Environmental Monitoring of Seabed Sediment Stability, Transport and Benthic Habitat at the Reference Site and the Vicinity of the NSPI TISEC Location in the Minas Passage

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March 17 /2011

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Executive Summary

As part of a monitoring plan for the FORCE in stream tidal power demonstration site, surveys were conducted at the pre determined Reference Site and the location of the Nova Scotia Power Inc/Open Hydro test deployment site in the northern region of Minas Passage, Bay of Fundy. Surveys were undertaken by Seaforth Engineering using a towed sidescan sonar system as well as towed video camera. The sonograms were processed and sidescan sonar mosaics were produced. This information was interpreted, compared and contrasted with previously collected multibeam bathymetry and derived backscatter and slope imagery, as well as sidescan sonograms to determined both natural change and possible effects of the turbine placement, operation and removal over a one year time frame.

The reference site showed no detectable seabed change since the original data was collected over 5 years ago. The seabed is dominantly exposed bedrock ridges with intervening flat regions of gravel with boulders. The turbine site showed a minor change to the seabed. Two of the gravity platform feet appear to have eroded small depressions on the seabed within volcanic bedrock approximately 1 m in diameter. The turbine was placed on a very hard exposed broad basalt platform with minor regions of gravel with boulders. No other changes in the morphology or gravel distributions of the seabed were detected and no fine grained sediments occur both in the nearfield and farfield. The turbine base produced only a minimal effect on the seabed.

Introduction

As part of the requirements for the development of an in stream tidal power test facility in Minas Passage, an Environment Effects Monitoring Program has been developed to assess the effects of the devices and cables on seabed sediment, stability and benthic habitat. This report is part of that plan and concerns two sites: a chosen Reference Site, herein referred to as RS, and the site of the December 2010 retrieved Nova Scotia Power Inc./Open Hydro turbine, referred to as NSPI/OH1. Seaforth Geosurveys Inc. (2011) conducted a field survey of the sites using high resolution sidescan sonar systems and towed video camera.

This report describes the original characteristics of the sites and changes in water depth, sediment type, distribution, scour, sediment erosion and transport and biological communities. The assessment of change at the reference site is intended to provide control information for comparison with the effects of the individual devices on the seabed and associated benthic communities. It will also provide an understanding of longer term natural changes to the seabed and sediment distributions of the region. This is the first time that a detailed assessment of the seabed at the RS has been undertaken.

This report provides a background regional overview of the Minas Passage bedrock and surficial geology and seabed processes, and specifically describes the seabed conditions of the Reference Site and the site of the first turbine deployment of Nova Scotia Power Inc. /Open Hydro. It draws from documents provided to the overall project Environmental Assessment, legacy published reports in the literature, data collected as part of the initial selection of the demonstration sites, and more recently, sidescan sonograms and towed bottom video specifically collected as part of this monitoring study.

Figure 1 shows the location of the study area in Minas Passage, Bay of Fundy, the location of the Crown Lease Area (CLA) south of Ram Head where the demonstration project will take place, and the regional bathymetry of the area taken from a Canadian Hydrographic Service Chart. Figure 2 shows the location of the CLA with the three test sites identified (A, B and C) as well as the RS to the west of the CLA and the NSPI/OH1 site within the CLA. A new test site D, to the south east of Site A in the Crown Lease Area has recently been established. Figure 3 is a multibeam bathymetric map of the area showing the CLA, the device berths, the RS and OH1. Chart datum for the study was LLWLT and the elevations were determined using RTK. The Nova Scotia Monument # 215028 was the reference point. The separation between geodetic elevation and chart datum is 6.59 m.

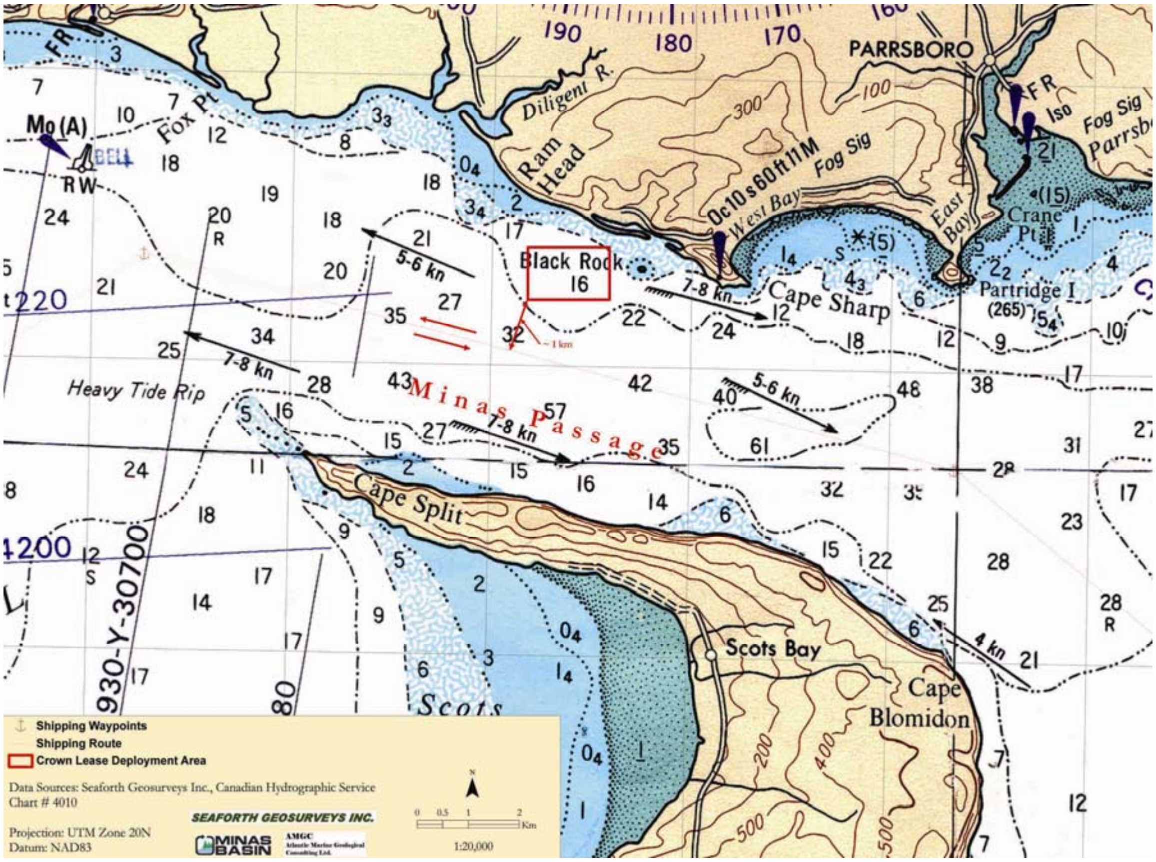

Figure 1 A section of Canadian Hydrographic Chart 4010 of Minas Passage, inner Bay of Fundy. The TISEC demonstration Crown Lease Area lies in the northern part of Minas Passage (red box).

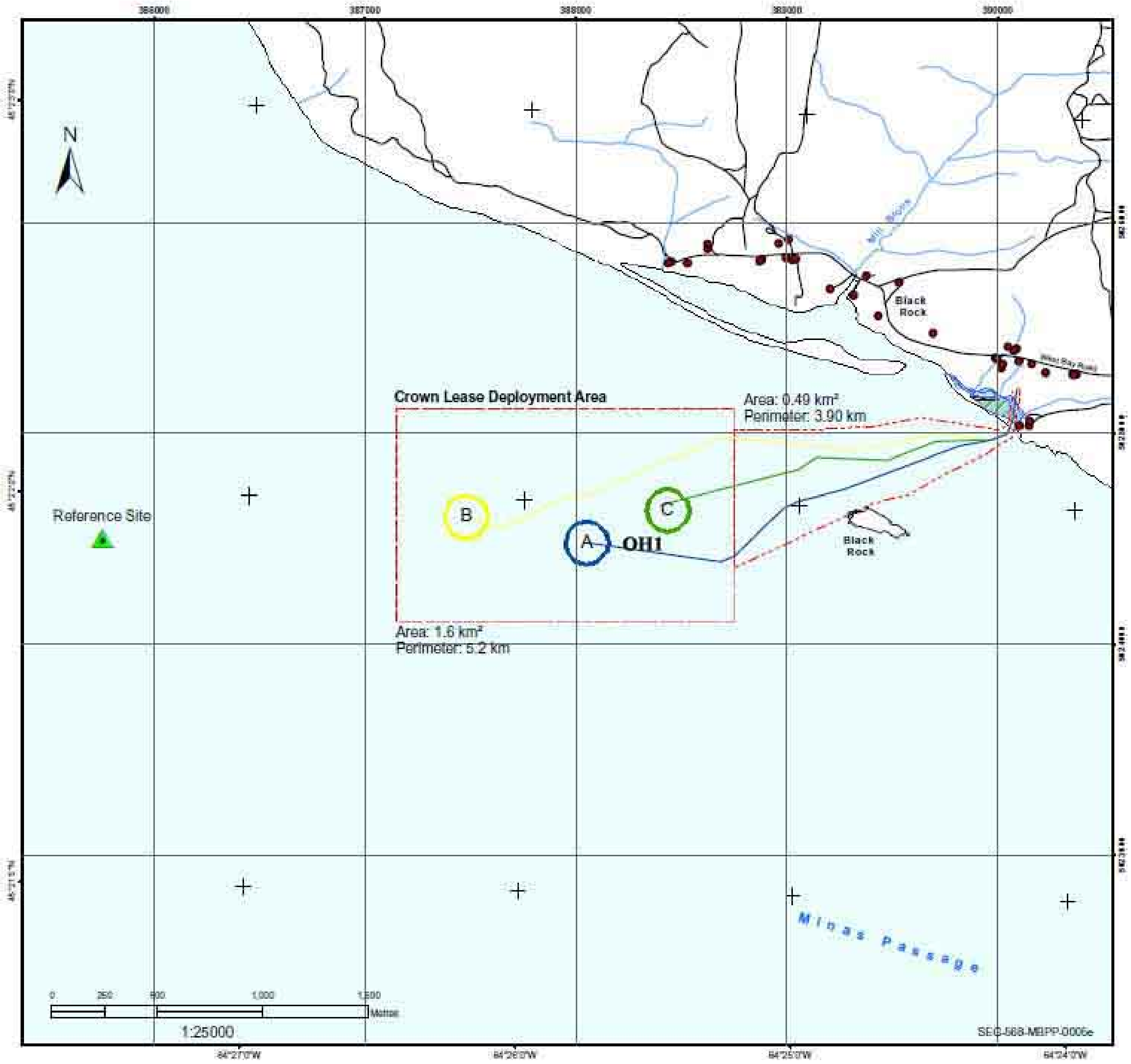

Figure 2 Map of the Crown Lease Area (red dashed box) with the three designated berths (A,B,C), the location of NSPI/OH1(OH1) and the Reference Site (RS) (green triangle) to the west. A new berth has been chosen to the south of C, termed D.

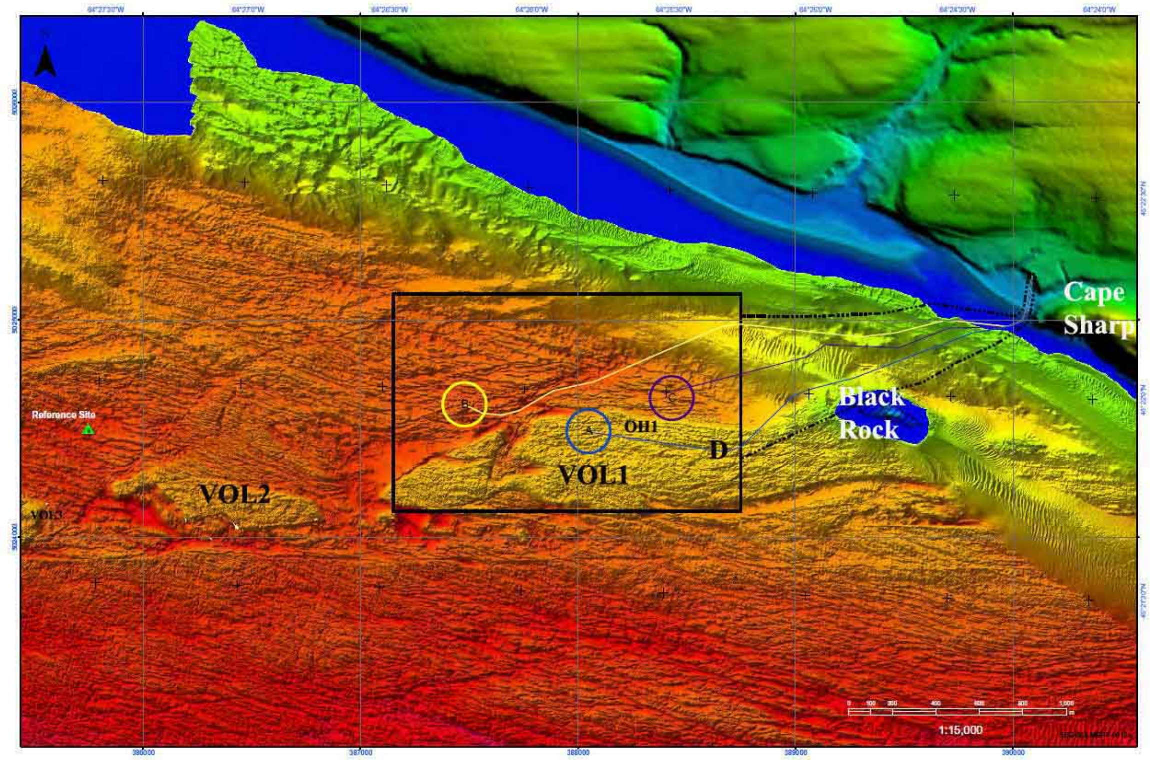

Figure 3 Multibeam bathymetric shaded-relief image of Minas Passage from data collected by the Geological Survey of Canada and the Canadian Hydrographic Service. Superimposed on the map is the Crown Lease Area (black box), the three original test berths, the new berth D, the location of NSPI/OH1, the Reference Site, and the three volcanic platforms of the region.

The RS was chosen to the west of the CLA, position 45 21' 53"N, 64 27' 32"W. The pre existing data base for the RS is different than that for the location of the NSPI/OH1 site. The position of the NSPI/OH1 is 45 21.897 N, 64 25.576 W. The CLA was studied in more detail and has several generations of multibeam bathymetry and sidescan sonar collected over the area. The RS multibeam bathymetry is of lower resolution (2 m) and was collected by the Geological Survey of Canada and the Canadian Hydrographic Service and provided to the project. Previously collected sidescan sonar imagery only exists for the OH1 site.

In order to keep survey costs to a minimum and to obtain the best assessment of seabed change, it was decided for the monitoring surveys to concentrate on the collection and interpretation of high resolution sidescan data as an indicator of change and not collect multibeam bathymetry. The resolution of the sidescan sonograms is approximately 0.25 m, whereas the multibeam bathymetry has a resolution of 0.5 m. Dropped still bottom camera studies were not undertaken, but bottom towed video was collected during the monitoring survey and has been interpreted as ground truth information. Multibeam bathymetry for both sites has been processed for bathymetric contours, seabed slope and backscatter and these results will be presented and discussed.

Regional Physiography, Geography and Bathymetry of Minas Passage

Physiography

The location of the tidal power demonstration facility falls within one major physiographic province of eastern Canada known as the Appalachian Region. Within the Appalachian Region there are two physiographic divisions: the Atlantic Uplands and the Carboniferous-Triassic Lowlands (Williams et al, 1972). The tidal power demonstration site (Minas Passage) falls within the Carboniferous- Triassic Lowlands that is so named because it is underlain largely by rocks of Carboniferous and Triassic age.

Minas Passage

Minas Passage is a rectangular – shaped body of water that connects Minas Channel to Minas Basin and is approximately 14 km long. At its narrowest constriction, it is 5 km wide and that area occurs between Cape Sharp and the southern shore of North Mountain. It is 10 km wide at its widest point between Parrsboro and Cape Blomidon on the southern shore. The Passage is oriented northwest – southeast. The four corner points and boundary lines of Minas Passage are Ramshead Point west of the mouth of the Diligent River in the northwest, south to the western tip of Cape Split, southeast to Cape Blomidon and northeast across the passage to Second Beach, at the eastern headland of the entrance to Parrsboro Harbour. Black Rock is a small basalt island that lies in the northern part of Minas Channel to the east of Cape Sharp, approximately 0.5 km offshore. Black Rock is a local reference point for the demonstration tidal power project that lies to the west (Figure 2 and 3).

Bathymetry

The Canadian Hydrographic Chart for Minas Passage is Chart # 4010 (Figure 1). The sparse bathymetry presented on this chart is in fathoms and it depicts Minas Passage as a narrow body of water constricted to the north of Cape Split as defined by the 20 fathom contour that broadens toward the east to the north of Cape Blomidon. The deepest depths in the Passage are 61 fathoms in the central area to the south of Cape Sharp.

Chart #4010 also shows a number of current velocity vectors with the highest values 7 - 8 knots off Cape Split and Cape Sharp. A current velocity of 5 – 6 knots is plotted on the north side off Ram Head. Minas Passage is the region of highest currents in the Bay of Fundy.

Minas Passage has previously been studied as part of previous tidal power proposals in the 1960s and 70s and geological/geophysical surveys were conducted to investigate seafloor conditions and sediment distributions although these were of low resolution.

Multibeam Bathymetry

Modern bathymetric mapping technologies have significantly evolved over the past several decades and now utilize multibeam sonar systems that provide for 100% seabed coverage, precise measurements of depth and location, and an ability to display the information in a variety of interpretation friendly images and fly-throughs. At the start of the demonstration project, multibeam bathymetry had just been collected (2006) from the Minas Channel and Minas Passage region of the Bay of Fundy by the Geological Survey of Canada and the Canadian Hydrographic Service at the Bedford Institute of Oceanography and was provided to the project. Subsequent multibeam surveys (2008) were conducted in the region of Minas Passage by Seaforth Geosurveys for Minas Basin Pulp and Power Ltd. on behalf of the proponents to obtain very high-resolution information for project needs and infrastructure micro siting. Multibeam bathymetry not only provides water depth information, but through processing of the data, images of backscatter (proxy for seabed hardness) and seabed slope can be generated.

The bathymetric imagery can be presented as shaded-relief maps that depict the seabed as a digital terrain model with an artificial sun shining across the imagery to enhance relief. They are similar to aerial photographs of land surfaces. The data can also be displayed using conventional, but very precise bathymetric contours. These maps and images can be interpreted in conjunction with seabed samples and photographs, and seismic reflection and sidescan sonar data to understand in considerable detail seabed materials and processes active on the seabed. The following is a description of the regional bathymetry of Minas Passage based on multibeam bathymetry.

Minas Passage Bathymetry

The regional multibeam bathymetric shaded relief image in Figure 3 shows the water depths of Minas Passage in a colour depth-coded presentation. The image extends from the western Reference Site to Black Rock in the east in the northern region of Minas Passage.

The region of the Crown Lease Area is a rough surface of exposed bedrock ridges and some fields of ripples in gravel. A prominent series of three, 30 – 40 m shallow flat-topped platforms extend to the west from Black Rock and collectively form a ridge that is over 4 km in length. These are areas of volcanic outcrop of North Mountain Basalt on the seabed confirmed by magnetic maps of the region and bottom photographs. For this presentation they are identified as VOL1, VOL2 and VOL3. Directly to the south of the volcanic platform is a prominent linear fault that runs east-west parallel to the trend of the platform extending from the southern area of Cape Sharp to the west. The region to the north of the volcanic ridge consists of rough morphology similar to the area to the south of the platform and is a region of outcropping bedrock and gravel with boulders. The seabed shallows abruptly toward the north shore of Minas Passage with a shore platform at about 20 m water depth that is approximately 0.5 km wide extending from the low water shoreline.

To determine appropriate locations for the in-stream tidal power demonstration project, an interpretation of the Minas Channel and Minas Passage region was first undertaken by Minas Basin Pulp and Power Co. Ltd. utilizing previous published material and reconnaissance seismic reflection, sidescan sonar and sample data collected by the Geological Survey of Canada. This analysis determined that the most appropriate location for a demonstration tidal power project was located in Minas Passage and that such a location occurred to the west of Black Rock in the northern area of Minas Passage. This siting analysis was based on criteria such as avoidance of seabed hazards, preference for hard and stable seabed, water depth limits for devices, length reductions for marine cables, avoidance of shipping lanes and fishing zones, proximity to the electrical grid and distance from adjacent parkland or protected areas. Once the area was selected, it was necessary to conduct very high-resolution surveys in order to characterize the seabed in considerable detail and to determine appropriate sites for device micro siting.

The prime system utilized for the high resolution survey (2008) was a Reson multibeam bathymetric sonar that could present the morphologic information at approximately 0.5 m resolution, considerably higher than the previous multibeam data collected by the Geological Survey of Canada that was gridded at 2 m. The multibeam information from the high resolution survey was collected over a smaller area than the GSC surveys. The following is a general description of the bathymetry based on the detailed multibeam information (Figure 4).

The high resolution multibeam bathymetric survey was conducted in an area in and around Black Rock extending to the west across the volcanic platform (VOL1). It also continued to the low water shoreline to the north of Black Rock and was conducted at high water to provide as much near shore coverage as possible from a large survey vessel (Figure 4). The survey covers a region of approximately 4 km by 1.6 km.

The high resolution multibeam bathymetric shaded-relief map, Figure 4 shows the east west trending volcanic ridge as the dominant morphologic feature of the southern part of this study region. Water depths across the ridge show that it is defined by the 30 m contour in the eastern portion near Black Rock, and increases in depth to 35 m at the western tip of the feature. It is a broad flat platform with very minor relief of a few m across its surface and is 500 m wide at its widest location tapering to a triangular-shaped western end. Several broad deep channels occur across the surface of the platform near the western part of the feature and reach over 50 m water depth. A few localized linear depressions occur along the northern flank of the volcanic ridge and appear as erosional moats where seabed scouring takes place. The volcanic ridge protrudes above the surrounding areas by as much as 15 m but averages 5 m in height and has very steep slopes. The slopes are steeper and higher in the western portion of the platform area. Some local scouring appears to occur around the volcanic ridge flank in the west.

A broad region of northwest trending bedrock ridges lies to the north, south and west of the volcanic platform in deeper water. The ridged region to the north has water depths that range between 35 and 40 m in the east and is slightly deeper in the west, ranging between 40 and 50 m. A few intervening deeper regions between ridges are over 50 m water depth. The ridges are rough and undulating with generally flat regions occurring between ridges in the troughs.

In the northern region of the study area at approximately 45 m water depth, the seabed becomes smoother and the bedrock ridges appear to be buried beneath sediments as the area approaches the shoreline. Continuing to the north and northeast, the seabed presents a gradual shallowing slope with increasing steepness, and at 10 m water depth a scarp occurs where the seabed flattens to the north. This flat region is a broad platform that continues to the shoreline across the intertidal zone. The edge of the scarp is convoluted in places and only a few areas are straight and well-defined. These regions of convoluted scarp are interpreted to represent slump scars. It is not know when the slumping took place or if the process remains active.

Bedrock Geology

The bedrock geology of most of the floor of Minas Passage is mapped as Triassic/Jurassic sedimentary bedrock (King and Webb, 2004, King and Maclean, 1976). This compilation is regional in nature and presents the geology at a scale of 1:1,000,000 and does not show details at any given location. The passage is depicted as being underlain mostly by Triassic sedimentary rocks but a long linear volcanic deposit occurs parallel to the passage just south of the north shore and is mapped as Triassic McKay Head Basalt. Along the northern coast the bedrock is complex and consists of the McCoy Brook Formation of fluvial, deltaic, lacustrine, playa and aeolian clastic rocks. Lacustrine limestone and basalt agglomerate are common.

Surficial Sediments

With the exception of the nearshore regions of Minas Passage, much of the seabed consists of exposed bedrock in the form of ridges with slightly deeper troughs between ridges, composed of gravel with boulders (Fader, 2009). Additional information on the regional marine geology is contained in the Appendix to the Environmental Assessment report for the demonstration facility. In the northwest region thick surficial sediments overlie the bedrock and have large linear furrows, ridges and isolated scour depressions on their surface. An area of bedforms in gravel, termed gravel waves, occurs in the deepest part of Minas Passage. Other areas of gravel waves occur in the eastern part of Minas Channel and to the northwest and southeast of Black Rock. These gravel waves overlie a thicker deposit of surficial sediments that may represent coarse deposits in the lee of the island associated with strong currents. They may also represent a buried remnant of a deposit of till or glaciomarine sediment that once covered much of the seabed of Minas Passage but has survived erosion.

The volcanic flat ridge that extends to the west from Black Rock is mostly exposed bedrock but pebbles, cobbles and boulders are common. No fine-grained clays, silts and sands appear to be present. In the region of exposed bedrock sedimentary ridges to the north and south of the volcanic platform, sediments occur in the flat areas between the exposed ridges. They have a gravel cover of granules, pebbles, cobbles and boulders. Several seismic reflection systems were used to determine the nature and thickness of the surficial sediments between the exposed bedrock ridges. Little acoustic penetration was achieved and side echoes were common acoustic artifacts on the profiles that result from the hardness and steepness of the nearby bedrock ridges. A covering of rounded boulders also scattered the acoustic energy from the systems degrading penetration and resolution of subsurface events.

Regional interpretations of the seismic reflection data from the Minas Channel region and indeed the inner Bay of Fundy show that glaciomarine muddy stratified sediments are widespread and very thick, in contrast to thin or absent glacial till. This suggests that Minas Passage once contained thick glaciomarine sediments in early post glacial time and today it is a large scoured depression formed by beach erosion during times of lowered sea level and strong currents. The surficial material that occurs between the bedrock ridges and underlies the gravel is more likely to represent glaciomarine muddy sediments than till. Wider areas of flat seabed between bedrock ridges would be expected to contain thicker glaciomarine sediments.

Surficial Sediments of Crown Lease Area

The surficial sediments at the seabed of the Crown Lease area are all gravel – that is granules, pebbles, cobbles and boulders and have been determined from a large grid of bottom photographs. This is also interpreted from the MB backscatter that indicates no mud or sand at the seabed. The sidescan sonograms also show high reflectivity indicating that the seabed is very hard – gravel. The high-resolution multibeam bathymetry shows large boulders on the gravel and exposed bedrock surfaces. Boulder measurements indicate that some are up to 5 m in diameter and they often appear in clusters. Indeed, conditions that occur at the demonstration site are similar to those over much of Minas Passage.

Questions have been posed about the stability and nature of the device sites and the potential for local scour and effects on sediment transport and both local and regional morphology associated with device installations. Sediment samples are a very important component of sediment modeling but they are very difficult to collect in Minas Passage. Subsurface sampling is even more difficult because of the widespread occurrence of protective lag gravel with rounded boulders. Large areas of the seabed of the demonstration site are exposed bedrock in the form of upturned jagged ridges or flat volcanic rock areas. Attempts were made at sampling the gravels and were only partially successful returning a few gravel clasts in most cases. Bottom photographs and video of the seabed provide critical evidence for an understanding of sediment transport, sediment deposition and erosion. Bottom photographs have been collected regionally in the area and over 2200 have been analyzed for particle size, shape, sorting, distribution, stability and biological growth. This information has been integrated with the results from the interpretation of the sidescan sonograms and high resolution multibeam bathymetry.

No sand sized sediments or silts and clays were observed on the seabed of the Crown Lease Area. Most of the photographs were taken during times of slack water or close to it, and sand sized material that may have been in suspension as well as silts, clays and organic matter would be expected to settle temporarily on the seabed. This was not observed from the photographic data suggesting that in the study area there is little sand in suspension and that silt and clay are either in low concentration in the water column or don’t settle to the seabed. Additionally; - pebbles, cobbles and small boulders have no attached biological growth. Larger boulders and adjacent bedrock have broad coverings of low growth that appear to start at about 20 cm above the seabed. This suggests that the smaller gravel sizes that have clean surfaces may be moving and rolling around as bedload and preventing biological growth in the zone immediate to the seabed. The movement is likely local and confined by the bedrock ridges and large boulders of the region. No boulders on the photographic imagery showed tilted sediment lines that would indicate recent movement and repositioning. The seabed appears as a mature hard scoured bottom of bedrock and gravel.

Most of the gravel clasts in the study area are round to subround in shape. A few clasts are angular and may have been transported by ice. A simple interpretation is that the rounding is due to present day active movement. However the larger rounded boulders that occur in the same area do not move. The rounding is interpreted to have occurred during times of lowered sea levels. Relative sea level in the region could have fallen by more than 40 m in early post glacial time as the land quickly rebounded from the removal of nearby glaciers. At times of lowered sea levels, large regions would have been above or near sea level and beach processes of high energy during regressions and transgressions would have produced the roundness of the boulders. Additionally the lowered sea level would have resulted in erosion of both tills and glaciomarine fine grained sediments that were previously deposited over bedrock. Thus the present seabed is largely a relict exhumed bottom with modern elements of granule, pebble and cobble bedload movement. These lag gravel surfaces are termed “relict”; that is, they reflect deposition and formation under differing conditions (very high energy) in the past and have maintained these characteristics for thousands of years to the present. They are not necessarily in dynamic equilibrium with present energy conditions. For these reasons, it is difficult to use gravel in sediment transport models that consider the entire seabed to be in equilibrium with present energy conditions.

Monitoring Methodology

For the NSPI/OH1 site, the approach to study the effects of the turbine/gravity structure on seabed morphology, materials and sediment transport has been based on two surveys using multibeam bathymetry. The highest resolution information – 0.5 m collected for site surveys by Seaforth Geosurveys Inc. in 2008 has been processed to enhance relief and clearly shows details of the morphology (Figure 4). Fortunately, multibeam bathymetry was collected at the NSPI/OH1 site shortly after device installation and this data shows the location and orientation of the turbine and gravity platform on the seabed (Figure 5). The reported position for the device provided by the Canadian Hydrographic Service is a location that occurs near the southeastern rear foot of the device and does not represent the centre. Without the multibeam map of the device overlying bathymetry, it would be impossible to locate with precision each of the device feet. Figure 6 is a reprocessed shaded relief image of high resolution multibeam bathymetry showing the location and orientation of the NSPI/OH1 device and the position of the reported site relative to seabed morphology.

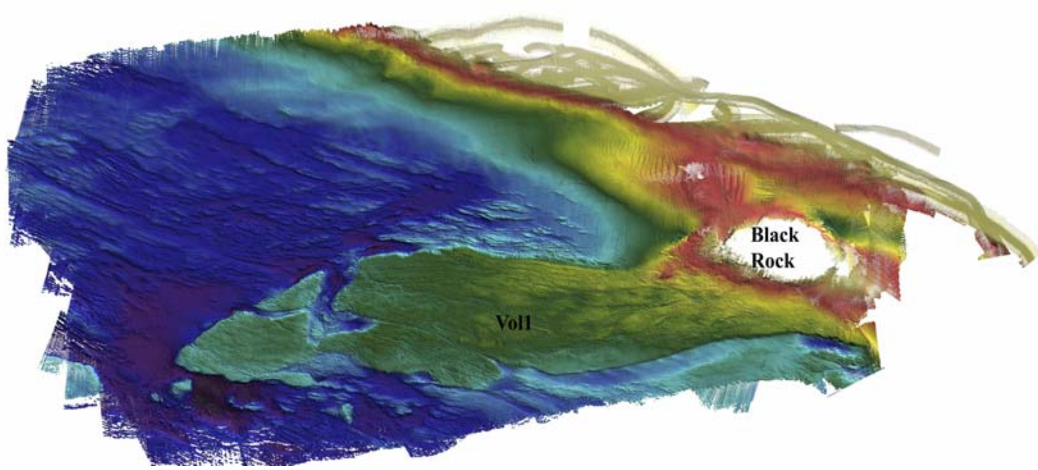

Figure 4 High-resolution multibeam bathymetric map of the area to the west of Black Rock in Minas Passage, produced by Seaforth Geosurveys Inc. This data formed the basis for a variety of seabed maps on backscatter, slope and relief.

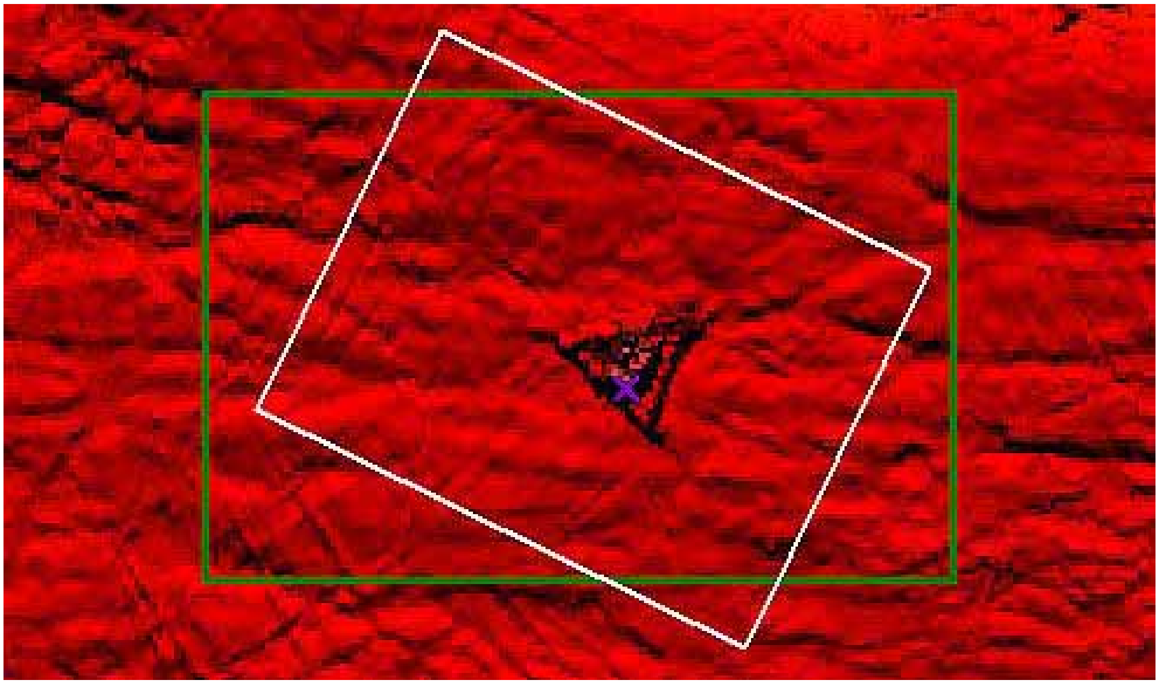

Figure 5 A multibeam bathymetric map of the seabed during the deployed phase of NSPI/OH1 by Seaforth Geosurveys Inc. showing the shape of the gravity platform and the surrounding topography of the seabed. This information provided the exact georeferenced location of the device. X marks the position of the coordinates of the device provided by the Canadian Hydrographic Service. North is to the top of the image and the device is 21 by 25 m in size.

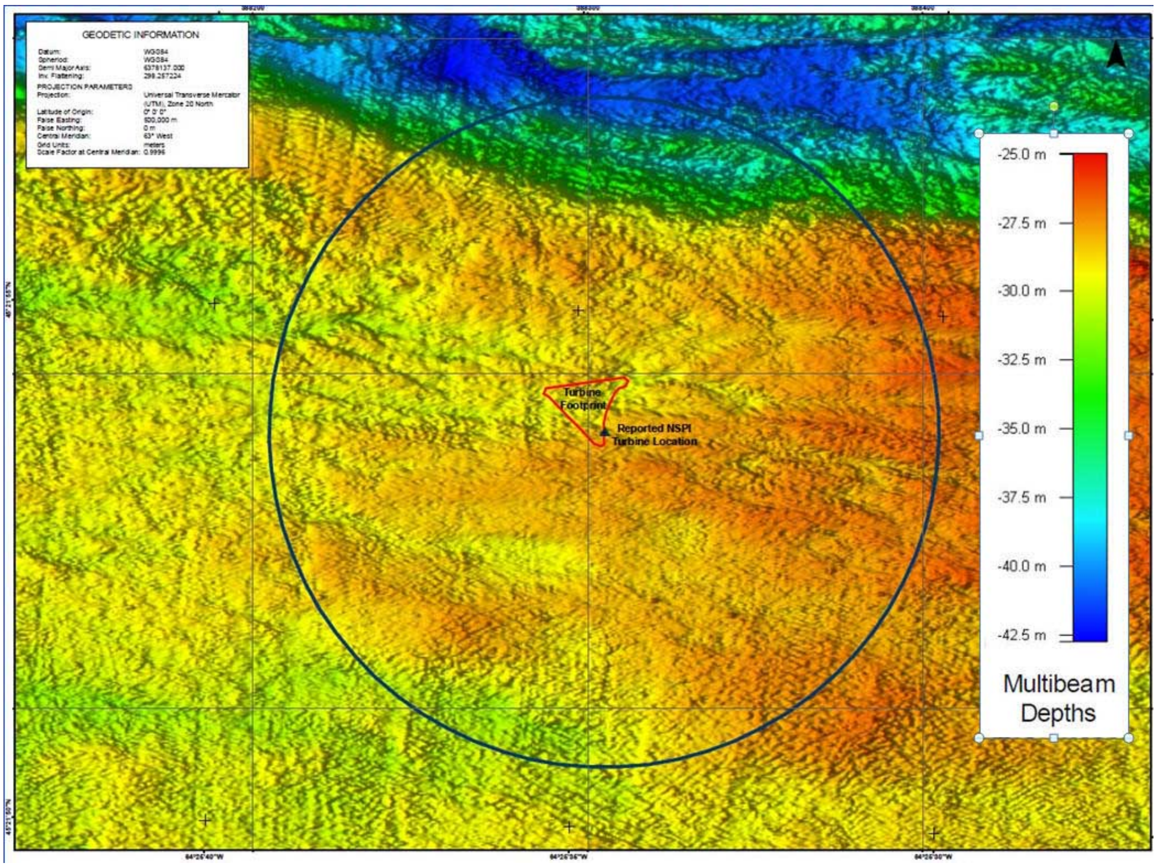

Figure 6 A multibeam bathymetric shaded relief map of the NSPI/OH1 site showing the location of the device (red triangle) relative to detailed bathymetry. The multibeam data was collected by Seaforth Geosurveys and is presented at 0.5 m resolution. The CHS reported location for the device is also shown as a small black triangle. The circle is 200 m in diameter centered on the officially reported position.

A sidescan sonar survey (Seaforth Geosurveys Inc., 2011) was conducted for the monitoring study over and around the device and a mosaic has been constructed (Figure 7). The sidescan information was draped over the multibeam bathymetry and was in good agreement with the location of the major morphological features on the seabed. However, to maximise an understanding of the effects of the device, in particular the feet, it was necessary to precisely locate their positions on the sidescan sonograms. This was a difficult process brought about by the strong currents and limits of sidescan surveying that produces distortion of features. The sidescan data was of high quality with few artifacts and this allowed for a direct overlay and comparison with the multibeam information and the location of the device. Through rubber sheeting methods and landmark identification, it was possible to adjust the sonograms in the GIS for direct correlation. This facilitated the accurate plotting of the locations of the device feet on the raw sidescan sonograms (Figure 8). The original sonograms are the highest resolution imagery from the survey. It is considered that they have been plotted with +- 1 m accuracy. The sidescan sonograms have resolution of 0.25 m and are thus able to show very small features of the seabed as will be discussed in the following sections.

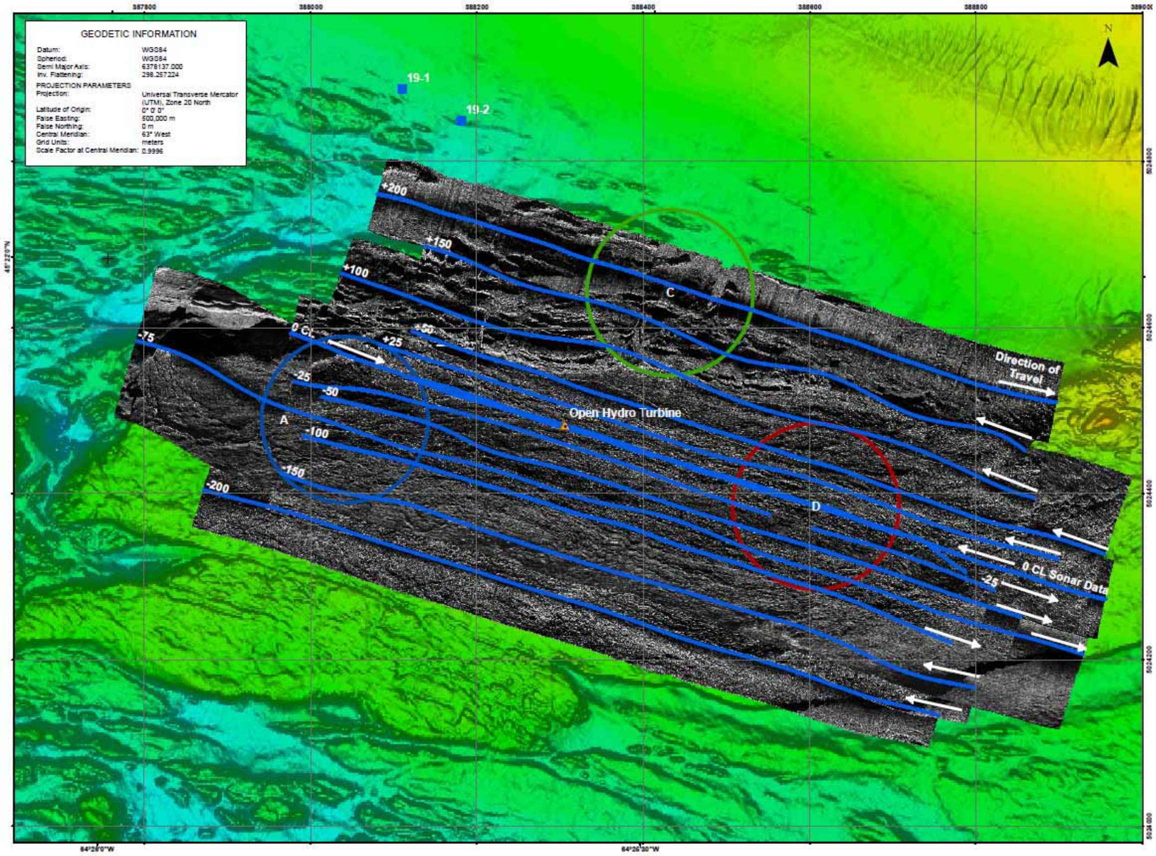

Figure 7 A sidescan sonar mosaic produced from data collected during the monitoring survey. It is superimposed over the multbeam bathymetry (Background). The location of sites A, C, D and NSPI/OH1 are shown. Direction of travel of the sidescan tow fish is shown by arrows.

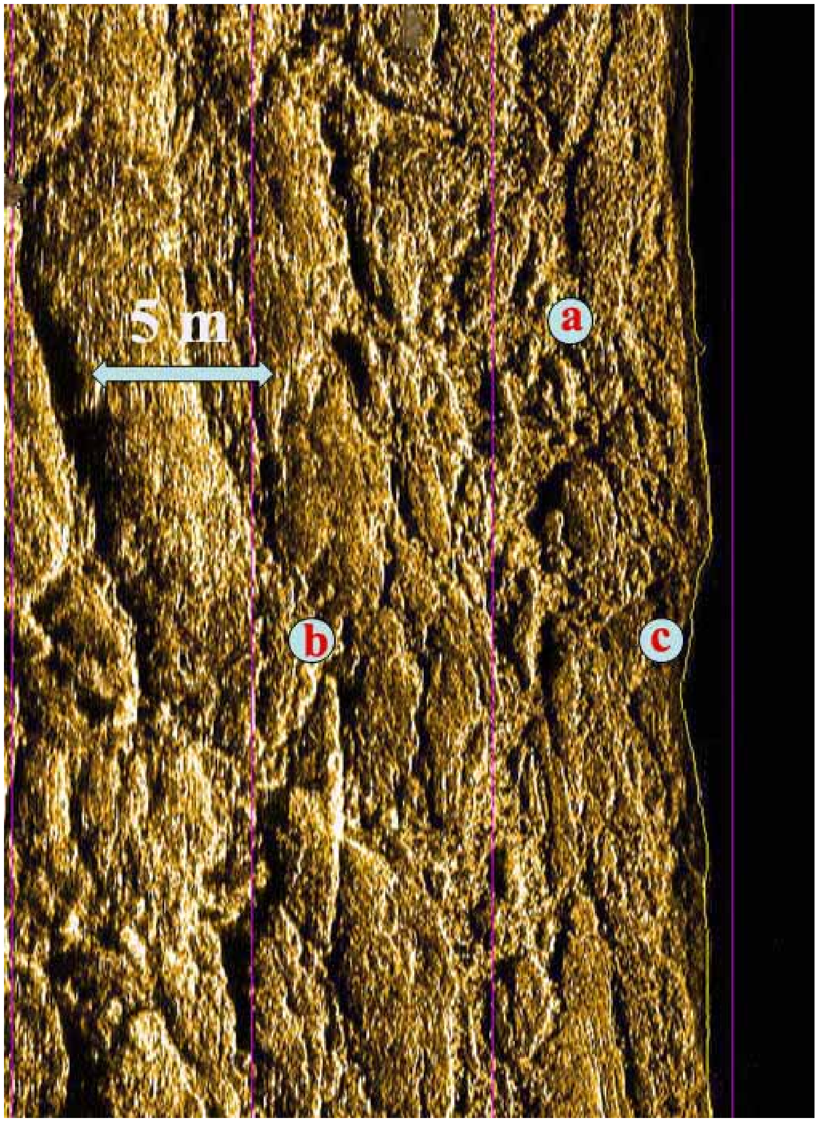

Figure 8 Line -25 sidescan sonogram from the monitoring survey over site NSPI/OH1. The interpreted position of each of the device feet is indicated.

The reference site (RS) previously only had 2 m resolution multibeam bathymetry collected across the area in 2006 and no sidescan data. The sidescan sonograms collected for the monitoring assessment were run in a grid pattern and a sidescan mosaic has been constructed (Figure 9). A series of screened mosaics at various levels of transparency were laid over the multibeam bathymetry to facilitate correlation of seabed features and to assess seabed change.

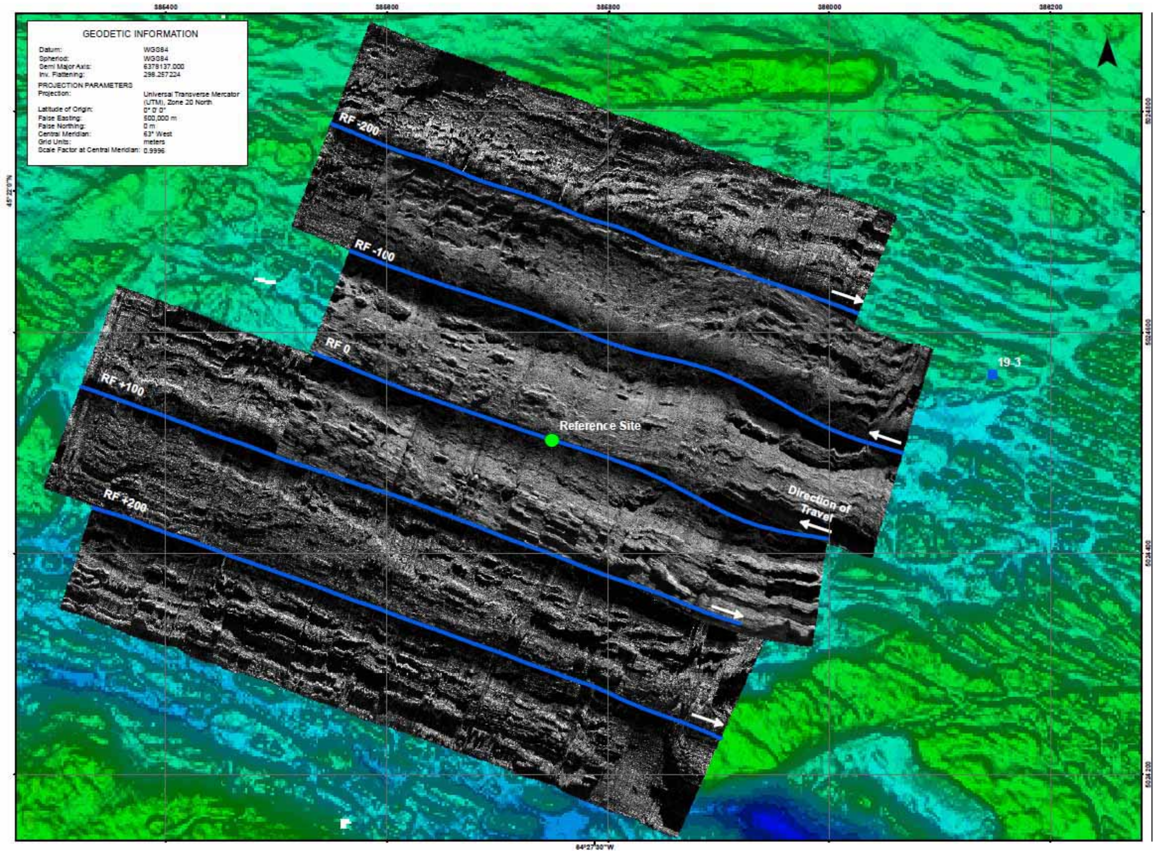

Figure 9 A sidescan sonar mosaic from the Reference Site overlying multibeam bathymetry. The Reference Site occurs in the centre of the mosaic (green dot). Survey lines and direction of travel are indicated.

Bottom towed video cameras were towed across both the RS and the NSPI/OH1 and the track plots are shown in Figure 10 and 11. The data is of moderate quality and the speed of the camera moving across the seabed and particulates in the water column have reduced visibility. The camera varies in height above the seabed during the tows and where it is near the seabed it provide definition of boulders and cobbles, their shape, biogenic growth and the presence of exposed bedrock. The video imagery was compared with the sidescan sonograms and previously collected multibeam bathymetry to assess seabed change.

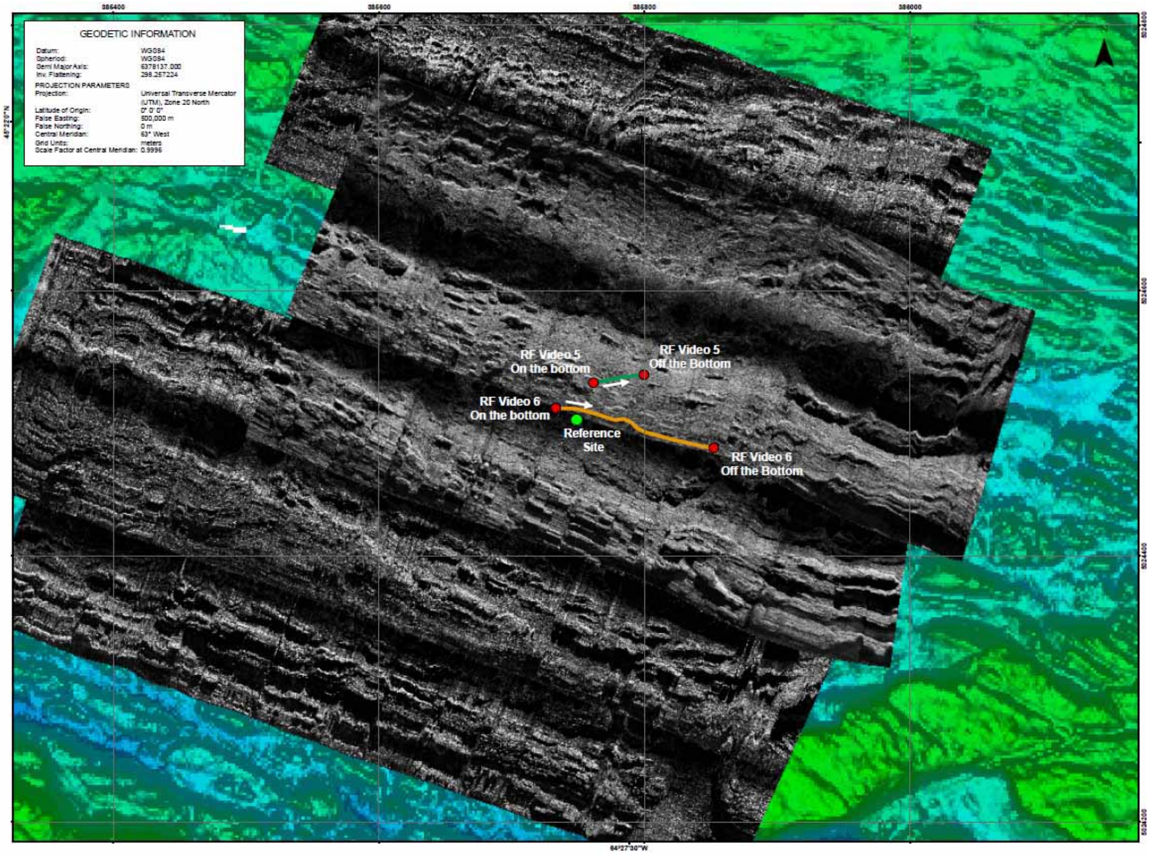

Figure 10 Sidescan sonar mosaic of the Reference Site showing the tracks of the towed video system and the reference site.

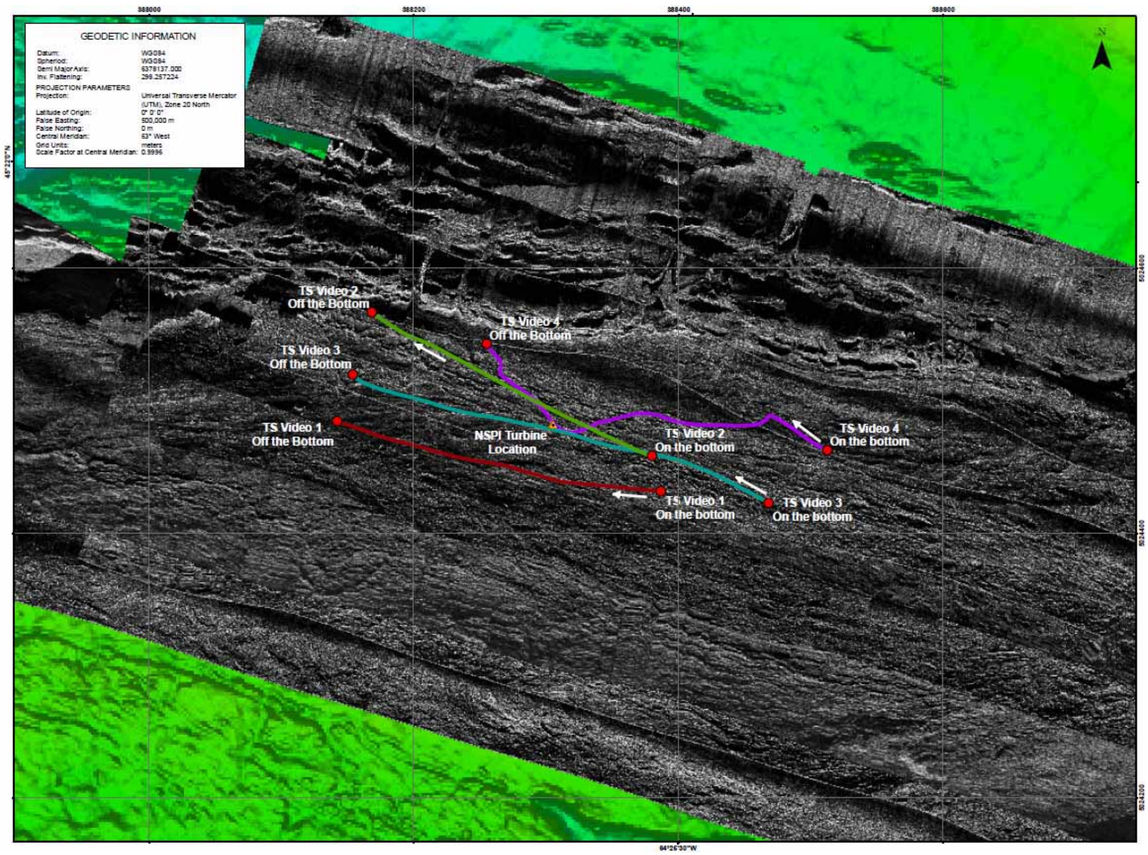

Figure 11 Sidescan sonar mosaic of NSPI/OH1 site showing the tracks of the video transects. The background is a multibeam bathymetric image.

An assessment of benthic habitat based on the collected information was attempted, but the resolution and speed of camera movement limited this activity. Where the towed camera moved close to the seabed, benthic organisms encrusting boulders and bedrock could be detected but details were lacking. There was no disturbance of the biological communities that covered the surfaces at both sites. The high resolution sidescan information showed no change to the bedrock and gravel areas of the seabed and this can be used as a proxy for assessment of benthic habitat.

Reference Site

The reference site lies 1.4 km to the west of the western edge of the CLA at lat and long and in 54 m water depth. Figure 12 is a multibeam bathymetric image at 2 m resolution from the region of the RS and Figure 13 is a contoured bathymetric map from the same area, contoured at 2 m intervals. The region of RS has never been described in detail. No bottom photographs or video have been collected from this site but it was the first site chosen for a current meter deployment and that information has been collected, processed and presented in earlier reports.

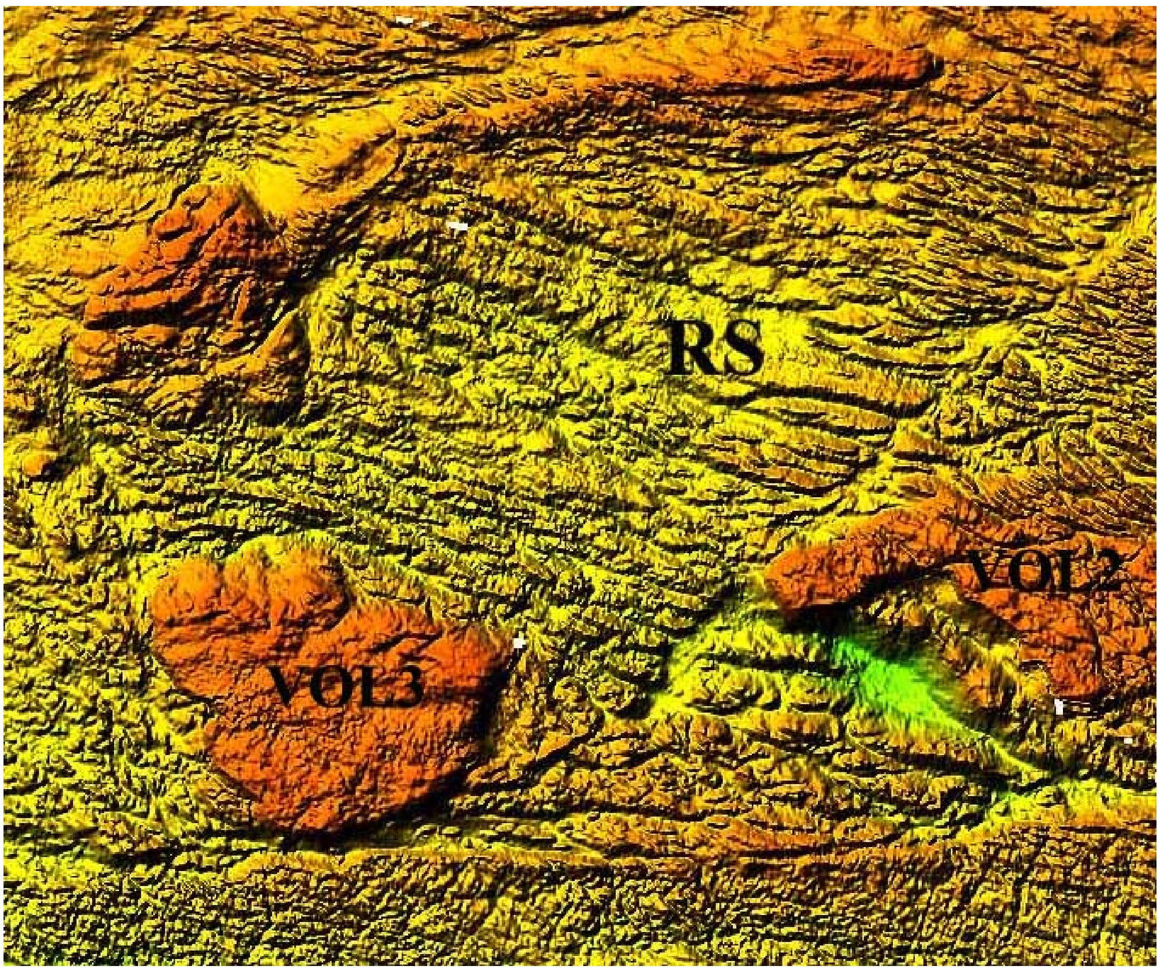

Figure 12 A multibeam bathymetric, shaded relief, colour depth-coded map of the Reference Site with the volcanic platforms identified as VOL2 and VOL3.

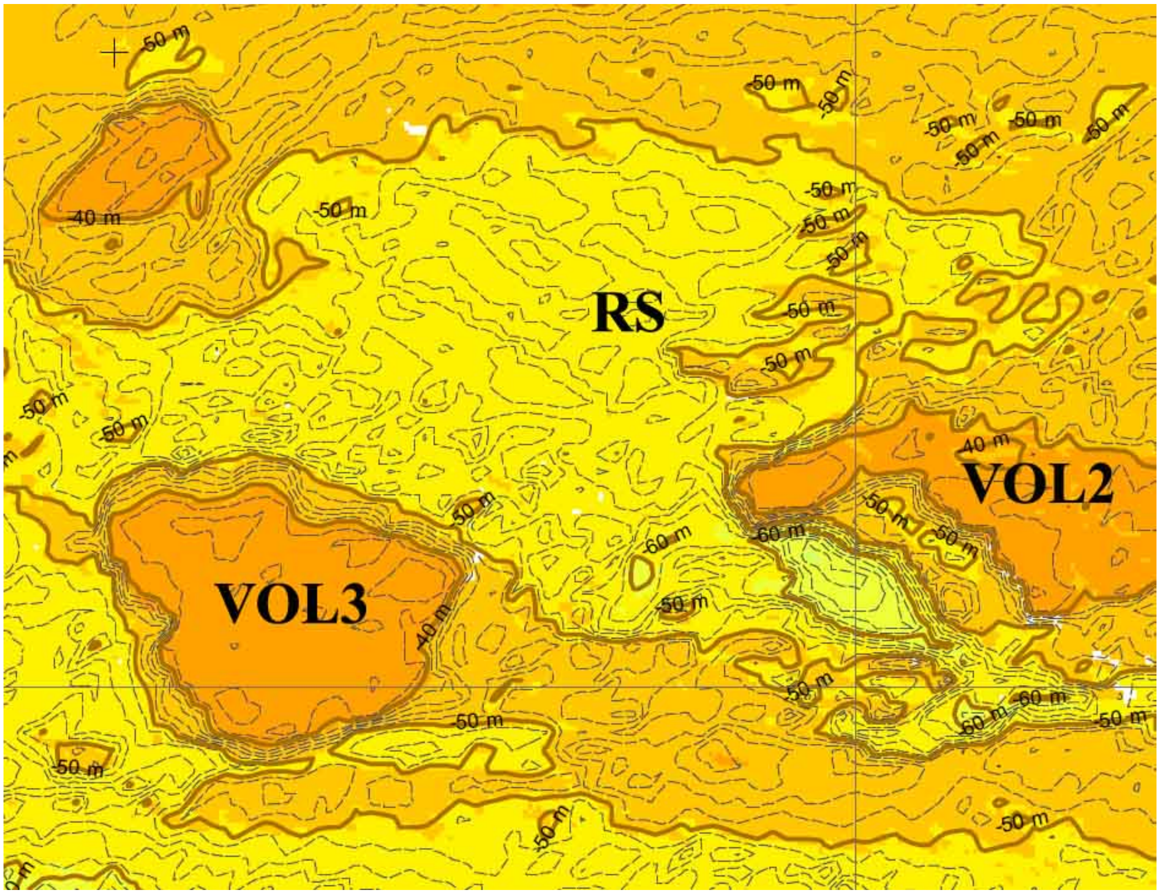

Figure 13 A contoured bathymetric colour-coded and contoured map of the Reference Site. Contour intervals are 2 m.

Bathymetry

RS lies in a slight depression surrounded in the southwest by the high of VOL3, in the southeast by the high of VOL4, and in the north by a shallower ridge trending northeast. The multibeam bathymetric image of Figure 12 shows that RS occurs in a region of southeast trending ridges interpreted to represent outcrops of bedrock with deeper flatter and linear troughs between ridges. Here the bedrock consists of Carboniferous sandstone, siltstone and mudstone. The beds dip to the northeast with the steepest flanks to the southwest as portrayed as shadows on the multibeam bathymetry. The multibeam bathymetry shows that the region around RS is flatter and smoother indicating a cover of surficial sediments. The flatter regions show up more clearly on the slope imagery extracted from the multibeam bathymetric data (Figure 14). The slope imagery shows the steepness of the seabed in dark tone with flat regions showing as light tone. Some of the flat regions can also represent exposures of bedrock. Figure 15 is a low resolution backscatter image of the region that represents a proxy for seabed hardness where dark tone is bedrock and gravel, and light tone sand and mud. The image shows RS as dark tone, therefore, a hard seabed of exposed bedrock or gravel. Linear light tone regions of this image are artefacts of data processing over steep slopes. The backscatter imagery indicates no sand or mud at the seabed of the region. The multibeam bathymetry has been reprocessed from this site to provide the highest resolution possible (Figure 16). This image shows that RS occurs over a rough bottom as part of a broad ridge. Deeper regions to the north and south are troughs of bedrock outcropping ridges and are flatter. RS shows typical characteristics of the region of exposed bedrock ridges throughout Minas Passage. Based on the multibeam imagery, exposed bedrock with gravel would be expected to occur at the seabed.

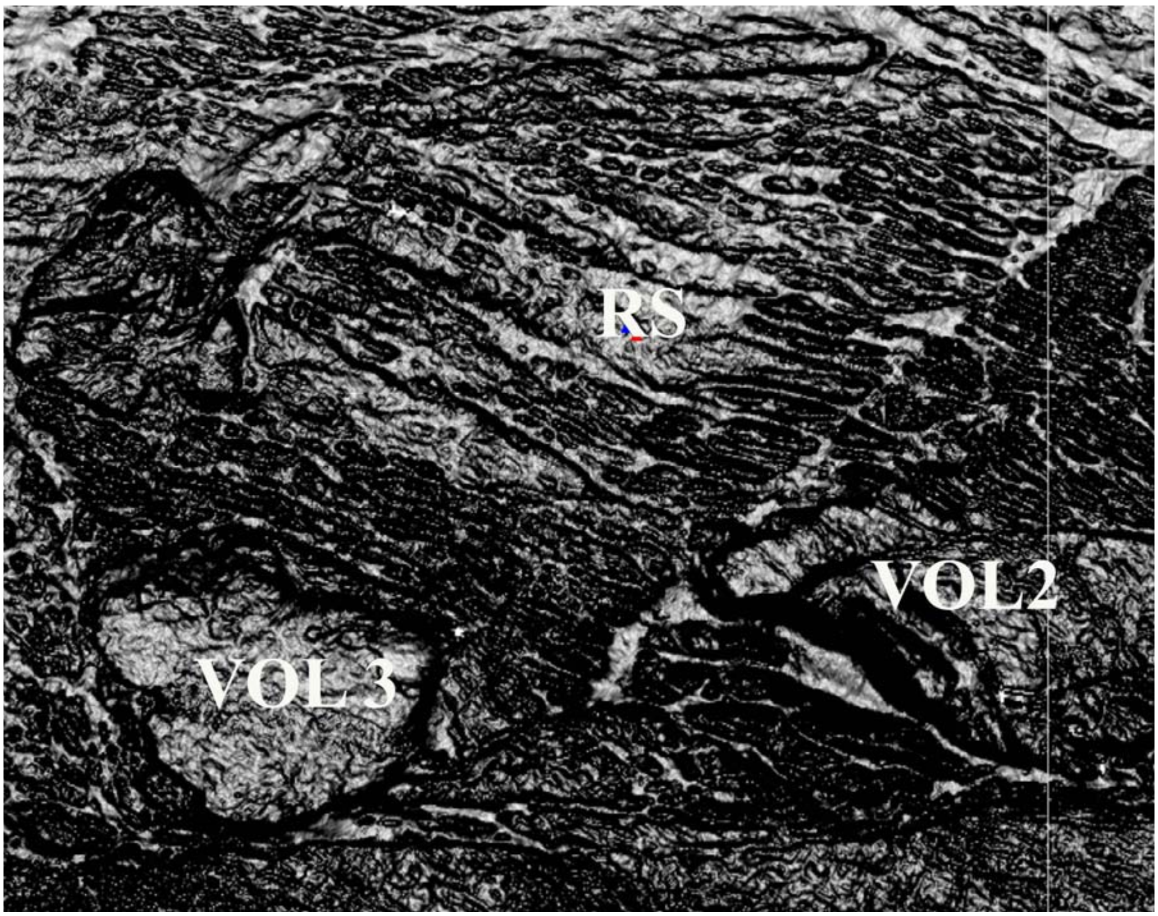

Figure 14 A slope map of the Reference Site produced from the multibeam bathymetric data. Flat areas are light toned and steep areas are dark toned.

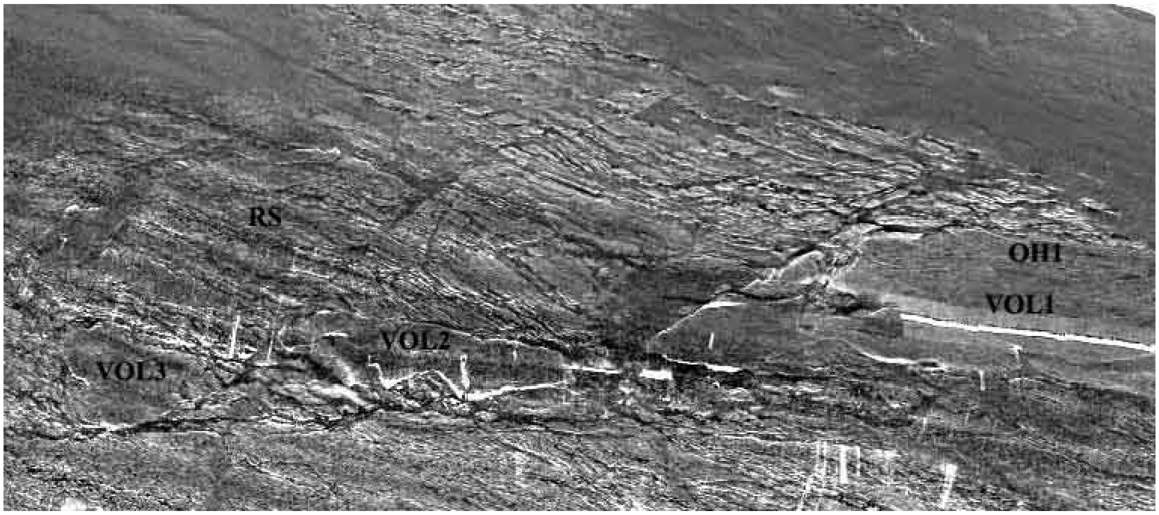

Figure 15 A regional backscatter image of the sites NSPI/OH1 and RS showing that they occur over a very hard seabed of gravel and bedrock. Volcanic ridge segments 1 -3 are identified for reference.

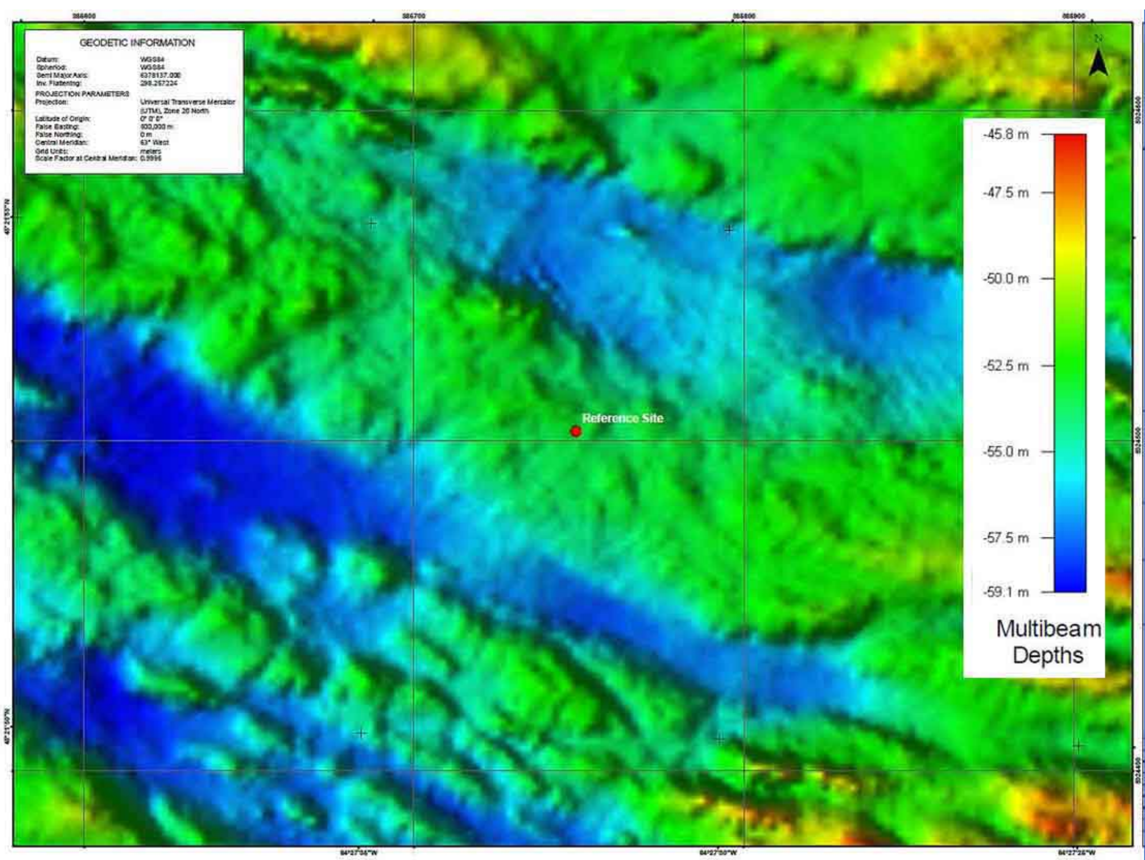

Figure 16 A high resolution multibeam bathymetric image of the Reference Site based on the 2 m resolution survey. It lies on a hummocky seabed of a broad ridge trending southeast.

The monitoring survey of the RS consisted of a sidescan sonar survey, the construction of a sidescan mosaic (Figure17) and the collection of towed video imagery across the site. The sidescan data were draped over the multibeam bathymetry to determine if the seabed has changed over the 5 years since the multibeam bathymetry was collected. A series of screened mosaics were prepared at varying transparencies to aid in this assessment (Figure 17, 18).

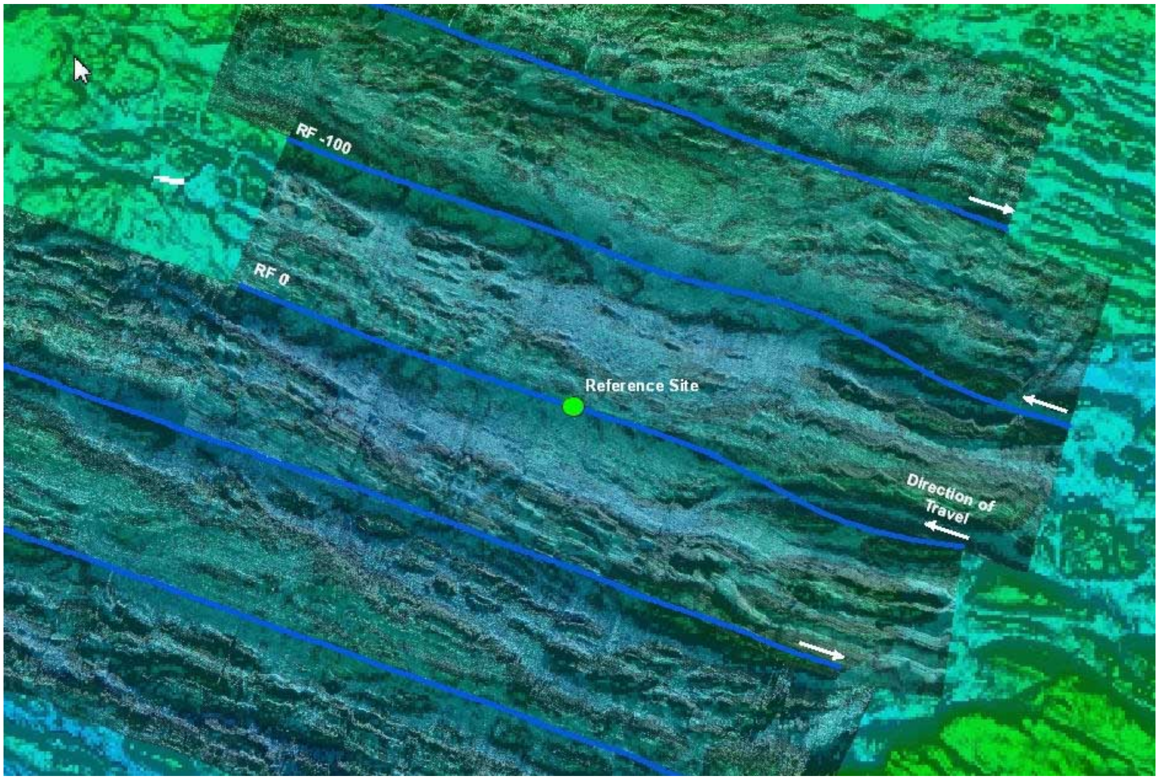

Figure 17 A sidescan mosaic from the Reference Site, screened at 50% transparency to allow for direct comparison with the underlying multibeam bathymetry.

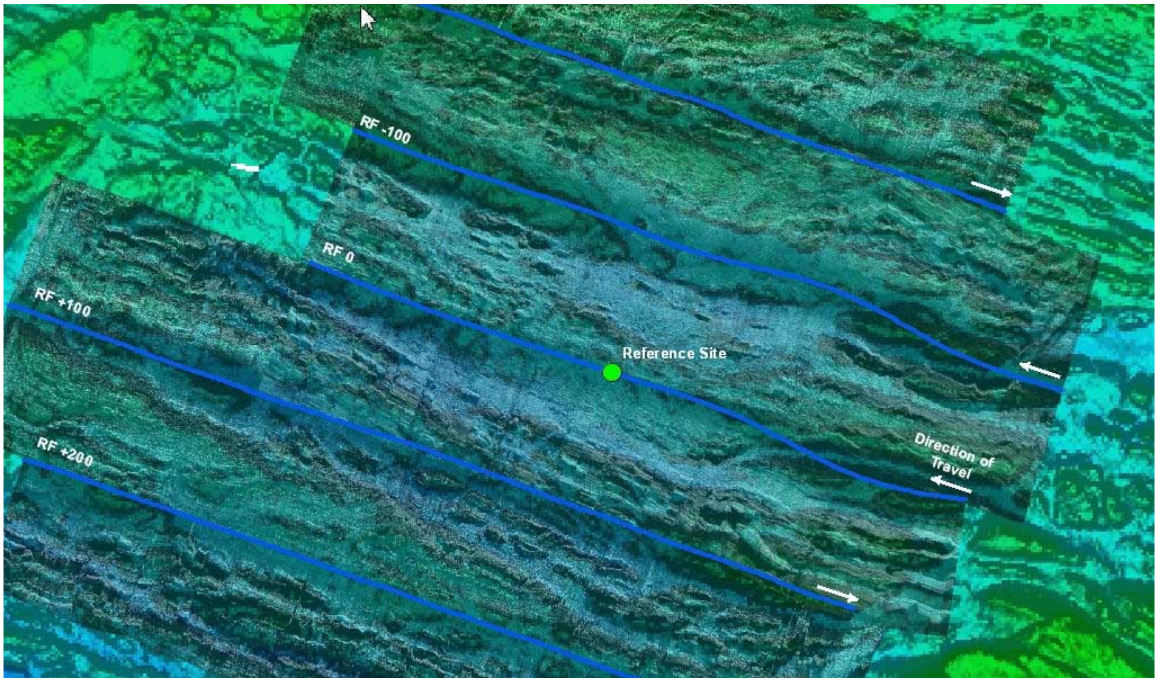

Figure 18 A sidescan mosaic from the Reference Site, screened at 20% transparency to allow for direct comparison with the multibeam bathymetry.

The RS is located near the centre of the sidescan mosaic. The survey lines were run parallel to the bedrock structure in a northwest direction. The mosaic shows that the RS is located in a broad region of sediments overlying bedrock. Although many bedrock ridges crop out on the seabed, they represent approximately 30% of the seabed area. The sidescan imagery show considerably more detail about seabed sediments and bedrock than the multibeam bathymetry. The sidescan has a resolution of 20 cm as compared to the 2 m resolution of the multibeam bathymetry for this site.

Video Imagery

Video or bottom photographs had not been collected at the RS before the monitoring study. The closest existing bottom photographs were from sites A1 to A20 to the east north of VOL2 (Figure 19) and they were taken over a similar seabed character as defined by the multibeam bathymetry and sidescan data. Figure 20 is a selection of bottom photographs from those sites that show a seabed mostly composed of gravel with boulders and exposed bedrock. Between the boulders granules, pebbles and cobbles are present. Large boulders and bedrock have biogenic growth covering their surfaces. These photographs are contained in a report by Envirosphere Consulting to FORCE. Examination of the video transects 5 and 6 across RS shows the seabed dominated by rounded boulders with occasional bedrock outcrop. Pebbles and cobbles lie at the base of the boulders. The large boulders and bedrock outcrop are covered with breadcrumb sponge and other benthic encrusting organisms.

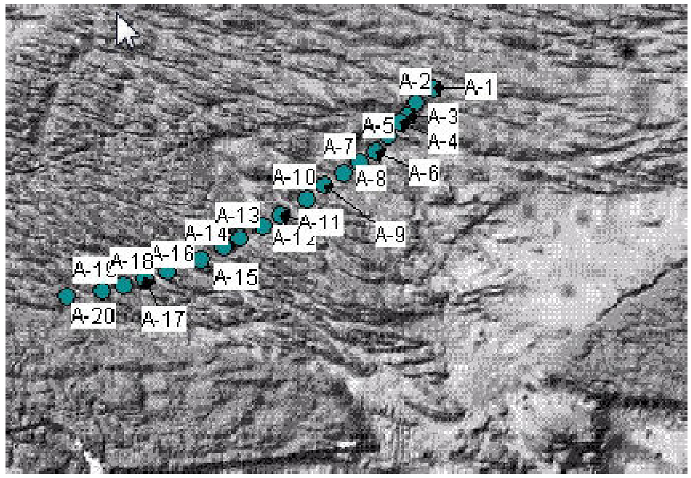

Figure 19 A map of the positions for the closest bottom photographs A1 – A20 to the Reference Site. The RS lies to the west of these locations.

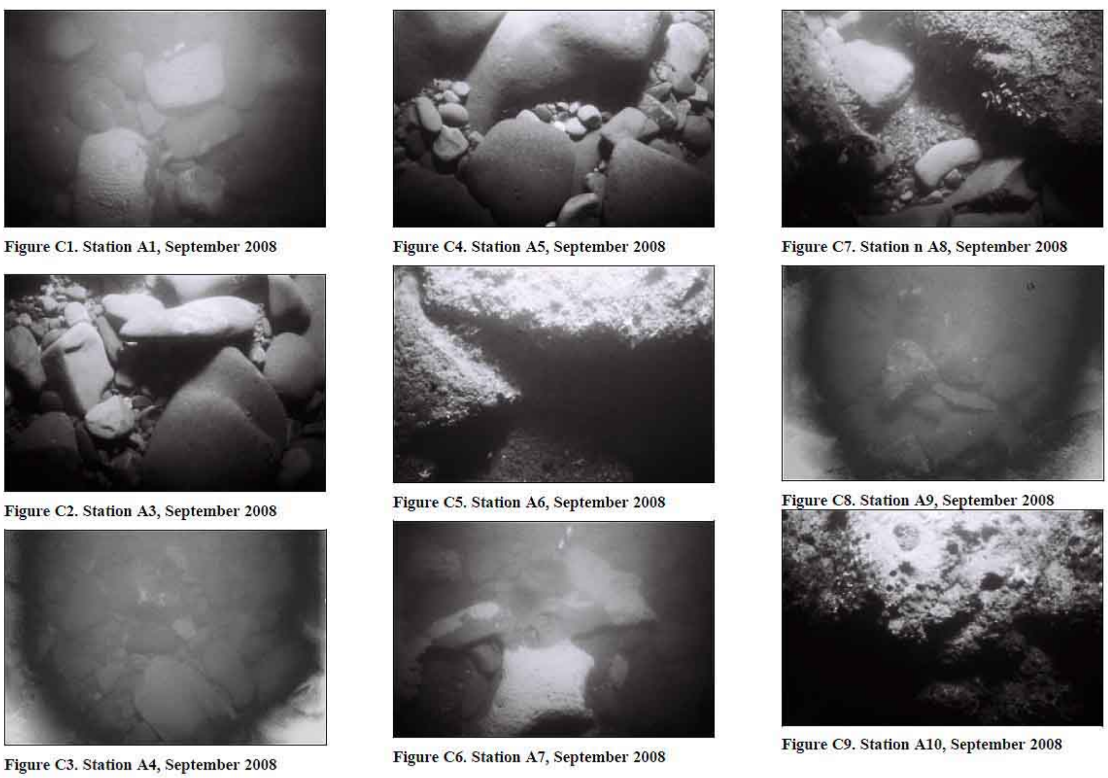

Figure 20 Selected bottom photographs from sites A1 – A10 to show common characteristics of the seabed that occur in the region of the Reference Site.

Interpretation

Interpretation of the sidescan and video imagery from the monitoring survey of the RS and comparison with the previously collected multibeam bathymetry indicates that the seabed has not changed since the first multibeam bathymetry survey was conducted in 2006. Bedrock ridges remain in the same location and flatter regions of gravel with boulders have the same distribution and characteristics. A lack of growth on pebbles, cobbles and small boulders suggests that they may move slightly on the seabed and become rearranged. No gravel bedforms were found at RS as occur in other areas of Minas Passage. Future study of the reference site will now have the sidescan imagery for direct comparison at high resolution.

NSPI/OH1 Site

Assessment of change at the NSPI/OH1 site is based on the 2006, 2 m resolution multibeam bathymetric survey of the site obtained from the GSC; the high resolution 0.5 m multibeam bathymetry survey conducted over the study area in 2008 to choose suitable sites; sidescan sonograms and produced sidescan mosaics from the first survey; a post deployment multibeam bathymetric survey; sidescan sonar and towed camera surveys for this monitoring study; and a review of previously collected bottom camera and video imagery from nearby. The location of NSPI/OH1 has been plotted on backscatter (Figure 15) and slope imagery (Figure 21) for a better understanding of the regional seabed characteristics.

Figure 21 A slope map of the NSPI/OH1 site on Volcanic Platform 1. The seabed is uniform and flat in this region.

The most informative data set for assessment of the seabed at the site of the installation of NSPI/OH1 is the sidescan sonar imagery. The multibeam bathymetric survey of the turbine while in place on the seabed, (Figure 5) has provided an opportunity to determine a very accurate position for the device relative to seabed features, including the position of each of the gravity base feet. This can be correlated with both the first sidescan sonar survey data and the most recent sidescan survey to accurately determine where the device was positioned on the seabed. Without the multibeam survey of the device while in position, this could not be accomplished with any degree of precision. The official position of the installed device provided by the Canadian Hydrographic Service is different than the position obtained from the multibeam survey while the device rested on the seabed by 11 m.

The NSPI/OH1device was carefully oriented and positioned during deployment and was placed on the seabed once and not repositioned. A combination of sonar imagery and DGPS were used during deployment and for later confirmation. Marker buoys were used to assist with positioning but were later removed.

Regional Setting

The NSPI/OH1test installation position lies on the northern part of the volcanic platform that extends to the west from Black Rock (Figure 2 and 3). The site lies to the east of Site A and southwest of site C. It lies 255 m west of the centre of site A in 28.5 m water depth. The 2 m resolution multibeam bathymetric data (Figure 22) shows that the location occurs to the east of a linear and rough region of the volcanic platform. A contoured map of bathymetry (Figure 23) shows that the region lies in water depths slightly below 30 m water depth and that this part of the volcanic platform is relatively flat and broad with water depths between 30 and 28 m (contour interval 2 m). The backscatter imagery (Figure 15) shows that NSPI/OH1 lies in a region of homogeneous dark tone – suggesting a hard and consistent seabed. The backscatter imagery has been processed at low resolution of less than 5 m, so backscatter details of the setting cannot be determined. The slope imagery (Figure 21) shows the location in a region of low slope with minor ridging and isolated flat circular areas.

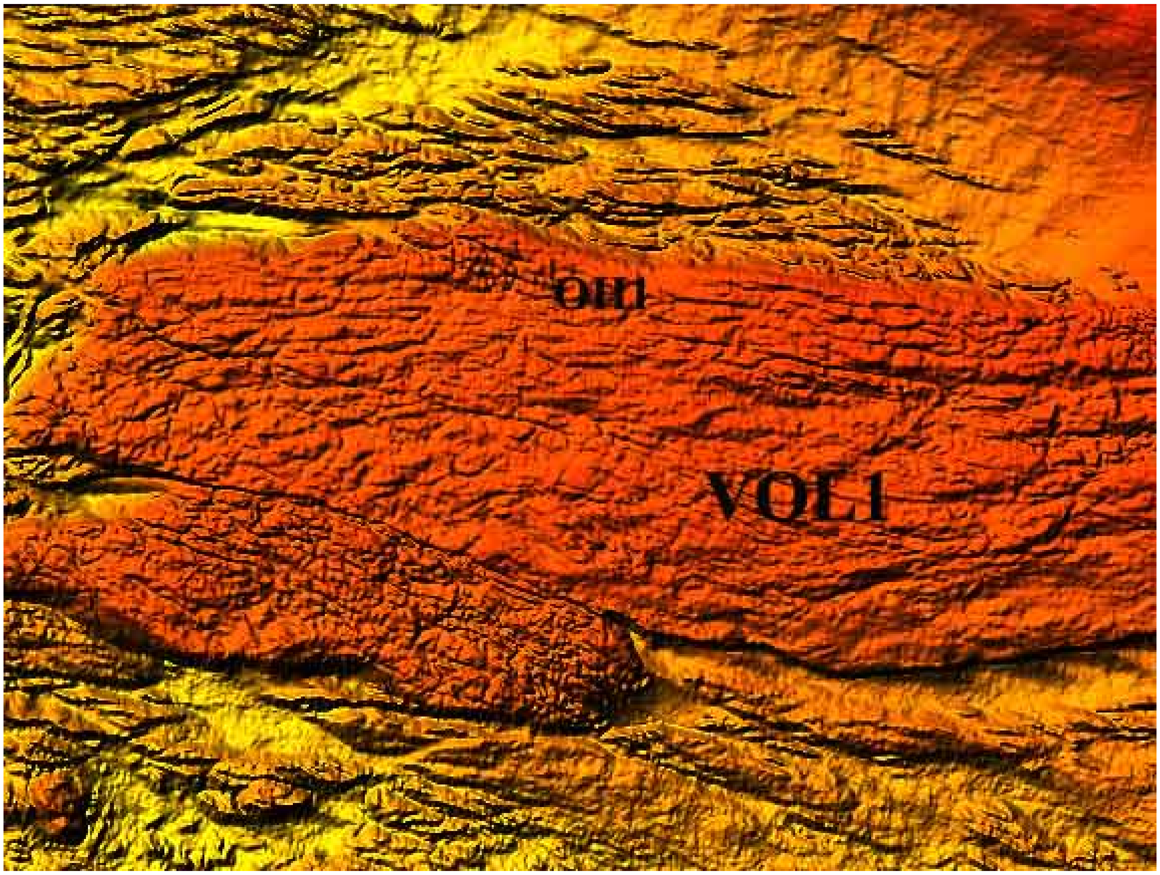

Figure 22 A 2 m resolution multibeam bathymetric map of NSPI/OH1 showing its location on the volcanic platform VOL1. Directly to the west of the site the seabed is rougher and more ridged.

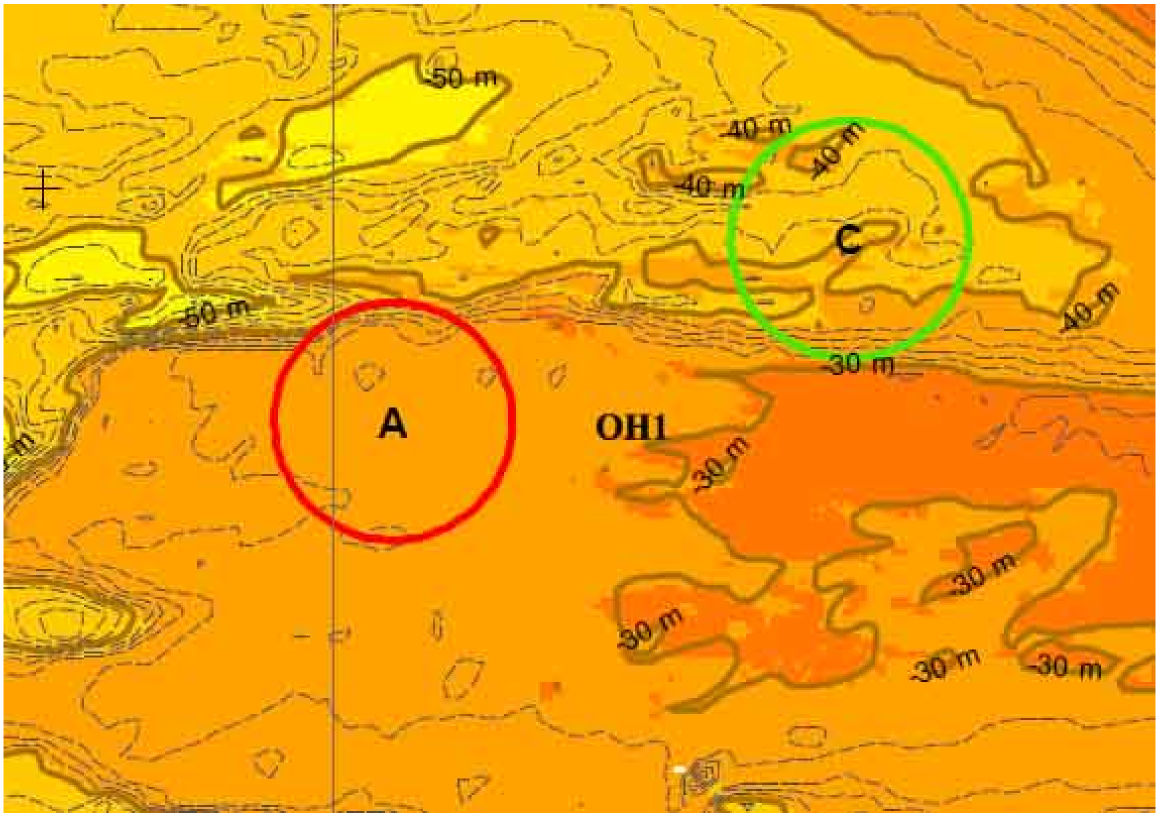

Figure 23 A bathymetric contoured map of the site of NSPI/OH1, site A and site C. The contour interval is 2m and shows that the volcanic platform is quite flat.

The multibeam bathymetric survey of the device on site (Figure 5) clearly shows its relationship to the topography of the volcanic platform as well as the shape of the gravity base. It lies on the seabed with the apex pointing to the northwest. The frame extensions that hold the eastern two feet can be seen on the east side of the gravity base. The device is 25 m by 21 m in size. For purposes of this discussion, the western most foot is termed Foot 1, the southernmost eastern foot, Foot 2, and the northeastern foot, Foot 3. Topographic elements of the volcanic platform can clearly be seen and used to control the correlation of the sidescan imagery with the position of the device. Figure 24 is a shaded relief multibeam bathymetric map of the NSPI/OH1 site showing the highest resolution attainable from the 0.5 m resolution survey conducted during initial site selection, with the outline of the gravity base and reported position superimposed.

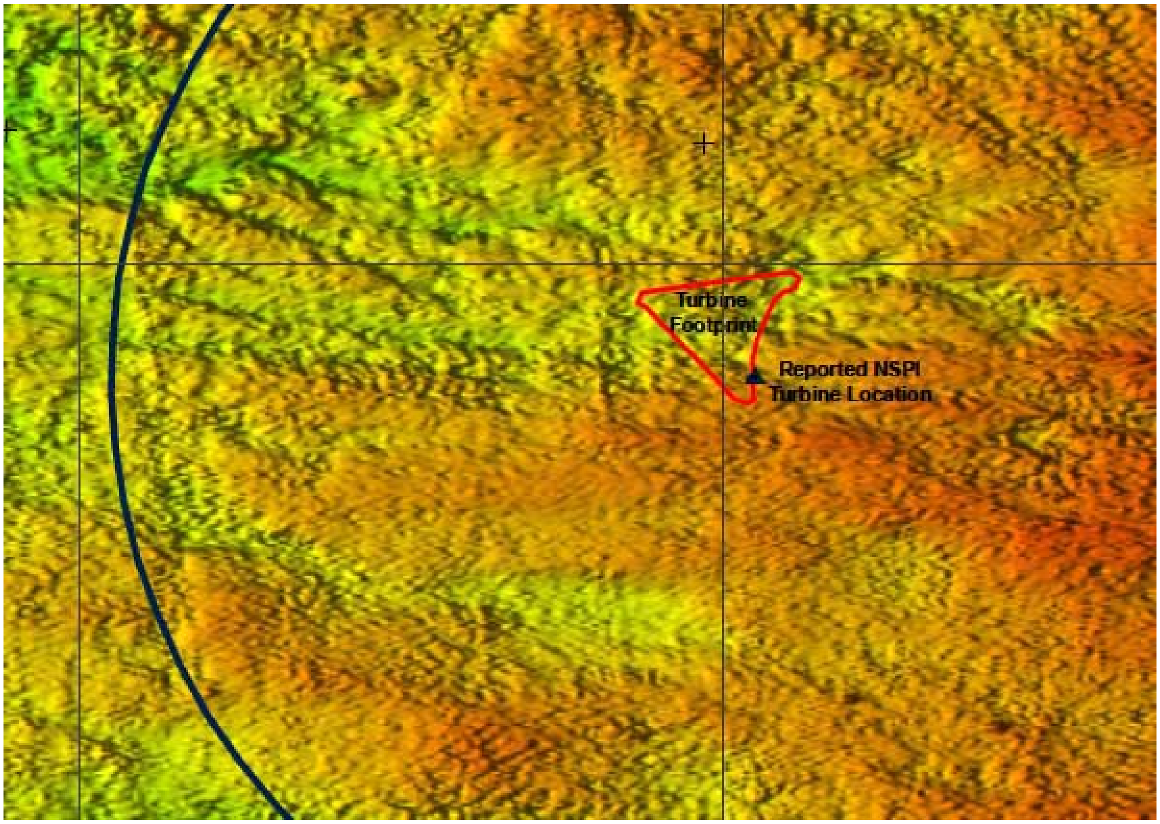

Figure 24 A high resolution multibeam bathymetric image showing the location of the NSPI/OH1 site on the seabed and the relief of the bottom. From this image the exact location and water depths of the position of the feet can be determined.

The sidescan sonograms and the mosaic were processed in the GIS and the position of the device was superimposed on the imagery. This provides a high resolution location of the device and its individual feet relative to the sidescan sonar data. This relationship has been extrapolated to the raw sidescan high resolution imagery and provides a near -optical view of the orientation of the device and the relationship between the feet and the seabed. We have also been fortunate in this correlation in that the monitoring survey sidescan data is of superior quality with minimal current induced motion as is common for surveys in Minas Passage. They data are not distorted and this allows for a direct comparison and placement of the device and individual feet. The position of the device has also been compared with the original sidescan data to confirm the location and to compare for seabed change. The earlier collected sidescan data was of lower quality mainly because of poor survey water conditions where the tow fish was subjected to severe motions. A very careful comparison and correlation was undertaken and a number of seabed landmark points were established amongst the various data sets to provide a high level of confidence in obtaining the exact site of the device and feet for location on the monitoring sonograms. Sidescan sonar systems are less quantitative that multibeam systems for georeferencing seabed features because of extreme operating conditions and a certain amount of minor adjustment is required for precise positioning.

OH1 Device Site Description

The NSPI/OH1 device lies on a hummocky and ridged volcanic surface (Figure 24). The multibeam imagery shows that the feet occur in different water depths indicating that the structure was tilted slightly to the north. The western front foot is in -29.2 m, the south back foot in -28.3 m and the north back foot in -29.6 m water depths. This shows a difference of 0.9 m across the device. The southern foot lies on a bedrock ridge while the western and northern ones are in slight depressions. For detail on the characteristics of the site it is necessary to examine the raw sidescan sonograms. The sidescan survey passed over the site three times, over the centre, and at -25 and +25 m on either side.

Sidescan Sonar Interpretation

The sidescan sonar image that best depicts the seabed and the position of the device feet is line -25 (Figure 25 and 8). It shows the seabed as a series of hummocky broad ridges and smaller isolated linear ridges. Sidescan information shows both seabed hardness and relief. Shadows from objects are differentiated from depressions by the presence of high backscatter (light tone) followed by dark regions (shadows). Depressions are represented by a shift to dark tone without a sonar facing region of high backscatter. Of particular note is that two feet appear to coincide with small depressions on the seabed (Figure 25). Given that the major part of the area around the device is flat, this suggests that it may have shifted to self locate the feet in slightly deeper areas for greater stability. A close inspection of the sidescan sonogram shows that at least two of the feet (A and B) may have eroded small depressions in the volcanic bedrock (Figure 25). If this occurred, the device may have sunk downward approximately 1 m until a flange on the base of the feet was reached and a more stable position was achieved. An examination of device tilt information and abrasion marks on the feet post recovery should provide information on such a hypothesis.

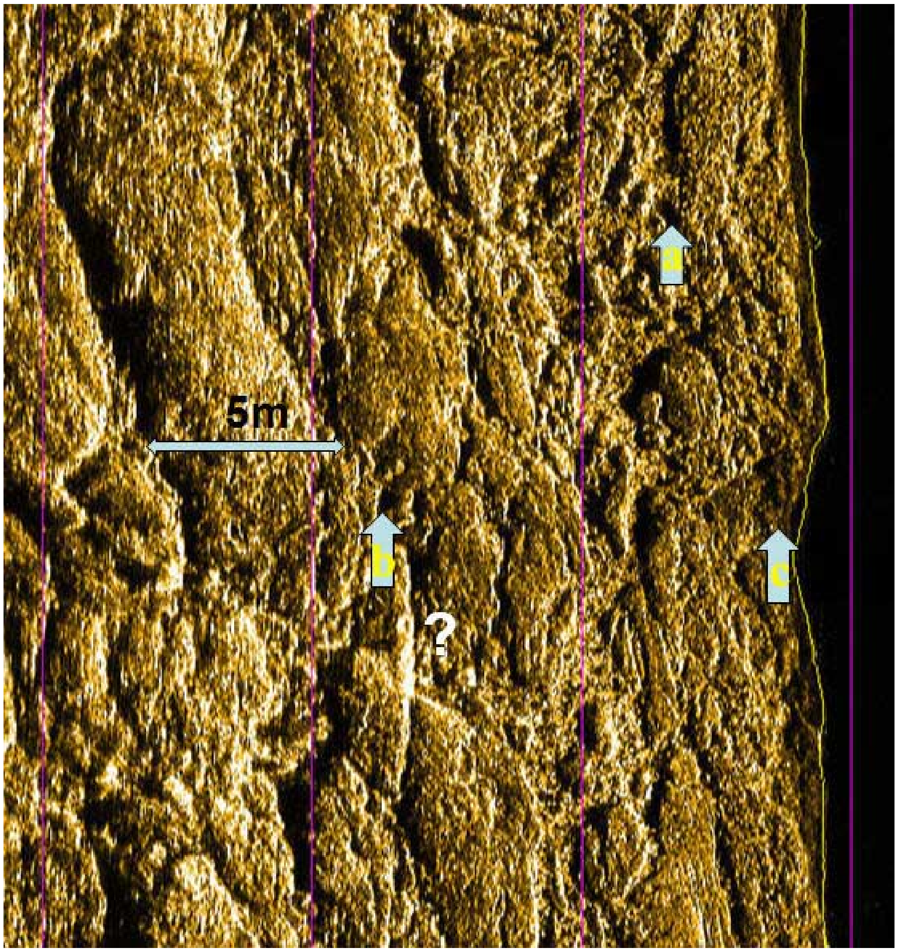

Figure 25 A sidescan sonogram of the site of NSPI/OH1 showing the position of the feet on the seabed. Arrows are used to indicate the locations and not obscure the actual positions. Note the linear unusual feature near the foot b noted with ?.

As mentioned above, the survey sidescan data is of very high quality with no operational degradation of the data as is common in high velocity flow conditions. A linear object has been detected lying on the seabed near the southern foot (B) of the gravity platform (Figure 25). It appears unnatural on the sonar imagery and may represent the lost centre ring of the turbine. It cuts across the natural structural features of the bedrock exposed at the seabed. Foot C lies in a slightly deeper region of the sonogram near nadir. The seabed of this area appears to be gravel covered bedrock. In the nearby region of all the feet there does not appear to be any disturbance of the seabed. No linear marks, sediment piles, or other patterns of movement can be detected. The feet may have excavated up to 1 m deep local depressions in the bedrock and gravel. This would have liberated small quantities of fine grained ground bedrock. However there is no evidence for these materials being deposited in the area around the turbine and they cannot be detected on the sidescan sonograms.

Figure 26 is the pre deployment sidescan sonogram from the same region that was collected during the first survey of the area to choose the sites in 2008. The tow fish was subjected to severe motion by the currents and turbulence during that survey and this presents the information with distortion. A direct comparison of the two surveys identifies some larger common features of the site but details as provided by the sonograms of the monitoring survey cannot be seen. This limits the ability to assess change at the seabed caused by the turbine.

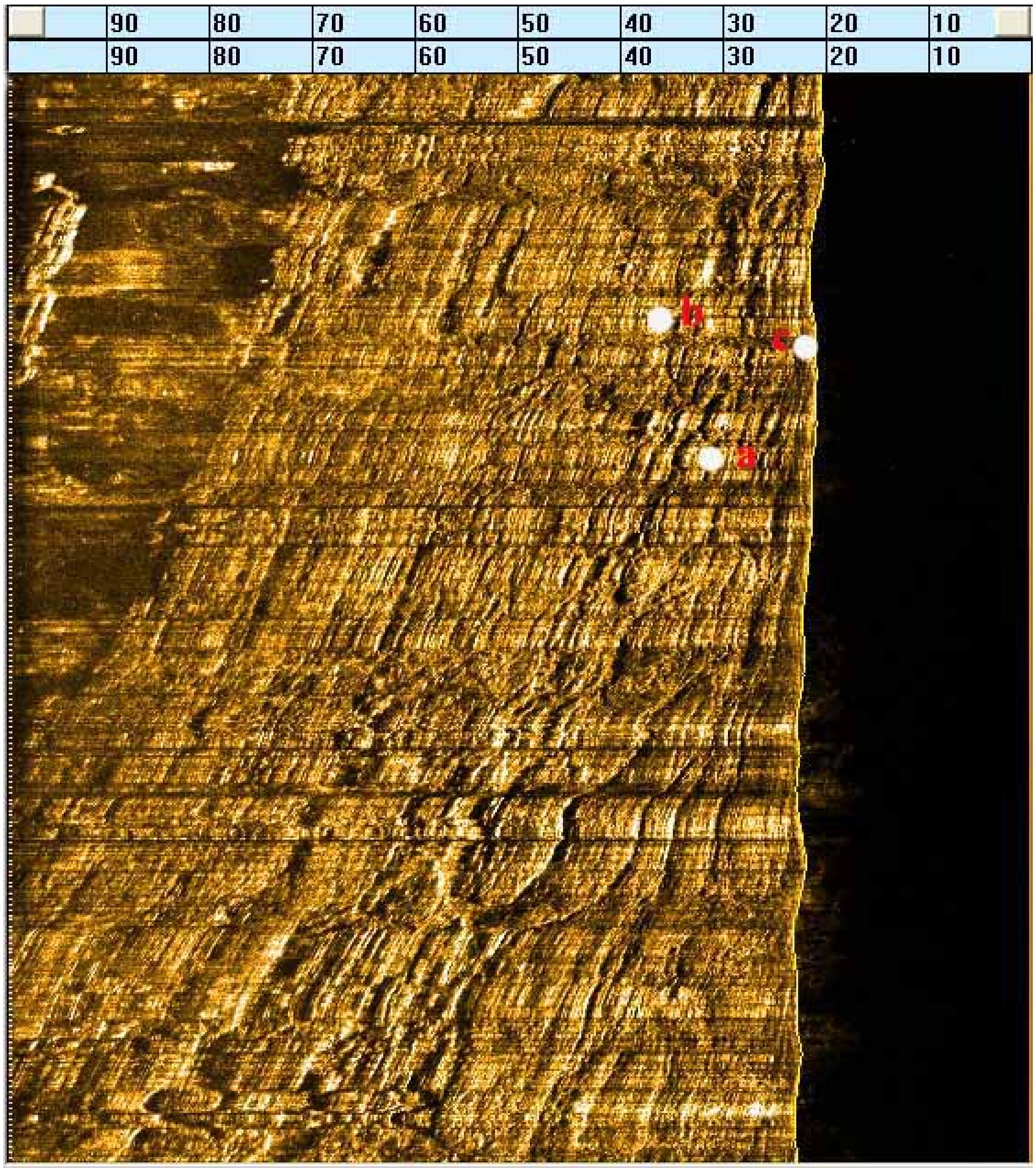

Figure 26 A sidescan sonogram from the site of NSPI/OH1 collected in 2008. It has been compared with the sonograms collected for the monitoring survey to detect change. However, the quality of the first survey data was less because of excessive fish motion due to strong currents and turbulence that was not present during the monitoring survey. The locations of the three feet of the gravity structure are indicated.

Video Information

Four transects across the site were undertaken with towed video camera. Assessment of the imagery shows that the seabed is dominantly bedrock with boulders in places. Many of the boulders are rounded in shape. Linear bedrock cracks and depressions can also be seen. The camera tow speed is quite rapid and suspended particulates reduce the clarity of the imagery. Many of the large boulders and bedrock surfaces are covered with biogenic growth and the breadcrumb sponge stands out because of its yellow colour. It occurs as both complete coverings and in a patchy distribution. The video imagery shows no features that could be attribute to impact or movement by the turbine. No anthropogenic debris was seen on the imagery. The transects covered a large area that extended beyond the deployment site and the seabed appeared to be similar along the entire transects.

Summary for NSPI/OH1 Site

Assessment of the monitoring survey sidescan sonograms shows little change to the seabed from the device. The bottom is very hard bedrock with gravel in slight depressions. Two 1 m diameter circular depressions could have been formed by the feet of the gravity structure. Their depth is not able to be determined. Towed video camera transects show a typical seabed for the Minas Passage region and no features associated with the deployment or retrieval could be detected.

Conclusions

The Reference Site appears not to have changed over a five year period since the first multibeam bathymetry was collected. This includes the distribution of bedrock, gravel and morphology. The deployment, operation and recovery of the Nova Scotia Power Inc. /Open Hydro device have had a minimal effect of the seabed. Two small 1 m diameter depressions are interpreted to have resulted from erosion by the feet of the gravity platform. These occur on exposed basalt bedrock. No other change in bathymetry, sediment distribution, or seabed scouring could be detected from the high resolution survey data.

Suggested Activities for Future Deployments

Based on the results from the monitoring study of NSPI/OH1, the following suggestions are put forth. This information will help future monitoring studies.

1) The position of the sites for future devices needs to be accurately known both before and after deployment. This should also include the positions of device feet if gravity platforms are deployed.
2) Post deployment surveys are recommended to determine the exact location and orientation of devices with respect to seabed morphology and features for accurate georefferencing. This is best accomplished by multibeam bathymetric surveying.
3) A pre deployment plan that includes the methods, intended position, orientation, and slope would be useful in assessing effects.
4) A post recovery report should include details of the recovery operation and measurements of the behaviour of the device over the period of deployment. This should include shifting, reorientation and settlement of the device and marks on the device that indicate abrasion by seabed materials. Sensors should be positioned on the device to periodically record these measurements. Only when the exact location for the device is known relative to seabed materials and morphology, can monitoring surveys be properly conducted.
5) The use of ROVs should be assessed for their applicability to monitoring studies in the future. Despite the strong currents, precise photographic imagery can help determine localized effects and could be undertaken at times of low velocity currents. The resolution of photographic imagery is mm compared to decimetres using sidescan sonography. Simple dropped cameras are difficult to position in these waters so ROVs offer the best method for targeted photo imagery.
6) It is recommended that a bottom photographic survey be conducted at the Reference Site at the time of the next opportunity where equipment is deployed for other investigations. This would provide a high resolution assessment of sediment distribution, texture, benthic habitat and benthic organisms.

Acknowledgements

Seaforth Geosurveys Inc. and staff are thanked for their seagoing efforts to collect high quality data and processing of the information for this assessment. In particular Arthur Abbott is thanked for data processing and manipulation of sidescan sonogram data for comparison purposes. Nova Scotia Power Inc. and Open Hydro are thanked for their provision of information on the deployment and recovery operations.

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