Context:
Geology, basic structural, Gabriola

Citation:
Doe, N.A., Sandstone and shale—Gabriola's origins, *SHALE* 1, pp.26–35, November 2000.

Copyright restrictions:

Errors and omissions:
The preferred name for the late-Cretaceous basin between Vancouver Island and the mainland is now the "Nanaimo Basin" because its geography was different to the present-day Strait of Georgia **1** (26).

Wrangellia was probably below sea level when it reached North America **1** (27).

Early sedimentation was from Vancouver Island contrary to what is suggested in the footnote, **1**(fn. 4).

The process described in the box "Transformations" **1** (32) is wrong in suggesting that the Nanaimo Group sandstones are cemented with calcite and laumonite. The most common upper Nanaimo Group sandstone cement is clay.

Later references:
Geology "special issues", *SHALE* 7, 9, and 20.

Date posted:
April 14, 2009.

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Sandstone & shale—Gabriola's origins

by Nick Doe

Starting with a bang

Bangs, it seems, are important events in the history of the world. Before anything at all—at the instant when time as we know it began—there was the big bang that marked the birth of the Universe, 12 000 million years ago.

Within one or two thousand million years, the infant Universe was big enough, and cool enough, for galaxies like our own to form. Among the galaxy's "billions and billions" of stars, some of the bigger ones ended their lives as spectacular supernovas. These massive explosions scattered throughout interstellar space atoms of carbon, silicon, oxygen—elements that the stars had forged from hydrogen and helium in their thermonuclear furnaces. Most of what we are, and most of what surrounds us, has been made from the ashes of these long-dead giants.

About 4700 million years ago, the particular supernova that led to the formation of the solar system and some of its neighbours occurred. That explosion sent shock waves through vast clouds of interstellar gas and dust, nudging denser patches into gravitational collapse, one of which eventually became our tiny oasis in the immensity of space. Even though it was so long ago, the radioactive afterglow of that explosion lives on in the earth's depths.

The evolution of life has also, it seems, been moved from chapter to chapter by bangs. When a huge meteorite slammed into the Yucatán Peninsula of Mexico, just 67 million years ago, the atmosphere was filled with dust, blocking the sunlight, and bringing to an end the age of the dinosaurs.

Genesis of the Gulf Islands

One might imagine that the birth of the Gulf Islands[1] was, in contrast, a fairly quiet, even serene event. But it is not so. The islands too can claim to have been born as the result of bangs. The bangs were almost-infinitely slower, and were nowhere near as fiery, nor as fierce, as those we've mentioned, but they were, nonetheless, very forceful events.

Bang one

The first of the two bangs that put us where we are today accompanied the arrival of Vancouver Island. Vancouver Island, along with the Queen Charlotte Islands and what are now mountains on the Alaskan-Yukon border, once formed a micro-continent, called by geologists *Wrangellia*.[2]

The now-fractured and dispersed Wrangellia first appeared off the coast about 90 million years ago.[3] It came from somewhere far to the south and west of here—perhaps as far away as Indonesia is now—moving about the width of your finger every year. The subsequent "collision" of Wrangellia with the mainland created the high hills that were destined to become the mountains around us, and the depression between them, the Georgia basin, which we now call the Strait of Georgia.

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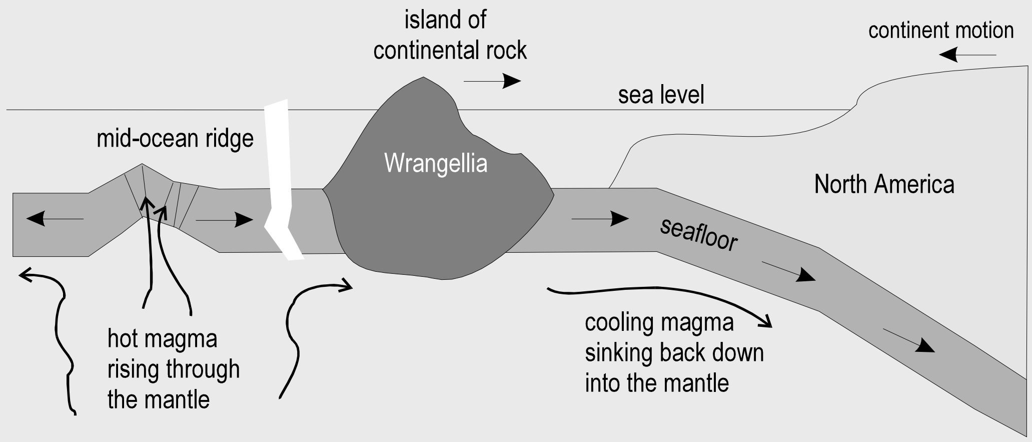
[1] The geology of the San Juan Islands is different from that of the Canadian islands.

[2] Wrangellia includes small parts of the mainland, and there is possibly a fragment on the Oregon/Idaho border (the Seven Devils area).

[3] Where exactly is controversial. It was probably here, but some geologists have suggested it was at the latitude of Baha California (*Science*, Sept.12, 1997).



A "bang" in the making. An island complex, *Wrangellia*, approaches the west coast of North America from somewhere far away to the southwest. It travels with a massive slab of Pacific seafloor, which is moving like a conveyor belt away from a mid-ocean ridge and then deep down under a westward-moving North American continent (see the "Drifting continents" box, page 35). NOT TO SCALE

The world was different then, 90 million years ago. While Vancouver Island was docking itself alongside North America, the whole Indian sub-continent was still an island; the Atlantic Ocean was just a narrow seaway; and there was no land bridge between North and South America.

For millions of years after the arrival of Wrangellia, rocks, sand, gravel, and silt were washed from the hills into the Georgia basin, forming thick carpets of sediment.[4] These were the days of the late *Cretaceous* —the balmy, autumn days of the dinosaurs. A higher concentration of atmospheric carbon dioxide (greenhouse gas), aided by a landmass disposition that allowed ocean currents to circulate more freely, kept the climate warm, and sea levels higher than they are today.[5]

As the sediments were slowly buried, the rotting, tropical vegetation of the lagoons became coal; the stones and unsorted debris brought down by mountain creeks became the pebble- and boulder-filled cement that geologists call *conglomerate*; the sand became sandstone; and silt that had been carried further out to sea became mudstone and shale.[6]

Although there are exceptions around Nanaimo, most of the sediments that form the Gulf Islands were deposited in the sea hundreds of metres deep. These sediments were derived from thick, near-shore, shelf deposits, like the tidal flats at the mouth of the Fraser River, which periodically collapsed sending flows of material (*submarine fans*) out onto the ocean floor.

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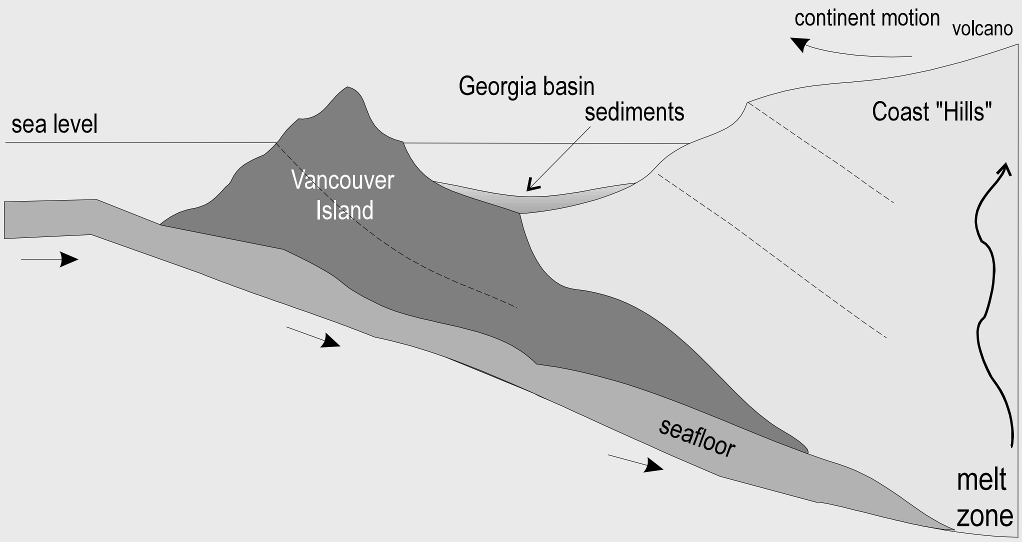
[4] Many of the Gulf Island sediments originated from the northwest Cascades (south) and the mainland (east), not as you might suspect, from Vancouver Island.

[5] It was during this time that southern England was a shallow, warm sea. In that sea, a myriad of microscopic plants and animals lived and died, leaving as their legacy the chalk that was to become the downs. The chalk has also given us the name of the geological period in which it was created: "cretaceous".

[6] Mud- and silt-stone are shale-like rocks but without the fine bedding-plane lamination of shale. Everything is just called "shale" in this essay. Underwater flows of silt-laden water are known as *turbidites*.



After the first bang, Wrangellia, part of which is now Vancouver Island, has docked alongside North America. The descent of the seafloor now begins on the west side of Wrangellia instead of the east. The Georgia basin, bigger then, begins to fill with sediments brought down by major river systems.

NOT TO SCALE

The collision that formed the Georgia basin took millions of years to complete. If you are uncertain how long a million years is, think of it this way. If a million years were scaled so that it was just one year, then an average human lifetime would be over in about half an hour. Apart from the occasional volcanic eruption, the bang would have been no more exciting to watch than a warping plank. But in very fast-forward, there is no doubting its reality.

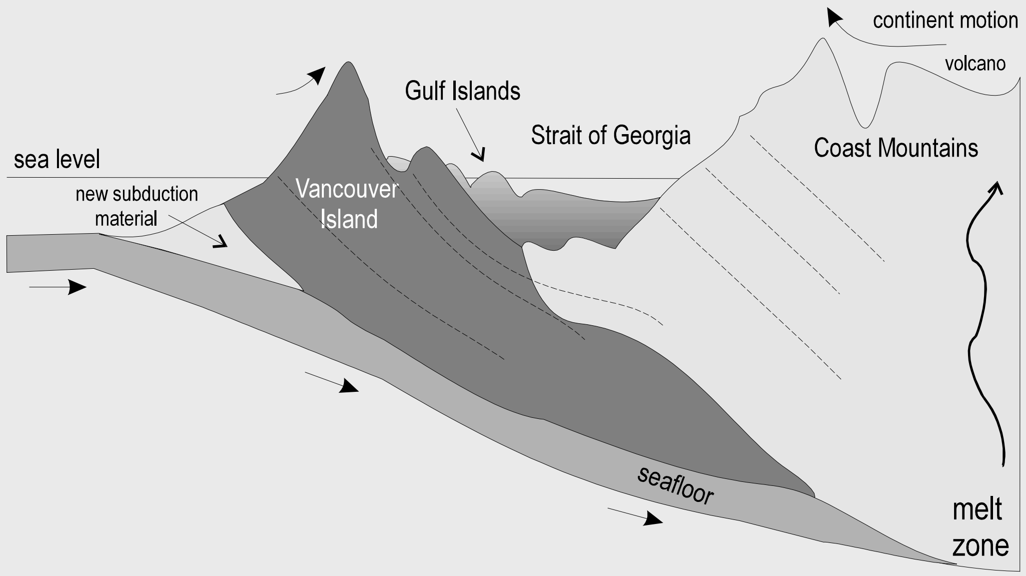
Bang two

So far, we have a gulf and Vancouver Island, but no Gulf Islands. For islands we needed a second bang, and that came some 42 million years ago when a group of underwater volcanoes (a *seamount*), which had formed far out in the Pacific, arrived off the coast, just as Vancouver Island had 50 million years earlier. Slabs of crust were added to, and forced beneath southwestern Vancouver Island, thrusting the hills upward into mountains. The collision squeezed Vancouver Island closer to the mainland, and crumpled the seabed of the Georgia basin. The folds of the rucked-up carpet of sediments became new islands, the Gulf Islands. And the underwater volcanic complex, our island's midwife as it were, was pushed up out of the sea to become western Washington's Olympic Mountains.[7]

Home run to the present

The bases were loaded for the 40-million year home run. With the change of climate, tropical palm trees gave way to conifers, and the sea level fell. Flowering plants and butterflies appeared; and the ancestors of wolves and bears evolved. Herds of miniature horses, the size of modern cats,

[7] A simplification that not all geologists accept, but it will suffice. Two different terranes were involved: the Pacific Rim Terrane and the Crescent Terrane. There may have been a change in direction of the subsiding seafloor, which complicates matters. Although former seafloor does form western Washington and the southwest tip of Vancouver Island, not all of it may be an exotic terrane.



After the second bang, Vancouver Island has been tilted and squeezed up against North America by newly arrived material brought by the seafloor, which accreted to and underplated the island. The mountains have been thrust higher. The Strait of Georgia (a gulf at the time as the Juan de Fuca Strait was not open) is now at least 25% narrower than the former basin, and some of the sediments, now folded, have become islands—Gabriola among them. Outcrops of the sediments that form the Gulf Islands are found in the mountains of east Vancouver Island, and as far west as Port Alberni.

ADAPTED FROM MUSTARD (1994)

and tiny gazelle-like camels roamed the prairies now that the dinosaurs were gone. India collided with Eurasia and prepared to build the Himalayas. North Africa collided with Europe to form both the Alps of Switzerland and the far-off gently, rolling chalk downs of southern England. Oh! And in the final few million years of the run, there was time for human beings to evolve.

Finishing touches

By the time the late-Cretaceous deposition of sediments on the floor of the strait was finished, their uncompacted thickness would have been more than five kilometres. As it is, beneath Gabriola, the sediments are over three kilometres thick.

If you drilled down far enough, you might, depending exactly where you drilled, successively encounter eleven different major formations.[8] Finally, at the bottom of the very deep hole you would hit volcanic rock—you would hit Wrangellia.

What does all this mean exactly?—who knows? Not enough geologists have lived long enough to investigate it all!

[8] See box on the next page. The Protection-Pender-Extension formations (3-4-5) are sometimes counted as one multi-membered formation in the Nanaimo area making only nine formations in the Nanaimo Group. Further south, these three formations are more like the other formations and are easier to identify. At Vesuvius Bay, Saltspring Island you can see all three within a short walking distance.

NANAIMO GROUP FORMATIONS

SURFACE

11 Gabriola formation: 350-m thick
marine sandstone with conglomerate

10 Spray (Mayne) formation: 100-m thick
marine shale

9 Geoffrey (Galiano) formation: 150-m thick
marine conglomerate and sandstone

8 Northumberland formation: 250-m thick
marine shale with very fine-grained sandstone

7 De Courcy formation: 270-m thick
marine sandstone and conglomerate

6 Cedar District formation: 230-m thick
marine silty shale

5 Protection formation: 200 m;

4 Pender formation, incl. Newcastle: 500 m; and Cranberry: 120 m;

3 Extension formation: 180 m; incl. East Wellington: 10 m

3-4-5 around Nanaimo, deltaic sandstone & lagoonal shale with conglomerate & coal; elsewhere marine sandstone-shale-sandstone

2 Haslam formation: 180-m thick
marine shale with some siltstone

1 Comox (Benson) formation: 30-m thick
talus, fluvial conglomerate, and sandstone with some lagoonal coal in the Nanaimo area

BOTTOM

Thicknesses are only a very rough guide; they vary considerably from place to place. The sediments were deposited 90–66 million years ago. Later formations (58–40 million years old) are rare; but the fluvial deposits on Tumbo Island, off Saturna Island, are an example.

Absence of substantial coal deposits in the upper formations indicates land rising steeply from sea to mountains without extensive coastal plains; perhaps a consequence of a higher sea level.

Spray is after Spray Point in Tribune Bay, Hornby Island. Geoffrey is after Mount Geoffrey, Hornby Island. Formation names vary according to geologist, publication date, and location (Comox or Nanaimo Basin).

For the most part though, it seems that the sediments that make up the Gulf Islands were deposited, as we have described, in fairly deep ocean water over a period of 25 million years, before being lifted above the sea to form the islands we live on today.

Once above the level of the sea, erosion by wind, rain, and above all ice continued to shape them into forms that would be utterly unrecognizable to someone from the very ancient past. Erosion, although extensive everywhere, has been increasingly severe the further southwest from the centreline of the Georgia Strait one travels. This is because Vancouver Island is being pushed upward from the southwest. The higher land erodes faster, thereby exposing older, deeper formations (see the map on the following page).[9]

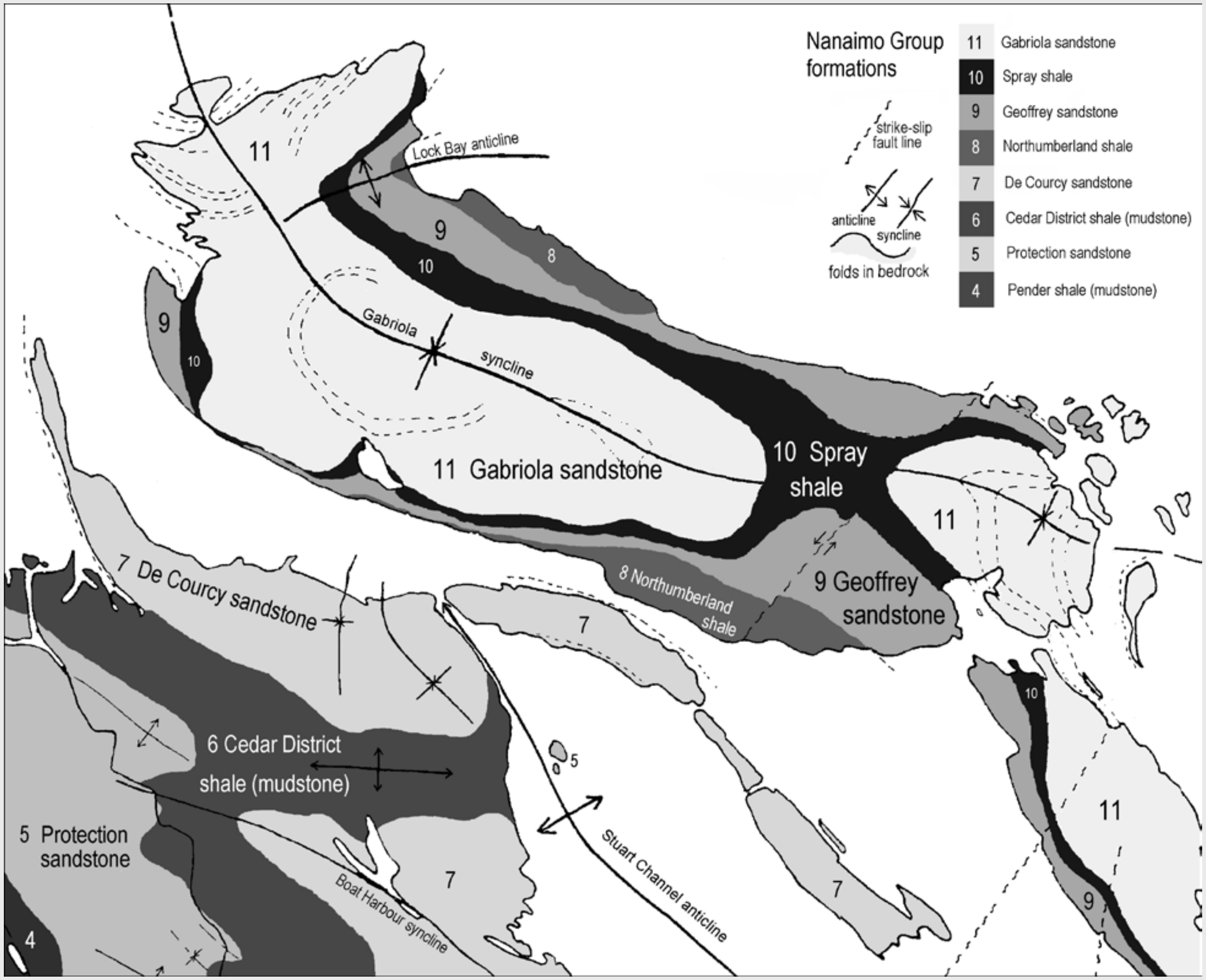
Ice age

Before we end the tale of Gabriola's birth, we must talk for a moment about the ice age. Many of the surface features of the islands we see around us have been shaped by the ice age. Compared with the millions of years we have been talking about, changes wrought by the ice age happened in a very short time span.

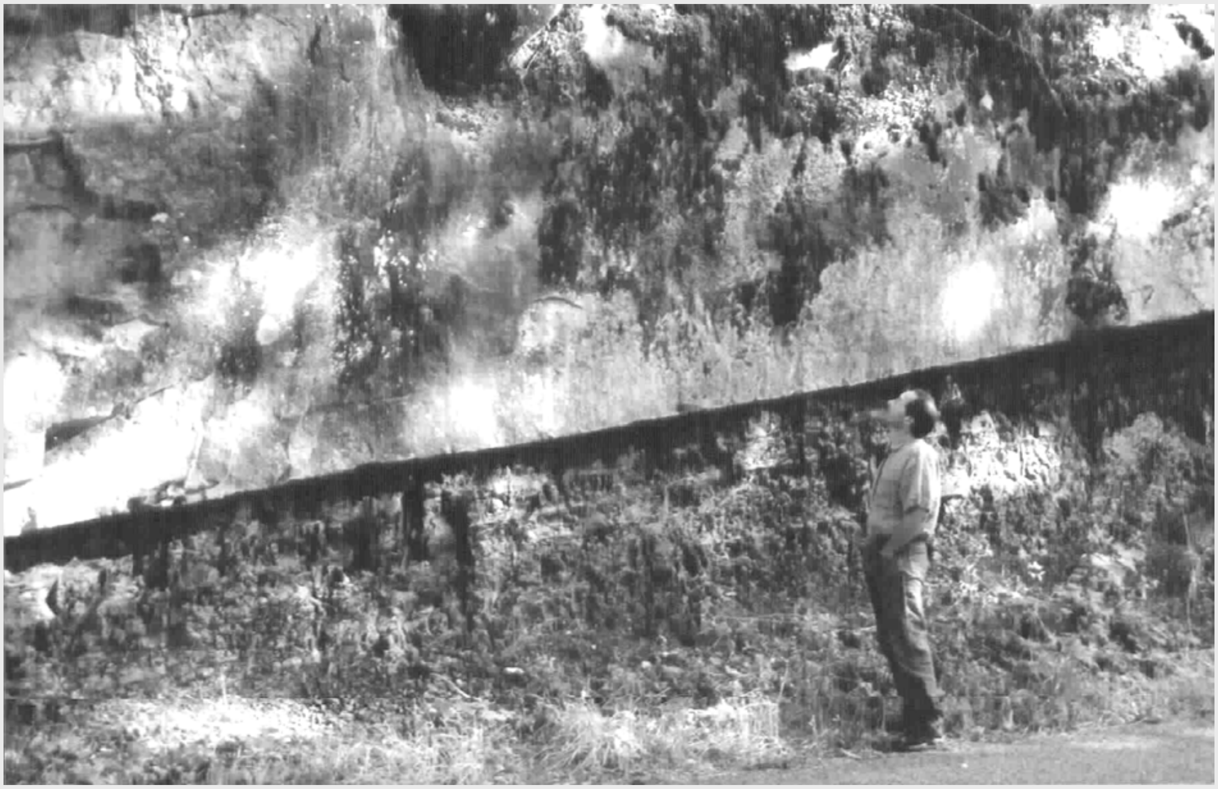
There have been many ice ages in the past, but nearly all traces of earlier glaciations have been obliterated by the most recent, which is known locally as the Fraser Glaciation. The Fraser Glaciation began about 30 000 BC and ended about 11 000 BC. During this time, a large glacier moved down the strait, terminating ...

(*continued on page 34*)

[9] One should not underestimate the extent of the erosion. In places, kilometres of rock have been removed. Even on Gabriola, which is one of the least eroded areas, an estimated 400 metres of rock has been stripped from the surface.



Bedrock geology of Gabriola and its surroundings. Differential erosion has exposed formations of different ages (see box opposite). The formations tend to alternate between sandstone and shale with Gabriola sandstone (11) being the youngest formation and at the top. Differential erosion—soft shale, relatively hard sandstone & conglomerate—has resulted in precipitous cliffs, points, islands, and well-protected bays. The subdued relief of eastern Vancouver Island is due to the softness of all the Nanaimo Group formations in comparison with the older, mostly crystalline rocks that make up the rest of the island. Faults on the outer Gulf Islands are minor. One strike-slip (horizontal) fault is shown here on Gabriola running northeast from the Maples near False Narrows to the bay at the end of Dragon's Lane. ADAPTED FROM ENGLAND (1989)



A sandstone-shale boundary along Easthom Road seen in dappled sunlight. The upper layer of coarse-grained sandstone is the Gabriola formation (11), formed 66–69 million years ago, before Gabriola Island was pushed up from the sea. The lower layer of shale is the Spray (Mayne) formation (10), formed 69–72 million years ago when the future Gabriola Island was in deeper water. Both formations are sedimentary rocks formed at the fronts of ancient river deltas. The sand, which became sandstone, was deposited closer inshore than the silt, which became shale.

AUTHOR'S PHOTOGRAPH

Transformations

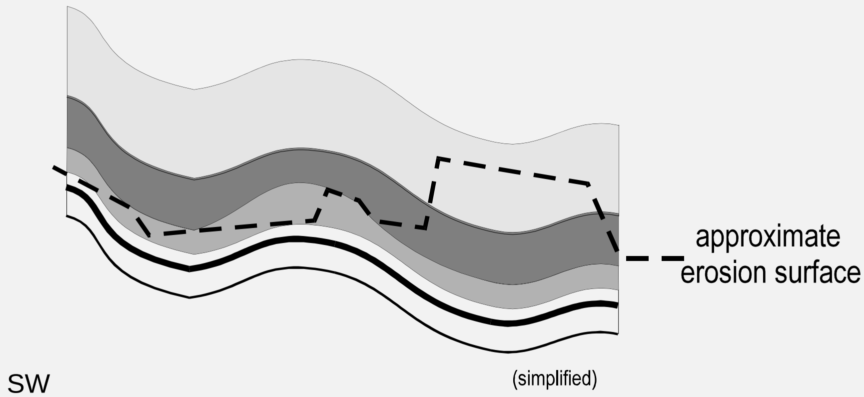
How does sand and mud become sandstone and shale? *Compression, dewatering,* and *concretion*.

As sediments are buried deeper and deeper, the weight of the overlying burden squeezes out the water. The process is aided by warmer temperatures deeper in the earth. What happens next is the same as happens in some water purifiers. If you force impure water through a ceramic filter, the freshwater escapes leaving behind impurities. The same happens in the sediments. The concentration of impurities in the remnant water in the compressed sediments becomes greater the deeper the sediments are buried. Eventually, there is no water left. The impurities, which in this region are most frequently calcareous (calcite and laumontite), then make their appearance in the same way that "fur" forms in a kettle of hard water that has been boiled completely dry. The precipitate cements the grains of sediment together. And presto! Sand becomes sandstone, and mud becomes shale.

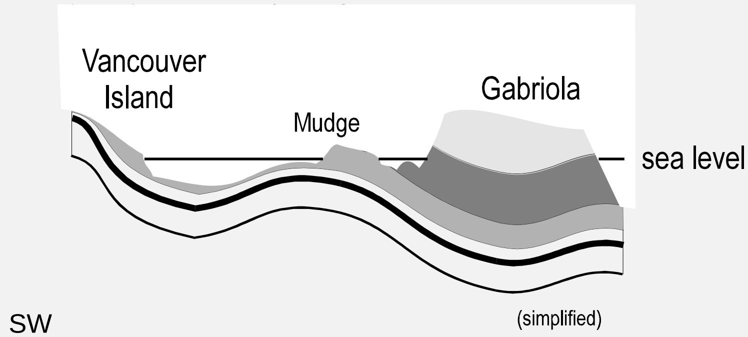
Many of the variations in the constituency of sedimentary rocks look as though they are biological in origin, but in fact are often chemical. Quartz (silica) and iron-oxide (hematite) also act as cements.

How to make some islands

1. Slowly form layers of sediment on the seafloor—a few centimetres every century will do. To change the character of the sediment, move the shoreline. Tidal flats (shelf deposits) at the mouths of major rivers are good sources of material. When these shelves collapse along their outer edges, as they periodically do, fans of material spread out into deeper water. Coarse sand settles to the bottom first; finer silt drifts further offshore. For thin layers, use earthquakes to cause landslides.



2. Fold by squeezing and tilt by raising the left (southwest) side. Lower relative sea level by lifting the land, by cooling the sea so that it contracts, and by locking away some of the world's water in polar and alpine icefields. Erode the surface for millions of years until it is like a rotten tooth that has decayed to the gum line. Erode softer sediments faster than others. Use ice as well as water. Cracks (faults) will allow blocks to be more easily moved away. Remove lots of material.



3. After 90 million years, the sedimentary rocks might look like this. Note that in this example although both Mudge and Gabriola are capped with erosion-resistant sandstone, the sandstone on Mudge is older than that on Gabriola. The rocks of adjacent Vancouver Island are older still; even coal is almost at the surface. Shale, which is easily eroded, occurs at the beach level on both sides of Gabriola. Although Gabriola is an island, it sits in the trough of a U-shaped fold (syncline). Cliffs are common along the shores of all the outer islands, especially on the southwest sides.

(*from page 30*) ... in Puget Sound near Tacoma. Ice also flowed along the Juan de Fuca depression, scouring out the strait.

At its peak, ice over Gabriola was up to two kilometres thick. The flow of ice from the northwest scraped away all the topsoil, and planed smooth the exposed bedrock. It is no coincidence that the best millstones were quarried from the coarse-grained sandstone around Descanso Bay. These were the rocks that survived the frontal assault of the ice.

The glacial retreat began around 18 000 BC and areas of the strait were probably already ice-free by 13 000 BC. When the ice finally disappeared, it left behind the sand, gravel, and boulders it had carried with it. Along with this *glacial till*, streams of meltwater left behind pockets of mud, sand, and clay.

Most deposits left by the melting, "dirty" ice are easily identified. They contain boulders and stones of all shapes and sizes—they have never been sorted by flowing water. The matrix of glacial till is often a sandy "flour" of ground-up rock. On Gabriola, many granodiorite stones (the white ones with shiny black speckles) were brought by the glaciers from the mountains around Campbell River and Desolation Sound.

The huge weight of the ice depressed the land, so relative sea level at the time rose by 100 metres or more. That's high enough to submerge practically all of Gabriola Island. As the ice melted, the land rapidly re-emerged, rising several centimetres a year, and by the end of the ice age, 11 000 BC, relative sea level had fallen to what it is today. But, the land did not stop there; the land went on rising until relative sea level had dropped as much as 15 metres lower than at present—certainly enough to completely dry out False Narrows. Then, about 8500 BC, it was the sea's turn to rise. By then, the water once locked in the vast continental ice-sheets had returned to the sea, and the sea was expanding as its temperature rose. By 2500 BC, relative sea level was back to within a metre or so of what it is today.

Relative sea level continues to rise, albeit more slowly than in the past. These changes have left behind beaches on the island that are both above and below the present level of the sea. Earthquakes have also caused minor local changes in sea level.

So that, so far as we know, is how it all began. The rest is just history. ◊

Acknowledgement

I should like to thank geologist Dr. Steven Earle of Malaspina University-College who very kindly read the manuscript, corrected several errors, and made constructive suggestions. Any errors that remain are mine alone.

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Drifting continents

About 70% of the earth's surface is covered with lava which is, geologically speaking, quite fresh. This lava erupted, not violently from the few volcanoes we see on land, but gently from long fissures (cracks), called mid-ocean ridges, that run for thousands of kilometres around the earth along the bottoms of the major oceans where the earth's crust is thinnest.

The mid-ocean ridges are where rising magma (lava) from the mantle reaches the surface, instantly solidifying the moment it makes contact with the cold ocean water. Convection currents within the mantle move away from the ridges in both directions dragging the seafloor with them, like a conveyor belt, at rates of a few centimetres each year. As fast as the seafloor is dragged apart at the ridges, new magma rises to fill the cracks and create new seafloor. It is expanding seafloors that force continents like Africa and South America apart.

As fast as new seafloor is created, old seafloor somewhere else disappears. Plates of old seafloor, which are heavier because they are cooler and overlain with sediments, are forced down into the interior of the earth where they melt. Along the west coast of North America, old seafloor is thrusting deep under the continent. You might think that the closest open-ocean seafloor to Gabriola is out at Port Alberni, but it's not—it's underneath your feet.

Vancouver Island moved here from somewhere far to the southwest, happily drifting along a few centimetres a year with the seafloor in which it was embedded. But when it reached the west coast of North America—whether here, or further south—the seafloor went down under the continent, and Vancouver Island, which like all land masses is made of lighter, granitic rocks, remained on the surface, attaching itself to the continental margin. Most of British Columbia, and all of Alaska, are made up of former Pacific islands. The original shoreline was near the Alberta border; and the Rockies are what's left of the former continental shelf.

Why was the collision so violent? Because, just as Vancouver Island was drifting north-eastward away from the mid-ocean ridges in the Pacific, North America was drifting westward away from Europe, driven by the mid-ocean ridges in the Atlantic Ocean. The mountains around us are a consequence of the struggle for room on the limited surface of the earth between the now-old Pacific Ocean, and the Atlantic Ocean, which, in geological terms, was born only yesterday. And all this activity is because the earth still has a warm heart fuelled by the remnant radioactivity from the supernova that created it. The earth constantly needs to cool off, something it cannot easily do when it is encrusted with solid rock kilometres thick—rock that, like any good blanket, hardly conducts heat at all.