Chapter 5: GEOLOGY OF NORTH AND SOUTH PENDER ISLAND

5.1 Introduction

Airphotos were used to map bedrock type on the basis of the shape of the shoreline. Henderson (1998) noted the following correlations between shoreline morphology and geology: a jagged coastline and conglomerates; a linear coastline and sandstone; and rectangular shaped inlets and shale (mudstone). Variations in vegetative cover also indicated possible locations of springs and variations in the type of overburden material (Henderson, 1998).

Bedrock exposures were mapped in road cuts and along the shoreline at low tide. Samples of various rock units were collected and sent to the University of Calgary for measurement of primary porosity and permeability. Overburden type was also noted in road cuts and along the shoreline at low tide.

A review of water well records provided further information on bedrock type, depth to bedrock, and location of the groundwater table (www.srmapps.gov.bc.ca/apps/wells). The water well logs were used to supplement geologic mapping where possible. However, overburden stratigraphy and bedrock type are not always clearly defined in water well records (Section 2.6.). Integration of existing information with results of field mapping enabled the preparation of geologic maps and cross-sections for North and South Pender Islands.

Geological mapping provided a basic understanding of the controls on the availability of groundwater resources exerted by the local geology. This dissertation was not intended to be a detailed geological investigation. The geological data provided a complementary data set to assist in the interpretation and interpolation of the geophysical data. This information contributed to a better understanding of the groundwater resource potential for North and South Pender Islands.

5.2 Bedrock Geology

North and South Pender Islands occur within the Nanaimo Lowland, which is located on the west side of the Georgia Depression (Holland, 1976). The bedrock in the study area consists of poorly sorted, massive sandstone, shale and conglomerate of the Nanaimo Group of Upper Cretaceous age (approximately 80 million years ago) (Halstead and Treichel, 1966). The bedrock geology plays a large role in the topography of the islands, with the steep rugged topography following the trends of the major resistant bedrock units (sandstones and conglomerates); the valleys are located over less resistant shale and along fault lines (Williams and Pillsbury, 1958). The Nanaimo Formation rests unconformably on older volcanic and metasediments of the Insular Group of Carboniferous and Devonian ages (315 to 360 million years ago) (Pacht, 1984).

The Nanaimo Group is an assemblage of conglomerate, sandstone, siltstone, and shale derived from four major tectonic provinces: the North Cascades; terranes of the San Juan Islands; the Insular Belt; and the Coastal Plutonic Belt (Pacht, 1984). The rapid accumulation of sediments of the Nanaimo Group accounts for their being poorly sorted, massive, and, in general, lacking pore spaces and conduits for transmission of water (Halstead and Treichel, 1966; Denny *et al.*, 2007). The nomenclature used for the stratigraphic units follows the definitions by Clapp (1912, 1914), with revisions by England (1989). Table 5.1 presents a description of the stratigraphic units.

Field measurements of strike and dip at bedrock exposures were made and used to prepare a geological map (Figure 5.1) and four cross-sections of the islands (Figures 5.2 to 5.5), and to confirm the previous geological work of Clapp (1912, 1914), Williams and Pillsbury (1958), Halstead and Treichel (1966), Muller and Jeletzky (1970), Pacht (1984), Clowes *et al.* (1987), England (1989), and Henderson (1998).

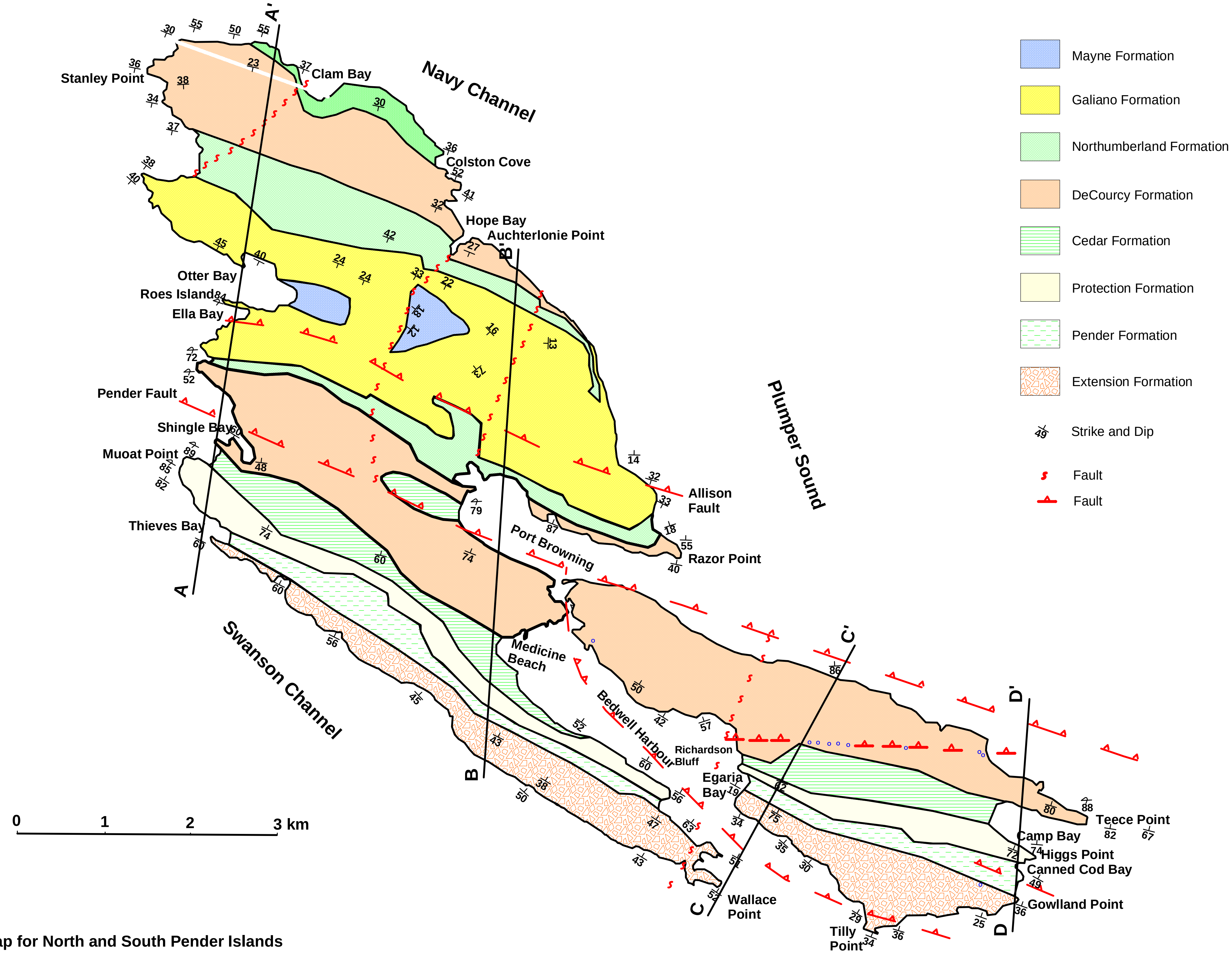

Figure 5.1: Bedrock Geology Map for North and South Pender Islands

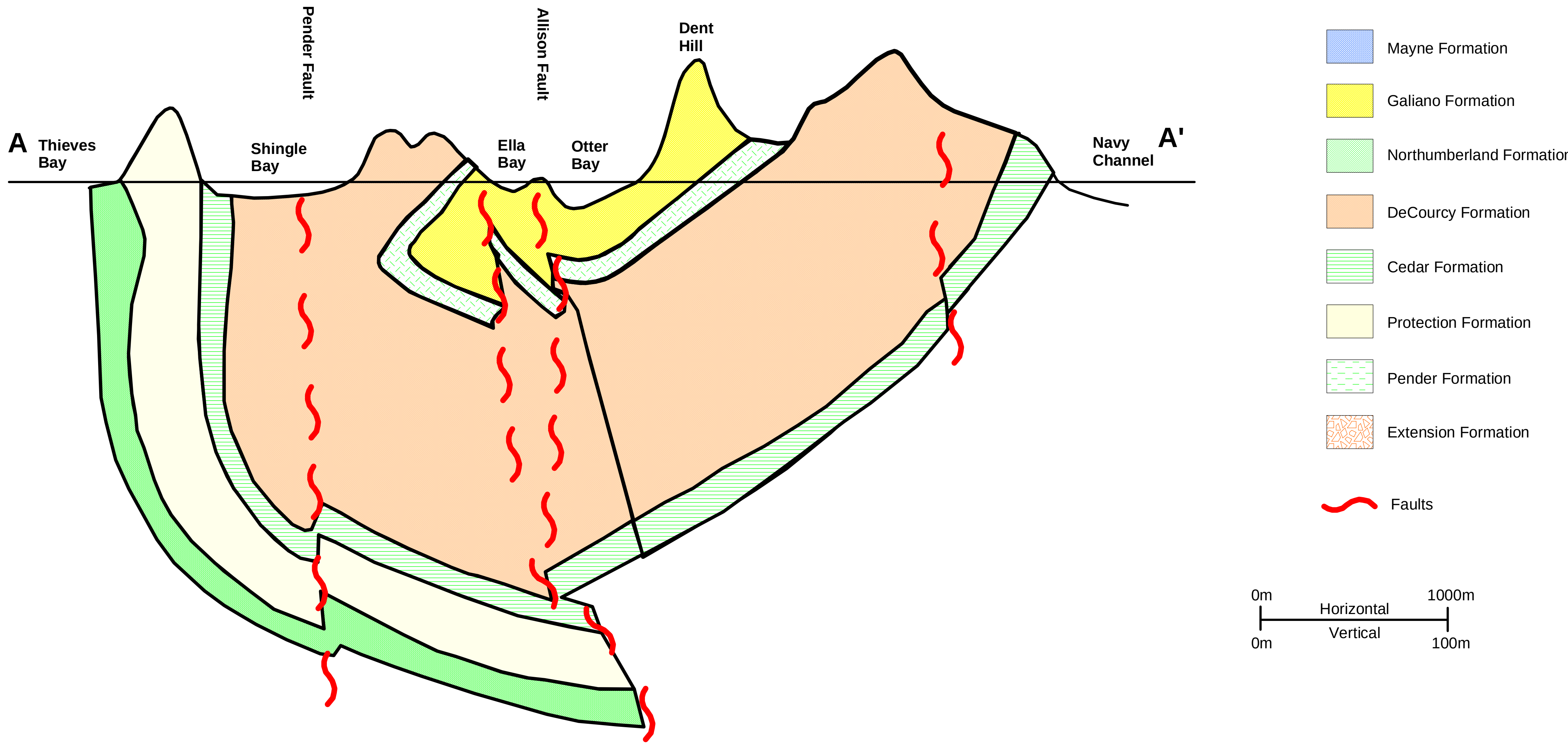

Figure 5.2: Geologic cross-section A-A', North Pender Island

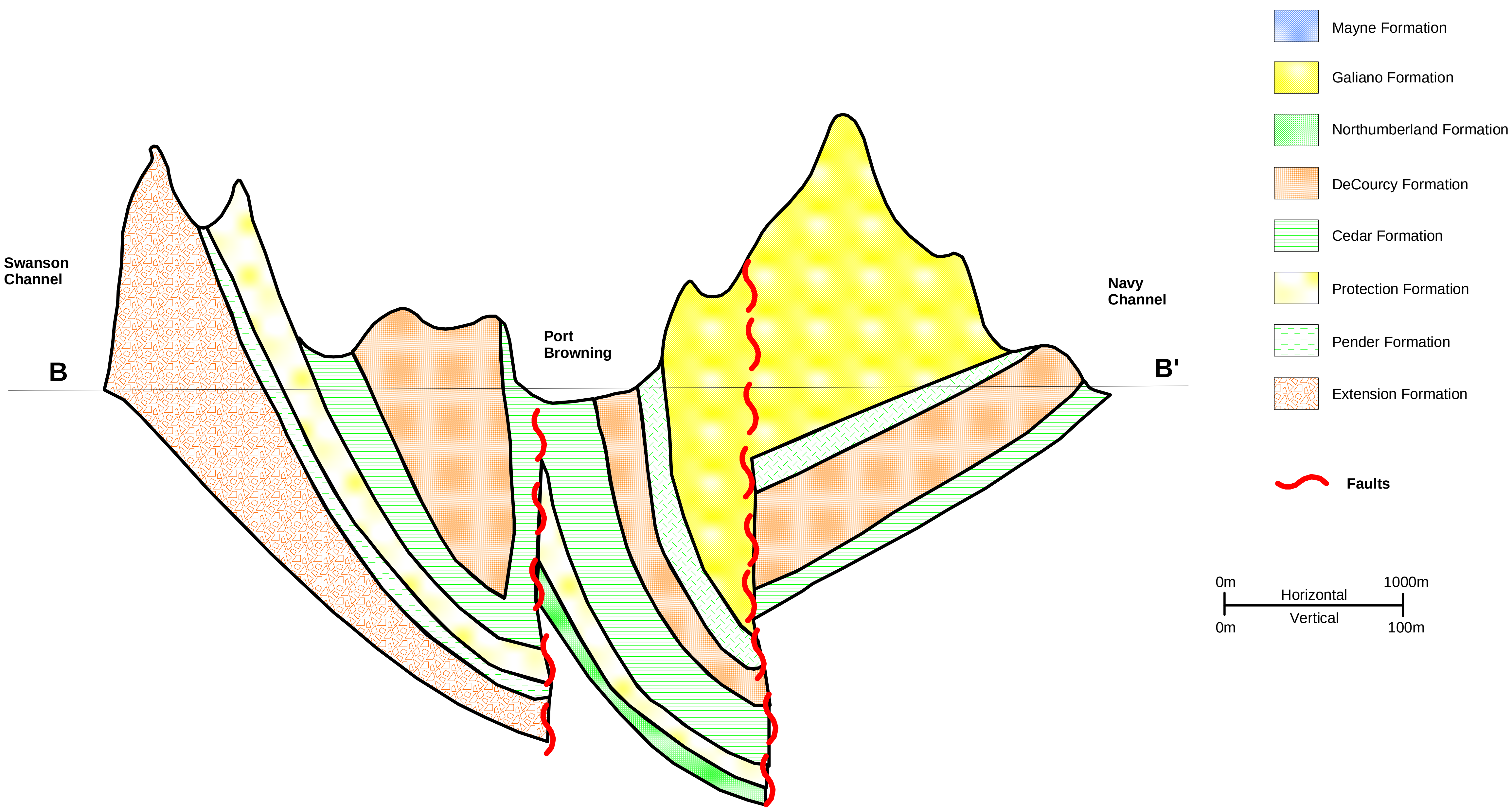

Figure 5.3: Geologic cross-section B-B', North Pender Island

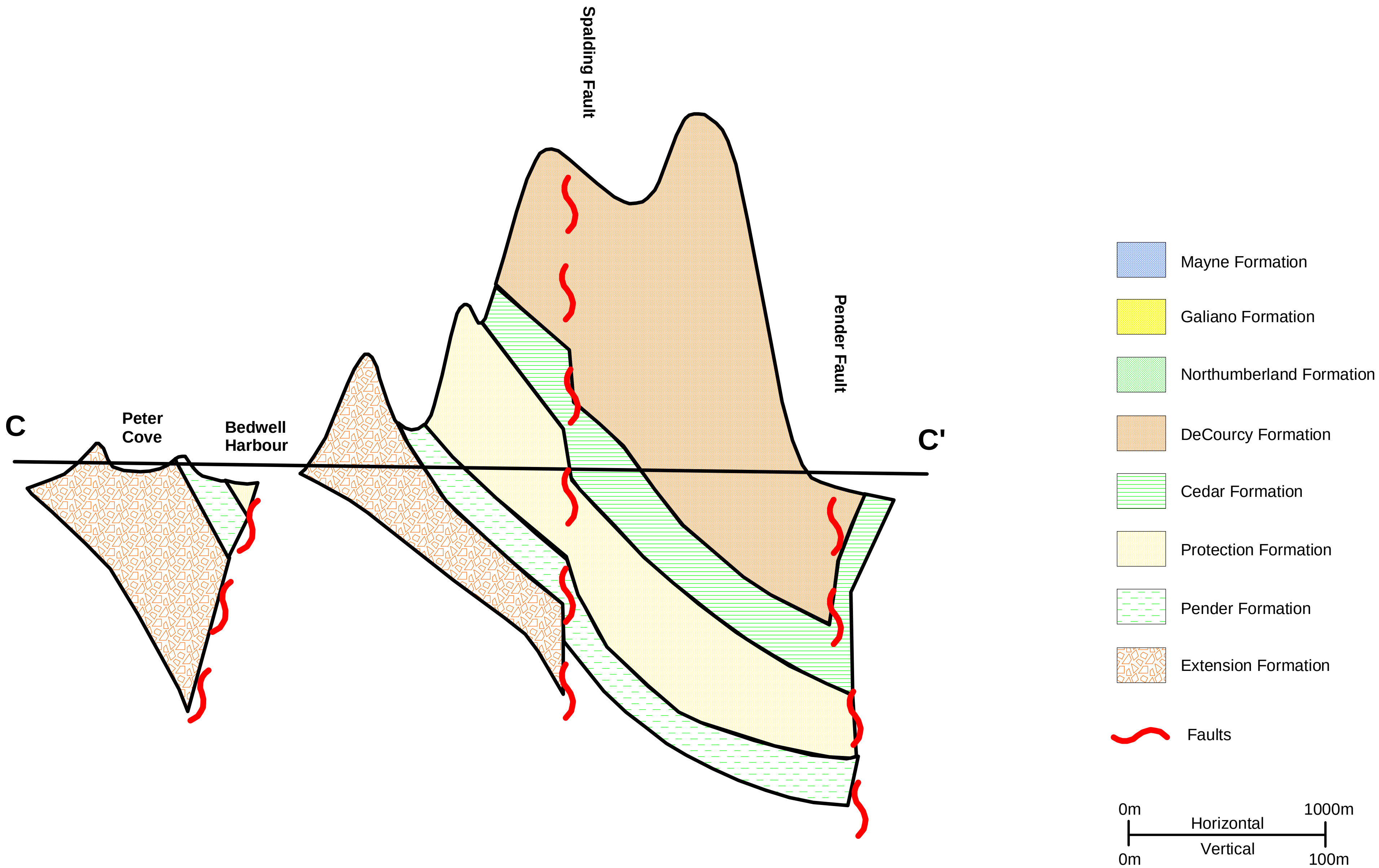

Figure 5.4: Geologic cross-section C-C', North and South Pender Islands

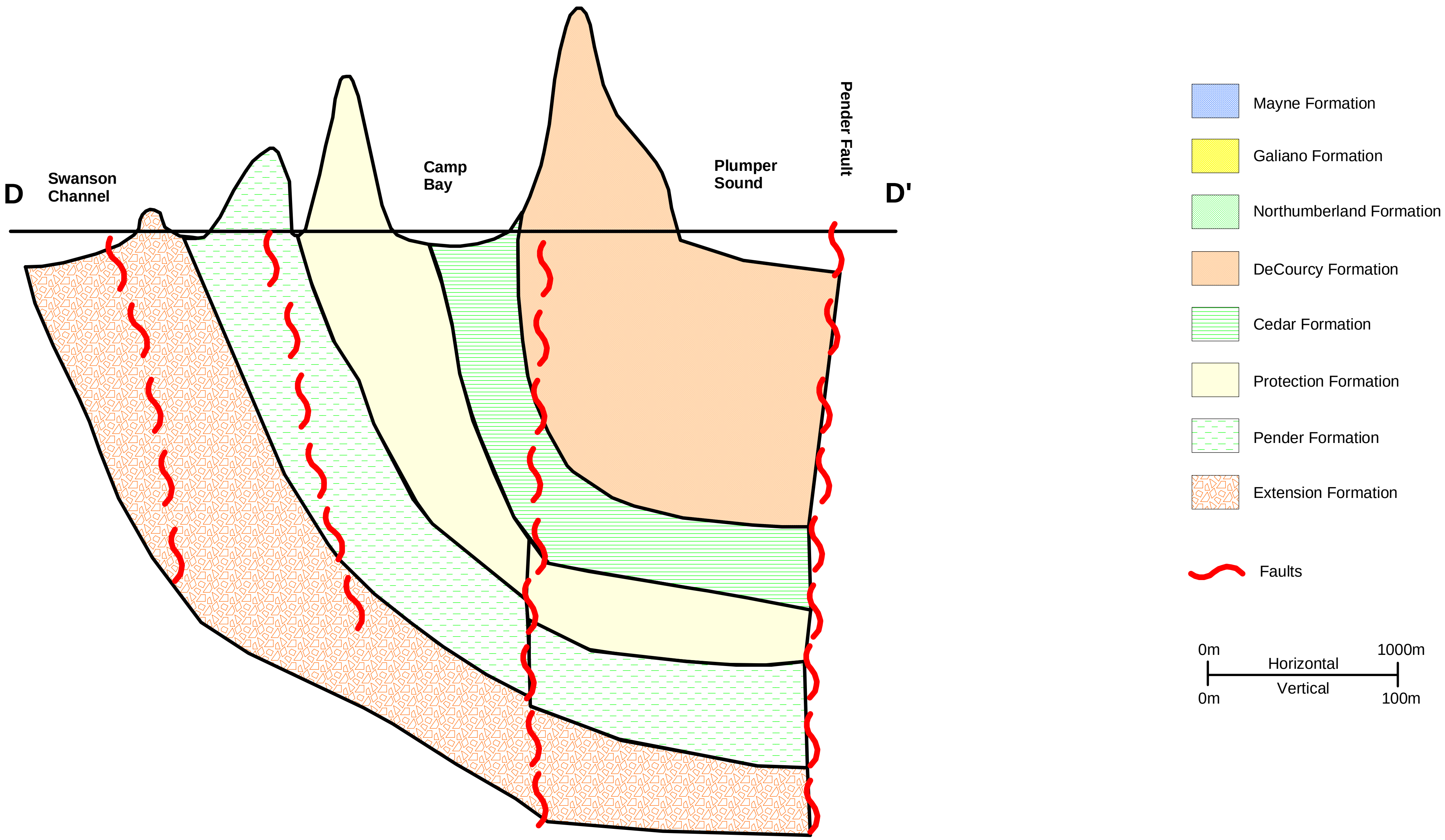

Figure 5.5: Geologic cross-section D-D', South Pender Island

Table 5.1: Stratigraphic units of the Nanaimo Group Occurring on North and South Pender Island (adapted from England, 1989)

Formation	Thickness	Stratigraphy	Depositional Environment	Principal Outcrop Locations
Extension	Up to 480 m	Conglomerate	Marine	Along the southwest coast line of both islands (i.e. Gowlland Point)
Pender	150 m	Shale, siltstone, fine-grained sandstone	Marine	Thieves Bay; Egaria Bay to Canned Cod Bay
Protection	200 to 550 m	Coarse-grained sandstone with fine-grained sandstone, siltstone	Marine	Mouat Point to Bedwell Harbour; Richardson Bluff to Higgs Point
Cedar	Up to 500 m	Shale interbedded with fine-grained sandstone, siltstone	Marine	Forms shoreline along Navy Channel; Medicine Beach; Hamilton Beach: Mortimer Spit, Little Bay
DeCourcy	450 m	Medium to coarse-grained sandstone with siltstone and shale interbeds, minor conglomerate	Marine	Along northeast coast line of North Pender; between Shingle Bay and Ella Bay; Colston Cove to Hope Bay; Hoosen Road; Mount Norman and Spalding Hill; Teece Point
Northumberland	100 to 350 m	Shale interbedded with fine-grained sandstone and siltstone	Marine	Brackett Cove; Grimmer Bay; Pollard Cove
Galiano	150 to 550 m	Medium to coarse-grained sandstone and conglomerate	Marine	James Point and Dent Hill; Allison Farm
Mayne	220 to 340 m	Siltstone and shale with fine-grained sandstone	Marine	Otter Bay

5.2.1 Extension Formation

The Extension Formation consists primarily of thick bedded, massive, poorly sorted, polymictic, pebble to boulder conglomerate (Figure 5.6) and medium to coarse grained sandstone (England, 1989). The Extension Formation outcrops along the southwest coast from Wallace Point to Thieves Bay on North Pender Island and from Gowlland Point to Hay Point on South Pender Island. Prominent cliffs are formed by the Extension Formation. England (1989) estimated the thickness of the Extension Formation to be in excess of 400 metres but noted that several thrust faults may thicken the sequence.

Figure 5.6: Outcrop of poorly sorted, Extension Formation conglomerate

5.2.2 Pender Formation

The Pender Formation is predominantly fine grained consisting of thin bedded, fossiliferous mudstone, siltstone and fine grained sandstone (England, 1989). The estimated thickness of the Pender Formation is typically on the order of 150 metres (England, 1989).

On North Pender Island, the Pender Formation outcrops along the shoreline of Thieves Bay and is locally exposed in the valley occupied by Magic Lake. On South Pender Island, the Pender Formation extends from Egaria Bay in the north to Canned Cod Bay in the south encompassing the narrow valley occupied by Greenburn Lake.

5.2.3 Protection Formation

The Protection Formation consists of thin to thick bedded, medium to coarse grained sandstone which is commonly cross-bedded with planar laminated, fine grained sandstone, siltstone, and rare mudstone and coal (England, 1989). Pacht (1980) estimated the thickness of the formation to be 544 metres at Mouat Point, North Pender Island. England (1989) notes that the formation thins to the southeast to 150 to 200 metres.

The Protection Formation forms a continuous ridge from Mouat Point to Bedwell Harbour on North Pender Island and outcrops along the ridge. On South Pender Island, the Protection Formation forms a ridge extending from Richardson Point in the north to Higgs Point in the south.

5.2.4 Cedar Formation

The Cedar Formation consists of thin bedded silty shale, siltstone, and fine grained sandstone, as well as massive to crudely laminated silty shale (Figure 5.7) (England, 1989). England (1989) estimates the Cedar Formation to have a thickness of up to 500 metres but notes that it may be tectonically thickened.

The Cedar Formation outcrops along the shoreline of Shingle Bay at the northwest end of North Pender Island and along Medicine Beach and Hamilton Beach, North Pender Island. Outcrops can also be found along the coastline from Colston Cove in the south to north of Clam Bay along Navy Channel. At Shingle Bay, the Cedar Formation is tightly folded and faulted. The formation forms the valley encompassing Buck Lack in Magic Lake Estates.

On South Pender Island, the Cedar Formation is exposed along the coast at Mortimer Spit, along road cuts beside Canal Road, and along the coastline of Clam Bay. In the vicinity of Clam Bay, the formation forms a broad valley extending to the northwest.

Figure 5.7: Cedar Formation outcrop, Medicine Beach, North Pender Island. Note the steep dip (photograph taken along strike) and the interbeds of shale and sandstone.

5.2.5 DeCourcy Formation

The DeCourcy Formation typically comprises thick, bedded, medium to very coarse grained sandstone, with fine grained sandstone, siltstone and mudstone interbeds, and minor conglomerate and pebbly sandstone (England, 1989). The formation thickness is estimated by Pacht (1980) to be in excess of 450 metres.

The major outcrops on North Pender Island occur from Stanley Point to Willy Point along the northeast coast, along the coastline of Shingle Bay, along the coastline from Colston Cove to Hope Bay, along the coastline from Auchterlonie Point to Bald Cone, along Hoosen Road, and along the coastline at Port Browning. Figure 5.8 presents a photograph of the DeCourcy Formation from Stanley Point and illustrates the medium to coarse grained sandstone along with fine grained interbeds. On North Pender Island, the DeCourcy Formation forms Georges Peak, Mount Elizabeth, Bald Cone, Cramer Hill, and Lively Peak. On South Pender Island, the DeCourcy Formation forms Mount Norman and Spalding Hill. The major outcrops occur along the coastline of Bedwell Harbour, at Teece Point, and along the northern shoreline.

Figure 5.8: DeCourcy Formation massive sandstone outcrop with inclusions of shale, Stanley Point, North Pender Island.

5.2.6 Northumberland Formation

The Northumberland Formation consists of grey, silty shale interbedded with thin, very fine grained sandstone and siltstone, and minor thick bedded, medium to coarse grained sandstone (Figure 5.9) (England, 1989). The formation thickness has been estimated to be up to 350 metres (England, 1989).

The major outcrops occur along the shoreline of Brackett Cove, Grimmer Bay, Pollard Cove and adjacent to Mount Menzies near Perry Rock. The formation occupies the valley extending from Bald Cone to Grimmer Bay and a valley adjacent to Razor Point Road. The formation does not outcrop on South Pender Island.

Figure 5.9: Northumberland Formation outcrop. Note interbedding of shale, siltstone, sandstone.

5.2.7 Galiano Formation

The Galiano Formation consists predominantly of thick bedded, medium to coarse grained sandstone with minor fine grained interbeds and conglomerate (Figure 5.10) (England, 1989). England (1989) estimated the thickness of the formation to be up to 550 metres.

The major outcrops on North Pender Island occur along the north and south shores of Otter Bay, along coast at Ella Bay, and on the Allison Farm. The formation forms Dent Hill and Mount Menzies. The spring on the Allison Farm emanates from the Galiano Formation. The Galiano Formation does not outcrop on South Pender Island.

Figure 5.10: Outcrop of massive sandstone of Galiano Formation, Allison Farm, North Pender Island.

5.2.8 Mayne Formation

The Mayne Formation generally comprises thin bedded, brownish-grey siltstone and grey mudstone, with fine grained sandstone (England, 1989). The formation thickness has been estimated to be up to 340 metres (England, 1989).

On North Pender Island, the Mayne Formation outcrops at the head of Otter Bay. It also forms the valley along Bedwell Harbour Road near the Community Hall.

5.3 Structural Geology

The study area occurs in a tectonically active area. England (1989) hypothesized that the area is part of the Cowichan thrust and fold belt that may have resulted from the collision of the Pacific Rim and Crescent terranes with North America during the late Eocene (40 million years ago). Several major faults traverse North and South Pender Islands (Figure 5.1). The Gulf Islands are defined by a sinuous belt of northwest-trending buckle folds and associated northeast thrust faults (Journeay and Morrison, 1999). The Pender Fault (referred to as the Ganges Fault by Journeay and Morrison, 1999) is the most prominent. A number of minor faults trend at right angles to the major faults. Folding has been interpreted as consisting of a series of normal to inclined, parallel folds that have amplitudes and half-wavelengths of several kilometres. Pacht (1980) determined that during the Late Cretaceous, there was readjustment along the west coast of Canada following the collision of Wrangellia. This would explain the post-depositional folding and faulting which impacted the secondary porosity and permeability of the lithologic units of the Nanaimo Group.

The geologic structure of the islands is significant from a water resource potential, as faulting and folding impact the secondary porosity and permeability of the bedrock. The increased secondary porosity and permeability associated with the faulting and folding likely represent the zones of greatest potential for groundwater storage and production. Journeay *et al.* (2004) list the structurally controlled bedrock aquifers as the primary groundwater resource in the region.

The major structural features can also have an influence on water quality since sulphide bearing-minerals are often located along fault zones (Brown, 1967). Some water well users on North Pender Island have complained of the sulphur odour of their water. Additionally, the increased secondary porosity and permeability can result in the rapid transport of contaminants through the fault zones. It is therefore imperative that the major structures be clearly defined in any groundwater assessment program.

5.4 Hydrogeological Properties of Bedrock Formations

The hydrogeological properties of the various bedrock units are controlled by a number of factors including grain-size, degree of cementation, and tectonic history. The sediments comprising the bedrock units are poorly sorted and well-cemented (Denny *et al.*, 2007) so that there is a lack of significant storage capacity or connectivity for movement of groundwater based on primary porosity and permeability. The lack of storage capacity and poor connectivity of pore spaces leads to the conclusion that the bedrock formations occurring on the islands are characteristically poor aquifers (Halstead and Treichel, 1966). For this study, permeability can be equated to hydraulic conductivity. The tectonic history of the area, in conjunction with geologic mapping, indicates the occurrence of significant folding and faulting, which will enhance the secondary porosity and permeability of the bedrock units, thereby locally increasing the hydraulic conductivity.

Henderson (1998) had bedrock samples tested in the laboratory at the University of Calgary to determine the porosity and permeability of several of the bedrock units found on North and South Pender Islands (see Table 5.2). The samples obtained were all from sandstone outcrops. All outcrops of shale exposed only very badly weathered bedrock that at best would have produced chip samples. On the basis of research conducted by Davis *et al.* (1966), the porosity of sandstones from the various formations on North and South Pender Islands is at the extreme low end of typical sandstone porosity. The low porosity reflects the poor sorting due to the rapid deposition of the sediments and subsequent cementation. Primary porosity of less than 6% does not provide significant storage capacity for groundwater supplies and places limits on the potential for high hydraulic conductivity. The primary porosity does not guarantee that the pore spaces are connected to enable groundwater flow, nor does it provide any information on the total volume of water available for production. The lack of storage capacity, hydraulic conductivity and porosity are all factors in the generally low yield for water wells on North and South Pender Islands (Sections 5.6.1 and 5.6.2). It should be noted that the porosity measurements presented in Table 5.2 do not however incorporate the influence of fracturing, which has the potential to significantly increase secondary porosity. In addition, a limited number of samples were collected to confirm previous work undertaken on the islands and to maintain the objective of developing a cost effective approach to groundwater resource assessment.

Table 5.2: Hydrogeological characteristics of Nanaimo Group Sandstone Units, North Pender Island (Henderson, 1998).

Sampling Location	**Stratigraphic Unit**	**Primary Porosity, %**	**Permeability, Darcys (cm^2)**
4823 Cannon Cres.	Extension sandstone	5.55	3.5×10^{-5}
4823 Cannon Cres.	Extension sandstone	5.74	1.3×10^{-5}
Magic Lake	Protection sandstone	3.31	1.0×10^{-5}
Higgs Point	Protection sandstone	3.37	0.3×10^{-5}
S.W. Bedwell Harbour	Protection sandstone	3.82	0.5×10^{-5}
N.E. Shingle Bay	DeCourcy sandstone	3.47	2.9×10^{-5}
South Pender	DeCourcy sandstone	4.38	0.3×10^{-5}
	Galiano sandstone	5.75	3.3×10^{-5}
N.E. Otter Bay	Galiano sandstone	3.51	76.0×10^{-5}

The permeability for the sandstone units is also relatively low (Table 5.2), and since permeability is analogous to hydraulic conductivity, it can be inferred that the hydraulic conductivity is also low. Fracturing in the sandstone units creates the potential for increased secondary permeability. An anomalous measurement was recorded for the Galiano Formation sandstones in the vicinity of Otter Bay, North Pender Island. Groundwater wells located close to mapped fault locations have significantly higher yields, indicating the influence of the increased secondary porosity and permeability in these areas.

Halstead and Treichel (1966) proposed the use of airphoto interpretation and geophysical investigations as a means of identifying faults and fracture zones that may have increased secondary porosity and permeability for groundwater storage and supply. A more recent study by Berardinucci and Ronneseth (2002) prescribes airphoto interpretation and geologic mapping to map aquifers with no mention of the applicability of geophysical surveys. To date, no such integrated surveys have been reported in the study area to map the structural features that influence water well production.

5.5 Surficial Geology

The surficial geology of North and South Pender Islands plays an integral role in the islands groundwater resource assessment. Soils, climate, vegetation cover, and surface topography work together in a complementary manner. Soils directly influence the infiltration rate of rainfall, the rate of surface runoff, and ultimately the groundwater recharge/discharge as well as soil moisture content (American Society of Civil Engineers, 1996). All those factors are parameters of the water balance equation (see Section 4.2). Each of the parameters is difficult to measure with any degree of accuracy (American Society of Civil Engineers, 1996).

The sediments found on the islands reflect the recent geologic events that have helped to shape the islands. For North and South Pender Islands, the glacial periods of the Pleistocene have played a significant role through both erosion and deposition by the ice, variations in sea level (including isostatic rebound), and subsequent fluvial and marine deposition (Clague, 1977; Mathews *et al.*, 1970). Eis and Craigdallie (1980) determined that the Gulf Islands had two periods of glacial deposition, with the first occurring beneath the ice sheet as a result of the abrasion and crushing of rocks beneath the weight and movement of the ice sheet. The second occurred as a result of deposition of material transported within or on the ice sheet and consists of unsorted, unstratified, gravelly, sandy and loamy till (Eis and Craigdallie, 1980).

After the glaciers retreated, the low-lying areas were inundated by the sea, leaving marine clay deposits (Mathews *et al.*, 1970). Marine clay deposits can be found in the low lying valleys on North and South Pender Islands. Variations in sea level due to isostatic rebound would also have resulted in the deposition of beach ridges at elevations well above current sea level (Mathews *et al.*, 1970).

The islands' soil types have been mapped in detail by Agriculture Canada (1988). Many of the topographic highs have little or no soil cover, and its absence influences vegetative cover as well as surface runoff/groundwater recharge. The soil types mapped by the geophysical investigations are described during the discussion of the groundwater basins (see Sections 7.3.1 and 7.3.2). In general terms, the geophysical results confirm the soil types identified by Agriculture Canada mapping marine clays in the low-lying areas and sandy loam when soil occurs on the slopes and topographic highs. The forest cover on the slopes tends to enhance the interception of precipitation, thus assisting in groundwater recharge by slowing down the surface runoff (American Society of Civil Engineers, 1996).

5.6 Water Well Correlation

5.6.1 North Pender Island

The current water well database maintained by B.C. Land, Water and Air provides information on 526 water wells. Of that number, 22 are dug wells that provide little or no information on the soil type, depth to bedrock, type of bedrock, or the water production capability of the wells. The earliest dug well was dug in 1900 and dug wells continue to provide a source of water for a number of residents on the island. The remaining 504 water wells have been reviewed to determine statistical measures for water production (Table 5.3).

Table 5.3: Statistical data based on water well information for North Pender Island.

	All producing wells	**Minus 41 best producing wells**
Range	0 to 378.5 lpm (100 gpm)	0 to 45.4 lpm (12 gpm)
Number of wells	504	463
Total Production	9019.7 lpm (2383 gpm)	4802.5 lpm (1268.8 gpm)
Average	17.87 lpm (4.72 gpm)	10.18 lpm (2.69 gpm)
Median	7.57 lpm (2 gpm)	7.57 lpm (2 gpm)
Standard deviation	32.3 lpm (8.5 gpm)	9.43 lpm (2.49 gpm)

The 2001 census lists the island’s population as 1,776. Since the island has 2101 lots (Islands Trust, 2004), it would appear that the water well database does not include all water wells. Thirty-eight lots have had multiple water wells drilled, and these account for 94 of the 504 wells

(18.6%). That figure indicates either poor production or a decrease in water quality in the initial well, necessitating additional drilling. This situation translates into the water well's database including information from a mere 21% of the lots on the island. This number may also reflect the fact that 1241 lots are located within Magic Lake Estates, which has a community water supply system. Perhaps not as many water wells have been drilled in Magic Lake Estates. Nevertheless, the limited percentage of lots with water wells in the database cannot be explained solely by the potential lack of water wells from Magic Lake Estates. There is clearly water well information that has not been included in the database. In view of the number of lots on the island, the ratio of water wells to lots is one water well per four lots.

Productivity ranges from 0.0 lpm to 378.5 lpm (100 gpm), but a histogram of well productivity shows that the data are skewed to the left indicating that most wells are generally considered poor producers (Figure 5.11). The average productivity of the water wells is 17.87 litres/minute (4.72 gallons/minute), which would easily meet the daily requirements of most residents. If the 41 best producing water wells are subtracted and the average productivity re-calculated, the average drops to 10.18 litres/minute (2.69 gallons/minute) (see Table 5.3). This figure indicates that the subtraction of 41 out of 504 producing wells reduces the average productivity for the island by approximately 43%. Thus, a few good wells can skew the average numbers for the island. The median productivity of the water wells on North Pender Island is 7.57 litres/minute (2 gallons/minute), but again, the histogram in Figure 5.12 clearly illustrates that there are many poor producing water wells. On the basis of the water requirements per lot as listed in the Official North Pender Island Community Plan (2003), approximately 10% of the water wells listed in the data base would not meet current requirements for water supply. The standard deviation (see Table 5.3) calculated on the basis of the water well information further confirms the variability in well production. In view of all of these numbers for production, it should be remembered that production of water does not necessarily translate into water supply; these figures provide no information regarding water quality.

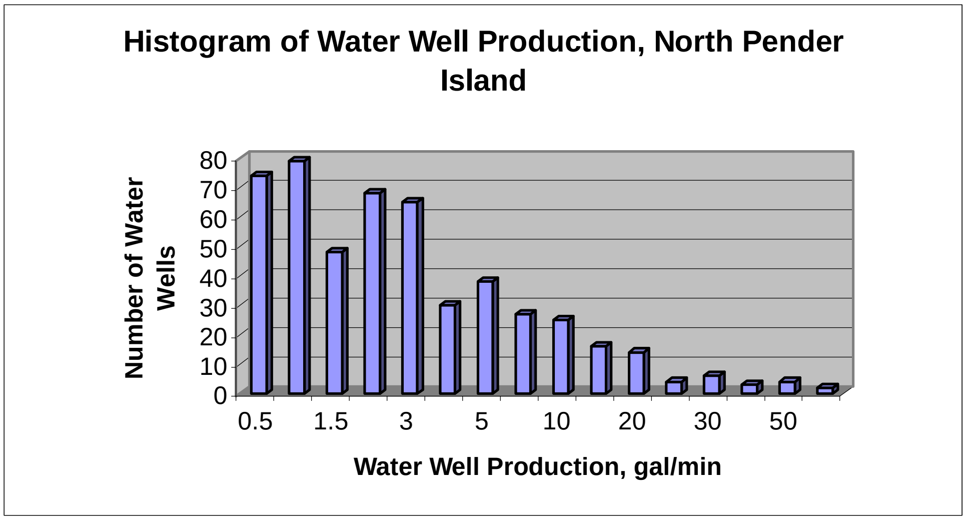

Figure 5.11: Histogram of water well production, North Pender Island

Six producing wells account for 15% of the total water production for the island, while the 41 best-producing wells account for 53% of the total water production (Table 5.4). These figures clearly indicate that most of the current water production from individual water wells comes from a limited number of them. It is equally important, however, to investigate not just the numbers but also the spatial distribution of the best producing water wells, depth of water production, relationship to stratigraphic boundaries and structural features.

Table 5.4: Best-producing water wells on North Pender Island

Easting	Northing	Production	Water Bearing Fractures
481865	5402625	378.5 lpm (100 gpm)	16.8 m, 24.4 m, 36.6 m, 51.8 m, 83.8 m
		238.8 lpm (63 gpm)	121.3 m
480956	5401309	189.3 lpm (50 gpm)	No record
477188	5405334	189.3 lpm (50 gpm)	No record
477431	5406468	172.8 lpm (45 gpm)	61.0 m, 152.4 m, 157.0 m
479276	5406490	172.8 lpm (45 gpm)	22.9 m
477319	5406413	151.4 lpm (40 gpm)	31.1 m
478769	5406094	125.7 lpm (33.2 gpm)	42.7 m, 57.9 m
479472	5405717	124.9 lpm (33 gpm)	125 m
479034	5406601	113.6 lpm (30 gpm)	14.0 m, 25.0 m
479521	5402172	113.6 lpm (30 gpm)	41.2 m
480007	539982	113.6 lpm (30 gpm)	56.4 m
479360	5402846	113.6 lpm (30 gpm)	7.0 m, 14.9 m, 19.2 m
479730	5402663	113.6 lpm (30 gpm)	12.2 m
481083	5404123	113.6 lpm (30 gpm)	No record

Easting	Northing	Production	Water Bearing Fractures
477918	5405034	94.6 lpm (25 gpm)	16.8 m, 18.3 m
481451	5402448	94.2 lpm (24.9 gpm)	41.8 m
476517	5406777	94.2 lpm (24.9 gpm)	77.1 m
477054	5406112	94.2 lpm (24.9 gpm)	39.6 m, 57.3 m, 73.8 m
479225	5406590	75.7 lpm (20 gpm)	30.5 m
481211	5399205	75.7 lpm (20 gpm)	68.6 m
476623	5405708	75.7 lpm (20 gpm)	38.1 m, 57.9 m, 61.0 m, 68.6 m
477495	5405320	75.7 lpm (20 gpm)	35.1 m
477891	5405172	75.7 lpm (20 gpm)	11.6 m
477406	5405321	75.7 lpm (20 gpm)	18.9 m, 19.5 m, 20.4 m, 21.3 m, 22.9 m
		68.1 lpm (18 gpm)	No record
476879	5407550	64.3 lpm (17 gpm)	42.7 m, 70.1 m, 73.2 m
481118	5402424	62.8 lpm (16.6 gpm)	12.8 m, 33.5 m, 45.7 m
477069	5404397	62.8 lpm (16.6 gpm)	36.6 m, 44.2 m
481221	5402720	62.8 lpm (16.6 gpm)	48.8 m
476577	5407136	62.8 lpm (16.6 gpm)	30.5 m, 79.3 m
480939	5404381	62.8 lpm (16.6 gpm)	54.9 m, 77.7 m, 85.3 m
481166	5403867	62.8 lpm (16.6 gpm)	35.1 m
476976	5407557	56.8 lpm (15 gpm)	48.8 m, 70.1 m
476419	5407568	56.8 lpm (15 gpm)	16.8 m, 36.0 m
479215	5403518	56.8 lpm (15 gpm)	33.5 m, 50.3 m
478765	5407034	56.8 lpm (15 gpm)	42.7 m
481261	5399180	56.8 lpm (15 gpm)	25.9 m, 84.4 m
482895	5398216	56.8 lpm (15 gpm)	78.6 m
480192	5400145	56.8 lpm (15 gpm)	68.6 m
479662	5400396	56.8 lpm (15 gpm)	12.2 m, 35.7 m, 41.2 m

Responses to a questionnaire distributed by the local trustees of North Pender Island show that a number of water wells cannot sustain the pumping rates listed in the water well records, as 20 of 89 respondents had their water wells run dry in the past (Henderson, 1998). When combined with the statistical variability in water well production, this fact should raise a flag about the usefulness of the statistics. On the basis of the available information, it would be difficult or impossible to predict which water wells would run dry in any given year. This may account for the high proportion of respondents (77%) to the questionnaire that indicated concern over future water supplies (Henderson, 1998).

Another piece of missing information is the pumping rates of individual water wells and the drawdown cone that would result. When that information is combined with knowledge of the depth to the water table, the bedrock type, and abundance of fractures, it may show that particular water wells would be prone to run dry under specific conditions.

The water wells on North Pender Island do not provide any reliable bedrock stratigraphic information. An example is an observation well drilled for the provincial government in the Extension Formation conglomerates on Pirates Road. There is no mention of the presence of conglomerates in the water well record which would place the usefulness of the stratigraphic information in question.

The depth to bedrock was noted in 90% of the drill holes in the water well database. The range in depth to bedrock recorded is 0 to 25.9 metres while the average depth to bedrock is 3.87 metres. The majority of the water production comes from either water-bearing fracture zones or stratigraphic contacts; not all water wells make any mention of fractures. A summary of the water well logs is presented in Appendix D.

5.6.2 South Pender Island

The current water well database maintained by B.C. Land, Water and Air provides information on 165 water wells on South Pender Island. Of the total number of water wells on record, 11 represent dug wells, which provide no information on water availability and often little or no information on the soil type or depth to bedrock. There is a general tendency for the early wells to have been either dug or drilled to a shallow depth, with most of the deeper wells drilled in recent times. The majority of the dug wells date to before 1950. The earliest data is from a well dug in 1910, while the most recent data is from a well drilled in 1994.

Since the number of residential lots currently available is 281, it would appear that the water well database does not include all water wells. At present, it is not required that water well records be submitted to B.C. Land, Water, and Air for inclusion in the database, although the submission of that information became a requirement in 2005 (B.C. Government, 2005). Eleven lots have had multiple water wells drilled. Water well information is therefore only available for approximately 50% of the lots on the island.

A review of the water well information can provide very misleading statistics (Table 5.5). Productivity ranges from 0.0 lpm to 378.5 lpm (100gpm), but a histogram of well productivity shows that the data are skewed to the left, indicating that most wells are generally considered to be poor producers (Figure 5.12). There are, however, some excellent producers. The average productivity of the water wells is 15.1 litres/minute (4 gallons/minute), which would easily provide the daily requirements of most residents. On the basis of the population density figures compiled by the Islands Trust (2004), the average water well would produce 10,370 litres/person/day (2,740 gallons/person/day). If the 14 best-producing water wells are subtracted and the average productivity re-calculated, the average drops to 5.87 litres/minute (1.55 gallons/minute) (see Table 5.5). This figure indicates that the subtraction of these 14 producing wells reduces the average water well productivity for the island by slightly more than 60%. Thus, a few good wells can skew the average numbers for the island. The same calculation for the revised average, would now yield approximately 4,025 litres/person/day (1060 gallons/person/day) for any given lot. The median productivity of the water wells on South Pender Island is 3.79 litres/minute (1 gallon/minute), but the histogram in Figure 5.12 illustrates that there are many wells producing less than either the median or the average levels. With the use of the median, the production per person per day decreases to 2,592 litres (685 gallons). This indicates that more than ample water supplies are present to meet the needs of the present and planned future populations of the island (future population is estimated to be 620 persons based on 2.2 persons per lot). The figures do not, however, provide any indication of the temporal and spatial variation in water supply. The standard deviation calculated on the basis of the water well information is equal to the average well production when the 14 best producing wells are not included, so there is a high degree of variability. For all wells, the standard deviation is approximately three times the average well production, for an even greater illustration of the degree of variability.

Table 5.5: Statistical data based on water well information for South Pender Island.

	All producing wells	**Minus 14 best producing wells**
Range	0 to 378.5 lpm (100gpm)	0 to 31.42 lpm (8.3 gpm)
Number of wells	156	142
Average	15.1 lpm (4 gpm)	5.87 lpm (1.55 gpm)
Median	3.79 lpm (1 gpm)	3.79 lpm (1 gpm)
Standard deviation	45.8 lpm (12.1 gpm)	5.87 lpm (1.55 gpm)

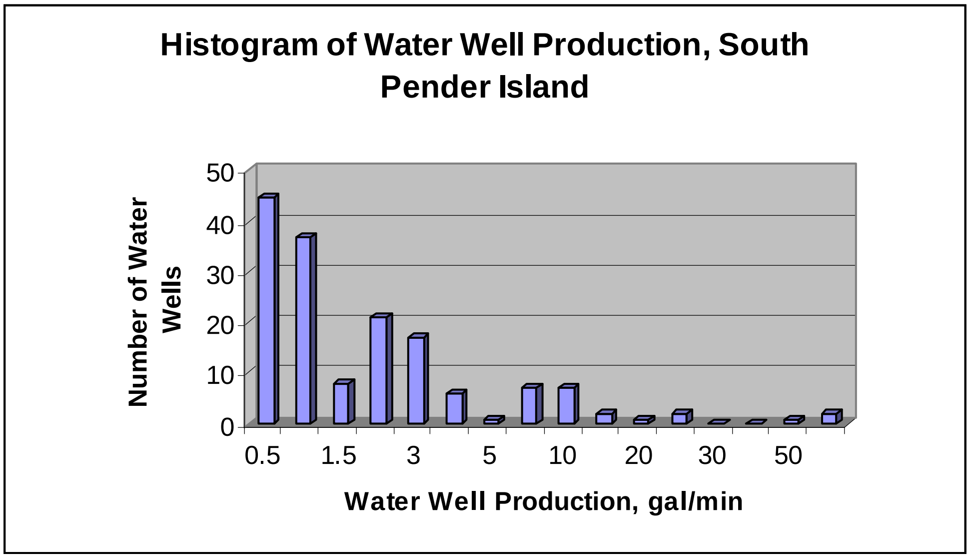

Figure 5.12: Histogram of water well production, South Pender Island

It should be noted that the two best-producing wells account for 39.8% of the total water production for the island, while the best fourteen producing wells account for 64.6% of the total water production. This clearly indicates that most of the water production comes from a limited number of water wells. It is equally important, however, to investigate not just the numbers but also the spatial distribution of the best producing water wells. The two best-producing wells are located within 100 metres of each other (Table 5.6).

Table 5.6: Best-producing water wells, South Pender Island

Easting	Northing	Production	Fracture Zones (Water bearing)
484059	5399819	378.5 lpm (100 gpm)	no record
483961	5399838	378.5 lpm (100 gpm)	83.8 m
484552	5399911	170.3 lpm (45 gpm)	83.8 m
481455	5400971	94.6 lpm (25 gpm)	79.3 m, 86.9 m
485868	5399772	94.6 lpm (25 gpm)	6.1 m, 18.3 m
484200	5399802	75.7 lpm (20 gpm)	4.6 m, 30.5 m
484959	5398234	56.8 lpm (15 gpm)	130.4 m
481384	5400968	47.3 lpm (12.5 gpm)	36.6 m
485833	5399852	37.9 lpm (10 gpm)	5.5 m
484248	5399804	37.9 lpm (10 gpm)	14.9 m
484018	5399827	37.9 lpm (10 gpm)	16.8 m
485028	5399735	37.9 lpm (10 gpm)	6.7 m, 14.6 m
484880	5399851	37.9 lpm (10 gpm)	14.9 m
484100	5399812	37.9 lpm (10 gpm)	6.7 m, 14.6 m

Table 5.6 indicates that there is overlap in the water bearing fractures representing the producing zones for the best water wells listed in the database. The second and third wells listed in Table 5.6 are located along the same fault zone, are approximately 600 metres apart, and are producing from the same fracture zone at a depth of 83.8 metres. This has important implications from both a water supply and quality perspective, as will be discussed later in this chapter. Table 5.6 indicates that the variability in production rates of the water wells is influenced by variations in the secondary porosity and permeability since all but one of the best-producing water wells receives their production from water bearing fracture zones.

On the basis of the water well data available for South Pender Island, the depth to bedrock appears to range from 0 to 38.1 metres while the average depth to bedrock is 4.0 metres. A comparison of the average depth to bedrock for all water wells and that for the best-producing water wells indicates that the average depth to bedrock for the best-producing water wells is 2.0 metres.

The water well database does provide limited information on water quality as several of the water wells have comments that the water is salty or has a sulfur odour. A summary of the water well logs is presented in Appendix D.

5.7 Relation to Groundwater Resource Assessment

The general low primary porosity and permeability of bedrock on North and South Pender Islands (Henderson, 1998) indicates the reduced potential for water storage and accessibility. There is a resulting need for a groundwater resource assessment so that planners may better understand the physical limits of the resource and ultimately use that information in community planning. The location of the islands in a tectonically active area has the potential advantage of enhanced secondary porosity and permeability. Water availability, as related to porosity and permeability, is a critical issue for water supply and allocation planning (Henderson, 1998). Halstead (1966) noted that groundwater occurred not only in faults and fractures but also at stratigraphic boundaries particularly at sandstone/shale contacts. This is true of the best-producing wells on Dent Hill, North Pender Island, where water production appears to be from the contact of the Galiano sandstone and underlying Northumberland shale.

Hodge (1995) states that thick unconsolidated deposits may also provide storage for recharge to bedrock aquifers. This is counter to the normal scenario of groundwater recharge in the topographic highs and groundwater discharge in the topographic lows since the thickest unconsolidated sediments occur in the low-lying areas.

Geological mapping provides a means of developing a general overview of the subsurface conditions that control groundwater storage and flow. Geologic mapping relies on having bedrock exposures to enable the interpolation of subsurface conditions. When drill hole data are available, detailed information can be obtained but it is from a 4 or 6 inch diameter drill hole; the results of which are then interpolated over large distances. The next chapter discusses the results of geophysical investigations on North and South Pender Island. The geophysical investigations provide a means of interpolating subsurface geological information as well as highlighting areas that may have increased secondary porosity and permeability.