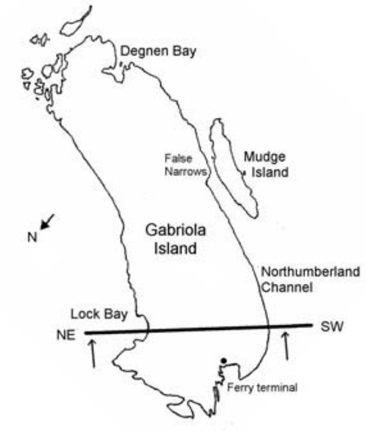
Geochemistry of Gabriola's groundwater

by Steven Earle and Erik Krogh

The Geology and Chemistry Departments at Malaspina University-College are engaged in a study of the geochemistry of the groundwater used by residents of eastern Vancouver Island and the Gulf Islands. This project has included a survey of private water wells on Gabriola Island. With the permission of homeowners, we have sampled water from 72 wells on the island, and have analysed those samples for a wide range of chemical constituents.

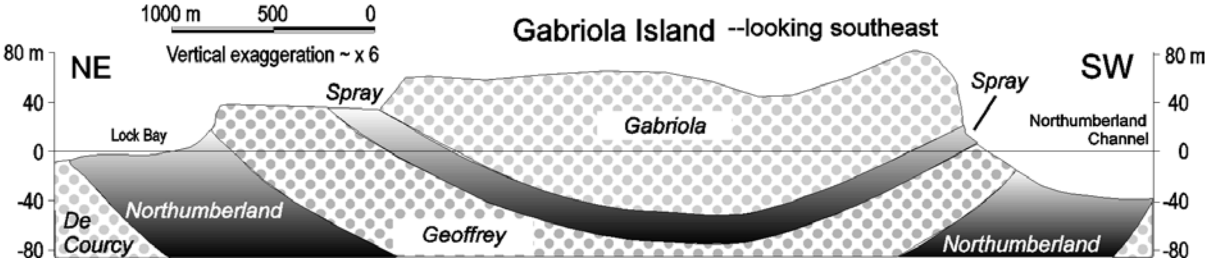
Our objective is to study the natural variations of the groundwater in this region, and to understand how the water is affected by the geological features of the rocks through which it flows. We are interested in determining the extent and origin of elevated levels of fluoride, boron, and selenium; the degree to which high salt levels are a problem; and whether or not there are areas with elevated levels of arsenic or other potential toxins. In order to keep our study focussed, we have not considered biological contamination, for example, coliforms, although we are aware that this is a concern for some residents.



Geology

Gabriola Island has geological similarities to many of the other Gulf Islands and to most of the eastern lowland parts of Vancouver Island extending from Duncan to Campbell River. The island is made up mudrock (also referred to as shale), sandstone, and conglomerate of the late-Cretaceous Nanaimo Group. Gabriola Island includes the uppermost one-third of the Nanaimo Group formations—*Gabriola* (mostly sandstone), *Spray* (siltstone and mudstone), *Geoffrey* (sandstone and conglomerate), and *Northumberland* (mostly mudstone).

The island forms a large syncline (∪-shaped fold), which explains why the Northumberland Formation is exposed both



Cross-section of Gabriola Island, from Lock Bay to the Northumberland Channel, showing its Nanaimo-Group geological formations—*Gabriola*, *Spray*, *Geoffrey*, and *Northumberland*.

along False Narrows on the south side of the island, and in the Whalebone beach area on the north side.

As can be seen in the diagram, *previous page*, the upland and steep parts of the island mostly comprise the more resistant rocks—sandstone and conglomerate—while the lower and flatter parts are made up of less resistant mudrock. Cliffs along the Northumberland Channel, visible from the ferry, just around the corner from Descanso Bay, are made up of Geoffrey Formation sandstone and conglomerate, while those farther south toward Dodd Narrows are made up of sandstone of the Gabriola Formation. Cliffs along the north side of the island are mostly Geoffrey Formation sandstone.

The geology of Gabriola Island is very similar to that of Hornby Island, which has recently been described in some detail by Katnick and Mustard (2003).

Hydrogeology

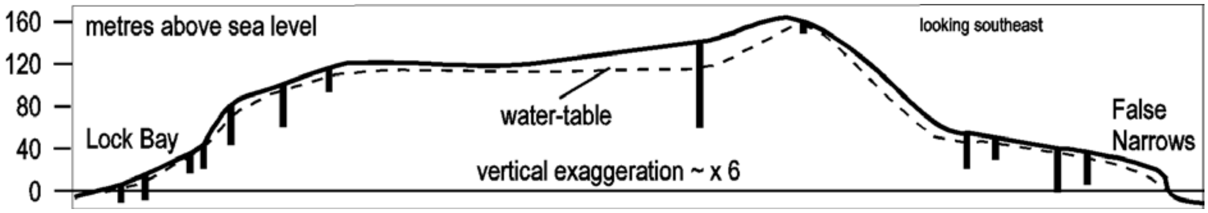
The sandstones and conglomerates of the Nanaimo Group are what geologists describe as impure or immature, meaning that they are not just made up of grains of sand and gravel, but they include a relatively high proportion of clay, and other fine-grained material, including organic matter. Water cannot flow easily between the grains (clasts), as it would through unconsolidated beach sand. These rocks do not transmit water very well, and most of the permeability that they have, is interpreted to be related to fractures.

The mudrock of the Nanaimo Group, like most other mudrock, is predominantly composed of clay. Most mudrock is relatively impermeable, but since much of the mudrock in the Nanaimo Group is quite strongly fractured, considerably more fractured than the sandstone, formations such as the Northumberland and Spray can be quite good aquifers.

The water-table is defined as the surface below which all of the pores and fractures in the rock are filled with water. Based on well-water data compiled by the BC Ministry of Water, Land, and Air Protection, we can see that the water-table is within about five metres of the surface across most of Gabriola Island (see sketch *below*).

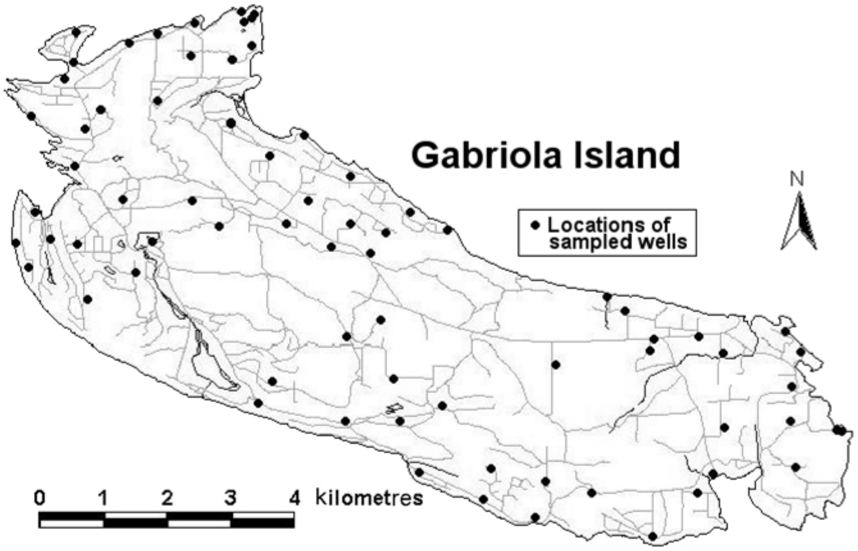
Groundwater flow theory tells us that this water will flow—at rates in the order of centimetres to tens of centimetres per week—from areas where the water-table is high, the upland areas, to areas where the water-table is low, near the coast.

All of the groundwater on Gabriola Island is derived from the rain and snow that falls on the island, which amounts on average to an equivalent of about 900 mm (35 inches) of rain. Some proportion of this precipitation runs off of the island as surface water, and the rest infiltrates into the ground and becomes groundwater. We do not know the proportions of runoff and infiltration, but because of the relatively low permeability of the rocks, and the fact that, like most other



Well locations and water-table profile for a cross-section from Lock Bay to the False Narrows area

Data from the Ministry of Water, Land and Air Protection



Gulf Islands, there are few extensive deposits of sand on Gabriola, we can assume that the proportion of direct runoff is higher than it is in some other areas, such as the Courtenay-Comox area.

Sampling and analysis

We collected 81 samples from 72 different wells (locations shown *above*) during May and June of 2001. The wells were selected on the basis of randomized geographical location, and the willingness of homeowners to participate. They ranged in depth from 3 to 110 metres (10–360 ft). The average depth is just over 40 metres (130 ft).

At all sites we let the water flow for about ten minutes before taking a sample, and we avoided sampling water that had been treated in any way. We measured a number of parameters in the field, including pH (acidity), water temperature, conductivity, sulphur and turbidity, and we filtered the samples to remove all suspended solids before taking them back to the lab.

The remaining analysis was done in the Applied Environmental Research Lab at Malaspina University-College and at the School of Earth and Ocean Sciences at the University of Victoria. We analysed the samples for a wide range of constituents, including the major elements that make up the bulk of the dissolved content: calcium, magnesium, sodium, chloride, bicarbonate and sulphate, plus about 25 trace elements, including iron, manganese, fluoride, boron, copper, zinc, lead, arsenic, and selenium.

All analytical data are maintained in confidence and all participating homeowners have been informed of their results.

Groundwater geochemistry

Groundwaters on Gabriola Island are chemically similar to those from other parts of this region that are underlain by the Nanaimo Group sedimentary rock. The main dissolved constituents are sodium and bicarbonate, with lesser amounts of chloride, calcium, and sulphate. This is consistent with what we have seen in the Yellow Point area, and also with the observations of Allen and Suchy (2001) on Saturna Island.

Bicarbonate levels fall generally within the range from 50 to 250 mg/L[1] (expressed as

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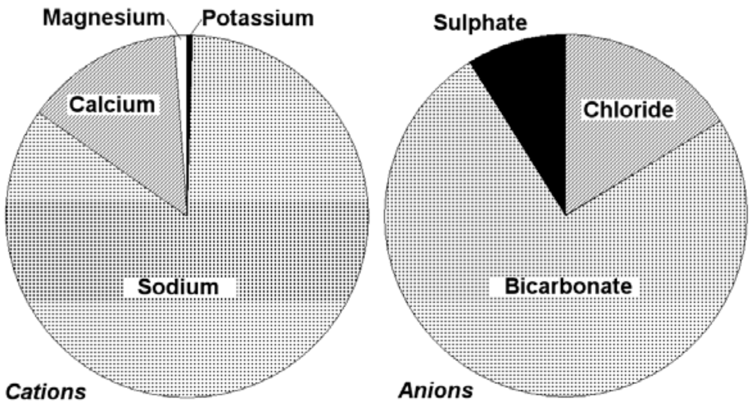
[1] mg/L (milligrams per litre) is equivalent to ppm (parts per million).



Relative proportions of the major dissolved constituents in Gabriola groundwaters, with cations (positively charged ions) *left* and anions (negatively charged ions) *right*

$CaCO_3$) with an average of 140 mg/L. Sodium levels range from 30 to 200 mg/L, with an average of 110 mg/L. The average levels of chloride, calcium, and sulphate are 31, 19, and 17 mg/L respectively.

Most other constituents have average concentrations of just a few mg/L or less. The more important ones include silicon: 6.5 mg/L, magnesium: 1.5 mg/L, fluoride: 0.65 mg/L, potassium: 0.64 mg/L, boron: 0.43 mg/L, and iron: 0.27 mg/L.

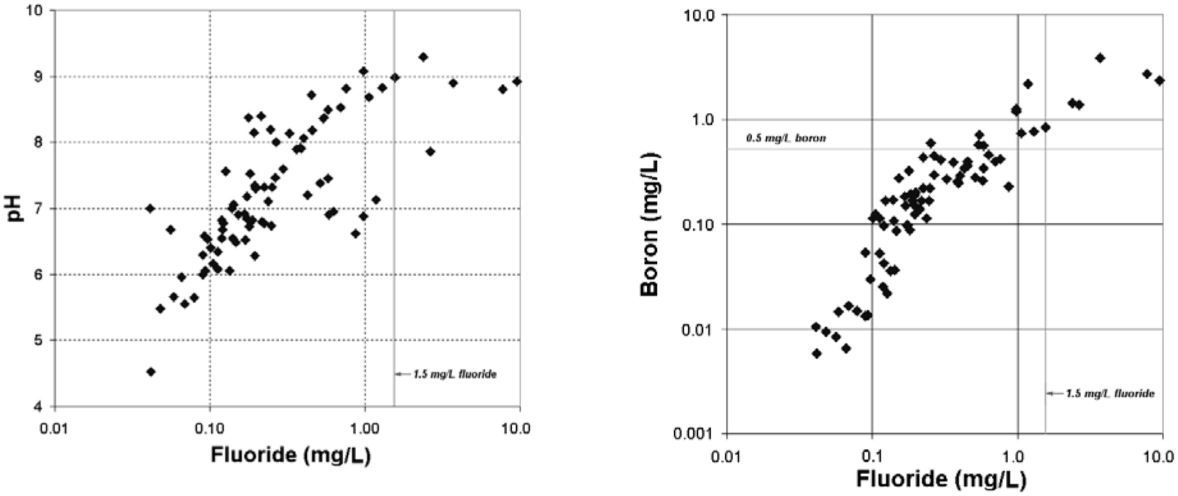
The pH of Gabriola groundwaters ranges from under 6.0 to over 9.0, with an average of 7.3. Groundwater with pH of greater than 8.0 is relatively uncommon in other areas, except under arid conditions or in very deep groundwaters (Langmuir, 1997). As discussed below, there are some specific reasons why we see such high pH levels here.

Since groundwaters are in constant contact with the rocks that surround them, there is plenty of opportunity, in most cases, for chemical interaction between the water and the rock. Nanaimo Group rocks have relatively high levels of reactive minerals such as clays and calcite, and there is evidence that the waters within them change quite significantly as they flow through the rock.

Allen and Suchy (2001) propose that Nanaimo Group groundwaters evolve from being relatively rich in calcium and magnesium near to surface, to strongly sodium rich as they migrate through the aquifer to greater depths, and that the calcium and magnesium is replaced in solution by sodium that was loosely attached to clay minerals in the rock. A similar process has been suggested for groundwaters in comparable sedimentary rocks in southeast New Brunswick (Boyle, 1992).

We have data from a location south of Nanaimo that support this concept. The data come from several pairs of adjacent wells, in each case one about ten metres deeper than the other. In almost every case the shallower well has higher levels of calcium and magnesium, and lower levels of sodium, than the deeper well. The deeper wells have consistently higher pH levels than the shallower wells, which is consistent with the process of exchange of sodium for calcium and magnesium.

The solubility of fluoride is controlled by several factors, including pH and calcium content. Fluoride solubility is enhanced at high pH and in waters with relatively low calcium content, factors that we observed in our data, as did Boyle (1992) in data from New Brunswick (diagram *next page*, *top left*).



Left: pH versus fluoride in Gabriola Island groundwater samples. The higher the pH, the greater the amount of dissolved fluoride.

Right: Boron versus fluoride in Gabriola Island groundwater samples. The more fluoride in the water, the more boron also.

We have also observed a strong correlation between fluoride and boron (*above right*), an observation that is consistent with data for groundwaters from an area underlain by similar rocks in the Münster region of Germany (Queste et al., 2001).

Groundwater geochemistry issues on Gabriola Island

Fluoride

Approximately 8% of the wells sampled on Gabriola have fluoride levels that exceed the provincial and national Maximum Acceptable Concentration (MAC) of 1.5 mg/L. The maximum fluoride level observed in our study is 9.5 mg/L, but since we sampled only a fraction of the wells on the island, we anticipate that there may be wells with even higher levels. Consistent consumption of water with elevated fluoride levels can lead to mottling and malformation of teeth in young children, and to skeletal problems in older adults.

Of the ten samples that have more than 1.0 mg/L of fluoride, nine are from wells completed in the Gabriola Formation, and one is from a well into the Geoffrey Formation.

Boron

The World Health Organization has established a provisional guideline for boron in drinking water of 0.5 mg/L (WHO, 1998). The guideline is designated as being provisional only because there are no readily available methods to reduce boron to 0.5 mg/L in areas where the levels may be consistently high. Canada and British Columbia have an Interim MAC (IMAC) for boron of 5.0 mg/L. Almost 20% of the wells sampled on Gabriola have boron contents in excess of the World Health Organization guideline of 0.5 mg/L, although none exceed the Canadian IMAC of 5 mg/L. Several samples have more than 2 mg/L boron, with the highest at 3.9 mg/L. According to the WHO (1998) consistent consumption of groundwater with too much boron can lead to problems in the male reproductive tract. Elevated boron in water is also a serious problem for plants.

As is the case for fluoride, almost all of the boron-rich samples are from wells completed in the Gabriola Formation.

Selenium

The national and provincial MAC for selenium is 0.01 mg/L. This value is exceeded in 9% of the Gabriola water samples that we tested, although only three samples have more than 0.02 mg/L selenium. While small amounts of selenium are necessary for human health, consistent consumption of water with higher levels can contribute to disorders such as jaundice, gastrointestinal disease, and dermatitis.

Salt-water intrusion

Salt-water intrusion into wells is a significant issue in near-shore regions of many of the Gulf Islands (Allen and Suchy, 2001). Of the 72 wells that we tested on Gabriola, only one showed clear evidence of salt intrusion, with a chloride level of over 2600 mg/L (compared with the average of 31 mg/L) and a sodium level of over 860 mg/L (compared with the average of 110 mg/L). Since we did not specifically sample in near-shore areas, our results may easily have underestimated the salt-water intrusion problem.

Iron, manganese, sulphur

Many of the wells on Gabriola, and in other parts of this region, have noticeably elevated levels of iron, manganese, and sulphur. These elements are commonly associated with low oxidation levels in water, which in turn may be a result of the relatively high levels of organic matter in the Nanaimo Group rocks. Iron and manganese can lead to staining of plumbing fixtures and sulphur imparts a strong smell to the water. Iron, manganese, and sulphur are not known to contribute to health problems.

Arsenic

Arsenic in well water does not appear to be a significant problem on Gabriola Island. None of our 81 samples had an arsenic concentration in excess of the Canadian IMAC of 0.025 mg/L, although one sample, at 0.013 mg/L arsenic, exceeds the US and WHO guideline of 0.010 mg/L.

Hydrogeology of trace elements

Elements that are not abundant on the surface of the earth are known as *trace elements*. The usual cut-off level for trace elements is that they are present at concentrations of less than 0.1% (or 1000 ppm) in the crust. Most trace elements either exist in relatively rare minerals (such as boron in the mineral *tourmaline*), or they are present in only minor amounts in common minerals (such as flourine in the mineral *biotite*).

There are several factors that control how much of a certain trace element will be present in groundwater. One is the amount of the element in the rock through which the water flows, another is the solubility of that element under the conditions that exist in the aquifer, and a third is the flow rate of the water and hence the contact time between the water and the rock.

Looking at fluoride, for example, we have rock sample data that shows that the Nanaimo Group strata on Gabriola Island have fairly typical fluorine levels for rocks of this type. The average fluorine level in the sandstone units is around 350 ppm, while that for the mudstone units is around

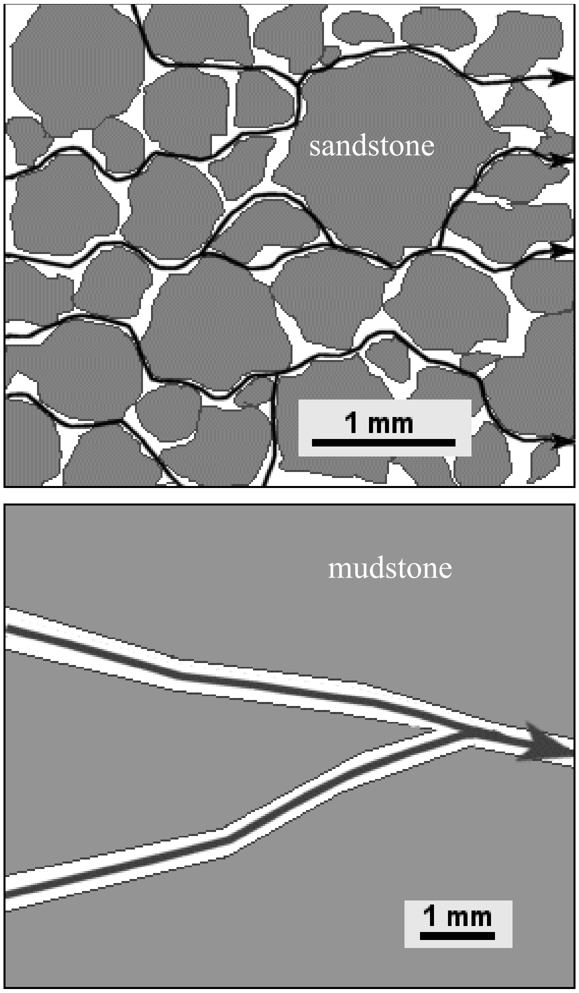
484 ppm.[2] This difference is likely due to the differing proportions of micaceous minerals in the mudstones versus sandstones, since fluorine is a minor component of several of the micas, including *biotite* and *muscovite*, which are quite common in these rocks.

As noted above, all of the samples with high fluoride levels come from wells that were completed in sandstone units, so it appears unlikely that the amount of fluorine in the rock is the major factor controlling fluoride in the water.

On the other hand, we have evidence that fluoride levels are quite closely related to pH levels, which, in turn appear to be controlled by the process of calcium from the water being exchanged for sodium attached to clay minerals. pH levels are consistently higher in waters from sandstone wells, and we interpret that this is because the calcium-sodium exchange process is much more effective in the sandstone than in the mudstone.

Although we don't understand exactly why the exchange process may be more effective in sandstone, it probably has something to do with the physical characteristics of the two rock types. As noted above, mudstones are rich in clay, and as a result water does not tend to move through them easily. Most mudstones are very poor aquifers, but the Nanaimo Group mudstones—especially the Northumberland Formation—can be quite good aquifers because they tend to be well fractured. This implies that water flowing through the mudstones moves primarily along fractures, and not through the rock matrix (Allen and Suchy, 2001), (Mackie et al., 2001). Sandstones tend to be better aquifers than mudstones because their grains are sufficiently large that water can move around them. Although the Nanaimo Group sandstones are less permeable than many other sandstones, they do have enough intergranular permeability to allow for the flow of some water through the solid rock.

It is likely that the groundwater in the



Top: Schematic diagram of possible water flow paths in a sandstone aquifer

Bottom: Schematic diagram of possible water flow paths in fractured mudstone aquifer

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[2] These values are generally consistent with those quoted for average sandstones (280 ppm) and shales (680 ppm) by Rose et al. (1979).

mudstone units moves primarily along relatively large fractures (in the order of mm wide), and therefore makes relatively little direct contact with individual mineral grains. On the other hand, much of the water moving through the sandstone units moves within intergranular spaces that may only be a few microns in width (diagram *previous page*).

It is probable, therefore, that groundwater in the sandstone units moves generally more slowly than that moving through the fractures in the mudstone, and has a much greater degree of contact with the minerals in the rock. The greater opportunity for water-rock interaction means that sodium-calcium substitution can take place more readily, pH levels can increase, and fluoride and boron levels can become more significantly elevated.

Acknowledgements

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