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Science Teacher's Geology Field Trip: Britannia Mining Museum to Vancouver

Jim Monger and Bert Struik

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SCIENCE TEACHER'S GEOLOGY FIELD TRIP: BRITANNIA MINING MUSEUM TO VANCOUVER

Jim Monger, emeritus scientist, and Bert Struik, Geological Survey of Canada

Purpose and route

The trip provides an overview of the geology of that part of the Coast Mountains between the former Britannia Mine, site of the present B.C. Mining Museum, and the city of Vancouver. We leave the Museum, head northward for a very short distance, and then return south on the east side of Howe Sound along Highway 99 (Sea-to-Sky). We join Highway 1 (Trans-Canada) near Horseshoe Bay, skirt the southern limit of the Coast Mountains in West Vancouver and North Vancouver, and return over Second Narrows (Ironworker's Memorial) Bridge to the parking lot near the PNE.

Big picture background

Vancouverites live on the western edge of the big North American Plate, ~80 km above the small, Juan de Fuca Plate. The latter forms the ocean floor west of the toe of the continental slope in water $\geq$2000 m deep. The oceanic plate dives, or *subducts*, beneath Vancouver Island and the mainland. Places where tectonic plates come together in this fashion are called *convergent plate margins* and contain two, and generally, three, components (Figure 1):

- a **subduction zone:** the surface on which one plate dives beneath and descends into the mantle. Its position in the mantle in this region is traced by seismologists from earthquakes generated by one plate "rubbing" against the other to depths of ~200 km. The surface trace of the subduction zone is the place where the oceanic plate, made of crust and the uppermost mantle, disappears beneath the overlying plate. Our local example, called the *Cascadia subduction zone*, is where the small Juan de Fuca Plate converges with and attempts to move beneath the big North American Plate at rates of ~4-4.6 cm/y. It appears that the Cascadia subduction zone currently is jammed; its subsequent release could generate a very large (~magnitude 9) earthquake, popularly known as the "big one". It is this kind of earthquake that worries our regional authorities.

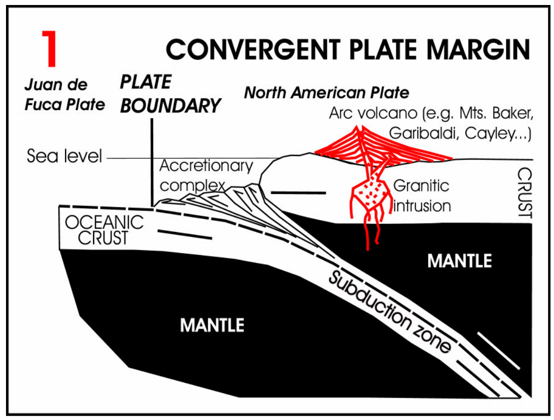

Figure 1. *Cartoon cross-section of a subduction zone representing the one under Vancouver Island and southwestern BC mainland. Some local features are identified on the figure.*

- an **accretionary complex:** made of sediments deposited on the ocean floor, and in some cases the underlying basalt, that have been scraped-off, squeegee-fashion, from the lower, oceanic, plate at the subduction zone and plastered on to the upper plate. Accretionary complexes are not everywhere present but we have one near here. It mostly underlies the submerged continental shelf and slope between northern Vancouver Island and northernmost California, but pieces of it are exposed on land on southernmost Vancouver Island and in the Olympic Mountains.

- a **magmatic arc:** located on/in the upper, overriding plate generally 100-300 km from the plate margin. It is manifest at surface by a chain of volcanoes, and in the subsurface by bodies of granitic rock. Our local example is the *Cascade magmatic arc*, which here includes the dormant or recently extinct volcanoes such as Mount Baker, which last erupted in 1872, and Mount Garibaldi. The arc extends southward, landward of the Cascadia subduction zone, includes Mount St. Helens in Oregon, the sound of whose spectacular eruption 26 years ago was heard in Vancouver, and terminates near Mount Shasta in northern California.

Geo-methodology…
This is today's tectonic situation in the region. By applying the ~200 year-old geological adage "*the present is the key to the past*" to ancient rocks, we hopefully may learn something about how the geology of the region came to be the way it is today. The Cascade magmatic arc can be traced back in time, in this region, for ~35 million years.

Still further back in time….
There is good evidence that a succession of magmatic arcs existed along what is now the western margin of the North American Plate beginning as far back in time as Middle Devonian (~390 million years ago (ma)). Much of the region between Revelstoke and western Vancouver Island is underlain by remnants of these arcs.

Most of the rocks we will see on the field trip are **remnants of an Early Cretaceous (~120-95 ma) magmatic arc** that underlies much of the southwestern Coast Mountains near Vancouver (Figure 2). This comprises arc-related volcanic rock (which hosts the ore deposits at Britannia) interbedded with marine sedimentary rock, both of which are intruded by (geologically!) slightly younger granitic rock. Along Highway 99 between Squamish and Whistler are granitic rocks that belong to a still older arc that perked away in Middle and Late Jurassic time (~170-145 ma).

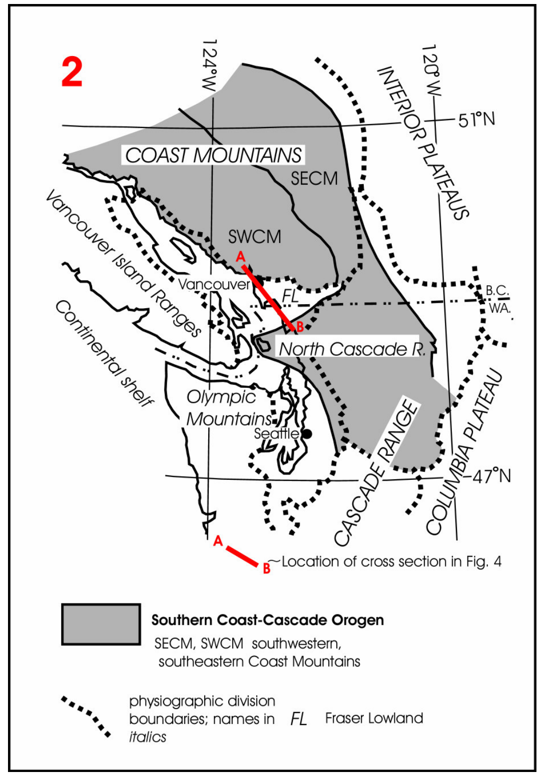

Figure 2. *Location of major physiographic features (in italics) and* geological features *in southwestern B.C., and northwestern Washington. "*Coast-Cascade Orogen*" refers to older* bedrock geology*, not physiography, although it occupies more-or-less the same region as the physiographic features called Coast Mountains and North Cascade Ranges.*

Nature and origins of the southern Coast Mountains

The Coast Mountains have a maximum elevation of ~4000 m (Mount Waddington[1], ~300 km NNW of Vancouver), and typically feature very rugged topography. The topography reflects the abundance of hard, granitic rock which is very resistant to erosion, the high precipitation in the region that causes sculpting by ice and torrents, and the geologically young (≤10 ma) uplift of

[1] Highest mountain in British Columbia.

the region. The Cascade volcanoes in this area contribute to the topography but are mere "pimples" built upon the uplifted surface.

The mainly (~80%) granitic bedrock of Coast Mountains (Fig. 2) comprises one of the largest continuous masses of this type on Earth. It forms a tract 100-200 km wide that extends north-northwestwards for ~1700 km from the lower Fraser River, along the mainland coast of British Columbia and southeastern Alaska, to end in southwestern Yukon near latitude 62°N. South-southeastward, the tract can be traced for ~200 km along the axis of the North Cascade Ranges to a point southeast of Seattle, where it is buried beneath the extensive younger volcanic rocks of the Cascade magmatic arc that form the High Cascades.

Both Coast Mountains and North Cascades are underlain by the *Coast-Cascade Orogen* (Fig. 2). (The word "orogen", concocted from the Greek for "mountain forming", is geo-jargon for a distinct, discrete belt of folded and faulted rocks accompanied by metamorphic and granitic rocks). This orogenic belt formed between about 95 and 45 million years ago.

The southern Coast Mountains contain two different kinds of bedrock geology. The *southeastern* Coast Mountains, east of Harrison Lake and the Pemberton Valley, have many features in common with the North Cascade ranges, south and east of Fraser River. They contain typically highly metamorphosed and strongly deformed rocks mostly derived from ocean floor remnants and overlying sand and shale deposited in deep water, that are intruded by granitic rocks isotopically dated as Late Cretaceous and early Tertiary (~95-45 ma). By contrast, the *southwestern* Coast Mountains, examined today, are underlain by abundant Middle Jurassic to mid-Cretaceous (~170-95 ma) granitic rocks. The distribution of plutonic rocks throughout the area is shown in Plate 1 at the end of the guide. These intrude older rocks similar to those found on Vancouver Island, as well as younger volcanic and sedimentary rocks that in places, such as Britannia, are only a few million years older than the granitic intrusions. The deformation in these rocks is localized along big faults, or shear zones, between which the rocks are little deformed. Britannia Mine is located on one of these faults. Recognition of this **two-part division** led to the model of the geological evolution of the southern Coast Mountains shown in Figure 3.

- **Before ~100 million years ago**, there was **no discrete orogen**. The site of what is now the southeastern Coast Mountains was a mainly deep-water basin, founded at least in part on oceanic crust and flanked to the east by an arc that formed on what was then the western edge of the North American continent (that arc can be seen along Highway 1 near Spences Bridge). The site of what became the southwestern Coast Mountains was a magmatic arc founded upon rocks widely exposed on Vancouver Island (Wrangellia terrane[2]). The arc shows no sign of having been near the basin to the east until about mid-Early Cretaceous time (~130 ma) when it probably slid southwards and overlapped the basin to the east (Fig. 3).
- **Between 95-45 million years ago,** the western arc and its foundation collided with the Cretaceous continental margin, and in so doing **created the Coast-Cascade Orogen as a discrete geological entity**. The basin in the southeastern Coast Mountains was caught between the jaws of the "orogenic vise" created by the continental margin to the east and the arc rocks now in the southwestern Coast Mountains and "scrunched". The former basin rocks were deeply buried, strongly folded and faulted, metamorphosed, intruded by granitic rocks and uplifted by as much as ~15 km between ~95-85 million years ago. The uplift was accompanied by erosion whose products

[2] The concept of terranes is explained in Appendix A

are the Late Cretaceous-early Cenozoic (~90-50 ma) sand, mud and gravel (now sandstone, conglomerate and shale) exposed in Stanley Park, near Kitsilano Beach, in the Gulf Islands, and the lowlands along eastern Vancouver Island, and where we will see them later today, in the lower Capilano River canyon.

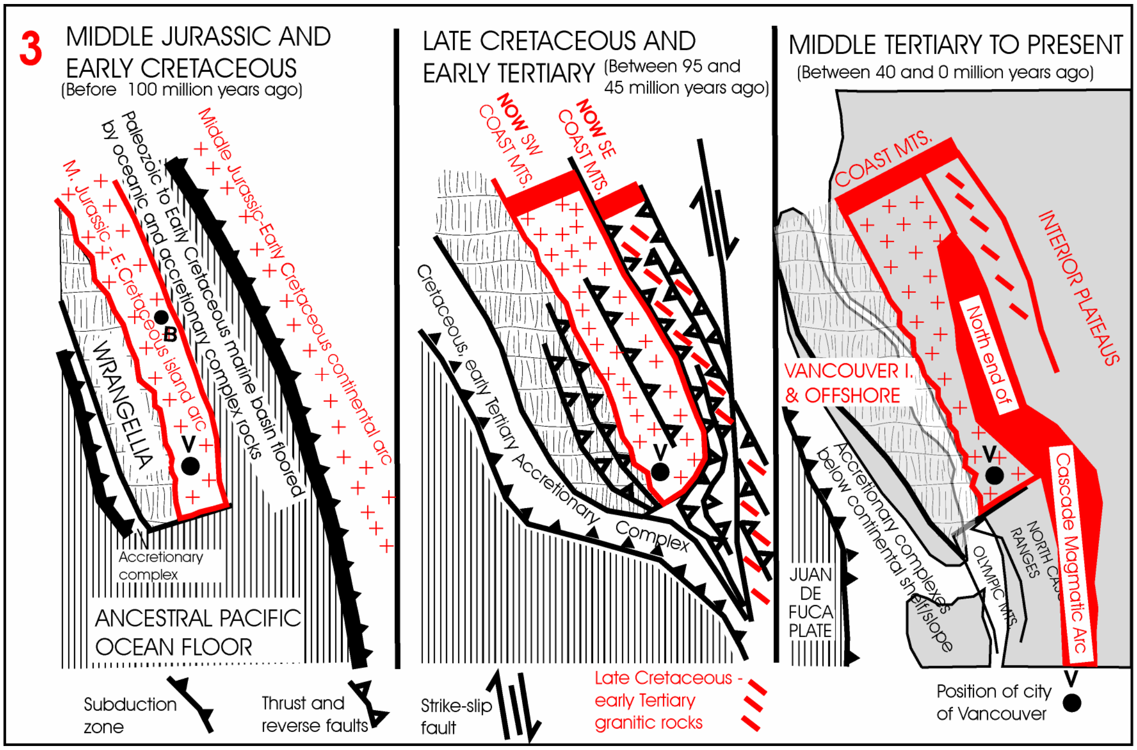

Figure 3. *Three stages in the geological evolution of southwestern B.C. and northwestern Washington. (1) A western Middle Jurassic-Early Cretaceous magmatic arc containing the Britannia ores (B) is located west of a basin floored by oceanic rocks; (2) the middle diagram shows features that characterize the Coast-Cascade Orogen; (3) the right hand diagram shows currently active and geo-recently past features.*

- **From ~40 to 0 million years ago,** the northern end of the **Cascade magmatic arc** was emplaced across the Coast-Cascade Orogen. Youngest parts of the arc near Vancouver are the volcanic edifices of Mount Baker, and Mount Garibaldi, Mount Cayley, The Black Tusk, and Meager Mountain. Older (about 31-34 million year old) volcanic and shallow intrusive parts of the arc are represented by the black basalt in Queen Elizabeth Park and the dark *dykes* and *sills* in the sandstone cliffs near the south abutment of Lions Gate Bridge. The "roots" of the arc, exposed by uplift and erosion, are light coloured granitic rocks exposed along Highway 1, east of Mount Cheam near Chilliwack, and near Chilliwack Lake, that are 18-35 million years old.
- The Coast Mountains were last uplifted **~10 million years ago** and much, if not all, of the present topography is due to this latest uplift episode. The southward slope (~10°) of the mountains and dip of the bedding of sandstone in Stanley Park and the north shore, reflect this uplift. Figure 4 shows a schematic cross-section of the relationship between Vancouver and Bellingham.

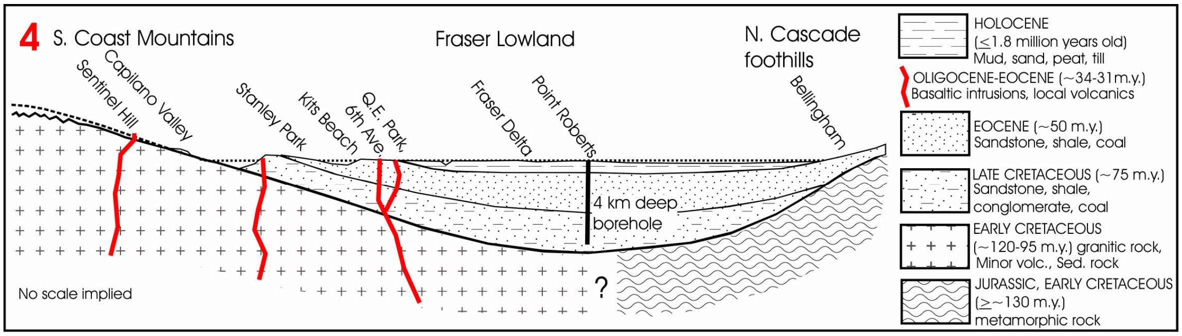

Figure 4. *A schematic cross-section, not drawn to scale, from the southernmost Coast Mountains near Vancouver to Bellingham; location of the section on Figure 2.*

Road log and comments on geology along Highway 99, between the B.C. Mining Museum at the former Britannia Mine and Vancouver

Stop 1: The Britannia Mine

The Britannia Mine ore bodies were located within a narrow northwest to southeast trending zone of intensely sheared, schistose, volcanic rocks, called the Britannia shear zone. We can see these in the Museum parking lot. They were derived from the Early Cretaceous Gambier Group rocks, which are little deformed where exposed on the hill just north of Britannia Creek. The ore was concentrated in the shear zone and occurred over a vertical range of 1.3 km and a horizontal distance of 3 km. The ore is related to volcanic activity and formed both massive deposits and concentrations of irregular quartz veinlets (called stringer lodes) composed mainly of pyrite and lesser amounts of chalcopyrite and sphalerite (respectively iron, copper-iron, and zinc-lead sulphides). The shear zone fabrics probably formed during later stages of intrusion and cooling of the widespread granitic rocks in the area, whose isotopic dates range from ~96-106 ma, that is late Early to mid-Cretaceous. The younger age is about the same as the time of onset of the big "crunch" (see Fig. 3) that is most clearly recorded in the southeastern Coast Mountains and created the Coast-Cascade Orogen as a discrete geo-entity.

Background

Discovery in 1894 of a surface exposure of copper mineralization led to development of the Britannia Mine, which came into production in 1905. Its location, on tidewater and later a railway, allowed for cheap ore transportation. The mine operated until 1974, by which time it had produced more than half a billion kilograms of copper, 15 million grams of gold, 180 million grams of silver, 125 million kilograms of zinc, and lesser amounts of lead and cadmium. At metal prices of the mid-1980s, the Britannia Mine contributed metals worth almost 1.5 billion dollars over its long history.

The delta of Britannia Creek, below the mill, was the site of the administrative offices for the mine, housing for many of the workers, and of loading facilities and dock for the community, which in its early days was accessible only by water. In an effort to reclaim more flat land in the 1920s a retaining wall was built of mine waste across the intertidal zone and then was backfilled with mill tailings. Before long the reclaimed land had slumped beneath the waters of Howe Sound and debris of the composition of mill tailings has since been found on the fjord floor. This was probably the first recognized example on the British Columbian coast of a submarine delta-front collapse induced by man's activities.

A landslide in 1915 killed 56 people working in the upper part of the Britannia Mine. Just after midnight, in the morning of March 22, 1915, a slide of snow, mud, and rock cascaded down a gully in the upper reaches of the mine area and engulfed part of a miner’s camp. The slide probably was started by a rock fall at the upper reaches of Mammoth Bluffs, picking up debris as it moved down Jane Creek.

In the late evening of October 28, 1921, an outburst flood along Britannia Creek killed 37 people and destroyed more than 50 homes in the Britannia town site. The flood was caused by the collapse of a man-made dam across Britannia Creek during an interval of heavy rains. Geotechnical studies were in their infancy in those days. Hopefully we can do better today!

Stop 2: Little deformed Gambier Group volcanic rocks

Leave the Museum parking lot and drive north up hill for about 0.5 km to see Gambier Group volcanic rock (*andesite*) with large angular fragments (called a *volcanic breccia*; Fig. 5) exposed in a large roadcut.

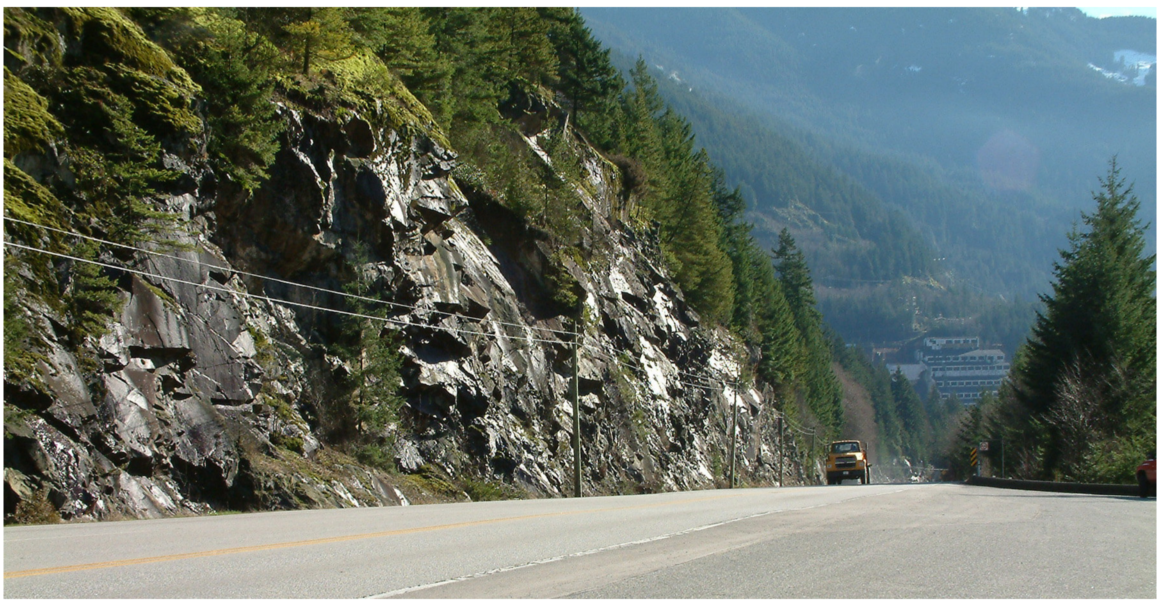

Figure 5: *view to the south toward Britannia from the viewpoint parking lot at Stop 2. Outcrops along the east side of the road are of Gambier Group andesite.*

The rock has been heated by the big granitic body just to the north, which caused changes in its original mineralogy, but is relatively little deformed so that the original fabric can be seen. Dykes and the breccia fragments within the andesite mass are composed of plagioclase porphyritic andesite (Fig. 6, 7). The plagioclase crystals are well-formed, 2-6 mm in size and densely packed in a finely crystalline matrix. On weathered surfaces the andesite is pitted, caused by dissolution of spots rich in calcite crystals. Some calcite has concentrated in visible thin veinlets and clumps (Fig. 8).

Figure 6. *Typical Gambier Group andesite at stop 2. Pull tab and ladybug for scale.*

Figure 7. *Light-coloured plagioclase phenocryts in fine-grained andesite matrix of Stop 2. Two dollar coin for scale.*

Figure 6. *Contact between finely crystalline and porphyritic andesite. Two dollar coin for scale in centre left of picture.*

Figure 8. *Calcite rich knot in the Gambier Group andesite of Stop 2. Pull tab for scale.*

Just north of this, the volcanic rocks are intruded by granitic rocks, which are exposed in roadcuts more-or-less continuously for the next ~7 km as far as that climber's mecca, the Stawamus (Squamish) Chief, near Squamish. Return down hill, cross Britannia Creek and continue southward along Highway 99.

An aside: something about granitic rock - typical Coast Mountains bedrock

Granitic rock forms within the Earth's crust and underlies ~80% of the Coast Mountains. It probably originates by melting of the less refractory minerals, quartz and feldspar, in deeply buried and metamorphosed, sedimentary and volcanic rock, mostly great depths ($\geq$25 km) within the crust, and mostly in magmatic arcs. The melted or partly melted material, perhaps forming a "crystal mush", may stay in place (to be later uplifted, cooled, and exposed as *banded gneiss*) or migrate upwards in the crust and there cool and crystallize as granitic rock.

The generic names "granitic rock" and the more-or-less interchangeable name "plutonic rock" (from the abode of the underworld god Pluto) embrace a wide range of silica-rich rocks that crystallized slowly in the crust, so that the entire rock is made of crystals. "*Quartz diorite*" is a variety of granitic rock composed of white or grey crystals of the mineral called plagioclase feldspar, which contains sodium and calcium rather than potassium, glassy quartz, and lesser amounts of dark coloured iron and magnesium rich minerals called biotite and hornblende. This is the most common variety of granitic rock in the Coast Mountains. "*Granodiorite*" with increased but minor amounts of potash feldspar in not uncommon as is "diorite", which is typically a black and white rock with plagioclase feldspar but little if any visible quartz. True "*granite*", defined by its high content of pink or white potassium feldspar, is extremely rare in the Coast Mountains.

The general term for a body of granitic rock is a "*pluton*", but just to confuse things big plutons may be called "*batholiths*" (from Greek = "deep rock"). Some plutons made mainly of quartz diorite may vary in composition from a granodiorite core to a dark diorite rim with little or no quartz. Still others contain abundant angular to rounded fragments of diorite or rock made up largely of hornblende; these fragments are called "*xenoliths*" (from Greek = stranger rock). Different bodies of granitic rock may be distinguished from one another by differences in mineralogy, proportions of minerals, rock texture, degree of alteration and shearing, intrusive relationships, and absolute and relative ages. In the Coast Mountains, plutons intrude plutons that intrude plutons, (the name Coast Plutonic Complex is common in the geo-literature) so separating different bodies may require extreme care! In places, boundaries, or "contacts" between a pluton and the surrounding rock, called "country rock", are sharp, whereas elsewhere they may be indistinct across a width of a kilometre or more. There may be clear signs of the invasion of liquid granitic melt into the adjacent hosting rock (a good place to see this is in the small waterfront park at Caulfeild, West Vancouver). This is shown by cracks filled with granitic rock, and by small fragments of the host rock that are partly separated, or displaced and rotated away from their original sites and now are frozen in suspension within the enclosing granitic rock. Other contacts may be narrow faults or broad shear zones rather than intrusive ones. A few contacts are depositional, in which lava or sediment was laid down on top of a pluton exposed by erosion. We will (almost) see this at the Stop 4 today.

Britannia Creek is 0 km for the road log. All distances given are approximate

Gambier-granite contact: 1.8 km: Highway 99 crosses the contact between strongly foliated, schistose rocks of the Gambier Group and granitic rock. The contact, where exposed along strike (or on trend) on the west shore of Howe Sound, is a reverse fault that dips southwestward at 75º, on which rocks on the southwest side of the fault moved up and over those to the northeast.

Between here and a point just south of Porteau Cove, a distance of ~8 km, outcrops along the road are all granitic rock. Thus near the Britannia Mine, a band of Gambier Group rocks, ~2 km wide along the highway, are enclosed within granitic rocks that are exposed for distances of 7 km to the north and 8 km to the south. The Gambier Group here forms a big, northwest trending elongate inclusion, called a "screen" or "septum", within the enclosing granitic rocks. West of Howe Sound near Woodfibre, the continuation of this screen is only about 1 km wide, and it disappears entirely within the body of granitic rock to the northwest. This pattern of mostly granitic rock with northwest elongate (in plan) screens of variably metamorphosed volcanic and/or sedimentary rock is very typical of southwestern Coast Mountains bedrock.

5.7 km Pass Furry Creek golf course and residential development, developed on the site of a former gravel pit.

Stop 3: Porteau Cove: granitic rocks, engineering problems, and the work of glaciers: 8.3 km

Bedrock at Porteau Cove Provincial Park is well exposed along the highway at the foot of the grade leading down to the level of the British Columbia Rail line. There, it consists of a pale grey granitic rock (Fig. 9) with numerous dark and finer grained orientated elongated and flattened inclusions in places (Fig. 10). The dark inclusions (*xenoliths*) were derived from fragments of country rock surrounding the granite that were softened, squeezed, and stretched, probably by plastic flow in the granitic rock before it finally crystallized.

Figure 9. *Hornblende quartz diorite of Porteau Cove.*

Figure 10: The finely crystalline olive-grey inclusion right of the dollar coin has been transected by a small fault (shear zone) and its parts displaced 3 cm dextrally.

The granitic rock at Porteau Cove is mid-Cretaceous, with an isotopic date of 96 million years. It appears to be part of a much larger body, about 120 km long and 40 km wide, that includes most of the granitic rocks along Howe Sound. From its size, the body could well be called the "Howe Sound batholith".

Fracture systems, which are sets of nearly parallel breaks in the rock, are conspicuous on the cliff north of the cove. The most significant set of fractures dips westward towards the road at about 50° at an angle less steep than the cliff face and presents a major engineering problem (Fig. 11).

Figure 11. *View to the north along Sea-to-Sky highway at Porteau Cove entrance showing the fractures in the quartz diorite dipping toward the road way. These fractures provide sliding surfaces and require engineering works to stabilize the rock.*

In November 1964 and January 1969 rock falls occurred, due to slip that was lubricated by precipitation, along the westerly-dipping fractures. Remedial work included the installation of rock bolts 1 to 9 m long, some blasting and scaling, the diversion of runoff from heavy rain or snowmelt away from the top of the cliff, and the boring of horizontal drainage holes from the foot of the face. To provide data for a warning system movement gauges were set across open fractures at the top of the slide and listening devices at the bottom.

Aside from the ice-carved steep walls and U-shaped profile of Howe Sound, a typical ice-sculpted “fiord”, the most conspicuous work of glaciers here is the locally exposed ice-polished surface (Fig. 12). The surface was buried under a former cover of weakly cemented gravel that protected it from weathering until construction of the highway in the late 1950s. Close inspection of the ice-polished surface reveals numerous nearly parallel scratches (called "striae") running north to south across the face, that formed where the corners of rock fragments embedded in the glacial ice were dragged across the bedrock. Where there are small steps in the glaciated surface facing northward, the outer edge of the step is more or less rounded; where the step faces southward, its outer edge tends to be sharply broken off, which shows that the ice flowed from north to south.

Figure 12. *Glacial striations on quartz diorite at the Porteau Cover highway cut. Dollar coin for scale.*

9.0 km Southernmost exposure of the granitic rocks crossed for the next ~7 km along Highway 99.

9.1 km Northernmost outcrop of (more) Gambier Group rocks.

Gambier Group volcanic rocks between 9.1-20.9 km. The name "Gambier" is taken from Gambier Island to the west in Howe Sound. This part of the highway is a bad (and locally illegal) place to stop and look at the rocks. The best place to examine them undisturbed by the near-continuous traffic, is by boat or along the railroad track between Lions Bay and Porteau Cove.

The volcanic rocks of the Gambier Group here are either the thin beds of volcanic ash and mud (now *tuff* and *argillite*; Fig. 13) best seen in more northerly exposures along the highway or else angular blocks and fragments like the volcanic breccia seen at Stop 1, here seen closer to Lions Bay. The rocks here have been altered mainly by heat and hot water, which is not surprising as they form a narrow "screen" oriented roughly parallel with the east side of this part of Howe Sound that lies within the granitic rocks, which are exposed higher up above the road, about 2 km east of the shore of Howe Sound. The rusty weathering of many rocks is due to their high content of iron pyrites (iron sulphide).

Figure 13. *Beds of volcanic ash of the Gambier Group at the approximately 40.5km mark and at the north end of the anticline described in the text. Pull tab for scale.*

Although bedding may be hard to see from a vehicle as many of the road cuts are covered with wire mesh to prevent rocks falling on the highway it is visible in many places, and in one place outlines a broad, very gently folded arch or *anticline*.

Marine sedimentary rocks of the Gambier Group exposed on the shoreline (below the highway near Brunswick Point) contained an ammonite (an extinct cephalopod akin to the modern *Nautilus*), whose features are diagnostic of its age. It is late Early Cretaceous (~105 ma). The age is important as it is *only* (for geologists!) about 10 million years older than the isotopically dated granitic rocks exposed at Porteau Cove.

20.9 km: Development in steep terrain, on unconsolidated rock, and in a wet climate: Pass the southern turnoff to the village of Lions Bay. Note the extensive (and expensive) engineering remedies to control debris flows and stop bridge washouts in the several creeks along this part of Highway 99. Some houses higher up in the community of Lions Bay are built on unconsolidated debris flow and overbank deposits that were laid down by the creeks that descend the steep hillside. These creeks now run in concrete lined channels.

Municipalities these days (mostly) pay much more attention than previously to potential geotechnical problems before releasing land to developers.

~ 22-25 km: Granitic and metamorphic rocks of unknown affinity and age; the metamorphic rocks may be related to rocks on Bowen Island, and on the far side of Howe Sound where they are of Early Jurassic age (~183 Ma) and equivalent to an older arc on Vancouver island that is part of Wrangellia terrane (see Fig. 3).

27.9 km: Roadcuts in granitic rock, which may be a westerly part of the Early Cretaceous (~118 Ma) pluton in Cypress Park.

31.8 km: Junction of Highway 99 with Highway 1 (Trans-Canada) above Horseshoe Bay. Between here and the bridge over Cypress Creek are roadcuts in Early Cretaceous(?) granitic rock, cut by dark dykes of unknown (Gambier?) age.

34.3 km: Bridge over Cypress Creek.

More roadcuts in Early Cretaceous quartz diorite; an isotopic date of 118 ma was obtained from the Cypress Park road above here. Similar exposures occur to the east.

Note the relatively gentle (~10º) southwest-dipping surface slope of the southernmost Coast Mountains. This mirrors the dip of the erosional surface below the Late Cretaceous sediments to be seen at Stop 4.

43.0 km: The knoll to the right just before Taylor Way off-ramp is underlain by an Oligocene basaltic intrusion, which is an older part of the Cascade magmatic arc that here intrudes Cretaceous sandstones. (This relationship is well exposed in the cliff face near the south abutment of Lions Gate Bridge, above Stanley Park seawall. The intrusion there is dated at ~31 ma)

Stop 4: Capilano Canyon: basal contact of Late Cretaceous sediments with underlying granitic rock: ~44 km: Cross the bridge that carries Highway 1 over the Capilano River and take the off-ramp immediately east of the bridge, which merges with Capilano Road. Park in the pullout (old road) behind the gas station, and cross the road at the traffic lights, walk south almost to the bridge and descend old wooden stairway to the level of the river.

Across on the west side of the Capilano River, is a cliff of mostly coarse conglomerate that contains cobbles and blocks of mainly granitic rock (Fig. 14). Recessive, readily eroded, layers of shale near the base of the cliff show the gentle southward dip of the rock. This rock unit can be examined on the east side of the river just south of the bridge, and a bit farther north in the trees, where they form a cliff directly below Capilano Road. About 100 m upstream on the west side of the river is an exposure of dark, sheared and weathered granitic rock with roughly horizontal jointing, and similar rocks are exposed ~400 m upstream on the east side (Fig 14).

Figure 14. *Cretaceous sandy conglomerate and sandstone dip to the south (downstream and to the left in the photograph) and form the support to the west abutment of the Capilano River Bridge of Highway 1.*

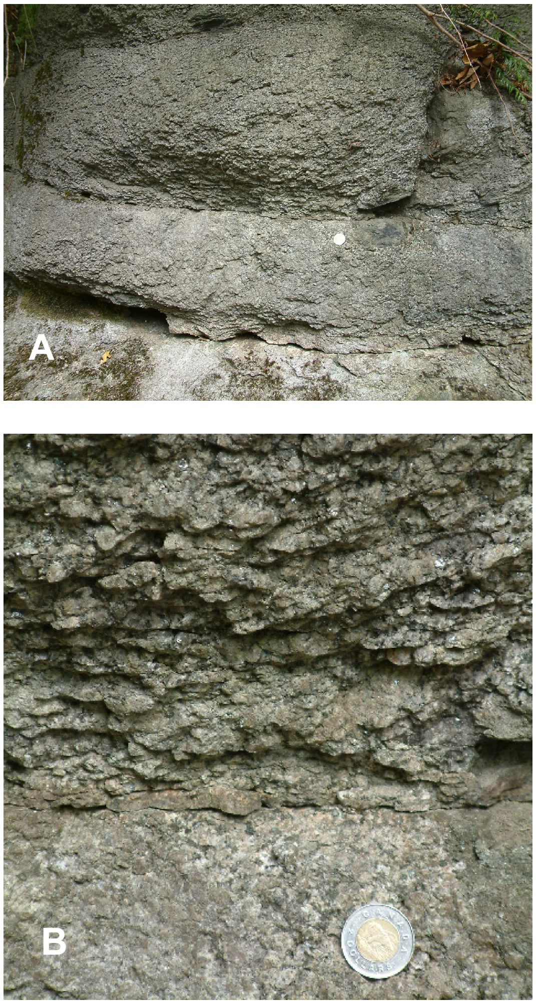

Figure 15. *A) Weathered texture characteristic of the Jurassic granodiorite on the east side of the Capilano River, to the north of, and underlying the Cretaceous sandy conglomerate and sandstone that is under the Capilano River Bridge (Fig. 14). B) Enlarged view of the weathering texture of the granodiorite (two dollar Canadian coin for scale in A and B).*

This is the basal contact (almost) of the thick succession of conglomerate, sandstone, shale, and local coal that dips southward and is the bedrock directly beneath the City of Vancouver. The strata become thicker and younger southward. We know this from a 4,400 m deep hydrocarbon exploration borehole drilled near Point Roberts (Fig. 4). They re-emerge, folded, at surface along Chuckanut Drive, south of Bellingham. The last part of the trip takes us through North Vancouver. If it is clear the cone of Mount Baker may be seen ~100 km away. Cross Second Narrows (Ironworkers Memorial) Bridge. Tertiary conglomerate could be seen in exposures made during construction of the tunnel and off-ramps on the south side. Similar rocks underlie Burnaby Mountain.

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More information

Geology books aimed at the general public:

- Clague, J.J. and Turner, R.J.W., 2003, Vancouver, City on the Edge, Tricouni Press, Vancouver, B.C., 192 p.
- Mathews, W.H. and Monger, J.W.H., 2005, Roadside Geology of southern British Columbia, Mountain Press Publishing Company, Missoula, Montana, 402 p.

More technical, but with many references:

- Monger, J.W.H., (editor) Geology and Geological Hazards of the Vancouver Region, southwestern British Columbia, Geological Survey of Canada Bulletin 481, 316 p.
- Monger, J.W.H. and Price, R.A., 2000, A Transect of the southern Canadian Cordillera from Vancouver to Calgary, Geological Survey of Canada Open File 3902, 170 p.

The books are available at the Geological Survey of Canada, Vancouver Office, located at #101, 605 Robson Street, Vancouver. On the 15th floor of the same building, there is also an excellent geoscience library that is open to the public that contains these books and many other references.

Article describing the landslide and flood:

- Evans, S.G., 2000: The 1915 and 1921 disasters at the Britannia Mine Complex, Howe Sound, British Columbia: Geotechnical implications for intensive resource development in steep mountainous watersheds in the Coast Mountains. Canadian Society of Engineering Geologists, Annual Meeting 2000, Abstract 896. on line at: http://www.cseg.ca/conferences/2000/2000abstracts/896.PDF

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APPENDIX A

Terrane Concept

A terrane is a fragment of a tectonic plate that has a consistent suite of rocks that formed in a similar plate tectonic environment and went through the same geological history. The terrane is bounded by plate penetrating faults from adjacent terranes. As an example the plate tectonic environments of Figure 1 reproduced below could become terranes when they are compressed and deformed into a mountain belt.

The Accretionary wedge is bound by faults from the oceanic crust and the continental crust intruded by a volcanic arc. When these rocks are compressed into a mountain belt those faults would be terrane boundaries and the rocks of the accretionary wedge would represent a terrane.

Some mountain building events are quite complicated and in the Canadian Cordilleran we have tended to keep rocks formed in broader similar environments together. For instance the Cache Creek Terrane is an amalgamation of rocks formed as ocean crust, sea mounts, volcanic ocean islands like Hawaii, and accretionary complexes. The Cache Creek Terrane represents an ocean that separated two volcanic arc terranes that eventually came together collided and trapped the Cache Creek Ocean (Panthalassa) in between.

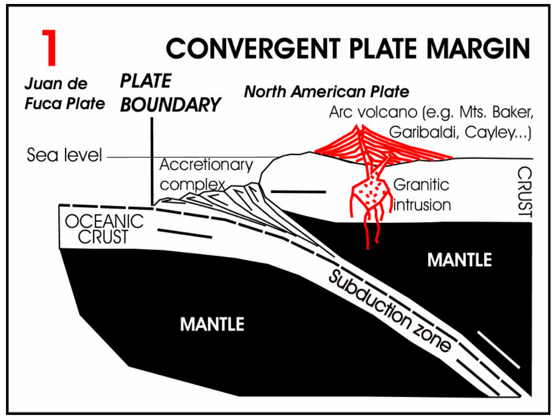


Figure 1. *Cartoon cross-section of a subduction zone representing the one under Vancouver Island and southwestern BC mainland. Some local features are identified on the figure.*

PLATES

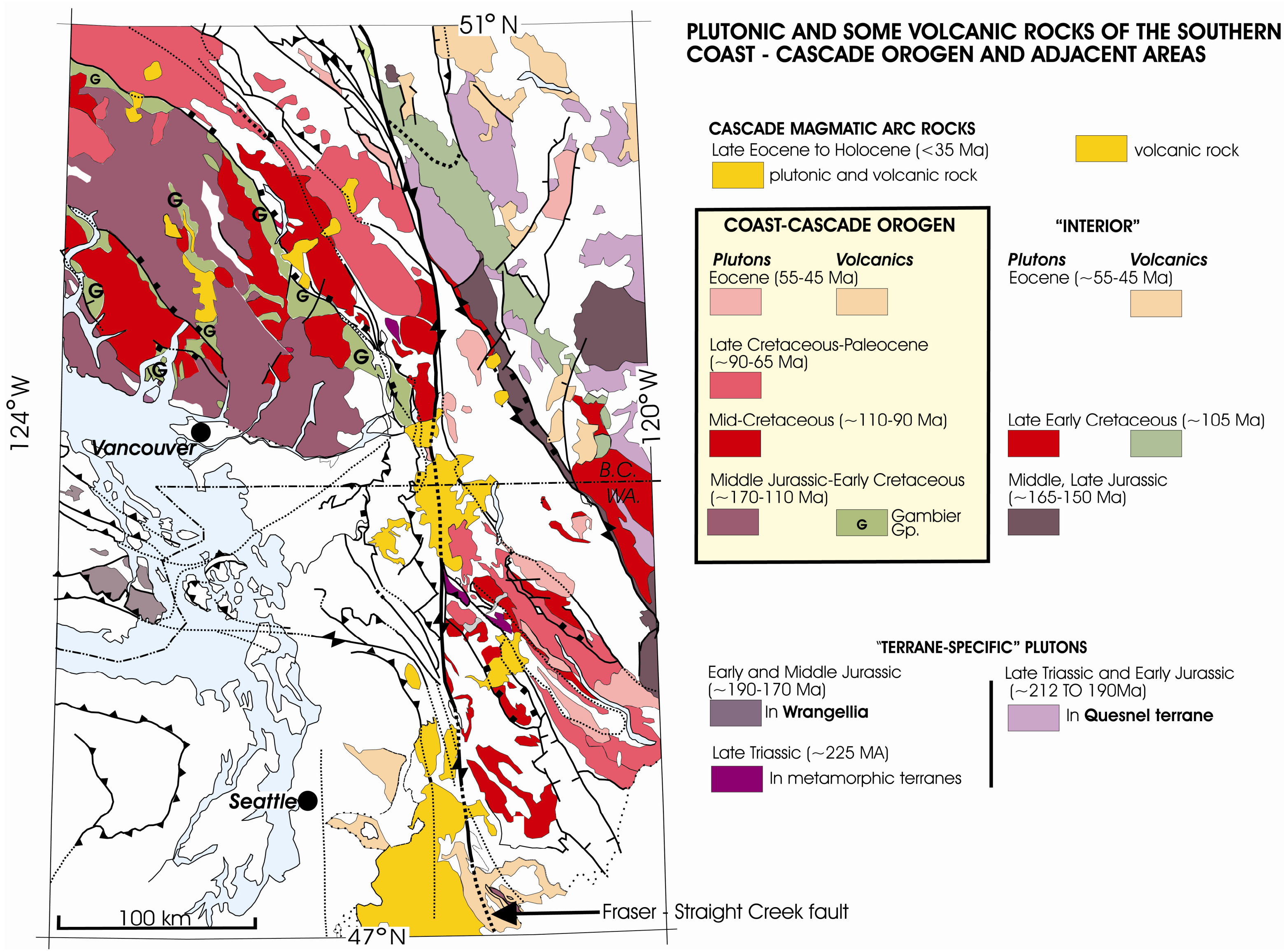


Plate 1. The map of southwestern British Columbia shows the distribution of the plutonic and volcanic rocks of the Coast – Cascade Orogen in which the Britannia Mine was formed.

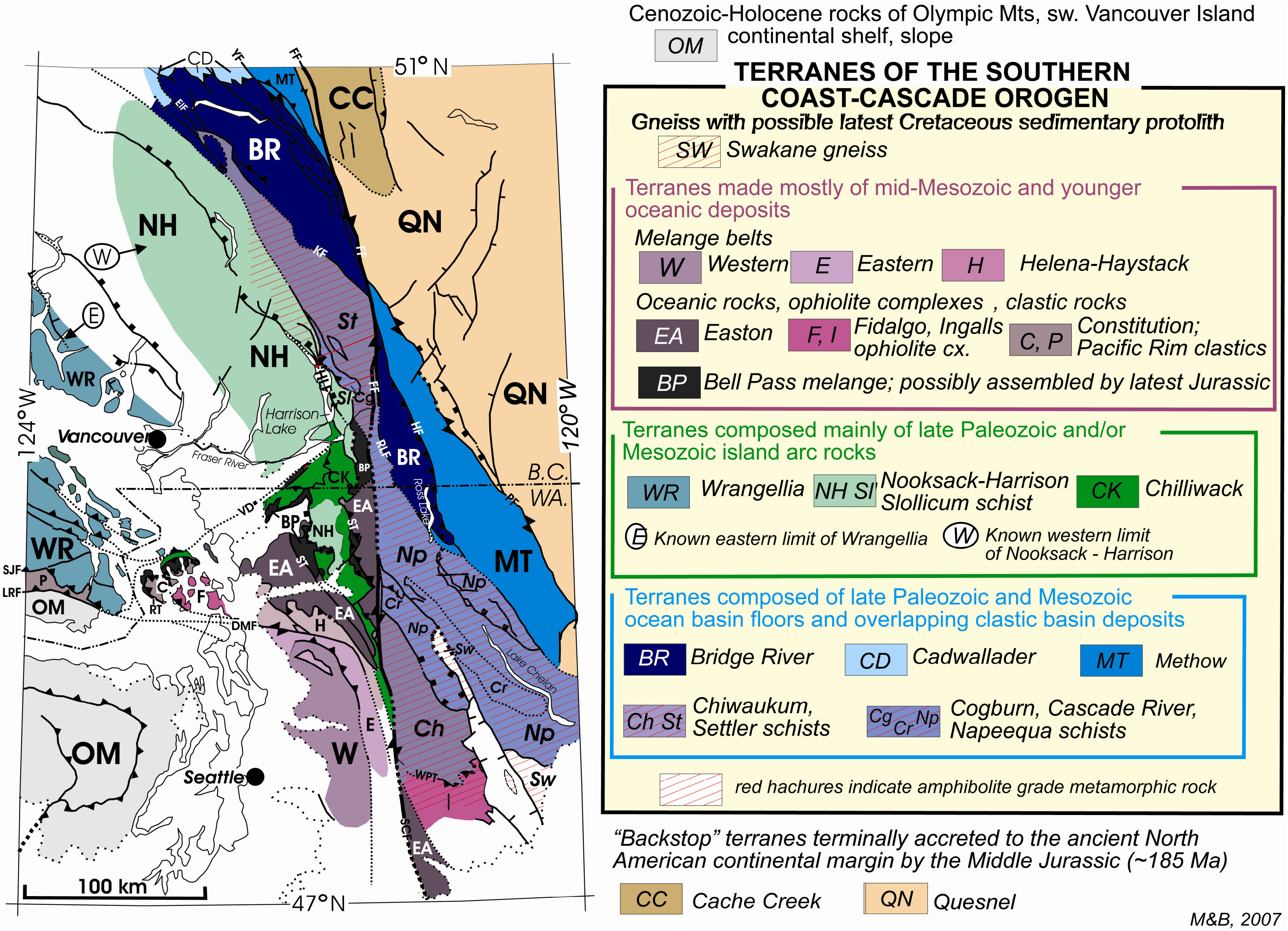


Plate 2. The map of southwestern British Columbia shows the distribution of the segments of tectonic plates called terranes that formed in distinct plate tectonic regimes as described in the legend.

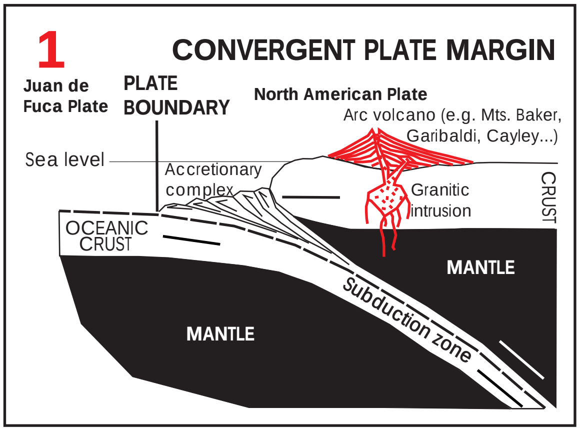
OVERVIEW-FIGURE CAPTIONS

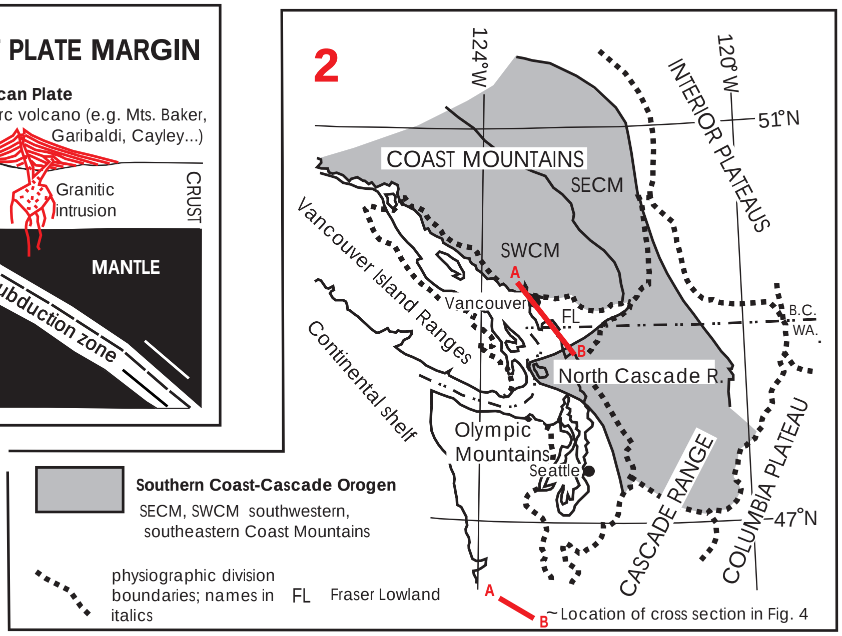
Figure 1. Cross-section, not to drawn to scale, of a "generic" convergent margin: some local features are identified on the figure.

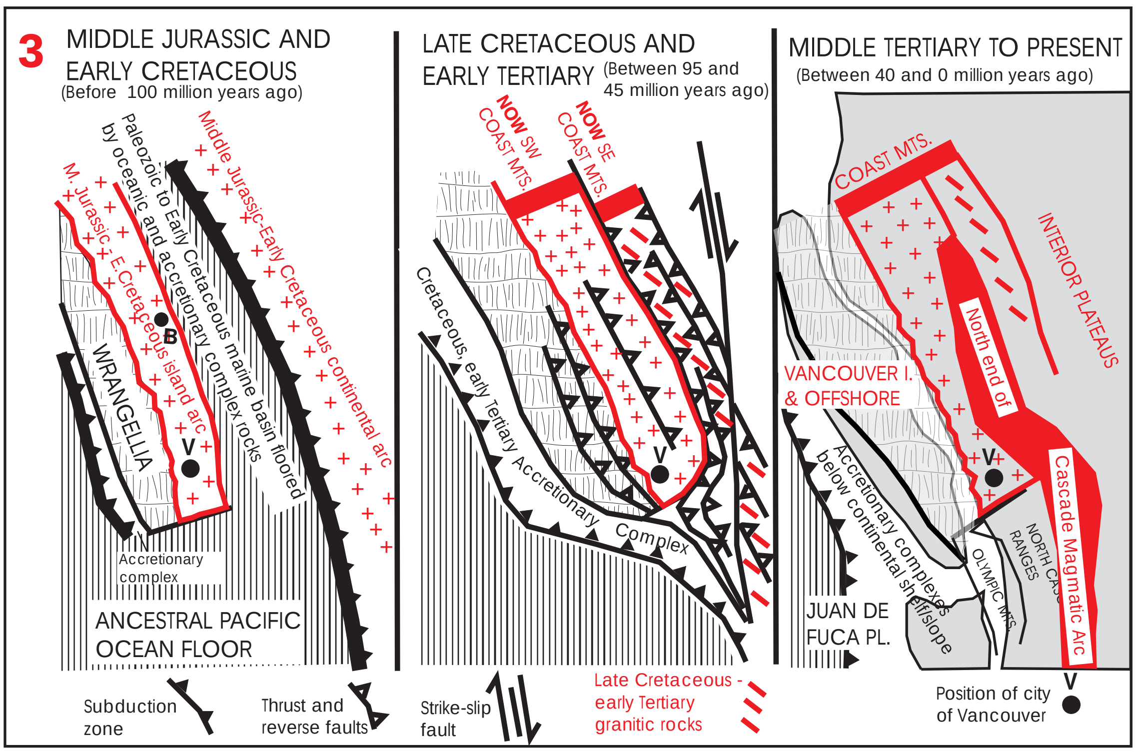
Figure 2. Names, locations of major physiographic/geological features in southwestern B.C., and northwestern Washington. Note that "Coast-Cascade Orogen" refers to bedrock geology, not physiography, although it occupies more-or-less the same region as the physiographic Coast Mountains and north Cascade ranges.

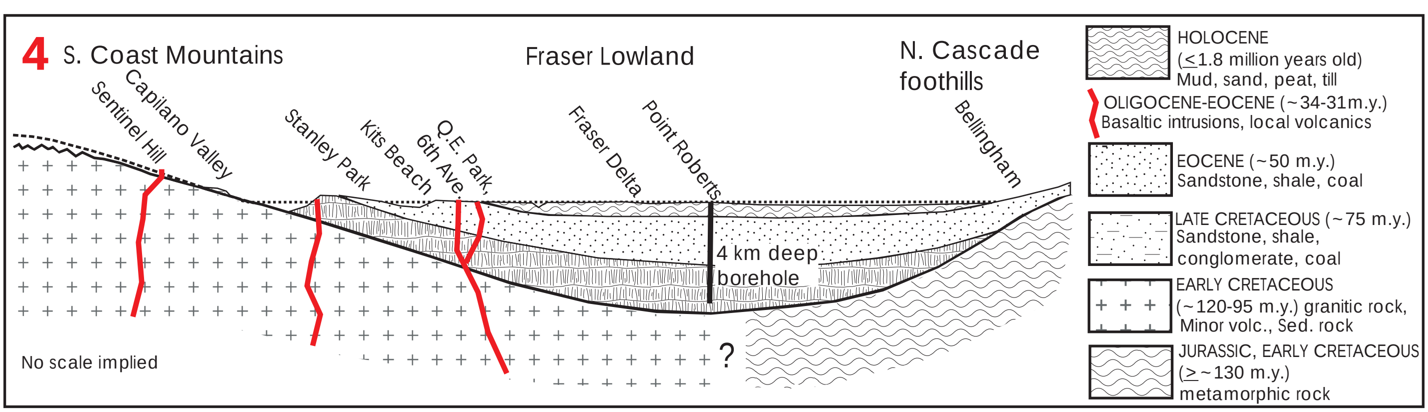
Figure 3. Three stages in the geological evolution of southwestern B.C. and northwestern Washington. The Britannia mine (B) is located within the Middle Jurassic-Early Cretaceous arc, just north of Vancouver. Currently active features are shown on the right hand diagram.

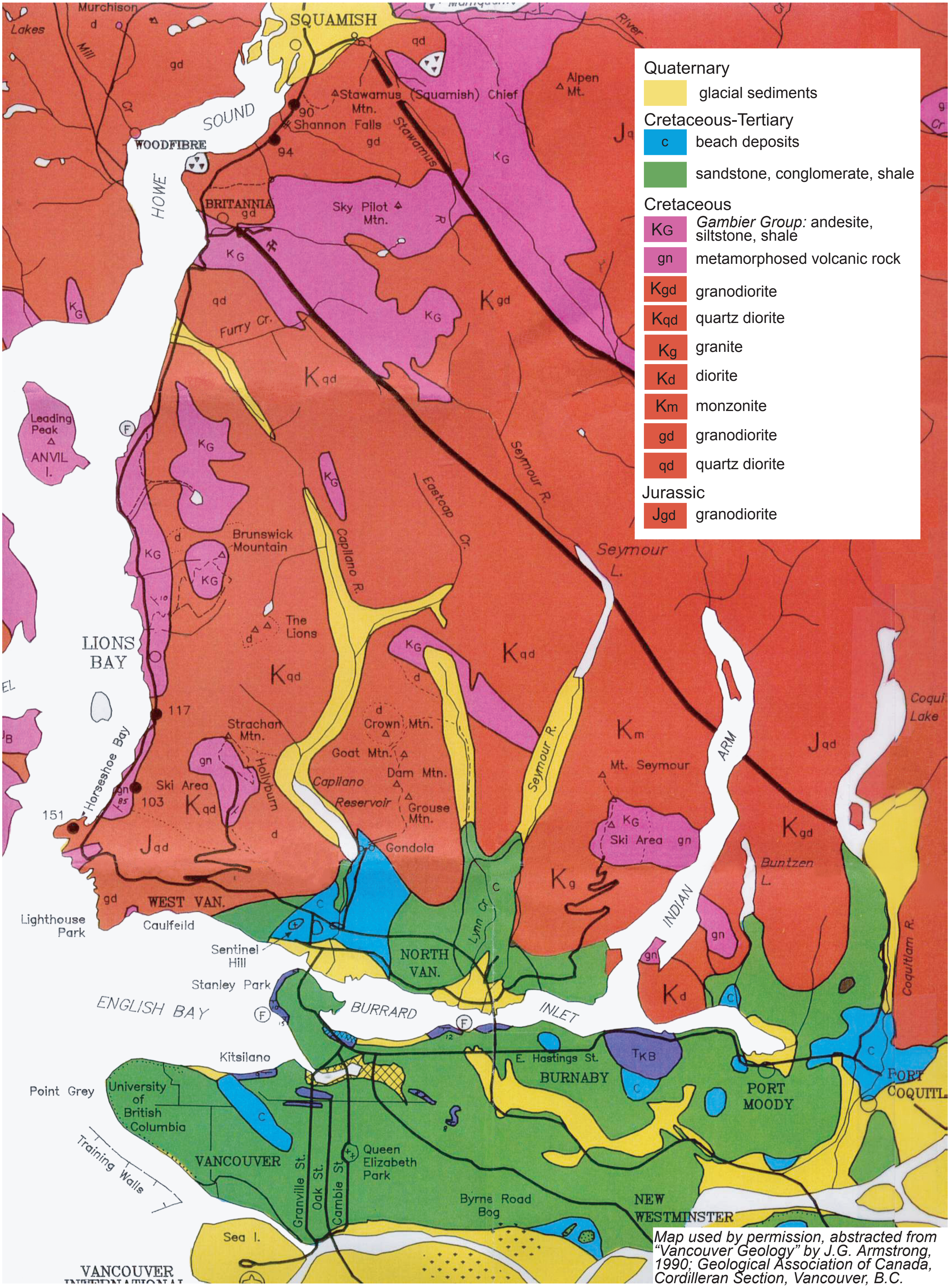
Figure 4. A schematic cross-section, not drawn to scale, from the southernmost Coast Mountains near Vancouver to Bellingham; location of the section on Figure 2.


1
CONVERGENT PLATE MARGIN
Juan de Fuca Plate
PLATE BOUNDARY
North American Plate
Arc volcano (e.g. Mts. Baker, Garibaldi, Cayley...)
Sea level
Accretionary complex
Granitic intrusion
CRUST
OCEANIC CRUST
MANTLE
MANTLE
Subduction zone


2
124°W
120°W
51°N
47°N
COAST MOUNTAINS
SECM
SWCM
INTERIOR PLATEAUS
Vancouver Island Ranges
Vancouver
FL
A
B
B.C.
WA.
North Cascade R.
Continental shelf
Olympic Mountains
Seattle
CASCADE RANGE
COLUMBIA PLATEAU
Southern Coast-Cascade Orogen
SECM, SWCM southwestern, southeastern Coast Mountains
physiographic division boundaries; names in italics
FL Fraser Lowland
~Location of cross section in Fig. 4


3
MIDDLE JURASSIC AND EARLY CRETACEOUS
(Before 100 million years ago)
Middle Jurassic-Early Cretaceous continental arc
Paleozoic to Early Cretaceous marine basin floored by oceanic and accretionary complex rocks
M. Jurassic - E. Cretaceous island arc
WRANGELLIA
B
V
Accretionary complex
ANCESTRAL PACIFIC OCEAN FLOOR
LATE CRETACEOUS AND EARLY TERTIARY
(Between 95 and 45 million years ago)
NOW SW COAST MTS.
NOW SE COAST MTS.
Cretaceous, early Tertiary Accretionary Complex
V
MIDDLE TERTIARY TO PRESENT
(Between 40 and 0 million years ago)
COAST MTS.
INTERIOR PLATEAUS
VANCOUVER I. & OFFSHORE
North end of
Cascade Magmatic Arc
V
Accretionary complexes below continental shelf/slope
OLYMPIC MTS.
NORTH CASCADE RANGES
JUAN DE FUCA PL.
Subduction zone
Thrust and reverse faults
Strike-slip fault
Late Cretaceous - early Tertiary granitic rocks
Position of city of Vancouver


4
S. Coast Mountains
Fraser Lowland
N. Cascade foothills
Sentinel Hill
Capilano Valley
Stanley Park
Kits Beach
Q.E. Park, 6th Ave
Fraser Delta
Point Roberts
Bellingham
4 km deep borehole
?
No scale implied
HOLOCENE (≤1.8 million years old) Mud, sand, peat, till
OLIGOCENE-EOCENE (~34-31m.y.) Basaltic intrusions, local volcanics
EOCENE (~50 m.y.) Sandstone, shale, coal
LATE CRETACEOUS (~75 m.y.) Sandstone, shale, conglomerate, coal
EARLY CRETACEOUS (~120-95 m.y.) granitic rock, Minor volc., Sed. rock
JURASSIC, EARLY CRETACEOUS (≥~130 m.y.) metamorphic rock



Map used by permission, abstracted from "Vancouver Geology" by J.G. Armstrong, 1990; Geological Association of Canada, Cordilleran Section, Vancouver, B.C.