VANCOUVER GEOLOGY

DR. JOHN E. ARMSTRONG

edited by Charlie Roots and Chris Staargaard

CORDILLERAN SECTION

GAC

GEOLOGICAL ASSOCIATION OF CANADA

Vancouver 1990

Geological Association of Canada, Cordilleran Section
P.O. Box 398, Station A
Vancouver, B.C. V6C 2N2

Production: Terri Wershler
Design: Fiona MacGregor
Typesetting: The Vancouver Desktop Publishing Centre Ltd.
Printing: Imprimerie Gagné Ltée.

ERRATA

Geological Association of Canada
Vancouver Geology
Dr. John E. Armstrong

p. 23	line 3 for “Coast Range” read “Coast Mountains”
p. 30	line 16 for “Bowen Island Formation” read “Bowen Island Group”
p. 47	photo caption substitute “Glaciomarine stony mud (top left) overlies till consisting of rounded stones in a darker mixture of sand and silt”
p.47	diagram for “glaciomarine till” read “glaciomarine stony mud”
p. 51	photo caption for “ Glaciomarine mud” read “ Glaciolacustrine mud”
p. 61	photo caption for “Agassiz”, “1928" read “Mission”, “1948"
p. 69	photo caption for “Eocene” read “upper cretaceous”
p. 74	upper photo caption for “glaciomarine” read “glaciofluvial”
p. 83	paragraph 5, line 4, for “150m” for “250m”
p. 85	in photo caption add last sentence, “The bouldery till layer immediately above the sand bags is now thought to have been deposited during the Semiahmoo Glaciation.”
P. 85	paragraph 3, line 1, for “green banded glaciomarine” read “green banded glaciolacustrine”
Map	legend add “Quadra sand, minor silt, Coquitlam till” to be included under “Vashon drift” heading and glaciation terminated about 10,000 years before present time

VANCOUVER GEOLOGY

SUBDIVISIONS OF GEOLOGICAL TIME			Millions of Years Ago
ERA	PERIOD	EPOCH	
CENOZOIC	Quaternary	Holocene	0.01
		Pleistocene	1.6
	Tertiary	Pliocene	5
		Miocene	24
		Oligocene	37
		Eocene	58
		Paleocene	66
MESOZOIC	Cretaceous		144
	Jurassic		208
	Triassic		245
PALEOZOIC	Permian		286
	Pennsylvanian		320
	Mississippian		360
	Devonian		408
	Silurian		438
	Ordovician		505
	Cambrian		570
PRECAMBRIAN			1000
			2000
			3000
			4650

Chapter Four

Chapter Two

Chapter Three

Oldest Rocks Found

Birth of Planet Earth

CONTENTS

John E. Armstrong

Born in Cloverdale in the heart of the Fraser Lowland, Jack loved the outdoors and collected agates in his boyhood. He entered the geological engineering program at the University of British Columbia and received his doctorate from the University of Toronto. In the summer of 1934 he assisted in mapping the geology of the central Yukon. Joining the staff of the Geological Survey of Canada in 1937, Jack's entire career was devoted to understanding the rocks and sediments of western Canada. From 1940 to 1949 he supervised the systematic geologic mapping of north-central British Columbia. Jack's friendship and insistence upon higher education encouraged a remarkable number of his summer assistants to pursue geology in their own careers.

In 1949 Jack was transferred to the Vancouver office of the Geological Survey. After several years of geologic mapping in the mountains north of the city, he entrusted the work on granitic rocks to his senior assistant, Jim Roddick, and concentrated on the Pleistocene (mostly glacial) sediments of the Fraser Lowland. The complex distribution and interleaving of deposits were elucidated here on a scale matched in few other parts of the world. He recognized that during the Ice Age an arm of the sea extended as far east as Chilliwack, and glaciers surged out of the mountains at least three times. Jack headed the Vancouver office from 1955 to 1968, after which he was seconded to Ottawa to organize the 24th International Geological Congress. With Bill Mathews, a close friend and professor at the University of British Columbia, he organized section meetings in Vancouver for the Geological Society of America in 1960 and 1985.

Jack's enthusiasm for geology extended beyond office hours and he founded the Vancouver Geological Discussion Club. This club eventually became the Cordilleran Section of the Geological Association of Canada, and Jack served many years as the secretary-treasurer and continues as honorary councillor. He has also been president of the Vancouver Natural History Society, and is an honorary life member. With more than forty years of local geological experience, Jack has greater familiarity with the rocks and sediments of the Vancouver area than any other individual. The Cordilleran Section salutes his scientific career and acknowledges his efforts in helping us all to better appreciate our geological environment.

Jack Armstrong's original manuscript of *Vancouver Geology*, more technical than this book, is available from: The Geological Association of Canada, The Cordilleran Section, P.O. Box 398, Station A, Vancouver, B.C. V6C 2N2.

ACKNOWLEDGEMENTS

The first edition of *Vancouver Geology* was written in 1972 by G.H. Eisbacher with the support of other officers of the Geological Survey of Canada, as well as former professors at the University of British Columbia and Simon Fraser University. This third and expanded edition has been produced by the Cordilleran Section of the Geological Association of Canada between 1988 and 1990.

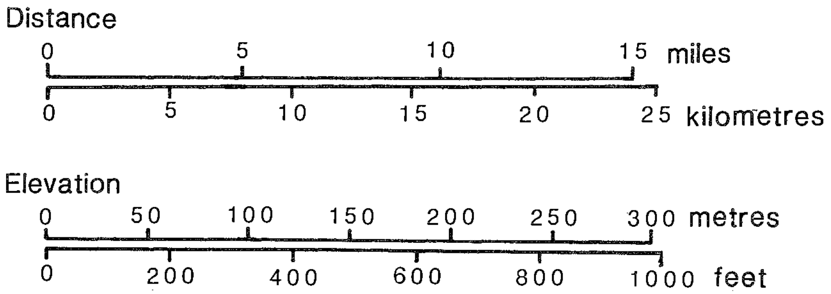
Most of the information was supplied by J.E. Armstrong, and portions of the text have been addressed by these members: G. Carlson, M. Hitzman, M. Keep, C. Roots, C. Staargaard and S. Taite. Field trips near sea level were described by J.E. Armstrong, and the mountain hikes by C. Roots. Reviews by C. Kissinger, J. Ricker and A. Tempelman-Kluit have also guided our efforts. Significant improvements in the manuscript were suggested by our independent editors, B. Scrivener and N. Thompson. Ultimate responsibility for the final draft, however, rests with us.

Technical aspects of production have been expedited by many volunteers. Early drafts were transcribed by E. Woolverton, secretary for the Cordilleran Section, with additional typing by J. Getsinger and B. Vanlier. Diagrams were drafted by M. Keep, C. Roots, C. Staargaard and A. Stanta. Donations of time, money and effort were instrumental and many of these were procured by V. Sterenberg, President of the Cordilleran Section. Contributions included computer plotting by R.W.R. Mineral Graphics and Placer Dome Inc. as well as drafting by the Geological Survey of Canada. A digitized base map was supplied by the B.C. Forest Service, where K. Lee, P. Pitzakis, and D. Herchmer were most helpful. Gulf International Minerals Ltd. supported some of the plotting with a generous grant. Various photographs were contributed by Gary Wesa and Jack Armstrong and the Vancouver Public Library is thanked for their cooperation. The concept and much of the cost of the cover were respectively supported by MacDonald Dettwiler and Advanced Satellite Productions Inc.

A start-up grant from the Canadian Geological Foundation allowed the project to proceed. The editors are grateful to the original *Vancouver Geology* committee: G. Carlson, J. Getsinger, V. Sterenberg, P. Wojdak, E. and R. Woolverton for their interest and foresight. J. Getsinger proofread the galleys and compiled the index. The Council thanks the members of the Cordilleran Section and acknowledges the Local Organizing Committee of the GAC-MAC Annual Meeting in Vancouver, 1990, for support in printing this guidebook.

C. Roots
C. Staargaard

Conversion scales:



100 metres = 328 feet

1000 feet = 305 metres

1 Mile = 1.6 Kilometres

5 kilometres ≃ 3 miles

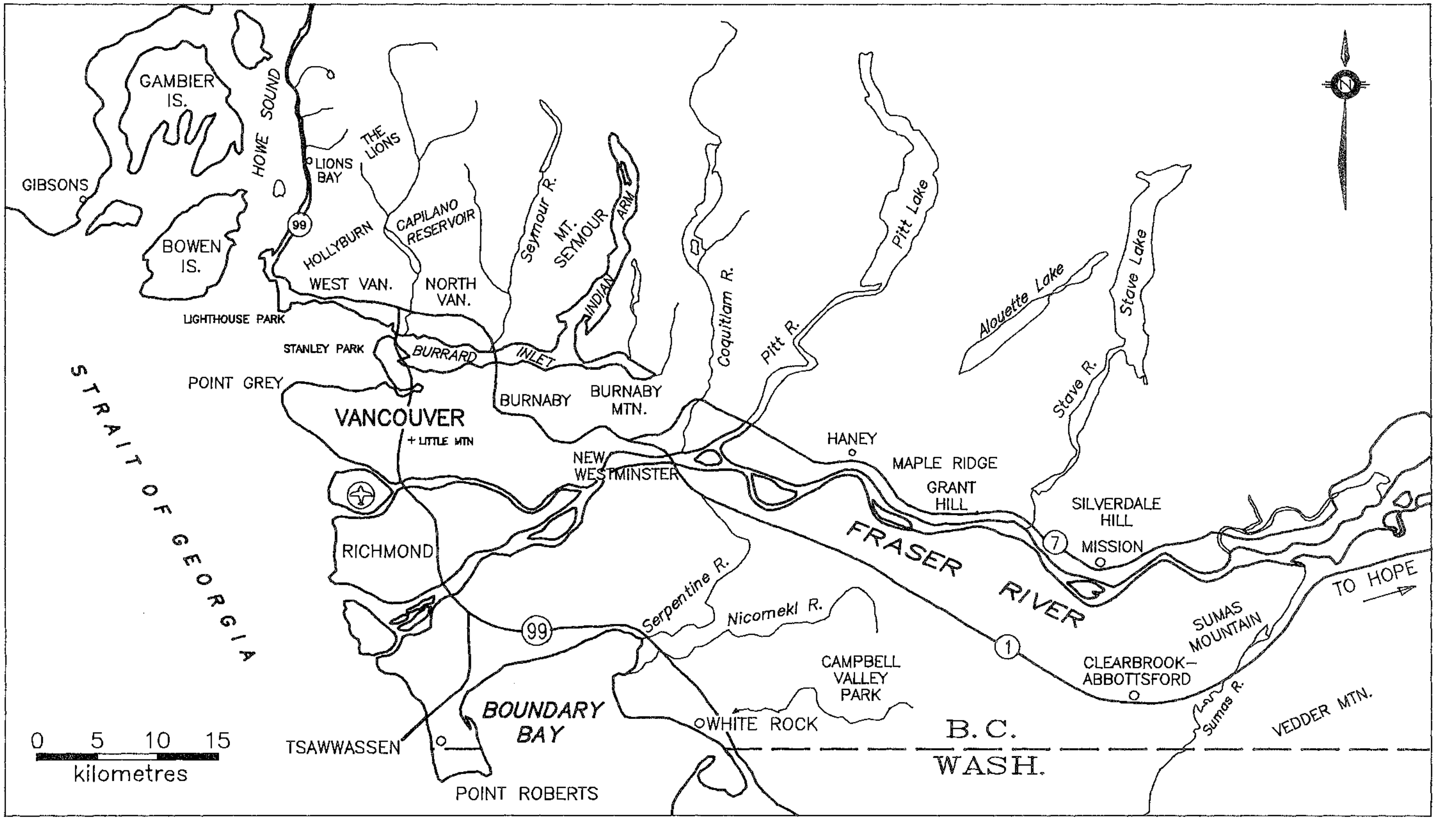
INTRODUCTION

The natural attributes of Vancouver make it one of the most beautiful cities in North America. Many people have chosen it as their home on the basis of its magnificent setting. How many of us, though, have stopped to wonder why the Vancouver area has such a splendid combination of mountains, lowland and sea? Our natural surroundings appear permanent in comparison with Man's continuous effort to excavate, build and modify. But processes such as the uplift of mountains, the subsidence of plains, and the advance and retreat of glaciers have had a much more profound impact on the final architecture of our land.

The study of the Earth and natural forces acting on the land is called geology. Geologists are still a long way from understanding the ultimate causes of the processes shaping the planet but by careful work in the field and laboratory, they have pieced together an intriguing history of the Earth. For geologists, periods millions of years long are distinct and comprehensible geological time intervals during which the Earth has changed its face many times. Some of the changes are slow, as in the uplift of mountains and the movement of continents, but others are rapid, such as floods and volcanic eruptions. It is by understanding these natural processes that we can minimize the adverse impacts of our own activities.

This book offers some glimpses into Vancouver's past and the geological framework that has uniquely determined the distribution of water and land here. It has two parts. The first describes local geography, the structure of the Earth's crust below us, the rocks visible at the surface and the loose sand and gravel deposits overlying them. The second part includes field trips to show some of the accessible geological features in the Vancouver area.

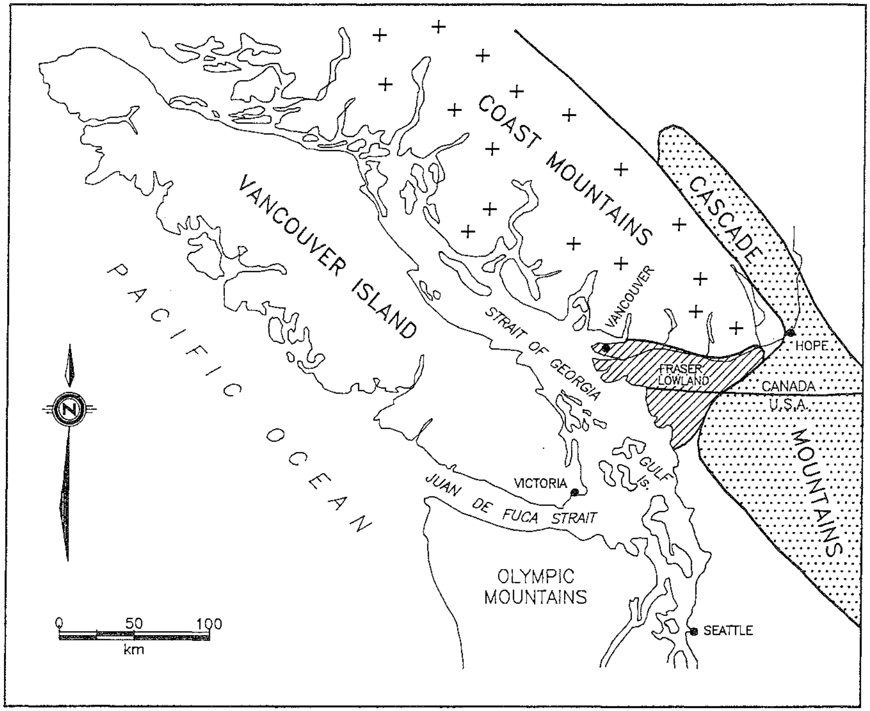
We hope this book encourages you to learn and experience more of our natural surroundings. It will help you to see how the landscape has changed, and is changing, through time.



GAMBIER IS.
HOWE SOUND
GIBSONS
LIONS BAY
THE LIONS
BOWEN IS.
99
HOLLYBURN
CAPILANO RESERVOIR
Seymour R.
MT. SEYMOUR
INDIAN ARM
WEST VAN.
NORTH VAN.
LIGHTHOUSE PARK
STANLEY PARK
BURRARD INLET
POINT GREY
STRAIT OF GEORGIA
VANCOUVER
+ LITTLE MTN
BURNABY
BURNABY MTN.
Coquitlam R.
Pitt R.
Pitt Lake
Alouette Lake
Stave Lake
Stave R.
HANEY
MAPLE RIDGE
GRANT HILL
SILVERDALE HILL
NEW WESTMINSTER
RICHMOND
FRASER RIVER
7
MISSION
Serpentine R.
Nicomekl R.
99
CAMPBELL VALLEY PARK
1
SUMAS MOUNTAIN
TO HOPE
CLEARBROOK–ABBOTTSFORD
Sumas R.
VEDDER MTN.
BOUNDARY BAY
WHITE ROCK
B.C.
WASH.
TSAWWASSEN
POINT ROBERTS
0 5 10 15
kilometres

VANCOUVER LANDSCAPE

The Vancouver area is composed of two distinct geographical areas: the Coast Mountains along the North Shore and the Fraser Lowland encompassing much of the city and extending south to the Canada-USA border. These are flanked on the south and east by the Olympic and Cascade Mountains and to the west by the Strait of Georgia and the Insular Ranges on Vancouver Island.



The Fraser Lowland is a triangular plain, not a true valley that resulted from erosion by rivers. It is a depression between the Coast Plutonic Complex, Vancouver Island and the Cascade Mountains that has been filled with sediments during the last 70 million years.

The southern peaks of the Coast Mountains are a lofty backdrop to the city of Vancouver, seen here from Queen Elizabeth Park. The Lions are on the left, Crown Mountain on the right, and the Capilano River valley, Vancouver's water supply, between them. (GW)

Coast Mountains

The most striking geologic feature in the Vancouver area is the backdrop of rugged mountains rising up from the North Shore. These mountains form the southern end of the Coast Mountains which extend 1700 km north from Vancouver to the Yukon. Unlike the Rocky Mountains along the British Columbia-Alberta border, which are made of sedimentary rock, the Coast Mountains are composed primarily of granite and other igneous rocks. These are the frozen remnants of subterranean magma chambers which formerly lay beneath and supplied magma (molten rock) to ancient volcanoes on the Earth's surface above. What we see as mountains today are actually the roots of volcanoes similar to the Cascade volcanoes stretching from Mt. Lassen in Northern California to Mt. Baker just south of British Columbia in Washington State.

As the Coast Mountains began to be uplifted, they were subjected to erosion by streams and rivers but maintained their existence since the rate of uplift was greater than that of the erosion. However, the streams and rivers cut deep, narrow canyons and valleys in the mountains, many of which are still visible today. Later, between

11,000 and 100,000 years ago, the shape of these valleys was dramatically altered during a number of ice ages.

Ice accumulated on the mountains, due to high snow fall and the absence of a warm enough climate to melt it during the summer months, and glaciers were slowly formed. At least three major periods of glaciation are recognized in the Vancouver area. Glaciers from the Coast Mountains and the Cascade Mountains formed large ice sheets which covered the Fraser Lowland and extended out into the Strait of Georgia.

Because sea level was lower during each major ice advance, the glaciers were able to cut below the present day sea level in the coastal portions of many valleys. As sea level rose during the last 10,000 years, these valleys were partially submerged, resulting in the creation of fiords. The fiords in the Vancouver area, such as Indian Arm and Howe Sound, are among the most southerly ones in

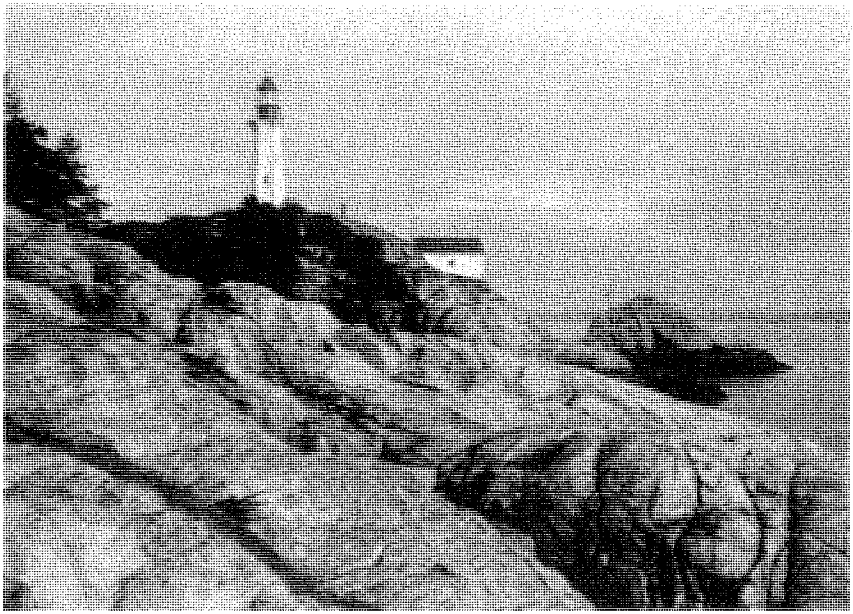
BRIEF DESCRIPTION OF VARIOUS CLASSES OF ROCKS

Igneous rocks are those formed by cooling of molten rock. If the cooling takes place beneath the Earth's surface, the rock is called plutonic. These rocks consist of an interlocking mass of mineral crystals. The most common minerals are quartz, white feldspar, tan to pink potassium feldspar, black, flaky biotite mica, light-coloured, flaky muscovite mica, and dark ferromagnesian silicate minerals such as amphibole and pyroxene. Many combinations of these are found.

If the molten rock cools after it has been erupted onto the Earth's surface, it is known as volcanic. These rocks are made up of the same minerals as plutonic rocks except that they are generally in much smaller crystals, many or all of which may not be visible to the naked eye. Rapid cooling doesn't allow them time to grow. Volcanic rocks may occur as lava flows or as deposits of fragments from more explosive volcanism. Typical examples include basalt, andesite, dacite and rhyolite.

Sedimentary rocks are formed from small grains of mineral and rock eroded from pre-existing rocks and deposited by water, wind or ice in relatively uniform, horizontal layers called strata or beds. Initially unconsolidated deposits of mud, silt, sand and gravel become hard when they are buried and compacted. Sedimentary rocks are composed of many of the same minerals as igneous rocks but also include fragments of older rocks and fossils. The most common sedimentary rocks seen in the hills in the Fraser Lowland area are sandstone, shale, siltstone and conglomerate.

A metamorphic rock is formed when changes in temperature, pressure or a few other factors cause changes in a pre-existing rock. These might be changes in the types of minerals present, how the minerals are arranged, or the chemistry of the rock. Metamorphic rocks generally form at some depth in the Earth and include schist, gneiss, marble, and amphibolite.



Point Atkinson lighthouse is built upon granodiorite of the Coast Plutonic Complex. Lighthouse Park includes some of the best exposures of granitic rock near Vancouver.

Howe Sound, which extends 32 km north from Vancouver, is a fiord that was occupied by a glacier as recently as 12,000 years ago. Highway 99 follows the eastern shoreline, passing the former mining town of Britannia on its way to Squamish and points north.

Northern Hemisphere. Before being blocked by Fraser River sediments, Pitt Lake was an arm of the sea.

Fraser Lowland

The Fraser Lowland forms the southwest corner of the Pacific Coast mainland of Canada and the adjoining northwest corner of the United States, an area of approximately 3,500 square kilometres. It is surrounded by the Coast Mountains to the north and the Cascade Mountains to the east and southeast.

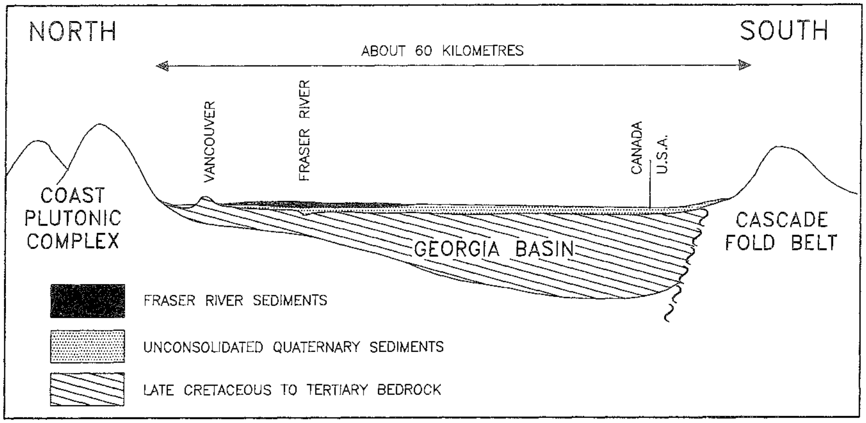
The Fraser Lowland consists of gently rolling and flat-topped uplands, separated by wide, flat-bottomed valleys. Several larger hills and low isolated mountains rise above it. Prominent landmarks, such as Burnaby Mountain, Grant Hill, Silverdale Hill and further east, Sumas Mountain, expose the oldest rocks. These are mainly freshwater sedimentary rocks that were deposited in a depression called the Georgia Basin starting about 70 million years ago. Geologically, these are relatively young rocks. The Canadian Shield contains rocks more than 3.9 billion years old.

Although these sedimentary rocks were deposited horizontally, they have been tilted over the ages and are now slightly inclined to the south. Along the northern edge of the Fraser Lowland they form only a thin veneer over the granitic rocks of the Coast Mountains. However, they thicken to the south and reach a maximum thickness of 4400 metres near the Canada-USA border.

The Late Cretaceous and Tertiary sedimentary rocks are covered by up to 300 metres of unconsolidated sediments, those which have not yet hardened into rock. The latter include material deposited during glaciation by both water and ice together with that deposited

BURRARD INLET

Burrard Inlet is part of the Indian Arm fiord. Looking at a map of the Vancouver area, it is tempting to speculate that Burrard Inlet was once a branch of the Fraser River. However, there is no geologic evidence to support this and it appears that the present course of the Fraser River was established after the final retreat of the last ice sheets 11,000 years ago. Burrard Inlet is in fact the drowned valley of a stream which drained the Indian River and Seymour River valleys. The Capilano River presently deposits sediment at the Inlet's entrance and until the Capilano dam was built in the 1950's, a dredge was needed to remove this sediment so that the channel could be kept open for ship traffic. Without man's intervention, Burrard Inlet would soon turn into Burrard Lake.



Beneath the Fraser Lowland are glacial and river sediments underlain by sedimentary rocks of the Georgia Basin.

in water between glacial events. They are best seen in the sea cliffs around UBC (Spanish Banks and Point Grey), at White Rock and along the narrow Coquitlam River valley near Port Moody.

Because these sediments are unconsolidated, they are potentially unstable and can be easily washed away by major floods along rivers and streams that cut through them. Exposed headlands composed of

DATING ROCKS

One of the ways in which geologists are able to estimate the age of a rock is through the use of isotopic dating. There are a number of naturally occurring radioactive elements and isotopes which are widely distributed in common minerals. Over time, they decay into other elements or isotopes at a constant rate which is different for each element. By carefully determining the relative proportions of new and old elements in a sample, geologists are able to determine how long the radioactive element has been decaying and thus the amount of time since that mineral, and presumably the rock, was formed. The analysis is done in a laboratory and requires great care and patience.

Different pairs of elements are used, depending on the time involved. Radiocarbon dating is useful for the last 50,000 years or so. If the rock or fossil was formed before that, all of the measurable radioactive carbon will have changed into ordinary carbon and no ratio can be calculated. Other element pairs commonly used include:

K-Ar	potassium-argon 1 million to 4.5 billion years
Rb-Sr	rubidium-strontium 10 million to 4.5 billion years
U-Pb	uranium-lead 10 million to 4.5 billion years
Sm-Nd	samarium-neodymium more than 200 million years

The choice of any of these will depend on the quality and abundance of radioactive minerals in the rock and the approximate age expected by the geologist on the basis of other criteria.

The organic-rich soil and river silt, as well as flat ground and favourable climate make the Fraser Lowland one of Canada's prime agricultural areas. As the urban area of Vancouver (middle distance) expands, this land is increasingly used for housing and industrial development. (GW)

this material, such as in the Point Grey area, are vulnerable to erosion by storm-generated waves and could quickly be eroded if there were a significant rise in sea level.

The oldest Quaternary sediments were deposited in a shallow arm of the sea which probably covered much of the present day Fraser Lowland. The hills of older rocks, such as Burnaby Mountain, formed islands similar to the Gulf Islands we know today. During the major glaciations, and the intervening nonglacial intervals, the areas between the islands were filled by debris carved from the surrounding mountain valleys by the ice.

Fraser River and Delta

The Fraser River, one of the largest in Canada, occupies a late glacial to post-glacial valley which is 5 kilometres wide and 225 metres deep. The river branches into three main arms as it flows across its triangular shaped delta, which extends from New Westminster into the Strait of Georgia, a distance of nearly 30 kilometres. On the coast, the delta is 20 kilometres wide and covers the area between the Oak Street Bridge and Tsawwassen. The delta also extends at least 20 kilometres underwater into the Strait of

Georgia as an area of shallow water and banks. In geologic time, the delta could eventually form a land bridge connecting the mainland with the Gulf Islands.

The Fraser delta is some of the best agricultural land in the Lowland because of its rich silt and sand. Although the sand is normally suitable for the foundations of large buildings, when saturated with water it is prone to liquifaction. The wet sand becomes fluid during vibration such as that occurring during an earthquake and large structures built on it tend to settle and even topple over.

In addition to the Fraser River, two other flat bottomed valleys cross the Fraser Lowland. The Nicomekl and Serpentine Rivers begin near Fort Langley and flow into Boundary Bay. The valley in which they flow is about 30 kilometres long and 5 kilometres wide and is bordered by low lying hills. The Sumas valley, which extends from Chilliwack to the Canada-USA border, is about 25 kilometres long and averages 5 kilometres in width.

Cascade Mountains

Although the Cascade Mountains do not form part of the immediate Vancouver area, they bound the east and southeast edge of the Fraser Lowland and are prominent on the Vancouver skyline.

The Cascade Mountains extend from Washington State northward to Lytton, in the Fraser Canyon. They are made up of sedimentary and volcanic rocks of Mesozoic and Paleozoic age, many of which have been highly deformed and metamorphosed. These rocks are cut by plutonic rocks of several younger ages. Like the Coast Mountains, most of these rocks did not form in North America but are exotic fragments which formed in the Pacific Ocean and collided with and attached to the continent.

The most obvious features of the Cascade Mountains in Washington are major volcanoes, one of which, Mt. Baker, is visible from Vancouver. Geologically speaking, the Cascade volcanoes are very young and all of them are potentially active. The Cascade Mountains present a picture of what the eroded top of the Coast Mountains must have looked like in the geologic past.

Vancouver Island and the Olympic Peninsula

The other mountain ranges visible on a clear day from Vancouver are on Vancouver Island and on the Olympic Peninsula of Washington State. The Vancouver Island ranges are composed of heavily faulted sedimentary and volcanic rocks primarily of Mesozoic age. Plutonic rocks are less common than in the Coast Mountains. Compared with the other mountains around Vancouver, the Olympic Mountains are very young, containing 15 to 55 million year old basalt and sedimentary rocks. These rocks originally formed a portion of the Pacific Ocean floor and were pushed up onto the continent in the last 10 million years.

WATER SUPPLY FOR VANCOUVER

Unlike most of the rest of the Fraser Lowland which depends on groundwater, the City of Vancouver relies on rivers, namely, the Capilano and Seymour Rivers flowing into Burrard Inlet and the Coquitlam River flowing into the Fraser River. Their watersheds are closed to the public. The high annual precipitation in the Coast Mountains, normally in excess of 2500 mm, ensures a good runoff, which is stored for use in reservoirs created by dams on all three rivers. Several pipelines under Burrard Inlet and the Fraser River carry the water to the city.

The rivers flow in U-shaped valleys with steep slopes developed in granitic and metamorphic rock of the Coast Plutonic Complex, which in most places is covered by up to several metres of soil, glacial deposits, and talus. This mantle maintains about a 60-80 year old second growth conifer forest. Because these rocks aren't easily dissolved or otherwise weathered, the water is of outstanding quality, the hardness rarely exceeding 10 parts per million (ppm), with total dissolved solids at 23 ppm. Chlorination is the only treatment required. On occasions, mainly during the period from October to April, the water may become dirty looking as a result of landslides, which increase the silt content of the water in the reservoirs. However, it remains perfectly safe to drink.

PLATE TECTONICS

One of the great revolutions in our understanding of geological processes has been the concept of plate tectonics. Geologists now know that the Earth is composed of a number of concentric shells, with a central core of nickel-iron surrounded by a thick mantle of silicate rock rich in iron and magnesium. The crust is the thinnest and outermost shell; its proportion to the remainder of the Earth is less than that of the skin of an apple to the fruit inside. Two types of crust exist, oceanic and continental, and both overlie the upper mantle, which is relatively cold and rigid. The crust and uppermost mantle together are called the lithosphere.

According to plate tectonic theory, the lithosphere is divided into six major and numerous smaller plates which float like rafts on a partly molten portion of the mantle and are constantly in motion at speeds comparable to the growth rate of fingernails (about 5 cm per year). Much of the volcanism and earthquake activity as well as most of the younger and higher mountain ranges we see on the Earth today are concentrated at the boundaries where the plates are in contact. They are a direct result of this slow but steady motion.

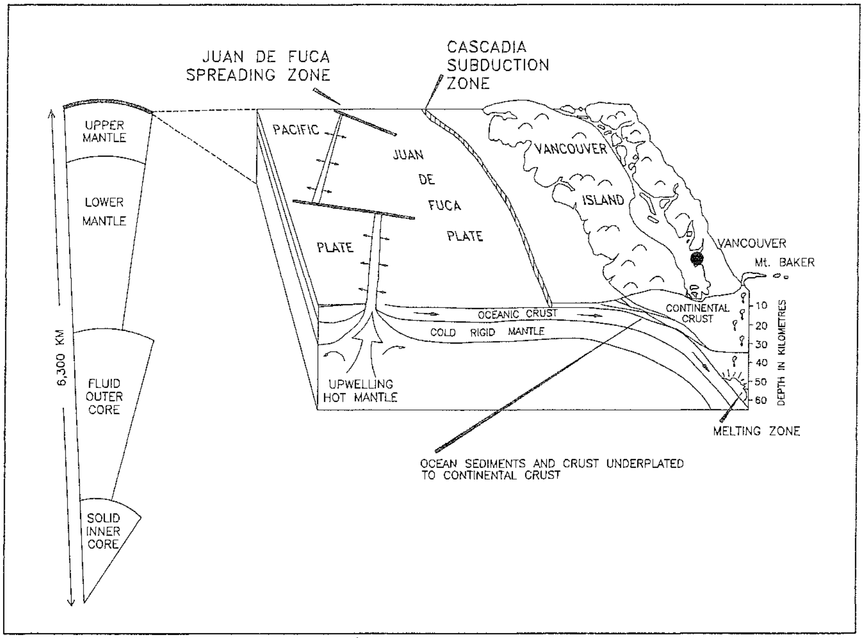
Three main types of plate boundaries exist:

1) Divergent – Here two plates move away from each other and new crust is formed between them. An example would be the two plates carrying North and South America moving away from those

TYPES OF CRUST

There are two types of crust making up the tectonic plates on the Earth's surface. Continental crust, that forming the continents, is rich in aluminum and silicon and is between 30 and 80 km thick. It often consists of a very old central portion called a shield, as much as 3.9 billion years old, surrounded and partly overlain by younger rocks.

Oceanic crust underlies most of the world's oceans, is rich in silicon and magnesium and ranges between 5 and 10 km in thickness. Because it is continually forming at spreading zones and being consumed in subduction zones, none of it is older than about 200 million years.



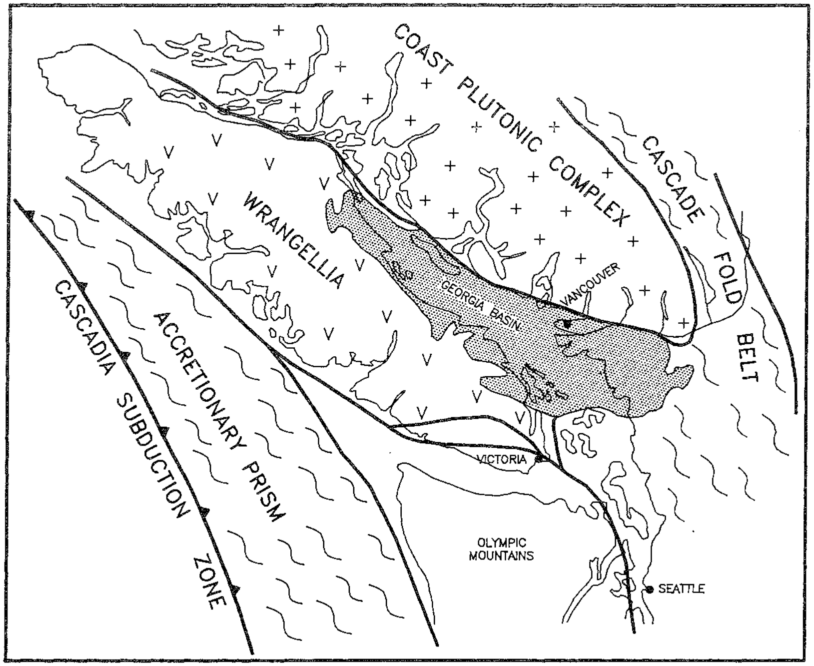
The wedge at left shows the various parts of the Earth's interior. At right is an enlarged view of the Earth's crust and surface showing the tectonic elements of southwestern British Columbia. The Juan de Fuca plate under the ocean is being subducted beneath continental crust and Vancouver Island.

carrying Europe and Africa along a split down the middle of the Atlantic Ocean. Volcanic activity is producing new ocean crust along this split, also known as a spreading zone or ridge.

2) Convergent – Here two plates approach one another, with one sliding beneath the other and the compression forming chains of mountains in the upper plate. As the lower plate descends, melting occurs and some of the resulting magma rises through the upper plate to accumulate in large chambers. These eventually freeze in place to form plutons. Magma also may reach the surface to form volcanoes, which are typically found in belts parallel to the plate boundary. Earthquakes are often generated in the downgoing plate.

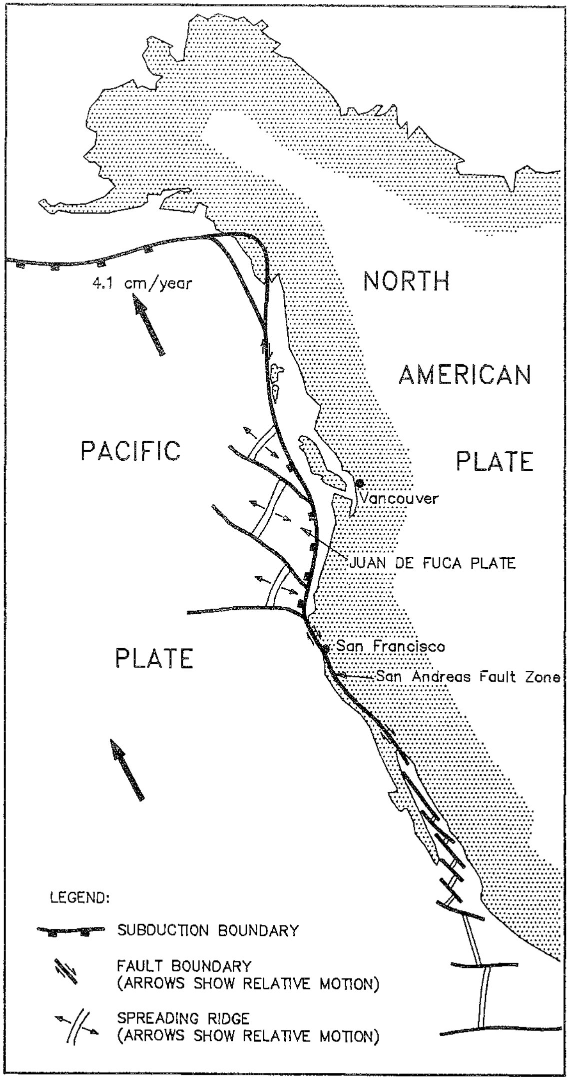
Depending on the types of plates involved, different things can happen. If the downgoing plate is oceanic, it may be overridden by either an oceanic or continental plate and the process is called subduction. An example is the west coast of South America, under which the Pacific plate is being consumed. The other possibility is that a continental plate is being overridden, in which case the process is called collisional. Because continental plates are less dense than oceanic plates, they resist going down and these boundaries are marked by extreme deformation and mountain building. The Himalayan area, where the Indian plate has collided with the Eurasian plate, is an example of this type of margin.

3) Conservative – Here the motions of the plates are largely parallel to their mutual boundary. A good example is the west coast of the United States, where the Pacific plate is sliding northwards past the North American plate. Some of this motion takes place along the well known San Andreas fault zone.



Tectonic elements in southwestern British Columbia. The Georgia Basin overlaps the junction of three thicker crustal blocks: Wrangellia, the Coast Plutonic Complex and the Cascade Fold Belt. It has existed as a depression for about 70 million years as a result of tectonic stresses between these blocks. The accretionary prism consists of fault-bounded slices of sediments eroded off Vancouver Island and pushed up along the leading edge of the North American plate.

British Columbia can be divided into five geologically distinct areas which are all products of the convergence of crustal plates. They include fragments of older continents and islands together with various remnants of ocean floor. These pieces (accreted terranes) have been stuck against North America as the North American plate moved westward over the Pacific Ocean floor over at least the past 150 million years. Geologists examine and interpret



Nature of the tectonic plate boundaries near the west coast of North America. The San Andreas fault, characterized by strike-slip motion, bends westward offshore. The Cascadia Subduction Zone or boundary along the coast of British Columbia intersects the north end of the San Andreas Fault near Mendocino, California.

the rocks in each area and can make good estimates of the ancient surroundings of these fragments. Many of the older sedimentary and volcanic rocks in central B.C., the Coast Range and Vancouver Island probably originated hundreds or thousands of kilometres to the south and southwest as island arcs, chains of volcanic islands formed over ancient subduction zones. The various collisions and accretions through time resulted in great pressure and thickening of the crust along the western coast of North America, forming the mountain ranges we see today.

As little as 200 kilometres offshore from Vancouver Island, new oceanic crust is being formed at the Juan de Fuca spreading ridge at a rate of between 2 and 6 cm per year. Magma from the Earth's mantle moves upward and adheres to the edges of the Pacific and Juan de Fuca tectonic plates. Portions of this ridge have been extensively studied and it is becoming one of the best known underwater spreading zones in the world. Geoscientists have observed deposits of metallic sulphide minerals forming around hot springs related to the volcanic activity. These are similar in many ways to the mineral deposit formerly mined at Britannia. Even more unusual are entire communities of exotic worms, crabs and giant clams thriving around the hot springs in total darkness.

As the Pacific plate moves to the northwest, the Juan de Fuca plate moves southeasterly, eventually plunging beneath the North American plate at a rate of about 4.5 cm per year in the Cascadia Subduction Zone. This zone lies between 60 and 150 kilometres off the west coast of Vancouver Island. The Juan de Fuca plate is the last of many oceanic plates that have been subducted under North America. Geologists estimate that over 11,000 kilometres of oceanic crust have already been consumed at this boundary.

EARTHQUAKES IN THE VANCOUVER AREA

One of the more common situations in which large or mega-earthquakes are generated is in a subduction zone. If the contact between the plates is well-lubricated and the relative motion is continuous, few, if any, earthquakes happen. However, if the contact is sticky, the plates will not slide smoothly past one another and long periods of little or no movement, when stresses are building, will be interrupted by sudden motion of several or more metres. When this happens, large earthquakes result, reaching values of magnitude 8 and more on the Richter scale.

British Columbia's southwest corner is the most active earthquake region in Canada. More than 200 earthquakes are recorded each year on the Fraser Lowland and Vancouver Island and although most are too small to be felt, an earthquake capable of structural damage can be expected to occur somewhere in the region about once every ten years. These are earthquakes registering at least 6 on the Richter scale. Within a radius of 200 km from Vancouver, eight earthquakes measuring 6 or more have been recorded in about the last 120 years and four of these have been at a magnitude of 7 or slightly higher. Two occurred on Vancouver Island (1918, 1946), one east of Vancouver, possibly in the Hope area (1872), and one to the south in Puget Sound (1948).

Contrary to a widely held misconception, the San Andreas Fault Zone does not lie off the Coast of British Columbia. Although we are also near the boundary between the Pacific and North American plates, the nature of this boundary differs along its length. In the B.C. area, it is a subduction zone rather than a fault. Our earthquakes are mainly related to the subduction process but seismic monitoring of the Cascadia Subduction Zone has shown

The North American plate has a complex structure in this area, consisting of slices of rock thrust or shoved onto each other by the converging motion of the plates. In addition to this piling up, at least some of the sediment lying on the ocean floor is scraped off by the North American plate and attached to its leading edge in a deposit called an accretionary prism. Recent research has also suggested that the sediments and basalts of the ocean floor from time to time stick to the bottom of the overriding plate in a process known as underplating. The entire package of rocks and sediments attached to the moving plates is known as an accretionary complex.

Joining the accretionary prism on its eastern side, and partly overlying it, is an accreted terrane known as Wrangellia. Vancouver Island is part of this terrane, which consists of volcanic rocks and related sediments of Mesozoic age. Still further east is the Coast Plutonic Complex, a large body of granitic rocks underlying the Coast Mountains. Both are surrounded on the east and to the south by the Cascade Fold Belt, a series of very strongly deformed volcanic and sedimentary rocks underlying the Cascade and eastern Coast Mountains.

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that not even very small earthquakes occur on the interface between the Juan de Fuca and North American plates. All of the ones recorded here so far have originated either in the overriding North American plate, or in the downgoing Juan de Fuca plate. The lack of earthquake activity at the interface between the plates is cause for concern. Are they actually stuck and is there a chance for a very large earthquake?

Studies of other seismically active areas in the world have suggested that earthquakes of this type take place in stages. Before the earthquake, since the plates are not moving across each other, the upper plate will gradually bend and shorten somewhat, with some areas being uplifted and others depressed. When the plates become unstuck and the earthquake occurs, sudden changes in elevation (and thus sea level) take place. In both cases, patterns of sedimentation will be affected and these changes preserved in the rock record. While not complete, studies in the southern British Columbia coastal area indicate that many sudden changes in sea level have taken place in the past, the most recent about 300 years ago. In addition, precise surveys carried out on Vancouver Island show that shortening and deformation is taking place in the upper plate at the rate and in the patterns expected in a "locked plate" situation.

As to whether a large earthquake can be expected in Vancouver, the best answer we have so far says that the geological setting is right and that large earthquakes appear to have taken place in the past. Most West Coast seismologists believe that a mega-earthquake of magnitude 8 or higher should be expected at anytime in the next 200 years. Unfortunately, not enough information is available to make a better guess of when it will occur. One thing *is* for sure, however. It can't hurt to be prepared.

Vancouver Island, the Coast Mountains, and the Olympic Mountains have acted as relatively rigid bodies during plate tectonic movement in the last 50 to 60 million years. These have experienced uplift and some compression without much internal deformation. Much of the movement and deformation have taken place in the more easily deformed rocks of the North Cascade Mountains and portions of the accretionary prism west of Vancouver Island.

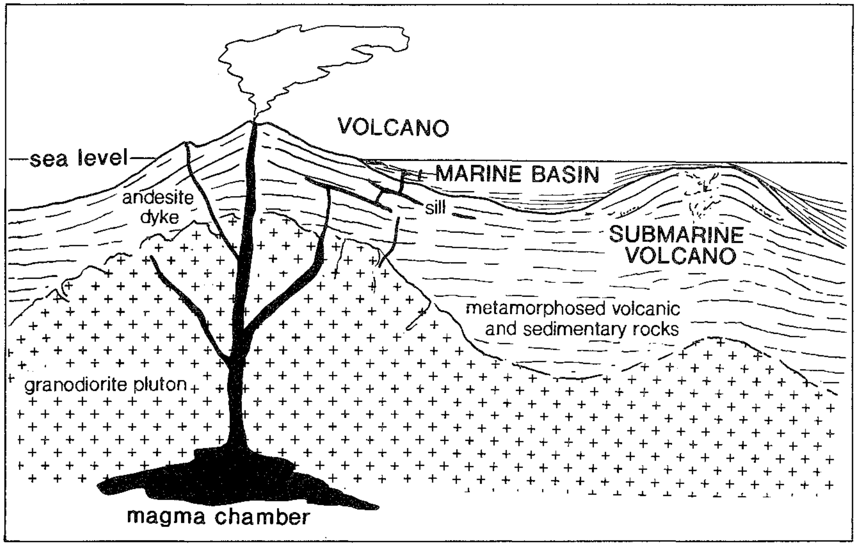
Vancouver itself is situated on Upper Cretaceous to Upper Tertiary rocks that were deposited in the Georgia Basin beginning about 70 million years ago. The basin was a depression that formed over the more rigid portions of the crust here, possibly as Vancouver Island was tilted up at its western edge by the underplating of ocean floor. In the last 15 million years or so, compression between Vancouver Island and the Mainland have caused folding in the Georgia Basin rocks. The shapes of many Gulf Islands reflect some of this folding.

Crustal plates move very little in a human lifetime, and we are tempted to think that tectonics no longer affect this region. Geologists, however, call the West Coast an "active continental margin" as all of this activity is still taking place. Precise measurements between mountain tops on Vancouver Island show the northeasterly directed squeezing of the land and the Coast Mountains are still rising—almost a centimetre during our lifetime. Rain and streams wear down the mountains at a similar rate, and the material they remove eventually ends up in the lowland areas, modifying the landscape there as well. In some ways, tectonically active regions, with their steep mountains and spectacular scenery, provide an agreeable environment in which to live. However, this area may not be without geologic risks from earthquakes, and more remotely, from volcanic eruptions.

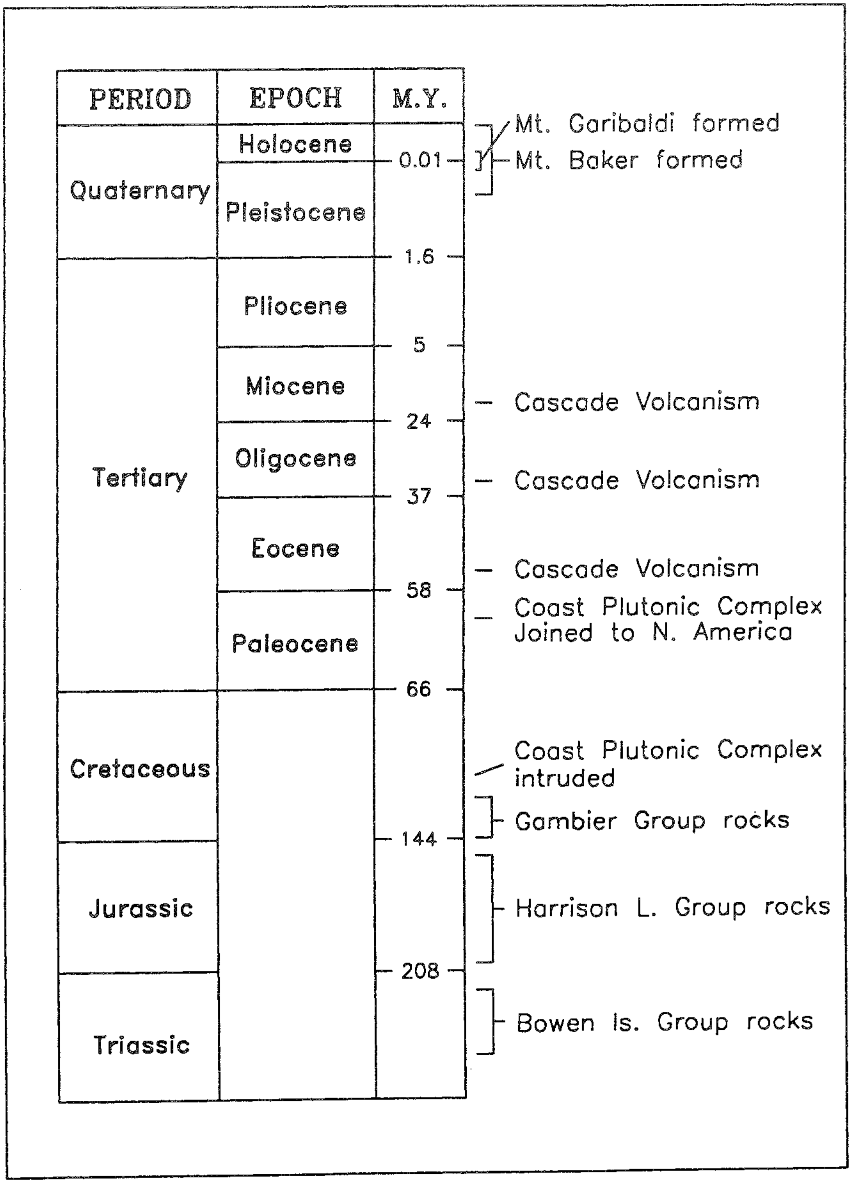
BEDROCK

Bedrock includes all plutonic and stratified rocks that underlie unconsolidated surficial deposits. This chapter is divided into four main sections based on the ages of the bedrock in the Vancouver area. Beginning with Pre-Jurassic to Middle Cretaceous metamorphosed volcanic and sedimentary rocks, succeeding sections describe Jurassic and Cretaceous intrusive igneous rocks of the Coast Plutonic Complex, Upper Cretaceous to Miocene sedimentary rocks of the Georgia Basin and finally, Tertiary and Quaternary volcanic rocks.

Before 140 million years ago, volcanic islands and shallow seas gave rise to the rocks now uplifted in the Coast Mountains. Deep



Before 140 million years ago, volcanic islands and marine basins formed the rocks that presently underlie the Vancouver area. These rocks were buried, metamorphosed and intruded by granodiorite plutons between 140 and 95 million years ago. Later volcanic activity resulted in the andesite dykes and sills that are presently exposed in the Vancouver area.



below these islands, large masses of magma slowly rose through the pile of volcanic and sedimentary rock that was being deposited, layer by layer, on the Earth's surface. During its slow ascent, the magma cooled, forming plutonic rocks such as granite. Parts of the older volcanic islands and existing sedimentary rocks were incorporated into the hot granitic magma. Later erosion exposed the

TYPES OF DYKES

Many types of dykes cut the Coast Plutonic Complex. In general, the lightest coloured dykes contain mainly quartz and feldspar. With increasing amounts of darker minerals such as hornblende and pyroxene, they are called andesite. The darkest coloured dykes are dominated by hornblende and pyroxene and are called basalt.

partly-absorbed older rocks which are known as roof pendants and inclusions. Roof pendants reveal much of the original character of the volcanic and sedimentary rocks—they are the only record of environmental conditions before the intrusive rocks formed. Fractures in both were filled by liquid magma at three intervals: 50, 35 and 17 million years ago. These cooled to form dykes. All the granitic rocks, roof pendants, inclusions and dykes are known as the Coast Plutonic Complex, which stretches from Vancouver to the Yukon.

Beginning in Late Cretaceous time, the Coast Plutonic Complex was elevated above sea level, reaching its present day position within the last 5 million years. Rivers began to wear down the newly created land mass and the sediments washed from these hills were gradually cemented into conglomerate, sandstone, siltstone and shale. After burial by other sediments, layers of plant debris changed into thin seams of lignite, a type of coal.

Starting about 20 million years ago and continuing to the present, large volcanoes have erupted basalts and andesites in a long chain along the west coast of North America. On Mount Baker, only 100 kilometres southeast of Vancouver, hot steam still escapes from the ice-filled crater. Near Mount Garibaldi, volcanic eruptions took place only a few thousand years ago.

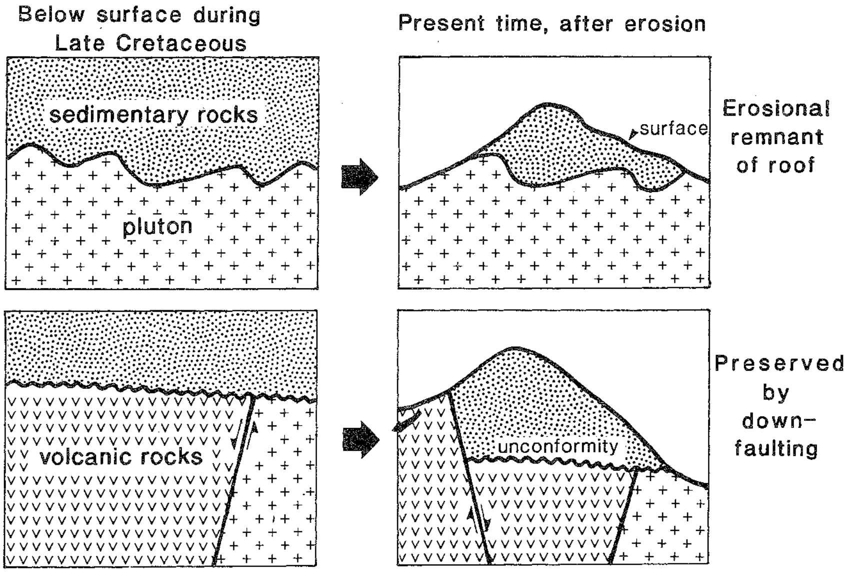
STRATIGRAPHIC TERMS

One of the basic methods in geology involves the organization of rocks into units based on their character. The fundamental unit is known as a "formation". This is a body of rock strata which is distinct from adjacent strata on the basis of one or more unifying features. It may consist dominantly of one rock type or combination of related types and was deposited or put in place under uniform conditions. Formations may be combined into "groups" which in turn may be combined into "supergroups".

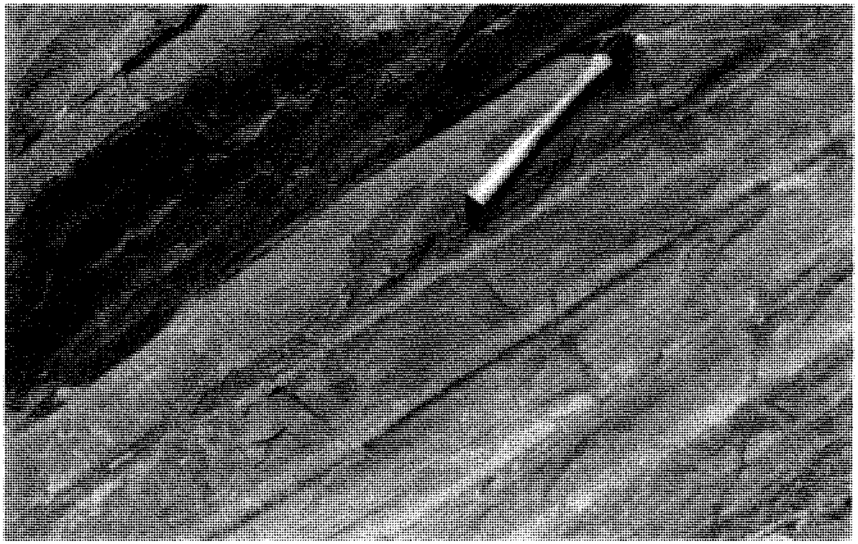
Older Volcanic and Sedimentary Rocks

Most of North and West Vancouver are underlain by 100 million year old granitic rocks. Only remnants of earlier sedimentary and volcanic rocks remain in the sea of granite. These roof pendants are isolated, contain few fossils that could be used to date them and are complicated by intense folding and faulting. In addition, the very high temperatures and pressures they experienced when being absorbed into the plutonic rocks have changed the rock types in a process known as metamorphism. What were once volcanics and sediments are now amphibolite and gneiss. As a result, the relationships between individual pendants are almost impossible to ascertain. In spite of this, geologists have been able to distinguish between several different ages of pendant.

What might be the oldest of all the rocks are found in the pendants between Indian Arm and Buntzen Lake, and at Horseshoe Bay and Caulfeild Cove. Rocks in the pendant on Bowen Island are appropriately known as the Bowen Island Formation. They are less metamorphosed than those in the previously mentioned pendants, which may suggest that they are younger in age, not having had as



Two possible ways in which pendants are formed and surrounded by granitic rocks. Older sedimentary rocks, which form the roof above a pluton, may be almost completely eroded. Other pendants are formed by faults, along which portions of the overlying strata are dropped down into the pluton.



Beds of siltstone, now metamorphosed, belonging to the Gambier Group. These rocks are best exposed where Highway 99 has been blasted through cliffs near Brunswick Point on Howe Sound.

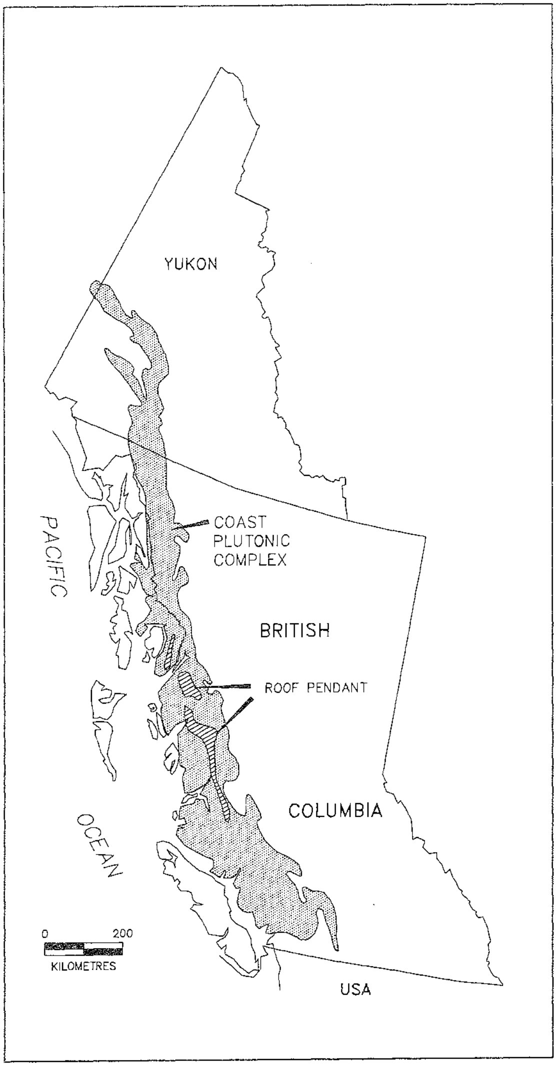
much time to be metamorphosed. The only accessible outcrops of the Harrison Lake Formation in the Vancouver area are in a pendant on Sumas Mountain.

The largest pendants of these older sedimentary and volcanic rocks belong to the Gambier Group and are found mainly on Gambier Island and along Howe Sound at Brunswick Point and Porteau Cove. Smaller examples can also be seen in Mt. Seymour Park and in the upper reaches of Lynn Creek. They include andesitic volcanic rocks as well as banded green, brown and white sediments such as siltstone and argillite. A single fossil of Cretaceous age has been found in these rocks, indicating that they are approximately 110 million years old.

Intrusive Rocks – The Coast Plutonic Complex

The Coast Plutonic Complex is a 60 to 200 kilometre wide belt of granitic rocks stretching from the Fraser River 1700 kilometres north to the Yukon border. It is one of the largest collections of plutons in the world, the intricate relationships between them leading to the name "complex". The most common rocks within it are quartz diorite or granodiorite, with roof pendants of metamorphosed sedimentary and volcanic rocks. Masses of molten granitic rock, 10 km or more across, were formed deep within the crust, rose slowly as they tended to be less dense than their surroundings, and were

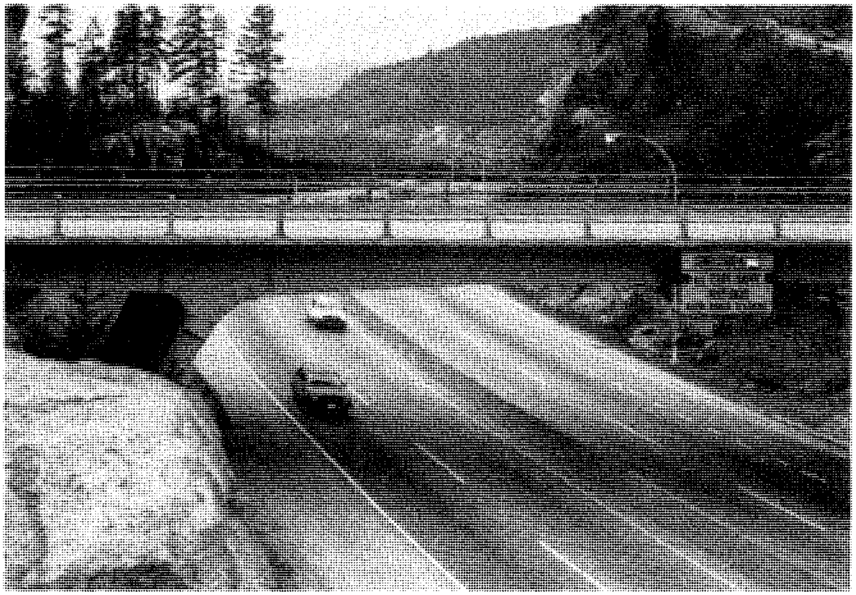
The Coast Plutonic Complex is one of the longest chains of granitic intrusions in the world. Where older rocks remain above the intrusions, they are called roof pendants. Some of the largest pendants are shown here.



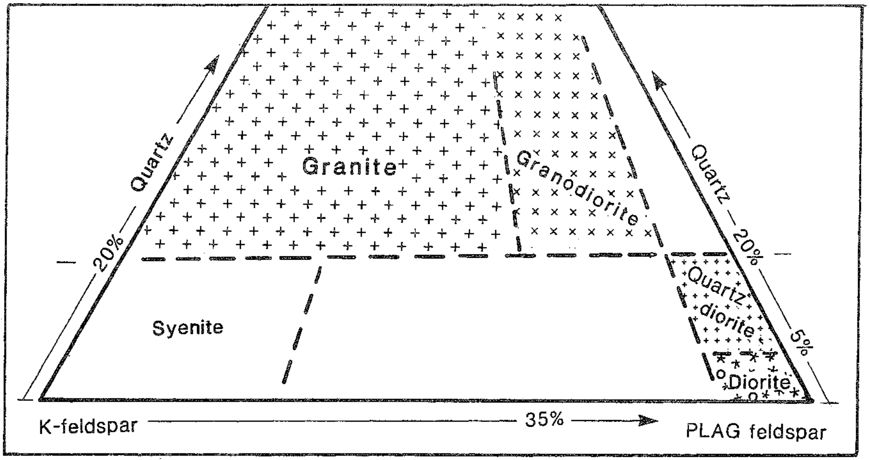
frozen in place about 100 million years ago. Between 40 million years ago and the present day, the overlying rocks have been eroded to expose them.

The North Shore Mountains are underlain by the southern end of the Coast Plutonic Complex. Several different ages and types of plutonic rock are present. The oldest is hornblende diorite, which forms the pinnacles of the Lions and Crown Mountain. The quartz diorite that underlies most of Grouse Mountain and Mount Seymour includes several individual bodies that in places varies in composition to granite. It is well exposed in the sea cliffs of Lighthouse Park.

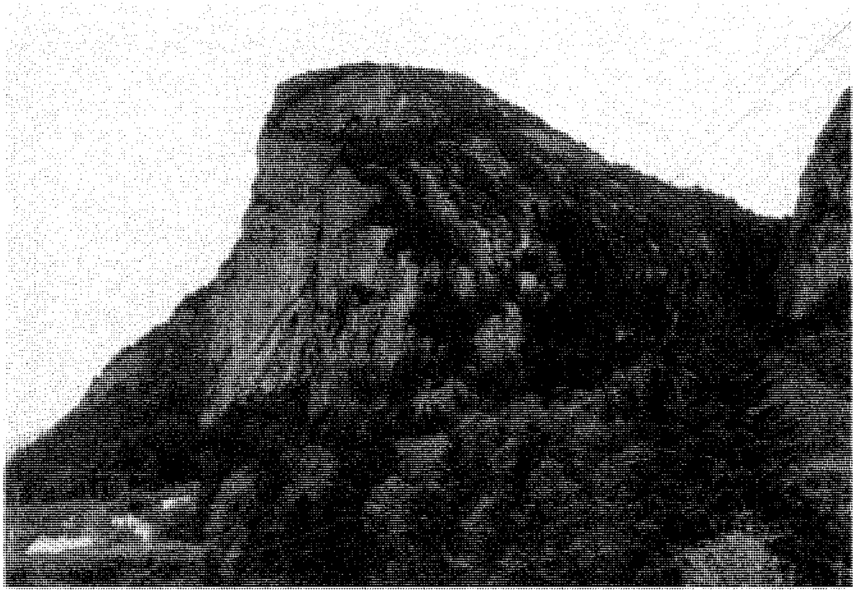
The Lions, seen here from Unnecessary Mountain on the Howe Sound Crest Trail, are composed of vertically jointed, hornblende-rich diorite. Lower ridges are younger granodiorite, also of the Coast Plutonic Complex.



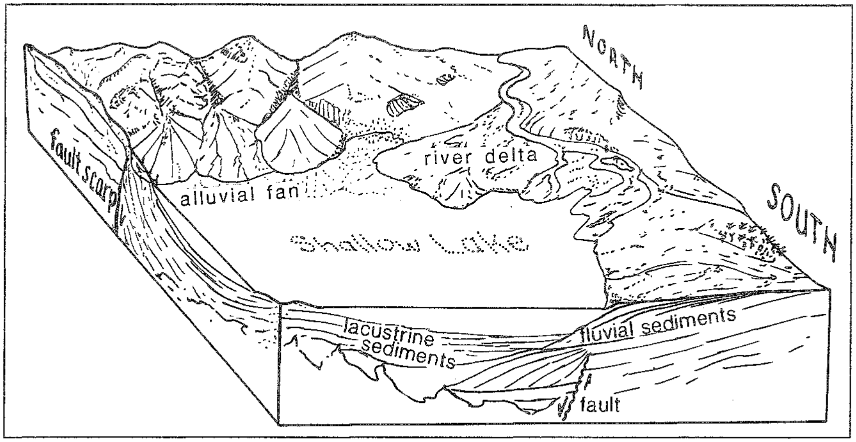
The Upper Levels Highway in West Vancouver was carved through granitic rocks of the Coast Plutonic Complex (Caulfeild interchange).



Granitic rocks are given names according to the proportions of quartz, potassium feldspar, and plagioclase. These three minerals are the corners of a classification triangle. Only the lower portion is shown here, in which diorite consists of almost pure plagioclase and syenite is mostly potassium feldspar. Local granitic rocks occur in the patterned area. A quartz diorite, for example, has between 5 and 20% quartz, 90-100% plagioclase and less than 10% potassium feldspar (in addition to biotite and hornblende which are not used to classify the rock).



Squamish Chief is part of a granodiorite pluton near Squamish. The western cliff, rising 600 m above Highway 99, is a mecca for experienced rock climbers, although the top can be reached by a well-built trail up the valley on the right hand side.



This schematic diagram shows some of the sedimentary environments during formation of the Georgia Basin.

Squamish Pluton, part of which comprises Squamish Chief, together with the Porteau Pluton, is granodiorite between 90 and 100 million years old.

Sedimentary Rocks – the Georgia Basin

Beginning about 70 million years ago, the rocks of the Coast Plutonic Complex were eroded by streams which carried gravel, sand, mud and plant debris down into a large freshwater lake occupying an area that is now bordered by the Coast and Cascade Mountains. During this time, the Coast Mountains were only a series of low hills with a temperate, humid climate similar to parts of the coastal region of present day California. The depression within which the lake was situated is known as the Georgia Basin.

The Georgia Basin has a complex history of uplift, when rocks are often eroded away, and subsidence, when they are likely to be deposited. Three main periods when rocks were deposited have been identified by studying plant fossils. Each of the three is separated from the others by an interval in which either erosion occurred or sediments were not deposited, and these breaks are called unconformities. These occurred during the Paleocene, Lower Eocene, and Oligocene epochs.

All of the rock types are very similar and can often only be distinguished from one another by studying their palynology, that is, their fossil pollen content. Most of them originated as sediments deposited by streams flowing south and southwest off local hills and mountains. The streams deposited their load in coalescing alluvial

Sandstone beds exposed at low tide at the west end of Kitsilano Beach (below Trafalgar Street). They were deposited in the Georgia Basin during the Eocene epoch. Faint diagonal streaks in the rock are cross-beds indicating deposition by currents from the north (left to right).

plains in the freshwater basin, which continued to subside as more and more sediment was laid down. Conglomerates appear to have formed from gravels in stream channels at edges of alluvial plains. However, where they are very thick, as in the Burnaby Mountain area, they may represent fan deltas such as the present day mouth of the Capilano River. With the possible exception of conglomerates, all the alluvial sediments were deposited in flat lying beds. Subsequent tectonic activity has tilted them 8-12° towards the south.

An idea of the amount of uplift and erosion in this area can be had by considering the amount of sedimentary rock present. All of it is believed to have been deposited in shallow fresh water yet the entire accumulation is up to 4400 metres thick. As the basin collected sediment, it grew deeper at about the same rate sediment was filling it up. The surrounding hills were in turn being uplifted from below at about the same rate as erosion was wearing them down, so that they maintained a constant height relative to the lowland. Given enough time, a very thick pile of sediments can form in this manner.

Among the oldest and lowest sedimentary layers is a conglomerate of Upper Cretaceous age up to 60 metres thick which rests directly on quartz diorite of the Coast Plutonic Complex. The conglomerate contains fragments up to 30 cm across with occasional

PALYNOLOGY: THE STUDY OF FOSSIL SPORES AND POLLEN

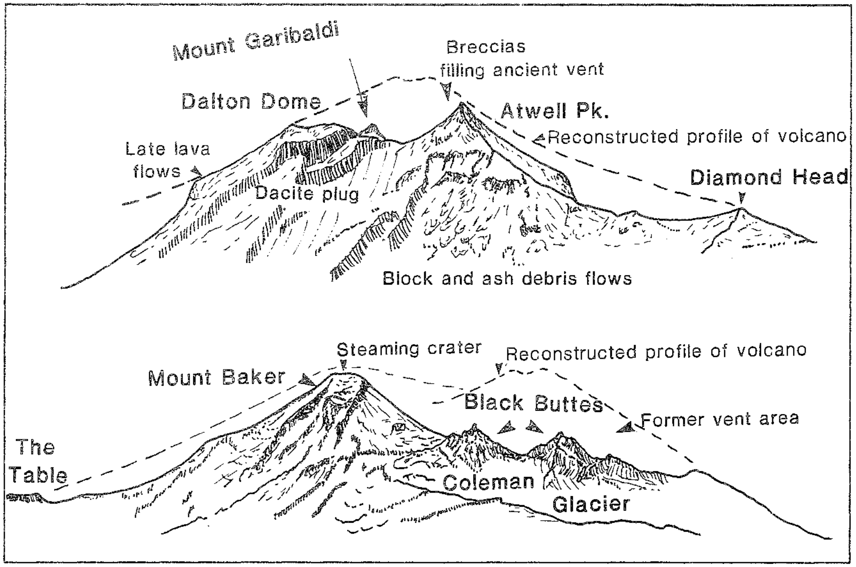
Palynology is the study of pollen and spores. It is very useful to the geologist as fossil pollen and spores are abundant in alluvial sediments and are generally recognizable after burial and lithifaction. Specialists are able to determine plant species, geographical location, and the prevailing climate from them. By compiling this information and correlating it with other geological data, they are able to catalogue the various types of pollen and spores that were produced at different times in geologic history. Some sedimentary rocks may then be dated on the basis of which types are present. Study of the rocks in the Vancouver area show that the climate changed from tropical to subtropical in Late Cretaceous and Eocene time to a warm, temperate climate in Miocene time.

rounded boulders in a matrix of mica and feldspar-rich sandstone weathered from the underlying quartz diorite. It represents the first deposit derived from erosion of the Coast Mountains and can be seen near the Upper Levels Highway bridge across the Capilano River.

On top of this is a 540 metre thickness of interbedded feldspar-rich sandstone, siltstone, and silty to sandy shale. The sandstones found between Prospect Point and Third Beach in Stanley Park exhibit cross-bedding and cut-and-fill channels, structures created by moving water at the time the sediments were deposited. These features allow geologists to estimate the current direction and speed at the time the sediment was deposited.

Rocks deposited during Eocene time included interbedded feldspar-rich sandstone, siltstone, sandy shale and conglomerate having a total thickness of as much as 1600 metres in some areas. The conglomerate contains stones derived from the Coast Plutonic Complex and is 150 metres thick where exposed on Burnaby Mountain. Thicknesses of up to 250 metres have been encountered elsewhere in drill holes. The sandstones often show good cross bedding and cut and fill channeling. Seams and lenses of coal are also found interlayered with some of the finer grained sediments, having formed from plant debris which accumulated in bogs and swamps.

Although they have a total thickness of about 1200 metres, rocks of Miocene age are buried beneath surficial deposits in the Vancouver area and cannot be seen in outcrop. Drill holes have penetrated poorly consolidated shale, sandstone and conglomerate with interbedded volcanic ash and coal.



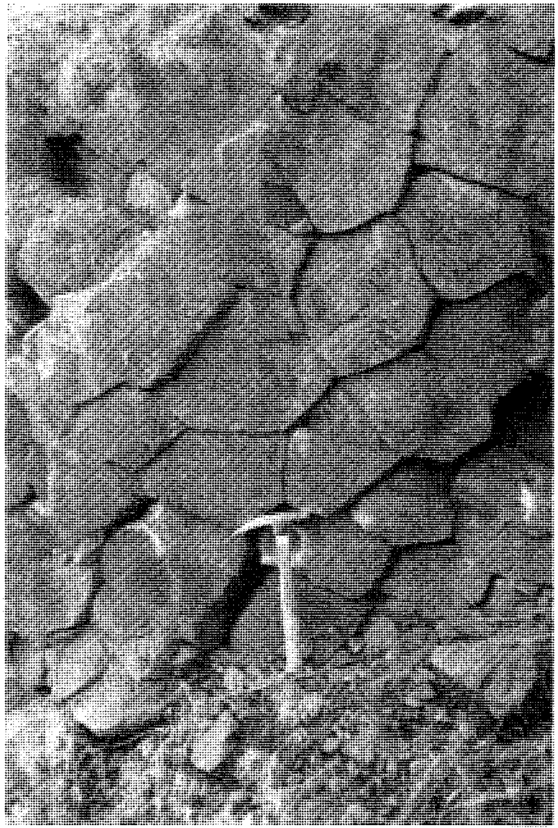
Mount Garibaldi (top) is an inactive volcano about 60 km north of Vancouver. Mount Baker (bottom), 110 km south of the city, is an active volcano that last erupted in 1843.

Cascade Volcanic Rocks

Volcanic activity along the west coast of North America is part of the so-called "Pacific Ring of Fire", a series of subduction-related volcanoes around the edges of the Pacific plate. A chain of these volcanoes extends from California to southern British Columbia. Vancouver lies between the two northernmost: Mount Garibaldi to the northeast of Squamish and Mount Baker in Washington State, about 40 km southeast of Chilliwack. Both volcanoes had major eruptions during Late Quaternary time and are presently dormant, but their cycle of activity is not yet complete. The rock types and past history of these particular volcanoes indicate that their eruptions occur hundreds to thousands of years apart, and are usually small, producing only steam and ash. Some of the others, such as Mount St. Helens in Washington State, have erupted more violently.

Mounts Garibaldi and Baker are only the most recent demonstrations of volcanic forces in this area. Evidence of three separate periods of volcanic activity, collectively called Cascade volcanism, can be found around and under Vancouver. Most Cascade volcanic rocks in the Vancouver area are remnants of intrusive dykes and sills. They are hard and resist erosion, forming cliffs or underlying hills. The oldest examples, with an age of about 50 million years, are not seen at the surface and were found by drilling beneath the city in

Andesite exposed below apartments on Great Northern Way. The cracks are called columnar joints and result from shrinkage during cooling of the magma.



the northern part of False Creek. About 180 m below sea level are thin layers of basalt within the Eocene sandstone and shale beds. They are pockmarked with holes that were gas bubbles, which indicate that the rock formed as lava at or near the surface.

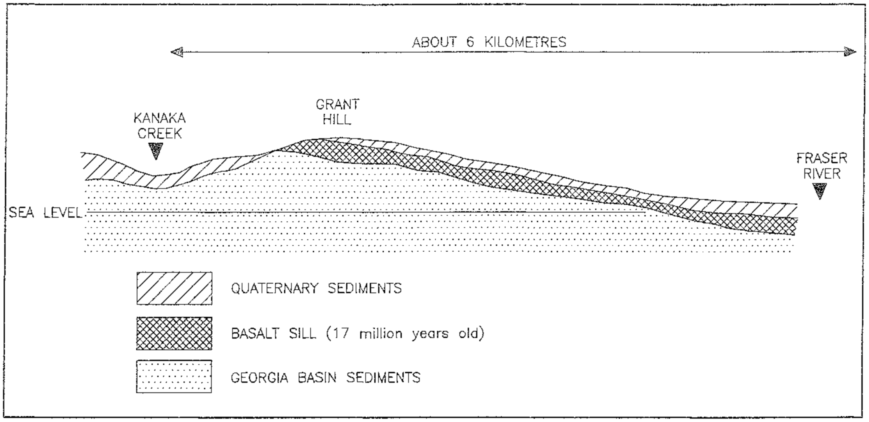
The next period of Cascade volcanism took place between 31 and 34 million years ago. This particular event was responsible for some well-known landmarks in the city. Sentinel Hill in West Vancouver is a small remnant of an andesite sill. Little Mountain, now Queen Elizabeth Park, is also underlain by andesite, and the former quarries provide a splendid backdrop to the attractive gardens. Much of the rock quarried from here was used as road material in the Gastown area. Another andesite outcrop, which may have been part of a sill or a lava flow, occurs along Great Northern Way just west of China Creek Park. At these three localities, the rock is fractured with a polygonal pattern. These "columnar joints" formed by shrinkage during cooling of the magma.

Siwash Rock is part of a 32 million year old andesite dyke that crosses the western edge of Stanley Park.

Siwash Rock and Prospect Point, at the west end of Stanley Park, are part of a single vertical mafic dyke that intruded about 32 million years ago. The rock is dark grey and contains larger black augite crystals in a matrix of microscopic feldspar and hornblende crystals. Both these landmarks are prominent because the igneous rocks resisted erosion by the waves and runoff better than the enclosing sandstone.

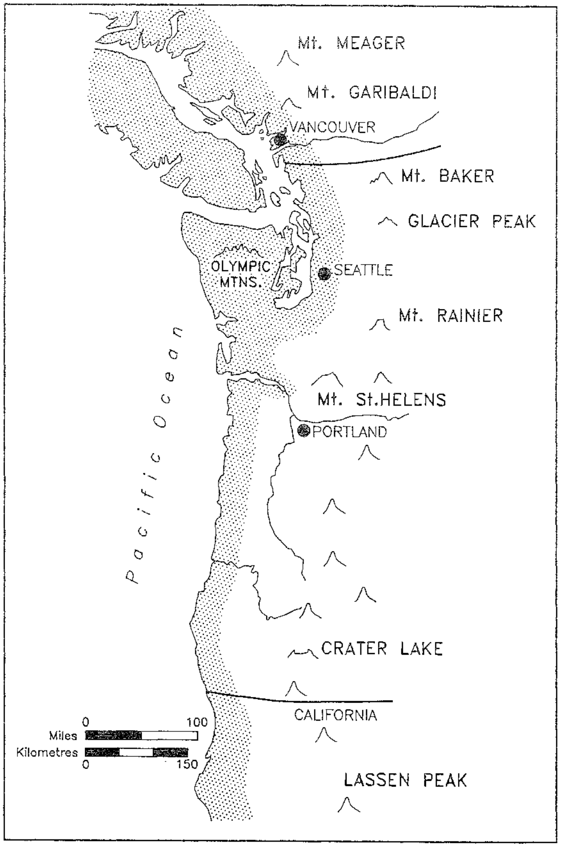
Grant and Silverdale hills, which are two cuestas (hills with one steep and one sloping side) on the north side of the Fraser River east of Haney, are upheld by resistant basaltic layers that have been dated at 17 million years. The layers are exposed where Lougheed Highway cuts through the southern edge of Grant Hill and Silverdale Hill. The basalt is dark grey and has small cavities containing minute crystals of quartz, the last to form as the rock cooled.

In addition to these major periods of nearby Cascade volcanism, the rock record shows evidence of volcanic activity much further away. Quaternary sediments in the Fraser Lowland contain thin volcanic ash layers, sometimes visible in road cuts as narrow white bands in sediments that were deposited in quiet water. These cover a wide area and act as a time marker, allowing geologists to correlate rocks in widely scattered areas.



A schematic cross-section of Grant Hill shows how the resistant basalt layer (probably a sill) has protected underlying sediments from erosion. Hills with one gentle slope and one steep side where the resistant rocks are exposed are called "cuestas".

Basalt sill, exposed in a roadcut on Silverdale Hill, shows crumbling layers caused by seepage of water into regularly spaced cracks. The water causes the mineral structure to weaken and progressively destroys the igneous rock outward from the original cracks.



The Cascade volcanoes are related to subduction of oceanic crust beneath the continental crust of southwestern B.C., Washington, Oregon and northern California.

In summary, rocks in the Vancouver area are the product of four distinct geological episodes. Before about 140 million years ago, islands formed, composed of volcanic flows and sediments. These were intruded by numerous granitic plutons between 140 and 90 million years ago. As the rocks were uplifted over the next 70 million years, they were eroded by streams and rivers. The resulting sediment was deposited in a large freshwater lake occupying the Georgia Basin, a large depression between the Coast and Cascade Mountains. Finally, volcanic activity at several times forced dykes and sills into the sedimentary rocks and constructed Mounts Baker and Garibaldi. The relatively recent sculpturing of the land by glaciers together with the reduced but continuing sedimentation in the Georgia Basin is the subject of the next chapter.

RECENT VOLCANOES

Our two local volcanoes, Mounts Baker and Garibaldi, are very young in geological terms. Although they are among the highest peaks in the area, volcanic rock actually forms only the uppermost 600 metres of their summits. Both were built on an irregular surface of older rocks beginning about 6 million years ago. Since that time, erosion has lowered the surrounding hills and valleys, so the volcanoes on their pedestals of older rock are even more prominent. Heavy precipitation falls on these summits mostly as snow, and the resulting glaciers are grinding down the mountains that were cone-shaped originally.

Mount Baker (3,285 m) is an andesitic volcano that reached its present form over the last 400,000 years, with the most recent ash eruption in 1843. A 90 m wide crater south of the summit has issued sulphurous gases and steam since 1975. There is no present hazard from the mountain, but if upwelling magma supplies more heat to the vent in the future, it could melt the glacial cap, causing mudflows and floods down surrounding valleys.

Mount Garibaldi (2,678 m) has andesite flows as old as 100,000 years, but most of its surface features were created by dacite lava flows filling valleys during the last ice age, between 25,000 and 8,000 years ago. The angular south peak is a remnant of the old volcanic cone, but the irregular main mass of the mountain consists of block and ash rubble, and a central dacite plug of lava too viscous to flow. The most recent flows were extruded from nearby satellite vents: one heading north to Garibaldi Lake, another southeast from the Opal Cone. These youngest volcanic features can be reached in a full day's hike from the Barrier and Diamond Head trailheads respectively.

GLACIAL AND RIVER SEDIMENTS

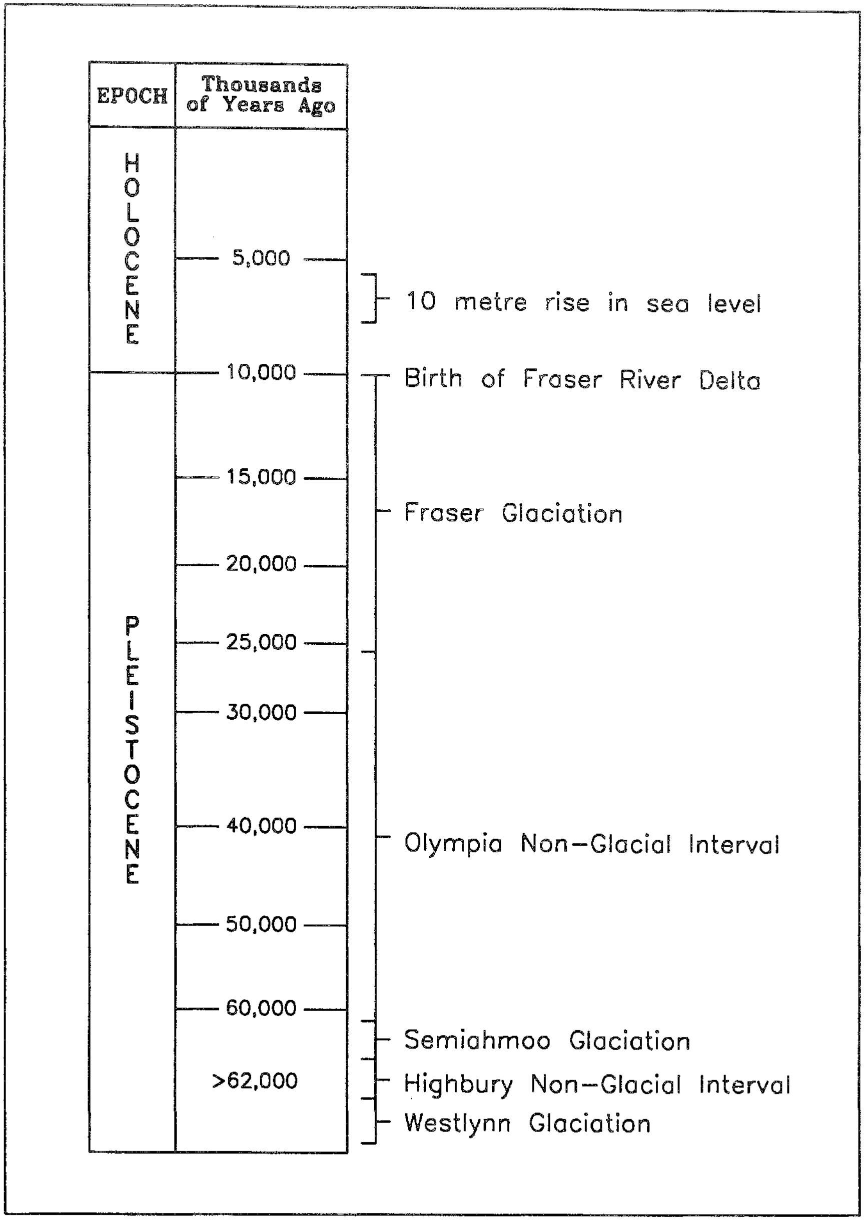
The erosion, transport and deposition of clay, silt, sand and gravel have defined many of the familiar landforms in and around the Fraser Lowland. These sediments, up to 300 metres thick, were deposited by glaciers and rivers during the last one million years in the Quaternary Period.

Quaternary sediments have not been subjected to heat and pressure by deep burial. They are not yet rock but form unconsolidated deposits, such as those seen in sand and gravel pits. Their study, called surficial geology, is particularly important to civil engineers, city planners and farmers. Buildings and roadways throughout the Fraser Lowland are situated on Quaternary deposits as is all of the most fertile agricultural land. Our day to day lives in many ways depend upon our understanding of their properties.

The study of surficial geology provides many clues to past climatic and environmental fluctuations—their timing, intensity and causes. What caused the glaciers to invade and then retreat from large portions of North America not once, but several times? Does the short term global warming we are now being warned about, the so-called Greenhouse Effect, have significance on a longer, geological time scale? Are we on the threshold of a major environmental readjustment which could have a significant effect on life as we know it? The study of the Earth's Quaternary history in particular may give us some idea of what the future holds.

Glaciers

One of the dominant forces in shaping the land surface in the Vancouver area has been glaciation. Giant, slow moving rivers of ice scoured and shaped mountain valleys, pushing enormous amounts of eroded rock in their paths and in the process, grinding it down. As the glaciers melted back, they left great sheets, mounds and sinuous ridges of glacial till. Large rivers of meltwater further modified the landscape, possibly even more than the glaciers them-



selves, by carving new channels and redistributing the glacial deposits. The distribution of sediment types in the Vancouver area results from multiple glaciations and fluctuations in sea level which left the Fraser Lowland underwater during parts of Quaternary time.

At least three, and possibly many more, major periods of glaciation took place in the northern hemisphere in the last two million years. Glaciers initially formed in the mountains and northern latitudes and grew much larger, merging into giant continental ice sheets that moved south and covered as much as 90 percent of Canada. In southwestern British Columbia, the Ice Age included at least three major advances and retreats of the glaciers. During each advance, ice filled the valleys of the Coast Mountains and only the highest peaks rose above its surface.

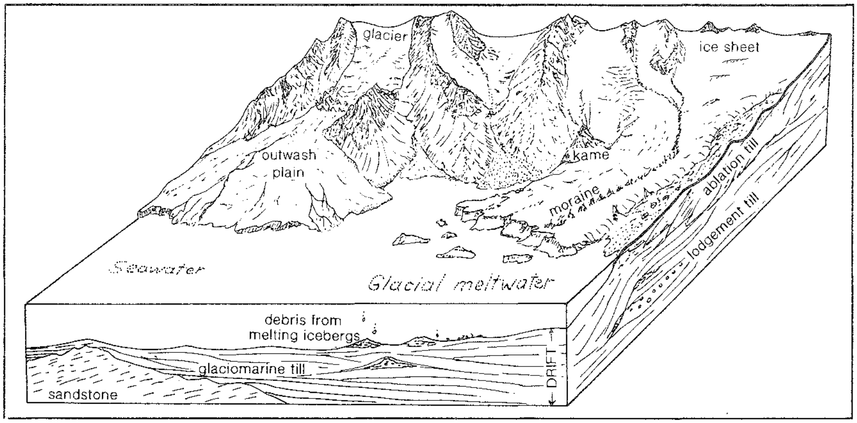
The two earliest glaciations, known as the Semiahmoo and Westlynn, occurred more than sixty thousand years ago. Much of the evidence for these and the intervening non-glacial intervals has either been removed or covered up by the last advance. Where they can be seen, deposits laid down during the Olympia non-glacial interval between 60,000 and 25,000 years ago are not as widely distributed or thick as the glacial deposits. Most areas of subdued topography were probably relatively stable and did not experience either significant erosion or deposition. Rivers deposited layers of clay, silt, sand and gravel and peat formed in swamps. The climate at that time was cool and relatively dry, similar to that of the northern

GLOBAL WARMING

Increasing concentrations of atmospheric carbon dioxide, methane, nitrous oxide, chlorofluorocarbons (CFC), and other greenhouse gasses are changing and even destroying the ozone layer which protects us from some of the sun's rays. As a result, the temperature of the Earth is expected to increase by several degrees over the next decades or century. This is likely to increase melting of mountain glaciers and the continental ice sheets in the Arctic and Antarctica, causing the oceans to warm and expand. Global sea levels will undoubtedly be higher in the next century.

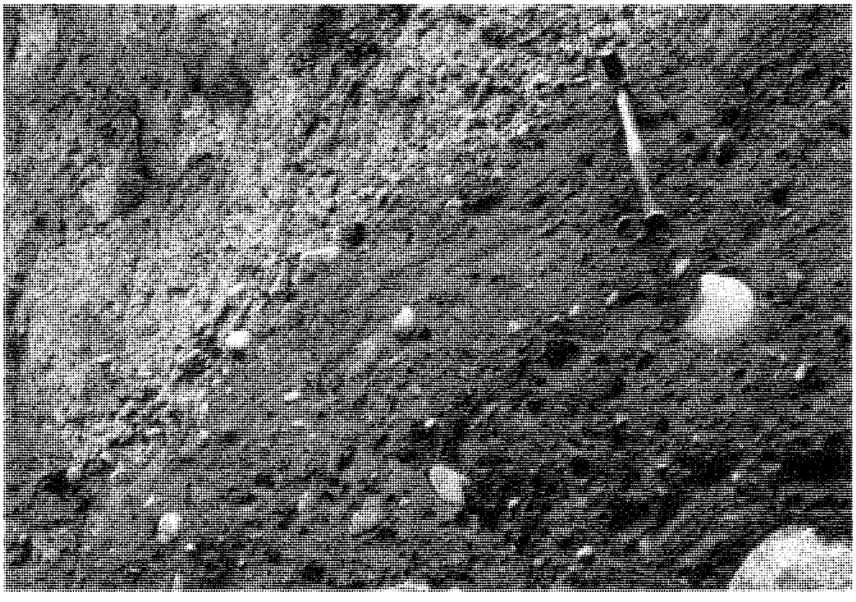
Uncertainty in rates of emission of greenhouse gases, their atmospheric lifetimes, oceanic heat absorption, and many other factors make it difficult to predict sea levels in the future. A current range of estimates indicates that sea level is likely to rise 3-5 cm by the year 2000, 10-21 cm by 2025, 20-55 cm by 2050, and 36-192 cm by 2075. However, the largest destruction of the ozone layer is over Antarctica and the second largest over the Arctic. If these ice-sheets were destroyed first, sea level would be increased much more rapidly, even catastrophically, ending up as much as 5-7 m higher in the span of a few years.

Areas around Vancouver that would suffer most from sea level rises are the low-lying deltas and floodplains along major rivers such as the Fraser. The municipalities of Delta and Richmond are only an average of about four metres above present sea level. They are now surrounded by dykes to protect them from floods and high tides. As sea level rises, the lower reaches may flood more frequently than in the past. The dykes will have to be upgraded at considerable expense if the expected sea level rises occur.

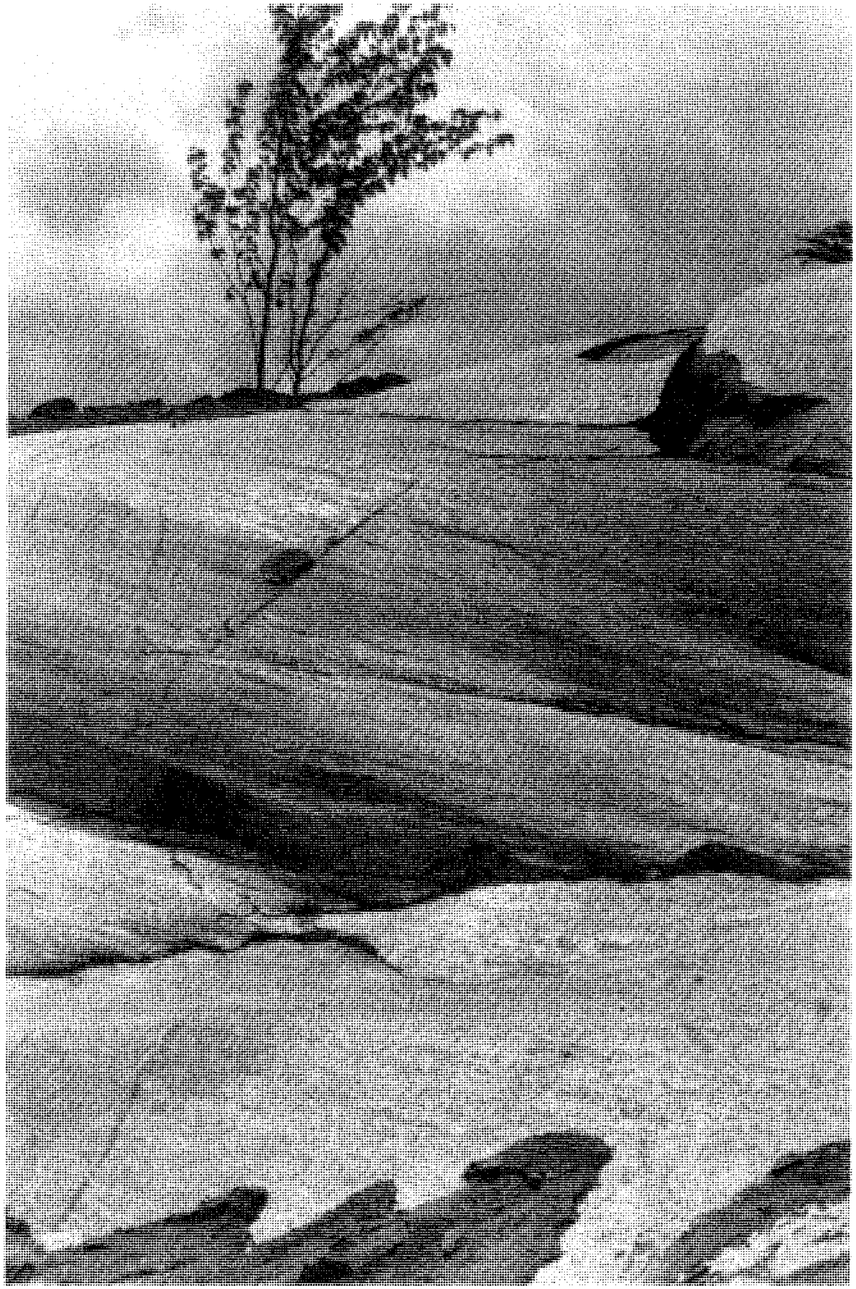


Schematic diagram showing some of the sedimentary environments present near the end of Fraser Glaciation, about 12,000 years ago.

Yukon today. Animal life probably abounded. Several sets of mammoth tusks were found in clay-rich silt in the eastern part of the Fraser Lowland near Vedder Crossing. Radiocarbon dating has shown them to be between 24,000 and 21,000 years old, placing them at the beginning of the Fraser Glaciation. They are currently displayed in the museum at Simon Fraser University.



Till consists of rounded stones embedded in a mixture of sand, silt and clay, all of which were dropped out of a melting glacier as it receded. (JEA)



Glacially polished and scratched (striated) granodiorite. This outcrop is in the pullout beside Highway 99 below the Squamish Chief.

The large boulder is a glacial erratic left by ice receding from the Fraser Lowland about 12,000 years ago. Near 12th Avenue and 200th Street in South Surrey. (JEA)

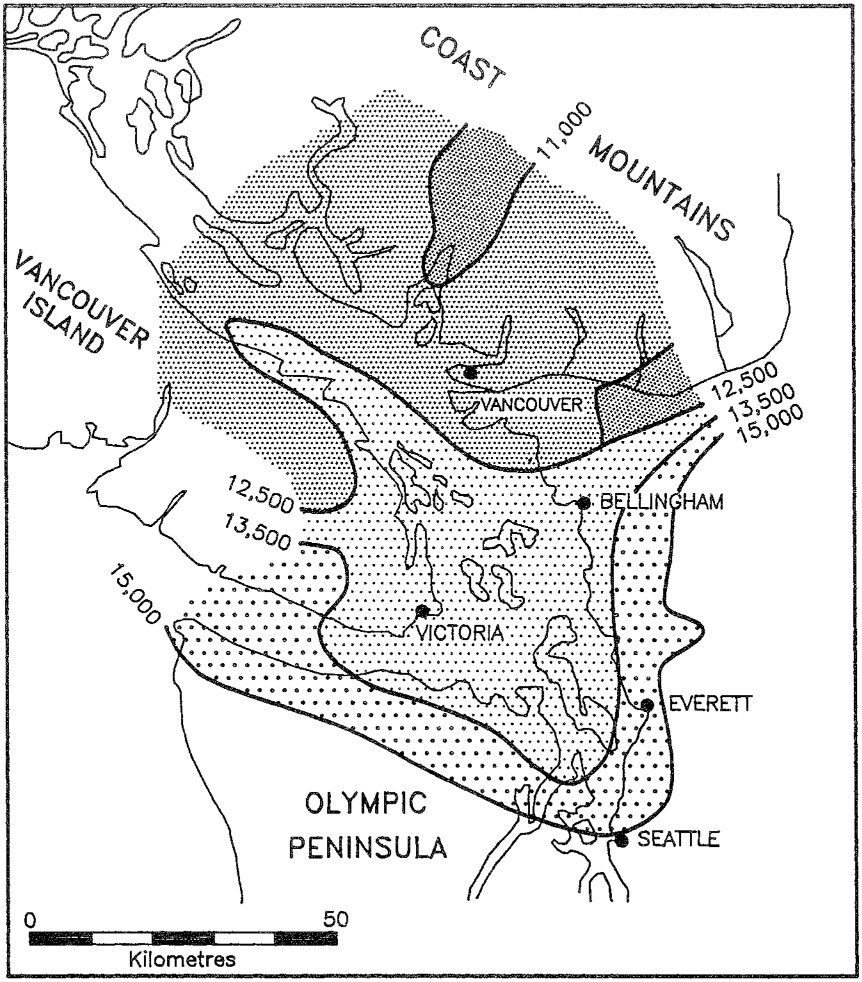
The Fraser Glaciation, which began about 25,000 years ago and lasted until about 12,000 years ago, was the last major advance in the Vancouver area. At its peak, a glacier up to 1,800 metres thick flowed down what is now the Fraser Lowland, at one point extending

GLACIAL DEPOSITS

The general term for all types of rock material moved or deposited by glaciers or the water melting from them is drift. Drift can include any combination of material ranging in size from boulders to extremely fine silt and clay. The form and composition of various glacial drift deposits reflects how the sediments were carried and deposited by the ice and whether they were subsequently modified by water.

As the glacier moves, the rock material is carried within it, mainly concentrated at the base. The weight and grinding action of the moving glacier not only breaks up the material being carried, it erodes and polishes the underlying bedrock. Till is the name for unsorted and unlayered boulders, clay, sand and gravel, deposited in a random fashion as the glacial ice simply melts away. Where this material accumulates at the end of or along the side of an ice sheet, it is called a moraine.

The further action of water on these deposits tends to separate the coarse from the fine material. In other words, the sediments are sorted. While the coarser boulders are moved only by the most torrential streams, the fine clays and silts are carried into lakes and oceans before they settle out to form sedimentary deposits. When the glacier itself reaches the sea, icebergs may carry rocks even further out.



The extent of Fraser Glaciation ice at various points in time during its recession between 15,000 and 11,000 years ago. Since then, the area formerly covered by ice has been rising, in a process called "isostatic rebound".

out into the Strait of Georgia and south into Puget Sound. Other glaciers moved down side valleys to merge with the larger ice sheet covering the Lowland. The effect on the valleys was pronounced. Once relatively angular, with "V" shaped cross-sections, they were broadened and rounded out into "U" shapes. The Capilano and Seymour Rivers and Lynn Creek all begin in these broad glacial valleys, although their lower reaches include narrow gorges and glacial drift deposits.

Enormous volumes of rock were scraped from the valley floors and sides, carried with the ice and finally deposited in ridges and

Glaciomarine mud and silt layers exposed below the Cleveland Dam, on the east side of Capilano Canyon.

hills called moraines. Many of the glacial deposits that are more prominent today, however, result from the melting of ice rather than its direct action. When the glaciers finally retreated between 13,000 and 11,000 years ago, much of the rock debris in the ice dropped out as a thick layer of till blanketing many parts of the Lowland.

The smaller glaciers occupying the valleys of the North Shore mountains melted and retreated before the ice covering the Lowland did, resulting in the formation of temporary glacial lakes. At other times, meltwater streams from these smaller glaciers formed small deltas called kames. Kame sediments have been exploited by many sand and gravel pit operations.

Geologists have noted that typical glacial landforms like eskers and moraines were more common in the Fraser Lowland east of Abbotsford than further west. The distribution of fossil shells indicates that an arm of the sea once extended across the Lowland as far east as Abbotsford. Furthermore, sedimentary structures suggest that much of the material here was actually deposited by icebergs.

These deposits, now called "glaciomarine", were initially recognized by Jack Armstrong of the Geological Survey of Canada. They are more varied and complex in the Vancouver area than anywhere else in North America.

There was a close association between the fluctuating ice front in the central and eastern Fraser Lowland and sediment deposition on the sea floor to the west. The ice front calved into the sea to produce icebergs which, upon melting, dropped stones taken from the Coast Mountains into the muds on the sea floor. Thick layers of sand and gravel were deposited in marine deltas and kames on the landward side of the calving ice margin. Most of the fine sediment was carried by glacial meltwater out into the sea. Later, some of these glaciomarine sediments were then redistributed as a result of underwater slides and turbidity currents.

Many of the larger shells found in the glaciomarine sediments are from species still found off the coast of North America. They lived in a shallow water environment similar to that in the Gulf of Alaska today. The water's salinity changed from time to time due to varying inflows of glacial meltwater.

Sea level fluctuated greatly during each glaciation. For example,

CHANGING SEA LEVEL IN THE VANCOUVER AREA

The Vancouver area has undergone more than one sea level change of up to 50 or 60 metres in the past 10,000 to more than 100,000 years. Two main factors have been responsible for this. The first is the depression of the Earth's surface under the weight of an ice sheet (called isostasy).

The second factor is the amount of water in the ocean (called eustasy). When much of the Earth's water is frozen as ice in glaciers, as during periods of major glaciation, sea level can be lowered 100 metres or more relative to what it is presently. On the other hand sea level during especially warm periods between glaciations was probably higher than it is now. This complex interplay between ice and ocean water continues. The current concerns with the greenhouse effect stem from the melting of glaciers that the warming would cause. Almost all of the resulting water would drain into the oceans and raise sea level.

Earthquakes have also resulted in changes of sea level. In 1960, a major earthquake caused about 2 metres of sudden subsidence along the coast of Chile. About 7,500 years ago, sea level suddenly rose 10-12 metres in the Vancouver area and one possible explanation is that a very large earthquake dropped the level of the land. Many smaller and apparently sudden changes in sea level here have also taken place, the last about 300 years ago. In spite of this, the most dramatic ones in terms of size have been mainly due to isostasy or eustasy.

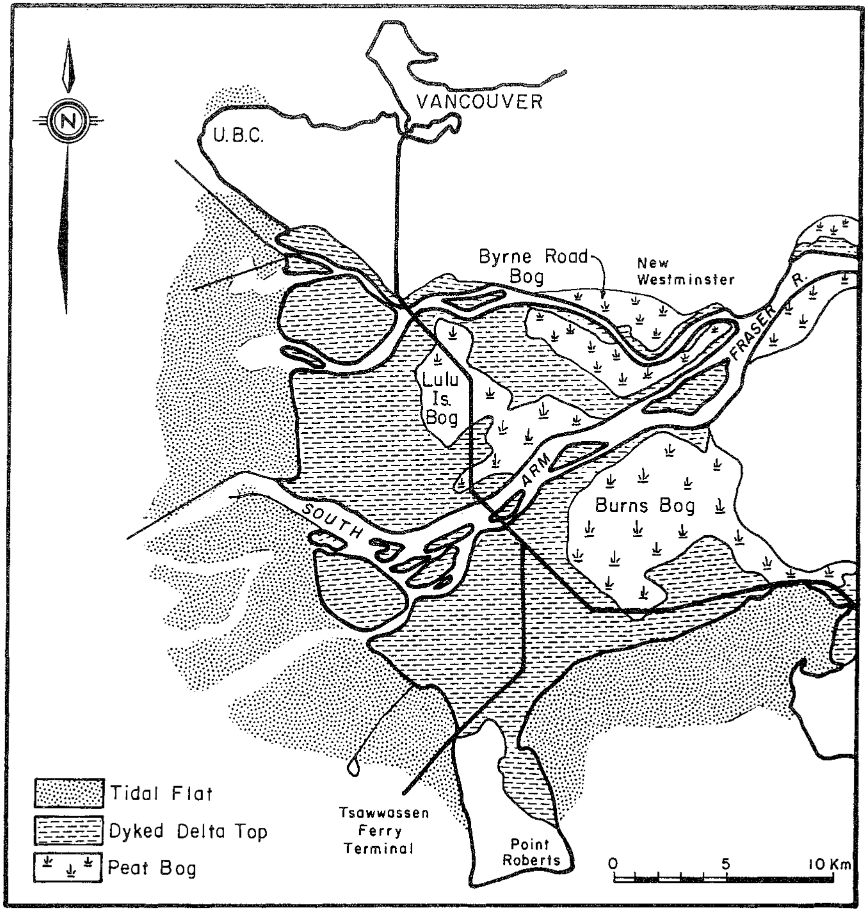
the enormous weight of the Fraser valley glacier depressed the land about 250 metres, placing much of the Lowland under shallow water. Once the ice sheet melted, the land rebounded to near its present position over a period of about 3,000 years. The many strandlines and terraces found on coastal slopes around White Rock are evidence that the land has risen relative to sea level. At the same time but to a lesser degree, absolute sea level was rising because much of the water that had been locked up in ice worldwide was now refilling the oceans. Many of the glacial valleys along the coast of southwestern B.C. were partially submerged during this rise in sea level after the end of the Fraser Glaciation. The submerged valleys are called fiords and Howe Sound and Indian Arm are the most southerly in Canada.

Fraser Delta

Most of the landforms in the Fraser Lowland were produced during or since the last major glaciation. The most important agent for the deposition and sculpturing of these sediments has been the Fraser River, which developed after ice left the Lowland some 8,000 to 10,000 years ago. Currently, it discharges approximately 18 million tonnes of sand silt and mud each year, mostly during May, June and July. In order to keep the river channel open for navigation, about 2.4 million tonnes of sediment, mostly sand, has to be dredged annually.

The nearly flat delta top is nowhere more than a few metres above high tide level. Between it and the open water, tidal flats are swept by currents and waves. A three metre high dyke or berm has been constructed around the seaward edge of the municipality of Richmond. The dyked area is largely underlain by fine sediments, laid down when the Fraser River overflowed its banks and when the sea flooded over the land during storms and at extremely high tides. On Lulu Island, and south of the present course of the river, these sediments are overlain by peat which accumulated in large swamps and bogs. Sand underlies most of the tidal flats and mud occurs in a fringe of marsh around the edge of the delta.

Crossing both dyked area and tidal flats, river channels floored by sand and minor gravel are the arteries of the Fraser Delta. Because the channels are now guided by manmade training walls, most of the sediment discharged by the river is deposited underwater, on the western foreslope of the delta. The distribution of sediment there is governed by patterns of currents and waves. Typically, mud is



The Fraser Delta, built outward from New Westminster during the last 10,000 years, has a surface of fertile land and peat bogs that has been drained and is protected from flooding by a dyke. The tidal flats outside the dyke are a vital habitat for migrating birds and other shore life.

deposited north of the main distributary channel while sand is diverted to the south.

By studying the buried sediments in drill holes and using radiocarbon dating, geologists have been able to reconstruct the delta's evolution over time. About 10,000 years ago, the entire area of the present Fraser Delta was an expanse of sea, and Point Roberts peninsula was an island. Sea level was lower than it is now but sediment accumulated and the delta emerged above the sea. A ten metre rise in sea level between 7,500 and 6,000 years ago flooded the young delta top but sediments carried by the river rapidly rebuilt this submerged surface above water. Since sea level has not changed significantly for the past 5,000 years, the delta continued to grow.

As the delta has expanded into the Strait of Georgia, the various sedimentary environments it contains have moved along with it. Its outer edge, the foreslope, and the tidal platform have migrated seaward, trailed by the advancing Fraser River floodplain. The most important result of this has been that sediments typically deposited at the mouth of the delta have gradually been covered by those typically deposited further in towards the head. In addition, the river channels have repeatedly shifted their position. Long, relatively narrow bodies of sand within the upper part of the sedimentary sequence record long-abandoned river channels.

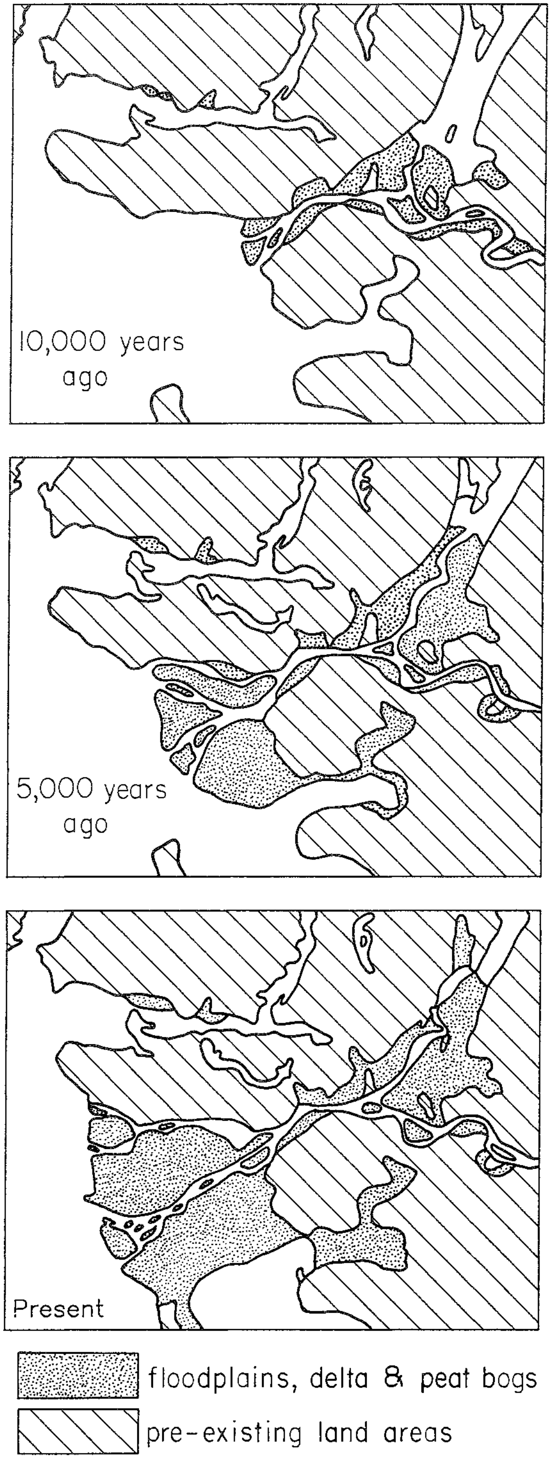
PEAT BOGS

Until recently, several of the major peat bogs of the Fraser Delta contained the largest agricultural peat operations in Canada. The Byrne Road bog covers more than 600 hectares, of which more than one half are under cultivation. The peat here is from less than 1 m to 5 m thick. The Lulu Island bog covers about 1400 ha, of which only about 100 ha are under cultivation. Much of the peat in this bog, which is from 1 to 7 m thick, has been badly burnt—fires are common in the bogs in dry summers. The Burns Bog extends over an area in excess of 4500 hectares, the margins of which are under cultivation. Much of this bog has also been damaged by fire. The peat varies in thickness from less than 1 m to 8 m. These bogs and others have very acid topsoils well-suited for growing blueberries and cranberries.

All the peat produced from these bogs is composed of sphagnum moss. The top layer is referred to as unhumified peat. This is dead sphagnum moss only slightly decomposed. It is fibrous, elastic, light greyish green or yellowish to light brown, becoming somewhat darker on drying. It has an absorptive value of up to 26 times its own weight of water and is light in weight and porous. The layer of moss of high quality varies greatly in thickness; in some places it is as much as 2.15 m thick, but averages nearer 1.22 m. This undecomposed peat grades down into and is interlayered with humified peat. Humified peat in its natural state is dark brown to black, with homogeneous composition and texture and is somewhat elastic. It dries into a hard solid mass that will not float and does not absorb very well. A piece of dried humified peat may be under water for weeks without taking up any water. Unhumified peat left in its natural state will humify in the course of time, and all fibrous material eventually disappears.

Burns Bog landfill is the main garbage disposal site for Vancouver City. There has been a proposal for the city to install a methane gas collection system there. Estimates are that as much as 17 million cubic metres would be generated annually over the next ten years. In the interim, the gas will be flared in the same way as at the Coquitlam landfill in order to prevent odour.

Stages in the growth of the Fraser Delta since glacial ice receded from the Fraser Lowland about 10,000 years ago.



ENGINEERING GEOLOGY ON THE FRASER DELTA

Peat bogs present major foundation problems for highways and other structures, including lighter ones such as homes. Peat will hold up to 26 times its own weight of water and will settle unevenly and in a large way when loaded. Presently, where the peat is less than 2 m thick, it is normally excavated. If it is more than 2 m thick, the standard procedure in recent years has been preloading. This is done by placing fill, normally sand, on the peat to compact it as much as possible. A geotechnical engineer calculates the amount of fill required and the period of time it should be in place to bring about this compaction. On completion of the preloading, part of the fill is removed and the structures and highways are built on the remainder. However, Highway 99 was built before this preloading technique was developed. At the time it was built, the approach was to remove all the peat and fill the excavation with sand. This was done successfully where Highway 99 crosses a major peat bog on Lulu Island.

Also during the construction of Highway 99, a major tunnel was constructed under the Fraser River at Deas Island. It was constructed as precast sealed lengths that were floated over the tunnel line and sunk into place in a previously prepared trench in the sands of the Fraser River bed. The trench was prepared by dredging. During construction, water wells were drilled along the line of the tunnel and pumped at the highest rate possible in order to lower the local groundwater table.

FORCES AT WORK

Up to this point, we have looked at the geology of the Vancouver area as a history. From the few outcrops, gravel pits and drill cores, geologists have pieced together the ancient environments in which the various rocks formed, the forces that eventually deformed them, and how, much later, glaciers and rivers reworked them and their erosional products. It all seems long ago but the geological story does not end with the present. Many of the forces at work in the past are still at work today and will be in the future. Some of them, such as the movement of crustal plates, will take place despite our presence. Others, such as the formation of deltas and the glacial cycle, may be influenced for better or worse by human activity.

Ongoing Geological Evolution

The most obvious of the major ongoing geological processes is continued sedimentation by various rivers. Most of the deltas in the Fraser Lowland area have built themselves up since the end of the Fraser Glaciation 10,000 to 12,000 years ago. Currently, the Fraser River discharges approximately 18 million tonnes of sand, silt and mud each year, mostly during May, June and July. In a relatively short geological time span, the Fraser Delta might have eventually formed a land bridge connecting the mainland with the Gulf Islands. The delta of the Capilano River was also formed during the past 10,000 years and was almost 6 km wide before being built over. Left to itself, it would probably have extended across First Narrows in a few thousand years, turning Burrard Inlet into Burrard Lake.

The normal evolution of many of these deltas has been interrupted, however, by extensive human modification of natural sedimentation patterns. For instance, the channels of the Fraser River are now guided by manmade training walls and the river can no longer shift its course on the delta. As a result, most of the sediment it carries is now deposited underwater on the western foreslope of the delta and further out to sea. The river rarely overflows its banks anymore to deposit mud on the delta top. In the long term, parts of the delta front which no longer receive sediment may retreat. Also, sediment no longer accumulates on the delta top to raise the level of the land above the sea. Consequently, its surface may become more susceptible to severe drainage problems and flooding caused by either a rise in sea level or a fall of the land. Changes in sediment influx to the tidal flat may adversely affect the rich fauna and flora.

The Capilano delta has also been affected by human intervention. Until the 1930's, the river mouth was east of the footing for Lions Gate Bridge but has now been artificially channelled further west. Furthermore, the obstruction of Cleveland Dam and controlled water flow have reduced sediment transport in the lower river and the delta no longer expands at its previous rate. However, relatively large amounts of sediment are still deposited at the inlet's entrance and dredging is periodically required at the mouth of the river.

On a somewhat longer time scale, both volcanic activity and the glacial cycle become important geological forces. Within the last several hundred thousand years, numerous glacial cycles have occurred, including the Fraser, Semiahmoo and Westlynn. In the normal course of events, it could be expected that many more will follow. During each, large ice sheets covered the area of the Fraser Lowland and extended out into the Strait of Georgia. Studies have shown that the buildup and advance of ice takes much longer than does melting and retreat. The pattern of future glaciations would likely be similar.

In terms of volcanic activity, both Mounts Baker and Garibaldi were constructed within the last 400,000 years. Hot steam still escapes from the ice-filled crater at Mount Baker, where the last eruption was in 1843. Volcanic eruptions were quite common near Mount Garibaldi only a few thousand years ago. Activity at both, however, has tended to involve mainly steam and ash. Even in the event of a larger eruption, the Vancouver area would probably only experience ash fall and then only if an easterly wind were blowing. Several ash layers in the Quaternary sediments indicate that this has happened from time to time in the past and almost certainly will in the future.

More extensive periods of volcanism involving the emplacement of lava flows and dykes, such as Siwash Rock in Stanley Park, have occurred at intervals of about 17 million years in the last 50 or so million years. It is possible that in the next few few million years, another such event will take place.

In addition to the above processes, the more subtle but inexorable movement of tectonic plates continues beneath our feet. The Juan de Fuca plate currently plunges beneath the North American plate at a rate of about 4.5 cm per year. This results in other stresses and movements in the North American plate, some of which can actually be observed. Precise measurements between mountain tops on Vancouver Island show the northeasterly directed squeezing of the land at rates of 2-4 mm per year. The Coast Plutonic Complex was elevated to its present position within the last 5 million years and is still rising, up to 4 mm per year in some places.

Geological Hazards

Some of the longer term geological processes include events that happen on a short enough time scale that we may directly observe them. Unfortunately, some of these are almost too quick and may impact adversely on our lives. Floods and landslides are relatively common in the Vancouver area, mainly because the climate, physical features and geology of the Fraser Lowland and adjoining mountainous areas make them inevitable under natural conditions.

The Fraser River would normally overflow its banks in the spring of every year if it were not for the extensive system of dykes that has been built over the years. Some flooding still occurs because the dykes are in many places built on permeable sand and gravel which let some water through when the river level is higher than the land. During periods of particularly heavy rainfall, mainly in the autumn and winter, lower reaches of the Fraser delta may be inundated at high tide. Mountain streams may overflow their banks during these heavy rainstorms and cause much damage to surrounding communities.

Landslides are mixtures of water and solid debris that move downhill after slope failure. Many result from the same basic causes as floods, often grade into them and are capable of great destruction. The slides along the Squamish Highway are only the most well-known.

The most significant (to us) short term geological processes are, strangely enough, related to those of the longest term. Earthquakes are a fact of life on the southwest coast of British Columbia. They are caused primarily by the subduction of oceanic crust under continental crust in the nearby Cascadia Subduction Zone. In the last 90 years, seven earthquakes large enough to do damage have occurred here. Recently, geoscientists have begun to understand that we are at

Fraser River in flood near Agassiz, at the eastern end of the Fraser Lowland, circa 1928. (Vancouver Public Library Photo #44489A.)

risk from another and much more serious event called a "mega-earthquake". Studies have suggested that no movement is taking place along the contact of the converging plates and that sooner or later, all of the built-up stress will be relieved in a very large and destructive earthquake. We cannot be sure that this will not occur during our lifetimes.

Human Involvement

People have been able to intervene directly in some geological processes, mainly when they constituted a threat or formed an obstruction. We construct dykes and retaining walls to channel rivers and control floods and landslides. In other cases, there is little that can be done to influence the course of events. Earthquakes are phenomena that we must withstand rather than expect to control. In addition to our direct intervention in some parts of the geological process, however, we have had a more subtle and significant impact on others. This has largely been through the addition of our civilization's byproducts to the natural environment.

The effects of pollution are wide ranging and are present at a variety of scales. In the simplest cases, pollution may involve local contamination of land and water with artificial substances. Poorly designed sewage systems, uncontrolled garbage disposal and landfills, industrial effluents and fertilizers of various types all contribute to the gradual accumulation of substances toxic to life. More complex and subtler types of pollution are beginning to be recognized, ones with even greater potential impacts. Atmospheric carbon dioxide and methane generated during generations of agricultural and industrial activity have reduced and are reducing the ability of the Earth to reflect solar energy back into space. This will result in global warming, affecting not only the weather patterns on which we all depend but also the glacial cycle. A rise in average temperature of even a few degrees would be enough to melt all of the glacial ice and raise sea level enough to flood large areas of coastal land, including the Fraser Delta.

In the foreseeable future, civilization is here to stay. Its interaction with nature, including geological processes, is inevitable and global in scale. It is possible, however, to minimize both the extent to which our impact on nature is an adverse one and the extent to which natural disasters affect us. We must be able to make informed decisions in these matters and the best means of achieving this is through knowledge of how natural processes occur and why.

As in many other sciences, there is a growing concern in geology that we should see the world in a larger context. What sorts of long-term natural fluctuations are there and how do they compare with the changes we incur? To what extent have we harvested the Earth's resources and what are the most responsible ways of continuing to do so, both in terms of our needs and the effects of their extraction? In which ways are the byproducts of our civilization assimilated by the Earth and how can we minimize their adverse impacts? How may we avoid the catastrophic natural disasters that have plagued us in the past? The answers to these questions start with the desire to know and understand how the Earth works.

FIELD TRIPS

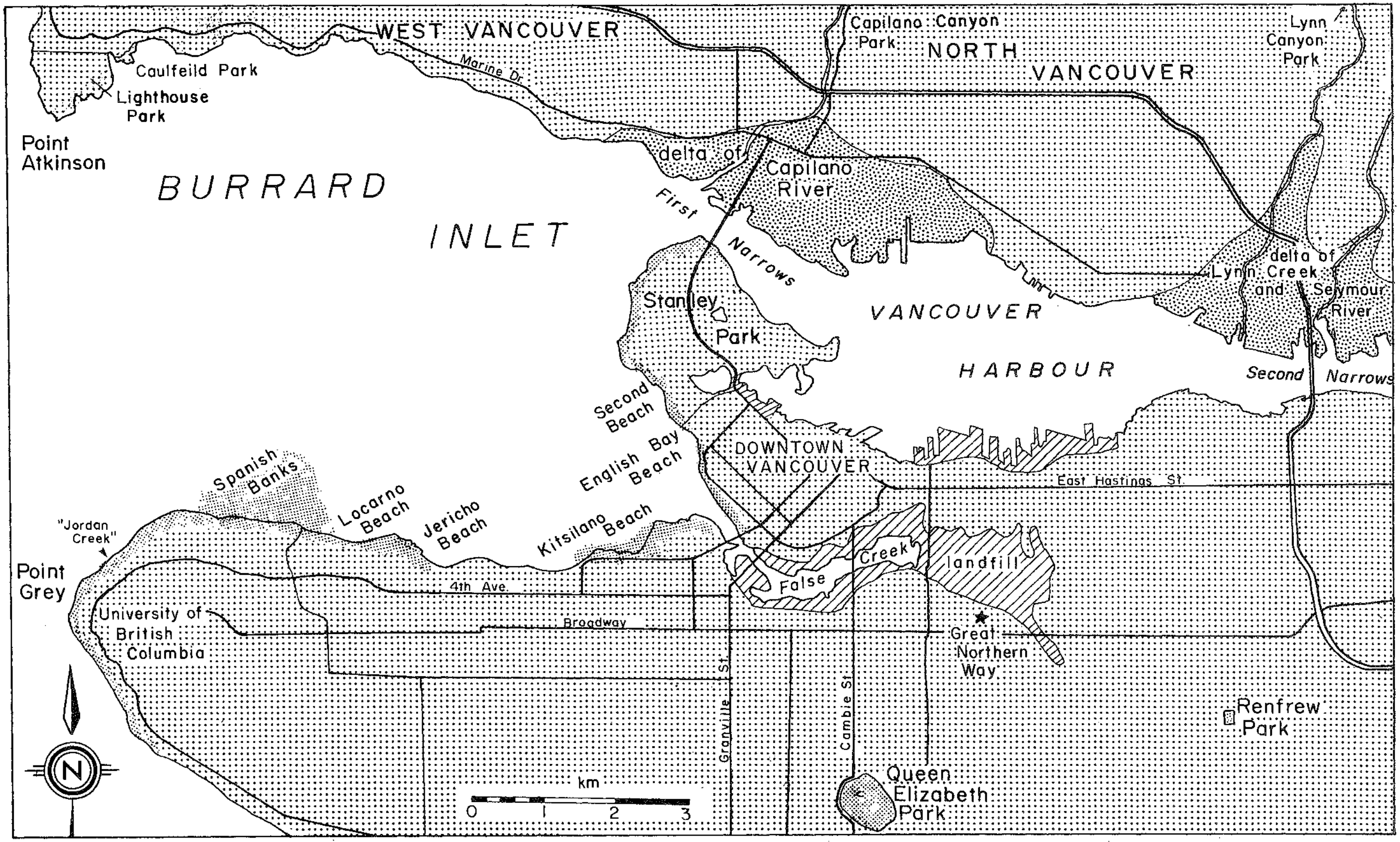
The geologic history outlined in preceding chapters is not the product of library or laboratory research—it was worked out by geologists "in the field". The act of going outside to examine rocks and sediments can be fun, a challenge for body and mind, as one tries to imagine what took place so long ago. Although rock outcrops are uncommon in urban Vancouver, many public parks contain visible geological features in addition to their well-known attractions. Their geology is described in the following field trips spiralling outward from downtown. These areas provide nature walks lasting from an hour to a full day. In addition, a driving tour on Highway 99 leads along Howe Sound, where many of the landforms and rock types of the Coast Mountains may be seen. We hope that you'll use these brief guides to enhance your explorations of Vancouver's scenery.

Stanley Park

An oasis of forest and seashore only 2 km from downtown by city bus, this park can rejuvenate your spirit. It provides a place to walk, run and cycle, to observe plants and animals and to see the mountains and ocean surrounding the city. The park covers a 400 ha peninsula jutting into Burrard Inlet, and is connected to North Vancouver by the Lions Gate Bridge. If you are on foot, you can explore forest paths, or walk around the edge on the seawall. For a person city-bound, Stanley Park is a haven of natural beauty, fresh air and sea breezes.

History

Until the 1870's, the Coast Salish people under Chief Khatsahlano had a village near present-day Prospect Point. There were (and still are) cormorant colonies on cliffs and seals on nearby shoals, as well as good fishing in the tidal rip off Brockton Point. When the young shantytown spread westward from Gastown during the 1880's,


WEST VANCOUVER
Capilano Canyon Park
NORTH VANCOUVER
Lynn Canyon Park
Caulfeild Park
Lighthouse Park
Marine Dr.
Point Atkinson
BURRARD INLET
delta of Capilano River
First Narrows
Stanley Park
VANCOUVER HARBOUR
delta of Lynn Creek and Seymour River
Second Narrows
Second Beach
English Bay Beach
DOWNTOWN VANCOUVER
East Hastings St.
Spanish Banks
Locarno Beach
Jericho Beach
Kitsilano Beach
"Jordan Creek"
Point Grey
False Creek
landfill
4th Ave.
Broadway
University of British Columbia
Great Northern Way
Granville St
Cambie St
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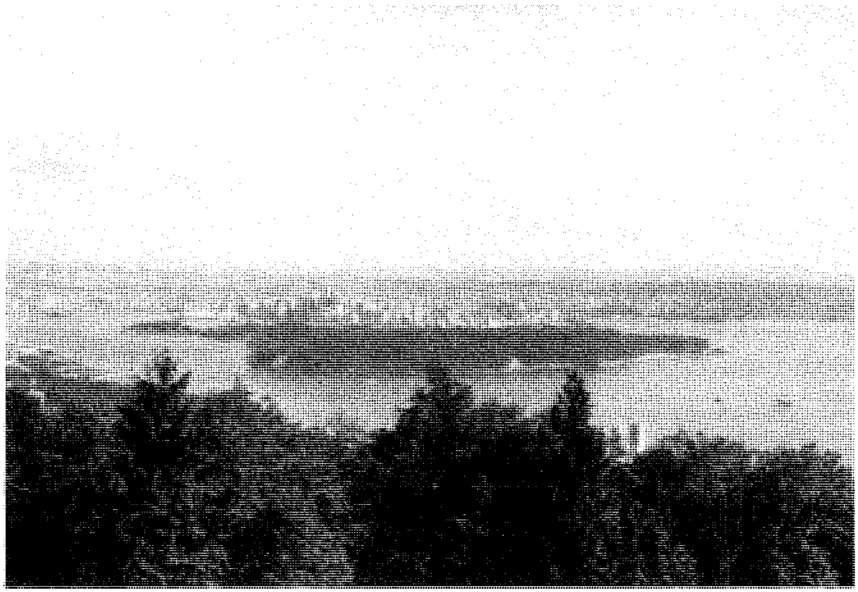


The forested peninsula of Stanley Park, the downtown area and Fraser Lowland beyond are visible from the lookout on Cypress Parkway above West Vancouver.

glaciomarine clay near Lost Lagoon for brickmaking and lignite attracted developers. They wishfully dubbed the area Coal Harbour. Most of the large trees were removed, and the British Royal Engineers took over the land for their barracks. After lobbying by city councillors (some say to protect land prices in the West End of Vancouver) a city park was dedicated in 1886 and named after the Governor-General of the time, Lord Stanley.

The park's management must balance the demands of those wishing to develop public attractions and those desiring to minimize human disturbance in this "pocket wilderness". The geography has already been considerably modified by human activity. In 1889, a bridge was built across the inlet of Coal Harbour and was later replaced by a causeway, creating Lost Lagoon in 1936. Lions Gate Bridge and the expressway leading to it were built then, virtually bisecting the park. At that time, few imagined that vehicle traffic using the bridge would reach the volume it has today. Only enclaves of old-growth forest remain (north and west of the "Hollow Tree"). Removal of deciduous trees and undergrowth are part of the current management plan.

Parks near downtown Vancouver. The sand for the many beaches is naturally supplied by three sources: the North Arm of the Fraser River, erosion of glacially deposited sand in cliffs at Point Grey, and the deltas of mountain rivers flowing from the north.

Geology

Upper Cretaceous and Eocene sedimentary rocks and the blanket of glacial till overlying them are hidden beneath the lush coastal vegetation and landscaping of roads and grounds. You can plan walking routes to watch birds (Beaver Lake) or big trees (east of Beaver Lake, across Pipeline Road), but if you wish to look at rocks, the following route will lead you past some of the best in a stroll of two to three hours. You will be walking along the seawall at the foot of cliffs between Prospect Point and Siwash Rock. Numbers correspond to localities shown on the map.

Where to go

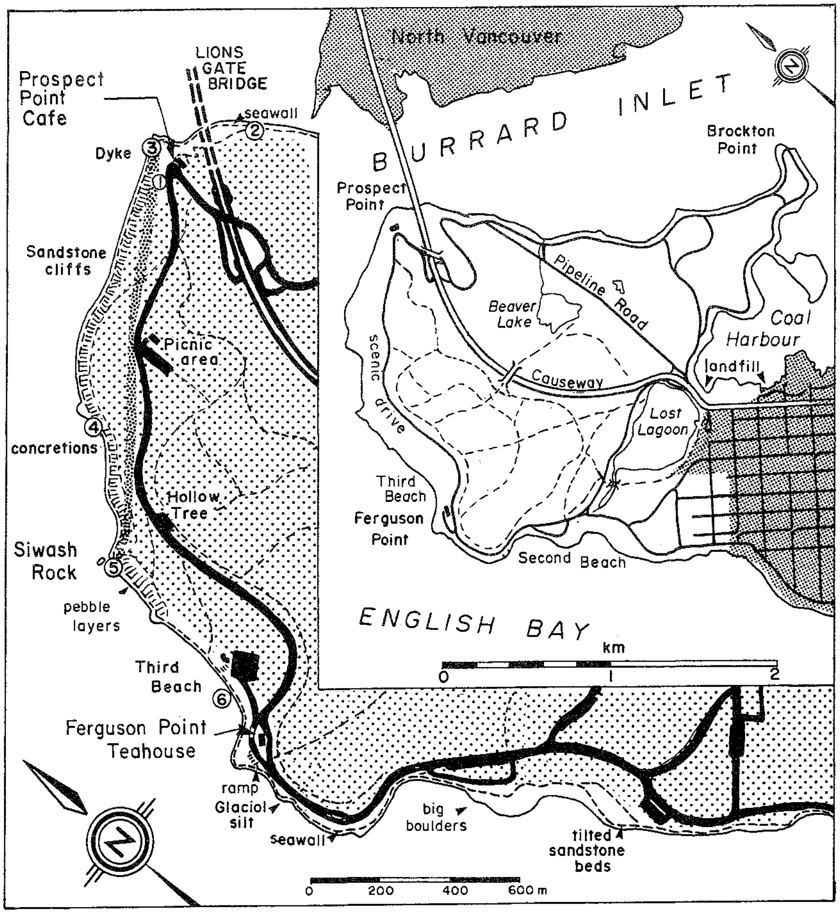
1) Begin your trip at the Prospect Point Cafe, where you can park your car (or bicycle). From the lookout you can see a splendid view of West Vancouver extending 380 m up the slope of Hollyburn Mountain. The forest above that point is second growth—much of Vancouver's early prosperity derived from logging of the North Shore mountains. Far to the left along the North Shore is the winking Point Atkinson light. Lighthouse Park is one of the best nearby places to view granitic rocks of the Coast Plutonic Complex.

From the lookout, a set of concrete steps leads to the top of the cliff. This platform was built for a searchlight and gun battery, part of the harbour defenses during the Second World War. We'll be looking up at the rocks of this cliff later on.

Immediately behind the cafe is a secondary path (near the washrooms) that descends to the right. Follow switchbacks beneath the deck of the Lions Gate Bridge, where the glacial clay and silt that cover most rock in the park are visible between the bushes. When you reach the seawall, turn left.

2) Above the seawall and beneath overhanging bushes are outcrops of sandstone. Within them, dark lines slant from east to west. These "cross-beds" indicate that the current that deposited the sand swept from the north.

The south abutment for the Lions Gate Bridge is set in sandstone and engineers are concerned about this footing. Strong tidal currents scour the rock underwater, and the bridge is subjected to increasingly heavy use and attendant vibration. Steel pilings have been driven at the sides of the abutment to improve its strength. From the bridge, it is 1.5 km along the seawall to Siwash Rock, and 2.3 km to Ferguson Point where the geology trip ends. (There are no shortcuts

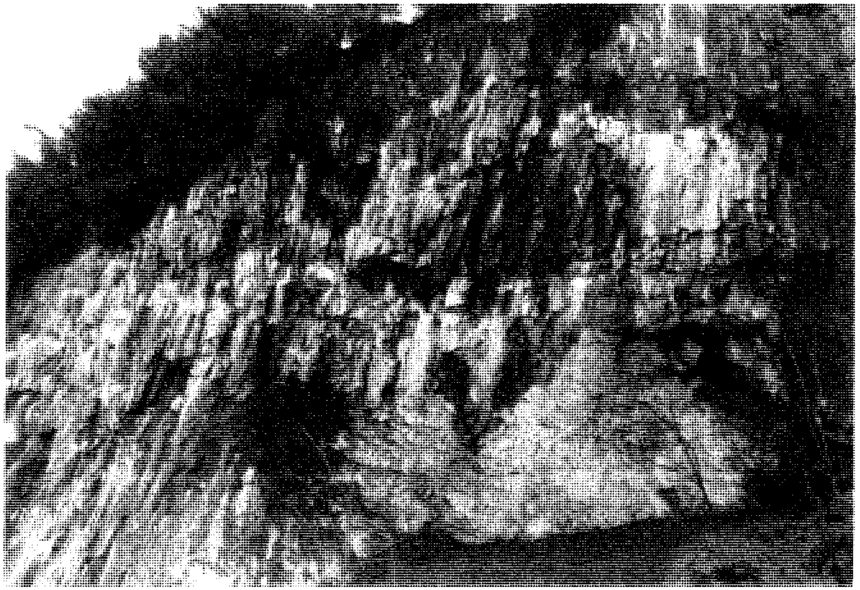


Map of Stanley Park. Numbers correspond to stops described in the field trip.

up the cliffs, but from Ferguson Point you can return to Prospect Point Cafe on paths through the forest.)

3) Just past the whitewashed ship's beacon (during heavy fog its booming note is heard downtown and throughout West Vancouver), is a 20 m high cliff with the Prospect Point lookout on top. The cliff is igneous intrusive rock called andesite—the same as Siwash Rock. The rock is blocky and hard: it is resistant to erosion and keeps the sandstone behind it from wearing away. Was this a lava flow? There are two clues that it was not.

Firstly, high in the cliff you can see a network of cracks that break the rock into columns, the ends of which are sticking out like cordwood. Called columnar joints, these cracks form at right angles to the cooling surface of the magma. In this case, if the rocks in the



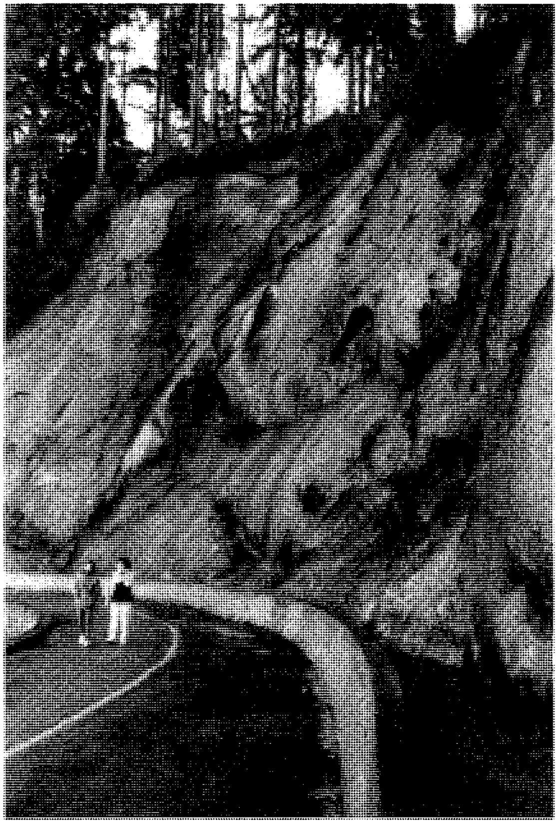
Andesite dyke exposed in the cliff below Prospect Point Cafe. The fractures are rows of columnar joints, a common feature in mafic volcanic rocks.

cliff were lava flows, the columns would be upright, as the cooling surfaces would be the ground below and the air above. In fact, they are on their side, indicating that the andesite here is a dyke. Here, the magma cooled at right angles to the enclosing wall rock, whose contacts with the dyke are vertical.

Secondly, if this rock were a part of a flat lying lava flow, the same rock would occur in outcrops nearby. Instead, it only reappears at Siwash Rock, where it is exposed as a vertical band through the sandstone, indicating that it is a dyke. It is possible that the dykes at Prospect Point and at Siwash Rock are connected. Nobody would want to excavate in the park to find out, but a geophysical survey involving the measurement and comparison of magnetic and electromagnetic fields over the ground could locate the connection if there was one.

Dark grey and brown sandstone cliffs are almost continuous to Siwash Rock. The beds of sandstone are very thick and only occasionally the contact between adjacent beds is visible as a thin, dark groove sloping south. These rocks were deposited in the Georgia Basin in Late Cretaceous time (before 66 million years ago) as determined from the study of pollen grains in the sandstone, and plant fossils found in thin shaly layers.

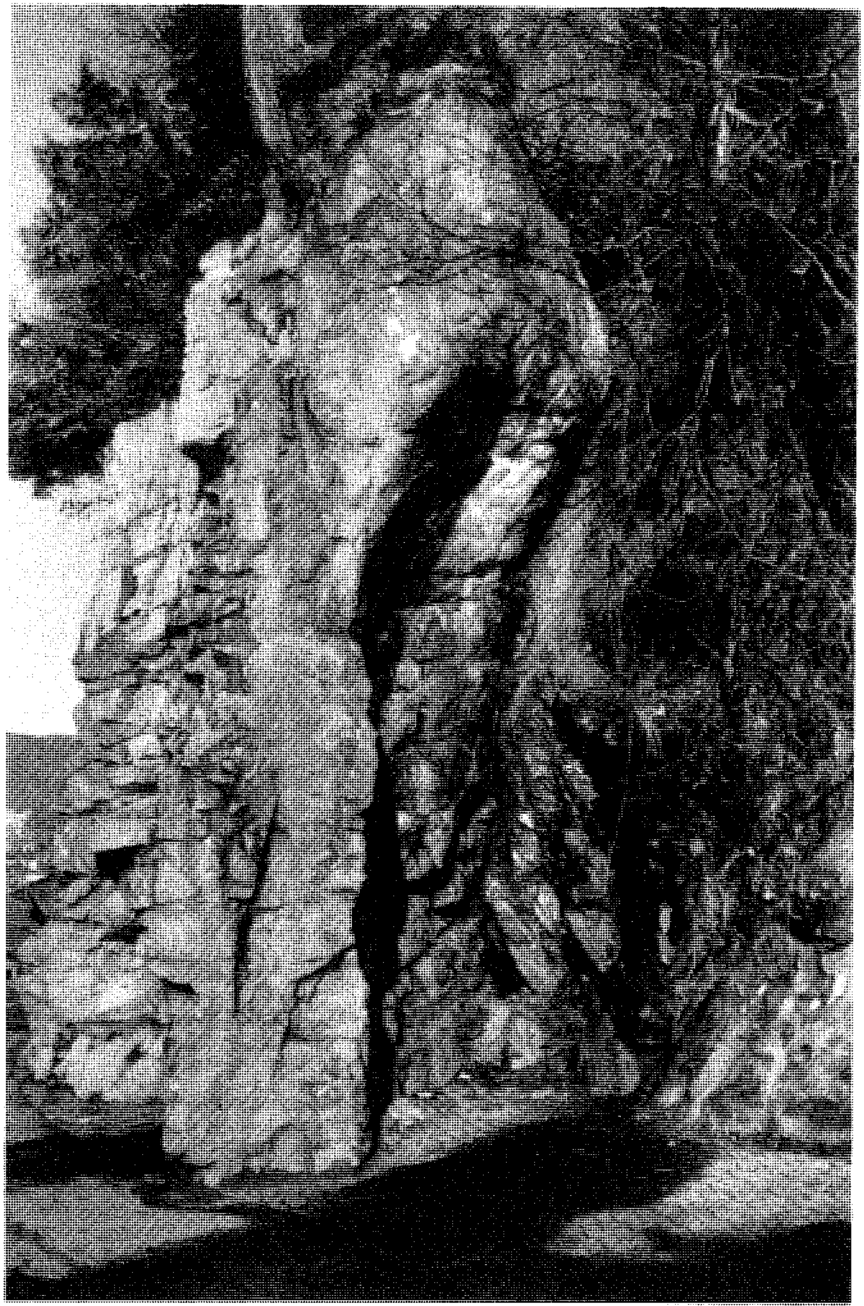
4) As you walk within sight of Siwash Rock, look in the



Cliff of Eocene sandstone beside the seawall in Stanley Park (location 4). The thick sandstone beds dip gently to the south (right), but are obscured by water marks and flaking of the surface.

sandstone for large rounded lumps that show dark brown stains when the rock is dry. These are "concretions", formed after the sand was deposited when water seeped through the sand and cemented parts of it with iron oxide. The cement is more resistant to weathering than the nearby sandstone and so it sticks out. You might have thought these were boulders in the sandstone, but if you look closely at the edges, you'll see traces of the bedding passing right through the concretion.

5) Siwash Rock is a favourite Vancouver landmark, popular with photographers, would-be climbers and cormorants. Indian legend has it that a great man was turned to stone here, but the rock is actually the last remnant of a dyke that once continued far out into English Bay. An observation deck above the seawall here was built for a searchlight used from 1941 to 1945 to scan the harbour entrance for enemy ships.



The cliff near Siwash Rock contains an andesite dyke (middle) that intrudes layered sandstone at left. Location 5 in Stanley Park.


Large boulders along the shore of Stanley Park remain from glacial till that once covered this area. West Vancouver and Lighthouse Park are visible across Burrard Inlet.

Beside Siwash Rock, the seawall walk passes through a gap in the dyke; here you can examine the igneous rock more closely. It contains black crystals of augite in a fine groundmass of plagioclase feldspar, hornblende and volcanic glass. Using the potassium-argon isotopic dating method, the andesite was found to be 35 million years old.

A few metres beyond Siwash Rock, in a brick-tiled niche, you can look at the contact of the dyke with the sandstone. The andesite was hot, and water within the adjacent sandstone became hot and corrosive, partly altering the sandstone to clay.

In the sandstone a little further on are lines of pebbles along the sedimentary beds. When deposited, they may have formed a small beach or riffle in the channel of a river, eventually covered by the shifting sand. If the tide is out when you reach Ferguson Point, try searching for imprints of ancient leaves and stems on flat slabs. Think about how these are fossils of plants that lived over 66 million years ago.

Did you wonder why the beach is mostly boulders? At low tide, you can see the flat slabs of sandstone extending into the water, but many of the boulders on top are granitic. One of them is 3 m across, too large to be moved by almost any river or beach. They were brought here by Pleistocene glaciers, and lay within the thick blanket of glacial drift until the sea eroded the sandstone beneath. Because the boulders consist of rock types harder than sandstone, they remain as the other rocks are broken down and washed away.

Rock outcrops are scarce once you pass Ferguson Point, although dark green glacial silt is exposed beside the seawall. The sandstone near Second Beach is light brown and white, and Eocene in age (35 to 50 million years old). It is believed that there was a period of many millions of years between the times at which the sandstone here and that further back was deposited. During this period, little if any sediment was laid down. The contact between the two ages of rock is known as an unconformity but it can't be seen here because it is covered by vegetation and glacial deposits.

If you wish to end your tour here, there is a teahouse and concession stand. On summer weekends, you can take the bus around the park to your starting place. Alternatively, several forest paths lead directly back to Prospect Point.

Books for further reading

The Natural History of Stanley Park by the Vancouver Natural History Society, 1989. Available from the VNHS, P.O. Box 3021, Vancouver, B.C. V6B 3X5.

Hiking Guide to the Big Trees of Southwestern British Columbia by Randy Stoltmann, 1987. Published by the Western Canada Wilderness Committee.

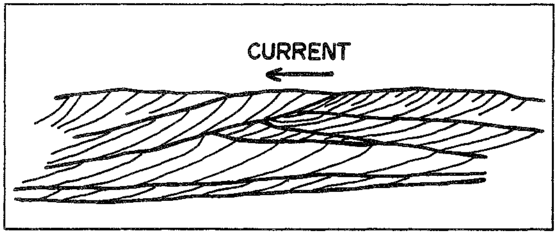
Kitsilano–Point Grey Beaches

The shoreline between Burrard Bridge and Point Grey is almost continuous city parkland. It is best explored on foot or by bicycle, as there are many attractions other than geological.

1) Most of the area is underlain by brown sandstone and shale that was deposited in the Georgia Basin. Outcrops of these rocks can be seen during low tide at the foot of Trafalgar Street, west of Kitsilano Beach. In order to have a good look at them, one should hike along the rocky beach during low tide, when they form elongated ridges on the tidal flat.

The bedding in the rock layers runs east-west and is gently inclined to the south. A common feature of the sandstone is cross-bedding, which indicates the direction of currents when the sand was deposited. At that time (35 to 50 million years ago), the rivers flowed to the west and south.

Cross-beds. The direction of current that deposited the sand is along the downward slope of the cross-beds.

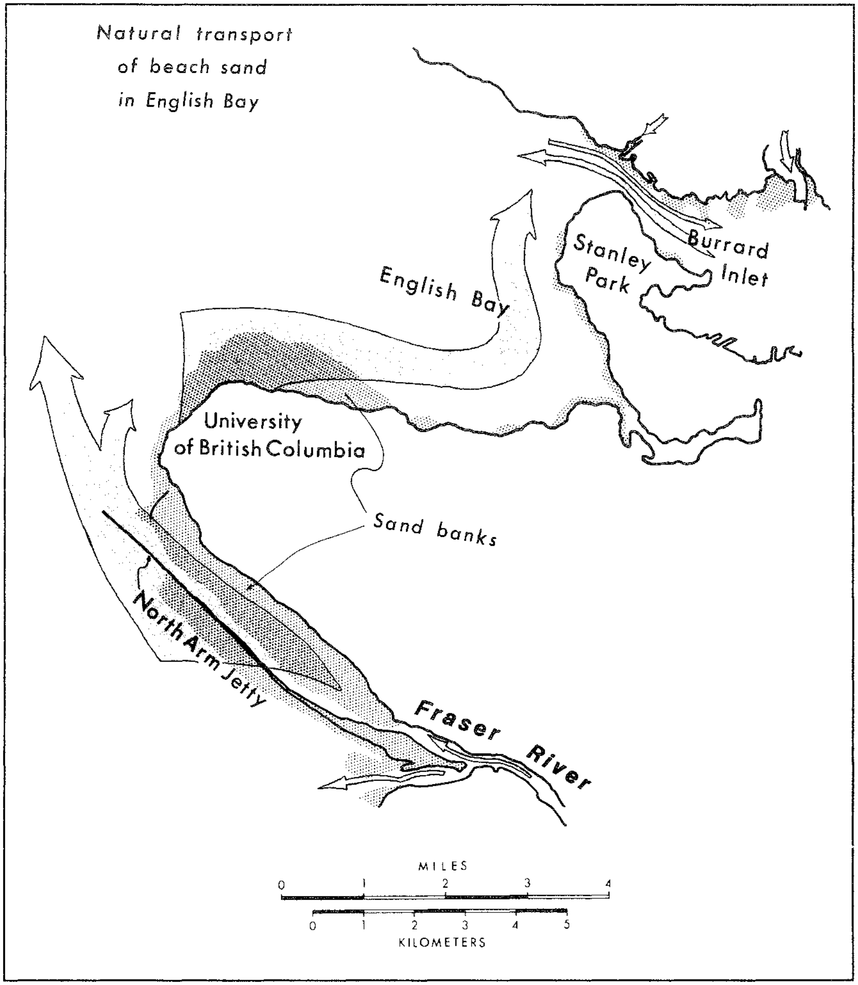


2) Jericho, Locarno, Tower and Wreck beaches are the landward extent of a large shoal called Spanish Banks. The sand comes from two sources: the North Arm of the Fraser River, and from erosion of sea cliffs below the University of British Columbia. These cliffs expose a cross-section with silty clay at the base, sand in the middle, both overlain by glacial till and 12,000 year old beach gravel. The sand (Quadra sand) was deposited in front of advancing glaciers about 20,000 years ago and is easily eroded. During heavy rains, the runoff cuts steep-sided gullies through the upper till. In January of 1935, following 37 cm of rain and snow in four days, a deep gully was carved overnight about 1 km east of the Museum of Anthropology. Normal drainage was blocked and runoff washed out an existing gully, in the process removing about 100,000 tonnes of material.

Outcrops of Eocene sandstone of the Georgia Basin, exposed between Kitsilano and Jericho Beaches. Gently south-sloping (to the left) bedding is accentuated by erosion of the thin mudstone layers between them.

Quadra sand exposed in the University Endowment Lands along Northwest Marine Drive. These glaciomarine sands were deposited 18,000 to 26,000 years ago in front of the ice sheet covering the Lowland during the Fraser glaciation.

This gully in the University Endowment Lands was carved in a single night and day in January, 1935. Heavy rain and snow could not drain into the frozen ground, and spilled down a minor stream, eroding the Quadra sand beneath. (Vancouver Public Library photo.)

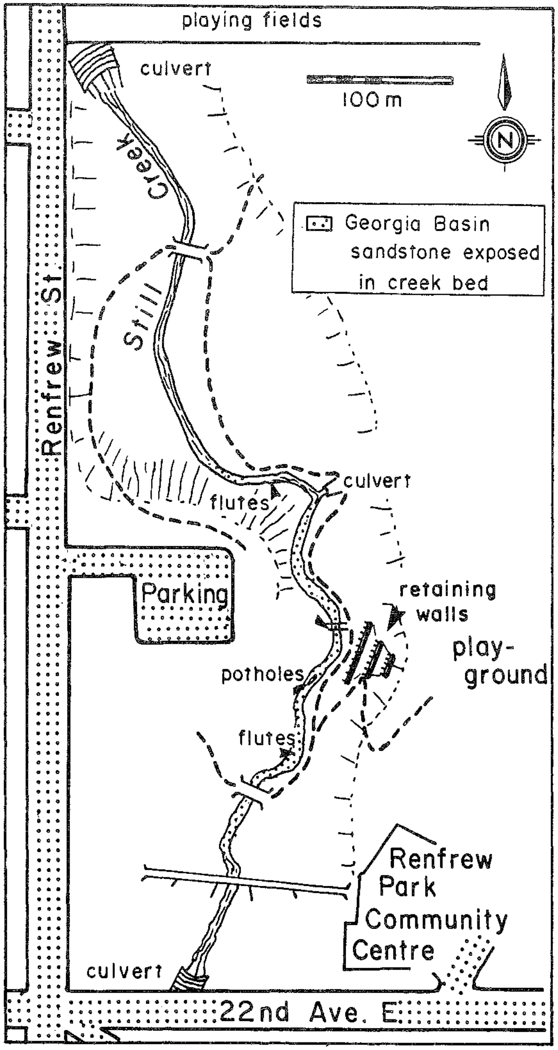


Transport of sand from the Fraser River and erosion of Point Grey to beaches along English Bay.

Erosion also results from storm waves striking Point Grey head-on. On average about 30 cm of the north side of the U.B.C. campus is removed annually. As the base of the cliff is removed, vegetation and material slumps down from above. Once it is carried a short distance out to sea, the sand joins suspended sediment brought by longshore currents from the Fraser River. Moving eastward, these currents feed beaches around English Bay. Ultimately, much of the sand is moved around Prospect Point and is swept into deeper water by tidal currents from Burrard Inlet. This natural transport cycle of beach sand has continued for thousands of years. Unfortunately, it has been interrupted by attempts to halt erosion of the sea cliffs, as well as the training walls and dredging in the Fraser River. The beaches are no longer resupplied with sand from these sources and will eventually disappear. Nowadays, sand is periodically trucked in to many of them.

Renfrew Park

The park is on the east side of Renfrew Street below East 22nd Avenue, about 0.5 km south of the Grandview Highway. Although the geology takes only a few minutes to see, the park is pleasant for a picnic or an evening stroll. Children can explore the adjacent



Map of Renfrew Park in East Vancouver, showing geological features.

playground, and the Renfrew Park Community Centre is close by.

Still Creek flows quietly in a shallow ravine through the park, eventually reaching Burnaby Lake. Although the sides of the stream have been built up with cement, it flows on bedrock—sandstone of the Georgia Basin. In the waterfalls you can see the rough beds, 5 to 20 cm thick. Like the outcrops near Kitsilano Beach, the sand in these beds was deposited by rivers flowing from the north about 40 million years ago.

The smooth, fluted surfaces of the rock have resulted from slow erosion by the stream. At one place are small "potholes"—irregular, polished cavities where a pebble has been spun in an eddy, wearing away the rock. If you reach into the pothole, you may find a well-rounded pebble, the "grinder", trapped inside. (You might find other things, too.)

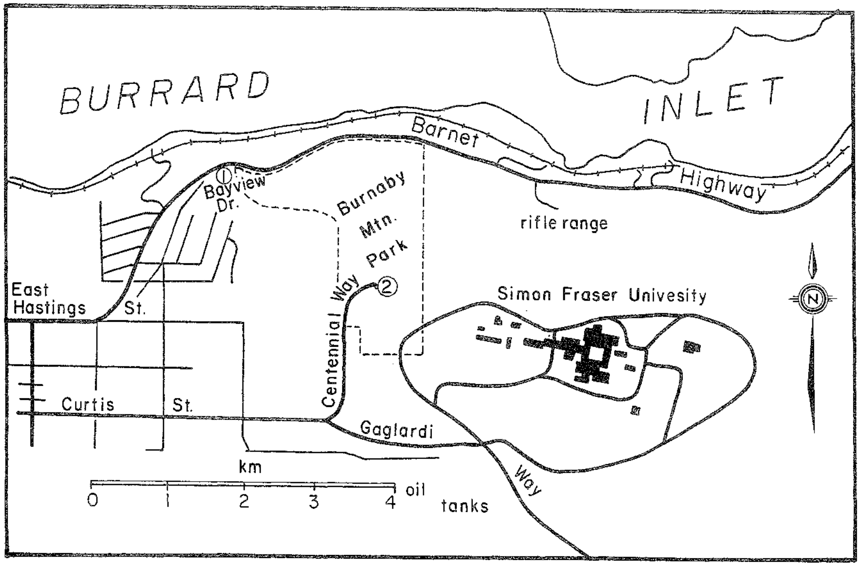
On the east bank, below the playground, is a log retaining wall. The logs keep the steep slope of the ravine from sliding into the stream. Instability of the glacial sediments that blanket this area results from clay, as well as undermining by the creek before the bed was confined by cemented walls.

Burnaby Mountain

Although everyone knows it as Burnaby Mountain, the official name is actually Mount Burnaby. The mountain is 403 metres high and covers an area of about 10 square kilometres. Simon Fraser University occupies the summit and Burnaby Mountain Park is on the higher part of the western slope. They are easily reached via East Hastings Street and Curtis Street, or from the south via Gaglardi Way.

Burnaby Mountain is underlain by layers of conglomerate, sandstone, siltstone and shale deposited in the Georgia Basin during the Eocene (39-45 million years ago). The mineralogical composition of the pebbles and cobbles in the conglomerate indicates that they were brought in by rivers from the north. Triggered by uplift of the Coast Mountains about 5 million years ago, erosion first destroyed the layers of shale and later, ledges of more resistant sandstone and conglomerate. Burnaby Mountain is therefore a remnant of a vast alluvial plain that once covered much of the southern slope of the Coast Plutonic Complex.

The south side is mantled by glacial till (11,000-13,000 years old) as well as shell-bearing, silty and stony glaciomarine sediments.



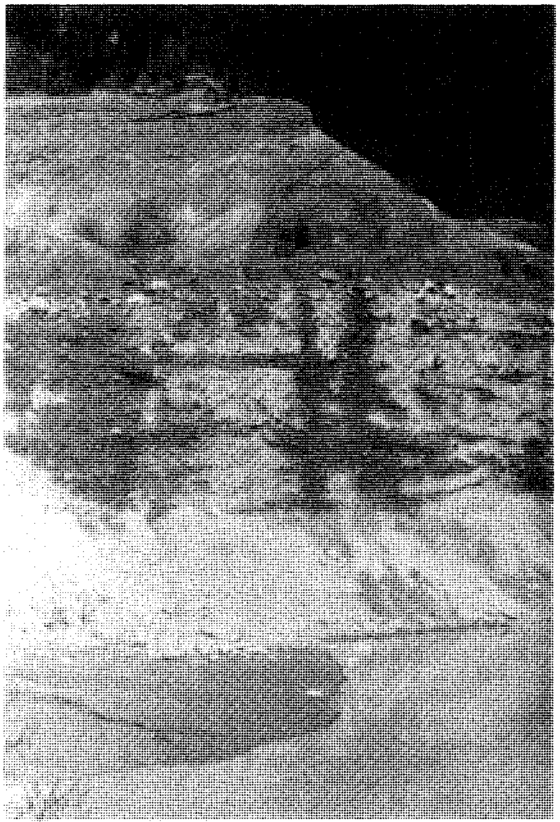
Roads near Burnaby Mountain, with locations of two geological sites.

Large granitic boulders called "erratics" are found on the surface. They were transported from the Coast Mountains by glacial ice, and remained after the ice melted. On the steep north side, sedimentary rocks have broken off in blocks of several million tonnes and slumped downhill. Construction of the railway and Barnet Highway along the base of the hill caused new slumps in the unstable deposits. Housing development above the road is restricted as a result of small slides that destroyed driveways in the Bayview Drive area during the 1950s.

1) The Eocene conglomerate is well exposed where the Barnet Highway descends around the northwest corner of Burnaby Mountain. The conglomerate is at least 15 m thick and contains rounded boulders in a sandy matrix. The cliff appears to consist of loose stones and in 1952 a company tried to operate a gravel pit here. They discovered that solid rock is not far behind the face. Many of the boulders in the conglomerate contain iron-rich biotite and pyrite. When exposed in a roadcut, weathering causes rusting in these minerals and the boulders loosen in the resulting crumbly sandy matrix.

2) Burnaby Mountain Park includes the Centennial Pavilion and a fine restaurant. Large granitic boulders scattered throughout the grounds are glacial erratics.

Bouldery gravel, older than 21,500 years, overlain by layered glaciomarine sand, silt and mud of the Fraser glaciation. Northwestern pit in the Coquitlam Valley.



Coquitlam Valley

The valley is a few kilometres north of the Coquitlam Shopping Centre (16 km east of downtown Vancouver along East Hastings Street and Barnet Highway). Follow Pinetree Way from the shopping centre for a short sightseeing drive.

Lafarge Park, 1 km north of the shopping centre, includes a lake that fills a gravel pit excavated in the 1950's and is now stocked with fish. This terrace is a raised delta left by a glacial meltwater stream during a "stillstand" as the land rebounded from the weight of the ice, and sea level was subsiding.

Bear right along Pipeline Road, which follows the Coquitlam River. Except during flood periods, this stream is diverted for water supply and hydroelectric power. The road enters a narrow valley with high cliffs of glacial sediments on the west side. The sand and gravel are excavated, as you may surmise from dump trucks hurtling along the winding road. Unlike rock outcrops, the best exposures of sand and gravel are always changing—they are soon removed or become covered with loose material and vegetation. To visit active sites will require permission of the pit operators.

The Coquitlam Valley contains overlapping glacial deposits from three periods: outwash from the Semiahmoo glaciation, silt and silty sand deposited during the Olympia non-glacial interval, and varied sediments laid down during the Fraser glaciation. The lower gravel and till layer contains large boulders that indicate the ice was very close by. The upper layer of interbedded sand, gravel and till was deposited between 21,500 and 18,500 years ago by rivers flowing from the melting glaciers. Temporarily blocked by ice in Burrard Inlet, meltwater also flowed northward into Coquitlam Valley, as indicated by cross-beds in the sand.

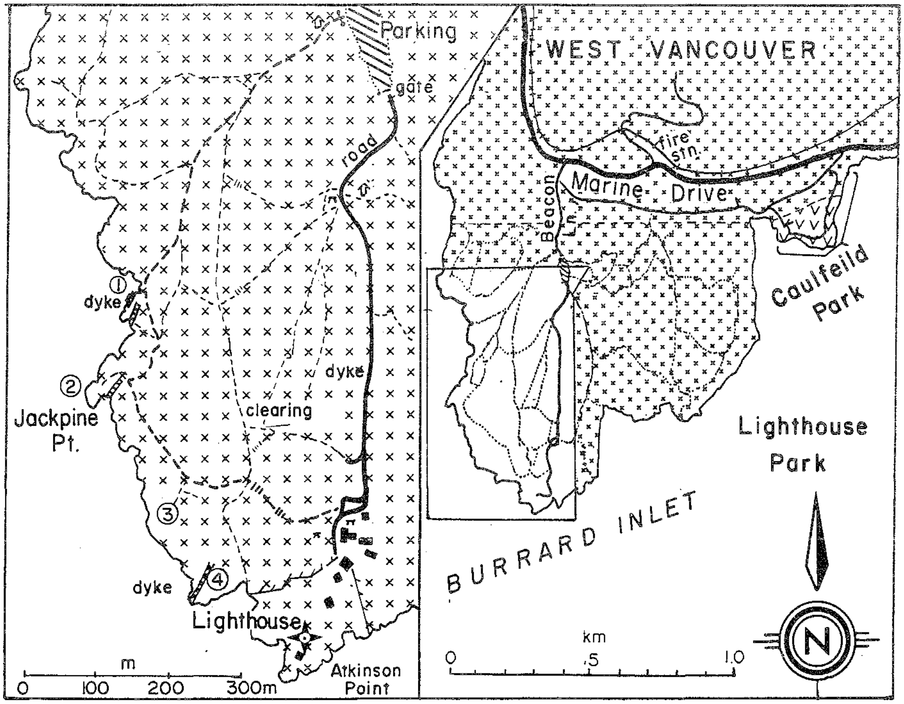
Like other rivers along the North Shore, the Coquitlam River is dammed to form a reservoir. The pipeline beneath the road continues under the Fraser River to supply Surrey and Langley. In addition, a tunnel was driven beneath Eagle Mountain in 1913 to add water to Buntzen Lake which is used to generate hydroelectricity on Indian Arm.

Caulfeild Cove and Lighthouse Park

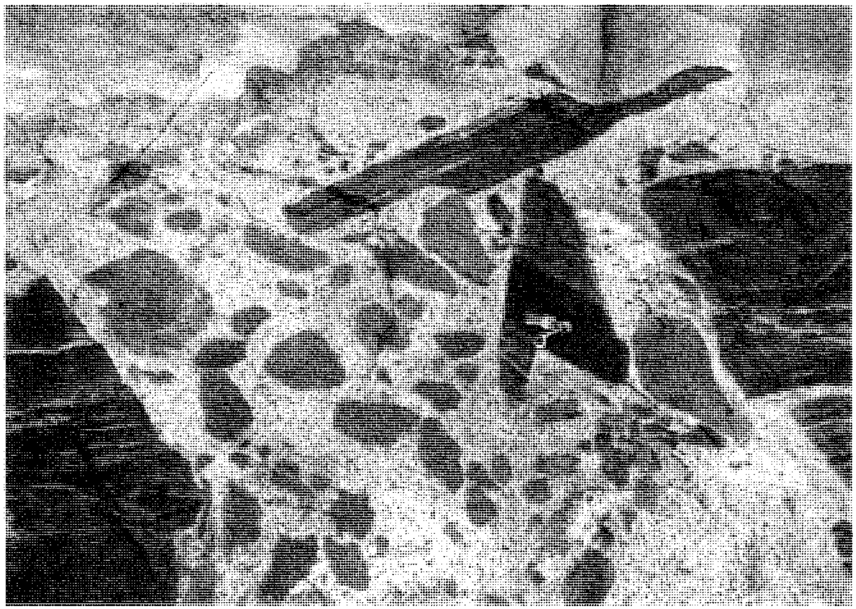
These two municipal parks in West Vancouver are 14 km west of the Lions Gate Bridge. Signposts along Marine Drive indicate the entrances. The coastline in this area consists of smooth, wave-washed outcrops, some of the finest exposures of granite in the Vancouver area.

At both locations, granitic rocks of the Coast Plutonic Complex are cut by two sets of dykes that were originally andesitic. The older set appears to have formed at the same time the granitic rocks were formed. In places, the older dykes are recrystallized to a granitic texture, and elsewhere they are cut by granitic rocks including granodiorite, aplite and pegmatite. The younger set of andesitic dykes cuts all the other rocks exposed in these areas and has sharp boundaries. They may be equivalent to those at Prospect Point. Lighthouse Park contains a high proportion of granitic plutonic rocks while metamorphosed volcanic and sedimentary rocks are exposed in a pendant at Caulfeild Cove. Many geologists have visited these outcrops which demonstrate the complexity of intrusions typical of the Coast Plutonic Complex.

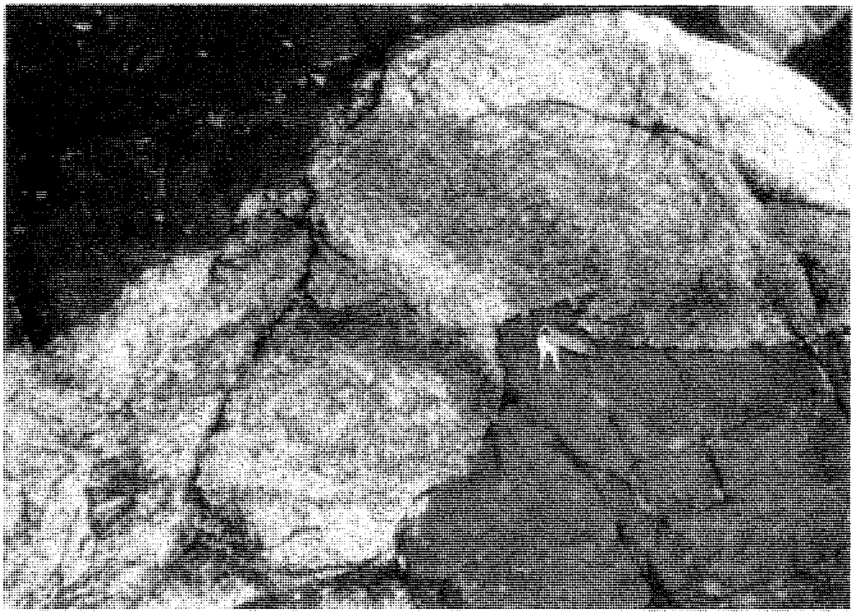
For an hour's walk to view the granitic rocks in Lighthouse Park,



Caulfeild Park and Lighthouse Park in West Vancouver. Enlarged area shows numbered stops described in the field trip.



The white rock is a granitic dyke that intruded amphibolite (dark rock). Pieces of amphibolite and diorite in the dyke, called xenoliths, were probably stripped from the wall rocks during intrusion. Shoreline outcrop in Caulfeild Park.



Light coloured granitic dyke in darker andesite. Location 1 in Lighthouse Park.

take the trail that leaves the west side of the parking area. This trail passes two outhouses and intersects with several other paths. Follow the main trail marked with two wooden triangles, one orange and one white, nailed to trees. After about 500 m, this trail reaches an overlook with a plaque indicating that the granitic rocks are about 100 million years old.

1) The granodiorite below the trail is cut by a 2-3 m wide andesite dyke. In it are square, white plagioclase crystals called "phenocrysts". Two features indicate that this dyke belongs to the older of the two sets of dykes in these rocks. The first is that the edges of the dyke have been recrystallized to some degree by the still hot plutonic rocks, giving them a fuzzy-looking texture. The second is that the andesite in turn is cut by younger dykes of granite pegmatite.

2) At low tide, one can explore a flat expanse of smooth granodiorite at Jackpine Point. Gouges and striae on this surface were cut by glaciers moving south during Quaternary time.

3) A dome of granodiorite rises 40 m above the sea beside the trail here.

4) On the granodiorite slope is a 2.5 m wide andesite dyke. It contains plagioclase and hornblende phenocrysts and, unlike the dyke at the first stop, has sharp contacts. This suggests that it was

intruded into the plutonic rocks after they had cooled.

From the lighthouse you can return to the parking lot by various paths. Geologic features near the trails are indicated on the accompanying map.

Further reading

Nature of the West Coast compiled by the Vancouver Natural History Society (1973).

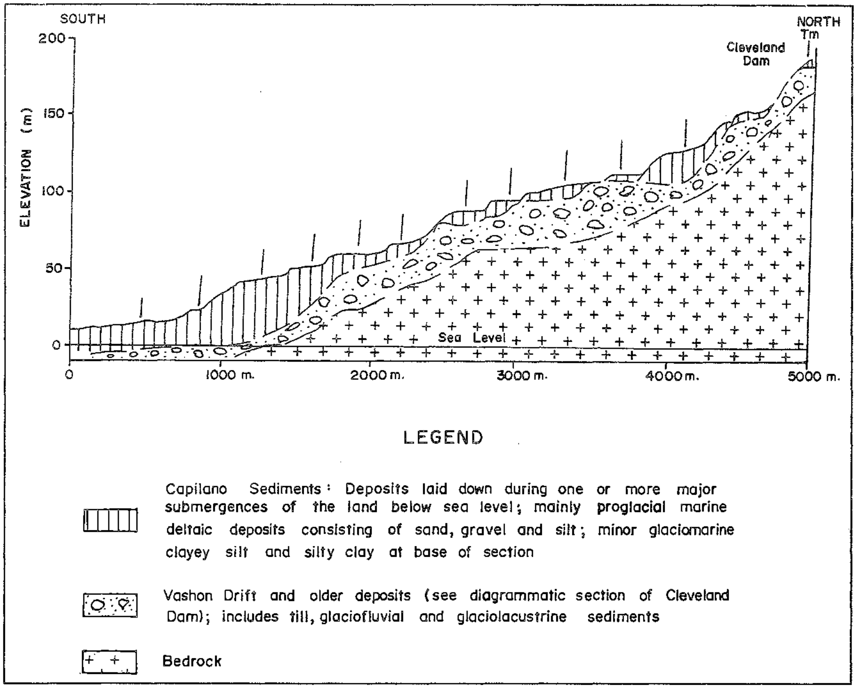
Capilano and Lynn Canyons

These two regional parks are described together because their geological settings are similar. Both can be reached by city bus in North Vancouver. Follow Capilano Road or Lynn Valley Road respectively, about 3 km north of the Upper Levels Highway. The parks have well engineered trails through the woods, and places to get close to the cool, shaded rivers. The information displays at the Capilano Fish Hatchery and the Ecology Centre at Lynn Canyon are themselves worth the trip.

Both watersheds are broad, U-shaped valleys in their upper reaches, where the streams flow on wide, bouldery beds. Lower down, the stream character changes abruptly. Both Capilano River and Lynn Creek squeeze through exceedingly narrow, twisting canyons until they are able to spread out into broad deltas at sea level. The Cleveland Dam, at the head of Capilano Canyon, was built in 1951 to hold back a 5 km long reservoir that supplies drinking water for Greater Vancouver. The dam on Lynn Creek was abandoned in 1985 and the reservoir opened as Lynn Headwaters Park.

About 12,000 years ago, a wide arm of the sea, up to 60 m higher than today, covered most of the Fraser Lowland. In addition, the land had been depressed by the weight of ice. Glaciomarine clay and shells indicate ancient beaches up to 150 m above present sea level. The beach and river deposits are exposed in cuts along Capilano Road, which climbs as many as 14 terraces (a practised eye is needed to recognize some of them) left during "stillstands" of falling sea level.

Following retreat of the glaciers, coarse gravel washed down Capilano and Seymour Rivers and Lynn Creek to be dumped upon the glaciomarine deposits. As the land rebounded, the streams began to erode through their own gravel and underlying glacial deposits, encountering the bedrock beneath. They had enormous cutting



Cross-section of lower slopes beside the Capilano River, showing terraces that were formed by short-lived beaches as the land rose from the sea following the retreat of glacial ice.

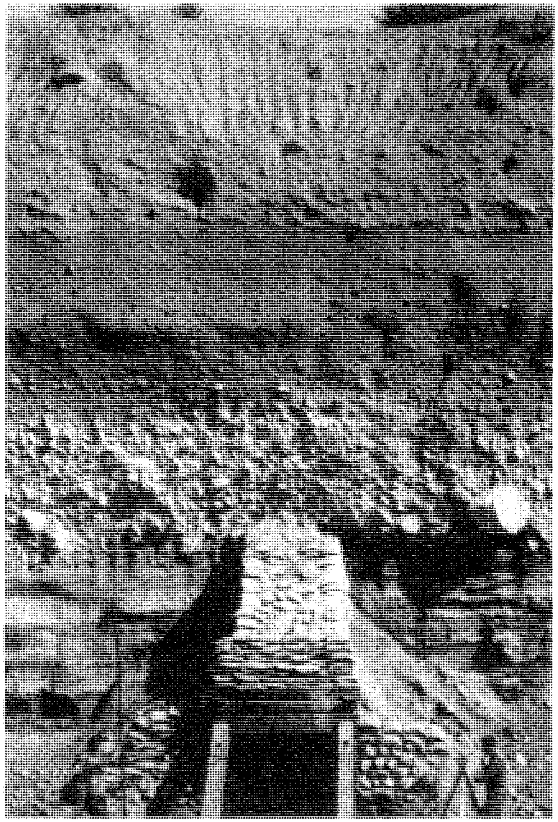
power, especially when loaded with material up to boulder size during their flood stage, and exploited weaknesses in the plutonic rock. There are faults beneath Capilano Canyon (discovered during construction of the dam) and Lynn Canyon. Apparently, bedrock was eroded more quickly than the compacted till because the deeper, pre-glaciation channel in bedrock is still buried several hundred metres east of both canyons.

Features along the Capilano River

Although it is possible to hike along the west side of the Capilano River from tidewater to the reservoir (7.3 km), most exposures of geological or engineering interest can be seen in a short stroll near the Cleveland Dam. The turf near the dam provides a famous view of the Lions, two pinnacles of hornblende diorite of the Coast Plutonic Complex.

Steps from the east side of the dam lead down to a bedrock overlook of the gorge. The hornblende granite underfoot has ridges where epidote and quartz filled fractures are more resistant to erosion. Across the gorge, several light-coloured aplite dykes are

Shortly after the construction of the Cleveland Dam, this tunnel was excavated to reduce the hazard of landslides caused by seepage. The tunnel drains a porous sand layer (behind the sand bags) overlain by bouldery till and clay, all deposited in the waning stages of the Fraser glaciation.



visible together with the outlet of the diversion tunnel used during construction of the dam.

Follow the winding gravel road past the chlorination plant (the water supply pipe beneath the road continues beneath Burrard Inlet). At one of the bends, a stream trickles from a door in the hillside. This is the entrance to one of three drainage tunnels in the glacial deposits upon which the eastern end of the dam rests. Seepage through a permeable sand layer is drained to avoid slides of overlying material from the steep hillside.

About 50 m down the road, green banded glaciomarine silt and sand are exposed on the slope above. The fine repeated layers or "varves" were deposited in a glacial lake more than 25,000 years ago. The darker horizons may have been deposited in winter and the lighter, sandy layers could reflect rapid deposition in spring or summer.

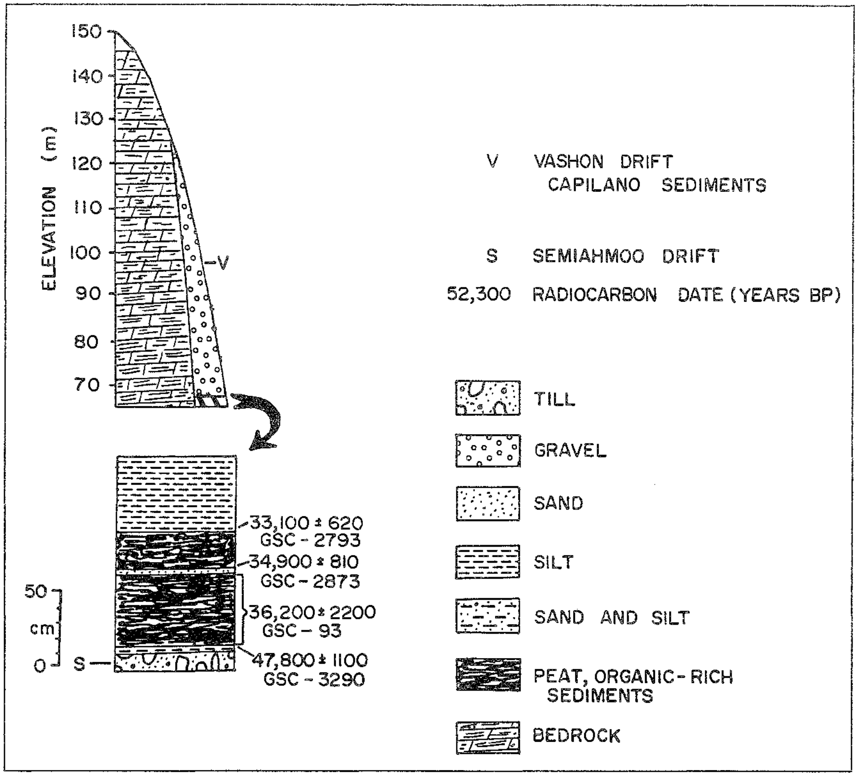
A switchback trail leads back up to the parking lot near the dam, or you could continue your walk down to the Fish Hatchery. Baby coho salmon are raised to compensate for the fry damaged passing

During construction of the Cleveland Dam in 1952, the upper canyon of the Capilano River was temporarily exposed. The white band along the canyon bottom (centre) is a fault, the weak zone along which the canyon was eroded.

the dam. At the head of the lower canyon are a log bridge, numerous fishing holes and kayakers practising among slalom poles. Trails across the river follow grades of the timber railway of the 1920s, and that of a flume used to transport cedar logs or "shinglebolts" to mills on Burrard Inlet. The trail that leads to the Giant Fir—a lone survivor on a terrace not accessed by the logging railway—passes cut banks of sand and silt left by glaciation. Trail maps near the hatchery indicate other routes that will return you to your starting point.

Several kilometres further down Capilano River, a toll suspension bridge is easily reached from Capilano Road. Nothing of geological interest can be seen here but the bridge has been a popular tourist attraction for more than a century. The only reason for crossing is a small wooded enclosure on the other side.

Just upstream of the Upper Levels Highway bridge along the Capilano River, and reachable only during low water, is the unconformity of Georgia Basin sediments atop Coast Plutonic rocks. The underlying rusty quartz diorite appears to have been weathered before Late Cretaceous time when the overlying conglomerate was deposited. The conglomerate is 15 m thick and contains pebbles to boulders of granitic and metamorphic rock in a sandy matrix. It is



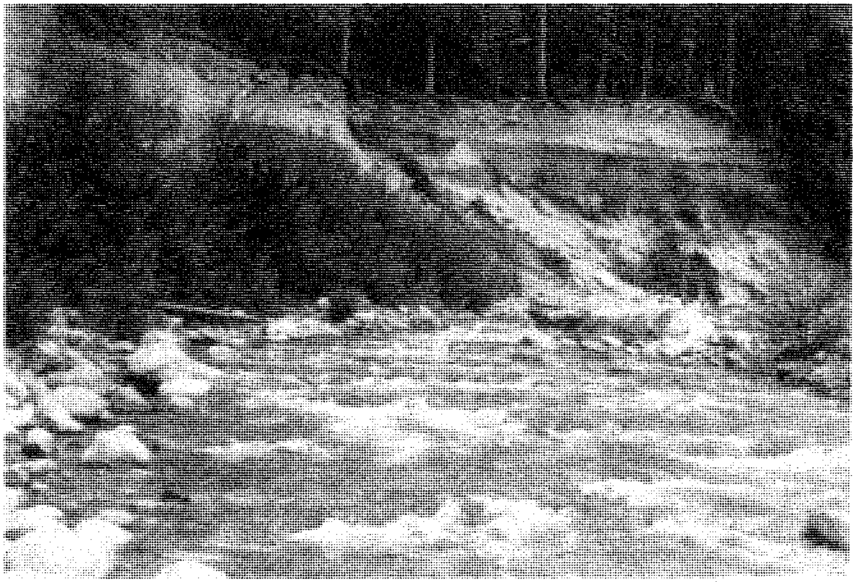
Cross-section of part of the west bank of Lynn Creek, north of the suspension bridge. The enlarged section shows peat and silt layers deposited during the Olympia non-glacial interval.

one of the few places where the base of the Georgia Basin is exposed.

Features near Lynn Canyon

Caution is advised when hiking in the canyon. The amount of water in Lynn Creek fluctuates, as it is the only significant watershed along the North Shore not controlled by a dam. From a crossable trickle at the height of a dry summer, it can swell up to 10,000 times this volume after a prolonged rain. The many plaques commemorate people who have died from diving and in floods.

The suspension bridge across Lynn Canyon is free and more exciting than the one in Capilano Canyon. The roaring waterfall below drops through a canyon of quartz diorite. Erosion of the stream bed occurs in tumbler-shaped depressions. These "potholes" are formed when an eddy drives smoothly rounded stones or "grinders" around and around, wearing the hole larger. Near the



This cutbank along Lynn Creek, upstream from the suspension bridge, reveals glacial drift at the bottom (mostly covered) overlain by glaciomarine sand layers and gravel with boulders at the top. The stream deposits overlying these were left by Lynn Creek before it eroded the canyon.

west end of the bridge is a fine outcrop of hornblende diorite, cut by andesite dykes.

A series of steps switchbacks down to the west side of Lynn Creek above the entrance to the canyon. Bouldery till is exposed about 30 m west of the bottom of the steps. A 1.5 m band of silt, sand and black peat separating the till was deposited between 48,000 and 33,000 years ago during the Olympia non-glacial interval. Fossil pollen and seeds collected from the peat show that coniferous trees, grasses and mosses grew then in a climate that was cooler by at least several degrees compared to the present.

Continuing upstream, the trail climbs a high bank of glacial outwash left from the Fraser Glaciation. It is overlain by stream gravels deposited by Lynn Creek before it eroded the canyon. The trail ends 400 m further on at Lynn Valley Road, which can be followed 1 km back to the Ecology Centre.

For further reading

Late Quaternary geology of the Fraser Lowland, southwestern British Columbia, By J.E. Armstrong, J.J. Clague and R.J. Hebda; in *Field Guides to Geology and Mineral Deposits in the Southern Canadian Cordillera,* edited by D.J. Tempelman-Kluit. Compiled

for the Geological Society of America Cordilleran Section meeting, May 1985.

The Capilano River, Vancouver's North Shore; a chapter in *The Best of B.C.'s Hiking Trails* by Bob Harris. Maclean-Hunter Ltd. Special Interest Publications Division, 1986.

Hiking in the North Shore Mountains

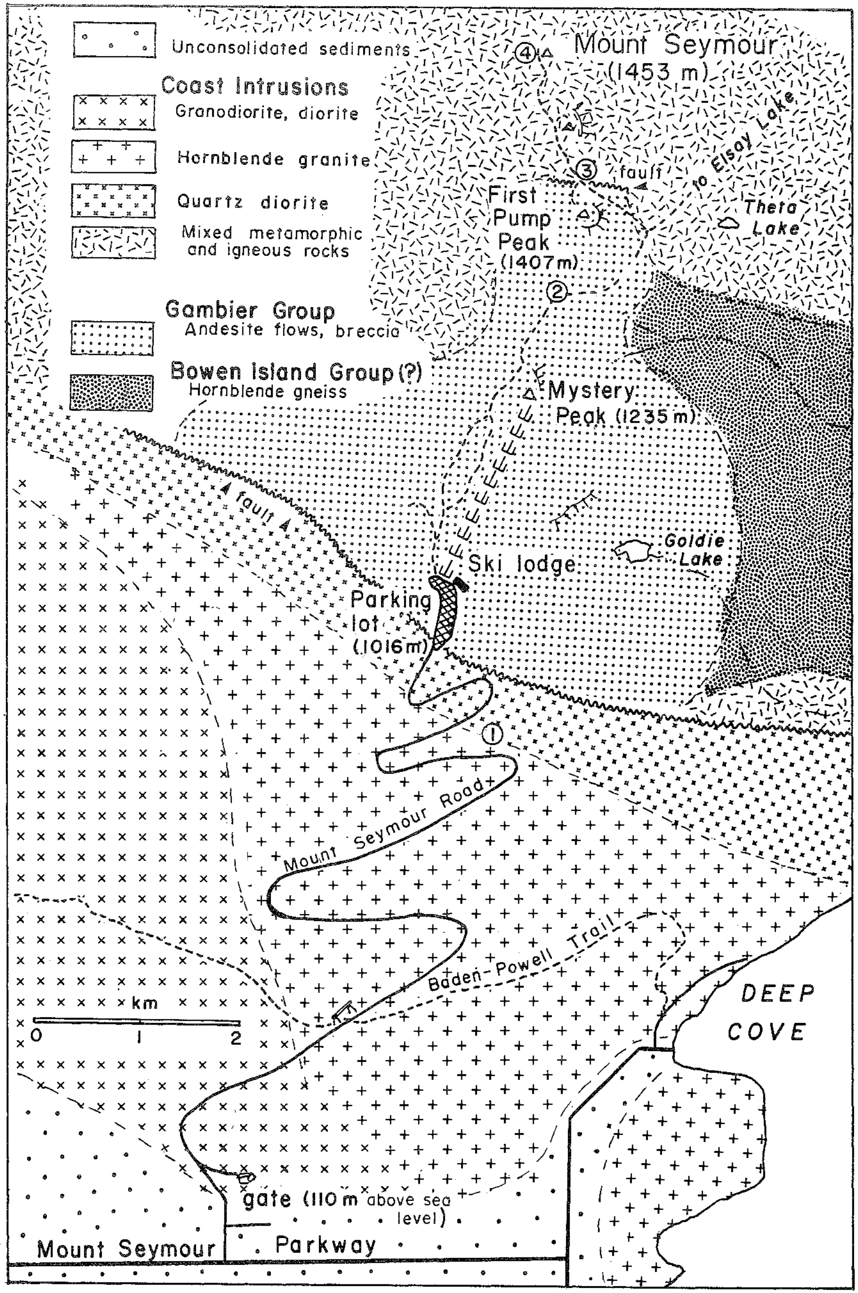
In some respects, the mountains north of Burrard Inlet are one of Vancouver's least discovered recreational assets. Although ski resorts lure skiers in winter, not many people visit between May and November. The high country is rugged and would rank high on any hiker's list. Today, one can travel from the city to the mountaintops in less than an hour. Few alpine areas on the continent are so accessible from a major city, and have a simultaneous view of island-dotted ocean and a sea of snow-capped peaks. For many, this panorama is the essence of British Columbia.

The trails constructed for day-hikers on Mount Seymour, Grouse Mountain and Black Mountain are within the ability of anybody reasonably fit and with sturdy footwear. Pamphlets are seasonally available near the parking lots, and information boards display maps of the trail networks. Directions for specific trails may be found in guides in bookshops and outdoor equipment stores. No detailed trail information is presented here; these geologic notes are meant to enhance your appreciation of your natural surroundings. The maps supplement those in the pamphlets and guidebooks.

Caution: Mountaintops can be exhilarating places, especially during warm and clear days. The enjoyment can plummet, however, if weather conditions change and one is not prepared, physically or mentally, to withstand the elements. When you lose the trail beneath snow, are engulfed in low cloud or are overtaken by darkness, these mountain tops suddenly seem a maze of cliffs and dense scratchy bush. Every year, people require rescue from the supposedly easy trails, and those unprepared are lost in the back country. Even in fine weather, you should allow plenty of time for your return, carry food and bring long-sleeved outer garments.

For further information

Geology: *Vancouver North, Coquitlam and Pitt Lake Map Areas, B.C., with Special Emphasis on the Evolution of Plutonic Rocks*, by



Geological map of the Mount Seymour area, showing numbered field trip stops.

J.A. Roddick, Geological Survey of Canada, Memoir 335, 1965 (out of print, although the maps are still for sale).
Hiking: *Exploring Vancouver's North Shore Mountains*, by Roger

and Ethel Freeman, Federation of B.C. Mountain Clubs, Vancouver, B.C., 1985.

Mount Seymour

In winter, during favourable weather and snow conditions, one can go on snowshoes, skis or foot, taking care to avoid steep areas and avalanche hazard. In summertime, this is a pleasant half-day hike along mountaintops and one may see a variety of metamorphic and plutonic rock types. The magnificent views northward into the Coast Range and southward over the Fraser Lowland to Mount Baker alone are worth the trip.

Where to go

A 12 km paved road leaves the Mount Seymour Parkway 5 km from Second Narrows Bridge and ends with a parking lot at 1016 m. Trails lead out from the alpine ski resort. It takes about 3 hours, along a ridge with several bumps, to complete the 4.5 km hike to Mount Seymour (1453 m).

Rocks to note

1) Switchbacks along the road expose "colluvium", the mass of rocks and soil creeping imperceptibly downhill under the influence of frost, rain and snow. Outcrops of grey quartz diorite contain ragged darker patches or xenoliths of amphibolite. The highest switchback passes chalky white rock in which original minerals have been turned to clay by hot corrosive waters circulating in the rock not long after its formation.

The parking lots are on an undulating surface unusual at this elevation in the mountains. Grouse Mountain has a similar landform, emphasized by the southern ski runs, that is seen in profile from this point. Several million years ago, these areas were joined as part of a broad, gently south-dipping surface or "peneplain" when topography to the north was low and rolling. Uplift, perhaps along a fault beneath Burrard Inlet, triggered rapid downcutting by streams. The valleys were broadened and deepened by glaciation, leaving only remnants of the former erosion surface preserved near the tops of these mountains. That they remain is fortunate for learning skiers because it provides the only gentle slope of any significant distance at both resorts.

Andesite lava flows are exposed in outcrops beside the ski runs. The area is underlain by a pendant of pre-Jurassic Gambier Group and older metamorphosed sedimentary and volcanic rocks.

2) About 1 km after leaving the highest ski runs, the trail emerges from a clump of gnarled spruce trees onto an expanse of brown rock. This is volcanic breccia, full of angular white fragments that could be either dacite or silicified andesite. The breccia may have formed by explosion or the crackling of a hardened lava flow top.

3) East of the first high knob (First Pump Peak) is a natural ditch trending west across the ridge. On the south side is dacite, with white feldspar phenocrysts, and on the north side, granitic rock with black hornblende. The ditch is a fault, no longer active but one of those that bounds areas of older rock with the granite. Shattered rock and lacy quartz veins are preserved along it. Vertical faulting is believed to have accompanied compression of this area and formation of the Georgia Basin.

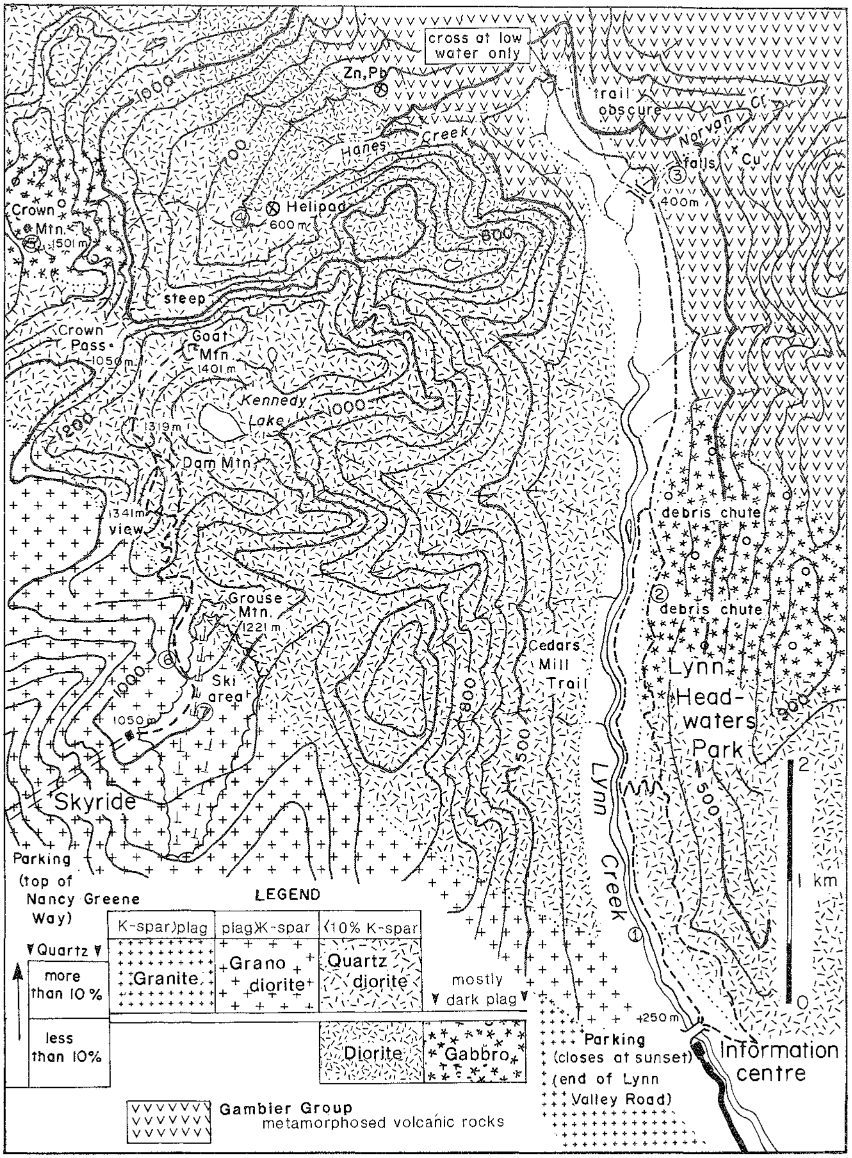
4) The summit of Mount Seymour is granodiorite with abundant purplish quartz. With diligent looking, you may find small cavities into which project minute crystals, left over from cooling of the rock under lower pressure at a relatively high level in the Earth's crust. The north end of the peak is another outcrop of Gambier Group volcanic rocks.

Lynn Headwaters and Grouse Mountain

You can stroll in the forest alongside Lynn Creek, or hike among ponds and clearings on a ridge that extends northward from Grouse Mountain. For a challenging day trip, the experienced hiker can link these trail systems. Beginning at Lynn Headwaters Park, this route requires fording a major stream and a 500 m ascent in rock rubble of a back valley, to emerge at the back of the Grouse Mountain ski resort. Although not for everybody, this trip provides a deep wilderness experience less than a dozen kilometres from downtown, and the opportunity to "earn the mountaintop" by walking all the way up. The trip ends at a restaurant perched high over North Vancouver, a fitting place to eat before riding the gondola back down.

Where to go

For shorter half-day walks, make a loop in the Lynn Headwaters Park or start at the top of the Grouse Mountain gondola. The park is reached by city bus or car at the north end of Lynn Valley Road, 4.5 km from the Upper Levels Highway. The gate closes at dusk, so plan an early start to retrieve your car in time. Near the entrance of Lynn Headwaters Park the trails are broad and easy. Second growth forest



Geological sketch map of the area described in field trips around Lynn Headwaters and Grouse Mountain.

in the valley bottom lets in light and obscures the remains of old timber camps. On a bench along the east side of the valley is a trail in the dark forest with viewpoints and well-constructed log bridges. The loop trail extends 5 km upstream, beyond which the trail is increasingly rough.

The Grouse Mountain ski resort at 1100 m (3600') elevation is reached without effort at any time of year by riding up the gondola, which starts at the top of Capilano Road/Nancy Green Way, 5 km from the Upper Levels Highway. Hardy souls scramble up the old chairlift cut from the top of Skyline Drive, but there is little rock exposed there. From the centre of the ski area, a well-engineered trail leads to Dam Mountain (2.4 km) and Goat Mountain (4 km), with a moderate climb to 1340 m.

The hike linking valley and peaks requires an early start and registration at the trailhead in Lynn Headwaters Park. Follow the trail to Norvan Falls and flagging tape beyond, which leads to a place where Lynn Creek may be crossed. Here, a length of rope or webbing for belay and a crossing pole are wise precautions. If the water is high, do not cross, because you cannot risk an accident where rescue will be long, delayed and costly. If safely across, a less distinct path ascends the north side of Hanes Creek, past a stone crib helicopter landing pad, and avalanche wands mark the way up the headwall to Crown Pass. Turning left, the well-worn trail across the Pass leads into the network on Dam Mountain, and down to the gondola.

Rocks to note

1) The flat valley bottom is filled with glacial and river deposits constantly reworked by Lynn Creek. During floodstage, the channel usually changes, leaving stony bars in midstream and eroding cut banks that cause rerouting of the trail. The creek also exposes high cliffs of boulder-filled mud that were moraine left during retreat of the glacier 12,000 years ago. The slopes above Lynn Creek were oversteepened as a glacier scoured the floor of the valley.

2) The creek-side trail crosses several unvegetated alluvial fans of cobbles and broken trees. These have been recently deposited by short-lived torrents flooding down the side valleys after prolonged heavy rain. Usually the fans are dry, but if you arrive to find one of these streams flooding, do not attempt crossing; conditions are probably worse higher up and you may not get back.

3) Norvan Falls is a 25 m high cataract. The sericite-chlorite schist at its base reflects alteration near the edge of the granitic pluton. Nearby are copper, lead and zinc sulphide minerals in the metamorphosed zone around the intrusive rocks. These mineral showings attracted considerable interest in the early part of the century.

4) At the head of Hanes Creek, the trail winds among slabs of quartz diorite with abundant dark xenoliths. This is a classic cirque, dug deep by a pocket glacier and now filling with rubble from the oversteepened sides. The valley reverberates from waterfalls plunging down Goat Mountain.

5) Crown Mountain has a sheer northeast face of outward dipping slabs of hornblende diorite. This rock type also forms the two pinnacles of the Lions. Crown Pass is crossed by a climber's trail. Near the summit medium-grained gabbro is well exposed, cut by veins containing prismatic hornblende crystals 2 cm long. Mineralogists will also enjoy a pegmatitic portion of the intrusion with a hornblende matrix. It is crossed by the trail on a boulder slope just below the open ridge.

From Crown Pass, the trail to Grouse Mountain goes left. Quartz diorite outcrops along the ridge are laced with epidote-filled fractures. Descending toward the ski area, the trail follows a pipeline which supplies the facility with water from Kennedy Lake. The difficulty of a sufficient water supply and safe sewage disposal has limited commercial development of the mountain tops. A road has been blasted in the granodiorite around the peak of Grouse Mountain. In contrast to the quartz diorite seen earlier, pink potassium feldspar is visible in this rock. Some fractures contain bronze-coloured mica.

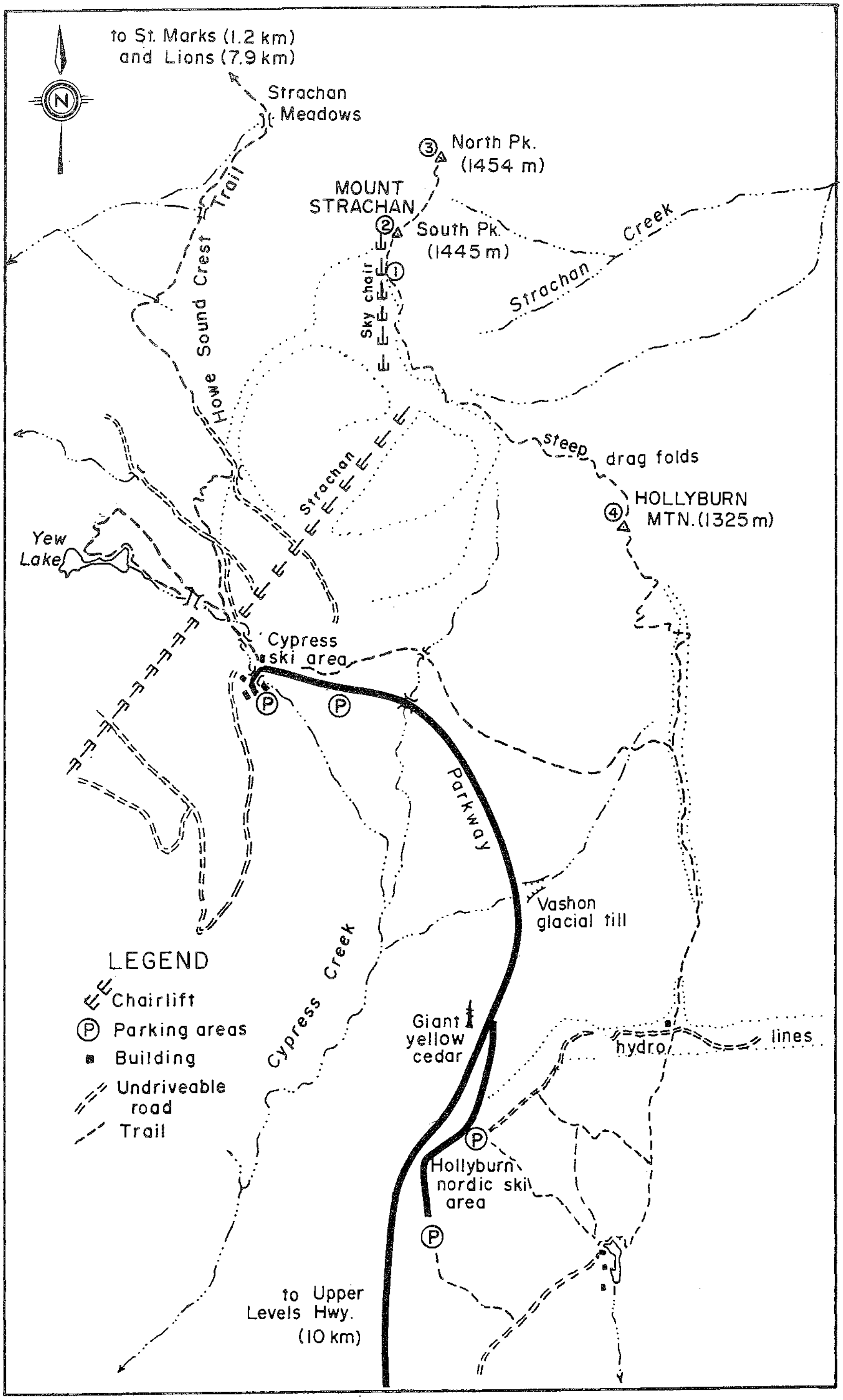
6) Outcrops poke through the grass on the ski slopes of Grouse Mountain, and many bear the scars from skis too early or late in the season. Most are granodiorite and some expose xenoliths that are banded mixtures of chlorite, plagioclase, calcite and quartz. These were probably volcanic and sedimentary rocks of the Gambier Group. As described at Mount Seymour, the wide ski run sloping toward Vancouver is built upon a relict of the peneplain surface.

Mount Strachan and Hollyburn

The trails on ski slopes offer a pleasant 3/4 day hike to summits of open rock. From here, you have a front row view of the Lions, and overlook Howe Sound.

Where to go

Cypress Bowl Parkway leaves the Upper Levels Highway about 2 km west of 21st Street in West Vancouver. Parking lots are at Hollyburn cross-country ski area (RH turnoff at 14 km/900 m elevation) or at the road's end at Cypress (downhill) ski resort (19 km).



Hiking trails to Mount Strachan and Hollyburn, with numbered field trip stops.

To hike a six hour loop, park at Cypress and take the open ski trails up the north (right) side of the valley. Near the top of the Strachan chairlift, the Sky chairlift goes up a steeper pitch to the South Peak of Mount Strachan (1445 m). You can continue on to the North Peak (1454 m) on a trail to the right of the bare rock. From the South Peak, a trail in the woods passes pieces of a plane that crashed in the fifties, and then follows ski runs on the east side to a notch below Hollyburn Peak. The trail up the north side of Hollyburn is steep but lined with good rocks. Well built trails go down the south side. Keep to the right for the Baden-Powell Trail, which leads down through big timber to the parking lot at Cypress.

Rocks to note

Both parking areas and lower slopes are in hornblende granodiorite but the peaks of Strachan and Hollyburn are underlain by a pendant of banded amphibolite and metasedimentary rocks belonging to the Bowen Island Group.

1) The meadows around the last few pylons of the Sky Chairlift reveal 3-4 m wide, dark-coloured, chlorite-rich layers, with thin-bedded brown bands separating them. All the layers dip steeply to the north. The greenish layers were probably basaltic flows, although they have been metamorphosed to a finer grain size. The original dark minerals (mostly hornblende and pyroxene) altered to chlorite. This outcrop also contains centimetre-wide quartz veins and wider hornblende diorite dykes. Both were intruded later and cut across the schist layers. The quartz veins are folded and fractured, and thus may be older than the dykes, which are not. The dykes could be the same age as that at Prospect Point in Stanley Park.

2) On the South Peak of Mount Strachan is a large bare area of banded chloritic (green) and beige to black schist that has been strongly metamorphosed. The layers might represent sediments (for example the quartz-rich band could have been a sandstone bed), but this is uncertain. Heat and pressure during burial can cause a rock to partly melt and segregate into bands of distinct minerals. Some granitic rocks appear to have formed by slow but complete melting of rocks such as these.

3) Between South Peak and North Peak, the schistose volcanic and sedimentary rocks are vertically cleaved, resulting in a natural staircase. Chloritic mafic dikes contain abundant albite crystals and fresh-looking hornblende, minerals that formed during metamor-

phism, probably from pyroxene and other types of feldspar. On the North Peak are thinly bedded siltstone and sandstone with green, brown and black hues. Their sedimentary origin is revealed by size grading and abrupt, clearly defined compositional changes between layers. One layer appears to be a mafic volcanic tuff because it contains black streaks (possibly devitrified glass) and angular chips that may be crystals broken during its formation by explosive eruptions.

4) At Hollyburn Peak, chlorite schist is well exposed on the large, rounded outcrops, worn bare by trampling and many picnics. Centimetre-wide quartz veins cut across the folded layers; their minute offsets and folds indicate that they were emplaced in fractures while the rock was still hot enough to deform like plastic. They are in turn cut by several 30 cm wide hornblende diorite dikes. These dikes have streaky margins, resulting from shearing and we infer that the diorite had partly cooled and solidified before it was forced through these fractures. Jagged pieces of the sedimentary rock surrounded by the dike rocks were probably torn from the sides or wall rock during intrusion.

The north sides of these mountains are steep, with many cliffs. They were probably undercut by southward-moving glaciers during various glaciations and are subjected to active freeze-thaw cycles, both causing the fractured rock to detach. The glaciers deposited till on the south-facing flanks, and vegetation grows better here. To the north and west of these summits is the deep U-shaped valley of the Capilano River, dammed in 1958 to provide a water reservoir for Greater Vancouver. The watershed is mostly floored with granitic rocks, the minerals in which are not readily dissolved by water. As a result, the runoff emptying into the reservoir does not contain much lime or soda and the water is "soft". Such a water body is, however, prone to become more acid if fed by rain and snow containing sulphurous and nitrous combustion by-products (acid rain). This problem is often worst following warm days in spring, which cause rapid melting of the accumulated acidic snow.

From North Peak, you can look northward into the sharp, glaciated peaks of the Coast Range. Mount Garibaldi dominates the view. It is the remnants of a volcano built between 20 and 6 million years ago. To the east, a broader, lower mass of peaks and glaciers constitute Mount Mamquam.

Mount Brunswick and Howe Sound Crest Trail

This is a full day mountain-climbing hike from Lions Bay and requires sturdy knees on the descent. The 6 km trail ascends 1750 m and is rewarded by fine views and fresh air. Heavy snow confines hiking at higher elevations to between June and October. The autumn is particularly scenic when the bushes in the logged areas turn scarlet and yellow. Be careful in the high country; steep, slippery slopes of grass and loose rock are real hazards, and an enormous snow cornice that persists on the crest of Mount Brunswick into mid-June could give way if you stood on it. If on the day of your hike the cloud level is lower than the mountaintops, you might save this hike for a brighter day; its greatest value is the stupendous view.

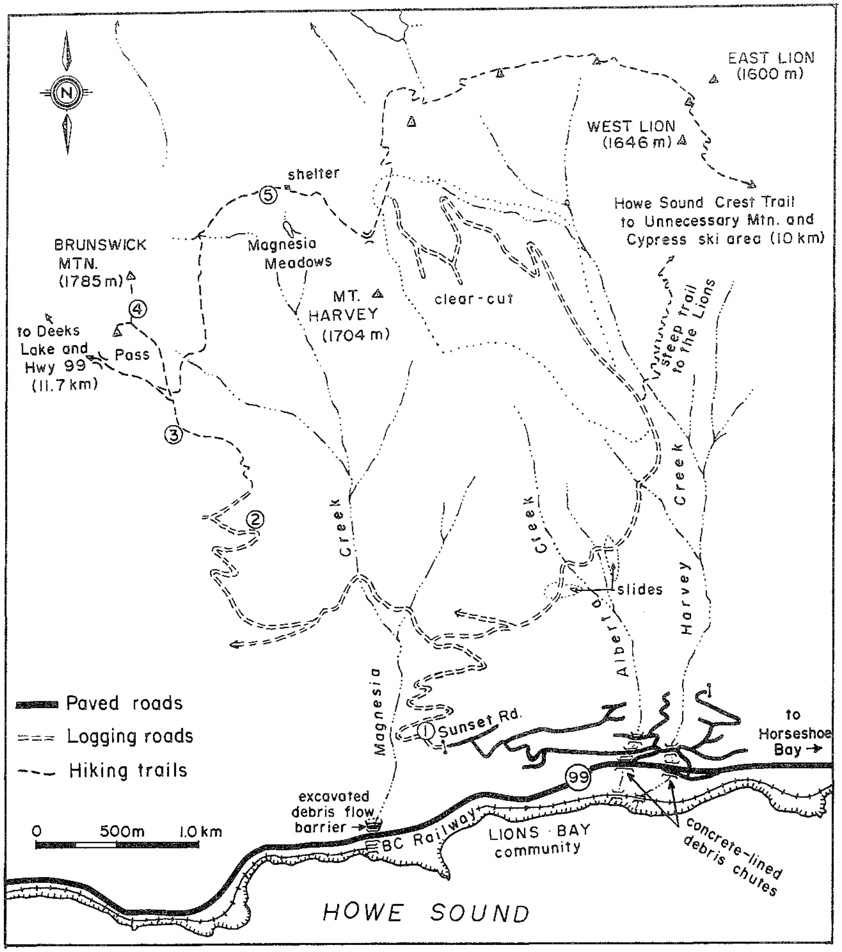
Where to go

Drive along Highway 99 and exit at Lions Bay. From the General Store, follow the main streets to the top and north end of the community. The hike begins at the gate at the left end of Sunset Drive where parking is very limited and signs are somewhat hostile. The trail, a road used for logging until 1976, begins 225 m above sea level. After the third switchback turn is an important junction. The right fork leads to the Lions and is the Harvey Creek road; on a loop trip you'll return this way.

To ascend Mount Brunswick, take the left fork, a level road which crosses two branches of Magnesia Creek before beginning switchbacks. There are frequent views over Howe Sound from 885 m elevation on. The road ends at 1050 m, and a trail continues steeply up, crosses the Crest Trail at 4.4 km, and reaches the triple summits of Mount Brunswick (1725 m) 5 km from the start. To make a loop, return to Howe Sound Crest Trail and follow it south. Magnesia Meadows is 2.2 km from the junction, and after crossing Harvey Pass (no additional elevation gain) you can descend along the Harvey Creek logging road, a total of 11 km back to the parking lot.

Rocks to note

1) A road cut 50 m past the gate at the start of the trail exposes grey volcanic dacite breccia containing feldspar phenocrysts. The outlines of the chlorite-rich clasts within the breccia are indistinct because the breccia was soaked in hot fluids, probably as it was lifted by the underlying pluton, and the original minerals have been

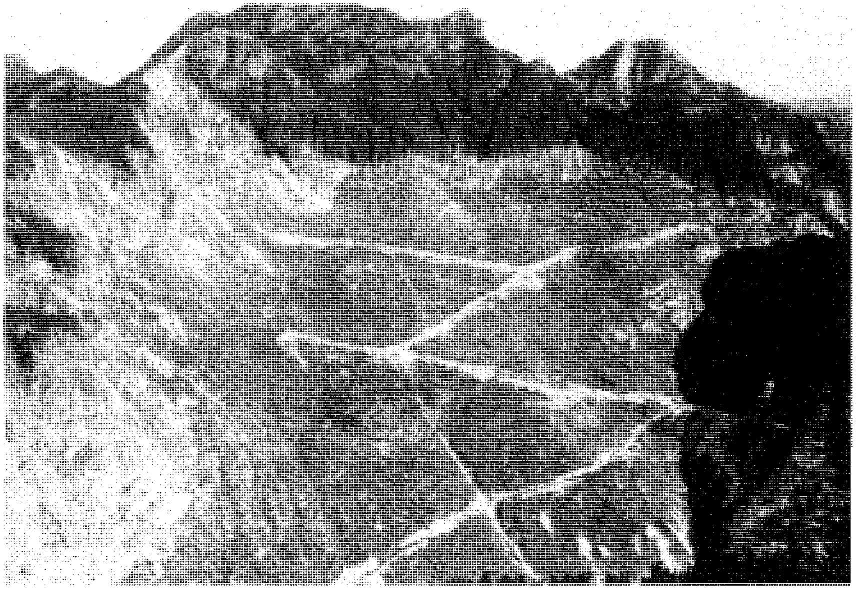


Map of trails above Lions Bay leading to Mount Brunswick, with numbered field trip stops.

converted to white clays and silica.

2) On the upper levels of the Brunswick logging road are outcrops of fractured volcanic rock containing feldspar phenocrysts and pyrite crystals. Although the rock was probably a dark green andesite originally, its generally chalky white colour indicates alteration by hot fluids. Some areas have a black and rusty coating which is iron oxide stain rusting out of the pyrite in the rock.

Several boulders near the end of the road are granodiorite containing hornblende-rich xenoliths. As the bedrock in this area is volcanic, these are probably erratics moved here thousands of years ago by glaciation. Outcrops of texturally similar granodiorite also containing xenoliths occur above the pass at the top of Harvey Creek



Mount Brunswick, seen to the north from the Lions. The Harvey Creek logging road traverses a replanted slope, almost reaching the Howe Sound Crest Trail at extreme right.

logging road, about 5 km southeast.

3) The ridge at 1450 m elevation consists of massive andesite, possibly thick flows, that have suffered less mineralogical change than similar rocks at lower elevations. Some outcrops expose veins containing crystals of black hornblende and yellow-green epidote.

4) Beautifully banded layers of brown sandstone, siltstone and possibly tuff, all steeply dipping northwest, are found at the top of Brunswick Peak. The 30 cm thick white bands are probably recrystallized limestone. Note the pronounced cleavage of the finer grained sediments; they contain abundant mica which splits easily.

5) Several whaleback-like outcrops in Magnesia Meadows are of chloritic volcanic breccia containing angular clasts up to 20 cm across. These have been altered to an albite-rich composition.

North from the top of Mount Brunswick, one can see three lakes nestled step-like in rock hollows along a steep-sided valley. Their clarity indicates that they are not fed by glaciers, even though the snow patch in the cirque remains throughout the summer. Note the different shapes of the nearby mountains. Mount Brunswick has a serrated top, like a shark's fin, that results from breaking of the sedimentary rocks along cleavage and bedding. Mount Hanover, to the northeast, has smooth, curved sides and a rounded top that appears to be made of overlapping plates. It is composed of massive granodiorite, which does not break along any particular direction. The platy nature of the exposed rocks is due to exfoliation, the splitting off of huge shells of rock parallel to the weathering surface. When plutonic rocks are exposed by erosion over short periods of geologic time (tens of thousands of years), slabs commonly split off in a process called exfoliation. This is due to the relatively rapid decrease in pressure due to uplift.

The Lions are like two thumbs—steep and straight on almost every side. They are composed of hornblende diorite and are full of planar fractures. Water drains into these fractures and freezes. Because it expands during the freezing process, the cracks are levered apart.

Howe Sound

Captain Vancouver sailed into Howe Sound in June, 1792. He wrote of the shoreline: "a stupendous snowy barrier, thinly wooded and rising from the sea abruptly to the clouds; from whose frigid summit the dissolving snow in foaming torrents rushing down the sides and chasms of its rugged surface, exhibiting altogether a sublime, though gloomy spectacle . . ." Although outside the Vancouver area, this tour is included because those interested in geology and landforms commonly make the trip. The drive along one of Canada's most southerly fiords reveals a panorama of mountains and the sea, as well as some of the geological hazards to human development in such places.

The western terminus of the Pacific Great Eastern Railway was established at Squamish in 1912, about the time that a mining community developed at Britannia. It was not until the 1950s that the railway and highway were built along the shore to connect these towns. Falling rock and flash flooding of the creeks have made these among the most costly transportation links of this length in the province.

The landscape and geology along Howe Sound are described in distances northward along Highway 99 from Horseshoe Bay, which is 15 km from the Lions Gate Bridge. From its start, the trip stretches 45 km north to Squamish and would take about half a day to complete, depending on how much time was spent at each stop. A two to three hour walk at the Squamish Chief is also described.

Please use extreme caution along this highway: shoulders are narrow, traffic hazardous, and the terrain mostly cliffs. Stop only with ample warning and where you can pull completely off the road.

Road Log

The sheltered harbour of Horseshoe Bay lies is a hollow between granodiorite cliffs. B.C. Ferries leave for Nanaimo, the Sunshine Coast and Bowen Island. Highway 99 along Howe Sound leaves the Upper Levels Highway partway down the hill to the ferries. This exit is km 0 of the road log.

2-3.5 km: The oldest rocks in the Vancouver area are exposed in cliffs along the first section of the road. Highly metamorphosed sedimentary and volcanic rocks are at least 185 million years old and cut by granite and diorite intrusions. Bands of dark amphibolite alternate with lighter, feldspar-rich gneiss and may represent the original sedimentary layers, or may result from segregation of minerals when the sediments were heated to a nearly molten state. The metamorphic mineral assemblage indicates that these rocks were once buried about 30 km beneath the Earth's surface where they were heated by intrusions of the Coast Plutonic Complex.

4.6 km Schlufield Creek: At the north end of this rock cut is 250 m of breccia within quartz diorite. Fragments of granitic rock are rounded and mixed with angular gneiss and amphibolite. The breccia probably formed when hot gases, escaping above an intrusion, shattered the metamorphic rocks. Spaces between the fragments in the breccia were filled with rock dust that has hardened to form the rock matrix.

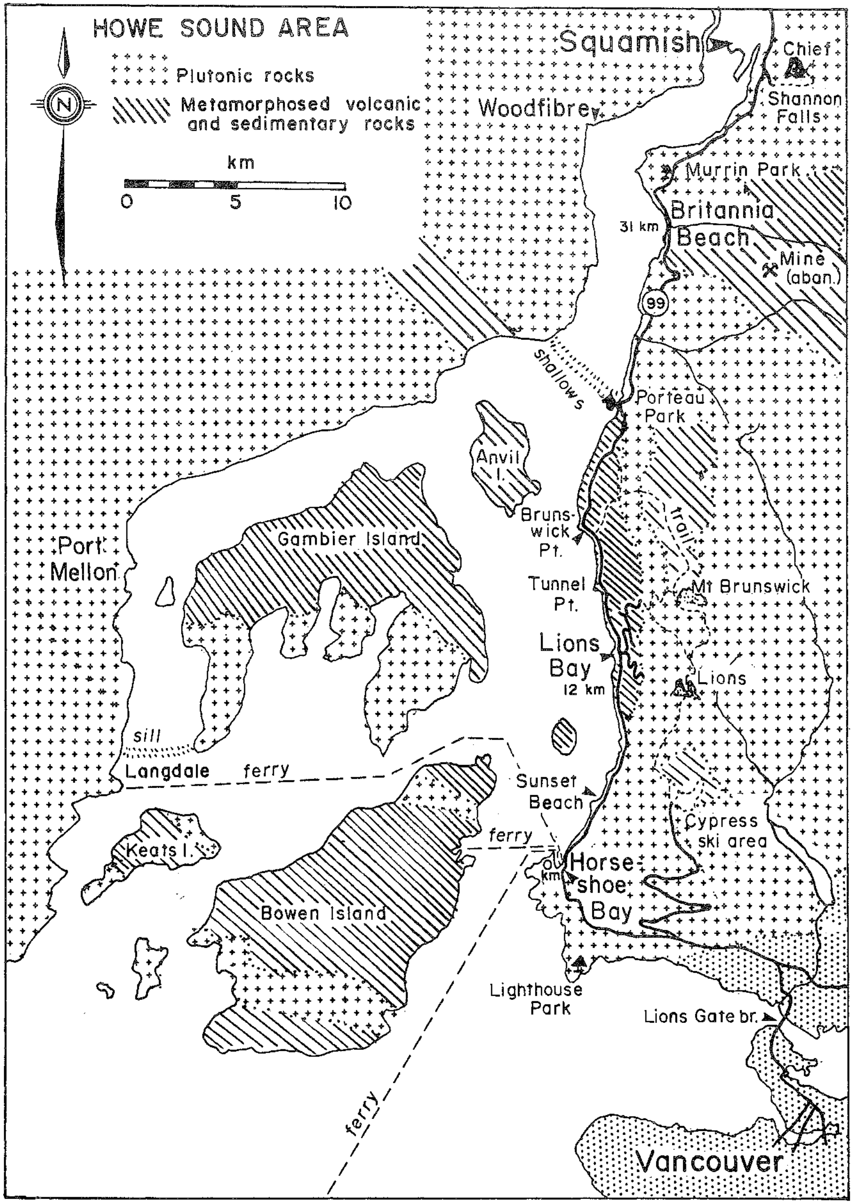
5.1 km Montizambert Creek (Sunset Beach turnoff): On the north side of the next bridge is pink medium- to coarse-grained granite.

6.0-6.5 km: This immense excavation is in hornblende quartz diorite that has been altered by percolating water. The shattered and oxidized rock has little internal strength and has been partly covered with sprayed cement (known as shotcrete, gunite or grout) to reduce rockfall hazard.

6.7 km Charles Creek: Concrete catch basin above the road.

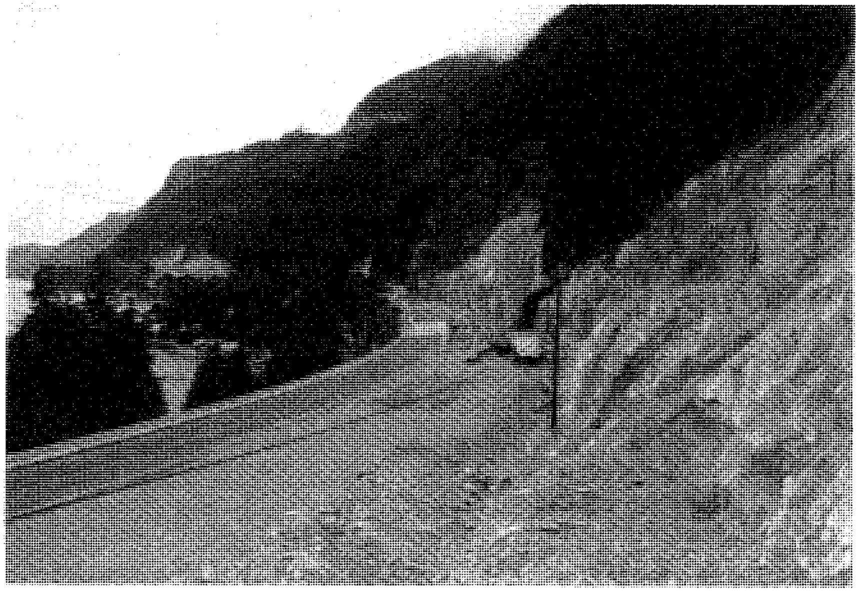
8.0 km Newman Creek: Concrete spillway. These structures are designed for the occasional debris torrents, described later in this chapter.

10-12 km Lions Bay: This community began with shoreline cottages but expanded uphill after the highway opened. The newest homes



Geological sketch map of Howe Sound with places along Highway 99 to Squamish.

are 250 m above sea level. The older settlement is located on the alluvial fan of Harvey and Alberta creeks deposited in the past 10,000 years by periodic debris torrents. These torrents are flash floods that incorporate rocks and broken trees from the steep stream bed, and can no longer be allowed to sweep across the alluvial fan.



Near Montizambert Creek, Highway 99 is built above a wall of keyed concrete blocks to separate it from loose cliffs prone to rockfall.

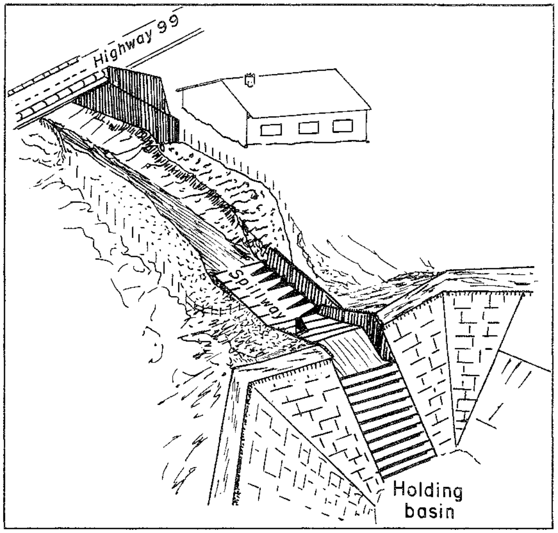
One torrent that struck in February 1983 destroyed all road bridges and five homes. Visible from the highway are concrete channels and reinforced abutments designed to pass future debris torrents without damage to life or property. There is a country general store in Lions Bay, and access to hiking trails is from the uppermost streets in this community.

12.5 km: North of Lions Bay, Highway 99 makes a long, curving descent beside a gravel quarry. The boulder-filled sand and gravel formed a stream delta at a time when the glacier that filled Howe Sound had partly melted and sea level was about 60 m higher. There are other large sand and gravel deposits at Porteau, Furry Creek and Britannia.

13.7 km: The highway at M Creek has been widened by considerable blasting and extended away from the cliff by construction of a mortised wall below. Before construction, falling rock occasionally closed this section and cars had been squashed by boulders. In late October 1981, a debris torrent destroyed the M Creek bridge at night and nine people perished when their cars plunged into the gaping hole.

14.4 km Tunnel Point Rest Area: Toilets, tables and view back to Lions Bay.

Concrete block catch basin (foreground) and spillway (looking downstream) on Harvey Creek, designed to forestall debris torrent damage to the community of Lions Bay. (Sketch from photograph in an article by O. Hungr and others, 1987.)



16.2 km Loggers Creek

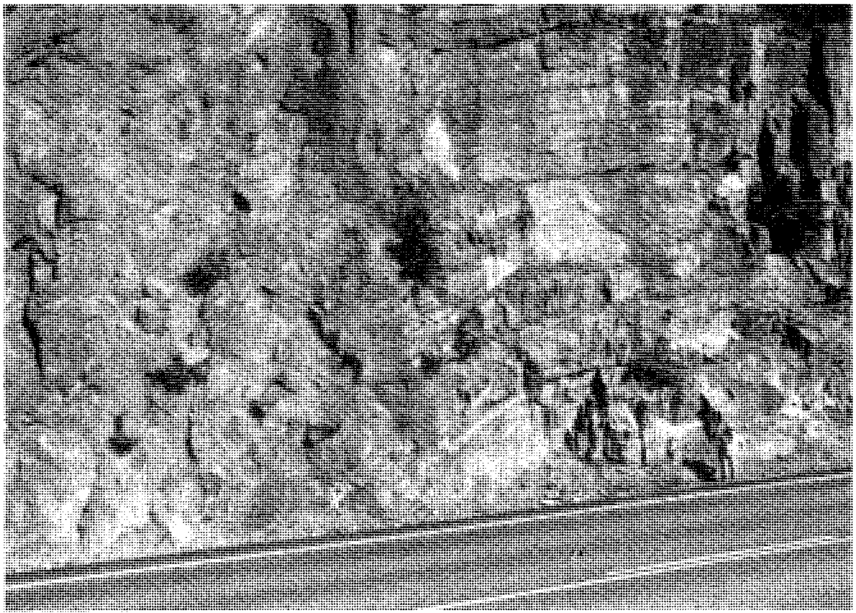
16.4 km: Pullout with view over Howe Sound

16.7 km Deeks Creek: A steep trail ascends the north side of the stream.

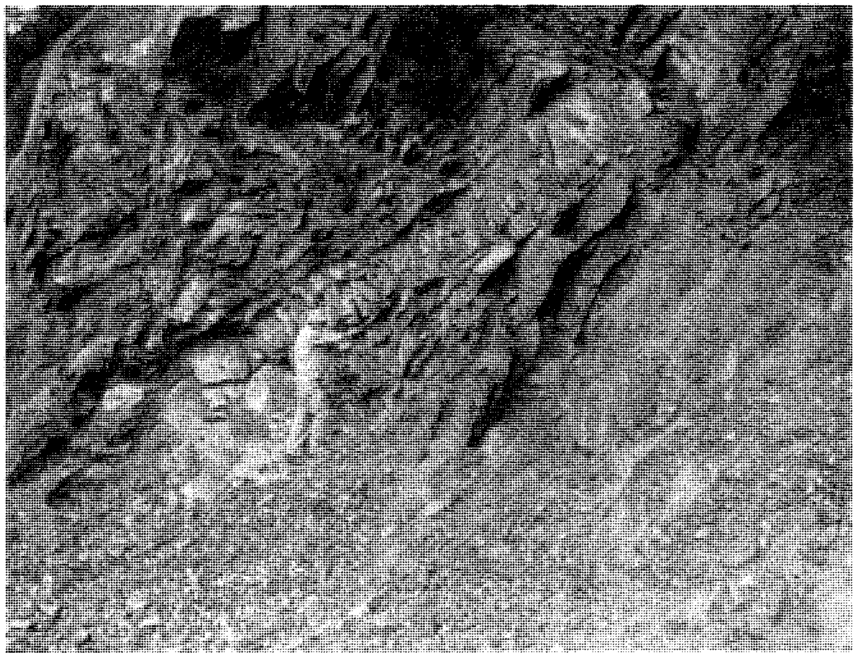
19-21 km Brunswick Point anticline: In the high cliffs beside a long downhill grade is the only large fold exposed in the metamorphic pendants near Vancouver. The safest place to park your vehicle is in a scenic pull-out (with a plaque on the Pacific Great Eastern Railway). For walking, the wider shoulder is on the Howe Sound side, which gives the best view of the anticline across the road.

Near the bottom of the hill are andesite flows and breccia. Quartz diorite blocks in the breccia are rusty with pyrite in the andesitic matrix. Farther up the highway, a steep fault shown by a cleft in the cliff separates the metavolcanic rock from thin-bedded argillite, siltstone, and grey sandstone, also metamorphosed. On the surfaces of some beds you can find ripple marks left by ancient waters. These beds dip northeast, but further south the sedimentary rocks appear flat lying, and 30 m beyond are dipping moderately south. Both the volcanic and sedimentary rocks belong to the Gambier Group. A 4 m wide dyke and sill of granitic rock intrudes the anticline in its hinge zone, which is the crest of the fold here.

North of Brunswick Point, Highway 99 leaves the pendant of metamorphic rocks and re-enters the Porteau quartz diorite pluton. Near the contact between the two, the rocks have been altered and shattered. They are covered with concrete spray and other sections

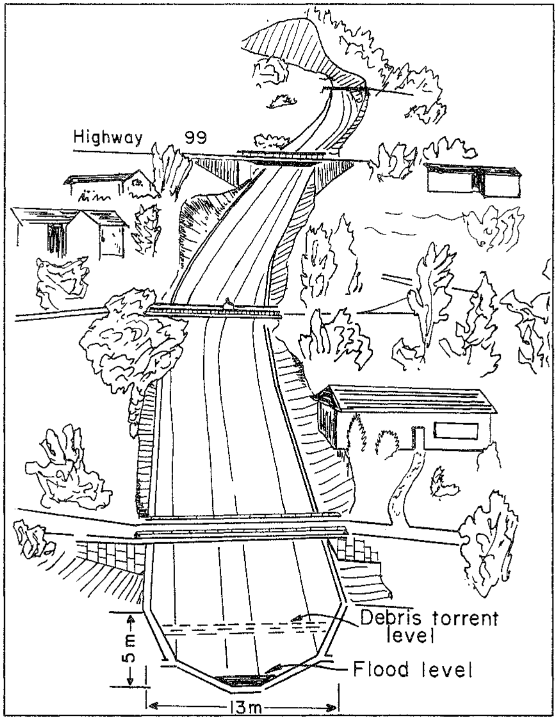


Layered metamorphosed siltstone of the Gambier Group, exposed beside Highway 99 near Brunswick Point. The figure is standing near the hinge of the anticlinal structure.



A granite intrusion cuts Gambier Group metasedimentary rocks near the hinge of Brunswick Point anticline.

Concrete-lined channel of Alberta Creek through the community of Lions Bay. (From an original sketch by Ker Priestman Associates in an article by O. Hungr and others, 1987.)



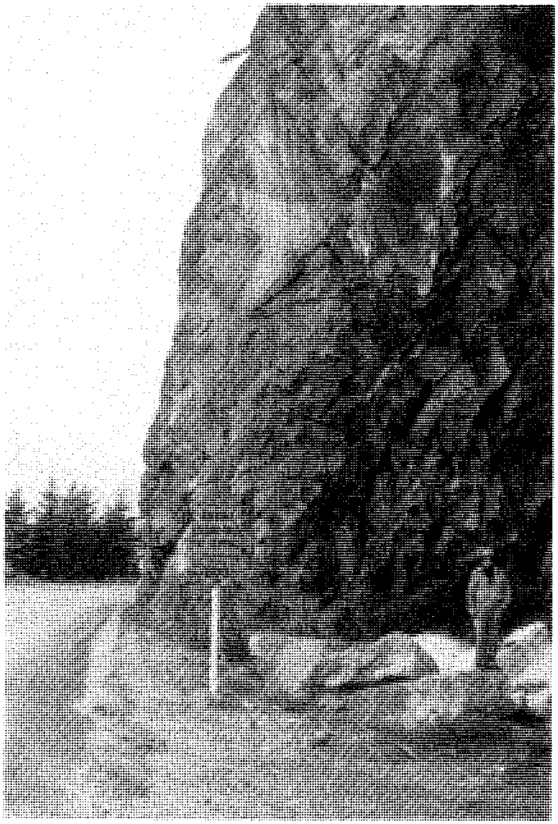
are draped with steel mesh to keep loose rocks from falling onto the roadway.

21.8 km: Parking lot at the north end of the Howe Sound Crest Trail. Several half-day and longer hikes can be planned (see brochure at trailhead). If you can spare half an hour, walk 300 m up the trail to some open rocks beneath the power line. The rock is silicified andesite breccia and there is a fine view of Howe Sound.

23 km Porteau Marine Park: This provincial park is popular with divers exploring marine life on an underwater ridge that extends across the neck of Howe Sound. Called a sill, it represents a moraine left by the valley glacier that occupied Howe Sound until about 10,500 years ago. In a gravel pit beyond the picnic area, beds of sandy gravel, clay and silt represent a stream delta and are overlain by beach deposits from a period when sea level was higher than today.

Directly across the highway from the turnoff is a glacially striated cliff of quartz diorite. A potassium-argon isotopic date on this rock indicates that it cooled 100 million years ago. The quartz diorite contains hornblende crystals and some finer-grained amphibolite inclusions.

The blasted rock near Porteau Provincial Park is hazardous because it has outward dipping joints. Water seeping into these cracks may cause large blocks to fall onto Highway 99.



At the north end of the pullout, the highway and railway follow the shoreline around a nearly overhanging cliff. Note the cracks (called joints) in the rock that form parallel sets, one of which dips steeply toward the highway. Vibration and cycles of freezing loosen the rock slabs, which constitute a threat to the highway. The joints are regularly measured and steel bolts have been installed to postpone rock fall. Broken pavement or new patches of tarmac beneath the cliffs indicate recent failures. Slides in 1969 and 1970 resulted in tragedy.

31 km Britannia: The settlement of Britannia Beach has shrunk since its heyday as the terminus for the Britannia Mine which for years was the largest source of copper in the British Empire. Some of its glory and the methods used in the mine are recreated in the B.C. Museum of Mining there. Facing the town is the defunct concentrator building, which was powered mainly by gravity. Broken mineralized rock was loaded into the top from a tramline and two tunnels. The ore was ground to a fine powder and the metal-bearing minerals extracted in the form of a fine grey powder. This powder, known as concentrate, was stockpiled for shipment to Tacoma, Washington, and later to Montana, where it was further refined.

The first indications of copper mineralization were discovered high on the ridge in 1888. Mining began about 1905 in a number of large pits 1700 m above sea level and continued in underground tunnels and shafts until closure in 1974. The last orebody to be mined was deep within the mountain beneath the mill, and several hundred metres below sea level. The mine eventually produced 500,000 tonnes of copper, 122,000 tonnes of zinc, 15,000 tonnes of lead, 14 million grams of gold and 84 million grams of silver—worth about four billion dollars at today's prices!

The ore deposit was composed of the minerals pyrite, chalcopyrite, and sphalerite, all of which accumulated around a hot spring on the flanks of a volcano on the sea floor about 160 million years ago. After it formed, more sedimentary and volcanic rocks were deposited on top, burying it more and more deeply. Later tectonic activity deformed the deposit, with faults splitting it into many separate orebodies. All of the rocks were eventually uplifted such that erosion was able to reveal them to view.

Some of the host rock which contained the ore deposit is exposed near the highway. It is a green sericitized schist belonging to the Gambier Group. Look for green and blue copper staining in seeps behind the pieces of antique mining equipment. This is where copper and other metals naturally dissolved in the water are deposited in minerals such as malachite (green) and azurite (blue). Despite the high metal content of the water, some of the best fishing in Howe Sound lies just off the mouth of Britannia Creek.

The area is not without geologic hazards. In 1915, a rockslide hit one of the bunkhouses in the mine area, killing more than 50 people. Britannia Creek has flooded repeatedly, most seriously in October 1921, when many buildings were washed into Howe Sound. Some of the boulders left from this flood are near the highway bridge over Britannia Creek. This catastrophe, and other floods in 1933 and the 1960s occurred when logging debris or slides temporarily dammed the creek, then broke loose. To reduce this hazard in future, old dams in the headwaters that formerly held reservoirs for mining operations have been breached.

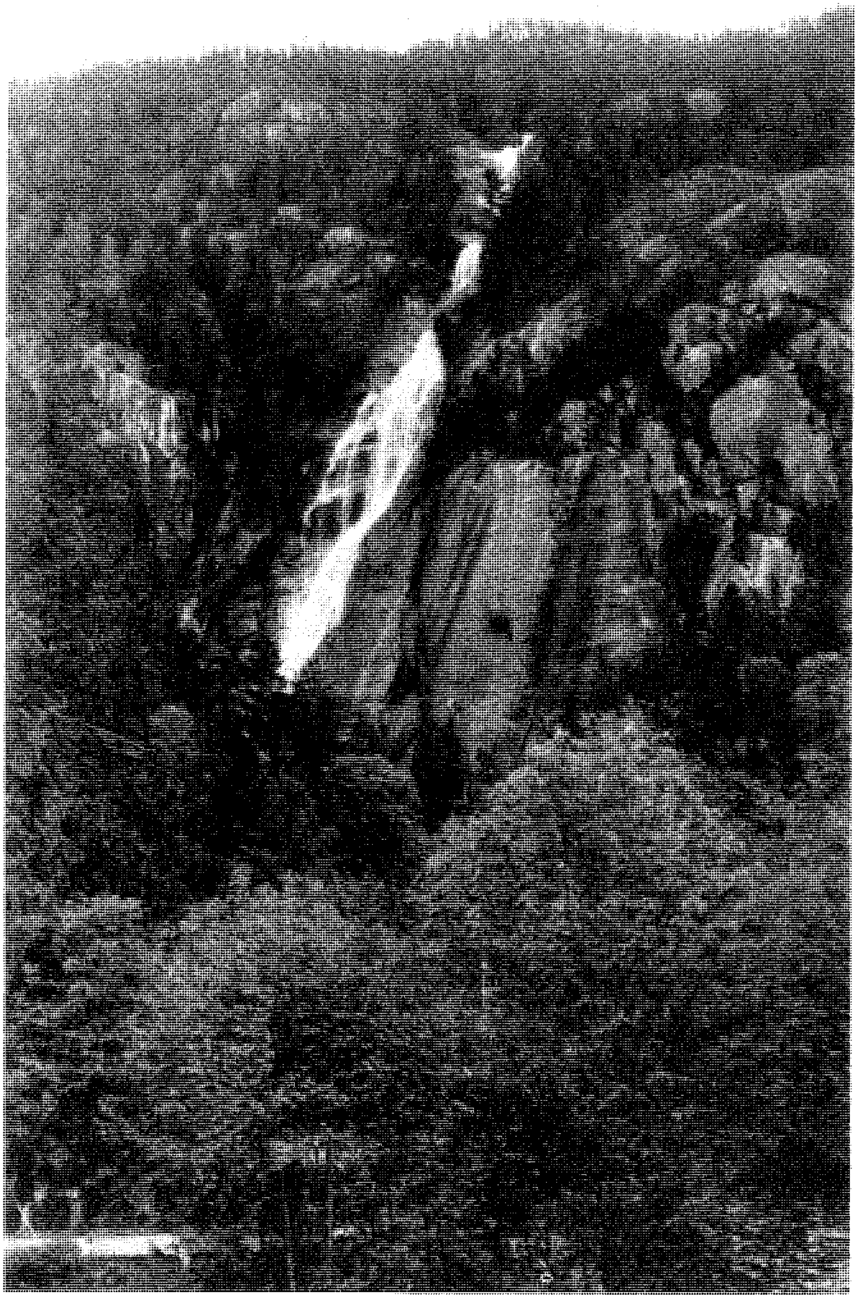
Heading north, the highway climbs a long hill (with a pullout for fine views of Howe Sound and Britannia) and enters the Squamish granodiorite pluton. Murrin Park is located in a cool cleft between tall cliffs. At the north end of this cleft, a road toward the sound leads to quarries in columnar jointed dacite. The Watts Point flow is the nearest Holocene age volcanic centre to Vancouver. From this point, Highway 99 begins a long downhill toward Squamish, with a pullout and plaque commemorating Guiseppe Garibaldi. The striking, snow-capped peak of Mount Garibaldi, nearly 3,000 m high, was an erupting volcano as recently as 9,600 years ago.

33 km Shannon Falls: Spectacular in May, the water cascades down a granodiorite cliff 335 m high. The steep walls at the head of Howe Sound result from the convergence of several valley glaciers. The top of glacial ice, roughly equal to the height of the falls, filled and carved the valleys, but left the uplands relatively untouched.

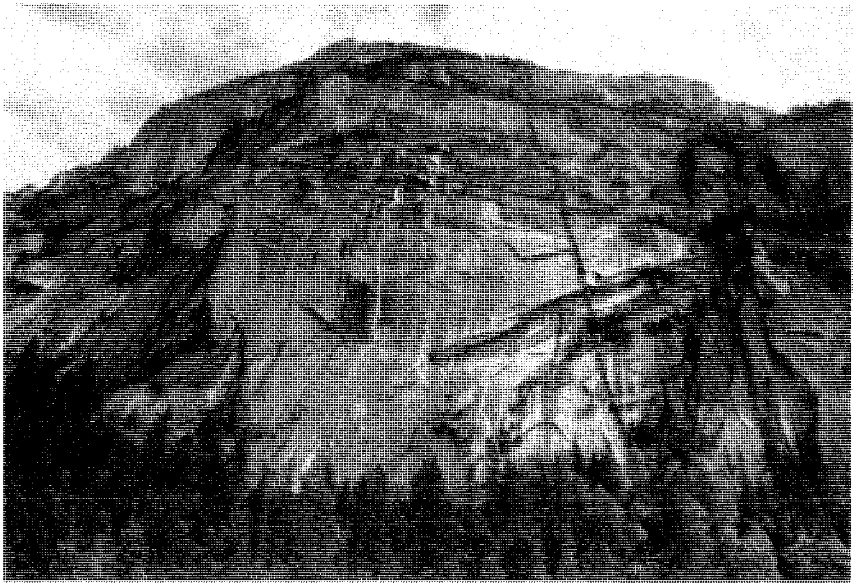
34 km Squamish (Stawamus) Chief: The Chief is a monolith of granodiorite with a west face 670 m high. The rock is medium-grained granodiorite. Isotopic dates indicate that it cooled between 90 and 100 million years ago. The Chief is remarkably free of cooling joints, but like most granitic rocks has slabs that flake off the top and sides. This is called exfoliation and occurs when minerals in the rock, which cooled under pressure within the Earth's crust, begin to accommodate to lower pressure and fluctuating temperatures at the surface. A 2 m wide diorite dike runs like a dark strip up the cliff, a classic route for big wall climbers that takes several days to complete. The diorite is 33 million years old, the same age as the dyke at Prospect Point in Stanley Park.

At the south end of the parking area is a smoothly polished outcrop of the granodiorite. It contains grey translucent quartz (about 40%), white plagioclase (30%), and light pink potassium feldspar (20%), with some biotite mica and magnetite. Scratches on the surface of the outcrop were made by a glacier moving south about 12,000 years ago, before it was covered by sand and gravel.

The Chief is a mecca for rock climbers, and from the pullouts you may see some on the cliffs. If you wish to climb up by a less demanding route, drive to the end of a dirt road passing beneath the power lines at the south end of the cliffs. From a parking lot in the forest, a trail with lengthy, beautifully constructed staircases follows the brook and up the back side, 3 km to the South Peak. The elevation gain is 800 m, so allow several hours for the hike. You'll be rewarded with a superb view of the Howe Sound area, the port of Squamish with its lumber yards, and people and cars on the highway below.



Shannon Falls



Looking up the west face of Squamish Chief. The black stripe right of centre is a 2 m wide hornblende diorite dyke. The fainter vertical stripes are water stains.

Near the top, and just before the trail leaves the forest, you'll cross the diorite dyke that you saw from below. In the first large expanse of bare rock are numerous hollows where inclusions of dark green amphibolite have eroded faster than the enclosing granodiorite. The large number of inclusions suggests that country rock was only partly absorbed into the magma, and that these rocks might have been near the top of the intrusion.

36 km: Traffic lights and turnoff to Squamish, a prosperous town based on the timber industry and a chemical plant near its deep-water port. From here you can explore the town, return to Vancouver or continue another hour's drive to the Whistler area.

More detailed information on the geology

Deformed Mesozoic volcanogenic Cu-Zn sulfide deposits in the Britannia district, British Columbia by J.G. Payne, J.A. Bratt and B.G. Stone; Economic Geology 75, p. 700-721. 1979.

Debris flow defenses in British Columbia by O. Hungr, G.C. Morgan, D.F. Van Dine and D.R. Lister, in *Debris Flow/Avalanches: Process, Recognition and Mitigation,* Editors: J.E. Costa and G.F. Weiczorek; Geological Society of America Reviews in Engineering Geology VII, p. 201-222. 1987.

DEFENSE FROM DEBRIS TORRENTS

As you drive Highway 99 toward Lions Bay, you'll pass enormous concrete fortifications around several of the creeks. These are not bunkers from wartime nor slides for a defunct amusement park. The B.C. Department of Highways has constructed them to protect the road (and railways and adjacent houses) from destructive debris torrents that occasionally flow down these little creeks.

It is hard to believe that the small trickle you might observe in the concrete spillway could swell to a raging flood. It happens, typically without warning, about once every five or ten years. Many occurred between 1981 and 1984. This geologic hazard is more common in southwestern B.C. than elsewhere in Canada. Steep mountain slopes and luxuriant vegetation choking the streambed contribute to the problem. In the fall and winter storm fronts move in from the Pacific. As the warm, moist airmass is pushed eastward over the mountain front, up to several metres of snow may be dumped above Lions Bay. Not only is precipitation much greater at high elevations than at sea level, but fluctuating temperature resulting in snow followed by rain may leave a saturated snow pack poised to slough off steeper slopes.

The torrents are triggered by snow or rock slides high in the valley. Runoff dammed behind this temporary blockage breaks free and sweeps fallen trees and loose soil and rock downstream. Many of these valleys are actually steeper in their middle reaches, so the debris-choked flood gathers momentum, and comes roaring down to sea level, seemingly without warning. These catastrophic torrents don't occur with every storm, but the winter storms of some years are much worse than others. Bridges and homes were destroyed along Harvey and Strachan creeks in 1969, and flows down Charles Creek and M Creek in 1981 both involved loss of life. People died when their cars drove into a gaping hole after a bridge had been swept away. Some houses have also been swept out into Howe Sound.

In hindsight, it is easy to point out that settlement of the alluvial fans of these steep creeks was unwise. Debris torrents represent a continuing geologic hazard, in that rock slides and deadfall always accumulate in the upper reaches of the creeks and will be periodically swept by these torrents. Like earthquakes, small events frequently spaced have less impact upon human affairs than the rare debris-choked flood that might strike an area where people have become less vigilant about the hazard. Nevertheless, settlements like Lions Bay are here to stay. Structures that reduce the damage of periodic torrents have been designed (by Thurber Consultants, in Vancouver) and built by the Department of Highways.

The engineering solutions are of two types. On Charles Creek, Harvey Creek and Magnesia Creek, large basins have been dug to catch the debris torrent. Looking up from the highway you can only see the concrete spillway extending down from the dam. Once the danger of a torrent has passed, the debris is scooped out of the basin by bulldozers and made ready for the next event.

The second solution is used at Newman Creek and Alberta Creek. In Lions Bay, you will see stream channels built up with concrete in which boulders have been set, like a giant (and bumpy) bobsled run. It is intended that a debris torrent will pass beneath the highway and right into Howe Sound without piling up and spilling over the walls. The shape and gradient of these chutes, and the many bridges over them, are designed for the worst case situation anticipated to occur in 200 years.

Other remedial measures not requiring engineering are also effective in reducing the damage from these destructive flows. Anything that might cause blockage in the headwaters of these streams should be avoided, including log bridges, slash and slides from poor logging practices. To reduce this hazard, the old reservoirs of Utopia and Park Lane lakes on Britannia Creek are no longer intact. Certain amounts of precipitation within a few hours may trigger debris torrents, so in 1983 automatic weather stations were installed in the headwaters of some creeks. They consist of a water collector (including a heater to melt snowfall) with measurements transmitted via satellite to the Department of Highways office. When debris flows are predicted, observers are stationed at critical bridges, and the highway may be closed to traffic. Road closures are a wise precaution because rockfalls are also likely at these times, and cars have been crushed by boulders while waiting at obstructions.

About the Cover

Remote sensing imagery supplies us with a method for monitoring and evaluating the surface of the earth. The detailed and up-to-date information provided by image data finds numerous applications in many fields, including mining, forestry, land use, mapping and environmental studies.

When satellite data are ordered, they are received as a series of numbers stored on computer tapes. The data include information in seven bands or portions of the electromagnetic spectrum. Only three of these are visible to the human eye. The others are in the infrared bands and allow us to distinguish features on the Earth's surface that we can not normally see.

To make the best use of these numerical data, computerized image analysis and interpretation techniques are required. Using highly specialized software, one can analyze numerous combinations of bands and create new images which enhance important features. In geological work, for example, various combinations are frequently able to discriminate between different rock types, either directly, or indirectly through variations in vegetation or soil type that reflect differences in the underlying rocks. Once the most appropriate combination of bands is found, features of interest are further enhanced by using image processing techniques such as contrast stretching and filtering.

The image on the cover of this book was processed from digital data from the Landsat 5 remote sensing satellite by Advanced Satellite Productions Inc.

SOURCES OF GEOLOGICAL INFORMATION

The following is a list of professional associations, and government bodies (both federal and provincial), willing to assist you.

Geological Association of Canada (G.A.C.), Cordilleran Section
840 West Hastings St.
Vancouver, B.C. V6C 1C8 Monday & Wednesday: (604)684-7254

The Cordilleran Section of the Geological Association of Canada, a non-profit association, consists of a diverse group of people who have an interest in and professional affiliation with the earth sciences as they apply to the mountainous terrain of western Canada known as the Cordillera.

Its mandate is to provide a common meeting ground for representatives from industry, the provincial and federal governments, educational institutions and to some extent, the general public. It organizes field trips, has an ongoing program directed to increasing the awareness of geological sciences within the public school system, and co-sponsors geological lectures and conferences with other groups.

British Columbia & Yukon Chamber of Mines
840 West Hastings St.
Vancouver, B.C. V6C 1C8 (604)681-5328

The Chamber's membership comprises some 1,800 individuals and organizations representing all facets of the industry: prospectors, mining companies, mining service and supply companies, consultants and financial institutions.

The principal function of the Chamber is collecting and disseminating information about mineral exploration and development to the public, governments, and industry. The Chamber conducts its Prospecting School and the Exploration and Mining for Brokers course each fall, as well as the Placer Prospecting course in spring.

The Chamber is a non-profit-earning institution organized to foster mining in B.C. and its services are still free to all "irrespective of whether they are subscribers or not".

Geological Survey of Canada (G.S.C.), Cordilleran Division
100 West Pender St.
Vancouver, B.C. V6B 1R8 Maps & Publications: (604) 666-0271
Library: (604) 666-3812
Inquiries: (604) 666-0529

Offices for 30 federal government scientists, a research library open to the public, and an outlet for publications of the division is located at 100 West Pender Street. They can provide geological maps for most areas west of Alberta, and most scientists are available to informally discuss aspects of their work.

Geological Survey of Canada, Pacific Geoscience Centre
P.O. Box 6000
West Saanich Rd.
Sidney, B.C. V8L 4B2 Inquiries: (604) 356-6500

The Pacific Geoscience Centre offers services similar to those available at 100 West Pender St. in Vancouver. It specializes in geophysics and oceanography, particularly of the Vancouver Island area.

British Columbia Geological Survey (B.C.G.S.)
B.C. Ministry of Energy, Mines and Petroleum Resources
159-800 Hornby St.
Vancouver, B.C. V6Z 2C5 (604)660-2812
Emergency Preparedness Canada: (604)388-3621
Emergency Response (B.C.) –
Earthquake Information (604)387-5956
Emergencies only: 1-800-663-3456

Mining Association of British Columbia
1066 W. Hastings St.
Vancouver, B.C. (604)681-4321

Geology Department, University of British Columbia
6339 Stores Road
Vancouver, B.C. V6T 2B4 (604) 228-2449

With its demanding curriculum and modern facilities, the department is among the most prominent in Canada, and offers a challenge to students at all levels. Current specialties range across the entire spectrum of the earth sciences, including a strong geological engineering programme. Interdisciplinary research with departments such as Geophysics and Oceanography broadens the scope even further. Degree programmes offered include B.Sc., B.A.Sc., M.Sc., M.A.Sc. and Ph.D.

Also at the Department of Geology is the MDRU or Mineral Deposits Research Unit, set up to promote ties between industry and academia in respect to their mutual interest in the geology of mineral deposits: (604)228-4563.

M.Y. Williams Geology Museum
6339 Stores Road (604)228-5586
Open Monday through Friday, 8:30 – 5:00 p.m.

Our earth has a long history which is summarized, in part, by the beautiful and interesting objects formed on and within it during the past 4.5 billion years. Enjoy some of these examples of nature's treasures, presented for your information and appreciation. An excellent assortment of mineral and fossil specimens are available for sale at the museum, located in the Geology Department at UBC.

B.C. Museum of Mining
Britannia Beach, B.C. 1-896-2233
Toll Free: (Vancouver) 688-8735

Simon Fraser University, Geography Department
Burnaby Mountain Campus
Burnaby, B.C. (604) 291-3321

Advanced Satellite Productions Inc.
170 – 10651 Shellbridge Way
Richmond, B.C. V6X 2W8 (604) 270-4648

Advanced Satellite Productions produces satellite photos of this region useful for mining, forestry, land use, mapping and environmental studies. The cover photo of this book is an example.

GLOSSARY

Accreted: Attached or joined onto.

Albite: A relatively sodium-rich type of plagioclase feldspar.

Alluvial: Pertaining to sedimentary deposits laid down by a stream.

Amphibole: A group of rock-forming iron and/or magnesium-rich silicate minerals related in crystal form and composition; hornblende is by far the most common.

Amphibolite: A metamorphic rock consisting of amphibole and feldspar, often formed by metamorphism of mafic volcanic rocks.

Andesite: Dark-coloured, fine-grained volcanic rock composed of feldspar, biotite, hornblende, pyroxene, and minor quartz. The name is derived from the Andes Mountains, South America.

Anticline: A fold in layered rock, with youngest rock on the convex side and oldest rock on the concave side.

Aplite: A sugary textured and light-coloured igneous rock consisting of quartz and feldspar.

Aquifer: A groundwater reservoir that yields economically significant quantities of groundwater to wells and springs.

Argillite: A rock derived either from shale or siltstone, that has been weakly metamorphosed.

Augite: A type of pyroxene mineral.

Basalt: A dark-coloured volcanic rock made up of calcium-rich feldspar and pyroxene in a glassy matrix.

Batholith: A mass of plutonic rock, larger than 100 square kilometres in area, and having no known floor.

Bedrock: A general term for the solid rock that underlies the unconsolidated materials.

Biotite: A dark mica containing iron and magnesium; one of the more common rock-forming minerals.

Breccia: A rock consisting of coarse, angular rock fragments held together by a mineral cement or a fine grained matrix. Igneous breccias are formed by volcanic explosions, fractures in moving lava and subterranean earthquakes.

Calcite: A very common mineral with composition $CaCO_3$.

Chalcopyrite: A mineral with composition $CuFeS_2$.

Chert: A hard sedimentary rock consisting mainly of extremely fine-grained silica.

Chlorite: A group of rock-forming, ferromagnesian minerals, usually greenish. They are widespread in low-grade metamorphic rocks, especially intermediate to mafic volcanics, and as alteration products of earlier-formed ferromagnesian minerals in plutonic rocks.

Cirque: An amphitheatre-like hollow situated high on the side of a mountain, commonly at the head of a glacial valley, and produced by the erosive force of a glacier.

Clast: Fragment of rock produced by mechanical rather than chemical weathering.

Clay: Material consisting of mineral fragments and crystals smaller than 0.002 mm.

Cobble: A rock fragment ranging in diameter from 6 to 25 cm.

Colluvium: A general term for loose and incoherent material deposited by slow downslope creep or rainwash, often at the base of a slope.

Columnar Jointing: Fractures in igneous rocks, caused by cooling and resulting in the formation of prismatic columns, particularly in basalts.

Concretion: A nodular-shaped concentration of material such as calcite in sedimentary rocks. They are generally more resistant than the surrounding rock and often stand out on weathered surfaces.

Conglomerate: A rock consisting of rounded rock fragments held together by a mineral cement or, more commonly, finer grained sediment.

Correlate: To compare in geological time and stratigraphic sequence, two or more geological deposits or phenomena in separated areas.

Cross-bedding: Beds within a single sedimentary layer that are inclined at an angle to the main planes of layering in the rock body.

Crust: The outermost layer of the Earth, ranging in thickness between 15 and 100 kilometres.

Cuesta: Hill having one steep and one gently sloping side.

Cut and Fill: A sedimentary structure consisting of a small eroded channel that later was refilled with sediment.

Dacite: A type of volcanic rock with a silica content intermediate between andesite and rhyolite.

Deformation: A general term for the processes of folding, faulting, shearing, compression or extension of rocks as a result of forces in the Earth.

Detritus: A collective term for loose rock and mineral material that is worn off or removed directly by mechanical means from older rocks.

Devitrified: Descriptive term for glass that has partly or wholly crystallized.

Diorite: An intrusive igneous rock composed of amphibole, plagioclase, pyroxene, and sometimes a little quartz.

Drift (glacial): A general term applied to all material deposited by a glacier or glacial meltwater.

Dyke: A tabular igneous intrusion cutting across the structure of the enclosing rock.

Eocene: A subdivision of geologic time lasting between 57.8 and 36.6 million years ago.

Epidote: A greenish mineral with formula $Ca_2(Al,Fe)_3Si_3O_{12}(OH)$.

Erratic: A rock fragment transported by a glacier to an area with a different type of bedrock.

Eustasy: Pertaining to world-wide sea level and the changes in it due to absolute changes in the amount of water in the oceans.

Fan deposit: An accumulation of debris brought down by a steep stream and deposited on the plain below, commonly where a significant change of slope occurs. The deposits spread out in the shape of a gently sloping fan.

Fault: A zone of rock fracture along which there has been displacement between two rock masses on either side.

Feldspar: The most common mineral in the Earth's crust; it is a light-coloured aluminum bearing silicate.

Felsic: A general term used to describe igneous rocks containing abundant light-coloured minerals.

Ferromagnesian: Containing or composed of iron and magnesium compounds.

Fiord: A long, narrow, winding, U-shaped, and steep-walled inlet or arm of the sea which originated as a glacial valley.

Floodplain: The flat area adjacent to a stream channel which is built from sediment carried by the stream when it overflows its banks during flooding.

Fluvial sediment: Sediment transported by, suspended in, or laid down by a river.

Foliated: Descriptive term for the planar arrangement of structural or textural features in a rock, especially the flattening of mineral grains in a metamorphic rock.

Geomorphology: The branch of both physiography and geology which deals with the form of the Earth, the general configuration of its surface, and the changes that take place in the evolution of landforms.

Glaciation: The formation, movement, and recession of glaciers or ice sheets.

Glaciofluvial: Pertaining to the sedimentary deposits laid down by meltwaters flowing from glacier ice.

Glaciolacustrine: Pertaining to the sedimentary deposits laid down by meltwater streams flowing into lakes bordering a glacier.

Glaciomarine: Pertaining to the sedimentary deposits laid down by glaciers and floating ice at an ice-sea interface.

Gneiss: A metamorphic and generally coarse-grained rock in which bands rich in granular minerals such as feldspar and quartz alternate with bands in which flaky minerals such as mica or amphibole predominate.

Granite: A light coloured plutonic rock composed mainly of quartz and potassium-rich feldspar.

Granitic rock: A term loosely applied to any light coloured, coarse-grained plutonic rock consisting of quartz and feldspar, with or without dark minerals, e.g. granite, granodiorite, and quartz diorite.

Granodiorite: A light coloured plutonic rock composed mainly of quartz, plagioclase, and some potassium-rich feldspar.

Gravel: An unconsolidated accumulation of rock fragments consisting predominantly of particles greater than 2 mm in diameter, including pebbles, cobbles, and boulders.

Greywacke: A sandstone consisting of quartz, feldspar, and a variety of small, dark mineral and rock fragments embedded in a clay-rich matrix.

Groundmass: The finer grained material between the larger crystals in a porphyritic igneous rock.

Groundwater: Subsurface water of which the upper boundary is the water table.

Holocene: A subdivision of geologic time lasting from 10,000 years ago to the present.

Hornblende: The most common amphibole mineral.

Ice-contact: Stratified glacial drift deposited in contact with melting glacial ice.

Igneous rock: One of the three main classes of rock, formed from the crystallization of molten or partly molten rock material either at or below the Earth's surface.

Inclusion: A relatively small fragment of an older rock incorporated into a younger plutonic or igneous rock mass.

Intrusion: The process of emplacement of magma into pre-existing rock or a term for the solidified body of magma itself.

Iron oxide: One of the chemical components of rust.

Isostatic rebound: The adjustment of the crust of the Earth to maintain balance between areas of varying mass and density. If huge quantities of ice (e.g. ice sheets) are loaded onto the crust in an area, the crust will be depressed by this load; if the ice is removed, the land surface will rise.

Joint: A usually planar fracture in bedrock along which no appreciable movement has occurred.

Jurassic: A period of geologic time lasting between 208 and 144 million years ago.

Kame: Glacial drift deposited in a fan or delta by a meltwater stream at the margin of a melting glacier.

Lacustrine deposit: A deposit formed in a lake.

Lens: Descriptive term for a deposit or bed which is thick in the middle and thins out at the edges.

Levee: An artificial bank confining a stream channel or limiting areas subject to flooding.

Limestone: A sedimentary rock composed mainly of calcite.

Lithification: The conversion of loose sediment into a coherent rock by processes such as compaction, crystallization, and cementation.

Lithology: The description of geological material on the basis of mineralogical composition, grain size, and colour.

Lithosphere: The upper portion of the Earth, comprising the crust and the uppermost relatively cold and rigid mantle.

Mafic: Descriptive term for a rock dominated by ferromagnesian minerals or for the minerals themselves.

Magma: Naturally occurring molten rock material, generated within the Earth and from which igneous rocks are derived by cooling and crystallization.

Magnetite: A black magnetic mineral composed of a form of iron oxide.

Mantle: The intermediate portion of the Earth, surrounding the metal-rich core at the centre and surrounded in turn by the crust.

Matrix: Fine grained material surrounding larger fragments in a sedimentary rock.

Meltwater: Water derived from the melting of glacier ice.

Mesozoic: A major subdivision (era) of geologic time lasting between 245 and 66.4 million years ago.

Meta-: A prefix signifying rocks that have been metamorphosed, e.g. metavolcanic, metasediment.

Metamorphism: The process by which a rock changes in response to the application of heat and/or pressure.

Mica: A common group of flaky rock-forming aluminum silicate minerals, such as biotite, muscovite and phlogopite.

Migmatite: A rock made up of a mixture of metamorphic rock and igneous rock.

Mineral: A naturally formed inorganic chemical compound or element having characteristic crystal form and properties.

Miocene: A subdivision of geologic time lasting between 23.7 and 5.3 million years ago.

Mollusc: A marine invertebrate animal of the phylum Mollusca, such as snails, oysters and squid.

Moraine: A mound, ridge, or other distinct accumulation of glacial drift, deposited mainly by direct glacial action.

Mudstone: A rock consisting of a mixture of clay, silt, and sand particles of varying proportions.

Oligocene: A subdivision of geologic time lasting between 36.6 and 23.7 million years ago.

Outcrop: Crustal rock that is exposed at the Earth's surface.

Outwash: Stratified glacial drift washed out from a glacier by meltwater streams and deposited in front of or beyond the margin of the active glacier.

Paleocene: A subdivision of geologic time lasting between 66.4 and 57.8 million years ago.

Paleontology: The branch of geology concerned with the study of life in past geologic time.

Paleozoic: A major subdivision of geologic time encompassing the era between 570 and 245 million years ago.

Palynology: The branch of science concerned with the study of pollen and spores.

Peat: Unconsolidated deposit of slightly carbonized plant remains in a water-saturated setting, such as a bog.

Pebble train: A layer among sandstone beds containing pebbles that were left by a slightly stronger water current than that which deposited the other beds.

Pegmatite: A very coarse grained igneous rock, usually occurring as dykes and veins, often at the margins of larger intrusions.

Pendant: A large body of unmelted older rock situated within the intrusive rock which consumed it.

Peneplain: A land surface worn down by erosion to a nearly flat or broadly undulating plain.

Physiography: The study of the genesis and evolution of landforms.

Pleistocene: A subdivision of geologic time lasting between 1.6 million and 10,000 years ago.

Pluton: Igneous intrusion.

Plutonic rock: A rock formed at considerable depth by the crystallization of a magma.

Plutonism: A general term for the phenomena associated with the formation of plutonic rocks.

Porphyroblast: A conspicuously larger crystal in a rock produced by metamorphic recrystallization.

Porphyritic: The texture of an igneous rock in which larger crystals are embedded in finer grained material which may be crystalline, glassy, or both.

Postglacial: Pertaining to the time interval since the last continental glacier withdrew from an area.

Prismatic: Columnar, with geometrically regular sides.

Pyrite: A common brassy-coloured metallic mineral with composition FeS_2, also known as fool's gold.

Pyroclastic: A general term applied to fragmental volcanic materials that have been explosively or aerially ejected from a volcanic vent.

Pyroxene: Dark, rock-forming ferromagnesian silicate mineral.

Quartz diorite: A plutonic rock containing plagioclase feldspar, quartz, hornblende and/or biotite.

Quartz: Crystalline silica, a common and important rock-forming mineral.

Quartzite: A metamorphic rock derived from quartz-rich sandstones and consisting mainly of quartz.

Quaternary: A subdivision of geological time lasting from 1.6 million years ago to the present.

Radiocarbon dating: A method of determining the age of organic material by measuring the concentration of radioactive carbon within it.

Richter scale: A relative scale of earthquake strength devised in 1935 by seismologist C.F. Richter. The higher the number, the stronger the earthquake.

Salinity: A measure of the amount of salts dissolved in water.

Schist: A medium- to coarse-grained metamorphic rock containing a large proportion of aligned platy or flaky minerals.

Sediment: Fragmental material originating from the weathering or erosion of rocks.

Sedimentary rock: A rock resulting from the consolidation of loose sediment that has accumulated in layers or beds.

Seismic: Pertaining to abrupt movements in the Earth's crust, the largest of which are earthquakes.

Sericite: Fine-grained muscovite mica.

Shale: A fine-grained sedimentary rock, formed by the consolidation of clay, silt, or mud.

Silicate: General term for minerals containing important proportions of silicon and oxygen.

Sill: A tabular igneous intrusion that parallels the planar structure, e.g. bedding, of the rock it intrudes.

Silt: Rock or mineral fragments having a diameter in the range of 0.002 to 0.05 mm.

Siltstone: A rock composed of silt grains.

Slate: A fine-grained metamorphic rock formed from shale, with the tendency to easily break along parallel planes.

Sphalerite: A black to yellow mineral, sometimes somewhat metallic in appearance, with composition ZnS.

Stillstand: A temporary halt in the fall of sea level or isostatic rebound, resulting in the formation of a shoreline.

Strandline: A former beach, especially one raised above present sea level.

Stratigraphy: The branch of geology that deals with the definition and description of major and minor natural divisions of geological materials, particularly sediments and sedimentary rocks and their arrangement in chronological succession.

Striae: Fine grooves or lines engraved on a surface, often parallel.

Subaerial: Formed, existing, or taking place on the land surface.

Subduction: The process in which one of the Earth's crustal plates descends below another as they move toward each other. The descending plate is consumed in the Earth's mantle.

Subsidence: Downward sinking or lowering of the Earth's surface with little or no horizontal movement.

Surficial geology: The geology of the unconsolidated materials overlying bedrock.

Tectonic: Of, pertaining to, or designating the rock structure and forms resulting from the deformation of the Earth's crust.

Terrace: Terraces or benches are relatively flat, horizontal or gently inclined surfaces, which are bounded by a steeper ascending slope on one side and a steeper descending slope along the other side.

Terrane: A region or tract of the Earth's surface with a unifying set of geological characteristics, distinct from those characterizing adjacent regions.

Tertiary: A period of geologic time lasting between 66.4 and 1.6 million years ago.

Till: Generally unsorted, unstratified sediment carried and deposited directly by a glacier. All types of till consist of mixtures of clay, silt, sand, gravel, and boulders varying widely in shape and size.

Tuff: A compacted deposit of volcanic ash and dust.

Turbidity current: A bottom-flowing current of water laden with suspended sediment that moves down underwater slopes and then spreads across the floor of the body of water.

Unconformity: A surface or level in a rock sequence that bears evidence of a break, or gap, in the depositional history. Such a break may be caused by a period of uplift and erosion, or by nondeposition.

Volcanism: The process by which magma and its associated gases rise through the Earth's crust and are extruded onto the surface and into the atmosphere.

Water table: The upper boundary of groundwater.

Xenolith: A foreign inclusion of one type of rock inside another, usually an intrusive.

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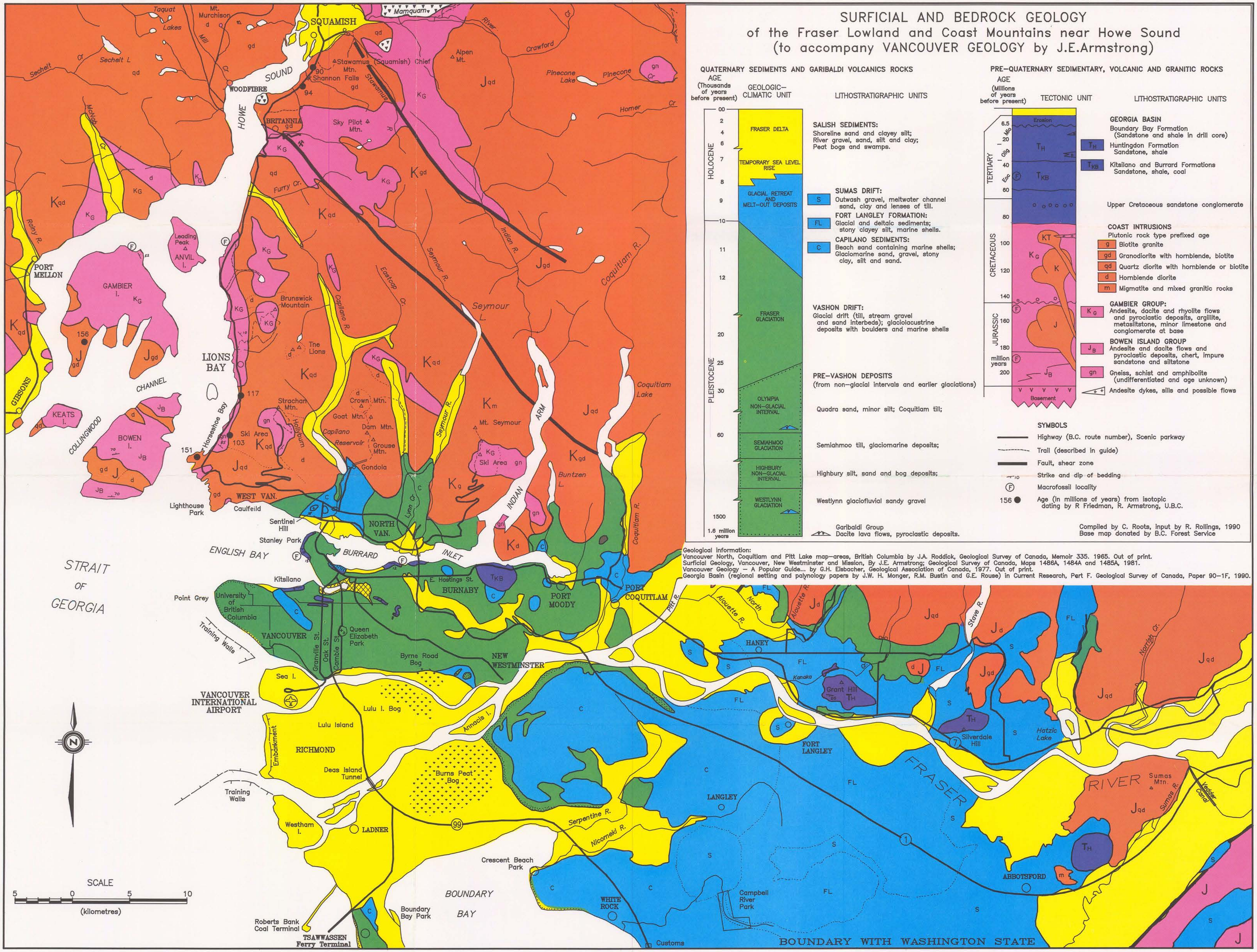
(suffix 'p' indicates photograph; 'f' indicates figure)



SURFICIAL AND BEDROCK GEOLOGY
of the Fraser Lowland and Coast Mountains near Howe Sound
(to accompany VANCOUVER GEOLOGY by J.E.Armstrong)
QUATERNARY SEDIMENTS AND GARIBALDI VOLCANICS ROCKS
AGE (Thousands of years before present)
GEOLOGIC–CLIMATIC UNIT
LITHOSTRATIGRAPHIC UNITS
HOLOCENE
PLEISTOCENE
FRASER DELTA
TEMPORARY SEA LEVEL RISE
GLACIAL RETREAT AND MELT–OUT DEPOSITS
FRASER GLACIATION
OLYMPIA NON–GLACIAL INTERVAL
SEMIAHMOO GLACIATION
HIGHBURY NON–GLACIAL INTERVAL
WESTLYNN GLACIATION
1.6 million years
SALISH SEDIMENTS: Shoreline sand and clayey silt; River gravel, sand, silt and clay; Peat bogs and swamps.
SUMAS DRIFT: Outwash gravel, meltwater channel sand, clay and lenses of till.
FORT LANGLEY FORMATION: Glacial and deltaic sediments; stony clayey silt, marine shells.
CAPILANO SEDIMENTS: Beach sand containing marine shells; Glaciomarine sand, gravel, stony clay, silt and sand.
VASHON DRIFT: Glacial drift (till, stream gravel and sand interbeds); glaciolacustrine deposits with boulders and marine shells
PRE–VASHON DEPOSITS (from non–glacial intervals and earlier glaciations)
Quadra sand, minor silt; Coquitlam till;
Semiahmoo till, glaciomarine deposits;
Highbury silt, sand and bog deposits;
Westlynn glaciofluvial sandy gravel
Garibaldi Group Dacite lava flows, pyroclastic deposits.
PRE–QUATERNARY SEDIMENTARY, VOLCANIC AND GRANITIC ROCKS
AGE (Millions of years before present)
TECTONIC UNIT
LITHOSTRATIGRAPHIC UNITS
TERTIARY
CRETACEOUS
JURASSIC
Erosion
Basement
GEORGIA BASIN
Boundary Bay Formation (Sandstone and shale in drill core)
Huntingdon Formation Sandstone, shale
Kitsilano and Burrard Formations Sandstone, shale, coal
Upper Cretaceous sandstone conglomerate
COAST INTRUSIONS
Plutonic rock type prefixed age
Biotite granite
Granodiorite with hornblende, biotite
Quartz diorite with hornblende or biotite
Hornblende diorite
Migmatite and mixed granitic rocks
GAMBIER GROUP: Andesite, dacite and rhyolite flows and pyroclastic deposits, argillite, metasiltstone, minor limestone and conglomerate at base
BOWEN ISLAND GROUP Andesite and dacite flows and pyroclastic deposits, chert, impure sandstone and siltstone
Gneiss, schist and amphibolite (undifferentiated and age unknown)
Andesite dykes, sills and possible flows
SYMBOLS
Highway (B.C. route number), Scenic parkway
Trail (described in guide)
Fault, shear zone
Strike and dip of bedding
Macrofossil locality
Age (in millions of years) from isotopic dating by R Friedman, R. Armstrong, U.B.C.
Compiled by C. Roots, input by R. Rollings, 1990
Base map donated by B.C. Forest Service
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SCALE
(kilometres)
STRAIT OF GEORGIA
BOUNDARY WITH WASHINGTON STATE