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REPORT ON

PRELIMINARY GEOTECHNICAL ASSESSMENT NEW GROTTO BAY / CASTLE HARBOUR CROSSING BERMUDA

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EXECUTIVE SUMMARY

The Government of Bermuda is undertaking a feasibility study for a proposed new Grotto Bay/Castle Harbour Crossing, located between Hamilton Parish and St. George's Parish in Bermuda. As requested by the Government, Golder Associates Ltd. (Golder) has carried out a preliminary geotechnical investigation to obtain information on the subsurface soil and bedrock conditions within the study area for the purpose of feasibility level foundation assessment and crossing option evaluation.

The entire study area encompasses the waters and surrounding lands of Grotto Bay/Castle Harbour; however, for feasibility level purposes, specific subsurface geotechnical investigation was only carried out where land access was readily available for drilling equipment. A marine geophysical investigation was also carried out by Golder over water to supplement the borehole data. Detailed drilled boreholes were put down at Blue Hole Hill Park, Longbird Bridge, Kindley Field Park, Coney Island, and on the existing Causeway. The borehole drilling program was specifically carried out to evaluate the nature and engineering properties of the near-surface coralline deposits that mantle the study area as well as determine the general depth and engineering properties of the underlying volcanic basement rock that is known to form part of the Bermuda Seamount.

TABLE OF CONTENTS

SECTION PAGE

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

The Government of Bermuda is undertaking a feasibility study for a proposed new Grotto Bay/Castle Harbour Crossing, located between Hamilton Parish and St. George's Parish in Bermuda. As requested by the Government, Golder Associates Ltd. (Golder) has carried out a preliminary geotechnical investigation to obtain information on the subsurface soil and bedrock conditions within the study area for the purpose of feasibility level foundation assessment and crossing option evaluation.

The scope of this preliminary geotechnical investigation and assessment is limited to the geotechnical aspects of the proposed crossing project only, and does not include any provision for the investigation, testing or assessment of the potential presence or impact of soil and/or groundwater contamination at the site.

This report should be read in conjunction with the **"Important Information and Limitations of This Report"** which is appended following the text of the report. The reader's attention is specifically drawn to this information, as it is essential that it is followed for the proper use and interpretation of this report.

2.0 BACKGROUND

The Government of Bermuda is currently undertaking an overall feasibility study of replacement options for the existing causeway and swing-bridge structure that spans across Grotto Bay and Castle Harbour in Bermuda. At present, this approximately 900 m long facility acts as the sole road link between the Parish of St. George's/Bermuda International Airport and the remainder of the Islands of Bermuda. The link has historically been subject to damaging wave and wind action during storm activity and was significantly damaged as a result of a Category 3 hurricane (Fabian) in 2003. In addition, the existing swing span bridge, referred to as Longbird Bridge, is subject to significant corrosion due to its close proximity to sea water and ocean spray.

The feasibility study encompasses a relatively large area which generally includes the waters of Grotto Bay/Castle Harbour and surrounding land masses including Blue Hole Hill Park, Coney Island, Ferry Reach Park and Kindley Field Park. The new crossing alignments currently under consideration are located within three corridors, as follows:

- Parallel or adjacent to the existing causeway structure;
- Through Coney Island to Kindley Field Park; and
- Through Coney Island to Ferry Reach Park to Kindley Field Park.

Various concepts are being considered for the different alignments including fixed high-level bridge structures, low-level structures with a swing-span bridge, low-level causeway embankments with a swing-span bridge, and tunnels. The high level crossing options include establishment of a new navigation channel south of the existing channel. We understand that it is proposed to extend the existing partially excavated channel located west of the existing causeway for this purpose.

It is noted that for preliminary evaluation purposes, the axial Serviceability Limit State (SLS) pier loads for structural foundations have been assumed to be in the range of 5,300 to 9,400 kN based on information provided by the design team, with Ultimate Serviceability State (ULS) loads up to 12,500 kN. Similarly, the shear SLS pier loads have been assumed to range between 200 and 700 kN, with ULS shear loads up to 2,300 kN.

3.0 COLLECTION AND REVIEW OF AVAILABLE SUBSURFACE INFORMATION

Available published geological and geotechnical information on the general geology of Bermuda and, more specifically, the geology of the Castle Harbour/Grotto Bay study area, was collected and reviewed as part of the preliminary assessment and investigation planning process.

The following documents were included in our review:

- *"An Explanation of the Geology of Bermuda"*, Bermuda Government, Ministry of Environment, M. P. Rowe, 1998;
- *"The Geological Map of Bermuda"*, Bermuda Government, Ministry of Works and Engineering, H. L. Vacher, M. P. Rowe, P. Garrett, 1989;
- *"On the Nature and Origin of Some Paleogene Melilititic Pillowed Lavas, Breccias, and Intrusives from Bermuda"*, J. M. Peckenham, 1981;
- *"Geology of the Bermuda Seamount"*, F. Augmento, B. M. Gunn, 1974;
- *"A Continuous Seismic Survey of the Bermuda Platform, Part I: Castle Harbour"*, R. A. Gees, F. Medioli, 1970;
- *"Geological Significance of Recent Borings in the Vicinity of Castle Harbour"*, W. S. Newman, 1959; and
- *"Dredging Castle Harbour, Subaqueous Exploration Borings"*, United States Engineers Office, 1941.

The information presented in the above documentation was used to assess the likely existing stratigraphy and general engineering properties of the geological formations beneath Castle Harbour/Grotto Bay, and in planning the geotechnical investigations.

4.0 FIELD WORK

The geotechnical field work included inspection of outcrop exposures, a marine geophysical survey and borehole investigations carried out in two phases.

4.1 Geotechnical Investigations

4.1.1 November 2005 Investigation

A single drilled borehole was drilled at the east side of the Longbird Bridge (immediately adjacent to BH06-2 in Figure 2 attached) in November 2005 in an attempt to confirm the depth to the volcanic rock. The borehole was put down to a depth of 32.9 m below the ground surface using a truck-mounted Schraam air-rotary drill owned and operated by Atlantic Water Development Ltd.

A nominal 200 mm diameter tri-cone drill bit was advanced below the ground surface with the drill cuttings returned to the ground surface by compressed air circulation. Non-conventional Standard Penetration Tests (SPTs) were carried out at selected depths to assess the relative density or consistency of the soils encountered, and to obtain disturbed samples of the soils. The SPTs used a 63.5 kg weight that was dropped from a nominal height of 760 mm to advance a 52 mm diameter split-spoon sampler into the undisturbed (undrilled) soil formations. It is noted that this testing was not carried out in full compliance with ASTM standards.

The drilling activities were monitored by a member of Golder's geotechnical engineering group who logged the subsurface soil and groundwater conditions encountered in the borehole, and obtained soil samples for detailed examination.

Due to the limitations of the drilling equipment and techniques, the information collected is considered of very limited value compared to the results of the October 2006 investigation described below. Consequently, a detailed description of the conditions encountered within the November 2005 borehole is not included herein.

4.1.2 October 2006 Investigation

The Government of Bermuda retained Aardvark Drilling Ltd. of Ontario, Canada to supply and operate a trailer-mounted rotary drill rig to carry out a more detailed subsurface geotechnical investigation within the Grotto Bay/Castle Harbour study area in the fall of 2006. The purpose of the investigation was to obtain general subsurface soil and rock information for feasibility level evaluation of foundation options for the proposed new crossing. The geotechnical investigation involved putting down five land-based boreholes to depths ranging between 41.5 and 44.5 m below the existing ground surface at Blue Hole Hill Park, Longbird Bridge, Kindley Field Park, Coney Island, and the existing Causeway. The surveyed borehole locations are shown on

Figure 2 attached following the text of this report. Selected photographs of each drill site location are presented in Appendix III. While over-water boreholes would have been preferred, given the uncertainties regarding the likely alignments combined with the significant additional cost, a program of land-based drilling combined with marine geophysics was considered an acceptable compromise for present purposes.

The boreholes were put down using a trailer-mounted CME 55 rotary drill rig that was configured to advance 57 mm inside diameter hollow-stem augers, NW drill casing and NQ rock core barrel, as well as conduct conventional SPTs using a 63.5 kg, 762 mm drop, cathead operated drop hammer. In general, SPTs were carried out at regular intervals within the upper coralline deposits, except where refusal of the SPT sample tube was encountered. Where conditions were considered to be too dense/hard for conventional SPTs, and/or where conditions were considered favourable for rock coring an NQ core barrel was used to obtain samples. The rock core barrel was advanced at least 6 m into the volcanic basement rock at each borehole location. No geotechnical instrumentation was installed within the boreholes and each borehole was backfilled using imported granular fill upon completion.

All of the drilling activities were monitored by a member of Golder's geotechnical engineering group who located the test holes in the field, logged the subsurface soil and groundwater conditions encountered in each borehole, and obtained representative soil and rock samples for detailed examination and laboratory testing.

All test holes were marked in the field for future survey pickup by others. All of the soil samples and the majority of rock samples obtained during the investigation were packaged and brought back to Golder's Geotechnical laboratory in Burnaby, British Columbia, Canada.

4.2 Marine Geophysical Survey

The marine geophysical survey procedure utilized single-beam bathymetric sounding, low frequency single channel seismic reflection for delineation of sub-bottom stratigraphy and real-time differential global positioning system (DGPS) positioning. Bathymetric and DGPS data were recorded digitally and integrated with the seismic data during post-processing.

The geophysical surveys were conducted between August 2nd and 9th, 2005 by an experienced Golder marine geophysicist, with assistance from Bermuda Biological Station for Research (BioStation) personnel. The work boat and operator were supplied by the BioStation. Data were collected over a three day period along pre-planned survey lines, generally within Grotto Bay, and extended as close to the existing causeway as feasible. Shallow water restricted access to some areas of the site for the survey boat, and consequently these areas were not surveyed.

Preliminary analyses of the data were undertaken following each day of field operations. This analysis consisted of plotting the track line maps, editing the bathymetric data for extreme depth values, and reviewing and verifying the quality of the seismic reflection data. Following completion of the October 2006 geotechnical borehole investigation, we re-interpreted the seismic reflection data based on a calibrated velocity for the deepest acoustic reflector which is interpreted in our analyses to represent the volcanic basement rock.

4.2.1 Bathymetry

Seabed elevation data were measured using a Reson Navisound 215 precision echosounder operating at 200 kHz. This instrument produced a continuous record of the water depth along the transects. The depth sounder was interfaced with real-time DGPS data using Hypack software (Coastal Oceanographics) operating on the navigation computer. The depth sounder was mounted on the BioStation boat. Some areas could not be surveyed due to limited water depth. Aerial photography taken in 1997 was used to blank out known shallow areas; however, it is possible that tropical storms (specifically Hurricane Fabian) may have altered the seabed in shallow areas since these photos were obtained.

Sound velocity in water was verified with a sounding line. Water depths are considered to be accurate to 0.3 m. Variations may be expected in the vicinity of steep slopes due to off-vertical bottom reflection.

Bathymetric analysis was completed using Coastal Hypack single beam processing to remove spurious data and apply offset corrections. Bathymetric data have been gridded and contoured to provide visual information. Gridding was performed using minimum curvature and TIN methodology to improve the contour rendition of the data set using Surfer (Golden Software). Bathymetry data was not recorded for water depths less than 0.9 m.

4.2.2 Seismic Reflection Sub-bottom Profiling

The low frequency single channel seismic reflection data were collected in an attempt to penetrate deeply below the seabed to collect acoustic images of the sub-bottom stratigraphy, including layers of varying relative density or cementation, voids/cavities, and possibly the inferred volcanic basement rock.

The data were acquired with a Datasonics Bubble Pulser System (400 Hz centre frequency) and recorded in real-time on an EPC printer. The hardcopy printing was annotated automatically through an interface with the navigation system.

Low frequency seismic reflection results were interpreted for layer thickness and combined with bathymetric results and contoured. We have used a sound velocity of 2000 m/s within the sediments, which is an average value for the anticipated type of seabed sediments based on results of the October 2006 drilling program and observed depth to volcanic rock. However, it is important to note that the sub-bottom velocity could vary from 20 to 40 per cent (or possibly more in rock and cemented rock) throughout the survey area. The interpreted depths are considered to provide a shallow limit based on an interpretation of compact coralline deposits.

4.2.3 Survey and Datum

The position of the survey vessel during survey activities was determined using DGPS. The navigation data were acquired with a Trimble PROXRS DGPS interfaced with Coastal HYPACK navigation software. The shipboard receiver output differentially corrected WGS 84 latitude and longitude values ten times per second with sub-metre accuracy. The position of the survey vessel and completed survey track lines were displayed in real-time on a colour monitor. The Geodetic Datum for UTM coordinates is Bermuda Grid, Zone BDA-2000.

The vertical datum was taken from the 1984 Memo of Bermuda Datums as provided by the project team at the time of the survey. Chart Datum is Mean Lower Low Water (MLLW) which is 0.61 m below the 1999 Ordnance Datum Geodetic Benchmark. Tidal corrections were taken from predicted tides at the BioStation Ferry Reach station.

5.0 LABORATORY TESTING PROGRAM

The majority of soil and rock samples obtained from the 2006 boreholes were brought back to our laboratory in Burnaby, British Columbia, Canada for detailed examination and selected laboratory testing. The laboratory testing carried out for this project is described in the following sections.

5.1.1 Soil Testing

The soil samples obtained during the field investigation generally comprise SPT samples from the drilled boreholes. A total of fifty water content determination tests (ASTM D-2216), seventeen grain size distribution analysis tests (ASTM C-136/ASTM D-422), and five Atterberg Limit Determination tests (ASTM D-4318) were carried out on selected soil samples.

The results of the water content determination tests and Atterberg limit determination tests are presented on the Record of Borehole sheets included in Appendix I. The detailed results of the grain size distribution analysis tests and Atterberg limit determination tests are presented in Appendix II. A summary of the grain size test results is presented in Table 1 immediately following the report text.

5.1.2 Rock Testing

A total of thirteen rock core samples were selected for Unconfined Compression Strength (UCS) testing (ASTM D2938-95). The detailed UCS testing results, including observed failure modes are presented in Appendix II and a brief summary of these results is presented in Table 2 following the text of this report.

The detailed nature and composition of the volcanic rock was not readily identifiable in the field. Supplemental evaluation and analysis was carried out by Golder geologists who logged the rock in detail and selected additional rock samples for petrographic examination. These examinations were carried out using a polarizing Petrographic microscope. Petrographic examinations were carried out on a total of eighteen specially prepared rock samples (thin sections) enabling the identification of minerals and textures that were not discernible with the naked eye or using a stereobinocular microscope. The detailed petrographic results are included in Appendix II.

6.0 INFERRED SUBSURFACE SOIL AND GROUNDWATER CONDITIONS

6.1 General Geology

The geology of the Castle Harbour and Grotto Bay Area, similar to the remainder of Bermuda, generally includes an extensive sequence of sandy aeolian (wind blown) and marine sediments of coralline (calcium carbonate) origin overlying volcanic rock that comprises the Bermuda Seamount. The nearer surface sandy aeolian, and sometimes marine, deposits have typically been subjected to widely varying degrees of weathering, including cementation and cavity formation due to solution processes. Locally within the study area, the coralline deposits have been observed to range from unconsolidated, uncemented to weakly cemented granular deposits of sand and gravel (most common within the northern and eastern study areas) to highly-cemented calcareous limestone with variable sized cavities (most common in the southern and western study areas). In general, the older limestone deposits, typically referred to as Walsingham deposits, are more cemented in nature and include more cavities. They have been observed at or near the ground surface in the southern portion of the study area, sloping down towards the north and east where they are overlain by younger, and generally less-cemented, coralline deposits. Voids and/or cavities within the more-cemented deposits are sometimes filled, or partially filled, with sediment.

In the northern and eastern portions of Grotto Bay, fine-grained marine and/or pyroclastic sediments, including silt and clay, are known to exist immediately beneath, or interlayered within the bottom portions of, the coralline deposits.

Volcanic rock forming the upper portion of the Bermuda Seamount directly underlies the coralline and marine deposits discussed above. Available information indicates that the volcanic rock is composed of a complex and highly variable sequence of basaltic lava, pyroclastic and intrusive flows. The volcanic rock likely extends down several thousand metres below the ground surface and/or sea floor, and is variably weathered and altered within the upper regions of the formation, possibly becoming more competent and intact with depth. However, given its geological origin, the volcanic rock can be highly variable and interlayered with more and less competent materials.

6.2 Drilling Investigation Results

Detailed descriptions of the subsurface soil and groundwater conditions encountered during the geotechnical investigation(s) are presented on the Record of Test Hole Log sheets in Appendix I. A profile illustrating the inferred stratigraphy along the existing causeway alignment is presented in Figure 3. Further, the results of laboratory testing carried out on selected samples obtained during these investigations as well as detailed lithology of the basement volcanic rock strata is presented in Appendix II.

It is noted that significant variation in subsurface conditions was observed at each borehole location. Similar, and possibly greater, variation should be expected across the study area. It is recommended that the reader refer directly to the Record of Test Hole Log sheets and laboratory testing results for detailed soil and groundwater information encountered during the subsurface investigation.

The following sections present a brief overview of the inferred soil and groundwater conditions based the borehole information obtained.

6.2.1 Topsoil

A relatively thin layer of organic topsoil comprised of brown sand, some silt with organics (grass and roots) was encountered at BH06-1 and BH06-4 at Blue Hole Hill Park and Coney Island which we understand have historically been undeveloped. The topsoil was encountered at the ground surface at both locations with thicknesses ranging between about 0.2 and 0.4 m. Based on the observed resistance to auger drill string penetration, the topsoil deposits are considered to be loose.

6.2.2 Fill

At other borehole locations including BH06-2, BH06-3 and BH06-5, where previous site grading activities have occurred, fill materials were encountered at the ground surface. The fill materials generally consisted of heterogeneous white-grey to light brown to black, sand with a trace to some gravel and silt, to sand and gravel with a trace to some silt. Pieces of asphaltic concrete were observed within these fill materials at BH06-5. Where encountered, the fill layer was observed to extend to depths ranging between about 2.3 and 5.5 m below the existing ground surface.

The results of water content determination testing carried out on selected samples obtained from the fill deposits gave natural water contents ranging between about 11 and 24 per cent, although upper samples may be unsaturated. Based on the observed resistance to auger drill string penetration and uncorrected SPT blowcounts ranging between 7 and 37 blows per 0.3 m, the fill materials are considered to vary from loose to dense.

6.2.3 Coralline Deposits

Immediately beneath the topsoil and fill layers, coralline deposits comprised of uncemented granular deposits to highly cemented calcareous limestone were encountered at each borehole location. Based on the geological history of the area, these deposits are of coralline origin (calcium carbonate based) and have undergone varying degrees of lithification as a result of consolidation and cementation. Consequently, the subsurface stratigraphy can be extremely variable over relatively short horizontal and vertical distances.

Generally over the study area, however, uncemented to weakly cemented coralline granular deposits generally overlie more highly cemented deposits, and they typically do not exhibit extensive weathering properties like the highly cemented materials. As such, the uncemented to weakly cemented deposits are considered likely to have been deposited more recently. The weakly and highly cemented deposits are discussed separately below, considering their differing engineering properties.

<u>Uncemented to Weakly Cemented Coralline Sediments</u>

Uncemented to weakly cemented coralline deposits consisting of pink-white to light grey sand, with a trace to some gravel and silt, to gravel, some sand, with a trace of silt were encountered at each borehole location, except at BH06-1. The upper surface of these deposits were encountered at depths ranging between about 0.2 and 5.5 m below the existing ground surface and were observed to extend to depths ranging between about 13.4 and 16.8 m.

The results of grain size distribution analysis testing carried out on selected samples obtained from the uncemented to weakly cemented coralline deposits indicate that the samples tested ranged from sand, some gravel, trace silt, to sand and gravel, some silt. These results are presented graphically in Appendix II. In addition, the results of water content determination testing carried out on other selected samples obtained within the stratum gave natural water contents ranging between about 5 and 40 per cent.

Based on the observed resistance to drill string penetration, and SPT results ranging between 5 and 93 blows per 0.3m, the uncemented to weakly cemented coralline deposits are considered to be loose to very dense, but generally compact.

Highly Cemented Coralline Deposits

Highly cemented coralline deposits, generally comprised of white to light brown, moderate to highly weathered, laminated to thinly bedded, fine to medium grained, vuggy, porous, limestone, were encountered beneath the topsoil layer in BH06-1 and beneath the uncemented to weakly cemented coralline deposits in BH06-2 through BH06-5. At the borehole locations, these highly cemented limestone deposits contained frequent voids and cavities, some up to 4.6 m vertical height, and layered precipitates due to solution processes and weathering. Some of these voids and cavities were filled, or partially filled, with unconsolidated and uncemented fine-grained sediments and deposits of shell fragments.

These highly cemented limestone deposits were encountered at depths ranging between about 0.4 and 18.4 m below the existing ground surface, and were observed to extend to depths ranging between about 23.8 and 35.8 m.

The detailed results of grain size distribution analysis testing carried out on selected SPT samples obtained from this deposit are presently graphically in Appendix II following the text of this report. They indicate that the samples tested range from sand, some gravel, to gravel, some sand with a trace to some silt. The gravel sized particles in the sample tested typically appeared to consist of cemented sand or hardened precipitate. The results of water content determination testing also carried out on selected samples obtained from the stratum gave natural water contents ranging between about 8 and 32 per cent, although this not represent the saturated in-situ condition because of drainage following retrieval in these porous materials. Based on the observed resistance to drill string penetration, SPT test results ranging from 5 to over 75 blows per 0.3 m, and UCS test results typically ranging between about 20 and 39 MPa, the highly cemented limestone deposits are considered to be weak to moderately strong in their intact confined state.

It is noted that SPT sampling in hard, thinly layered deposits, such as encountered within this deposit, can significantly alter, or destroy, the overall geological structure of the deposit at the sample location. As such, the sample gradations noted above, the soil descriptions in the Record of Test Hole Log sheets, and the SPT blowcounts may not accurately represent the in-situ properties of the deposit, and caution should be exercised when using this information for evaluation purposes.

6.2.4 Silt and Clay Sediments

In BH06-2, BH06-3 and BH06-5, fine-grained sediments generally comprised of dark grey-green to light grey-white, silt, some clay, to clay, trace to some silt, with a trace sand to sandy was encountered beneath, or within the lower portions of the coralline sediments described above. The upper surface of these materials was encountered at about 19.5 to 24.4 m depth beneath the existing ground surface with the sediments extending to about 29.3 to 31.9 m depth. A thinner layer of these fine-grained sediments was also encountered between 16.8 and 18.1 m in BH06-2 within the coralline deposits.

The results of grain size distribution analysis testing carried out on selected dark green-grey samples obtained from these strata indicate that the samples comprise clay, trace silt and sand. Similarly, testing carried out on selected light grey-white samples indicate that the samples tested comprise silt and clay trace sand. The detailed results are presented in Appendix II. In addition, the results of water content determination testing gave natural water contents ranging between about 23 and 58 per cent.

Atterberg limit determination testing carried out on selected samples yielded the following results:

- Plastic Limit (PL): 32 to 35 per cent;
- Liquid Limit (LL): 72 to 103 per cent; and
- Natural Moisture Content (MC): 44 to 58 per cent.

One sample obtained from BH06-5 at about 21 m depth yielded a non-plastic Atterberg limit test result. The dark grey-green samples plot as clay with high plasticity according to the Casagrande Plasticity Chart and a light grey-white sample plots as silt with low plasticity. The detailed Atterberg limit test results are presented in Appendix II.

The results of the laboratory index testing, as well as the visual appearance, imply that the interlayered dark-green grey and light grey-white sediments may have been deposited during different geological periods. Although testing has not been carried out to confirm the source of these materials, it is possible that the light grey-white sediments are of volcanic ash (pyroclastic) origin and the green-grey sediments are of volcanic rock and/or pyroclastic origin. It is possible volcanic rock may have been eroded, and the finer grained particles from the erosion process deposited in a relatively low-energy, lagoon-like setting and that the light grey-white sediments were introduced during periodic, early Pleistocene era volcanic events.

Based on the observed resistance to drill string penetration, and SPT blowcounts ranging between 6 and 15 blows per 0.3 m, the marine deposits are inferred to be of firm to stiff consistency.

6.2.5 Volcanic Basement Rock

Each borehole was terminated with the volcanic basement rock that is inferred to form part of the Bermuda Seamount. The volcanic rock was encountered at depths ranging between about 29.3 and 35.8 m beneath the existing ground surface with the upper 3 to 8 m of the rock mass in a completely to highly weathered state. The volcanic rock generally became less weathered to fresh at depths ranging between about 36.0 and 39.8 m below ground surface at the borehole locations.

In general, the rock is described as a suite of altered ultramafic and mafic porphyritic volcanic rocks. They are interpreted to frequently be broken by discontinuities (fractures, joints), which have served as conduits for emplacement of mineral-charged fluids, which have contributed to formation of secondary and tertiary mineralization, and to alteration of the rocks. Vein-filling is variable and replacement of original minerals is in some cases extensive.

It is not clear from close examination of the rock core which facies may have been the original host rock and which facies may represent later intrusions, since the thickness of some units is small, and there appear to be numerous repeats in the thin sections examined during petrographic analysis. It is possible that the original host formation may have been broken by subsequent volcanic activity, and intruded repeatedly, resulting in several similar-lithology units.

The results of UCS testing carried out on selected intact rock core samples gave unconfined compression strengths ranging between about 2 and 40 MPa, indicating that the volcanic rock is generally very weak to medium strong. However, many of the lower strength tests results typically failed on weak joints or planes, and the intact in-situ confined rock mass is generally considered to be weak to medium strong. The detailed UCS test results, including failure modes and photographs are included in Appendix II.

6.2.6 Groundwater Conditions

There was no geotechnical instrumentation installed in any of the boreholes put down as part of this investigation. Consequently, the stabilized groundwater level could not be accurately measured. In addition, pressurized water was used to flush the drill cuttings from each borehole during drilling, therefore the water levels in the boreholes may not represent the surrounding water levels at the time of drilling.

Due to the relatively porous nature and presence of voids and cavities in the coralline deposits, it is expected that the subsurface groundwater levels located within close proximity to Grotto Bay/Castle Harbour will be significantly influenced by the water levels in these water bodies. It is considered likely that the groundwater level in this area will be at approximately the same elevation as the water level in Grotto Bay/Castle Harbour.

Some variations related to the lower permeability clay or basement rock deposits may be present but, given the relatively low elevations of the adjoining land masses, significant artesian pressures are considered unlikely to be present. However, it is noted that a significant increase in water pressure was encountered during drilling at BH06-3 between about 36 and 41 m below the existing ground surface, and that the increased water pressure decreased to normal levels immediately below 41 m depth. Water flow from the top of the drill casing was observed at the end of work day on October 15, 2006 and this flow had stopped by the start of drilling on October 16, 2006. It is inferred that the increase in water pressure was related to possible artesian groundwater conditions within the volcanic basement rock. Similar localized artesian conditions should be anticipated within the study area.

6.3 Geophysical Survey Results

The geophysical survey results are summarized in AutoCAD drawings using base drawing information provided by others. Given the significant additional costs incurred as a result of weather delays in the field, and that the most likely crossing alignments will be in close proximity to the existing causeway or near Coney Island Channel, we have focused our interpretation efforts in these areas. If requested and/or warranted, we can interpret the data collected within the remaining area of Grotto Bay/Ferry Reach. Figures 4 and 5, attached following the text of this report, present contours of bathymetry and two acoustical reflecting layers in the area of the causeway. We note that depths to the acoustic reflections have been adjusted from our previous draft report titled *"Marine Geophysical Survey for Proposed New Crossing, Castle Harbour/Grotto Bay, Bermuda"* (November 9, 2005), based on higher sound velocity estimates calibrated to the October 2006 borehole information.

An interpreted sub-bottom profile of the Coney Island Channel is shown in Figure 6, with the location map on Figure 7. Bathymetry has been represented as depth below Chart Datum. The sub-bottom reflection layers have been contoured using geodetic elevation. Figure 6 provides an example of the data as well as the interpreted profile.

6.3.1 Interpreted Seabed Bathymetry

Figure 4 attached, shows the area of interest in Grotto Bay, as identified to us prior to the fieldwork, as well as the interpreted seabed bathymetry which is contoured for depth below Chart Datum (MLLW). Some additional data was collected outside of this area (to the northeast), and this can be processed should it be required. The maximum depth encountered was in the dredged channel near the causeway. The coastline was used to set a zero water depth and contouring between 0 and 1 m is estimated.

6.3.2 Interpreted Sub-bottom Stratigraphy

Two notable sub-bottom horizons were identified in the seismic reflection data essentially throughout the surveyed area. These are identified as Acoustic Reflection Horizon 1 and Acoustic Reflection Horizon 2. Parallel lines were surveyed along the causeway providing sufficient data to contour the surfaces of these two interpreted horizons. Figure 5 includes contour maps of the two data sets. Figure 6 provides a cross-section with original data, obtained from the Coney Island Channel.

The shallower Acoustic Reflection Horizon 1 is the interpreted shallowest strong reflector below the seabed. This horizon was observed within the first 4 m below the seabed throughout most of the survey area (some deeper areas exist within the Coney Island Channel). In shallow bathymetric areas, we interpret this reflector as potentially coarse or cemented coralline sediments. In deeper bathymetric areas this reflector may not be the same material as in the shallower areas, but it is still the shallowest strong reflector.

Acoustic Reflection Horizon 2 is relatively flat-lying, and it is considered likely that the reflector indicates similar properties throughout the profiled area. This reflector may be a potential bedrock surface, although a coarse sediment or cemented sediment layer cannot be ruled out.

The October 2006 borehole information was compared to nearby seismic data to calibrate the interpreted reflector depth. In our November 9, 2005 draft geophysics report, a sound velocity of 1600 m/s was assumed which produced interpreted horizons that are consistently shallower than rock depths present in the boreholes. Based on the 2006 borehole data, Acoustic Reflection Horizon 2 was interpreted as rock and the overlying sediment velocity was calibrated to 2000 m/s to provide similar depths as observed in the boreholes. This sound velocity indicates a more compact and cemented sediment. In the area of the deep bathymetry in proximity to the dredged channel, it is likely that the apparent deeper bedrock contouring is a result of variable sound velocity in the overlying sediments.

It is noted that the depth of Horizon 2 does not appear to be consistent with the depth to volcanic rock recorded in the boreholes put down within the south portion of the profiled area. Further geotechnical investigation over water is considered necessary to verify geophysical results in these areas.

A third reflector, not present in all areas, has also been identified in the dataset, but has not been included in any of the figures. This layer is present approximately 6 to 10 m above the interpreted basal reflector. In the vicinity of Grotto Bay, this reflector is present on all lines and shallows towards the south shorelines. This layer may represent a zone of compaction and/or density change in the overlying limestone and coralline sediments or possibly finer grained sediments as observed in some of the boreholes.

6.3.3 Limitations on Geophysical Interpretations

Golder's geophysical services are conducted in a manner consistent with the level of care and skill ordinarily exercised by other members of the geophysical community currently practicing under similar conditions subject to the time limits and financial and physical constraints applicable to the services. Sub-bottom and seismic reflection profiling are remote sensing geophysical methods that, because of geologic and other conditions, may not be able to detect all subsurface features of interest.

IMPORTANT INFORMATION AND LIMITATIONS OF THIS REPORT

Standard of Care: Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practising under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

Basis and Use of the Report: This report has been prepared for the specific site, design objective, development and purpose described to Golder by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. Any change of site conditions, purpose, development plans or if the project is not initiated within eighteen months of the date of the report may alter the validity of the report. Golder can not be responsible for use of this report, or portions thereof, unless Golder is requested to review and, if necessary, revise the report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client. No other party may use or rely on this report or any portion thereof without Golder's express written consent. If the report was prepared to be included for a specific permit application process, then upon the reasonable request of the client, Golder may authorize in writing the use of this report by the regulatory agency as an Approved User for the specific and identified purpose of the applicable permit review process. Any other use of this report by others is prohibited and is without responsibility to Golder. The report, all plans, data, drawings and other documents as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder, who authorizes only the Client and Approved Users to make copies of the report, but only in such quantities as are reasonably necessary for the use of the report by those parties. The Client and Approved Users may not give, lend, sell, or otherwise make available the report or any portion thereof to any other party without the express written permission of Golder. The Client acknowledges that electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore the Client can not rely upon the electronic media versions of Golder's report or other work products.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to Golder by the Client, communications between Golder and the Client, and to any other reports prepared by Golder for the Client relative to the specific site described in the report. In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be made to the whole of the report. Golder can not be responsible for use of portions of the report without reference to the entire report.

IMPORTANT INFORMATION AND LIMITATIONS OF THIS REPORT (cont'd)

Unless otherwise stated, the suggestions, recommendations and opinions given in this report are intended only for the guidance of the Client in the design of the specific project. The extent and detail of investigations, including the number of test holes, necessary to determine all of the relevant conditions which may affect construction costs would normally be greater than has been carried out for design purposes. Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, safety and equipment capabilities.

Soil, Rock and Groundwater Conditions: Classification and identification of soils, rocks, and geologic units have been based on commonly accepted methods employed in the practice of geotechnical engineering and related disciplines. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Golder does not warrant or guarantee the exactness of the descriptions.

Special risks occur whenever engineering or related disciplines are applied to identify subsurface conditions and even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions. The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between and beyond sampling points may differ from those that actually exist. In addition to soil variability, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. **The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report.** The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, etc.) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

IMPORTANT INFORMATION AND LIMITATIONS OF THIS REPORT (cont'd)

Sample Disposal: Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.

Follow-Up and Construction Services: All details of the design were not known at the time of submission of Golder's report. Golder should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of Golder's report.

During construction, Golder should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Golder's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Golder's report. Adequate field review, observation and testing during construction are necessary for Golder to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Golder's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

Changed Conditions and Drainage: Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Golder be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Golder be employed to visit the site with sufficient frequency to detect if conditions have changed significantly.

Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Golder takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.

TABLE 1: Summary of Grain Size Distribution Analysis Testing

Test Hole	Sample Number	Sample Depth (m)	Gravel Portion (75mm - 4.75mm)	Sand Portion (4.75mm - 0.075mm)	Fines Portion (<0.075mm)	Clay Portion (<0.002mm)
BH06-1	Run 8	14.9 to 15.2	0.0	3.0	97.0	34.4
BH06-1	Run 15	24.1 to 24.4	0.0	4.6	95.4	31.4
BH06-2	SA 5	7.6 to 8.1	18.9	73.7	7.4	
BH06-2	SA 7	12.2 to 12.8	10.8	74.0	15.2	
BH06-2	SA 9B	18.0 to 18.1	18.8	32.4	48.8	1.6
BH06-2	SA 10	20.7 to 21.3	81.8	13.5	4.7	
BH06-3	SA 5	7.0 to 7.5	48.7	36.7	14.6	
BH06-3	SA 9	16.2 to 16.6	77.4	10.0	12.6	
BH06-3	SA 12	25.3 to 25.8	0.0	6.8	94.2	36.7
BH06-3	SA 13	28.3 to 28.8	0.0	4.5	95.5	83.6
BH06-4	SA 2	3.1 to 3.5	23	65.1	11.9	
BH06-4	SA 7	11.6 to 12.0	49.9	37.8	12.3	
BH06-4	SA 9	17.7 to 17.8	69.7	26.7	3.6	
BH06-5	SA 3	4.6 to 5.0	21.2	66.4	12.4	
BH06-5	SA 6	8.5 to 9.0	33.2	49.9	16.9	
BH06-5	SA 8	14.6 to 15.1	56.0	36.4	7.6	
BH06-5	SA 12	26.8 to 27.3	0.0	4.2	95.8	90.0

TABLE 2: Summary of UCS Test Results

Test Hole	Sample Depth	Stress (MPa)	Failure type
BH06-1	7.6 to 7.8m	38.1	Vertical Splitting
BH06-1	15.5 to 15.7m	29.7	Vertical Splitting
BH06-1	29.0 to 29.2m	20.1	Vertical Splitting
BH06-1	40.2 to 40.4m	1.8	Single Diagonal Shear Plane on Foliation or Joint
BH06-1	42.2 to 42.4m	9.4	Single Diagonal Shear Plane
BH06-2	37.8 to 38.0m	22.6	Vertical Splitting
BH06-2	41.6 to 41.8m	13.8	Single Diagonal Shear Plane
BH06-3	42.2 to 42.4m	22.4	Vertical Splitting
BH06-3	44.3 to 44.5m	5.9	Vertical Splitting
BH06-4	34.4 to 34.6m	16.7	Conical
BH06-4	42.1 to 42.3m	20.4	Single Diagonal Shear Plane
BH06-5	39.8 to 40.0m	4.1	Single Diagonal Shear Plane on Foliation or Joint
BH06-5	40.8 to 41.0m	40.7	Conical