GEOLOGICAL SURVEY OF CANADA

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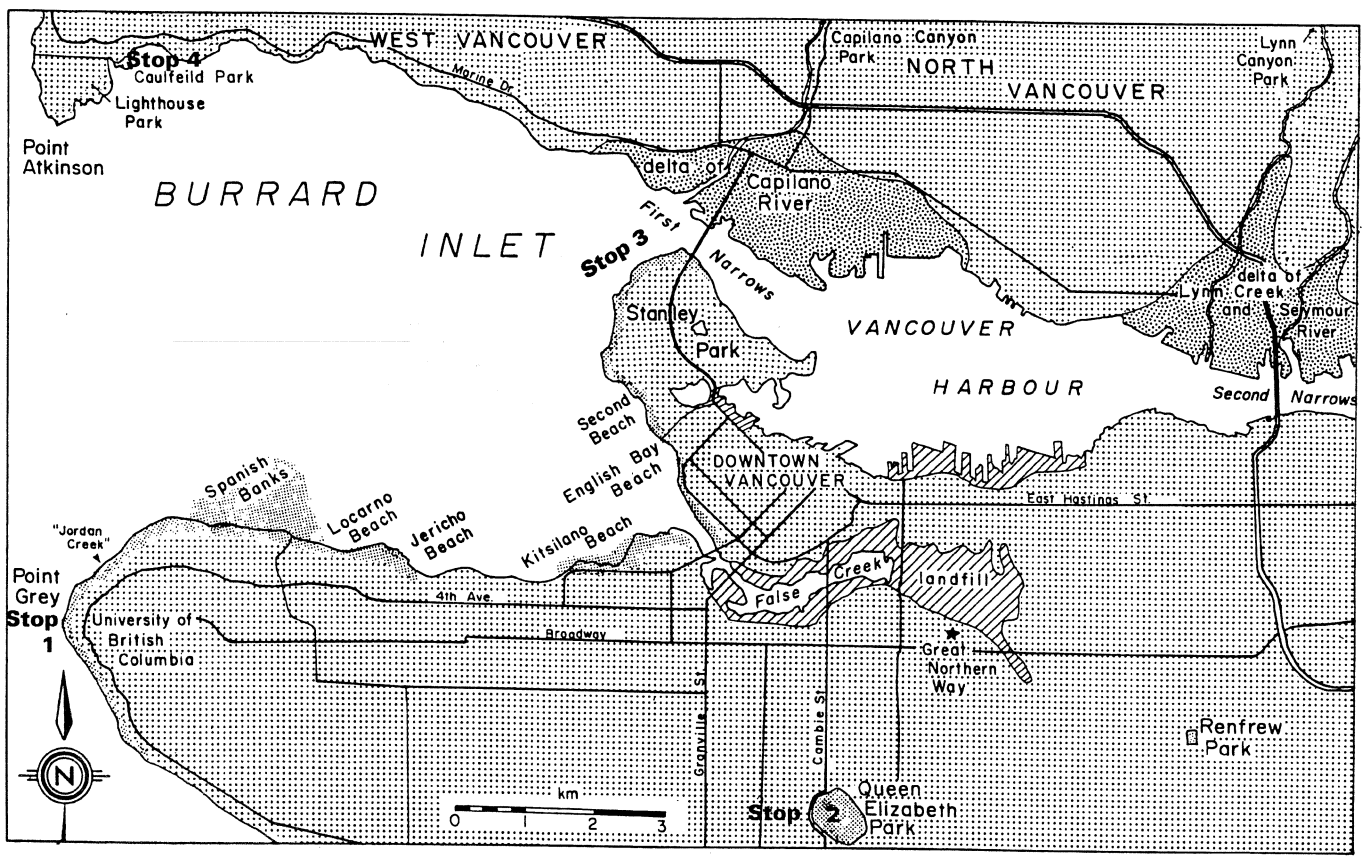

GSC TEACHER'S FIELD-TRIP GUIDE TO THE GEOLOGY OF THE VANCOUVER AREA

J.A. Roddick and J. Luternauer

1994

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Preface

This short guidebook was prepared for one-day field excursions for two groups of Secondary School teachers in the Lower Mainland. The trips were run on two Saturdays in early October 1994, with about 30 teachers in each group. The weather was great but the trip is feasible under less favourable conditions.

An attempt has been made to follow a middle road that reduces, where possible, the geological jargon found in the technical descriptions of the region, but not reduced to the lowest common denominator of newspaper articles, where over-simplification may be misleading. In human terms, the major topographic features of the Vancouver area are timeless; in geological terms, they are temporary. The region in the past did not look like it does today, nor will it look like this in the future. The rates vary, but geological processes are continuous, both at the surface and deep in the crust.

One of the challenges in a guide such as this, is to convey an awareness of the geological setting and a feel for the enormity of geological time, without trivializing either. The stops selected are both interesting in themselves, and fairly representative of the main components of region. They also set the stage for the discussion of broader implications.

Along the base of the fast-eroding sea cliffs of Point Grey, the first stop, we probe the near geological past, that is, the last 26,000 years. The sands and the numerous boulders of far older rocks that litter the beach lead us deeper into the Ice Age, its causes, what it did, and what it still will do.

The second stop at, Little Mountain, exposes remnants of a probably extensive volcanic flow that made Vancouver an interesting site in the Oligocene, about 34 million years ago.

Between Lions Gate Bridge and Third Beach along the seawall, the third stop, we see the underlying sandstone and conglomerate which form the bedrock of the city and move us deeper into the past, into the Cretaceous of 8o million years ago, when the dinosaurs were staging their *finale*.

At Caulfeild, the fourth stop, the main components of the Coast Mountains are spectacularly exposed. The outcrop contains more than a hint of the complexity of granitic rocks and the processes that formed them. The features there have for many years been the subject of several reasonable, but conflicting, interpretations. Geological controversy remains alive and well! These rocks take us back, possibly, to the Triassic (> 180 million years ago). In the Vancouver area, we cannot go farther back in time, but that is no hindrance to speculation.

From the final stop, above the Upper Levels Highway, the previous stops and the entire region can be surveyed. The uplifted and exhumed, Cretaceous, erosion surface is clearly seen on slopes to the east, and some visualization of the effects of plate tectonics is possible.

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INTRODUCTION

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 following is the slightly modified description of the Vancouver Landscape written by Roots and Staargaard for the booklet Vancouver Geology (J.E. Armstrong[1]).

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 granitic and metamorphic rocks. They have been described as the roots of volcanoes similar to the Cascade volcanoes, but those volcanoes were actually built on top of the granitic complexes from magma which originated far below.

As the Coast Mountain belt was uplifted, it was subjected to erosion by streams and rivers, producing a rugged terrain that perseveres because the rate of uplift was (and is) greater than that of the erosion. However, the streams and rivers cut deep, narrow canyons and valleys. Although many are still visible today, between 11,000 and 100,000 years ago, the shapes of these valleys were dramatically altered during a number of ice advances. V-shaped valleys were commonly converted to steep-walled U-shapes.

1. Armstrong, J.E., "Vancouver Geology", eds. Roots, Charlie and Staargaard, Chris, Geological Association of Canada, pp. 11-19, 1990.

Glaciation: When more snow falls during winter than is melted during the summer, ice begins to accumulate on the mountains, and forms glaciers. The current ice age (yes, we are still in the ice age) began about 4 million years ago when the north pole wandered from the Pacific Ocean, where ocean currents could moderate temperature extremes, into the relatively confined Arctic Ocean basin where they cannot. Eventually, considerably after our time, the North Pole will wander into the north Atlantic, and the South Pole out of Antarctica. Good times will return to the earth, and last for millions of years. Or will it? Another factor may alter the scene; that is us.

The advance of glaciers requires precipitation, otherwise they retreat. When the Arctic Ocean freezes over, like it is mainly today, precipitation is greatly reduced. In fact the Arctic is today technically a desert, and the climate is slowly warming. The ice will eventually melt, evaporation and precipitation will increase. The thickening cloud cover will gradually reduce temperatures, and once again glaciers will pour down Howe Sound and the Capilano Valley. Most of us will have changed our addresses by then.

Although human activity had long affected local geological processes, it is only now beginning to affect global processes. The buildup of carbon dioxide in the atmosphere will cause, probably, a hotter but shorter interglacial, and may affect subsequent interglacial periods.

At the height of the Fraser Glaciation (the last one) our lots were under about 1800 metres of ice. 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. Maximum extent of Pleistocene glaciation is shown in Figure 1.

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. When glaciers retreat, water is returned to the oceans, and sea level rises. As sea level rose during the last 10,000 years, these valleys were partly 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 in the Northern Hemisphere. Before being blocked by Fraser River sediments, Pitt Lake was an arm of the sea.

Unloading of ice allows depressed land to rise, a form of isostatic rebound, and local sea level seems to drop. Before

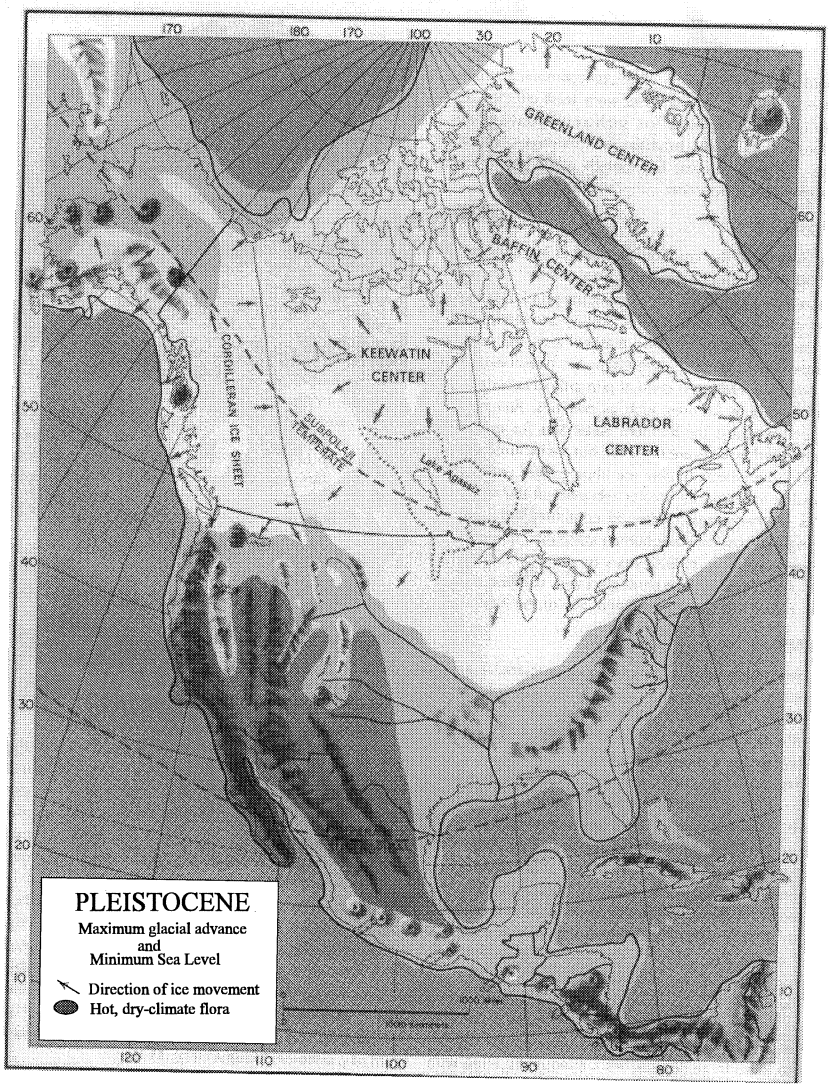

Figure 1: Maximum extent of Pleistocene glaciation in North America.

From Dot and Batten, 1971.

this rather slow rebound takes place, however, the depressed land is flooded. The flooding is enhanced by the transfer of water from glaciers to the oceans.

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 bordered 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 farther east, Sumas Mountain, expose the oldest rocks. These are mainly freshwater sedimentary rocks that were deposited in a depression now 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 as the Coast Mountains rose, (mostly since mid-Miocene time) and are now gently 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 in water between glacial events. They are best seen in the sea cliffs around UBC (Wreck Beach), 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 this material, such as in the Point Grey area, are vulnerable to erosion by storm-generated waves and would be quickly 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 6 to 9 kilometres underwater into the Strait of Georgia as an area of shallow water and banks. Beyond that, the delta front slope and submarine flows carry deltaic material practically across the strait. 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 liquefaction. (This happens when the grains lose contact with each other.) The wet sand becomes fluid during vibration such as that created by an earthquake and large structures built on it can 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.

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 part of the Pacific Ocean floor and were pushed up onto the continent in the last 10 million years.

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 about 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.

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 a 60- to 80-year old second growth conifer forest. Because these rocks aren't easily dissolved or otherwise weathered, the water at the source 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 form 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.

Geological time: The fundamental dimension in geology is time. It involves very large numbers, which are beyond real comprehension. The oldest earth rocks come from the cores of Precambrian shields. In Canada the oldest granites are north of Lake Superior (3.9 billion years). The oldest zircon dated recently from British Columbia came from a metamorphosed conglomerate southwest of Bella Coola (3.6 billion years). In western Australia, zircons from the felsic volcanic rocks of the Duffer Formation have yielded ages of 4.1 to 4.3 billion years. The fact that we have not dated older rocks, means just that. They may exist, or may have existed. Most meteorites are somewhat older; the oldest have been dated at about 4.6 billion years. Currently we guess that the earth and planetary system are probably about 5 billion years old. It is, of course, speculative, but a major event seems to have taken place about that time, and we are unable to "see" through it. On the basis of different theory astronomers estimate the sun's age at about 16 billion years.

One way to get a feel for geological time is to reduce its 5 billion years to a single calendar year, as is done in Figure 2. On that scale, abundant evidence of life did not appear until the 19th of November (570 million years ago), but scarce, soft bodied, cryptic forms appear in much older rocks. Fossils of very primitive organisms have been found in the oldest known unmetamorphosed sedimentary rocks, the Onverwacht Series of South Africa. They are about 3.4 billion years old, about April 27th on our calendar. Some calcareous stromatolites, peculiar, finely laminated masses formed probably by blue-green algae, are about 2.8 billion years old (June 9th).

The best preserved assemblage of Precambrian microfossils occur in the Bitter Springs Formation of central Australia. Although mainly blue-green algae, they include spores. They are about 900 million years old (September 16th).

After the beginning of the Cambrian period (November 19th) the major life forms developed "rapidly". Some milestones of note include:

- **first vertebrates**, Late Ordovician, 440 ma, Nov. 29th.
- **first fish**, Late Silurian, 410 ma, Dec. 1st.
- **first land plants**, Late Silurian, 410 ma, Dec 1st.
- **first large trees**, Early Devonian, 390 ma, Dec 2nd.
- **first amphibians**, Late Devonian, 367 ma, Dec 4th.
- **first reptiles**, Early Pennsylvanian, 318 ma, Dec 8th.
- **first mammal-like reptiles**, mid-Permian, 256 ma, Dec 12th.
- **first dinosaurs and first true mammals**, Late Triassic, 223 ma, Dec 15th.

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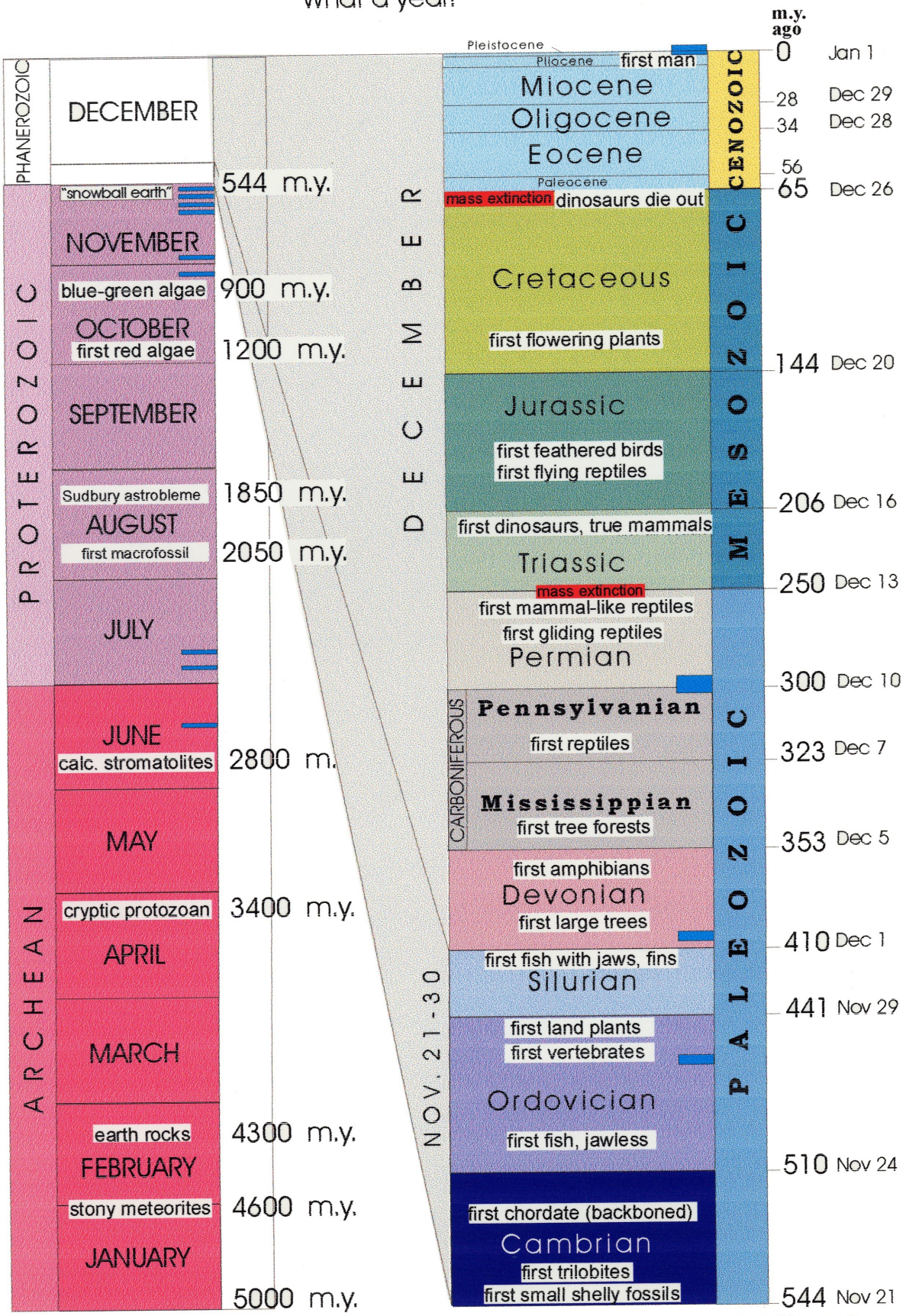
PART 2

GEOLOGIC TIME IN A YEAR

What a year!



J.A. Roddick, 2001
GSC, Vancouver

Figure 1. Geological Time Scale

(geological time scale based on Okulitch, 1995)

- **first flying reptiles and feathered birds**, Middle Jurassic, 166 ma, Dec. 19th.
- **first flowering plants**, Early Cretaceous, 135 ma, Dec 21st.
- **first man**, depends on definition, 2-5ma?, Dec 31st. The first hominid foot prints that look like ours are about 4 million years old. First tools are about 2 million years old. First art may be 100,000 years old.

The days passed by more quickly in the Paleozoic. Annual growth lines are found in trees, fish scales, sediments, etc. Some Devonian corals show not only annual, but also daily growth lines. This is of more than passing interest, because, when counted, they average 399 days for the Devonian year. This is consistent with modern measurements which indicate that the earth's rate of rotation is slowing by about one second every 50 thousand years. The Cambrian day was about 21 hours, and the year was about 420 days.

STOP 1: Point Grey sea cliffs

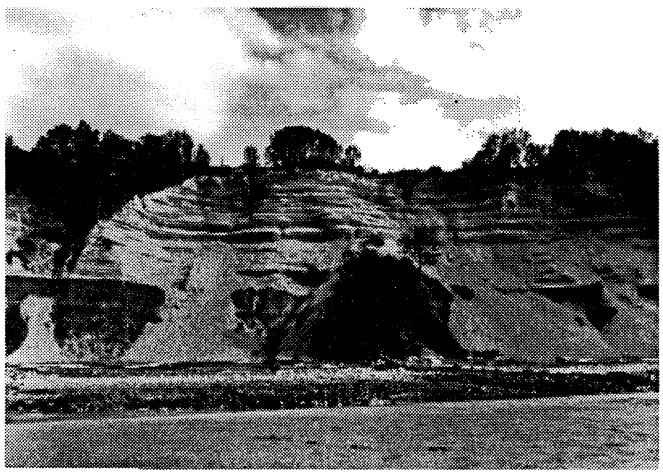


Figure 3. Quadra sand capped by till at west end of Point Grey. Photo by J.J. Clague, 1976.

The sea cliffs at the west end of the University of British Columbia (9 km west of downtown Vancouver) expose 62 metres of sand, overlain by thin till, glaciomarine mud with pebbles, and beach gravel (Fig. 3). Most of the geological information about these strata is taken from Clague, 1977[2], and Clague, et al., 1987[3]

How are the strata here interpreted? Much geology is based on the simple premise that upper strata are younger than lower strata. Events are ordered in time by superposition. Later folding and thrusting can reverse the sequence, or leave the strata near vertical. In all cases, it is necessary to know which way is up before the history of a section can be unraveled. For young near horizontal strata, such as we have here, we don't have to worry about the many complications found in older rocks.

The sand has been named the Quadra Sand and is found in many places around the margins of the Georgia Basin (see Figure 4). As it does in most places the unit here consists of well sorted sand and minor gravel and silt. Silt is restricted to the lower 18 metres, and forms horizontal beds and laminae within the sand. Plant remains are common in this lower part of the unit and have yielded four radiocarbon dates ranging from 24,400 +/- 900 to 26,100 +/- 320 years BP, respectively.

The sand is horizontally laminated and cross-stratified, the result of deposition in the channels of braided rivers. Detailed analysis of the axial orientation of crossbeds in troughs in the Quadra Sand was undertaken here and elsewhere in the Strait of Georgia region to determine flow directions during deposition of the unit. The study showed that the Quadra Sand was deposited by streams flowing from the west, northwest, and north, and that the flow direction shifted repeatedly during deposition (Fig. 5). Flow indicators from the lower, silt-rich portion of the unit are more southerly directed than those from the upper part.

The lower part of the unit at Point Grey also differs mineralogically from the upper part. Sediment below 18 metres elevation contains abundant volcanic rock fragments (including glass), and hypersthene is the dominant heavy mineral. The provenance of this volcanic detritus is the Mount Garibaldi area about 70 km north of Vancouver. In contrast, sand above 18 metres elevation consists almost entirely of feldspar (mainly plagioclase), quartz, and minor lithic fragments derived from granitic rocks of the Coast Mountains; the main heavy minerals are hornblende, biotite, chlorite, magnetite, and hematite. These observations indicate that the lower part of Quadra Sand at this site was deposited by streams flowing south-southwest down Howe Sound from the Mount Garibaldi area, and that about 24,500 years ago (the age of the uppermost silt bed) the flow changed towards the east and southeast, bringing granitic detritus down the axis of the Georgia Depression.

Mathewes[4] examined plant microfossils from stringers

2. Clague, J.J., "Quadra Sand", Geological Survey of Canada, Paper 77-17, 24 p., 1977.

3. Clague, J.J., Evans, S.G., Fulton, R.J., Ryder, J.M., and Stryd, A.H. "Quaternary geology of the southern Canadian Cordillera", International Union for Quaternary Research, Excursion Guide Book A-18, 67 p., 1987.

4. Mathewes, R. W., "A paleoecological analysis of Quadra Sand at Point Grey, British Columbia, based on indicator pollen", Canadian Journal of Earth Sciences, 16, pp. 847-858, 1979.

of peaty silt about 16-18 metres above sea level at this site and reported that the non-arboreal pollen (especially *Cyperaceae* and *Gramineae*) are dominant, and support the geologic evidence that the Quadra Sand was deposited in a braided-river environment under a cooler macroclimate than exists at present. High concentrations of pollen in the peat stringers, however, are incompatible with tundra conditions. Rather, the climate seems to have been montane or possibly subalpine 24,500 years ago.

some villages that may be established in the Greenland interior after the ice melts from there, the current time will not be referred to by either term!

The sand is younger to the south, and wasn't over-ridden in the Seattle area for another 6000 years (about 16,000 years ago), by the Puget Lobe of the Cordilleran ice sheet. That lobe began retreating about 14,000 years ago, but Point

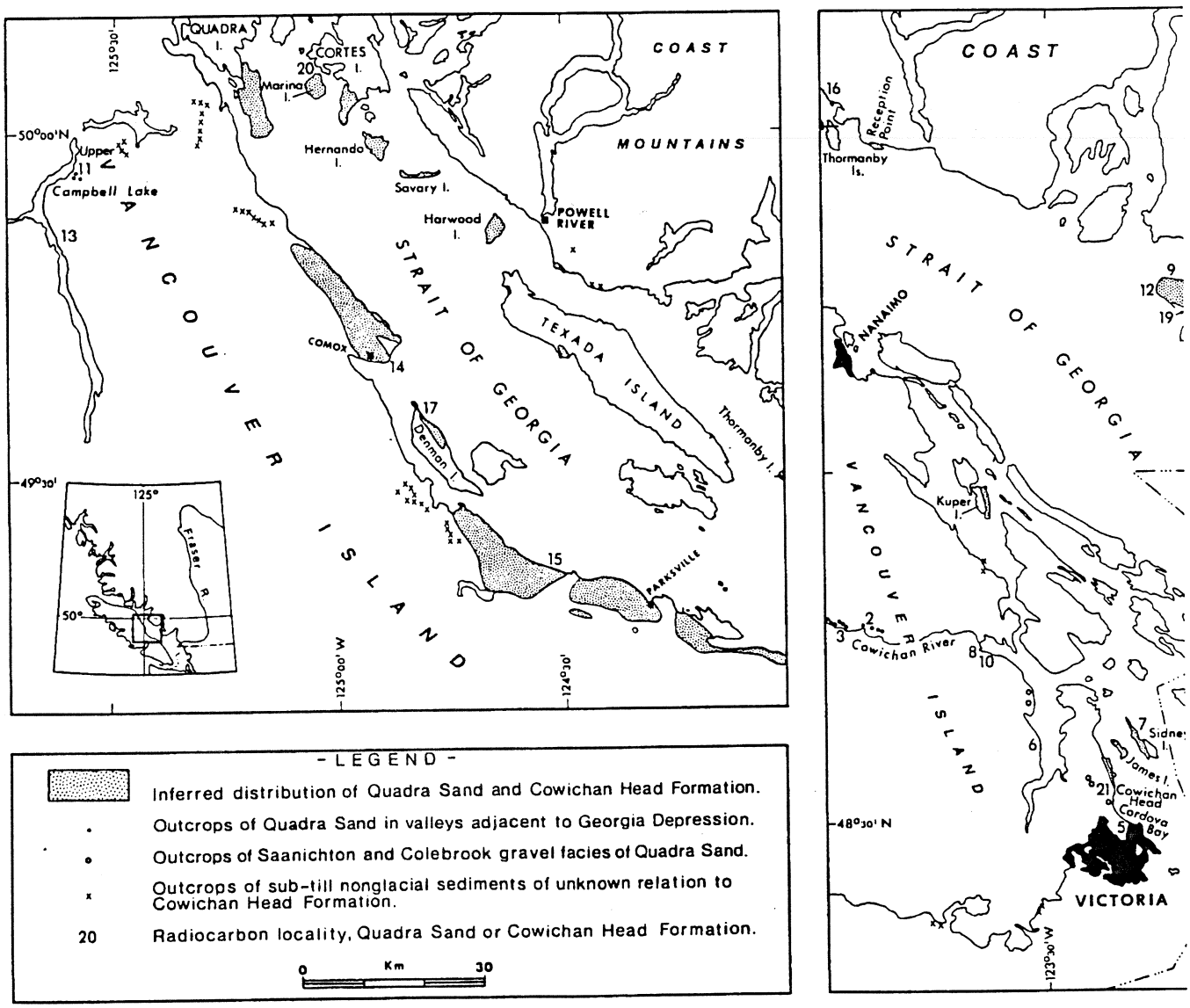


Figure 4. Distribution of Quadra Sand in the Strait of Georgia. (J.J. Clague, 1977)

The scenario that emerges has the Quadra sand being deposited in front of the advancing ice of the Fraser Glaciation. The till at the top of this section announces that the ice had arrived. That was about 22,000 years ago. This concluded what has been termed the Olympia nonglacial interval. 'Nonglacial', or the slightly more mindless 'interglacial' are terms that have only local relevance. For

Grey was not free of ice until 12,900 years ago, and Langley, more than a thousand years later.

Although the Fraser Glaciation was a feature event locally, the maximum advance of Pleistocene ice had occurred earlier, about 40,000 years ago, judging from the age of the greatest of at least four major drops in sea level

(Dott and Batten[5]). That data is derived from corals, whose living parts have a strong affinity to sea level (as well as temperature).

The route of the excursion from the University is eastward on rocks which we won't see *en route*, but will at later stops. Vancouver is built on two low east-trending ridges separated by the estuary of False Creek.

ridge, which is the higher of the two within the city limits. The crest is underlain by a thin veneer of glacial deposits and alluvium. They become thicker on the lower slopes. The veneer covers a thick sequence of Upper Cretaceous to Oligocene sandstone and conglomerate known as the Burrard Formation.

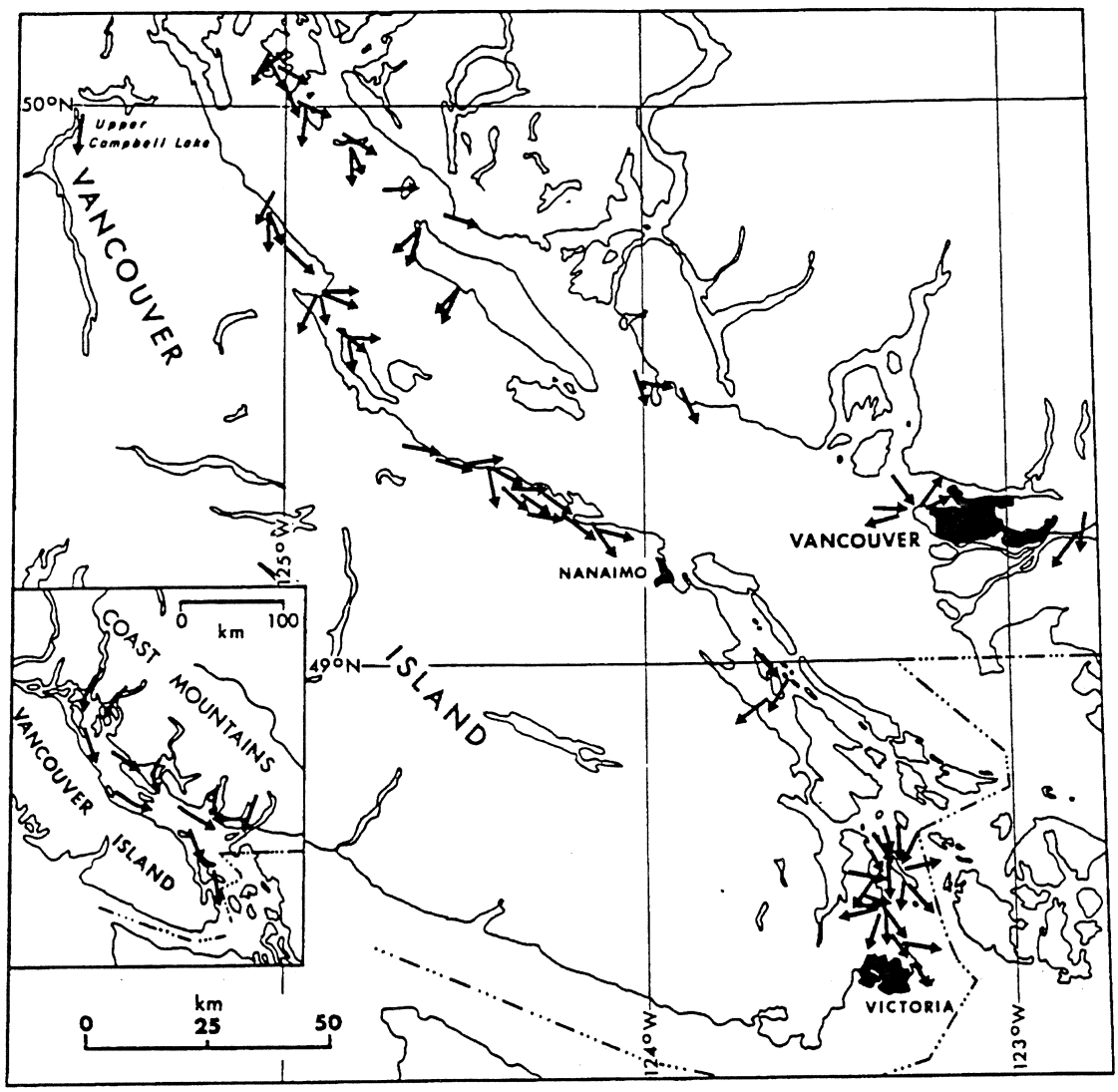


Figure 5. Flow direction of Quadra Sand streams in the Strait of Georgia. (J.J. Clague, 1977)

They form two peninsulas, the northern between Burrard Inlet (the city's inner harbour) and False Creek, and the southern between False Creek and the North Arm of Fraser River. We will travel along the upper part of the southern

STOP 2: Little Mountain, Queen Elizabeth Park

Most volcanic rocks in the Vancouver area are remnants of Cascade volcanism. The oldest examples, with an age of about 50 million years, are not seen at the surface but were found by drilling beneath the city in the northern part of False Creek. About 180 metres 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 the surface.

5. Dott, Robert H., and Batten, Roger L., "Evolution of the earth", McGraw-Hill Book Company, 649 p., 1971.

The next period of Cascade volcanism took place between 31 and 34 million years ago. This particular event was responsible for Little Mountain (this stop), the dykes at our next stop in Stanley Park. and Sentinel Hill in West Vancouver.

columns converged in places as if cooled mainly from a restricted or an uneven surface. In most places the basalt exhibits fairly well developed columns which range from about 20 cm to a metre across; some are about 10 metres high. Their attitude generally suggests a dip to the south,

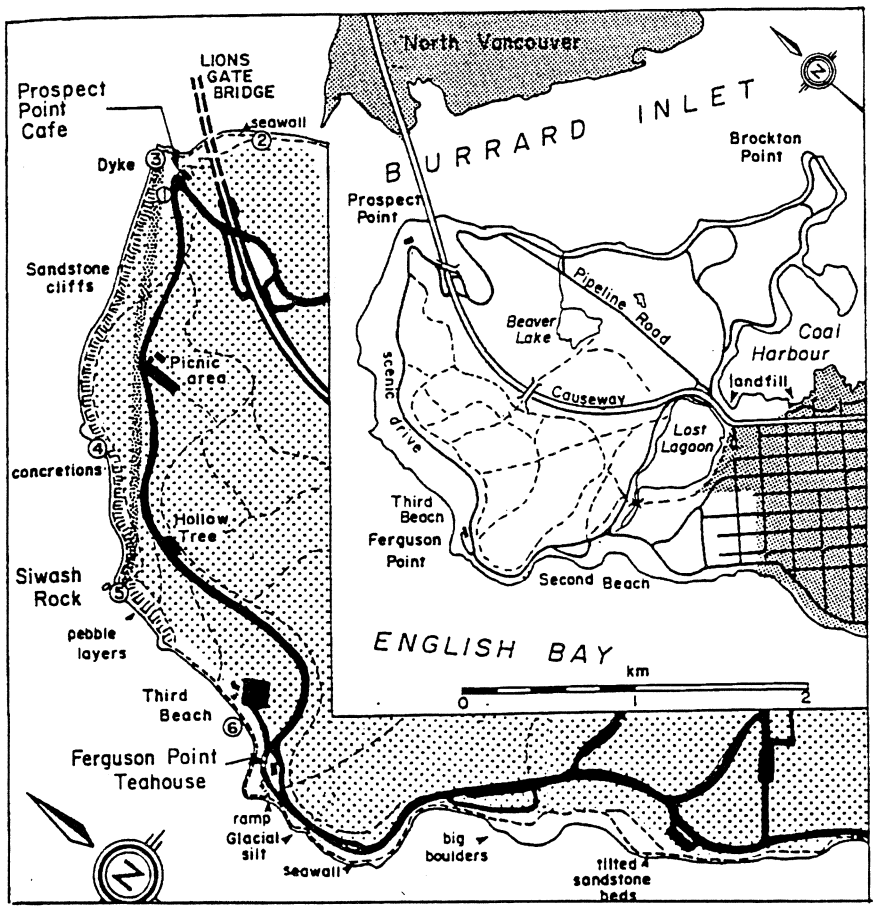


Figure 6. Between Prospect and Ferguson Points, Stanley Park. (J.E. Armstrong, 1990)

Little Mountain is a prominence because of a resistant mass of volcanic rock (augite-olivine basalt) which forms an elliptical outcrop about 1800 feet along the northwest-trending axis and 1200 feet across the short axis. The best exposures are in an old quarry which was operated in the early part of the century, for road material used in the Gastown area. It has since been converted into an impressive garden. The adjacent Bloedel Conservatory, a geodesic dome, houses more-tropical plants.

When it was less covered by vegetation, Johnston[6], a GSC geologist, examined the quarry and noted that the

but they are not consistent. No conclusive evidence has been found to establish whether the body is a flow or a sill. Johnston thought that the finely vesicular character and converging columns suggested a sill rather than a flow. The upper surface, however, had been rounded by glaciation and a more vesicular and scoriaceous top could have easily been removed by coeval erosional processes or the later glaciation. The well-developed columns are in themselves strong evidence that they are part of a thick flow. Wooton[7], an undergraduate at UBC in 1959, recorded that a dyke of

6. Johnston, W. A., "Sedimentation of the Fraser River Delta map-area," Memoir 135, Geological Survey of Canada, 1923.

7. Wooton, A.E., "The Tertiary eruptives at Vancouver, British Columbia," B.Sc. thesis, unpublished, University of British Columbia, 1959.

of the park contained pebbles and much sand, evidently derived from the underlying Eocene Burrard Formation.

A radiogenic age determination by R.L. Armstrong (U.B.C.) in 1980 yielded a cooling age for the basalt of 34.3 ± 1.2 million years which places the extrusion in the Early Oligocene. Although lithologically similar, this rock appears to be slightly older than that in Stanley Park.

From this stop the view to the north includes downtown Vancouver, Burrard Inlet and the north shore mountains.

From here our route will be along Cambie street and bridge over False Creek, then westward along Georgia Street to Stanley Park.

STOP 3: Third Beach, Stanley Park

The lower part of the Burrard Formation (Lions Gate Member) is well exposed from Third Beach to Siwash Rock. The formation consists mainly of arkosic sandstone and fine conglomerate beds with concretionary layers and scattered pebbles, and dips gently (about 11 degrees) to the south. These rocks are about 80 million years older than the Quadra Sand and are much more indurated (cohesive, not crumbly), but are not metamorphosed. According to Rouse[8] the pebbles include sandstone and siltstone from lower parts of the unit as well as granitic and metamorphic rocks. Granitic pebbles are rather rare in the exposures we will see here. Assuming no complications by faulting, Rouse calculated that about 340 metres of the strata were exposed in the park, and that they lie about 500 metres stratigraphically above the basal conglomerate exposed in the lower canyon of Capilano River on the north shore. Complications, however, do exist. When the tunnel that brings water from Capilano Valley to Vancouver was driven, a number of steep faults in the Burrard Formation were encountered. They posed no serious engineering problems, but their offset, age and significance were not established.

The conglomerate in Capilano canyon lies unconformably on a deeply weathered granitic surface that was part of a widespread peneplane that developed in the Late Cretaceous. Study of pollen by Rouse[9] from material from both the Capilano River canyon and Stanley Park discovered flora of the Campania stage of the Upper Cretaceous (about 80 million years old). The underlying plutonic rock in Capilano River canyon has not been dated, but related plutonic rocks to the west have been dated at about 100 million years. The peneplane development is, therefore, fairly well restricted to the early part of the Late Cretaceous. Rouse noted that the sediments above the erosion surface contain two distinct flora, one of Late Cretaceous and one of Eocene age. The Cretaceous (and Paleocene) part qualifies as Burrard Formation; the Eocene part may be considered Kitsilano Formation but rocks of this age are better defined south of the US border as Huntingdon Formation. Blunden[10] estimated a total thickness of about 5000 feet (1500 m) for the Early Tertiary sediments in the Vancouver area.

On the way to Siwash Rock from Third Beach, if the tide is low, a three metre-thick dyke can be seen trending westerly perpendicular to the shore. This dyke is strongly jointed and consists of a dense basalt, more basic than the basalt that forms most of Siwash Rock. It is also probably younger but no isotopic dating has been done on it.

As described in the Vancouver Geology booklet (see Fig 6), Siwash Rock appears to be related to the dyke that forms a much larger cliff at Prospect Point. The contact between the dyke near Siwash Rock and the Burrard sandstone shows minor alteration. The clay there, however, may be the result of increased alteration owing to the barrier effect of the dyke on groundwater.

At Prospect Point the dyke is large, basaltic and rises vertically about 60 metres from sea level. The dyke is about 30 metres wide at the base of the exposure, and extends southwest about 1200 metres to just south of Siwash Rock, but is not exposed at the seawall there. The dyke consists of a slightly porphyritic, fine grained basalt. The phenocrysts are mainly augite, but some are olivine crystals partly altered to serpentine. The groundmass has a well developed trachytic texture. Horizontal jointing at the base gives way to vertical columns in the upper parts, which display irregular vesicles partly filled with quartz (Johnston, 1923), possibly transitional to a flow. According to Wooton (1959), Victor Dolmage (a GSC geologist in the '20s and a successful consultant later) told him that much volcanic rock was encountered in excavations made for the present road. The present surface outcrops by the road are, unfortunately, deeply weathered.

8. Rouse, G.E., W.H. Mathews, and R.H. Blunden, "The Lions Gate Member; a new Late Cretaceous sedimentary subdivision in the Vancouver area of British Columbia," Canadian Journal of Earth Sciences, vol. 12, pp. 464-471, 1975.

9. Rouse, G.E., "Plant microfossils from the Burrard Formation of western British Columbia," Micropaleontology, vol. 8, pp. 187-218, 1962.

10. Blunden, R.H., "Vancouver's downtown peninsula urban geology," MSc. thesis, unpublished, p. 48, University of British Columbia, 1971.

The upper part of the dyke and the surface extension to the southwest is either a flow or a sill. Although no conclusive evidence is available, it may be a remnant of what was once a fairly large lava field. The Prospect Point dyke is so large it probably breached the upper strata of the Burrard Formation. Apparently identical rock on Sentinel Hill (directly across Burrard Inlet) may be a larger remnant of the field.

A whole rock K-A age of 31.5 + 1.1 Ma by R.L. Armstrong of UBC indicates an Early Oligocene age, slightly younger than the basalt at Queen Elizabeth Park.

Because of the one-way road around the park we must complete the circuit of Stanley Park before we can cross to the north shore via the causeway through the park that leads to the Lions Gate bridge. At the north end of the bridge is the mouth of Capilano River which separates the municipalities of West Vancouver to the west from North Vancouver to the east.

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 metres thick and contains pebbles to boulders of granitic and metamorphic rock in a sandy matrix. It is one of the few places where the base of the Georgia Basin is exposed.

Our route continues through West Vancouver's Ambleside and Dundarave commercial areas to Caulfeild.

STOP 4: Caulfeild

Most of the coastline in West Vancouver consists of rounded, wave-washed granite outcrops, but these have deteriorated over the years owing to big-city grundge and encroaching vegetation. Here at Caulfeild (the unconventional spelling is correct; it was derived from the name of the original settler) the small scenic headland is underlain by a large inclusion of amphibolitic gneiss (exposed for about 900 m) immersed in and cut by granodiorite (varying to quartz diorite), pegmatite and aplite (Fig. 7). In its general complexity it is typical of many areas on the west side of the Coast Plutonic Complex, but in its particular combination of diverse features this area is possibly unique. As one of the more interesting sites of geological controversy in the Vancouver area, it has since been visited by countless U.B.C. students and many practising geologists. It was first studied in considerable detail in 1930 by Phemister[11], a visiting professor at U.B.C. from Aberdeen, Scotland. His report was delayed until 1945 by his other duties and the war.

The gneiss is layered (near vertically) and streaky. The dark layers (amphibolite) and consist mainly of plagioclase feldspar and hornblende, whereas the broader light-coloured granitoid-looking areas consist mainly of a slightly more sodic plagioclase, quartz and minor K-feldspar. Phemister concluded that the gneiss was derived from mafic flows, tuffs and breccias possibly correlative with those on Bowen Island to the west.

The Caulfeild gneiss is lithologically similar to and structurally parallel with that on Mount Strachan to the northeast and at Horseshoe Bay to the northwest. The gneiss is cut by dykes of aplite (sugary-textured), pegmatite (very coarse grained), granodiorite (less potassic than true granite) and andesite (intermediate volcanic rock). Discontinuous layers of feldspathization and, in places, irregularly-shaped pegmatite masses can be seen in the gneiss. The inclusions in the granodiorite are irregularly distributed and locally abundant. They show all stages of conversion from amphibolite and gneiss to granodiorite.

Like most sciences, geology has had its share of controversies. The origin of granite is one. Although it is too complex a problem to deal with here, except in the broadest terms, One aspect is shown by the synplutonic dyke on the west side of the Caulfeild outcrop. Phemister thought that it was actually pre-batholithic. He noted that although the dyke is bordered by granodiorite, it is also, in places, cut by the granodiorite. He further pointed out that here and there remnants of Caulfeild gneiss seem to be adhering to it. He postulated that the dyke had originally intruded the gneiss, but most of that had later been removed by delicate magmatic stoping during intrusion of the granodiorite. He favoured a magmatic origin for the granodiorite based mainly on dilation-offset shown by granodiorite dykes, rotated slabby xenoliths, and inclusions of different lithologies in close proximity to one another. He maintained that had the granodiorite formed by granitization, such features could not exist. H.H. Read disagreed.

Read, the most well known of British granite geologists of the time, had agreed to present Phemister's paper to the Geological Society of London. Read was a great lecturer, and he presented Phemister's paper on these rocks, probably better than Phemister, himself, could have done. Magmatists hold that granites are merely products of slower cooling

11. Phemister, T.C., "The Coast Range Batholith near Vancouver, B.C.," Quarterly Journal, vol. 101, pp. 37-89, Geological Society of London, 1945.

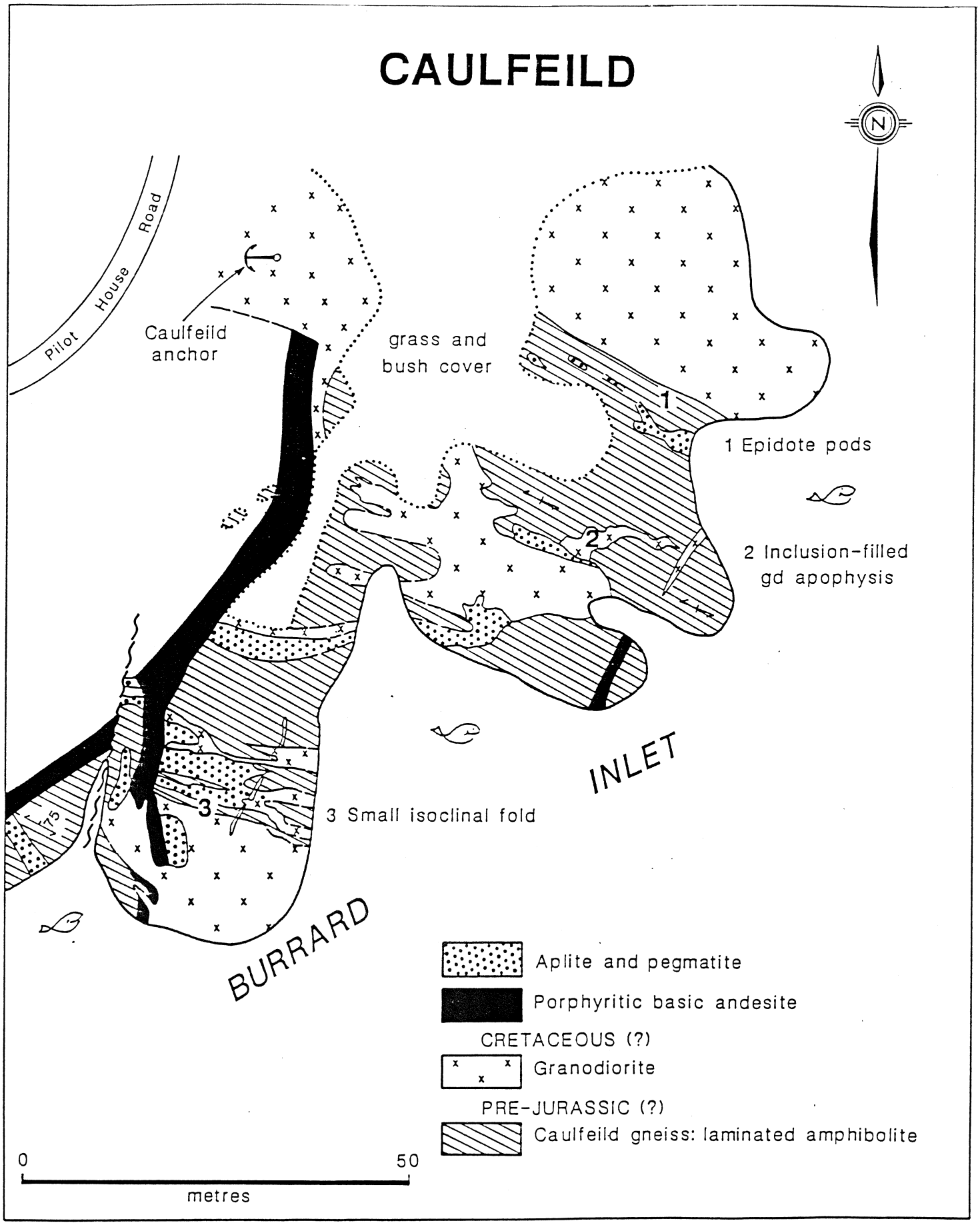


Figure 7: Geology of Caulfeild headland. After McTaggart, Greenwood and Read, 1972.

magma that, had it reached the surface, would have otherwise produced common volcanic rock. Read, on the other hand, was 'an old soak' as he often said, that is, a granitizer, who maintained that granites formed at below melting temperatures by metamorphism and metasomatism (a passive mineralogical and textural evolution).

Although on opposites sides of, perhaps, the greatest controversy in geology, the two were good friends and highly respectful of each other. The magmatic view is overwhelmingly predominant in the geological community of today, but after forty years of working on granites around the circum-Pacific region, this writer (Roddick) remains on the opposing side.

Read maintained that Phemister's 'pre-batholithic' dyke could have been more easily preserved if the original country rock (i.e., the gneiss) had been removed by selective replacement.

As a graduate student in the early 1950s (at Cal Tech and the University of Washington), Roddick investigated many similar dykes in the surrounding region and concluded that neither process could free the dykes from the country rocks. The dykes had formed from magma that obviously had filled fractures in granitic rock. Magma cannot sustain fractures; the granitic rock, therefore, could not have been magmatic at that time. Yet, the dykes had later clearly been intruded, torn apart, and feldspathized by the same granitic rock.

The evidence indicated that they had intruded the granitic mass as well as its inclusions and pendants when the plutonic rock had sufficient strength to sustain fractures, yet reacted to long applied stress by very slow plastic creep which was more than sufficient to rupture bodies such as dykes and country rocks. The granitic rock was also in a stage of active recrystallization, in which it could cause the same type of crystals to form in the dykes as were forming in the granitic rock. In the resulting thesis Roddick[12] introduced the term 'synplutonic' for these dykes. Synplutonic dykes are an intriguing feature of the B.C. Coast Mountains and are found also in many other places around the world. Those at Caulfeild lack the features of the better examples that can be seen elsewhere in the Coast Mountains. (A couple of synplutonic dykes are shown in Figure 8). Briefly, this writer favours the view that granitic rocks form at depth by metasomatism and are subsequently forced upward in salt-dome fashion by plate tectonic pressures at less than magmatic temperatures. While evolving, the granite is susceptible to intrusion by synplutonic dykes.

If time allows, we will drive up the Cypress Bowl Road to the lookout.

STOP 5: Lookout on Cypress Bowl Road

On the road up to the lookout the plutonic rock shows well-developed joint planes, sub-parallel with the present slope believed by some to be an exhumed Late Cretaceous erosion surface.

This stop affords a good view of the Lower Mainland. When visibility is good, Vancouver Island appears on the horizon to the south and west, separated from the mainland by Georgia Strait and the Gulf Islands. To the southeast the southern margin of the Fraser Lowland is marked by the Chuckanut Hills south of Bellingham, Washington. More easterly is Mt. Baker, the 15,000-foot northernmost volcano in the U.S. cordillera, still steaming from the last ash eruption in the 1840s. Stanley Park and Lions Gate bridge are in the foreground below. To the east our view is obscured by bush but the south-sloping, exhumed, Late Cretaceous erosion surface can be seen. This surface can be projected beneath Sentinel Hill. The southern slopes of Burnaby Mountain and Capital Hill are controlled by bedding in the Burrard Formation, essentially parallel with the old erosion surface, perhaps a thousand metres below.

The wall at this stop consists of the underlying granodiorite and tonalite derived from a quarry above the lookout.

12. Roddick, J.A., "Vancouver North, Coquitlam and Pitt Lake map-areas," Memoir 335, p. 276 p., Geological Survey of Canada, 1965.

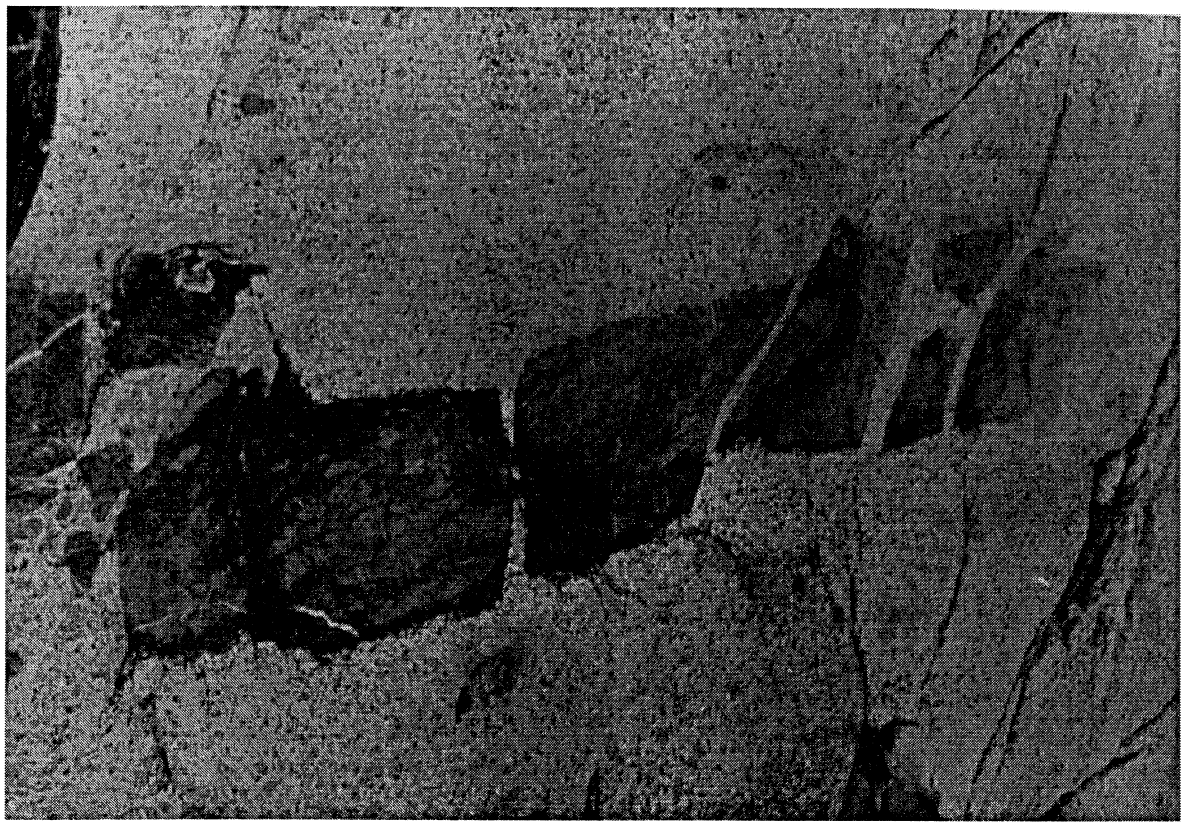


Figure 8A: Synplutonic dyke, Cortez Island, Bute Inlet map area.

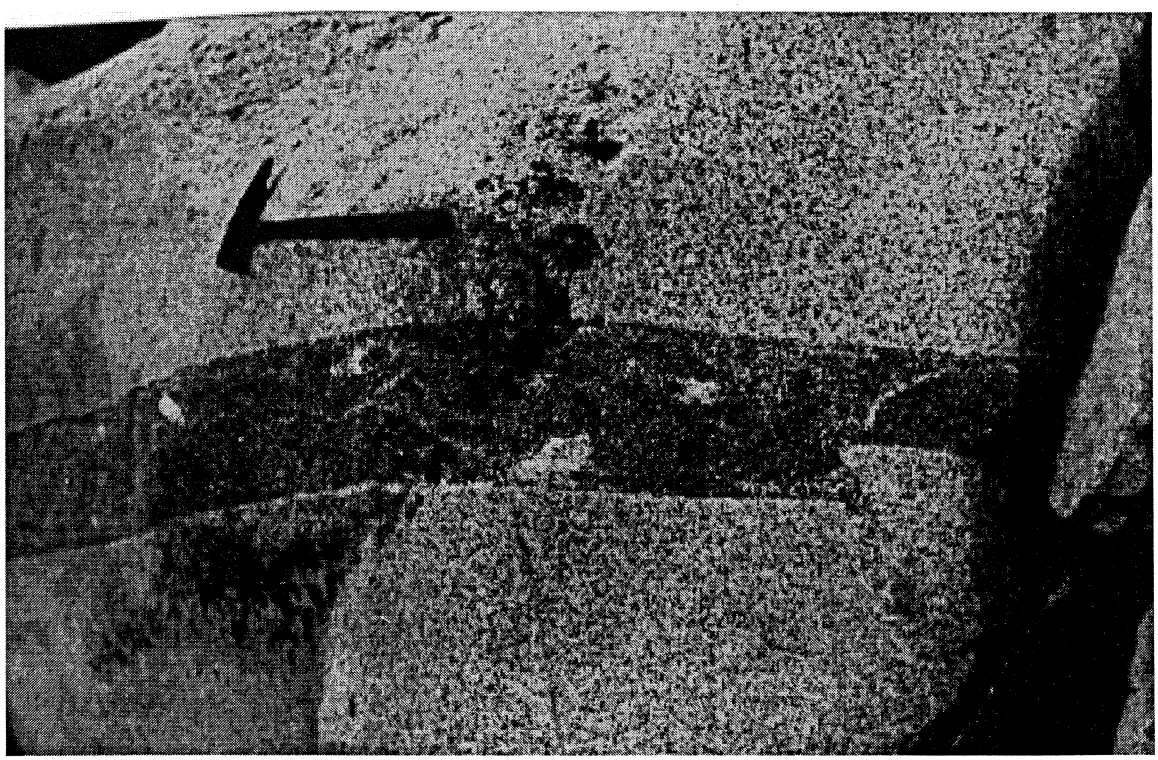


Figure 8B: Synplutonic dyke, Vancouver North map area.
Note the heavy feldspathization.

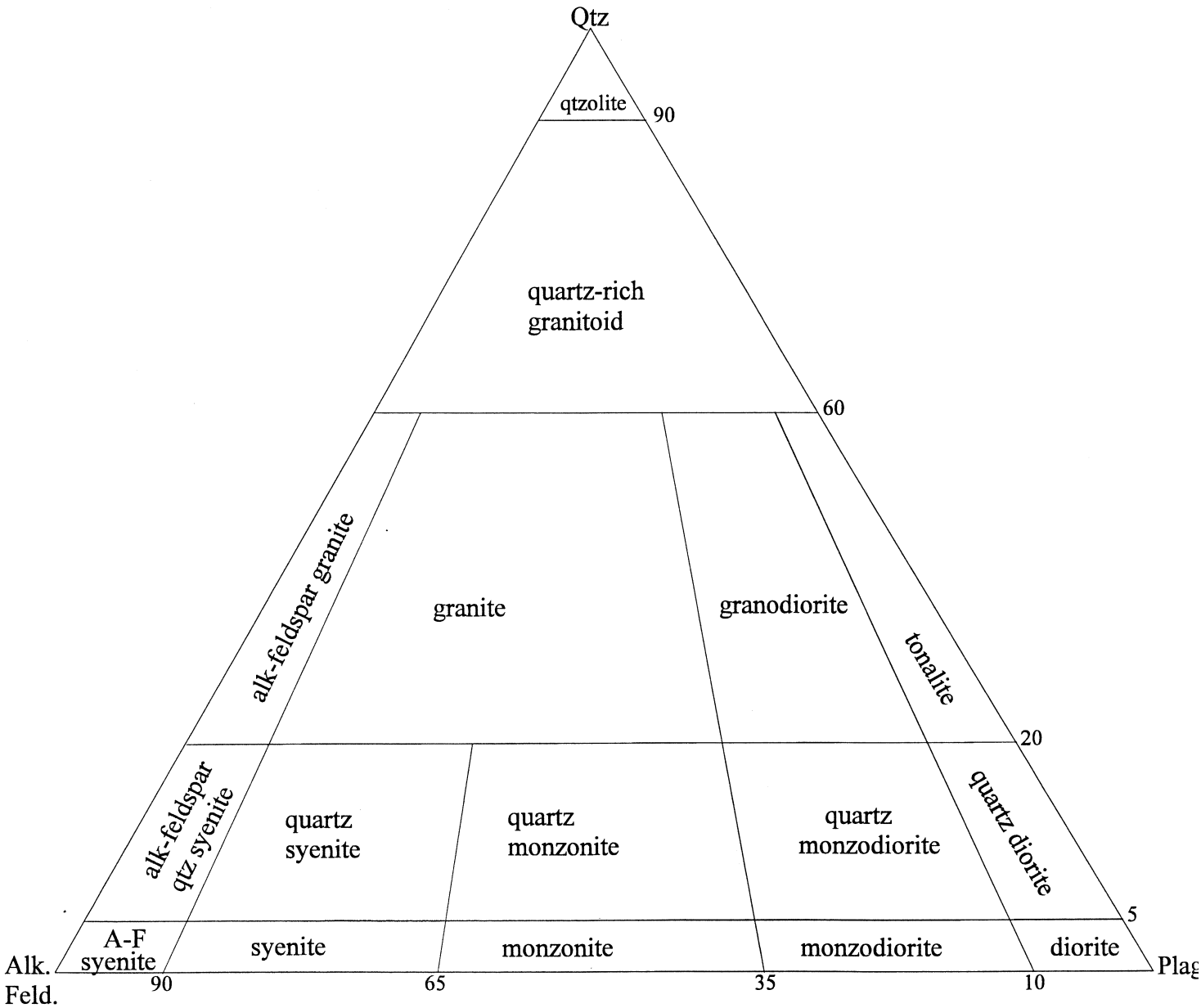


Figure 9: I.U.G.S. Classification of Plutonic Rocks

After Streckeisen, A.L. (1976). To each plutonic rock its proper name. *Earth Science Reviews,* v. 12, p. 1-33.

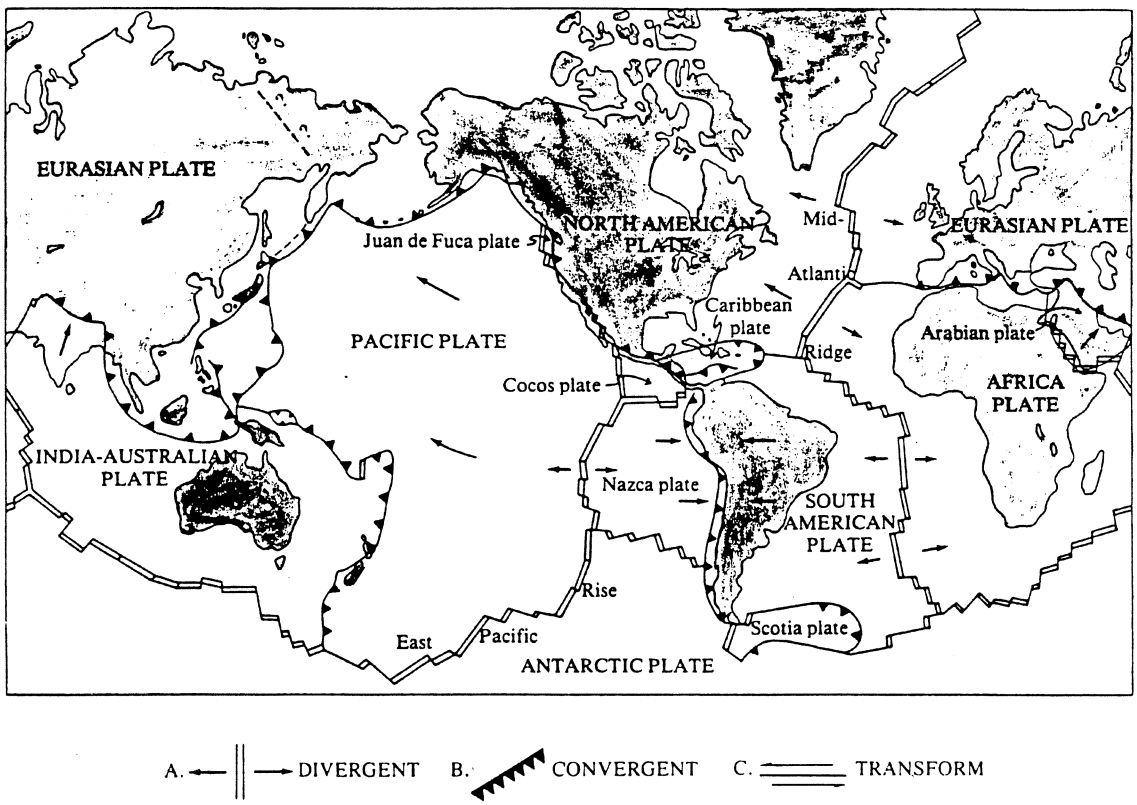


Figure 10: Mosaic of rigid plates that contitute the earth's outer shell

A. is a divergent boundary
B. is a convergent boundary
C. is a transform fault boundary.

(After W.B. Hamilton, U.S. Geological Survey)

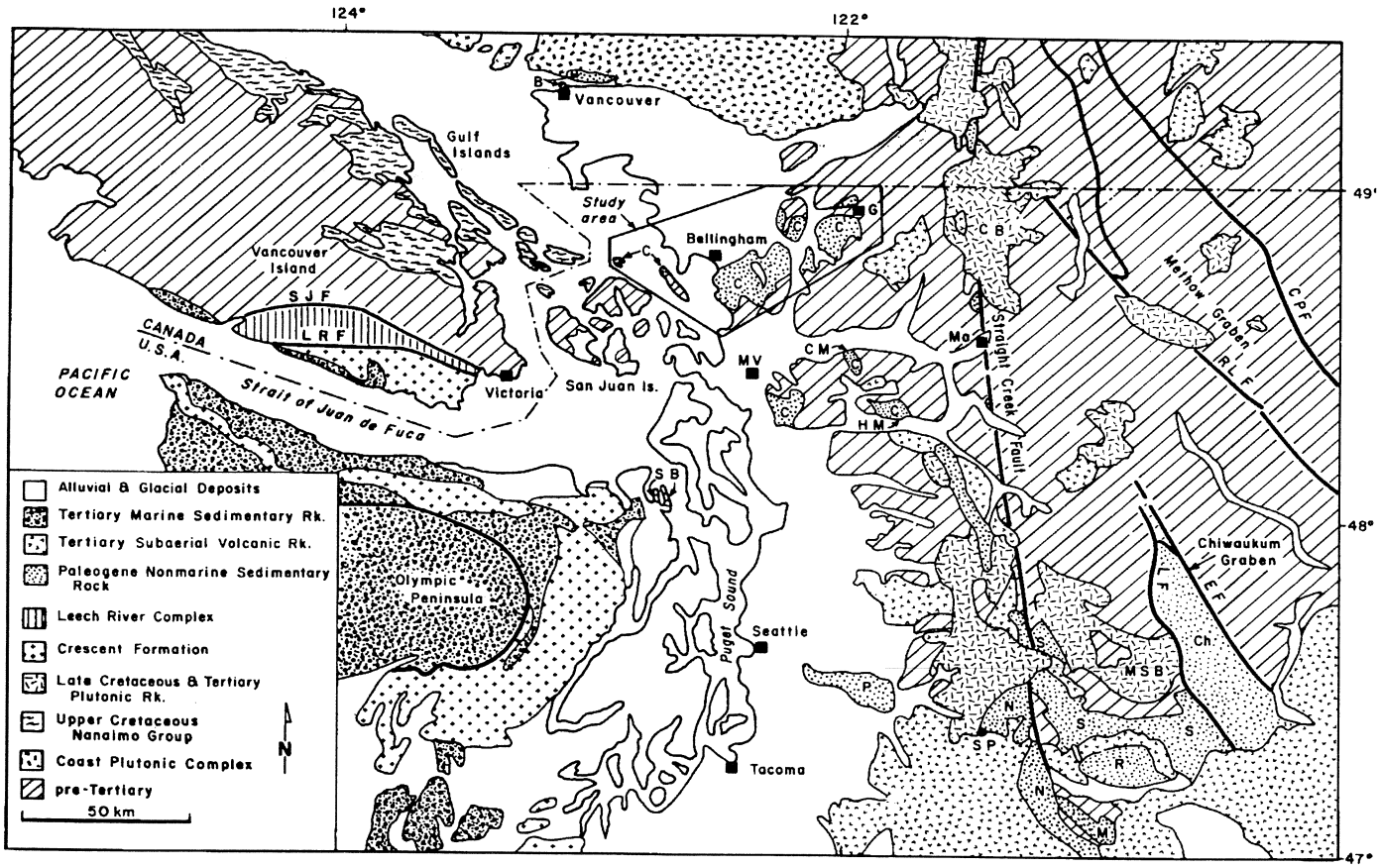


Figure 11: Generalized geological map of western Washington and southwestern British Columbia

Abbreviations: B = Burrard and Kitsilano Fm; C = Chuckanut Fm; CB = Chilliwack Batholith; CM = Coal Mountain; CPF = Chewack-Pasayten fault; Ch = Chumstick Fm; EF = Entitat fault; LRF = Leech River fault; M = Manashtash Fm; MSB = Mount Stewart Batholith; MV = Mount Vernon; Ma = Marblemount; N = Naches Fm; P = Puget Group; R = Roslyn Fm; RLF = Ross Lake fault; S = Swauk Fm; SB = Scow Bay unit; SJF = San Juan fault; SP = Snoqualmie Pass.

From: S.Y. Johnson, 1984, Stratigraphy, age, and paleogeography of the Eocene Chucanut Formation, northwest Washington: Canadian Journal of Earth Sciences, v. 21, p. 92-106.

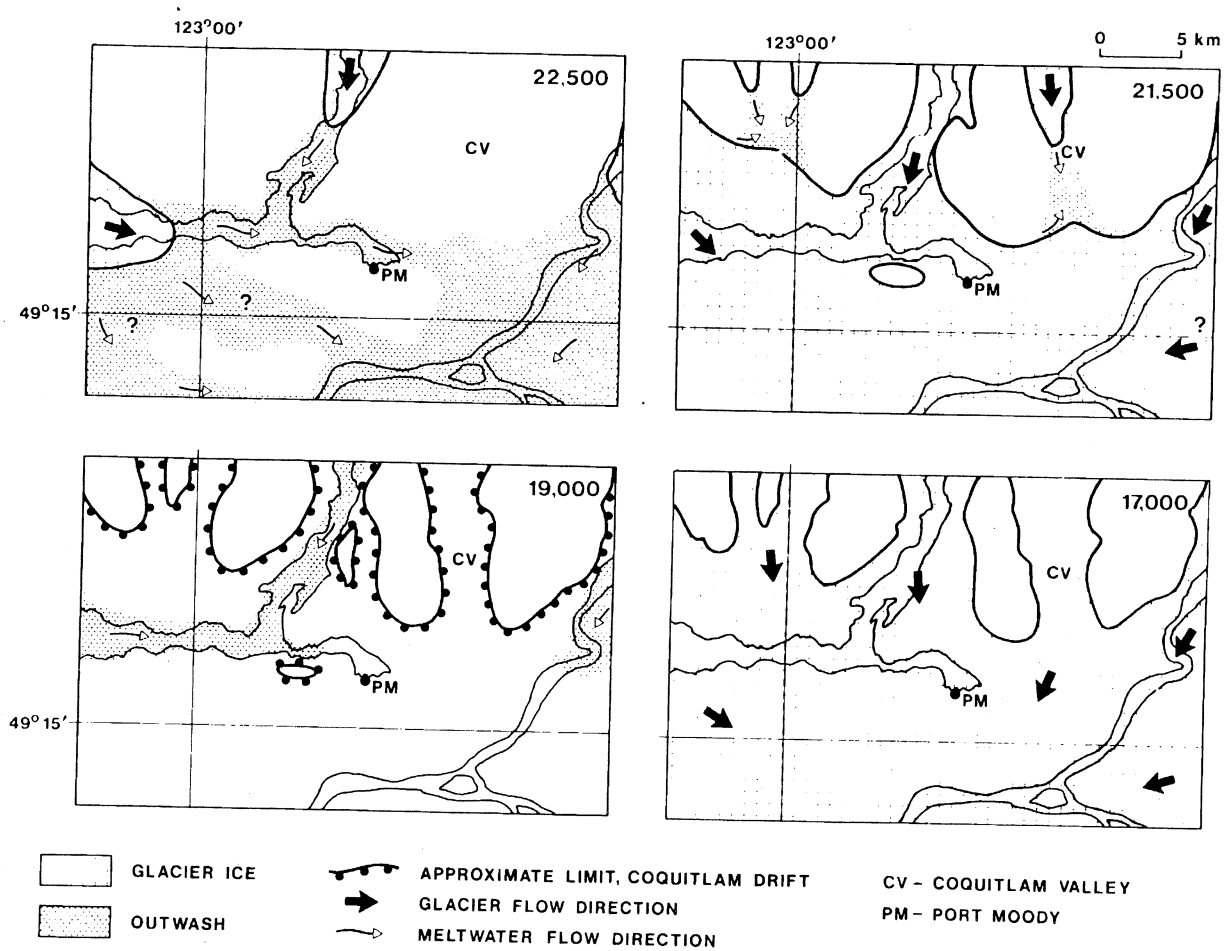


Figure 12: Paleoenvironmental reconstruction for late Quaternerary time, lower Coquitlam Valley and adjacent Fraser Lowland.

From Clague, J.J. and J.L. Luternauer and R.J. Hebda, 1983, Sedimentary environments and postglacial history of the Fraser Delta and lower Fraser Valley, B.C.; Canadian Journal of Earth Sciences, v. 20, 1314-1326.

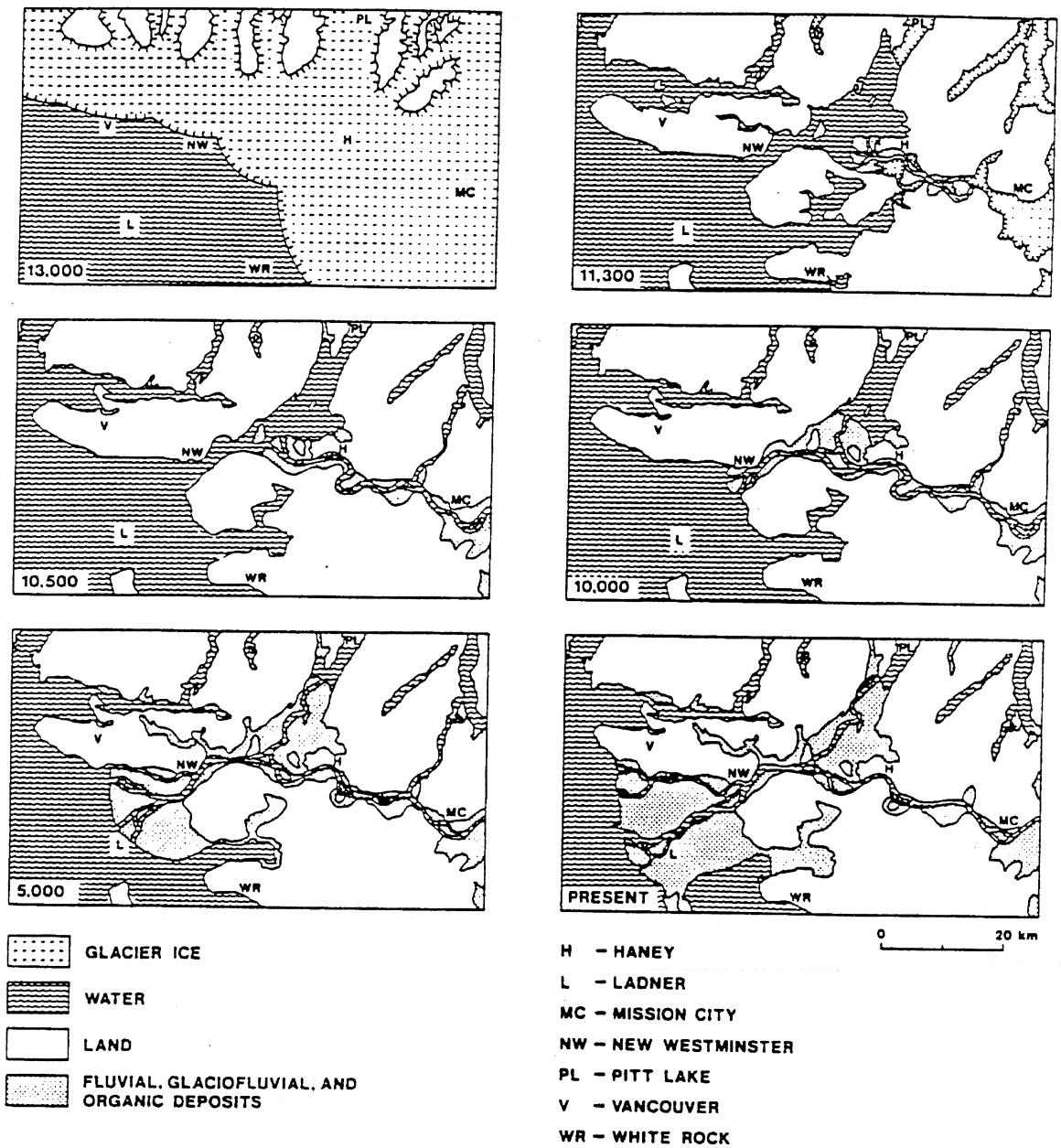


Figure 13: Evolution of the Fraser River floodplain and delta.

Dates are approximate, and ice margins hypothetical.

From Luternauer, J.L. and J.J. Clague, Geology of the Vancouver area: Late Quaternary evolution; IUGG fieldtrip guidebook B5, 1987.

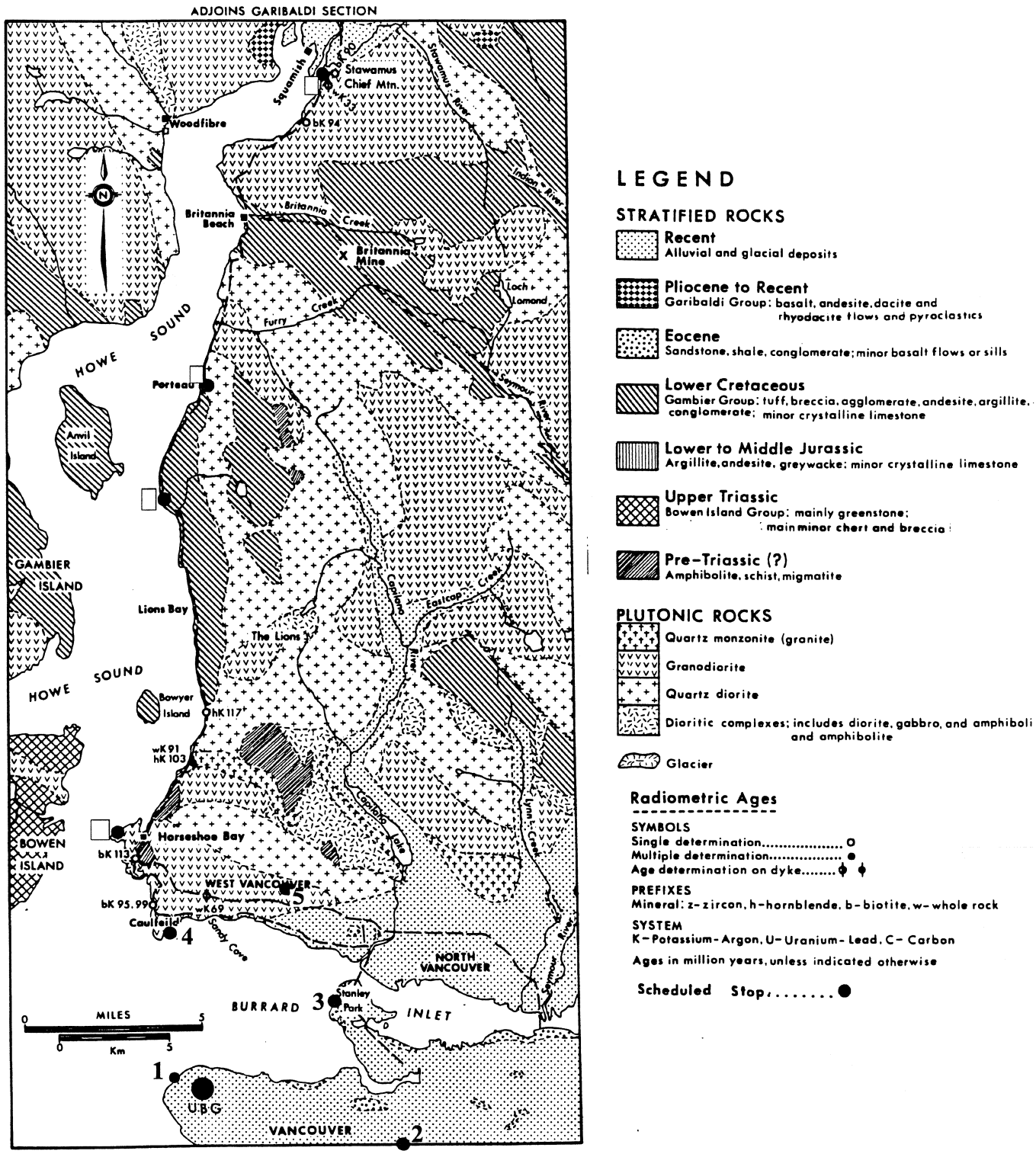


Figure 14: Generalized geology of Vancouver-Howe Sound area.

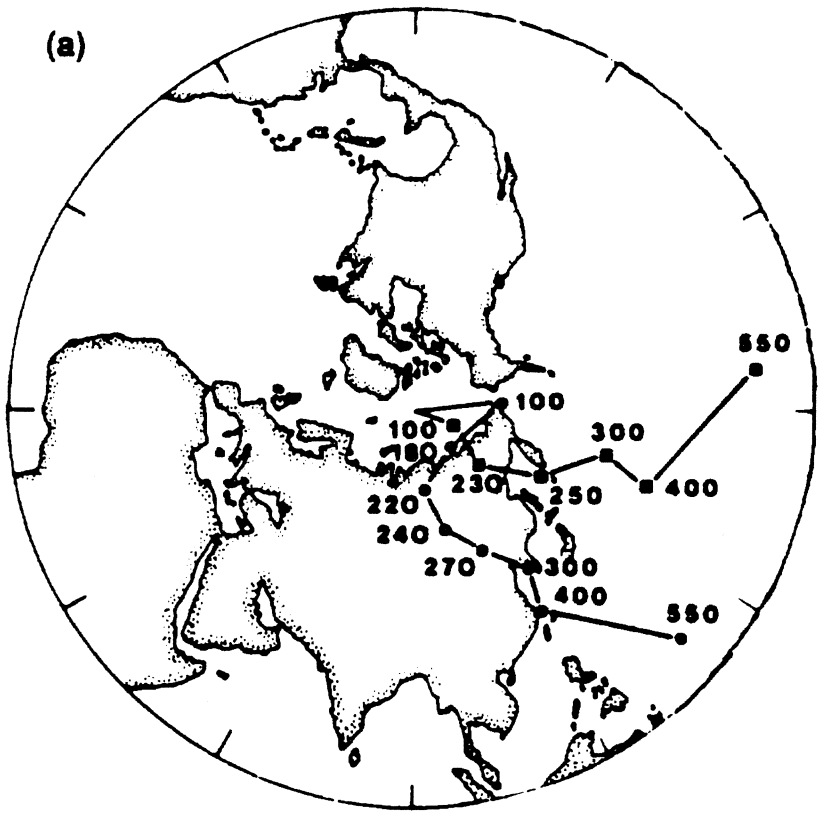


Figure 15a: Polar wander curves for North America (circles) and Europe (squares).

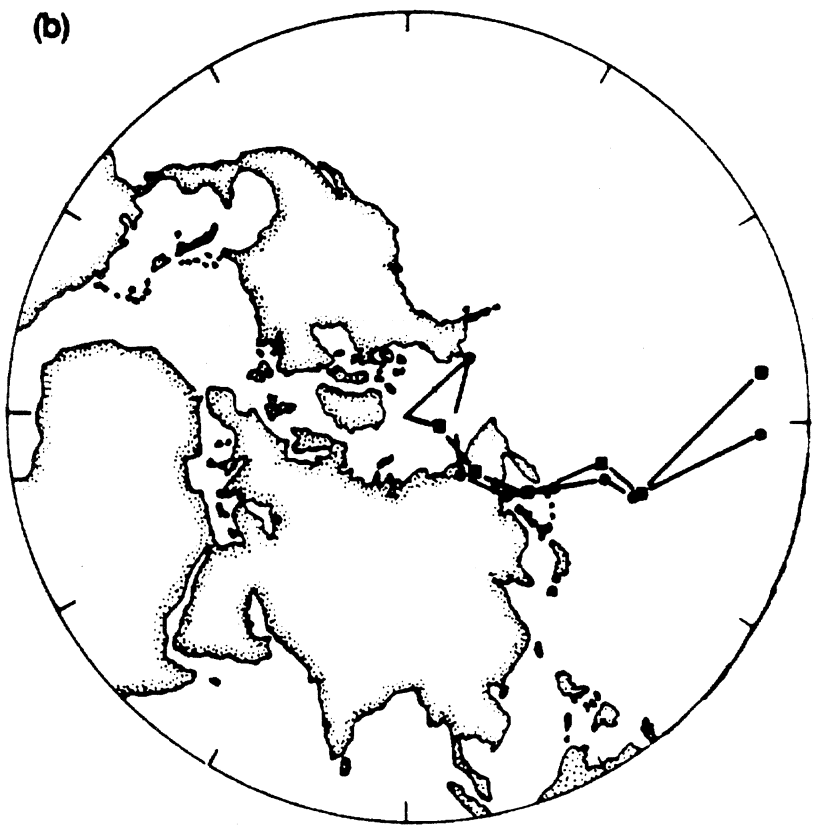


Figure 15b: Polar wander curves for North America and Europe when allowance has been made for the opening of the Atlantic Ocean. (After McElhinney, 1973).

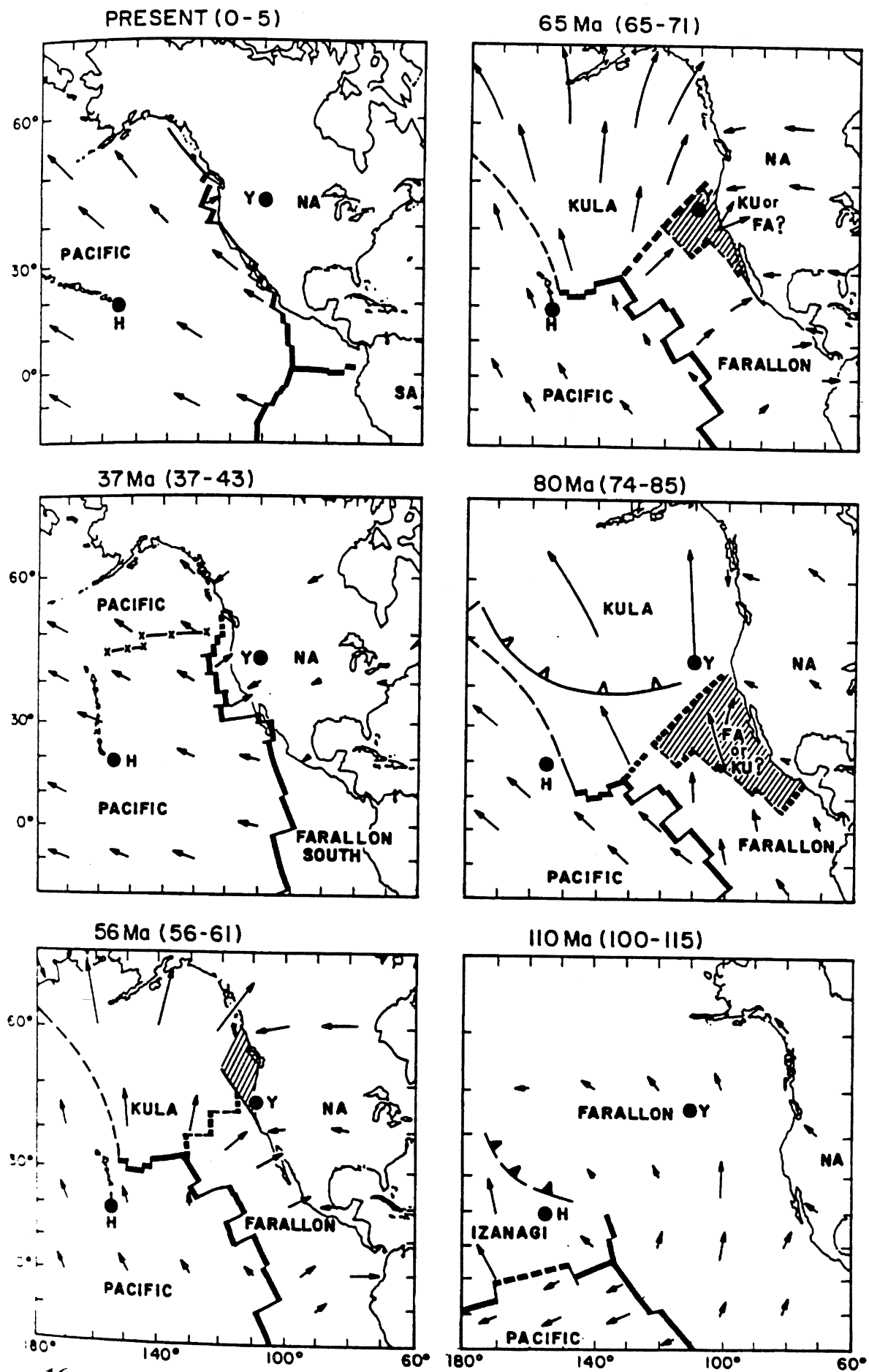


Figure 16:
Reconstruction of the motions of plates in the northeast Pacific Ocean: NA = North American Plate; Y = Yellowstone hot spot; H = Hawaiian hot spot. (after Atwater, 1989).

Capilano River Canyon section of the Lower Burrard Formation

Since Peter S. Mustard of the Geological Survey measured and described the section shown in Figure 17, changes have been made in the stratigraphic terminology on both sides of the U.S. border to achieve a consensual consistency. Mustard and Rouse (in press) have proposed that the terms Burrard Formation and Lions Gate Member be dropped, and replaced by Lower Nanaimo Group, and that the overlying Kitsilano Formation become the Kitsilano Member of the Huntingdon Formation (best developed south of the border). The new terminology is used in Figures 18 and 19.

The following description of the section exposed in the canyon of Capilano River used the older but still commonly used terminology.

Exposed here is the base of the Late Cretaceous part of the Burrard Formation (Lions Gate Member of Rouse). About 55 m of conglomerate and minor sandstone unconformably overlie undated quartz diorite of probable Late Jurassic age. Pollen assemblages from mudstones near here were interpreted as Campanian age (83 to 74 m.y.), suggesting correlation with the Extension-Pender-Protection Formations of the Nanaimo Group on eastern Vancouver Island (Rouse *et al.,* 1975). On the west bank of the river a few metres of the unconformity surface is exposed. The quartz diorite shows evidence of pre-Late Cretaceous exposure and weathering. It is directly overlain by poorly sorted conglomerates interpreted as alluvial fan debris flows. Higher in the section these change to interbedded arkosic sandstone and imbricated conglomerate (best seen on the east side of the canyon) which include silicified logs up to 20 cm in diameter and more than a metre long. Paleocurrents were southerly directed and the conglomerate cobbles are of local types. These are interpreted as lower fan, braided channel deposits.

Drill and tunnel construction records suggest that this exposure is overlain by about 300 to 350 m of mudstone and arkosic sandstone, all forming a fining- and thinning-upward megasequence. This succession is gradationally overlain by about 200 m of pebbly arkosic sandstone, well exposed along the seawall of Stanley Park. The overall succession is interpreted as an upward (and southward) transition from alluvial fan to fluvial floodplain environments, later buried by prograding fluvial sands.

The section measured by Mustard appears on page 24.

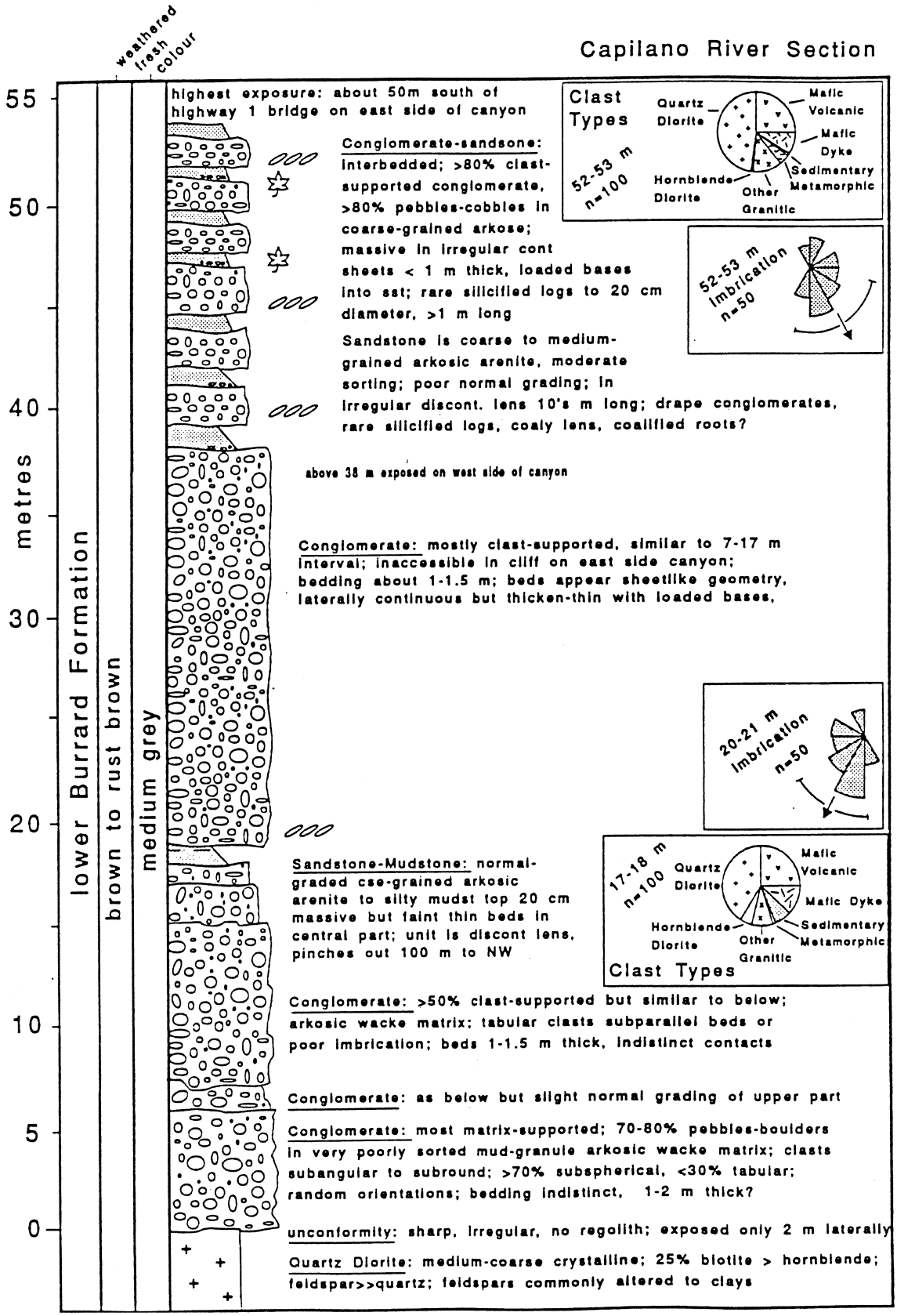


Figure 17: Lithology of Lower Burrard Formation, Capilano River Canyon

(From Peter S. Mustard, GSC)

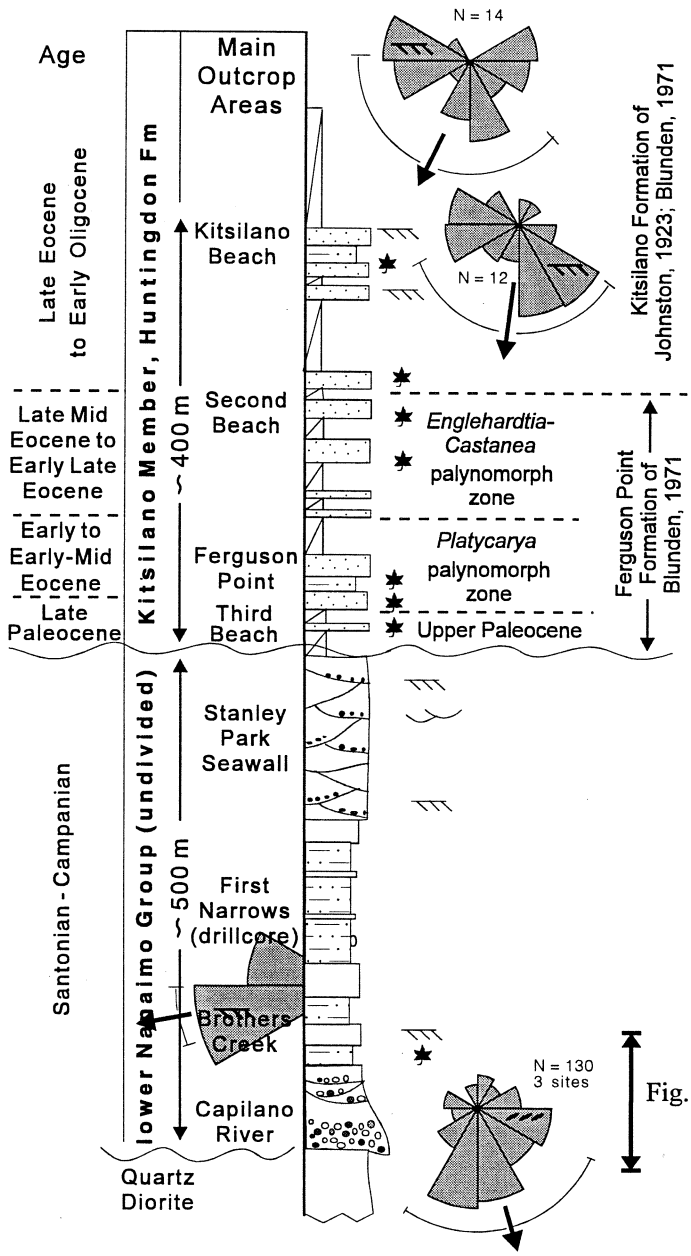


Fig. 17

Figure 18: Section of Lower Nanaimo Group (former Burrard Fm) and Kitsilano Member of Huntingdon Fm.

After Mustard and Rouse (in press)

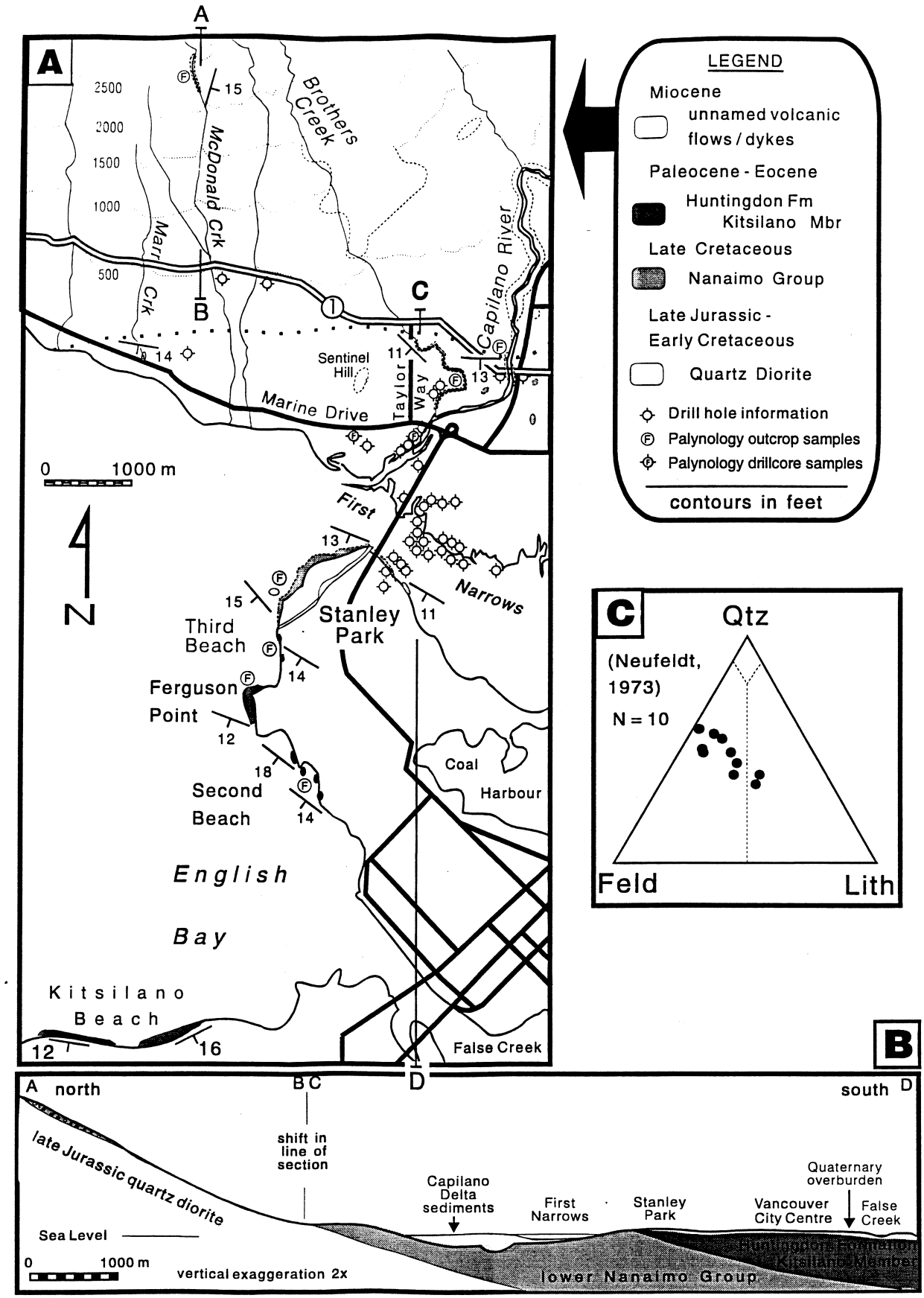


Figure 19: Distribution of Lower Nanaimo Group (former Burrard Fm) and Kitsilano Member in Vancouver area.

From Mustard and Rouse (in press)

Bibliography

Several publications of note are listed below. The first two pertain to the Vancouver area. The rest are general geology books that we have in the GSC Library, 5th floor, 100 West Pender St., Vancouver.

- Armstrong, J.E., "**Vancouver Geology**", eds. Roots, Charlie and Staargaard, Chris, Geological Association of Canada, 128 p., 1990. *Well written, easy to understand and contains a glossary of common geological terms.*
- Roddick, J.A., "**Vancouver North, Coquitlam and Pitt Lake map- areas,**" Memoir 335, p. 276 p., Geological Survey of Canada, 1965. *Old now; deals mainly with the granites; now out of print, but in Survey Library.*
- Dott, Robert H., and Batten, Roger L., "**Evolution of the earth**", McGraw-Hill Book Company, 649 p., 1971. *One of the best general geology books. Later editions are on the market but not presently in the GSC library.*
- Lutgens, Frederick K. and Edward J. Tarbuck, "**Essentials of Geology**", Charles E. Merrill Publishing Co., Columbus, Ohio, 284 p., 1982. *This soft cover book is a little newer than above, well illustrated and has a glossary. Suitable for high school students.*
- 23 'Contributing consultants', "**Geology today**", CRM Books, Del Mar California, 529 p., 1973. *Some good illustrations.*
- Gass, I.G., Peter J. Smith and R.C.L. Wilson (eds.), "**Understanding the earth: a reader in the earth sciences**", M.I.T. Press, Cambridge Mass., 355 p., 1971. *Authoritative, but not as well illustrated as the three above.*
- Fowler, C.M.R., "**The solid earth**": an introduction to Global Geophysics, 472 p., 1990. *Has a good glossary, and sound facts, but not really for the mathematically challenged.*

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http://sts.gsc.nrcan.gc.ca/page1/urban/geomap (English)
http://sts.gsc.nrcan.gc.ca/page1/urban/geomap/index_fr.htm (French)

GEOSCAPE WEBSITE

http:sts.gsc.nrcan.gc.ca/page1/urban/geoscape/geoscape.htm

GROUNDWATER QUESTIONS

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GSC WEBSITE

http://www.nrcan.gc.ca/ess/gscpacific/vancouver/gscvanhp.htm

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Monthly Circular

http://www.NRCan.gc.ca/gsc/gicd/pubs/publish.html