.

Leaming (1968) reported that during the early 1960's the operating pits in the valley used diesel shovels to load trucks which carried the gravel either out of the pit or to sorting equipment elsewhere in the pit. From most pits in the lower Coquitlam River valley, gravel, sand, and crushed rock was and is excavated for sale. The District operated the remaining pits for personal use. Tens of millions of cubic meters of material have been removed from these pits since the early 1940's. From April 1, 1975 to March 31, 1976, 1.25 million m^3 of sand and gravel, valued at approximately $1.5 million (for pit run material), were excavated from the pits.

Since the closure of the Mary Hill gravel pit in 1975 (pit A, Fig. 1), the Cewe pit has become one of the largest in the province, extending 1200 m along Pipeline Road with an average width of 300 m, containing vertical faces standing 100 m high and having a vertical drop of 150 m from top to bottom. Near-vertical faces in pit F reach 75 m in height. Sediment exposures in the pits are confined to near-vertical faces and to gullies as most of the pit areas are underlain by bulldozed and slumped material.

B. Measured Sections

Fig. 6 shows the stratigraphic sections which were measured with a Wallace and Tiernan altimeter in the gravel pits on the west side of the Coquitlam River valley. These measured sections lie along one cross section line parallel to the valley axis and four small cross section lines normal to it (Index map, Fig. 6). A diagrammatic block diagram incorporating all these sections is shown later in Fig. 7.

Field data are plotted on each section, where the work was done, and are coded in the legend. The data are also recorded on maps under "Quaternary History and Conclusions" in this chapter or in the appendices.

C. Diagrammatic Composite Sections

Fig. 7 is a diagrammatic block diagram of the west bank of the lower Coquitlam River valley containing the measured sections drawn in Fig. 6. This diagram illustrates the buried landscapes and multiple valleys that were formed in the sediments during Quaternary time. Geological contacts shown by solid lines indicate where information is known from other, less well-exposed sections, and broken contacts indicate where information was extrapolated.

The sediment units are described in the legend; however, additional information is given below, commencing with the oldest unit.

Unit 1, which consists of near-impervious pebble-cobble gravel (Figs. 44, 45), is exposed in vertical overhanging faces up to 20 m high in pits E, F, and G. It contains almost entirely

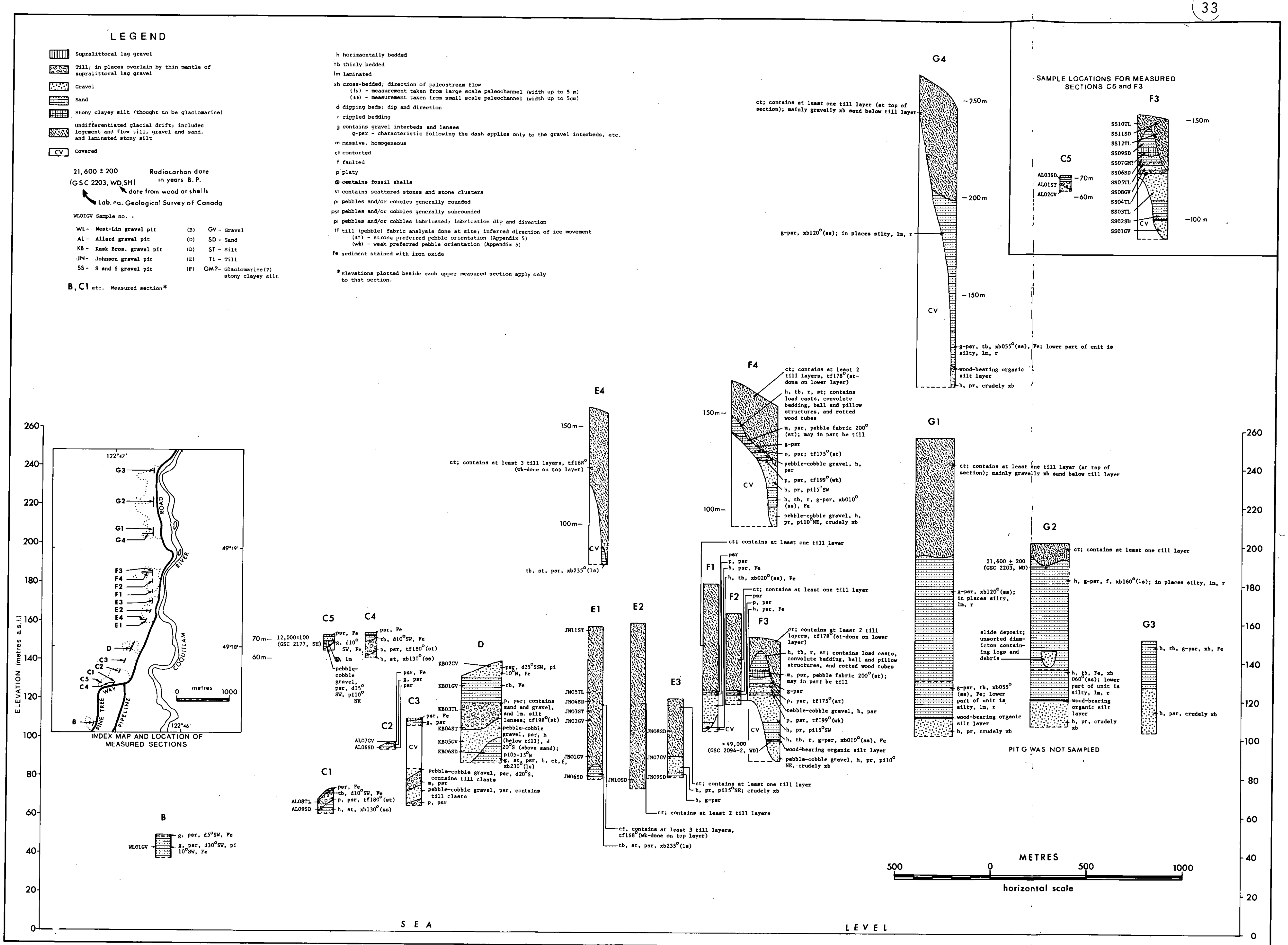


Figure 6 MEASURED STRATIGRAPHIC SECTIONS IN THE WEST BANK OF THE LOWER COQUITLAM VALLEY, B.C.

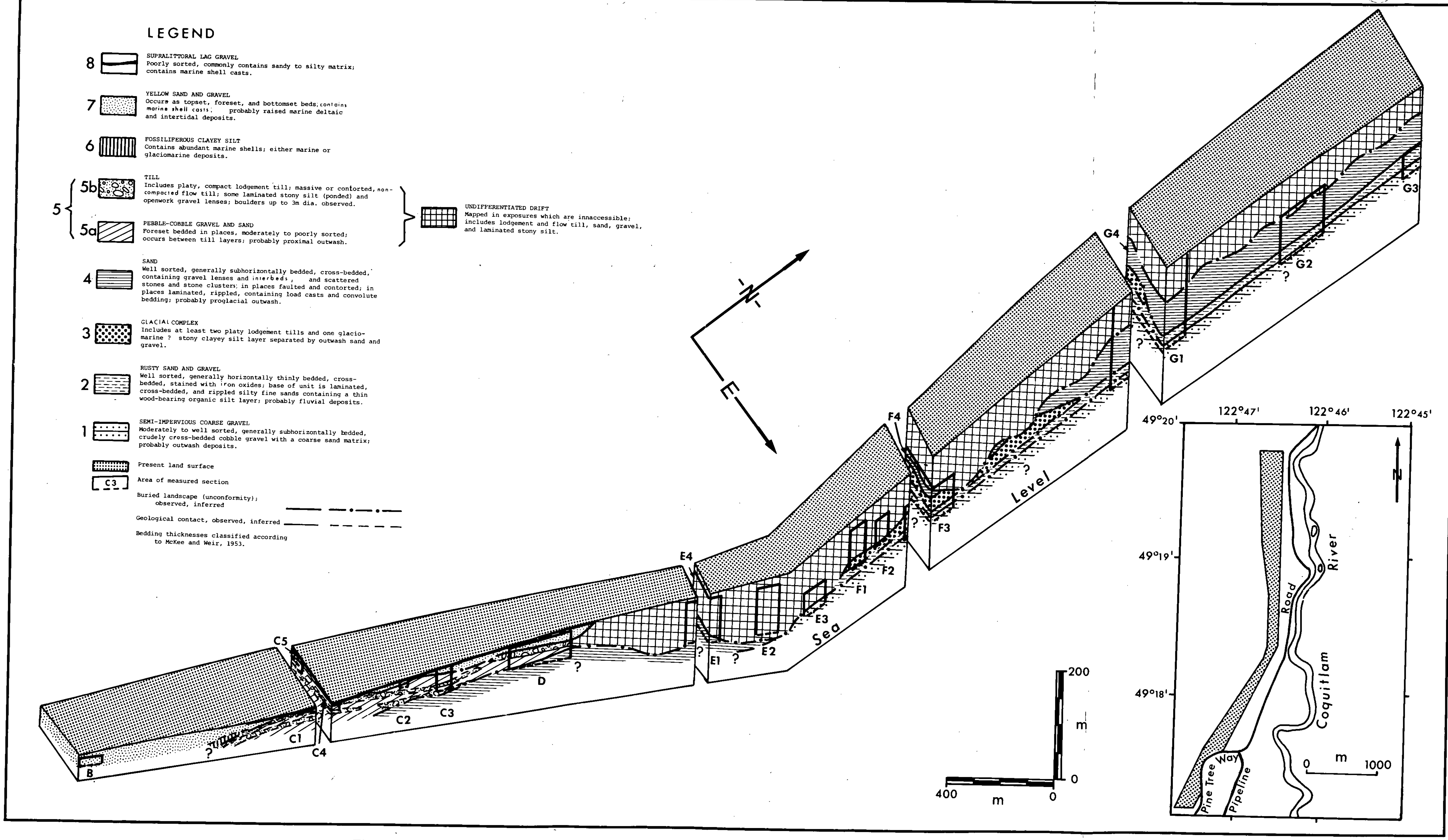


Figure 7 : BLOCK DIAGRAM, WEST SLOPE of the LOWER COQUITLAM RIVER VALLEY, B. C.

granitic stones and few sand lenses. The origin of this gravel is unknown; the moderate to poor sorting suggests it is glacio-fluvial.

Unit 2 (Figs. 41, 42, 43) is exposed in pits F and G. It is composed of well sorted fluvial sand, silt, and minor gravel and has a rusty colour. The strata are thinly bedded, cross-bedded (paleochannels up to 5 cm deep and 10 cm wide) and rippled. Wood from a thin organic silt bed (near the base of the unit) in measured section F3 was dated as >49,000 and >44,000 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.) and was identified by L. D. Wilson (pers. comm.): "...Picea sp. (spruce)."

Unit 3 occurs only in the gully at measured section F3 (Figs. 36, 37, 38) where it contains two lodgement tills and a massive stony clayey silt layer separated by horizontally bedded and cross-bedded sandy gravels. In other pits it has been covered by younger sediments and consequently is not exposed. The massive (weathers to a blocky structure) stony clayey silt (Fig. 37) has a finer matrix than the tills (Fig. 38), contains fewer stones, is less compact, and is probably glaciomarine; however, no shells or shell impressions were found in it. The gravels (Fig. 36) are probably glaciofluvial.

Unit 4 is exposed in pits D, E, F (Figs. 27, 28), and G and is mostly sand in a variety of textures and structures. It is probably proglacial outwash deposited by low-discharge meandering streams flowing in shallow (0.1 to 1 m deep), wide (1 to 10 m wide) channels. Scattered stones and stone clusters were probably dropped from ice or tree parts carried in the streams.

Faults and contortions in this unit were probably caused by the load of overriding ice that deposited unit 5. Wood from measured section G2, just below unit 5, dated 21,600$\pm$200 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.) and was identified by L. D. Wilson (pers. comm.): "...Picea sp. (spruce)."

Unit 5, till and associated drift, is exposed in all pits except B, where it is believed to be buried by younger sediments. In most pits it occurred in the higher parts of near-vertical, inaccessible exposures, where no attempt was made to differientiate the many sediment layers within it. In pits C and D, however, unit 5 could be differentiated into till (5a) and coarse outwash gravel and sand (5b). Till clasts were found in the outwash at pit C. The till is heterogeneous, containing within it lenses of sand, gravel, and laminated stony silt. It is most commonly dark grey in colour but pale orange portions are also seen where the till has been oxidized. One till was found at pit D, two tills within unit 5 occur at pits C and F, and at least three exist at pits E and G. Both compact lodgement and non-compacted flow(?) tills were observed in this unit. In many places unit 5 is highly contorted and various sediment layers are intermixed, as in ice-contact deposits (Fig. 23). Tills are truncated by the next youngest till and represent local ice advances during the last glaciation; each eroding sediments deposited by previous advances. Unit 5 mantles the Coquitlam valley fill, dips southward at pit C, and disappears below pit B under a thick cover of younger sediments.

Unit 6, clayey silt, occurs at pit C only and contains abundant marine shells including pelecypods, gastropods, annelids, and an echinoid (Fig. 18). Pelecypods occur with both valves and muscle intact, completely surrounded and filled with dark blue-grey clayey silt. A matching pair of Saxidomus Giganteus valves (identified by A. H. Clarke, pers. comm.) dated 12,000±100 radiocarbon yr. B.P. (W. A. Blake, Jr., pers. comm.). No stones were found at this site but were found in similar material elsewhere; therefore, this unit probably has a glacio-marine origin.

Unit 7, sand and gravel, occurs as a composite marine delta increasing in elevation from pits B (Fig. 17) to D. The sands and gravels are rusty and display topset, foreset, and bottomset bedding. Shell casts were found in the bottomset sand beds by Armstrong (pers. comm.) and they are probably intertidal. The delta was probably formed in a rising sea and was later terraced by wave action as the sea-level fell.

Unit 8 is a thin (up to 1 m thick) mantle of wave-washed supralittoral lag gravel at the top of the terraces and was found in pits B, C, and D. It formed as a result of storm waves and spray reworking unit 5 on the slopes of the lower Coquitlam valley when the terraces were formed. In places a transition occurs between grey, compact till of unit 5 and the overlying rusty lag gravel.

In most exposures the sediment units have undulatory contacts with and truncate older sediments. In many places these contacts were observed in three dimensions (Fig. 7).

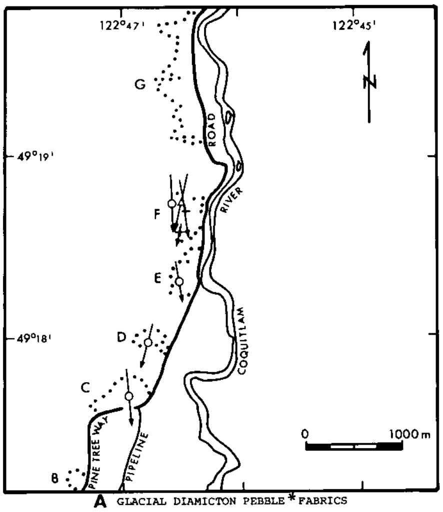
For the reasons stated in Chapter Two, a geological map was not drawn for the lower Coquitlam valley gravel pits.

D. Quaternary History and Conclusions

Quaternary sediments were deposited in the lower Coquitlam valley during at least two major advances and retreats of continental glaciers and during at least one nonglacial interval. Two glaciomarine layers indicate that the Coquitlam valley became a fiord at least twice during the Pleistocene epoch. Multiple valleys roughly parallel to the present Coquitlam River valley were developed in these sediments (Fig. 7). During the formation of each valley older sediments were eroded and removed by ice and/or water action, then filled in by more sediments.

Unit 1 is the oldest sediment found in the lower Coquitlam valley, probably glaciofluvial in origin, and was deposited more than 49,000 years ago (probably more than 62,000 years ago, according to QL-194 at Mary Hill). Unit 1 was deposited by streams flowing southward (Figs.8B, C, D, Appendix 2) down the valley from the Coast Mountains, presumably when the climate was cooler than that of today. The streams depositing unit 1 needed discharges great enough to transport cobble-sized material, that occurs in a sediment which is moderately to poorly sorted, and outwash streams are likely candidates. This was followed by a period of erosion developing a landscape which represents a radical change in sediment regime.

The climate warmed and northeastward-flowing streams (Fig. 8B) laid down unit 2 more than 49,000 years ago (probably more than 62,000 years ago) during a nonglacial interval. These were low-discharge streams compared to those depositing unit 1. An organic-rich silt layer containing spruce twigs, possibly



A GLACIAL DIAMICTON PEBBLE* FABRICS

Inferred direction of ice movement, based on:

Strong preferred pebble (long axis) orientation (Appendix 3)

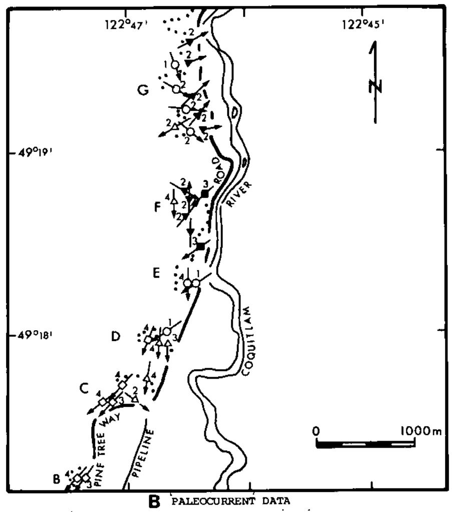
Weak preferred pebble (long axis) orientation (Appendix 3)

○ Till (unit 5b, Fig. 7)

+ Till phase of Glaical Complex (unit 3)

△ Massive stony clayey silt phase of Glacial Complex (unit 3)

*The ratio of long axis length/intermediate axis length for most pebbles was 1.5 to 2.0, 90% of all pebble long axis dipped less than 25°, and 57% dipped less than 10°; 15% dipped Northward (against direction of ice movement)



B PALEOCURRENT DATA

□ Yellow Sand and Gravel (unit 7, Fig. 7)

△ Pebble-Cobble Gravel and Sand (unit 5a)

○ Sand (unit 4)

▼ Rusty Sand and Gravel (unit 2)

■ Semi-Impervious Coarse Gravel (unit 1)

Measurements done on:

1 Cross-bedding; paleochannel widths 5cm to 5m (large scale)

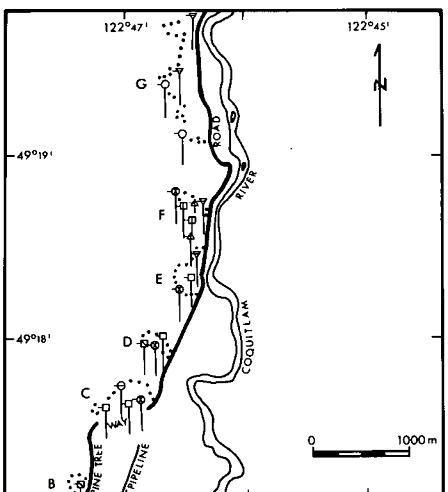
2 Cross-bedding; paleochannel width up to 5cm (small scale)

3 Pebble imbrication

4 Foreset bedding

Inferred direction of stream flow

4△△3 More than one measurement taken from same site. (e.g. Foreset bedding and pebble imbrication in unit 5a were both analyzed at same site)



C PEBBLE* PROVENANCE (see Fig. D for source areas)

Samples taken from:

⊖ Supralittoral Lag Gravel (unit 8, Fig. 7)

⊠ Yellow Sand and Gravel (unit 7)

⊗ Till (unit 5b)

□ Pebble-Cobble Gravel (unit 5a)

○ Sand (unit 4)

□ Glacial Complex (unit 3)

▲ Rusty Sand and Gravel (unit 2)

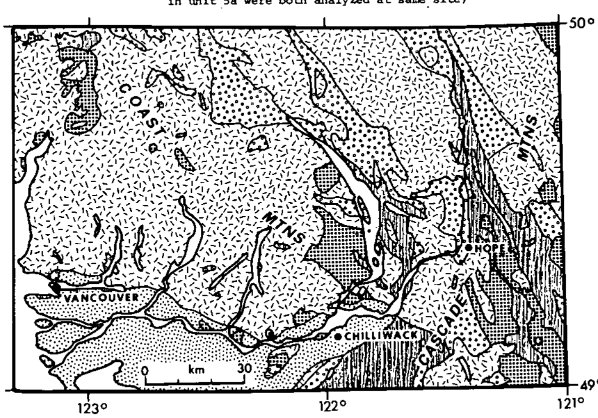
▽ Semi-Impervious Gravel (unit 1)

% Pebble sample having Cascade Mtns. source (Eastern provenance)

100 0 0 100 % pebbles having Coast Mtns. source (northern provenance)

e.g. Pebble sample from unit 5a in which 90% of the pebbles have a Coast Mtns. source (Northern provenance) and 10% have a Cascade Mtns. source (Eastern provenance)

*Pebbles ranging from 1 to 8 cm. dia. were analyzed.



D GENERALIZED REGIONAL GEOLOGY: PEBBLE SOURCE AREAS.
(modified after Roddick et. al., 1973: G.S.C. Open File Geological Map #165)

GRANITIC AND ASSOCIATED ROCK TYPES (including low grade metamplutonics and metavolcanics)

VOLCANIC ROCK TYPES (including flows, tuffs, and breccias)

QUARTZITE, CHERT, PELITE, AND ARGILLITE

OTHER ROCK TYPES (including medium to high grade metamorphics, sedimentary, and ultramafics)

UNCONSOLIDATED (QUATERNARY) SEDIMENTS

Fig. 8 RESULTS OF SOME FIELD WORK DONE IN THE LOWER COQUITLAM RIVER VALLEY GRAVEL PITS: A, GLACIAL DIAMICTON PEBBLE FABRICS; B, PALEOCURRENT DATA; C, PEBBLE PROVENANCE; D, GENERALIZED REGIONAL GEOLOGY SHOWING SOURCE AREAS FOR PEBBLES IN C.

with some trees growing in it, formed at this time. Scattered pebbles in unit 2 have a dominantly northern provenance (Figs. 8C, D, Appendix 2) and may have been reworked from older sediments by streams flowing northeastward into the valley. An erosional period followed this and a landscape was developed on these deposits.

As the result of a cooling climate and the onset of another glaciation, southward-flowing meltwater streams modified the landscape and covered it with sandy gravel outwash of unit 3. The first till of unit 3 was deposited on the outwash when ice advanced south, from the Coast Mountains to the north (Figs. 8A, C, D, Appendix 2), and filled the Coquitlam valley. Following a brief retreat of the ice, more outwash of unit 3 was laid down; then the ice readvanced, depositing the second till of unit 3. With renewed climatic warming the ice retreated again, more outwash was laid down, and the sea appears to have invaded the valley, which became a fiord. The fiord later disappeared with land uplift. During this deglaciation a stony clayey silt layer interpreted to be glaciomarine sediments was formed to at least 135 m a.s.l. when floating ice probably dropped stones into mud on the sea floor. Fig. 8C indicates that almost all of the stone are derived from the Coast Mountains and suggests that icebergs drifted southward down the fiord. Fig. 8A suggests these pebbles are strongly oriented, perhaps imbricated, and their long axes dip generally northward. This glaciomarine? layer may in part be till; however, the pebble orientation may be coincidental. The layer contains fewer stones than the tills, the matrix is finer than the tills of unit 3, and this layer is massive and little compacted; whereas the tills are platy and highly compacted. Similar sediments in the same stratigraphic position occur elsewhere in the Fraser Lowland and contain marine shells (Armstrong, in press). Therefore, a glaciomarine origin for this layer is preferred. Absolute sea-level changes due to isostatic and eustatic events during deposition of these sediments is unknown; only the net change relative to present sea level was determined. Lack of radiocarbon dates prevents control on the timing of these events. Clasts of peat were found in the outwash gravels of unit 3 and may have been reworked from unit 2. Landscapes were developed on each of the deposits in unit 3.

After further isostatic uplift (assuming the stony clayey silt layer is glaciomarine) southward-flowing streams from the Coast Mountains (Figs. 8B, C, D, Appendix 2) cut into the sediments deposited earlier, and unit 4 was deposited by about 21,600 years ago on a new landscape, filling in the valley formed. If the stony clayey silt is not glaciomarine, it is probably till or ponded sediments and the sea would not have entered the valley at that time, but instead another ice advance may have occurred. Climatic cooling had begun again by the time of unit 4 deposition and the low-discharge streams that carried the sands in shallow (o.1 to 1 m deep), wide (1 to 10 m wide) channels debouched from southward-advancing ice of the ensuing glaciation, probably still far to the north in the Coast Mountains. Scattered stones and stone clusters found in this unit were probably dropped from melting ice blocks and tree parts carried by the proglacial streams. The dated spruce stick from unit 4 (GSC-2203 21,600±200 radiocarbon yr. B.P.) had rounded ends and a smooth surface and may have been reworked from a wood-bearing sediment layer representing a nonglacial interval and not exposed in the lower Coquitlam River valley. It may be that a nonglacial interval occurred between the periods when units 3 and 4 were deposited, and is now represented only by a buried landscape. Perhaps two nonglacial intervals are recorded in the Pleistocene sediments in the lower Coquitlam valley, although only the deposits of one (unit 2) are exposed.

The advancing glacier eventually moved southward from the Coast Mountains (Figs. 8A, C, D, Appendix 2) and entered the valley while southward-flowing meltwater streams (Figs. 8B, C, D, Appendix 2) cut into unit 4 and older sediments and formed a new valley, filling it with unit 5a. These streams had greater discharges and flowed in channels deeper and narrower than the streams depositing unit 4. As the ice filled the Coquitlam valley, it remodelled previous landscapes and deposited till of unit 5b. The sediments overridden by this ice (units 5a, 4) were faulted and contorted in some places. At least three tills (unit 5b), separated by outwash sand and gravel (unit 5a), and containing lenses of ponded laminated stony silt and fine sand, were deposited in the valley by local glacier advances and retreats during this glaciation. Most are compact platy lodgement tills formed at the base of the glacier ice; however, some non-compacted, contorted flow tills were deposited as viscous stony mudflows at the edge of wasting ice. During the deposition of each till and outwash layer, ice and water action reshaped the older landscapes and formed a new one.

By 13,000 years B.P. (based on radiocarbon data outside the thesis area from J. E. Armstrong), another deglaciation was in progress. The climate had warmed and as the ice retreated, the sea entered the Coquitlam valley, which became a fiord again, and marine and glaciomarine sediments of unit 6 were deposited on a landscape to at least 70 m a.s.l. Absolute sea-level changes due to isostatic and eustatic events during this time are unknown; only the net change relative to present sea level was determined.

Following this, unit 7 was formed as a composite marine delta by recessional outwash being carried down the valley to the sea by southward-flowing meltwater streams (Figs. 8B, C, D, Appendix 2) debouching from the retreating ice to the north.

As the land isostatically rose above the sea, surf pounded against the valley walls. Waves and spray reworked the drift of unit 5, forming a supralittoral lag gravel, unit 8, up to 175 m a.s.l. while carving terraces up to 140 m a.s.l. into the delta of unit 7. This marine action modified older landscapes and formed yet a new one, similar to the present-day landscape.

Later ice advances (Fort Langley, Sumas) occurred to the east of the Coquitlam valley, after the last ice advance into the valley, but did not reach it (Armstrong, in press).

During the post-glacial (Recent) time sediments have been deposited and eroded by the present Coquitlam River in the bottom of its valley, and by mass wastage processes and human activity on the river banks.

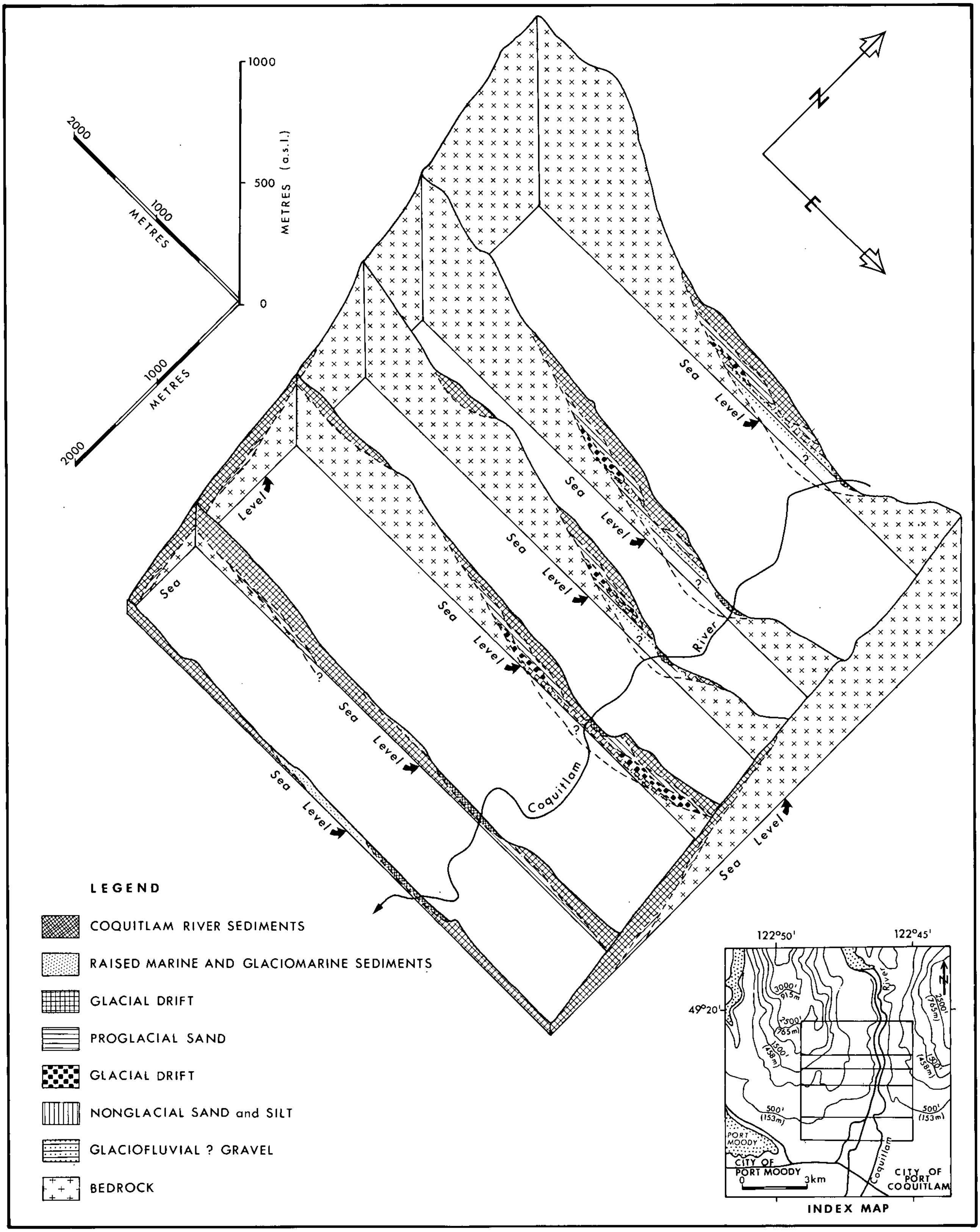


Figure 9 HYPOTHETICAL FENCE DIAGRAM, LOWER COQUITLAM VALLEY, B.C.

Throughout the history of sediment deposition in the Coquitlam valley, tectonic adjustments probably occurred; however, their importance and magnitude are completely unknown.

The lower Coquitlam valley is the best illustrated example of the complex geological makeup of Quaternary sediment fills found in glaciated bedrock valleys bordering the Fraser Lowland. Fig. 7 demonstrates the sporadic occurrence of sediment units and buried landscapes in the western slope of the lower Coquitlam River valley. A hypothetical model for the distribution of these units in the sediment fill occupying the bottom of the lower Coquitlam (bedrock) valley is shown in Fig. 9. This sketch illustrates the multiple valley development that occurred in the sediment fill throughout Quaternary time. Other sediment-filled, glaciated bedrock valleys bordering the Fraser Lowland may also contain similar phenomena.

Because of the multiple valley fills making up the Quaternary sediments in the lower Coquitlam valley, correlations of sediment units made on other than a three-dimensional study supported by radiocarbon dates are at best tentative and may lead to misleading conclusions. Nine sediment units have been mapped in Fig. 7 and these can be further subdivided on a smaller scale. In some places a drill hole could penetrate more than twelve different sediment layers, and in others, only a few meters away, as few as two.

CHAPTER FOUR: PORT MOODY DISPOSAL SITE

A. Introduction

The best Pleistocene exposure in the area other than Mary Hill and the Coquitlam valley exposures occurs at the Port Moody sanitary landfill site on the Barnet Highway (Fig. 1). Here a section containing buried landscapes is exposed, and the section represents only a small part of a larger composite hill. The section observed occurs in a gullied vertical face 35 m high on the east side of a large creek gully south of the Barnet Highway.

The pit was originally opened on the west side of the gully in 1963 by Scott Bros. Gravel Co. Ltd. for sand sales. In the mid 1960's British-American Oil Co. gained control of the pit while the City of Port Moody opened another pit on the east side of the ravine. Garbage and sand were used to fill the gully and a drainage culvert was installed in place of a former bridge to permit the creek to enter Burrard Inlet. The present road was then built over the fill. The city also used their pit on the east side of the ravine for garbage disposal but excavated only minor amounts of sand for their own use outside the pit. In the late 1960's the city became the sole owner of both pits and since then have filled almost the entire gully with garbage and sand. During field work a front end loader filled dump trucks with sand and the trucks dumped the sand on the garbage piles. A bulldozer then levelled the garbage and spread a blanket of sand over it. Only minor amounts of sand were being excavated and trucked out of the pit when the writer examined it. The city is not digging further into the hillside as the vertical east face is too high and must be benched before further excavation can proceed.

B. Measured Sections

The best exposed stratigraphic sections in the pit were measured with a Wallace and Tiernan altimeter and are shown in Fig. 10. They lie along one short cross section line parallel to the pit face on the eastern side of the gully mentioned in the Introduction. The diagrammatic cross section is shown later in Fig. 11. Field data are plotted on each section where work was done and coded in the legend. The data are also recorded on separate maps under "Quaternary History and Conclusions" in this chapter or in the appendices.

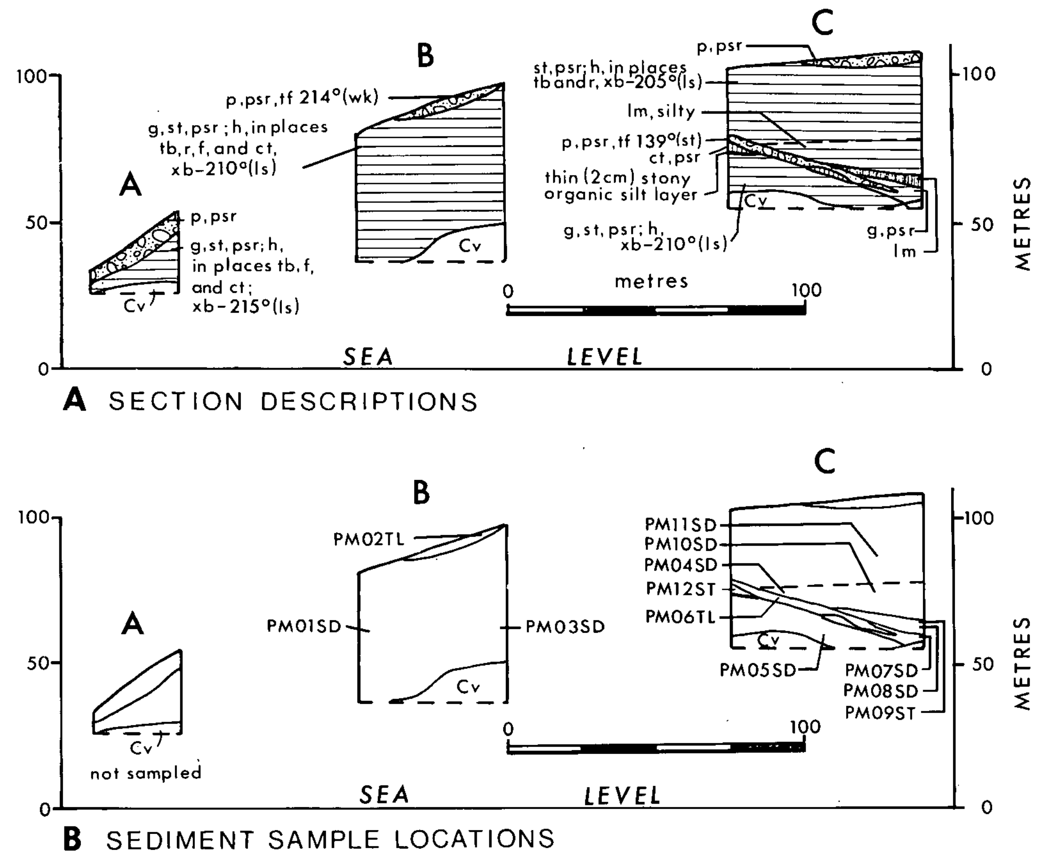
C. Diagrammatic Composite Section

Fig. 11 is a diagrammatic cross section through Quaternary sediments exposed at the Port Moody sanitary landfill site. The measured sections in Fig. 6 and the base of exposure at the time of mapping are plotted on the cross section. Geological contacts shown by solid lines indicate where information is known from other, less-well exposed sections, and broken contacts indicate where information was extrapolated.

Sediment units are sufficiently described in the legend. A geological map of the pit was not drawn for the reasons stated in Chapters Two and Three.

D. Quaternary History and Conclusions

The Port Moody site has been subjected to at least two



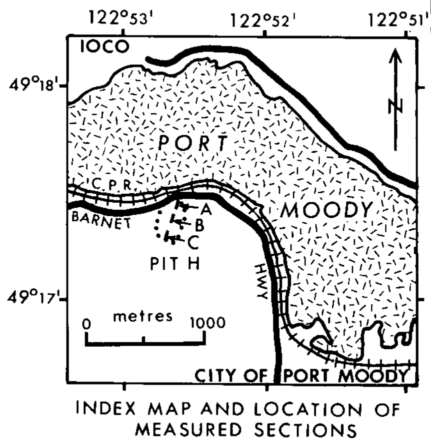
Till

Sand

Stony Silt

Wood-bearing organic silt layer

Cv Covered



PM01SD Sample Number

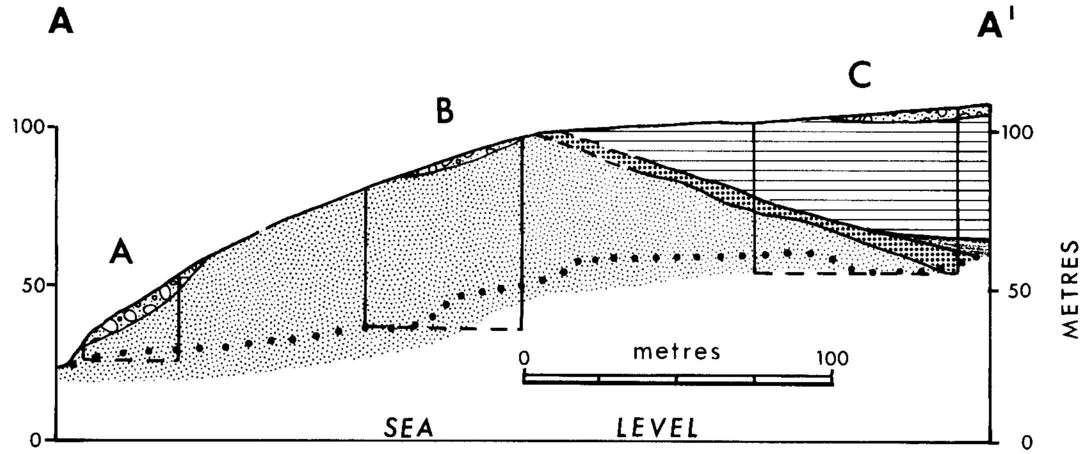
SD Sand ST Silt

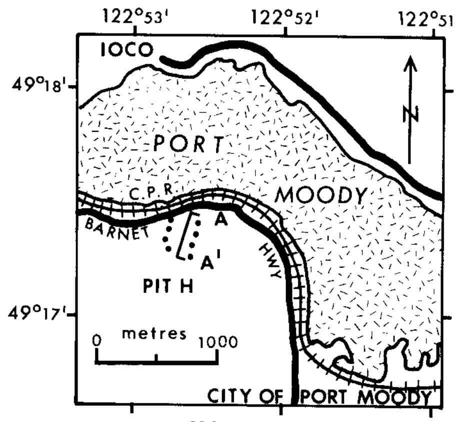
TL Till PM Port Moody site

A, B, C Measured stratigraphic sections

- h horizontally bedded
- tb thinly bedded
- lm laminated
- xb cross - bedded; direction of paleostream flow
  - (ls) - measurement taken from large scale paleochannel (width 1 to 5 m)
- r rippled bedding
- g contains gravel interbeds and lenses
- ct contorted
- f faulted
- p platy
- st contains scattered stones and stone clusters
- psr pebbles generally subrounded
- tf till (pebble) fabric analysis done at site; inferred direction of ice movement
  - (st) - strong preferred pebble orientation (Appendix 3)
  - (wk) - weak preferred pebble orientation (Appendix 3)

Fig. 10 MEASURED STRATIGRAPHIC SECTIONS AT THE PORT MOODY DISPOSAL SITE (PIT H, Fig. 1): A. SECTION DESCRIPTIONS, B. SEDIMENT SAMPLE LOCATIONS.





INDEX MAP

5 — TILL
Platy lodgement till.

4 — UPPER SAND
Contains scattered stones and stone clusters; grades downward from horizontally bedded, cross-bedded med. sand to thinly bedded and rippled fine sand; probably proglacial outwash and fluvial deposits.

3 — FOSSIL SWAMP DEPOSIT
Laminated fine sandy silt containing fossil leaves, twigs, and logs up to 1 m long and 15 cm dia.; swamp and fluvial deposits.

2 — DRIFT LAYER
Includes logement till, contorted stony silt, and gravelly sand; stony silt probably glaciolacustrine; sand probably glaciofluvial.

1 — LOWER SAND
Identical in texture to unit 5; faulted, subhorizontally bedded, cross-bedded, in places thinly bedded and rippled; contains minor gravel lenses and interbeds, and scattered stones and stone clusters; probably glaciofluvial deposits.

— — — Buried land scape (unconformity) and geological contact; observed, inferred.

••••• Base of exposure.

A — Area of measured section.

Fig. 11 DIAGRAMMATIC COMPOSITE SECTION, PORT MOODY DISPOSAL SITE, PORT MOODY, BRITISH COLUMBIA.

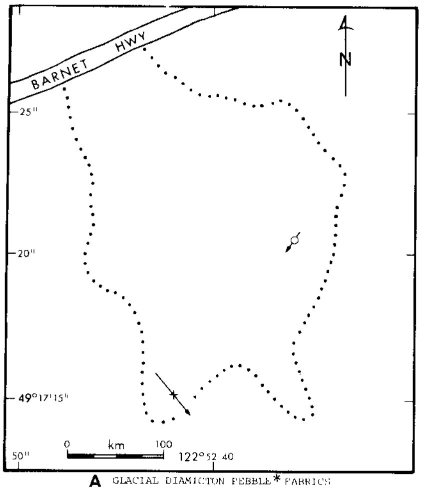
glaciations separated by at least one nonglacial interval. During these events sediments were deposited on landscapes of hills which were later reshaped by water and ice action. These sediments and landscapes eventually made up a composite hill, a remnant of which exists at Port Moody today.

The oldest unit exposed is the sand of unit 1. It was probably deposited as proglacial channel and flood plain deposits, during a climate cooler than that of today, by southward-flowing streams debouching from a glacier to the north in the Coast Mountains (Figs. 12B, C, D, Appendix 2). Scattered stones and stone clusters probably dropped from melting ice blocks and tree parts carried in the streams. The low-discharge streams flowed in shallow (0.1 to 1 m deep) and wide (1 m to 10 m wide) channels. Faults in the sand were probably caused after deposition by the load of overriding ice that deposited unit 2. A landscape was formed on this unit by water and ice action.

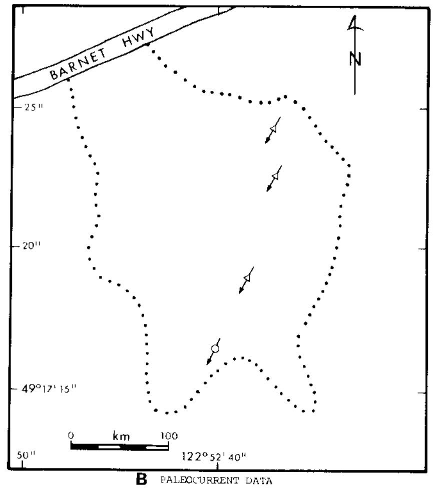
The ice advanced further southward (Fig. 12A) into the Port Moody area and lodgement till was laid down on the landscape with outwash sand and gravel and ponded stony silt of unit 2.

As the result of a warming climate, the ice retreated and a nonglacial interval began. Laminated silt and fine sand of unit 3 were deposited in a swamp, containing trees, against the slope formed on top of unit 2.

The climate cooled again after that and proglacial sands of unit 4 were deposited by southward-flowing streams from ice to the north in the Coast Mountains (Figs. 12B, C, D, Appendix 2). The sands grade from thinly bedded and stoneless at the base of



A GLACIAL DIAMICTON PEBBLE* FABRICS



B PALEOCURRENT DATA

Inferred direction of ice movement, based on:

Strong preferred pebble (long axis) orientation (Appendix 3)

Weak preferred pebble (long axis) orientation (Appendix 3)

O Till (unit 5, Fig. 11)

+ Till phase of Drift Layer (unit 2)

*The ratio of long axis length/intermediate axis length for most pebbles was 1.5 to 2.0. Almost all pebble long axis measured dipped Northward (against direction of ice movement)

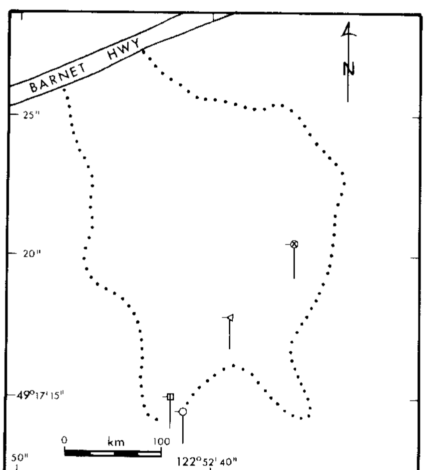
O Upper Sand (unit 4, Fig. 11)

Δ Lower Sand (unit 1)

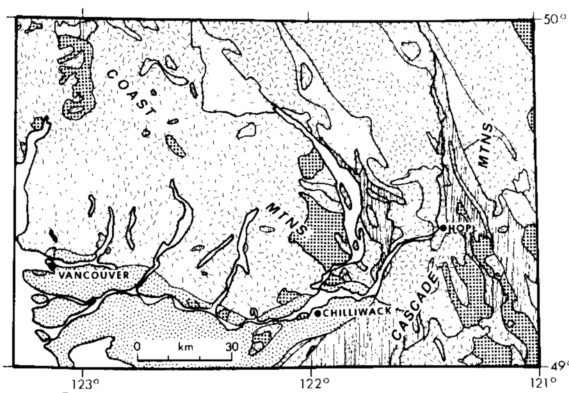
Measurements done on

Cross-bedding; paleochannel width 1 to 5 m (large scale)

Inferred direction of stream flow



C PEBBLE* PROVENANCE (see Fig. D for source areas)



D GENERALIZED REGIONAL GEOLOGY: PEBBLE SOURCE AREAS.

(modified after Roddick et. al., 1973: G.S.C. Open File Geological Map #165)

Samples taken from:

⊗ Till (unit 5, Fig. 11)

O Upper Sand (unit 4)

⊞ Drift layer (unit 2)

Δ Lower Sand (unit 1)

% pebbles having Cascade Mtns. source (eastern provenance)

100 0 — 0 — 100: % pebbles having Coast Mtns. source (northern provenance)

pebble sample from unit 4 in which 85% of the pebbles have a Coast Mtn. source (northern provenance) and 15% have a Cascade Mtns. source (eastern provenance)

*Pebbles ranging from 1 to 8 cm in dia. were analyzed.

GRANITIC AND ASSOCIATED ROCK TYPES (including low grade metaplutonics and metavolcanics)

VOLCANIC ROCK TYPES (including flows, tuffs, and breccias)

QUARTZITE, CHERT, PELITE, AND ARGILLITE

OTHER ROCK TYPES (including medium to high grade metamorphics, sedimentary, and ultramafics)

UNCONSOLIDATED (QUATERNARY) SEDIMENTS

Fig.12 RESULTS OF SOME FIELD WORK DONE AT THE PORT MOODY DISPOSAL SITE: A, GLACIAL DIAMICTON PEBBLE FABRICS; B, PALEOCURRENT DATA; C, PEBBLE PROVENANCE; D, GENERALIZED REGIONAL GEOLOGY SHOWING SOURCE AREAS FOR PEBBLES IN C.

the unit into gravelly cross-bedded sands in deep (10 to 20 cm deep) and narrow (30 to 50 cm wide) channels at the top, indicating that the streams increased in discharge and competence as the advancing ice approached the Port Moody area. A landscape was developed on unit 4 by water and ice action.

As the glacier advanced southward (Fig. 12A), covering the site, it remolded the landscape and deposited till of unit 5 which truncated the older units.

Marine and glaciomarine deposits were formed in adjacent areas during the last ice retreat (Chapters Two and Three); however, these deposits were not found at the Port Moody site.

Lack of radiocarbon dates from this pit prevents control on the timing of Quaternary events; however dates from adjacent areas can probably be extrapolated for some of the units. The wood layer is expected to be 25,000-60,000 years old, based on dates from similar sediments at Mary Hill and elsewhere in the Fraser Lowland.

During post-glacial (Holocene) time sediments have been deposited and eroded by local stream action, mass wastage processes, and human activity.

The Port Moody section contains four buried landscapes within it. These landscapes occur at the base of each sediment unit and each unit is, in most cases, truncated by younger ones. In the small area that Fig. 11 represents unit 1 is truncated by unit 2; which was deposited on a southward-sloping landscape; unit 3 abuts against unit 2; unit 4 overlies unit 3, and also abuts against unit 2; and finally, unit 5 truncates units 4, 2, and 1. If these buried landscapes are extrapolated to the north

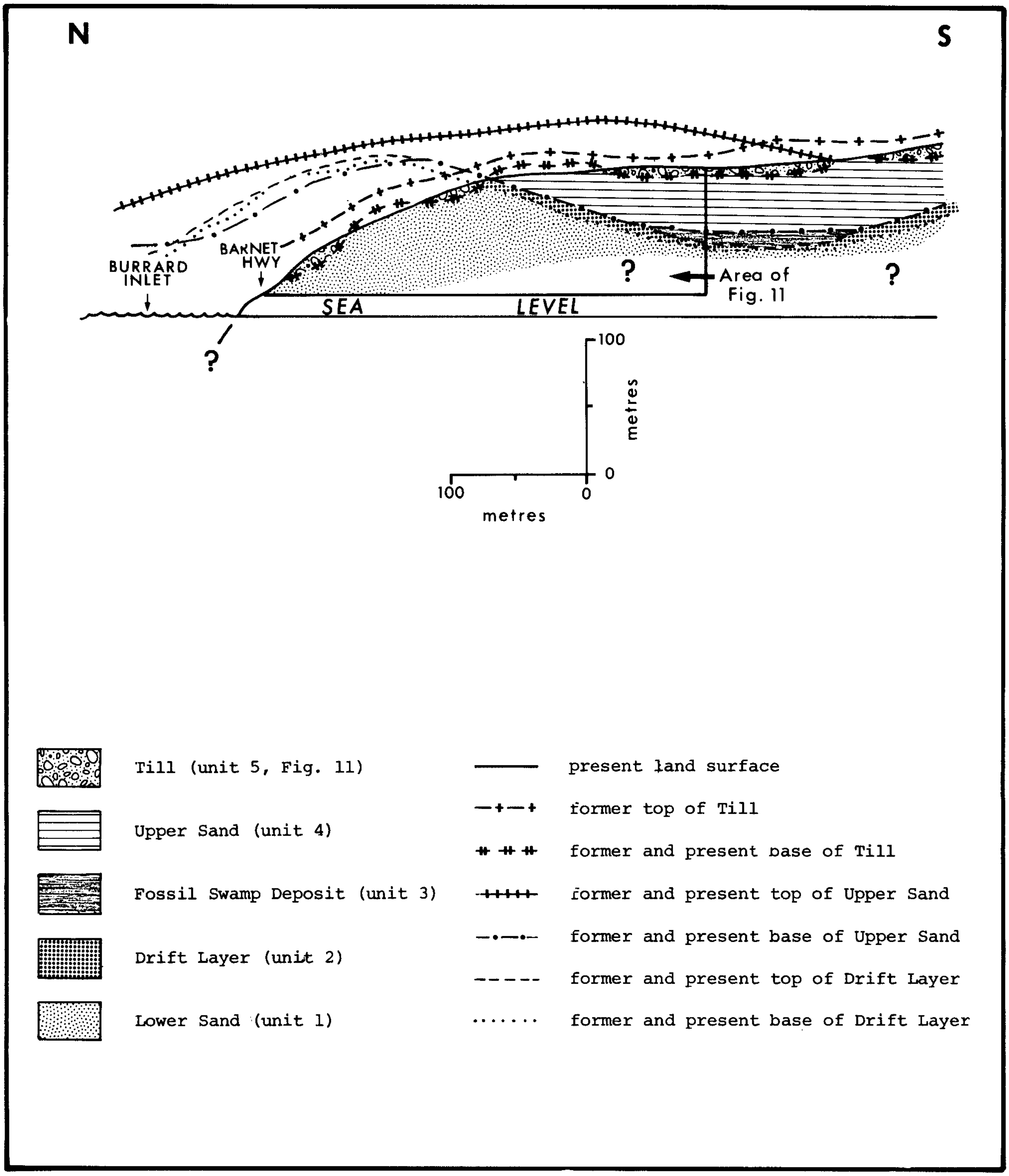


Figure 13 HYPOTHETICAL RECONSTRUCTION OF PARTS OF HILLS DEVELOPED DURING QUARTERNARY TIME NEAR PORT MOODY, BRITISH COLUMBIA.

and south of the pit, a series of hills formed at various stages throughout Quaternary time would be reconstructed and this is illustrated by the hypothetical diagram in Fig. 13. In this sketch each sediment unit has a sloping contact with adjacent units and in most cases is truncated by younger units.

The Port Moody sanitary landfill site is only a small part of a larger composite hill, not unlike Mary Hill described in Chapter Two, and is another example of the Quaternary composite hills, containing many buried landscapes, that occur in the Fraser Lowland.

CHAPTER FIVE: QUATERNARY STRATIGRAPHY

A. Correlation of Sediment Units

Fig. 14 is a hypothetical fence diagram through the Coquitlam-Port Moody area showing the Quaternary stratigraphy and correlation of sediment units described in Chapters Two to Four. The correlation is based on the composite sections drawn in these chapters, supplemented by drillhole information. Nine formational lithostratigraphic units are distinguishable in the Quaternary deposits exposed in the area. Each unit represents a geologic-climatic unit that has a glacial, stadial, nonglacial (interglacial), or interstadial rank. Formal names have been assigned to the nine lithostratigraphic units in Fig. 14, which have been correlated with the Quaternary stratigraphic succession established for the Fraser Lowland (in which the Coquitlam-Port Moody area is located) during 1974 to 1976 by J. E. Armstrong and S. R. Hicock. Correlations of sediment units (described in Chapters Two to Four) with this established succession are listed in Table II. A brief history of the derivation of the succession follows.

Armstrong (1975a) established that five major Pleistocene formational units, each probably representing a major geologic-climatic unit, are exposed in the Fraser Lowland. These units are as follows (youngest to oldest): Fraser Glaciation: Fraser Drift; Olympia Nonglacial Interval: Quadra Sediments; Major Glaciation: Semiahmoo Drift; Nonglacial Interval: Highbury Sediments; Major Glaciation?: Westlynn Drift.

TABLE II: CORRELATION OF LITHOSTRATIGRAPHIC UNITS

GEOLOGIC-CLIMATIC UNITS (After Armstrong, in press and Armstrong and Hicock, 1976)	RADIOCARBON AGES YEARS B.P.	ESTABLISHED STRATIGRAPHIC SUCCESSION FOR THE FRASER LOWLAND (mod. after Armstrong, in press)	SEDIMENT UNITS AT MARY HILL (Fig. 3)	SEDIMENT UNITS AT COQUITLAM VALLEY (Fig. 7)	SEDIMENT UNITS AT PORT MOODY (Fig. 11)
HOLOCENE	11,000 to present	Holocene Sediments	Fraser River Sediments	----	----

PLEISTOCENE
LATE WISCONSIN
FRASER GLACIATION
	26,000 to 11,000	Capilano Sediments {
		Vashon Drift {
		Quadra Sand
		Coquitlam Drift
			Supralittoral Lag Gravel (10)*
			---- 	
			Glaciomarine Stony Clayey Silt (9)
			Till (8)
			Pebble-Cobble Gravel (7)
			Sand (6)
			Stony Clayey Silt (5)
				Supralittoral Lag Gravel (9)
				Yellow Sand and Gravel (8)
				Fossiliferous Clayey Silt (7)
				Till (6)
				Pebble-Cobble Gravel & Sand (5)
				Sand (4)
				---- 	
					---- 	
					---- 	
					---- 	
					Till (5)
					---- 	
					?Upper Sand (4)
					---- 	

MIDDLE WISCONSIN OLYMPIA NONGLACIAL INTERVAL	60,000? to 26,000	Cowichan Head Formation {	Sandy Gravel (4) Fossil Bog and Gyttja Deposits (3) ?Stony Colluvial Organic Complex (2)	---- ---- ----	---- ?Fossil Swamp Deposit (3) ----
MIDDLE OR EARLY WISCONSIN MAJOR GLACIATION	probably >62,000	Semiahmoo Drift {	Undifferentiated Glacial Complex (1) ----	Glacial Complex (3) ----	?Drift Layer (2) ?Lower Sand (1)
EARLY WISCONSIN? MAJOR NONGLACIAL INTERVAL	probably >62,000	Highbury Sediments	----	Rusty Sand and Gravel (2)	----
EARLY OR PRE-WISCONSIN MAJOR GLACIATION	>62,000	Westlynn Drift	----	?Semi-Impervious Cobble Gravel (1)	----

* Numbers in brackets refer to sediment unit numbers in each figure. ? Question marks indicate that sediment units behind them may not belong where they are placed in the established stratigraphic succession.

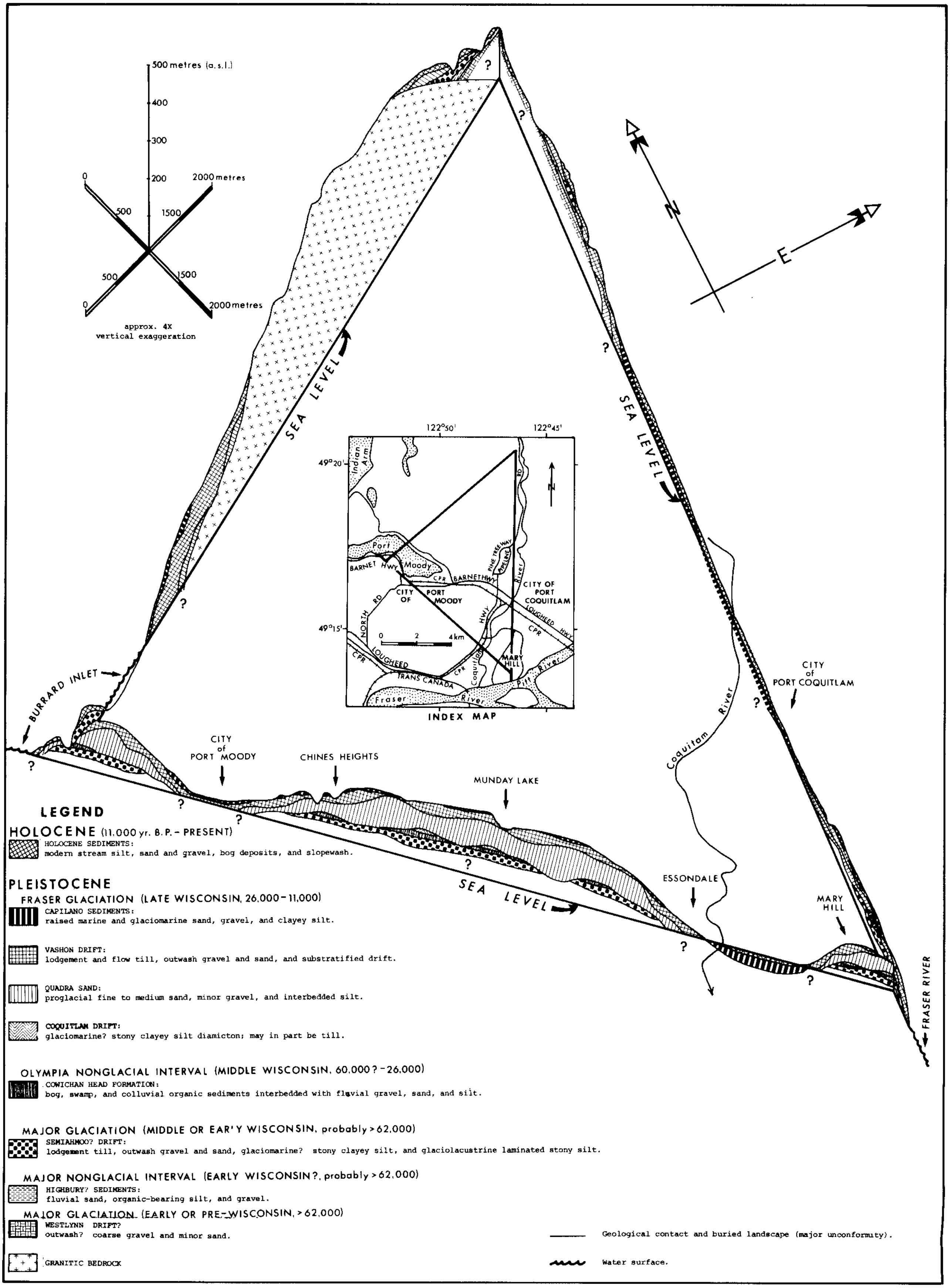


Figure 14 HYPOTHETICAL QUATERNARY FENCE DIAGRAM: COQUITLAM-PORT MOODY, BRITISH COLUMBIA

Armstrong and Hicock (1975) described five major litho-stratigraphic units exposed at Mary Hill and assigned them to four of the major geologic-climatic units (youngest to oldest): Fraser Glaciation: Capilano Sediments, Vashon Drift; Olympia Interglaciation: Quadra Sediments; Major Glaciation: Semiahmoo Drift; Nonglacial Interval: Highbury Sediments.

Armstrong and Hicock (1976) later established six major lithostratigraphic units in the lower Coquitlam valley and correlated them with four of the major geologic-climatic units (youngest to oldest): Fraser Glaciation: Capilano Sediments, Vashon Drift, Quadra Sand; Major Glaciation: Semiahmoo? Drift; Nonglacial Interval: Highbury? Sediments; Glaciation?: Pre-Highbury? Gravel.

Additional information showed that some of the above correlations needed modification.

The term "Quadra" was applied to deposits known to be inter-till fluvial, glaciofluvial, marine and glaciomarine sediments exposed in coastal southwestern British Columbia and northwestern Washington and the deposits were assigned to a nonglacial interval by Armstrong and Brown (1953) and Fyles (1963). Armstrong et al. (1965) and Easterbrook (1969) later assigned Quadra deposits to the Olympia nonglacial interval. Recently Clague (1976) demonstrated a glaciofluvial origin for most of the level-bedded and cross-bedded sand in these deposits, and Armstrong and Clague (1976) redefined the "Quadra" sediments, establishing two new stratotypes. They defined "Quadra Sand" as the proglacial upper sands associated with the Fraser Glaciation, and the "Cowichan Head Formation" as the lower bog, swamp, fluvial, estuarine, and marine silt, sand, gravel, and organic deposits associated with the Olympia nonglacial interval. Thus, at Mary Hill the "Quadra Sediments" of Armstrong and Hicock (1975) may be split into Quadra Sand of the Fraser Glaciation including: proglacial and fluvial sand and minor gravel (unit 6, Fig. 3); and the Cowichan Head Formation of the Olympia non-glacial interval including: organic sediments, silt, sand, and gravel (units 2?, 3, and 4, Fig. 3). Recently received radio-carbon dates indicate that the deposits correlated with Highbury Sediments at Mary Hill by Armstrong and Hicock (1975) are probably part of the Cowichan Head Formation and that true Highbury Sediments are not exposed at Mary Hill; the oldest unit exposed there is Semiahmoo? Drift.

Radiocarbon dates from Mary Hill also indicate the existence of a drift unit (unit 5, Fig. 3) older than Vashon and younger than the Cowichan Head Formation. This unit has not been described previously for mainland British Columbia and may correlate with the Evans Creek Stade which occurred in Washington State, early during the Fraser Glaciation (Armstrong, et al., 1965). Thus a new lithostratigraphic unit associated with the Fraser Glaciation may be added to the established stratigraphic succession for the Fraser Lowland.

Correlations in the lower Coquitlam valley by Armstrong and Hicock (1976) are believed to be correct.

B. Composite Section and Description of Lithostratigraphic Units

Detailed descriptions of sediment units exposed at individual sites are given in Chapters Two to Four. The following is a composite section of lithostratigraphic units exposed in the Coquitlam-Port Moody area, listed from youngest to oldest, using the nomenclature established for the Fraser Lowland. Plates 1 to 5 illustrate most of the sediment units described.

Description	Max. Thickness (m) Observed
HOLOCENE	
Holocene Sediments	
Sediments deposited by the Fraser, Coquitlam, and Pitt Rivers, by mountain and lowland streams, in bogs and swamps, and by mass wasting and man.	?
PLEISTOCENE	
Fraser Glaciation	
Capilano Sediments	
Rusty sandy to silty supralittoral lag gravel (Fig. 15) containing subangular granitic pebbles. The matrix is mainly composed of subangular granitic detritus, and contains marine shell casts (Fig. 16). Forms a mantle up to 1 m thick on Capilano glaciomarine sediments and Vashon Drift. Formed by sea waves and spray reworking these latter deposits.	1
Interbedded yellow sandy gravel and gravelly sand (Fig. 17) containing subangular to subrounded granitic pebbles. Sand is subrounded to subangular, composed mainly of quartz and feldspar with minor hornblende and granitic rock fragments. Occurs in southward-dipping foreset and subhorizontal topset beds and was deposited into the sea as a composite delta.	15
Fine to medium yellow sand, subhorizontally thinly bedded, containing subrounded grains composed mainly of quartz and feldspar with minor hornblende, biotite, and granitic rock fragments. Contains marine shell casts and was deposited as marine littoral and deltaic sediments.	14

Stony to stoneless clayey silt containing abundant marine shells (Fig. 18). Bedded in places, it has a blocky structure with manganese oxide staining on joint surfaces (Fig. 19). Stones are mainly rounded and granitic and the fines are composed of quartz and feldspar with minor hornblende and granitic rock fragments. Marine and glaciomarine deposits. GSC 2177 (shells-12,000±100) collected from this layer. 4

Major Unconformity

Vashon Drift

Till (Fig. 20), at least three sheets representing local ice advances, separated by outwash gravel and sand. Mostly lodgement, but probably includes flow till. Contains lenses of ponded, laminated stony silt. Contains subrounded to subangular granitic pebbles to boulders up to 5 m dia. (Fig. 21). Matrix grains are angular faceted, and mainly composed of quartz and feldspar with minor hornblende, epidote, and granitic rock fragments. 14

Sandy gravel and gravelly sand, under, between, and over Vashon till sheets, containing thinly bedded silty fine sand lenses. Extremely variable in texture and structures; from foreset cobble gravel beds (Fig. 22) to faulted and contorted sand and gravel displaying ice-contact features (Fig. 23). Contains subrounded to subangular, frosted and composed mainly of quartz and feldspar with minor hornblende, epidote, biotite, and granitic rock fragments. Outwash deposits; grades downward into Quadra Sand. 20

Major Unconformity

Quadra Sand

Medium to fine sand (Figs. 24, 25, 27, 28) containing sandy silt interbeds; gravel lenses and interbeds; scattered stones and stone clusters; and detrital coal and peat clasts. Generally subhorizontally bedded, cross-bedded; in places rippled, faulted. Contains subrounded to subangular granitic pebbles; sand grains are subangular to subrounded, slightly frosted and mainly composed of quartz and feldspar with 85 minor hornblende, epidote, biotite, and granitic rock fragments. Deposited as proglacial outwash, but may in part be fluvial deposits. GSC 2194 (Fig. 26) (wood in peat layer--18,600 ±190) and 2203 (wood--21,600±200) were collected from this unit.

Major Unconformity

Coquitlam Drift

Stony clayey silt diamicton (Figs. 29, 30) 10
containing marine shell fragments. Stones are a mixture of subrounded granitic, volcanic, chert, quartzite, and pelitic rock types; fines are mainly composed of subangular, faceted grains of quartz and feldspar with minor hornblende and argillaceous, amphibolitic?, and cherty rock fragments. This is the only unit exposed in the Coquitlam-Port Moody area that contains a significant proportion of Cascades Mtns,-derived material. Probably glaciomarine deposits, but may in part be till.

Major Unconformity

Quadra? Sand

Medium sand (Fig. 30) containing gravel 7
lenses, scattered stones and stone clusters. Cross-bedded and faulted, containing detrital coal and peat clasts. Contains subrounded to subangular granitic pebbles and subangular to subrounded medium sand mostly composed of quartz and feldspar with minor hornblende, epidote, and granitic rock fragments. Probably deposited as proglacial outwash but may in part be fluvial deposits associated with the Cowichan Head Formation.

Major Unconformity

Olympia Nonglacial Interval

Cowichan Head Formation

Rusty sandy gravel grading downward into 8
silty fine sand (Fig. 31), both containing wood-bearing organic silt layers. Wood layers contain logs up to 4 m long and 30 cm dia. Subhorizontally bedded; contains subrounded granitic pebbles and subrounded to subangular sand grains mainly composed of quartz

feldspar with minor biotite, hornblende, epidote, and granitic rock fragments. Probably fluvial and swamp deposits. GSC 2273 (wood from organic silt--25,800$\pm$310). 2277 (wood from gravel--26,000$\pm$310), 2191 (wood from gravel--26.200$\pm$320), and 2217 (wood from organic silt--26,900$\pm$320) were collected from this unit. Quadra? Sand, below Coquitlam Drift may in part belong to this unit.

Interbedded peat, sapropel, and silty 15
fine sand sequence (Figs. 33, 34, 35) containing fossil logs up to 3 m long and 30 cm dia. Fossil leaves, insects, and diatoms also found in this unit. Silty sand is subrounded to subangular and is mainly composed of quartz and feldspar with minor biotite, hornblende, epidote, and granitic rock fragments. Deposited as bog and swamp deposits. GSC 2263 (wood from peat--27,000$\pm$490), 2107 (Fig. 35) (wood from peat--27,400$\pm$420), 2139 (wood from peat--28,200 $\pm$200), and 2140 (sapropel--29,600$\pm$200) were collected from this unit.

Cowichan Head Formation?

Stony organic colluvium, comprised of a 5
stony, woor-bearing silt-rich phase and a stony, wood-bearing dense organic-rich phase (Fig. 32) containing fossil leaves and insects; both are products of mass wasting. Stones from this unit are mostly subrounded and granitic. GSC 2137 (wood from the organic-rich phase--40,200$\pm$430), 2167 (wood from the silt-rich phase--40,500$\pm$1700) were collected from this unit.

Major Unconformity

Major Glaciation

Semiahmoo? Droft

Rhythmically laminated silt (Fig. 39) 10
containing scattered subrounded granitic stones. The silt is composed of angular granitic detritus. Probably glaciolacustrine deposits. GSC 2120 (wood-->48,000) and QL-194 (Struiver, U. of Wash., wood-->62,000) were collected from this unit.

Massive stony clayey silt (Figs. 36, 37) 8
containing scattered subrounded granitic stones. Weathers to a blocky structure. Fines are made

of angular granitic rock flour composed mainly of quartz and feldspar with minor hornblende, epidote, and granitic rock fragments. Probably glaciomarine deposits, but may in part be till.

Sandy gravel and gravelly sand (Fig. 36), subhorizontally bedded and cross-bedded, deposited below, between, and above Semiahmoo? tills. Contains subrounded to subangular granitic pebbles and subangular, slightly frosted sand grains are mostly composed of quartz and feldspar with minor hornblende, biotite, epidote, and granitic rock fragments. Outwash deposits. At Mary Hill this unit underlies the massive glaciomarine? unit and contains lenses or clasts of stony clayey silt, possibly picked up from a lower glaciomarine unit. 14

Lodgement till (Figs. 36, 38). at least two layers representing local ice advances, between outwash sand and gravel. Contains lenses of ponded, laminated stony silt. Pebbles are mostly subrounded to subangular and granitic. Matrix varies from angular, faceted, sandy silt and is mainly composed of quartz and feldspar with minor hornblende, epidote, and granitic rock fragments. 3

Medium to fine sand exposed at the Port Moody disposal site (Fig. 40) containing silty fine sand interbeds, gravel lenses and interbeds, and scattered stones and stone clusters. Generally subhorizontally bedded, extensively cross-bedded, in places rippled, faulted. Contains granitic pebbles and sand is subangular to subrounded, slightly frosted and mostly composed of quartz and feldspar with minor hornblende, biotite, epidote, and granitic rock fragments. Probably proglacial outwash deposits, but may in part be fluvial. The writer considers this to be the Semiahmoo? equivalent of Quadra Sand (deposited during the Fraser Glaciation). 60

Major Unconformity

Major Nonglacial Interval

Highbury? Sediments

Rusty silt, fine sand and minor gravel (Figs. 41. 42, 43) exposed in the lower Coquitlam River valley. Subhorizontally thinly bedded, cross-bedded, and rippled; contains a wood-bearing organic silt layer. Pebbles are mainly 18 subrounded and granitic and the subrounded to subangular sand and silt grains are mostly composed of quartz and feldspar with minor hornblende, biotite, epidote, and granitic rock fragments. Probably fluvial flood-plain sediments. GSC 2094-2 (wood from organic silt-->49,000) was collected from this unit.

Major Unconformity

Major Glaciation?

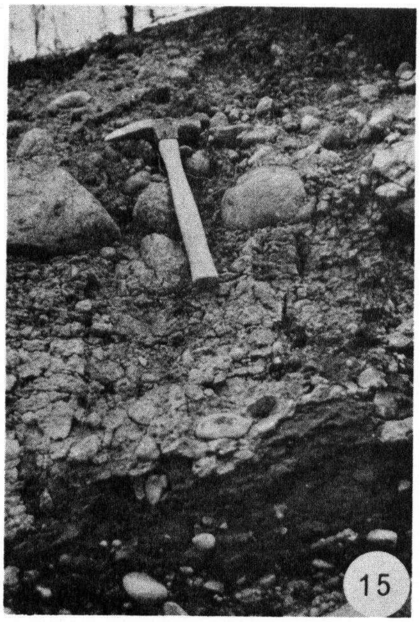
Westlynn Drift?

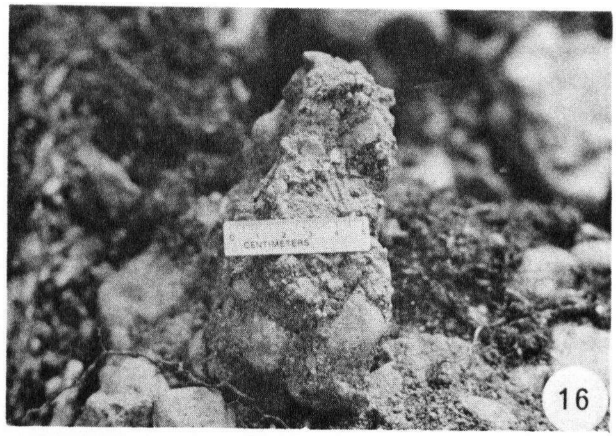
Semi-impervious cobble gravel (Figs. 43, 44) exposed in the lower Coquitlam River valley, 23
containing minor sand lenses. Subhorizontally bedded, crudely cross-bedded; contains over 90% rounded to subrounded granitic pebbles and cobbles with minor matrix of medium to coarse subangular sand grains mostly composed of quartz and feldspar with minor hornblende, biotite, epidote, and granitic rock fragments. Probably glaciofluvial deposits.

C. Till and Glaciomarine Deposits

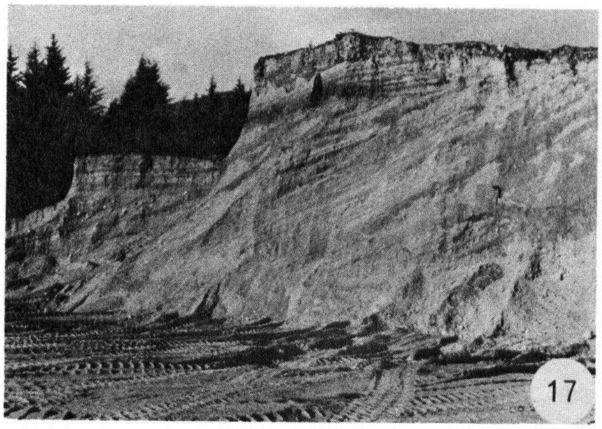
Armstrong and Brown (1954) described glaciomarine sediments exposed in the Fraser Lowland and discussed their origin. They suggested that the till-like "stony clays" were formed by stones dropping into sea-floor muds from floating ice, rather than as till deposited directly under glacier ice, as was believed by workers before them. Today this theory is widely accepted.

Vashon till and Capilano glaciomarine sediments, both deposited during the Fraser Glaciation, are easily distinguishable in the Coquitlam-Port Moody area. Vashon till is grey to dull orange (oxidized), very stony, commonly compact and platy. Capilano glaciomarine sediments are dark blue-grey, containing few scattered stones, and are not compacted. They have a characteristic blocky structure with manganese oxide staining on joint surfaces and commonly contain fossil marine shells and

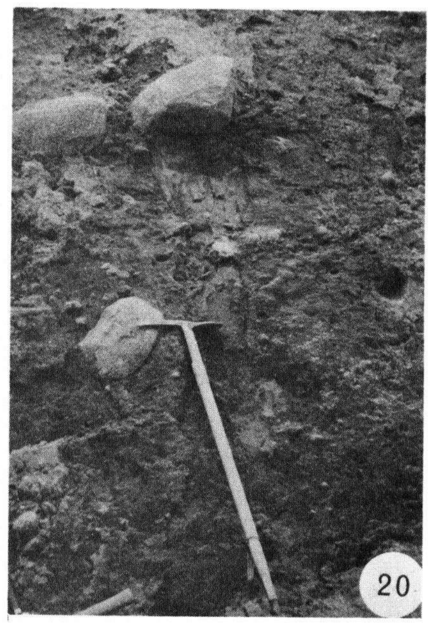




15. Supralittoral lag gravel grading downward into dark grey Vashon lodgement till, Mary Hill (section N, Fig. 2).
16. Shell cast from supralittoral lag gravel in Fig. 15.
17. Foreset and topset bedded Capilano raised deltaic sand and gravel, Coquitlam valley (pit B, Fig. 6).



18. Fossiliferous marine clayey silt, Coquitlam valley (section C5, Fig. 6).
19. Blocky Capilano glaciomarine stony clayey silt overlying platy Vashon till, Mary Hill (near section L, Fig. 2).
20. Compact, bouldery Vashon till, Mary Hill (section E, Fig. 2).



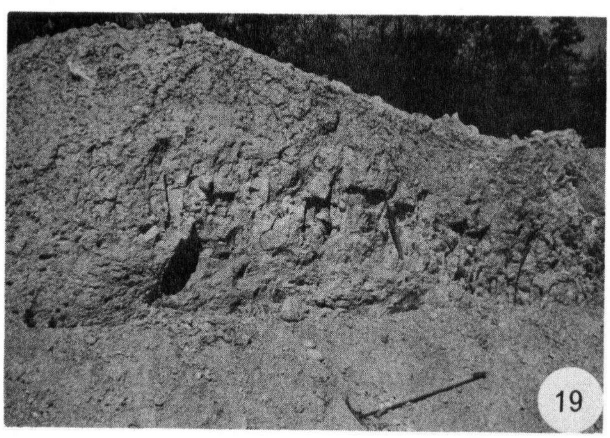
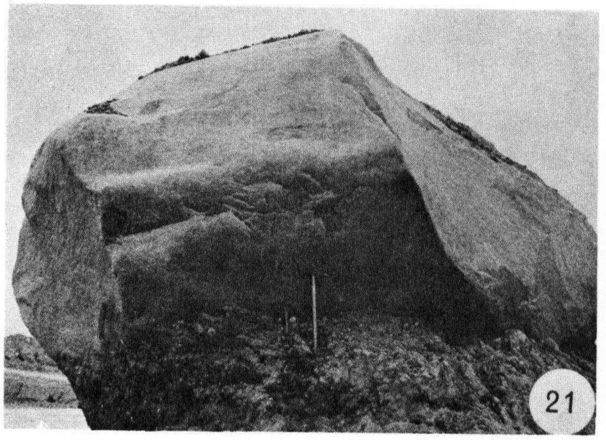
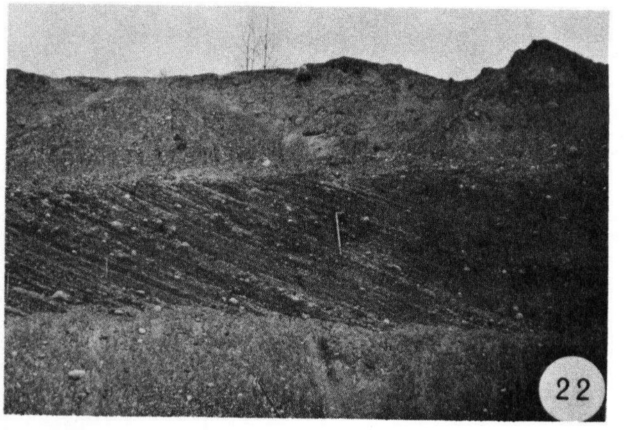
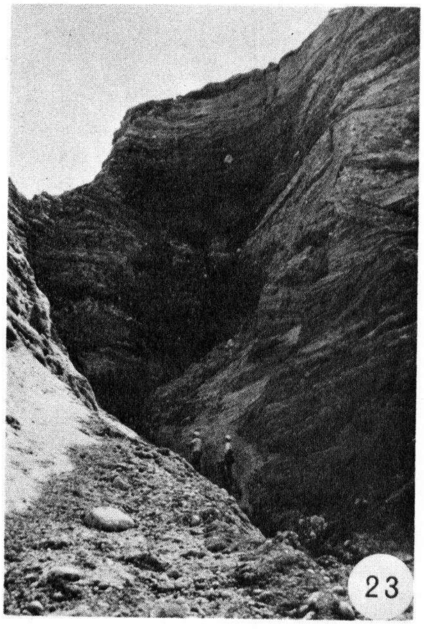


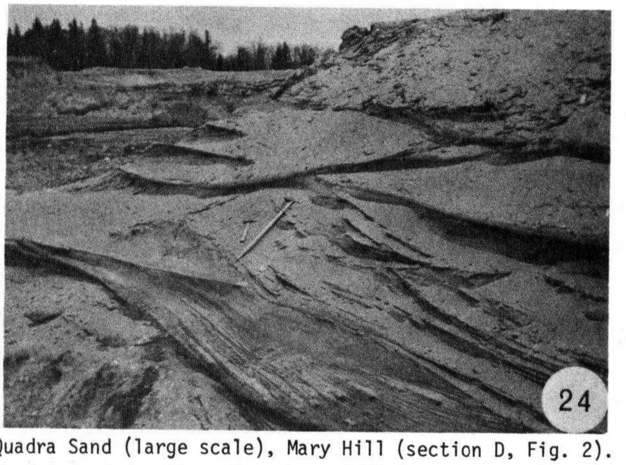
Plate 1: Figs. 15 to 20.





21. Polished, grooved, striated, and chattermarked granitic erratic resting on Vashon till, Mary Hill (near section E, Fig. 2).
22. Foreset bedded Vashon outwash sandy gravel, Mary Hill (section K, Fig. 2).
23. Contorted ice contact Vashon sand, gravel, and flow till, Coquitlam valley (section G2, Fig. 6). Drs. J.E. Armstrong and J.J. Clague for scale.





24. Cross-bedded Quadra Sand (large scale), Mary Hill (section D, Fig. 2).
25. Cross-bedded Quadra Sand (small scale), Mary Hill (section D, Fig. 2).
26. Thin peat layer (under boots) overlying Semiahmoo? stony silt, Mary Hill (section D, Fig. 2). Wood from peat dated as 18,600 ± 190 yr. B.P.

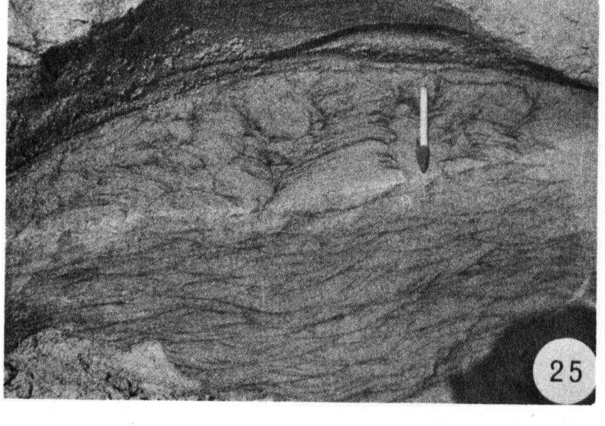
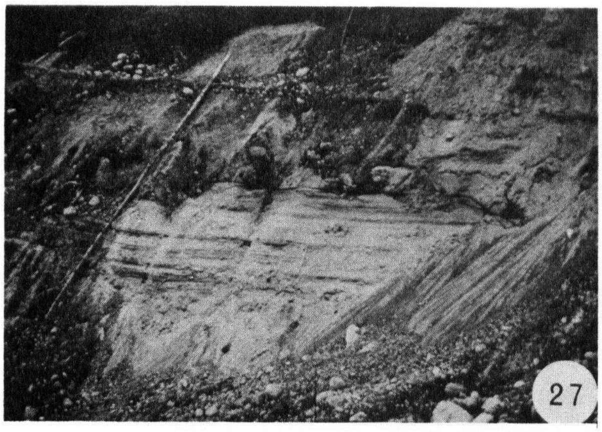
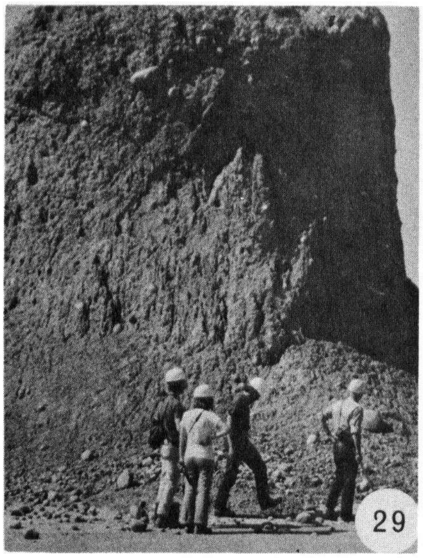
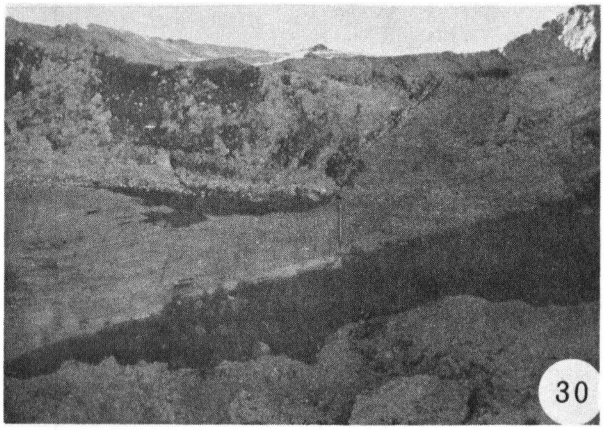


Plate 2: Figs. 21 to 26.

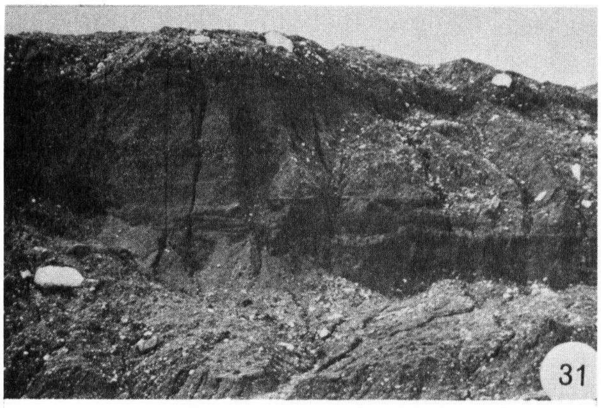


27. Thinly bedded Quadra Sand underlying Vashon Drift, Coquitlam valley (section F4, Fig. 6). Pick for scale in centre of photo.
28. Load casts, ball and pillow structures, and convoluted bedding in silty fine sand in Fig. 27.
29. Massive stony Coquitlam Drift, Mary Hill (section J, Fig. 2). L to R, Drs. J.J. Clague, J.M. Ryder, R.J. Fulton, and J.E. Armstrong for scale.





30. Sharp angular contact: Coquitlam Drift overlain by Quadra Sand and underlain by sand, either Quadra or part of the Cowichan Head Formation, Mary Hill (section J, Fig. 2). Pick for scale in centre of photo.
31. Cowichan Head fluvial gravel and sand unconformably overlying Cowichan Head? dense stony organic colluvium (dark, lower right in photo), Mary Hill (section C, Fig. 2). Bluff is 10 m high.
32. Cowichan Head? stony organic colluvium, Mary Hill (section A, Fig. 2). Dr. R.J. Fulton for scale. Wood from Fulton's shoulder-level dated as 40,200 ± 430 yr. B.P.



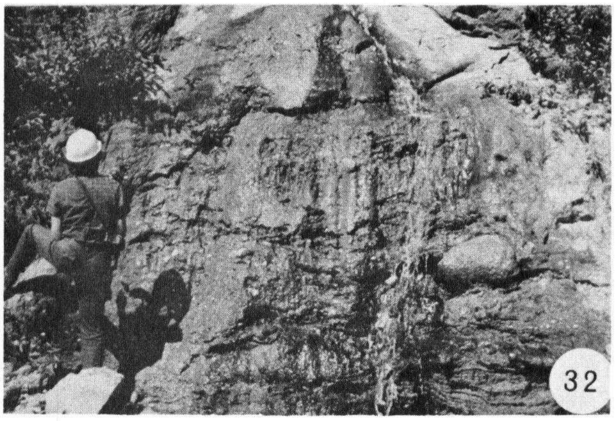
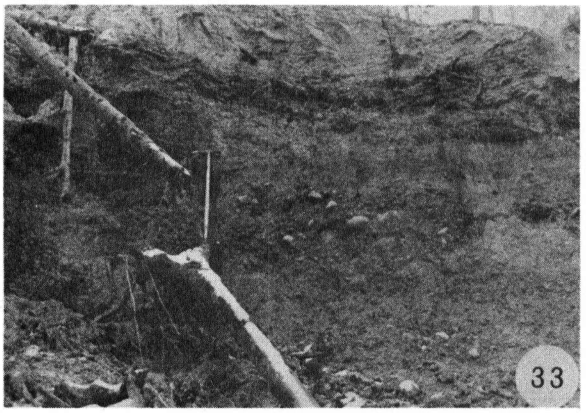
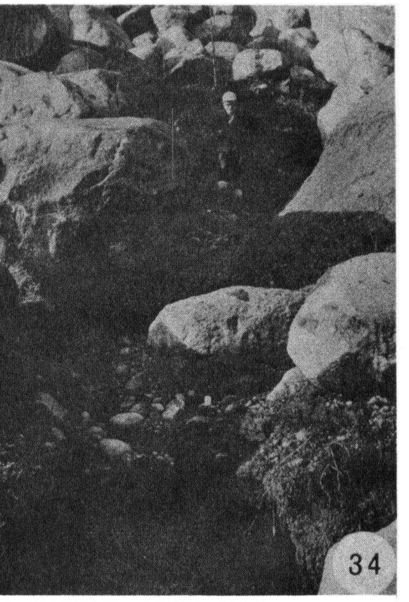
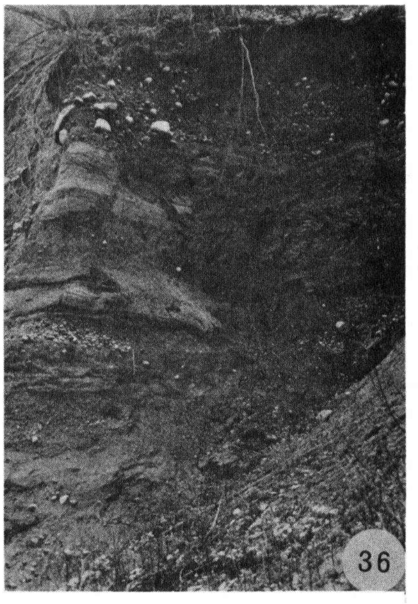


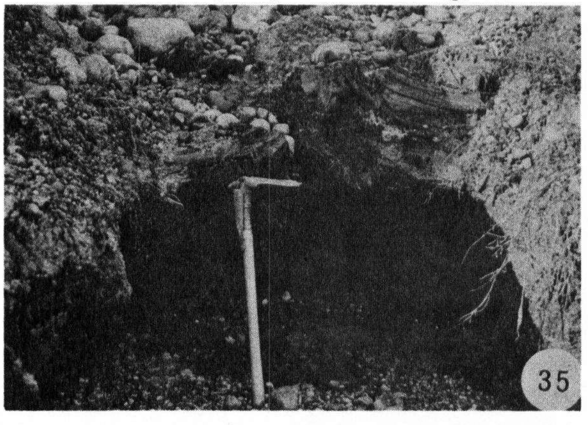
Plate 3: Figs. 27 to 32.

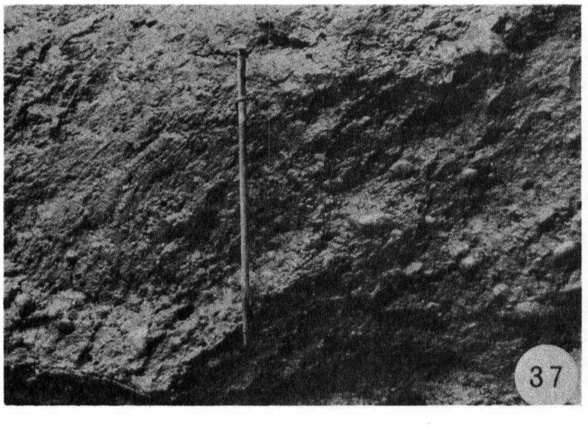


33. Cowichan Head? wood-rich organic silt layer between Quadra? laminated silty fine sand (above) and Semiahmoo? till and outwash gravel (below), Port Moody (section C, Fig. 10).
34. Buried landscape: Cowichan Head peat layer containing a spruce stump (below boulder in centre of photo) abuts against the slope formed on Cowichan Head? stony organic colluvium (on which Dr. J.E. Armstrong is standing), Mary Hill (section B, Fig. 2).
35. Fossil spruce stump in peat layer in Fig. 34. Stump dated as 27,400 $\pm$ 420 yr. B.P. Stony organic colluvium can be seen below at the base of the shovel handle.
36. Semiahmoo? Drift, Coquitlam valley. Two lodgement tills separated by outwash gravel are overlain by outwash gravel and sand and then by massive glaciomarine? stony clayey silt; Vashon Drift overlies the stony silt (section F3, Fig. 6). Pick for scale at the top of the upper till, lower left centre of photo.
37. Semiahmoo? glaciomarine? stony clayey silt in Fig. 36.
38. Semiahmoo? platy lodgement till in Fig. 36.









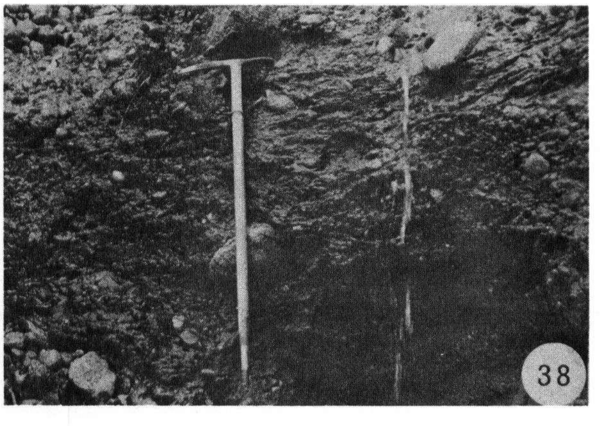
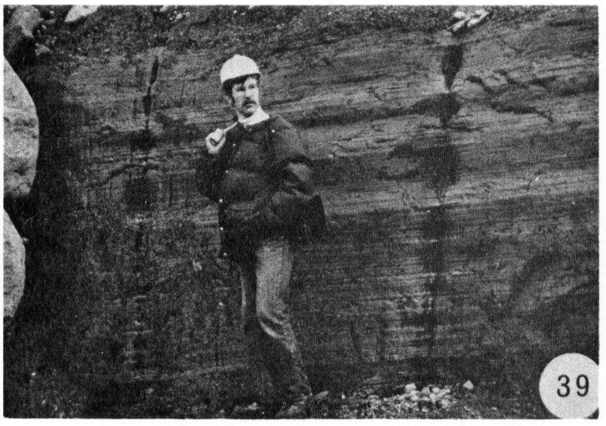
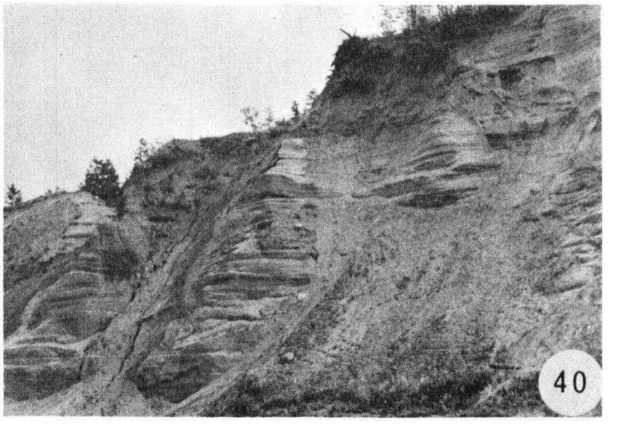
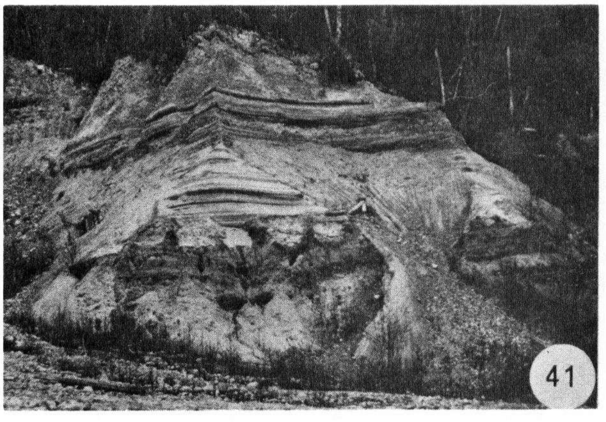
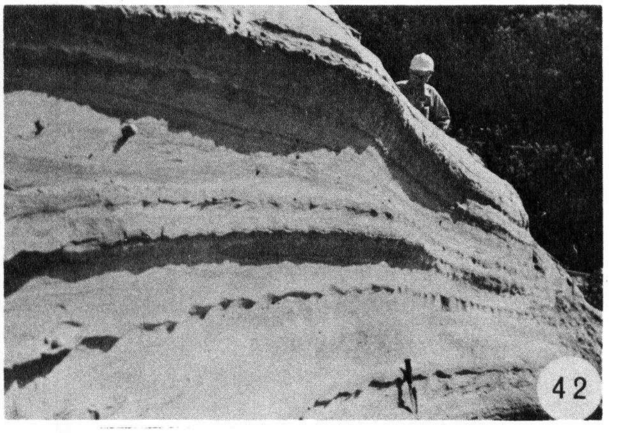


Plate 4: Figs. 33 to 38.









39. Semiahmoo? glaciolacustrine rhythmically laminated stony silt, Mary Hill (near section M, Fig. 2).
40. Semiahmoo? proglacial sand, Port Moody (section B, Fig. 10).
41. Highbury? fluvial thinly bedded sand, silt, and minor gravel (light and dark stripes) between Semiahmoo? outwash gravel and sand (above) and Westlynn? outwash? gravel (below), Coquitlam valley (section F3, Fig. 6).
42. Rippled, thinly bedded Highbury? sand in Fig. 41. Dr. J.E. Armstrong for scale.
43. Contact: Highbury? thinly bedded sand, silt, and minor gravel unconformably overlying Westlynn? outwash? gravel, Coquitlam valley (section G1, Fig. 6).
44. Semi-impervious Westlynn? outwash? coarse gravel, Coquitlam valley (section G3, Fig. 6). Water flows over gravel, not through it. Dr. Aleksis Dreimanis at base of waterfall for scale.

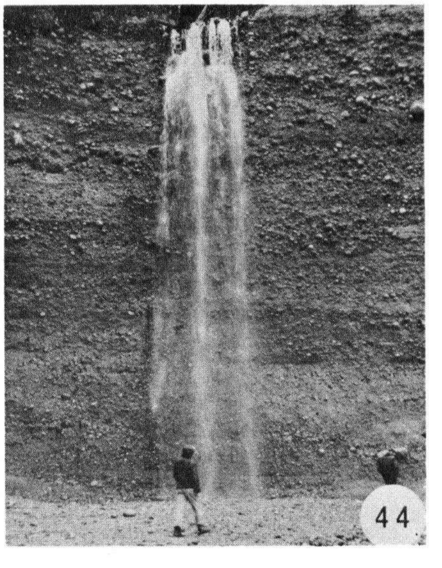


Plate 5: Figs. 39 to 44.

shell casts.

Differences between pre-Vashon tills and glaciomarine sediments, however, are not as obvious (Figs. 36, 37, 38) and the older glaciomarine units may in part be till. Where dark blue-grey fine sediments (in places bedded) containing few, widely scattered, rounded stones and blocky structure are encountered (Fig. 19), they are considered to be glaciomarine. Where a grey to dull orange (oxidized), compact diamicton containing abundant sugangular to subrounded stones is found with a sandy to silty matrix, it is considered to be till (Figs. 15, 20). These two examples are textural end members in a transitional series, between which macroscopic differentiation of till and glaciomarine deposits is very difficult. Grain size analyses of the matrix in the two sediment types are plotted in Fig. 15. It illustrates that the glaciomarine sediments generally contain a finer matrix than the tills. Some overlap occurs, however, and is thought to result from glacier ice overriding glaciomarine sediments, disturbing and mixing them with till.

Both till and glaciomarine pebbles are generally rounded in contrast to the angular matrix grains. This was probably caused by glacier ice advancing over and incorporating its own rounded outwash gravels (and older gravels) and then redepositing them as the framework grains in till or as dropstones in glaciomarine deposits.

Theoretically lodgement till pebbles should be strongly oriented in the direction of ice movement and glaciomarine pebbles should not be oriented, having been randomly dropped

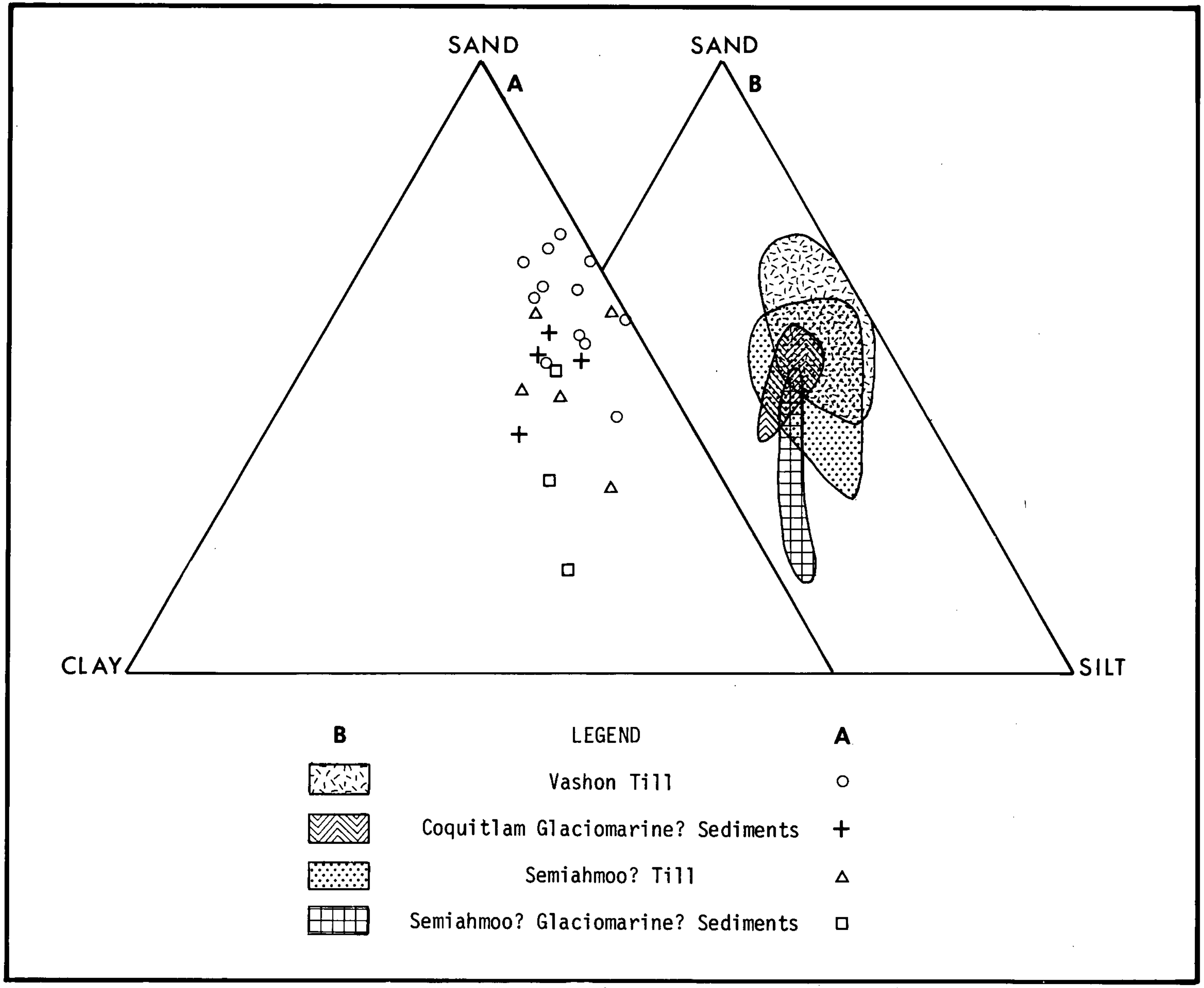


Fig.45 MATRIX GRAIN SIZE DISTRIBUTION OF TILL AND GLACIOMARINE DEPOSITS:

A. PLOT OF ANALYSES B. AREAS OF GRAIN SIZE DISTRIBUTION to the sea floor by floating ice. Pebble fabric analyses done on both types of sediment in this study (Fig. 16, Chapter Six) are, however, inconclusive. This also suggests that some of the pre-Vashon glaciomarine deposits have been disturbed by overriding ice and mixed with till.

The only conclusive evidence of a glaciomarine origin for a sediment unit appears to be the occurrence of scattered stones and marine shells, in near to growth position, embedded in it. Such is the case for the Capilano glaciomarine sediments, in which undisturbed pelecypods and barnacles still attached to pebbles occur, both completely infilled and surrounded by clayey silt. However, Capilano glaciomarine deposits have not been overridden or disturbed by glacier ice.

CHAPTER SIX: QUATERNARY HISTORY

A. Fraser Lowland

Armstrong (1965, 1975a, b, and other papers in press and prep.) has written about the Quaternary history of unconsolidated sediments exposed in the Fraser Lowland, in which the Coquitlam-Port Moody area is located. He concludes that during Wisconsin and probably earlier time the Lowland was subjected to repeated glaciations separated by nonglacial intervals. Each major glaciation went through an advance stage involving coalescing piedmont glaciers, a maximum when the ice reached a thickness of at least 1,800 m and overrode much of the adjoining mountainous areas, and a retreat (deglaciation) stage when ice mainly occupied valleys and arms of the sea before readvancing locally as surging glaciers. Each major glaciation was accompanied by isostatic, eustatic, and probably tectonic adjustments resulting in repeated sea-level changes up to at least 200 m. As a result of this complex geological history very thick Quaternary sediments at least 300 m thick, of widely diversified origin including marine, non-marine, and glacial, were deposited and eroded. Armstrong's composite stratigraphic section of the Fraser Lowland is incorporated in Table II for Vashon and older deposits.

Armstrong (in press) mapped deposits representing at least three glaciations in the Lowland, including three stades in the last glaciation: Vashon, Fort Langley, and Sumas. He describes the Fort Langley and the (last) Sumas ice advances as piedmont glaciers advancing from the east and northeast and terminating in the sea for much of their histories (like Malaspina glacier of Alaska) about 15 km east of the Coquitlam-Port Moody area. Fort Langley marine and glaciomarine sediments were also deposited before the Sumas ice advance. To the west of the Sumas ice terminus Capilano marine and glaciomarine sediments were laid down during post-Vashon time. According to Armstrong, Sumas and Fort Langley Formation deposits extend westward to a point approximately 5 km east of this study area, in which Capilano sediments are the only post-Vashon Pleistocene deposits to occur.

During this study the writer discovered a drift unit that probably represents a fourth stade in the last glaciation, earlier than the Vashon Stade, and designates it as Coquitlam Drift. This may be a correlative of the Evans Creek Stade found in northwestern Washington. Armstrong and Hicock (in prep.) discuss this drift unit more extensively in a joint paper.

B. Coquitlam Port-Moody Area

Westlynn Drift?, outwash? gravel, is the oldest Quaternary sediment exposed in the area and was deposited more than 62,000 years ago, probably by southward-flowing meltwater streams (Fig. 47G), under a climate cooler than that of today, debouching from a glacier further north up the Coquitlam valley in the Coast Mountains (Fig. 48H). An erosional period followed and a landscape resulting from a radical change in sediment regime developed.

The climate probably warmed and nonglacial streams flowed northward (Fig. 47F) into the lower Coquitlam valley depositing Highbury? fluvial sediments more than 49,000 and probably more

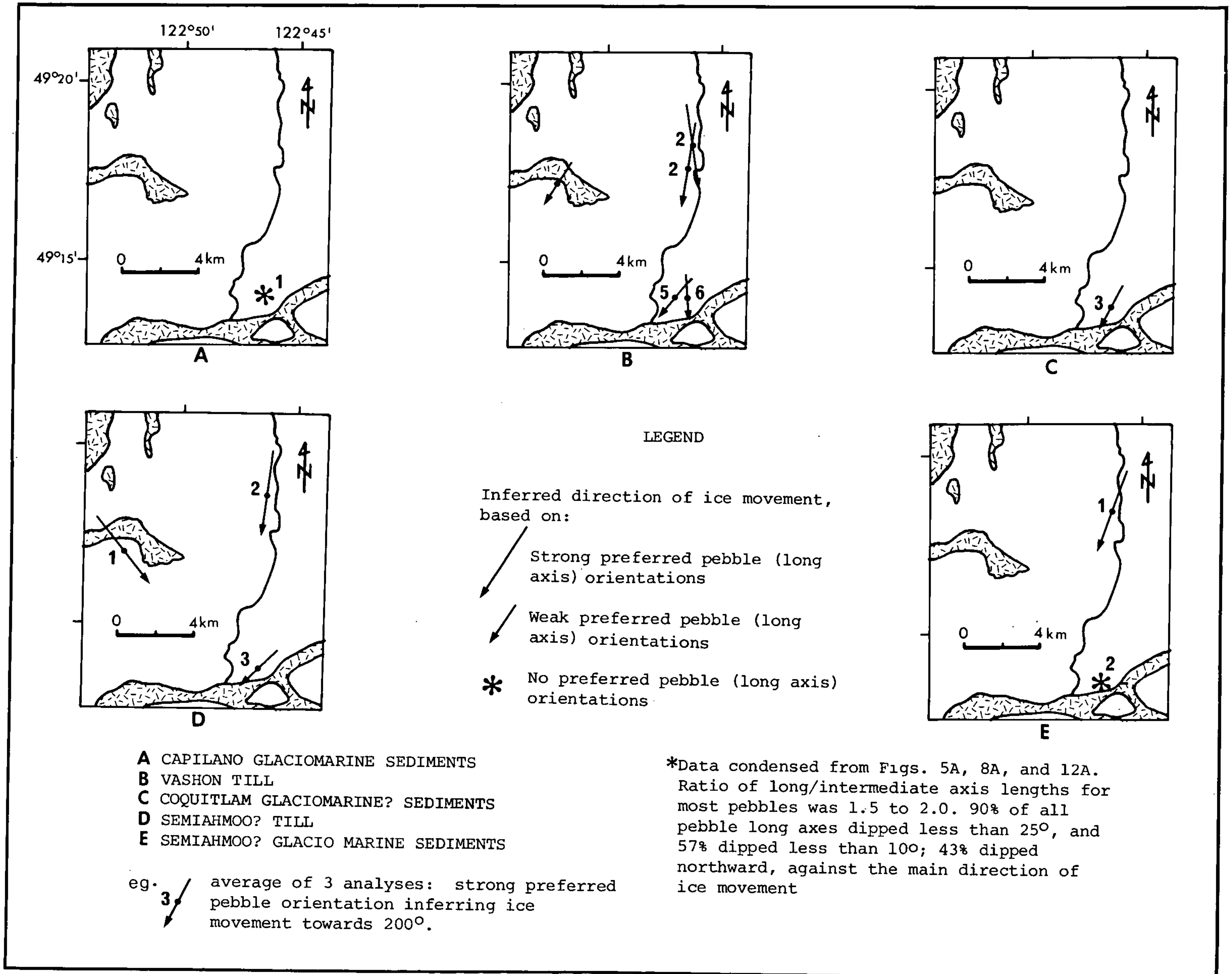
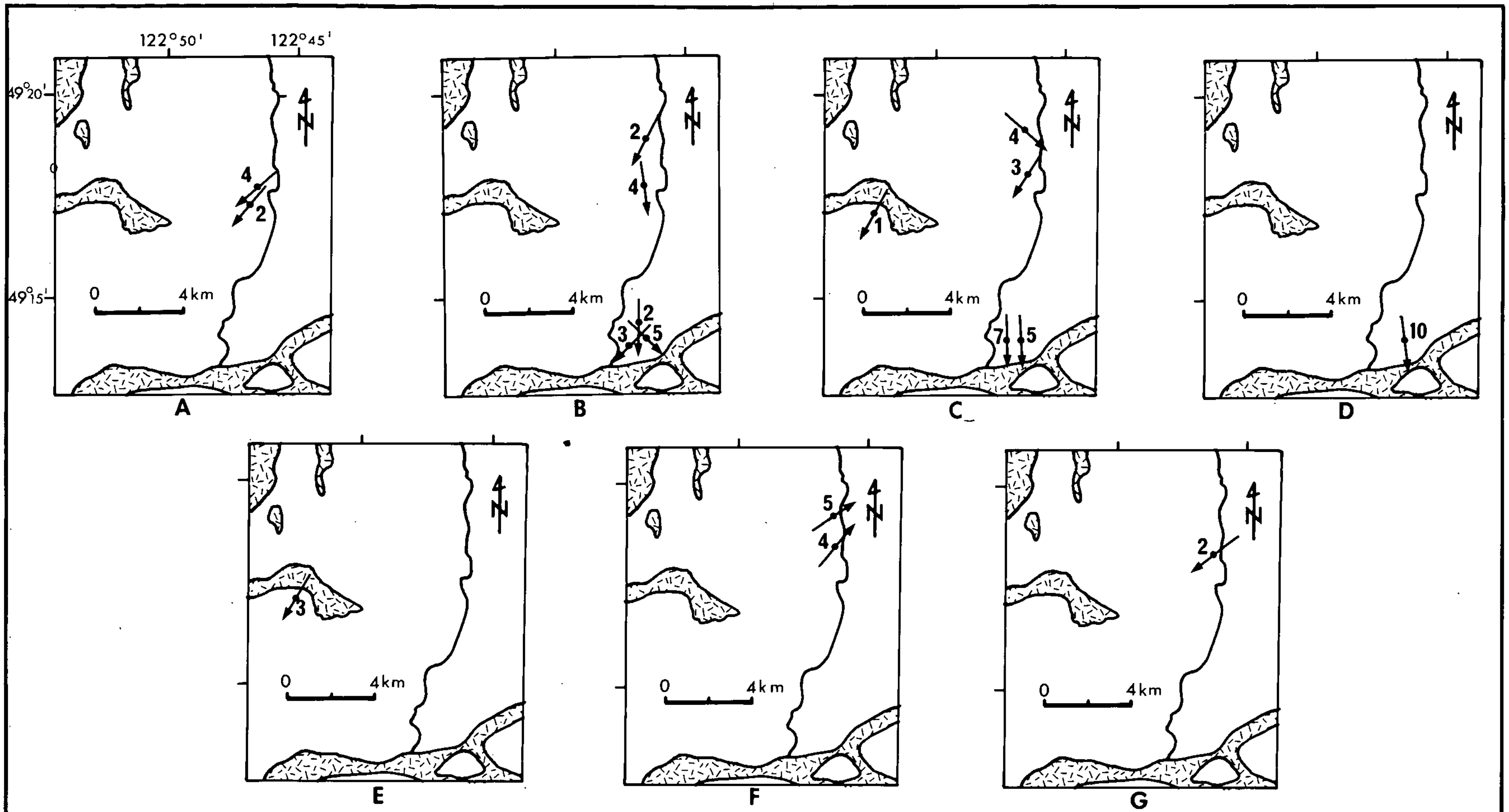


FIG. 46 INFERRED ICE MOVEMENT DIRECTIONS FROM PEBBLE FABRICS* IN EXPOSED PLEISTOCENE GLACIAL DIAMICTONS: COQUITLAM - PORT MODDY AREA, BRITISH COLUMBIA



A CAPILANO SEDIMENTS

B VASHION DRIFT

C QUADRA SAND

D COWICHAN HEAD FORMATION

E SEMIAHMOO? DRIFT

F HIGHBURY? SEDIMENTS

G WESTLYNN DRIFT?

eg. 3 average of 3 analyses: inferred direction of paleostream flow (200°)

*Data condensed from Figs. 5B, 8B, and 12B

Fig. 47: PALEOCURRENT DIRECTIONS* IN EXPOSED PLEISTOCENE SAND AND GRAVEL: COQUITLAM-PORT MOODY AREA, BRITISH COLUMBIA

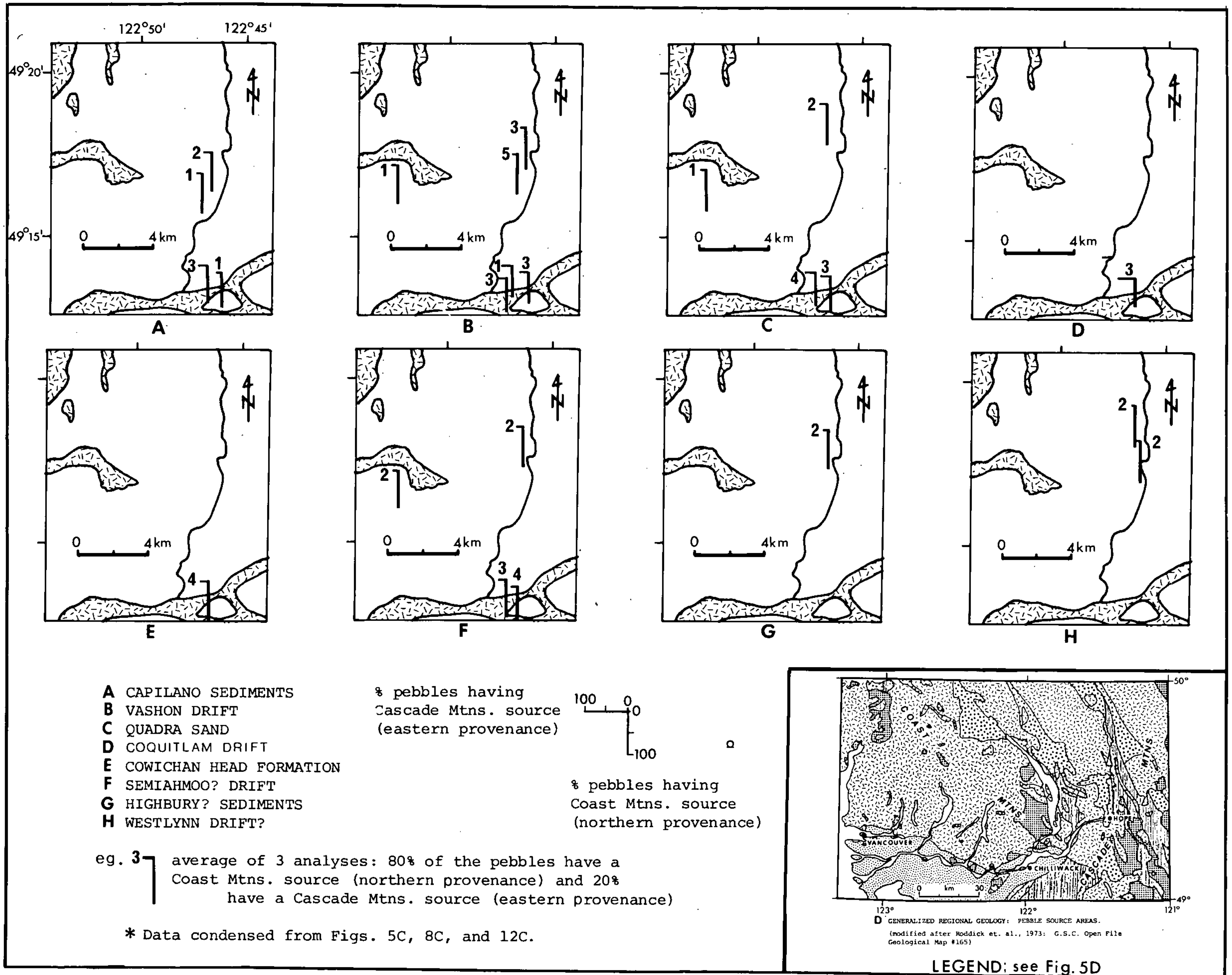


Fig. 48 : PEBBLE PROVENANCE* OF EXPOSED PLEISTOCENE SEDIMENTS: COQUITLAM - PORT MOODY AREA, BRITISH COLUMBIA.

than 62,000 years ago. Pebble provenance (Fig. 48G) suggests that either the northeastward stream flow was a local phenomenon in stream meander bends or back eddies where the flow was against a main, southward, stream flow; or that the gravel was transported by a main northeastward stream flow which reworked older sediments that were deposited by streams flowing southward out of the Coast Mountains. Streams probably flowed off the Coast Mountains and diverted up the lower reaches of the Coquitlam valley, depositing material of northern provenance and reworking older sediments. During this time a thin organic silt layer containing pieces of spruce wood was formed. Sharp protuberances on the wood suggest that it was not transported very far from its growth position. A period of erosion followed and a landscape was developed on Highbury? Sediments.

The climate cooled again with the onset of a major glaciation and Semiahmoo? proglacial? sand was laid down at Port Moody by southward-flowing meltwater streams (Fig. 47E) probably more than 62,000 years ago from an advancing glacier to the north in the Coast Mountains (Fig. 48F). Pieces of ice and possibly tree parts floated in the streams, dropping stones and stone clusters into the sand. The sand was eroded by increasing meltwater discharges as the glacier advanced further southward. Coarser outwash gravel and sand were deposited by these larger, more competent streams at Mary Hill and in the Coquitlam valley. Eventually the southward-advancing Semiahmoo? glacier (Figs. 46D, 48F) overrode the Coquitlam-Port Moody area, carving out new landscapes and reshaping old ones while developing faults in

Semiahmoo? proglacial? sands with its weight at Port Moody. At least two advances and brief retreats of this ice are represented in the Coquitlam-Port Moody area by lodgement tills separated by gravel and sand outwash. During Semiahmoo? deglaciation the sea eustatically rose and closely followed the ice retreat; Mary Hill, and presumably the whole area, was drowned and the Coquitlam valley probably became a fiord. Glaciomarine sediments were formed by drifting ice melting and randomly dropping stones into sea floor mud (Fig. 46E) and were deposited up to 135 m a.s.l. The land then isostatically rose above the sea and at Mary Hill glaciolacustrine laminated silts with dropstones were deposited in a raised sea floor depression (possibly formed by scouring and/or percussion by drifting ice keels) by meltwater forming a pond or lake in it. Wood (QL-194) from the laminated silts was dated as >62,000 radiocarbon yr. B.P.. It may represent reworked wood from older nonglacial sediments. An erosional interval followed Semiahmoo? deglaciation and a landscape was formed on Semiahmoo? Drift. The topography of the Coquitlam-Port Moody area has remained basically the same since Semiahmoo? time and has only been locally modified by ice and water action. The stratigraphic record prior to Semiahmoo? time is too sparce in the area to comment on the topography before then. The uplands at Mary Hill, Port Moody, Maillardville, and Harbour Village existed in Semiahmoo? time, although in a different shape. The lowlands between Port Moody and Ioco, and between Essondale and Mary Hill also existed then, also in a different form.

The next sediment to be deposited in the area was the stony organic colluvium exposed at Mary Hill and tentatively grouped with the Cowichan Head Formation. It formed on a slope at the edge of a depression at Mary Hill about 40,000 years ago, probably during a nonglacial interval, by mass wasting processes acting on and mixing organic deposits (containing spruce and western hemlock trees) and glacial sediments. Armstrong (in prep.) has evidence of a nonglacial interval existing in North Vancouver (20 km west of the Coquitlam-Port Moody area) at 36,200 radiocarbon yr. B.P. (GSC 93 rerun) and 32,200 radiocarbon yr. B.P. (IGSC 214), and in Vancouver at 32,580 radiocarbon yr. B.P. (GSC 221). From east Delta (10 km southwest of the Coquitlam-Port Moody area) Armstrong (pers. comm.) had wood from a buried forest dated as $58,800^{+2900}_{-2100}$ (QL-195, Stuiver, U. of Wash.) and believes that the age of the Cowichan Head Formation may range from 25,000-60,000 radiocarbon yr. B.P. By about 30,000 years ago bog and swamp deposits of the Cowichan Head Formation had formed at Mary Hill during the Olympia Nonglacial Interval. Spruce trees were growing in the peat and interbedded sand layers, which abutted against a slope developed on the organic colluvium. From about 26,000 to 25,500 years ago fluvial silt, sand, gravel, and swamp deposits (in which spruce and western fir trees grew) of the Cowichan Head Formation were laid down over the bog deposits and also abutted against the slope on the organic colluvium. These fluvial sediments were deposited by streams flowing southward (Fig. 47D) off the Coast Mountains (Fig. 48E). At Mary Hill a sand unit, texturally and structurally similar to Quadra Sand, overlies swamp deposits of the Cowichan Head Formation and underlies Coquitlam

Drift; thus it has been mapped with the Cowichan Head Formation. However, this lower sand may in fact be Quadra Sand deposited early in the Fraser Glaciation, prior to the deposition of Coquitlam Drift. A landscape was formed on the Cowichan Head Formation.

The climate cooled again with the onset of the Fraser Glaciation, less than 26,000 years ago. Probably proglacial Quadra Sand was the earliest sediment to be deposited in the advancing Vashon? ice to the north in the Coast Mountains. It appears that at Mary Hill early in the Fraser Glaciation Quadra Sand deposition was interrupted by the westward advance of a local piedmont ice lobe, possibly surging, from the Cascade Mountains. This stadial event is represented by Coquitlam Drift, which is thought to be mainly glaciomarine sediments (contains fossil marine shell fragments), but may in part be till. The pebble provenance for this unit has a strong eastern component (Fig. 48D) and pebble fabrics suggest ice movement was from the east and north (Fig. 46C). This mixture of till-like and glaciomarine sediments was probably caused by westward-advancing Coquitlam ice overriding and disturbing Coquitlam glaciomarine sediments. The sand below Coquitlam Drift probably developed faults under the weight of overriding Coquitlam ice.

The Coquitlam ice lobe appears to have blocked the mouth of the Coquitlam valley while proglacial Quadra Sand was deposited (behind an ice dam) up to 250 m a.s.l. in the valley by 21,600 years B.P. Without this ice dam Quadra Sand may have filled the whole Fraser Lowland and Strait of Georgia to that elevation. If the latter was the case, most of the Quadra Sand has been eroded and redeposited elsewhere; however, evidence for the latter hypothesis is lacking. The western limit of advance for the Coquitlam ice is unknown; however Halstead (1968) and Fulton and Halstead (1972) described a drift unit on the Saanich Peninsula, Vancouver Island, which they correlate with Evans Creek Drift found in northwestern Washington. Their drift unit may correlate with Coquitlam Drift, which may also correlate with Evans Creek Drift. A landscape was formed on Coquitlam Drift.

Coquitlam ice must have withdrawn from Mary Hill by 18,600 years B.P., when the Vashon ice sheet was still (?) advancing from the Coast Mountains, towards the Coquitlam-Port Moody area, and the climate had warmed enough to allow the formation of a thin peat bed containing spruce trees at Mary Hill. Stagnant ice may have continued to block part of the Coquitlam valley, diverting stream flow around ice-free Mary Hill during this time. Evidence to support this hypothesis may have been erased later during the Vashon Stade. During and after retreat of the Coquitlam ice block southward-flowing meltwater streams (Fig. 47C) eroded much of the Quadra Sand in the lower Coquitlam valley and redeposited it, with new Quadra Sand, in the Fraser Lowland. At Mary Hill and probably in the Maillardville-Harbour Village upland, both immediately south of Coquitlam valley, Quadra Sand was deposited up to 50 m thick. The Guildford area, south of Mary Hill across the Fraser River, contains Quadra Sand at least 60 m thick. Streams flowed in shallow, wide channels and stream discharge and competence was low during initial Quadra Sand (fine to medium) deposition, when Coquitlam ice was retreating, and stagnant ice may have blocked most of the mouth of the Coquitlam valley. As the stagnant ice block disintegrated, allowing more water to pass, and as the Vashon ice advanced closer to the area, stream discharge and competence increased and water flowed southward in deeper, narrower channels, depositing more and more Coast Mountains-derived gravel (Fig. 48C) with the sand. Water action created a new landscape on Quadra Sand.

Eventually Vashon ice advanced southward off the Coast Mountains and onto the Fraser Lowland. Southward-flowing, high-discharge outwash streams (Fig. 47B) deposited Coast Mountains-derived (Fig. 48B) Vashon coarse gravel outwash as foreset beds into the sea as the land was isostatically depressed. During this time flow tills and ice-contact deposits were deposited in the lower Coquitlam valley. Coarse outwash and ice-contact deposits were not observed at the Port Moody disposal site, perhaps because they were erased by Vashon ice or perhaps because Port Moody was too far to the west of the Coquitlam River and away from the main stream flow down the Coquitlam valley. The latter is unlikely as Vashon ice passed over the site and came down Indian Arm, to the north of Port Moody, and would have deposited outwash at the site.

Vashon ice eventually passed over the area, mostly reworking and redepositing its own outwash deposits, and deposited lodgement and flow tills. Stones in the Vashon tills are subrounded where tills overlie Pleistocene sediments in the area. This indicates that Vashon ice reworked older sediments when it overrode the land where bedrock was buried deeply below the surface. Semiahmoo? tills contain many rounded stones and Semiahmoo? ice probably acted in a similar manner. At least three Vashon tills separated by outwash gravels are found in the area and represent local ice advances that occurred during the Vashon Stade. Pebble fabric and provenance studies (Figs. 46B, 48B) indicate southward ice movement for all three advances. Each ice advance eroded older sediments and deposited till which truncated the ones laid down before it. Laminated stony silt and fine sand lenses in the tills were formed by fine sediments and ice-rafted dropstones being deposited in small meltwater ponds occupying hollows on the till surface. A major landscape was developed on Vashon Drift.

By 13,000 years B.P. the climate was warming and Fraser deglaciation had begun in the Coquitlam-Port Moody area, although the Fort Langley and Sumas Stades had started in the eastern Fraser Lowland (Armstrong, in press). The sea closely followed the retreating Vashon ice into the Coquitlam valley where Capilano fossiliferous marine and glaciomarine sediments were deposited to at least 70 m a.s.l., 12,000 years ago. During this time the Coquitlam valley was a fiord; Mary Hill, Port Moody, and the Maillardville-Harbour Village upland were drowned by the sea; and floating ice randomly dropped stones into sea-floor muds (Fig 46A). With further retreat of Vashon ice into the Coast Mountains the land started to isostatically rise faster than the eustatically rising sea level. A Capilano composite marine delta was formed up to 140 m a.s.l. at the mouth of the Coquitlam valley by southward-flowing meltwater streams debouching from the retreating glacier to the north (Figs. 47A, 48A). As the land rose above the sea, storm waves and spray pounded against the upland slopes in the area, reworking Capilano glaciomarine sediments and Vashon Drift. Supralittoral lag gravels and littoral sands winnowed from them, both containing marine shell casts, were formed and deposited up to 175 m a.s.l. by this wave action. At the same time terraces were cut into the composite delta at the mouth of the Coquitlam valley. During the deposition of the raised deltas and supralittoral lag gravel the Coquitlam-Port Moody area was entering post-glacial time, while eastern Fraser Lowland was still in the Sumas Stade (Armstrong, in press), about 11,500 years ago.

During post-glacial time the ancestral Coquitlam River incised the Coquitlam valley sediment fill and deposited sand and gravel, largely reworked from older sediments exposed along the river banks, along its lower course from Coquitlam Lake to the Fraser River. It also built a flood plain extending from the lowest slopes of Burke Mt. to its mouth. Over the Coquitlam River flood plain between Essondale and Mary Hill, and below Maillardville, the Fraser River has deposited flood plain and estuarine sand and silt. In places peat bog and swamp deposits have also formed on the Fraser flood plain. Mountain streams, lowland streams, slides, mass wasting, and human activity have also played roles in the deposition and erosion of unconsolidated sediments since the retreat of the last ice from the Coquitlam-Port Moody area.

CHAPTER SEVEN: ENGINEERING AND ENVIRONMENTAL GEOLOGY

Environmental problems related to surficial geology, and sources of granular aggregate have been discussed for the Fraser Lowland by Armstrong (1953, 1957, 1961) and Leaming (1968). This chapter is a summary of these papers for the Coquitlam-Port Moody area, including minor input from this study. Information on the types and distribution of geological materials aid the engineer, planner, and contractor in solving problems pertaining to construction materials, foundation materials and drainage, sewage disposal, flood control, slides, and washouts.

A. Construction Materials

Gravel and sand are the only materials mined from Quaternary sediments in the Coquitlam-Port Moody area for construction purposes, and gravel and sand production is an important industry in the area. Sources and types of sand and gravel deposits have been described by Armstrong (1953, 1957) and Leaming (1968, pp. 40-49) has described in detail the sand and gravel operations in the Coquitlam- Port Moody area during the 1960's.

Gravel and sand deposits in the area may be classified into four types: 1. outwash gravel and sand (Figs. 22, 23, 36, 43, 44), 2. raised delta and alluvial flood plain gravel and sand (Figs. 17, 31, 41, 43), 3. supralittoral gravel and sand (Figs. 15, 16), and 4. present-day river gravel.

Deposits of the first type are the most extensive and economic, especially Vashon outwash deposits, which were the last deposits of this type to be laid down. The other outwash units are: Quadra Sand, Semiahmoo?, and Westlynn?. These sediments were laid down by meltwater streams debouching from advancing and retreating glaciers.

Fig. 49 illustrates grain-size curves for three of the four types of gravel deposits exposed in the study area. Samples of modern river gravels were not analyzed and Quadra Sand (Figs. 24, 25, 27, 28) contains very minor gravel. All three types of gravel deposits contain grains ranging in size from silt to boulders; however, the abundance of these sizes is less than 1%. Outwash gravels (Fig. 49A) generally contain 75% (by weight) gravel-sized material; the remaining 25% is largely composed of sand. Most of the gravel fraction is pebble-sized (4 to 32 mm) stones. Raised deltaic and alluvial flood plain deposits (Fig. 49B) generally contain 65% (by weight) gravel-sized material and 35% sand; most of the gravel fraction is made of smaller pebbles (4 to 20 mm) than the outwash. These gravels are slightly better sorted than outwash gravels as they contain little or no mud fraction and very few boulders. Raised delta deposits(Fig. 17) are actually recessional outwash deposited at the end of the last glaciation. However, they were laid down by streams derived from retreating ice that was farther from the area than glaciers associated with the outwash gravels. Longer transport distances and greater travel time resulted in better sorting of the raised delta gravels. Raised delta gravels are also slightly more rounded than the outwash. Nonglacial alluvial flood plain gravels (Figs. 31, 41, 43) (Cowichan Head, Highbury?) were not, of course, deposited by glacier-derived streams but were deposited as channel and flood plain deposits and are better sorted than outwash.

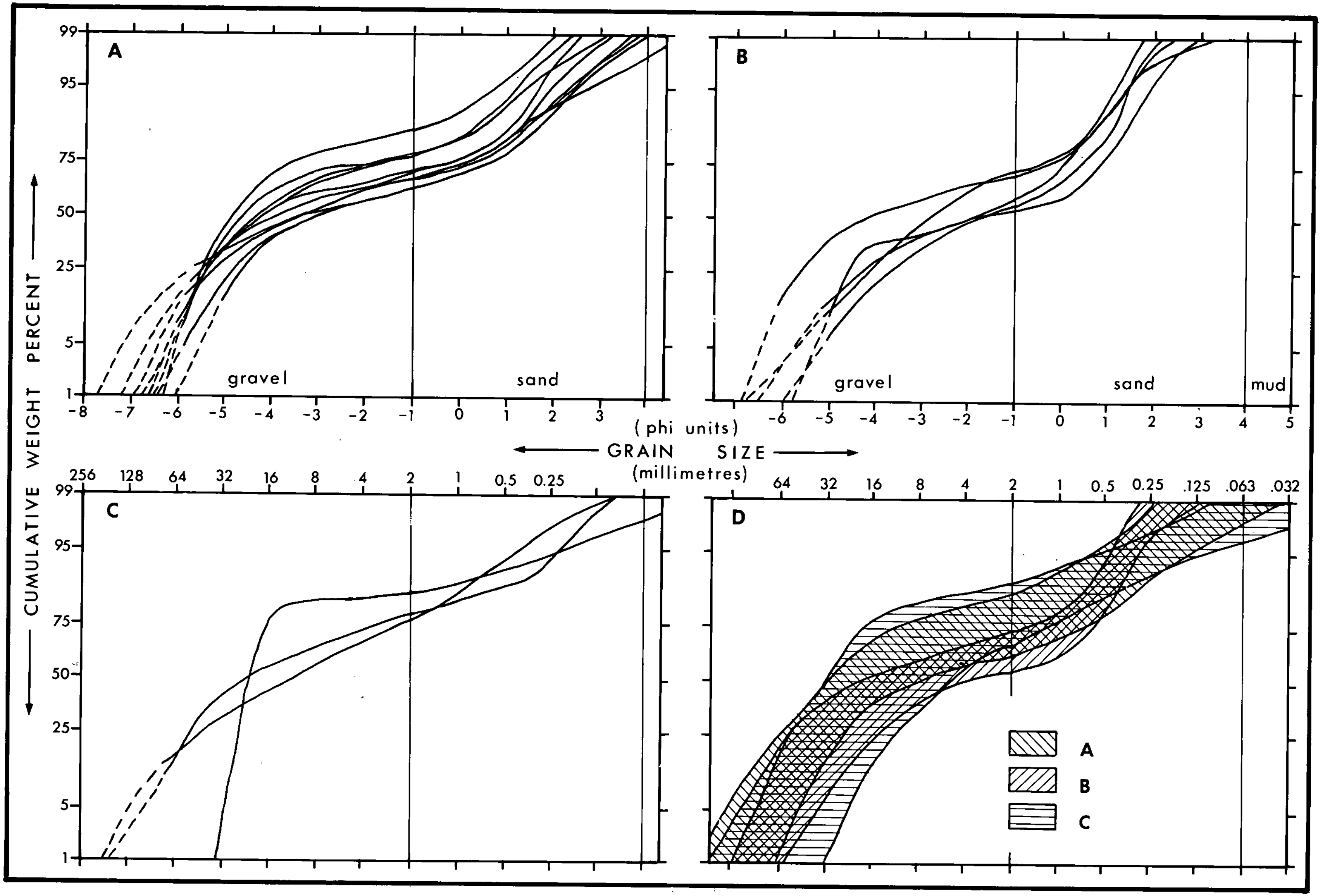


Fig. 49: GRAIN SIZE DISTRIBUTION OF PLEISTOCENE GRAVEL DEPOSITS: COQUITLAM-PORT MOODY AREA, BRITISH COLUMBIA. A. GLACIAL OUTWASH B. RAISED DELTA AND ALLUVIAL FLOODPLAIN C. SUPRALITTORAL D. AREAS OF GRAIN SIZE DISTRIBUTION.

Supralittoral gravels (Fig. 49C) generally contain 80% gravel-sized material, commonly heavily stained by iron oxides, but the remaining 20% is mostly composed of fine sand and mud. In this type the gravel fraction is mostly pebble-sized (4 to 32 mm) stones. These gravel deposits are bimodal, containing a large gravel fraction surrounded by a lesser mud matrix. This bimodality resulted from sea waves and spray reworking Vashon till and Capilano glaciomarine sediments and partly winnowing out the fines to form the supralittoral lag gravel. In Fig. 49D field limits for the three Pleistocene gravel types are superimposed for direct comparison. Supralittoral gravel analyses were difficult to perform and only three were done; thus field limits have been estimated for this type.

Limited exposures of pre-Vashon outwash deposits occur in the west bank of the lower Coquitlam River valley and some companies operating there are mining them. Elsewhere in the study area pre-Vashon outwash is only exposed at Mary Hill and Port Moody. In the Coquitlam River valley Semiahmoo? outwash 14 m thick is exposed at pit F (Figs. 1, 7) and Westlynn? outwash at pits E, F, and G. Semiahmoo? and Vashon outwash gravels are overlain by till and/or glaciomarine sediments, which must be removed with or prior to extraction of outwash gravel. No till was found to directly overlie Westlynn? outwash. Vashon and Semiahmoo? outwash vary in thickness and their contacts with adjacent sediment units are three-dimensional undulating surfaces. These surfaces are buried landscapes formed by water and ice action. Because of them estimation of gravel and sand reserves and of the lateral and vertical continuity of pit run material is extremely difficult. Westlynn? outwash, however, appears to have a planar upper contact with Highbury? sediments in the lower Coquitlam River valley; the lower contact was not exposed.

Raised delta and alluvial flood plain gravel deposits include Capilano raised deltas, Cowichan Head Formation fluvial sediments and Highbury? fluvial interbedded sand and gravel. As stated in Chapter Six, Capilano sediments were deposited at the end of the last glaciation as a composite marine delta up to 140 m a.s.l. at the mouth of the ancestral Coquitlam River. Cowichan Head gravel was deposited by nonglacial streams as flood plain sediments during the Olympia Nonglacial Interval. Highbury? sediments were deposited as channel and flood plain deposits during a pre-Olympia nonglacial interval. Curves in Fig. 49B plotted from analyses of Highbury? gravel are based only on the gravel beds in this unit. There is more sand than gravel in Highbury? sediments (Figs. 41, 42, 43).

In places Capilano deltaic gravel is overlain by a mantle of supralittoral lag gravel up to 1 m thick. Cowichan Head gravel is overlain by Coquitlam stony clayey silt which must be removed with or prior to gravel extraction. Highbury? sand and gravel lies between Westlynn? and Semiahmoo? outwash in the lower Coquitlam River valley and is easily mined. Capilano deltaic gravel is fan-shaped and pinches out northward against a buried landscape formed on Vashon Drift in the lower Coquitlam valley. Highbury? Sediments appear horizontally bedded and continue at uniform thickness for 2 km along Pipeline Road, on the west side of Coquitlam River, from pit G almost to pit E (Figs. 1, 7), where they are truncated by Vashon Drift.

Capilano supralittoral lag gravel was formed by the reworking of Vashon till and Capilano glaciomarine sediments by marine action, discussed previously, and occurs as a thin mantle covering these diamictons. It usually too thin and too dirty (commonly contains 20% fine sand and mud matrix, iron stained) to be economically important; however, where marine action cut through the underlying diamicton it may directly overlie Vashon outwash and together these deposits can be mineable.

Present-day stream gravel mainly occurs as channel bars and bed material of the Coquitlam River. Most of this gravel is eroded from the river banks, which are largely composed of Pleistocene glacial sediments, and transported by torrential winter runoffs. Most of the sand and finer materials are winnowed out and a lag gravel is left, mainly consisting of well sorted, subrounded granitic cobbles and boulders. Smaller mountain streams associated with mass wasting processes produce a range of gravels from well sorted gravel stream beds to dirty alluvial and colluvial slopewash gravels in stream banks and on hillsides.

In summary, raised beach lag gravels are widespread but too thin and dirty to be economical. Present-day river gravel is an important source, but limited in extent; however, it is constantly being replenished by torrential winter runoffs. Raised delta and alluvial flood plain deposits form an important source and are the best sorted of the Pleistocene gravels but they are also limited in extent. They are also commonly mined with underlying outwash. The most extensive and economically important are the outwash deposits. Vashon outwash is the most accessible, being usually nearer to the land surface than older outwash deposits; however, in the west bank of the lower Coquitlam River valley thick sections of older outwash have been exposed by gravel operators. Buried in Mary Hill (see Figs. 14 and 3 for depths) and probably deep beneath the uplands above Port Moody and Maillardville large pre-Vashon outwash, and fluvial gravel and sand reserves also exist; however, their lateral and vertical extents will be difficult to determine by drilling methods because of the irregular, three-dimensional buried landscapes bounding these units.

Municipal zoning regulations present the largest problem to gravel and sand operators in the Coquitlam-Port Moody area. The gravel and sand industry is the major mining industry in the Fraser Lowland. Before the closure of the Mary Hill operation in 1975, the annual pit-head production probably exceeded 5 million cubic meters with a present-day value of at least 6 million dollars at the pit sites. The Greater Vancouver area has been fortunate in the abundance of good gravel and sand deposits within easy transport of urban centres, and as a result, has enjoyed some of the lowest-cost gravel and sand deposits in North America. The Coquitlam-Port Moody area alone has supplied many tens of millions of cubic meters of gravel at a value of many millions of dollars to the Greater Vancouver area for construction purposes. Municipal zoning regulations have closed the largest gravel and sand operation in British Columbia at Mary Hill. Houses and apartment buildings will probably cover large reserves of Vashon and pre-Vashon outwash deposits and some Cowichan Head Formation fluvial gravel and sand. With further urban development and land rezoning other gravel and sand operations may also be phased out and more large reserves covered by buildings. Gravel and sand will then have to be transported from areas much farther away from the Vancouver area, thereby greatly increasing transportation and possibly mining costs.

Other problems, related to the surficial geology of the area, that might hinder gravel and sand excavation are as follows:

1. Excessive overburden of till or glaciomarine stony clayey silt. Both are difficult to remove with a shovel or loader and both present a disposal problem.

2. Discontinuity of gravel and sand units, due to irregular buried landscapes bounding the strata, causing them to randomly swell and pinch out (Fig. 30). Discontinuous gravel lenses in dominantly sand units also cause problems in gravel reserve estimation.

3. Oversized boulders up to 5 m dia. (Fig. 21) in glacial units, which cannot be handled by equipment without blasting.

4. Occurrences of interbedded thin fine sand and silt strata can cause problems in washing and sizing, and washouts in steep slopes.

5. Occurrence of till and stony clayey silt ridges (Fig. 30) between sand and gravel units. Both are difficult for machinery to handle and when wet they form mudholes. If the ridges are high, they make the overlying gravel and sand too thin to mine economically.

6. High groundwater tables, particularly troublesome for a small operator with only a shovel or loader operation.

B. Foundation Materials and Drainage

Armstrong (1957, 1961) summarized characteristics pertinent to foundations of the various Pleistocene sediments found in the Fraser Lowland. A knowledge of the properties of foundation materials is particularly desirable wherever the stability and durability of structures may be affected by the nature of underlying materials.

The most important consideration is whether the sediments on which foundations are to be built have been preloaded by glacier ice. Vashon till and older deposits have been preloaded by at least 1800 m (5900 ft.) of ice at various times during the Pleistocene epoch, whereas post-Vashon deposits in the Coquitlam-Port Moody area have been preloaded only by the weight of the sediments overlying them.

Most tills in the area are lodgement tills, deposited under great weights of ice, and they should remain relatively undeformed under heavy loads. In tills fine particles fill voids between coarse particles and bind them together to form a natural physical concrete. Thus tills can harden and become impervious again after sliding, or after excavation when used as fill. However, they have very poor drainage. Till-like glaciomarine deposits, however, were formed by stones dropping into sea-floor muds from drifting ice, and post-Vashon glaciomarine deposits (i.e. those that have not been preloaded by ice) may fail when subjected even to relatively light loads.

Where post-Vashon glaciomarine deposits attain thicknesses of approximately 5 m (15 ft.) or more, major urban and industrial development on these deposits may encounter local settling and drainage problems quite unlike those of the tills that they may resemble lithologically. Examples in the Coquitlam-Port Moody area are the Chines Heights and Harbour Village subdivisions on the hillside south of the Barnet Highway, between the cities of Port Moody and Port Coquitlam. In these subdivisions some houses were built on Capilano (post-Vashon) fossiliferous glaciomarine stony clayey silts up to 8 m (25 ft.) thick and are experiencing drainage problems in some places and may encounter bearing problems. As the name indicates, Chines Heights is a series of washout or slide gullies caused by excessive pore water pressure built up in the Capilano glaciomarine and underlying deposits. Here the underlying Quadra Sands have washed out from beneath the Capilano glaciomarine sediments, causing them to fail and even flow. Under these conditions very light loads would cause these sediments to fail. Glaciomarine deposits have very low permeabilities, which control downward drainage; therefore, pore water pressure should be controlled in these (and underlying) deposits where urban or industrial development is occurring, especially on hillsides. Armstrong (in prep. and Fig. 1 of this thesis) has remapped the surficial deposits in the area, including the distribution of Capilano glaciomarine sediments and Vashon till.

Table III (modified after Armstrong, 1961) summarizes foundation and drainage characteristics of Pleistocene sediments found in the Coquitlam-Port Moody area. All the materials listed in the table are easy to excavate except for the tills and to a lesser extent the glaciomarine deposits. Cohesion may be high enough in the tills to require blasting and some of the boulders in both the till and glaciomarine deposits will have to be broken to be removed.

TABLE III: FOUNDATION MATERIALS AND DRAINAGE, COQUITLAM-PORT MOODY AREA, B.C.

Type of Deposit	Preloaded by Glacier Ice	Bearing Value for Foundations	Drainage
Till: Vashon, Semiahmoo?	yes	excellent	surface drainage only
Sand and Gravel: Vashon (where overlain by till), Cowichan Head, Semiahmoo?, Highbury?, Westlynn?	yes	good to excellent	excellent downward and lateral
Sand and Gravel: Capilano, Vashon (where not overlain by till)	no	good	excellent downward and lateral except where groundwater table near surface
Glaciomarine stony clayey silt: Port Coquitlam, Semiahmoo?	yes	fair to good	very poor downward and lateral drainage
Glaciomarine stony clayey silt and marine clayey silt: Capilano	no	poor to fair; may have excessive settlements	surface drainage only
Glaciolacustrine laminated stony silt: Vashon (where overlain by till), Semiahmoo?	yes	fair to good	very poor downward and lateral drainage
Medium to coarse sand: Holocene--deposited by modern streams in low flat-lying areas	no	fair to good, depending on density	poor most of the year as groundwater table near surface
Fine sand, silt, and clay: Holocene--deposited by modern streams in low flat-lying areas	no	very poor to fair; in areas underlain by mostly silt and clay excessive settlements may occur; areas underlain by mostly fine sand and silt are susceptible to liquefication	surface drainage only
Fossil peat, organic fine sand, silt and clay: Quadra (minor), Cowichan Head, Highbury?	yes	poor to fair	very poor downward and lateral drainage
Peat, organic fine sand, silt, and clay: Holocene--modern bog and swamp deposits	no	preload extensively or remove from foundations; undergoes extreme compaction and excessive settling occurs	very difficult; peat holds up to 26 times its own weight of water

C. Sewage Disposal

Wherever sewage disposal is dependent on septic tanks, drainage and sub-soil conditions must be considered. Mary Hill and the slopes of Maillardville, Essondale, Harbour Village, Harbour Chines, Port Moody, and the upland northeast of Ioco are covered with Capilano glaciomarine sediments and Vashon till. These deposits permit almost no downward drainage. In places they are mantled by a thin layer of Capilano supra-littoral lag gravel and/or Capilano littoral sand which permit downward drainage to the impervious materials underlying them; however, during the rainy seasons the groundwater table is near the surface of the thin sand and gravel mantle and drainage becomes very poor. Much of the overflow from septic tank absorption fields in these upland areas must, therefore, eventually drain downslope by surface and near-surface runoff. The upland northeast of Ioco and the southern upper slopes of Burke Mountain, where bedrock is at or near the ground surface, have only surface drainage and are not favourable for septic tank installation. If septic tanks must be used under these unfavourable conditions, they should be placed sufficiently far apart so as not to affect development on adjacent lots.

Mary Hill, the slopes of Maillardville etc. east of Burnaby Mountain, and the bench on the west side of the lower Coquitlam valley are underlain by Vashon till and Capilano glaciomarine sediments which overlie Vashon or Quadra gravel and sand. In these areas some downward drainage can be accomplished by putting drainage holes through the overlying impervious material; however, this should not be done where groundwater contamination is a problem.

In the lower Coquitlam valley, 2-3 km north of the Lougheed Hwy., Capilano permeable sand and gravel form terraces which permit easy downward circulation of septic tank effluent except where the groundwater table is near the surface. Again, where groundwater contamination is a problem, care must be taken in the construction and spacing of septic tanks, and the groundwater supply checked periodically for contamination.

In the Coquitlam River valley between Essondale and Mary Hill, in the lowland south of Maillardville, and in the lowland area at Port Moody, septic tank sewage disposal will not operate satisfactorily where the groundwater table is at or close to the absorption tile, or in places that are periodically flooded, especially during rainy seasons.

D. Flood Control

Flooding is not a serious problem in the Coquitlam-Port Moody area. Dykes along the Fraser River are effective in controlling it. The Coquitlam River floods frequently between Essondale and Mary Hill near its mouth and mountain streams north of the cities of Port Moody and Port Coquitlam occasionally flood. Vegetative cover, check dams, and other measures are used effectively to minimize destruction caused by flooding in the Coquitlam-Port Moody area.

E. Slides and Washouts

Large slides have occurred in the area over the years, mainly on steep slopes under unstable soil conditions caused by heavy rainfall and excessive land clearing.

The steep west slope of the lower Coquitlam River valley north of the Lougheed Hwy. has undergone much sliding due to heavy rainfalls and human activity. Washouts due to overloaded water tables and water draining out of this slope through pervious fine sediment layers, causing overlying materials to fail and slide, have been documented by Armstrong (1957). Large natural slide scars also occur near the Greater Vancouver Watershed Gates below Coquitlam Lake. At Port Moody Armstrong (1957) discovered a major slide at least 100 years old in a building excavation. The slide was probably caused by excessive rainfall during a rainy season and the material came out of the gullies at Chines Heights. In 1953 a large washout occurred at the Mary Hill gravel pit on the south slope of the hill. It occurred during gravel excavation when the shovel cut through a thin silt bed, tapping a buried water reservoir, which was overlain by two Vashon till sheets separated by outwash gravels. The saturated silt layer became a mudflow and a large pit was excavated by the slide.

As previously mentioned, pore water pressure in poorly drained fine sediments (and underlying sediments) in the area must be monitored and controlled where steep slopes occur, especially during rainy seasons and where urban and industrial development is taking place. Areas of low slope stabilities, and therefore, potential slide areas, within the Coquitlam-Port Moody area occur along the west bank of the lower Coquitlam River valley, the north side of the upland between Port Moody, Harbour Village and Maillardville, the west and south slopes of Mary Hill, and a small, steep, area on the south slope of Maillardville. Less hazardous areas are the east side of the lower Coquitlam River valley (underlain mostly by bed-rock), on top of the gently sloping bench on the west side, the east and north slopes of Mary Hill, the lower slopes of Burke Mountain, the Ioco area, and near the top of the upland between Port Moody, Harbour Village, and Maillardville, where slopes are gentle. Stable areas are the upper slopes of Burke Mountain and above Ioco, where bedrock is at or near the surface, the lower reaches of Coquitlam River and other flat areas around Port Coquitlam and Port Moody (however settling may occur on peat bogs), and on top of the uplands at Mary Hill and between Port Moody, Harbour Village, and Maillardville. The tops of the uplands are excellent for building foundations as they are under-lain by glacier-loaded till and they have high slope stability; however, surface and downward drainage may be a problem.

CHAPTER EIGHT: CONCLUSIONS

A. Quaternary Geology

Exposed Quaternary sediments in the Coquitlam-Port Moody area indicate it has been subjected to two and possibly three glaciations, represented by drift deposits, separated by non-glacial intervals which are represented by organic sediments. Each major ice advance and retreat was accompanied by eustatic and isostatic sea-level changes of up to 230 m, relative to present sea level, and probably tectonic adjustments. Two or three local advances and retreats were associated with each major advance. During the last major glaciation two stades (smaller glacial intervals within the major glaciation) occurred, possibly separated by an interstade (an interval in the glaciation warmer than the stades, in this case, during which peat formed). Coquitlam Drift, identified during this study, represents the earlier stade and has not been recognized before on the B.C. mainland. Marine invasion occurred in the area at least three times during the Pleistocene epoch, and is represented by fossiliferous marine and glaciomarine deposits.

Nine formational lithostratigraphic units have been described in the area, each probably representing a geologic-climatic unit, and the following succession has been established: Holocene Sediments (11,000 yr. B.P.-present); Fraser Glaciation (Late Wisconsin, 26,000-11,000): Capilano Sediments, Vashon Drift, Quadra Sand, and Coquitlam Drift; Olympia Nonglacial Interval (Middle Wisconsin, 60,000?-26,000): Cowichan Head Formation; Major Glaciation (Middle or Early Wisconsin, probably >62,000): Semiahmoo? Drift; Major Nonglacial Interval (Early Wisconsin?, probably >62,000): Highbury? Sediments; Major Glaciation? (Early or Pre-Wisconsin, >62,000): Westlynn Drift? These units are separated by unconformities representing buried landscapes which were later modified by stream and/or ice action.

During the deposition of each formational sediment unit former landscapes were reshaped and new ones formed. The Coquitlam valley sediment fill was carved out and the uplands in the area remodelled several times during Quaternary time. Consequently, the unravelling of the stratigraphic succession becomes very complex, especially as lithologic units of different chronologic ages may closely resemble one another and may be impossible to separate without absolute chronologic ages or complete stratigraphic sections. Sediment units occur sporadically because of the development of buried landscapes and correlations made on other than a three-dimensional study are at best tentative and should be supported wherever possible by radiocarbon dates. Thus a study based purely on drill hole information may lead to completely misleading conclusions. In some places in the area a drill hole could penetrate more than 15 different sediment layers, and in others, only a few meters away, as few as two.

"Quadra" sediments have in the past been considered as nonglacial or interglacial deposits (Armstrong and Brown, 1953; Fyles, 1963; Armstrong, 1965). Clague (1976) proposed, and the present writer agrees, that Quadra Sand is proglacial (distal) outwash deposited by meltwater derived from Vashon ice. However, as a lithostratigraphic unit Quadra Sand has been mapped separately from Vashon Drift, as Armstrong, et al. (1965) have defined Quadra sediments to be the lower bounding strata for Vashon Drift. The present writer suggests that in the Coquitlam-Port Moody area proglacial Quadra Sand deposition, by streams derived from southward-advancing Vashon? ice to the north in the Coast Mountains, started early during the Fraser Glaciation about 25,800 years ago. It was interrupted by westward-advancing Coquitlam ice which blocked the mouth of the Coquitlam valley while Quadra Sand was deposited behind the ice dam up to 250 m a.s.l. about 21,600 years ago. Quadra Sand deposition continued in the Coquitlam-Port Moody area during the retreat of Coquitlam ice, which occurred by 18,600 yr. B.P., when peat was growing at Mary Hill. During this time Vashon ice advanced further south towards the area and meltwater streams carved out much of the Quadra fill in the Coquitlam valley and redeposited it in the Fraser Lowland.

The topography of the area has remained basically the same since Semiahmoo? time and has been modified only locally by the reshaping of older landscapes. The pre-Semiahmoo? stratigraphic record is too sparce to comment on the Pleistocene topography before that time.

B. Engineering and Environmental Geology

Outwash sand and gravel are the most extensive sources of granular aggregate for construction purposes. Vashon outwash is the most accessible and commonly mined gravel deposit; however, Semiahmoo? and Westlynn? outwash are of equally high quality but they are usually too deeply buried to be economic. These latter deposits are found buried in uplands underlain by thick Quaternary deposits (e.g. Mary Hill), and in river banks in Quaternary sediment fills occupying valleys in the Coast Mountains which border the Fraser Lowland (e.g. lower Coquitlam River valley). Raised delta and alluvial floodplain gravels are the best sorted but are confined to the mouths of mountain valleys, or buried in uplands and mountain valley sediment fills. Supralittoral lag gravel is widespread and underlies upland surfaces but is usually too thin, muddy, and iron stained to be economic. Modern river gravel deposited by streams flowing out of the Coast Mountains, and cutting through and redepositing Quaternary sediments, is also a good source for granular aggregate (e.g. Coquitlam River gravel). Where one uneconomic gravel type directly overlies another the combination may become mineable (e.g. Capilano supralittoral overlying thin Vashon outwash).

Some problems encountered by pit operators will be the removal of overburden, especially till and glaciomarine deposits; the irregular distribution of pit run due to buried landscapes; and especially municipal urban and industrial rezoning of land underlain by good gravel reserves.

Land surfaces of low slope which are underlain by bedrock and by sediments that have been pre-loaded by glacier ice (Vashon Drift and older sediments) are best locations for buildings and roads; however, drainage may be poor where bedrock, till, or glaciomarine deposits are at or near the surface.

Capilano glaciomarine sediments have not been pre-loaded by glacier ice and can cause serious settling and drainage problems for engineers and contractors where these deposits become thick. When these sediments become water saturated, they can flow even on very small slopes. This is especially true on steep slopes where pore water pressure in the underlying sediments becomes high, underlying pervious strata may wash out as water drains through them, and the overlying glaciomarine sediment may fail and flow. Sewage disposal by septic tanks is a problem in areas underlain by impervious till, glaciomarine sediments, and bedrock, and where the groundwater table is near the surface. Consideration must also be given to groundwater contamination when installing septic tanks. Flat areas underlain by peat bogs pose serious settling, drainage, and sewage disposal problems to urban and industrial development. Flooding has not been a serious problem in the area.

C. Recommendations for Further Study

1. Detailed stratigraphic and sedimentological study of pre-Vashon Pleistocene sediments elsewhere in the Fraser Lowland and adjacent regions to work out the correlation and history of these sediments, aided by radiocarbon dating, palynology, micropaleontology, and fossil insect studies.

2. Detailed sedimentological and stratigraphic study of Vashon Drift with emphasis on facies relationships of the ice-contact deposits.

3. Palynological and fossil insect studies of the sediments containing organic materials.

4. Detailed comparative study of glaciomarine and till deposits including: pebble fabric, chemical, bulk density, mineralogic, grain size and roundness, penetration, Atterberg, and other analyses.

5. Detailed study on the cause of disintegration of some granitic stones compared to intact granitic stones found in juxtaposition in the Quaternary sediments in the area.

6. Detailed study of potential engineering and environmental problems to construction in the Coquitlam-Port Moody area involving the study of case histories and field work to produce "hazard" maps for the area.

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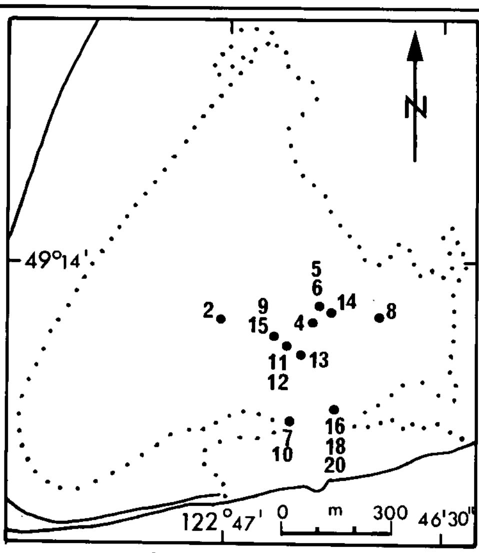
A P P E N D I C E S

Number on Maps	Laboratory Number	Date radiocarbon year before present	Elevation (metres)	Material	Collector
1	GSC 2177	12,000±100	69	marine shells from Capilano glaciomarine fine sandy silt	J.E. Armstrong
2	GSC 2194	18,600±190	61	wood from peat at base of Quadra Sand	J.E. Armstrong
3	GSC 2203	21,600±200	190	wood from fine sand in Quadra Sand	J.E. Armstrong
4	GSC 2273	25,800±310	50	wood from organic silt at top of Cowichan Head Formation	J.V. Matthews
5	GSC 2277	26,000±310	40	wood from sandy gravel in Cowichan Head Formation	S.R. Hicock
6	GSC 2191	26,200±320	40	wood from sandy gravel in Cowichan Head Formation-located 1 m from GSC 2277	S.R. Hicock
7	GSC 124	26,450±520	35	peaty silt from silty fine sand in Cowichan Head Formation	J.E. Armstrong
8	GSC 2217	26,900±320	37	wood from sandy silt in Cowichan Head Formation	S.R. Hicock
9	GSC 2263	27,000±490	49	wood from peat in Cowichan Head Formation	S.R. Hicock
10	GSC 536	27,180±460	35	wood from silty clay in Cowichan Head Formation	J.E. Armstrong
11	GSC 2107	27,400±420	39	wood from peat in Cowichan Head Formation	J.E. Armstrong
12	GSC 2139	28,200±200	38	wood from peat in Cowichan Head Formation	J.E. Armstrong
13	GSC 2140	29,600±200	35	sapropel in Cowichan Head Formation	J.E. Armstrong
14	GSC 2137	40,200±430	34	wood from stony organic colluvium, probably in Cowichan Head Formation	J.E. Armstrong
15	GSC 2167	40,500±1700	45	wood from stony organic colluvium, probably in Cowichan Head Formation	S.R. Hicock
16	GSC 2091	>44,000	23	wood from stony laminated silt in Semiahmoo? Drift	J.E. Armstrong
17	GSC 2094	>44,000	114	wood from organic silt in Highbury? Sediments	J.E. Armstrong
18	GSC 2120 rerun of GSC 2091	>48,000	23	wood from stony laminated silt in Semiahmoo? Drift	J.E. Armstrong
19	GSC 2094-2 rerun of GSC 2094	>49,000	114	wood from organic silt in Highbury? Sediments	J.E. Armstrong
20	QL-194*	>62,000	20	wood from stony laminated silt in Semiahmoo? Drift	S.R. Hicock

*QL-194 was run by M. Stuiver, University of Washington. All other dates were run by the Geological Survey of Canada.



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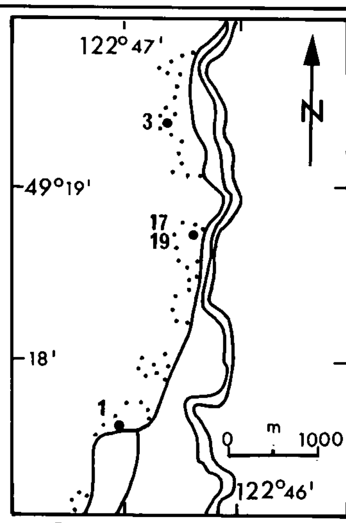


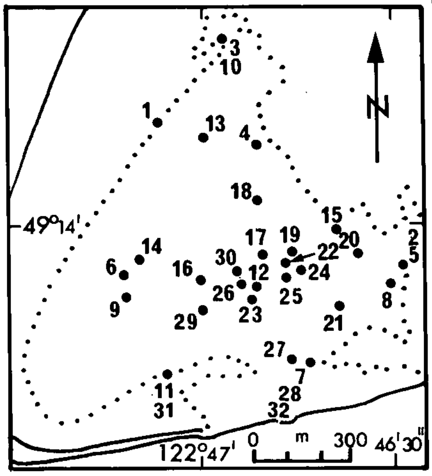
LOWER COQUITLAM RIVER VALLEY

APPENDIX 1: RADIOCARBON DATES

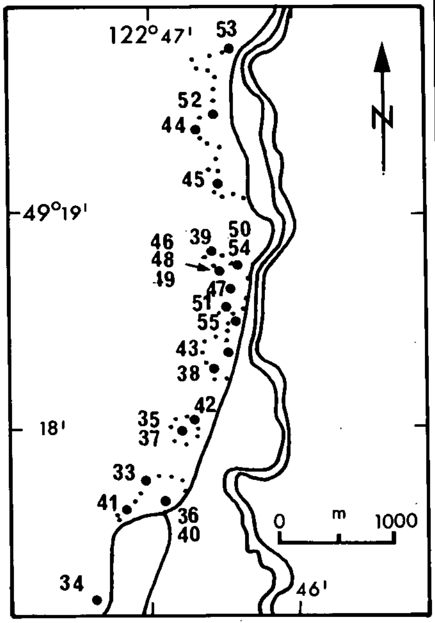
Rock Types → Localities ↓	% Granitic and Associated*	% Volcanic	% Garibaldi type	% Quartzite, Chert, Pelite, Argillite	% Quartz	% Other**	Total % Derived from Coast Mtns.	Total % Dervied from Cascade Mtns.
Mary Hill; estimated ratio Coast/Cascade provenance:								
	9:1	1:4		0	1:1	2:3	-	-
Capilano Supralittoral lag. gravel:								
1	92	4	-	4	-	-	84	16
2	93	5	-	2	-	-	85	15
3	91	3	2	3	-	3	85	15
Capilano Glaciomarine:								
4	82	8	-	8	1	1	76	24
Vashon Till:								
5	85	8	-	7	-	-	79	21
6	79	11	-	7	-	3	74	26
7	83	6	3	9	-	2	80	20
Vashon Outwash:								
8	78	7	-	11	2	2	73	27
9	80	6	-	11	2	1	74	26
10	80	8	-	11	1	-	74	26
11	89	2	1	7	-	2	82	18
Quadra Sand:								
12	80	6	-	6	6	2	77	23
13	83	5	-	7	2	3	78	22
14	77	6	-	13	3	1	72	28
15	77	8	-	9	2	4	74	26
16	87	8	-	3	1	1	81	19
17	78	7	-	12	3	-	72	28
18	80	5	-	11	2	2	75	25
Coquitlam Drift:								
19	47	10	-	38	4	1	46	54
20	63	14	-	20	-	3	61	39
21	89	9	-	2	-	-	82	18
Cowichan Head Formation:								
22	92	5	-	1	-	2	85	15
23	92	3	-	3	-	2	84	16
24	95	4	-	-	-	1	87	13
25	91	5	-	3	-	1	83	17
Semiahmoo?Drift:								
26	88	3	-	4	-	5	81	19
27	86	6	-	4	1	3	79	21
28	93	5	-	-	-	2	86	14
29	92	6	-	2	-	-	84	16
30	86	5	-	5	2	2	80	20
31	86	7	-	7	-	-	78	22
32	82	7	2	9	1	1	77	23
Lower Coquitlam River Valley; estimated ratio Coast/Cascade provenance:								
	19:1	1:9		0	1:1	2:3		-
Capilano Supralittoral:								
33	95	2	1	1	2	-	92	8
Capilano deltaic sand and gravel:								
34	93	5	1	2	-	-	89	11
35	89	4	-	3	2	2	87	13
Vashon Till:								
36	91	3	2	4	1	1	90	10
37	98	-	-	1	-	1	93	7
38	92	4	1	2	2	-	89	11
39	95	3	-	1	-	1	90	10
Vashon Outwash:								
40	87	5	-	8	-	-	84	16
41	91	4	2	2	1	2	89	11
42	94	3	-	2	1	-	89	11
43	96	2	2	1	1	-	93	7
Quadra Sand:								
44	88	5	-	5	1	1	86	14
45	89	4	-	5	-	2	86	14
Semiahmoo ? Drift:								
46	86	7	-	5	1	1	84	16
47	97	2	-	1	-	-	92	8
48	92	5	2	2	-	1	89	11
49	94	5	-	1	-	-	90	10
Highbury? Sediments								
50	92	4	-	4	-	-	87	13
51	90	5	-	4	-	1	87	13
Westlynn Drift?								
52	98	1	-	-	-	1	93	7
53	93	3	-	2	-	2	90	10
54	95	2	-	1	1	1	91	9
55	99	1	1	-	-	-	95	5
Port Moody; estimated ratio Coast/Cascade provence:								
	9:1	1:4		0	1:1	2:3	-	-
Vashon?Till:								
56	94	3	-	2	1	-	87	13
Quadra?Sand:								
57	96	1	-	-	3	-	88	12
Semiahmoo?Drift:								
58	95	2	1	3	-	-	87	13
59	86	7	5	1	2	4	85	15

* Granitic and associated rock types include migmatites, metasedimentary, metavolcanic, amphibolites, and greenstones

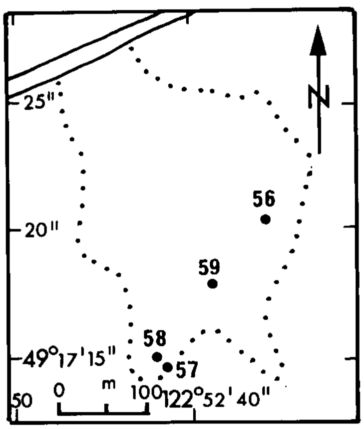
** Others includes Tertiary rock types and older sedimentary rocks.



MARY HILL



LOWER COQUITLAM RIVER VALLEY



PORT MOODY

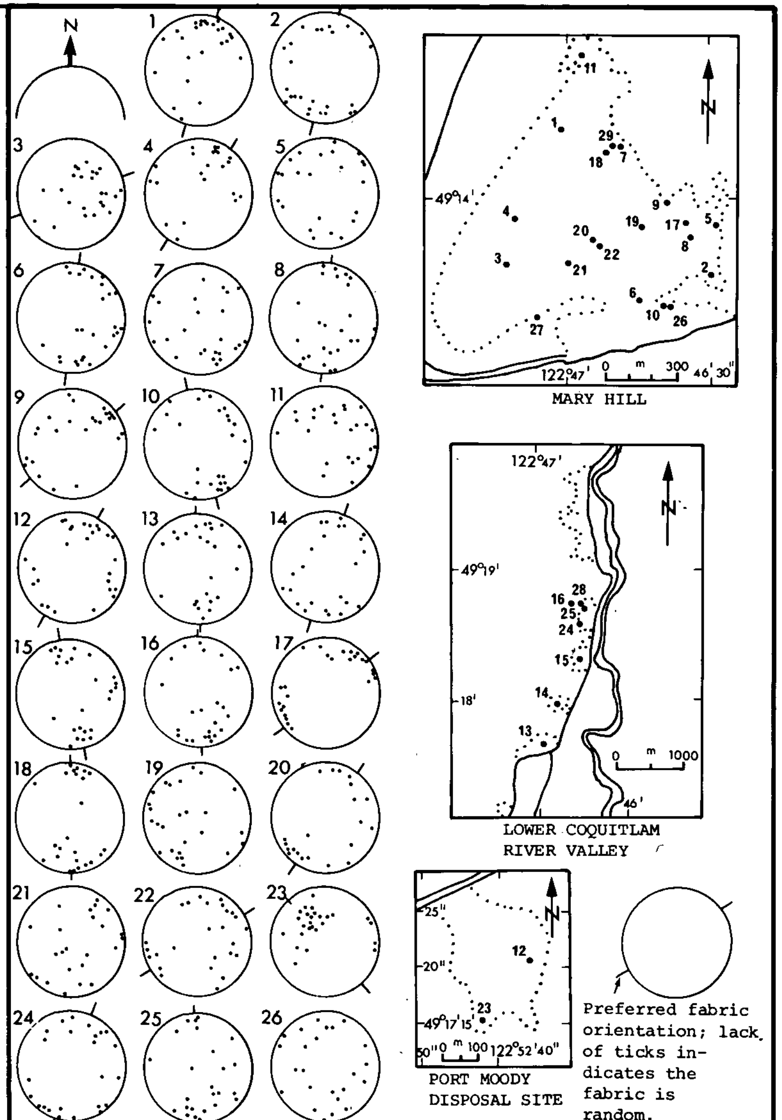
APPENDIX 2: PEBBLE PROVENANCE ANALYSES AND LOCALITIES

GLACIAL DIAMICTON PEBBLE FABRICS*
(based on samples of 25 pebbles)

Analysis No.	Plunge Direction of Preferred Pebble Long Axis	Amount of Plunge	Fabric** Strength
VASHON TILL:			
1	015°	13°	Strong
2	196	05	Weak
3	069	50	Strong
4	035	14	Strong
5	-	-	None
6	186	07	Weak
7	-	-	None
8	186	15	Weak
9	051	09	Weak
10	166	05	Weak
11	-	-	None
12	034	07	Weak
13	180	01	Strong
14	198	01	Strong
15	168	05	Weak
16	178	15	Strong
COQUITLAM GLACIOMARINE?			
17	053	02	Strong
18	180	07	Strong
19	-	-	None
SEMIAHMOO? TILL:			
20	215	09	Strong
21	-	-	None
22	060	12	Weak
23	319	45	Strong
24	019	03	Weak
25	175	14	Strong
SEMIAHMOO? GLACIOMARINE?:			
26	-	-	None
27	-	-	None
28	200	25	Strong
CAPILANO GLACIOMARINE:			
29	-	-	None

* Data was taken from a computer analysis of the writer's field measurements done by D.M. Mark, Geography Department, Simon Fraser University. Data for #27 was taken from Rowe, 1975.

** Fabric Strength is based on Mark's statistical interpretation of the data at the 95% confidence level.



Preferred fabric orientation; lack of ticks indicates the fabric is random.

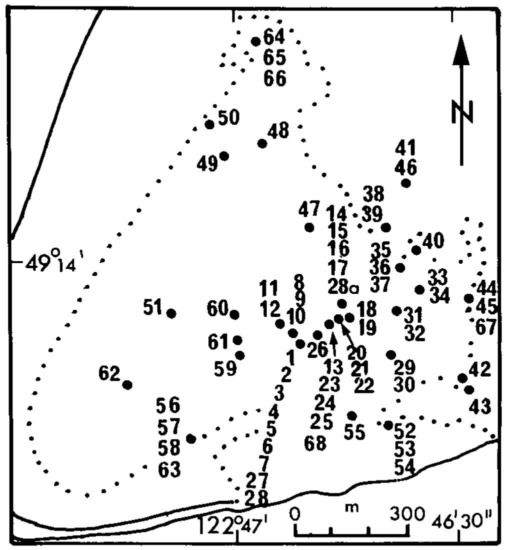
*Stereograms are equal-area lower hemisphere projections of pebble long axes. Ratio of long/intermediate axis lengths ranged from 1.5 to 2.0

APPENDIX 3 : STEREOGRAMS* AND LOCALITIES OF GLACIAL DIAMICTON PEBBLE FABRIC ANALYSES

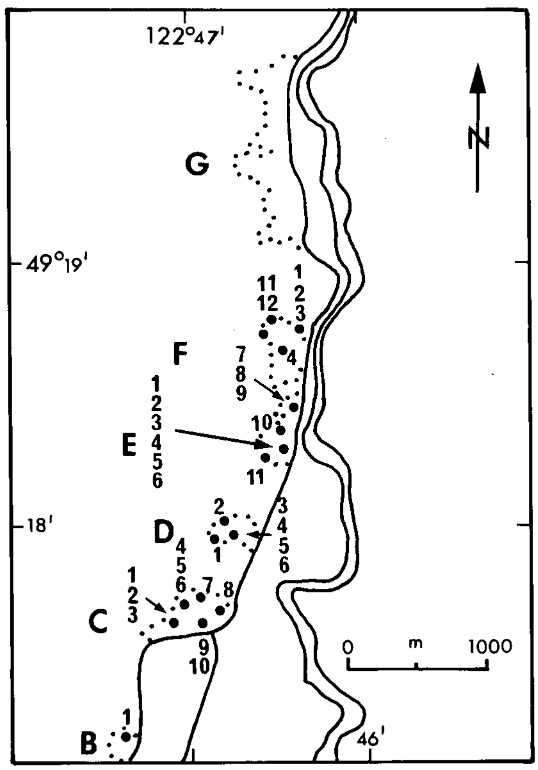
Sample No.	Lithostratigraphic Unit
Pit A (Mary Hill):	
MH01SD	Cowichan Head Formation
MH02GV	Cowichan Head Formation
MH03SD	Cowichan Head Formation
MH04PT	Cowichan Head Formation?
MH05PT	Cowichan Head Formation?
MH06SD	Cowichan Head Formation
MH07GV	Cowichan Head Formation?
MH08ST	Semiahmoo? glaciolacustrine
MH09ST	Cowichan Head Formation?
MH10ST	Semiahmoo? glaciolacustrine
MH11TL	Semiahmoo? lodgement till
MH12ST	Semiahmoo? glaciolacustrine
MH13PT	Cowichan Head Formation
MH14PT	Cowichan Head Formation
MH15GV	Cowichan Head Formation
MH16SD	Cowichan Head Formation
MH17SD	Cowichan Head Formation
MH18GV	Cowichan Head Formation?
MH19SD	Cowichan Head Formation?
MH20SD	Cowichan Head Formation
MH22GV	Cowichan Head Formation
MH23GV	Cowichan Head Formation
MH24SD	Cowichan Head Formation
MH25SD	Quadra
MH26GV	Quadra
MH27SD	Quadra
MH28SD	Quadra
MH28aGM	Coquitlam Drift
MH29SD	Cowichan Head Formation
MH30GM	Coquitlam Drift
MH31ST	Cowichan Head Formation
MH32SD	Cowichan Head Formation
MH33SD	Cowichan Head Formation or Quadra-below Coquiltam Drift
MH34GM	Coquitlam Drift
MH35SD	Cowichan Head Formation or Quadra-below Coquitlam Drift
MH36GM	Coquiltam Drift
MH37GV	Cowichan Head Formation or Quadra-below Coquitlam Drift
MH38TL	Vashon lodgement till
MH39SD	Quadra
MH40SD	Quadra
MH41GV	Vashon outwash
MH42GV	Vashon outwash
MH43TL	Vashon lodgement till
MH44GV	Vashon outwash
MH45TL	Vashon lodgement till
MH46SD	Quadra
MH47SD	Quadra
MH48SD	Vashon outwash
MH49TL	Vashon lodgement till
MH50GV	Capilano supralittoral
MH51SD	Quadra
MH52GM	Semiahmoo? glaciomarine?
MH53GV	Semiahmoo? outwash
MH54TL	Vashon lodgement till
MH55ST	Semiahmoo? glaciolacustrine
MH56GM	Semishmoo? glaciomarine?
MH57SD	Quadra
MH58SD	Semiahmoo? glaciolacustrine?
MH59TL	Semiahmoo? lodgement till
MH60ST	Semiahmoo? glaciolacustrine
MH61SD	Quadra
MH62TL	Vashon lodgement till
MH63GV	Vashon outwash
MH64TL	Vashon lodgement till
MH65GV	Capilano supralittoral

Sample No.	Lithostratigraphic Unit
MH66GV	Vashon outwash
MH67GV	Capilano supralittoral
MH68GV	Cowichan Head Formation
Pit B (G.V.S. & D.D., or West-Lin):	
WL01SD	Capilano raised deltaic
Pit C (Allard):	
AL0.ST	Capilano glaciomarine
AL02GV	Vashon outwash
AL03SD	Capilano raised littoral
AL04ST	Capilano glaciomarine
AL05ST	Capilano glaciomarine
AL06SD	Capilano raised deltaic
AL07GV	Capilano supralittoral
AL08TL	Vashon lodgement till
AL09SD	Vashon outwash
AL10ST	Vashon glaciolacustrine?
Pit D (Kask Bros.):	
KB01SD	Capilano raised deltaic
KB02GV	Capilano raised deltaic
KB03TL	Vashon lodgement till
KB04ST	Vashon glaciolacustrine
KB05GV	Vashon outwash
KB06SD	Quadra
Pit E (Johnson):	
JN01GV	Vashon flow till?
JN02GV	Vashon outwash
JN03ST	Vashon glaciolacustrine
JN04SD	Vashon glaciolacustrine?
JN05TL	Vashon lodgement till
JN06SD	Quadra
JN07GV	Westlynn? outwash?
JN08SD	Vashon outwash
JN09SD	Westlynn? outwash?
JN10SD	Vashon outwash?
JN11ST	Vashon glaciolacustrine?
Pit F (S and S):	
SS01GV	Westlynn? outwash?
SS02SD	Highbury? fluvial
SS03GV	Highbury? fluvial
SS04TL	Semiahmoo? lodgement till
SS05TL	Semiahmoo? lodgement till
SS06SD	Semiahmoo? outwash
SS07GM	Semiahmoo? glaciomarine?
SS08GV	Semiahmoo? outwash
SS09SD	Quadra
SS10TL	Vashon flow? till
SS11SD	Vashon glaciolacustrine?
SS12TL	Vashon lodgement till
Pit G (Cewe): not sampled	
Pit H (Port Moody):	
PM01SD	Semiahmoo? proglacial
PM02TL	Vashon lodgement till
PM03SD	Semiahmoo? proglacial
PM04SD	Quadra
PM05SD	Semiahmoo? proglacial
PM06TL	Semiahmoo? lodgement till
PM07SD	Cowichan Head Formation?
PM08SD	Cowichan Head Formation?
PM09ST	Cowichan Head Formation?
PM10SD	Quadra
PM11SD	Quadra
PM12ST	Semiahmoo? glaciolacustrine?

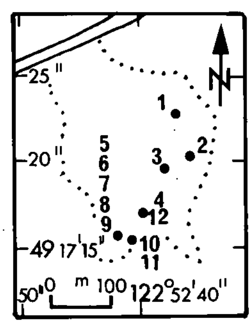
SD	Sand	TL	Till
ST	Silt	GM	Glaciomarine?
GV	Gravel	PT	Peat or organic colluvium



PIT A



PITS B to G



PIT H

APPENDIX 4: SEDIMENT SAMPLE LOCALITIES

FIGURE 3

DIAGRAMMATIC CROSS SECTIONS
MARY HILL GRAVEL PIT
PORT COQUITLAM, B. C.

LEGEND

10 SUPRALITTORAL LAG GRAVEL
Very poorly sorted, commonly contains sandy to silty matrix; marine shell casts found in places.

9 GLACIOMARINE STONY CLAYEY SILT
Blocky structure, manganese oxide staining on joint surfaces; contains fossil marine shells and shell fragments.

8 TILL
Platy and well compacted in places, includes some laminated stony silt (ponded) and openwork gravel lenses; boulders up to 8 m dia. observed: probably mainly lodgement but may in part be flow till where massive or contorted and poorly compacted

7 SANDY PEBBLE-COBBLE GRAVEL
Foreset bedded, moderately to poorly sorted, dipping up to 30° away from hill; occurs between till layers in places; probably proximal outwash.

6 SAND
Faulted, contorted, cross-bedded, and contains gravel lenses and interbeds in upper part of unit; well sorted, subhorizontally thinly bedded and cross-bedded; contains detrital coal and peat clasts, scattered stones and stone clusters; probably proglacial (distal) outwash.

5 STONY CLAYEY SILT
Massive, generally poorly compacted, contains fossil marine shells and shell fragments; probably glaciomarine but may in part be till.

4 SANDY GRAVEL
Fe-stained, moderately sorted; in some exposures grades down wards into very thinly bedded, cross-bedded, and rippled fine sand and silty fine sand at the base of the unit; contains scattered coal, wood, and peat clasts, and one or more thin peaty wood layers with fossil logs up to 30 cm dia. and 4 m long; probably fluvial and glaciofluvial deposits; wood dates range from 25,800 to 26,900 yr. B.P.

3 FOSSIL BOG AND GYTTJA DEPOSITS
Thinly interbedded peat, sapropel, and well sorted fine sand layers; peat layers contain fossil tree stumps up to 30 cm dia., roots, and logs up to 3 m long; sand layers contain finely disseminated organic material and fossil insects; sapropel is diatomaceous; probably fluvial and lacustrine deposits; dated peat and sapropel layers range from 27,000 to 29,600 yr. B.P.

2 STONY COLLUVIAL ORGANIC COMPLEX
Two crudely interbedded phases: a dense, stony and gritty, detrital organic-rich phase containing fossil wood, leaves, and insects (weathered surface resembles till); and a contorted, stony, wood-bearing silt-rich phase containing clasts of laminated stony silt, and gravel and sand lenses; whole complex thought to represent reworked orgainc and glacial sediments by mass wasting processes on a buried landscape; a piece of wood from the detrital organic-rich phase dated 40,200 ± 430 yr. B.P., and a root from the contorted silt-rich phase dated 40,500 ± 1700 yr. B.P.

1 UNDIFFERENTIATED GLACIAL COMPLEX
Includes lodgement till, massive stony clayey silt (weathers to blocky structure), rhythmically laminated silt and fine sand containing scattered stones, gravel and sand; massive stony clayey silt probably glaciomarine, laminated silt and fine sand probably glaciolacustrine, and gravel and sand probably outwash; wood from laminated silt was dated as >62,000 yr. B.P.

Major Unconformity; observed, inferred

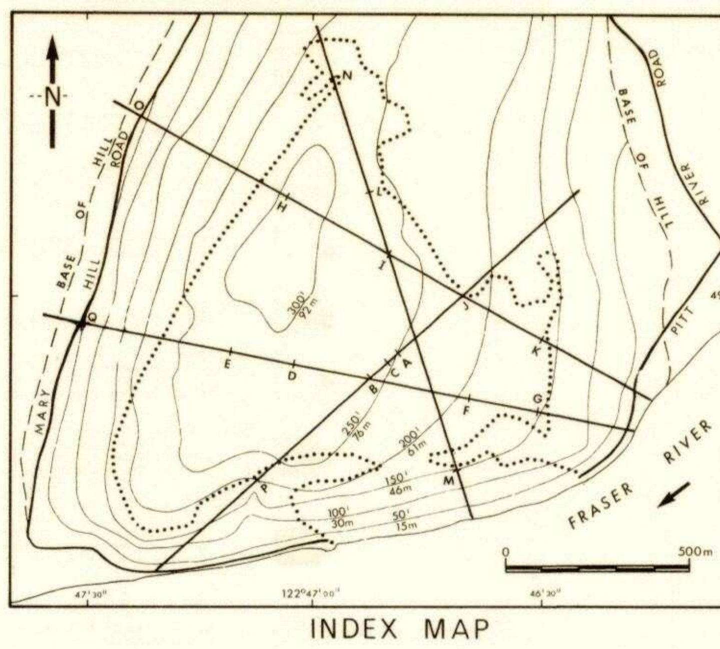
Geological Contact; observed, inferred

Reconstructed Mary Hill profile

Topographic profile at time of mapping

Area of measured section

Bedding thicknesses classified according to McKee and Weir, 1953.



INDEX MAP