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CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA

PAPER 57-5

SURFICIAL GEOLOGY OF NEW WESTMINSTER MAP-AREA, BRITISH COLUMBIA

(Report and Map 16-1957)

By

J. E. Armstrong

OTTAWA
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Price, 50 cents

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CONTENTS

Illustrations

SURFICIAL GEOLOGY OF NEW WESTMINSTER MAP-AREA, BRITISH COLUMBIA

INTRODUCTION

This report deals mainly with the geology of the surficial (unconsolidated) deposits of the New Westminster area, British Columbia. The primary aim of the report, geological map, and table of surficial deposits is to assemble the geological information needed in the industrial and agricultural and, to lesser extent, forest development of the area. The general stratigraphic succession and geological history of the Pleistocene and Recent epoch, which are discussed briefly herein, will be dealt with more fully at a later date in a final report on the surficial geology of the Lower Fraser Valley.

The field work for this report and map was done intermittently during the years 1950 to 1953. The writer was assisted in the field by W. L. Brown, W. M. Draycot, L. J. Brandon, Reverend R. Sanschagrin, O. M. I., W. Atamanchuk, J. Darker, D. Cooksey, James Frederick Allan, James Francis Allan, T.E. Petrie, G. R. Murphy, G. M. Hughes, O. L. Hughes, J.G. Fyles, H. Naismith, P. Odynsky, and B. Young. Miss F. J. E. Wagner and W. M. Draycot collected and identified Pleistocene and Recent marine fossils. The field work consisted of the examination of all natural and artificial exposures, such as sea-cliffs, stream and river banks, landslides, excavations, gravel and sand pits, drainage ditches, etc. This information was augmented by extensive digging and augering of shallow holes 3 to 20 feet deep. Much information south of the Fraser River was also obtained from several thousand holes drilled and dug for ground water. The collecting of ground-water information was supervised by W. L. Brown in 1950, 1951, and 1952, and by E. C. Halstead in 1954, and 1955. Separate ground-water reports have been or will be published. Wherever possible, information was obtained from holes drilled for oil and gas exploration and for foundation tests.

The writer wishes to thank all those individuals and organizations that supplied drill-hole information; without it he would have been unable to make some of the conclusions and correlations contained in this report. All information was plotted on maps on the scale of 1 inch to 1/2 mile with a contour interval of 25 feet and from these a map was constructed.

Many of the geological boundaries on the map are gradational and accurate only to within 1/4 mile. Furthermore, map-units are to some extent generalized so that a pattern representing a certain type of deposit may contain small areas of another related type of deposit shown elsewhere by a different pattern. No attempt has been made to study in detail the physical and chemical properties of the various materials discussed.

PHYSICAL FEATURES

The region under discussion lies within two major physiographic divisions; namely, the Coast Mountain area and the Coastal Trough.

The Coast Mountain area, whose southern fringe lies within the area mapped, consists of rugged mountains rising abruptly 5,000 to 7,000 feet above sea-level, separated by deep U-shaped valleys with floors up to a few hundred feet above or below sea-level. The principal mountain valleys in the area are those occupied by Indian Arm, Pitt, and Alouette Rivers.

The Coastal Trough lies between the Coast Mountain area and the Outer Mountain area of Vancouver Island. That part of the Coastal Trough within the map-area is called the Fraser Lowland. It is commonly referred to as the Lower Fraser valley or the Lower Mainland and was considered by Bostock to be part of the Georgia Depression.

The Fraser Lowland consists of extensive low hills (in this report called uplands) ranging in elevation from 50 to 1,100 feet separated by wide, flat-bottomed valleys. The uplands are of four main types; (1) a core of unconsolidated deposits with rolling, hummocky surfaces of glacial till and glacio-marine deposits; (2) a core of unconsolidated deposits with commonly flat, terraced surfaces of glacial outwash; (3) a core of bedrock overlain by a thin mantle of glacial and glacio-marine deposits; and (4) raised marine deltas with a possible core of bedrock. Uplands of type 1 vary in size from about 1 square mile to 100 square miles and in elevation from about 50 to 400 feet. Uplands of type 2 vary in size from about 1/2 square mile to 15 square miles and in elevation from about 25 to 300 feet. The above two types comprise all the uplands south of the Fraser River and, north of the river, include uplands in the New Westminster-Port Coquitlam area and in the Port Hammond-Albion area. Uplands with a bedrock core, type 3, include the following: Capitol Hill, elevation about 400 feet; Burnaby Mountain, elevation about 1,100 feet; and Grant Hill, elevation about 1,100 feet. These range in area from about 1/2 square mile to 5 square miles. Raised marine deltas, type 4, occur along the Seymour, Coquitlam, and Alouette Rivers. They are terraced, and range in elevation from 50 to 600 feet and in size from less than 1/2 square mile to about 4 square miles.

Flat-bottomed valleys up to 3 miles wide separate the uplands. The major valleys, which range in elevation from a few feet to 75 feet above sea-level, are as follows: the present valley of the Fraser River; the valley occupied by the Pitt River from Pitt Lake to the Fraser River; the valley occupied by the Alouette

River from north of Haney to the Pitt River valley; Burnaby Lake-Still Creek valley; upper Nicomekl River-Salmon River valley; lower Nicomekl River-Serpentine River valley; and the lower part of Campbell Creek valley. All the valleys, with the exception of the Burnaby Lake-Still Creek valley and the present valley of the Fraser River, are former embayments of the sea and were not cut by the streams now occupying them. The Still Creek valley is, at least in part, the result of stream erosion. The present valley of the Fraser River has been in a large part cut by post-Glacial stream erosion.

One other major valley is that occupied by Burrard Inlet, separating the Coast Mountains from the Fraser Lowland. This may represent an old river valley, and may be the former course of the Pitt River.

GENERAL GEOLOGY OF PLEISTOCENE AND RECENT DEPOSITS

Types of Deposits

Before describing the stratigraphy and historical geology of the area some of the terms to be used will be defined and some information regarding the types of Pleistocene and Recent deposits found will be given.

The term Pleistocene in this report refers to that epoch in the earth's geological history when large areas of the earth's surface were covered more than once by great glaciers many thousands of feet thick. The epoch is estimated to have started about one million years ago and to have continued in the New Westminster area to within about five to ten thousand years of the present. The term Recent is used in this report to refer to the post-Glacial time.

The deposits formed during the Pleistocene and Recent periods are extremely varied and occur as bodies of differing texture, form, and extent, that for the most part have been deposited by glacial ice or in streams, lakes, swamps, and the sea. They consist of clay, silt, sand, gravel, varved clay and silt, stony, clayey silt and related till-like mixtures, and till. The terms clay, silt, and sand as used in this report are based on the diameter of the constituent particles and are used as follows: clay, less than 0.002 mm.; silt, 0.002 to 0.05 mm.; and sand 0.05 to 2 mm.

The clays and silts of the New Westminster area contain only a small proportion of clay minerals; they consist largely of fine particles of quartz, feldspar, and other common rock minerals. The sands consist of quartz, feldspar, and rock fragments, the proportions varying from place to place but quartz normally predominating.

Varved silt and clay are glacial lake deposits consisting of alternating light and dark coloured layers from a fraction of an inch to several inches thick.

The stony, clayey silt and related till-like mixtures are in a large part glacio-marine and to a lesser extent normal marine deposits that were laid down in the sea during the advance and retreat of an ice-sheet and during the subsequent uplift of the land. The glacio-marine deposits are marine drift; that is, the stones and part of the fine material were transported by floating ice and the remainder of the fine material carried by meltwater and sea water. The somewhat similar deposits of normal marine origin are mainly reworked till and marine drift resulting from submarine slumping as the land rose above the sea. Mechanical analyses of stony, clayey silts similar to those found in the map-area show that, exclusive of the stones, they comprise about 50 per cent silt, 40 per cent sand, and 10 per cent clay. Many of these deposits are very similar in appearance to true till.

Glacial till, as used in the report, refers to a very compact, unsorted mixture of sand, silt, clay, and stones deposited directly beneath glacial ice. Mechanical analyses of the fine fraction of representative samples of tills from lowland areas within and adjoining the map-area, yielded the following average results: Surrey till, 57 per cent sand, 41 per cent silt, and 2 per cent clay; Semiamu till, 47 per cent sand, 45 per cent silt, and 8 per cent clay; and Seymour till, 44 per cent sand, 46 per cent silt, and 10 per cent clay. Tills in the mountain valleys have a greater proportion of sand than tills of the same age in the lowlands.

Outwash refers to sediments deposited by streams issuing from glaciers, and in this area consists mainly of interbedded sand and gravel deposited in deltas, flood plains, and channels.

Stratigraphy and History of Deposits

The table of surficial deposits that accompanies this report shows graphically the complex interrelations and age of the surficial materials. The oldest deposits are shown at the bottom of the table and the youngest at the top. Deposits shown along side one another indicate that they are the same general age but were laid down in different environments. Note that the graphic representation illustrates, for example, that the Sumas (13, 14) glacial deposits were laid down in part of the area at the same time as non-glacial Capilano (7-11) deposits were laid down elsewhere in the area.

All the ages are relative, although radio-carbon age determinations have been made on wood and marine shells collected from several of the formations both within and outside the map-area. The results of these radio-carbon age determinations may be summarized as follows: wood from base of Sumas till and hence part of the Capilano (7-11) group was dated as 11,250 ± 1,000 years old (average for two localities). Wood from Whatcom (13) glacio-marine deposits and hence again probably part of Capilano group (7-11) was dated as 11,350 ± 150 years old (average for three localities). Marine shells from Newton (5) stony clay deposits, which have been included in the Vashon group, have been tentatively dated as 11,800 years old. Wood from the Quadra group (2) inter-till sediments was dated as older than 30,000 years.

Study of the table of surficial deposits indicates that the area was subjected to four glaciations: three probably major, namely Seymour (2f), Semiamu (2f), and Vashon (3-6), and one, Sumas (13, 14), probably valley glaciation only. The Seymour (2f) and Vashon (3-6) glaciations reached ice-sheet proportions during their maxima at which time they were probably 7,500 feet or more thick over the valleys. At these times the ice moved in a general southerly direction; that is, off the Coast Mountains. The Semiamu (2f) ice was probably also of ice-sheet proportion, but, due to later erosion, deposits of this group are so few and poorly exposed that a reliable history of this ice advance cannot be pieced together. South of the Fraser River valley ice of Sumas (13, 14) age advanced into the northeastern part of Langley municipality immediately east of the map-area and recessional Abbotsford (14) outwash, related to this ice, spread westward across the municipality into Surrey municipality. North of the river recessional outwash is found as far west as Pitt Meadows.

During each major glaciation the land was depressed relative to the sea, and this lowering of the land surface amounted to at least 1,000 feet in the case of Vashon (3-6) glaciation. At the maximum of Vashon (3-6) glaciation the ice rested on the sea floor. Maryhill (2b) outwash was deposited in advance of the ice and Surrey (4) till beneath the ice. During the retreat of Vashon (3-6) ice, largely by wasting, the ice thinned and floated, and glacio-marine Newton (5) stony clay deposits were laid down below elevations of approximately 500 feet. Above elevations of 500 feet in the northeastern part of the map-area Haney (6) outwash was deposited during this recessional stage. After the Vashon (3-6) ice melted and as the land rose above the sea, the off-shore marine Cloverdale (7) sediments and the marine-shore Sunnyside (10) sandand Bose (11) gravel deposits were laid down.

During the post-Vashon time the Sumas valley ice advanced westward into the Fraser Lowland. In its initial advance stages this ice-sheet terminated in the sea and deposited glacio-marine Whatcom (13) deposits in front of and beneath the ice. At the same time normal marine deposits, Cloverdale (7) sediments, were laid down in the sea west of the Sumas (13, 14) ice-sheet. As the land rose the Sumas glacier was grounded and advanced and retreated across the Whatcom (13) glacio-marine drift depositing Sumas till and recessional Abbotsford (14) outwash.

Up to the end of 1955 a total of about 45 species of marine fossil shells had been collected and identified from Newton (5), Whatcom (13), Cloverdale (7), Sunnyside (10), and Bose (11) deposits. They were collected from more than 50 localities within the Lower Fraser Valley area ranging from 5 to 575 feet above sea-level. Marine shells similar to those assemblages are now found in the sea in latitudes ranging from 60° to 63° north; that is, 760 to 950 miles north of the area[1].

As shown in the table of surficial deposits one probable interglacial period, the Quadra (2) group, has been recognized between the Seymour (2f), and Semiamu (2f) ice-sheets. Apparently climatic conditions existing at that time could have been somewhat similar to those at present as is indicated by a study of the pollen and plants from peat in the Point Grey beds.

Huntingdon (8) gravel deposits of the Capilano group underlie Whatcom (13) glacio-marine deposits. They appear to be stream deposits that were laid down following the retreat of Vashon (3-6) ice but before the advance of Sumas (13, 14) ice. West of Langley municipality the deposition of similar gravel probably continued throughout Capilano time.

Two major erosion intervals are shown on the table of surficial deposits, one separating the Semiamu (2f) group from the Quadra (2) group below and the other separating the Semiamu (2f) group from the Vashon (3-6) group above. The hills in the Fraser Lowland were shaped during the latter erosion interval and were mantled by Vashon (3-6) group deposits. Surrey (4) till for instance conforms to the slopes of the hills and truncates underlying older deposits.

The Salish (15-19) deposits, which are still in the process of formation, consist of deltaic, channel, and flood plain deposits of the Fraser River and smaller streams and peat bogs.

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[1] F.J.E. Wagner, personal communication

Distribution of Deposits

With the exception of Huntingdon (8) gravel, the distribution of Capilano (7-11) and Salish (15-19) group deposits is fairly obvious from a study of the geological map accompanying this paper. The Salish (15-19) deposits and Cloverdale (7) sediments are confined to valleys; Capilano (9) gravel is restricted to raised marine deltas and raised channels; Sunnyside (10) sand and Bose (11) gravel are found in both valleys and uplands as thin raised marine shore deposits, overlying older deposits.

Whatcom (13) glacio-marine deposits appear to be restricted to uplands. Abbotsford (14) outwash overlies Whatcom (13) glacio-marine deposits and Cloverdale (7) sediments.

The Huntingdon (8) gravel deposits underlie Whatcom (13) glacio-marine deposits throughout much of the area east of the Langley-Fort Langley valley. They are exposed only on steep slopes of creeks that have cut below the Whatcom glacio-marine deposits, but many holes drilled for water intersect them.

Haney (6) outwash is found only in the eastern part of the map-area near the Alouette River.

The distribution of Newton (5) stony clay deposits west of the Langley-Fort Langley valley and south of the Fraser River can be seen on the accompanying map. East of the Langley-Fort Langley valley, and in the Haney-Albion area what has been called Newton (5) stony clay deposits for ease of reference occur beneath lithologically similar Whatcom (13) glacio-marine deposits, and except where separated by Huntingdon (8) gravel the contact between the two is in many places arbitrarily drawn. Furthermore, the surface mapping of the Newton (5) and Whatcom (13) formations has been done partly on a geographic basis, the area west of the Langley-Fort Langley valley being shown as Newton (5) and that to the east as Whatcom (13), although direct local evidence to support this may be lacking. North of the Fraser River west of Coquitlam no attempt was made to map Newton (5) stony clay deposits and Surrey (4) till separately, owing to their lithological similarities and to the extreme scarcity of drill-holes to augment the field mapping.

Exposures of Surrey (4) till occur at many places south of the Fraser River west of the Langley-Fort Langley valley, and north of the river along the flanks of the Coast Mountains. However, drill-holes indicate that this till is also widespread beneath Newton (5) and Whatcom (13) deposits.

Maryhill (2b) outwash is exposed on the slopes of several small streams and the Coquitlam River in the Maillardville-Coquitlam area, and in gravel pits at Maryhill and Grant

Hill. Probably, in much of the area adjoining these exposures, Maryhill (2b) outwash underlies Surrey (4) till.

Pre-Vashon (2f) tills are exposed at only five places in the map-area; two are along Burrard Inlet west of Port Moody, a third is along Brunette River near the North Road, a fourth is in the sea-cliffs about half-way between White Rock and Ocean Park, and a fifth is along Kanaka Creek northeast of Albion. The tills exposed along Brunette and Kanaka Creeks are the only ones that may possibly be Seymour (2f); the others are probably Semiamu (2f). Semiamu (2a) sediments outcrop in the sea-cliffs between White Rock and Ocean Park.

Semiamu (2) deposits have been identified in many drill-holes in Surrey municipality and the northwestern part of Langley municipality and a few holes east of the Langley-Fort Langley valley have intersected similar deposits. Some of the sediments indicated on the map as pre-Surrey (2f) till deposits may belong to the Semiamu (2) group but have not been mapped as such, due to lack of conclusive stratigraphic evidence. However, the writer believes that throughout much of the area the Semiamu (2) deposits were removed by erosion before the advance of Vashon (3-6) ice as is indicated on the table of surficial deposits accompanying this paper.

South of the Fraser River, Colebrook (2c) gravel and Nicomekl (2d) silt of the Quadra (2) interglacial group are exposed in the lower slopes of the uplands of Surrey and the northwestern part of Langley municipalities, and north of the Fraser River on the southern slope of Burnaby municipality. Drill records indicate that similar deposits are widespread in the cores of all the uplands south of Fraser River. Similar deposits also occupy the cores of some of the uplands north of the Fraser River but little is known of their extent. On the map accompanying this paper, especially north of the Fraser River, some areas mapped as pre-Surrey till (2a) in age include Quadra interglacial deposits, in particular those listed as stream deposits on Figure 1.

Sapperton (2e) sediments in the New Westminster-Burquitlam area are shown on the map. The age of these deposits is uncertain, and although the writer believes they are older than the Surrey (4) till they were not seen below this till and they may possibly be younger.

Pre-Seymour and Seymour unconsolidated deposits are not exposed in the area but deep drill-holes intersect thick sections of unconsolidated and semi-consolidated sediments below what the writer believes to be the equivalent of Seymour (2f) till. The Seymour (2f) till is identified in drill-holes from its stratigraphic position below recognizable Quadra (2) interglacial deposits or from the fact that it is the third distinct till from the surface. This latter criterion is not always correct as locally at Maryhill, for example, Vashon ice is known to have advanced and retreated more than once, each cycle being marked by till deposits. Nonetheless, in general the conclusion is true.

The areas in which bedrock is exposed are shown on the map. South of Fraser River bedrock is extremely deeply buried, there being 500 feet or more of unconsolidated deposits. In wildcat oil and gas wells in the Boundary Bay area, for example, more than 2,100 feet of drift overlies the Tertiary bedrock, in the Newton area there is more than 1,300 feet, and in the eastern part of the area there is more than 800 feet.

APPLICATION OF GEOLOGICAL STUDIES

The geological study and mapping of the Pleistocene and Recent unconsolidated deposits of the New Westminster area was undertaken to afford information essential to the orderly development of the area.

A proper appreciation of the influence of geological conditions is essential to the orderly development of industry and agriculture and may result in saving considerable sums of money and in avoiding floods, slides, and other disasters. In order to explain the geological conditions it is necessary to unravel the stratigraphy and geological history of the area. To do this all information available on the physical nature, origin, and extent of surficial deposits was obtained even from areas where it has no practical application. Some of the present and future applications of this basic geological knowledge are discussed in the sections below.

ENGINEERING GEOLOGY

Adequate data on the kind and distribution of geological materials aid the engineer and contractor in solving many problems pertaining to foundation materials, sewage disposal, flood control, slides and washouts, and construction materials.

Foundation Materials

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 more important properties are permeability which controls drainage, stability and shearing strength, and workability.

Information on these properties is valuable in the design and location of buildings, roadways, airport runways, bridges, dams and playing fields.

In areas of clay, silty clay, stony silty clay, glacio-marine till-like mixtures, till, and bedrock most of the drainage is by surface run-off, as these materials are nearly impervious and permit very little downward percolation of water. Areas of sand and gravel are, however, rather pervious and allow much downward drainage, except where the water-table is at or near the surface, as is the case in much of the Fraser River delta and other low-lying areas. Although the tills contain relatively little clay and a high percentage of sand, their coherent nature tends to make them nearly impervious. The dense coherent nature of the tills is partly a result of the weight of the glacial ice beneath which they were deposited and is partly a result of their mechanical composition; that is fine particles fill voids between coarse particles and bind them together to form a natural physical concrete. This latter is the reason the till reconsolidates itself after sliding, or after excavation and used as fill.

Of particular interest is the fact that the Surrey (4) till and older deposits have been pre-loaded by up to 7,500 feet of ice, whereas the post-Surrey deposits have only been pre-loaded by the weight of the sediments above them. Consequently the Surrey (4) till remains undeformed under heavy loads, whereas the very similar Newton (5) and Whatcom (13) glacio-marine deposits fail when subjected to only small loads. The very different reaction of the similar appearing material to load is readily explainable when the origins of the two are considered. The till was deposited under a great weight of ice, whereas the till-like glacio-marine deposits were dropped from floating ice. Fortunately for builders, the glacio-marine deposits are in most places less than 25 feet thick and rest directly on till in the parts of the New Westminster map-area undergoing most extensive industrial development; that is in the Burnaby, New Westminster, Fort Moody, Port Coquitlam and North Surrey areas. However, even in these areas the deposits may present many local problems involving settling and drainage. When major industrial expansion extends eastward into Maple Ridge and Langley municipalities, especially where Whatcom (13) glacio-marine deposits underlie wide areas and are up to several hundred feet thick, settling and drainage problems will be the rule.

The Cloverdale (7) sediments and Fraser flood plain (18, 19) deposits, which underlie large lowland areas, have been only naturally loaded by weight of the overlying material; consequently they will support only light loads without deformation. Pile foundations will take care of this in most places.

The peat bogs of the Fraser River delta and other low-lying areas present greater foundation problems than any of the other deposits mapped. The peat undergoes extreme compaction when loaded and it is very difficult to drain. Hard surfaced roads laid across these bogs tend to develop alternating swells and depressions and deteriorate very rapidly unless the peat is excavated and, where necessary, replaced by fill before building the road.

With the exception of the tills and to a much lesser extent the glacio-marine sediments, all the unconsolidated deposits found in the area are easy to excavate. In the tills, cohesion is so high in places that they may have to be blasted before being excavated. Occasionally large stones in both the tills and glacio-marine sediments may have to be broken to be removed.

Sewage Disposal

Wherever sewage disposal is dependent on septic tanks a knowledge of drainage and sub-soil conditions is desirable. Many of the uplands are covered by nearly impervious to impervious Surrey (4) till and Newton (5) and Whatcom (13) glacio-marine deposits at or within a few feet of the surface. For all practical purposes these materials permit no downward drainage. In the western half of the map-area they are overlain in many places by thin deposits of Bose (11) beach gravel and Sunnyside (10) sand, deposits that permit downward drainage to the impervious materials underlying them. These sands and gravels are however so thin that in the rainy season, the water-table is close to or at the surface even in these permeable deposits. It is, therefore, evident that much of the overflow from septic tank absorption fields in many of the uplands must eventually drain down the slopes by surface or near surface run-off. Also uplands in which bedrock is at or near the surface are not favourable to septic tank installation. If septic tanks must be used under the unfavourable conditions outlined above they should be placed sufficiently far apart so that the development of adjacent lots will not be affected.

The impervious tills and glacio-marine deposits nearly everywhere overlie either impervious bedrock or permeable interglacial sediments, and, in the latter case especially on the higher parts of the uplands, some downward drainage could be brought about by putting drainage holes through the overlying impervious material. This procedure is practical only where ground-water supply is not a problem and should not be considered in most of Surrey and Langley municipalities.

In addition to the uplands already discussed are those underlain by thick deposits of Abbotsford (14) outwash, Haney (6) outwash, and Capilano (9) gravel. These all consist of thick deposits of permeable gravel and sand permitting easy downward circulation of septic tank effluent. However, in much of the map-area these deposits are a source of domestic ground-water supply and contain free ground-water reservoirs, the water-table in many places rising to 10 or 15 feet of the surface. Consequently, great care should be taken in the construction and spacing of septic tanks and the ground-water supply should be checked periodically for contamination.

Septic tank sewage disposal systems will not operate satisfactorily in areas where the ground-water level is up to, or nearly up to the absorption tile, or in areas that are periodically flooded. These conditions exist in much of the Fraser delta and the other lowlands of the area especially during the rainy season.

Flood Control

To combat flooding effectively along rivers by means of dyking and dredging the nature of the river-bank and bottom deposits must be known. Most of the dyking problems along the Fraser and Pitt Rivers are caused by dykes having been built on permeable sand. This sand is either at the surface or lies beneath a few feet of silt and clayey silt. Consequently, when the rivers are in flood the water level is higher than the land behind the dyke, the hydrostatic head developed forces some of the water through the sand beneath the dyke resulting in seepage, which in places has brought about dyke failure. A contributing factor to the unstable condition is the fact that the ground-water table in these areas is at or near the surface during the rainy season and floodwater therefore cannot be dissipated into the ground.

The streams that flow off the Coast Mountains occasionally flood and bring destruction. Except for raised Capilano delta (9) deposits along some of the streams most of the slopes have impervious till or bedrock at the surface, which allows extremely fast run-off especially where the vegetative cover has been removed. In the map-area the Alouette and Coquitlam Rivers are the two streams that frequently flood in their lower reaches. Vegetative cover, check dams, and other expedients are designed to minimize the destructive effect of these natural forces. The maintenance of dams by the Greater Vancouver Water Board on the Coquitlam River and by the British Columbia Electric Company on the Alouette River has helped prevent more serious flooding.

The Nicomekl and Serpentine Rivers, which are contained by dykes throughout most of their length, flow across areas underlain by impervious clayey and silty deposits of the Cloverdale (7) sediments and Fraser flood plain (18, 19) deposits. These streams are subject to floods resulting from heavy rainfall, at any time of the year except the dry summer. Flooding results because the ground-water body is perched so near the surface that excess rainfall cannot be absorbed. This condition is aggravated by rapid run-off from the adjoining uplands, run-off that has undoubtedly speeded up over the years due to clearing of forest growth for settlement. The lower parts of Kanaka and Campbell Creeks are subject to flooding to a lesser extent, due to the same reasons. The Nicomekl and Serpentine Rivers occupy one large valley for the last 5 miles of their courses. This valley is dyked on the seaward side as a protection against tidal flooding. During the winter of 1951-52 these dykes broke when very high tides combined with strong gales.

Slides and Washouts

Over the years large slides and washouts have occurred in the Lower Mainland area. Many of these slides and washouts occur in unconsolidated deposits on steep slopes where the soil conditions are rendered unstable by heavy rainfall and generally excessive clearing of the land. However slides also occur in heavily forested areas and a few slide areas in bedrock were found. The more spectacular examples of slides and washouts in unconsolidated deposits are at: (1) west side Coquitlam River near northern border of map-area; (2) north slope of Capitol Hill; (3) Port Moody; (4) south side of Maryhill in Gilley Brothers gravel pit; and (5) near Ocean Park on Great Northern Railway.

The washout on the west side of the Coquitlam River occurred during the winter of 1951-52 and was started by a small spring-fed stream issuing from the bottom of about 300 feet of Quadra (2) sand with minor silt and gravel overlain by about 10 feet of Surrey (4) till. During a heavy rainfall a small slide removed the vegetation in the lower part of the area exposing the saturated Quadra (2) sand to surface erosion. This commenced to flow and a pit about 200x200x500 feet was formed. The washout occurred in an area of second growth forest on which no recent land clearing had been undertaken.

The slide on the north slope of Capitol Hill took place in the winter of 1952-53 during construction of the Standard Oil of British Columbia refinery. In the slide area Tertiary (1) bedrock is overlain by a discontinuous layer of Surrey (4) till up to 15 feet thick which in turn is overlain by 5 to 25 feet of Bose (11) beach gravels. Ground-water drainage off Capitol Hill enters these beach gravels, but downward circulation stops at the till and bedrock and then the water drains laterally. Over the years the gravels had established an angle of repose that could take care of this drainage, however during construction a road was cut through these gravels, thus disturbing the angle of repose. Heavy rain saturated the gravels, and slides resulted along a series of faults, which dipped steeply north at their emergence but flattened off rapidly near bedrock. The condition was corrected in part by drainage ditches and in part by re-establishment of original angle of repose. The vertical displacement on some of the faults was at least 10 feet.

During construction of a steel rolling mill at Port Moody in 1954 an old washout of major dimensions was exposed. The area at the northeast end of Burrard Inlet in which the plant was built consists of 10 to 30 feet of very poorly sorted gravel overlying till. The gravels contain small pockets of clay and silt and when the area was bulldozed a buried forest was uncovered in which all the trees were sheared off at approximately the same height. The evidence cited above suggested a washout and, as will be seen on the accompanying map, the source of the material was found to be more than 1/2 mile south on the hill back of Port Moody. Here the Surrey (4) till has been breached over a fairly extensive area and the underlying Maryhill (2b) outwash deposits exposed. Probably the washout commenced with a small slide during the rainy season. It occurred at least 100 years ago.

In the spring of 1953 a large washout occurred in the Gilley Brothers gravel pit at Maryhill. In the area of the washout Maryhill (2b) outwash gravel was being excavated beneath two discontinuous beds of Surrey (4) till. The outwash gravel beds dipped at 20° to 30° to the south and interbedded with them was a silty bed up to 2 feet thick. When the shovel cut through this silty bed a reservoir of ground water impounded behind it was tapped. At first the flow was only a few gallons a minute and not considered dangerous, however during the night, apparently as a result of the fines being washed out, the whole slope commenced to slide and flow, and within a few hours a pit in excess of 100x100x200 feet was opened; a conveyor belt, monitor, shovel, bulldozer, and part of the road were buried under 10 feet or more of gravel, sand, and till. The original flow of water was several million gallons a day, although within a few months this diminished to a flow of probably less than 100,000 gallons a day.

Another spectacular slide, although small, occurred along the Great Northern Railway between Ocean Park and White Rock a few years ago. The sea-cliffs exposed in this area present an unstable slope especially during heavy rainfall and clearing of land on top of the cliffs, which resulted in a much increased speed of run-off, has aggravated the condition. The slide took place during a very wet period when unstable conditions were developed on this slope. Apparently the vibration of the train triggered the slide, as it occurred when the train was passing, hitting the third car back and pushing two cars off the track over the embankment on the beach. The area in which most of the slides occur consists of Semiamu (2f) till and sediments at the base overlain by Colebrook (2c) gravel, Surrey (4) till, and Sunnyside (10) sand. The Semiamu (2f) till and sediments contain a relatively high silt and clay fraction and when saturated are in an unstable condition especially on steep slopes. The Great Northern Railway maintains a slide warning fence along the right-of-way.

The whole north slope of Burnaby Mountain and part of the north slope of Capitol Hill consist of a Tertiary (1) bedrock slide area. All the slides took place prior to the arrival of the first white settlers. From a geological study of the area and of the air photographs the indications are that the movements that brought about the slides took place along definite deep reaching shear surfaces. Probably, two or more roughly parallel slip surfaces were present, and the displaced bedrock moved in a series of blocks, the surfaces of which are tilted back into the slope from which the slides descended. In the surrounding country, the Tertiary sedimentary rocks dip about 10 degrees south, but in the slide area the dips are irregular and locally are vertical. Some of the slide blocks were several million tons each. The displaced materials are best exposed along Barnet Road. The probable old slip surfaces, modified by erosion, are exposed near the summit where near vertical cliffs, more than 100 feet high, are exposed.

Construction Materials

Construction materials produced from deposits found in the map-area consist of gravel and sand and common structural clay products.

The production of gravel and sand is an important industry in the New Westminster area. At present at least 58 pits are operated intermittently or year around, 24 by private companies and 34 by municipal governments. No accurate figure on total production is available; however it probably exceeds two million yards a year. The operations range from small pits removing 15,000 to 50,000 yards a year to several large operations producing 150,000 to 450,000 yards a year. In most of the smaller operations, particularly those operated by municipalities, only pit run sand and gravel is produced. All of the larger operations, crush, wash and size their materials to obtain a full range of products. The value of production before treatment probably exceeds a million dollars and after treatment would be at least two million dollars. The bulk of these materials are used for concrete aggregate, for fill, and for base course or surfacing of roads.

Geologically the deposits in which the pits are located may be classified as follows:

(1) Colebrook (2c) gravel of Quadra interglacial deposits (16 pits)

(2) Sapperton (2e) sediments probably belonging to Quadra interglacial deposits (4 pits)

(3) Maryhill (2b) outwash of Vashon group (6 pits)

(4) Haney (6) outwash of Vashon group (1 pit)

(5) Huntingdon (8) gravel of Capilano group (1 pit)

(6) Abbotsford (14) outwash of Sumas group (20 pits)

(7) Bose (11) gravel of Capilano group (5 pits)

(8) Capilano (9) gravel of Capilano group (3 pits)

(9) Nonmarine mountain stream deposits of Salish (16) group (2 pits)

The Colebrook (2c) gravel and sand deposits comprise Quadra interglacial deltaic, channel, and flood plain materials deposited before the advance of the later ice-sheets; consequently, except where exposed by post-Vashon erosion, they are overlain by 5 to 60 feet of Surrey (4) till and Newton (5) stony clay deposits. In addition to the exposures shown on the accompanying map, well records indicate the Colebrook (2c) deposits underlie most of the uplands of Surrey and Burnaby municipalities. They are undoubtedly widespread in much of the remaining part of the map-area but buried deeper. The maximum observed thickness is 85 feet, but normally the exposures are between 20 and 30 feet thick. The bedding may be either horizontal or dip at 15 to 20 degrees. The stones are probably 90 per cent or more pebble size; the remaining are of cobble size. Granitic rocks comprise 50 to 80 per cent of the stones.

The Sapperton (2e) sediments are exposed only in the vicinity of Brunette River and Lougheed Highway in Burnaby and Coquitlam municipalities. Geologically the deposits are very similar to the Colebrook deposits.

Maryhill (2b) outwash is advance outwash of Surrey ice and is exposed only on the north side of the Fraser River between Port Moody and Albion. Similar materials undoubtedly underlie Surrey till in much of this area. The deposits consist mainly of poorly sorted gravel and minor interbedded sand and till lenses up to 200 feet thick. The stones comprising the gravel range from pebble to boulder size, and are at least 90 per cent granitic in composition. Gilley Brothers plant at Maryhill, the largest in the Lower Mainland, utilizes these deposits.

Haney (6) outwash is recessional Vashon outwash and is found only above elevations of 500 feet in the northeast part of the map-area. The gravel is mainly of pebble and cobble size and granitic in composition. Much of it forms eskers. Only one small pit operates in these outwash deposits, however they constitute a potential future source.

Huntingdon (8) gravel deposits underlie Whatcom glacio-marine deposits and as a result may be buried beneath as much as 300 feet of clayey and silty materials. Well records indicate these buried gravels are widespread in Langley municipality. They are exposed only on the sides of stream and river valleys, and where seen consist of well sorted pebble gravel with a few cobbles. In the map-area only one pit is developed in them, but east of the map-area they are used more extensively.

The Abbotsford (14) recessional outwash deposits are widespread in Langley municipality and north of the Fraser River in the vicinity of Haney. As they were deposited by Sumas ice, the last ice advance, they are exposed at the surface in the uplands and are very economical to develop. The deposits vary in thickness from 10 to 125 feet. The two largest areas cover 7 and 10 square miles and average at least 50 feet thick, forming a gravel and sand reserve in excess of 1,500,000,000 yards. These gravels consist of well sorted pebble and cobble gravel interbedded with medium to coarse sand. The stones are at least 60 per cent granitic.

Bose (11) beach gravel deposits are widespread but generally do not exceed 5 feet in thickness, although in a few isolated localities they reach a maximum thickness of about 25 feet. As a rule they are very poorly sorted and contain more boulders than most of the other gravel. Locally these deposits are used as road gravel.

Gravel and minor sand are being deposited in the intertidal delta of Seymour Creek and along the lower reaches of Alouette and Coquitlam Rivers. All the above are torrential mountain streams capable of transporting gravel of cobble, and, occasionally, of boulder size. This present-day stream gravel is well sorted, clean, and up to 50 feet thick. It consists mainly of well rounded granitic pebbles.

The Capilano (9) gravel deposits were laid down in the same way as the present-day stream deposits and later, when the land rose above the sea following the retreat of Vashon ice sheet, were elevated to their present positions, 25 to 1,000 feet or more above sea-level. They now form raised terraced deltas along Seymour Creek, Coquitlam and Alouette Rivers. These raised delta deposits overlie Vashon group and older deposits, some of which are gravel and sand, and in places, lie directly on pre-Vashon gravel and sand, the intervening till having been removed by erosion. The raised deltaic deposits are very similar to the present-day stream deposits except that they contain more interbedded sand. In many places most of the deposit consists of foreset delta beds dipping at 10 to 30 degrees outward from the face of the deposit. In all the operating pits the foreset beds are overlain by up to 10 feet of topset beds consisting of poorly sorted, and bedded cobble gravel.

In most of the smaller operations, pit-run gravel and sand only are produced. This material without crushing or screening is loaded by gasoline or Diesel-driven shovels (3/8 to 3/4 cu. yd.) directly from the workings into trucks for transport to the place of use. At most of the medium-sized and larger pits shovels up to one cubic yard and draglines are used at the face, and the pit-run materials are hauled in trucks to crushing plants, generally at or near the pits. The Deeks-McBride operation, at the mouth of Seymour Creek, is using a dragline shovel to depths of 40 feet below sea-level to take gravel out of the delta of the river. This gravel is loaded on a conveyor belt 1,500 feet long for transport to the crushing plant. The common range of products includes fine and coarse sand, gravel in various size ranges from less than 3/8-inch to more than 2 1/2-inch, 'mulch' (pit-run crushed gravel for road material), and 'navy jack' (a mixture of sand and gravel).

Some of the difficulties encountered in the operation of gravel and sand pits that may be attributed to geological conditions are as follows:

(1) Excessive overburden of glacial till or stony clay, both of which are difficult to handle with a shovel and hard to dispose of.

(2) The 'lensy' nature of many of the gravel beds; as a result the pit-run contains much sand for which the market is limited.

(3) The large size of some of the boulders, which in many places are from 4 to 12 feet in diameter and cannot be handled without blasting.

(4) The occurrence of interbedded thin strata of silt or clay, materials which cannot be handled satisfactorily in the washing and sizing.

(5) The presence at the base of the deposits of ridges of varved clay or glacial till, both of which when wet form mud-holes. Indeed, if these ridges are high, they make the overlapping gravel and sand deposit too thin to mine economically.

(6) The presence of high ground-water tables, a particularly troublesome problem to the small operator using only shovels, and not washing or crushing.

Other difficulties might be mentioned, but the writer believes those enumerated above are the most common.

The Lower Mainland is indeed fortunate in the abundance of good gravel and sand deposits close to the city, and, as a result, enjoys some of the lowest-cost gravel and sand products in North America.

Common structural clay products are produced at three plants in the map-area, one at Barnet using Tertiary (1b) shale from a nearby pit, fireclay from Kilgard and scrap brick; a second at Haney using Cloverdale (7) silty clay and glacio-marine Whatcom (13) silty clay; and a third on Mahood (Bear) Creek, Surrey using Cloverdale (7) clay. During the past 50 years at least 5 other plants have operated, in some cases for years, on Whatcom (13) and Cloverdale (7) deposits.

Mainland Clay Products, Limited,at Barnet manufacture dry-pressed common brick and firebrick in rectangular coal fired kilns. Port Haney Brick Company Limited operates a large plant at Haney producing mainly structural tile and drain-tile and to a much lesser extent, facebrick, common brick, and roman brick in beehive kilns. A plastic marine silty clay constitutes the source material. This clay is moist the year around and must be dried before processing. A chemical analysis of a typical specimen is as follows: SiO_2 - 58.5%, Al_2O_3 - 21.1%, Fe_2O_3 - 8.6%, CaO - 6.5%, MgO - 0.5%, ig. loss - 4.8%. Mechanical analysis of a similar sample gave the following results: clay, 46%, silt, 42.5%, andfine sand, 11.5%. In 1954, 12,598 tons of clay products were produced at this plant.

Bear Creek Brick Company operates a plant on Archibald Road, Surrey municipality where they manufacture common brick from Cloverdale (7) silty clay. Wood-fired stove-kilns are built for burning the bricks.

AGRICULTURAL APPLICATIONS

The information contained in this report and map aids in the study of agricultural soils, in problems concerning drainage and irrigation, and in outlining a source of agricultural peat.

Agricultural Soil

Modern soil classification is based upon the nature of the soil profile, which reflects the influence of various factors of soil development including parent material, climate, organisms, topography, time, and geological environment. Parent material and topography are elements in geological environment but in this report the term is used to refer to geological features outside the soil body itself but which may directly or indirectly affect the development of the soil. For example the stratigraphy and geological structure in and around a particular soil may be an important factor in soil development. This is illustrated by the varieties of soil on the same parent material that have resulted from the different kind of deposits underlying the parent material and thereby setting up different soil development patterns. Drainage generally is recognized as highly important in soil development, but drainage depends mostly on the permeability of the underlying material, which is in turn dependent on the stratigraphy and depth to the saturated zone. This latter is commonly a function of the regional geomorphology and geologic structure. Each of the soil factors mentioned above is in itself directly or indirectly dependent on the geological history of the area; parent material, topography, and geological environment as used in this report are directly dependent on the geological history and climate and organisms are indirectly dependent. Parent material, climate, and organisms primarily control differences in kind of weathering and topography, time, and geological environment in the degree of weathering.

The geologist is most able to help the soil scientist in his interpretation of soils by indicating the role played by parent material and geological environment. The soil profiles in the New Westminster map-area, for instance, are poorly developed and the texture and composition of the parent material is still dominant. The writer believes that when the agricultural soils of the area are remapped that the broad divisions of the completed soil map will show a very marked similarity to the geological map accompanying this paper.

Undoubtedly significant soil differences are to be found in soils developed from similar parent materials but in different geological environments. As stated above a very important factor in these differences is changes (or variations) in the deposits underlying the parent material. For example, as shown on the map, in the Fraser River delta the top 15 feet may consist of any one of the following; all peat; all silty clay and clay; all sand; silt above peat above silty clay and clay; peat above silty clay and clay; peat above silty clay and clay above sand; silty clay and clay above sand; and silt above sand. The clay, silty clay and silt are impermeable; the sand is permeable; and the peat has a very high absorptive value, that is, it will store as much as twenty-six times its own weight of water. Obviously the drainage pattern encountered will vary greatly depending on which of the combinations described above is found and therefore the moisture and other soil-climate conditions in the soil may show very significant differences.

Variations in materials underlying the upland soils also play an important role in their development. Furthermore, variation in surface drainage conditions may result in differences in the kind of upland soil developed from a single parent material.

The geological history of the western part of the New Westminster map-area has greatly affected the nature of many of the upland soils particularly those developed on till, and glacio-marine stony silty clays and till-like mixtures. Following the retreat of the Vashon ice the land rose above the sea and during this uplift, that part of the uplands now below 600 feet, underwent marine erosion. As a result much of the fine material was washed out leaving a mantle of boulders and gravel, and sand (Bose Gravel).

The New Westminster map-area has a large number of soil units covering a wide range of characteristics. The soil units developed from different types of unconsolidated materials that outcrop at the surface in areas of agricultural development may be roughly classified as follows:

Parent Material	Main Soil Types
Glacial	
Surrey till	Stony sandy loam and stony silt loam
Glacio-fluvial	
Abbotsford outwash) Haney outwash) Maryhill outwash)	Gravelly loam, gravelly sandy loam, and sandy loam
Glacio-marine	
Whatcom glacio-marine deposits) Newton stony clay)	Silt loam, clayey silt loam, silty clay, and clay, all with scattered stones

Parent Material	Main Soil Types
Marine-offshore	
Cloverdale sediments	Clay loam and silt loam
Marine-offshore and shore	
Sapperton sediments	Gravelly sandy loam, sandy loam, silt loam, and stony silt loam
Marine-shore	
Present-day shoreline deposits	Gravelly sandy loam, sandy loam and loamy sand
Bose gravel	Gravelly sandy loam and gravelly loamy sand
Sunnyside sand	Sandy loam, loamy sand, and sand
Marine-estuarine and deltaic	
Marine delta gravel	Gravelly sandy loam, loamy sand, and sandy loam
Marine and Nonmarine estuarine, deltaic, channel, and flood plain	
(Capilano gravel) (Colebrook gravel)	Gravelly sandy loam, loamy sand, and sandy loam
(Interglacial stream deposits)	Silt loam, silty clay loam, sandy loam, loamy sand, and gravelly loam
Nonmarine-channel and flood plain	
Fraser flood plain	Silt loam, silty clay loam, silty clay, clay loam, loamy sand, and sandy loam
Lowland stream deposits	Silty loam, silty clay loam, loamy sand, and sandy loam
Mountain stream deposits	Gravelly loam, gravelly sandy loam, and sandy loam

Parent Material	Main Soil Types
Huntingdon gravel	Gravelly loam and gravelly sandy loam
Nonmarine-Swamp	
Peat and muck	Peat and muck

Drainage

Drainage has been discussed briefly above as a factor controlled largely by geological environment. A few additional remarks are included here enlarging on the above statements.

The moisture content of a soil depends partly on the slope on which it rests, partly on the permeability of the profile itself and the underlying parent material, and partly on the presence or absence of a permanent water-table. The soils of the region fall naturally into two classes based on the downward drainage (permeability), namely: those with restricted downward drainage and those with good or adequate drainage. The soils with restricted downward drainage may be subdivided into those with good surface drainage and those with poor surface drainage.

Soils developed on the following parent materials have restricted downward drainage, namely; till, glacio-marine stony clayey silt and related till-like mixtures, varved clay and silt, marine clay and silt, alluvial clay and silt, and peat. All are impervious or nearly so. The surface drainage on these soils is controlled by local topography, therefore if they occur on slopes the surface drainage is good, but if they occupy hollows or flat-lying areas the surface drainage is poor. The areas underlain by till are mainly hilly, and except locally in depressions and flat areas, have excellent surface drainage. The stony glacio-marine silty clay and related till-like mixtures normally have a rolling to relatively flat topography and as a result have limited areas only with good surface drainage. All the remaining deposits with restricted downward drainage underlie flat-lying areas and have poor surface drainage.

Sand and gravel of all origins normally have good downward drainage. Exceptions are found in low-lying areas where the water-table is near the surface permitting little downward circulation of water. Most sand and gravel deposits have flat surfaces such as terrace tops and valley bottoms.

Agricultural Peat

The largest peat operations in Canada, about two-thirds of the Canadian production, are on the Lower Mainland of British Columbia. The production in 1954 was in excess of 51,000 tons with a value of about $2 million; the present production is higher. More than 90 per cent of the peat produced is exported to the United States.

Numerous bogs are partly or entirely in the area. Those from which peat moss and associated products are being produced are: Pitt Meadows bog south of the Pitt River Bridge; Byrne Road bog, along southeast Marine Drive, Burnaby, near the western border of the area; small Lulu Island bog, of which only the eastern part is in the area; and Delta bog in Delta municipality. Seven peat plants are operating in these bogs at present.

The Pitt Meadows bog is up to 25 feet thick and covers about 1,000 acres, part of which is under cultivation. The Byrne Road bog covers approximately 1,500 acres, of which more than half is under cultivation. The bog varies in depth from 2 to 15 feet. The small Lulu Island bog covers about 3,500 acres, of which only a few hundred are under cultivation. Much of the peat in the bog has been badly burnt. It varies in depth from 2 to 20 feet. The Delta bog underlies an area in excess of 10,500 acres. The margins of the bog are under cultivation and a very considerable part of peat in the bog has been destroyed by fire. It varies in thickness from 2 to 25 feet.

All the peat produced from these bogs is sphagnum moss peat. The stratum of moss of high quality varies greatly in thickness. In some places it is as much as 7 feet thick, but averages nearer 4 feet. The top layer is referred to as unhumified peat. This is dead sphagnum moss only slightly humified. It is fibrous, elastic, light greyish green, or yellowish to light brown, becoming somewhat darker on drying. It has an absorptive value of up to twenty-five times its own weight of water and is light in weight and porous. Humified peat in its natural state is dark brown to black, colloidal, plastic, homogeneous, and somewhat elastic. It dries into a hard solid mass with specific gravity higher than water. It has almost no absorptive value. A piece of dried humified peat may be under water for weeks without absorbing any water. Unhumified peat left in its natural state will humify in the course of time and all fibrous matter eventually disappears. From descriptions of the peat moss bogs mentioned above it is clear that the lower peat strata are darker and consist of intermixtures of humified and fibrous peat with a bottom stratum of well humified peat.

SELECTED REFERENCES

Armstrong, J.E.
(1954): Preliminary Map, Vancouver North, British Columbia; Geol. Surv., Canada, Paper 53-28.

(1956): Surficial Geology of Vancouver Area, British Columbia; Geol. Surv., Canada, Paper 55-40.

Armstrong, J.E., and Brown, W.L.
(1953): Ground-water Resources of Surrey Municipality, British Columbia; Geol. Surv., Canada, Water Supply Paper No. 322.

(1954): Late Wisconsin Marine Drift and Associated Sediments of the Lower Fraser Valley, British Columbia, Canada; Bull. Geol. Soc. Amer., vol. 65, pp. 349-364.

Bostock, H.S.
(1948): Physiography of the Canadian Cordillera, with Special Reference to the area North of the Fifty-fifth Parallel; Geol. Surv., Canada, Mem. 247.

Halstead, E.C.
Ground-water Resources of Langley Municipality, British Columbia; Geol. Surv., Canada, (in press).

Roddick, J.A., and Armstrong, J.E.
(1956): Pitt Lake (Vancouver, East Half) Map, New Westminster District, British Columbia; Geol. Surv., Canada, 8-1956.