Self-guiding geology tour of Stanley Park

Points of geological interest along the sea-wall between Ferguson Point & Prospect Point, Stanley Park, a distance of approximately 2km.

(Terms in bold are defined in the glossary)

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Introduction:-

Geomorphologically Stanley Park is a type of hill called a **cuesta** (Figure 1), one of many in the Fraser Valley which would have formed islands when the sea level was higher e.g. 7000 years ago. The surfaces of the cuestas in the Fraser valley slope up to the north 10° to 15° but approximately 40 **Mya** (which is the convention for "million years ago" not to be confused with **Ma** which is the convention for "million years") were part of a flat, eroded **peneplain** now raised on its north side because of uplift of the Coast Range due to **plate tectonics** (Eisbacher 1977) (Figure 2). Cuestas form because they have some feature which resists erosion such as a bastion of resistant rock (e.g. volcanic rock in the case of Stanley Park, Sentinel Hill, Little Mountain at Queen Elizabeth Park, Silverdale Hill and Grant Hill or a bed of conglomerate such as Burnaby Mountain).

Figure 1: Stanley Park showing its cuesta form with Burnaby Mountain, also a cuesta, in the background.

Figure 2: About 40 million years ago the Coast Mountains began to rise from a flat plain (peneplain). The peneplain is now elevated, although somewhat eroded, to about 900 metres above sea level. The average annual rate of uplift over the 40 million years has therefore been approximately 0.02 mm. The original peneplain surface is indicated by the heavy black line in this view looking north across the North Shore.

Geologically, Stanley Park hill is composed of sandstone with minor bands of carbonaceous shale, siltstone and mudstone laid down in the Georgia Basin or Georgia Depression during the last approximately 100 million years to a maximum depth at the international border of 3.5 km. Interbedded within these sedimentary rocks are rare layers and pockets of coal **(lignite).** Bands of coarser sandstone with small cobbles can occasionally be seen indicating variability in the sediment transport capacity of the stream.

The Georgia Basin sediments are cut through (**intruded**) by volcanic **dykes (dikes), sills** or **laccoliths** of basaltic composition**.** These basaltic rocks have been dated at 32 million years old.

Stanley Park hill is capped by a thin layer of glacial **till** of clay, sand and cobbles with some larger boulders called **erratics.** The till and the erratics were left there by the last retreat of the ice about 12500 years ago. At the greatest extent of the glaciation (the **glacial maximum**) about 26,500 years ago, the ice thickness at Stanley Park would have been about 1800 metres which meant that all the peaks of the North Shore would have been covered. That is why the Lions (1646 metres & 1606 metres) are rounded. The highest peaks of the Tantalus Range (Mt Tantalus is 2603 m) located west of the Squamish River and 40 km north of Vancouver would have protruded above the ice as jagged **nunataks.**

The largest erratic boulder on our tour can be seen on the shore at the northern end of Third Beach. Smaller cobbles and pebbles also seen along the shoreline have been eroded out of the glacial till as well as the sandstone as wave-action has eaten away the cliffs.

The till and the erratics were originally carried south during the last glacial advance which completed 12,500 years ago and represent rock types of the bedrock north of Vancouver, probably as far as the Mount Garibaldi area. They are mostly various types of granitic rock, **metavolcanics** and **metasediments** and lesser amounts of unmetamorphosed **basalt** from the Garibaldi area. The pebbles eroded from the sandstone had a different provenance and were originally laid down by rivers flowing out of the Cascade Ranges to the east and south-east during the Tertiary and Cretaceous (40 to 70 Mya). These pebbles are mixed with the glacial till pebbles on the beach and are difficult to separate from the glacial till.

Georgia Basin or Georgia Depression (Figures 3 & 4):-

The Georgia Depression or Georgia Basin is a **forearc** basin that overlaps both the **Wrangellian** part of Vancouver Island and the **Coast Belt** at the leading edge of the **North American Plate**. During the **Olympia interglacial** period most of the basin was filled with sediment and then subsequently excavated during the **Fraser Glaciation**.

The Georgia Basin surrounds an inland sea that encompasses three areas: Puget Sound, the Strait of Georgia and the Juan de Fuca Strait and connecting straits. In part it overlaps two older sedimentary basins; a Late Cretaceous **foreland** basin preserved as the Nanaimo Group (Mustard, 1994; Mustard and Rouse, 1994; England and Bustin, 1998) and an early Tertiary non-marine basin dominated by the sedimentary rocks of the Chuckanut Formation (Johnson, 1984; Mustard and Rouse, 1994). The basin lies between southern British Columbia, Vancouver Island and Washington State. Subsidence began in the Late Cretaceous (90 Mya) and the tectonic regime, over the last 40 Ma, has been dominated by subduction of the Juan de Fuca Plate. The North American Plate is presently overriding the oceanic Juan de Fuca Plate at a rate of about 45 mm/yr (Riddihough and Hyndman, 1991). The basin consists of a series of structural depressions, over-deepened by Tertiary erosion and Quaternary glaciation, and partially infilled by glacial and post-glacial sediment. It has resulted from **down-warping** caused by uplift of western Vancouver Island above the subduction zone.

The Georgia Basin extends 220 km NW to SE and averages 40 km wide covering the Strait of Georgia, eastern Vancouver Island, the Fraser River lowlands and NW Washington State. It is filled mainly with sandstone deposited by rivers that flowed between 97 Mya (Late Cretaceous) to 1.8 Mya (Pliocene). The basin postdates the mid- to Late Cretaceous amalgamation of the Wrangellia **Terrane** onto the North American **Cordillera**. Its maximum thickness of sediment, which is near the international border, is about 3.5 km. It was sometimes a sea and sometimes a freshwater lake as indicated by pollen, plant, shell and vertebrate fossils found in its sediments.

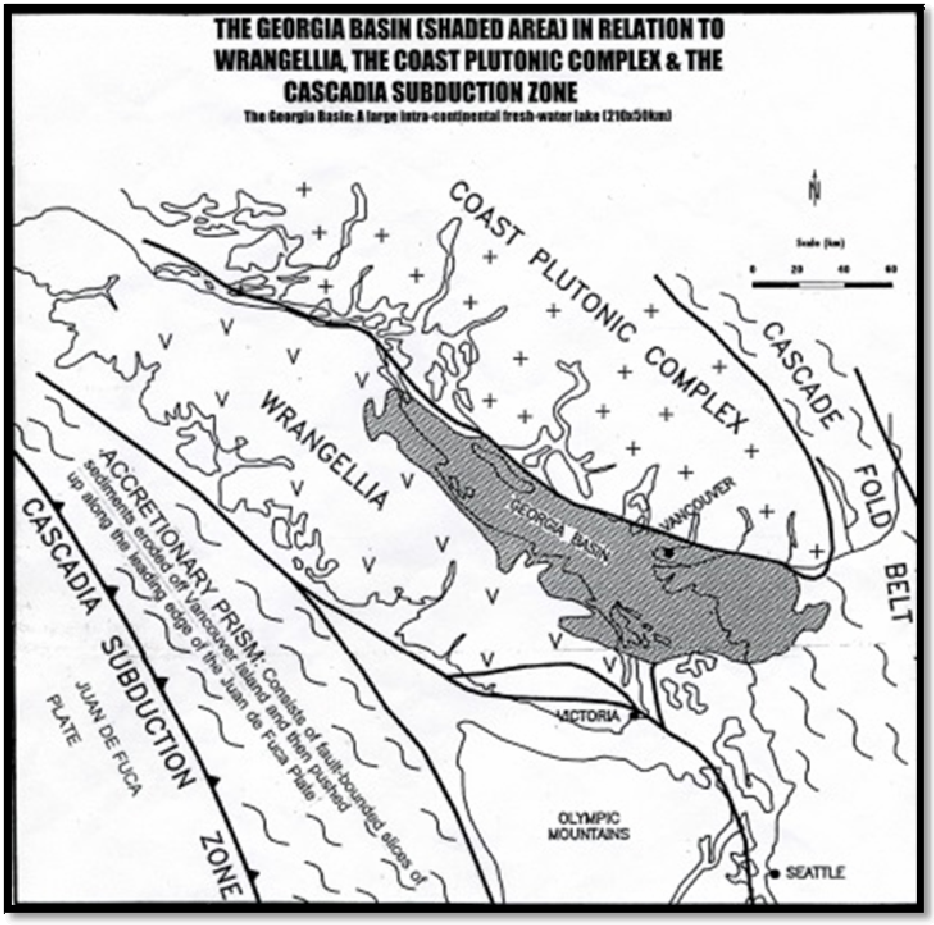

Figure 3: Plan view of the Georgia Basin

The Georgia Basin comprises 2 sub-basins; the younger Chuckanut Basin and the older Nanaimo Basin:-

- The Chuckanut Basin (Eocene to Palaeocene: 34-65 Mya). The rocks that fill this basin are known as the Huntingdon Formation in British Columbia and the Chuckanut Formation in Washington State. Their environment of deposition was deltaic-estuarine-lagoonal. The Huntingdon Formation can be seen around Burrard Inlet south of Third Beach and into the United States. It lies **disconformably** on the Nanaimo Group.

- The Nanaimo Basin (Upper Cretaceous: 65-97 Mya). The rocks of this basin, known as the Nanaimo Group, can be seen between Third Beach and Prospect Point and various locations on the North Shore such as the lower reaches of Capilano River and Brothers Creek (at Keith Road) and also on Burnaby Mountain, Sumas Mountain, the Gulf Islands and the east side of Vancouver Island. The environment of deposition is submarine **fan facies.** On the North Shore of Burrard Inlet the Nanaimo Group lies **unconformably** on granitic basement of the **Coast Belt**. On Vancouver Island the Nanaimo Group lies unconformably on Wrangellian Terrane**.**

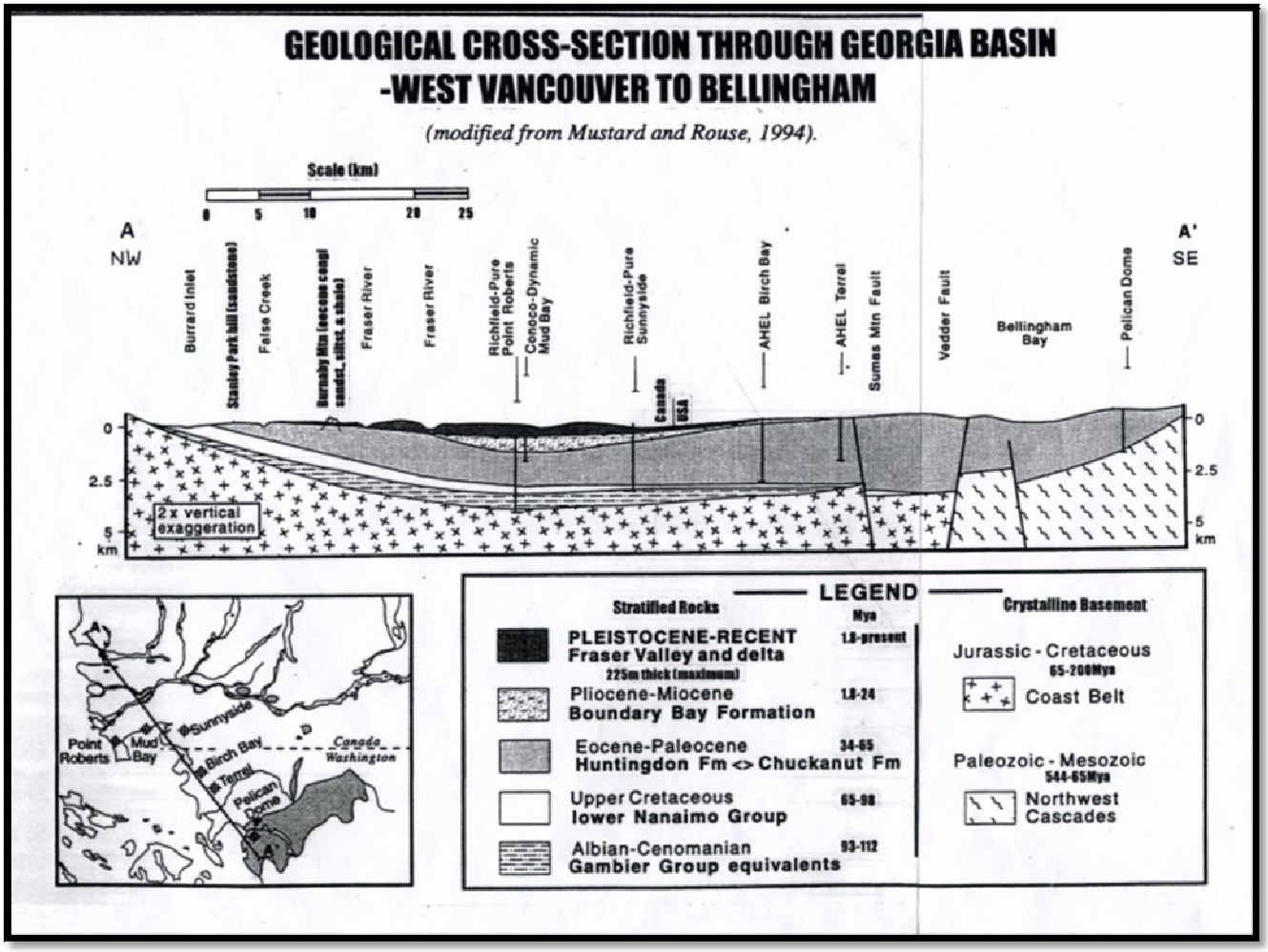

Figure 4: NW-SE section through the Georgia Basin

The Georgia Basin sediments in the Burrard Inlet area have been tilted upwards to the north by the slow rising of the North Shore mountains over the last approximately 40 Ma due to the forces of **plate tectonics**. The average rate at which the mountains have risen over that 40 Ma period has been estimated at approximately 0.02 mm/y. As we walk from Ferguson Point to Prospect Point we are passing through about 50 Ma of geological time. However all of that 50 Ma is not represented in the rocks that we see as there was a period of no deposition known as a **disconformity** for an unknown number of years. Because of this disconformity, the **K/T boundary,** the 65 Mya boundary between the Cretaceous and the Tertiary when the non-avian dinosaurs became extinct probably due to an asteroid impact, is not represented.

The following are the stops of geological interest between Ferguson point and Prospect Point. To maximise the interpretive experience, the tour should be conducted during low tide.

1. **Ferguson point to Third Beach:**

    a. The rocks in the cliffs of the sea-wall and those that make up the flat area seaward of the sea-wall (known as a **wave-cut platform)** at Ferguson Point proper are

sandstone of the Huntingdon Formation (Tertiary age) which at this location is about 50 Ma old. The Huntingdon Formation is a coarse, sand-dominated, terrestrial/fluvial system which would have had an active floodplain. How is the wave-cut platform formed? Is it the relentless back and forth of wave action? Yes, but it is more than that. It is the tiny rock and sand particles known as **load** in the water that perform the abrasive action. Observe how far the platform extends away from the beach and you will gain some idea as to how much erosion of the sea cliffs and beaches of Stanley Park have taken place by wave action since the sea level stabilised 5000 to 6000 years ago.

b. Within the sandstone that forms the cliffs and wave-cut platform are more resistant beds where the sand grains are cemented with calcite (Figure 5). Less resistant beds are probably loosely cemented with clay minerals. Calcite can be detected by testing with dilute hydrochloric acid (HCl) also known as muriatic acid. If dissolution bubbles of carbon dioxide (CO_2) form when you place a drop of the acid on a freshly broken rock surface then calcite is present; known as the "fizz" test. Vinegar can be substituted for HCl but a hand lens (loupe) may be needed to see the bubbles.

c. When the wave-cut platform is exposed by the retreat of the tide, prominent fractures or **joints** can be seen cutting through the sandstone as sets of parallel lines called **joint sets**. Joints are generated by the failure of the rock in response to **compressional** or **tensional** stresses set up during plate tectonics.

d. On the pebbly and boulder-strewn beach in the Ferguson Point area, particularly to the north, are numerous rounded **concretions** that have eroded out of the sandstone cliffs (Figure 6). The cement that binds the grains of the concretions is calcite similar to the resistant beds of sandstone.

e. In the cliff-face between Ferguson Point and the Third Beach concession stand is another bedrock exposure of the Huntingdon Formation where sandstone overlies **carbonaceous shale**. (Figure 7). The shale is dark in colour caused by high carbon content. Note the iron oxide bleeding from the contact zone between the shale and the sandstone. Pyrite (FeS_2), a common mineral associated with carbonaceous shale because of the anoxic environment of deposition, has been broken down by carbonic acid (H_2CO_3) present in percolating waters, liberating its iron as ferrous iron (Fe^{++}). On being exposed to the oxygen of the atmosphere, the ferrous iron is oxidized and precipitated as **goethite** and **limonite** which are visible as a rusty stain covering the rock surface. Carbonaceous shales have less than 5% organic matter. Oil shales have 5% or more organic content. The organic matter is possibly of bacterial or unicellular algal origin because no identifiable fossils are present.

f. North end of Third Beach: When the tide is low, the sandstone is exposed offshore and clearly shows tilting of its beds at about 10^o to 15^o upwards to the north (Figure 8). Why are they tilted? The tilting is reflecting the slow uplift of the Coast Range due to **plate tectonics** i.e. the North American crustal plate is moving west and the Juan de Fuca plate west of Vancouver Island is moving east.

The two opposing forces result in both uplift to form the Coast Range and down-warping to form the Georgia Depression.

g. The contact between the Huntingdon Formation (Eocene to Palaeocene: 34-65 Mya). and the other major rock formation that fills the Georgia Basin (the Nanaimo Group of Upper Cretaceous age: 65 – 97 Mya) should lie somewhere south of the Third Beach concession stand but there is no bedrock exposed and it is probably a **disconformity** as explained above. That contact, when it exists elsewhere in the world is known as the K-T (Cretaceous-Tertiary) or K-Pg (Cretaceous-Palaeogene) boundary and formed 65 million years ago. It is famous as the boundary between the Age of Dinosaurs and the Age of Mammals when an asteroid is thought to have impacted the Earth and caused the demise of the avian dinosaurs.

2. Northern end of Third Beach to Siwash Rock:

a. Looking north-west across Burrard Inlet to Black Mountain and Lighthouse Park note notches or terraces into Black Mountain. These are called **strath terraces** and are thought to represent one side of an ancient wide river valley formed by a laterally eroding river. The terraces are cut into bedrock and stepped downward as the river eroded downward and the land was uplifted. When they were formed is not clearly understood but may have been during the last **interglacial** called the **Olympia Interglacial** which lasted for approximately 40,000 years between 20,000 and 60,000 years ago..

b. A large granitic boulder (Figure 9) lies on the beach at the northern end of Third Beach. This is a glacial **erratic** which was stranded there by the final melting of the glaciers about 12,500 years ago. It contains inclusions of rounded fragments of a darker rock which has the composition of **amphibolite** and is probably a metamorphosed volcanic rock of Wrangellian age. Another smaller erratic close by shows glacial **striations** on a smooth somewhat flat face (**facet**). The striations and facet were produced when the boulder, embedded in the ice, was abraded against bedrock forming the sides or bed of the glacier.

c. North of the erratic in the cliff-face landward of the groin and memorial benches is a vertical **dyke (dike)** of a volcanic rock of **basaltic** or **andesitic** composition (Figure 10) which intruded the sandstone probably about 32 or 35 Mya because a similar rock in the Siwash Rock area gave those dates using the K/Ar isotopic dating method. The dyke is a little over a metre in thickness.

When the tide is out this same dyke can be seen continuing out into the ocean (Figure 11). The black angular boulders on the beach nearby are blocks that have been broken away from the dyke by wave action. Note the many small rounded cavities in these blocks (Figure 12). At first these cavities appear to be **vesicles**. However in freshly broken rock no vesicles are visible. They are thought to be

weathered out phenocrysts of **augite** and **olivine** altered to **serpentine** (Roddick 2001).

d. In the cliff-face just south of the Siwash Rock gate are minor bands of coarse, gritty sandstone containing some pebbles, which indicate deposition of sediment by higher energy streams. Occasional thin bands of carbonaceous siltstone or mudstone, also in this area, indicate lower energy stream action.

e. If you look very closely on clean surfaces of the sandstone cliff-face south of Siwash Rock gate you can see micro-faulting and slumping of sandstone beds. These are common features in the sandstones throughout the area and are due to compaction of the sandstone before consolidation by continuing deposition above them. Also in this area (south of the gate) is an example of honeycomb or **tafoni** weathering (Figure 13). Certain beds of sandstone seem to be compositionally more susceptible to this type of weathering than others.

f. There is considerable basaltic or andesitic volcanic rock in the cliff-face near Siwash Rock (Figure 14) and Siwash Rock (Figure 15) itself is of this type of rock. The mineral composition of this volcanic rock is black **phenocrysts** of **augite** lying in a **groundmass** of **plagioclase**, **hornblende** and volcanic glass. While these volcanic rocks have certainly intruded the sandstone it is not clear whether they were intruded as **sills**, **dykes** or a combination of both. They may also be a **laccolith** similar to the laccolith at Queen Elizabeth Park (Little Mountain). The volcanic rock in Stanley Park has been dated by K/Ar isotopic analysis as 32 or 35 million years old. They are considered to be the westernmost exposures of older parts of the Cascade Magmatic Arc. Siwash rock is called a **sea-stack** by geologists and a **transformer** or **ancestor stone** by First Nations people. The Squamish name for Siwash Rock is Skalsh. Fishermen call it Nine Pin Rock. Read the plaque that tells the First Nation legend about Siwash Rock. The plaque states that it is "Skalsh the unselfish," who was transformed by "Q'uas the transformer" as a reward for unselfishness. There is some controversy over the name of the rock. "Siwash" is a Chinook word for a person of First Nations or Native American heritage. Though the word 'siwash' in the jargon did not necessarily have a negative connotation and was used by native peoples themselves, its etymology can be traced to the French word "sauvage," which means wild or undomesticated.

g. When the tide is out many black, angular boulders of the volcanic rock can be seen on the beach north and south of Siwash Rock which has broken away from the cliff face and Siwash Rock itself over the last few thousand years. They are angular because they have not moved far from their original bedrock location. The lighter-coloured boulders that are mixed in with the volcanic boulders are of granitic and metamorphic composition and are more rounded because they were brought from the North Shore mountains by the ice.

3. Siwash Rock to First Nations canoe runway and fish trap:

a. For 370 metres north from Siwash Rock is a continuous section of well-exposed sandstone cliffs. At various points along this section are major **joints** and pebbly sandstone beds.

See 1c above for more about joints. This section of the tour is good for observing features indicative of the mode of deposition of the sandstone. Some of these are:

- The presence or absence of pebbles and cobbles in beds which indicate variations in stream carrying capacity which would be related to seasonal **freshets**.
- **Current bedding** (Figure 25) can be seen where laminations lie oblique to the plane of the main bedding. Examples can be seen where subsequent stream action has incised these current beds forming **cross bedding**.
- Occasional rounded clasts and clumps of mudstone or claystone can also be found sitting in the sandstone and probably represent fragments plucked out of the banks of the stream where finer, partially consolidated finer beds occurred.

b. In the cliff-face ~40 metres north of Siwash Rock there is a **wave-cut notch** clearly visible high in the cliff-face (Figure 16). This indicates a higher sea level. The lower wave-cut notch, well preserved along most of the sea-wall, is or was being formed by present-day wave action. However it is now covered by the sea-wall in Stanley Park. Elsewhere in Burrard Inlet it can be clearly seen at various locations along Kitsilano Beach.

c. Tilted bedding of sandstone of Nanaimo Group can be seen in the sea-wall cliff north of Siwash Rock (Figure 18).

d. Concretions can be seen protruding from the cliff face at a couple of locations along this section of the walk (Figures 17 & 19). South of the fish trap on the wave-cut platform can be seen many concretions in relief still embedded in the sandstone of the wave-cut platform (Figure 22).

e. A claystone or mudstone clast is visible in sandstone north of Siwash Rock (Figure 20).

f. Just before reaching the fish-trap, minor patches of coal can be seen in the sandstone at the base of the cliff which probably represents pieces of wood caught up in the stream flow (Figure 21). A clue to finding the small coal fragments is patches and streaks of iron oxidation (rust) in the face of the cliff. Due to the anoxic environment under which coal is formed, iron is also deposited, usually in the form of pyrite (FeS_2). When the pyrite is exposed to the atmosphere it oxidizes forming goethite which bleeds out of the rock.

4. First Nations canoe runway (Figure 23) and fish trap (Figure 24):

a. The fish trap has been constructed on a wave-cut platform by man-handling of boulders that probably once covered the platform. The boulders were used to form a fence which would have impeded the escape of fish as the tide receded. Similarly, the canoe runway was also cleared of boulders and was probably used to bring canoes in and out of the fish-trap area for loading of fish.

5. Fish trap to Prospect point:

a. Sixty metres north of the fish-trap interpretive sign is a clean section of cliff-face that shows very fine **cross bedding** and **current bedding** (Figure 25). The current beds slope down and in front of an advancing mini-delta illustrating how sand is moved down the bed of the stream. The advancing front of a river delta produces the same effect but on a much larger scale. The beds that slope down in front of the delta are called **fore-set** beds and the horizontal bed above and upstream from them is called the **top-set** beds. The top-set beds at this location have been removed by a change in the course of the stream or by an increase in the erosional power of the stream. When incised like that, the term **cross bedding** is used. This feature is common at

many places in the cliff face along our walk. However it is only apparent where the cliff face is clear of **biofilm** and vegetation. Current or cross bedding can be used for determining the direction of flow of the ancient streams that deposited the sand that became sandstone. See 3a above for further explanation. The beds stand out because of thin bands of black minerals which were identified as either **hornblende** or **pyroxene** and not **magnetite** or fine carbon as first thought. Further mineralogical study is required to narrow down the determination. The black grains show **conchoidal** fracturing and a lack of rounding suggesting they have not been transported far from source. Because pyroxene has a higher specific gravity than amphibole and therefore more likely to be sorted out by stream action from the lighter quartz, the black mineral is thought to be pyroxene.

b. Geologically, the cliffs at Prospect Point are basaltic or andesitic in composition. They exhibit vertical **columnar jointing** (Figure 26) and are described in the literature as a **sill** 40 metres thick extending back southwesterly from the water's edge. The sill can be seen in contact with the sandstone at the foghorn building (the white-washed building). The joints of the columns form at right angles to the cooling surface so that is how we know it is a sill. The strength of the volcanic rock at Prospect Point and its resistance to erosion has been useful for anchoring the southern end of the Lions Gate Bridge.

Figure 5: Resistant sandstone bed of quartz grains cemented with calcite. Interbedded with less resistant sandstone of quartz and feldspar grains most likely cemented by clays. In Huntingdon Formation at Ferguson Point

Figure 6: Concretion eroded out of sandstone showing a spheroidal fracture reflecting concretionary nature of the cobble. On beach north of Ferguson Point.

Figure 7: Sandstone overlying carbonaceous shale within the Huntingdon Formation between Ferguson Point and Third Beach.

Figure 8: Rocky point south end of Third Beach showing sandstone beds tilted upwards to the north by the rising of the North Shore mountains.

Figure 9: Erratic boulder of granitic rock, Third Beach (north end). Note large rounded inclusions of darker rock (amphibolite) in the boulder which are Wrangellian in origin.

Figure 10: Vertical basaltic or andesitic dyke north end of Third Beach intruding sandstone.

Figure 11: Basaltic or andesitic dyke seen in Figure 9 trending seaward, north end of Third Beach intruding sandstone of Nanaimo Group showing jointing at right angles to dike walls

Figure 12: Texture on surface of a basaltic boulder displaced from the dyke shown in Figures 10 & 11. The cavities in the basalt are considered to be weathered out phenocrysts of augite and olivine that had been altered to serpentine (Roddick 2001).

Figure 13: Tafoni (honeycomb weathering) in sandstone of the Nanaimo Group south of Siwash Rock.

Figure 14: Basaltic rock (the dark-coloured rock above) intruding sandstone (light-coloured rock below) immediately south of Siwash Rock. Configuration of the contact between the basaltic rock and the sandstone suggests the basalt may have been intruded as a sill or laccolith.

Figure 15: Siwash Rock, a sea-stack of basaltic or andesitic rock. Also a First Nations ancestor or transformer stone. Note Great Blue Heron sitting on the Douglas-fir.

Figure 16: Upper wave-cut notch in sandstone of the Nanaimo Group immediately north of Siwash Rock.

Figure 17: String of concretions in a sandstone bed of the Nanaimo Group north of Siwash Rock.

Figure 18: Tilted bedding of sandstone of Nanaimo Group in sea-wall cliff north of Siwash Rock

Figure 19: Concretion in sandstone of the Nanaimo Group. North of Siwash Rock.

Figure 20: Claystone or mudstone clast in sandstone of the Nanaimo Group in the cliff-face north of Siwash Rock and 125 metres south of the First Nations fish trap.

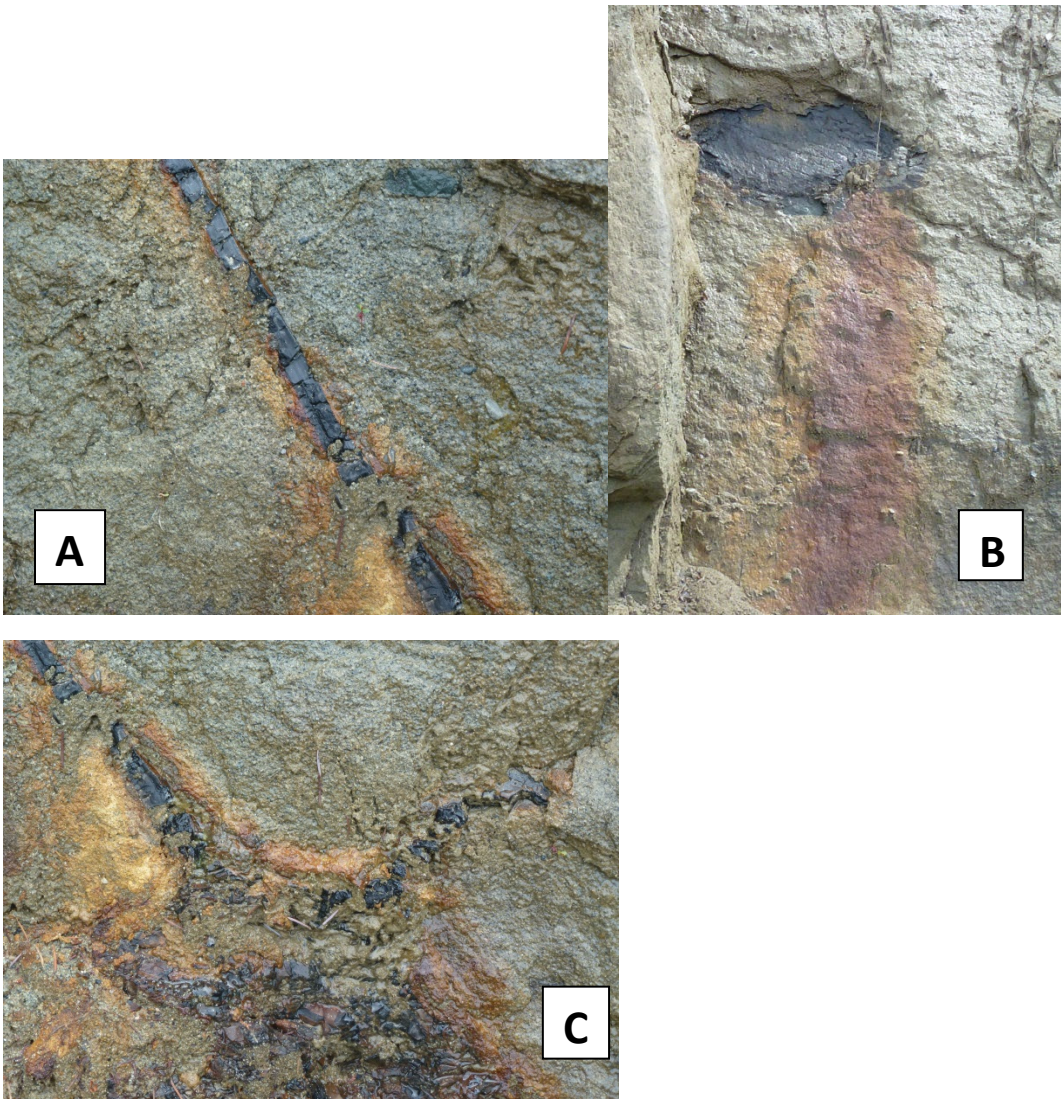

Figure 21: Coal in sandstone of Nanaimo Group. North of Siwash Rock. These examples may have been a root (A), log (B) and stump with roots (C)

Figure 22: Wave-cut platform of sandstone with concretions partially eroded out of the sandstone south of the fish-trap. Siwash Rock in background

Figure 23: First Nations canoe runway south of Siwash Rock

Figure 24: First Nations fish trap outlined by a train of man-handled boulders. North of Siwash Rock

Figure 25: Current or cross bedding in sandstone. North of fish trap.

Figure 26: Columnar jointing of basaltic or andesitic rocks near Prospect Point

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Glossary:

Amphibolite: A generally hard, dark rock made up primarily of the mineral amphibole and formed when basalt and gabbro are metamorphosed.

Andesite (andesitic): A fine-grained volcanic rock, chiefly plagioclase and feldspar. It is intermediate in silica content. The extrusive equivalent of diorite.

Angular unconformity: An unconformity where horizontally parallel strata of sedimentary rock are deposited on tilted and eroded layers producing an angular discordance with the overlying horizontal layers.

Ancestor stone: See transformer stone.

Augite: An important rock-forming mineral in many igneous rocks, especially in gabbros and basalts.

Basalt (basaltic): A common extrusive volcanic rock. It is usually grey to black and fine-grained due to rapid cooling of lava at the surface of a planet. Composed mostly of calcium plagioclase and pyroxene. The extrusive equivale3nt of gabbro.

Biofilm: An aggregate of micro-organisms in which cells adhere to each other on a surface; in this case the wet surface of sandstone. These adherent cells are frequently embedded within a self-producing matrix of extra-cellular **polymeric** substance (EPS).

Carbonaceous: Rich in carbon.

Cascade magmatic arc: A belt of Tertiary (<65 Ma) and younger intrusive and extrusive rocks which stretches from northern California to the southern end of the Alaska Panhandle.

Coast Belt: An igneous province in British Columbia. It consists of terranes accreted to the continent about 95 Ma and includes:

a. 170-110 Ma granitic rocks of an island arc.

b. Granitic rocks of the Coast Mountains belonging to a continental arc that formed 95-45 Mya

c. Young volcanic rock of the Cascade Volcanic Arc.

Columnar jointing: Results when basalt or other igneous rock cools from the outside in, causing shrinkage and the development of hexagonal jointing.

Compressional: Compression in geology refers to a set of stresses directed toward the center of a rock mass. Compressive strength is the maximum compressive stress that can be applied to a material before failure occurs. When the maximum compressive stress is in a horizontal orientation, thrust faulting can occur, resulting in the shortening and thickening of that portion of the crust. When the maximum compressive stress is vertical, a section of rock will often fail in normal faults. Compressive stresses can also result in folding of rocks.

Concretions: A **concretion** is a hard, compact mass of matter formed by the precipitation of mineral cement within the spaces between particles, and is found in sedimentary rock or soil. Concretions are often ovoid or spherical in shape, although irregular shapes also occur. What caused the precipitation of calcite in the first place? Evidence from stable carbon isotope analysis of the calcite at Kettle Point, Lake Huron suggests an origin involving **bacterial sulphate reduction of organic matter**. Sulphate reduction is one of numerous pathways by which certain types of bacteria can metabolize organic matter. The process can be represented by the following simplified equation:

$2CH_2O + SO^{2-} \rightarrow H_2S + 2HCO_3^-$ where CH_2O represents organic matter and dissolved sulphate (SO_4^{2+}) is derived from seawater.

Conchoidal: A type of fracture in a solid (such as flint or quartz) that results in a smooth rounded surface resembling the shape of a scallop shell.

Cordillera: An extensive chain of mountains or mountain ranges. The Spanish word originates from *cordilla*, a diminutive of *"cuerda"*, or "rope". The North American Cordillera is the North American portion of the American Cordillera which is a mountain chain along the western side of the Americas. The North American Cordillera covers an extensive area of mountain ranges, intermontane basins, and plateaus in western North America, including much of the territory west of the Great Plains. It is also sometimes called the Western Cordillera, the Western Cordillera of North America, or the Pacific Cordillera.

Craton: An old and stable part of the continental lithosphere, where the lithosphere consists of the Earth's two topmost layers, the crust and the uppermost mantle. Having often survived cycles of merging and rifting of continents, cratons are generally found in the interiors of tectonic plates. They are characteristically composed of ancient crystalline basement rock. They are the stable portion of the continental crust in contrast to regions that are more geologically active and unstable. Cratons can be described as shields (e.g. the Canadian Shield), in which the basement rock crops out at the surface, and platforms, in which the basement is overlaid by sediments and sedimentary rock.

Cross bedding or cross lamination or cross stratification: Any arrangement of strata that are locally inclined at some angle to the overall planar orientation of the stratification of a sedimentary unit. Cross-bedding can be caused by water when it is known as current bedding or by wind as in sand dunes.

Cuesta: In structural geology and geomorphology is a ridge formed by gently tilted sedimentary rock strata. Cuestas have a steep slope where the rock layers are exposed on their edges called an escarpment or if more steep a cliff. The other side of the ridge has a gentler and longer slope. This gentle slope (called a dip slope) is usually a more erosion resistant rock layer and is the main reason that the cuesta exists.

Current bedding: See cross bedding.

Disconformity: A specific type of hiatus (unconformity) wherein the layers above and below an unconformity surface have the same orientation (strike and dip). Disconformities may be difficult to recognise; however as with all unconformities, disconformities involve a significant time gap-typically on the order of tens of millions of years. The absence of strata representing a gap in the geological record can be due to a number of factors; crustal deformations, erosion, seas level changes and absence of deposition being a few.

Docking: Addition or accretion of sediment, volcanic arcs, seamounts or other igneous features to a tectonic plate or land mass.

Downwarping: A segment of the crust of the Earth that bends downward.

Dyke (dike): A vertical to sub-vertical sheet-like intrusion of magma and occasionally sediment into other types of tock.

Erratic: A boulder that differs from the bed-rock on which it rests and was carried by glacial ice for distances up to hundreds of kilometres. When the ice melted, the boulder was stranded. Erratics can be any size but the term is usually applied to unusually large specimens such as "Big Rock", a 15000 metric ton boulder in Alberta.

Eustatic: Any uniformly global change of sea level that may reflect a change in the quantity of water in the ocean or a change in the shape and capacity of the ocean basins.

Exfoliate: Separation of successive thin shells, or spalls, from massive rock.

Extrusive: A mode of igneous volcanic rock formation in which hot magma from inside the Earth flows out (extrudes) onto the surface as lava or explodes violently into the atmosphere to fall back as **pyroclastics** or tuff.

Facet: When boulders are held firmly in ice they may be ground against the floor or walls of the glaciated valley or against their fellows to form flattened faces or facets.

Facies: A rock unit that reflects its environment of deposition and allows it to be distinguished from rock or sediment deposited in an adjacent environment.

Fan or Fan facies: A fan-shaped accumulation of silt, sand, gravel, and boulders deposited by fast-flowing mountain rivers when they reach flatter land.

Forearc: The region between a subduction zone and a volcanic arc.

Foreland: A foreland basin is a structural basin that develops adjacent and parallel to a mountain belt. Foreland basins form because the immense mass created by crustal thickening associated with the evolution of a mountain belt causes the lithosphere to bend, by a process known as lithospheric flexure.

Foreset beds: Beds laid down on the sloping surface of a delta or dune. Beds above and below the foreset beds mark the horizontal direction.

Flow: A stream of molten rock.

Fraser glaciation: The last glacial advance and retreat in the Pacific Cordillera of North America that occurred between about 29,000 to 12,000 years ago.

Freshet: The flood of a river from heavy rain or melted snow.

Geomorphology: The study of the processes that have shaped the Earth's surface.

Glacial Maximum: Usually refers to the Last Glacial Maximum (LGM) when the extent of the ice was greatest about 26,500 years ago**.**

Goethite: Goethite is an iron oxyhydroxide containing ferric iron. It is the main component of rust and bog iron ore. Goethite often forms through the weathering of other iron-rich minerals, and thus is a common component of soils. It may also be precipitated by groundwater.

Granitic: Felsic to intermediate intrusive rocks of many varieties, including granite.

Groundmass: The matrix or groundmass of rock is the finer grained mass of material in which larger grains, crystals or clasts are embedded.

Holocene: The current geological epoch. It began after the Pleistocene, approximately 12,000 years before present. The Holocene is part of the Quaternary period.

Holocene Climatic Optimum:

Honeycomb weathering: See tafoni.

Hornblende: A black or dark green mineral that typically occurs as prismatic elongate crystals. The most common mineral of the amphibole family, it has a complex and variable composition featuring Ca, Na, Mg, Fe, Al, O and H.

Hypsithermal: A warm period during approximately the interval 9,000 to 5,000 years BP. Also known as the Holocene Climate Optimum (HCO).

Interglacial: A period of temporary retreat of ice during a glacial stage.

Intruded: In geology an intrusion is any formation of intrusive igneous rock; rock formed from magma that cools and solidifies within the crust of the planet. In contrast, an extrusion consists of extrusive rock; rock formed above the surface of the crust.

Isostatic (isostacy): Is the state of gravitational equilibrium between Earth's crust and mantle such that the crust "floats" at an elevation that depends on its thickness and density. Isostasy is not a process that upsets equilibrium, but instead is one which restores it.

Joint (jointing): Planes of separation in rock on which no shear displacement has taken place. The two walls of the resulting opening typically remain in tight (matching) contact. Joints may result from regional tectonics (i.e. the compressive stresses in front of a mountain belt), folding (due to curvature of bedding), faulting, or internal stress release during uplift or cooling. They often form under high fluid pressure (i.e. low effective stress), perpendicular to the smallest principal stress.

Joint set: A joint set is a group of joints with similar orientation and morphology. Several sets usually occur at the same place with no apparent interaction, giving exposures a blocky or fragmented appearance. Two or more intersecting sets of joints present together in an exposure compose a joint system. Joint sets in systems commonly intersect at constant dihedral angles. They are conjugate for dihedral angles from 30 to 60°, orthogonal when the dihedral angle is nearly 90°

Juan de Fuca plate: A tectonic plate generated from the Juan de Fuca Ridge which is subducting under the northerly portion of the western side of the North American Plate at the Cascadia subduction zone. It is named after the explorer of the same name. One of the smallest of Earth's tectonic plates, the Juan de Fuca Plate is a remnant of the once-vast Farallon Plate, which is now largely **subducted** underneath the North American Plate.

Laccolith: A sheet intrusion (or concordant pluton) that has been injected between two layers of sedimentary rock. The pressure of the magma is high enough that the overlying strata are forced upward, giving the laccolith a dome or mushroom-like form with a generally planar base.

Cooling underground takes place slowly, giving time for larger crystals to form in the cooling magma.

Lignite: Brown coal. A soft brown combustible sedimentary rock formed from naturally compressed peat. It is considered the lowest rank of coal due to its relatively low heat content. It has a carbon content around 60–70 percent. It is used almost exclusively as a fuel for steam-electric power generation, but is also mined for its germanium content in China.

Limonite: A mineral composed of iron oxides and water. Rust. Very common in many rocks after weathering at the Earth's surface. Imparts brown or yellow colors to many rocks.

Load: The solid matter carried by a stream. Erosion and bed shear stress continually remove mineral material from the bed and banks of the stream channel, adding this material to the regular flow of water.

Ma: The convention for abbreviating "million years".

Macerals: A component, organic in origin, of coal or oil shale. Dehydrogenated plant fragments. Evidence for this includes remnant pollen spores, fossilised leaves and remnant cellular structure.

Magnetite: A mineral with the chemical formula Fe_3O_4. It is ferrimagnetic. It occurs in almost all igneous and metamorphic rocks. Magnetite is black or brownish-black with a metallic luster, has a Mohs hardness of 5–6 and leaves a black streak.

Metasediments: Metamorphosed sedimentary rock.

Metavolcanics: Metamorphosed volcanic rocks. Such a rock was first produced by a volcano, either as lava or tephra. Then, the rock was buried underneath subsequent rock and was subjected to high pressures and temperatures, causing the rock to recrystallize.

Micro-faulting: Faults at the scale of a millimetre or less.

Micro-tektites: Tektites are black, green, brown or gray natural glass formed from terrestrial debris ejected during meteorite impacts. Millimeters-size tektites are known as **microtektites**

Mya: The convention for abbreviating "million years ago".

Neoglacials or neoglaciation: ("renewed glaciation"). A cooling trend in the Earth's climate during the **Holocene**, following the retreat of the Wisconsin glaciation, the most recent glacial period. Neoglaciation has followed the **hypsithermal** or **Holocene Climatic Optimum**, the warmest point in the Earth's climate during the current interglacial stage. The neoglaciation has no well-marked universal beginning because local conditions and ecological inertia affected the onset of detectably cooler (and wetter) conditions.

North American Plate: A **tectonic plate** covering most of North America, Greenland, Cuba, the Bahamas, extreme northeastern Russia, and parts of Iceland and the Azores. It extends eastward to the Mid-Atlantic Ridge and westward to the Chersky Range in eastern Siberia. The plate includes both continental and oceanic crust. The interior of the main continental landmass includes an extensive granitic core called a **craton**. Along most of the edges of this craton are fragments of crustal material called **terranes**, accreted to the craton by tectonic actions over the

long span of geologic time. It is thought that much of North America west of the Rocky Mountains is composed of such terranes.

Nunatak: From Inuit nunata. An exposed, often rocky element of a ridge, mountain, or peak not covered with ice or snow within (or at the edge of) an ice field or glacier. They are also called glacial islands.

Olivine: A rock-forming mineral of magnesium iron silicate with the formula $(Mg^{2+}, Fe^{2+})_2SiO_4$.

Olympia Interglacial: A period of glacial retreat between 20,000 and 60,000 years ago.

Peneplain: (from the latin parene = almost. So almost a plain) designates a wide almost uniform plain, with slight unevenness a result of prolonged erosion and the coalescence of watersheds. It is a set of watercourses and watersheds of low altitude with regard to the valleys, with some residual reliefs along the basin of the rivers. The peneplain would therefore be the result of the last stage of the geographical cycle produced by the river waters.

Periostracum: A thin organic coating or "skin" which is the outermost layer of the shell of many shelled animals, including molluscs and brachiopods.

pH: (potential of hydrogen). A numeric scale used to specify the acidity or basicity of an aqueous solution. It is approximately the negative of the base 10 logarithm of the molar concentration, measured in units of moles per liter, of hydrogen ions. More precisely it is the negative of the logarithm to base 10 of the activity of the hydrogen ion. Solutions with a pH less than 7 are acidic and solutions with a pH greater than 7 are basic. Pure water is neutral, at pH 7, being neither an acid nor a base. Contrary to popular belief, the pH value can be less than 0 or greater than 14 for very strong acids and bases respectively.

Phenocrysts: Large crystals embedded in a mass of finer crystals (groundmass) in an igneous rock

Plagioclase: A member of the feldspar mineral family. Plagioclase feldspars are silicates that contain considerable sodium and calcium. Feldspar crystals are stubby prisms, generally white to gray and a glassy luster.

Plate: The Earth's outer shell is divided into several plates that glide over the mantle, the rocky inner layer above the core. The plates act like a hard and rigid shell compared to Earth's mantle. This strong outer layer is called the lithosphere.

Plate tectonics: The theory that the Earth's outer shell is made up of about a dozen lithospheric plates that move about and interact at their boundaries.

Polymer: Greek = many parts. A large molecule, or macromolecule, composed of many repeated subunits. Because of their broad range of properties, both synthetic and natural polymers play an essential and ubiquitous role in everyday life. Polymers range from familiar synthetic plastics such as polystyrene to natural biopolymers such as DNA and proteins that are fundamental to biological structure and function.

Pyroclastics: Broken (clastic) rock composed solely or primarily of volcanic materials. pyroclastic deposits are commonly formed from airborne ash, lapilli and bombs or blocks ejected from the volcano itself, mixed in with shattered country rock.

Redox: Short for reduction–oxidation reaction, a chemical reaction in which the oxidation states of atoms are changed. Any such reaction involves both a reduction process and a complementary oxidation process, two key concepts involved with electron transfer processes. a type of chemical reaction that involves a transfer of electrons between two species. It is any chemical reaction in which the oxidation number of a molecule, atom, or ion changes by gaining or losing an electron.

Sea-stack: A geological landform consisting of a steep and often vertical column or columns of rock in the sea near a coast, formed by wave erosion. Stacks are formed over time by wind and water, processes of coastal geomorphology. They are formed when part of a headland is eroded by hydraulic action, which is the force of the sea or water crashing against the rock. The force of the water weakens cracks in the headland, causing them to later collapse. Stacks also form when a natural arch collapses under gravity,

Serpentine: A group of rock forming minerals known as magnesium silicates with the general formula $Mg_3(OH)_4(Si_3O_5)$. Usually green. They form the rock-type serpentinite.

Shale: Sedimentary rock derived from mud. Commonly finely laminated (bedded). Particles in shale are commonly clay minerals mixed with tiny grains of quartz eroded from pre-existing rocks

Sill: A tabular sheet intrusion that has intruded between older layers of sedimentary rock, beds of volcanic lava or tuff, or even along the direction of foliation in metamorphic rock. The term sill is synonymous with concordant intrusive sheet. This means that the sill does not cut across pre-existing rocks. In contrast dikes are discordant intrusive sheets which do cut across older rocks. Sills are fed by dikes. A sill is also the terminal moraine of fjord glacier.

Slumping: A type of landslide in which a mass of rock breaks away along a curved surface and rotates more or less intact, downslope. The sliding mass of rock is called a slump block.

Stack: See **sea-stack.**

Strath terraces: Remnants of a flat, broad valley floor (a strath) that was carved flat in bedrock, with subsequent downcutting leaving the side of the old rock floor hanging along the sides of the valley.

Striations: Linear scratches on bedrock formed by rocks embedded in the bottom of a glacier as the glacier moves along. The direction the glacier can be determines by the direction that the lines point.

Subducting (ion): A geological process that takes place at convergent boundaries of tectonic plates where one plate moves under another and is forced or sinks due to gravity into the mantle. Regions where this process occurs are known as subduction zones.

Tafoni (honeycomb weathering): Small, cave-like features found in granular rock such as sandstone, limestone and granitic rocks. Tafoni have rounded entrances and smooth, concave walls. They often occur in groups that can riddle a hillside, cliff or other rock formation. Small versions of tafoni such as those in Stanley Park are called alveoli. They can be found in all climate types but are most abundant in upper intertidal areas, semi-arid to arid areas, hot deserts and cold deserts such as in the Antarctic and Arctic. They can also develop on stone work of buildings. The currently favoured explanation controlling their formation include salt heaving where, depending on the porosity of the rock, salt solution penetrates the rock, the water evaporates and the salt crystals formed pry or heave rock crystals loose. Along coastlines the salt is sodium chloride, in desert areas the salts can also be sodium bicarbonate (baking soda), calcium sulphate (gypsum) and sodium carbonate (washing soda). The factors that control the honeycomb pattern of the alveoli, although poorly understood, may be related to microscopic algae colonizing the side-walls of the alveoli and preventing further growth of the alveoli or case-hardening of the walls by a similar process to the formation of desert varnish. Heterogeneous wind-flow over the rock surface also seems to be a factor in forming the alveoli.

Tectonic plate: Tectonic plates are pieces of Earth's crust and uppermost mantle, together referred to as the lithosphere. The plates are approximately 100 km (62 mi) thick and consist of two principal types of material: oceanic crust (also called sima from silicon and magnesium) and continental crust (sial from silicon and aluminium).

Terrain and Terrane: Terrain is a geomorphological term applying to landforms, topography and drainage. Terrane is a block of the earth's crust that differs from the surrounding material, and is separated from it by faults

Tensional "tension": A stress which stretches rocks in two opposite directions. The result can be **jointing** in rocks which is the way the rock relieves stress.

Till: Unsorted, unstratified rock rubble or debris carried on and/or deposited by the ice of a glacier.

Top set beds: A horizontal layer of coarse sand and gravel deposited on top of a river delta. The topset beds of an advancing delta are deposited in turn over the previously laid foresets, truncating or covering them. Topsets are nearly horizontal layers of smaller-sized sediment deposited on the top of the delta and form an extension of the landward alluvial plain. See **foreset** beds.

Transformer stone: Stones representing supernatural figures common in many First Nations' origin stories. Transformers often have a deep concern for human well-being and moral conduct. A physical manifestation of First Nations spirituality. Transformer characters in First Nations stories can also be tricksters. The trickster is a special, often very witty and humourous character that demonstrates the opposite characteristics to those that are valued in human beings. Through his actions, he shows people the consequences of acting in an unacceptable manner. In a reverse way, the trickster is a moral, ethical, and philosophical teacher. Stories featuring the trickster often teach a moral lesson. The trickster often also plays a creator role in stories, but he is also a lair, a cheat, lazy, and lustful.

Unconformity The contact between older rocks and younger sedimentary rocks in which at least some erosion has removed some of the older rocks before deposition of the younger. An **angular unconformity** shows that the older rocks have been deformed and eroded before the younger sedimentary rocks were deposited; there is an angle between the beds of the older and the younger.

Vesicles: In geology a small gas bubble formed in volcanic rock during solidification most commonly basalt.

Wave-cut notch: Is formed when sea waves undercut the base of a cliff. As the force of the waves continually weaken the base, the overhanging rock or the area above the notch eventually caves in.

Wave-cut platform: A flat area often found at the base of a sea cliff or along the shoreline of a lake, bay, or sea that was created by the erosion of waves. Wave-cut platforms are often most obvious at low tide when they become visible as wide areas of flat rock.

Wrangellia(n) a geologic concept encompassing a large arc of terrain extending from the south-central part of the U.S. state of Alaska through southwestern Yukon and along the Coast of British Columbia in Canada. Although not generally accepted, some workers contend that Wrangellia extends southward to Oregon. Wrangellia was originally created in the Pennsylvanian to the Jurassic somewhere, but probably near the equator, in the Panthalassic Ocean off of the west coast of the North American craton as island arcs, oceanic plateaus, and rock assemblages of the associated tectonic settings. Although composed of many different rocks types, of various composition, age, and tectonic affinity, it is the late Triassic flood basalts that are the defining unit of Wrangellia. These basalts, extruded onto land over 5-million years about 230 Mya, on top of an extinct Pennsylvanian and Permian island arc, constitute a large igneous province, currently exposed in a 2,500 km (1,553 mi) long belt. Wrangellia collided and amalgamated with the Alexander Terrane by Pennsylvanian time. By the end of the Triassic Period, the Peninsular Terrane had also joined the Wrangellia Composite Terrane. A subduction zone existed on the west side of Wrangellia. Seafloor rocks too light to be subducted were instead compressed against the western edge of Wrangellia; these rocks are now known as the Chugach Terrane. A complex fault system, known as the Border Ranges Fault, is the modern expression of the suture zone between Wrangellia and Chugach Terranes. Over time, plate tectonics moved this amalgamation of crust generally northeastward into contact with the North American continental margin. The Wrangellia Composite Terrane collided with and docked onto North America by Cretaceous time. Strike-slip displacement, with Wrangellia travelling northward, continued after docking, although the amount of post-accretion displacement is controversial.