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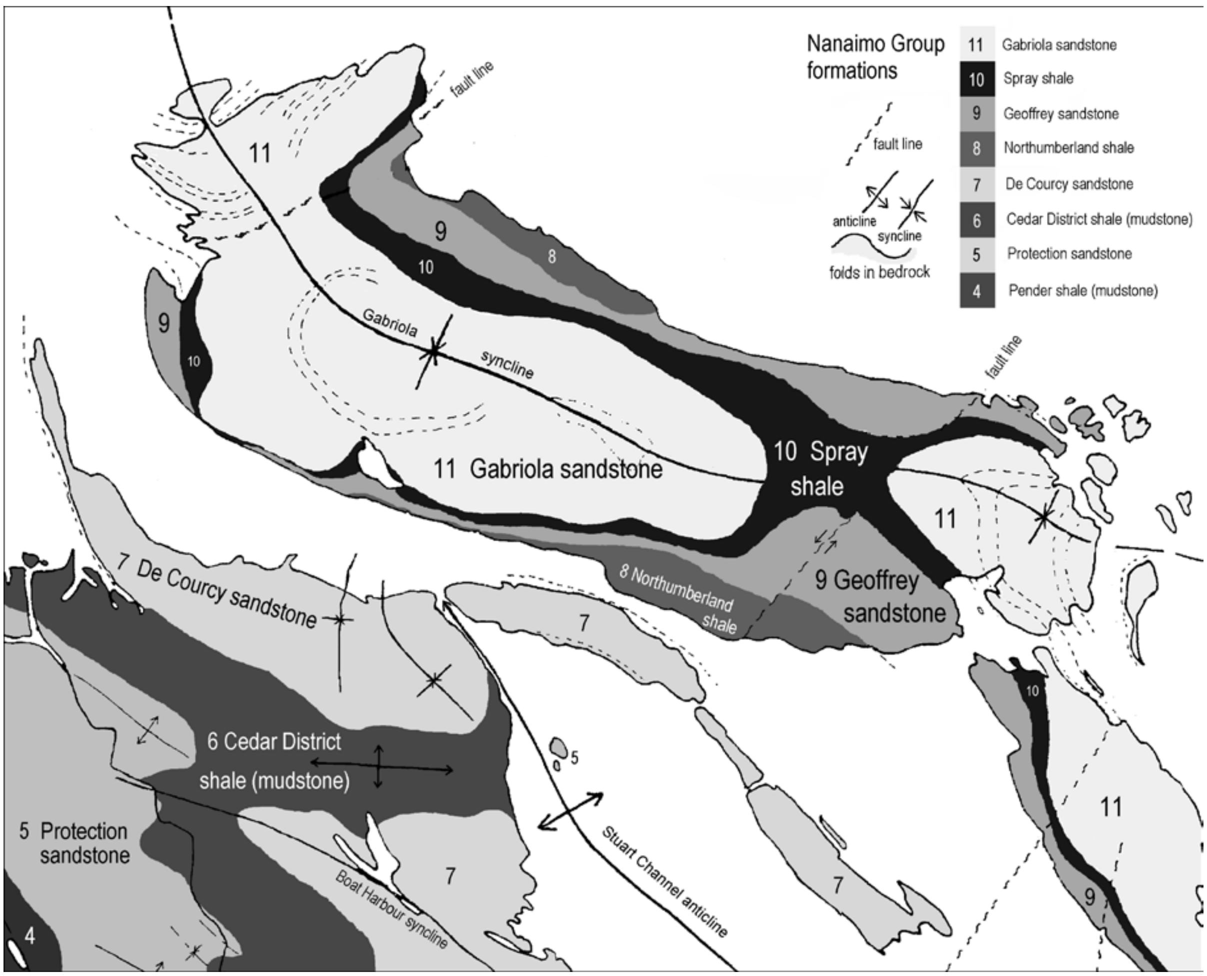
Gabriola's submarine-fan formations

by Nick Doe

Gabriola and its smaller neighbours—Mudge, Link, De Courcy, and Valdes—are islands composed entirely of sedimentary rock belonging to the late-Cretaceous Nanaimo Group. The sand, mud, and gravel, from which the rocks were made, once formed a submarine fan in the delta of a large river. The fan was oriented north to northwest, because there was no Juan de Fuca Strait at the time, and therefore no other way for freshwater to reach the open sea.

The five uppermost formations of the Nanaimo Group are present in the area. These are, from youngest to oldest: **Gabriola** (sandstone); **Spray (**mudrock); **Geoffrey** (sandstone with conglomerate); **Northumberland** (mudrock); and **De Courcy** (sandstone). The age span of these five formations is about ten million years—from 65 million years to 75 million years (Maastrichtian down to upper-Campanian).

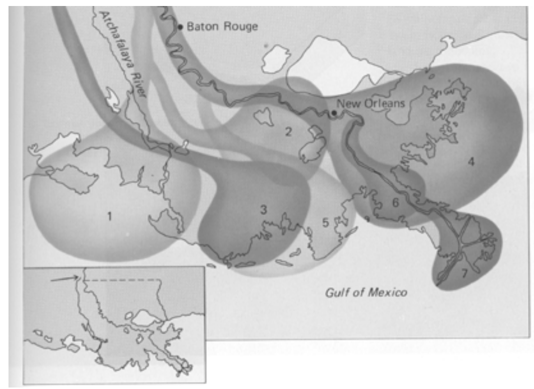


Gabriola's bedrock. Contrary to earlier interpretations, Gabriola is not heavily faulted on a regional scale, although there are sharp erosional contacts. The bedrock is however fractured as a result of folding. These fractures are far too numerous to be mapped—they occur everywhere on the island and are seldom more than a few tens of metres apart.

Adapted from (England, 1989), (Mackie, 2002)

The upper-Nanaimo Group formations alternate between being sandstone-dominant and mudrock-dominant. This pattern reflects changing positions of the depositional sites within the submarine part of the delta (the prodelta). Such changes were due to:

- changes in the course of the river as the region and its mountains evolved tectonically
- changes in the topography of the submarine deposits in response to ever-increasing volumes of sediment. The modern Fraser Valley, for example, is much wider than the river itself and it's clear that, even over short periods of geological time, the river makes major changes in its course. The sketch *right* shows seven deltas used by the Mississippi River at various times in the last six thousand years
- rising land-levels around the rim of the depositional basin, together with possible subsidence of its floor. Falling sea level increases the velocity of rivers; allows them to erode new and deeper channels through their former tidal flats; increases the volume of sediment discharged into the sea; and moves deltas seaward (progradation)
- environmental and climate change increasing or decreasing the weathering rate of rocks and the volume of water in the river.



Thompson, Turk, Levin, 1995

There may also be an as-yet-unrecognised element attributable to eustatic sea-level changes.

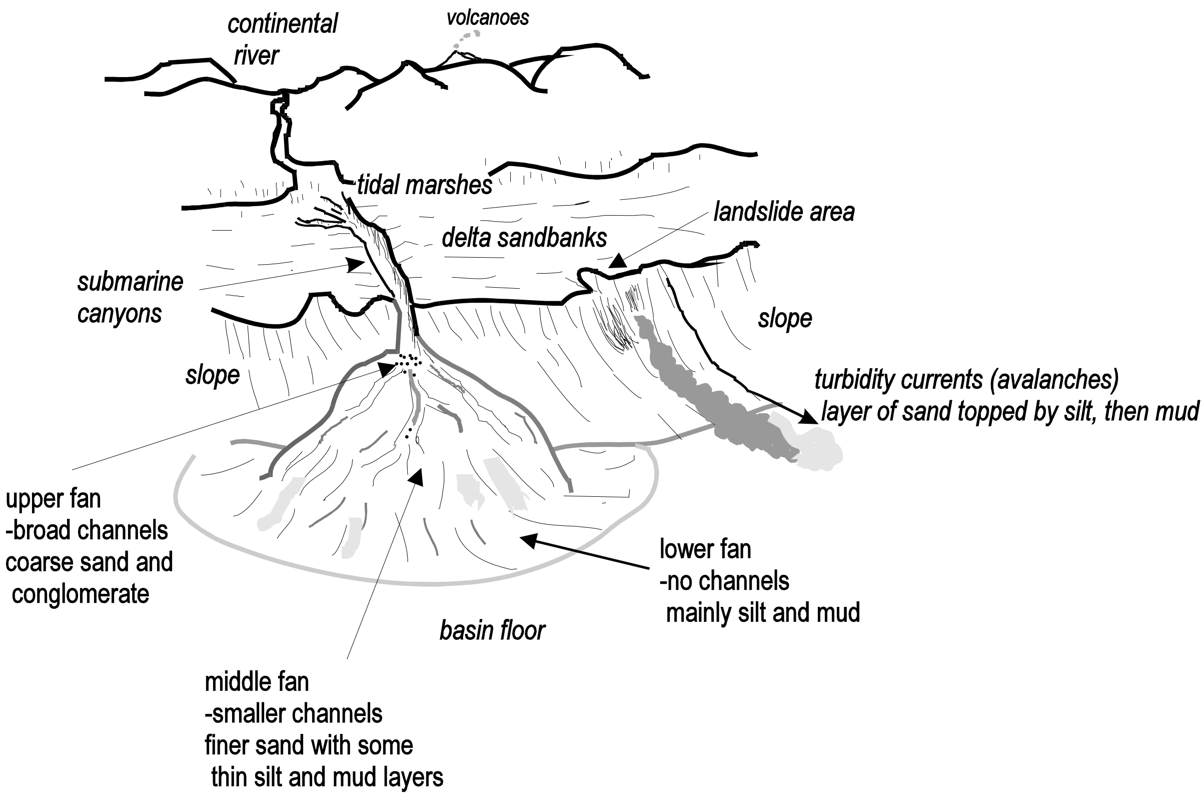
Except for local deformations in areas like Leboeuf Bay,[1] the strata of the upper-Nanaimo Group in the Gabriola area are only gently tilted and fractured, and the formations are not thought to contain any regionally-significant disconformities. Deposition however was far from being a slow, continuous process. There is abundant evidence in the rocks of events that lasted only a few hours, and at times of rising sea level, erosion of the sediments would have been severe.

The total thickness of the Nanaimo Group approaches 5000 metres, which is comparable with the modern-day fan deposits of the River Amazon, but only the top 1300 metres or so of these are represented in the formations around Gabriola Island.

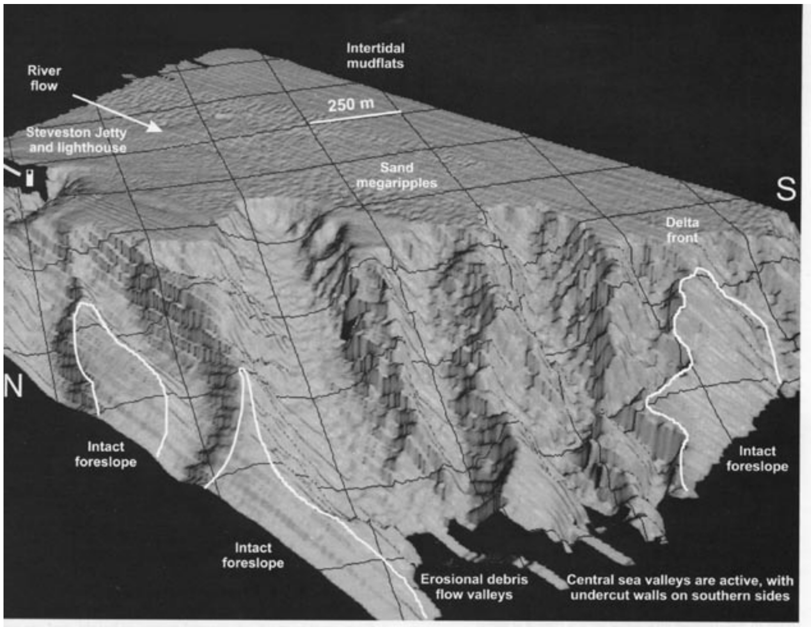
Depositional environment

The local late-Cretaceous climate is believed to have been semi-tropical and the water near the floor of the basin was likely warm and stagnant. There were no ice-ages and no polar ice-caps during the whole of the Mesozoic Era. In general, fossils are not plentiful, and in the Gabriola Formation in particular, they are rare.

[1] Strata in Leboeuf Bay have been kink-folded and up-ended. The strike of the contact bedding does a sharp rotation at the northwest corner of Lock Bay, interpreted by Timothy England as the nose of a small anticline, but now known to be the site of an oblique or reactivated thrust fault (England, 1992), (Mackie, 2002).



Gabriola's bedrock was formed in a submarine-fan complex, a simplified version of which is shown above. The sediments were deposited in the sea, a hundred or more metres deep, on slopes leading down to the basin floor at the outer edge of a major river delta. The sediments were subsequently lithified by being buried, compressed, de-watered, and cemented by clay. The lithified sediment was uplifted by folding more than 40-millon years ago, long after deposition had ceased. Gabriola was one of a number of rolling hills in a broad valley for long periods of time.



Left: Future islands? The upper submarine slope and canyons of the present-day Fraser River delta. This submarine fan has been formed only in the last few thousand years—it is still very young, loaded with methane, and not very stable. It consists of sand, silt, and mud. For the time being, gravel needed to make conglomerate stays in the upstream river bars, awaiting a time when there is enough momentum to carry it down to the estuary.

Shaded-relief multibeam echo-sounder image is adapted from Christian et al., 1998.

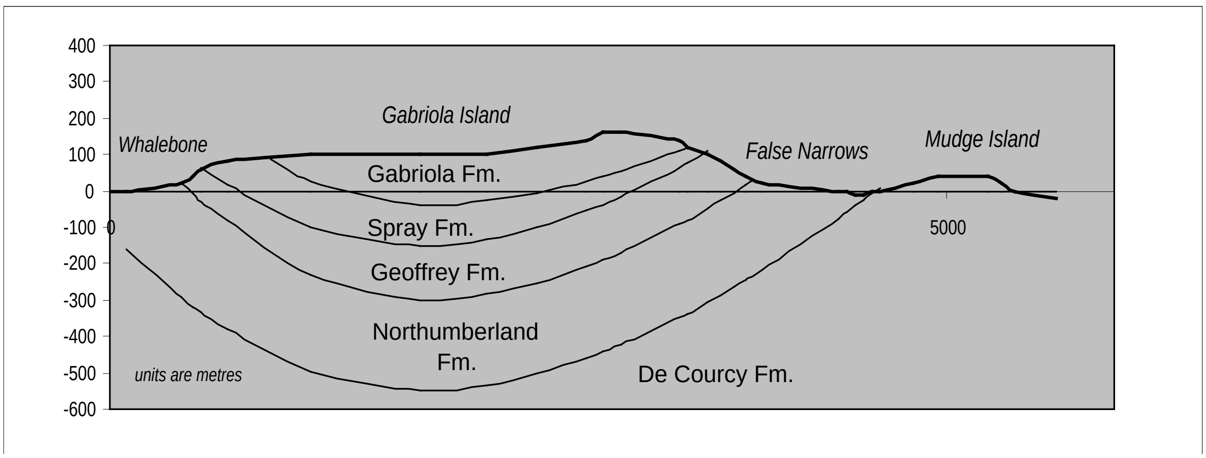
Gabriola area stratigraphy

Although topographically, Gabriola is now an island, its bedrock forms a broad, shallow ∪-shaped fold (a syncline). Cliffs on both of the long sides of the island point gently skyward at elevations of 10–20 degrees, something you may have noticed from the ferry.

Mudge Island, which lies off the south coast of Gabriola, has been more heavily eroded, and its sandstone dips down below Gabriola and never appears at the surface there.

Left: ferry view, note shallow U-shaped skyline.

Below: bedrock profile, east Whalebone directly south through El Verano to Mudge. Depths are conjectures.



The bedrock of the central part of Gabriola is sandstone of the uppermost **Gabriola Formation**. This sandstone, with many thin interbeds of mudrock, is seen along both extremities of the island, from Descanso Bay to Berry Point, and on the Flat Top Islands.

Spray Formation mudrock, which underlies the Gabriola Formation, weathers easily and is often covered with soil and vegetation—the bedrock below farms at the south end of the island is a good example (Oswald, 1977). The Spray Formation is however well exposed in Leboeuf Bay and along the middle section of Easthom Road in Descanso Bay.

The sandstone cliffs on Gabriola's long northeast side, from just beyond Berry (Orlebar) Point to Silva Bay, and again on the long southwest side, from Descanso Bay, just west of the ferry terminal, to Degnen Bay, belong mainly to the **Geoffrey Formation**. The southern exposures of this formation commonly contain beds of conglomerate, which are most easily viewed at the top of Brickyard Hill on South Road, on Ferne Road, along the False Narrows escarpment, and on Spring Beach. On the other side of the island, these massive conglomerate deposits have thinned to pebbly lenses in the sandstone.

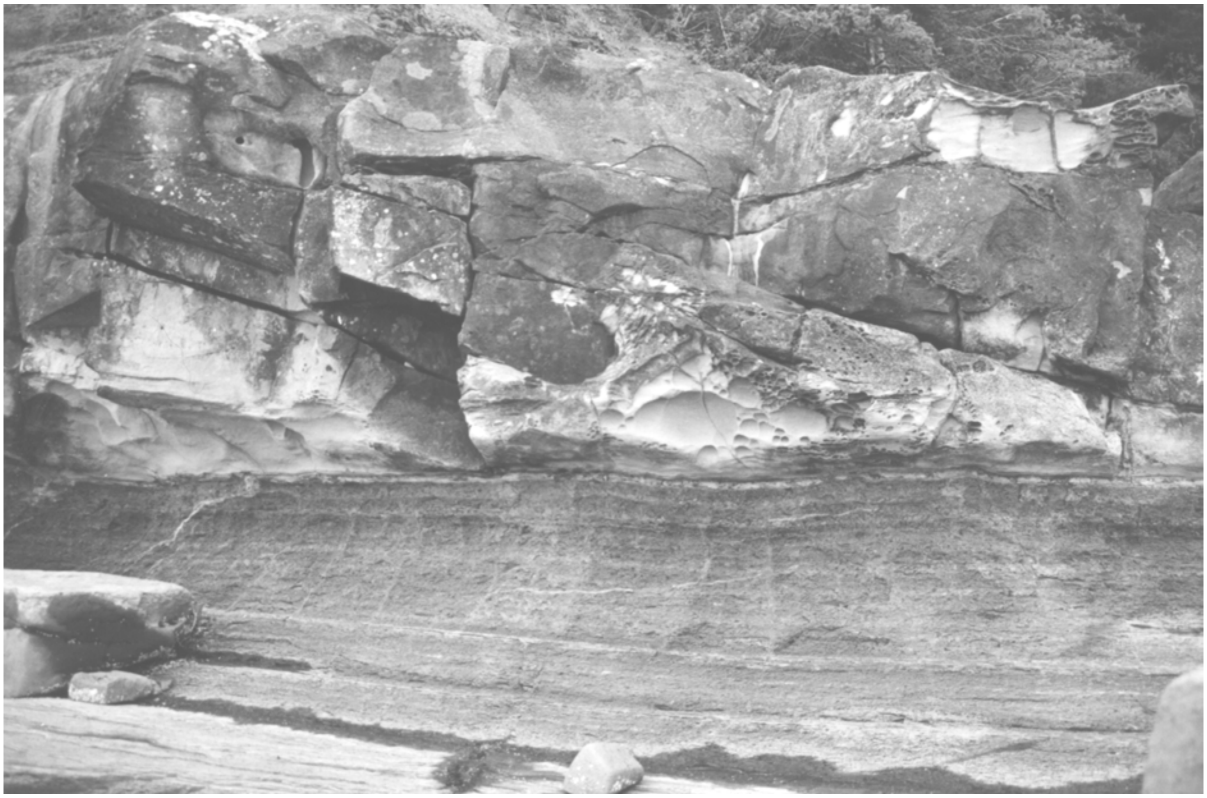
Low-lying, recessive areas on Gabriola's long sides, around Sandwell, Whalebone, False Narrows, and the Maples, are softer mudrocks of the **Northumberland Formation**.

Associated with Gabriola's syncline is a broad anticline (∩-fold) that runs from Dodd Narrows, southeast down the Stuart Channel west of Mudge and the De Courcy Group. This anticline has also been heavily eroded leaving progressively older formations exposed as one approaches its central axis. Conspicuous cliffs along the southwest coast of Valdes Island are part of the **Geoffrey Formation**. The **Northumberland Formation**, which lies beneath the Pylades Channel, is not visible, but the underlying oldest bedrock, **De Courcy Formation** sandstone, appears on Mudge, Link, and De Courcy Islands.

Nanaimo Group formations older than the De Courcy are found locally only on the east coast of Vancouver Island (England, 1989).


Mudrock in Leboeuf Bay, Spray Formation (*left*); and at The Maples, Northumberland Formation (*right*). Thin beds of mudstone with interbeds of fine- to medium-grained sandstone.

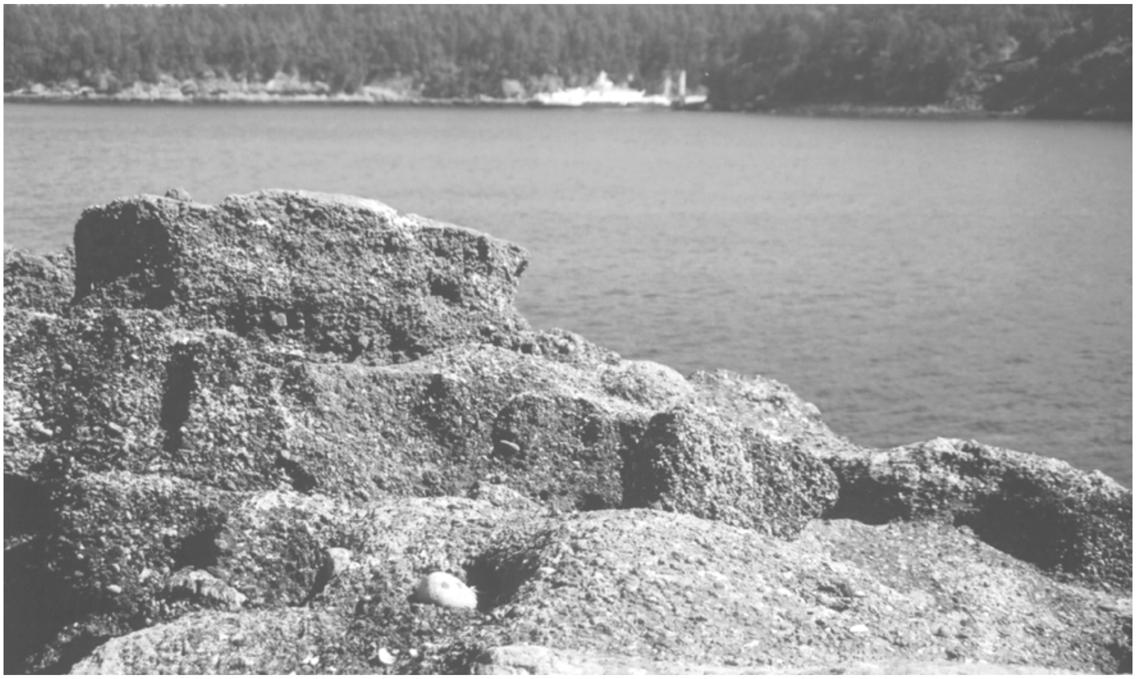
These are *turbidites*, and they were formed near the foot of a submarine cliff, out beyond the tidal flats of a large river. Each sandstone interbed marks the partial collapse of the cliff, which sent an "avalanche" of sediment down the slope and out over the ocean floor. Sand settled from each turbulent cloud first, followed by finer-grained silt. In between the "landslides", there was a very slow accumulation of clay deposited from the river's plume. Avalanches were triggered by slope instability as a result of too much sedimentation, accumulation of gases, tidal pressures, storms, floods, and earthquakes. Note the rather tortuous path of the vertical fractures on the right. Groundwater can seep down through shale, but only very slowly compared to fractured sandstone.



Contact between sandstone of the Gabriola Formation (*top*) and mudrock of the Spray Formation (*below*). This conformable contact (no time-gap) is just around the coast from Berry Point. It dips beneath the island, re-appearing mid-way along Easthom Road, (*SHALE* 1, 2000, p.32).

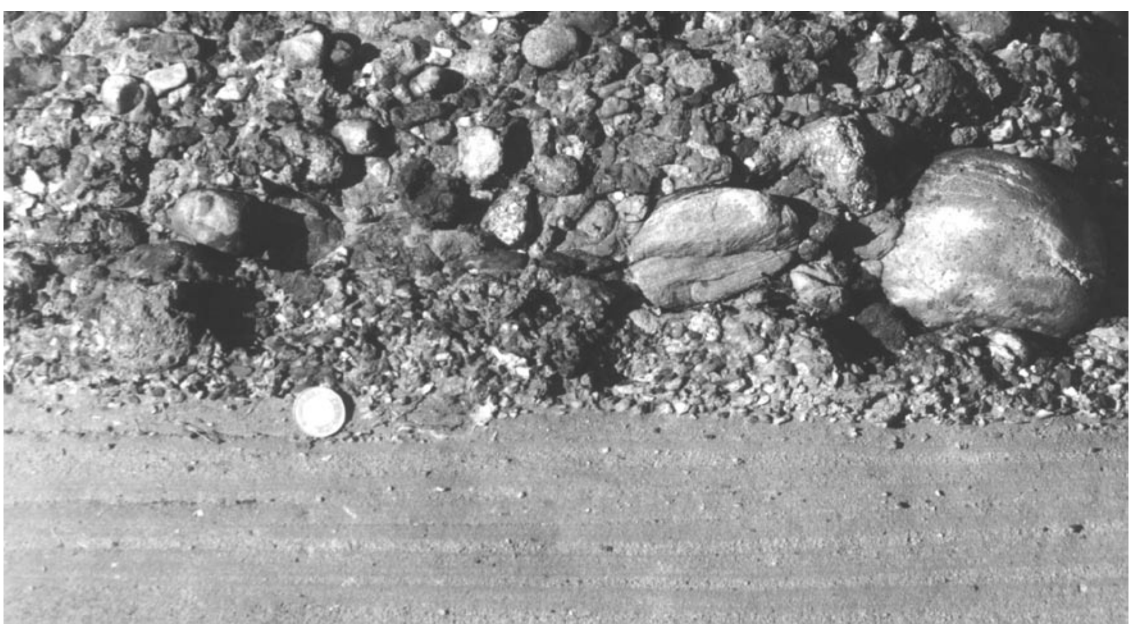
This contact occurs on other Gulf Islands. The name "Spray" is from Spray Point in Tribune Bay on Hornby Island, and in older literature the Spray Formation was called the Mayne Formation. Exactly why the sediment changed from mud to sand at the time that it did is not known.

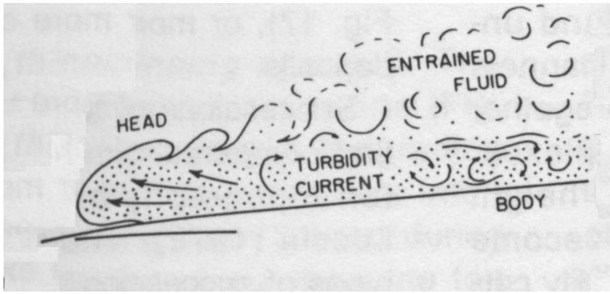
A dyke of fine-grained sandstone cuts up through horizontal beds of Northumberland Formation mudrock near False Narrows. The sand was liquefied and injected into a fracture from below during a late-Cretaceous major earthquake. When the mudrock was later compacted, the less-compliant sandstone of the dyke crumpled and folded.

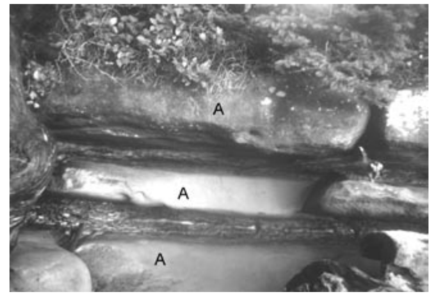


Pebble-sized conglomerate watches the ferry come and go on from the west side of Descanso Bay. This is the top of the Geoffrey Formation. Pebbles are of various sizes (poorly sorted) and mineral composition (polymictic). Such deposits occur in the upper part of submarine fans in channels and gullies that restrict and concentrate the turbulent flows.

Cobble-sized conglomerate (*below*, two-dollar-coin for scale, precariously perched on the near-vertical rockface). Geoffrey Formation on Spring Beach. The cobbles have been well rounded in a river and are made of chert (quartz), granite, and volcanic minerals, probably from the Cascades and San Juans. They were part of an upper-fan debris flow, likely triggered by an earthquake. Note the occasional pebble embedded in the silt laid down by previous smaller avalanches down the submarine channel. At the time, the trickle of pebbles must have been an ominous warning of the major landslide about to come.





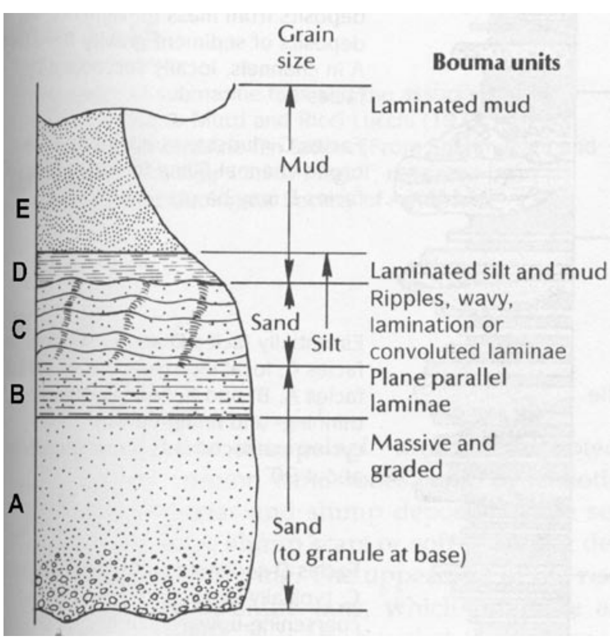


Bouma sequences.

Above: "A" sequences (marked) with thinner "BCDE" sequences in-between.

Left: "BCDE" details.

Anatomy of an avalanche. This interbed of sand- and mudstone, is about 600-mm thick (Gabriola Formation, Clark Bay), but only the top 200-mm is shown here. It is the result of an avalanche of sand, silt, and clay down a submarine slope. Avalanches (turbidity currents) are propelled by the weight of the suspended material. As the flow slows down, suspended material settles out in a so-called "Bouma" sequence, ABCDE. Sandstone at the top is the bottom of the next A.



E: the current has stopped; clay-sized particles gradually settle and the water clears

D: thin sheets of silt and mud, now moving only slowly, come to rest on C

C: the current rapidly slows, and most of the remaining particles in the turbulent cloud collapse chaotically

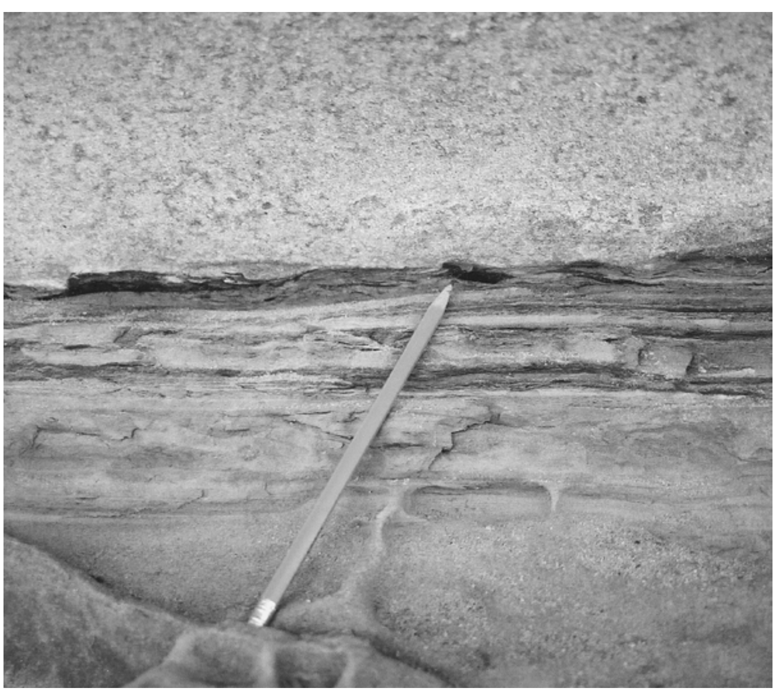
B: thin sheets of medium-grained sand sweep rapidly over the surface of A

A: coarse-grained sand drops from the current, which races on down the slope.

Only the top of A, which is by far the thickest layer, is shown in the photograph in the middle of the page (see top right).

In this example, B contains fragments of coal.

Above: A "flame" structure (the field of view is about 10-cm high), in the back wall of the Malaspina Galleries (*top right*), Gabriola Formation. It freezes a moment in time, millions of years ago, when an avalanche down a submarine cliff dumped a load of sand on to a fine layer of mud on the ocean floor. As far as we know, nobody at the time took any notice. The "flame" has been made far more visible than usual by colourful oxidation of iron-rich minerals (*hornblende* and *biotite*) on the surface of the mudrock.



The pencil points to a 4-mm-thick coal deposit in the uppermost layers of a thin interbed of mud within sandstone, Malaspina Galleries. This interbed may be the result of the collapse of a distant part of the submarine-fan that kicked up a cloud of silt and mud, or possibly it's from erosion of the levee of the channel.

The coal, which is often found in mudrock immediately below thick beds of sandstone, is from waterlogged wood and mats of rotting vegetation. The sea was too deep here for the coal to be part of the Nanaimo coal beds, which were formed about 10 million years earlier in a narrow belt of coastal swamps, and are part of the lower-Nanaimo Group Formations.

A striking feature of the Nanaimo Group sandstones is their "honeycomb" or *tafoni* weathering patterns. The holes, cavities, and galleries are created by de-cementation of the sandstone, most probably by salt water. The water soaks into the matrix of the sandstone where it evaporates. As the salt crystallizes, it expands and pries apart the clay that holds the grains of sand together.

The salt is brought to the erosion surfaces by groundwater, which seeps out from *inside* the rock and evaporates in the heat of the summer sun. The erosion process is self-perpetuating. The deeper the hole, the easier it becomes for groundwater to collect on the backwall of the hole, hence the greater the concentration of salt, and the more severe the erosion. The water is made salty when rain percolating into the rock is mixed with sea spray aerosols during winter storms.

Note the *stonecrop* growing along the top of the rock. This delightful location on Link Island is sheltered from the open sea by a small islet, which belies the assertion that honeycomb weathering is due to erosion by wind and waves. The bottom of the rock, where most of the wave action is, is actually free of holes.

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