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DEPARTMENT OF MINES AND TECHNICAL SURVEYS

MEMOIR 318

SURFICIAL GEOLOGY OF HORNE LAKE AND PARKSVILLE MAP-AREAS, VANCOUVER ISLAND, BRITISH COLUMBIA

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J. G. Fyles

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PREFACE

Information on water supply, foundation material, construction aggregates, and distribution of soils becomes increasingly important as settlement of the eastern coastal region of Vancouver Island progresses. Much of this information depends on a knowledge of the nature and distribution of the unconsolidated material lying beneath the soil and upon bedrock.

This report presents a detailed account of these deposits and relates them to the rather remarkable Pleistocene history of the region.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, June 8, 1962

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SURFICIAL GEOLOGY OF HORNE LAKE AND PARKSVILLE MAP-AREAS, VANCOUVER ISLAND, BRITISH COLUMBIA

Abstract

This report is concerned with part of the eastern coastal lowland of Vancouver Island, the first range of mountains and the intermontane Alberni Valley. Thick surficial deposits on the coastal lowland record two glaciations separated by a major interstadial interval. The principal surficial deposits are, from oldest to youngest: Mapleguard sediments, Dashwood drift, Quadra sediments, Vashon drift, Capilano sediments (early post-glacial), and Salish sediments (modern).

The Mapleguard sediments are unfossiliferous clays, silts, and sands. The Dashwood drift consists of a till-sheet complex deposited during an 'old' regional glaciation. The Quadra sediments comprise a lower marine (and glaciomarine) clay unit, a middle plant-bearing silt-gravel unit, and a thick upper fluvial sand unit. The Quadra records a major cool interstadial interval and has yielded radiocarbon ages ranging from 25,000 years to more than 40,000 years.

Varied glacial deposits comprising the Vashon drift relate to a single glacial invasion equivalent to the 'classical' Wisconsin. An ice-sheet complex covered the entire region, except for a few high peaks, at the glacial climax, and then separated into a network of glaciers and glacial remnants during deglaciation. Retreating glacial lobes in the Georgia depression and Alberni Valley were bordered by the sea.

Since retreat of the glaciers, marine, fluvial, lacustrine, swamp, and colluvial deposits have accumulated. Deglaciation was followed by a cool interval during which the land rose relative to the sea by 500 feet in the coastal lowland and 300 feet in Alberni Valley. Organic materials formed during the later half of this uplift have radiocarbon ages of 11,500 to 12,350 years. The last several thousand years (possibly 5,000 or more) have been characterized by a climate like the present and a sea-level that was within a few feet of the present.

Résumé

Le présent rapport porte sur une partie des basses terres de la côte orientale de l'île Vancouver de même que sur la première chaîne de montagnes et la vallée Alberni d'entremont. Les épais dépôts meubles rencontrés dans les basses terres côtières permettent d'établir la présence de deux glaciations distinctes séparées par un intervalle interstadial important. A commencer par les plus anciens, les dépôts meubles les plus importants que l'on y trouve, sont: les sédiments Mapleguard, le drift glaciaire Dashwood, les sédiments Quadra, le drift Vashon, les sédiments Capilano (début de l'âge post-glaciaire) et les sédiments Salish (d'âge moderne).

Les sédiments Mapleguard se composent d'argiles non fossilifères, de sablons et de sables. Le drift Dashwood comprend un ensemble de bancs de till déposés lors d'une glaciation régionale antérieure. Quant aux sédiments Quadra, ils se composent d'une unité inférieure argileuse marine (et glacio-marine), d'une unité intermédiaire de sablon et gravier renfermant des plantes, et d'une unité supérieure de forte puissance formée de sable fluvial. Les sédiments Quadra portent par ailleurs des traces d'un important intervalle interstadial frais et ont fourni des déterminations d'âge au radiocarbone variant entre 25,000 et plus de 40,000 ans.

Divers dépôts glaciaires, dont entre autres le drift Vashon, indiquent une invasion glaciaire distincte correspondant à la glaciation «classique» Wisconsin. Un ensemble de calottes glaciaires recouvrait toute la région au point culminant de la glaciation à l'exception de quelques sommets élevés, pour ensuite se disperser au cours de la déglaciation en un réseau de glaciers et de vestiges glaciaires. Lors du retrait, les langues glaciaires recouvrant la dépression Georgia et la vallée Alberni étaient entourées par la mer.

La récession glaciaire a par la suite cédé sa place à l'accumulation de dépôts marins, fluviaux, lacustres, marécageux et colluviaux. La déglaciation a été suivie d'un intervalle frais au cours duquel s'est exercé un soulèvement post-glaciaire atteignant 500 pieds au-dessus du niveau de la mer dans les basses terres côtières et 300 pieds dans la vallée Alberni. Des déterminations d'âge au radiocarbone sur des matières organiques formées durant la dernière moitié de ce soulèvement ont donné des valeurs variant entre 11,500 et 12,350 ans. Au cours des derniers millénaires (peut-être 5,000 ans ou plus) le climat était semblable à celui d'aujourd'hui et le niveau de la mer à quelques pieds près du niveau actuel.

Chapter I

INTRODUCTION

A thick cover of surficial materials, providing a remarkable record of glacial and non-glacial environments, characterizes the lowlands that border the Strait of Georgia and Puget Sound in southwestern British Columbia and northwestern Washington. This report is concerned with a part of east-central Vancouver Island—Horne Lake and Parksville map-areas—in which these surficial deposits are particularly well exposed.

Field work was begun towards the end of the 1950 field season and continued during the summers of 1951, 1952 and 1953. Able assistance in the field was rendered by M. G. Christie and K. L. Markland in 1951; by J. A. McCann, J. R. Southwell and J. Terasmae in 1952; and by R. L. Craig and J. W. Gregory in 1953. Some of the mechanical analyses were done by F. J. Fraser and W. R. Wellwood of the Geological Survey. The writer is grateful to the residents of the area for many courtesies and services, particularly to the logging operators who granted permission to use their private roads. Special thanks are due to Dr. R. P. Goldthwait of the Geology Department, Ohio State University, for his friendly guidance in various phases of this project. Some of the concepts set forth have been developed jointly with J. E. Armstrong of the Geological Survey.

East-central Vancouver Island consists of a series of northwest-trending mountain ranges bordered on the northeast by a coastal lowland averaging 4 miles in width. The area described here includes about 40 miles of this coastal lowland, the easternmost range of mountains and the intermontane Alberni Valley. The last is a basin 25 miles long and 5 miles wide surrounded by mountains and connected to the west coast of the island by a narrow fiord known as Alberni Inlet.

Almost the entire population of the area is in the coastal lowland and Alberni Valley. The principal centres are the twin cities of Alberni and Port Alberni at the head of Alberni Inlet (populations about 3,500[1] and 8,000 respectively) and the villages of Parksville and Qualicum Beach on the coastal lowland (populations about 900 and 800 respectively). Lumbering is the main industry, and during periods like the present, when the demand for timber products is great, most of the people are employed in logging camps and sawmills. Small mixed farms are scattered through the coastal lowland and Alberni Valley. Commercial salmon fishing is carried on in Alberni Inlet and in the Strait of Georgia. During the summers, tourists throng the seaside resorts of the coastal part of the area.

[1] Population figures based on 1951 census.

A good highway extends along the east coast of the island within the map-areas, and a branch highway connects the coastal lowland with Alberni Valley, via the valley of Cameron Lake. Secondary roads provide access to the settled parts of the coastal lowland and Alberni Valley. Logging roads, in various stages of repair, extend into the unsettled parts of the lowlands, onto the lower parts of the mountain slopes, and into some of the mountain valleys. Dense coniferous forest covers much of the area, making foot travel between roads extremely slow and concealing many of the geological features.

Nature of Investigations

The field work was concentrated in the lowlands and valley bottoms, where unconsolidated deposits are relatively continuous. The main object of the studies has been to determine the stratigraphic sequence of the surficial deposits and the succession of environments represented by them as well as by the physiographic features related to them. A second objective has been to produce a map of the unconsolidated deposits on a scale of 1 inch to 1 mile. Because of the thinness and discontinuity of many of the stratigraphic units and the lateral gradation of one facies into another, the deposits can be subdivided on a map in various ways. The maps illustrating this report attempt to show the stratigraphic divisions of the unconsolidated deposits and the principal facies in each division. They do not undertake to indicate all the textural changes in the materials forming the ground surface. The position of many of the geological contacts that do not outline clear-cut landforms has had to be inferred from textural changes in the surface soil, changes in vegetation, and so on; accurate location of these contacts would require much more trenching and augering than is warranted in work on this scale. Some contacts, marking changes in facies, represent broad transitional zones and cannot properly be represented by lines on a map. An attempt has been made to show the stratigraphy of the unconsolidated materials through which the lowland stream valleys have been cut, even though the nature and distribution of these materials is known only where recent gullying has removed the valley-wall mantle of fluvial and colluvial materials. Hence the distribution of the various map-units on the valley walls, as mapped, must be considered tentative. The mountainous parts of the area have been excluded from the geological map because they are largely rocky and because the main surficial deposits (in narrow valleys) form bodies that are too small to be separated on a map of this scale.

In making the pebble counts presented in this report, about 100 pebbles 1 inch to 3 inches in diameter were collected at random from an exposed face of till, stony clay, or gravel, and were then grouped according to rock type. Most of the grain-size data is based on screen and hydrometer analysis, but for some samples pipette analysis replaced the hydrometer analysis. The hydrometer-analysis procedure was adapted from that outlined in the A.S.T.M. Standards, 1949, pt. 3, pp. 1152-1162. The pipette analysis was modified from the procedure presented by Krumbein and Pettijohn (1938, pp. 166-172)[1]. Sodium metaphosphate served as the dispersing agent. In this report, sand, silt, and clay are defined in terms of the M.I.T. grade scale: particles ranging in diameter from 2 to 0.062 mm are classified as sand, those 0.062 to 0.002 mm as silt, and those less than 0.002 mm as clay.

In determining till-fabric orientations, a more or less horizontal surface 18 to 30 inches across was excavated in the till and the azimuth of the long axes of the exposed pebbles was measured to the nearest 5 degrees with a Brunton compass. Then successive increments of till were removed from the surface and the orientation of pebbles was recorded in the same way until 100 measurements had been made. Equidimensional pebbles and pebbles whose major diameter was steeply inclined were not recorded. The pebble orientations were then plotted in 10-degree intervals on a rose diagram. The preferred fabric orientation was considered to be that of the modal interval on the rose diagram, or where several modes are present, the preferred orientation was estimated from the shape of the diagram.

Previous Work

Although several geological reports describe the bedrock of parts of the area and together provide a broad outline of the bedrock geology, none gives more than passing attention to the surficial deposits and physiographic features. MacKenzie's (1923) report contains brief descriptions of the clays and other surficial deposits of Alberni Valley, but most of his extensive observations of the surficial materials of the region have never been published, as a result of his untimely death.

Descriptions and interpretation of surficial deposits of the coastal lowland of Vancouver Island northwest of the map-areas are included in Dawson's report (1887, p. 99 and following) on the northern part of the Strait of Georgia and northern Vancouver Island. The Nanaimo map-area, which embraces the coastal part of Vancouver Island southeast of the area discussed here, has been described by Clapp (1914). His report contains a map of the surficial materials as well as notes regarding their occurrence and the associated glacial and non-glacial events.

Bedrock Geology

East-central Vancouver Island consists of basins of soft shale, sandstone, and conglomerate lying on a basement of altered basic volcanic rocks, altered sedimentary rocks, and small granodiorite bodies (*see* Fig. 1). The basin sediments—termed the 'Nanaimo Group'—underlie most of the coastal lowland and Alberni Valley and occur in a few places on the mountains. They are typically rather poorly sorted with an abundance of angular grains of unstable minerals, and are characterized by numerous local facies changes. They are of late Cretaceous age and include both marine and non-marine beds. A good

[1] Dates in parentheses are those of publications listed in the References.

summary of the stratigraphy of these rocks is presented by Usher (1952, pp. 6-30); their structure and mode of deposition are discussed by Buckham (1947a).

The basement rocks are principally altered basaltic and andesitic lavas and pyroclastic rocks that have been traditionally assigned to the Triassic Vancouver Group. Areally intermingled with these volcanic rocks—and as yet incompletely distinguished from them—are belts of quartzite, chert, argillite, greywacke, and green schist, interbedded with limestone bodies that locally have yielded Permian and possibly Pennsylvanian fossils. These sedimentary rocks are exposed principally near Nanoose (Buckham, 1947b; Richardson, 1874, p. 98) and as a belt extending from Horne Lake to Cowichan Lake (Stevenson, 1945; Fyles, J. T., 1955).

Small plutons of granodiorite occur along the west side of Alberni Valley, at Nanoose, and along the northeastern side of the mountains between Horne Lake and Englishman River; larger and more numerous bodies of a similar nature lie to the west and south of the area. These granodiorite bodies cut the basement volcanic and sedimentary rocks and are overlain by sediments of the Nanaimo Group, but northwest of Courtenay, two small granodiorite masses of different and distinctive lithology have invaded the Nanaimo Group (Gunning, 1930).

Physiography

The map-areas straddle the boundary between two northwesterly trending physiographic elements—the Vancouver Island Ranges and the Georgia depression (Bostock, 1948, pp. 89, 91). The Georgia depression, separating the Vancouver Island Ranges from the Coast Range and northern Cascade Range, is the northern, Canadian part of a northwest-trending structural valley averaging 25 miles in width and extending 250 miles from the northern end of the Strait of Georgia to the southern end of Puget Sound. It is represented in the map-areas by the coastal lowland that borders the northeastern side of Vancouver Island and by a few small islands in the Strait of Georgia (*see* Fig. 1). The Vancouver Island Ranges, which constitute almost the entire island, are typified by northwest-trending ridges and valleys crossed by transverse valleys with preferred north, northeast, and east trends (Peacock, 1935). The two principal elements of the Vancouver Island Ranges within the area are a narrow northwest-trending range of mountains including Beaufort Range and Mount Arrowsmith, which rises steeply from the inland edge of the coastal lowland, and the broad Alberni Valley, also trending northwest, which separates this front range from the more extensive mountains to the southwest.

Coastal Lowland

Between the Strait of Georgia and the front of the Vancouver Island Ranges is an undulating lowland averaging 4 miles in width that constitutes the unsubmerged southwestern edge of the Georgia depression (*see* Plate IA). Within the area, this lowland surface rises gradually from the seashore to meet the steeper mountain slope at an elevation of about 700 feet, but between Chef and Waterloo Creeks a bench about 1,000 feet above sea-level separates the lowland proper from the mountain face. The greater part of the coastal lowland is underlain by shale and sandstone of the Nanaimo Group, and in many places the boundary between lowland and mountain slope approximates the contact between these sediments and the basement rocks. However, near Nanoose and on the 1,000-foot bench between Chef and Waterloo Creeks, basement rocks extend into the coastal lowlands. Outcrops are rare except in these areas of basement rocks and, throughout most of the coastal plain, a mantle of overburden several tens of feet to several hundreds of feet thick completely covers the bedrock and controls the topography. The most prominent physiographic features of the coastal plain are sea cliffs and steep-walled river valleys incised up to 300 feet into the thick cover of unconsolidated materials. Between these valleys the ground surface is characterized by gentle slopes and by broad ridges and depressions with local relief of less than 100 feet.

Alberni Valley

Alberni Valley is a northwest-trending structural depression 25 miles long and averaging 5 miles wide, lying within the Vancouver Island Ranges. Although completely surrounded by mountains, it is connected to the Pacific Ocean by the narrow fiord valley of Alberni Inlet. The axis of the floor of Alberni Valley is at sea-level where it meets the head of this fiord valley and rises gradually to 1,500 feet above sea-level at its northwestern end. Most of the valley bottom, characterized by gently rolling hills and depressions a few tens of feet high, is underlain by shale and sandstone of the Nanaimo Group and is surfaced with unconsolidated deposits several tens of feet thick. The western part of the valley, on the other hand, consists of hummocky outcrops of the basement rocks separated by drift-filled depressions. The valley is bordered on the northeast by a steep and almost straight mountain face marking a fault contact between Nanaimo Group sediments and the basement volcanic rocks. The southwestern margin of the valley is a more gently rising mountain slope cut by westward-trending steep-walled valleys.

Mountains and Mountain Valleys

The mountainous sections of the area for the most part consist of broad-topped ridges and uplands separated by deep glaciated valleys. Mountain summits are merely high points on ridge crests, although locally, encroachment of valleys and cirques into the ridge sides has carved sharp arêtes and precipitous horns. Summits are mostly 3,000 to 5,000 feet above sea-level, although Mount Arrowsmith, standing well above the general level, reaches an altitude of 5,962 feet. Northwest of the area, in Forbidden Plateau and beyond, is a belt of higher country with many summits approaching 7,000 feet above sea-level.

Valleys in the mountainous parts of the region are typically narrow steep-walled troughs shaped by glacial erosion, although some of the smaller valleys with steep gradients have V-shaped, stream-cut forms. The longer valleys have gentle gradients and some of them contain closed rock-basins that impound the larger lakes of the district. The valleys of Sproat and Great Central Lakes are

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similar in form to typical fiord valleys of the nearby coasts. Most tributary valleys meet the trunk valleys almost at grade although a few are hanging valleys. The valleys on the slopes of the higher mountains characteristically head in cirques, many of which contain tarns.

Uplands and most ridge tops are typically gently sloping and rolling areas set off from the surrounding hillsides and valley walls by an abrupt change of slope (clearly discernible in the contoured topographic maps, *see also* Plate IB). Crests of narrow arêtes exhibit longitudinal profiles closely accordant with nearby broad ridge tops, and here and there widen into tiny plateaux. The presence of these remnants of a low-relief upland surface throughout southern and central Vancouver Island has been noted by Clapp (1914, p. 19): "In the southern part of Vancouver Island it seems as if this surface before uplift was nearly a plain with only a few rounded hills composed of especially resistant rocks remaining a few hundred feet above the general level. In the central part of the island, however, the surface appears to have been one of considerable relief with larger and higher residual hills and small ranges of mountains." Within the map-areas, ridge tops and inter-valley uplands typically have a local relief of several hundred feet, although here and there they include plateau-like areas with a local relief of less than 200 feet. Along parts of the mountain front bordering the coastal lowland, ridge-summit uplands grade imperceptibly into fairly gentle regular slopes, some of which pass into the lowlands without being interrupted by steep faces. The slopes contrast sharply with the steep walls of valleys cut into them and with adjoining over-steepened segments of the mountain front.

Ridge-top uplands are found at many elevations within the area. In Beaufort Range, for instance, they form the crest of much of the main summit ridge between 4,500 and 5,000 feet above sea-level. Southwest of Mount Irwin, where the main ridge of the Beaufort Range drops off gradually to merge with a knobby plateau south of Horne Lake, the crest of the ridge includes about half a dozen gently sloping upland segments between 4,200 and 1,500 feet above sea-level. The contour maps and a series of projected profiles have provided no suggestion of distinct, separate upland levels, but rather convey the impression that the uplands and the gentle slopes are remnants of a rolling surface of considerable relief. Projected profiles across Beaufort Range reveal a broadly rounded surface rising from the coastal plain, first rather steeply and then very gently, to culminate along the top of the steep scarp bordering Alberni Valley. Extensive fault movements have taken place along this scarp and the inclination of the upland surface may perhaps be the result of these movements. Possibly, the steepening of the profile immediately southwest of the coastal lowland may reflect similar though smaller relative movements of the mountains and the Georgia depression.

Origin of Mountains and Lowlands

The main elements of the physiography of the region are genetically related to the bedrock structure. Alberni Valley and the coastal lowland conform closely to basins of soft Upper Cretaceous sediments. Their depressed position relative to the mountains probably is partly due to rapid erosion of the basin sediments but, to a large extent, is the result of down-faulting of these basins relative to the mountains. The valleys within the mountains consist dominantly of north-, northeast-, and northwest-trending segments that parallel the regional fault and fracture pattern (Peacock, 1935) and for the most part appear to have resulted from differential erosion along fault and fracture zones.

Elevation of the rolling upland surface of the mountainous parts of the area to approximately its present position relative to the lowlands, and dissection of this surface by narrow valleys, appear to have taken place before the deposition of any of the surficial deposits found in the area today and before erosion of any elements of the present glacially sculptured landscape. All the surficial materials and glacial features so far recognized in the area are believed to have formed since mid-Pleistocene time. Therefore, the elevation and dissection of the rolling upland surface may possibly have taken place as recently as the middle part of the Pleistocene epoch, although it may well have occurred earlier. The youngest coastal-plain sediments along the southwestern side of Vancouver Island are Miocene in age, and it has been suggested (Clapp, 1917, p. 17; Hoadley, 1953, p. 45) that uplift of these sediments and of the old erosion surface farther inland took place during Pliocene time.

Glacial Sculpture

Glacial ice has overriden the entire area except perhaps the summit ridge of Mount Arrowsmith. Narrow valleys have been extensively remodeled by glacial erosion, as is evident in their trough-like shape, in the closed rock-basins on their floors, and in the cirques at their heads. The remarkable steepness of many hillsides (e.g. the front of the mountains bordering the Georgia depression) also appears to be largely the result of glacial erosion. On the other hand, the topographic form of hill, ridge, and mountain tops and of relatively flat areas, appears to have been but little modified by overriding glacial ice, even though the smoothed and rounded form of outcrops in such places provides evidence of universal small-scale glacial erosion. The area has undergone at least two separate glaciations. During the later glaciation and probably also during the earlier one, a complex succession of changes in the direction of ice-movement accompanied changes in ice thickness and source. Hence, glacial sculpture in most parts of the area must be the result of ice-movements in more than one direction. As would be expected, the best recorded small-scale erosional features are those produced during the latest glacial movement. On the other hand, the major elements of the glacially sculptured landscape, with a few exceptions, are the result of ice-movement down valleys in the same direction as the natural drainage, even where movement in this direction has been succeeded by movements in radically different directions.

The most striking glacial-erosional features of the region are the cirques and U-shaped mountain valleys (*see* Plate IB). Cirques and U-shaped valleys heading in cirque-like basins record the former presence of local mountain glaciers. They occur on most mountain masses with summits more than 4,500 feet above sea-level and are rare on those with summits below 4,000 feet. Cirques within the area average $\frac{1}{2}$ mile in diameter and between 500 and 1,000 feet in depth, but some cirque-like heads of U-shaped valleys are $1\frac{1}{2}$ miles across with headwalls more than 2,500 feet high. In Beaufort Range, floors of cirques range from 3,000 to 4,200 feet above sea-level, and floors of cirque-like heads of the larger U-shaped valleys, such as those of Wilfred and Rosewall Creeks, are 1,500 to 2,500 feet above sea-level. On the northeastern side of Mount Arrowsmith, cirques with tarns range from 2,600 to 4,500 feet above sea-level and shallow incipient cirques carrying permanent snow patches occur above 5,000 feet. Two or even three cirques occur in vertical succession at the heads of some valleys—for instance, Rosewall Creek heads in a cirque-like basin about a mile across with a floor 1,800 feet above sea-level and a headwall 2,500 feet high. Notching the west side of this amphitheatre is a cirque $\frac{1}{2}$ mile across with a floor 3,200 feet above sea-level, and perched on the headwall of this cirque is another, $\frac{1}{4}$ mile across, containing a tarn about 3,700 feet above sea-level. The cirques and U-shaped valleys have undergone little modification since they were formed. The steep cirque and valley walls are still separated from the less-steep ridge tops by an abrupt change in slope, and, as revealed by the abundance of tarns, stream-notches in the bedrock sills of the cirques are shallow.

Some U-shaped valleys extend through the mountains instead of heading in them and have no tributaries from which mountain glaciers could have emanated. Glaciation of such valleys can only have been accomplished by ice moving into or through the range from the adjoining low country; the steep-walled valley containing the rock-cut basin of Cameron Lake is of this type. Horne Lake valley is part of a broad depression crossing Beaufort Range and appears to owe its glaciated form to movement of ice through the range. A much smaller through valley forms a prominent U-shaped notch in the steep north wall of Cameron Valley at the west end of Cameron Lake. From the notch, the valley slopes downward to the north, away from Cameron Lake and towards the coastal lowland. This appears to be a reverse hanging valley eroded into a 'U' form by south-moving ice squeezing between Mount Wesley and Mount Horne to merge with ice in Cameron Valley.

The significance and history of these large-scale glacial erosional features in terms of the glacial history of the area are discussed in the next chapter, following consideration of the glacial deposits and ice-flow directions. This discussion is found principally under the heading 'Vashon Drift and the Last Regional Glaciation'.

Chapter II

SURFICIAL GEOLOGY

Stratigraphy and Nomenclature of Surficial Deposits

'Standard' Succession*

The principal surficial materials of the coastal lowland comprise two groups of glacial deposits, a thick intervening succession of non-glacial deposits, and varied late-glacial and post-glacial marine and fluvial deposits. This 'standard' succession is used here as the basis for stratigraphic subdivision of the surficial deposits throughout the map-areas (*see* Fig. 1). The 'standard' succession is based on the following sequence of deposits, whose members are widely recognizable in the sea cliffs and river banks along the coast.

Unit		*Maximun Thickness (feet)*
8	Gravel, sand, silt, and clay of marine and fluvial origin; complex	80
7	Till, grey and sandy	100
	(erosional unconformity)	
6	Sand, white, horizontally stratified, current-bedded; local beds of gravel and plant-bearing silt	250
5	Silt, fine gravel, sand peat, and wood; distinctive orange-green colours	25
4	Clayey silt; contains stones and marine shells; massive	80
3	Silt and clay, laminated	5
2	Till, grey, silty to sandy; contains gravel and silt interbeds	70
1	Sand, silt, clay	50+

The succession is well exposed in localities 1 to 6 (Fig. 1), although the lowermost unit has been seen at localities 2 and 4 only. The succession has been mapped for 3 miles along the Dashwood sea cliff (*see* Fig. 1, locality 2; also Map 1111A, section A-B) and has been traced for similar distances along the valley of Qualicum River (*see* Fig. 1, locality 3) and along Komas Bluff on Denman Island (locality 6). The plant-bearing beds (unit 5 of 'standard' section), so far as known, can be correlated from place to place with some assurance. Unfortunately the two tills (units 2 and 7) cannot in most places be differentiated on the basis of lithology; the silt and stony clay (unit 3) overlying the lower till are identical to deposits (unit 8) overlying the upper till; and the

* (1962) Studies elsewhere in the Georgia depression as well as radiocarbon dates have indicated that the sequence of sub-till deposits is more complex than was envisioned when this report was written. As yet however, the regional sequence is imperfectly known. This account is still thought to be representative of the deposits and map-areas under consideration.

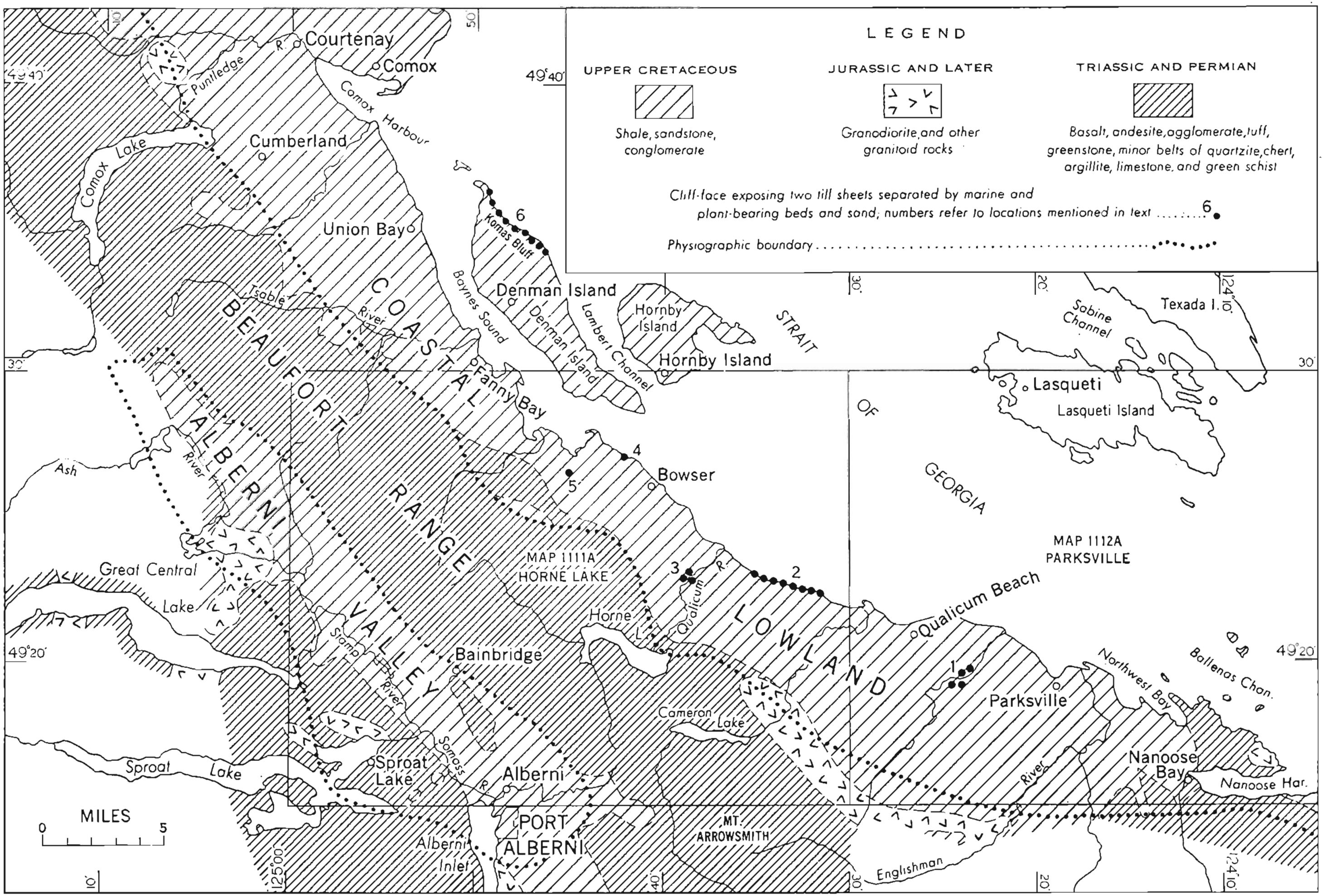

Figure 1. *Bedrock geology, physiographic divisions, and exposures of 'standard' succession, east-central Vancouver Island.*

white sand beneath the upper till (unit 6), although differing from the sand beneath the lower till (unit 1), has been locally redeposited as post-glacial marine and deltaic accumulations (unit 8) nearly similar to the parent deposit. Nonetheless, certain combinations of two or more of these units (for instance till overlying white horizontal sand) do appear to be stratigraphically distinctive. Such distinctive combinations of deposits are exposed in many places, and, together with the fewer exposures of the plant-bearing beds, are a basis for correlation with the 'standard' succession throughout much of the coastal lowland. Deposits may possibly be missing from the above sequence at the erosional unconformity between the upper till (unit 7) and the underlying sand (unit 6). Indeed, a series of deposits consisting of till, gravel, sand, silt, and clay, and lying between two erosion surfaces, has been assigned to this stratigraphic position in Lower Fraser Valley. No remnants of such deposits have been found on Vancouver Island* and the writer has tentatively assumed that the 'standard' succession approximates the natural sequence of deposits in the area and may be used to reconstruct the local sequence of events.

Nomenclature

History

Sequences of deposits similar to the 'standard' succession outlined above are exposed in many places throughout the Georgia depression and the Puget lowland. Dawson, working the northern part of the Georgia depression northwest of this area, seems to have been the first to record the more-than-local distribution of such deposits and to speculate on their significance. He noted a sucession of two tills separated by stratified silts and sands and suggested that it records an early major, and a later minor glaciation, separated by a period of glacial retreat (Dawson, 1887, p. 105). During the 1890's, Willis made the first comprehensive study of Pleistocene features of the Puget lowland, at Tacoma. He found rusty gravel and stratified sand underlain by till and clay, and overlain with erosional unconformity by an upper sheet of till. He applied the name "Vashon" to the till above the unconformity "distributed by the northern glacier during the last glacial epoch" (Willis, 1898, p. 150) and included in the Vashon glacial epoch all correlative glacial features. Believing the lower till and clay to belong to a distinct, earlier glaciation, he assigned them to a separate glacial epoch that he called "Admiralty". He described the intertill strata as outwash and glacial-lake beds and assigned both these deposits and the succeeding erosional interval (represented by the unconformity between them and the Vashon till) to the Puyallup interglacial epoch.

During comprehensive Pleistocene investigations in the Puget Sound region, Bretz (1913) found a similar succession of deposits throughout much of the

* Since this report was written, silts and sands that may occupy this stratigraphic position have been found in shore exposures about 10 miles east of Parksville map-area.

Puget lowland. He encountered numerous exposures of peaty beds within the intertill sediments, as well as isolated mammoth teeth, elk horns, whale(?) vertebrae, and marine shells. Willis apparently believed that the present patchy distribution of the intertill sediments approximates their original constructional form and that they accumulated between remnant tongues of Admiralty ice occupying the present sites of the Puget troughs. But Bretz (1913, p. 15) argued that the sediments are the eroded remnants of "a great plain of terrestrial deposits, containing a few marine beds in the lower portion" that "is conceived to have been aggraded in front of the waning Admiralty glacier as it withdrew to the north." He therefore termed the intertill beds the "Admiralty sediments", placing them in the Admiralty glacial epoch and restricting the Puyallup interglacial epoch to the period of erosion represented by the unconformity that truncates them.

During extensive geological studies in southern Vancouver Island (1908 to 1913), Clapp noted glacial drift overlying sand, gravel and clay in many places and reported the presence of two sheets of till separated by marine clay in a very few exposures at Victoria (1913, Fig. 5). He correlated these deposits with the similar deposits described by Willis at Tacoma and classified them together with the overlying outwash-delta deposits and alluvium, as tabulated below (Clapp, 1913, p. 108).

Post-Glacial epoch—
- Beach alluvium
- Valley and swamp alluvium

Vashon glacial epoch—
- Stage of glacial retreat
  - Colwood sands and gravels
- Stage of glacial occupation
  - Vashon drift

Puyallup interglacial epoch—
  - Cordova gravels and sands
  - Maywood clays

Admiralty glacial epoch—
  - Admiralty till

Clapp noted the presence of raised post-glacial marine deposits but described them as being "thin and of small extent" (1917, p. 253) and assigned the extensive marine clays of the region (both buried and veneering the surface) to the Puyallup interglacial epoch. On the other hand, Arnold and Hannibal (1913) and Newcombe (1914) reported abundant post-glacial raised marine "beach" deposits on southern Vancouver Island, which they designated as the "Saanich Formation." They included in this category some of the deposits that Clapp assigned to the Puyallup interglacial epoch.

Geological investigations around Vancouver by Burwash and Johnston revealed a succession of deposits similar to that on Vancouver Island and in the Puget Sound region. Burwash (1918, p. 81) subdivided the deposits as follows:

5. Outwash and delta sands and gravels
4. Vashon till
   Unconformity (Puyallup interglacial period)
3. Admiralty clays and sands
2. Admiralty till
1. Nicomeki (Nicomekl?) sand and silt

Like Bretz, Burwash classified the intertill sediments as outwash associated with the retreat of the Admiralty ice and considered the succeeding interglacial interval to be one of uplift and erosion. Johnston, on the other hand, assigned to the interglacial interval a succession of peat-bearing beds—which he called the "Point Grey Formation"—lying within the Admiralty sediments at Point Grey. He therefore classified only the lowermost of the sub-till (Admiralty) sediments in this locality, beneath the Point Grey Formation, as outwash of the Admiralty ice and considered the uppermost beds, above the Point Grey Formation, to be advance outwash of the succeeding Vashon glaciation. Overlying the upper (Vashon) till sheet, Johnston found stony marine clays that he related to a minor late-glacial ice-advance, and clays, deltaic deposits, and beach deposits that he considered to be of post-glacial marine origin, but he did not apply stratigraphic or age names to any of these materials.

During recent years the Pleistocene deposits of the Puget lowland have been studied in much detail by geologists of the United States Geological Survey and by J. Hoover Mackin and his students of the University of Washington. This work has revealed stratigraphic complications not accounted for in the simple schemes of Willis and Bretz. For instance, Crandell, Mullineaux and Waldron (1958) reported as follows regarding the area south of Seattle: "Willis' sequence of two glaciations (Admiralty and Vashon) and a single interglacial interval (Puyallup) is replaced by four glaciations separated by nonglacial intervals during which the climate approached or attained conditions like those of the present. The stratigraphic section now recognized consists of the Orting drift (oldest), Alderton formation (nonglacial), Stuck drift, Puyallup formation (nonglacial), Salmon Springs drift and Vashon drift. An erosion interval between the Salmon Springs and the Vashon drifts is thought to represent the third nonglacial interval. The name Admiralty is not used—because the stratigraphic position of the drift assigned to this glaciation by Willis appears to be equivocal in the sequence now recognized."

Present Use

In the current studies of the surficial stratigraphy of Vancouver Island and the Lower Fraser Valley by the Geological Survey of Canada, a great many formational units have been distinguished, particularly among the deposits that rest upon the upper till sheet. Formal formational names have been applied to

UNIT	GLACIAL	GLACIO-FLUVIAL	GLACIO-LACUSTRINE	MARINE (including glacio-marine)	MARINE SHORE	MARINE DELTAIC	CHANNEL FLOODPLAIN	LACUSTRINE	ALLUVIAL FAN	SLOPE	UPLAND SWAMP
SALISH SEDIMENTS (deposits related to present marine, river and lake levels)					Gravel, sand, silt, and clay at present shoreline	Gravel, sand, silt, and peat in deltas along Georgia Strait and Alberni Inlet	Gravel, sand, silt, and peat along streams	Gravelly shoreline deposits; gravel, sand, and silt in deltas	Poorly sorted gravel and silt	Colluvium, talus landslide rubble	Peat and muck
CAPILANO SEDIMENTS (deposits related to former marine, river, and lake levels)				Clay, stony clay, silt, sand, poorly sorted till-like mixtures, contains marine shells, rare wood and leaves; local basal laminated clay, silt, sand, and gravel.	Stony wave-washed lag veneer, gravel, sand, silt, clay, till-like materials; contain marine shells, rare driftwood and leaves	Gravel, sand, and minor silt; contain rare marine shells, driftwood.	Gravel, minor sand and silt beneath terraces	Gravel and sand terrace deposits; silt and clay, (not clearly distinguished from glacio-lacustrine deposits	Poorly sorted gravel and silt in fans and depression fillings; stony lag veneer		
VASHON DRIFT (glacial deposits)	Grey till, sandy to clayey texture	Gravel, sand, and silt forming ice-contact deposits	Sand and gravel, laminated silt and clay							Landslide rubble in part mixed with glacio-fluvial gravel	
				EROSION SURFACE (RELIEF OF SEVERAL HUNDRED FEET)							
QUADRA SEDIMENTS (non-glacial deposits)							Sand minor silt and gravel, local peat, peaty 'soil' and leaf layers				
				Clay, stony clay, silt, containing marine shells; local basal laminated clay and silt.	Silt, pebble gravel, sand and cobbly lag gravel; distinctive orange-green colouring; contain peat, peaty 'soil', driftwood						
DASHWOOD DRIFT (glacial deposits)	Grey till, silty to sandy texture, contains silt and gravel lenses										
MAPLEGUARD SEDIMENTS (non-glacial deposits)							Sand, silt, and clay				

Figure 2. *Stratigraphic and environmental chart.*

many of these units in the Lower Fraser Valley (Armstrong and Brown, 1953; Armstrong, 1956a). The 'epoch' time divisions that were introduced at Vancouver by Burwash, and on Vancouver Island by Clapp, have been discarded; this is in keeping with current feeling against the use of such local time terms and following the lead of geologists working in the Puget Sound region where these terms were originally applied. However, in the absence of major units or groupings to replace the 'epochs', the overall relatively simple succession of events becomes obscured in the bewildering array of formational units, many of which are merely stratigraphically equivalent deposits formed in different environments. Therefore, each group of glacial deposits recording a glaciation of the region, as well as each group of non-glacial deposits recording an interstadial or other non-glacial event has been set apart as a major stratigraphic unit. The units applying to this report are listed below (*see also* Fig. 2).

Salish sediments: shoreline and fluvial deposits and associated materials related to the present sea, river, and lake levels.

Capilano sediments: marine, fluvial, and lacustrine deposits related to former (higher) sea, river, and lake levels (unit 8, 'standard' succession).

Vashon drift: glacial deposits lying unconformably on the Quadra sediments or on deposits beneath the Quadra, and constituting the uppermost drift sheet of the region (unit 7, 'standard' succession).

Quadra sediments: sands; plant-bearing silts and gravels; marine stony clays and laminated clays (units 3, 4, 5, 6, 'standard' succession).

Dashwood drift: till locally intercalated with gravel, sand, and silt, and lying conformably beneath the clays of the Quadra sediments (unit 2, 'standard' succession).

Mapleguard sediments: sand, silt, and clay lying beneath the Dashwood drift (unit 1, 'standard' succession).

Mapleguard Sediments

Nature of Deposits

The term 'Mapleguard sediments' is here proposed for sand, silt, and clay exposed beneath Dashwood drift on the sea cliffs at Dashwood and about 2 miles southeast of Mapleguard Point (*see* Fig. 1, localities 2 and 4). In the Dashwood exposures, which constitute the type locality for this unit, sandy strata have been found beneath Dashwood till in seven measured sections in a 1-mile segment of the sea cliff, as shown in the cross-section on the geological map. Up to 40 feet of these beds is exposed, and auger borings in one place have shown that the sediments exceed 70 feet in thickness. The Mapleguard sediments at Dashwood consist of medium- to coarse-grained sand interbedded with a few thin strata of pea gravel and of laminated clayey silt and sandy silt.

The strata are horizontal, but in several of the exposures a few beds within the otherwise uniform and undisturbed succession are complexly folded and ruptured. A landslide scar on the otherwise bushy sea cliff about 2 miles southeast of Mapleguard Point exposes up to 55 feet of Mapleguard sediments between the Dashwood drift and high-tide line. There the sediments consist of medium-grained grey sand intercalated with numerous beds of thinly laminated grey silt and clay. At the base of the west end of the exposure is a 12-foot section of cross-bedded sand without silt interbeds. The strata dip gently to the east or southeast, and some of the beds in the upper part of the succession are locally contorted.

The base of these deposits has not been seen either at Dashwood or near Mapleguard Point and, in view of the absence of nearby bedrock outcrops in both localities, unconsolidated deposits of considerable thickness probably lie beneath those that are exposed. The Dashwood cross-section (*see* geological map) reveals broad hills and hollows, with a relief of several tens of feet, along the contact between these sandy strata and the overlying Dashwood till. These hills and hollows probably form an erosional topography carved out of the sand prior to the deposition of the Dashwood till. Alternatively, they may have resulted from differential compaction of unexposed underlying materials and, in view of the subparallel form of the three succeeding contacts in this cross-section, such deformation could have taken place after the deposition of the plant-bearing unit of the Quadra sediments. However, this mode of origin seems unlikely because of the magnitude of the differential movements involved (100 feet?) and because of the absence of disturbed structures in all but the Mapleguard sediments.

The Mapleguard sediments seem to differ sufficiently from the white sands of the Quadra sediments to be distinguished lithologically, in the absence of stratigraphic evidence. Thus the Mapleguard sands generally are coarser than the Quadra sands, are much less uniform in texture, and include more silty and clayey interbeds. Moreover, the Mapleguard deposits are darker in colour because of their larger content of dark rock and mineral grains.

Origin, Extent, and Correlation

The Mapleguard sediments are similar to fine-grained river flood-plain deposits and lake sediments. They may be outwash or glacial-lake deposits dating from the beginning of the Dashwood glacial interval, or may be non-glacial deposits formed during a preceding interstadial or interglacial interval.

The deposits described above are the only exposed materials that are known to lie beneath the Dashwood drift. Such deposits may nonetheless be present in a number of other places on the coastal lowland where thick, but unexposed, unconsolidated deposits are inferred to lie beneath the Dashwood drift or the lower part of the Quadra sediments.

Outside the area, deposits equivalent to the Mapleguard sediments may be present in many places in the thick unconsolidated deposits of the Georgia depression. Nonetheless, although stratified materials in various places are known or inferred to occupy the appropriate stratigraphic position (beneath till beneath Quadra sediments) no basis is yet available for regional correlation of these deposits with one another or with the Mapleguard sediments.

Dashwood Drift

Glacial deposits comprising unit 2 of the 'standard' succession of the coastal lowland are here named the 'Dashwood drift.' They consist of till and associated beds and lenses of gravel, silt, clay, and sand. They have been recognized in cliff section in localities 1 to 6 (Fig. 1). The type locality is the sea cliff near the small settlement of Dashwood (3 miles northeast of Qualicum Beach) where these deposits have been traced for 2 miles and where their contacts with the underlying Mapleguard sediments and overlying Quadra sediments are exposed (*see* Map 1111A, cross-section).

The Dashwood till is not lithologically distinct from the younger Vashon till and therefore its recognition has been possible only where the position of the deposits in the 'standard' succession is known; that is, where they lie beneath distinctive deposits of the Quadra sediments. Tills whose positions are not so distinguishable have been arbitrarily placed in the much more widely exposed Vashon drift.

Materials and Field Relations

The Dashwood till is a grey unoxidized mixture of boulder- to clay-size particles similar in appearance to concrete. It is solid enough to stand as near-vertical faces when newly cut, but disintegrates under the action of rain and weather. It generally contains enough carbonate to effervesce freely with dilute hydrochloric acid.

Most Dashwood tills are loamy- to silty-textured materials containing only about 10 per cent gravel and boulders (*see* Fig. 7). A typical sample from the Dashwood cliff consists largely of silt and fine sand and contains 11 per cent gravel and boulders. Its grain-size frequency diagram has a single mode at 0.03 mm. Tills of this sort are finer textured and less stony than the overlying tills of the Vashon drift. On the other hand, the Dashwood tills at French Creek and Chef Creek (Fig. 1, localities 1 and 5) are more sandy, more stony, and less silty and are identical in mechanical composition to nearby Vashon tills.

Stones in the Dashwood tills are largely subangular to subrounded and consist mainly of basic to intermediate volcanic rocks. Counts of pebbles in seven samples of the till revealed 76 to 91 per cent volcanic rocks; 6 to 19 per cent granitic rocks; and rare sandstones, shales, quartzites, cherts, argillites, limestones, schists, and vein quartz. Both the shape and constitution of the stones in the Dashwood till are similar to those of pebbles in the overlying Vashon till.

In most places the Dashwood drift consists of a single till sheet containing lenses and partings of laminated silt and clay, silty sand, and dirty pebble-gravel. Southeast of Mapleguard Point (Fig. 1, locality 4) this till sheet is 9 feet thick;

it ranges from 10 to 30 feet thick on the Dashwood cliff. Northwest of the area, on Komas Bluff, Denman Island, the Dashwood drift is represented by a glacial complex locally more than 80 feet thick, consisting of irregular, disturbed layers of silty to clayey till, silt, sand, and dirty pebble-gravel (*see* Plate IIA).

The contacts of the Dashwood drift have been traced only at Dashwood. There the basal contact follows the undulating (erosional?) surface of the underlying sands. The till mantles this surface as a sheet of rather uniform thickness, and such thinnings and thickenings as are present seem unrelated to the underlying topography.

Distribution

The Dashwood drift has been identified in only half a dozen cliff exposures, all within the coastal lowland. Nonetheless, in view of the distribution of these exposures (*see* Fig. 1), the continuity of the Dashwood deposits at Dashwood and on Denman Island, and the absence of bedrock outcrops near many exposures of the basal clay unit of the Quadra sediments, the Dashwood drift may underlie considerable parts of the coastal lowland. Dashwood tills almost certainly remain unrecognized amid similar materials of the Vashon drift, particularly in erosional areas where the overlying Quadra sediments are known to occur. For instance, some of the exposures of till along the valley of Nanoose Creek where it parallels the highway, and others adjacent to the Esquimalt and Nanaimo Railway east of Craig, may belong to the Dashwood drift.

In the higher, inland parts of the coastal lowland are various sub-till deposits that so far have not been correlated with the 'standard' succession and that include tills and gravelly materials possibly equivalent to the Dashwood drift. Such materials are exposed as local erosional remnants along Englishman River and underlie considerable areas between Thames and Chef Creeks, and between Rosewall and Cowie Creeks. The successions in which they occur will be discussed following the description of the Quadra sediments.

In Alberni Valley and along some of the valleys of the Beaufort Range, discontinuities within the exposed tills (such as boulder pavements, gravel beds, and pronounced changes in texture or stone content) provide abundant evidence of a complex history of glaciation, but as yet, no evidence has been found to indicate whether all the tills are equivalent to the Vashon of the coastal belt or whether some of them are correlative with the Dashwood. All have however, been tentatively placed in the Vashon drift.

Correlation

Till occupying a stratigraphic position similar to that of the Dashwood drift is known in a few places in the Georgia depression outside the area. Till beneath white sands beneath an upper till sheet has been reported on Texada Island a few miles north of the area (McConnell, 1914). Till in a few places in the Victoria and Saanich map-areas at the southeastern end of Vancouver Island was termed 'Admiralty till' by Clapp (1913) and assigned to a stratigraphic position similar to that of the Dashwood drift. Although some of Clapp's Admiralty tills appear to be equivalent to the Vashon drift of this report, other tills in that area (particularly at Cordova Bay) lie beneath sands and peaty materials similar to the Quadra sediments and may correlate with the Dashwood.

In the Lower Fraser Valley region, Armstrong and Brown (1953) have identified two groups of buried glacial deposits—the Seymour Group and the Semiamu Group. Till of the Seymour Group underlies peat-bearing beds that have been correlated with the type Quadra beds at Point Grey, which in turn appear to be equivalent to the Quadra sediments of Vancouver Island. On this basis, the Seymour Group may be correlated with the Dashwood, but the possibility that the Semiamu Group correlates with the Dashwood cannot be ignored.

Age and Historical Significance

The Dashwood drift records a glacial invasion of the coastal lowland of Vancouver Island (and probably of the surrounding region) that preceded the non-glacial interval represented by the Quadra sediments and which, therefore, was distinct and separate from the Vashon glaciation. On the basis of information presently available (*see* 'Significance and Age of the Quadra Sediments', p. 36) the Dashwood drift is younger than the Sangamon but older than the classical Wisconsin.

Stone counts of the Dashwood tills suggest that the depositing ice flowed along the Georgia depression rather than off the Vancouver Island mountains or across the Georgia depression from the Coast Range. Thus, the percentage of granitic stones is higher than would be found in materials derived from the Beaufort Range of Vancouver Island and is lower than would be expected from sources to the north or northeast. Moreover, the pebble counts are similar to those of nearby tills of the Vashon drift which, on other grounds, are believed to have been deposited by ice moving southeastward along the Georgia depression.

In a mountainous region of this sort, the accumulation, movement, and melting of glacial bodies is controlled in large measure by topography. The history of the Dashwood glaciation was therefore probably similar to that of the later Vashon glaciation, about which we know much more.

Quadra Sediments

Definition

The Quadra sediments of the area are non-glacial strata lying between the Dashwood drift and the Vashon drift and comprising (1) a lower unit of marine 'clay' and stony 'clay' (unit 4, 'standard' succession) with basal lenses of unfossiliferous laminated clay (unit 3); (2) a middle unit of plant-bearing silt, gravel, and sand (unit 5); and (3) a thick upper unit of white sand, with local gravels and plant-bearing silts (unit 6). The sea cliff at Dashwood is considered to be the type locality for the Quadra sediments as defined and used in this report.

The name 'Quadra' was first used geologically by Armstrong and Brown (1953, formational table) for sub-till sands forming white prominent cliffs on Point Grey at Vancouver. In this section the Quadra strata include plant-bearing beds designated by Johnston (1923) as the Point Grey Formation. At Point Grey, neither the base of the Quadra nor the underlying deposits are exposed, although Armstrong and Brown (1953) define the Quadra as "intertill sediments". The writer applies the same name to the intertill sediments of Vancouver Island on the basis of the remarkable similarity of the widespread white sands (unit 6, 'standard' succession) to the Point Grey Quadra deposits.

On the high, inland parts of the coastal lowland in the map-areas, between Thames and Cowie Creeks and locally along Englishman River, are sub-till gravels, silts, and sands with local peaty beds. Possibly these materials are stratigraphically equivalent to the Quadra sediments, but as yet the successions in which they are found have not been correlated with the 'standard' succession of which the Quadra is a part.

Basal 'Clay' Unit*

Overlying the Dashwood till are silts and 'clays' averaging 20 feet in thickness. They are mainly more or less massive stony marine 'clays' but include stone-free marine silts and 'clays' and basal lenses of laminated silt and clay. These deposits appear to record transition from glacial to marine conditions and to include materials derived from floating glacial ice as well as more normal marine sediments.

Laminated Clay and Silt

In most places where the contact between the Dashwood and Quadra deposits was seen, lenses of pale grey, compact, laminated silt and clay a few inches to several feet thick lie between the Dashwood till and the marine 'clay'. Typically, these deposits consist of layers a fraction of an inch to an inch thick, of silt, clayey silt, and sandy clayey silt. Lenses of pebbly sandy silt similar to the underlying till are intercalated with the better-sorted materials. No evidence has been found of drying or erosion between these laminated materials and either the underlying till or the overlying marine 'clay', but rather, both contacts are transitional. In places where the laminae are indistinct these deposits differ little from the overlying marine 'clay', except for the absence of marine shells.

Marine 'Clay' (including Glacio-marine Deposits)

The marine 'clay' of the Quadra sediments is typically a blue-grey, more or less massive, silty and clayey material that commonly contains a scattering of sand, gravel, and boulders (*see* Plates IIB, IIIA). It is compact, and where stony it looks like clayey till. Commonly, indistinct stratification can be seen on

* In such terms as marine 'clay', stony 'clay' etc., clay refers to clayey materials in general, including the following textural classes: clay, sandy clay, silty clay, clay loam, sandy clay loam, silty clay loam (*see* U.S. Dept. Agriculture Handbook No. 18, p. 209).

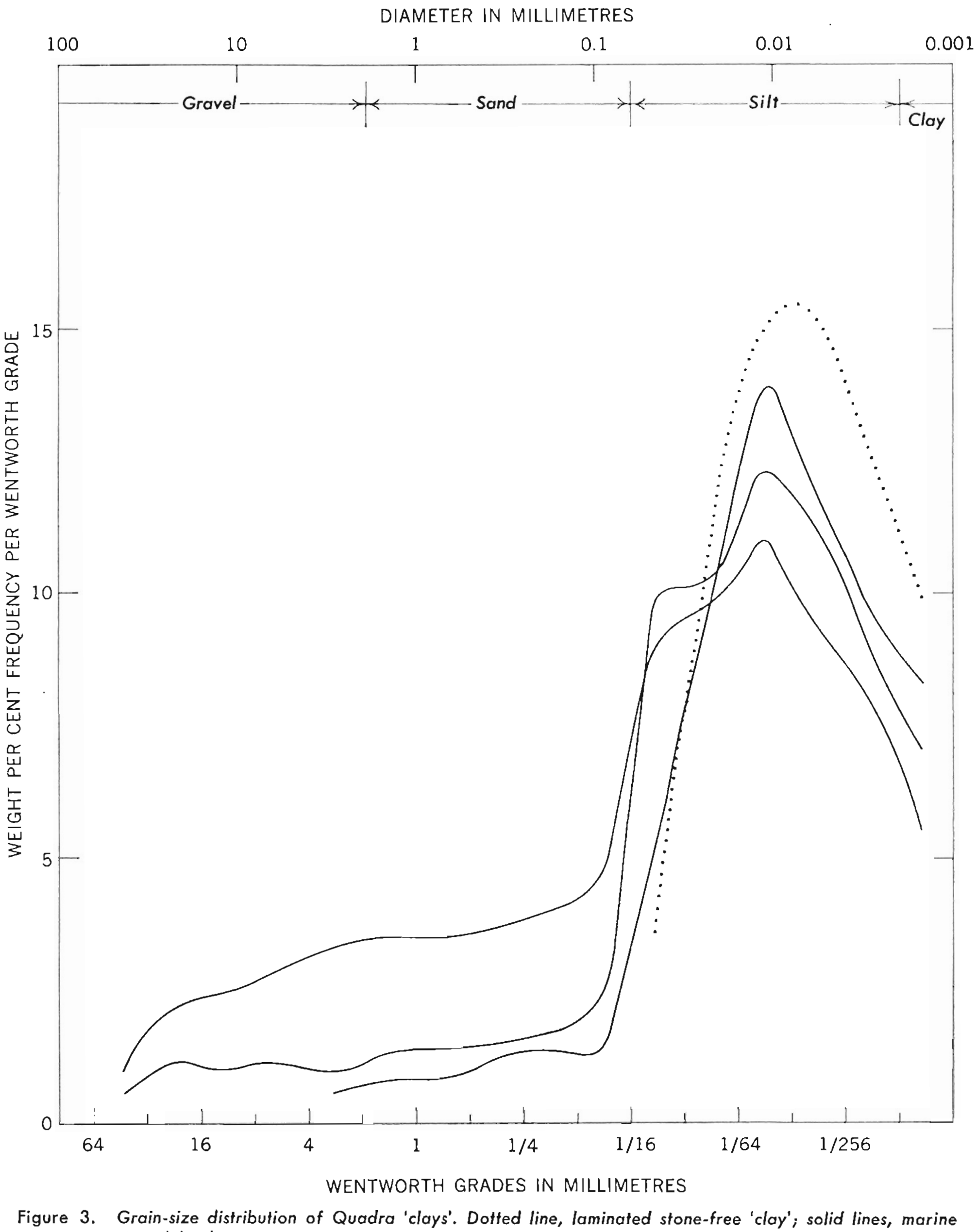

Figure 3. *Grain-size distribution of Quadra 'clays'. Dotted line, laminated stone-free 'clay'; solid lines, marine stony 'clays'.*

cliff faces when viewed from a distance, although only rarely is there any sign of bedding in hand specimens. The bedding planes are outlined by layers of pebbles or shells and by slight differences in mechanical composition that give rise to discontinuities on drying.

Although the marine clay and stony clay have the consistency and appearance of clay, the three samples for which mechanical analyses have been made are poorly sorted clayey silts with a modal diameter of 0.01 mm and containing 40 per cent or less of clay-size material. Their sorting coefficients range from 4.5 to 7.0. Average stony clay contains 5 to 10 per cent of sand- to boulder-size material. The grain-size curves (*see* Fig. 3) for the three analyzed samples illustrate the distinction between the clay-silt matrix, represented by the modal part of the graphs, and the admixed coarse material. Despite differences in the sand and gravel content of the three analyzed samples, the clay-silt matrices are similar to one another and to the one sample of the underlying stone-free laminated clay, as illustrated by their almost identical modal diameters. Pebbles in the stony clays at Dashwood and near Mapleguard Point include about the same proportion of granitoid and volcanic types as those of the underlying till, but are more angular.

Shells of marine molluscs and hard parts of a few other types of marine invertebrates are present in almost all known unoxidized exposures of these clays. They are numerous in some places and rare in others, and seem to be as abundant in the most stony materials as in those that are stone-free. The shells are typically unbroken, many pelecypod shells are paired or even closed in their growing position, and barnacle and *Serpula* shells have been found attached to stones.

The marine clays rest conformably upon the laminated clays in some places and upon the Dashwood till in others. Their upper contact with the plant-bearing silt-gravel unit of the Quadra sediments is in part gradational and in part erosional. On Denman Island a few miles north of the area the upper contact of the clays is horizontal, like the basal contact, and is gradational rather than erosional. For instance in one exposure the uppermost few feet of marine material is almost stone-free, becomes progressively more silty, and is marked by a succession of pale greenish bands from which the calcareous shell materials have been removed by leaching and which appear to be incipient soils. On the Dashwood sea cliff the stony clay ranges from zero to 80 feet in thickness and the upper contact forms hills and hollows similar to, but only partly conforming with those of the bottom contact. Parts of this upper contact at Dashwood are transitional but parts are veneered with lag concentration of gravel and boulders like that on the present erosional beaches of the region. In the highway exposure just east of Chef Creek (*see* Fig. 1, locality 5), the Dashwood till is overlain by a few feet of indistinctly stratified and stone-free silt and clayey silt containing abundant marine pelecypod shells and rare spruce cones. These clays grade laterally into sand and silt containing driftwood, as described in connection with the plant-bearing beds of the Quadra sediments (*see* Fig. 4).

Organic Remains

Collections of marine shells from the Quadra clays at Dashwood, Mapleguard Point, Chef Creek, and Denman Island are described by Wagner (1959). These collections comprise 17 species, most of which are molluscs and none of which is extinct. The assemblages present in the larger collections are comparable to the assemblages living today in the southern part of the Bering Sea. They include no forms that are exclusively littoral, and appear to represent an epineritic environment.

Origin

The clays of the Quadra sediments record an interval of marine submergence during and following the disappearance of the Dashwood glacial ice. The stone-free marine clays appear to be normal shallow-sea bottom muds and some of them, grading upward or laterally into plant-bearing beds, record a transition towards littoral conditions. The stony clays, although till-like in appearance, are interpreted to be primary marine deposits because of the unbroken condition of the contained marine shells, because they are locally stratified, and because they commonly grade upward into stone-free marine clay or into plant-bearing strata. Nonetheless, the admixture of stones and sand with the silt-clay matrix, and the clear distinction of the matrix from the coarse fraction seem to indicate that the conditions of deposition were complex and that the component materials came from two separate sources. Such mixtures could result from submarine landslides or from mixing of normal sea-bottom muds with gravelly material dropped by floating debris or floating ice. In addition, stony muds are found—and apparently are forming—in the low-tide zone along parts of the present shore of Vancouver Island. The stony clay of the Quadra sediments is much thicker than these modern intertidal muds (10 to 80 feet as opposed to 1 foot to 3 feet) and the marine fossils in the Quadra clays include only rare intertidal forms. The Quadra stony clays contain no slump structures and the random distribution of the large stones in the clays cannot be explained by slumping. The formation of the stony clay is therefore ascribed to mixing of rafted stones and sand with sea-bottom mud, and, on account of the size and quantity of stones involved, the rafting agent must have been floating ice rather than floating logs or other debris. The rafting may have been done by bergs derived from glacier tongues or floating ice shelves or by sea ice. In view of the above, as well as the close association of the basal Quadra clays with the Dashwood till, it is inferred that at least some of the stony clays are glacio-marine and that the marine body in which they formed was bordered in part by the waning Dashwood glacial ice.

The origin of the basal lenses of laminated clay and silt is a matter of conjecture. They may be marine, like the overlying materials, or may be glacial meltwater deposits associated with the underlying till. Similar materials occur higher in the stratigraphic succession of the region along the contact between the till of the Vashon drift and marine clay of the Capilano sediments. It is suggested (*see* 'Capilano Sediments') that these younger laminated materials formed in a narrow zone of fresh water beneath the marginal part of a glacier bordered by the sea where the floating part of the glacier met the grounded part.

Little is known of the extent of the submergence associated with the Quadra clays. The known deposits are all less than 150 feet above the present sea-level, although a local pocket of marine silt and clay on Englishman River, which probably correlates with the Quadra clays, is 250 feet above present sea-level.

Plant-bearing Silt-gravel Unit

Nature of Deposits

Silt, gravel, and sand containing driftwood and peaty beds lie on the Quadra clays. These deposits range from a few feet to 40 feet in thickness and are exposed in the six localities marked on Figure 1 as well as near the head of Nanoose Bay. The brownish colour of the peaty beds and the greenish and rusty-orange colour of many of the associated sediments are distinctive.

The silts are compact, generally well sorted, and form horizontal beds a few inches thick. One sample from Denman Island that has been subjected to mechanical analysis has a median diameter of 0.011 mm and a sorting coefficient of 1.98. Two samples of silt from Denman Island—one green and the other brown—have been examined microscopically; both contain a remarkably large proportion of epidote, chlorite, and green cryptocrystalline material. The gravels typically are horizontally stratified and consist of well-rounded, well-sorted pebbles mixed with a subordinate amount of sand. Most of the component stones are volcanic but a few per cent are granitic; pebble counts are similar to those of the underlying till and stony clay. In a few places, the unit includes basal, poorly sorted cobbly gravel that appears to be a lag concentrate of stones from the subjacent till or stony clay. The sands of the plant-bearing unit occur as thin beds among the more common silts and gravels, and range in texture from coarse to very fine. Beds of hard, wood-like peat and of softer peaty soil are intercalated with the mineral sediments as layers a fraction of an inch to a few feet in thickness. The peaty soils consist of a mixture of finely divided organic matter with silt or, less commonly, coarser sediments. Twigs, branches and roots occur in the gravels, in some of the peaty beds, and locally in silt or sand. A few silts and sands contain imprints of leaves and thin 'mats' of fine woody detritus. (A more detailed account of the organic components of the plant-bearing unit is given on page 27).

The colours of the sediments in the plant-bearing unit are distinctive and apparently are related to the associated plants and plant materials. The yellow-green-to-olive colour of many unoxidized beds (Munsell colour chart designation 5GY 5/2, 10Y 6/2) is restricted to beds containing buried plant materials, whether peat, peaty soil, leaf accumulation, or driftwood. This colour is probably due to the presence of ferrous iron compounds formed by the reducing action of (or associated with) the plant materials, both during the existence of the boggy environment in which they were deposited and after burial beneath the overlying sediments. Most gravels and sands associated with the peaty beds are rusty-orange and some of the green silts are mottled with the same colour. This colour is partly the result of recent oxidation of green materials, although in gravel and sand beds beneath peaty layers it probably developed through soil-forming processes during deposition of the peaty materials. Peats, peaty soils and other layers containing plant materials are characterized by yellow-brown to olive-grey colours (Munsell colour chart designation 10YR 4/2, 5Y 5/2) that are unlike the colours of other brownish sediments of the area and which provide a reliable basis for recognizing sediments containing finely divided vegetable matter. Beneath some of the peat and peaty soil layers and in each of the incipient soil profiles of the Denman Island section outlined above, are ashy-white layers an inch or so in thickness. Microscopic examination of samples of the white materials revealed no concentration of diatoms and no mineralogical peculiarities that would account for the colour. The white materials probably are bleached (reduced) or leached (podzol) layers like those in some modern organic soil profiles.

Stratigraphic Successions

The appearance of the plant-bearing unit and the nature of the component sediments are uniform throughout the area but the sequence of beds within the unit varies from place to place. The four measured sections given below illustrate the nature of the unit in the Dashwood sea cliff, where it ranges in thickness from 10 to 40 feet. In each exposure the plant-bearing unit rests on stony clay and is covered by thick white sand. The lower contact is transitional in some of these sections and erosional in others; the upper contact is everywhere transitional.

Exposure 4, Dashwood Cross-section	*Thickness*
Silt, horizontally stratified	3′
Sand, medium-grained	1′ 6″
Covered	4′
Pebble gravel, fine-grained, well-sorted, rusty	2′
Silt, fine sand, *peaty* partings	9″
Pebbly sand, coarse-grained, silty partings, rusty	4′
Pebble-cobble gravel, well-sorted, indistinctly stratified; includes silty sand lenses with *twigs*	7′

Exposure 18, Dashwood Cross-section	
Sand, very fine, brown and *peaty*	6″
Sand, very fine, black and mottled	1′ 6″
Covered	1′
Pebbly sandy silt, brown, *peaty*	1′
Pebble gravel, rusty	3′
Gravelly silty sand, greenish	2′

Exposure 20, Dashwood Cross-section	
Silt with *leaf* imprints, *peaty* partings, flattened *twigs*	5′
Gravel, rusty in upper part, green in lower part; lateral change from stratified fine pebbly gravel to cobble-boulder lag concentrate	5′

Exposure 28, Dashwood Cross-section	
Silt containing *twigs*	1′
Peat containing *twigs*; includes peaty sand layers and pebbles at the base	3′ 4″
Pebble gravel, horizontally stratified, crossbedded	34′

Southeast of Dashwood, similar peat-bearing successions are exposed at two places on French Creek (Fig. 1, locality 1) between sand and stony clay.

In the upstream exposure, 1½ feet of peaty silt is underlain by 3 feet of rusty pebble-gravel; and in the downstream exposure, 1 foot of grey silt rests on 2½ feet of brownish silt with peaty and pebbly partings. West of the Dashwood sea cliff on Qualicum River (Fig. 1, locality 3) the peaty unit is represented by 10 inches of brown, silty, peaty soil underlain by 10 feet of rusty, crossbedded, pebble and cobble gravel with two peaty partings.

The plant-bearing silt-gravel unit of the Quadra sediments is well exposed a few miles north of the map-areas on Denman Island (Plates IIIA, IIIB). The thickness of the unit there ranges from 8 to 35 feet. One of the more complex successions through the unit, between stony clay and white sand, is as follows:

	Thickness
Silt	1′
Silt and fine sand, laminated	14′
Silty sand and fine sand with brownish *organic (?) partings*, laminated	2′
Peaty silt	3″
Silt, greenish	1′ 6″
Pebble gravel, rusty	4′
Silt, greenish to brown	1′
Silty *peaty* soil	3″
Silt	3″
Pebble gravel and coarse sand, rusty	5″
Clayey silt, green, massive	2′
Silty *peaty* soil	2″
Silt, green, massive	2′ 6″
Silty *peaty* soil	2″
Silt, green, massive	4′
Clayey silt, greenish, massive, pebbly	3′

Near the northwest end of the Denman Island exposures, the plant-bearing unit clearly grades upward from the stony clay, as illustrated in the following succession.

Erosional Surface	*Thickness*
Silt, greenish and white with brownish *peaty* layers	2′
Pebble gravel, rusty, horizontally stratified	3′
Silt, pale greenish, contains three brown *peaty* layers	8″
Silt; greenish, pale grey and white horizontal bands outline three incipient soil profiles. Casts of marine shells in lower part	6′
Stony clay, blue-grey, contains marine shells.	

A cut on the Island Highway east of Chef Creek (Fig. 1, locality 5) exposes Dashwood, Quadra, Vashon, and marine Capilano deposits in a succession only 30 feet thick. As shown in Figure 4, intertill (Quadra) sand and silt dip away from a small knob of Dashwood till extending just above the road level. The beds resting directly on this till are clayey silts containing marine shells and rare spruce cones. These shell-bearing beds wedge out to the west and grade upward into fine and then coarse sand. To the east, both the shell-bearing silty beds and the overlying sand grade laterally into thin-bedded silt and fine sand with numerous driftwood layers. These last are continuous beds a fraction of an inch thick, consisting of

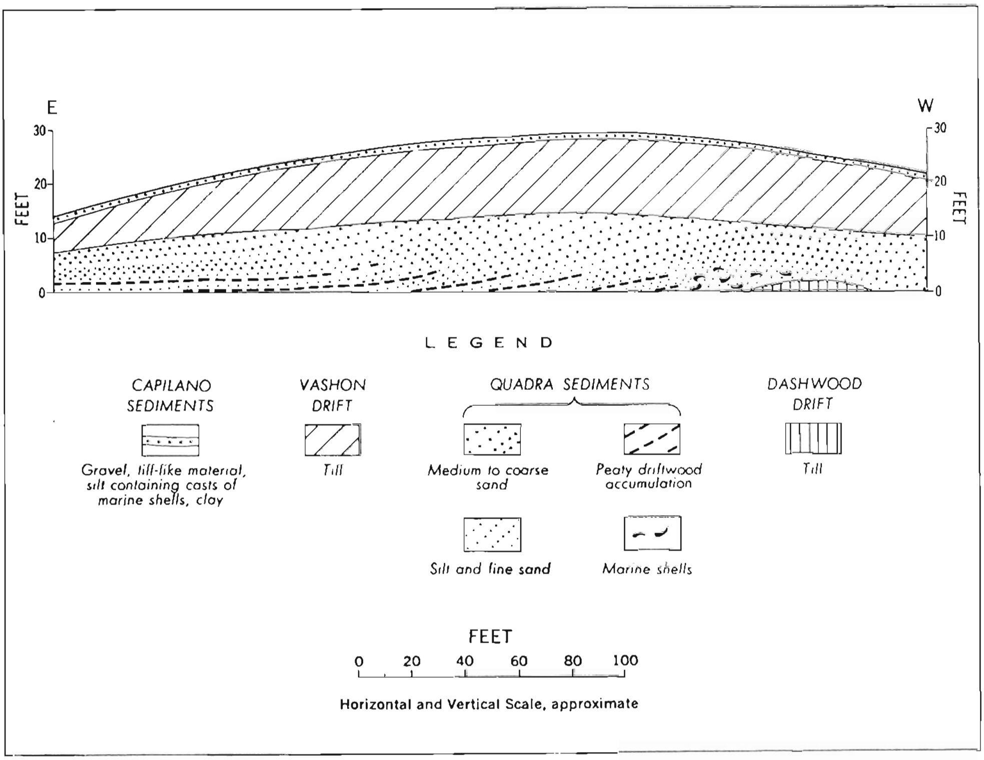

Figure 4. *Sketch of cut-bank, south side of Island Highway, ¼ mile east of Chef Creek, Horne Lake map-area.*

mats of small twigs, needles of conifers, and tiny (apparently abraded) wood fragments. Scattered within the woody mats are sticks up to 3 inches in diameter and several feet long. These plant-bearing beds are tentatively correlated with those described above at Dashwood, Denman Island, etc.

Organic Remains

The peaty materials of the plant-bearing silt-gravel unit of the Quadra sediments consist essentially of finely divided plant material mixed with a small to large proportion of mineral sediment. The peats, which contain little mineral material, are dark brown, hard, and wood-like, and have sometimes been mistakenly called lignite. Peaty materials containing appreciable admixtures of mineral matter are softer and paler in colour and are here referred to as 'peaty soils'. Parting planes in peats and in some peaty soils bear the imprints of grasses, sedges, mosses, seeds and locally of insects. One thin peat bed on Denman Island consists of a carpet of moss in its growing position. Flattened branches, stems, and roots of woody plants are present in most of the peaty beds but only locally are they abundant. Although the ends of most of the sticks are broken, bark is commonly intact and the broken ends show no sign of abrasion.

The peaty soils and associated materials constitute fossil organic soils in the pedological sense. Some such soil profiles, consisting of a layer of peaty material underlain by a thin layer of whitish mineral soil, probably are groundwater podzols. Others in which the mineral soil beneath the peaty layer is greenish or rusty-orange may be glei soils whose characteristic colours have been modified since burial, although some rusty material beneath peat may reflect an original soil colour.

Pollen analysis of the peaty materials thus far has proved disappointing, but abundant and varied pollen is present in some of the driftwood-bearing silts. Most of the peats and peaty soils studied so far (J. Terasmae, personal communication) contain few pollen grains; in some, the pollen that is present is too poorly preserved for identification and in others only pine pollen and fern spores are present. A peaty soil near the base of the silt-gravel unit on Denman Island has yielded an abundance of non-arboreal pollen (mostly fern spores) and rare grains of pine, spruce, and fir (Abies) pollen. A higher peat bed at the same place contains pollen of pine and spruce in moderate abundance and rare grains of pollen derived from fir (Abies), alder, and non-arboreal plants. Silty driftwood 'mats' from the Island Highway cut near Chef Creek (Fig. 1, locality 5) have yielded much pollen, principally of coniferous forest trees. Pollen of pine, western hemlock, and spruce is abundant, and pollen of fir (Abies), alder, birch, mountain hemlock, yellow cedar (?), and various non-arboreal species is present in small amounts. The trees represented in this assemblage all grow at present on Vancouver Island, but the assemblage, lacking in Douglas fir and with abundant spruce, is more typical of the lowland coastal forests bordering the Gulf of Alaska than those of Vancouver Island, and thus appears to record a climate somewhat cooler than the present one.

Mode of Deposition

The plant-bearing silt-gravel unit of the Quadra sediments appears to have originated in a swampy coastal lowland during, and probably following a regression of the sea in which the underlying marine clay had accumulated. A succession of intercalated silts, gravels, sands, and peaty (bog) deposits such as this could accumulate either in the channels, flood plains, and back-swamps of a river plain, or in the bars, dunes, lagoons, and marshes along a shelving shoreline. Both environments appear to be represented in these deposits. Thus, in some places the silt-gravel deposits grade laterally or vertically into the Quadra marine clays and are clearly of marine-shore origin. Other deposits that have not yielded remains of marine organisms and do not grade into marine beds probably were deposited along streams extending back from the seashore across the emerged sea-bottom plain.

Sand Unit

The upper unit of the Quadra sediments typically consists of distinctive white sands that locally exceed 250 feet in thickness. These sands are well sorted,

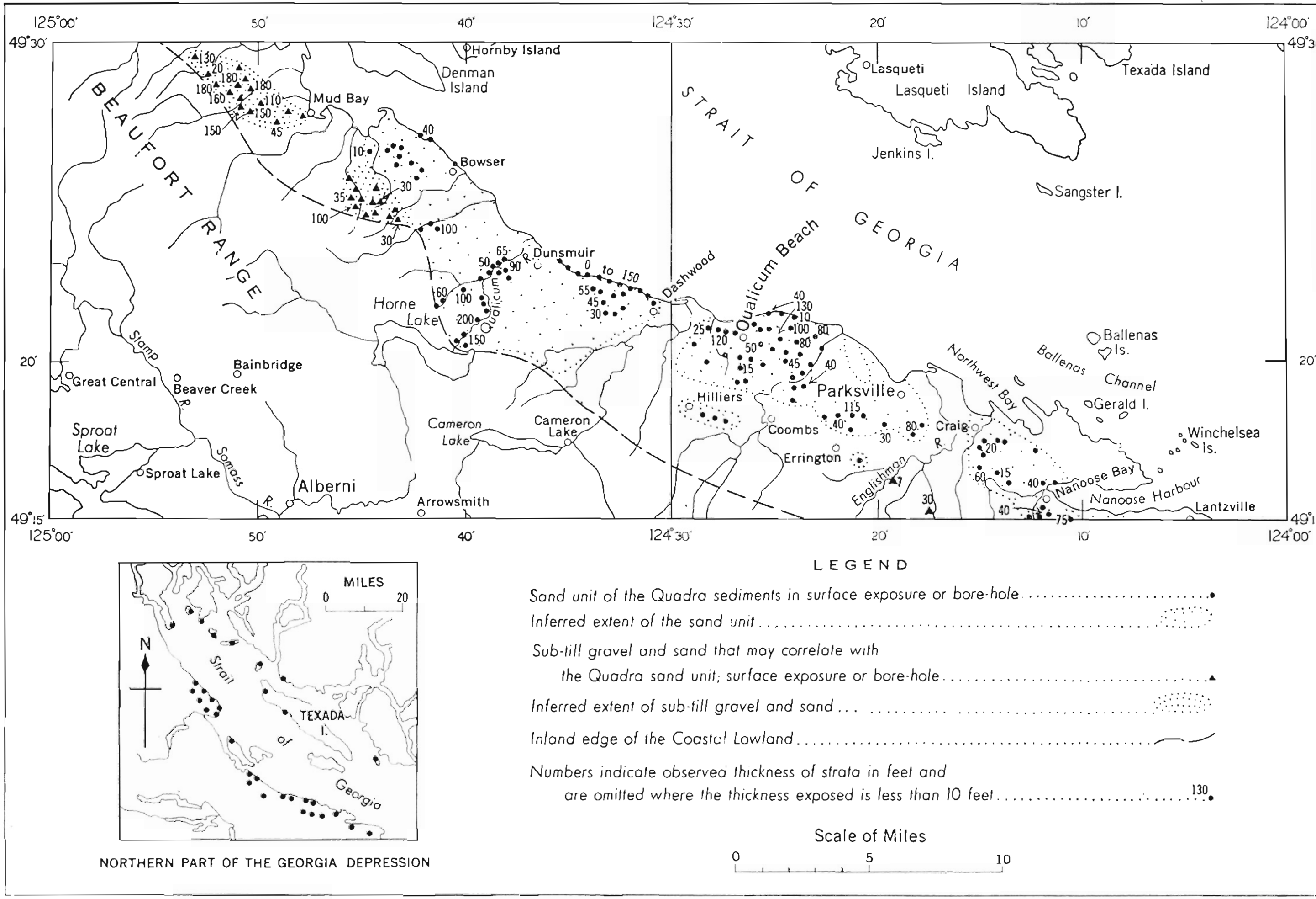

Figure 5. *Distribution of the sand unit of the Quadra sediments and of sub-till gravel and sand that may correlate with the sand unit, Horne Lake and Parksville map-areas; and the main occurrences of the Quadra sand unit in the northern part of the Georgia depression.*

horizontally stratified and extensively crossbedded, and are remarkably uniform. Locally the sand unit includes gravel beds and plant-bearing silts. The Quadra sand unit is widely distributed through the coastal part of the map areas, as shown in Figure 5. It forms prominent white cliffs along rivers and the seashore where erosion has penetrated below the base of the Vashon till; in addition, it occurs at the surface or below a few inches of lag gravel where wave action along former higher seashores has removed the overlying till.

In practice, any thick white horizontal sands beneath till have been assigned to the Quadra sediments unless other evidence suggests that they belong in the Mapleguard sediments. Similar sands not covered by till may be Quadra deposits uncovered by erosion or marine or deltaic deposits of the Capilano sediments derived from sands of the Quadra sediments. The distinction of Quadra sands from Capilano sands in such circumstances is aided by (1) the strictly horizontal attitude of sands of the Quadra sediments in contrast to the undulating or fore-set stratification of the Capilano deposits, (2) the local presence of marine shells or shell casts in Capilano sands, and of plant-bearing beds in the Quadra, and (3) the presence on sands of the Quadra sediments of a lag veneer of stones (particularly boulders) left during erosion of the Vashon till; large stones are rarely found on the surface of marine Capilano deposits.

Materials

The typical and most abundant constituent of the sand unit of the Quadra sediments is well-sorted, fine- to medium-grained sand occurring as white to pale grey beds a fraction of an inch to a foot in thickness, intercalated with thinner, darker grey beds. Five analyzed samples of these typical sands have a median grain size ranging from 0.12 to 0.2 mm and a sorting coefficient between 1.2 and 1.5. The individual sand grains are angular to subangular and typically are clean, without clay coatings or stain. In the paler-coloured beds, about half the grains are feldspar; one quarter are quartz, and one quarter are dark minerals, principally hornblende, magnetite and biotite. In the darker beds, hornblende and magnetite are more abundant, and a few thin beds of 'black sand' contain as much as 75 per cent magnetite. Rock grains are rare in all samples that have been examined. Cummings, in making a mineralogical study of the sands of the Strait of Georgia region while investigating silica sand, has noted (1941, p. 3) that most "bank sands" (Quadra sediments) around the northern part of the Strait of Georgia "consist essentially of plagioclase and quartz, with lesser amounts of other minerals. The constituents of this group are present in proportions approximating those of quartz diorite. All the accessory minerals, with the exception of topaz, tourmaline, kyanite, and phlogopite, have been reported in Coast Range batholithic rocks."

Associated with the fine sands in many places are coarse sands and pebbly sands of similar appearance and constitution. In a few places beds of clean pebble-gravel are also present. Thin beds of greenish, plant-bearing silt and peaty silt very like those of the underlying silt-gravel unit are locally intercalated with the sandy strata. Northwest of the area, and locally within it, the Quadra sand unit includes beds of distinctive coherent sandstone-like material that is commonly pinkish, pale brown, or chalky-white. This material is a medium to coarse sand in which clay coats the grains and partly fills the voids between them. Many of these clay-bonded sands contain isolated pebbles and lenticular concentrations of coal and mica fragments.

Bedding planes within the sands of the Quadra sediments almost everywhere are horizontal and are traceable for long distances on cliff faces. Lenticular and tabular crosslamination is abundant in all but the clay-bonded sands, but as yet, no consistent pattern of the dip direction of crosslaminated units has been recognized. In a few exposures, erosional contacts can be seen cutting across several tens of feet of strata within the sand succession.

Field Relationships

Most cliff exposures of the Quadra sand within the area are near the coastal edge of the lowland and some distance from the mountain front. In these coastal exposures the sand unit consists of fine- to medium-grained sand with only rare interbeds of coarse-grained and pebbly sand, and where the base of the unit is exposed it rests conformably upon the plant-bearing silt-gravel beds. Farther from the coast (that is, nearer to the mountains) the sand succession includes a larger proportion of coarse and pebbly sands and pebbly gravels, and in the few places where the base of the unit has been seen, the sand rests directly upon bedrock. The coarsening of the sand unit from coast to mountain front is particularly evident in the exposures bordering Qualicum River. Between Nile and Cowie Creeks, the part of the coastal lowland adjoining the mountain front is underlain by sub-till gravels, sands and silts rather different from the materials typical of the Quadra sand unit. Possibly these materials record a further textural change of the Quadra sand unit like that outlined above, but as yet no basis has been found for correlating them with the Quadra sands.

A pit at the junction of the Alberni Highway with the Errington road exposes about 40 feet of well-sorted pebble-gravel beneath remnants of till. The gravel, whose full thickness is not known, has been assigned to the Quadra sediments and the overlying till to the Vashon drift. Stones in the gravel are 75 per cent volcanic, 20 per cent granitoid, 1 per cent sandstone and shale, and include isolated pebbles of quartz, chert, quartzite, and white-weathered honeycomb rock of a type seen in the Permian strata along Horne Lake. The horizontally stratified, crossbedded gravels are intercalated with a few beds of clean sand, and, in the eastern part of the pit, the upper 10 feet of gravel is replaced by sand. Shallow excavations both east and west of the gravel pit encountered typical Quadra sand, and a well-boring less than a ¼ mile to the east intersected only 10 feet of gravel 40 to 50 feet below the surface within a 115-foot section of sand. (Data provided by J. Rainsford, Pacific Water Wells Limited.) Thus, the gravel in the Errington pit probably is of no great extent; it may well be a river-channel deposit within the sands.

Organic Remains

In the upper part of the gravel succession in the western part of the Errington pit is a lens 4 feet thick and 10 feet long of greenish sandy silt, bearing imprints of twigs and grasses. Within the boundaries of the map-areas, this lens is the only known occurrence of plant-bearing materials in the sand unit of the Quadra sediments. On the other hand, plant-bearing strata are widely distributed in these sands elsewhere, as on Willemar Bluff near Comox, 10 miles northwest of the area (*see* Plate IV). The nature of the forest succession represented by the plant material within the sand unit of the Quadra sediments of Vancouver Island remains a subject for future study.

Distribution

The upper surface of the Quadra sand unit (contact with the Vashon till) is erosional, so that direct observation of the original extent and the depositional form of the sands has not been possible. The sands now occupy about one third of the coastal-lowland part of the map-areas (*see* Fig. 5) and are widely distributed elsewhere in the Georgia depression. Their patchy distribution is controlled partly by hills and hollows of the surface upon which they lie, partly by erosion along their contact with the Vashon till, and partly by irregularities in the present ground surface. Despite this patchy occurrence, the sands are remarkably uniform. For instance, on Willemar Bluff near Comox, where the sands are exposed continuously for $\frac{3}{4}$ mile, the strata throughout the full length of the cliff are horizontal and uniform in character. The Quadra sand unit displays similar uniformity and continuity on Komas Bluff of Denman Island, on the Dashwood sea cliff, and along Qualicum River. In each of these localities the sands have been traced through closely spaced exposures for about 3 miles. Nowhere is there any evidence that the sands were originally deposited as isolated or local bodies, but rather it appears that they originally were much more extensive than now.

Source

The sand unit of the Quadra sediments consists in part of locally derived material and in part of far-travelled material that apparently came from the Coast Range. The gravel within the Quadra sand unit and some constituents of the sand itself consist of rocks and minerals that may have been derived locally from the Nanaimo Group and from the dominantly volcanic 'basement' rocks of Vancouver Island. Moreover, the decrease in abundance of gravelly beds in the sands with increasing distance from the front of Beaufort Range supports this inference. On the other hand, the main bulk of the sand, consisting of minerals typical of a granodiorite terrain, cannot have come from any nearby source. The most likely source is the Coast Range granodiorite around the head of the Strait of Georgia to the northwest.*

Origin

The sand unit of the Quadra sediments clearly is a fluvial-plain deposit. In no other environment would it be possible to accumulate this thick, horizontal, widespread, uniform sand—characterized by cut-and-fill structures, containing beds of gravel and plant-bearing silt, and composed to a large extent of far-travelled debris from the Coast Range.

Evidence bearing on details of the fluvial environment is less definite. Thus, the sands may have accumulated as a series of broad, flat, coalescent fans or may have resulted from progressive fluvial filling of a lake or lakes or an arm of the sea. If bodies of standing water were involved, the horizontal sands could not have been built outward as in a normal delta but rather accumulated by progressive upward building of the river plain, as if in response to rising water-level.

The present distribution of the Quadra sand unit as more or less separate bodies around the northern part of the Strait of Georgia and on islands within the strait (*see* Fig. 5) might be interpreted as suggesting that the sands accumulated as ice-contact or outwash deposits. If, however, the sands relate to the preceding Dashwood glaciation, large remnants of the Dashwood ice must have persisted throughout deposition of the marine stony clay, throughout the ensuing lowering of sea-level that accompanied accumulation of the plant-bearing silt-gravel beds, and during the period of upbuilding of the sands; such persistence of remnant ice seems most unlikely. A more reasonable possibility is that the sands accumulated as successive outwash fans along successive positions of the margins of glaciers advancing into and along the Georgia depression, during the onset of a period of glaciation. Nonetheless, proof of association of the sands with advancing glaciers has yet to be found, and it is quite possible that glaciers did not extend into the Georgia depression during the interval of sand accumulation. If not, the sand probably was deposited as a continuous fluvial-plain or estuarine complex that occupied the full width of at least the northern part of the Georgia depression. The volume of sediment in such a plain would have been exceedingly large, and much of it would have to have been eroded away before the Vashon till was spread across it.

Deposits that may Correlate with the Quadra Sediments

Parts of the coastal lowland adjoining the mountain front are underlain by thick strata that have not yet been correlated with units of the 'standard'

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* Since this report was written, numerous measurements have been made of the trend of miniature channel beds in the Quadra sands of the coastal lowland of Vancouver Island and on some of the islands within the Strait of Georgia. These channel beds record currents that flowed south-southeast across the northwestern part of the Georgia depression and southeast along the Vancouver Island side of the depression. The direction of these currents lends support to the inference, based on the mineralogy of the sands, that the main bulk of the sands come from a source on the mainland rather than on Vancouver Island.

succession. Among these deposits are gravels, sands, and silts that lie beneath till and locally contain peaty beds; these may be equivalent to the Quadra sediments.

The most extensive deposits of this sort lie beneath a few feet of till throughout much of the area between Rosewall and Cowie Creeks (*see* Fig. 5). They consist mainly of well-sorted pebbly gravel intercalated with sandy gravel, but also include layers of sand and silt that locally contain plant remains. Cutbanks along the valleys of Waterloo and Wilfred (Coal) Creeks expose up to 150 feet of these materials. Exploratory bore-holes drilled for Canadian Collieries (Dunsmuir) Limited between Wilfred and Cowie Creeks encountered up to 180 feet of gravel and sand, and a bore-hole between Waterloo and Rosewall Creeks intersected 440 feet of dominantly gravelly material. Stratigraphic sections illustrating the nature of these materials are given below; deposits that may correlate with the Quadra sediments are marked with an asterisk.

		Thickness (feet)
1. East branch of Waterloo Creek, 1.1 miles from E. and N. Railway. Elevation at top 520 feet.		
	Till	10
*	Pebble-cobble gravel	10
*	Silt, sand, and fine pebble gravel	15
*	Rusty silt and fine sand, thin *peat* bed, casts of *wood* and *leaves*	12
*	Covered	6
*	Fine pebble gravel	6
2. Waterloo Creek, west bank, 1.1 miles from E. and N. Railway. Elevation at top 480 feet.		
	Delta gravel	25
	Till	5
*	Silt, sand, pebble gravel	18
*	Incomplete exposures of pebble gravel and coarse sand; beds dip down the valley	90
	Sandy till and cemented gravel	20
	Covered to stream bed	80
3. Waterloo Creek, west bank, 1.5 miles from E. and N. Railway. Elevation at top 620 feet.		
	Till	10
*	Incomplete exposures of well-sorted pebble gravel and sand	150
	Till, silty to pebbly	10
	Silt, fine sand, pebble beds	25
	Pebble gravel	20
	Covered	40
	Sandstone	—
4. Wilfred Creek, west bank, 1.5 miles from E. and N. Railway. Elevation at top 550 feet.		
	Till	10
*	Small exposures of clean pebble-gravel and sand	100
*	Silt	2
	Covered	150
	Till	30
	Sandstone	—

5. Wilfred Creek, west bank, 1.3 miles from E. and N. Railway. Elevation at top 550 feet.

	Thickness (feet)
Till	3
* Incomplete exposures of clean pebble-gravel with sandy interbeds; bedding lenticular	85
* Silt-filled gravel; beds dip up the valley	10
* Slump slopes of sand and pebbles (in place?)	55
* Laminated silt and sand with pebble-gravel interbeds; *wood* imprints and ½-inch *peat* bed†	20
Cemented bouldery gravel and sand; poorly sorted; bedding inclined	50
Covered	165
Shale	—

Along the upper part of Chef and Thames Creeks, cut faces and gullies expose up to 100 feet of pebble gravel, sand, and silt beneath a few inches to a few feet of till. In many places, the overlying till is so thin that it is completely broken up in the soil profile. On the steep-gullied slope where the main branch of Chef Creek reaches the base of the mountain slope, stratified gravels, sands and silts blanket the steep rock-face through a vertical range of 400 feet. Till overlies these deposits in only a few places and it has not been possible to determine whether all of these materials were once covered by till or whether some of them were formed later than the till as ice-contact deposits. The sub-till deposits are typically well sorted and regularly horizontally stratified. Stones comprising the gravels are of pebble- to small-cobble size and most are well rounded. Most consist of the ubiquitous green volcanic rocks although a few are sandstone or granodiorite. The sands resemble typical white sands of the Quadra sediments. The Quadra sediments nearest to these deposits—along Nile Creek—contain numerous gravel beds, and possibly the sub-till gravelly deposits along Thames and Chef Creeks are a still more gravelly phase of the Quadra. However, parts of the sub-till surface (as reflected by the present ground surface) bear small, shallow, closed depressions. The depressions may be modified kettle holes, and if so, the sub-till deposits probably should be correlated with the Vashon drift rather than the Quadra.

Very local sub-till peaty sands and silts that have been found in two places along the Englishman River system probably are equivalent to the Quadra sediments. Two miles down Englishman River from the falls the following strata form a lens about 200 feet long between shale and till.

	Thickness (feet)
Gravel, poorly sorted, stones to boulder size	10
Sand and silt, thin-bedded, rusty, thin brown *peaty partings* on fresh surfaces	7
Clayey silt and sandy silt with marine shells	6
Laminated silt	2
Blocky till-like rubble composed of broken shale and cobbles of volcanic rock	10

† Peat from this bed has a radiocarbon age of greater than 37,600 (GSC-78). On the basis of this date, the enclosing deposits appear to be older than the plant-bearing unit of the Quadra sediments.

This lens appears to be an erosional remnant of a much more extensive deposit and probably owes its preservation to the sloping face of shale against which it rests. The peaty sand and silt and the underlying marine and laminated clays may correlate with the Quadra sediments. Beneath the Northwest Bay Logging Company trestle over the south fork of Englishman River is a 30-foot section of similar rusty sands and silts with numerous thin peaty partings. These materials butt into an almost-vertical rock-face and are covered by 70 feet of till. The sub-till strata are exposed for only a few feet and certainly lense out within 200 feet. Sand and gravel rather than marine beds underlie the peaty beds in this locality. The peaty materials in both of these Englishman River localities consist of tiny woody flakes and probably are thoroughly comminuted driftwood.

Correlation

Sub-till sands and gravels like those of the sand unit of the Quadra sediments in the map-areas are widely distributed around the Strait of Georgia. They are exposed at intervals along the coastal lowland of Vancouver Island from Campbell River to Victoria. At Victoria they have been called 'the Cordova sands and gravels' and have been assigned to the Puyallup interglacial epoch (Clapp, 1913, p. 110). 'Quadra type' sands are abundantly represented on the islands of the northern part of the Strait of Georgia and particularly on Thormanby, Texada, Harwood, Savary, Hernando, Cortez, Marina, and Quadra Islands (Dawson, 1887; LeRoy, 1908; McConnell, 1914). Sub-till sands and gravels underlie large parts of the city of Vancouver and the Lower Fraser Valley; some of these have been assigned to the Quadra and some to a younger unit called the 'Semiamu' (Armstrong and Brown, 1953). Marine stony clay (Clapp, 1913) and peat-bearing silts and gravels lie beneath the Cordova sands and gravels in the region around Victoria at the south end of Vancouver Island, and clays containing marine shells have locally been encountered beneath the sub-till sands and gravels of the Lower Fraser Valley (Armstrong and Brown, 1953; Armstrong, 1956a).

Correlation of these materials can be based only on similarities of lithology and on their position beneath a till sheet. However, sub-till sandy strata are not confined to the Quadra sediments, but occur in the Mapleguard sediments in the Horne Lake area and in the Semiamu Group of the Lower Fraser Valley. The latter group is considered to lie between the Quadra and Vashon deposits (Armstrong and Brown, 1953). Definite regional correlation of the sub-till deposits throughout the Georgia depression, based on lithology, is therefore not possible. Nonetheless, the writer is of the opinion that the widespread white sub-till sands of the northern part of the Georgia depression do correlate with the Quadra sand unit in Horne Lake and Parksville map-areas.

Significance and Age

The Quadra deposits record a major non-glacial interval, within the map-areas and apparently throughout the Georgia depression. In an earlier report

(Fyles, J.G., 1956) it was suggested that this Quadra interval may correlate with the Sangamon interglacial of central North America. It now seems more likely that the Quadra was a major interstadial that was later than the Sangamon but predated the classical Wisconsin.

The clays and plant-bearing strata forming the lower part of the Quadra sediments accumulated under cool conditions, possibly like those today in southern coastal Alaska, during and following retreat of the Dashwood glaciers. This retreat cannot have been less than 60 miles—from the southernmost known occurrence of Quadra sediments over Dashwood drift to the northernmost known exposure of Quadra sediments—and probably involved complete or almost complete deglaciation. The latter conclusion is based on the observation that the lower units of the Quadra sediments record a change in the relative positions of land and sea (glacial rebound ?) of the same order of magnitude as the post-glacial emergence.

The climatic conditions that obtained during the accumulation of the Quadra sand unit remain largely unknown. The meagre evidence so far provided by pollen and leaf imprints indicates that part of the region at least was forested and suggests that the climate was cool or temperate. There is certainly no indication of conditions warmer than those prevailing today. The presence of fresh grains of readily weathered minerals in the sands indicates that chemical weathering was slow relative to both the rate of degradation in the source areas and the rate of deposition of the sands. Such sands might have accumulated rather slowly (perhaps over several thousand years) through fluvial denudation under a temperate or cool climate, or more rapidly in response to glacial activity in the mountains, or still more rapidly as advance outwash of glaciers spreading into the Georgia depression.

The development of the erosion surface that separates the Quadra and Vashon deposits probably involved a considerable interval of time. This erosion interval may have directly followed the accumulation of the Quadra sediments, and if so, it was part of the Quadra non-glacial interval. On the other hand, the Semiamu drift of Fraser Valley is considered by Armstrong and Brown (1953) to relate to a glaciation that came between the Quadra interval and the sub-Vashon erosion interval.

The Quadra non-glacial interval preceded the last regional (Vashon) glaciation which apparently was the Wisconsin glaciation of the district (using Wisconsin in the classical sense, c.f. Flint, 1957, p. 391). Hence, in the past the Quadra has been considered to be pre-Wisconsin and probably Sangamon. Recently it has been concluded that various glacial and non-glacial deposits in central North America and elsewhere are older than the classical Wisconsin (i.e. pre-Farmdale) but younger than the Sangamon (Dreimanis, 1957; Goldthwait, 1958, p. 212; Karlstrom, 1957). The Quadra deposits now appear to belong in the same category.

The conclusion that the Quadra interval is post-Sangamon was based initially upon climatic considerations: that is, the interval appears to have been a cool interstadial rather than a warm interglacial. A much more definite basis for this age assignment has been now provided by the radiocarbon dates cited below, despite the puzzling questions that arise from the dates. Marine shells from the Quadra stony clays at exposure 20 at Dashwood (Lamont dating 475B) and at Komas Bluff on Denman Island (Lamont dating 475A) have been assigned ages of more than 41,500 and more than 35,600 years respectively. Three samples of wood and peat from the plant-bearing Quadra beds on Denman Island at the same locality as the shells have radiocarbon ages of about 30,000 years (Lamont datings 424B,C,E), whereas wood and peat from the thick peat bed in the plant-bearing unit of the Quadra at exposure 28 at Dashwood have radiocarbon ages of about 25,000 years (Lamont datings 221A,B). Wood from within the lower part of the Quadra sand unit on Marina Island at the northwestern end of the Strait of Georgia has an age of about 35,000 years (Lamont dating 455B)*. The 25,000-year age of the plant materials from Dashwood leaves an unexpectedly short time for subsequent Quadra and post-Quadra events. The marked difference in age of the plant materials and marine shells at Denman Island and Dashwood is likewise difficult to explain, for on purely geological grounds it was thought that the shell-bearing stony clays and the plant-bearing beds differ in age by at most 3,000 or 4,000 years and possibly by less than 1,000 years. Resolution of these problems will have to await further datings.

Sub-Vashon Erosion Surface

The Vashon drift is separated from the Quadra sediments by a prominent erosional discordance. The crosscutting nature of the till-sand contact is clearly illustrated in the stratigraphic cross-section of the Dashwood sea cliff on Map 1111A. In the parts of the coastal lowland where a thin veneer of relatively uniform thickness is formed by the Vashon and other deposits that are superposed upon the Quadra sands, hills and valleys of the present surface reflect the Vashon-Quadra erosion surface. In other places, for instance adjacent to Little Qualicum River, valleys or depressions in the erosion surface, 100 feet or more deep, have been filled with till and later deposits.

Some of the erosion involved in this discordance certainly was accomplished by the Vashon ice. Thus, Vashon till resting on Quadra sand and to the lee of bodies of Quadra sand is much more sandy than the till elsewhere. Moreover, if

*Radiocarbon dates:

Locality	*Sample*	*Lamont Dating No.*	*Age (years)*
Denman Island	marine shells from stony clay	L 475A	>41,500
	peat from plant-bearing unit	L 424B	30,200±1,300
	wood from plant-bearing unit	L 424C	29,300±1,400
	wood from plant-bearing unit	L 424E	30,000±1,200
Dashwood	marine shells from stony clay	L 475B	>35,600
	wood lignin, plant-bearing unit	L 221A	25,850±500
	wood cellulose, plant-bearing unit	L 221A	25,900±300
	peat lignin, plant-bearing unit	L 221B	25,050±300
	peat cellulose, plant-bearing unit	L 221B	23,450±300
Marina Island	wood from lower part of sand unit	L 455B	35,400±2,200

the till-sand contact had been eroded by any agency other than glacial ice it would bear a lag concentrate of stones, a veneer of colluvium, or a zone of weathering; but such features are entirely lacking.

On the other hand, it seems probable that only part of the erosion involved in the sub-Vashon discordance was caused by the Vashon ice, and that much of the erosion was fluvial. The distribution of the remnant bodies of Quadra sand is suggestive of fluvial rather than glacial dissection. The erosion surface is characterized by broadly curved, steep scarps, 100 feet or more in height, that look like river-cut features and are difficult to explain as glacial features. Moreover, if the Quadra sands were originally continuous, the amount of material removed during the pre-Vashon erosion must have been much greater than the total volume of the Vashon drift.

Pre-Vashon fluvial erosion of the Quadra deposits presupposes a lowering of base-level (presumably sea-level) by several hundred feet. Thus, if such fluvial erosion took place it must have involved a considerable lapse of time.

Vashon Drift and the Last Regional Glaciation

The name 'Vashon' is applied in this report to various glacial deposits that together constitute the uppermost drift sheet in the region. These deposits appear to relate to a single glaciation. Till and other components of the ground moraine resting upon Quadra sediments on the coastal lowland are considered to be the 'type' Vashon drift of the area. The various tills that form the ground moraine in the rest of the area have yielded no evidence of significant large differences in age or of distinct stages of glacial advance or retreat. They are therefore arbitrarily considered to belong to a single glacial invasion and are assigned to the Vashon drift, together with the attendant glacio-fluvial deposits. In practice, while mapping, all glacial deposits of the area were included in the Vashon drift, except those assignable to the Dashwood drift on account of their position beneath Quadra sediments and those on the higher parts of the coastal lowland northwest of Thames Creek that lie beneath thick gravels and sands in turn beneath a younger till. Therefore, some of the tills assigned to the Vashon drift, particularly in eroded areas, may belong to the Dashwood drift or relate to old and as yet unrecognized glacial invasions.

The name 'Vashon' was first used geologically by Willis (1898, p. 128) for the uppermost till of the Puget lowland and for the time interval of the last regional glaciation of that area. It has been applied in the same sense to similar deposits on Vancouver Island by Clapp (1913, 1914, 1917) and around the city of Vancouver by Burwash (1918) and Johnston (1923). It has gained general acceptance by geologists, pedologists, and civil engineers in this part of British Columbia. The writer, therefore, has retained the name although this does not imply that correlation with the Puget Sound deposits is, as yet, anything more than a guess.

Summary

Ground moraine deposits of the Vashon drift are found throughout the coastal lowland and Alberni Valley and, in addition, form local pockets and thin veneers in mountain valleys and on mountain slopes. In the coastal lowland, the ground moraine typically rests upon Quadra sand and is exceedingly sandy. Except near Englishman River, the component materials have been derived from sources within the Georgia depression rather than in the Vancouver Island mountains. Tills on mountain slopes and in mountain valleys are mostly more clayey than the lowland tills but a few are extremely sandy and stony. The mountain tills consist dominantly of detritus of the basic volcanic country rocks. The ground moraine of the eastern part of Alberni Valley is loamy in texture, but a belt of granodiorite-rich till along the western side of the valley is less clayey and more sandy. Small, isolated ice-contact deposits of gravel and sand also belong in the Vashon drift. Most of these appear to have accumulated in streams along glacier margins, but some are deposits of streams bordered on both sides by ice and a few are shore deposits of ice-dammed lakes. Most of them are classified as kames, kame fields, and kame terraces, but a few are eskers, ice-contact alluvial fans, and ice-contact deltas. An extensive landslide deposit in Alberni Valley is also interpreted as an ice-contact phenomenon.

During the climax of the glaciation associated with the Vashon drift, an ice-sheet covered the entire area except perhaps the summit of Mount Arrowsmith, and flowed south to southwest from the Georgia depression across the Vancouver Island mountains. After the ice level had receded below the crest of Beaufort Range, tongues of ice continued to flow southwest in the passes through the mountains at Horne Lake and Cameron Lake and probably merged with a southeast-flowing glacier in Alberni Valley. The Alberni Valley ice, in turn, was fed by glacial tongues flowing eastward out of tributary valleys and emanating from an ice-cap on the uplands of Forbidden Plateau northwest of the map-areas. During deglaciation, the margin of the Alberni Valley glacier withdrew northwestward up the valley and the tributary glaciers receded into their respective valleys. The retreating ice-margins on the floor of Alberni Valley appear to have been bordered in part by the sea, standing 300 feet above present sea-level. Ice in the valleys of Beaufort Range apparently stagnated as the ice level fell below the crests of the intervening ridges. Streams and small lakes bordering the stagnant ice left narrow terraces along the valley walls, and mountainside torrents built alluvial fans against the ice.

A southeast-flowing glacial mass occupied the Georgia depression. Ice-contact deposits along the southern edge of the depression record progressive lowering of the surface of this ice and outline streams that flowed southeastward along and adjacent to the lateral edge of the ice. Delta-like deposits of ice-marginal streams near the mouths of the Cameron Lake and Horne Lake valleys provide evidence that the ice terminated in the sea, standing between 450 and 500 feet above present sea-level, and that the glacier terminus receded progressively

northwestward. An active glacier flowed down Englishman River valley to merge with the Strait of Georgia ice and was fed by cirque glaciers flanking Mount Arrowsmith. Cirques on the Beaufort Range, however, have not been occupied by active glaciers since the climax of the last glaciation.

Ground-moraine Deposits

The tills of Vancouver Island, as of any mountainous area, are extremely varied in texture, thickness, and surface topography. Those within the map-areas that are assigned to the Vashon drift are compact concrete-like mixtures of stones, sand, silt, and clay that reflect, in texture and rock constituents, the underlying and nearby unconsolidated deposits and bedrock. Dry till near the surface is pale grey and hard and commonly breaks into horizontal plates. Moist till at greater depths is darker grey and somewhat softer, but nonetheless will stand in vertical faces. Local residents commonly refer to the dry till as 'hardpan' and the moist till as 'blue clay'. A few exceedingly gravelly tills of the mountainous parts of the area are looser in consistency than those described above and are like poorly sorted fluvial gravels.

In the lowlands and valley bottoms the ground-moraine deposits are relatively continuous and locally exceed 100 feet in thickness, but in the mountains and hilly areas they are generally thin and discontinuous. Much of the morainic material presents no distinctive topography but merely fills in irregularities in the surface of the underlying bedrock or surficial materials. Nonetheless, fairly extensive areas of rolling and hummocky ground moraine occur on the coastal lowland and in Alberni Valley, and an area of drumlinoid ridges and furrows occupies much of the northwestern part of Alberni Valley. End moraines appear to be absent.

Sandy Till of the Coastal Lowland

The till forming the ground moraine in much of the coastal lowland is sandy. This sandy till occupies most of the low country between Englishman River and Chef Creek, and its distribution seems to relate to that of the Quadra sand unit. This till consists of 20 to 40 per cent gravel and boulders set in a dense silty sandy matrix (*see* Figures 6 and 7). Grain-size frequency curves of this type of till are bimodal, with peaks at 0.2 and 20 mm. The 0.2-mm mode coincides with the median grain size of typical sands of the Quadra sediments and it seems certain that sand from this source is a major component of this till. Probably the abundant pebbles in the till (as indicated by the 20-mm mode) likewise have been derived from the Quadra sediments.

Stones in the sandy till of the coastal lowland are generally subangular to subrounded as if derived from water-laid gravel rather than directly from bedrock. Pebble counts of thirteen such tills are as follows: volcanic rocks 73 to 93 per cent, granitoid rocks 6 to 16 per cent, sandstone and shale 0 to 13 per cent, and other rocks 0 to 2 per cent. The pebble counts show no consistent variation throughout the part of the coastal lowland in which these tills occur (*see* Fig. 8) and bear no relation to either the underlying bedrock (mostly shale) or bedrock changes in adjoining parts of the Beaufort Range. Probably, the stones have been derived from various sources within the northern part of the Georgia depression.

The fabric orientations of nine sandy Vashon tills of the coastal lowland form two disperse groups: five fabrics trending north to northeast and four trending east to southeast (*see* Fig. 8). This distribution may indicate that the tills were deposited by two distinct glacial movements—one southeast parallel with the length of Georgia depression and the other south-southwest across the depression. Alternatively, both sets of fabrics may have been formed by ice moving in one of the preferred directions—one set parallel with the ice-movement and other transverse to it.

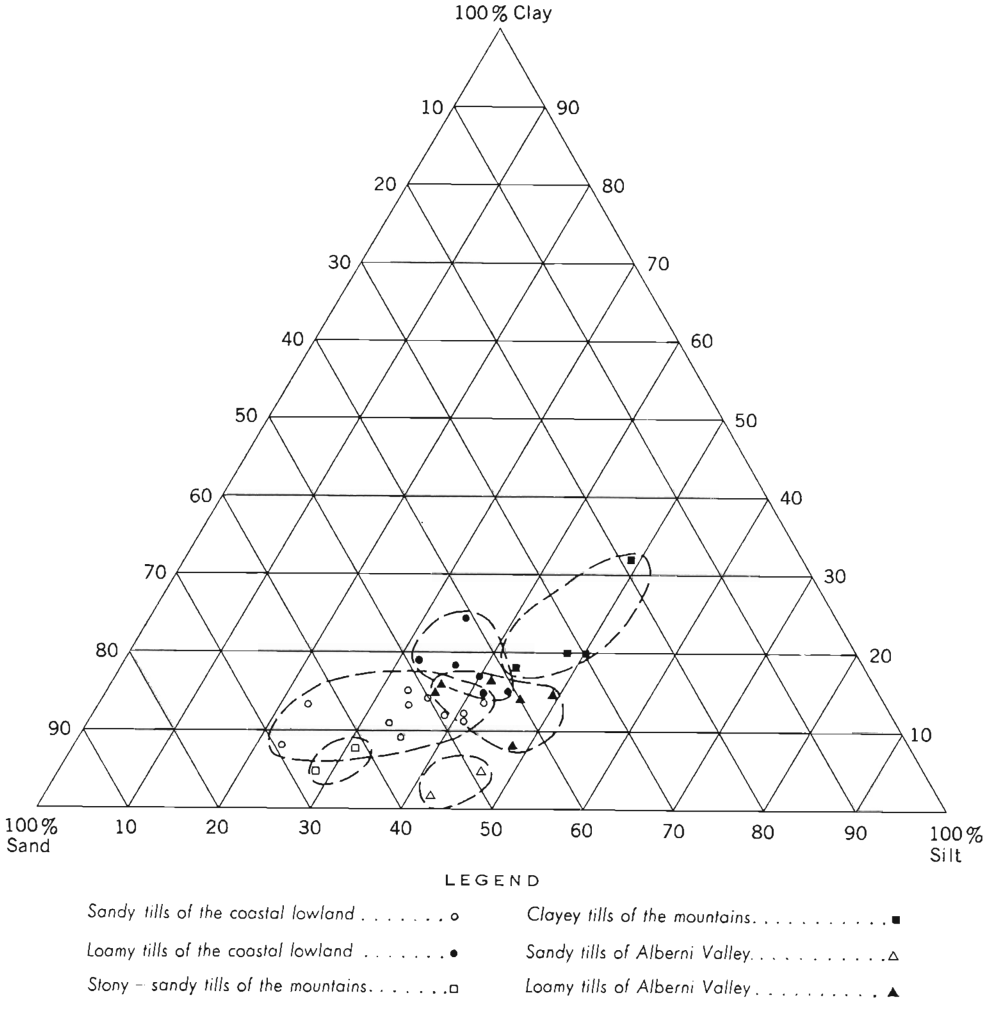

Figure 6. ***Mechanical composition of the minus 2 mm fraction of Vashon tills: Sand, 2 to .062 mm; silt, .062 to .002 mm; clay, less than .002 mm.***

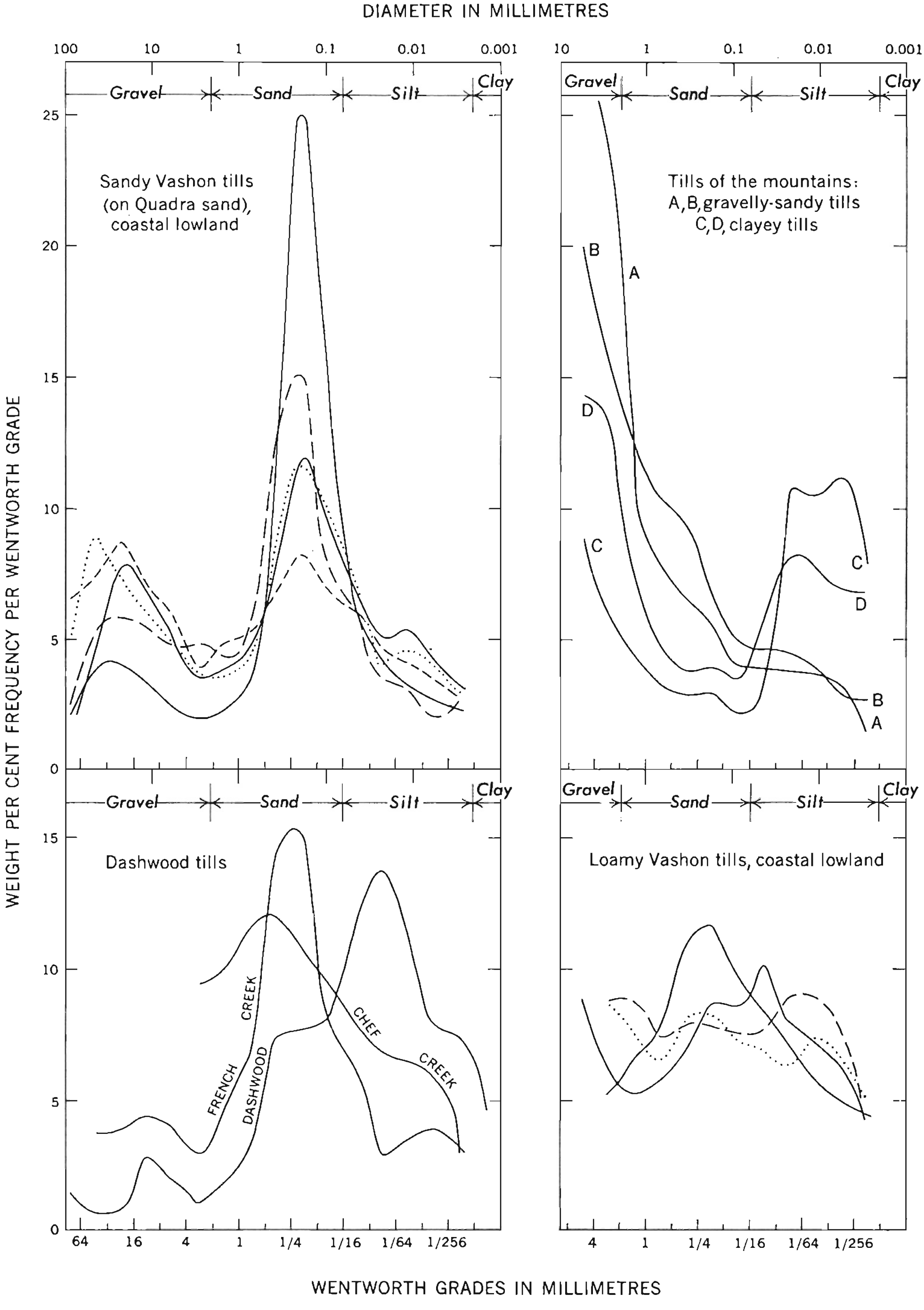

Figure 7. *Grain-size distribution of tills.*

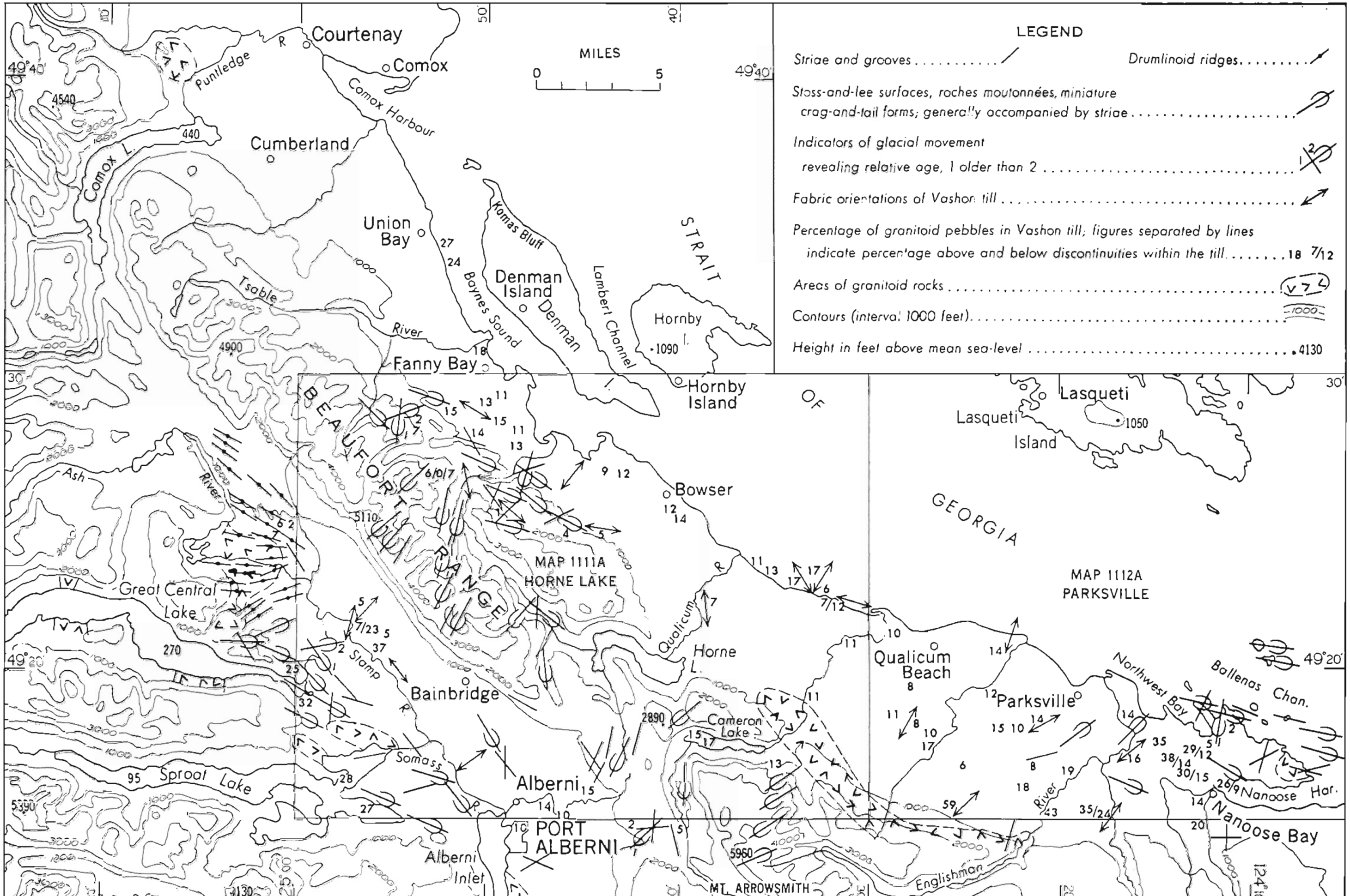

Figure 8. *Direction of glacial movement, east-central Vancouver Island.*

Generally the Vashon till mantles the irregularities in the eroded surface of the underlying Quadra sediments as a sheet that is relatively uniform in thickness, but in a few places it completely fills valleys or depressions. The constructional ground-moraine topography developed upon this sandy till consists of irregularly distributed, smooth, rounded hills, a few hundred feet across and generally less than 30 feet high; but this topography has been subdued in many places—and even obliterated in a few—by marine erosion and deposition. The till averages a few feet to a few tens of feet in thickness, but locally, as a result of marine erosion, it is represented only by a lag concentrate of large stones. The maximum recorded thickness of till overlying Quadra sand is 100 feet, but at the east end of the Dashwood sea cliff, where all the Quadra sediments have been removed by erosion, the Vashon till is more than 200 feet thick.

The sandy Vashon till of the coastal lowland seems to comprise a single sheet. Sand and gravel beds occur locally within the till but everywhere seem to be lenses of local extent. Pebble counts above and below such partings at French Creek and at two places on the Dashwood sea cliff are almost identical, and till fabrics above and below the partings are similarly oriented. Typically, Vashon till rests directly upon the eroded surface of undisturbed Quadra sand but, in some places, the till is separated from the undisturbed sand by a few inches to a few feet of sand containing till lenses and in which the original stratification has been faulted, brecciated, or completely destroyed (*see* Plate VA). The most sandy Vashon tills (*see* Map 1111A, Dashwood cross-section, exposures 15 to 17), which characteristically contain lenses and beds of sand and are locally barely distinguishable from unstratified sand, seem to be closely akin to these till-sand contact breccias.

Other Vashon Tills of the Coastal Lowland

The ground moraine in the northwestern and southeastern parts of the coastal lowland in the map-areas consists of loamy tills (*see* Fig. 6) that are slightly softer in consistency than the sandy Vashon tills discussed above. Like the sandy tills, they contain about 30 per cent gravel and boulders which, for the most part, are subrounded and water-worn. Grain-size frequency curves of these loamy tills are not distinctive although some have a poorly developed mode at 0.2 mm (*see* Fig. 7) as if they contain some sand derived from the Quadra sediments.

The Vashon tills in the eastern part of the Parksville map-area around Englishman River and Nanoose Bay, rest in part upon shale, sandstone, and conglomerate of the Nanaimo Group, in part upon basement volcanic and cherty rocks, and in part upon sand of the Quadra sediments. Pebbles of chert and quartzite derived from conglomerates of the Nanaimo Group and from the basement rocks around Nanoose characteristically make up a few per cent of the pebbles in these tills but, as in the sandy Vashon tills, most of the pebbles are of volcanic rocks. Tills near the mountains in this part of the area contain 20 to 50 per cent granodiorite stones that appear to have been derived from a granodiorite body to the south and west. Tills near the seashore, like the sandy Vashon tills to the northwest, contain only about 10 per cent granodiorite stones, but the marine gravel overlying them contains more than twice this concentration. This gravel is believed to be a lag concentrate of stones from the uppermost part of the till and, indeed, the same high percentage of granodiorite pebbles was found in the uppermost part of the till in a few places. The high granodiorite content of the surface material is suggestive of a late northeastward glacial movement down Englishman River valley, contrasting with the southeast and southwest movements associated with most other tills in the coastal lowland.

Vashon tills in the coastal lowland in the northwestern part of Horne Lake map-area (west of Chef Creek) lie in part upon gravel and sand, in part upon sandstone and shale of the Nanaimo Group, and in part upon the basement volcanic rocks. These tills contain slightly more granitic pebbles than the sandy Vashon tills to the southwest (an average of 13 per cent granitic pebbles as opposed to 11 per cent in the sandy tills). Northwest of the area the granitic-pebble content increases rapidly to about 15 per cent at Fanny Bay and to about 25 per cent at Union Bay, with a proportional increase in the number and size of granitic boulders littering the till surface. Many of these granitic stones consist of distinctive porphyritic granodiorite that occurs in the small plutons at Wolf Lake and west of Bevan near Courtenay. Thus, both the nature of the granitic stones in the tills and their change in concentration record glacial movement from northwest to southeast along the Georgia depression. Three fabric patterns of tills from this northwestern part of the area also trend southeast.

Mountain and Valley Tills

Morainic deposits of the mountainous parts of the area range from isolated patches a few inches thick to extensive valley-fillings a hundred feet or more thick, and from very stony, light-textured till to heavy-textured, sticky boulder clay. For the most part, they occur in depressions and valley bottoms and on the lower, less-steep parts of mountain slopes. They are not marked by any distinctive constructional topography and are extensively dissected. The morainic materials are texturally similar to the widespread colluvial and alluvial fan deposits of the mountain slopes and valleys, and, in many places, their distinction rests solely upon identification of their constructional topography which may, in turn, have been obliterated by dissection or concealed by the forest. Mapping is further complicated by intermingling of these hard-to-distinguish deposits.

Most of the thicker ground-moraine deposits of the mountainous parts of the area consist of silty clayey till (*see* Fig. 7) which contains up to 50 per cent gravel and boulders. The matrix of the tills is generally a clayey sandy silt (Fig. 6). These tills consist almost entirely of the disintegration products of volcanic rocks, and the few mountain tills containing appreciable amounts of other kinds of rock (e.g. sandstone or granodiorite) are more sandy and less silty and clayey. Stony sandy tills containing little silt and clay (Figures 6, 7) and up to 70 per cent gravel and boulders are found here and there in the mountains. They generally occur as a veneer on bedrock or on clayey till, but locally lie between layers of clayey till. Some of them may be of superglacial origin.

Stones in both the clayey tills and the stony, sandy tills of the mountains are dominantly angular fragments of the local bedrock but almost universally include isolated rounded foreign stones. Tills of Rosewall Creek valley and of the through valley from Rosewall Creek to Horne Lake contain a few granodiorite and sandstone pebbles and a few rounded volcanic pebbles that probably were carried from the Georgia depression by southward-moving glacial ice. Abundant granodiorite pebbles in the tills in Cameron Valley northeast of the Alberni pass appear to have been derived from the granodiorite pluton at the mouth of the valley and thus record westward and southward glacial movement up the valley (*see* Fig. 8).

Lenses of silt, sand, and gravel have been found beneath and within till in many of the mountain valleys but all seem to be of small extent, and nowhere has any indication been found of superposition of till upon extensive lacustrine or fluvial deposits. Cutbanks along the highway on the south side of Cameron Lake expose till-like materials overlying sand and silt which, in turn, rest upon till and bedrock. The presence of slump structures in the till-like materials overlying the sands suggests that they have been redeposited by downslope movements, and the sands and silts appear to have been formed during or since deglaciation in a lake standing about 50 feet above the present lake-level.

Superposed tills of different textures are to be found in some of the mountain valleys but little is known of their significance. A succession of three such tills is exposed in road-cuts adjacent to Rosewall Creek. The uppermost 10 feet of this succession consists of loamy till like the till of adjoining parts of the coastal lowland. Most stones in this till are subrounded or subangular although some are sharply angular; 7 per cent consist of granodiorite, 3 per cent of sandstone, and the rest of volcanic rocks. The underlying till, about 5 feet thick, is typical of the clayey tills of the mountains. Stones in this till are dominantly angular, and except for rare granitic pebbles, they consist of volcanic rocks. Beneath this clayey till is more than 5 feet of stony, sandy till containing both subrounded and sharply angular stones and including appreciable numbers of granodiorite, sandstone, and shale pebbles as well as some volcanic-rock pebbles. Fabric orientations of all three tills trend slightly east of south, almost exactly parallel with the direction of dip of the valley wall immediately below. But this trend is also parallel with the expected local direction of movement of glacial ice across the upland if it flowed either into or out of the mountains through Rosewall Creek valley. These superposed tills of contrasting texture and stone content may record successive glacial movements into and out of Rosewall Creek valley and along the southwestern margin of the Georgia depression and, if so, several stages of glacial advance and retreat must be represented. On the other hand, except for the top layer, which lies above the valley rim, they may not be undisturbed primary glacial deposits, but rather colluvially redeposited 'tills' that have crept in successive sheets down the steep valley-wall. The uppermost till, like the tills of adjoining parts of the coastal lowland, probably was deposited by glacial ice moving southeastward along the edge of the Georgia depression or, perhaps, southward into (across ?) the mountains.

Alberni Valley Tills

Most of the surficial deposits of Alberni Valley are till. It forms a relatively continuous mantle in the eastern part of the valley where it is locally more than 100 feet thick. In the western part, till merely fills the bottoms of depressions between bedrock hills a few tens of feet high and thinly veneers the hill slopes. Along the base of the steep northeast wall of Alberni Valley, till is mingled with colluvial and alluvial fan materials very similar to the till itself, to form a wedge of sediment locally more than 100 feet thick. In most places the till lies directly on bedrock, but locally, as revealed by isolated drilled wells southeast of Beaver Creek and by a few cutbanks along Stamp River, it is underlain by gravel, sand, or silt.

Much of the till topography of Alberni Valley is a subdued replica of the bedrock topography beneath it. On the other hand a narrow belt of hummocky constructional till topography with relief up to 50 feet extends along the east side of the valley floor from Spaht Creek southeastward to Cherry Creek. West of longitude 125° (i.e. in Great Central map-area west of Horne Lake map-area) the till surface is marked by small drumlinoid ridges and furrows averaging 1,000 feet long, 200 feet wide, and 10 feet high. These trend southeast, east, and northeast (*see* Fig. 8) and record glacial movements converging toward the junction of Lanterman Creek and Ash River. Many of them take the form of drift tails appended to bedrock knobs. Less-regular till ridges trending across Alberni Valley at right angles to nearby drumlinoid ridges occur along the northeast side of the valley, adjoining the drumlinoid zone. These ridges range from 3 feet high and 100 feet long to 50 feet high and 500 feet long. They may be crevasse fillings.

The till forming the ground moraine along the northeast side of Alberni Valley is loamy in texture (Fig. 6). About 10 per cent of the stones in it consist of granitoid rocks, 10 per cent are sandstone and shale, and 80 per cent are volcanic rocks. Such a mixture of rock types would probably result from southeastward glacial movement along the northeast side of the valley, although in a few places east of Port Alberni, this kind of till contains rare pieces of limestone, chert, and chlorite schist that are believed to have come from the northeast.

The ground moraine along much of the southwest side of Alberni Valley consists of thin sandy till (Fig. 6) containing lenses of silt, sand, and gravel. Granitoid rocks make up 30 to 60 per cent of the stones in this till and volcanic rocks make up the balance; sandstone and shale are absent. The granitoid stones presumably have been derived from various small granitic bodies along the west side of Alberni Valley and in the valleys of Great Central and Sproat Lakes. The coarse texture of this till relates, in part at least, to its content of granitic material.

Tills along the middle of Alberni Valley from the junction of Ash and Stamp Rivers to the head of Alberni Inlet are loamy in texture like those along the northeast side of the valley, but they contain abundant granitoid stones like the tills of the southwest side of the valley. The abundant granitoid stones in these tills may have been brought in from the west (ice-movement down Great Central and Sproat Valleys) but, alternatively, may have been brought down Alberni Valley from the granodiorite body east of Dickson Lake or may have been picked up by ice from granodiorite-rich gravels that have locally been found within and beneath the till. Fabrics of some of these granodiorite-rich loamy tills trend southeast parallel with the axis of Alberni Valley, whereas others trend northeast across the valley (Fig. 8). They may reflect two distinct glacial movements or may be parallel and transverse fabrics related to a single movement.

Little is known of the relative age of the various tills of Alberni Valley. Upper and lower tills separated by a few feet of gravel and sand are exposed in various cutbanks along Stamp River, and lenses of till are intercalated with sand and gravel in gravel pits adjacent to Somass River. None of these exposures gives any indication of a significant lapse of time. Half a mile down Stamp River from its junction with Ash River, two sheets of loamy till separated by a boulder pavement are exposed in the river bank. In the lower till, 23 per cent of the pebbles are granodiorite, 10 per cent are sandstone and shale, and 3 per cent are limestone, whereas in the upper till only 7 per cent of the pebbles are granodiorite, 5 per cent are sandstone and shale, and none is limestone. The fabrics of both tills trend northeast (*see* Fig. 8). In the acute angle between Lanterman Creek and Ash River close to the eastern edge of the belt of sandy-loam tills, a railway-cut exposes granodiorite-rich sandy till overlying less-stony, loamy till that contains a much smaller percentage of granodiorite pebbles. The two relationships outlined above suggest that the granodiorite-rich, loamy till of the middle of the valley is older than the granodiorite-poor loamy till along the east side of the valley, and that this, in turn, is older than the granodiorite-rich sandy till on the west side of the valley. The overall relationship, however, is probably much more complicated. As yet, it is not even known which tills were formed more or less contemporaneously by glacial ice converging from different sources and which, if any, represent successive glacial invasions.

Glacio-fluvial and Glacio-lacustrine Features

Resting upon the ground moraine of the Vashon drift are gravel, sand, and minor silt that appear to have originated in streams and probably lakes surrounded by glacial ice or confined between ice and higher ground. Some of these deposits show distinctive ice-contact topography whereas others are perched on hillsides in such positions that the streams or lakes in which they accumulated must have been dammed by glacial ice. A few small abandoned stream channels and indistinct shorelines appear likewise to have been formed by glacial streams and lakes. Many of the glacio-fluvial deposits within the area take the form of more or less conical hills (kames) or occur as groups of such hills interspersed with closed kettle depressions (kame fields). A few are elongated esker ridges. Other glacio-fluvial deposits form terraces that locally are pitted by kettle holes and in part are bordered by knob-and-kettle slump slopes. These include kame terraces, which appear to be the deposits of streams that flowed between glacial ice and higher ground; ice-contact alluvial fans, which formed where streams flowing down steep valleys reached the margin of a lowland ice-mass; and 'kame deltas', which appear to have accumulated where glacial streams entered the sea amid remnant masses of glacial ice.

Alberni Valley

The glacio-fluvial deposits of Alberni Valley outline several separate drainage systems that carried glacial meltwater around and beneath remnants of glacial ice during deglaciation. Some of these streams seem to have terminated in the sea.

Esker System

An esker-channel complex about 7 miles long extends from near Ash River 3 miles west of the area to Stamp Falls. This esker system heads in three tiny abandoned stream channels 1 mile to 2 miles long that trend east, east-southeast, and southeast parallel with adjacent drumlinoid ridges. Anastamosing esker ridges of pebble gravel extend about a mile eastward (across Lanterman Creek) from the junction of these channels, and lead to the kames and the channels cut in sandstone that are shown at the western edge of the Horne Lake map-area, about a mile north of Ash River. The esker system then disappears beneath glacial landslide deposits and reappears about a mile to the southeast as a series of pebbly kames and as subparallel pebbly and sandy esker ridges up to 50 feet high and 1½ miles long. About ¼ mile from the southernmost esker ridge and immediately east of the mouth of Spaht Creek is a pitted terrace underlain by pebbly sand. Pebble counts definitely relate this terrace deposit to the esker rather than to nearby kame-terrace deposits west of Stamp River. This terminal terrace of the esker system is about at the same altitude as the highest marine deposits in this part of Alberni Valley. Possibly the terrace is a delta built by the esker stream where it flowed from the ice into the sea.

Great Central Kame and Kame-terrace System

Gravels with ice-contact topography form an irregular complex belt up to ½ mile wide extending from Great Central to Stamp Falls. They seem to be deposits of glacial streams that originated in Great Central Valley and flowed eastward along the margins of low hills projecting through thin remnant ice.

Kames and narrow kame terraces follow the present drainage northward from the outlet of Great Central Lake for about 1½ miles to the junction of the main river with the overflow from Boot Lagoon. Thence, knobby and ridged gravels extend across a low divide (30-foot rise) to a swampy lake about a mile to the southeast. From the lake a kame terrace extends southeast about 2 miles between a till ridge on the north and a series of bedrock hills on the south. It is separated from the lower country to the southeast by an irregular ice-contact face. Extending northeast from the swampy lake, between the kame terrace and the supporting till ridge, is a narrow belt of kames standing a few feet above the terrace level. These kames lead to a small abandoned stream channel whose north end has been cut off by Stamp River. Another narrow belt of kames and kame terraces extends around the opposite side of the till ridge.

Both the terrace deposits and the knobby kame deposits consist dominantly of pebble and cobble gravel but include beds of sand and silt. The kame deposits are irregularly stratified and generally are less well sorted and coarser than adjoining terrace materials. Most terrace deposits are horizontally stratified although some near Great Central have slump and kettle-fill structures. Gravels become finer from west to east and the main kame-terrace deposit grades from pebble gravel in the west to pebbly sand (at least locally resting on sand and silt) in the east. The gradient of the terraces is very low and all terraces lie between 290 and 310 feet above sea-level.

This system of kames, kame terraces, and channels clearly records drainage of glacial meltwater from Great Central Valley by several routes to the east and northeast instead of via the present northward loop of Stamp River. Apparently, when these deposits were formed, solid glacial ice north of the outlet of Great Central Lake blocked the natural drainage route and diverted the meltwater streams eastward through and around thin and discontinuous ice. The downstream end of the main kame terrace (near Stamp Falls) lies within a few feet of the upper limit of marine submergence in this part of the valley, and it seems probable that the depositing stream terminated in the sea just west of the present site of Stamp Falls. This suggestion is based on the contrast between the fresh ice-contact features of part of the southeast face of the kame terrace and the smooth wave-modified appearance of other parts—as if some parts had been confined by ice while other parts were being built into standing water.

Sands and silts up to 20 feet thick occupy low ground adjoining Stamp River between the northern edge of the kame-terrace complex and Ash River. Although these deposits may be marine they are more prominently laminated than most of the sandy and silty marine deposits of the region and are not accompanied by the typical marine clays. Probably, they accumulated in a lake dammed at the north end by glacial ice. The ice dam appears to have been just south of the junction of Ash and Stamp Rivers—a mile or two north of the position of the earlier ice barrier against which the kame and kame-terrace complex had been built. A short abandoned channel through the till ridge that confines this area of sands and silts on the east may have been the outlet of the lake. The downstream end of this channel has been cut off by Stamp River and, therefore, its relation to the former high sea-levels is not known.

Stirling Arm Terraces

An ice-marginal river system that flowed eastward from Sproat Valley along the southern edge of the floor of Alberni Valley is represented by three small kame terraces and an abandoned river channel between Stirling Arm and the head of Alberni Inlet. The kame terraces are flat-topped bodies of pebble gravel and sand bordering small bedrock hills. Their outer edges are steep but relatively

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regular and lacking in kettle holes or other features indicative of ice-contact slopes. Isolated kettle holes occur in the terrace tops and between the gravels and the supporting bedrock hills. Stratification near the edges of the deposits parallels the bordering slopes but the few cut faces well back from the edge reveal horizontal bedding. In places, adjacent terraces differ in elevation by 5 or 10 feet but all seem to be between 260 and 280 feet above sea-level. Despite the absence of ice-contact forms along the margins of these deposits, the writer believes that their accumulation as isolated, flat-topped deposits on the sides of bedrock hills that lack any source for the gravels, can only have taken place in a river flowing in part on remnant ice and in part around the margins of hills projecting through the ice. They are localized at the base of the mountain slope at the south edge of the valley floor as if the river by which they were deposited was confined between the hills to the south and the wasting margin of glacial ice in Sproat and Alberni Valleys. The terrace surfaces are slightly (10 to 30 feet) below the limit of marine submergence. This similarity of level may be a coincidence but, alternatively, it may indicate that the level of the terrace surfaces was controlled by the level of the nearby sea. Sea water has surrounded and probably covered the terraces since their formation, as is indicated by the distribution of the surrounding marine clays. Probably the presence of sand fillings in some of the kettle holes in the terrace surface as well as the absence of ice-contact forms on the bordering slopes are attributable to marine action.

Somass Gravels

Extensive deposits of gravel and sand occur along the valley of Somass River and along Stamp River for a few miles above Somass River. Some of these lie beneath remnants of a terrace several tens of feet above the present river-level, and others form less well defined isolated bodies along the valley sides. The latter, although lacking distinctive ice-contact forms, are believed to be glacio-fluvial in origin. The terrace system is considered to be post-glacial and is discussed later in this chapter under 'Capilano Sediments'. Some gravels and sands beneath the terrace, however, are truncated by the terrace deposits and some of these probably are glacio-fluvial.

Some of the gravelly deposits within and adjoining the valley of Somass River are intermingled with lenses of till and thus are confidently considered to be glacio-fluvial in origin. The original form of these deposits is not known. For the most part they are small pockets of irregularly stratified pebble and cobble gravel surrounded by till and lacking clear-cut surface expression. A large and more distinctive deposit of this type forms an isolated hill 100 feet high on the west side of the head of Alberni Inlet. A gravel pit in the south side of this hill exposes 50 feet of irregularly stratified dirty bouldery gravel and silty sand that encloses a few lenses of till. In another cut face on the east end of the hill, till lenses are larger and more numerous, and the enclosing gravels are more regularly stratified, better sorted, and pebbly rather than bouldery. The hill in which these glacio-fluvial materials occur is veneered with a lag gravel and probably is a remnant of a much more extensive deposit.

West of Somass River between McCoy Creek and Sproat River are gravelly and sandy deposits up to 75 feet thick that are characterized by complex folded and faulted structures such as those illustrated in Plate VI. These disturbed gravels occur beneath a veneer of marine deposits both on the valley wall above the terrace remnants and beneath the terrace deposits in a pit at the junction of Sproat and Somass Rivers. They are best exposed in two gravel pits just west of Somass River at Hector Road. In these pits up to 40 feet of well-sorted pebbly, and locally cobbly, gravel rests upon a till-and-bedrock surface sloping towards the river. Overlying the gravel in some places is 10 to 15 feet of pebbly sand and in others an equal thickness of silt and clay interlaminated with pebbly sand. All these strata are involved in the folds and faults shown in Plate VI and most of the clays and silts are brecciated. Covering these deposits are undisturbed pebbly sands up to 10 feet thick and lenses of clay up to 5 feet thick, that contain casts of marine shells.

Where it has been possible to determine the direction of movement involved in the folding and faulting of these deposits, the deformation has resulted from movement down the valley wall as if by slumping. Probably these are ice-contact deposits of some sort that accumulated between the valley wall and glacial ice and that slumped when the supporting ice melted.

Mountain Valleys

Narrow terraces and tiny alluvial fans perched on the walls of some of the mountain valleys appear to have been formed by streams at the margins of remnants of glacier ice in the valley bottoms and as shore features of ice-dammed lakes. These small indistinct forms are, for the most part, recognizable and traceable only where the forest cover has been removed by recent logging or fires.

Within the map-areas these features are best displayed in the valley of Rosewall Creek and in adjoining parts of the valley leading thence to Horne Lake. Rosewall Creek valley contains many alluvial fans built by tributary streams. Most of these are either still being formed or were formed when the valley floor was 50 to 75 feet above its present level, but a few of them, perched several hundred feet above the present stream, are too high to have been built upon any post-glacial floor of the valley (*see* Plate IXB). One of the highest of these fan remnants borders Roaring Creek, a tributary of Rosewall Creek. If the surface of this fan is projected downslope across the valley of Rosewall Creek it passes above the top of the constructional till ridge that there forms the opposite wall of the valley. Hence, it must have been built against glacial ice or into a lake in Rosewall Creek valley. Other high fans bordering the valley lie at various elevations rather than at a single elevation and therefore they probably were built against ice rather than into a lake. Very narrow, scarcely perceptible terraces occur along the walls of Rosewall Creek valley and the valley leading from Rosewall Creek to Horne Lake. Some are notches cut into the thin till that mantles the valley walls and others are constructional deposits of pebble and cobble gravel. Although many occur at or close to the same elevation—and on this basis might be interpreted as lakeshore features—some of those visited on the ground are sloping in along-valley profile rather than horizontal and, hence, are interpreted as the beds of ice-marginal streams.

High terraces and fan remnants have been encountered on the wooded valley walls bordering Cameron Lake and Cameron River. They probably are ice-marginal or glacial-lake features but because of the forest cover, little is known of them. Deltas, beach terraces, and accumulations of stratified sand and silt are found on the lower hillsides bordering Cameron Lake. The most prominent of these record a former stand of the lake about 50 feet above its present position. It is not known whether these former lakes were dammed by glacial ice or dammed in the valley mouth by unconsolidated deposits that have since been removed by Little Qualicum River cutting its present channel.

Small terraces and fan deposits on the valley walls bordering Horne Lake and terrace deposits in the valley of Qualicum River west of the lake appear to be largely lakeshore features but may include ice-marginal features. There, as in Cameron Valley, no clear distinction has been made between the deposits of glacial ice-dammed lakes and those of the higher post-glacial stands of Horne Lake, which existed prior to the cutting of the present valley outlet of the lake.

Coastal Lowland and Mountain Front

Extensive glacio-fluvial deposits lie along the inland edge of the coastal lowland and on the lower parts of adjoining hillsides. They are particularly common where the larger mountain valleys meet the lowlands. Such deposits are rarely found more than a mile or two from the base of the mountain slope.

Belt of Fans and Kames Near Chef Creek

The northernmost glacio-fluvial deposits of the coastal part of the map-areas are ice-contact alluvial fans and kames at the base of the steep mountain-slope at the heads of Chef Creek and McNaughton Creek. There a number of alluvial fans have been built by small streams where they flowed from steep mountainside gullies onto the high bedrock bench that borders the inland edge of this part of the coastal lowland. The lower fans appear to be post-glacial but the highest fans are bordered by steep, scalloped slopes with kame-like hills, and are believed to have accumulated against glacial ice. Kames are found on the hillside between the fans. The high fans consist of poorly sorted angular gravel derived from the local bedrock but the kames and the ice-contact faces of the fans include better-sorted gravels containing an appreciable number of subrounded and foreign stones. Apparently both the ice-contact fans and the kames were deposited between the mountainside and the Strait of Georgia glacier. They may outline a single stand of the ice-margin, and if so their progressive decrease in altitude—from 1,700 feet in the west to 1,400 feet in the east—would appear to record the slope of the ice-margin.

A tiny esker ridge extends downslope from a prominent kame near the eastern end of the easternmost fan. The esker descends 800 feet in its 2 miles of length and trends approximately at right angles to nearby glacial striae and till fabrics. It may have been deposited by the stream that built the nearby fan, and appears to record the escape of meltwater beneath the ice rather than along the ice edge.

The belt of kames and ice-contact alluvial fans has been traced eastward only as far as the eastern end of the high bench separating the coastal lowland from the mountains. East of this, a thoroughly dissected apron of gravel, sand, and till borders the base of the mountain slope. On the geological map of Horne Lake the gravel and sand are classified as sub-till deposits possibly equivalent to the Quadra sediments, but some of them may, alternatively, be remnants of hillside kame or kame-terrace deposits related to the kames and fans to the west.

Belt of Kames, Chef Creek to Hunts Creek

A belt of hummocky gravel extends along the inland margin of the coastal lowland from Chef Creek to Hunts Creek. It is 3½ miles long, up to a mile wide, and for the most part, lies between 500 and 1,000 feet above sea-level. Most of this gravel area is characterized by closely spaced more or less conical hills a few feet to 100 feet high; locally these are interspersed with ridges transverse to or parallel with the axis of the belt. Kettle holes are fairly abundant near Nile Creek but are rare elsewhere. The kame deposits consist of well-sorted to poorly-sorted pebble to cobble gravel, pebbly sand, and sand. In many places lenses of till are intercalated with the gravel. In most places where stratification has been seen it parallels the hummocky ground surface, although one cutbank exposes faulted strata dipping into a kame almost at right angles to the side slope. Stones in the kame gravels are subangular to subrounded and, although most of them consist of volcanic rocks, several per cent are granodiorite and a few are sandstone. Large, more or less angular blocks of dark green trap are strewn here and there on the gravel surface, particularly in the western part of the belt. At the western end of the belt, adjacent to the amphitheatre-like valley of Chef Creek, the kames are poorly defined; the kame deposits there have not been distinguished with certainty from gravels and sand occurring beneath thin discontinuous till or from the esker gravels mentioned in the last section of this report. At one point on the northwest rim of the Chef Creek amphitheatre, two tiny river channels have been cut through the ridge crest. These terminate in the kame belt, half a mile to the north, as a fan-shaped group of high kames. These channels and terminal kames are believed to have been formed by a stream flowing off a glacial remnant in the Chef Creek valley and onto lower glacial ice to the northeast.

The kame belt is bordered on the northeast by marine deposits and by materials modified by marine action. Almost everywhere, the marine submergence obviously took place after the formation of the kames and, as indicated on the geological map, the easternmost part of the kame belt is covered by a thin marine wash. On the other hand, in the head of a small gully on the downslope side of Chef Creek forestry road, on the northern boundary of the kame belt, massive clay containing marine shells and isolated stones is overlain by a few feet of gravel and till-like material. This succession may indicate a glacial advance over marine deposits or may mean that marine waters penetrated into intra-ice openings while the kames were being formed. Alternatively, however, the material covering the marine clay may have been emplaced by downslope movements during marine submergence or may have been dropped by icebergs.

The kame belt is not associated with any terrace-topped, fan-like or delta-like deposits nor with channels or outwash deposits, and therefore cannot have formed along any ice-margin or series of margins but must have been flanked on both sides by ice. The long axis of the belt parallels the last glacial movement in this part of the area. Relative to this movement, the kame belt is in the lee of the steep slope, 500 feet high, separating the high bench between Waterloo and Chef Creeks from the lower coastal plain. If the glacial ice covering this slope were thin, a zone of crevasses would be expected to coincide with the belt now occupied by the kames. Possibly the kames were deposited on, within, or at the base of the ice by streams flowing along such a crevasse system. Parts of the kame belt are 1,000 feet above sea-level and must have been formed when the glacial surface was above that elevation, whereas the kames at the north end of the short channels cutting through the rim of Chef Creek valley must have formed when the ice surface was only 600 to 700 feet above sea-level. Thus, the meltwater drainage system in which the kames were formed probably persisted over a considerable range of positions of the upper ice surface and may well have been contemporaneous both with the mountainside fans and kames near Chef Creek (discussed in the last section) and with the Spider Lake terrace described below.

Spider Lake Ice-contact Delta

Blocking the mouth of Horne Lake valley east of the present course of Qualicum River is a gravel terrace pitted with numerous closed depressions, the largest of which is occupied by Spider Lake. As shown in Figure 9, the terrace is delta-like in outline, fanning out to the north and east from the top of the steep slope bordering the northeast corner of Horne Lake. It decreases progressively in elevation from 500 feet above sea-level in the narrow channel section adjacent to Horne Lake to 450 feet along the broad northeastern periphery and, clearly, was deposited by a northeast-flowing river. Within the terrace is a large depression, 20 to 50 feet deep, with triangular outline and margins more or less parallel with the outer borders of the terrace. The depression is floored with knob-and-kettle gravels and is traversed by esker-like gravel ridges trending northeastward. Some of these ridges are connected to the terrace at their upstream and downstream ends.

The terrace is confined on the south by the steep mountain-front and on the west by a low till-surfaced ridge. On the east it terminates in a steep scarp, 50

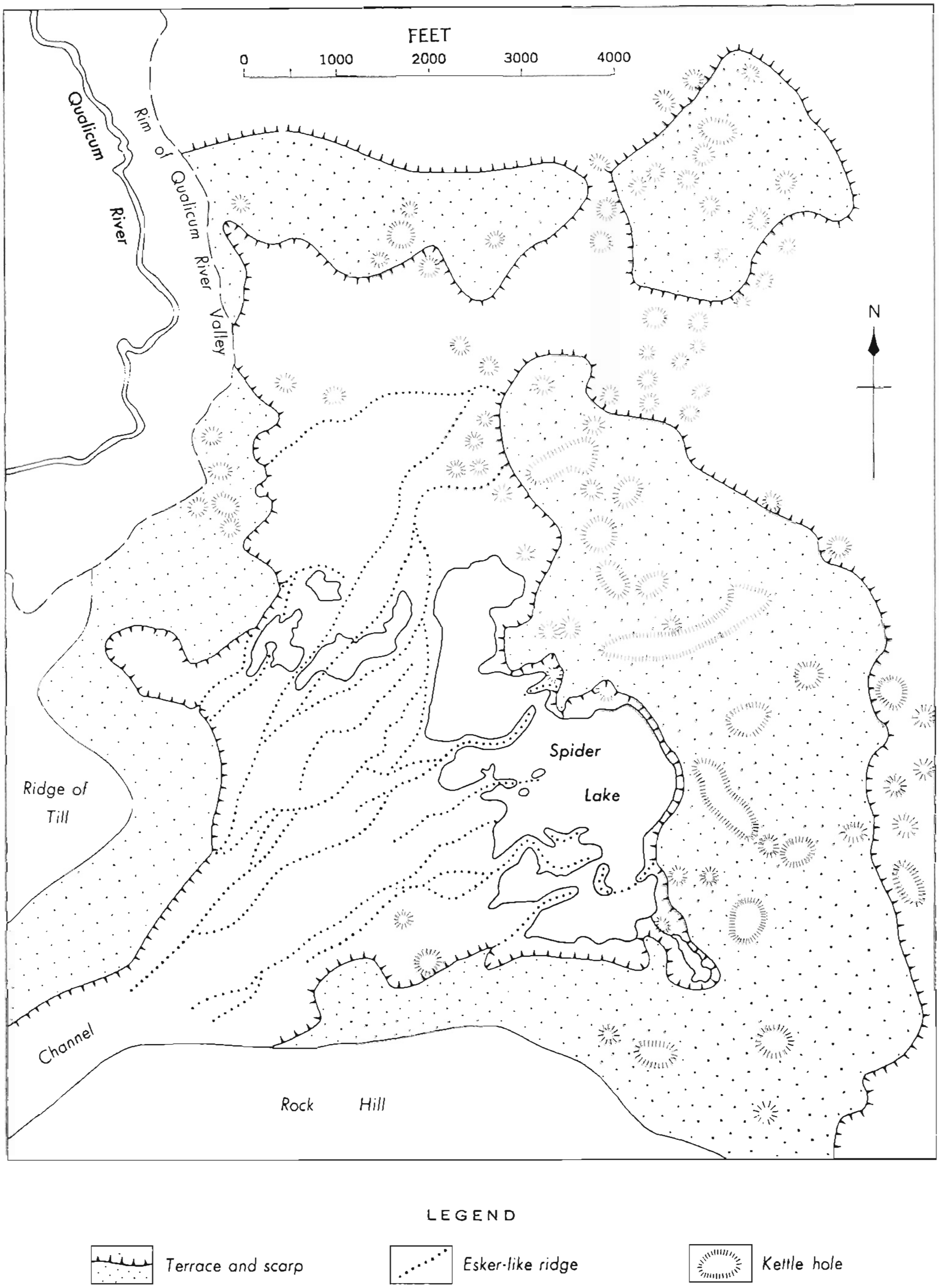

Figure 9. *Spider Lake ice-contact delta, Horne Lake map-area.*

to 75 feet high, that separates the terrace from lower, marine-veneered ground-moraine country. Parts of the scarp are smooth and regular like the front fore-set slopes of nearby deltas, but most of it presents an irregular scalloped outline and is indented by kettle holes. The northern part of the terrace, north of the central depression, stands 20 to 30 feet above the eastern part of the terrace and is separated from it by a hummocky zone in which neither terrace level is represented. The peripheral scarp bordering this northern part of the terrace is smooth and contains only rare, poorly defined kettle holes. This scarp and a series of lower gravel and sand terraces to the north appear to have resulted from truncation and redeposition of the marginal parts of the kettled terrace by waves and currents.

The steep slope dropping off from the head of the Spider Lake terrace to Horne Lake is hummocky and bears small kettle holes and narrow discontinuous terraces. One small terrace, part way up this slope, leads northwest around the hillside to a small abandoned stream channel that slopes down to the northwest and is cut off by the valley of Qualicum River.

The Spider Lake terrace and the steep slope separating it from Horne Lake are built of well-rounded pebble and cobble gravel and pebbly sand. Some 10 to 20 per cent of the pebbles in the gravel consists of granodiorite, and, in this respect, the deposits are similar to the glacial materials of the coastal plain and are unlike those of Horne Lake valley. Judging from the depth of kettle holes, the deposits may locally exceed 50 feet in thickness.

The Spider Lake terrace was built partly on the ground and partly on thin remnant glacial ice that melted to leave the large central depression and the kettle holes. If the ice-contact features of the peripheral northeast scarp are discounted, the terrace has the form of a delta that fortuitously buried or partly buried a remnant of glacial ice occupying the re-entrant between the mountain front and a north-projecting till ridge. The esker-like ridges probably outline successive positions of a river channel as it crossed this ice remnant. The ice-contact features of the peripheral scarp, on the other hand, seem to indicate that the terrace complex is a kame terrace built against glacial ice that occupied the coastal lowland to the north and east. The contrast between the unmodified kettle holes and ice-contact irregularities along parts of the peripheral scarp and the smooth wave-modified form of other parts that would be no more exposed to waves and currents during submergence, seems to indicate that parts of the terrace front were exposed to wave attack while other parts were protected by glacial ice. On this basis the terrace complex is inferred to be partly a delta built out into a water body and partly a kame terrace built against glacial ice. This ice may have been the broken frontal zone of a glacier ending in water, or individual isolated glacial remnants or perhaps merely grounded bergs. The delta sections of the terrace must have been built into a water body with surface between 450 and 500 feet above present sea-level. The coincidence of this level with the limit of marine submergence in this part of the area is believed to indicate that the Spider Lake terrace was built into the sea.

The river that built the Spider Lake terrace seems to have left no channels or deposits west of the terrace itself. It might, therefore, be assumed that the river flowed out of an ice-dammed lake that occupied the Horne Lake valley, except that such a stream would not be carrying any load upon leaving the lake and, in the absence of extensive erosion along the narrow channel section of the terrace east of the lake, it could not have picked up any substantial load along its course. This being so it could not have built the extensive Spider Lake terrace. Moreover, the presence of an ice-marginal channel on the kettled slope below the head of the channel section of the terrace indicates that glacial ice occupied the northeast bay of Horne Lake after formation of the Spider Lake terrace. Thus, the river that deposited the Spider Lake terrace can only have flowed across the Horne Lake depression on or within glacial ice. In view of the abundance of granodiorite pebbles in the terrace gravels, the river must have derived its load from the Georgia depression rather than from a source in Horne Lake valley. It probably flowed along the southwestern edge of the coastal plain on or within the marginal ice of the Strait of Georgia glacier and may have been the same river that deposited the Chef Creek - Hunts Creek kame belt. The course of the glacial river into the mouth of Horne Lake valley and out again rather than by a shorter route across the valley mouth is an indication that an active ice-tongue was not, at that time, flowing out of the Beaufort Range by way of the valley.

The small ice-marginal channel mid-way up the kettled slope below the upstream end of the Spider Lake terrace cannot have been formed by the same river that formed the terrace. Rather, it appears to have been made later by a smaller stream flowing out of Horne Lake valley along the margin of the residual ice. Still later, the present course of Qualicum River was established by drainage from thinner remnant ice in the Horne Lake depression and/or from a lake or lakes standing 50 feet or more above the present lake. A few narrow terraces and fans along the valley walls 50 to 75 feet above the present lake, and more extensive terraces (some of them delta-like) about 2 miles up Qualicum River from Horne Lake, probably date from this stage.

Little Qualicum Ice-contact Gravels

Terraced and knob-and-kettle gravel deposits including delta-like forms similar to the Spider Lake terrace, occupy the mouth of the Cameron - Little Qualicum Valley and adjoining parts of the coastal lowland. Knob-and-kettle gravels are abundant below an elevation of 1,000 feet along Cameron - Little Qualicum Valley northeast of Cameron Lake, and narrow discontinuous gravel terraces separated by belts of knob-and-kettle topography are found between 1,000 and 600 feet above sea-level along the lower parts of the mountain front for 1½ miles northwest and southeast of the valley. The terraces along the mountain front characteristically slope downward from northwest to southeast.

A delta-shaped gravel terrace 450 to 500 feet above sea-level and about a mile across, lies along the inland border of the coastal lowland west of Little Qualicum River. It is surmounted by isolated kames near the base of the mountain slope and is pitted by deep kettles. Its north boundary is a steep scarp with an irregular scalloped outline that drops 75 to 100 feet to a narrow belt of knob-and-kettle gravel and sand separating the terrace from an area of marine deposits. East of Little Qualicum River, the same terrace and arcuate peripheral scarp extend east and southeast to the Alberni Road at Whisky Creek. This eastern part of the terrace is separated from the mountain front by an area of kame-and-kettle gravels (Plate VIIA) in which the highest summits are at about the same altitude as the terrace surface. The kame-and-kettle area is bordered on the south by narrow terraces about 550 feet above sea-level, that follow the contour of the mountainside. Possibly the 550-foot terraces and the 450-to-500-foot delta-shaped terrace to the north are parts of a single sloping surface, but more probably they form separate levels. Both the 550-foot terraces and the kame-and-kettle belt extend about 2½ miles southeast from Little Qualicum River.

South of Hilliers in the Parksville map-area the kame-and-kettle belt terminates in a gravel-and-sand delta that is about ¾ mile across and 450 to 500 feet above sea-level. Along its outer eastern margin, the delta surface grades imperceptibly, with no break in slope, into an area of marine sand. Westward, the terrace rises very gradually in elevation, becomes progressively more gravelly, and is pitted by an increasing number of kettle holes. Between this Hilliers ice-contact delta and the delta-shaped terrace adjoining Little Qualicum River, the kame-and-kettle gravels are bordered on the north by marine sand, and their lower parts have probably been modified by marine action.

The ice-contact deposits in and around the mouth of Cameron - Little Qualicum Valley consist, typically, of well-sorted and rounded pebble and cobble gravel and pebbly sand, but some of the kame-and-kettle deposits include poorly sorted gravel, boulders, and lenses of till. In contrast to the situation at Horne Lake, pebble counts have not helped to distinguish the deposits of streams flowing out of the valley from those of streams originating in the coastal belt.

The narrow terraces and belts of kames sloping southeastward along the lower parts of the mountain slope near Little Qualicum River appear to be deposits of streams that flowed southeast along successive margins of a glacial body in the Georgia depression. The kame-and-kettle gravels in the mouth of Cameron - Little Qualicum Valley probably were deposited in part by these streams as they crossed the valley mouth on remnant ice, and in part by contemporaneous or later streams flowing out of the valley. The 550-foot terrace along the inland border of the coastal lowland and the kame-and-kettle gravels bordering the terrace on the north, form a kame-terrace system that, like the adjoining higher terraces, seems to have been deposited by a southeast-flowing stream confined between the mountain front and a glacial body in the Georgia depression. The absence of this terrace northwest of the mouth of Cameron - Little Qualicum Valley suggests that the stream originated in the valley rather than on the coastal lowland to the northwest. At first, the stream must have been closely confined against the mountain front in the belt now occupied by the terrace and must have escaped to the southeast by an unknown course. Later, it flowed at a slightly lower level over discontinuous ice along the present kame-and-kettle belt and built the Hilliers ice-contact delta where the broken ice terminated in water standing between 450 and 500 feet above present sea-level. The coincidence of this level with the limit of marine submergence and the gradation of the delta deposits into sand and clay similar to materials elsewhere containing marine shells are believed to be indications that the delta was built into the sea.

The 450-to-500-foot terrace straddling Little Qualicum River is bordered by a fresh ice-contact scarp on the northwest and by a smooth wave-modified slope on the northeast. The northeast face would be no more exposed to wave attack during submergence than the northwest face, and therefore, like the Spider Lake terrace, this deposit is believed to be partly a kame terrace built against ice and partly a delta built into marine water. Its symmetrical outline relative to the Cameron - Little Qualicum Valley and its slope away from the valley mouth west of the river indicate that it was deposited by a stream flowing out of the valley. Probably it was built by the same stream that deposited the Hilliers ice-contact delta after progressive disintegration of the glacial ice had permitted the sea to penetrate westward along the northern edge of the kame-and-kettle belt as far as the present course of Little Qualicum River. Remnant ice must nonetheless have remained beneath the gravels in at least the western part of the kame-and-kettle belt to provide a bed for the stream that built the eastern section of the kame delta. Still later persistence of remnant ice in this part of the kame-and-kettle belt is evident in the relationships of a small delta 30 feet below the main delta terrace and bordering it on the east. This delta occurs at the mouth of a kettle-floored channel that disappears headward among the much deeper kettles of the kame-and-kettle belt. It was therefore built by a stream that flowed over remnant ice and into a water body whose surface was about 30 feet below the water level during formation of the main 450-to-500-foot delta. If both water levels were marine, then glacial ice must have remained buried beneath gravels of the kame-and-kettle belt during the (considerable ?) time required for a change of 30 feet in the land-sea relationship.

The stream that deposited the Little Qualicum kame delta and the terraces and kames on the coastal plain to the east may have been fed by meltwater from a glacial body filling Cameron Valley or may have flowed out of a lake dammed above the present level of Cameron Lake by remnant ice and/or ice-contact gravels in the valley mouth.

Englishman River Eskers

Three small eskers head on the lower mountain slopes adjoining Englishman River valley several miles south of Parksville map-area and terminate about 500 feet above sea-level between Englishman River and South Englishman River (*see* Map 1112A). It is tempting to suggest that the eskers never extended much farther to the north and that their deposition (or non-deposition) was governed in some way by the 500-foot stand of the sea that appears to have been associated with the retreat of the Strait of Georgia glacier, but more probably the courses of the eskers to the north have been obliterated by marine and fluvial erosion and by the successions of marine deltas flanking the rivers.

The westernmost esker heads in a kame field on the mountain slope 1,200 to 1,600 feet above sea-level just west of where the northwest wall of Englishman River valley meets the mountain front. Isolated kames, kame-terrace remnants, and channel segments on the mountain front northwest of the kame field appear to have been formed by streams flowing southeast between the Strait of Georgia glacier and the mountain slope. Probably the kame field and the esker extending northeast from it were built by diversion of the same streams within or beneath ice of an active glacier that flowed out of Englishman River valley and that diverted the flow of ice in this part of the Georgia depression.

The highest delta terrace bordering South Englishman River contains a steep-walled, kettle-floored ice-contact depression ¼ mile across. This delta is between 450 and 500 feet above the present sea-level and, like the ice-contact deltas at Spider Lake and Little Qualicum River, seems to have been built into the sea and around remnant blocks of glacial ice during deglaciation. Gravel knobs up to 30 feet high that stand above the terrace surface west of the river are believed to be remnants of the nearby eskers that have been surrounded by the delta.

Along Englishman River, terraces 450 feet above sea-level and higher are inconspicuous and thoroughly eroded, and have lost any ice-contact form that they may originally have possessed. On the other hand, the highest (420 feet above sea-level) marine delta of any size southeast of the river contains three isolated kettle holes a few feet deep and a few tens of feet across. The ice-blocks that presumably melted out from within the gravels to form these pits may have been small pieces of berg ice that were buried by the delta as it advanced into the sea, or pieces of local glacial ice carried into position by the river. In view of the absence of kettle holes from all other delta terraces of the coastal lowland except those 450 to 500 feet above sea-level, it seems unlikely that bergs were widely distributed in the Georgia Strait while the 420-foot delta was being built.

Glacial Landslide

A landslide that left a prominent scar on the mountain slope along the northeast side of Alberni Valley just north of Mount Joan has spread rubble 3 miles southward along the floor of the valley as far as the junction of Ash and Stamp Rivers. The relationships of this rubble to the glacial deposits indicate that the slide must have come to rest on thin glacial ice in the bottom of Alberni Valley.

The slide material varies greatly in texture and sorting but is distinguishable from the other unconsolidated deposits of the valley floor because the contained stones are angular and consist exclusively of massive dark green trap and vein quartz. Some of the slide material looks like fault breccia, some is like glacial till, and some is fairly well sorted gravel. Isolated angular blocks 5 to 50 feet across are scattered amid the finer rubble. As far south as the road extending west from the Alberni Pacific Lumber Company camp, the slide deposits are continuous and probably average more than 100 feet in thickness. This northern part of the slide surface is characterized by more or less conical hills 50 to 100 feet high consisting of blocky rubble. Angular blocks as big as houses are scattered between the hills and are perched on their slopes and summits. South of this road the slide surface drops off steeply for about 50 feet to a flatter area in which the landslide rubble is discontinuous and, for the most part, is less than 10 feet thick. In much of this lower area the slide deposits take the form of a featureless till-like veneer, but in a few places they form conical hills up to 30 feet high. Locally, the slide is represented only by isolated blocks of trap lying upon till and other glacial deposits.

An esker, trending southeastward, appears from beneath the landslide deposit about ½ mile southwest of the Alberni Pacific Lumber Company camp. Slide material is not present where the esker crosses the north-south road about a mile south of the camp, but ¼ mile to the northwest up the esker from the road, isolated blocks of dark green trap up to 10 feet across are strewn about on the top and sides of the esker and on the surrounding ground moraine. Farther northwest the rubble on the esker surface becomes progressively more abundant until it completely veneers the pebbly esker gravel, although the form of the esker remains unmodified. Then, rather abruptly, the landslide rubble develops a hummocky surface and thickens sufficiently to obscure the esker completely. About a mile north of the junction of the Ash and Stamp River—adjoining the northwest-trending 'Comox' road—are two small groups of conical gravelly hills 10 to 30 feet high which are considered to belong to the esker system. Some of these are normal kames consisting of fairly well sorted and rounded pebble gravel including various rock types, but other hills are built of angular landslide gravel made up of pieces of dark green trap including blocks several feet across. A road-cut in one of the knobs surfaced with landslide-type gravel revealed a bed of round-pebble gravel containing various rock types. This bed is enclosed by about 5 feet of angular gravel composed exclusively of green trap. On the other hand, isolated angular blocks of dark green trap lie on the tops and slopes of some of the pebble-gravel kames, and a small gravel pit in one of these kames encountered several such blocks. These relationships seem to indicate that the kames of pebble gravel and the knobs of slide gravel had a common origin.

The landslide deposit lies upon both the ground moraine and the esker and must therefore have been formed after the climax of the last glaciation of the area. On the other hand, the presence of slide blocks in the kame gravels indicates that the slide could not have taken place after the disappearance of the ice. Moreover, distribution of the blocks of slide material on the top and sides of the kames and esker rather than in the adjoining hollows would be difficult to explain if the slide had spread over the ground rather than over the ice. It is therefore concluded that this slide came to rest on thin glacial ice during deglaciation, and as the ice melted, the slide materials became incorporated in some of the glacial deposits and were let down as a blanket on top of others.

Numerous landslide deposits are found below the steep valley-walls in the mountainous parts of the area, but the slide described above is the only one that has been demonstrated to have taken place during deglaciation. Nonetheless, the oversteepened hillsides would be less stable immediately after being uncovered by the glacial ice than at any subsequent time, and, in the absence of evidence to the contrary, it seems probable that many of the landslide deposits were formed during or soon after deglaciation.

Glacio-marine Deposits

Among the various marine deposits overlying the ground moraine and glacio-fluvial deposits of the Vashon drift are stony clays and till-like materials that, apparently, were formed by mixing of sea-bottom muds with debris dropped by floating ice. The materials provide no indication whether this floating ice was glacial or whether it was sea ice, but if the climate of southern Vancouver Island were cool enough to produce appreciable quantities of sea ice, glacial bodies would also be discharging icebergs into Georgia Strait and Alberni Inlet. If, as inferred from the ice-contact deltas, the glacial bodies in both Alberni Valley and the Georgia depression terminated in the sea during deglaciation, extensive rafting by bergs and floating glacier tongues must have taken place. It is therefore believed that many of the stony marine deposits contain material rafted by floating glacial ice and thus may be considered to be of glacio-marine origin. Nonetheless, a clear-cut distinction between these glacio-marine deposits and normal marine deposits has not been possible, either in mapping or in description. The glacio-marine deposits have therefore been included with the marine deposits and assigned to the Capilano sediments rather than to the Vashon drift.

Glacial Movements Associated with the Vashon Drift

The record of the last glaciation is found in the ground-moraine, ice-contact and glacial-landslide deposits of the Vashon drift (described above), and in the erosional glacial features inscribed upon the bedrock of the region. In the following, information on glacial movements derived from rock surfaces will be integrated with the information on the same subject derived from the Vashon drift (largely presented above) to outline the sequence and pattern of ice-movements during the last glaciation. Most of the pertinent data are shown in Figure 8.

Striae and related ice markings are clearly discernible on almost all glaciated rock surfaces that have been newly exposed by waves, rivers, and human agencies. Unfortunately, such surfaces are rare, and the weathered, more or less moss-covered surfaces that comprise most of the bedrock exposures of the region reveal such indicators of glacial movement in only a few places. In logged areas, on the other hand, striae and even grooves cut by sliding logs and cables simulate features of glacial origin. Such rock-inscribed features that are believed to be glacial-flow markings are plotted on Figure 8. Stoss-and-lee surfaces, miniature crag-and-tail forms, and *roches moutonnées* are assumed to reveal the direction of movement of the eroding ice, and are indicated on the map by a directional symbol, whereas striae and grooves are represented by a symbol showing merely trend or bearing.

It is assumed that most if not all of the glacial-flow markings shown in Figure 8 date from the last glaciation. This inference is supported by the observation that the direction of the ice-movement determined from stones in Vashon drift—wherever such determinations have been made—is parallel with the nearby striae, grooves, etc. Moreover, glacial movements associated with the Dashwood drift may well have been similar to those associated with the Vashon (see discussion of Dashwood till), and therefore the inclusion of a few striae etc. of the early glaciation with those of the last would probably not lead to radical inconsistencies. An entirely different intepretation, however, has been put forward by Clapp, who ascribed the glacial-flow markings on the rock surfaces of southern Vancouver Island to his Admiralty glaciation, which appears to be equivalent to the Dashwood of this report (Clapp, 1914, pp. 90-91; 1917, pp. 351-352).

Across the Mountains

Glacial-flow markings on the mountain crests of the area all appear to have been made by ice flowing south to southwest across Vancouver Island. On the ridge crests of Beaufort Range, striae and grooves trend exclusively north-south to northeast-southwest, and associated stoss-and-lee surfaces and crag-and-tail forms in half a dozen places reveal south-to-southwest glacial flow. Outcrops on the summits of the range are glacially rounded, and a *roches moutonnées*-like boss, shaped by the southwest-moving ice, was found only 10 feet below the summit of the highest peak (elevation 5,109 feet). Similar evidences of south-to-southwest glacial movement have been found on the ridges south of Cameron Lake bordering Mount Arrowsmith, but there the highest recorded striae and grooves, except in cirques, are only 4,600 feet above sea-level. Above this elevation, although many outcrops are rounded and smooth, positive evidence of glacial cover outside the cirque basins has yet to be found. Rock outcrops on the summit ridge above an elevation of 5,500 feet appear to be more deeply frost-heaved and disintegrated than on lower ridges. This difference may be due to an increase in frost action with elevation but may, alternatively, indicate that the summit ridge of Mount Arrowsmith was not covered by the last ice-sheet. The sharp arête-form of the summit ridge, contrasting with the typical broader ridges at lower elevations, is in accord with the inference that the summit stood above the ice as a nunatak, although its form certainly is partly due to undercutting by local glaciers in the flanking cirques.

The few published records of the direction of glacial movement on the mountain and ridge crests southeast of the area are in accord with the above observations. Thus, in the Cowichan Lake area: "on the ridge east of Mount Service, striae trend south to south 15 degrees west, and at an elevation of 4,500 feet on the ridge at the head of the southwest fork of Nitinat River, striae trend south 10 to 15 degrees east. Stoss-and-lee surfaces indicate that the ice moved southward" (J.T. Fyles, 1955, p. 9). Clapp (1913, 1914, 1917) has recorded many striae in southern Vancouver Island but most of these represent valley and lowland ice-movements. He has concluded, however, that ice moved southward across the uplands of the Sooke and Duncan areas.

Northwest of the area, glacial-flow markings on the ridge crests at the northern end of Beaufort Range and of Forbidden Plateau west of Comox Lake all record northeast glacial movement off the Vancouver Island mountains and towards the Georgia depression. Possibly the southwestward-moving ice that crossed the mountains in the area did not cross the higher mountains to the northwest, although it is alternatively possible that erosion by the northeast-moving ice has removed the evidence of earlier ice-flow in the opposite direction.

In Valleys Through Beaufort Range

Glacial ice moved southwestward in the passes and valleys through Beaufort Range in the same general direction as the ice flowed across the nearby ridge tops. Glacial-flow markings in Cameron Valley, on the low divide between Cameron and Alberni Valleys, and on the low plateau south of Horne Lake all vary in trend with the valleys and hillsides but record glacial movement from the Georgia depression towards Alberni Valley (*see* Fig. 8 and Plate VIIB). Glacial flow in this direction in Cameron Valley is also indicated by the presence of abundant granitoid stones in till along Cameron Lake (see discussion of mountain tills).

The ice in these valleys would have flowed southwestward during the climax of glaciation while the ice extended across the mountains and ridges, and also later when the ice surface had dropped below the ridge tops and the main ice-flow had been diverted along the mountain front bordering Georgia depression. Intersecting ice-movement indicators on the low divide between Cameron and Alberni Valleys appear to record changes in ice-flow direction with changes in ice thickness. There, grooves and miniature crag-and-tail forms made by southwest-moving ice are crossed by striae associated with stoss-and-lee surfaces indicating southward ice-movement. A third set of striae trends east-west; this set less clearly appears to be inscribed on the southwest-trending grooves, and the distribution of the striae on the eastern ends of outcrops suggests movement from east to west. The earliest, southwest movement across this divide probably took place when the ice was thick enough to flow undeflected across the west wall of Cameron Valley. The southward movement may then have occurred after the glacial tongue had thinned until its direction of flow was controlled by the west wall of Cameron Valley, but while it was still thick enough to cut across the shallow east-west pass at right angles. The east-west striae probably were formed by the Cameron Valley ice moving west over the divide after further wastage.

In Cirques and Cirque-headed Valleys Beaufort Range and Mount Arrowsmith

Cirques and associated valleys on the east side of Beaufort Range have yielded abundant evidence of up-valley glacial movements in the same general direction as the ice-flow recorded on nearby ridges. In Rosewall Creek valley, southward up-valley glacial movement is abundantly recorded by stoss-and-lee surfaces and miniature crag-and-tail forms on the valley floor and walls and by the presence of granitoid and sandstone pebbles (derived from the Georgia depression) in the till on the valley floor. Grooves and stoss-and-lee surfaces formed by this up-valley movement have been found on an outcrop a few tens of feet above the base of the steeply sloping valley headwall and also on the uppermost part of this headwall a few feet below the break in slope separating cirque from ridge crest. Similar evidence of southwestward, up-valley glacial movement has been found just below the top of the headwall of a cirque on the east side of the Beaufort Range south of Mount Joan and in the mouth of the cirque-headed valley extending east and northeast from Mount Irwin. All these cirques and valleys undoubtedly were sculptured by local glaciers that moved northeast down the valleys, and the up-valley ice-movements described above clearly took place after this sculpture. The flow of ice up the floors and steep heads of these valleys probably occurred mainly during the climax of glaciation—while the surface of the ice stood above the ridge crests at the valley heads—but perhaps may also have occurred along the retreating ice edge after it dropped below the valley-head divide.

Moraines and rock-inscribed indicators of down-valley ice-movement appear to be entirely lacking from those cirques and cirque-headed valleys of the Beaufort Range that have been examined on the ground, and therefore active local glaciers (as opposed to ice-sheet remnants) apparently have not reoccupied these valleys since the climax of the last glaciation. On the other hand, a cirque that was visited on the east side of Mount Arrowsmith (with floor 4,500 feet above sea-level and 500 feet above the highest cirque floors of Beaufort Range) contains *roches moutonnées* that record down-valley northeast ice-movement of a local glacier. Evidence of southeast up-valley ice-movement was not found in this cirque even though evidence of movement in that direction was found on neighbouring ridges. Apparently then, the snow-line at some time during or since deglaciation was low enough for the existence of active glaciers around Mount Arrowsmith massif, but at no time since the climax of the last glaciation has it been low enough to permit active glaciers to develop on Beaufort Range.

In Georgia Depression

Most glacial-flow features within the Georgia depression record southeastward movement of ice—more or less parallel with the length of the depression and the front of the Vancouver Island mountains. In only a few places on the lowlands is there evidence of south or southwest glacial movement like that so abundantly recorded on the mountains.

Glacial-flow markings have been found in only the northwestern and southeastern parts of the coastal lowland of the area—the only places where outcrops are plentiful. The most abundant striae and grooves trend southeast to east-southeast in the northwestern part of the lowland and east to east-southeast in the southeastern part (*see* Fig. 8). Stoss-and-lee surfaces and *roches moutonnées* provide abundant evidence that the associated ice-flow was southeastward. Surfaces of this type are especially prominent on Ballenas Islands and on Winchelsea Islands. Correlation of this southeast movement with the Vashon drift is supported by the southeast trend of the fabric orientations of some of the Vashon tills and by the direction of travel of erratics derived from bodies of distinctive granodiorite near Courtenay. All published information on the direction of glacial movement in adjoining parts of the Georgia depression (Bancroft, 1913; Clapp, 1914; McConnell, 1914) agrees that the ice flowed southeast.

Striae trending north-south to northeast-southwest have been found in a few places in both the northwestern and southeastern outcrop areas of the coastal lowland. Evidence that the associated glacial movement was southward is provided by crag-and-tail forms on Cottam Point (east of Northwest Bay), by stoss-and-lee surfaces about a mile south of Mud Bay, and by crag-and-tail forms on conglomerate on the mountain slope bordering the lowland near the head of Cowie Creek. Inscribed upon these crag-and-tail forms at Cowie Creek, and therefore younger than the southward glacial movement, are striae averaging N75°E which parallel another set of crag-and-tail forms indicating eastward ice-movement and which, in turn, may be equivalent to the abundant southeast-trending features of the coastal lowland. Association of north-south glacial movement with some Vashon tills of the coastal lowland is suggested by both fabric orientations and pebble counts (see discussion of sandy tills of the Vashon drift).

The rare and isolated indications of south-to-southwest glacial movement in the coastal part of the area (listed above) may possibly record a general movement of ice across the Georgia depression whose effects have been largely obscured during later southeast ice-movements along the depression. If so, the south-to-southwest-flowing ice-sheet that covered the Vancouver Island mountains may have been fed by ice moving in more or less the same direction across the Georgia depression from the Coast Range. The more abundantly recorded southeast movement of the Strait of Georgia glacier would then have resulted from diversion of the south-moving ice along Georgia depression when the ice had become too thin to push across the Vancouver Island mountains. On the other hand, the proportion of granitoid stones in tills of the coastal lowland is lower than would be expected if there had been extensive southward glacial flow across the Georgia depression from the Coast Range. The isolated records of south-to-southwest ice-movement in the Georgia depression may, therefore, have no regional significance but merely reflect local diversion of the southeast-flowing ice. If this is true, ice in Georgia depression throughout the last glaciation flowed dominantly southeast along the depression, and the southward movement of ice across the Vancouver Island mountains would then have been merely a lateral overflow of the southeast-moving Strait of Georgia glacier.

The coastal lowland adjacent to Englishman River has been overridden by an ice-tongue moving northeast out of Englishman River valley in addition to the southeast- and (?) south-moving glacial bodies discussed above. This northeastward ice-movement is recorded by crag-and-tail forms on conglomerate on Little Mountain and along the old Alberni road a few hundred feet east of Englishman River. It is also recorded by the localized distribution of granodiorite-rich till and till-derived gravels between Englishman River and Nanoose, and by the north-to-northeast fabric orientation of granodiorite-rich tills (see discussion of Vashon tills of coastal lowland, and Fig. 8). Near the coast, only the uppermost part of the Vashon till (now represented mainly by wave-washed lag gravel veneering the till) is rich in granodiorite stones, and therefore the northeast ice-movement there occurred late in the last glaciation. The ice moving out of the valley must, logically, have been fed by a mountain glacier heading on the east side of Mount Arrowsmith. This conclusion is supported by the evidence, presented earlier, that local glaciers existed in cirques on the Mount Arrowsmith massif at some time during or since deglaciation.

In Alberni Valley

Glacial ice flowed southeastward along Alberni Valley and eastward into the valley from its western tributaries. These directions of glacial movement are indicated both by glacially moulded forms and by the lithology of the drift. Evidence of southwestward glacial flow has been found only in the southeastern part of the valley opposite the low passes through Beaufort Range.

In the northern part of Alberni Valley drumlinoid ridges trend northeast, east, and southeast, as shown in Figure 8. They record flow of glacial ice into Alberni Valley from the tributary valleys to the west, and movement of ice down the northeastern side of Alberni Valley more or less parallel with the steep valley-wall.

The same pattern of glacial movements has been found southeast of the drumlinoid zone. In the eastern, drift-floored part of the valley, southeast glacial flow is recorded by a few striae and stoss-and-lee surfaces as well as by the low granodiorite content and high sandstone content of the till. In the western part of the valley, most striae and grooves trend east, east-northeast, and east-southeast, and, together with associated stoss-and-lee surfaces, indicate a fanning-out of ice into Alberni Valley from Great Central and Sproat Lake valleys. On a hill west of Stamp River, about a mile upstream from its junction with Ash River, *roches moutonées* formed by southeast-moving ice bear striae trending N80°E on their western sides but not on their eastern sides. This relation of striae to *roches moutonnées* suggests that, there, eastward movement of ice from Great Central Valley took place after southeast movement down Alberni Valley.

Evidence of the direction of glacial flow on the steep northeast wall of Alberni Valley has been found only near its southern end between Bainbridge and Rogers Creek, where the top of the valley wall is less than 1,500 feet above sea-level; striae on this low part of the valley wall trend southeast. In one place on the plateau a few hundred feet east of the top of the valley wall, striae trending southeast intersect another set trending south-southwest, but all other glacial-flow features found on the plateau near the valley wall have been formed by south- to southwest-moving ice. Thus apparently the southeast-flowing Alberni Valley glacier did not extend far beyond the valley rim.

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Both southeast and southwest glacial movements seem to be represented on the southeastern part of the floor of Alberni Valley east of Alberni and Port Alberni. Characteristically, 10 to 15 per cent of the pebbles in the tills of this part of the valley are composed of granodiorite and probably came from the northwest, but isolated pieces of purple chert, chlorite schist, and crystalline limestone in some of the tills have come from a source to the east and northeast. Intersecting sets of striae trending N60°E and N70°W have been found on an outcrop in the southern part of Port Alberni and may indicate that both the southeast and southwest glacial movements crossed this part of the area. Nothing is known of the relative age of these two glacial movements.

Elsewhere in Alberni Valley, evidence of southwest glacial flow is lacking even though ice crossed the adjoining part of Beaufort Range in that direction. There is no evidence of deflection of the ice-movement across Beaufort Range such as would be caused by contemporaneous ice-movement along Alberni Valley. Therefore during the climax of glaciation, the south-to-southwest-flowing ice must have crossed part if not all of Alberni Valley. The absence of any evidence of glacial flow in this direction on the floor of Alberni Valley in the lee of the high part of Beaufort Range may possibly indicate that only the upper part of the ice moved southwest while the basal ice was stationary or perhaps flowed southeast. As the ice surface dropped below the crest of Beaufort Range, the southwest flow of ice across Alberni Valley must have ceased and have been replaced by southeast flow, except near Alberni and Port Alberni where ice may have continued to enter the valley through the passes occupied by Horne and Cameron Lakes.

Outline of Deglaciation

Three glacier systems that emanated from different regions occupied the map-areas during and after the climax of the last glaciation. The most extensive was the Strait of Georgia glacier system, which was fed by ice from the Coast Range and from the mountains of Vancouver Island northwest of the map-area. Glaciers in Alberni Valley and its tributaries, at least after the climax of the glaciation, were fed by an ice-cap on the Vancouver Island mountains northwest of the area. An independent valley-glacier system occupied Englishman River valley and the cirques on the east side of Mount Arrowsmith during at least the later stages of deglaciation. Both the Englishman River glacier and the ice-cap northwest of Alberni Valley supplied ice to the Strait of Georgia glacier as the latter waned.

Strait of Georgia Glacier System

Ice of the Strait of Georgia system, during its maximum stand, covered both map-areas except perhaps the summit of Mount Arrowsmith and parts of Alberni Valley. As the supply of ice diminished and the surface of the ice became lower, the crest of Beaufort Range and the ridges surrounding Mount Arrowsmith cut off the southward flow of the Strait of Georgia ice across this part of Vancouver Island, except in valleys extending through the mountains such as those occupied by Cameron Lake and Horne Lake. Ice in the valleys heading on the east side of Beaufort Range apparently ceased active movement as the glacial surface dropped below the level of the valley heads and, with further lowering of the ice surface, the ice in the valleys of Cameron and Horne Lakes likewise became stagnant. Alluvial fans were built against the edges of these waning ice-tongues by mountainside streams. Rivers flowing along the ice-margins and small lakes ponded by the ice made small terraces along the valley walls. It would seem likely that the ice in many of these mountain valleys melted sooner than the much larger glacial mass in the Georgia depression although conclusive evidence remains to be found. On the other hand, ice certainly remained in Horne Lake valley until after construction of the Spider Lake terrace, when ice in adjoining parts of the Georgia depression was breaking up.

Changes in the southwestern edge of the Strait of Georgia glacier are evident in ice-contact features along the inland edge of the coastal lowland and adjoining hillsides. These features record the courses of streams that flowed off the land onto the side of the glacier and southeastward along the side of the glacier. Ice-marginal delta-like forms appear to mark the terminal edge of the glacier and to indicate that it was bordered by marine water standing 450 to 500 feet above present sea-level. The distribution of these various ice-contact forms points towards progressive lowering of the lateral ice-margin and northwest recession of the terminal margin.

Ice-contact alluvial fans along the mountain slope at the heads of Chef Creek and McNaughton Creek outline a former glacial margin about 1,500 feet above the present sea-level that sloped downward to the southeast. At one stage a stream from the southeast end of the belt of fans drained northward down the hillside beneath(?) the ice to form an esker. A belt of knobby ice-contact gravel extending southeast from Chef Creek parallel with the direction of glacial movement appears to have been deposited by a river system flowing southeast in a series of crevasses. This river system was initiated before the ice surface dropped below an elevation of 1,000 feet, and the rivers apparently continued to flow until the ice surface stood below 700 feet.

The Spider Lake terrace, in the mouth of Horne Lake valley, is interpreted as a deltaic body built partly in marine water standing between 450 and 500 feet above present sea-level and partly around and against remnant glacial ice. The river that deposited this terrace headed on or within the Strait of Georgia ice to the northwest and crossed the northern part of Horne Lake valley on ice. This may have been the same river that deposited the belt of kames on the coastal lowland to the northwest. On the basis of the above interpretations, the Spider Lake terrace marks the southwestern extremity of a terminus of the Strait of Georgia glacier. This ice edge seems to have been bordered by a series of glacial remnants separated by marine water.

Ice-contact features near Little Qualicum River record earlier events and changes like those described above along the southern margin and terminal edge of the Strait of Georgia glacier. Kame terraces, kames, and hillside channels on the lower part of the mountain slope northwest and southeast of Little Qualicum River and in the mouth of Cameron - Little Qualicum Valley appear to have formed in streams that flowed southeast along successive margins of the Strait of Georgia glacier as the level of the ice dropped from an elevation of about 1,200 feet to 600 feet. Much more extensive terraces along the inland margin of the coastal lowland 550 to 450 feet above present sea-level were deposited by a later, lower ice-marginal stream that flowed out of Cameron - Little Qualicum Valley. Initially, this stream flowed southeast along the base of the mountain slope but later it found a course east from the valley mouth across remnant ice and built a delta at an ice-sea margin south of Hilliers. Another delta-like body, straddling Little Qualicum River, seems to have been built by the same stream partly against ice and partly into standing water at another later position of the margin between sea and ice. These delta-like forms, like the Spider Lake terrace, are interpreted as marking positions of the terminal margin of the Strait of Georgia glacier and provide further evidence that the ice terminated in the sea, which stood between 450 and 500 feet above its present level, relative to the land.

Englishman River Glacier

Southeast of the features described above, a glacier occupied the valley of Englishman River and flowed into Georgia depression during the time of general deglaciation. Eskers on the lowland and the lower parts of the mountain front near Englishman River relate to the Englishman River glacier. A stream that flowed southeast along the margin of the Strait of Georgia glacier between Little Qualicum River and Englishman River appears to have been diverted northward beneath the Englishman River glacier to build one of these eskers. If this inference is correct, the Englishman River glacier coalesced with the Strait of Georgia glacier while the surface of the latter stood at an elevation of 1,500 or 2,000 feet. It is not known whether the Englishman River glacier continued to flow into the Georgia depression after the Strait of Georgia glacier had retreated to the northwest. The presence of a large ice-block hole in a delta between 450 and 500 feet above present sea-level along South Englishman River suggests that there, as to the northwest, the end of the retreating glacier was bordered by the sea. Evidence that glacial ice remained in Englishman River valley south of the Georgia depression until sea-level had dropped to 420 feet above its present position is provided by kettle holes in a delta at this elevation.

Alberni Glacier System

Deglaciation of Alberni Valley was controlled by the regimen of a system of glaciers emanating from the mountains of Vancouver Island to the northwest. During the climax of the glaciation, at least some of the ice in Alberni Valley emanated from the Strait of Georgia glacier system, but as the ice began to get thinner, this ice-flow was cut off by the Beaufort Range. Then the glacial ice in Alberni Valley became part of a mountain ice-sheet complex that covered the country to the northwest and apparently centred in the high mountains surrounding Buttle Lake. With further thinning of the ice, this ice-sheet separated into a network of valley glaciers, one occupying Alberni Valley. The Alberni Valley glacier and its western tributaries continued to be active and continued to coalesce even when they became thin. Support for this conclusion is provided by the southeast-trending esker system which, adjacent to Ash River, splits headward into tributaries trending southeast, east-southeast, and east parallel with adjacent drumlinoid ridges formed by the Alberni Valley glacier and by one of its western tributaries. Superposition of lithologically different tills records changes in the relative activity of the Alberni Valley glacier and of its tributaries, but details of these changes are not known.

The glacio-fluvial features of Alberni Valley indicate that the ice disappeared first from the southeastern part of Alberni Valley and suggest that the ice-margin retreated northeastward up the valley. An ice-contact stream that flowed eastward from Sproat Lake valley along the south end of Alberni Valley is recorded by an abandoned channel and by small kame terraces west of the head of Alberni Inlet. During the existence of this stream, the narrow valley occupied now by Alberni Inlet cannot have been entirely blocked by ice above the level of the stream bed and the approximate coincidence of the elevation of this stream bed with the limit of marine submergence may be an indication that the sea occupied the Alberni Inlet valley at this time. Ice-contact gravels outline the course of a river that at a later stage flowed eastward from the mouth of Great Central Valley over and around remnant glacial ice and probably terminated mid-way across Alberni Valley in marine water 300 feet above the present seashore. At this stage, the western part of Alberni Valley north of Great Central was occupied by ice. The margin of this ice is believed to have retreated northward and for a brief period dammed a lake north of the Great Central gravels in the northward-draining part of the Stamp River valley. The course of another meltwater stream is outlined by a southeast-trending esker system north of the features described above. This esker terminates in a kettled terrace 300 feet above the present seashore—a terrace that may be a delta formed where the esker stream flowed out of its ice-bordered channel into the sea. If so, the esker stream and the river that built the Great Central terraces terminated at the same, or nearly the same stand of the glacier front. While the esker was being built (or perhaps soon after) a landslide off the face of Beaufort Range spread debris across the surface of the thin glacial ice, and when the ice melted, this debris was let down upon the esker and became mixed with some of the associated deposits.

Age and Correlation of the Vashon Drift

The glaciers that deposited the Vashon drift in the map-areas are believed to have extended over all of the southern part of Vancouver Island and the Georgia depression, and probably into the Puget lowland. Therefore, it seems logical that the widespread 'latest regional' glacial deposits of the Georgia depression and Puget lowland all relate to the same glaciation. On the basis of this assumption, the Vashon drift of this report is tentatively correlated with the Vashon drift of southern Vancouver Island (Clapp, 1913, 1914, 1917), with the Vashon Group of the Lower Fraser Valley (Armstrong, 1956a), and with the Vashon drift of the Puget lowland (Crandell, Mullineaux, and Waldron, 1958).

The Vashon drift can logically be considered to be Wisconsin in age on the grounds that it was deposited during the last regional glaciation. Radiocarbon dates of early post-Vashon materials in the region lend support to this inference and indicate that the Vashon glaciation had passed its climax by mid-Wisconsin time. Thus various basal bog deposits resting on Vashon drift in the Puget lowland have radiocarbon ages of up to 14,000 years (Rigg and Gould, 1957; Crandell, Mullineaux and Waldron, 1958) and hence retreat of the Vashon ice from its maximum stand began more than 14,000 years ago.

Two deltas within the area which are related to the post-glacial interval of (isostatic ?) uplift, were built 12,000 years ago (Lamont datings 391D, E, and F). Retreat of the ice from this part of the Georgia depression took place somewhat earlier, perhaps 13,000 or 14,000 years ago. Glacial ice may of course have remained considerably later in Englishman River valley and in Alberni Valley, and in various valleys adjoining the Georgia depression outside the map-areas. Thus radiocarbon dates (L221D and E; L331A, B, and C) point to the presence of glacial ice in the inland part of the Lower Fraser Valley about 11,000 years ago (Armstrong, 1956b).

The Vashon drift and related glacial features of the area have not yielded any evidence of glacial advances, retreats, or marginal halts that might correspond to the named stages of the Wisconsin. On the other hand, glacio-marine and till-like deposits of the inland part of the Lower Fraser Valley are inferred by Armstrong (1956b) to record an advance of valley glaciers after general deglaciation. He correlates the advance with the Mankato interval on the basis of the 11,000-year radiocarbon age of the associated organic materials (see above).

Capilano Sediments

Classification of Post-glacial Deposits

Marine, fluvial, colluvial, and bog deposits have accumulated—and are still accumulating—in appropriate parts of the area since the land emerged from beneath the Vashon ice. The 'modern' seashore, lakeshore, fluvial, and related deposits formed at the present sea, lake, and river levels are set apart as the 'Salish sediments'. Marine, lacustrine, and fluvial deposits related to former sea, river, and lake levels significantly higher or lower (± 20 feet) than the present levels are termed the 'Capilano sediments'. Colluvial deposits and upland swamp deposits include equivalents of both the Capilano and Salish sediments but cannot be subdivided or assigned to either group; in the following they are simply termed 'undivided post-glacial deposits'. Lowland swamp deposits in river flood-plains or shoreline lagoons are considered to be part of the fluvial or shore deposits with which they are associated.

The Capilano sediments are raised or terraced marine, fluvial, and lacustrine deposits. They include shoreline and offshore marine and lake materials as well as deltaic, river-terrace, and alluvial-fan deposits. They rest upon the Vashon drift, and are post-glacial in the sense that they accumulated after the ice had evacuated the places in which they are found; nonetheless, some accumulated while glacial ice remained nearby. The name 'Capilano' was proposed by Armstrong (Armstrong and Brown, 1953) for deposits of the type described above; it is the name of a river bordered by extensive delta terraces north of the city of Vancouver.

The basic elements of the Capilano sediments are the marine deposits, marine-deltaic deposits, and river-channel and flood-plain deposits related to them. Together they provide a record of events between retreat of the glaciers from the lowland parts of the region and establishment of the present stand of the land relative to the sea. All such deposits discovered to date were formed when the sea stood higher relative to the land than it does now, but it is possible that materials related to lower stands of the sea are now submerged or lie within the sediments flooring the lower parts of some valleys. The raised lake deposits, terraced alluvial-fan deposits, and river deposits not tied in to former marine levels as yet cannot be related to the regional sequence of events. They have been studied in much less detail than the Capilano materials that relate to the sea.

Marine and Glacio-marine Deposits

The surface materials throughout most of the coastal lowland and Alberni Valley were deposited in the sea or modified by the sea. These marine materials are exceedingly varied gravels, sands, silts, and clays and range from a few inches to 50 feet in thickness. They are found up to about 500 feet above present sea-level on the coastal lowland and up to about 300 feet in Alberni Valley.

Characteristically, sloping ground is veneered by thin stony or coarse-textured deposits, whereas depressions and low areas are floored with thicker, relatively stone-free 'clay', silt, or sand. The marine deposits are most varied in texture where the former seashores were underlain by sandy-textured till and were exposed to wave erosion—conditions that obtained throughout much of the present coastal lowland. The deposits are more uniform and more clayey where the till is of finer (loamy) texture, where waves were small, and where rivers poured muddy water into the sea, as for instance in Alberni Valley.

Coastal Lowland

Marine Deposits in Depressions and on Low Ground

Depressions and low flat ground on the coastal lowland are floored with marine clayey, silty, and sandy materials 5 to 30 feet thick. On the accompanying geological map the clayey and silty materials are grouped together as a single map-unit and the sands are set apart as another unit. However, this subdivision is arbitrary and the positions of the contacts are gross approximations because the sands in many places form a thin veneer on the finer-textured materials and grade into them.

The clayey marine deposits of the coastal lowland typically are varied, poorly sorted, clayey silts containing a few per cent of sand and isolated pebbles or boulders (*see* Table 1). Some 'clays' are more sandy, and more stony, and resemble loamy to clayey-textured tills. Some are massive, whereas others display indistinct to moderately prominent bedding planes outlined by slight changes in texture; by silty, sandy, or stony layers; or by concentrations of shells. Above the water-table the clayey materials are yellowish grey and hard, and display blocky to columnar jointing. The fresh, unoxidized clays, on the other hand, are grey, soft, and sticky, and some of them are weak and unstable. Marine shells and black fetid organic matter are locally contained in the unoxidized material but only casts and moulds of the shells remain in the oxidized surface material. A black iridescent film that probably consists of manganese dioxide coats the fracture surfaces of the oxidized clays.

The silty marine deposits are uniform, massive, and generally stone-free, and in typical near-surface exposures present a distinctive mottled orange-brown to tan appearance. In the few places where they are unoxidized they are grey. Texturally these materials are moderately well sorted coarse silts, sandy silts, and silty very fine sands (*see* Table 1). Casts and moulds of marine shells and of shell fragments are widely distributed.

The marine sands are orange-brown to yellow in oxidized exposures and pale grey to white at depth. They are well sorted and medium to fine grained and locally contain pebbles. Some of the sands are massive but most display prominent bedding parallel with the ground surface. The characteristic undulations and gentle dips of the bedding planes of the marine sands serve as one basis for distinguishing them from identical but strictly horizontal sands of the Quadra sediments. The surface of the marine sands in depressions and on low flat areas is horizontal or gently sloping and is not marked by beach forms.

In general the 'clays' described above make up the greater part of the marine accumulations in depressions and on flat areas of the coastal lowland, and locally attain a thickness of 30 feet. The silts are a few inches to 5 feet thick and lie on top of the clays. The sands either rest directly on the clays or are separated from them by silt. They range in thickness from a few inches to 15 feet. Commonly sands and silts are confined to the marginal parts of depressions and flat areas, and clayey materials come to the surface in the middle of such areas. Marine deposits that lie downslope from exposures of sand belonging in the Quadra sediments consist dominantly of sand although, as elsewhere, the sand rests upon clay. Marine deposits are especially thick beneath and around the abandoned deltas. Generally, the marine beds associated with the deltas consist of clay overlain by loamy materials and sand and do not differ materially in character from the marine beds found elsewhere. Locally, however, the massive marine clay is replaced by laminated clay, silt, and sand, or by alternate irregular layers of sand, massive clay, and till-like material. The surface sandy marine beds bordering the deltas characteristically contain numerous pebbles.

Table 1

Grain-size Data for Clayey and Silty Marine Materials

Sample Number and Location	Gravel	Sand (%)	Silt (%)	Clay (%)	Modal Diameter (mm)	Median Diameter (mm)	Sorting Coefficient	Textural Description
'Clays', Alberni Valley								
53-38—Somas River	nil	3	39	58	.002	.0013	4	silty clay
53-36—Beaver Creek	nil	0	57	43	.005	.0028	3.8	clayey silt
57-17A—Stamp River	nil	1	56	43				clayey silt
57-17B—Alberni	trace	6	55	39				clayey silt
'Clays', Coastal Lowland								
53-34—Chef Creek	trace	3	67	30	.02	.007	3.9	clayey silt
No. 10, 17-27″—Arrowsmith Farms	trace	7	54	39	.01	.004	4.5	clayey silt
No. 24, 29-37″—Arrowsmith Farms	trace	9	60	31	.01	.006	4.1	clayey silt
No. 24, 37-48″—Arrowsmith Farms	minor	15	66	19	.015	.01	3.2	clayey silt
53-56—Englishman River	trace	2	73	25	.01	.008	3.2	clayey silt
Silty Materials, Coastal Lowland								
53-33—Chef Creek	nil	3	82	15	.04	.017	2.7	silt
No. 1, 15-22″—Arrowsmith Farms	nil	55	42	3	.08	.069	1.6	silty very fine sand
Till-like Materials								gravelly
53-32—Chef Creek	much	29	61	10	.06	.032	3.4	sandy silt
53-39—Somass River	much	19	58	23	.05	.013	4.4	clayey silt
51-7B—Errington	much	36	48	16	bimodal	.02	7	sandy silt
No. 10, 42-60″—Arrowsmith Farms	much	48	43	9	.05	.05	4.0	silty sand

In samples containing appreciable amounts of gravel, the minus 2 mm fraction only was used in determining modal and median diameters and sorting coefficient. Grain-size scale: sand 2 to .062 mm, silt .062 to .002 mm, clay less than .002 mm.

Locally the marine deposits are separated from the underlying till by lenses of stratified and laminated material of various textures. Typically these lenses are 1 foot to 3 feet thick, and consist of pale grey sandy silt and sandy clay with laminations a fraction of an inch to an inch in thickness. The materials generally contain isolated pebbles and larger stones, and in places include layers of sand and sandy, till-like material. Here and there, a few inches to a few feet of coarse poorly sorted gravel separates the laminated material from the underlying till. There is no evidence of drying or erosion between these laminated materials and either the underlying till or the overlying marine deposits, but rather both contacts are transitional. Locally these materials differ from the overlying marine clays only in the presence of lamination and the absence of marine shells.

Marine Deposits on Slopes, Hills and Rolling Ground

Sloping ground in the coastal lowland is veneered by exceedingly varied and dominantly gravelly marine deposits. These veneer deposits average less than 5 feet in thickness although they locally thicken into spits and bars up to 20 feet thick. In its most characteristic form the marine veneer of the coastal lowland consists of $1\frac{1}{2}$ to 3 feet of coarse bouldery gravel, but elsewhere it is dominantly pebbly or sandy gravel. Lenses of sandy, silty, clayey and till-like materials, resembling the marine materials in depressions, are generally associated with the gravels. Although leaching has generally removed calcareous shell material from the veneer deposits, casts of marine shells may be found in some silty and till-like components of the veneer and in a few cemented gravels.

Typical examples of the coarse gravelly phase of the veneer are illustrated in Plate VIII, A and B. These gravels are rather poorly sorted and consist of boulders, cobbles, and pebbles set in a matrix of sand. Screen analyses of the minus 64 mm fraction of three typical samples revealed that they consist of pebbles and sand in about equal proportions and contain less than 5 per cent silt and clay; an exceptionally stony sample contains 80 per cent pebbles and less than 3 per cent silt and clay. The sorting coefficient of each of the three typical samples is about 5. Stratification is absent or indistinct although cobbles and large pebbles in some of these gravels are rudely shingled and the large stones in a few are concentrated in the base of the gravel veneer (*see* Plate VIIIB). The stones in these gravels are typically subangular to subrounded and are similar in size, shape, and lithology to those in the underlying or nearby Vashon till. Surfaces of some of the stones are striated. These gravels appear to be a lag concentrate of stones and sand from the formerly uppermost parts of the till. The widespread presence of 'pebbles' of till in the gravel lends support to this conclusion.

In some places the veneer consists of coarse unstratified gravel containing more silt and clay than that described above; this material is intermediate in texture between the gravels just described and disaggregated till. Elsewhere, the veneer includes pebble gravels and pebbly sands that are much better sorted than the coarse gravels and display well-developed stratification. The individual beds generally are parallel with the contacts of the gravel veneer (and the ground surface) but some form a crosslamination dipping upslope or downslope.

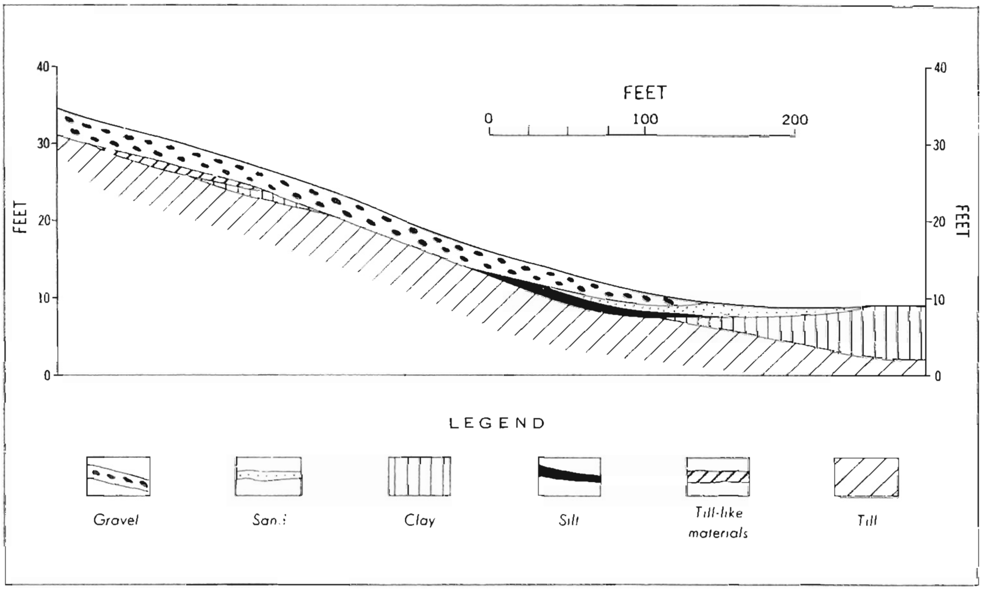

Figure 10. *Diagrammatic cross-section illustrating the typical arrangement of components of the marine veneer on a slope and their relation to thicker marine deposits in a depression.*

Sand, silt, clay, and till-like materials are all locally represented in the veneer. They are lithologically similar to the thicker, more continuous marine accumulations described in the preceding section. Till-like materials are more abundant and more varied than in the thicker marine accumulations. Some of them rest upon till and resemble till that has been slightly enriched in clay and silt. Such materials characteristically constitute a marginal phase of stony 'clay' or replace the 'clay' in small or shallow depressions. Other till-like materials are more silty (sample 53-32, Table 1) and typically are separated from the till by a few inches of clay. Commonly, they are covered, in turn, by stratified gravel. Upon superficial examination they might be classified as till and taken to record a glacial invasion following marine submergence, but careful search reveals that most of them contain casts of marine shells. They appear to be a thin stony phase of the silty marine deposits.

The varied marine deposits of the coastal lowland exhibit a consistent textural arrangement in relation to the hills and hollows of the ground surface. In most general terms, slopes and convex hilltops are covered by a gravelly veneer, whereas flatter areas and hollows are surfaced by clayey, silty, or sandy materials. The idealized cross-section in Figure 10 illustrates the typical arrangement of thin marine deposits on a slope and their transition into thicker marine deposits in an adjoining depression. The gravel on such a slope is well washed (i.e. contains very little silt and clay), and the sand, silt, clay and till-like materials form clear-cut lenses. Both coarse unstratified lag gravel and pebbly stratified gravel are typically represented. This distribution of deposits (*see* Fig. 10) obtains where hills and hollows are at least several hundred feet across and have a relief of several tens of feet and where the slope of the steeper parts of the hillsides exceeds 5 per cent. Similar although less-pronounced changes of texture with topography are found where the topographic features are smaller and the slopes gentler; they can be detected even where local relief is less than 10 feet and individual hills and hollows are only a few tens of feet across. In such places, depressions and flat areas are floored by till-like materials intermediate in composition between the underlying till and marine clay, whereas slopes and hills are veneered by a loose gravelly deposit only slightly less silty and clayey and slightly more stony than the till.

The marine veneer has here been represented as resting upon the Vashon ground moraine, but it also forms a patchy cover on the bedrock outcrops, rests upon sand and other deposits of the Quadra sediments where the Vashon till is absent, and covers small bodies of ice-contact gravel. In these situations the veneer consists mainly of gravel and sand although it locally includes lenses of clay and stony silt. Recognition of the gravelly veneer on gravelly ice-contact deposits is possible only where such lenses of clay and silt are found.

Here and there, shoreline forms can be traced amid the veneer deposits. These features are not portrayed on the accompanying geological map because they cannot be traced in the forest and, in the few places where it has been possible to trace them, they lack continuity. Only rarely can they be identified on the aerial photographs. However, it seems likely that if the forest were removed the whole area occupied by the veneer would be seen to display shoreline features.

Bars and spits have been identified in a number of places. Typically they take the form of elongated ridges of pebble gravel, 5 to 15 feet high and a few tens of feet wide, that connect at one or both ends onto higher ground. The cross-section sketched in Figure 11 includes a pebbly gravel bar bordered on the south by clayey, silty, and till-like materials that appear to have accumulated in a lagoon enclosed by the bar. Broad indistinct spits occur on the south and southwest sides of some of the low hills of the coastal lowland. These take the form of low ridges of pebble gravel and sand a few hundred feet to 1,000 feet wide, 1,000 to 2,000 feet long, and up to 20 feet thick.

Narrow, rather indistinct shoreline terraces extend along some of the sloping hillsides. Typically, each terrace comprises a narrow flat surface a few tens of feet wide eroded into the till slope, and each bears a veneer of marine clayey and silty materials that are partly covered by sand, sandy gravel and boulders. The downslope edge of each terrace and the slopes between the terraces are surfaced by a coarse veneer like that on the hill-slope illustrated in Figure 10. The lowest of a series of terraces of this type is shown at the left side of Figure 11. More prominent terraces are developed where the Vashon till sheet is discontinuous or absent and the easily eroded Quadra sand unit has been exposed to wave attack. Such terraces include a distinct constructional outer part consisting of sand, and an erosional inner part consisting of a thin bouldery sandy mantle lying on the eroded surface of the sandy Quadra sediments. Other terraces cut into the Quadra sand unit are not bordered by a constructional sand terrace but by a broad accumulation of marine sand.

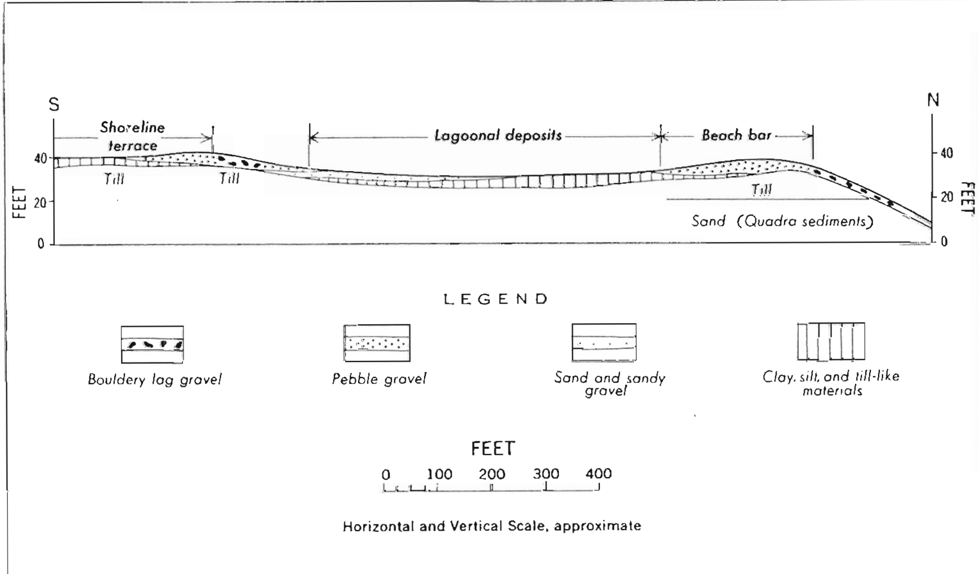

Figure 11. *Details of the marine veneer at Qualicum Beach along a line extending south from the high school, Parksville map-area. Ground profile is from hand-level survey, geology is from test pits and ditches, and is partly diagrammatic.*

Organic Remains

Shells or shell imprints of marine invertebrates are to be found in many of the marine deposits of the coastal lowland. Leaves, leaf imprints, and wood fragments are associated with the shells in a few places. (As most of these plant remains are in (marine) bottom-set beds of deltas they are discussed later under 'Marine Deltaic Deposits'.)

Assemblages of marine shells from various marine deposits at about a dozen places in the coastal lowland of the area have yielded between 40 and 50 species (Wagner, 1959). Most of the forms in these assemblages are molluscs; none of them is extinct. Miss Wagner reports that the assemblages are similar to those found today in the Cook Inlet - Prince William Sound region of Alaska. There appear to be no significant differences in equivalent latitude with differences in the altitude, stratigraphic position, or nature of the enclosing material. Some of the assemblages represent a shoreline or intertidal habitat and others apparently lived under bay or estuarine conditions in up to 15 fathoms of water (Wagner, 1959, p. 50). A few species that are exclusively littoral were found in sands and silts, and are not represented in the assemblages collected from the clays.

Mode of Origin

Most of the marine deposits of the coastal lowland were derived from nearby Vashon drift and from other adjacent pre-existing materials by waves and currents. Locally, however, rivers have contributed considerable amounts of sediments, as is indicated by the thickening of the marine clays and sands adjacent to deltas.

The marine veneer deposits of sloping ground were built along successive shorelines, although some of the clayey and silty lenses within the veneer may be offshore deposits that have been buried by shoreline materials. In some places the marine veneer displays wave-cut features or wave- and current-built forms. Elsewhere, where such definite shore forms are absent, the textural distribution of the marine deposits relative to the topography provides abundant evidence of the washing action of waves as the seashore migrated across the lowlands. Thus, sloping ground and hilltops that were accessible to wave erosion, are surfaced by stony and gravelly material from which clay, silt, and sand have been washed by waves. The surface materials on slopes that were exposed to strong wave attack are more stony and contain less silt and clay than those on nearby rolling ground, in re-entrants, and in other situations where waves were less vigorous. Flat ground and depressions less subject to wave erosion, bear a cover of sand, silt, and clay washed from nearby slopes.

The sands, silts, and clays in depressions and on flat ground probably include offshore, nearshore, and intertidal deposits. The sands do not display shoreline forms but rather are of uniform thickness and broad extent. They probably accumulated in the lower part of the intertidal zone and in shallow water below low-tide line.

Many of the clayey marine deposits of the coastal lowland are not normal marine deposits in that they contain isolated stones up to several feet across and appreciable quantities of sand. Some of these materials are believed to be glacio-marine in origin. As is the case with similar deposits of the Quadra sediments, such mixtures of coarse and fine material may originate adjacent to a shoreline by wave-and-current mixing, or may accumulate in deeper water by submarine slides, by turbidity currents, or by mixing of rafted material with sea-bottom muds. Rafting may have been accomplished by sea ice, floating glacial ice, or floating logs and other debris (*see* Armstrong and Brown, 1954). The till-like clayey materials and some of the most stony clays may possibly have originated by any or all of these processes. On the other hand, thick uniform clays containing isolated stones must be offshore sea-bottom muds containing rafted material. In view of the abundance of such stony clays in the marine deposits of the coastal lowland and of the size of the stones in these clays, the rafting must have been accomplished by ice rather than by logs or seaweed. The history of retreat of the Strait of Georgia glacier (outlined in connection with the Vashon drift) points to the presence of much floating glacial ice in the strait during the deposition of the earliest Capilano sediments. It therefore is likely that many of the stony clays are glacio-marine deposits containing material rafted by floating glacial ice. The clear-cut distinction of the glacio-marine deposits from normal marine deposits has not been possible.

The laminated, unfossiliferous, clayey, silty and sandy materials forming lenses between the marine clays and the underlying till are unlike any of the marine deposits and may be of fresh-water origin. They could readily be dismissed as having formed in ice-marginal ponds during deglaciation were it not that the sea seems to have advanced into the Georgia depression against the front of the retreating glacial ice. A possible explanation is that these materials were deposited in a narrow zone of fresh water beneath the glacier as the ice began to lift off the ground through the buoyant effect of encroaching sea water. Fresh water in and beneath the end of a tidal glacier would float on the salt water, as in the case of groundwater in permeable materials along a seashore. Nonetheless, if the supply of fresh water were large, as during rapid glacial melting, a narrow zone of fresh water in which these sediments could have accumulated may have been present beneath the ice along the boundary between the grounded part of the Strait of Georgia glacier and its floating tidal margin.

Alberni Valley

Nature and Occurrence of Marine Deposits

Marine deposits on the floor of Alberni Valley are more clayey and less varied than those in the coastal lowland of the map-areas. Depressions and low ground in the valley are surfaced by marine clay, whereas sloping ground bears a veneer of loose, stony, loamy material that has been reworked but only slightly modified by seashore processes. Well-washed gravelly seashore deposits are of limited extent.

Marine clay is the surface material throughout much of the lower part of the floor of Alberni Valley and locally attains a thickness of several tens of feet. It not only occupies the areas shown as clay on the geological map but also occurs in depressions throughout the areas mapped as marine veneer. Marine clay also lies beneath the few delta terraces in the valley, and beneath sand in a few places near ice-contact deposits. It also occurs as lenses in the terrace deposits bordering Somass River. Where the clay is found at the surface it generally rests upon till or rock but locally it covers glacial gravels. The clayey marine deposits of Alberni Valley are clayey silts and silty clays that commonly contain sand and isolated pebbles and boulders. They generally include a somewhat larger percentage of clay-sized material (Table 1) than the clays of the coastal lowland, but in other respects the description of the marine clayey materials of the coastal lowland will suffice for the Alberni clays. Shells of marine molluscs and casts of such shells have been found in the clays in

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many places in Alberni Valley, but appear to be entirely lacking in some of the areas of marine clay outlined on the accompanying geological map.

Sloping ground in those parts of Alberni Valley that have been subject to marine inundation is surfaced by a loose stony veneer that differs but little in appearance and texture from the disaggregated surface zone of the till outside the area of marine submergence. Commonly however, loose surface veneer in the areas of marine submergence is slightly more stony and sandy than the till upon which it lies, and it contains local lenses of sand and gravel that do not occur in the till. These slight differences between the surface veneer and the parent till are believed to have resulted from wave modification.

In a few places, shoreline forms have been recognized amid the nondescript marine veneer deposits, and probably others are concealed by the forest. A shoreline terrace surrounds the till ridge between the power transmission line and the logging railroad south of Rogers Creek. This terrace is about 50 feet wide and consists of a wave-cut boulder-strewn notch in the till, bordered on the downslope side through part of its length by a pebbly wave-built terrace. It is about 300 feet above present sea-level. A low pebble-gravel ridge that probably is a beach bar has been traced several hundred feet northwest and southeast from the road intersection 1.4 miles S20°E from Bainbridge. The gravel comprising this ridge is poorly sorted and less than 5 feet thick. The ridge adjoins the eastern, upper edge of the Alberni clay and lies between 300 and 310 feet above present sea-level. Similar gravels that also appear to be shore deposits occur at the same elevation at the road intersection 1 mile west of Bainbridge. A low scarp, interpreted as a wave-cut cliff, lies a few hundred feet east of Spaht Creek where the limit of marine submergence, as shown on the geological map, is east of the creek. The base of this scarp is about 330 feet above present sea-level.

Origin

The marine deposits of Alberni Valley have partly been derived from nearby till by waves and currents but include much material that was brought into the sea by rivers. Some of these rivers probably were glacial meltwater streams. The clayey nature of the marine deposits reflects the clayey texture of the till that formed the river banks and seashores during the interval of marine inundation. Some of the stony marine clays, like similar materials on the coastal lowland, appear to contain debris that was rafted by floating glacial ice and dropped into the sea-bottom muds.

The poor sorting of the marine veneer deposits on slopes appears to relate to the small size of waves in a landlocked basin like Alberni Valley, but probably also reflects the erosion-resistant nature of the clayey tills from which the veneer was derived.

Marine Deltaic Deposits

Nature and Occurrence

Delta terraces are to be found along and adjacent to most of the stream valleys of the coastal lowland and Alberni Valley within the areas of marine inundation (see geological maps). Some stream valleys are bordered by as many as ten such terraced deltas at different levels. Some of the deltas at the upper limit of marine submergence bear ice-contact features and have been described earlier in connection with the ice-contact deposits of the Vashon drift. The delta-terrace deposits are associated areally with the marine deposits and commonly grade into or rest upon them. Clearly they formed where the streams reached successive positions of the seashore during the interval of marine submergence.

The deltas are a few hundred feet to a mile across and are exceedingly varied in outline. The top surfaces are horizontal or slope gently seaward. The seaward edge of most deltas is bordered by a clearly defined scarp, a few feet to 100 feet high, that slopes away from the delta at 5 to 20 degrees (*see* Plate XA). In a typical delta, part of this face is constructional and parallels the fore-set beds within the delta whereas part has been undercut by lateral swinging of the stream while building the next lower delta. The constructional face locally is notched by small wave-cut terrace steps. Some deltas built upon relatively flat ground are bordered by recognizable spits and bars. Thin delta deposits along some of the streams are not bordered by a change in slope or by any distinguishing constructional features. The mapping of the contact between such deltaic deposits and the adjoining marine sands and sandy gravels is purely arbitrary.

All but the thinnest deltaic deposits display an internal 'delta structure' (*see* Plate IXA). The top-set beds are 1 foot to 8 feet thick and typically consist of pebble-cobble gravel that almost universally is coarser than that forming the underlying fore-set beds. Parts of some deltas, however, are surfaced by pebbly sand, silt, or 'clay'. The top-set beds generally show prominent horizontal bedding but locally are massive and identical in appearance to the coarse gravelly phase of the marine veneer. Almost everywhere, the top-set gravels truncate the underlying fore-set beds although, in a few places, individual top-set strata are traceable downward into the fore-set beds. The fore-set beds dip at 10 to 25 degrees and range up to 50 feet or more in thickness. Typically, they consist of pebble gravel and pebbly sand although in a few deltas they are dominantly sand and in a few they include numerous cobbly beds. Locally, sandy or silty strata within the fore-set sequence contain casts of leaves, twigs, or marine shells. The fore-set beds rest upon various materials. Commonly from a few feet to 20 feet of sand dipping gently seaward separates the fore-set gravels from underlying marine clay. Where this sand is unoxidized it commonly contains marine shells or plant debris. In some places, this sandy bottom-set layer is absent and the fore-set beds rest directly on marine clays, sandy clays, and till-like

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materials or are separated from these materials by a few inches of silt. Rarely, the bottom-set sands are replaced by up to several tens of feet of horizontally laminated sand, silt, and clay. Almost all the deltas whose internal structures are exposed consist of a single series of top-set and fore-set beds and would seem to have been built at one stand of the sea. However, a very few deltas consist of several alternations of horizontal and inclined strata; these may have resulted from superposition of several individual delta structures during an interval of rising water-level.

Plant Remains

Plant remains and marine shells originally were widely distributed within the marine deltaic deposits of the Capilano sediments but most of them have been removed by oxidation and leaching. Unoxidized wood fragments, leaves, cones, and pollen have been found in the very few places where bottom-set delta sands are exposed in the unoxidized state.

Table 2

Forest Pollen in Bottom-set Beds of Capilano Deltaic Deposits

(Identifications by J. Terasmae)

Sample Location	Number of Forest Pollen Grains					
	Total	Pinus	Picea	Abies	Alnus	Others
Englishman River delta, surface elevation 170 feet	65	45 small 6 large	1	4	9	....
Same, bottom bed	33	26	2	....	5	....
Same, middle bed	50	40 small 2 large	....	2	6	....
Same, upper bed	129	100	4	3	11	1 salix
Kinkade Creek delta, surface elevation 200 feet	78	33 small 4 large	22	13	5	1 salix
Puntledge River delta, surface elevation 175 feet (northwest of map-area)	87	52 small 12 large	8	7	8	....
Browns River delta, surface elevation 300 feet (northwest of map-area)	50	27 small 5 large	14	1	....	2 salix 2 Tsuga heterophylla
Wilfred Creek delta, surface elevation 70 feet	60	42 (2 sizes)	1	3	13	1 Pseudotsuga taxifolia

The forest pollens in these delta materials are principally of pine, although appreciable amounts of spruce, fir (*Abies*), and alder pollen are present in almost all the samples. Hemlock and Douglas fir, which are among the principal forest trees in the area today, are virtually unrepresented. The small pine pollen grains are derived from lodgepole pine; the fewer larger grains may belong either to western white pine or to lodgepole pine. Undoubtedly pine was less abundant in the forests from which the pollen came than in the pollen assemblages, but it clearly must have been the dominant forest species. Possibly the abundance of pine and alder pollen reflects in part the presence of these pioneer trees on newly formed river and deltaic deposits, but if other forest trees such as hemlock or Douglas fir had been present in any quantity in the mature forests on adjoining higher ground, they certainly would be represented in the pollen assemblage. A similar dominance of pine in the forest-pollen assemblage has been found in the lowest parts of bog deposits[1] in this part of Vancouver Island (Hansen, 1950; Terasmae, J., unpub. rept.) and in the nearby Puget Sound region (Hansen, 1947), although hemlock and Douglas fir are major constituents of the remainder of the bog profiles.

The dominant components of the forests associated with the Capilano deltas—lodgepole pine and alder—are pioneer trees that thrive under a wide range of climatic and soil conditions. Douglas fir and hemlock thrive under more specific soil conditions and climate, and their absence may relate either to cool climate or to immature soils. In view of the considerable duration of the Capilano interval, it seems likely that persistence of the pioneer forest reflects cool and perhaps dry climate and not merely inadequate time for soil development.

More definite evidence of a more rigorous climate than that prevailing in the area today is provided by leaves of *Dryas drummondii,* (J. Terasmae, personal communication) in bottom-set sands of a delta of Englishman River whose upper surface is 170 feet above present sea-level. Although *Dryas* is found at timber-line (elevation 5,000 feet) in the area today, it does not occur at sea-level anywhere in the surrounding region.

Wood from the Englishman River delta, whose surface is 170 feet above sea-level, has a radiocarbon age of 12,150 ± 250 years, and shells from marine clay immediately beneath the wood-bearing bottom-set sands have been dated at 12,350 ± 250 years (samples Lamont 391D and 391E respectively). Wood from the Wilfred Creek delta, whose surface is 70 feet above sea-level, although representing a somewhat higher stand of the land relative to the sea, has been assigned the almost identical age of 11,850 ± 300 years (sample Lamont 391F).

Fluvial Terrace Deposits of the Lowlands

Terraces on the walls of the stream valleys in the coastal lowland, and rare abandoned channels outside the valleys, outline former higher positions of the

[1] The upland bog deposits include equivalents of both the Capilano and Salish sediments and are described and mapped as undivided post-glacial deposits.

river beds. The downstream ends of many of these terraces merge with marine delta terraces.

Most of the river terraces are erosional features veneered by stony lag gravel that rests upon older unconsolidated deposits. These thin erosional terrace veneers are not shown on the geological maps. A few river terraces in the coastal lowland—particularly along Englishman River and Nanoose Creek—are constructional and are underlain by up to 20 feet of fluvial gravel and sand. Exposures showing the internal structure of these deposits have not been found. A clear-cut distinction between these channel and flood-plain deposits and the deltaic deposits has not been possible.

In Alberni Valley extensive terrace-topped deposits of gravel and sand containing lenses of marine clay are found within the valleys of Sproat, Stamp, and Somass Rivers a few tens of feet above the modern river flood-plain. The terraces seem to be remnants of a single surface that sloped at about the same gradient as the present valley floor. The terrace surface is about 100 feet above sea-level at the junction of Stamp and Sproat Rivers and 30 feet above sea-level at the head of Alberni Inlet. As outlined in connection with the Somass ice-contact gravels of the Vashon drift, some of the gravelly materials beneath the terraces are truncated remnants of glacial ice-contact deposits, but others lie conformably beneath the terrace surface and appear to be genetically related to it. These latter materials (termed 'terrace deposits' in this report) are a few feet to several tens of feet in thickness and consist mainly of pebbly sand, sand, and sandy gravel. They contain a few beds of silt and lenses of clay and of till-like, pebbly, gritty clay. Lenses of clay also rest upon the surface of the terrace deposits and separate them from underlying till. Stratification of most of the terrace deposits is undulatory but more or less horizontal, although locally gravels with a fore-set stratification dipping down the valley lie beneath the horizontally bedded materials.

Casts of shells of marine invertebrates and rare imprints of leaves are present in the clay lenses, and leaf imprints have been found in silty beds. Most of the leaf imprints are of *Dryas* (J. Terasmae, personal communication) and of paired pine needles. *Dryas* lives under climatic conditions considerably cooler than those now prevailing at sea-level in the area. Assemblages of the marine shell casts from three localities are reported by Wagner (1959, p. 43) to correspond to a present-day latitude of 61°(i.e. Cook Inlet - Prince William Sound).

These intermingled fluvial and marine deposits may have accumulated where the ancestral river entered the head of Alberni Inlet, just as similar deposits are forming today at the mouth of Somass River. These deposits extend for more than 4 miles along the valley, and their top, terraced surface drops about 80 feet in that distance. Consequently, if they originated as suggested above they must have accumulated as successive increments as the shoreline migrated down the valley during an interval of progressive emergence. An alternative explanation for the occurrence of marine materials in the terrace deposits is that the marine lenses accumulated on top of earlier fluvial deposits during an interval of marine transgression and later were buried by another set of fluvial sands and gravels as the seashore receded towards its present position.

Deposits in the Mountainous Parts of the Area

The Capilano sediments are represented in the mountains by abandoned lake deposits, fluvial terrace deposits, and terraced alluvial fans. These lie principally in the mountain valleys although, as shown on the geological map, a few terraced alluvial fans occur on the mountain slope bordering the coastal lowland.

Abandoned lake features surround Horne Lake and Cameron Lake and are to be found here and there in other mountain valleys. The presence of former high lakes in Horne Lake valley is recorded by local pockets of clay and silt up to 100 feet above the present lake level, by a few gravel terraces 50 to 100 feet above the present lake, and by sizeable fluvial (apparently deltaic) terraces in Qualicum River valley, 1½ to 2 miles upstream from the lake and 100 to 150 feet above its present level. These delta-terrace deposits consist of pebbly, cobbly, and sandy gravels up to 30 feet thick. In the valley of Cameron Lake, pebbly beach terraces, accumulations of stratified sand and silt, and tiny delta terraces bordering mountainside streams relate to lake levels higher than the present one. The most prominent raised shoreline features around Cameron Lake consist of terrace remnants a few feet wide. These are surfaced with angular pebble gravel and are about 50 feet above the present lake level. As suggested in connection with the ice-contact Vashon drift, it is not known which of the raised lacustrine deposits in the Cameron Lake and Horne Lake valleys accumulated in glacial lakes and which relate to post-glacial lake levels that existed before the valley outlets had been cut down to their present levels.

Constructional fluvial terraces have been found in a few places in the mountain valleys. Among the most prominent are terraced deposits of cobbly, pebbly, and sandy gravel along Qualicum River about 2 miles upstream from Horne Lake. As mentioned above, they appear to be partly deltaic and probably are related to a former higher level of Horne Lake. Most other accumulations of fluvial deposits in the mountain valleys are found upstream from bedrock hills that formed knickpoints in the gradient of the former streams.

Numerous, small, steep, terraced alluvial fans are to be found in the mountainous parts of the area, principally where streams in small steep valleys flow out into the larger valleys or onto the lower less-steep parts of the mountain slopes. They are especially well displayed along the sides of Rosewall Creek valley (*see* Plate IXB). The abandoned alluvial fans consist of poorly sorted, coarse, angular gravel that on large clean faces displays indistinct bedding planes parallel with the fan surface. On small exposures, the stratification is not evident and the fan material may be readily mistaken for till. Some fans include 'pedimented' areas consisting of a lag veneer of stones resting on till.

Historical Record

The marine and marine-deltaic components of the Capilano sediments provide a record of changes in the relative positions of land and sea during deglaciation and during the early part of post-glacial time. The land has risen and tilted relative to the sea during and since deglaciation, and the highest marine features, formed during the retreat of the glaciers, now stand between 450 and 500 feet above sea-level on the coastal lowland and about 300 feet above sea-level in Alberni Valley. Most of the marine features point to progressive uplift of the land from its initial lowest stand to its present level relative to the sea, but a few deposits seem to suggest that this emergence was complicated by at least one interval during which the land sank relative to the sea. It is possible moreover that the land may once have stood higher relative to the sea than it does today. The climate of the area remained considerably cooler than at present throughout the period of accumulation of the Capilano sediments.

Limit of Marine Inundation

The highest marine features on the coastal lowland are between 450 and 500 feet above present sea-level, as can be seen from the geological maps. Marine-type clays and sands are found abundantly up to an elevation of about 450 feet and marine shells are common up to an elevation of 400 feet. An isolated occurrence of stony clay containing marine pelecypod shells has been found in a gully a mile east of Chef Creek just north of the forestry road, at an elevation of 465 feet*.

On some hillsides underlain by till and displaying a moderately uniform slope, it has been possible to locate (within a vertical range of 10 or 20 feet) the boundary between 'washed' gravelly phases of the marine veneer on the lower part of the slope and 'unwashed' disaggregated till containing a substantially larger proportion of silt- and clay-size material higher on the slope. As shown on Table 3, this upper limit of wave-washing is about 470 feet above present sea-level.

Table 3

Limit of Wave-washing on Hillsides, Coastal Lowland

Location	Elevation (feet)*
Hill 2 miles east of Errington, north side	480
Hill 2 miles east of Errington, south side	470
Base of mountain slope southwest of Errington	450 (approx.)
Base of mountain slope south of Coombs	470 (approx.)
Base of mountain slope, Kinkade Creek	470
East branch of Waterloo Creek	480

* Elevation determined by Paulin Altimeter; may be in error by 20 feet.

Table 4

Elevations of Highest Deltas, Coastal Lowland

Location	Elevation (feet)*
South Englishman River, east side	465
Rosewall Creek, west side	470
Waterloo Creek, west side	475
Wilfred Creek, west side	485

* Determined by Paulin Altimeter.

The marine deltas bordering the various streams of the lowland provide an independent measure of the extent of the marine inundation. The highest delta terraces along South Englishman River, and along Hunts, Nile, Thames, Rosewall, Waterloo, Wilfred, and Cougar Smith Creeks are between 450 and 500 feet above present sea-level. The elevations of four of these highest deltas are listed in Table 4.

The highest marine features in Alberni Valley are about 300 feet above present sea-level—between 150 and 200 feet lower than the marine limit on the coastal lowland. Because of the nondescript nature of the marine veener in Alberni Valley the limit of marine submergence is not clearly marked. On the geological map the marine boundary shown in Alberni Valley is based largely on the highest occurrences of marine clay and is only approximate. Along the east side of the valley south of Beaver Creek, shoreline features, the highest deltas, and the highest marine-type clays, are all 300 ± 20 feet above present sea-level. Farther north on the east side of the valley, marine-type clays extend 20 or 30 feet higher and a cut shoreline has been found at an altitude of about 330 feet. In the south-western part of the valley the highest delta of Winder Creek is 270 ± 20 feet above sea-level, and the highest clays are at about the same altitude. Despite the inaccurate nature of the barometric observations upon which these altitudes are based, it seems certain that the highest marine features in the northern and eastern parts of the valley are at higher altitudes than those in the southern and western parts.

Various ice-contact deltaic deposits that appear to have been built into the sea by streams flowing off the retreating glaciers have upper surfaces at the same altitudes as the highest marine features discussed above (i.e. 300 feet in Alberni Valley and 450-500 feet on the coastal lowland). Hence it is inferred that the land stood lowest relative to the sea (that is, maximum marine inundation) when the Alberni Valley and Strait of Georgia glaciers were retreating from the area.

Changes in Sea-level

Most of the Capilano sediments can be explained in terms of progressive emergence of the land from the sea, perhaps complicated by intervals of still-stand but unaccompanied by intervals of resubmergence. Thus in general, marine off-shore deposits are overlain by shoreline deposits but the reverse is not true. Deltas characteristically consist of a single set of top-set, fore-set, and bottom-set strata without repetition of this succession; offshore marine deposits lie beneath the deltas but are not found within the deltas or on top of them.

On the other hand, a few Capilano deposits suggest that an interval or intervals of submergence may have complicated the general period of uplift. For instance, alternation of top-set and fore-set strata in a delta bordering Chef Creek may have resulted from a rise of local sea-level while this delta was being built. Moreover, on Komas Bluff of Denman Island, about 6 miles north of the northern edge of Horne Lake map-area, marine sands overlie breccias[1] that appear to be shoreline talus deposits that accumulated at the base of a cliff. If this interpretation is correct, these deposits record a rise of the seashore of at least 150 feet after it had retreated to about its present position. Lenses of marine clay within the Somass River terrace deposits of Alberni Valley may possibly record a similar fluctuation of the seashore after the land had risen to about its present stand.

The changes in the relative positions of land and sea recorded by the Capilano sediments probably were largely the result of isostatic earth-movements consequent on melting of the Vashon glaciers, although the net displacement must also have involved eustatic changes in sea-level through return of water to the sea from melting ice-sheets, and may also have included tectonic movements. As the highest marine features of the region were built during glacial retreat, there is no assurance that they are contemporaneous throughout the area. If they are contemporaneous, they record a tilting of the region with the amount of uplift increasing from south to north or from southwest to northeast, as would be expected from isostatic adjustments consequent on melting of the glaciers. Available information on the altitude of the highest marine deposits on adjoining parts of Vancouver Island is in accord with this pattern.

Climate

Even though glacial conditions were associated only with the earliest, highest Capilano deposits, the climate seems to have remained cool throughout the Capilano interval. Assemblages of marine shells from about a dozen sites within the area, ranging from close to sea-level to altitudes of more than 300 feet, record conditions like those now prevailing in the inlets bordering the Gulf of Alaska (Wagner, 1959). The abundance of pine and the virtual absence of hemlock and Douglas fir in the forest pollen contained in the Capilano deltas of the coastal part of the area also suggest climatic conditions cooler than the present (see discussion of delta sediments for details). Persistence of cold conditions until late in the Capilano interval is indicated by the presence of *Dryas* in a raised delta of Englishman River (top surface elevation 170 feet) and in the Somass River terrace deposits (terrace elevation 50 feet).

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[1] Marine shells from one of these breccias (elevation 120 feet) have a radiocarbon age of 11,500 $\pm$ 200 years (Lamont 441B).

Age

Accumulation of the Capilano sediments began when remnants of glacial ice still occupied parts of the area, and continued throughout much of post-glacial time. In terms of radiocarbon chronology, the earliest Capilano deposits probably are 14,000 years old and perhaps even older. This suggestion is based on the premise that the Vashon ice retreated from the Seattle area, 150 miles to the southeast, somewhat more than 14,000 years ago (Rigg and Gould, 1957, p. 358). The four radiocarbon dates[1] of Capilano marine deltaic and shoreline materials from the area, mentioned earlier, apply to the latter part of the Capilano interval when this part of Vancouver Island had risen about 300 feet higher relative to the sea than its initial post-glacial position. They indicate that about 11,700 years ago the area stood between 50 and 200 feet lower relative to the sea than it does now.

The Capilano interval ended, by definition, when the seashore became established at about its present level (± 20 feet), possibly between 5,000 and 10,000 years ago. Unfortunately, radiocarbon dates pertaining to this event are lacking. (Related evidence is summarized in the discussion on the Salish sediments which follows.) It is probable that the present seashore level, as well as earlier, higher seashore levels, were established at different times at different places within the Georgia depression.

Salish Sediments

The Salish sediments relate to the present sea, river, and lake levels and are represented in the area by channel, flood-plain, and alluvial-fan deposits along the rivers; deltaic deposits where the rivers enter the sea and lakes; seashore and lakeshore deposits; and Indian middens. In mapping, all marine shore-deposits up to 10 feet above the high-tide line and river deposits up to 15 feet above summer water-level are classified as Salish materials. The name 'Salish'—the Indian nation inhabiting the Georgia depression and surrounding regions—was first applied to deposits of this type by Armstrong (Armstrong and Brown, 1953).

Nature of Materials

The channel and flood-plain deposits on the floors of the river valleys and the deltas at the river mouths consist largely of gravel and sand, although parts of many of these alluvial deposits are surfaced by a few inches or feet of silt, clay, or peat. Locally, discontinuous beds of these materials also occur below the surface within the coarser deposits. The river-channel and flood-plain deposits are mostly less than 15 feet thick and in many places consist of less than

[1] Lamont datings—
L391D: 12,150 ± 250 years; Englishman River, bottom-set beds of delta, elevation 170 feet; wood.
L391E: 12,350±250 years; same locality as L391D; shells.
L391F: 11,850±300 years: Wilfred Creek, bottom-set beds of delta, elevation 70 feet; wood.
L441B: 11,500 ± 200 years; Denman Island, shoreline talus, elevation 120 feet; shells.

5 feet of cobbly or bouldery gravel. In contrast, parts of the floor of Somass River valley are underlain by several tens of feet of gravel, sand, and clay. The deltas along the seashore are generally less than a mile across and probably average several tens of feet in thickness. Little is known of their internal structure or of the nature of the component materials at depth, but they are probably similar in both respects to the raised Capilano deltas described earlier.

The seashore deposits of the area beyond the limits of the deltas are exceedingly varied, bouldery, gravelly, sandy, silty, and clayey materials a few feet thick. They are largely absent from the rocky shores between Englishman River and Nanoose but occur along the drift-bordered coast elsewhere in the area. Much of the shoreline consists of a platform cut into till and surfaced by 1 foot to 3 feet of bouldery to cobbly material derived from the till; commonly a discontinuous belt of pebbly and sandy gravel 2 to 5 feet thick mantles the shoreward part of the beach, and a few feet of sand and mud borders and covers the bouldery platform along and below the low-tide line. The shore is sandy adjacent to deltas and where it has been eroded into the Quadra sediments; in the latter situation boulders are commonly strewn on the sands. In most places where the shore has been cut into till or other surficial materials, a wave-cut cliff (commonly wooded) borders directly on the shore; but in some places the shore is separated from the wave-cut cliff by a pebbly sandy terrace about 5 feet above high-tide line and up to 200 feet wide. Miniature spits, bars, and swampy lagoons border some of the deltas, but such features are rare along the interstream parts of the shore. The only large spit in the area is Mapleguard Point at Deep Bay.

Indian middens or refuse heaps border the shore in many places. In these middens the local mineral soil is mixed with black organic matter, bones, fragments of pebbles (cooking stones), and a multitude of clam shells and shells of other marine molluscs. Most middens are several acres in extent and a few inches to 5 feet in thickness; a few are more than 10 feet thick.

Alluvial fans are formed where streams flow from steep mountainside gullies onto flatter ground. Within the area they occur in some of the mountain valleys, along the northeastern side of Alberni Valley, and locally along the inland edge of the coastal lowland. The fan deposits are commonly several tens of feet thick and consist dominantly of poorly sorted angular gravel, much of which contains interstitial silt and clay and is till-like in appearance. The gravels are coarsest, and commonly bouldery, at the apex or highest part of a fan and become progressively finer towards its lower margin. The lower edges of some fans in Alberni Valley (and depression fillings adjacent to these fans) consist of alternate layers of fine angular gravel and of clay or silt.

Historical Significance

The marine-shore and marine-deltaic deposits of the Salish sediments provide a sedimentary record of the present stand of Vancouver Island relative to the sea. As yet these deposits have provided little information regarding the nature and duration of this interval of stable local sea-level, but independent evidence suggests that both the local sea-level and the climate of the area have changed little during the last several thousand years. Other components of the Salish sediments, such as alluvial-fan deposits and lake deposits, relate to local base-levels that seem to be of little regional significance.

Broad wave-cut platforms bordering parts of the shore of the Strait of Georgia point to a long period of wave erosion at or a little below the present shoreline level. These platforms, up to several thousand feet wide and covered at low tide by less than 25 feet of water, are clearly evident on the hydrographic charts of the region. Platforms cut into till or into shale and sandstone of the Nanaimo Group commonly are more than 1,000 feet wide, and those cut into sandy Quadra sediments overlain by till are locally more than a mile wide. At Cape Lazo about 10 miles north of the northwest corner of Horne Lake map-area, a wave-cut platform 4,000 feet wide borders a wave-cut cliff of till and Quadra sand that is currently receding at somewhat less than 1 foot per year.

Within the area the seashore stood 100 or 200 feet above its present level between 11,500 and 12,000 years ago (see radiocarbon dates listed in the discussion of the age of the Capilano sediments), and hence stabilization of the seashore at its present level took place less than 11,500 years ago. At the city of Vancouver, charcoal from the lower part of an Indian midden apparently built during the present stand of the sea has a radiocarbon age of 2,430 $\pm$ 163 years (Borden, 1954, p. 26, Saskatchewan dating, S-3).

A few pollen profiles of upland bogs[1] within this part of Vancouver Island (Hansen, 1950; Terasmae, unpub. rept.) provide the only information available regarding the climate of the Salish interval prior to modern times. Lodgepole pine is the dominant forest tree represented in the lowest part of these pollen profiles. Douglas fir and hemlock, which are major components of the modern forest, appear in appreciable quantities not far above the bottom of the profiles, and the upper two thirds of the bog succession differ little in pollen assemblage from the uppermost modern layer. Thus, the cool conditions associated with the Capilano sediments, (and represented by the lowest part of the bog profiles) apparently were followed by an interval of increasing warmth, and then by a longer interval without major climatic changes that has continued until today. The few pollen profiles provide no evidence of a 'climatic optimum' interval of maximum warmth and dryness in middle post-glacial time. The spread of the modern-type Douglas fir and hemlock forests (warming from cool conditions to modern climate ?) took place either late in the Capilano interval or during the early part of the Salish interval of stable sea-level.

Hansen (1950) records the presence of a single layer of volcanic ash in his three pollen profiles of Vancouver Island and correlates this ash with a similar single ash layer in the bog deposits of Washington. In two localities in Washington this ash has a radiocarbon age of about 6,700 years (Rigg and Gould,

[1] The upland bog deposits include equivalents of both the Capilano and Salish sediments and are described and mapped as 'undivided post-glacial deposits.'

1957, p. 354). If this correlation of the volcanic ash is correct, the modern-type forests and modern climate were established on Vancouver Island between 11,500 and 6,700 years ago.

Undivided Post-glacial Deposits

The post-glacial landslide deposits, colluvium, and upland swamp deposits of the area include equivalents of both the Capilano sediments and the Salish sediments, but cannot be separated and assigned to either group. Landslide deposits have been formed at various and as yet unspecified times since deglaciation. Colluvium and talus have been accumulating more or less continuously during the same interval. Swamp deposits on the modern flood plains and deltas are an integral part of the Salish sediments, but the upland swamp deposits, resting on Capilano and earlier materials, are equivalent to both the Capilano and Salish sediments.

Landslide deposits up to several tens of feet thick and $\frac{1}{4}$ mile across are to be found at the base of many steep mountainsides in the area, and thinner smaller landslide accumulations occur locally at the base of river-cut and wave-cut scarps. These deposits commonly have a hummocky surface and are lobe-shaped in plan. Some slide deposits in the mountainous parts of the area consist of redeposited till, but most have been derived from the local bedrock and range from coarse blocky rubble to stony till-like material with an appreciable content of fines. Landslides at the base of cutbanks along the rivers and the seashore consist of till, clay, and other materials into which the banks have been eroded.

Steeply sloping aprons and cones of talus up to several tens of feet thick lie at the foot of parts of the steep rocky walls of the mountain valleys. These consist of a loose rubble of angular rock fragments a fraction of an inch to several feet in diameter, that only locally are mixed with much silt-size or clay-size material.

Most sloping drift-covered hillsides are surfaced by a few inches to several feet of colluvium or talus that has crept or slid from a source or sources higher on the slope. These materials are as varied as the sources from which they have been derived. Some consist of fragments broken from nearby bedrock outcrops, but most are of till, sand, gravel, clay, etc. Although this colluvium forms a distinctive layer in some places, it commonly differs little from the undisturbed material beneath it. It has not been shown as a separate unit on the geological map.

Swamp deposits up to 30 feet thick occupy poorly drained depressions in the surface of the unconsolidated deposits and bedrock of the area. Locally they also mantle sloping or flat ground downslope from springs, particularly along the margins of modern alluvial fans and raised deltas. The largest peat deposits in the area—some as much as 200 acres in extent—occur on the coastal lowland, in depressions in the ground moraine that have been modified by marine deposits. Other large bodies of peat occupy depressions in ice-contact deposits. Typically the surface of the swamps is flat rather than hummocky and consists of sphagnum peat supporting a shrub cover composed chiefly of Labrador tea. In some swamps, layers of impure diatomite, locally aggregating 6 inches in thickness, lie within the upper foot or so of the peat.

Historical Summary

The surficial deposits and glacially sculptured landscape with which this report is concerned originated in late Pleistocene and Recent time. Information concerning earlier Pleistocene events of the region is provided by deposits exposed in the Puget Sound region to the south (Crandell, Mullineaux, and Waldron, 1958) and encountered in bore-holes in the Lower Fraser Valley to the east. Possibly early- or mid-Pleistocene deposits occur locally on Vancouver Island but as yet remain unrecognized.

The major topographic elements of the region—the Georgia depression, the Vancouver Island mountain upland, and the Coast Range—existed in more or less their present form before the events recorded here.

Sand, silt, and clay beneath the Dashwood drift are the oldest Pleistocene materials that have been recognized in the area. They appear to have originated in a lake or broad-river plain in this part of the Georgia depression. Subsequently, glacial ice advanced over the area, eroding the upper part of the lake or river sediments and covering them with till and other glacial materials that are here classified as the Dashwood drift. The Dashwood ice-sheet or glacier appears to have been regional in extent and may perhaps have been similar to the later, Vashon ice-sheet complex.

Upon retreat or break-up of the Dashwood glacier, marine water entered the Georgia depression and covered at least those parts of the coastal lowland of the area that now stand within 250 feet of sea-level. Marine and glacio-marine stony clay and silt, constituting the clay unit of the Quadra sediments, accumulated on the sea-bed on top of the Dashwood drift. Silts, gravels, sands, and swamp deposits (also classified as Quadra sediments) formed along the seashore and on nearby river plains, and eventually overlapped the sea-bottom clays as the land rose and the seashore receded. Marine shells in the sea-bottom deposits and plant remains in the silty shoreline and river deposits record a cool climate probably like that prevailing today in southern coastal Alaska.

After the land had risen to its present level relative to the sea, or perhaps even higher, rivers flowing southeastward along the Georgia depression and carrying granitic detritus from the Coast Range deposited the thick widespread sand unit of the Quadra sediments. Concurrently, rivers heading on Vancouver Island left local gravels among the far-travelled sands. The sands may have accumulated under a temperate or cool climate as a continuous fluvial-plain or estuarine complex that occupied the full width of at least the northern part of the Georgia depression, or, alternatively, as successive isolated outwash fans along successive margins of advancing glaciers.

The Quadra non-glacial interval, involving the marine regression and fluvial aggradation outlined above, appears to have constituted a long interstadial younger than the Sangamon interglacial but older than the classical Wisconsin glaciation. Organic materials that originated during the fluvial aggradation have radiocarbon ages ranging from about 25,000 years to 36,000 years, but the earlier marine part of the sequence so far has yielded only "infinite" radiocarbon ages.

The knowledge of events immediately following the accumulation of the Quadra sediments is incomplete, for erosion has removed all traces of any materials that may originally have rested upon the Quadra sand unit, as well as much of the Quadra sediments themselves. This erosion appears to have been accomplished partly by rivers and partly by ice as glaciers again spread over the region.

During the succeeding glaciation which appears to have been the classical Wisconsin glaciation of the region, the Vashon drift accumulated through various glacial agencies and the glacial-erosional features of the mountains attained their present form. During the climax of this glaciation, an ice-sheet completely covered the area and the surrounding country except perhaps the summit of Mount Arrowsmith, and flowed south to southwest from the Georgia depression across the Vancouver Island mountains. When the ice surface dropped below the mountain crests, the ice-sheet separated into a network of glaciers in the mountain valleys and a large southeast-flowing glacier in the Georgia depression. Some of the former, in through valleys like those of Horne and Cameron Lakes, for a time continued active southwestward movement as outlet glaciers of the Strait of Georgia glacier. Others, in valleys heading on the east side of the mountains, apparently stagnated when the ice surface dropped below the valley-head divides. Mountainside streams built alluvial fans against the shrinking ice-masses in the valleys while ice-marginal rivers and lakes built and cut narrow terraces along the valley walls. During deglaciation, and probably during the climax of the Vashon glaciation as well, ice emanating from the high mountains of Vancouver Island northwest of the area flowed northeastward to merge with the Strait of Georgia glacier and southeastward into Alberni Valley.

The Alberni Valley glacier veneered the valley floor with till that locally has a drumlinoid surface. During the waning stages of the glacier, meltwater streams flowed along its margins and locally beneath the ice, and left behind terraced and ridged deposits of gravel and sand. Late in deglaciation a landslide from the steep northeastern wall of the valley near Mount Joan spread rubble on the surface of the ice for 3 miles along the valley floor. The terminus of the Alberni Valley glacier appears to have withdrawn northeastward up the valley and to have been bordered in part by the sea.

The Strait of Georgia glacier flowed southeastward across the coastal lowlands of the map-areas parallel with the front of the mountains. During deglaciation, as this glacier became progressively thinner, rivers flowed off the land onto the ice and southeastward along or near its lateral margin. When the ice melted away the deposits of these streams remained as ridged, hummocky, and terraced gravels and sands along the inland edge of the coastal lowland and on the lower part of the adjoining slope. The terminus of the Strait of Georgia glacier appears to have retreated northwestward and to have been bordered by marine water standing 450 or 500 feet above present sea-level. Some of the ice-marginal streams entered the sea at the south end of the glacier terminus, where they deposited marine deltas that partly were bordered by water and partly were built against remnants of glacial ice.

A glacier flowed down Englishman River valley during the latter part of the Vashon glaciation and caused a northeastward diversion of the direction of glacial flow in the adjoining part of the Georgia depression. This glacier apparently coalesced with the Strait of Georgia glacier when the southern edge of the latter stood 1,500 or 2,000 feet above present sea-level and may have remained in the Englishman River valley after the terminus of the Strait of Georgia glacier had retreated to the northwest. Meltwater streams associated with the Englishman River glacier built several small eskers on the inland part of the coastal lowland adjoining Englishman River. The Englishman River glacier was fed by glaciers in cirques on Mount Arrowsmith but nowhere in the lower Beaufort Range was the snow-line low enough since the climax of the last glaciation to permit development of such cirque or valley glaciers.

As the glaciers retreated, marine water entered the Georgia depression and Alberni Valley and covered much of the present coastal lowland and the floor of Alberni Valley. Since deglaciation, Vancouver Island has risen and tilted relative to the sea, and now the highest marine features, which formed while the glaciers were retreating, lie at an elevation of 300 feet in Alberni Valley and between 450 and 500 feet in the coastal part of the map-areas. It is possible that the general period of uplift was complicated by one or more intervals during which the land sank relative to the sea.

During the interval of marine regression, exceedingly varied 'clays' silts, sands, and gravels accumulated on the sea bottom and along successive positions of the shore. In places, wave erosion cut through the Vashon drift to expose the Quadra sediments. As long as glacial ice bordered the sea, glacio-marine stony clays accumulated through mixing of ice-rafted material with sea-bottom mud. As the land rose, rivers cut gullies into marine and other types of materials along their courses and built a succession of deltas, flood-plain and channel deposits, and alluvial fans.

The interval of marine regression—here termed 'the Capilano interval'—probably lasted several thousand years and possibly began as much as 14,000 radiocarbon years ago. Some 11,500 or 12,000 radiocarbon years ago the coastal lowland of the area stood 100 to 200 feet lower relative to the sea than it does now. Both marine shells and plant remains in the Capilano sediments provide evidence that the climate of the interval was cooler than the present one.

The land became stabilized in its present position relative to the sea (± 20 feet) several thousand years ago. It is probable that the warming of the climate and the establishment of conditions more or less like those of today took place at about the same time. During the ensuing modern interval of stable sea-level (land level)—here termed 'the Salish interval'—sizeable deltas have been built by rivers entering the Strait of Georgia; thin gravels, sands, and muds have accumulated along the interstream parts of the shore; and platforms up to several thousand feet wide have been cut where surficial materials and soft rocks are exposed to strong wave attack. The modern lakes, alluvial fans, and many river flood plains of the area are graded to local base-levels, and have existed for various intervals of time that as yet have not been related to the sea-level and climatic changes. Swamp deposits, landslide deposits, and colluvium have been accumulating in appropriate places since deglaciation, retreat of the sea, or fluvial cutting.

Chapter III

ECONOMIC GEOLOGY

The surficial deposits described in the foregoing exert an indirect influence upon travel, housing, work, and other phases of human activity within the region. The nature and topography of the unconsolidated earth materials have much to do with the suitability of a particular piece of country for agriculture as well as the value of timber growing upon it. Most roads, industrial plants, and houses are founded upon surficial deposits, and the cost of construction is influenced by the ease with which these materials can be excavated, by their load-bearing capacity, by their permeability and drainage, and by their stability in cut faces, as well as by the location of sources of concrete aggregate and fill. Many farms and rural homes as well as the communities of Parksville and Qualicum Beach draw their water supply from the surficial deposits, and to a large extent, disposal of household sewage is accomplished by septic tanks discharging into these deposits.

Foundations

The performance of earth materials as foundations for buildings, bridges, and roads depends upon local conditions, and predictions of their performance in a regional study such as this can be no more than gross generalities to be viewed in relation to each local situation. The following outline is based on field observations without support of soil-mechanics studies. It applies principally to the moderately uniform deposits of the coastal lowland and Alberni Valley.

Materials Beneath the Sand Unit of the Quadra Sediments

The glacial deposits, clays, and peaty silt-gravel beds of the Dashwood drift and Quadra sediments are to be found near the ground surface chiefly along the sea cliffs and on the walls and floors of stream gullies within the coastal lowland. They will be encountered most commonly in excavating for bridge piers.

The Dashwood drift, consisting of dense silty till with lenses of compact pebbly silt and silty gravel, will undergo little consolidation under load in its natural state and will stand in high-angle cuts. It is moderately hard and tough but can be excavated without blasting. When mixed with water, as for instance by vehicular traffic, these materials break down into a soupy slurry. Vertical movement of water through the drift sheet is exceedingly slow, but where gravel lenses are present, horizontal water-movement is moderately rapid. Because of the discontinuous nature of such gravel lenses and the widespread seepage of water from overlying strata, excavations in the drift fill with water unless some means of drainage is provided.

The clays of the Quadra sediments are compact and stiff in their natural state and will support moderately large stresses without being deformed. Steep cut-faces stand up well but wear back in time through rain wash and through spalling along desiccation cracks. The clays can be excavated with power tools but are tough and become exceedingly sticky when wet. Rare large boulders may require blasting. The permeability of the clays is low and excavations fill with seepage water unless a means of drainage is provided.

The plant-bearing silt-gravel beds of the Quadra sediments have a good load-bearing capacity and will stand in high-angle cuts in their natural undisturbed condition. In this condition the silts are compact and firm, and the peats are hard and wood-like. Excavation is easy except where thick peat is uncovered on a horizontal surface. Although water moves with relative ease in the gravelly beds, vertical percolation of water is prevented by peaty beds and silts. Commonly these materials support a perched water-body in the overlying sand.

Sand Unit of the Quadra Sediments

The white Quadra sand is to be found in gullies and along sea cliffs in the coastal lowland and locally is encountered beneath thin till and/or marine deposits in excavations dug into the rolling lowland surface. This sand is typically fine grained and exceedingly well sorted (i.e. poorly graded). Although most of the sand is dry and has a good load-bearing capacity, the lowest part of the sand almost everywhere is water-saturated and 'quick'. Similar zones of 'quick' sand are found here and there within the sand succession immediately above beds or lenses of silt or of clay-bonded sand.

With the exception of silty and clay-bonded layers, the sands have little dry strength and will not stand long in high-angle cuts. Most of the sand is so fine and well sorted that even low-angle slopes are subject to gullying and sand flows during heavy rains.

Till (Vashon Drift)

Till lies within a few feet of the ground surface throughout most of the drift-covered part of the region. Within the area of former marine submergence the till is covered by thin marine deposits, and at higher elevations it is generally veneered by glacio-fluvial gravel, disaggregated till, colluvium, or alluvium.

The tills of the area are all compact and hard despite their wide range of texture (see discussion of Vashon drift). They do not consolidate even under heavy loads and generally will stand indefinitely in near-vertical faces. Generally they can be excavated with power tools but locally they are hard enough to require blasting. When mixed with water (e.g. by vehicular traffic) the till breaks down into a silty mud that offers little support and flows as mud slides. Permeability of the till is low except where it contains lenses of gravel and sand, and near the ground surface where water can move through fractures and root holes. Excavations or natural depressions fill with seepage water unless drainageways are provided.

Ice-contact Deposits (Vashon Drift)

The ice-contact gravels, sandy gravels, and sands, which form terraced, ridged, and knob-and-kettle deposits, generally are good foundation materials and undergo little consolidation under load. Commonly these gravels and sands are loose and uncemented, but will stand at moderate slopes without slumping or gullying. Generally the ground surface of the glacio-fluvial deposits is several tens of feet above the water-table, but excavations at the base of these highly permeable materials will commonly encounter much water. Most sandy layers within these deposits are coarse, pebbly, and rather poorly sorted (i.e. well graded), and thus are much more stable below the water-table than are the Quadra sands.

Terraced Delta and River Deposits (Capilano Sediments)

Most river terraces in the area consist of a few feet of gravel resting upon rock, till, sand, or other unconsolidated materials. The foundation conditions on the terraces therefore are governed by the subsurface materials rather than by the terrace gravels.

The marine delta terraces that border many of the lowland streams and the fluvial-estuarine terraces along Somass River in Alberni Valley are built of gravels, sandy gravels, and sands rather similar to the ice-contact deposits, and generally are several tens of feet thick. The loose, permeable deltaic deposits are satisfactory foundation materials in themselves, but in many places they rest upon water-saturated fine sand or upon soft (locally sensitive) marine 'clay' that may settle markedly under load. The Somass terrace deposits contain lenses of marine 'clay'. Above the water-table these are oxidized and hard and do not appreciably decrease the load-bearing capacity of the enclosing gravels and sands, but below the water-table they are soft and readily deformed.

Marine 'Clay' (Capilano Sediments)

Marine 'clay' occurs at the surface, as shown on the geological maps, and also lies beneath many of the other marine deposits as well as the deltaic deposits. The 'clays' include various materials ranging from sandy silt to silty clay and commonly contain appreciable amounts of grit and stones. In an unoxidized condition, below the water-table, these materials are characteristically soft and readily deformed; some are sensitive. Some unoxidized clays, on the other hand, contain less water and are less readily deformed. The unoxidized clays are impermeable and commonly are difficult to excavate because of their stickiness. Some contain isolated large boulders that may require blasting during excavation. Unoxidized unstable clay occurs in poorly drained depressions, beneath thick oxidized clay in better-drained situations, beneath the terraced marine deltas, beneath marine sands, and beneath gravelly beach bars.

Above the lowest annual water-table level, drying and oxidation have converted the marine clay into hard, blocky material that undergoes little consolidation under load and which, in the undisturbed state, will stand in high-angle cuts.

Water is able to move through fractures in this oxidized clay. During heavy rains, and in winter when water fills the fractures, the oxidized clay adjacent to the fractures absorbs water, but if undisturbed the deposit remains much more stable than its unoxidized counterpart. Except in very wet situations, the oxidized clay is much easier to excavate than the unoxidized 'clay'.

Marine Sand (Capilano Sediments)

The widespread marine sand of the coastal lowland ranges from a few inches to several tens of feet in thickness and generally rests upon marine 'clay'. It ranges in texture from coarse to very fine, but for the most part is medium to fine grained and well sorted (i.e. poorly graded).

Dry marine sand is generally a satisfactory foundation material, although locally its performance under heavy loads may be modified by the presence of a substratum of unoxidized marine 'clay'. The sand has little dry strength and is stable only in low-angle cuts. Water-saturated marine sand commonly is 'quick' and rests upon soft unoxidized marine clay. It may therefore react poorly to load and be troublesome to excavate.

Some sands lying within the range of fluctuation of the water-table are weakly cemented by iron oxide and therefore have some strength both when dry and when wet. This cementing is most pronounced in very fine sand and silty sand, in which the water-table is bordered by a broad zone of alternate wetting and drying. In an undisturbed state these cemented sands will stand in moderately steep faces and do not consolidate substantially under heavy loads, although their load-bearing capacity may be modified by a substratum of soft 'clay'.

Marine Veneer (Capilano Sediments)

Thin marine veener deposits occupy the greater part of the lowlands of the map-areas, and in excavations are encountered more commonly than any other earth materials. Nonetheless, because they are generally less than 5 feet thick, most structures are founded upon the till or other material beneath them, rather than on the marine veener deposits themselves. The marine veener is a complex of shoreline and sea-bottom deposits ranging from sand to coarse gravel and from clay to stony concrete-like mixtures.

In Alberni Valley the marine veener deposits are dominantly clayey. They characteristically consist of silty clay or clay in depressions, and stony loamy-textured material on slopes and highs. Except in undrained depressions where the clay is soft and readily deformed, these marine deposits are oxidized and moderately hard, even when wet; they deform little under load and stand in moderately steep faces. Vehicular traffic readily works water into the oxidized clayey materials rendering them soft and sticky. Surface drainage moves downslope within the marine veneer deposits and on top of the underlying compact till to accumulate in low areas.

The marine veneer deposits of the coastal lowland are much more complex than those of Alberni Valley and generally consist of overlapping layers of radically different texture and small lateral extent. Slopes and highs commonly are veneered with gravelly materials, either resting directly on till or separated from the till by thin clay or silt. In depressions or flat areas the veneer generally consists of clay or stony, clayey material. Sand lies on slopes or highs as well as in depressions. The clayey veneer deposits are like the thicker clays described above. For the most part they are oxidized from top to bottom and will provide satisfactory support for most foundations. Unoxidized, readily deformed clays are to be found, however, in undrained depressions, commonly beneath a few inches of sand. The gravelly and sandy veneer deposits provide adequate support for heavy structures except in the few places where they rest on unoxidized clay. Such soft clay is to be found beneath broad low ridges (5 to 10 feet high) of pebble gravel or pebbly sand that constitute old beach bars and spits. In hummocky areas where the ground surface is dominantly gravelly, soft clay in depressions can readily escape detection and be buried in levelling foundations or in constructing road-beds, leading later to uneven settling of the superposed structure. The gravelly and sandy veneers on slopes and hilltops of the coastal lowland are moderately to highly permeable but generally rest upon an impermeable substratum of till, clay, or rock. Hence, surface water migrates downslope in the bottom of the veneer a few inches or feet below the surface to accumulate on or within the finer-textured deposits in adjoining low areas.

Modern Alluvial and Shoreline Deposits

Most river valleys in the lowland part of the area are floored by gravelly alluvium only a few feet thick that rests upon till, other unconsolidated materials, or rock. The performance of the alluvium as a foundation material is controlled by the near-surface position of the water-table, the presence or absence of surface or buried layers of peat, silt, or clay, and by the nature of the substratum. Most commonly the alluvium consists of 15 feet or less of coarse gravel without peaty or fine-textured layers, and rests upon till. Hence foundation conditions are good, although of course, substantial flows of water may be encountered. The floor of Somass River valley in Alberni Valley is underlain by several tens of feet (probably locally 100 feet) of gravel, sand, and clay. Possibly all this material is modern alluvium but it seems more likely that it includes older fluvial and glacio-fluvial deposits. These materials beneath the Somass River flood plain are expected to display considerable local variation in their capacity to support heavy loads, consequently when the building of a heavy structure upon them is contemplated, they should first be tested by deep borings.

The alluvial fan deposits of the area are largely good foundation materials. They consist of large to small angular rock fragments mixed with various amounts of sand, silt, and clay. On the other hand, the peripheral parts of some fans and alluvial depression-fillings adjoining some fans include beds of silt and clay that, although firmer than the unoxidized marine clay, may provide indifferent support for heavy structures. Most fan materials contain enough fines to stand in high-angle cuts, yet are loose enough to be excavated with ease, although the loose blocky material comprising the upstream part of some fans may present excavation problems. Although the bulk of the fan materials are of moderate to low permeability, permeable gravelly beds carrying much water occur here and there within the fans and upon their surface.

Deltas at the mouths of the rivers of Vancouver Island are commonly chosen as the sites for industrial plants. The deltas in the area are mostly less than a mile across and on the average are underlain by several tens of feet of water-saturated alluvium. The surface material is largely gravel and sand but includes local pockets of silt, clay, and peat. Little direct information is available regarding the materials beneath the surface, but they probably are more sandy than the surface deposits, contain lenses of silt and clay, and in part are separated from the underlying till or rock by marine clay. It is not known whether the succession of strata within the modern deltas is like that in the terraced deltas (Capilano sediments). Borings through the estuarine (deltaic) deposits at the pulp mill at Port Alberni, where Somass River enters Alberni Inlet, encountered up to 150 feet of sand and sandy gravel with lenses of clay, silt, and very fine sand. It is possible that only the upper part of this succession is recent alluvium, and that the lower part comprises older fluvial and/or glacio-fluvial deposits.

The modern deltaic deposits can be expected to provide adequate support for light structures, but they should be explored by deep borings before heavy construction is undertaken. Deltas terminating in deep water, and therefore built of thick water-saturated alluvium bordered by slopes at the angle of repose, are susceptible to marginal sliding and irregular settlement during earthquakes.

Most shorelines beyond the limits of the deltas are underlain at a depth of less than 10 feet by till or rock that will provide a firm foundation for most structures. However, some sandy shores, particularly those cut into the Quadra sediments, are underlain by thick, fine, water-saturated sand. Maple (Mapleguard) Point at Deep Bay is the only large spit within the area. It is surfaced by sandy gravel that probably rests upon sand and clay several tens of feet thick. Foundation conditions probably are similar to those outlined above for the modern deltas. Subsidence and marginal sliding may occur during earthquakes.

Slope Deposits

Accumulations of talus and landslide debris at the base of steep slopes generally have good load-bearing capacity, but some include clayey till-like materials that are saturated with water and readily deformed. Permeability and stability of cut faces vary greatly within short distances. Locally the presence of blocks too large to be handled by power tools adds to the cost of excavation.

Talus and colluvial materials on hillsides are commonly less than 5 feet thick. Their chief interest here is that they may conceal materials of a different nature that may be encountered in an excavation for a road-bed or other structure. Most commonly—and particularly on the relatively gentle slopes of the lowlands—the ground is surfaced by loose till-like colluvium that generally rests upon till. On the other hand, colluvium mantling the walls of stream gullies may be radically different in texture from the material upon which it lies. Thus loose gravelly colluvium, derived from the top of a gully wall may obscure the fact that the gully has been cut into till or clay. Till-like colluvium similarly may conceal the presence of sub-till sands or gravels. On the lower parts of mountainsides and valley walls, easily excavated talus makes up much of the ground surface but commonly it is merely a veneer over hard compact till or bedrock.

Gravel and Sand

Gravel and sand suitable for concrete aggregate and road-building are abundant among the surficial deposits of the region. The principal sources are the ice-contact deposits of the Vashon drift and the terraced delta deposits of the Capilano sediments (see geological map). Gravel and sand are also obtained in smaller quantities from modern deltas at river mouths, from alluvium in valley bottoms, from river terraces along valley walls, from alluvial fans and talus cones, from beach bars within the areas mapped as marine veneer, and from deposits beneath the Vashon till.

Most of the gravel and sand produced in the area is used for base course and surfacing of roads. Only one pit (in Alberni Valley) produces a range of washed and sized materials for sale, although various pits that normally supply road materials are drawn upon for various grades of concrete aggregate during the construction of industrial plants, bridge piers, and large buildings.

Pits supplying road gravel are operated by the municipal and provincial governments, by contractors engaged in highway construction, and by logging operators. In addition, the Esquimalt and Nanaimo Railway operates several gravel pits as sources of railroad ballast. Most of these operations produce only pit-run gravel and sand, but from time to time the British Columbia Public Works Department and various highway contractors employ portable screening, washing, and crushing plants in the production of aggregate for bituminous road-surfacing.

The production of gravel for road construction by logging operators has increased greatly during the last 15 years, partly because of the boom in the lumbering industry and partly because of the conversion of virtually all operations to truck haulage. In general, adequate easily exploited supplies of fill, base course, and surfacing material are available for main haulage roads on the lowlands and in valley bottoms, but as operations expand into higher valleys and onto valley walls and mountain slopes it is becoming increasingly necessary to rely upon small erratic sources of aggregate in building branch roads.

Lithology of Gravels

The pebbles and cobbles making up the gravels consist dominantly of basaltic and andesitic volcanic rocks. In addition, most gravels contain a considerable percentage of granodiorite stones and some contain a few per cent of sandstone and shale fragments. Isolated pieces of gneiss, schist, limestone, argillite, quartzite, chert, and quartz are locally present. Local variation in the constituents of the gravels are shown in Table 5.

Table 5

Lithology of Pebbles in Gravel

Location	Volcanic Rocks (%)	Granodiorite (%)	Sandstone and Shale (%)	Others
Coastal lowland, north of Englishman River	80-90	5-20	1-10 along Cowie, Wilfred, Chef, and French Creeks, rare elsewhere	less than 1%
Coastal lowland, Englishman River to Nanoose Bay	60-80	20-40	0-10	up to 5%, mainly chert, quartzite
Mountain valleys	80-100	0-10	rare	Cameron River and Horne Lake: chert, quartzite, argillite, limestone 0-20%
Alberni Valley:				
East of Stamp River, north of Stamp Falls	65-90	10-20	0-15	less than 1%
Great Central-Stamp Falls	50-60	40-50	0-1	less than 1%
Somass River etc.	55-75	25-45	rare	less than 1%
Rogers Creek	70-80	15	5	less than 1%, includes chert

The shale and sandstone fragments and a small proportion of the granodiorite stones are weathered and soft, but the other constituents of the gravels are characteristically firm and unweathered and stand up well to abrasion or load. In some gravels the stones are coated with a varnish of iron or manganese oxides, but calcium-carbonate coatings are exceedingly rare. Many of the volcanic stones are remarkably smooth. Some of the chert at least is microcrystalline, and nowhere has the author seen evidence of deterioration of concrete through chert reactivity.

Sub-till Gravel Deposits

Although the Quadra sediments and other sub-till deposits of the area are dominantly sandy, locally they contain appreciable thicknesses of gravel that can be exploited where the overlying till is thin. Gravels lying within the Quadra sand unit are being extracted from a pit 40 feet deep and several acres in extent about a mile north of Errington. The materials exposed in this pit are pebble gravel, sandy gravel, and sand. The gravel is well rounded and contains little silt or clay. The Vashon till that formerly covered the gravel is largely absent (removed by former marine wave-erosion) within the confines of the present excavation but patches of till will probably be encountered as the pit is expanded.

Sub-till gravels have been exploited on a small scale on the gullied hillside at the head of Chef Creek and a few feet above the highest delta west of Wilfred Creek. These gravels consist of subrounded pebbles and cobbles, and contain only a moderate amount of sand and little silt or clay. In both places the thin till that originally covered the gravel has been breached by stream gullying. Similar pits could be opened up in the same thick extensive gravels in a number of places on the higher inland part of the coastal lowland between Thames Creek and Cowie Creek.

Glacio-fluvial and Delta Terrace Deposits

The thick extensive glacio-fluvial and deltaic gravels and sands are well adapted to low-cost exploitation and provide a readily available source of aggregate in many parts of the area. Commonly, pits 10 to 50 feet deep can be excavated in these materials without removing any appreciable quantity of deleterious material from the ground surface or within the gravel succession. Most of these deposits are bounded on at least one side by a steep face, permitting lateral instead of downward excavation into the gravel.

The terraced delta deposits typically consist of pebble gravels, sandy gravels, and sands containing little silt and clay. Some deltas are cobbly and a few contain small boulders. Pebbles and cobbles in most deltas are rounded to subrounded. In contrast, some deltas in mountain valleys (e.g. bordering Horne and Cameron Lakes) consist of rather angular pebbly and cobbly gravels containing appreciable amounts of silt and clay. In any delta, the top-set beds, extending 5 to 10 feet below the flat delta surface, are coarser and less sandy than the underlying inclined fore-set beds. Locally, thin beds of silt are interlayered with the fore-set gravels and sands. In some places there is an appreciable decrease in the average size of gravel within a delta from the upstream apex to the lower margin. Although most of the deltas shown on the accompanying geological maps contain useful amounts of gravel, some are too thin and sandy for exploitation.

Gravels and sands comprising flat-topped ice-contact deposits are similar to the typical delta deposits described above but commonly display much less regular changes in coarseness and grading, and locally contain pockets of till or boulders. Ridged (esker) deposits likewise consist of gravels, sandy gravels, and sands with subrounded stones, and contain very little silt and clay. Although much of the esker gravel is pebbly, some is cobbly and some is bouldery, with stones up to a foot in diameter. Some of the eskers near Englishman River display a remarkable decrease in the size of the largest and average stones from south to north. Knobby ice-contact deposits (kames) typically consist largely of clean pebbly and cobbly gravels and sands like the deposits described above, but some contain many boulders or appreciable amounts of silt or clay, and may include irregular masses of till.

River Terrace Deposits

The gravel surfacing most terraces along the sides of the stream valleys of the area is cobbly to bouldery and only a few feet thick. It is locally used for concrete aggregate or road construction where thicker or pebbly gravel deposits are not available.

Terraces along the sides of Somass River valley are underlain by up to 50 feet of gravel and sand and supply most of the concrete aggregate and road-building material used in the vicinity of Alberni and Port Alberni. These terrace deposits consist principally of well-rounded pebble and cobble gravel, sandy gravel, and sand containing little or no interstitial silt and clay, but in many places they contain or are surfaced by beds of clay, silt, and stony sandy silt. These clayey and silty materials commonly are oxidized and hard, and generally can be separated from the gravel by selective quarrying. The deposits occur beneath long, narrow, discontinuous remnants of a single terrace 30 to 50 feet above the river level. They are bordered on the river side by a steep bank dropping off to the modern flood plain and are confined on the side away from the river by a gentle to steep face of till and rock that forms the valley wall. Isolated large boulders are enclosed in the gravel adjacent to this valley wall. Both glacio-fluvial ice-contact deposits and post-glacial river deposits appear to be included in these sub-terrace gravels and sands. This complexity of origin probably explains why some pits in them expose thick clean gravel whereas others nearby expose sandy materials with clay beds and little gravel.

Marine Veneer Gravels

The marine veneer of the coastal lowland is a widespread, easily available source of small quantities of gravel, and supplies the needs of many farmers and settlers for road-surfacing material and concrete aggregate. In only a few places, however, are the marine gravels thick enough to be exploited for larger projects. Those most suitable for gravel production form low ridges or terraces (ancient shoreline features) surfaced by pebbles and small cobbles. They differ from nearby thinner marine veneer gravels by the general absence of boulders, the uniform size of the contained stones, and the paucity of sand and fines. These thicker marine gravels are of small extent and generally range from 5 to 15 feet in thickness.

Modern Delta and River-bottom Deposits

Deltas at the mouths of the streams in the area commonly are underlain by gravels and sands that probably range up to 50 feet or more in thickness. So far they have been exploited only by shallow pits (depths of 10 feet and less) above the water-table. Greater production could be achieved by dragline operations. The near-surface gravels of most modern deltas consist of well-rounded pebbles and cobbles mixed with various amounts of sand and containing little silt or clay. They are locally covered by a few inches to a few feet of silt, clay, or peat. Little is known of the texture of the delta alluvium at depth.

The alluvium on the floors of the stream valleys consists largely of bouldery, cobbly, and pebbly gravel. These gravels are generally less than 10 feet thick and lie partly below the water-table, but nonetheless they constitute a valuable source of road-building material in mountain valleys and in some parts of the lowlands where larger gravel supplies are not present nearby.

Alluvial-fan Gravels

The alluvial fans in the area contain much material suitable for road construction. They consist of angular pebble- to cobble-size rock fragments mixed with a moderate amount of sand, silt, and clay. Such fan materials are the main source of aggregate in some mountain valleys where only small amounts of other kinds of gravel are available. They are commonly more than 10 feet thick, and in some terraced fans it is possible to open up gravel faces more than 50 feet high.

Landslide and Talus Gravels

Many talus and landslide accumulations in the mountainous parts of the area contain angular pebble- to cobble-size 'scree' (mixed with various proportions of fines) that is suitable for road-building. In some of these deposits are large uniform bodies of such gravelly material, but in others it is intermingled with coarse rubble or dense clayey material. Most talus and landslide accumulations are found at the bottom of steeply sloping valley walls, but a few are perched on mountainsides where they accumulated against the margins of former glaciers.

Agricultural Soils

The soils in the lowland parts of the area are brownish, yellowish, or reddish and contain little organic matter below the surface litter. They are leached, moderately to strongly acidic, and of low base saturation. The principal soils of the coastal lowland have been assigned to the 'Brown Podzolic' soil group and those of Alberni Valley to the 'Concretionary Brown' soil group (Day, Farstad, and Laird, 1959).

Almost all the soils are developed upon the transported unconsolidated deposits with which this report is concerned, although soils have been formed in a few places by the weathering in place of shale, sandstone, and limestone. The soils themselves—which result from the modification of geological parent materials by the interaction of biological activity and climate under particular moisture conditions and for particular intervals of time—lie beyond the scope of this report. Nonetheless in this region, local differences in the nature of the soil have resulted in large measure from differences in the geology, principally the texture and stoniness of the parent materials, the slope of the ground surface, and the moisture relationships within the ground. The moisture relationships (drainage) are controlled in turn by the slope of the ground surface, the permeability of the subsoil materials, and (where the subsoil is coarse) the level of the groundwater table. Materials with the same geological origin commonly vary from place to place in one or another of the above respects and will thus give rise to more than one kind of soil. Moreover, materials possessing the same texture, stoniness, slope, and drainage, and therefore assignable to a single soil series, may have originated in several different geological environments.

Time Involved in Soil Development

Most soils on the Vashon drift and Capilano sediments started to form at various times between the retreat of the glaciers, possibly about 14,000 years ago, and the establishment of the present level of the land relative to the sea. According to information currently available, almost all of the lowlands of Vancouver Island had emerged from the sea 10,000 years ago. Such old soils occupy the greater part of the area.

Soils on the alluvial, shoreline, and related deposits of the Salish sediments have originated for the most part since the present seashore level was established, and many of the Salish deposits have been deposited or modified within the last few centuries or decades.

Soils on Quadra Sand

The sands of the Quadra sediments come close enough to the ground surface to affect the soil in a few small areas within the coastal lowland (see geological maps) where wave erosion during the Capilano marine submergence removed the overlying Vashon till and left only a few inches of gravel covering the sand. In such places the thin marine gravel and the underlying Quadra sand together support dry, coarse-textured sterile soils of the Qualicum series[1].

The remarkable dryness of these soils is clearly illustrated by the stunted trees and sparse underbrush growing upon them, in contrast to the dense forest supported by adjoining soils of similar surface texture underlain by impervious till instead of sand.

[1] This and other soil series referred to here are defined and described by Day, Farstad, and Laird (1959).

Soils on Till

The Vashon till is the most widespread soil parent-material above the limit of marine submergence (above 450 to 500 feet in altitude on the coastal lowland and above 300 to 350 feet in Alberni Valley). Soils on the till, and on colluvial or alluvial materials derived from the till, are stony or gravelly and of sandy loam to loam texture. On the coastal lowland, sandy-textured tills support soils of the Shawnigan or Quinsam series, whereas loamy-textured tills support Royston soils. Soils on the loamy till of Alberni Valley belong to the Stamp series, and those on the sandy granodiorite-rich till of the west side of the valley belong to the Sproat series.

The compact till beneath the soil prevents water from moving downward, so that till soils in low places may be flooded during the winter, and those on higher ground are not as dry in summer as would be expected from their texture. Despite their moderate resistance to drought, these soils are little used for agriculture because of their stoniness, sloping or hilly topography, and remote location on the higher, inland parts of the lowlands.

Soils on Glacio-fluvial Deposits and Fluvial and Delta Terraces

The fluvial and deltaic deposits of the Capilano sediments form flat benches underlain by thick, dry gravel and sand. The Vashon glacio-fluvial deposits likewise consist of thick gravel and sand, but include ridged, hummocky, and pitted areas, as well as terraces.

Most of these deposits support exceedingly dry sterile soils that have been assigned to the Qualicum, Somass, and Kye series. Locally, silty or clayey alluvium lies upon the surface of the terrace deposits, particularly where they abut higher ground. The soils developed on these medium- to fine-textured deposits are better suited to agriculture than the other terrace soils, but are drier than marine soils of similar texture because they are underlain by excessively drained sand or gravel.

Soils on Marine Deposits

Most soils of the lowlands of Vancouver Island are developed from parent materials that have been deposited in the sea or modified by waves along the seashore (see discussion of Capilano sediments in Chapter III). In texture these marine materials are stony, gravelly, sandy, silty, or clayey, and typically form a veneer or mantle that is 1 foot to 5 feet thick on hills or slopes and 5 to 30 feet thick on low ground.

The marine soils of the coastal lowland vary greatly in texture, particularly where the till is sandy. On sloping areas and hilltops the soil parent-materials are gravelly loamy sand and loamy sand and, less commonly, gravelly sandy loam. Most of them contain boulders. Generally these materials are less than 5 feet thick. They contain discontinuous layers of clay and rest upon impermeable till, clay, or rock. Hence, although they have little resistance to the summer drought, they are not as dry as would be expected from their coarse texture and sloping topography. Where ground-slopes are gentle they are subject to winter flooding. The soils developed on these coarse marine materials belong principally to the Dashwood, Bowser, and Shawnigan series. Much drier coarse-textured marine soils, belonging to the Qualicum series, occur here and there where the deposits described above thicken to form shoreline terraces, spits, or bars, or (as described earlier) where they rest upon Quadra sediments instead of till. The coarse-textured marine soils are generally of little agricultural value because of their stoniness, hilly topography, or lack of resistance to drought.

Depressions and relatively flat areas within the coastal lowland are surfaced by marine sand, silty sand, silt, and clay that support soils of the Parskville, Puntledge, Tolmie, Fairbridge, and Cowichan series. These deposits are the lateral equivalents of the coarse-grained soil parent-materials described above. Generally the sandy to silty materials are to be found along the edge of a depression or flat area, whereas clayey materials come to the surface farther from sloping ground. The silty to clayey Tolmie, Fairbridge, and Cowichan soils are among the better agricultural soils of the region. The sandy to silty Parksville and Puntledge soils are of moderate agricultural value. Their parent materials generally rest upon clay and hence the soils offer considerable resistance to summer drought but are water-saturated in winter.

In many parts of the coastal lowland the marine soils occur on a rolling ground-moraine topography with hills and hollows a few tens to hundreds of feet across. In such places the soils are heterogeneous, and in extreme situations range within a few tens of feet from excessively dry to poorly drained or from gravelly to clayey.

In Alberni Valley the marine soils are less varied and generally finer textured than those of the coastal lowland. On low to flat ground the marine deposits are silty to clayey in texture and support soils of the Alberni and Cowichan series. These soils appear to be well suited for agricultural use although as yet they are largely forested. Sloping or rolling ground in all but the western part of the valley is surfaced by marine-modified materials of gravelly-loam texture derived from loamy-textured till. The soils on these materials, which are assigned to the Stamp series, differ little from nearby unmodified till soils outside the area of marine submergence. Compact, impermeable till beneath these soils causes flooding in poorly drained areas during the winter, but increases their moisture content during the summer drought. They are of some agricultural interest where their stone content is low and slopes are gentle. In the western part of Alberni Valley where the till is sandy, the marine-modified surface materials on sloping ground are stony and coarse textured. The soils developed upon them belonging to the Sproat series are of little agricultural value because of their stoniness and because of the hilly terrain upon which they occur.

Soils on Modern Alluvium (Salish Sediments)

Bottom lands bordering the rivers of the area and deltas at the river mouths are largely built of gravel and sand, but parts of many of them bear a surface veneer of fine sand, silt, or clay. Soils on gravelly or sandy alluvium, belonging to the Cassidy series, are of rather low agricultural value, but the finer-textured (loamy to clayey) alluvial soils of the Chemainus series are the most fertile in the area. The alluvium of most of the rivers is coarse and includes only small isolated patches of finer-texture material supporting Chemainus soils; the only large area of Chemainus soils within the area is on the flood plain of Somass River in Alberni Valley. In winter and spring many of the bottom lands and deltas may be flooded, but in summer when the water-table commonly drops a few feet (up to 15 feet) below the ground surface, the coarse-textured alluvial materials are exceedingly dry and the finer-textured materials are drier than would be expected because they rest on a permeable substratum. On the other hand, dugouts excavated in the coarse subsoils below the water-table provide a ready source of irrigation water.

Alluvial fans, built by streams where they flow from steep mountainside gullies onto flatter ground, consist dominantly of stony coarse-textured materials supporting soils of little agricultural value. However, loamy to clayey alluvium supporting soils of considerable agricultural potential occur on the lower marginal parts of some fans. These fine-textured fan deposits consist of alternating layers, a few inches thick, of loamy to clayey material containing few stones and of coarse angular sand or fine gravel. Commonly the sandy or gravelly strata are water bearing. Locally the fine alluvial materials fill depressions adjacent to the fans. Such alluvial fans and depression fillings are confined chiefly to the eastern part of Alberni Valley, although a few small fans lie along the inland edge of the coastal lowland.

Sewage Disposal

The disposal of sewage within the area is generally accomplished by means of septic tanks and weeping drains. To function properly these should discharge into permeable deposits that are not saturated with water. Where water supplies are derived from the ground, septic-tank systems must be so located that their overflow does not pollute the groundwater. The need to avoid pollution of surface water scarcely needs mention.

The recent fluvial, deltaic, and shoreline deposits comprising the Salish sediments are commonly saturated with water almost to the ground surface during the wet season, and some of them are subject to flooding. Septic-tank systems will not function effectively in such situations and only in the highest driest parts of these alluvial areas do they provide a satisfactory means of sewage disposal. Because of the high permeability of the alluvial deposits and the near-surface position of the water-table, the outflow from septic-tank systems readily gets into the groundwater and may cause pollution of shallow wells, even though the large volume, rapid movement, and high oxygen content of the groundwater in much of the alluvium tend to dilute and oxidize the polluting materials.

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Septic-tank systems function satisfactorily in the dry gravels and sands comprising the glacio-fluvial deposits of the Vashon drift and the fluvial and deltaic components of the Capilano sediments. However, surface drainage, including septic-tank effluent, entering such deposits moves vertically downward to the water-table to be incorporated in the groundwater; it then moves laterally, in the direction of flow of the groundwater and not necessarily in the direction of the slope of the ground. Hence, placing a septic tank downhill from a well may not always prevent the well from becoming polluted.

The marine and ground-moraine deposits of Alberni Valley are covered by loose or fractured clay or gravelly loam but are impermeable beyond a depth of only a few feet. Low areas are water logged, especially in winter, and the effluent from septic tanks is absorbed into the ground slowly or not at all. On sloping or high areas, septic-tank effluent is absorbed by the loose surface mantle but migrates downslope a few inches or a few feet below the ground surface to collect in low areas or to enter fractures in the till or clay that carry the small supplies of groundwater available in such areas. Hence, where wells are used for domestic water supply, septic tanks must be located with great care.

Exceedingly varied surface-drainage conditions and sewage-disposal problems are encountered in the marine and ground-moraine deposits of the coastal lowland. Areas of clay present problems of septic-tank operation similar to those in Alberni Valley (mentioned above). In areas of marine sand, marine veneer, and unmodified ground-moraine deposits, the surface material into which septic-tank systems discharge is highly to moderately permeable, but generally a substratum of clay, till, or rock a few inches or a few feet below the surface causes lateral rather than downward drainage. Thus in low or flat areas, septic-tank systems may be flooded during the wet winter season, and on sloping ground septic-tank effluent moves downslope to collect in low areas. Wells in the marine and ground-moraine deposits for the most part are shallow dug holes drawing on small near-surface seepages, and thus are highly susceptible to pollution by surface drainage. Hence, septic tanks should be so placed that their effluent drains away from any present or future wells. Where marine sands and gravels thicken to form shoreline spits or terraces and where marine veneer deposits rest directly upon Quadra sand instead of till, drainage is rapid and septic-tank effluent moves downward instead of parallel with the ground surface. Locally where the till is thin, downward drainage in otherwise wet areas can be induced by digging or drilling through the till to the underlying sand. The ease of sewage disposal in such areas of downward drainage is countered by the possibility of groundwater pollution.

Groundwater

Much of the water used in homes, farms, and commercial establishments in the area is derived from the surficial deposits by wells or springs. Moreover, groundwater contributes substantially to the flow of many streams at times of low water.

The dryness of the summer and remarkable seasonal variation in rainfall complicate the problem of maintaining adequate water supplies and enhance the importance of groundwater. The average annual precipitation ranges from 40 to 60 inches on the coastal lowland and approaches 70 inches in Alberni Valley; but only about 2 inches of rain falls during July and August and only 5 to 7 inches during all of the four summer months. The rainfall in the mountains is greater than in Alberni Valley. Consequently the flow of streams fluctuates greatly with the seasons, and small shallow groundwater supplies are subject to remarkable variations. Growth of crops is seriously affected by the summer drought, and irrigation (drawing upon surface water and groundwater) is being used increasingly to offset the shortage of rainfall.

Springs and wells are fed by water-saturated materials with large enough pores or cracks to transmit water. Within the area, gravel and sand are the principal materials that will transmit water quickly enough to yield useful water supplies, although some of the most sandy tills are sufficiently permeable to yield small amounts of water, and some clays and tills yield water from cracks. Small supplies of water probably could be obtained locally but at considerable cost from drilled wells tapping fractures in the bedrock. The largest groundwater reserves in the area are contained in recent alluvial deposits, terraced fluvial and deltaic deposits, glacio-fluvial deposits, and in Quadra and other sediments beneath the Vashon drift. The Vashon till and the Capilano marine deposits, which together form the near-surface deposits throughout much of the area, will yield only small and erratic water supplies.

Salish Sediments

The most obvious source of groundwater is the coarse-textured recent alluvium bordering rivers, lakes, and the sea. The water-table in these deposits lies within a few feet of the surface—approximately at the level of the adjoining free water-body. Shallow dug wells or sand points generally encounter permeable gravel and sand and yield plenty of water for household or farm use. Larger amounts of water could be obtained from drilled wells where the alluvium is thick, or from dugouts.

Deltas and adjacent bottom-lands are underlain for the most part by thick water-bearing sands and gravels interspersed with beds of less-permeable material. Large yields of water can generally be obtained from shallow wells or dugouts, although locally these encounter silty deposits from which the yield is disappointingly small. Community or industrial water supplies could be obtained from properly developed drilled wells. Deep wells beneath some deltas may encounter salt water.

Although the recent deposits along most of the seashore are too thin to yield much water, a few spits, bars, and shoreline terraces (particularly those extending laterally from deltas) provide water for shoreline homes and tourist establishments. The permeable gravels and sands comprising these deposits are up to 20 feet thick and will normally yield a satisfactory domestic water supply, although salt water may locally encroach into wells, and in some places where the shoreline borders swampy ground the water tastes of iron.

Inland from the seashore the river alluvium is generally less than 20 feet thick, but most such deposits are water-saturated to within a few feet of the surface and are permeable enough to yield plenty of water when tapped by shallow dug-wells or sand points. In some places, however, the deposits are of low permeability, and in others the water-table drops below the base of the permeable deposits during the dry season.

The alluvial fans in the area consist of irregular layers of permeable and impermeable gravelly materials. The water-table is generally within a few feet of the ground surface and water locally comes out on the surface as springs, but wells may have to be sunk some distance below the water-table before they encounter permeable water-bearing materials. The lower peripheral parts of some fans in Alberni Valley and a few alluvial depression-fillings adjacent to the fans are surfaced by silts and clays but commonly include layers of water-bearing gravel or sand within a few feet of the surface.

Glacio-fluvial and Fluvial Terrace Deposits

The numerous bodies of gravel and sand that constitute the eskers, kames, ice-contact terrace, and raised deltaic and fluvial deposits of the area contain substantial amounts of groundwater. In many parts of the coastal lowland this water is 'perched' on top of the Vashon till and feeds deeper aquifers in the Quadra sediments.

The water in these deposits occupies the interstices between the pebbles and sand grains below a gently sloping water-table. In flat areas the depth to water is relatively uniform, but in ridged, hummocky, or pitted areas the depth to water, of course, varies with the elevation of the ground surface. Locally the level of the water-table is marked by swamps or ponds in kettle holes or by springs around the sloping margins of the deposits. The elevation of the base of the gravels and sands, and hence the thickness of the aquifer, varies from place to place with the topography of the surface of the underlying clay, till, or rock. Where the level of this surface rises above the water-table the gravels and sands are dry throughout.

Wells in these materials encounter water at depths ranging from a few to more than 50 feet and, except where the deposits are dry throughout (see above), they yield abundant water for farm or domestic use. Where the water-bearing layer is thick, properly developed drilled wells could generally provide water for moderate-sized industrial, community, or irrigation systems. The water is of good quality although slightly harder than the exceedingly soft water in streams or lakes.

Marine and Ground-moraine Deposits

The marine and ground-moraine deposits of the area yield only small amounts of water. Throughout the large parts of the coastal lowland and Alberni Valley surfaced by these materials, domestic and farm water supply is typically derived from dug wells that are 10 feet to several tens of feet deep and are fed by fractures or gravelly lenses in the till or, on the coastal lowland, by slow seepage from the sandy till. Wells of this type act to a varying degree as cisterns, storing water in the wet season for use during the dry season. Commonly the water drawn from them during the dry season is moderately hard. The groundwater yield in such areas can be increased by deepening a well or by adding an additional well or wells to the system. Wells only a few tens of feet apart may yield markedly different amounts of water.

Where the till is several tens of feet thick, one or more dug wells, as outlined above, will generally yield a fairly satisfactory domestic water supply even during the dry season. Each well should be provided with a concrete cribbing—set on the compact till and extending a few inches above the ground surface—to reduce the possibility of pollution through entry of drainage from the ground surface or from the loose surface mantle. On the other hand, where the till is 'tight' or thin (e.g. rests on rock or sand) the yield of water from the till may be so small that wells go dry during the late summer. In such situations, the water yield can be increased by permitting seepage to enter wells from the loose surface mantle of marine deposits or fractured till, or by placing wells in low areas that catch drainage from higher ground. Such wells, of course, are highly susceptible to pollution.

Some of the thicker sandy and gravelly marine deposits in the coastal lowland contain small groundwater bodies that do not dry up during the summer. Because of their near-surface position they are readily susceptible to pollution. Marine sands in depressions or low areas receive and store drainage from adjoining higher ground, and during the winter they are commonly water-saturated to the ground surface. Where these sands are more than 5 feet thick, some water generally remains in them during the summer. On higher, drier situations, local permanent groundwater bodies a few inches to several feet thick are to be found at the base of gravels and sands forming shoreline terraces and spits where these deposits are 10 feet or more in thickness and where the underlying clay or till surface is relatively flat.

Some dug wells in Alberni Valley draw water from fractures in oxidized marine clay and from gravelly partings along the till-clay contact. Moreover, in a few places substantial thicknesses of water-bearing gravel have been found beneath the Alberni marine clays. In contrast, the clays of the coastal lowland yield little water.

Quadra and Other Sub-till Deposits

The sands of the Quadra sediments, the Mapleguard sediments, and other permeable deposits that lie beneath the Vashon till contain large reserves of groundwater. These materials underlie much of the coastal lowland (*see* Fig. 5), and gravels within or beneath the till are known to occur in a few places in the central part of Alberni Valley. The water in the sub-till deposits of the coastal lowland comes to the surface as springs both on the rolling lowland surface and along steep sea-cliffs and river banks. During the summer drought it contributes substantially to the flow of Qualicum River, Nile Creek, Chef Creek, Waterloo Creek, Wilfred Creek, and others. Springs emanating from the sub-till deposits are the source of the community water system at Parksville (which supplies about 400 water-users) and of various domestic water supplies elsewhere on the coastal lowland. The sub-till aquifers are also tapped by some (possibly 2 dozen) dug and drilled wells that are a few tens to more than a hundred feet deep. Wells of this sort yield much of the water used in the community water system of Qualicum Beach municipality. The water in the sub-till deposits is of good quality although slightly harder than the exceedingly soft surface-waters of the region.

Wells drawing upon gravels or coarse sands within the sub-till deposits can be expected to yield moderate to large amounts of water, but those in the widespread fine Quadra sands may require special treatment before they will yield any substantial amount of water. Dug wells in this sand commonly encounter quicksand at the water-table and cannot be dug the necessary few feet below the water-table to permit pumping at any appreciable rate. Sufficient water for domestic use, however, can generally be obtained from a sand point driven into the quicksand. Drilled wells, of course, can penetrate these fine quicksands but generally must be equipped with well-screens of the proper size and be surrounded by artificial gravel packing in order to produce the maximum yield of water, free of sand. Alternatively, a drilled well encountering water in fine sand can be deepened in the hope of reaching gravel or coarse sand from which water can be drawn without elaborate well-development.

Generally the water in the sub-till aquifers, occupying the interstices in sand or gravel, lies beneath a gently sloping water-table and above an impermeable substratum; but in some places, water saturates the permeable unit from bottom to top and is confined under pressure beneath the impermeable capping of till. Some sub-till aquifers are widely distributed and others are of only limited extent. Their thickness and elevation and the position of the water-table within them vary from place to place.

The sand unit of the Quadra sediments forms the most extensive sub-till aquifer within the area and is present throughout much of the settled part of the coastal lowland, but it is far from continuous (*see* Fig. 5). The water-table within it is graded to the seashore or river levels or is held at higher levels by impermeable strata within or beneath the sand.

Near the eastern border of the area, springs emanating from the Quadra sand are to be found at various elevations along the south shore of Nanoose Bay and about 20 feet above sea-level at the base of the hillside north of the head of the bay. Springs also occur along the walls of the valley of Bonell Creek. The general water level in the sands beneath the ridge between Nanoose Bay and Englishman River is not known, although two or three wells on the ridge draw water from these deposits. Springs emerge ¾ mile southeast of Craig about 200 feet above sea-level and ¾ mile south of the Northwest Bay logging camp about 300 feet above sea-level.

South of Parksville, a line of springs and seepages 170 or 180 feet above sea-level and more than 2 miles long extends east and west from the Parksville railway station. The springs supplying the Parksville waterworks lie in this zone. South of this spring line, adjoining the Alberni road, the water-table in the Quadra sand unit has been encountered about 200 feet above sea-level in several wells. Farther west along French Creek, 2 to 5 miles from the seashore, seepage emanates from the contact of the Quadra sand unit and underlying peat approximately 150 to 170 feet above sea-level, and the water-table beneath the adjoining region is probably a few feet higher.

Between French Creek and Qualicum Beach, the water-table in the sand is approximately at sea-level near the shore and has been encountered 30 to 50 feet above sea-level (and up to 150 feet below the ground surface) in several wells between the shore and the north branch of the railway. Beach Creek at Qualicum Beach apparently draws upon this water body. Farther inland a spring line extends 1½ miles eastward from the Qualicum-Hilliers road about 0.3 mile south of the railway and about 200 feet above sea-level. South of this spring line, in the Qualicum municipal wells (lot 3g) and in a domestic well in lot 70, the sub-till water-table is about 220 feet above sea-level, and water probably occurs at about the same level beneath the adjoining region and south to the edge of the sub-till deposits (Fig. 5). Between Grandon and Whisky Creeks, southwest of Qualicum Beach, short spring-lines 200 and 300 feet above sea-level within lot 78 may mark water-table levels in the Quadra sand unit beneath the surrounding country.

Along the Dashwood sea cliff between Little Qualicum and Qualicum Rivers (*see* Map 1111A, cross-section), springs and seepages emerge from the base of the Quadra sand unit, 50 to 150 feet above sea-level. Probably the water-table in the sand inland to the south is somewhat higher, possibly 150 to 200 feet above sea-level. Springs on the slope south of Dunsmuir, at an elevation of about 150 feet, probably draw water from the sand.

The valley of Qualicum River is cut into or through the sand unit of the Quadra sediments for much of its length. Near the power-transmission line and south to Hunts Creek, seepages and springs emerge from the base of the sand about 150 feet above sea-level in many places along the valley walls. About a mile south of Hunts Creek a series of large springs emanates from the sand along the eastern valley wall; they are somewhat more than 200 feet above sea-level. Still farther south, numerous seepages and springs draw upon a water-table in the sand at, or a few feet above, river level (elevation approximately 200 feet).

Nile Creek has cut deeply into the Quadra sand unit, and from 1½ to 3 miles from the seashore its level (250 to 300 feet above sea-level) appears to be graded to the water-table within the sands.

Between Bowser and Deep Bay, spring lines ¾ mile from the seashore at an elevation of about 250 feet and ¼ to ½ mile from the seashore at an elevation of about 150 feet draw large quantities of water from sub-till deposits (probably Quadra sediments). The seepage line at the base of the Quadra sand unit on the shore cliff to the north ($1\frac{1}{2}$ to 2 miles northwest of Bowser) is only 60 feet above sea-level. These three spring levels may relate to three separate water-tables or to a single sloping water surface.

The gravelly and sandy sub-till deposits along Chef Creek and between Rosewall and Cowie Creeks seem to contain much groundwater. Springs from these deposits feed Chef, Waterloo, Wilfred, and Cougar Smith Creeks, and emerge about 400 feet above sea-level on the slope between Wilfred and Cougar Smith Creeks.

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PLATES

JGF 3-6-53

A. Coastal lowland, mountain front, and Mount Arrowsmith, from near Parksville.

PLATE I

B. Small U-shaped valley incised into mountain upland.

JGF 5-2-56

JGF 6-4-53

A. Dashwood drift complex consisting of irregular beds and lenses of silty till and poorly sorted silt, sand, and gravel; Komas Bluff, Denman Island.

PLATE II

B. Stony clay of Quadra sediments exposed on the wave-cut beach platform at the foot of Komas Bluff, Denman Island. Most of the stones are embedded in the clay. The pick is 18 inches long.

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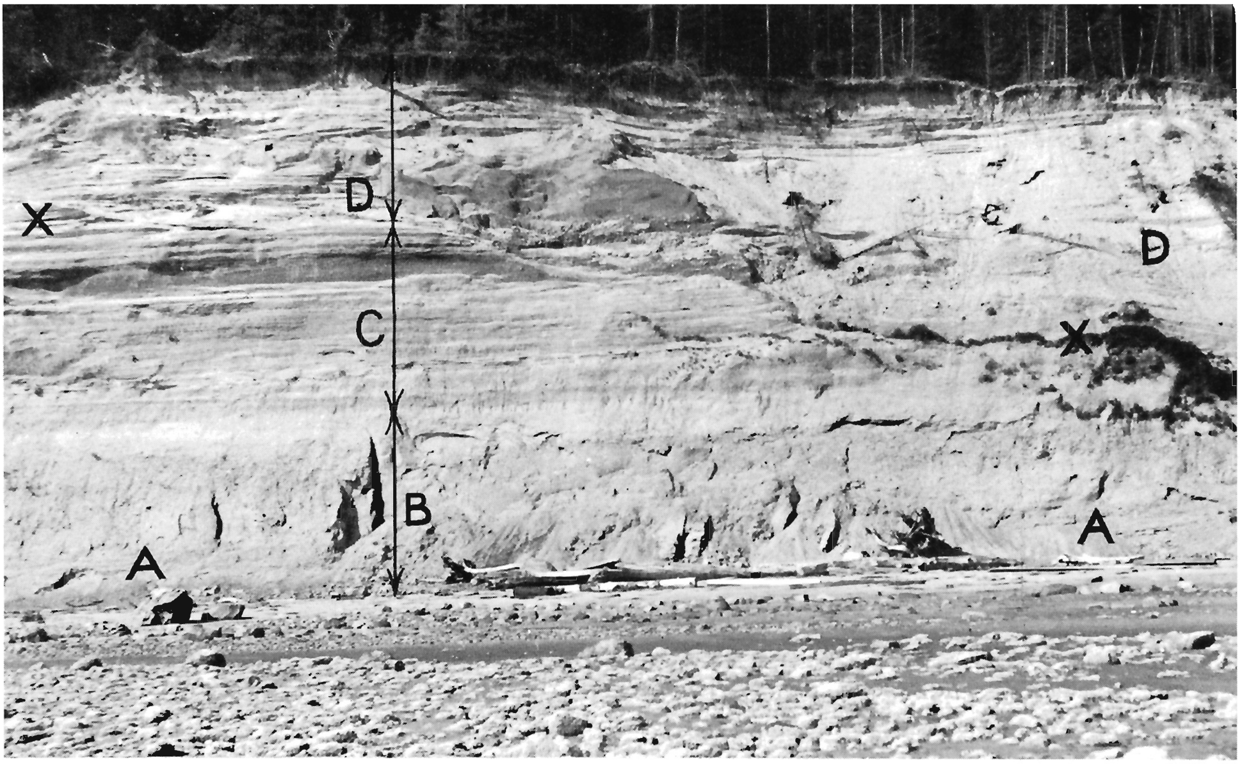
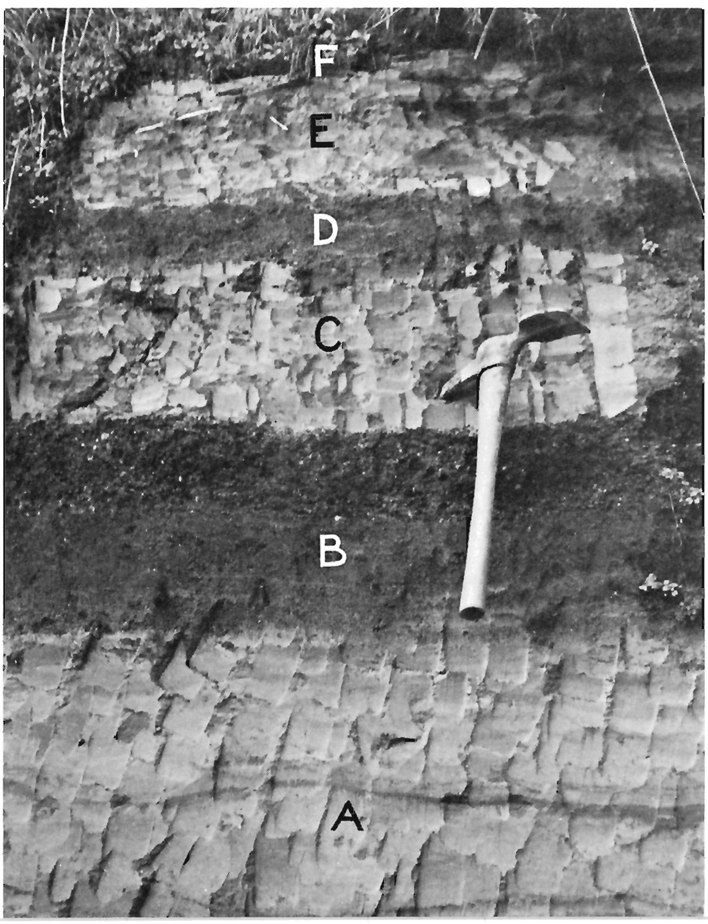


JGF 5-6-53

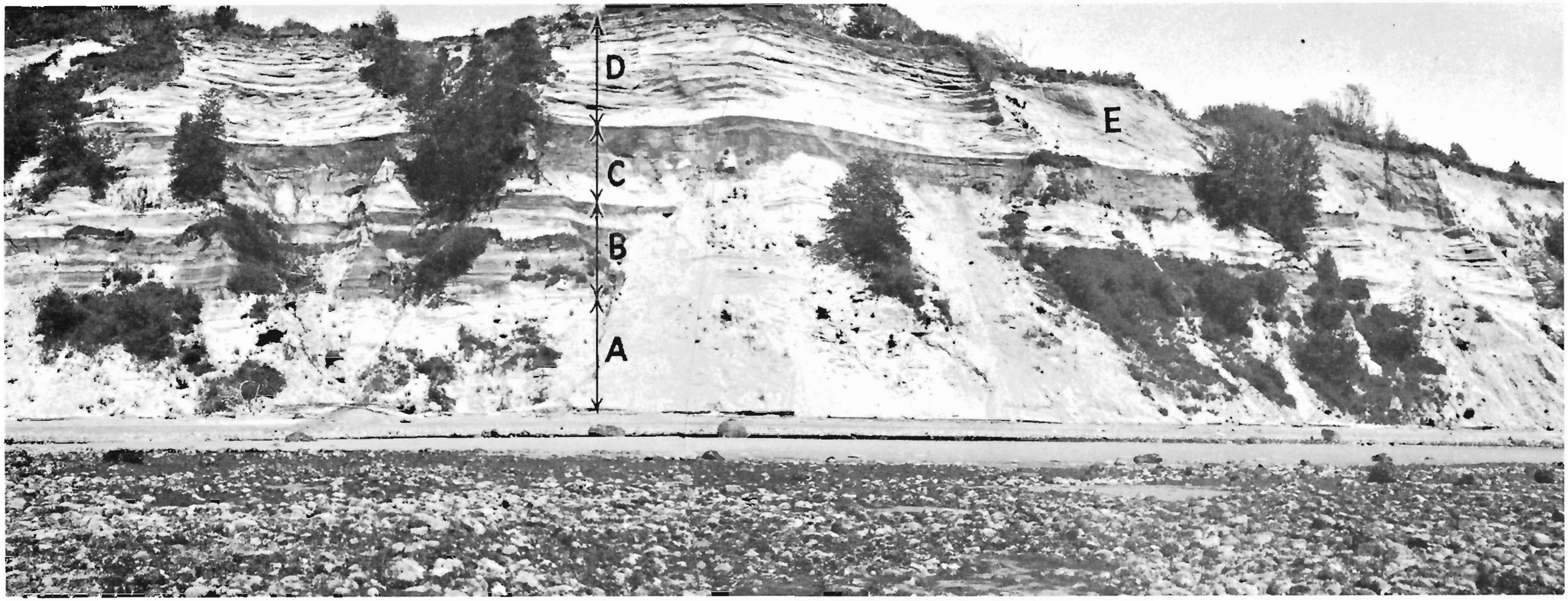
A. Quadra sediments on Komas Bluff, Denman Island. A—laminated clay; B—stony clay with marine shells; C—silt, gravel, sand with peat lenses and driftwood. Above the erosion surface (X-X) are postglacial marine sands and gravels (D). Cliff is about 90 feet high.

PLATE III



B. Part of the plant-bearing unit of the Quadra sediments, Komas Bluff, Denman Island. A—green silt with peaty partings (dark); B—rusty-orange pebble gravel; C—green silt; D—rusty-orange coarse sand; E—green silt with peat lenses (dark); F—dense peat (beneath overhanging vegetation).

JGF 12-4-53



JGF 6-2-52, 6-3-52

PLATE IV *Sand unit of the Quadra sediments, Willemar Bluff near Comox, on cliff face about 150 feet high. A—medium to coarse sand with rare lenses of peaty silt; B—medium and fine sand intercalated with green silt with wood, peat, and leaf imprints; C—coarse to fine sand alternating with beds of coherent clay-bonded sand, magnetite layers and rare driftwood; D—coarse to medium sand; E—till of the Vashon drift truncating the sand right of centre.*

JGF 9-7-53, 9-8-53

A. *Sheared and brecciated sand lying between undisturbed Quadra sand (below pick-handle) and Vashon till (above tape-measure). Rough areas in disturbed zone are lenses of till-like material. Exposure in pit adjoining Island Highway at Craig Creek.*

PLATE V

B. *Bouldery till 10 feet thick resting on less stony till, South Englishman River. Fabric orientations and pebble counts of the two tills are identical.*

JGF 2-3-53

JGF 6-5-52

A. Folded outwash deposits west of Somass River about a mile downstream from Sproat River. The 'basin' structure consists of laminated clay, silt, and sand, and rests upon thick gravel.

PLATE VI

B. Folded and faulted gravel in pit west of Somass River, 100 yards north of the face illustrated above. The disturbed structures appear to have resulted from slumping down the valley wall, right to left.

JGF 6-4-52

JGF 6-1-52

A. Topography of the kame-and-kettle area east of Little Qualicum River, looking south across Alberni Highway ½ mile west of Whiskey Creek.

PLATE VII

B. Stoss-and-lee surface formed by ice moving diagonally up west wall of Cameron Valley (right to left) towards the low pass leading to Alberni Valley.

JGF 10-2-53

JGF 1-4-53

A. Typical coarse gravelly phase of the marine veneer, underlain by till. The gravel is interpreted as a lag concentrate of stones left by wave-washing of the till. Exposure in road-cut near Comox.

PLATE VIII

B. Gravelly marine veneer in which the largest stones rest on the underlying till; same locality as A.

JGF 1-2-53

JGF 6-3-56

A. Small delta showing top-set beds truncating fore-set beds. The horizontal ground surface above the top-set beds is in the flat top of the delta; the slope at the left is the outer (downstream) slope of the delta.

PLATE IX

B. Alluvial fans, Rosewall Creek valley. The highest fan remnant left of the gully is believed to have been built against glacial ice occupying the valley bottom.

JGF 6-6-52

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