Appendix A: Geological Review
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1 Geology of Gabriola, Mudge, and DeCourcy Islands

1.1 Bedrock Geology

The bedrock geology maps for the Gulf Islands have changed significantly over time in level of detail and interpretation. The earliest map found was by Halstead (1963), followed by maps by Muller and Jeletzky (1970) and England (1989). 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). The depositional environments and definition of the sedimentary rocks of the Nanaimo Group are described in more detail in Mustard (1994) and a summary is presented in Table A-1. Journeay (2004) produced the most recent and detailed map of Gulf Islands bedrock geology, which is available in digital format in GIS (GSC, 2004) and was used in aquifer vulnerability mapping by Denny et al (2006). The surficial geology map of Gabriola and Mudge Island and nearby sea floor is included in Figure A-1 from Natural Resources Canada & Fisheries And Oceans Canada (Picard, 2010) and annotated by authors of this report and from a surficial geology map previously presented on the Gabriola Island community profile, and identical to the digital map used in this report.

Table A-1 Descriptions of the Nanaimo Group formations on Gabriola, Mudge, DeCourcy Islands (summary from Mustard 1994, Muller and Jeletzky, 1970, and Hodge, 1978)

<table>
<thead>
<tr>
<th>Formation Name</th>
<th>Dominant Lithological Units</th>
<th>Less Dominant Units</th>
<th>Thickness (vertical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gabriola</td>
<td>thick bedded sandstone</td>
<td>rare laminated silty mudstone interbeds</td>
<td>40 to 120m (eroded)</td>
</tr>
<tr>
<td>Spray</td>
<td>shale and siltstone sequences</td>
<td>sandstone interbeds (variable)</td>
<td>20 to 40m</td>
</tr>
<tr>
<td>Geoffrey</td>
<td>thick bedded sandstone and coarse conglomerate</td>
<td>prominent interbeds of shale</td>
<td>60 to 80m</td>
</tr>
<tr>
<td>Northumberland</td>
<td>silty shale (upper Northumberland) – with some clay alteration in layers, sandstone and conglomerate (lower Northumberland)</td>
<td>thin interbeds of sandstone and siltstone, minor thick beds of sandstone</td>
<td>200 to 300m in False Narrows between Gabriola and Mudge Islands</td>
</tr>
<tr>
<td>DeCourcy</td>
<td>thick bedded sandstone</td>
<td>siltstone and mudstone interbeds</td>
<td>N/A</td>
</tr>
<tr>
<td>Cedar District</td>
<td>thin bedded silty shale, siltstone and sandstone</td>
<td></td>
<td>N/A</td>
</tr>
</tbody>
</table>
1.2 Structural Geology of Nanaimo Group Sedimentary Rocks

Tectonic events caused uplifting and folding of sedimentary strata, resulting in faulting and fracturing. Isostatic rebound after the ice age may have also contributed to fracturing along bedding planes. Structural geological work has been done by many academic researchers and a good reference list is provided in Mustard (1994) and Mackie (2002). These were very rigorous scientific investigations at the regional scale.

Local geological and hydrogeological observations, and some interpretations, were recently written by Doe and Peirce (2010) in a journal of a local historical society. Although not reviewed and formally presented, there is a wealth of local observations and good interpretations in several articles in that journal. The most recent and most detailed geological discussion of Gabriola Island is in Doe (2009a, 2009b) and one map is shown in compilation Figure A-1.

On Gabriola Island the dominant structure is a syncline fold called the Gabriola Syncline (England 1989). The syncline axis runs along the middle of Gabriola Island. The stratigraphic units are bent by the syncline and dip at 10 to 15 degrees toward the syncline axis. An idealized cross-section is shown in Figure A-1 which was presented in a previous local article by Earle and Krogh (2004).

The syncline structure is of different shape on the north-west side of the Gabriola Fault; a large fault which extends from Lock Bay south to Northumberland Channel. Along Cox Bay (Leboeuf Bay), the rock strata dip very gently to the north and north-west away from the Gabriola Fault. Doe (2009a, 2009b, 2012) discuss the possible structural origins of north-west and south-east parts of Gabriola Island.

The largest faults on Gabriola Island are shown on Figure A-1. The three largest faults are:

- a) Gabriola Fault
  - this fault extends from Leboeuf Bay to Cox’s Bay in north end of Gabriola Island
  - Doe (2009a) suggests that this fault may be a continuation of the Chase River Fault on Vancouver Island, and that there may be surficial expression of the fault on the sea floor as well based on bathymetric charts. Coal mines traced this fault as continuing across the Northumberland Channel

- b) fault in south end of Gabriola Island
  - this fault extends along Maples-Dragon’s Lane in south end of Gabriola Island (this fault does not have an official name)
  - there is small geomorphic expression at the shoreline in the north, and a topographic low along the fault, which affects the surface drainage pattern
  - it may run along the break between Mudge and Link Islands
  - there is a permanent spring at the south end of the fault and a permanent groundwater fed lake at the end of Dorby Road

- c) Flat Top Islands Fault
  - runs mostly along the sea bed as seen on bathymetric maps

There are other possible structures, which may be expressed in ground topography and many fault zones are visible on island shores. Many “fault-like” features are most likely erosional features.
resulting from lithologic differences. The early maps produced by Brown and Erdman (1975) appear to associate too many topographic features with faults as pointed out by Doe (2009a). The latest map of major faults on Gabriola and other Gulf Islands is by Journeay (2004), provided by Simon Fraser University in digital format for this report.

Fractures occur predominantly in zones of intense deformation associated with larger structural features such as large faults. Secondary fractures are structurally caused but are not as continuous as primary fractures and faults. Smaller fractures or joints also connect larger fractures. Large fractures associated with fold-related tensile and compressive stresses on Gabriola Island are either parallel to the fold axis and are caused by tensile stress (longitudinal fold fractures) or are perpendicular to the fold and are caused by compressive stress (lateral fold fractures). There are also x-shaped conjugate fractures visible on beaches in sandstone.

Vertical joints also form locally where sandstone strata become unevenly supported by underlying mudstone due to weathering. Joint spacing in this case depends on thickness of sandstone layer (or “bed” in geology) – thicker beds have more widely spaced vertical joints. Vertical joints are important for allowing groundwater to infiltrate downward across and/or through sandstone beds. Joint aperture (size of joint space in rock) varies greatly from <1 mm to >50cm. Most are a few mm in size where seen on beaches (these have a larger aperture at surface than at depth because of effects of erosion).

1.3 Overburden Geology

Land topography on Gulf Islands is mostly coincident with bedrock topography, except where overburden sediments fill depressions. Overburden units are present in some places on top of bedrock. These are generally above the water table and are of minor importance for groundwater quantity, although overburden can locally control groundwater recharge. Hodge (1978) reported that only a few productive wells were completed in overburden deposits and these are typically dry and well drained. There is a good surficial geology map showing occurrence of Quaternary sediments on Gabriola Island in the Island Trust (2007) Gabriola Island Community Profile, provided by Natural Resources Canada.

The EBA (2011) report on geo-hazards on Gabriola Island includes is a good summary of soils, terrain, and overburden properties and reviews existing geotechnical reports dating from 1992 to 2009. Soils are sparse and thin (~2m), and are formed from bedrock weathering and from deposited glacial till and small pockets of glacial outwash. Overburden deposits on Gabriola Island are predominantly glaciomarine sediments. The thickest overburden deposits are in the SE corner of Gabriola Island (up to 25m of coarse gravel/boulder till deposits) west of Degnen Bay.

The shape of Gabriola Island and its ground topography are a result of its geology and erosional processes; a good summary is given in Gabriola Island Community Profile document (2007). The article by Doe (2000) explains the erosional and other processes which likely shaped the islands and produced bench-like topography in some places. Earle (2002) discusses the effect of past sea level changes on Gabriola Island surficial sediments and landforms.
1.4 **Mining Activities in Nanaimo Bay Near Gabriola Island**

Coal has been mined in the past under Nanaimo Bay but the old mine workings do not extend to Gabriola Island. EBA (2011) reviewed the Coal Mine Underground Workings Atlas to determine whether coal had been mined on Gabriola, and determined that there were no underground coalmine workings under the Island. National Resources Canada (2012) has a map of underground workings near Nanaimo.

2 **Preliminary 3D Geological Model of Gabriola Island**

As part of this project, a preliminary geological model was constructed for Gabriola, Mudge, and DeCourcy islands. The purpose of this model is to combine previously drawn cross sections, surficial geology maps, and well logs (well lithology database) to produce a digital product which can be used in Phase 2 assessment and for estimating volumes fractured rock aquifer in this report.

2.1 **Methods**

The data used were mainly from geological outcrops taken from a surficial bedrock geology map by Journejay (2004), provided by Simon Fraser University in GIS format. These data were draped onto a digital elevation model created from detailed ground topographic contours provided by the RDN. Previously documented geological descriptions, especially of structural geology of Gabriola Island, were used to guide the interpretation. The boundaries between geological formations were represented by surfaces, and solid volumes filled between these to calculate unit volume. The surfaces were tied in, where it was possible, with the available water well lithogs.

The Province of British Columbia maintains a water well database (WELLS), in which information obtained by the driller at the time of well construction is stored. Such information includes, for example, well depth, water depth at the end of drilling, construction method, an estimate of well yield, and a lithology log. Lithology data for the Gulf Islands had been previously extracted and standardized for use in vulnerability mapping for the Gulf Islands. Standardization is based on a set of rules that allow dominant material types to be identified based on first appearance of the term or by other qualifiers (e.g., silty sand means “sand” is the dominant material type with “silt” as the secondary material). Grain size and colour, as well as fracturing, are descriptors.

For the purpose of constructing the Gabriola Island geological model, the well lithogs were simplified and standardized by SRK again. The dominant units considered were: sandstone, sandstone & shale interlayering, shale, conglomerate, and clay from shale alteration. Well logs do not contain more specific descriptions in most wells.

All available water well lithogs were viewed in 3D software to help guide construction of the geologic layer surfaces. The data set contains mostly low quality simple geologicalogs where only major types of rocks are logged by drillers from rock cuttings. Very few logs were logged by geologists or hydrogeologists on site. The test well logs done by Piteau (1993) are some of the best documented and these were used exactly as shown in cross-sections in report by Piteau Associates.
2.2 Results

There is large uncertainty as to the boundaries of the geological formations inside of Gabriola Island and the model is preliminary and is the best current fit to a large (and often low quality) data set. The 3D model was constructed mostly from surficial geological outcrops and from clusters of well lithologs. The well logs are generally of unknown quality and often show conflicting lithologic information. The test holes by Piteau (1993) are of good quality and were used as control points.

Results of the model “layers” are shown in 3D profile view in Figure A-2 and the figure is annotated with additional comments.

There is not enough information at this time to construct a three-dimensional model of Mudge and DeCourcy islands, although the rock strata are known to dip down toward the east. The well logs do not contain sufficient detail to differentiate the Cedar District and DeCourcy Formations by lithology alone.

A series of figures from Figure A-3 to Figure A-8 shows close-up views of the geological model for various parts of Gabriola Island. The goal is to provide good overview of Gabriola Island geology in a visual manner to the island community and the Nanaimo Regional District staff.

The following observations were made:

- Figure A-3: North shore east from Lock Bay has a high and low terrace-like steps in ground surface, which are associated with outcrops of shale that were preferentially eroded. This area has a large number of water wells and well lithologs in MOE database. Many wells near shore are completed in the Northumberland Formation, a shale unit with many clay intervals. The shale is permeable enough to produce water and the clay interbeds may act as effective confining units.

- Figure A-4: In Silva Bay area there are clusters of residences with water wells. Only two well logs were found on the smaller islands off Silva Bay. The higher ground is composed of sandstone of Gabriola Formation south of the bay and Geoffrey Formation north of the bay. The Spray Formation shale has been eroded more to form a valley and it likely underlies Silva Bay, which is part of this valley.

- Figure A-5: The area around Degnen Bay has similar geology to Silva Bay in that the Spray shale has been eroded more to form a valley which forms Degnen Bay. The land topography reflects the erosional processes and the geological units. Shale layers are easily eroded and form valleys. Sandstones stand out as cliffs and ridges. The well lithologs show variable geology and some clay layers within the shale at depth.

- Figure A-6: Along the south shore of Gabriola Island near False Narrows channel, the geology is similar to the north shore of the island, although the land surface is steeper and high cliffs of sandstone outcrops are present. The Spray Formation shale is located higher up the slope and forms a land bench (as usual, it has been eroded preferentially). Many of the upper water wells drilled in upper slopes are completed in sandstone and partly in the Spray Shale. On the lower land terrace along the shore, the wells are completed in the Northumberland Formation, a shale with clay interbeds similar to the north shore.

- Figure A-7: The area south of Descanso Bay (Descanso Valley) is composed of a head-land of Geoffrey Formation sandstone, which forms high cliffs along the shore, and a valley
eroded into Spray shale, and very high cliffs of Gabriola Formation sandstones. Wells are completed to various depths and in various units. Wells drilled from the top of cliffs are necessarily deeper to access the water table. Wells drilled in the valley in Spray shale have clay intervals.

- Figure A-8: The north-western shores of Gabriola Island, to the west of Gabriola Fault, which runs from Lock Bay to Descanso Bay, has a different orientation of the geological strata and different thicknesses than on main part of Gabriola Island. Three layers of shale of an unidentified geological formation lie between relatively thin sandstone units, and dip to the west and north-west away from land. This is a different situation from the other shores of Gabriola Island. This area has large density of water wells, showing various lithologic units which are difficult to interpret. The interpretation was done mainly from surficial outcrops and land shape and clusters of well logs showing consistent lithologies. The dipping boundaries of the shale and sandstone units were extrapolated and projected down as almost planar surfaces and are shown in a section and profile views on this figure. Groundwater flow is away from land and well drawdowns often produce water levels at or below sea level along the shores. This area has a history of sea water intrusion along the shore. The shale layers are relatively thin and clay intervals are only present at larger depth, so there is less “geologic” protection from sea water intrusion in this area.

3 References


Denny, S.C; Journeay, J M; Allen, DM (2006) Susceptibility of ground water to contamination, southern Gulf Islands, British Columbia, Geological Survey of Canada, Open File, 5333


GSC (2004) Bedrock Geology Map, Faults, 1:50000 scale map, digital format

Island Trust (2007) Gabriola Island Community Profile


Surficial Geology and Shaded Seafloor Relief, Nanaimo, BC, Geology by Picard 2004-2008, Map 2118A – Gabriola Island area selected from original map by Natural Resources Canada & Fisheries And Oceans Canada (2010).

Labels of large fault lines were added on this map by author (after Doe, 1999) comments.

\( kfn = \) bedrock
\( Gmd, Gmp, Gmu = \) glaciomarine sediments
\( Ic = \) ice contact deposits
\( PG... = \) post glacial sediments
\( m = \) mud, \( s = \) sand, \( sr = \) sponge reefs, \( a = \) anthropogenic

**Gabriola Island**

Compilation of Geological maps of Gabriola and Mudge Islands from previous reports

**Water Budget Project: RDN Phase One (Gabriola, DeCourcy, and Mudge Islands)**


Cross-section of Gabriola Island (from Earle and Krogh, 2004), from Lock Bay to the Northumberland Channel.

**Surficial Geology of Gabriola Island,** from Gabriola Island Community Profile (November 2009), data from Natural Resources Canada
Northumberland Formation (shale and clay)

Under Gabriola Island the top of this Geological unit could only be determined along few deep test holes (Pileau, 1993) in this area.

Geoffrey Formation (sandstone)

There is little information on Mudge and DeCourcy except surficial geology map; a 3D model is not available at this time from the small number of well lithologs because most logs show a mix of sandstone and shale

Spray Formation (shale)

Spray Formation shale is shown as green solid; it overlies the Geoffrey Formation (yellow solid).

Gabriola Formation and other units on Gabriola Island

There is little information on Mudge and DeCourcy except surficial geology map; a 3D model is not available at this time from the small number of well lithologs because most logs show a mix of sandstone and shale

DeCourcy Island
Ground surface topography of north shore of Gabriola Island

Geological unit outcrop boundaries shown as dotted lines

North shore of Gabriola Island – topography, geological units, and well lithologs

Clay layers (shown in blue) are very common in Northumberland shale (shown in green), forming confining units for groundwater flow. Groundwater discharge likely occurs away from shore along sea bed, and this area is resistant to salt water intrusion despite large pumping demand.
Figure A-4

Date: Approved: JS

Job No:        1CR010.000
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April 2013

Gabriola Island - topography, geological units and well lithologs

Silva Bay area of Gabriola Island

Ground surface topography of Silva Bay area of Gabriola Island

Silva Bay

Ridge top

North

Sea water

Silva Bay

Islands

Well lithologs legend:

Materials:
- Overburden
- Sandstone
- Clay
- Shale
- Conglomerate
- Sandstone & Shale
- Sandstone & Conglomerate
- Unknown
- Other rock (granite etc)
- Conglomerate & Shale
- Water table

There is a high density of residences and water wells in this area. There is history of salt water intrusion to some wells near shore.

There is a high density of residences and water wells in this area. There is history of salt water intrusion to some wells near shore.

Geological units solid model showing outcrops at ground surface

Shale of Spray Fm. has been eroded to form a valley

Well lithologs:

- Sea water
- Islands

Ridge top
Degnen Bay area of Gabriola Island – topography, geological units and well lithologs

There is a high density of residences and water wells in this area. There is history of salt water intrusion to some wells near shore.

Ground surface topography of Degnen Bay area of Gabriola Island

Well lithologs legend:
- Materials
  - Overburden
  - Sandstone
  - Clay
  - Shale
  - Conglomerate
  - Sandstone & Shale
  - Conglomerate & Sandstone
  - Sandstone & Clay
  - Waterstable

Geological units solid model showing outcrops at ground surface

Water well lithologs and shore outlines

- Outcrop of Geoffrey Fm. (sandstone)
- Outcrop of Gabriola Fm.

Ground surface topography of Degnen Bay area of Gabriola Island

- Outcrop of Geoffrey Fm. (sandstone)
- Outcrop of Gabriola Fm.
- Ridge top
- Degnen Bay
- Gabriola Island
- Sea water
- Islands
- North
Ground surface topography of south shore of Gabriola Island along False Narrows

Clay layers (shown in blue) are very common in Northumberland shale (shown in green), forming confining units for groundwater flow. Groundwater discharge likely occurs away from shore along sea bed, and this area is resistant to salt water intrusion despite large pumping demand. This is the same shale/clay rock as found east of Lock Bay on north shore of island.
Gabriola Island

South of Descanso Bay on Gabriola Island – topography, geological units and well lithologs

Well lithologs legend:

- Overburden
- Sandstone
- Clay
- Shale
- Conglomerate
- Sandstone & Shale
- Sandstone & Conglomerate
- Unknown
- Other rock (granite etc)
- Conglomerate & Shale waterstable

Ground surface topography of south-west shore of Gabriola Island, and Descanso valley, south of Descanso Bay

Well lithologs show dominant shale and clay in Spray Fm.

Well lithologs show very variable lithology of rocks, mostly sandstone and shale

Geoffrey Fm. sandstone is dipping (sloping) toward the north-east here

shale of Spray Fm. has been eroded here, forming a valley along Descanso Valley Road

Geological units solid model showing outcrops at ground surface and water well lithologs

Water well lithologs and shore outlines

water lithologs show

Geoffrey Fm.

outcrop of Gabriola Fm.

north

Descanso Bay

outcrop of Gabriola Fm.

outcrop of Spray Fm. (shale)

outcrop of Geoffrey Fm. (sandstone)

outcrop of Spray Fm. (shale)

outcrop of Geoffrey Fm. (sandstone)

shale of Spray Fm.

Gabriola Island

outcrop of Gabriola Fm.

outcrop of Gabriola Fm.

outcrop of Spray Fm. (shale)

outcrop of Spray Fm. (shale)

Geoffrey Fm.

outcrop of Gabriola Fm.

North

Gabriola Island

outcrop of Geoffrey Fm. (sandstone)

Geoffrey Fm.

shale of Spray Fm.

outcrop of Gabriola Fm.

Water well lithologs and shore outlines

well lithologs show

Geoffrey Fm.

outcrop of Gabriola Fm.

outcrop of Spray Fm. (shale)

outcrop of Geoffrey Fm. (sandstone)

shale of Spray Fm.

Gabriola Island

outcrop of Gabriola Fm.

outcrop of Gabriola Fm.

outcrop of Spray Fm. (shale)

outcrop of Spray Fm. (shale)

Geoffrey Fm.

outcrop of Gabriola Fm.

North

Gabriola Island

outcrop of Geoffrey Fm. (sandstone)

Geoffrey Fm.

shale of Spray Fm.

outcrop of Gabriola Fm.

Water well lithologs and shore outlines

well lithologs show

Geoffrey Fm.

outcrop of Gabriola Fm.

outcrop of Spray Fm. (shale)

outcrop of Geoffrey Fm. (sandstone)

shale of Spray Fm.

Gabriola Island

outcrop of Gabriola Fm.

outcrop of Gabriola Fm.

outcrop of Spray Fm. (shale)

outcrop of Spray Fm. (shale)

Geoffrey Fm.

outcrop of Gabriola Fm.

North

Gabriola Island

outcrop of Geoffrey Fm. (sandstone)

Geoffrey Fm.

shale of Spray Fm.

outcrop of Gabriola Fm.

Water well lithologs and shore outlines

well lithologs show

Geoffrey Fm.

outcrop of Gabriola Fm.

outcrop of Spray Fm. (shale)

outcrop of Geoffrey Fm. (sandstone)

shale of Spray Fm.

Gabriola Island

outcrop of Gabriola Fm.

outcrop of Gabriola Fm.

outcrop of Spray Fm. (shale)

outcrop of Spray Fm. (shale)

Geoffrey Fm.

outcrop of Gabriola Fm.

North

Gabriola Island

outcrop of Geoffrey Fm. (sandstone)
Shale rock layers in west part of Gabriola Island

dipping to the west are shale layers which outcrop as bands of shale on ground surface, and are represented in model as dipping surfaces for visualization (see below for cross-section view along West-East)

Water well lithologs and land surface (looking south-east on shore of Pilot Bay and Taylor Bay)

There is a high density of residences and water wells in this area. There is history of salt water intrusion to some wells near shore.