Chapter 6 GEOPHYSICAL INVESTIGATIONS; NORTH AND SOUTH PENDER ISLANDS

6.1 Introduction

The geophysical investigations undertaken for this dissertation have proven to be useful. Prior to this research, several attributes of the physical setting were either not known or not fully appreciated. These include the following:

- Distribution of a perched water table
- The fact that groundwater recharge occurs over the entire islands
- The existence of possible paleo-channels on North and South Pender Island
- A thorough review of the water resources for the islands
- The depth to the underlying saline water and the implications for water well depths
- An estimate of the groundwater storage capacity

In this research, through the combination of knowledge of local geology and geophysical measurements, it was possible to estimate the porosity and permeability of a geologic formation and ultimately estimate the storage capacity for groundwater. Seismic and electrical measurements were acquired to map the electrical and acoustic properties of the soils and underlying bedrock units. As discussed in Section 2.7, the electrical properties of the subsurface are primarily controlled by the clay content and the total dissolved solids concentration in the pore water (Henderson and Bowman, 1994: Scanlon *et al.*, 1999). High levels of total dissolved solids, as can be expected in saline water, result in uniquely low resistivity values. It should be noted, however, that it can be difficult to distinguish between clay rich soils and rock and brackish water. The ability to map the presence of saline water proved useful in mapping the thickness of the freshwater column in select locations on the island. These will be discussed in the following sections.

Prassad (2003) noted that the combination of porosity and permeability in a formation controls the seismic wave propagation. These same parameters control the hydraulic conductivity of the geologic units. (Mazac *et al.*, 1985).

6.2 Survey Design

It was not the intention at the outset of this research to undertake an intensive grid of geophysical survey lines over North and South Pender Islands. The objective of the geophysical investigations was to use strategically placed survey lines to assist in the interpolation of the geologic mapping to provide a better understanding of the hydrogeological framework of the islands.

During the planning of the geophysical program, it was possible to review existing geological maps and cross-sections to assist in the design of the geophysical investigation. Little was known about the range of physical properties to be encountered, although on the basis of the researcher's experience, some assumptions could be made prior to commencement of field work. By carefully monitoring the survey results, the researcher could adjust the acquisition parameters in the field when necessary and practicable. In addition, the review of the geologic data eliminated the potential use of some geophysical methods, such as seismic reflection. The severe structure on the island would have made the processing of any seismic reflection data extremely difficult, if not impossible.

On North Pender Island, knowledge of the exact range of physical properties would not have benefited the overall design of the geophysical investigation, because most of the survey lines had to be located along existing roads for ease of access. Due to variations in topography, there are limited lengths of straight road; the options available for survey locations were reduced by the complex geology on the island. In addition, sources of cultural noise were abundant on North Pender Island. Power lines and telephone lines were typically located along roadways so that there was potential for 60 Hz noise, although a review of the data reveals no evidence of a negative impact on the data quality.

Another benefit of having pre-existing knowledge of the site geology is that the researcher can eliminate or reduce the impact of geologic noise and therefore the equivalence during the interpretation of geophysical data. In electrical methods, there would be little contrast in resistivity between a sand channel and an underlying sandstone unit; they are composed of material of the same grain size assuming there is little influence of cement in the matrix of the sandstone. Seismic refraction, on the other hand, would clearly define the sand/sandstone interface and the electrical results could be used to determine the composition of the surficial sediments. Seismic refraction and electrical methods are viewed as complementary geophysical methods and when the results of each survey are combined it is also possible to reduce geological noise.

At the survey design stage, the limitations of each of the geophysical methods were well understood. The geological maps produced by Henderson (1998) were used to determine the optimal location for geophysical investigations in light of the logistical limitations. It was necessary to investigate each of the bedrock types on the islands to determine their physical properties and groundwater storage capacity. The groundwater storage capacity could then be used to estimate the water resources available to meet human needs. The geophysical survey lines were located to ensure that all of the geophysical data acquired along a particular line are from the same bedrock unit (Figures 6.1a and b). By ensuring that the acquired geophysical data are from a particular geologic formation, the researcher could simplify data interpretation. Since both secondary porosity and permeability can be significantly greater in faulted and fractured bedrock (Davis and DeWiest, 1966; Domenico and Schwartz, 1998; Weight and Sonderegger, 2001), several geophysical lines were surveyed across known fault zones.

The geophysical data are presented as cross-sections illustrating the variations in physical properties along each survey line. On the basis of the geophysical data, the physical properties were then extrapolated over the entire bedrock unit under investigation. This approach is an oversimplification, since aquifer parameters are rarely homogeneous; however, without an intensive grid of geophysical lines, extrapolation provides the most reasonable approach to defining groundwater potential in a cost-effective manner.

The locations of the geophysical lines are presented in Figures 6.1a and 6.1b. Table 6.1 list the survey locations and the geophysical methods used. It should be noted that the Pender and Protection Formations were not surveyed during the investigation. On North Pender Island, these formations occur within the Magic Lake Estates development which is not directly reliant on groundwater.

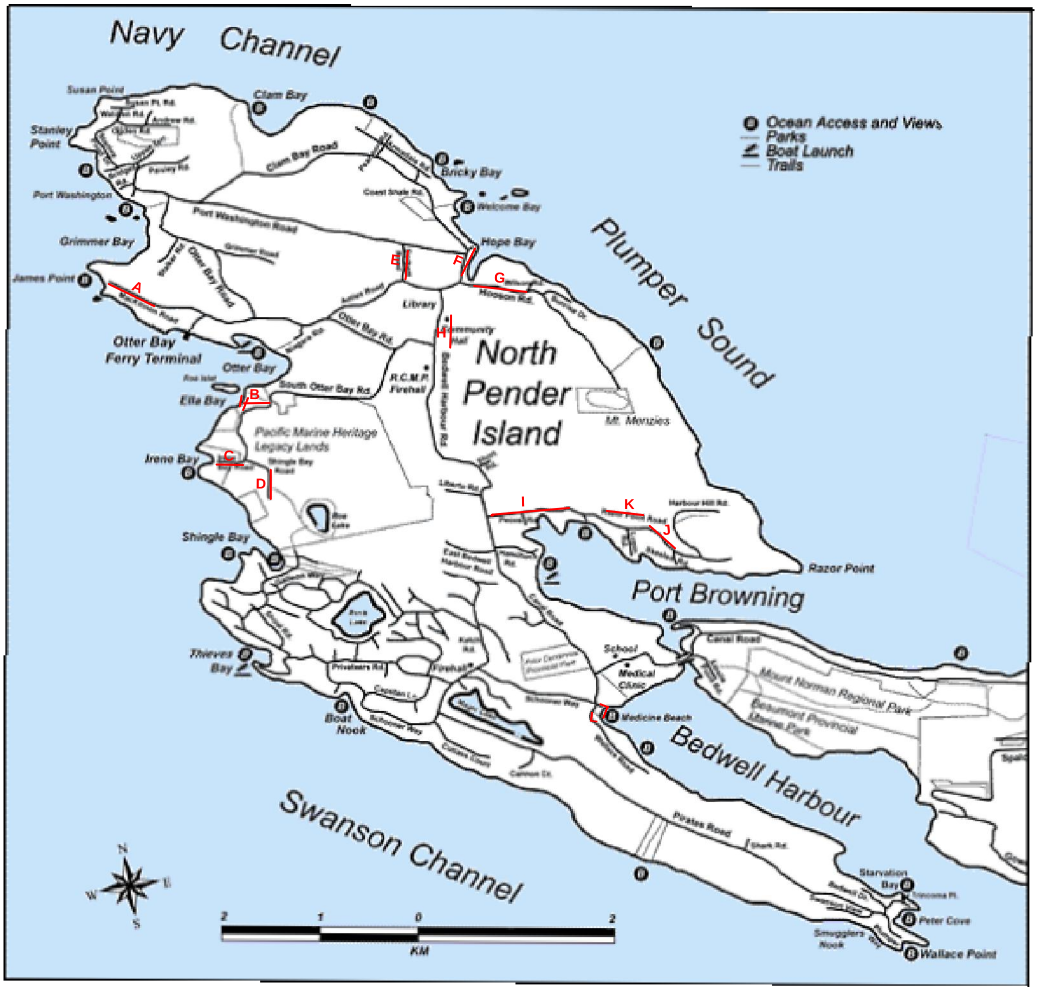

Figure 6.1a: Geophysical survey line locations, North Pender Island.

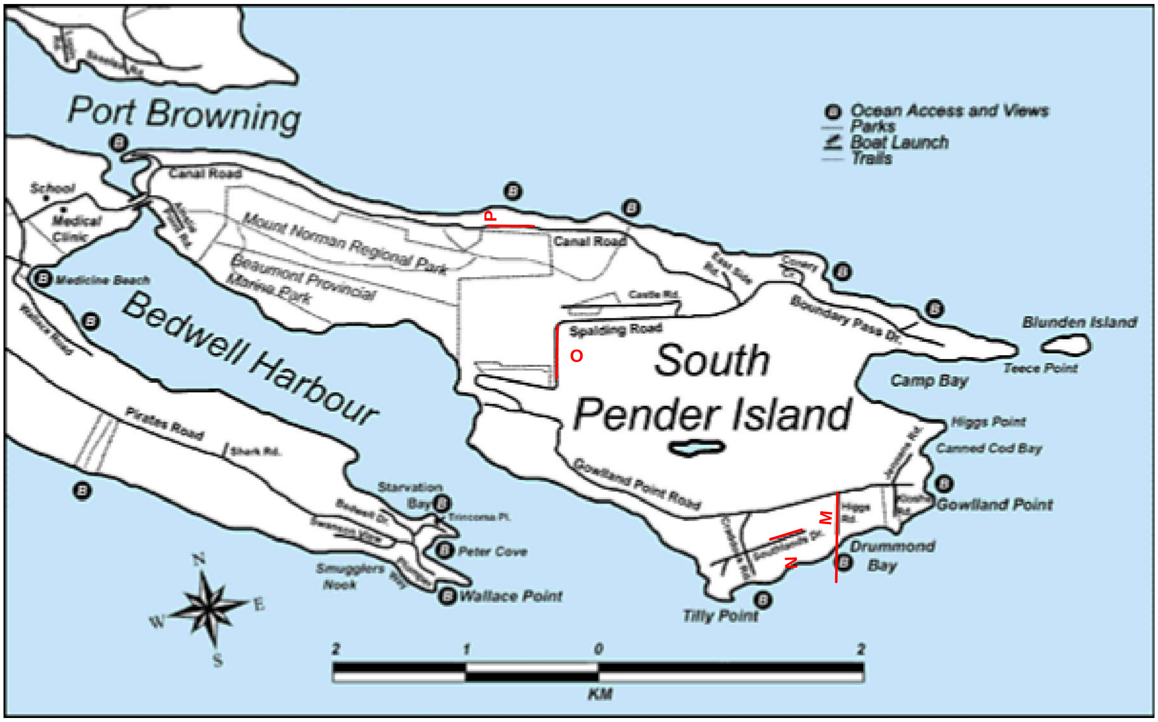

Figure 6.1b: Geophysical survey line locations, South Pender Island

The geophysical survey results are presented in the following sections as interpreted cross-sections with variations in electrical and acoustic properties given geological significance. The data from which these interpreted cross-sections have been derived are presented in Appendix C. The cross-sections also include any field observations or water well data that may have assisted in the interpretation. Correlation with test pits dug as part of a soil survey conducted by Agriculture Canada (1988) was hampered by the lack of precise locations of the test pits. No attempt was made to get the necessary approvals required to dig additional test pits.

Table 6.1: Geophysical survey locations and geophysical methods used

LINE LOCATION	GEOPHYSICAL METHODS	GEOLOGICAL FORMATION
MacKinnon Road (Line A), North Pender Island	Seismic Refraction, Electrical Imaging	Galiano Formation
Roes Island and Otter Bay (Lines B), North Pender Island	Seismic Refraction, Electrical Imaging, Transient Electromagnetic Soundings	Galiano Formation, Allison Fault
Irene Bay Road (Line C), North Pender Island	Seismic Refraction, Electrical Imaging	DeCourcy Formation
Shingle Bay Road (Line D), North Pender Island	Seismic Refraction, Electrical Imaging	DeCourcy Formation, Pender Fault
Corbett Road (Line E), North Pender Island	Seismic Refraction, Electrical Imaging, Transient Electromagnetic Soundings	Northumberland Formation
Hope Bay (Line F), North Pender Island	Seismic Refraction, Electrical Imaging	DeCourcy Formation, Fault
Hoosen Road (Line G), North Pender Island	Seismic Refraction, Electrical Imaging, Transient Electromagnetic Soundings	DeCourcy Formation, Northumberland Formation
Community Hall (Line H), North Pender Island	Seismic Refraction, Electrical Imaging, Transient Electromagnetic Soundings	Mayne Formation
Brackett Cove (Line I), North Pender Island	Seismic Refraction, Electrical Imaging, Transient Electromagnetic Soundings	Northumberland Formation, Galiano Formation
Allison Farm (Line K), North Pender Island	Razor Point Road, North Pender Island	Galiano Formation, Allison Fault
Razor Point Road (Line J), North Pender Island	Seismic Refraction, Electrical Imaging	Galiano Formation
Medicine Beach (Line L), North Pender Island	Seismic Refraction, Electrical Imaging, Transient Electromagnetic Soundings	Cedar Formation
Higgs Road (Line M), South Pender Island	Seismic Refraction, Electrical Imaging	Extension Formation, Fault
Southlands Drive (Line N), South Pender Island	Seismic Refraction, Electrical Imaging	Extension Formation
Spalding Road (Line O), South Pender Island	Seismic Refraction, Electrical Imaging, Transient Electromagnetic Soundings	Cedar Formation
Canal Road (Line P), South Pender Island	Seismic Refraction, Electrical Imaging	DeCourcy Formation, Pender Fault

Table 6.2: Physical properties of soil and bedrock units investigated on North and South Pender Islands (based on geophysical survey results).

Geologic Unit	Site	Soil Resistivity (Ohm-metres)	Bedrock Resistivity (Ohm-metres)	Water Table Depth (metres)	Bedrock Velocity (metres/ second)	Depth to Bedrock	Density of Bedrock (kg/m^3)	*Comments*
Cedar Formation	Medicine Beach	<5 20-70 10-75	40-350 90-750 55-550	0.8 0-1.9	3360-3850 3330-3670	2.8-5.1 2.1-7.8	2250-2340	Bedrock exposed
	Spalding Road	17-60	35-120	0.9-2.6	3300-3800	5.2-12.9		Bedrock escarpment beside road
	School	5-50	50-600	n/a	n/a	n/a		No seismic
Northumberland Formation	Corbett Road	15-70	70-700	0.9-2.6	3100-4000	3.6-14.8	2215-2360	Bedrock exposed
	Brackett Cove	10-100	50-300	1.0-1.8	3400-4600	2.7-11.2	2270-2445	Drainage way
Galiano Formation	Razor Point Road	35-200	85-360	0.7-3.2	3175-3700	6.3-10.9	2230-2315	
	Roes Island	30-100	45-600	0.4-1.3	2300-3000	3.1-11.9	2055-2200	Saturated ground near beach
	Allison Farm	25-1000	200-1000		3200-4800	1.5-10.8	2235-2470	Spring
	MacKinnon Road	100-200	200-1600	0.7-2.3	4200-4400	2.5-7.9	2390-2420	Weathered bedrock
Mayne Formation	Community Hall	10-50	50-120	1.0-1.7	3500-3770	5.7-9.3	2285-2325	
	Otter Bay	20-35	50-520		n/a	n/a		No seismic
Extension Formation	Southlands Road	20-85	85-700	1.0-3.0	2900-4300	7.8-14.0	2180-2405	Possible channel
	Higgs Road	15-300	30-300	0.8-2.6	3490-3750	3.0-7.8	2282-2325	Bedrock exposed at ocean
DeCourcy Formation	Otter Bay Road	20-150	50-500		3150-4000	3.1-9.0	2225-2360	Weathered bedrock
	Hope Bay		10-2500	1.8-5.0	3200-4500	6.9-14.6	2235-2432	High TDS, Weathered bedrock
	Hoosen Road	15-150	30-500		3440-3900	2.4-8.6	2275-2345	
	Canal Road	35-270	15-270	0.9-2.7	3150-4000	2.4-8.5	2225-2360	Weathered bedrock
	Irene Bay Road	30-300	150-2800	0.8-1.8	3700-4200	3.4-8.1	2315-2390	Weathered bedrock

6.3 North Pender Island Geophysical Survey Results

6.3.1 MacKinnon Road

The geophysical investigation was conducted along the edge of MacKinnon Road which trends northwest to southeast (Figure 6.1a, Line A). The north end of the line is approximately 12 metres above sea level. Sandstone of the Galiano Formation is exposed along the shoreline and within the embankment. Electrical imaging and seismic refraction surveys were conducted with an orientation parallel to strike of the bedrock with bedrock dips varying between 40 and 45^0. Bedrock outcrops were observed within the drainage ditch beside the road along the survey line. The depth to competent bedrock interpreted from the seismic refraction survey ranges from 2.5 metres at station 65 to 7.9 metres at station 120. Depths to bedrock from water well records range from 1.2 to 3.7 metres in the vicinity of the survey line (www.gov.bc.ca/cgi-bin/env_exec/wwwapps/waterbot/gwellout). The velocity of the competent bedrock varies between 4200 m/s and 4500 m/s indicating a lack of fractures within the bedrock in the vicinity of the survey line.

The integration of the electrical imaging and seismic refraction survey results indicates that the bedrock is resistive but variable in its electrical properties. A relative vertical conductor (300 ohm-m) within the bedrock occurs in the vicinity of stations 27 and 72 (see Figure C.1). These conductive zones likely represent silt-rich bedrock. A perched water table is anticipated along the northernmost 60 m of the survey line. Weathered bedrock is expected south of station 60 on the basis of bedrock outcrop observations. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.2).

Water well records indicate the presence of a perched water table at the soil/bedrock interface. The near-surface sediments are composed predominantly of coarse-grained sediments (Figure 6.2) with a few isolated pockets of fine-grained soils. Sandy soils were mapped by Agriculture Canada during their soil survey (1988).

Three good water wells are located in the vicinity of the survey line. The groundwater appears to occur at the Galiano Formation/Northumberland Formation contact rather than in fractures within the bedrock.

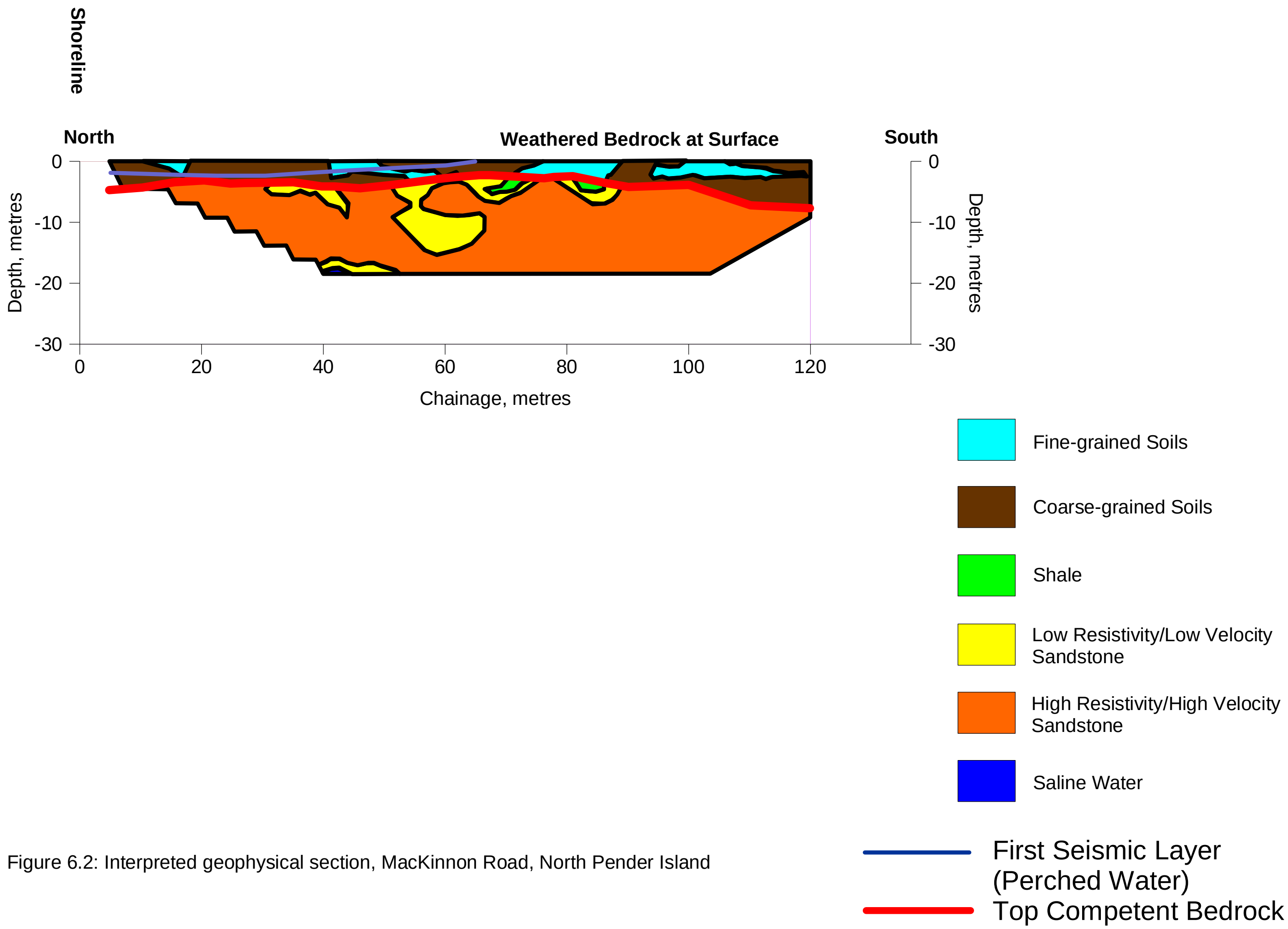

Figure 6.2: Interpreted geophysical section, MacKinnon Road, North Pender Island

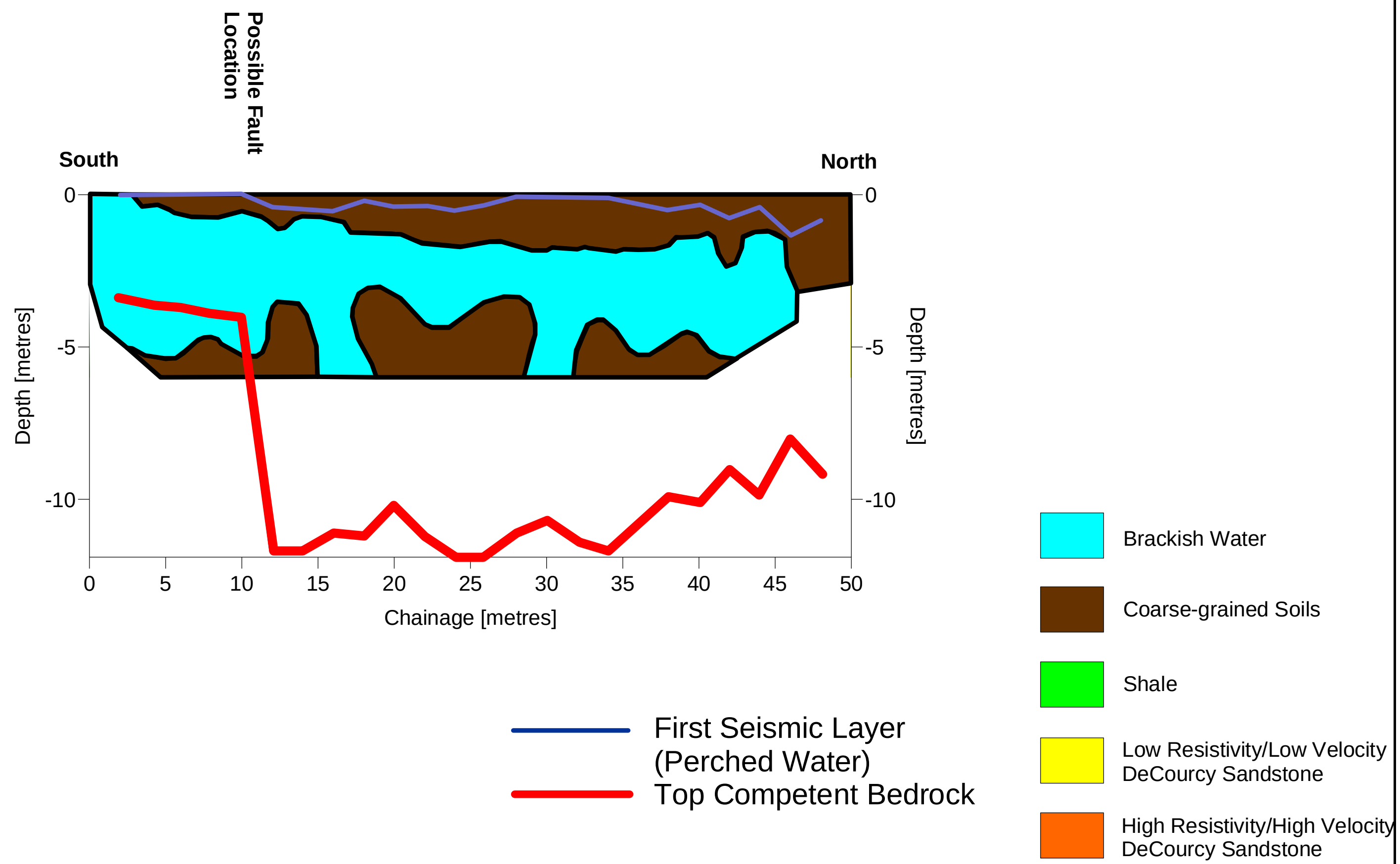

Figure 6.3: Interpreted geophysical section (parallel to beach), Line 1,
Roes Island, North Pender Island

6.3.2 Roes Island and Otter Bay Road

The land at Roes Island has been bequeathed to Parks Canada as part of a National Park on North Pender Island. At Roes Island, three survey lines were undertaken: one along the beach (Line 1), one 10 metres upslope from a break wall at the beach (Line 2), and one perpendicular to the beach (Line 3) (Figure 5.1a, Location B). The survey lines are located close to the Allison Fault in steeply dipping (~85^0) Galiano Formation sandstones. Electrical imaging, seismic refraction and time domain electromagnetic sounding measurements were acquired at this site. At the time of the survey, the soils were saturated to ground surface with excess water pooling on the surface along the southern portion of Line 2 (stations 33 to 48) and the western portion of Line 3 (stations 190 to 245). Residents indicated that these areas are generally wet year round. According to long time residents, a dug well to a depth of 6 to 8 feet located in this area of the site has never run dry (Davison, personal communication, 2004).

The electrical imaging results from Line 1, along the beach, have been interpreted as coarse-grained sediments overlying a conductive unit (Figure 6.3). In view of the proximity of the ocean, it is likely that the conductive unit is brackish water. The conductive unit is underlain by a more resistive unit, likely wet, silty sand. The higher resistivities for this unit (35 to 50 ohm-m) are indicative of freshwater influx from upslope of the beach. There are also two narrow, near-vertical zones of more conductive material at station 16 and 30 respectively. These two zones may represent preferred pathways for saline water to make its way back to the ocean at low tide. The electrical imaging modeled response is presented in Appendix C (Figure C.3).

The seismic refraction survey indicates that there is a sudden marked increase in depth to bedrock between stations 10 and 12. This increase in depth to bedrock may indicate a change in bedrock type or the presence of a fault or fracture zone. The velocity of the bedrock also decreases in the same area, consistent with the presence of a fault or fracture zone. The seismic velocities at the west end of the line range between 3000 and 3500 m/s while to the east of the possible fault the bedrock velocities to range between 2400 and 2800 m/s. The low velocities are indicative of a high degree of weathering and are very low for Galiano Formation sandstones.

The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.4).

Figure 6.4: Electrical imaging survey along the beach at Roes Island, North Pender Island Survey conducted along high tide line; sandstone of the Galiano Formation exposed in trees at far end of breakwall.

Line 2 is oriented in a west-east direction above the breakwall visible in Figure 6.4. The electrical imaging interpretation indicates that the near-surface sediments are either fine-grained or contain higher total dissolved solids in the groundwater (Figure 6.5). As mentioned previously, the area south of station 33 was saturated at the time of the survey and this area has the lowest measured resistivity values. Due to space constraints at the site, it was not possible to increase the electrode separation of the electrical imaging survey to investigate depths greater than 5.75 metres. The electrical imaging modeled response is presented in Appendix C (Figure C.5).

The seismic refraction results indicate that bedrock varies between 6.2 metres in the north to 12.1 metres in the south. The velocities in the bedrock low between stations 30 to 37 are low for Galiano Formation sandstone, ranging from 2250 to 2750 m/s. The calculated seismic refraction velocities for bedrock in the bedrock highs ranges from 3000 to 3800 m/s. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.6).

Line 3 is oriented perpendicular to the beach at Roes Island. The electrical imaging interpretation indicates a transition from saline water at the shoreline to surface clay to coarse-grained sediments, as one proceeds up the slope to South Otter Bay Road (Figure 6.6). The near-surface clays appear to be underlain by silt or sand or both at depth. The electrical imaging modeled response is presented in Appendix C (Figure C.7).

The depth to competent bedrock, as interpreted from the seismic refraction survey, ranges from 10 metres near the ocean to 3.3 metres at station 90. From station 90 to the end of the line, the depth to competent bedrock is relatively uniform. The integration of the electrical imaging and seismic refraction survey results shows that the bedrock is relatively resistive, typical of sandstone (Table 5.2). A steeply dipping conductive unit occurs within the bedrock in the vicinity of station 70 and likely represents a fracture zone. An alternative interpretation is a change in bedrock to a more clay-rich lithology. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.8).

A time domain electromagnetic sounding was acquired 32 metres from the breakwall along Line 3 (Figure 6.7). Due to space constraints, the largest transmitter loop that could be used was 20 m by 20m. Inversion of the data indicates a surface layer having a resistivity of 22.7 ohm-m and thickness of 11.1 m, overlying a resistive layer with a resistivity of 393 ohm-m and thickness of 21.3 m. The resistive unit is underlain by a conductive unit having resistivity of 10.7 ohm-m and thickness of 24.7 m and this unit is, in turn, underlain by a very conductive horizon having a resistivity of 1.4 ohm-m. This low resistivity can only be due to the presence of saline water. Using this information in the Ghyben-Hertzberg Equation, the water table should be located at 1.43 m above sea level.

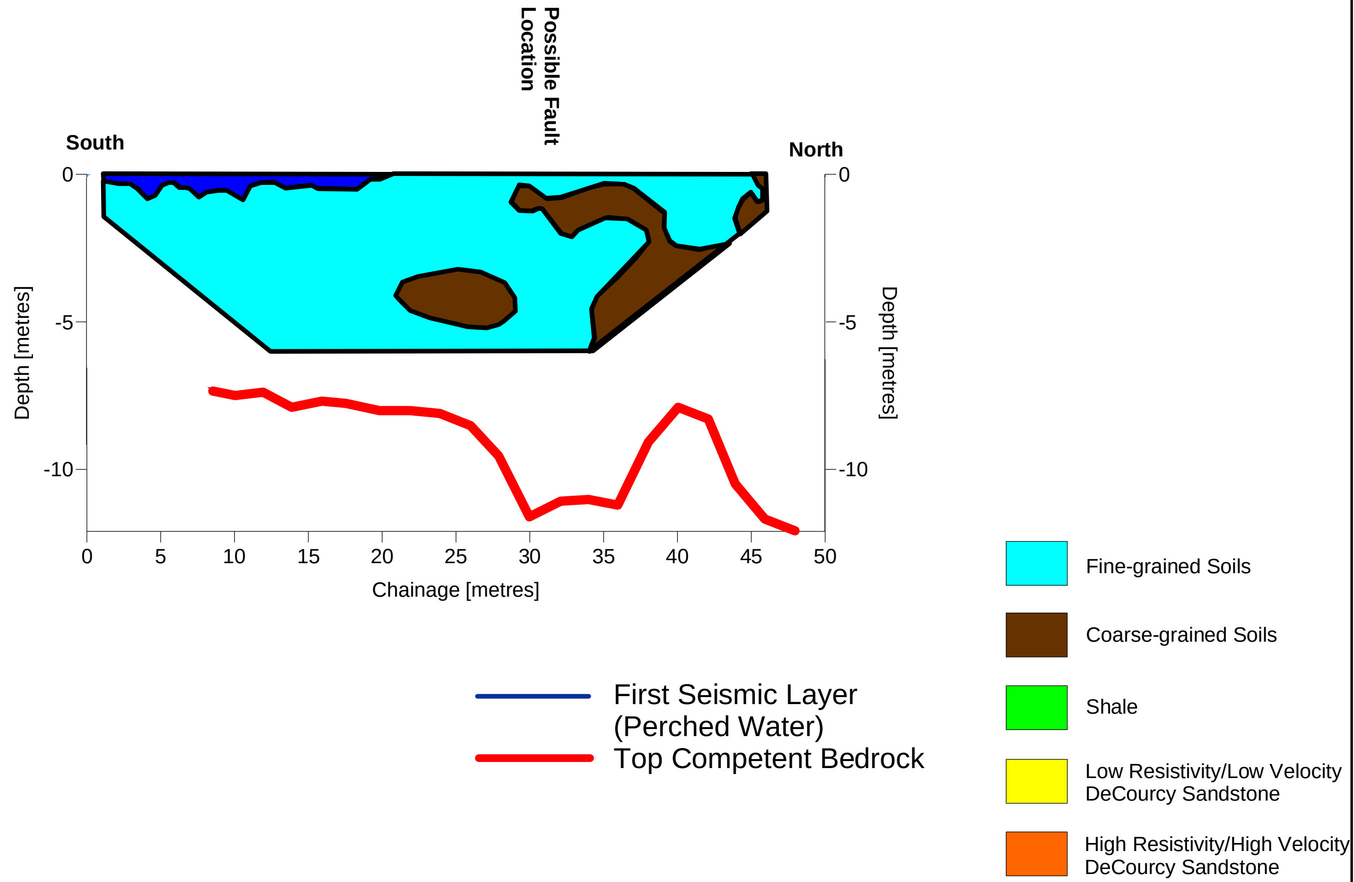

Figure 6.5: Interpreted geophysical section (along beach), Line 2, Roes, Island, North Pender Island

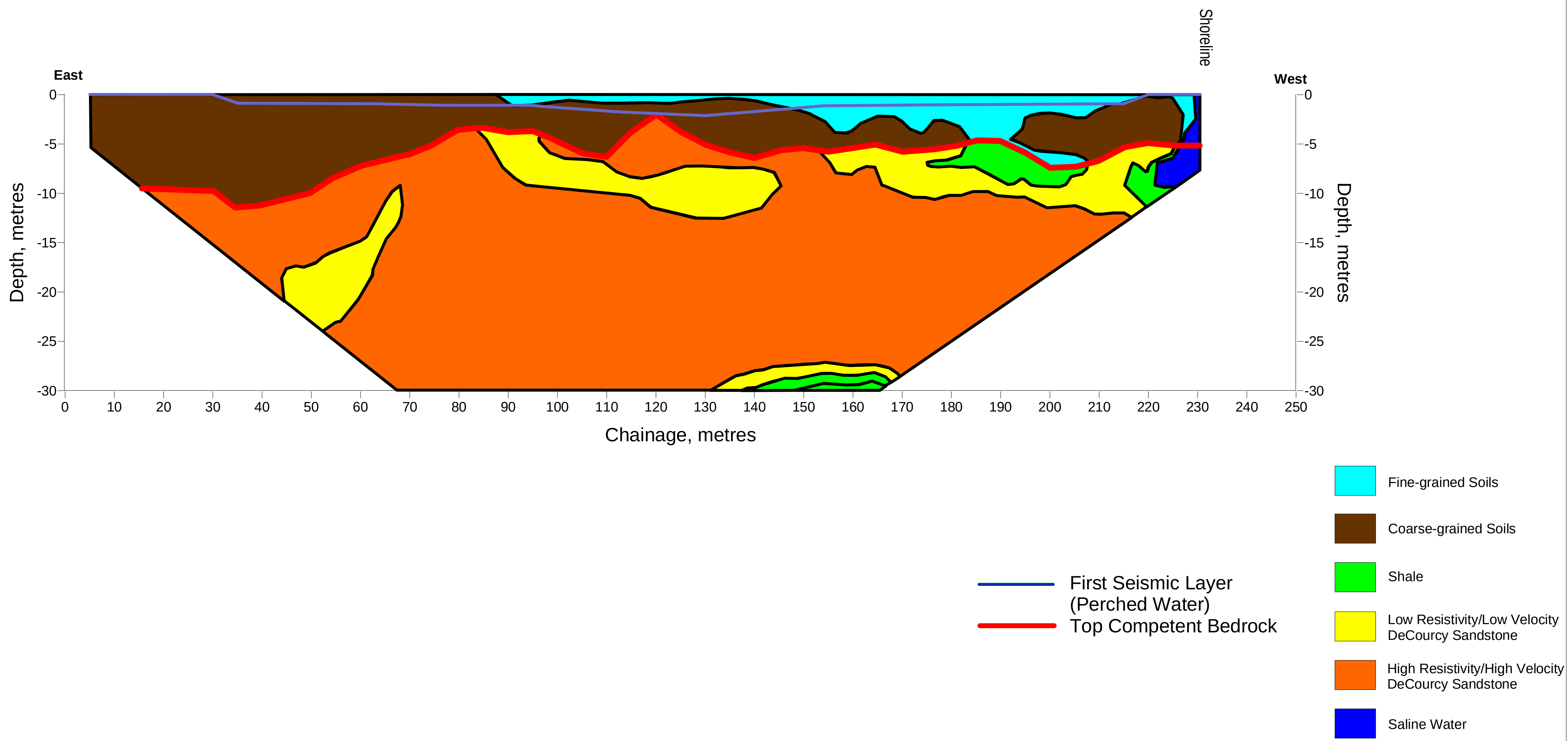

Figure 6.6: Interpreted Geophysical Section (perpendicular to shoreline), Line 3,
Roes Island, North Pender Island

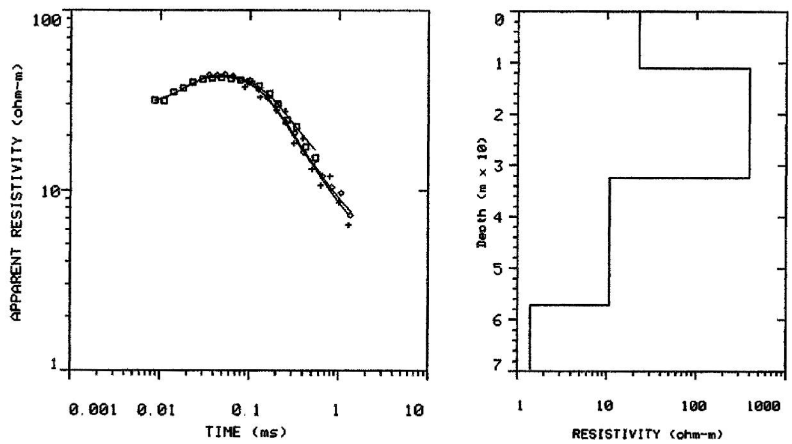

Figure 6.7: Time domain electromagnetic sounding at Roes Islet, North Pender Island. The apparent resistivity curve on the left illustrates the field data along with the model curve that fits the data. The model used is shown on the right.

Another time domain electromagnetic sounding was located only 10 metres upslope from the previous sounding. The results of the time domain electromagnetic sounding are presented in Figure 6.8. The inversion of the data indicates a surface layer having resistivities of 29.4 ohm-m and thickness of 12.4 m overlying a resistive layer having resisitivity of 400 ohm-m and thickness of 33.5 m. The resistive unit is underlain by a conductive unit having resisitivity of 30.1 ohm-m and thickness of 53 m and this unit is in turn underlain by a very conductive horizon having a resistivity of 4.6 ohm-m. This low resistivity can only be due to the presence of brackish water. Using the information obtained from the time domain electromagnetic sounding in the Ghyben-Hertzberg Equation, the water table should be located at 1.43 m above sea level. There is a significant increase in depth to brackish/saline water by moving a mere 10 metres further upslope from the beach.

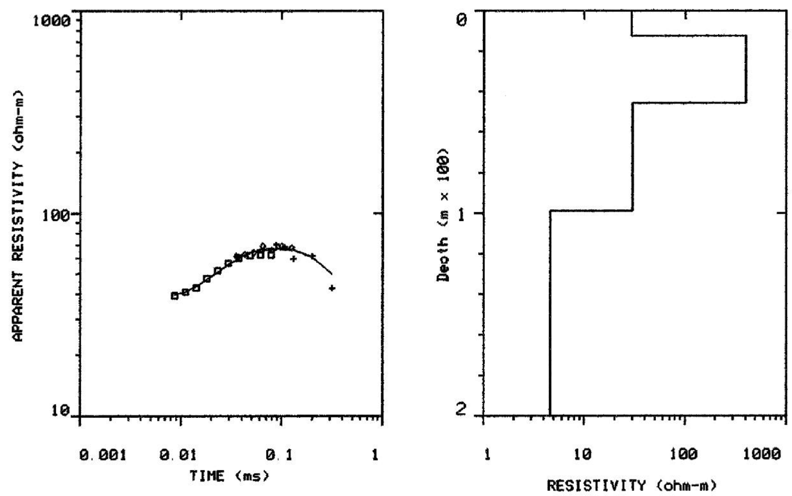

Figure 6.8: Time domain electromagnetic sounding at Roes Islet, North Pender Island. The apparent resistivity curve on the left illustrates the field data along with the model curve that fits the data. The model used is shown on the right. This sounding is located 10 metres upslope from the sounding shown in Figure 6.7.

In the vicinity of Otter Bay, a survey line was oriented along the strike of the Galiano Formation sandstone. The survey line extended from the beach area in the west up a gentle slope to an area of exposed weathered bedrock in the east. At this site, only electrical imaging data were acquired. They indicate a clay soil horizon overlying either coarse-grained soils or bedrock. Close to the ocean, the surface sediments become more coarse-grained. A soil mapping survey by Agriculture Canada (1988) indicates sand overlying clay in the vicinity of the survey line. The influence of saline water can readily be observed at shallow depths at the west end of the survey line close to the ocean. The resistivity of the bedrock is relatively high and correlates well with values from sandstone of the Galiano Formation. A pond is located between stations 30 and 50 (Figure 6.9). The elevation of the water in the pond is approximately 0.3 m below the ground elevation adjacent to the pond and likely indicates a perched water table close to the soil/bedrock interface. A conductive unit occurs at a depth of approximately 28 metres near station 160 and may represent the occurrence of brackish water. The conductive unit dips away from the shoreline. The electrical imaging modeled response is presented in Appendix C (Figure C.9).

6.3.3 Irene Bay Road

A geophysical survey line extended from the west end of Irene Bay Road, approximately 20 metres from the ocean, up a gentle slope to the east (Figure 6.1a, Line C). The survey line is oriented along the strike of the DeCourcy Formation, which has dips of 50 to 60^0 in this area. Bedrock is exposured in the drainage ditch beside the road. The electrical imaging survey suggests that the surficial sediments comprise predominantly marine clay from the start of the line to station 40 (Figure 6.10). The sediments become sandy beyond station 40. A study of soils by Agriculture Canada (1988) showed that the soils are predominantly sandy along Irene Bay Road. The electrical imaging modeled response is presented in Appendix C (Figure C.10).

The seismic refraction survey shows the bedrock surface to be gently undulating. The depth to competent bedrock varies along the line from 3.4 to 8.1 metres. The integration of the seismic refraction and electrical imaging results indicate that the bedrock is heterogeneous. The seismic velocities calculated for the bedrock range from 3800 to 4500 m/s, indicating relatively competent bedrock with few fractures. The resistivity of the bedrock is quite variable however, ranging from 30 to 260 ohm-m indicating that the bedrock changes over short distances. A possible fracture zone has been mapped in the vicinity of Station 112 within the sandstone. A perched water table was mapped along portions of the survey line. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.11).

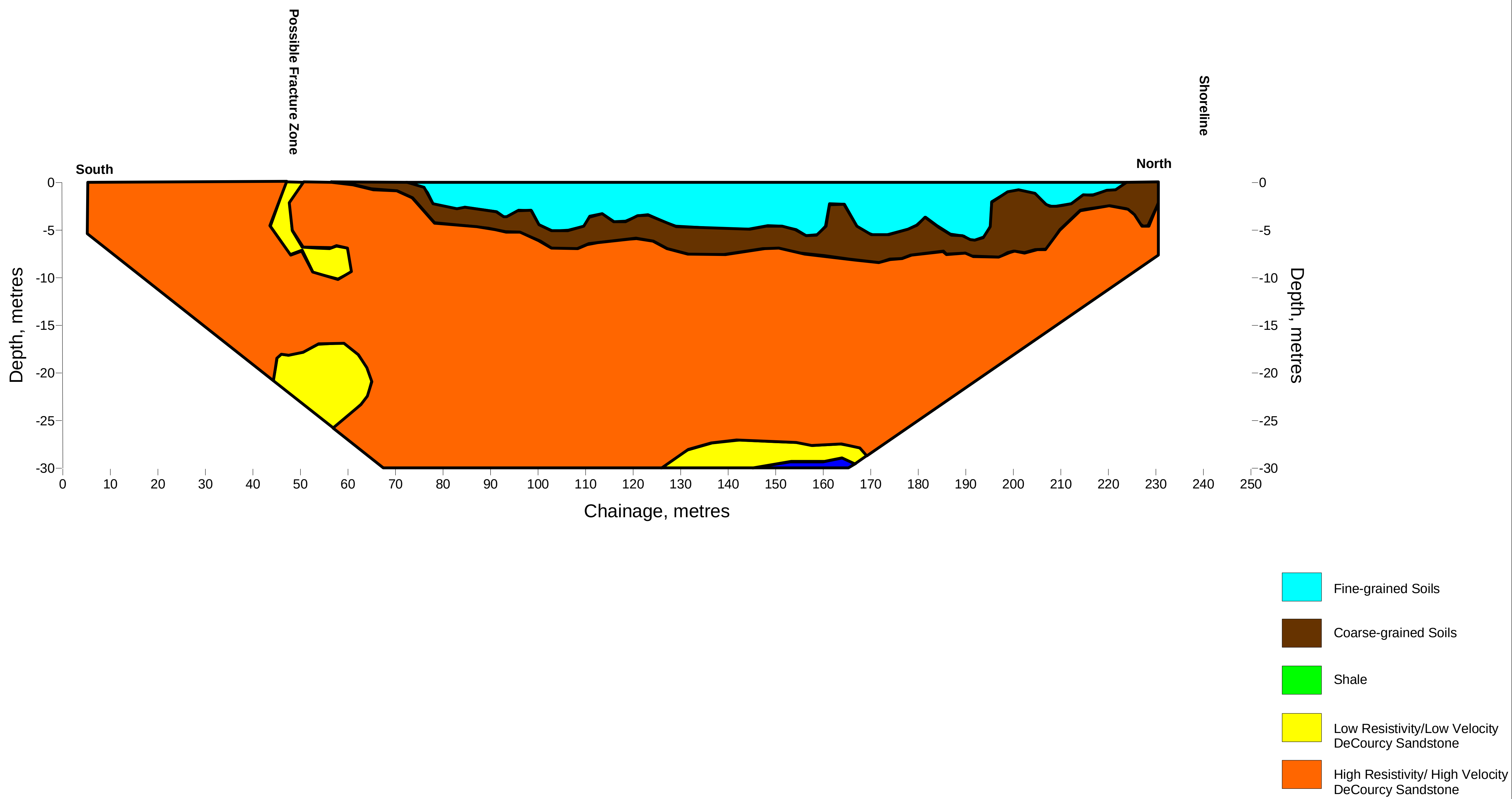

Figure 6.9: Interpreted geophysical section, Otter Bay, North Pender Island

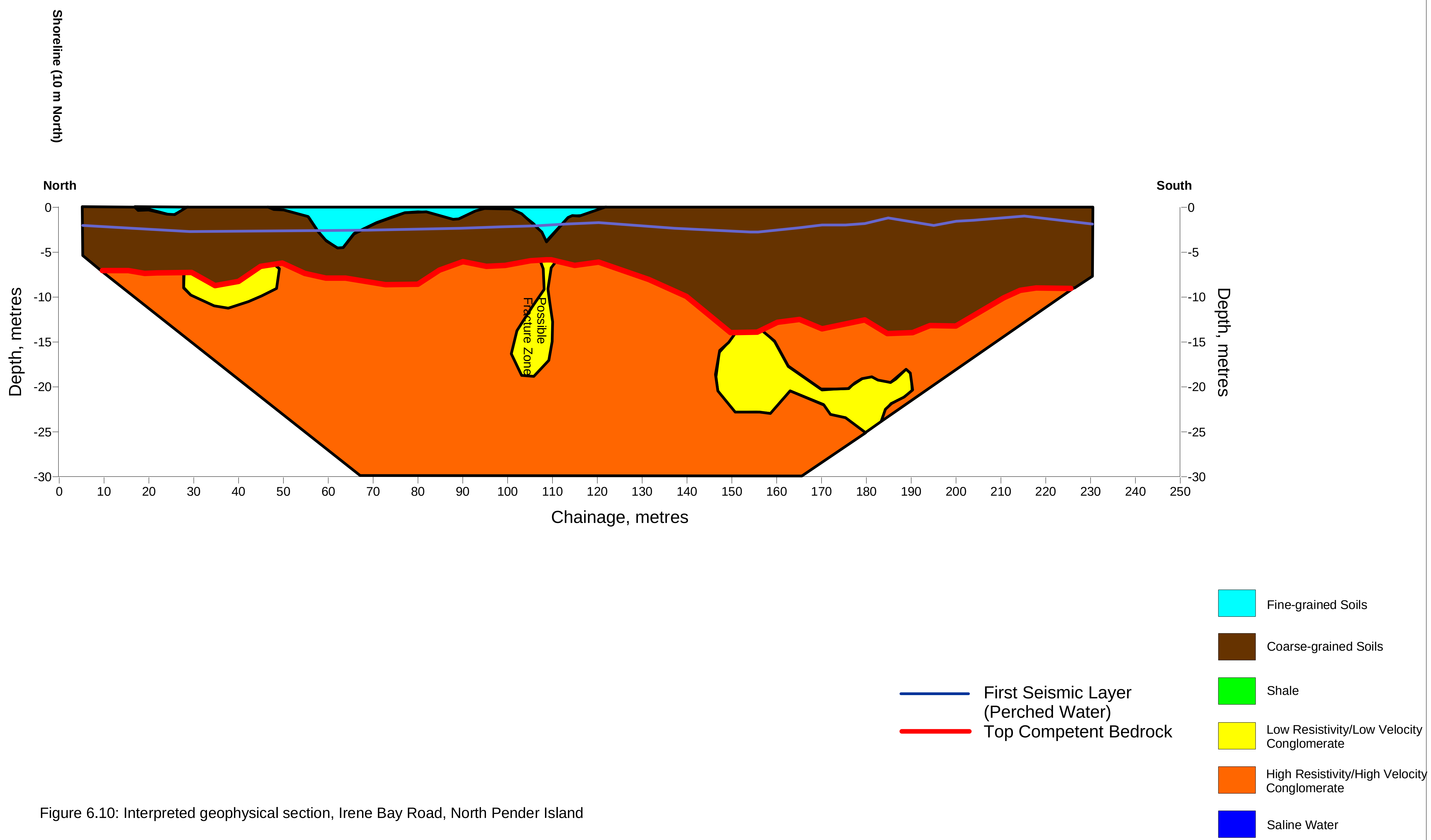

Figure 6.10: Interpreted geophysical section, Irene Bay Road, North Pender Island

6.3.4 Corbett Road

The survey line along Corbett Road was oriented in an north-south direction and extended from a bedrock exposure in the road cut (Figure 6.11) down across a broad valley and up the east side of the valley (Figure 6.1a, Line E). The bedrock consists predominantly of shales of the Northumberland Formation with dips ranging from 40 to 45^0. The survey line was oriented perpendicular to the known strike of the bedrock.

Figure 6.11: Outcrop of Northumberland Formation, Corbett Road, North Pender Island illustrating steeply dipping bedrock consisting of weathered shale with sandstone stringers.

The electrical imaging survey indicates that the surficial sediments are predominantly clay (<30 ohm-metres). The soil mapping survey conducted by Agriculture Canada (1988) indicates that, for most of the survey line, the near-surface soils are sand overlying clay. There is no evidence of a surface sand layer in the geophysical data. The sediments are underlain by bedrock of highly variable electrical properties, indicatative of interbedded shale, siltstone, and sandstone. The electrical imaging modeled response is presented in Appendix C (Figure C.12).

The depth to competent bedrock, as mapped by seismic refraction, varies from 2.6 to 14.8 metres. A bedrock high occurs between stations 90 and 170 m, with increases in depth to competent bedrock at both ends of the survey line (Figure 6.12). The zone of shallow bedrock correlates well with the depth to bedrock encountered in a dug well adjacent to the survey line (www.gov.bc.ca/cgi-bin/env_exec/wwwapps/waterbot/gwellout). The bedrock is resistive (>285 ohm-metres) in this section of the survey line and likely is sandstone. The seismic refraction velocities of the competent bedrock vary between 3200 and 4000 m/sec. The resistivity of the bedrock appears to decrease at a depth of 25 metres, indicating an increase in clay content or the presence of the water table. A dipping conductor is present within the bedrock in the vicinity of station 40 and may correspond to either a more fractured horizon or a greater predominance of shale. A perched water table was encountered over the eastern portion of the survey line but is likely either not present or too thin to be mapped over the western portion of the line. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.13).

Two time domain electromagnetic soundings were recorded near the centre of the survey line. The interpreted data indicate a near-surface layer of clay overlying a relatively resistive bedrock unit, which is likely sandstone (Figure 6.13). The base of the resistive bedrock unit occurs at an interpreted depth of approximately 27 metres correlating well with the electrical imaging data set. A further reduction in resistivity has been mapped at a depth of 75 metres, which may correspond to the presence of brackish water.

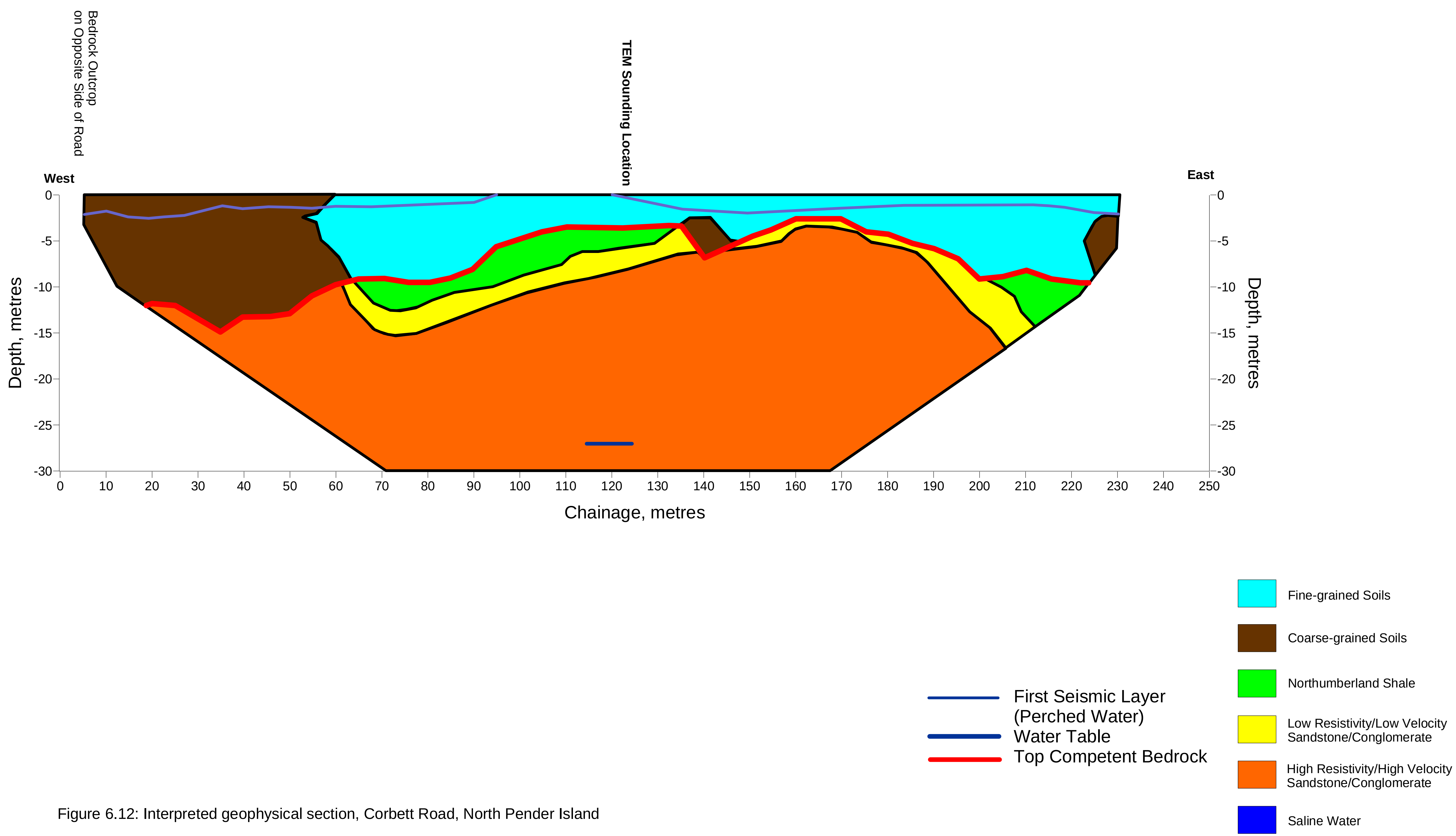

Figure 6.12: Interpreted geophysical section, Corbett Road, North Pender Island

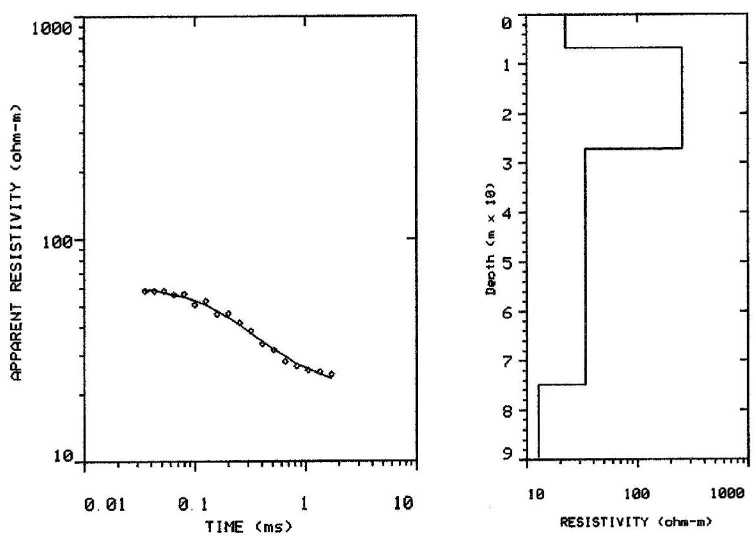

Figure 6.13: Time domain electromagnetic sounding along Corbett Road, North Pender Island. The apparent resistivity curve on the left illustrates the field data along with the model curve that fits the data. The model used is shown on the right.

6.3.5 Hope Bay

The survey line, along Hope Bay Road, is located parallel to a previously mapped fault (England, 1989) (Figure 6.1a, Line F). The survey traverses a contact between the DeCourcy Formation sandstone and the Northumberland Formation shale. Dip of the bedrock ranges between 25 and 30^0. Previous research by Mordaunt (1981) identified the area in the vicinity of the survey line as a region in which the groundwater has high iron and high chloride concentrations.

The electrical imaging survey results indicate that the near surface sediments are dry and coarse-grained. These sediments are generally underlain by fine-grained soils, which are in turn underlain by coarse-grained soils (Figure 6.14). In light of the variations in soil type, it is not surprising that the near-surface resistivities are quite variable; however, it is not possible to explain the variations simply by soil type. There is an extremely conductive zone occurring within the surficial sediments between stations 45 and 51. This unit is likely a result of increased total dissolved solids within the groundwater. The electrical imaging modeled response is presented in Appendix C (Figure C.14).

The depth to competent bedrock varies along the survey line from approximately 7.0 to 14.6 metres. There are three general lows in the bedrock topography: between stations 15 and 40 and between stations 115 and the end of the line. These lows likely correspond to paleo-channel locations or zones of fractured bedrock. There is a small creek located just beyond the west end of the survey line. An integration of the electrical imaging and seismic refraction results indicates that the electrical properties of the bedrock are also variable. There are two zones of relatively low resistivity, between stations 15 and 40 and between station 105 and the end of the line. The low resistivities mapped in these areas are expected to result from either increased total dissolved solids in the groundwater or to a change in bedrock type. The change in electrical properties near station 105 corresponds to the contact between the DeCourcy and Northumberland Formations. Interestingly, the low resistivity zones correspond to the lows in the bedrock surface mapped by the seismic refraction survey. A previous study by Mordaunt (1981) found increased total dissolved solids in the form of chlorides in the vicinity of Hope Bay, which may explain the low resistivities between Stations 15 and 40. A relatively narrow, lower resistivity zone occurs in the vicinity of Station 72 and may represent a near-vertical fracture zone. The seismic refraction survey indicated the presence of a perched water table occurring above the soil/bedrock interface. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.15).

A review of the water well records close to the survey line indicates the presence of a perched water table (www.gov.bc.ca/cgi-bin/env_exec/wwwapps/waterbot/gwellout). To the north of the survey line, water well records indicate that depth to bedrock varies from 0.0 to 5.5 metres.

Both the electrical and acoustic properties of the bedrock along Hope Bay Road exhibit significant variability indicative of the proximity to the ocean as well as a fault mapped through Hope Bay itself.

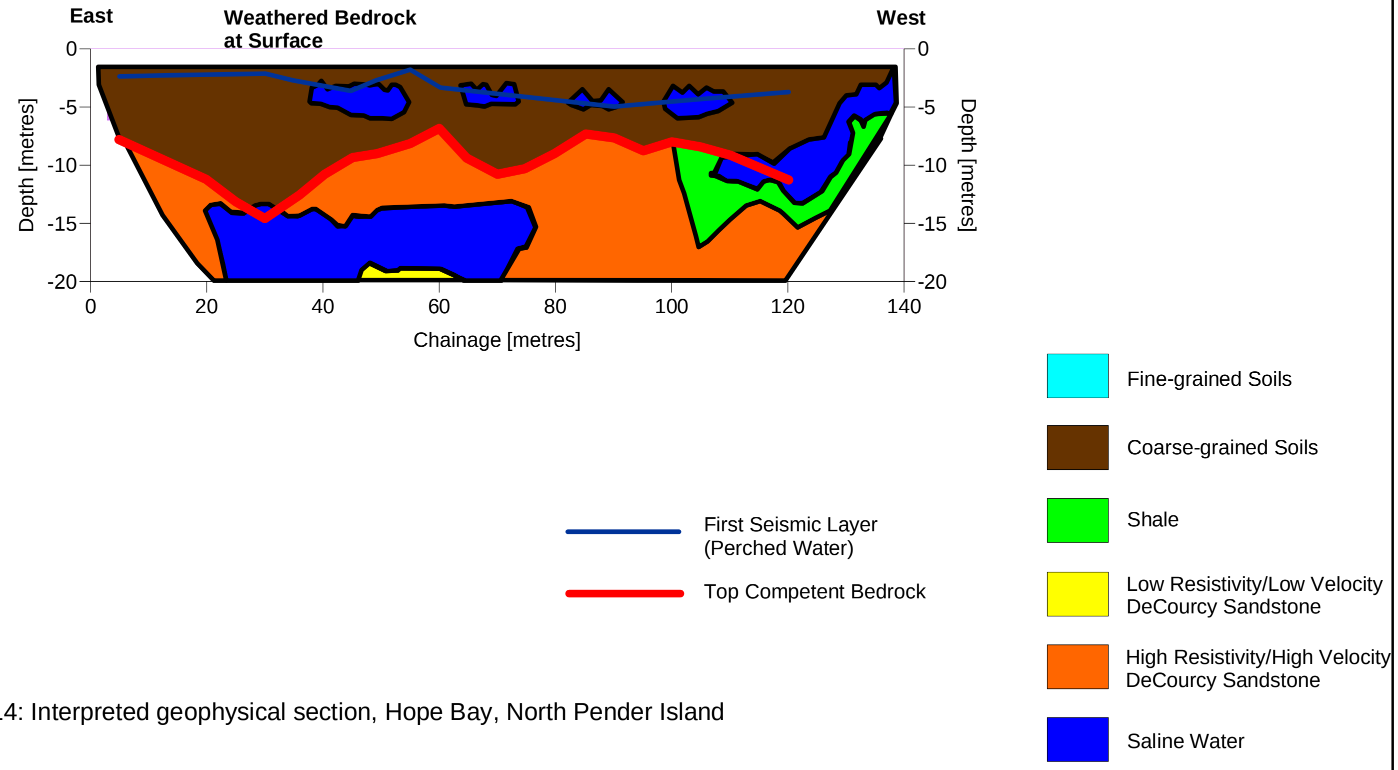

Figure 6.14: Interpreted geophysical section, Hope Bay, North Pender Island

6.3.6 Hoosen Road

Hoosen Road is located close to the contact of the DeCourcy Formation and the Northumberland Formation (Figure 6.1a, Line G). Bedrock dips vary from 25 to 30^0. The seismic refraction survey indicates that there was no perched water table above the soil/bedrock interface at the time of the survey. The results have been interpreted as unsaturated sediments overlying competent bedrock (Figure 6.15). The depth to competent bedrock along the line varies from 2.4 to 5.1 metres. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.16).

The interpretation of the electrical imaging survey results indicate that the near-surface sediments consist predominantly of clays. A resistive unit in the near-surface at station 80 corresponds to a bedrock outcrop. This indicates that weathered bedrock may occur within the unsaturated soil layer as defined by the seismic refraction survey. Agriculture Canada (1988) found that the near surface soils in this area consist of sandy loam to marine clay.

Integration of the seismic refraction and electrical imaging surveys shows that the resistivities of the bedrock are variable. The variability in electrical properties reflects the heterogeneity of the DeCourcy Formation. A lower resistivity zone dips north of station 110 and likely represents either a fracture zone or a shale horizon. Another lower resistivity zone occurs at depth (approximately 15 metres) between stations 120 and 195. The decrease in resistivity may be related to increased clay content, presence of fractures, increased total dissolved solids, or some combination of the three factors. The electrical imaging modeled response is presented in Appendix C (Figure C.17).

Two time domain electromagnetic soundings were conducted approximately 30 metres west of the beginning of the survey line. Interpretation of the transient electromagnetic data indicates that the depth to bedrock and as a result, the thickness of the clay sediments, increases to approximately 12 metres to the west, towards the centre of a narrow valley

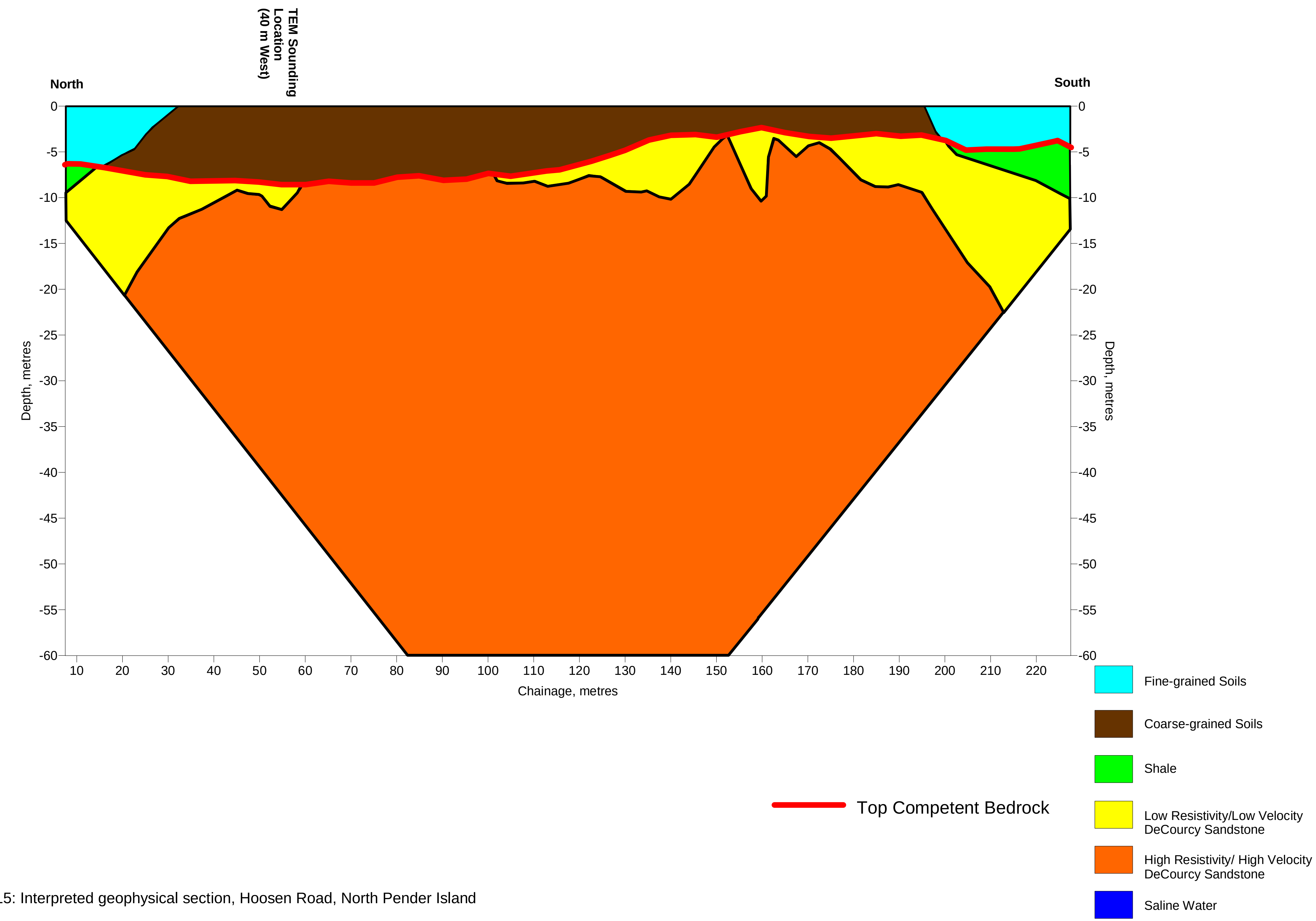

Figure 6.15: Interpreted geophysical section, Hoosen Road, North Pender Island

(Figure 6.16). The clays are underlain by a 15 metre thick sandstone unit, which is in turn underlain by a 26 metre thick shale horizon. The shale is underlain by a 63 m thick sandstone unit. At a depth of 114 metres, a conductive zone with a resistivity of 1.0 ohm-metre was mapped. A resistivity of 1.0 ohm-metre can only be explained in this geologic environment as indicative of saline water.

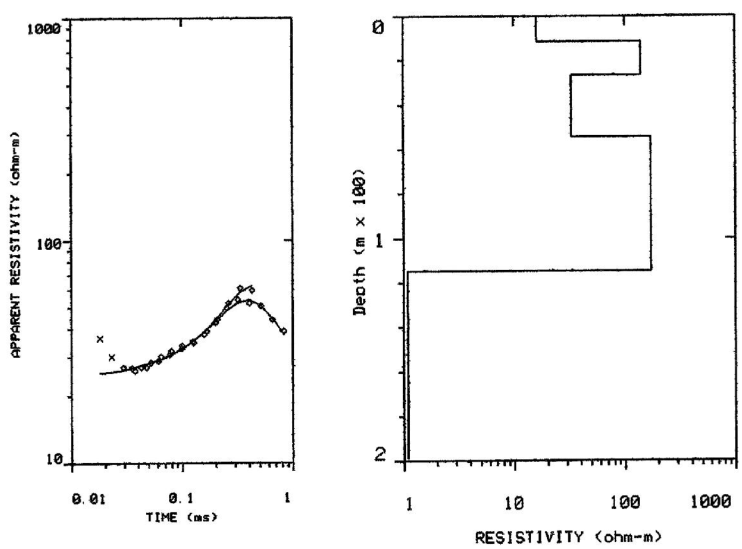

Figure 6.16: Time domain electromagnetic sounding beside Hoosen Road, North Pender Island. The apparent resistivity curve on the left illustrates the field data along with the model curve that fits the data. The model used is shown on the right.

A review of water wells in the vicinity of the survey line shows variations in depth to bedrock from 0.7 to 19.8 metres (www.gov.bc.ca/cgi- in/env_exec/wwwapps/waterbot/ gwellout). Since all the water wells are located some distance from the survey line, it is difficult to draw conclusions; however, the range in depth to bedrock encompasses depths found through the combined seismic refraction and transient electromagnetic surveys.

6.3.7 Community Hall

The bedrock at the Community Hall consists of shale of the Mayne Formation with dips ranging from 10 to 15^0. Three geophysical investigations were conducted: electrical imaging, seismic refraction profiling and transient electromagnetic sounding (Figure 6.1a, Line H). The electrical imaging interpretation indicates that the near-surface sediments consist of silty soils (Figure 6.17). The soil mapping survey by Agriculture Canada (1988) indicates that there can be a thin sand unit overlying the clay, although no clay was observed in the survey area. The electrical imaging modeled response is presented in Appendix C (Figure C.18).

The depth to competent bedrock interpreted from the seismic refraction data varies from 5.7 to 9.3 metres. The seismic refraction velocities measured for the competent bedrock vary between 3500 and 3770 m/s. Integration of the electrical imaging and the seismic refraction data sets indicates that the bedrock is relatively conductive and consists predominantly of clay (shale) or siltstone or both. A perched water table is anticipated along the entire length of the survey line on the basis of seismic refraction velocities of 1500m/s for the material overlying competent bedrock. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.19).

The time domain electromagnetic sounding indicates that the upper 10 metres are predominantly silty. The thin conductor occurring at a depth of approximately 10 metres may correspond to highly weathered, possibly wet shale (Figure 6.18). The resistivities of the underlying layers are typical of a dry shale (55 to 70 ohm-m), consistent with a recent dry water well drilled close to the site (K. Hanson, personal communication, 2004). The time domain electromagnetic sounding was offset from the electrical imaging survey line by approximately 30 metres, which may account for the discrepancy in near surface soil types.

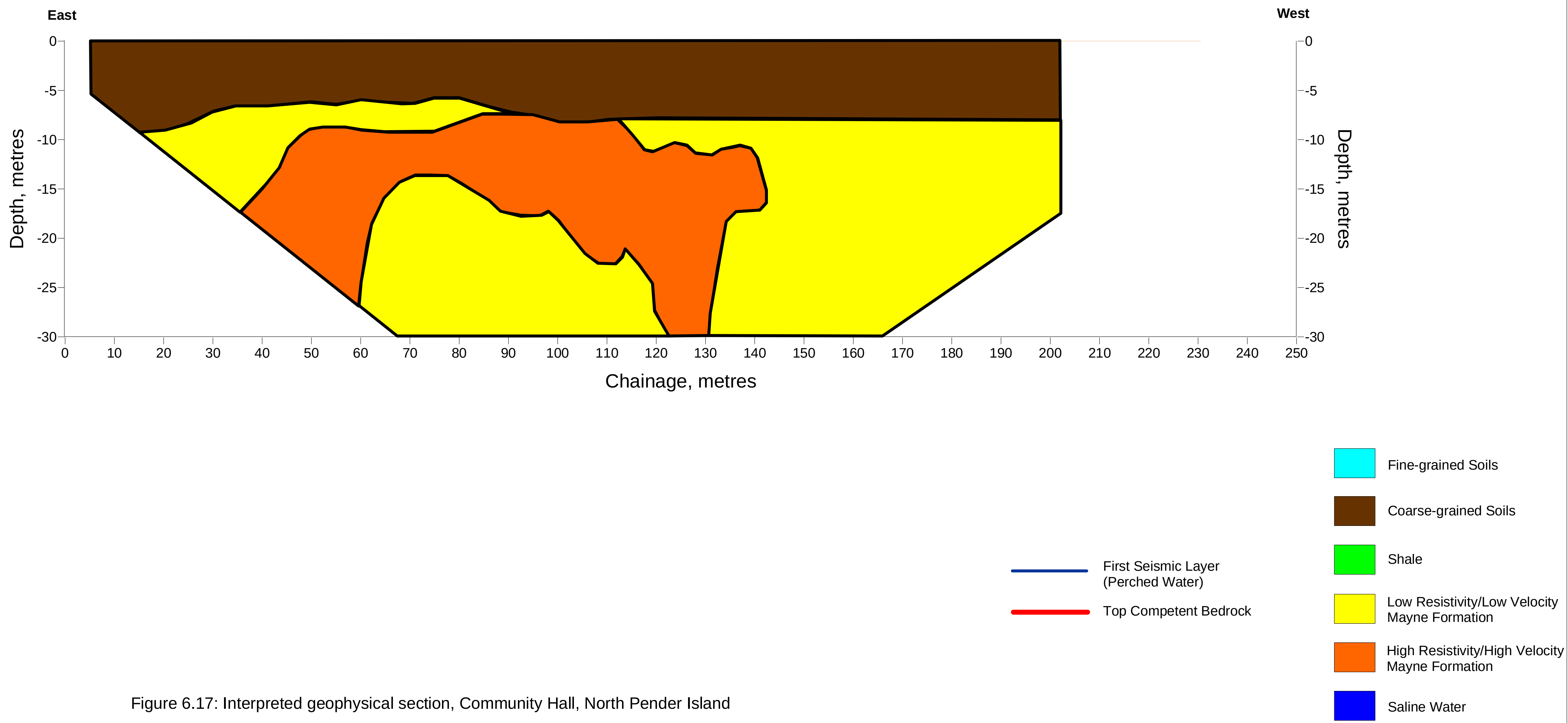

Figure 6.17: Interpreted geophysical section, Community Hall, North Pender Island

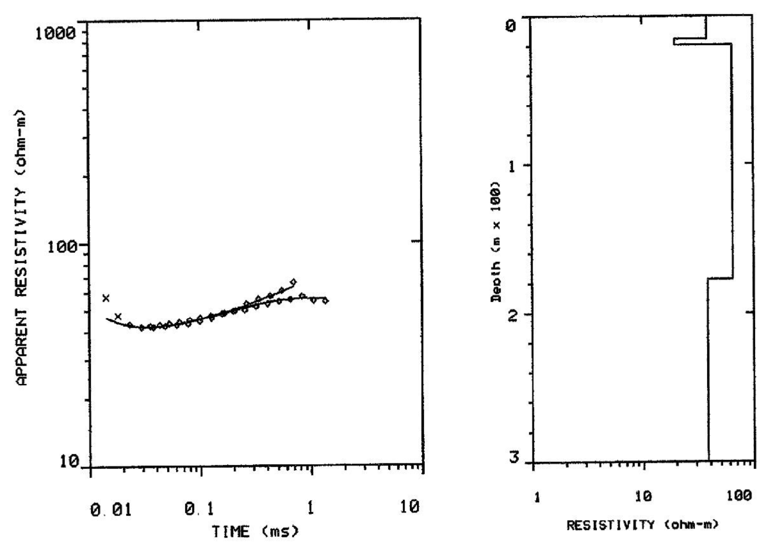

Figure 6.18: Time domain electromagnetic sounding beside Community Hall, North Pender Island. The apparent resistivity curve on the left illustrates the field data along with the model curve that fits the data. The model used is shown on the right.

6.3.8 Brackett Cove

A geophysical investigation, consisting of electrical imaging, seismic refraction and time domain electromagnetic sounding, was conducted in the vicinity of Brackett Cove along Razor Point Road, (Figure 6.1a, Line I). Bedrock is either Galiano Formation sandstone or Northumberland Formation shale dipping between 70 and 80^0.

The electrical imaging data indicate that the near-surface sediments are composed predominantly of coarse-grained soils (Figure 6.19). This correlates well with the findings of Agriculture Canada (1988), which indicates sandy soils overlying shallow bedrock. The electrical imaging survey also clearly identified the known location of a culvert extending beneath the road. The electrical imaging modeled response is presented in Appendix C (Figure C.20).

The interpreted seismic refraction data indicate that the depth to competent bedrock is variable along the survey line, ranging from 3.8 m at the south end of the line to 11.3 m at station 110 to 4.0 m at station 180 and 9.3 m at the north end of the survey line. The seismic refraction velocities calculated for competent bedrock vary between 3450 and 4400 m/sec. A near-vertical conductive unit was mapped within the bedrock at station 115; that unit likely represents a zone of increased fracturing or increased clay content. Since the bedrock dips at close to 90° in this area, the conductive unit may simply represent a steeply dipping, fractured shale horizon. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.21).

Two time domain electromagnetic soundings were located along this line. The time domain electromagnetic data were too noisy to interpret. The source of noise was likely the electric fence used to keep horses in the field, overhead power lines or some combination of the two.

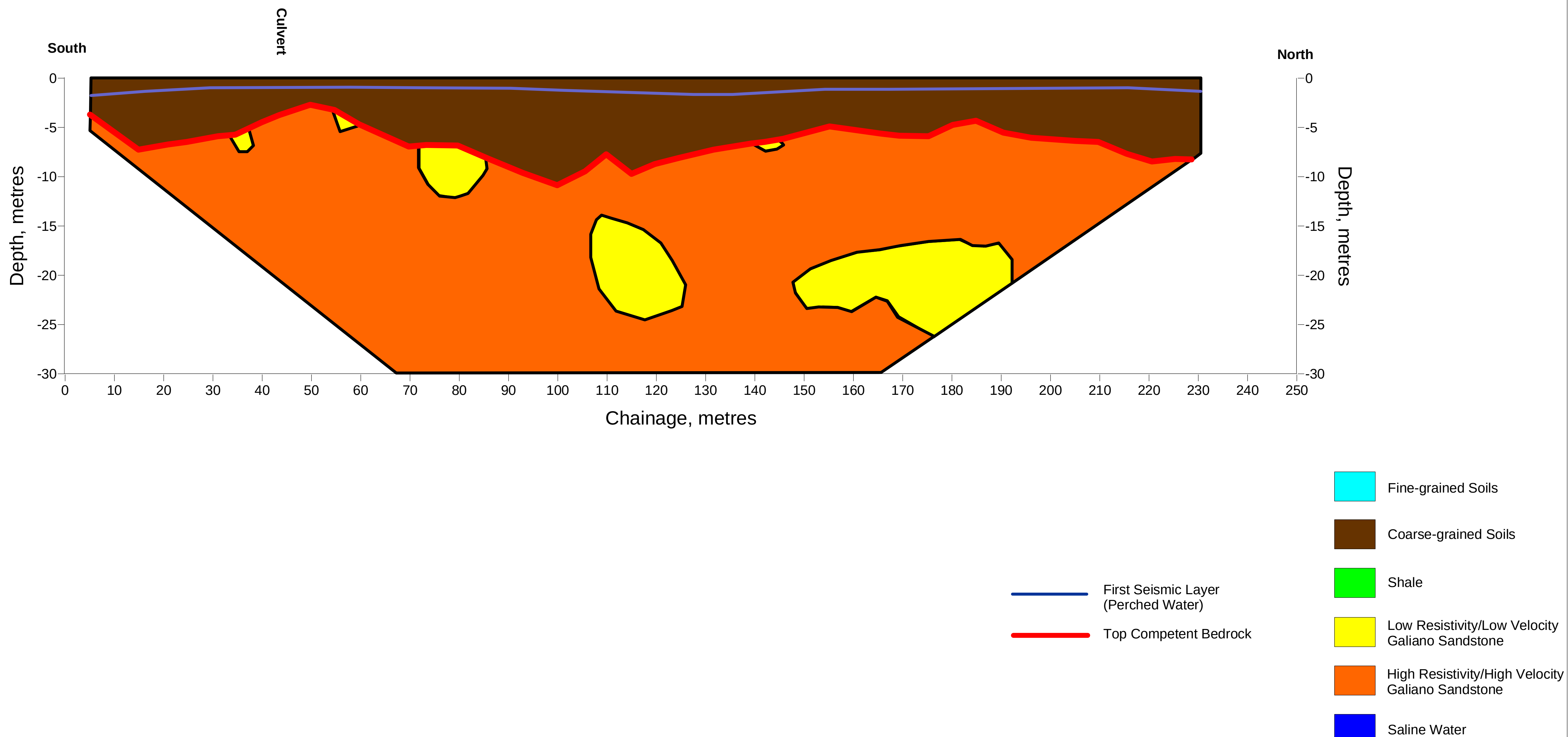

Figure 6.19: Interpreted geophysical section, Brackett Cove, North Pender Island

6.3.9 Razor Point Road

Seismic refraction and electrical imaging surveys were conducted along a survey line oriented roughly parallel to strike along Razor Point Road (Figure 6.1a, Line J). The bedrock is sandstone of the Galiano Formation dipping from 70 to 80^0. Field conditions, such as dense vegetative cover, private property, fences, and powerlines, made it impossible to apply time domain electromagnetic soundings at this site. The electrical imaging data indicate that the near-surface materials are relatively resistive; and that resistivity implies coarse-grained material (Figure 6.20). This interpretation corresponds well with the soil map of Agriculture Canada (1988), which shows the near-surface sediments to be gravelly sand. At depths corresponding to the interpreted second seismic boundary, there is a marked decrease in resistivity. This decrease may be due to the presence of a perched water table or an increase in clay content. The depth to the interpreted second seismic refraction boundary varies from 0.6 to 3.17 metres. The electrical imaging modeled response is presented in Appendix C (Figure C.22).

The seismic refraction interpretation indicates that depth to competent bedrock varies from 6.3 to 10.9 metres along the line. The seismic refraction velocities measured vary between 3175 and 3700 m/sec. A small drainage way was observed in the vicinity of station 65, which corresponds to a slight depression in the bedrock surface. A dug out filled with water is located in a field on the south side of Razor Point Road near station 65. The dug out is approximately 6 metres below the elevation of the survey line and is likely fed from the perched water table interpreted from the electrical imaging data set. The upper bedrock unit is relatively resistive (Table 5.2); that resistivity indicates that it comprises sandstone. The sandstone unit has three conductive horizons in it at a depth of approximately 15 metres, corresponding to either a shaley unit or a fracture zone. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.23).

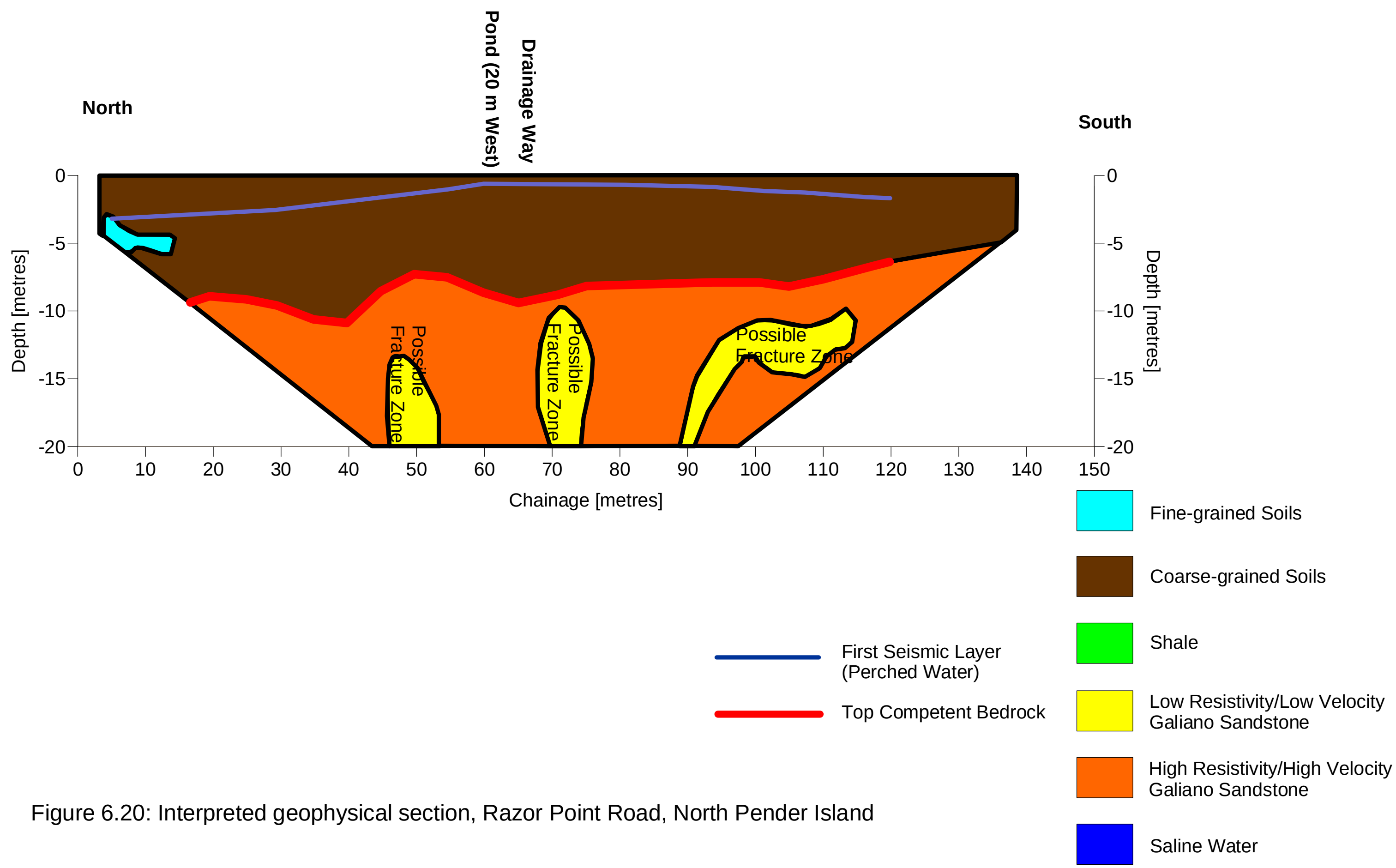

Figure 6.20: Interpreted geophysical section, Razor Point Road, North Pender Island

6.3.10 Allison Farm

The Allison Farm site was chosen because it has a spring and a mapped fault (Allison Fault; Henderson, 1998; England, 1989) (Figure 6.1a, Line K). Bedrock at the Allison Farm consists of Galiano Formation sandstones having dips ranging from 70 to 80^0. Electrical imaging indicates that the near-surface sediments are predominantly coarse-grained, particularly between stations 0 to 65 and 165 to 245 (Figure 6.21). In the region between stations 70 and 90, the near-surface sediments are fine-grained. The spring is located approximately 15 metres upslope of station 160. Water was visible on the ground surface in the vicinity of station 80 at the time of the survey. The electrical imaging modeled response is presented in Appendix C (Figure C.24).

Figure 6.22: Erratic on Allison Farm, North Pender Island

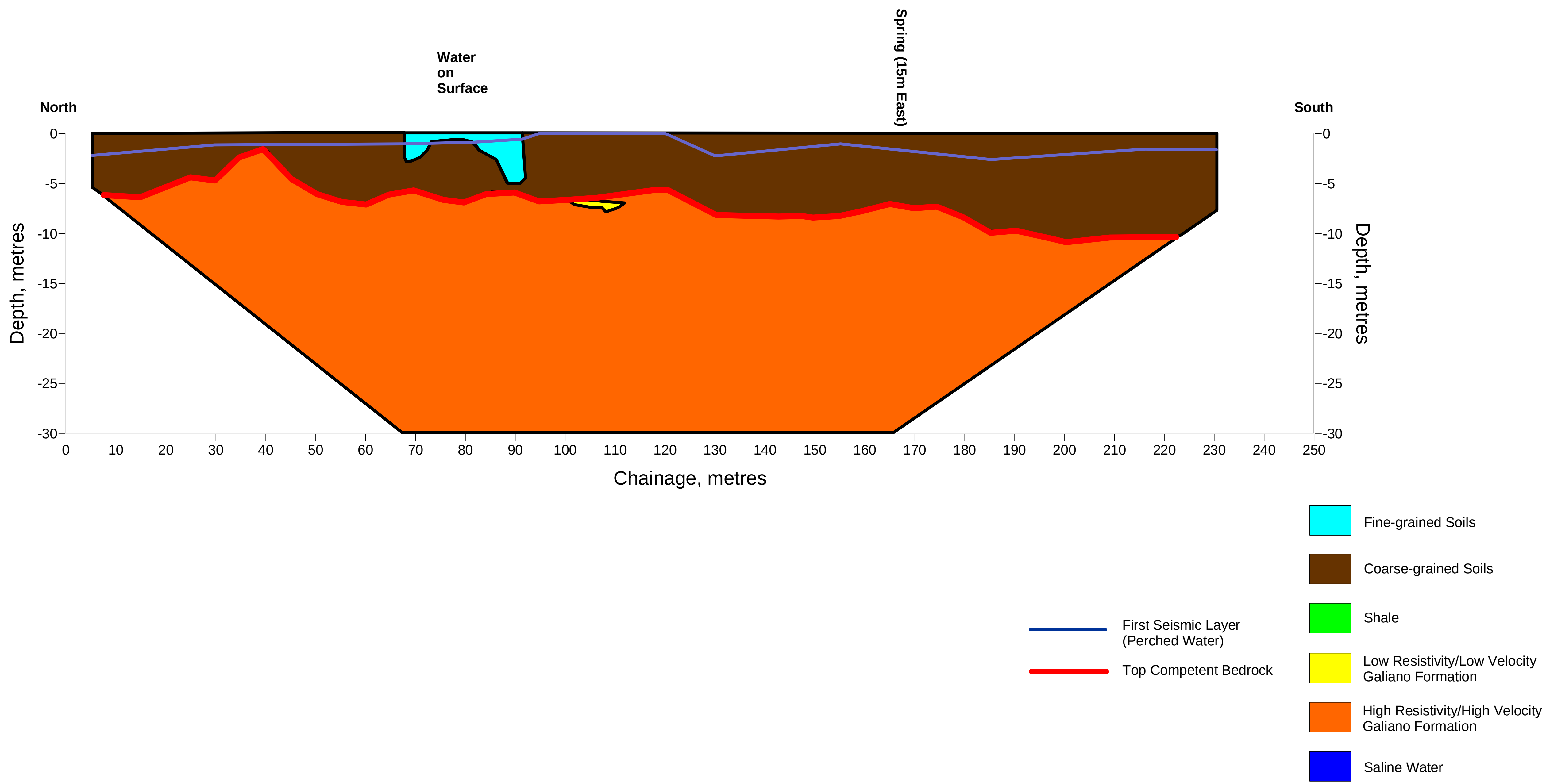

Figure 6.21: Interpreted geophysical section, Allison Farm, North Pender Island

The depth to competent bedrock at the site appears to be quite variable, ranging from 1.5 metres at station 40 to 10.8 metres at station 190. A perched water table is present along the eastern portion of the survey line. The second layer interpreted from the seismic refraction survey represents weathered bedrock along the western portion of the survey line. Integration of the electrical imaging and seismic refraction data sets indicates that the bedrock is resistive; that resistivity is interpreted as representative of homogeneous Galiano Formation sandstones. The relatively uniform seismic velocities of the bedrock indicate homogeneous bedrock at the site (see Table 5.2). The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.25).

The spring provides a reliable source of water for the farm and residences on the property (H. Allison, personal communication, 2003). Efforts have been made to capture water from the spring. Figure 6.23 illustrates the storage tank for the spring water located approximately 80 metres west of the spring. A garden hose carries water from the spring to the storage tank (Figure 6.23). An overflow from the storage tank was the root cause of the water on surface at the time of the survey.

Figure 6.23: Storage tank to store water from the spring located on the Allison Farm, North Pender Island. Note the hose running along the left side of the road to the storage tank.

6.3.11 Medicine Beach

Three geophysical lines were surveyed at Medicine Beach (Figure 6.1a, Location L). Two of the survey lines were located along the beach and perpendicular to the bedrock strike of the Cedar Formation shales while the third was perpendicular to the beach and parallel to strike. The third line followed the road from the beach to an access road to Wallace Point. Seismic refraction and electrical imaging surveys were conducted along all survey lines. In addition, three time domain electromagnetic soundings, with the use of a transmitter loop size of 20 x 20 metres, were conducted along Line 2 located parallel to the ocean/land contact. Field constraints did not allow for additional time domain sounding locations (a parking lot and access road). The surveys along the beach lines were conducted at low tide; that timing provided a greater beach surface for conducting the survey.

Figure 6.24: Cedar Formation shale outcrop, Medicine Beach, North Pender Island. Note the steeply dipping bedrock and the sandstone stingers present in the shale.

Line 1 was located as close to the water's edge as was deemed practical for the electrical imaging survey. There was little or no topographic relief along the survey line. The electrical properties indicate that the soils in the upper 2.5 metres along this line are saturated with seawater (<5 ohm-metres) (Figure 6.25), as would be expected in view of the proximity to the ocean. The adjacent survey line, located 10 metres upslope, indicates resistive coarse-grained soils overlying clay (Figure 6.26). The clay acts as an aquiclude and is likely responsible for the occurrence of the saltwater marsh that occurs further upslope at Medicine Beach. The transient soundings located along the beach indicate that there is freshwater beneath the saltwater horizon as noted by the increase in resistivity at depths ranging from 8.9 to 9.3 metres. There are steep slopes on three of the sides bordering the site. These slopes provide ample area for a steady flow of freshwater. Figure 6.27 illustrates a conceptual model of groundwater flow at the Medicine Beach site. The modeled resistivities from the transient electromagnetic soundings were used to estimate the formation resistivity for the coarse grained soils at the site. With the application of the value of resistivity for seawater, 0.2 ohm-m, (Telford *et al.,* 1990), the formation resistivity factor is equal to 5 (equation 2.4, Chapter 2). Incorporating this result into equation 3 and assuming a porosity exponent of 2 results in an estimate of porosity within the sands of 29%, which is within the range normally quoted for sands and gravels (Telford *et al.*, 1990).

Line 2 illustrates the influence of the outgoing tide (saline water). The surface sediments were observed, during the survey, to consist predominantly of sands and gravels (Figure 6.26). From station 0 to 8m, the surface sediments are relatively conductive (<35 ohm-metres); that conductivity indicates the presence of increased clay content or total dissolved solids or both. A small creek that drains the adjacent salt water marsh is located in this portion of the survey line and may be the source of increased total dissolved solids. Between stations 8 and 30, the surface sediments are more resistive (>280 ohm-metres). The thickest zone of coarse-grained sediments corresponds to the location of a small creek.

The surficial material along the survey line perpendicular to the beach is composed of both coarse-grained and fine-grained soils (Figure 6.28). A perched water table, as defined by the seismic refraction survey, exists above the soil/bedrock interface; this horizon could also be the top of weathered bedrock, which may have a similar acoustic velocity. The perched water table disappears approximately 35 metres upslope from the beach end of the parking lot. The depth to competent bedrock is shallow near the beach itself and increases upslope away from the beach, but at a much slower rate than the increase in elevation of the topographic surface. Bedrock outcrops were observed adjacent to the survey line at the beach, as well as at several locations within the roadside along the survey line. It is likely that the depth to bedrock delineated by the seismic refraction survey corresponds to the depth to competent bedrock and does not include a weathered bedrock layer. Seismic refraction velocities for competent bedrock measured at the site vary between 3300 and 3800 m/sec. The variations of electrical properties within the bedrock indicate that the Cedar Formation is not homogeneous in this location. It appears to be a mixture of sandstone, siltstone and shale. The lack of homogeneity is significant from a groundwater resource perspective, as each bedrock type would have a characteristic porosity and permeability impacting both the quantity of groundwater available and potential flow rates. Along the beach, the depth to competent bedrock appears to increase to the west and this corresponds to observations at the site, which include a bedrock outcrop to the east of the survey line (Figure 6.24). The weathered nature of the bedrock surface, as well as the steeply dipping beds are clearly visible in the bedrock outcrop.

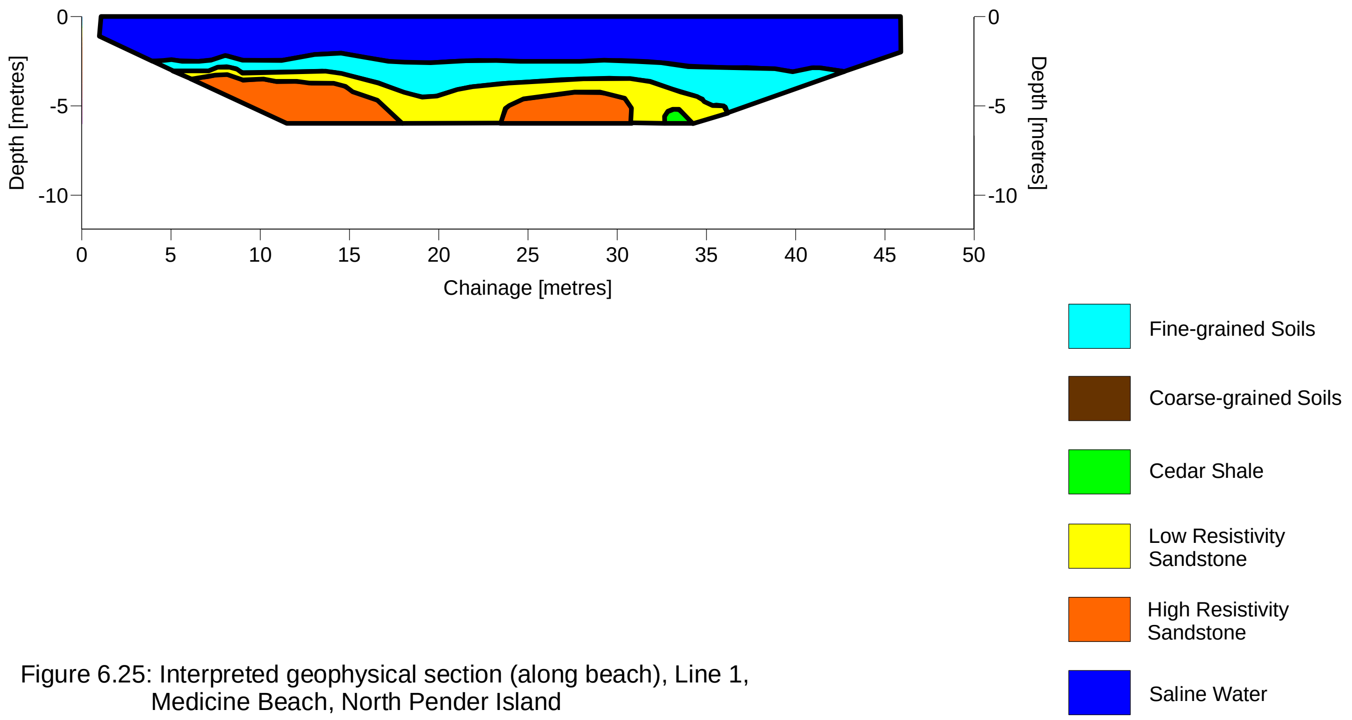

Figure 6.25: Interpreted geophysical section (along beach), Line 1, Medicine Beach, North Pender Island

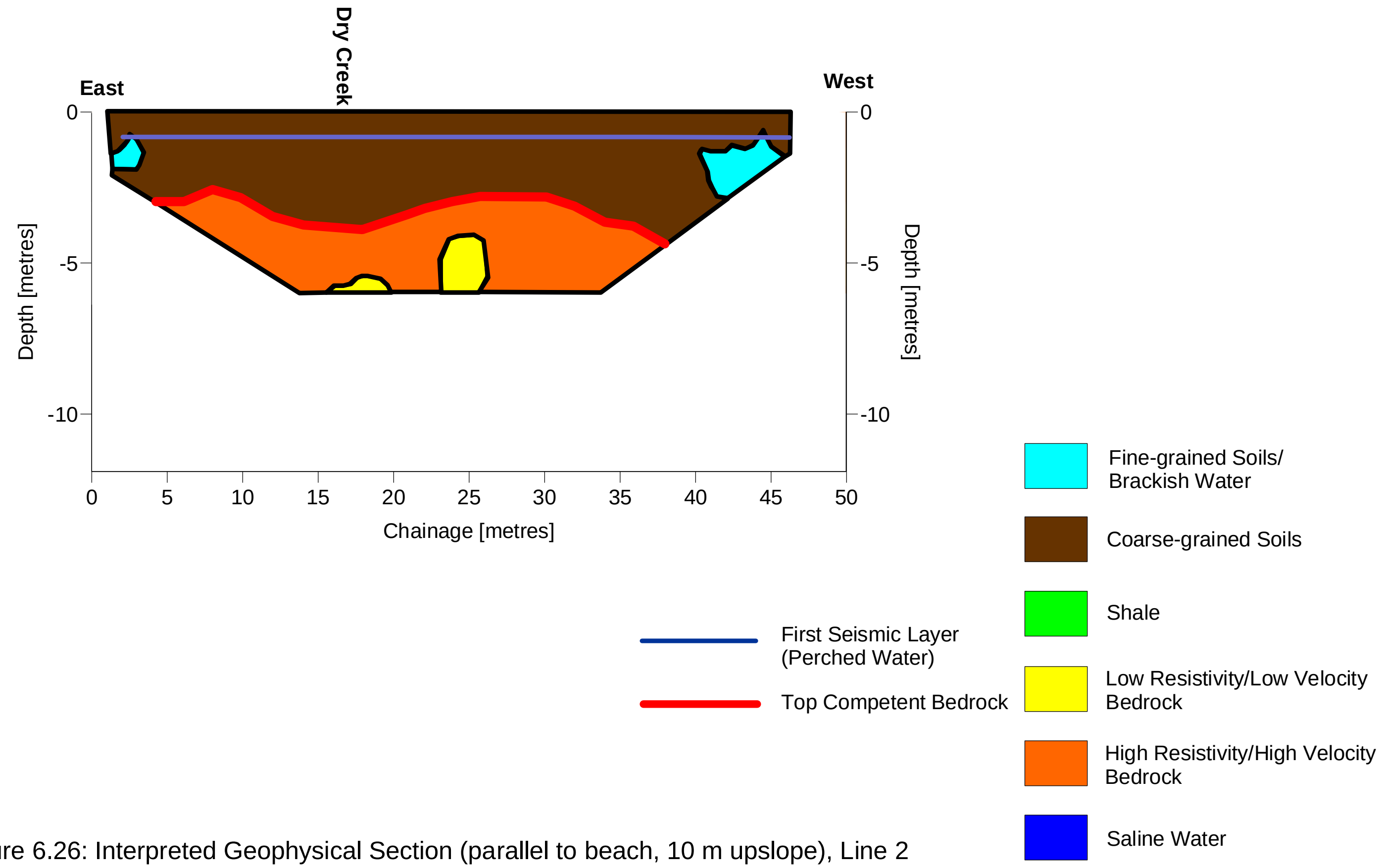

Figure 6.26: Interpreted Geophysical Section (parallel to beach, 10 m upslope), Line 2
Medicine Beach, North Pender Island

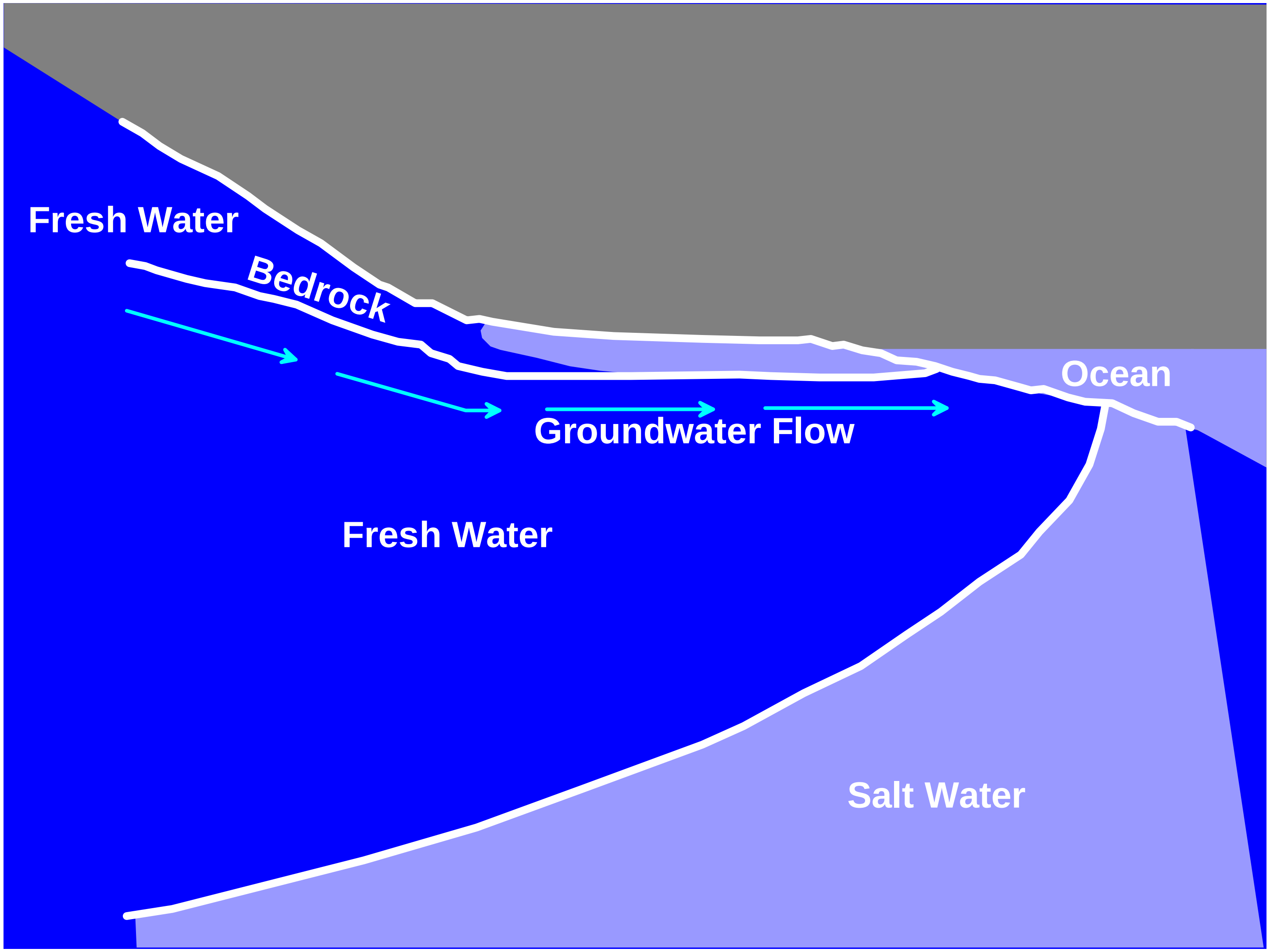

Figure 6.27: Conceptual groundwater flow model, Medicine Beach, North Pender Island

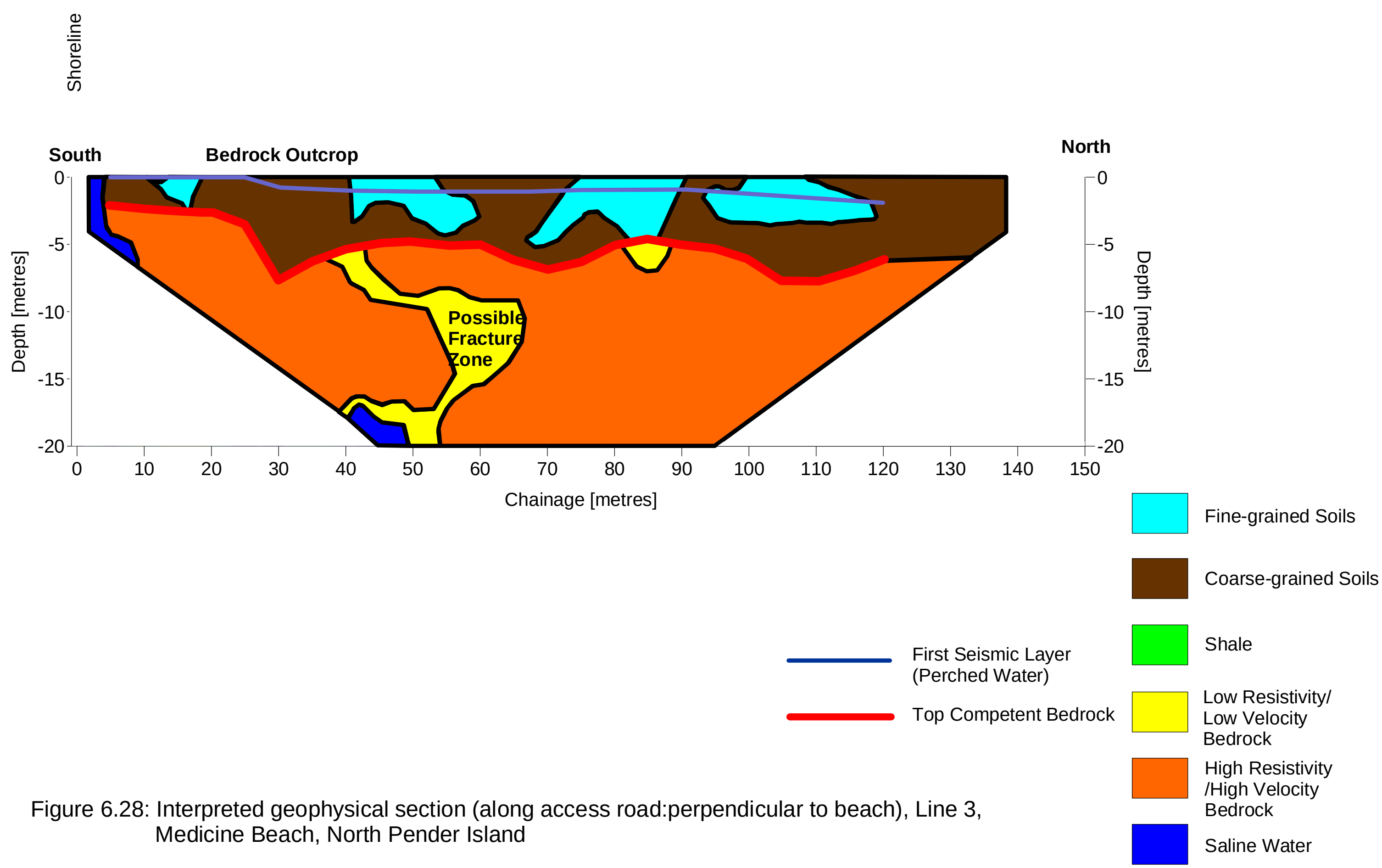

Figure 6.28: Interpreted geophysical section (along access road:perpendicular to beach), Line 3, Medicine Beach, North Pender Island

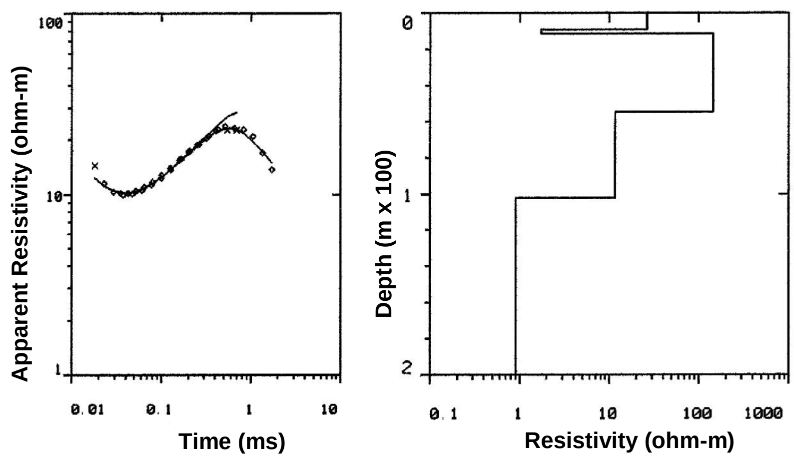

Figure 6.29: Time domain electromagnetic sounding beside Medicine Beach, North Pender Island. The apparent resistivity curve on the left illustrates the field data along with the model curve that fits the data. The model used is shown on the right.

The interpreted time domain electromagnetic sounding curve is presented in Figure 6.29. On the basis of field observations and the very low resistivity, the first layer represents a brine saturated sandy and gravel layer reflecting the influence of high tide. The survey was conducted as the tide was going out. The second and third layers are relatively conductive as would be anticipated for shale. The fourth layer has a very low resistivity, which indicates the presence of saline water at a depth of 100 metres. The presence of the more resistive second and third layers assists in explaining the presence of a salt water marsh since the clays of the Cedar Formation shales seem to represent an impermeable boundary that separates the salt water marsh from underlying freshwater. The freshwater is underlain by saline water.

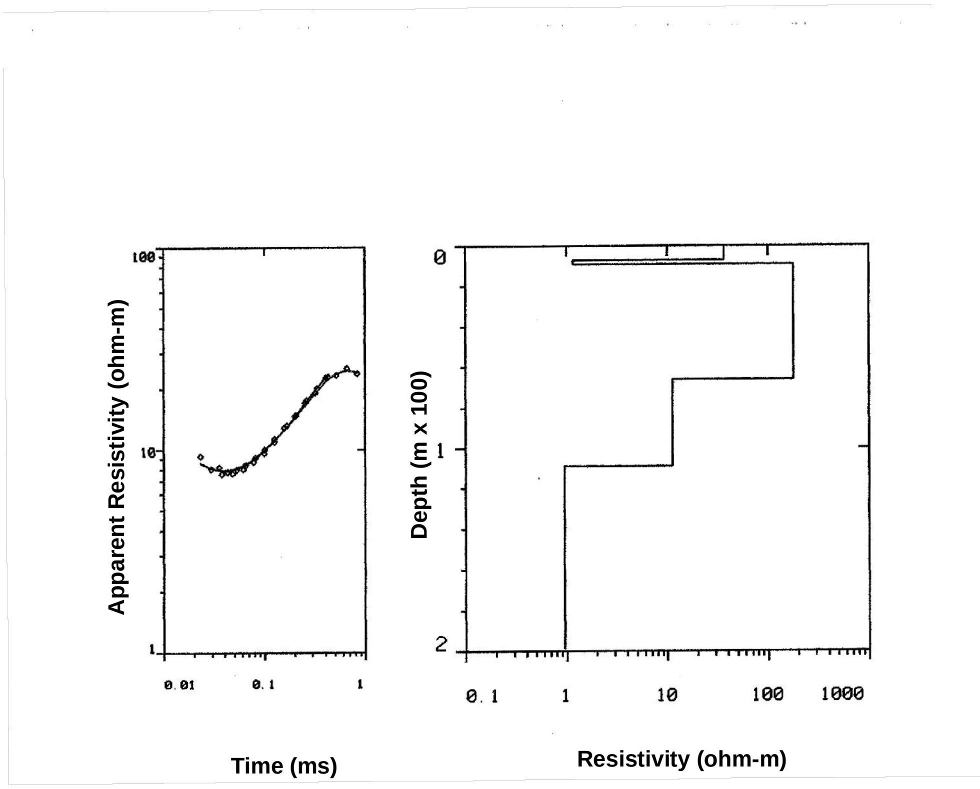

Figure 6.30: Time domain electromagnetic sounding beside Medicine Beach, North Pender Island. The apparent resistivity curve on the left illustrates the field data along with the model curve that fits the data. The model used is shown on the right.

The time domain electromagnetic sounding presented in Figure 6.30 was located at the same elevation on Medicine Beach and 10 metres to the southwest of the previous sounding. The very low resistivity layer is now the second layer and represents a thin zone of saline water.

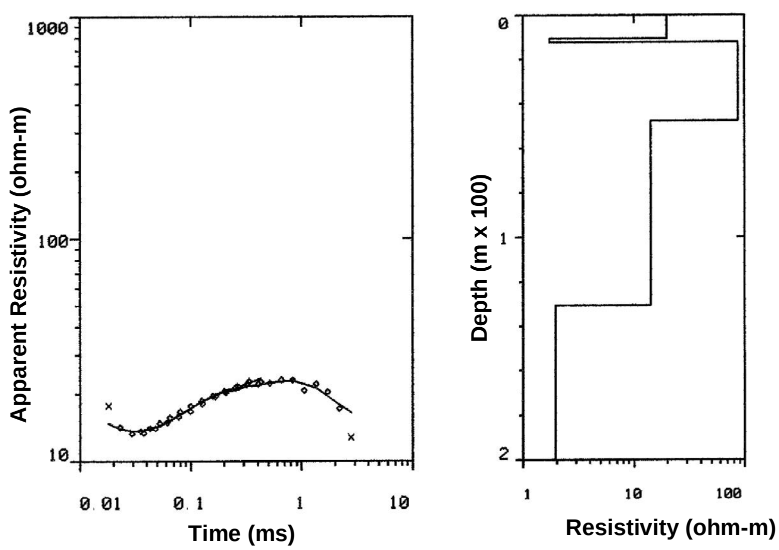

Figure 6.31: Time domain electromagnetic sounding beside Medicine Beach, North Pender Island. The apparent resistivity curve on the left illustrates the field data along with the model curve that fits the data. The model used is shown on the right.

The time domain electromagnetic sounding presented in Figure 6.31 is located 10 metres to the southwest of the previous sounding (Figure 6.30). The resisitivity of the second layer is higher than in the previous sounding reflecting the increased time since the tide had gone out. The lower resistivity of this layer reflects the decrease in salinity of the pore water.

6.4 South Pender Island

6.4.1 Higgs Road

Figure 6.32: Electrical imaging instrumentation along Higgs Road, South Pender Island. The vegetation along the road side is indicative of a soil cover. At the far end of the road is the shoreline.

The bedrock in the vicinity of the Higgs Road survey line is Extension Formation conglomerate having dips ranging from 25 to 35^0. The survey line was oriented in an east-west direction perpendicular to the mapped strike of the bedrock and traversed a fault mapped by England (1989) (Figure 6.1b, Line M). The electrical properties of the surficial material indicate a clay-rich soil horizon in the portions of the line possessing resistivities of less than 40 ohm-metres (stations 60 to 180, Figure 6.33). The clay is underlain by coarse grained soils. Silty or sandy soils or both are anticipated locally along the remainder of the survey line (Figure 6.33). The geophysical interpretation correlates well with the field research conducted by Agriculture Canada (1988). In the vicinity of station 220, the surficial materials become more conductive, and the increased conductivity is likely a response to increased total dissolved solids due to the proximity to the saline waters of Swanson Channel.

The electrical properties of the bedrock vary significantly along the line (50 to 350 ohm-metres). There are several near-vertical zones of lower resistivity (stations 70 and 155). These zones may be a result of increased clay content, increased total dissolved solids or fractures. The fault mapped by England occurs in the vicinity of station 155. The electrical imaging modeled response is presented in Appendix C (Figure C.32).

On the basis of the interpreted seismic refraction velocity values for the second seismic layer (1400 to 1500 m/sec.) from station 220 to the west end of the line, there is a perched water table occurring above the soil/bedrock interface. This interpretation also corresponds well with the conductive zone attributed to increased total dissolved solids in the groundwater. The depth to competent bedrock varies from 3.0 to 10.6 metres along the line, with the greatest depth occurring at the east end of the survey line. Bedrock outcrops beyond the west end of the survey line along the coast. The measured seismic refraction velocity for competent bedrock varies between 3500 and 3750 m/sec. A zone of decreased seismic velocity was observed between stations 120 to 150. The degree of fracturing calculated for this zone is 30%; that percentage indicates that this zone within the bedrock likely has significantly increased secondary porosity and permeability. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.33).

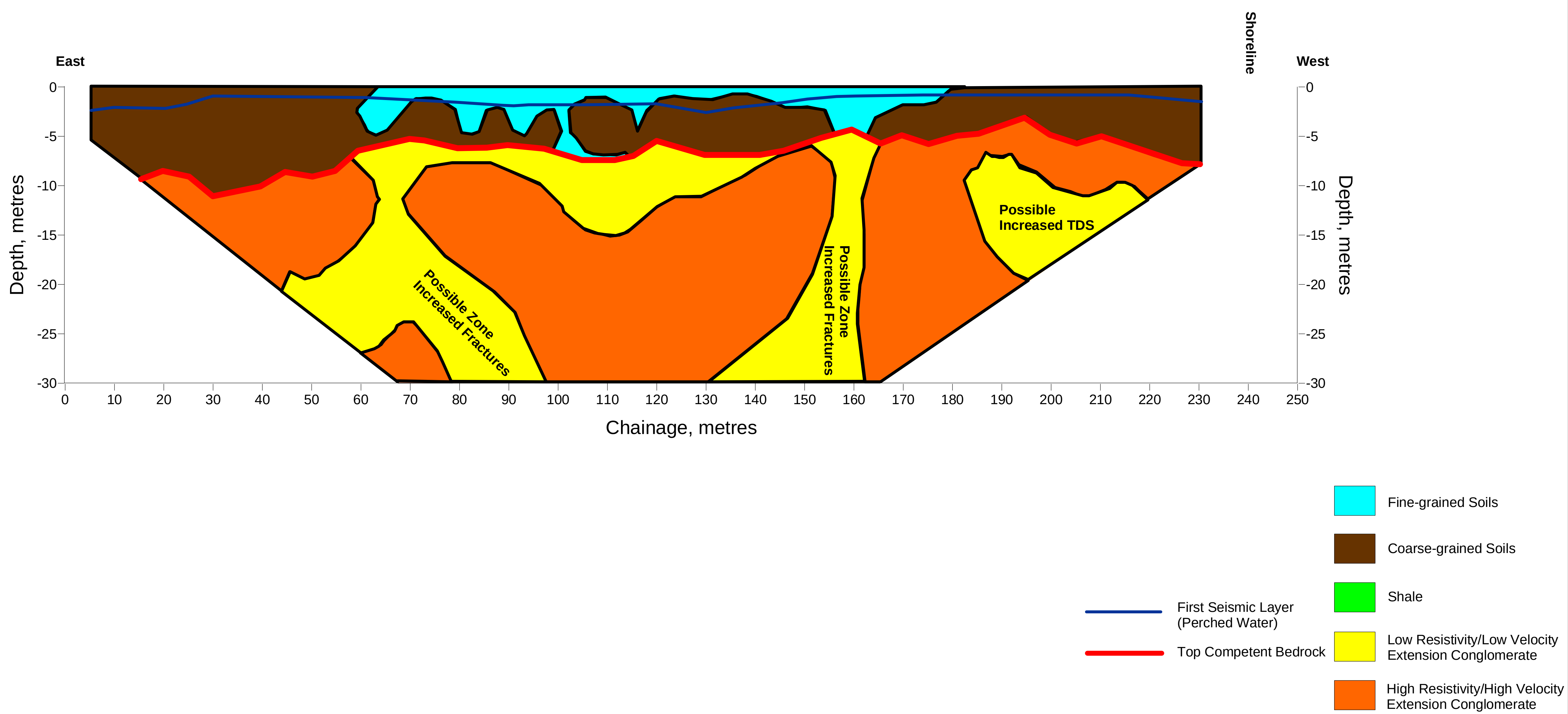

Figure 6.33: Interpreted geophysical section, Higgs Road, South Pender Island

6.4.2 Southlands Drive

At the Southlands Drive site, the bedrock comprises conglomerates of the Extension Formation with dips ranging from 25 to 35^{0}. The survey line was oriented east-west and was parallel to the known strike of the bedrock (Figure 6.1b, Line N).

The surficial materials encountered along Southlands Road (Figure 6.34) are interpreted to be clay (20 to 30 ohm-metres) near the surface, underlain by silty or sandy soil at depth between stations 75 and 225. This interpretation is based on increasing resistivity with depth. Between stations 0 and 75, the surficial material has been interpreted to be coarse grained soil. Agriculture Canada (1988) mapped the surficial material as well drained gravelly, sandy loam overlying conglomerate. The Agriculture Canada interpretation does not correlate well with the geophysical interpretation over the western portion of the survey line. The geophysical interpretation is, however, consistent with the available water well information on soil type. The electrical imaging modeled response is presented in Appendix C (Figure C.34).

On the basis of the seismic refraction velocities measured for the second seismic layer (1475 to 1750 m/sec), there is a perched water table occurring above the soil/bedrock interface. Between station 140 and the western end of the survey line, there appears to be a channel-like feature occurring within the overburden. The soils within this feature appear to vary, but to possess silt or sand, as indicated by the measured resistivity values of 50 to 80 ohm-metres. Water wells in the vicinity of the survey line indicate that the water table occurs within the bedrock itself (www.gov.bc.ca/cgi-bin/env_exec/wwwapps/waterbot/ gwellout). The depth to competent bedrock varies from 5.9 to 14.0 metres along the line. The greatest depth to competent bedrock occurs in the vicinity of the channel-like feature. Buried channels within the overburden represent potential zones of increased porosity and permeability that may provide a useful source of freshwater for local residents.

The seismic refraction velocities for the competent bedrock vary between 3000 and 4700 m/sec. with the lowest velocities occurring beneath the channel-like feature. The channel was likely responsible for increased weathering in the bedrock. That weathering would translate into increased porosity and permeability. The channel represents a preferred drilling location for water wells. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.35).

6.4.3 Spalding Road

Geophysical investigations conducted along Spalding Road include seismic refraction profiling, electrical imaging and time domain electromagnetic soundings (Figure 6.1b, Line O). The bedrock in the vicinity of the site consists predominantly of Cedar Formation shale having dips of about 60^0. The survey line was oriented perpendicular to the strike of the bedrock.

The electrical imaging survey indicates that the near-surface sediments are composed predominantly of clay (< 25 ohm-metres). Depth to competent bedrock increases to the east of station 190. There is a resistive unit, likely silt lies between the clay and the underlying bedrock. A near-vertical conductive feature is observed within the bedrock and may correlate to a more highly fractured zone (stations 90 to 100, Figure 6.35). The modeled resistivity of the bedrock is highly variable indicating heterogeneous bedrock rather than a uniform shale horizon. The electrical imaging modeled response is presented in Appendix C (Figure C.36).

The depth to competent bedrock varies along the line from 4.9 to 12.9 metres, with the deepest bedrock occurring east of station 140. A perched water table is anticipated along the line, on the basis of the seismic refraction velocities of the second layer (1450 to 1750 m/sec.). The depth to the perched water table, at the time of the investigation, varied from 0.9 to 2.6 metres. The second layer interpreted from the seismic refraction data may also be a reflection of weathered bedrock. The seismic refraction velocities measured for the competent bedrock vary between 3200 and 4300 m/sec. The variations in velocity represent a complex interaction between varying bedrock composition and degrees of fracturing. The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.37).

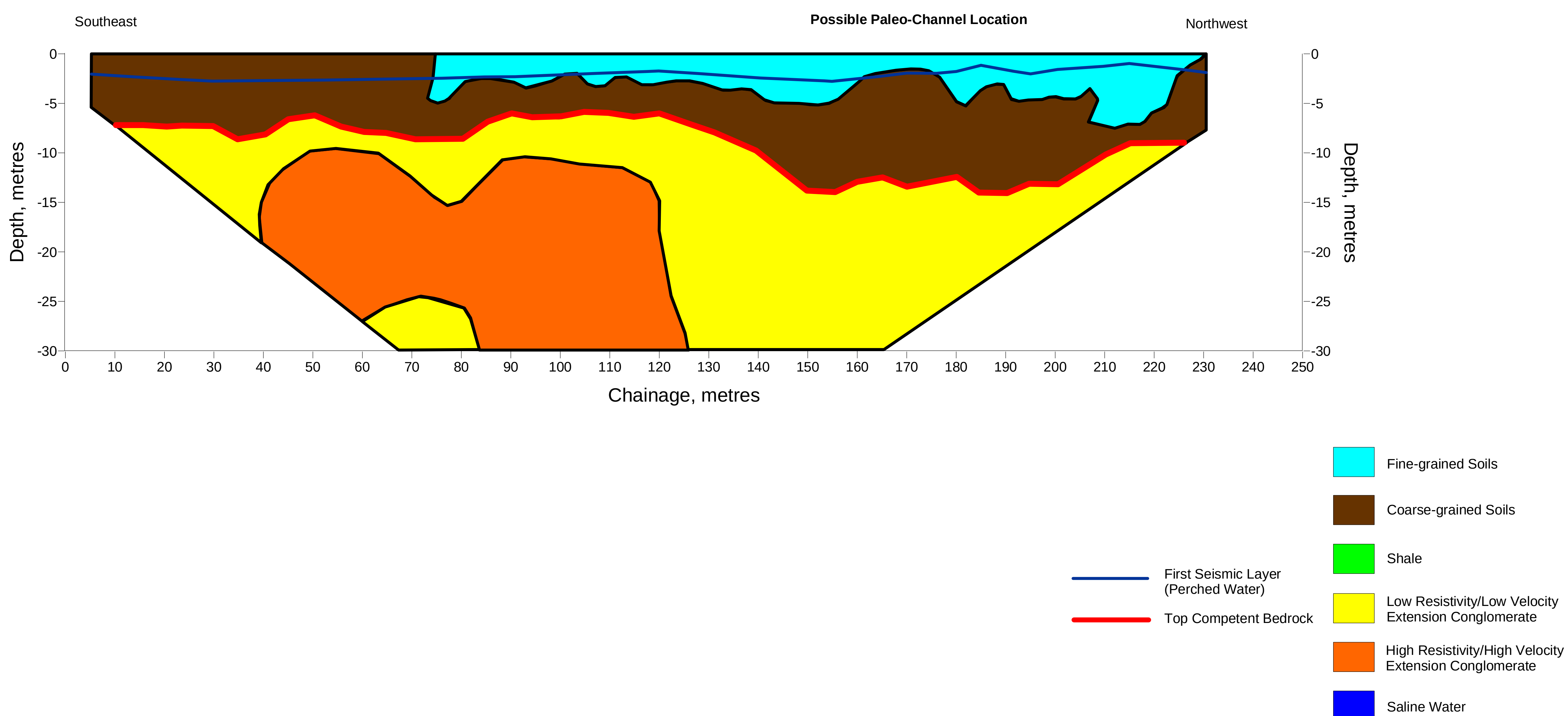

Figure 6.34: Interpreted geophysical section, Southlands Drive, South Pender Island

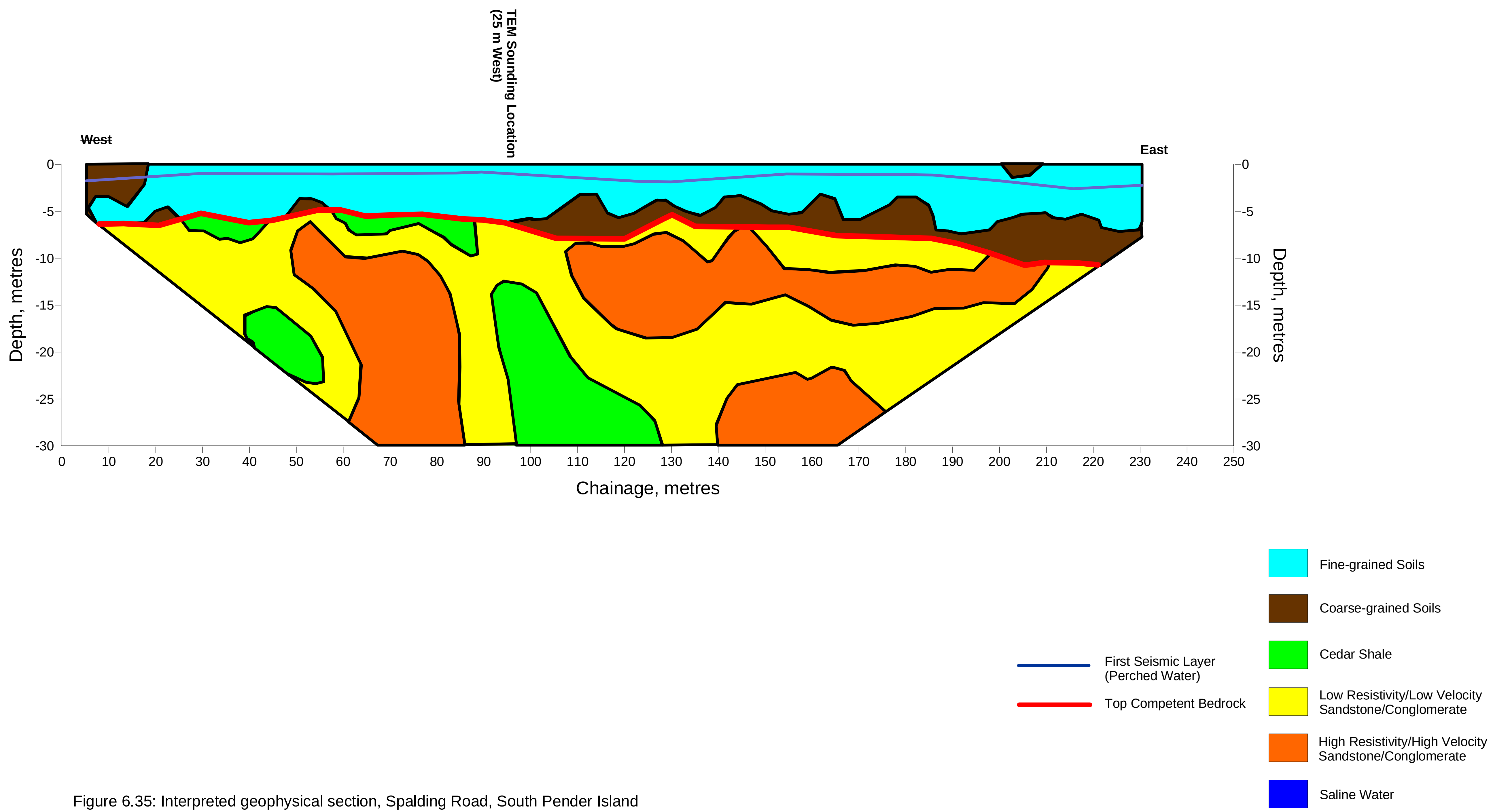

Figure 6.35: Interpreted geophysical section, Spalding Road, South Pender Island

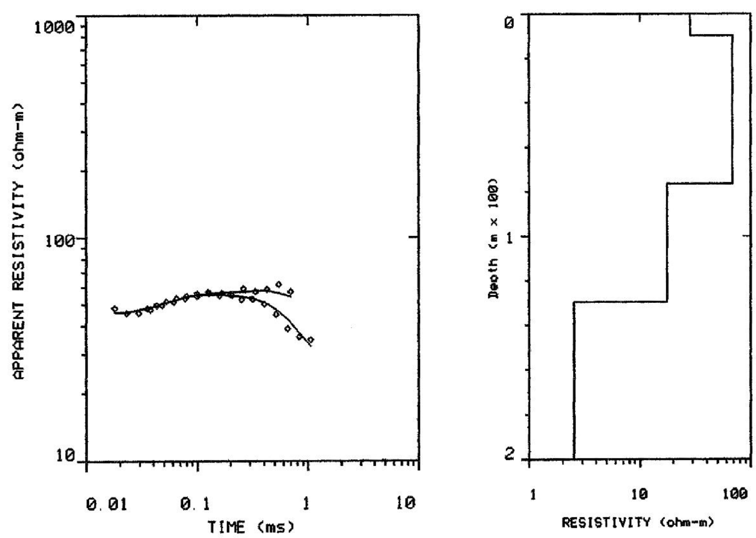

Figure 6.36: Time domain electromagnetic sounding beside Spalding Road, South Pender Island. The apparent resistivity curve on the left illustrates the field data along with the model curve that fits the data. The model used is shown on the right.

Two time domain electromagnetic soundings were located on the opposite side of Spalding Road. The interpreted sounding data correspond well with the other geophysical survey results (Figure 6.36). A four layer electrical section was interpreted. The first layer had a thickness of 8.6 metres and resistivity of 22 ohm-metres, indicating that it consists predominantly of clay-rich soils. The surficial clays are underlain by shale bedrock having a resistivity of 90 ohm-metres. It is expected that the water table occurs within the bedrock at a depth of approximately 70 metres, on the basis of the decrease in resistivity to 25 ohm-metres. At a depth of approximately 130 metres, saline water is expected to be encountered as the resistivity drops to 3 ohm-metres, indicative of increased total dissolved solids. The presence of a perched water table, depth to the water table, and presence of saline water all have implications in the design and implementation of groundwater management practices.

By substitution into the Ghyben-Hertzburg equation (Equation 2.4, Chapter 2), it can be estimated that the water table occurs at an elevation of approximately 3 metres above sea level or at a depth of 50 metres in the low-lying central portion of the basin. The seismic refraction data indicate the presence of a perched water table overlying the soil/bedrock interface. The presence of a perched water table is important; contrary to the normal hydrogeologic situation, it appears that groundwater recharge occurs in both topographic highs and lows. The lack of soil cover in the topographic highs results in significant surface runoff during times of precipitation. Although there is anticipated groundwater recharge through fractures and faults in the exposed bedrock, water flowing within the overburden in the topographic lows likely has a slower velocity and longer residence time; the result is increased potential for infiltration and groundwater recharge. This situation occurs within all of the groundwater basins on both North and South Pender Islands.

6.4.4 Canal Road, South Pender Island

A geophysical survey line was located along Canal Road (Figure 6.1b, Line P). The bedrock at this site consists of DeCourcy Formation sandstones with some shale. The bedrock dips between 80 and 90^0. The survey line was oriented in a north-south direction, parallel to the known strike of the bedrock. A bedrock outcrop of predominantly weathered shale was observed during the geophysical surveys (Figure 6.37). The survey line is also located close to and parallel to the Pender Fault.

Figure 6.37: Bedrock outcrop, DeCourcy Formation, Canal Road, South Pender Island. Note the high degree of weathering of the bedrock, as well as the apparent steep dip.

The electrical imaging interpretation indicates the presence of coarse-grained near-surface sediments along the survey line at Canal Road (Figure 6.38). A soil sampling survey conducted by Agriculture Canada (1988) found the near surface sediments to be predominantly sandy in the vicinity of the survey line. The electrical imaging modeled response is presented in Appendix C (Figure C.38).

The depth to competent bedrock along the survey line ranges from 8.0 metres at the south end of the line to 2.4 metres at station 120. The bedrock in the vicinity of the known outcrop exhibits velocities similar to those of saturated soils; those velocities can also be typical of weathered bedrock. Integration of the electrical imaging and seismic refraction data sets indicate that the electrical properties of the bedrock are highly variable, with no clearly defined patterns. This could simply reflect the influence of the Pender Fault, or may be indicative of the heterogeneity of the bedrock comprising the De Courcy Formation in this area.

The results of the inversion using Rayfract for the seismic refraction survey are presented in Appendix C (Figure C.39).

The bedrock exhibits a wide range of seismic refraction velocities (from 3170 to 4000 metres/second). The lower velocities likely represent a higher degree of weathering, which may be due to the proximity to the Pender Fault.

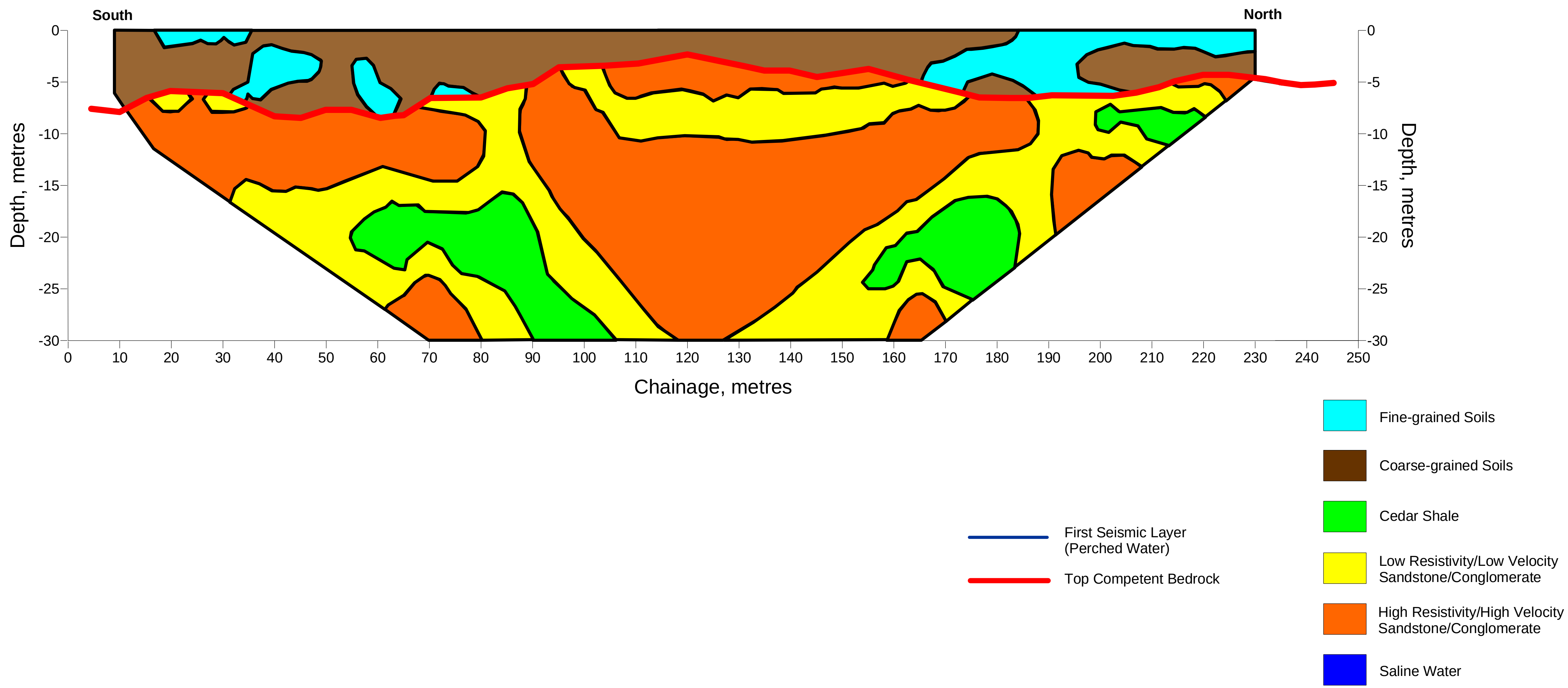

Figure 6.38: Interpreted geophysical section, Canal Road, South Pender Island

6.5 Summary

The geophysical investigations on North and South Pender Island, when combined with the geological mapping, provide additional understanding of the bedrock geology and groundwater flow. The geophysical investigations were limited in their extent due to restrictions of access, presence of cultural noise, and a requirement for relatively straight survey lines.

Denny *et al.* (2006) identified two types of aquifers on the islands: sand and gravel layers in the overburden; and fractured bedrock. This may be an oversimplification of the aquifer types. On the basis of the dug wells and the seismic refraction surveys, there are two types of aquifers within the overburden: sand and gravel layers, and a perched water table near the soil/bedrock interface. There are also two types of aquifers within the bedrock: fractured bedrock and at the contact of different bedrock lithologies. The ability to map variations in soil type, depth to bedrock, and bedrock type are important to understanding the availability of groundwater. This information cannot be attained by geological mapping alone.

Denny *et al.* (2006) state that fractured bedrock aquifers provide the primary source of freshwater for the majority of island residents. The fractured bedrock aquifers do provide the primary freshwater source for island residents reliant upon water wells but the majority of residents, on North Pender Island, live in Magic Lake Estates and rely on surface water sources.

Water quality is also an issue on North and South Pender Islands. The time domain electromagnetic soundings and electrical imaging revealed the presence of saline water. Knowledge of the depth to saline water can be important in the design of water well depths. Using the Ghyben-Hertzberg equation and knowledge of the depth to the water table, it is also possible to estimate the depth to saline water.

Knowledge concerning water quantity and quality can assist decision makers in managing land and groundwater resources. The next chapter provides an overview of land use on North and South Pender Islands and sub-divides the islands into groundwater basins.