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How Gabriola came to be

by Nick Doe

An introduction to the geology of Gabriola was published in SHALE 1 in November 2000. This is the first of several follow-up articles. If you find these articles tough-going, you might want to read, or re-read, the earlier article if you haven't already done so. If this doesn't work, don't give up; at least some of the articles in future issues will have a lighter touch.

Bedrock basics

Gabriola and its smaller neighbours—Mudge, Link, De Courcy, and Valdes—are islands composed entirely of sedimentary rock. Nowhere, above the deep basement, is the bedrock metamorphic or volcanic, nor are there any intrusive igneous rocks, such as *granodiorite*, excepting only the boulders and stones in surficial deposits left by the great glaciers of the last ice age.

The most common of the bedrocks is **sandstone**, but there are also thick beds of **mudrock** of various kinds, particularly, of course, shale; and there are, locally, beds of naturally cemented rubble that geologists call **conglomerate**. All these rocks are held together mainly by clay minerals, and all belong to formations of the late-Cretaceous Nanaimo Group.

The sand, mud, and gravel from which the rocks were made, were deposited in the marine delta of one or more large rivers. The courses of these rivers must have changed many times during the millions of years of their existence, but the details of these changes are, and probably always will be, virtually unknown; however, there is evidence that in the waning days of the Mesozoic Era, 65 million years ago, a major river was bisecting the Coast Mountains, just as the Fraser River does today, but with a very different topography.

Sediment is classified according to *clast* or grain size as *gravel*, *sand*, or *mud*.

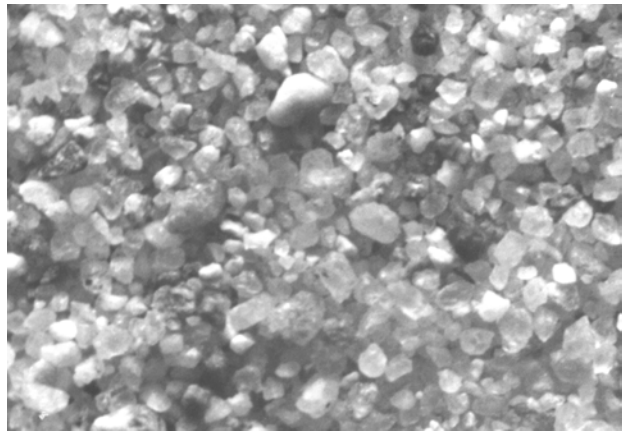
> **Gravel** is *boulders* (>256-mm), *cobbles* (>64-mm), *pebbles* (>8-mm), or *granules* (>2-mm).
>
> **Sand** is *very-coarse* (>1-mm), *coarse* (>500-µm), *medium* (>250-µm), *fine* (>125-µm), or *very-fine sand* (>64-µm).
>
> **Mud** is *coarse* (>32-µm), *medium* (>16-µm), *fine* (>8-µm), or *very-fine silt* (>4-µm); or *clay*.

The clasts in sedimentary rocks are always held together by a natural cement, which is usually *quartz*, *calcite*, *iron oxide*, or *clay*. It is not possible to lithify sediment by pressure alone.

> **Conglomerate** is lithified gravel with rounded clasts. *Breccia* is like conglomerate but with angular clasts.
> **Sandstone** is lithified sand.
> **Mudrock** is lithified mud. The mudrocks are *siltstone* and *claystone* plus *mudstone*, which contains both silt- and clay-sized particles. *Shale* is any kind of mudrock that is fissile (splitable into sheets). All mudrock is commonly, but not always correctly, known as "shale" on Gabriola on account of its thin bedding and extensive spheroidal weathering. This shouldn't however be taken to mean that individual beds of mudrock are fissile, which they are technically required to be in order to be classified as "shale". Some thin beds of mudrock on Gabriola are, at most, only vaguely laminated.

Imbrication of the sediments on Gabriola indicates that their source lay to the south and east of the island. Most, but not all, of the sediments came from the then-young Coast Mountains with minor, but significant, contributions from distant sources in the interior of the continent. Another major contributor was the Cascade Terrane and San Juan Nappes,[1] which arrived here from the Pacific in the early-Cretaceous, about 140 million years ago. The present-day San Juan Islands are deeply-glaciated remnants of what once was a mountainous country, and in those days, there was no Juan de Fuca Strait.

The depositional depth of the upper-Nanaimo Group sediments was at least a hundred metres below sea level, and almost certainly more (Mustard, 1994).



Above: sand from the beach in Taylor Bay. Minerals shown here make up about 90% of the rock of the Coast Mountains on the mainland.

Quartz is translucent; *plagioclase* is a milky-white feldspar; *orthoclase* is a pinkish-white feldspar; *hornblende* is greenish-black with glistening surfaces; and *biotite* is a black mica.

Unlike many sands in the world, Gabriola's is still young and has yet to fully weather.

Regional setting

For the past 180 million years or so, North America has been moving away from Europe as lava from on-going volcanic eruptions has added new seafloor to the Atlantic Ocean. As North America has moved westward, the Pacific Ocean has narrowed, and its older colder seafloor, which too has been growing, has slid down beneath the continent.[2] Patches of lighter felsic rocks on the sinking seafloor have been "skimmed off" and "stuck" (accreted) to the west coast, much like scum on the surface of skimmed water. Most of western British Columbia is made up of remnants of what were once islands, seamounts (submarine volcanoes), and oceanic plateaus, formed far away from their present locations.

The Rocky Mountains in the east of the province are the remains of a continental shelf that has been thrust back, like a rucked up carpet, over the prairies of central Canada for 200 kilometres or more. Volcanoes along the west coast—Mount Baker, Meager, Garibaldi—are the result of sinking seafloor, which is mainly *basalt*, becoming hot enough to cause mineral transformations that release huge volumes of superheated water. This water promotes melting of the mantle to form magma about 80 kilometres below the surface.

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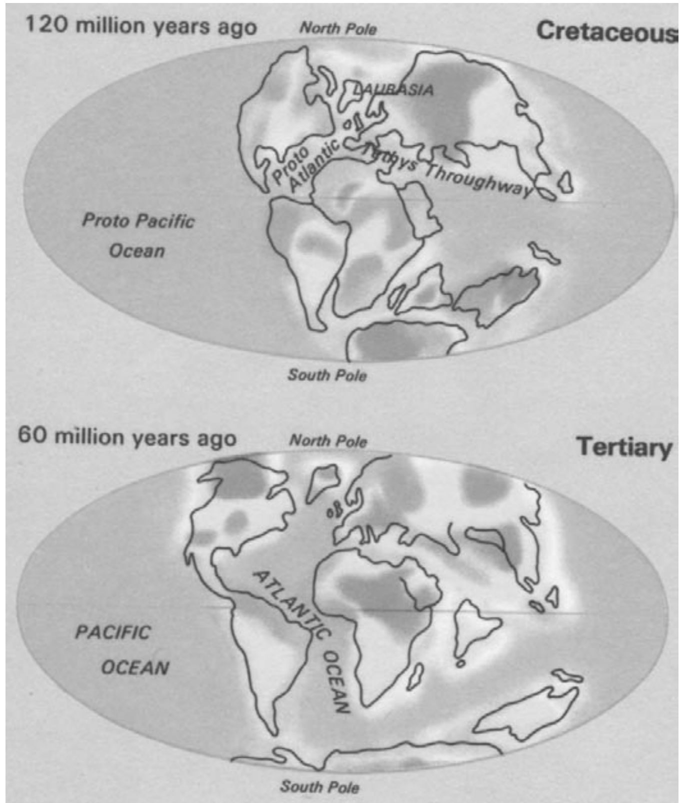
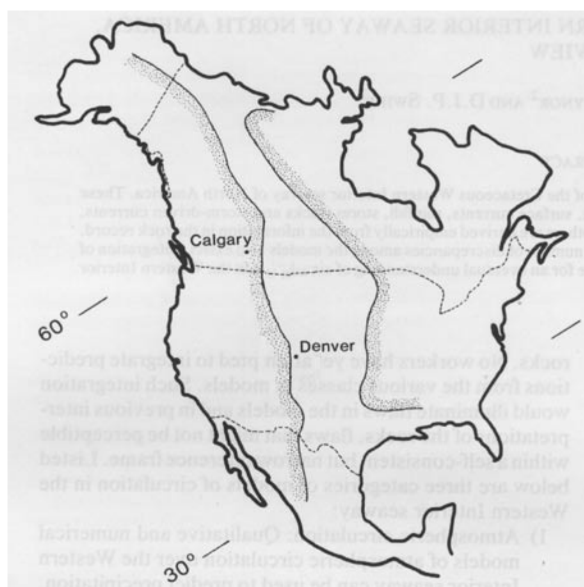
[1] A "terrane", also called a "micro-continent", is a coherent cluster of rock formations, smaller than a continent, and too small to be an independent tectonic plate. A "nappe" is smaller and more homogeneous than a terrane. Terranes and nappes have been transported far from their place of origin by some tectonic process.

[2] This on-going subduction currently starts about 100 kilometres off the west coast of Vancouver Island. The average speed of the subduction is about 40-mm per year, at which rate a continent could, in theory, have drifted completely around the earth almost five times within the earth's lifetime. The speed of continental drift has some surprising consequences; for example, mountains along the eastern seaboard of the United States may have been once connected to mountains that now run along the shore of the Weddell Sea in Antarctica.

During the Cretaceous Period, the weight of sinking seafloor combined with high eustatic (global) sea levels was sufficient to depress land east of the Rockies so much, that most of Alberta was part of a shallow North American inland seaway (map *bottom right*). Remarkably, a “ghost” of this depression still exists. It now runs under Hudson Bay, northward under the North Pole, and across Siberia. And the Farallon tectonic plate, which was once a major component of the Pacific’s seafloor, has recently been detected by seismologists as a cold sinking slab, 1600 kilometres below the eastern seaboard of the United States (Gurnis, 2001).

The heavier mafic[3] rocks of the Pacific Ocean’s floor continue to this day to slide down under Vancouver Island and into the mantle beneath the mainland. As a consequence, lighter, continental-type rocks brought in from the open Pacific continue to be stuffed beneath Vancouver Island, a process that pushes the island, albeit in jerks, toward the east. Currently, for example, Ucluelet on the outer coast of Vancouver Island is moving toward Whistler on the mainland at a rate of about ten millimetres per year; however, Nanoose on the east coast of Vancouver Island is only moving in roughly the same direction at four millimetres per year (Dragert, 2001). The difference is being made up by the “bowing” upward of Vancouver Island, a strain that will be released one day by a major earthquake (Clague, 2003, p.123).





The shallow inland sea that existed in North America during most of the Mesozoic Era, but which was finally withdrawing at the time Gabriola’s rocks were forming in the late-Cretaceous.

3 *Mafic* minerals are dark, heavy silicates, rich in iron and magnesium, and common in oceanic rocks. *Felsic* minerals are light-coloured silicates, rich in sodium and calcium, and common in continental rocks.

A familiar sight to Gabriolans. Mount Benson with Nanaimo Harbour (*left*), and Protection Island (*right*) as seen from the ferry. On the far right, in the distance, is the summit ridge of Mount Arrowsmith, which, 20 thousand years ago, was the only thing in this picture not buried under ice.

Mount Benson and its neighbours are part of the *Karmutsen* lava plateau. These lavas erupted along a mid-ocean ridge, thousands of kilometres away in the tropics, about where Indonesia is now. The lavas are *basalt*, a black, heavy crystalline rock, about 230 million years old (Triassic).

The Karmutsen plateau belongs to the terrane called *Wrangellia*, which drifted across the ocean and collided with the west coast of North America about 100 million years ago, long before Gabriola existed. When it arrived here, Mount Benson was probably close to or below sea level and the Nanaimo Basin was considerably wider than the present-day Georgia Basin. Pressure from the southwest has shoved Vancouver Island up against the mainland and raised mountains thousands of metres high on both sides of the strait (Monger, 1994).

You don't need to take the ferry to see the lava of Wrangellia. This example of *pillow-lava*—the kind of lava created by gently erupting submarine volcanoes—is a beauty. It was brought to Gabriola from Vancouver Island by glaciers and left on the beach in the inter-tidal zone in the cove just west of Drumbeg Park. It has been polished by the sea; has a lovely reddish- and greenish-sheen; and bright pistachio-green veins of the mineral *epidote*.

Noted by Bernard Wohlleben

Baja BC: In this article, I am going to adopt the view shared by many geologists that Vancouver Island first "came ashore" at about its present latitude. However, you should be aware that there is an alternative theory, known as the "Baja-BC" theory, which maintains that Vancouver Island first made contact at about latitude 23ºN (Baja-California, Mexico), and subsequently drifted 3500 kilometres northward to its present position (Ward, 1997). Although the paleomagnetic evidence for this theory is strong, adopting the Baja-BC theory would raise many difficulties in explaining the geological evolution of the Nanaimo Basin to the present-day Georgia Basin, which the currently favoured theory described here does not have. However, until the "discrepancy" in the paleomagnetic data is resolved, where Vancouver Island first made contact with North America must remain a completely open question (Enkin, 2001) (Williams, 2002).

Coastal trough

The depositional depression in which Gabriola was formed is known as the *Nanaimo Basin*,[4] a deeply-scoured remnant of which is now partially occupied by the Strait of Georgia (Mustard, 1994), (Katnick, 2003).[5] The Georgia Basin, which evolved from the Nanaimo Basin, is part of a coastal trough that extends from Puget Sound along the east coast of Vancouver Island, through the Hecate Strait east of the Queen Charlotte Islands, and on into southeast Alaska. This trough was formed roughly 100 million years ago by the accretion of a terrane called *Wrangellia* to the then continental margin. The west side is mostly Wrangellia, and the east side is mostly the Coast Mountains, which are light igneous rocks (plutons) that rose, and were subsequently pushed, to the surface as the leading edge of Wrangellia moved down into the mantle. Although building the Coast Mountains was largely complete by about 60 million years ago, some granites there are less than 20 million years old. The trough persists because of downward flexing of the lithosphere in response to the weight of the Coast Mountains.

Wrangellia

Wrangellia was an oceanic tectonic plate with volcanic island arcs, similar to the Caribbean Plate of today. Like the terranes that preceded it, Wrangellia has been elongated parallel to North America as part of the general northward movement of the Pacific Plate toward Alaska, which consists entirely of fragments of an oceanfloor that has now vanished beneath North America. Parts of Wrangellia form the Wrangell Mountains on the Alaska-Yukon border, the Queen Charlotte Islands, and most of Vancouver Island.

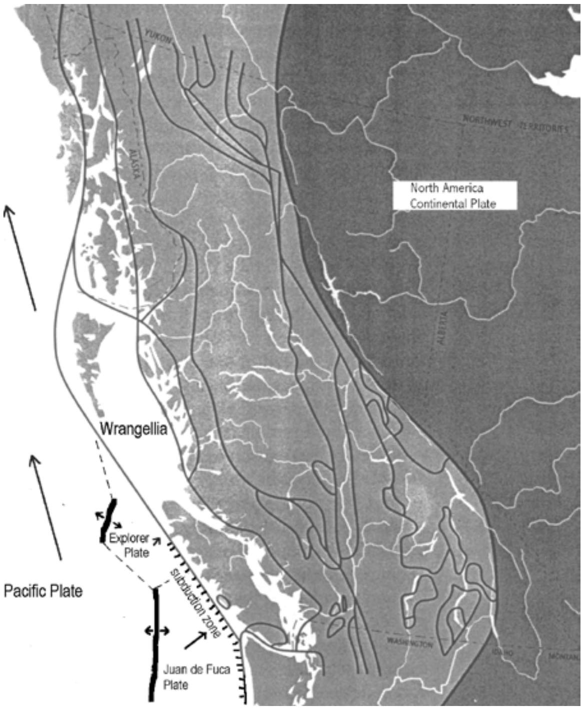
Nanaimo Basin

At the time of Wrangellia's arrival, the Olympic Peninsula was not yet in place, but the Cascade Terrane and San Juan Nappes, which form the present-day San Juan Islands and Mount-Baker area, were, and these, after being thrust upward as Wrangellia pushed underneath them, probably formed the **south**ern boundary of the basin.

The **north**ern boundary of the original basin extended at least up to Campbell River, but beyond that no ***Nanaimo*** Group deposits are known for certain, although there is a suspected outlier (the Suquash Outlier) of uncertain late-Cretaceous age near Port Hardy, which includes some coal deposits.

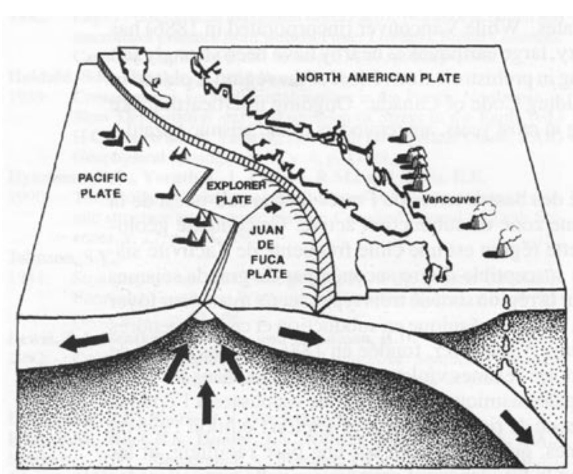
[4] The term "Nanaimo Basin" nowadays includes the former "Comox Basin" [GSC Paper 69-25, 1970] with the formation equivalencies: Hornby ≡ Gabriola; Mayne ≡ Spray; Galiano ≡ Geoffrey; Lambert ≡ Northumberland; and Denman ≡ De Courcy.

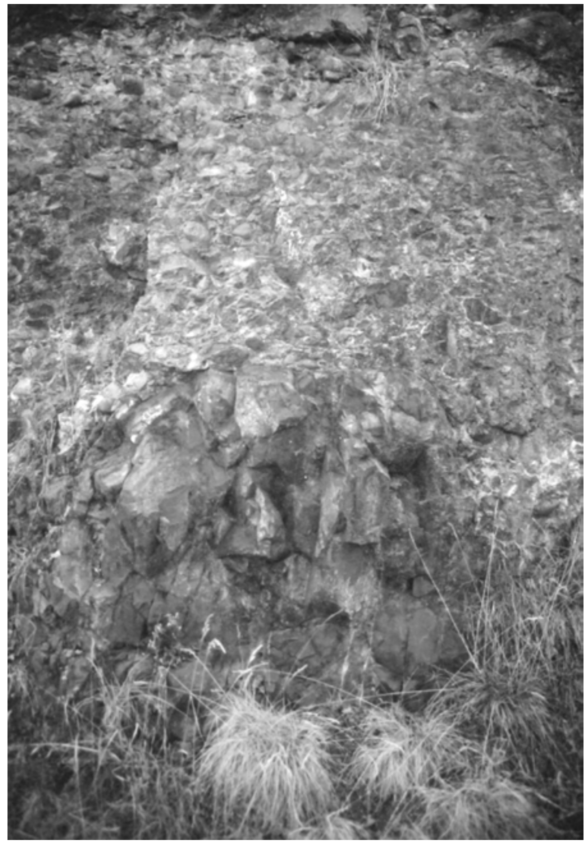
[5] The modern Georgia Basin is technically a *foreland* basin involving the older SE Coast Mountains, but with some *forearc* basin features involving the younger SW Coast Mountains.



BC is made up of pieces of crust (terranes and nappes) swept up against the edge of the ancient North American continent as it moved west. The dark area on the right is the old continent; the grey areas in the middle are some of the many terranes that once had independent existences way out to sea. Wrangellia is a terrane that forms the deep basement (but not all the bedrock) of much of Vancouver Island and Georgia Strait. Originally, subduction was to the east of Wrangellia; now it occurs to the west. Thick lines *left* are mid-ocean ridges, where lava is erupting, creating new ocean floor.

Adated from McGillivray, *Geography of BC*.
Cartoon below is from (Rogers, 1998)





The Island Highway above Malaspina University-College is the site of a sharp contact between lava of Wrangellia (*lower half*), which forms a basement for the Nanaimo Group, and the earliest of the sedimentary bedrocks—the lithified scree of the Nanaimo Group's Comox (Benson) Formation (*top half*).

This contact records a moment in time, about 90 million years ago, when ancient Pacific seafloor rose above the surface of the sea and began eroding away on slopes leading down into the Nanaimo Basin. If Gabriola can be said to have had a beginning in illimitable time, then here it is, right here. Chances are, it was raining at the time.

The original extent of the Nanaimo Basin to the **east** is unknown because so much was eroded away as the Coast Mountains grew, but outcrops of the Nanaimo Group occur in the Vancouver area, and there are deposits, several kilometres thick, below the surface of much of the Fraser Valley. Wrangellia forms the basement of the present strait, and it even outcrops sporadically on the other side; most of Bowen Island, for example, is Wrangellian fine-grained altered *andesite*, a volcanic rock, dating back to the early-Jurassic, about 200 million years ago (Monger, 1994, p.71), (Beaty, 1985).

Gulf Islands

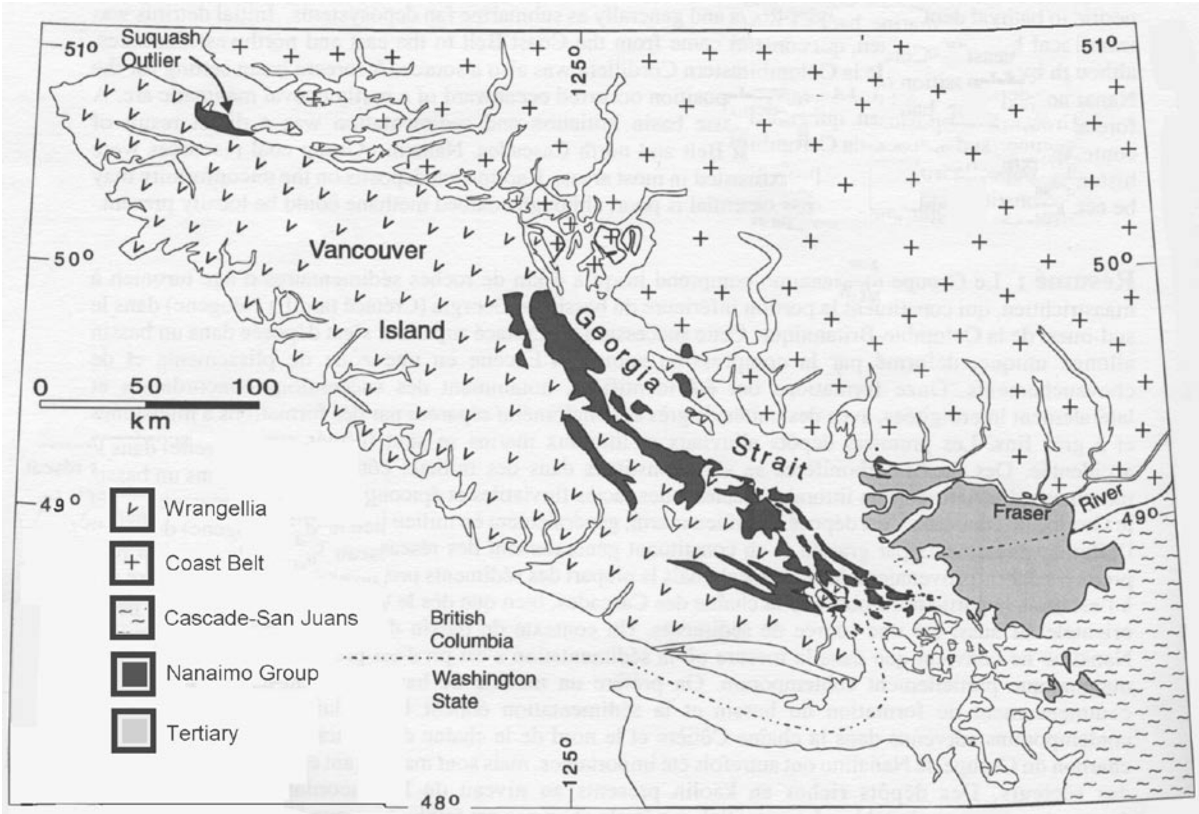
The Tertiary Period, which began just about as deposition of the Nanaimo Group seems to have ended about 65 million years ago, was a time of widespread global change. Continents moved to something like their present positions, mountain ranges were uplifted, the global climate cooled, and eustatic sea levels fell.

Uplift and southwest-directed folding of the floor of the Nanaimo Basin to form the Gulf Islands is primarily associated with the accretion and underplating of Vancouver Island by the Pacific Rim and Crescent Terranes in the Eocene, 55 and 42 million years ago respectively (Yorath, 1995). This folding reduced the width of the Nanaimo Basin by moving Wrangellia closer to the continent. Outcrops of uplifted Nanaimo Group rocks are now found in the Insular Mountains as far **west** as Port Alberni. The uplift and underthrusting of Wrangellia by the Pacific Rim and Crescent Terranes added new land to the southwest corner of Vancouver Island. In northwest Washington State, ancient volcanic rocks from the seafloor rose up to become the Olympic Mountains. Many of the fractures in the bedrock of Gabriola, visible on the beaches today, date back to this time.

Outcrops of rocks in the basin dating from the early-Tertiary, 65 to 30 million years ago, lie on Lasqueti Island, the southeast Gulf Islands (Tumbo and Sucia), below the Fraser Valley, and in northwest Washington State. All the deposits are non-marine river deposits; the basin was above sea level and had become an inland valley. Erosion of the upper-Nanaimo Group formations in the Tertiary was probably the source of sediment for the Chuckanut Formation in northwest Washington State (Mustard & Rouse, 1994).

Rocks in the basin that date back to the late-Tertiary, 30 to 2 million years ago (Neogene) are scarce and are only known from drill holes beneath the Fraser Delta. This appears to have been a time of rapid uplift of the Coast Mountains,[6] eastward tilting of Vancouver Island, and a continuing non-marine, or at most estuarine, environment for the basin.

[6] Sometime after 100 million years ago, the Farallon Plate, which had brought Wrangellia to the coast, split up. One fragment of the Farallon Plate, called the Kula Plate, became BC's offshore plate and remained so until about 40 million years ago, when it was replaced by the main body of the Farallon Plate. The Farallon Plate had a more easterly direction than had the northeast-moving Kula fragment, and it also had a shallower subduction angle. The change back to the Farallon Plate is probably responsible for the vigorous uplift of the Coast Mountains and the Olympic Peninsula in the Cenozoic. Because the Farallon Plate had a shallower subduction angle, the Rocky Mountains were pushed further east in the United States and Mexico than they were in Canada. The Explorer and Juan de Fuca Plates, which are among several small remnants of the Farallon Plate, are disappearing beneath Wrangellia and the Washington and Oregon coasts. Eventually, only the Pacific Plate, which is subducting beneath the Alaska Peninsula and Aleutian Island chain, will remain. When eastward pressure on the west coast of Vancouver Island is released, new mountains will probably rise from accretionary material currently being stuffed into the subduction trench.



The dark areas show where the tattered remains of the sedimentary rocks of the Nanaimo Group formations are to be found on the surface today—Gabriola included.

The geography of the basin at the time of Gabriola's formation, 75–65 million years ago, remains a topic for further research. Why is coal found where it is? Where now is the sediment that formed the west side of the basin? How far north did it extend? There's still lots to discover.

Adapted from (Mustard, 1994)

During the past two million years, the Georgia Basin was heavily glaciated several times with only brief interglacial periods. The most recent ice-age was not completely over until just 10 thousand years ago, and evidence for it—erratics, glacial till, marine clays, glaciofluvial sand, and gravel deposits—abounds on Gabriola. The ice removed bedrock several hundred metres thick, along with all the soil; and glaciations kept virtually all the island depressed below sea level for most of the Quaternary Period. There were however interludes. One of the most spectacular fossil finds in the Georgia Basin near Qualicum Beach is a complete walrus skeleton, more than 50 thousand years old. Douglas-fir, pines, and birches were also present in the Gulf Islands during brief interglacial periods. It was during the Quaternary that the San Juans became islands, and the Juan de Fuca valley became a strait.

The deepest part of the present-day Strait of Georgia is 420 metres, but this is an aftermath of glaciation and not a good indicator of its paleogeography. Its average depth however is around 155 metres—not very different from the depositional depths of the sediments that now make up Gabriola Island.

The present-day southern Georgia Basin showing the Fraser River delta and the river's plume, which is busily filling the Strait of Georgia with sediment. It's tempting to imagine that this scene bears some resemblance to what it looked like tens of millions of years ago. Perhaps it does, but remember that the entire Fraser delta below New Westminster has been added since the end of the last ice age, a mere 10 thousand years ago. A lot can happen in a million years.

Courtesy the Galiano Conservancy Association

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