REPORT S-05-1743 PHASE 2 and PHASE 3

GEOTECHNICAL INVESTIGATION –
BORINGS 4, 5, 6, and 7
LNG TERMINAL – CACOUNA ENERGY
GROS CACOUNA QUEBEC
APRIL 18, 2006
for
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EXECUTIVE SUMMARY

In October 2005, the Phase 1 geotechnical investigation was carried out and involved the drilling of three (3) shallow boreholes (BH-1 below tank T-100; BH-2 and BH-3 below tank T-101), a geophysical survey on the tank T-101 site, and mapping of the local rock conditions. In January 2006, Phase 2 involved the drilling a 52.6m long inclined borehole at the top of the quarry, which dipped (38^{o}) to the northeast and across the site for tank T-100 (Figure 3; Appendix A). The borehole was completed to 63.3m in April bringing it 4m past the future tank T-100 wall and to a final elevation of -16.7m. This borehole was drilled to detect whether a large, near vertical fracture, observed in the quarry face 80m south the tank T-100, continued through the footprint of the tank. Phase 3 involved investigations carried out in February 2006 and included a geophysical cross-hole survey to determine the shear wave velocity, an electrical resistivity survey of the rock underlying tank T-101, and a vertical, large diameter HQ (75 mm diameter) deep borehole (30m) in the footprint of tank T-101 to supplement the shallow (15m) boreholes done during Phase 1.

Tanks T-100 and T-101 are to be constructed at elevation +5 m or about 1 metre above the current floor of the quarry at elevation +4m±. Based on field observations and the survey provided by Sandwell, the southern half of tank T-100 site is covered by a bench at about elevation 15m, which was covered with a layer of blast rock. The northeastern section of the tank location will require excavating by drilling and blasting between 18m to 37m of solid sandstone (impure quartzite).

Geological mapping of the quarry face and shoreline identified massive, thick and resistant beds of well cemented solid sandstone (impure quartzite) formations with minor interbeds of softer more impure shaley zones and thin beds of conglomerate that pinch out as one approaches the river. These stratified massive sandstone bedrock formations slope gently down (dip) at a low angle of about 12^o towards the southeast. Associated jointing on a relatively close spacing is perpendicular to the bedding lithology. Down the hole video camera carried out in the dry section of BH-4 to elevation +1.3m confirmed the very solid nature of the rock at this location.

Uniaxial compression tests of the above material indicate high uniaxial compression resistances ranging from 66 MPa to 127 MPa. After removal of the 18 to 30 metres of bedrock, this formation will provide a good foundation for the LNG tanks as currently placed and specified.

In the vertical quarry face, a significant well defined near vertical dipping joint or fracture plane oriented in a northwest-southwest direction was described during the phase 1 geotechnical study. This structural feature crosses within 15m of the northeast perimeter of tank T-100. Borehole BH-4 was drilled at an angle to attempt to intercept this major fracture plane and determine if it extends into the footprint of tank T-100. The presence of any thick broken rock zones or "gouge" would confirm the presence of a fault. The angle borehole encountered solid, massive sandstone formations to an elevation of -16.7m (or 21.7m below the planned tank base), and this to 4 metres past the perimeter of the tank.

Although tight fractures and minor slickensides and striations were observed at two (2) different depths in the borehole, no fault gouge was detected along the length of the inclined boring taken to elevation -16.7m at a point 4 metres past the tank T-100 perimeter. This indicates that the fracture to the south will not affect the foundation of the tank.

The geophysical seismic lines and crosshole survey confirm the presence of a thin layer of quarry fines underlain by solid sandstone at the location of tank T-101. Based on the results of the seismic survey, no excessive fill or significant faults or fractures exists under tank T-101 and the current placement of the tank does not require adjustment.

In general the geophysical and borehole data support the following:

- A shallow (less than 1m) blast rock layer was observed in the vicinity of tanks T-100 and T-101,
- Solid, strong bedrock (sandstone and microconglomerate), suitable for the tank foundation, was encountered below the 1 to 2 metres of blast affected bedrock below the footprints of tanks T-100 and T-101, and
- No major fractures or fault gouge was observed in the vicinity of tank T-100.

Although seven (7) boreholes drilled in Phase 1 to 3 (BH-1 to BH-7) indicate good foundation support conditions on the floor of the quarry, additional boreholes are suggested on the eastern perimeter of tank T-101 once the bedrock tank platform has been prepared. These will help provide greater detail of any local anomalies, such as ancient stream channels, that could be present and require deeper excavation than are currently described.

However, the Phase 1 geophysical data revealed no features of concern that would suggest these anomalies on the tank T-101 site over the three 115m lines surveyed. Tank T-100 falls within the original bedrock outcrop that has been removed by blasting which provides good evidence that solid bedrock exists within the tank's foot print.

A deeper large diameter hole (HQ size – 75 mm diameter) as completed for tank T-101 (BH-7), but perpendicular to the bedding planes (inclined 12^{o} towards the southeast), is necessary at the centreline of each tank to investigate the presence of any soft rock layer, at greater depth below the 80-metre diameter tanks.

In conclusion, rock analysis of the rock cores recovered in the seven (7) borings confirms that the site is well suited to provide a strong foundation for the tank farm. The solid sandstone bedrock beneath the quarry floor offers a good bearing layer with an allowable design bearing value of 1,000 kPa (10 tons per square foot) for settlements limited to less than 10 mm.

Finally, the seismic information available in "*Earthquake Hazard Analysis: Gros Cacouna, Quebec*" (Atkinson, 2006) suggests that reported deep earthquakes, occurring along fault lines running under the St. Lawrence River, not exceeding magnitude 6.4, and in a region more than 20 kilometres distant, have not produced any evidence of recent geologic movements (<10,000 years). It is the opinion that it would be highly unlikely (extremely low probability) that seismic events less than magnitude 7 at 20km distant or at magnitude 7 at 25km to 40km distant, would cause damage to a structure designed to resist earthquakes of as prescribed per the design code.

1.0 INTRODUCTION

Within the scope of work for the construction of the new LNG storage tanks at the LNG Terminal in Gros Cacouna, Quebec, our firm was mandated to conduct a third phase geotechnical investigation including a cross-hole survey to measure shear wave velocity of the bedrock and an electrical resistivity test. Also reported are the results of the phase 2 geotechnical study that encompassed an angle drill hole in the vicinity of tank T-100 to investigate the potential continuation of a vertical fracture observed during the geological reconnaissance carried out in October 2005.

This report contains the results of the phase 2 and phase 3 geotechnical investigation, values of pertinent geotechnical parameters required for the design of foundations and our conclusions and recommendations.

2.0 BACKGROUND

The Ile du Gros Cacouna is northwest of Cacouna on the east shore of the St. Lawrence River. The rocks in the region belong to the supergroup of Quebec in the Appalachian tectonic province. The rocks on the Ile du Gros Cacouna where the tanks are to be located are of Cambrian age (544 to 505 million years old).

The former Ile du Gros Cacouna is approximately 2.5km long by 0.75km wide with elevations on the south west point of the island approaching 65m.

2.0 BACKGROUND (cont'd)

The cliff face in the immediate vicinity of the tanks is approximately 35m to 40m in height and was formed by previous blasting activity for purposes of constructing the breakwater for the harbour (Figure 1; Appendix 1).

The region surrounding Gros Cacouna has undergone major deformations resulting in rock layers (beds) that have been folded with axis of the fold crests running (striking) approximately parallel to the shoreline that is bearing north-east. A slaty rock cleavage (finer grained rock formed in the host sandstone) often forms perpendicular to the bedding as a result of the sandstone deformation. This was observed on site along the beach but was not as prevalent in the vicinity of the tanks. However, the slow folding of the bedrock through geological time may be the primary cause of the near vertical fractures and dislocated beds observed on the LNG site. The fractures, like the cleavage, are potentially a result of the rock accommodating the flex of non-ductile sandstone. Tight fractures with slickensides showing movements due to adjustments to accommodate the rocks changing orientation over geological time, along with a lack of significant fault gouge encountered in the core, indicate the lack of any major faults in the vicinity of the tanks.

3.0 SUB-SURFACE EXPLORATION

From January 24 to January 29 an inclined borehole (BH-4) was drilled in the vicinity of tank T-100 and encountered solid sandstone bedrock throughout with small zones exhibiting tight fractures and sandy siltstone. The inclined borehole was completed to a depth of 65.6m from April 11 to April 14 putting it 4m past the tank T-100 perimeter and at a final elevation of -16.7m resulting in the same strong sandstone without significant fractures or fault gouge. Boreholes BH-5, BH-6 and BH-7 were drilled on February 6 to 8 for the purposes of conducting the cross-hole survey in the vicinity of tank T-101. Borehole 7 was drilled to 30 metres (100') depth using an HQ sized core barrel (75mm) in order to supplement the phase-1 drilling for tank T-101. Electrical resistivity to a depth of 30m in the vicinity of tank T-101 was completed for design of tank grounding.

3.1 Phase 2: Inclined Borehole BH-4

Originally, three (3) vertical boreholes were drilled on site to evaluate the bedrock conditions below Tanks 100 and 101 and the suitability of the site for construction of the two tanks from a bearing capacity point of view (Figure 1; Appendix 1).

During the geological mapping of the near vertical 40-foot high quarry walls, a large, very well defined smooth fracture, dipping about 80^{o} west and striking in a northwest to southeast direction, was visible near the centre of the quarry outline (Photo 3).

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.1 Phase 2: Inclined Borehole BH-4 (cont'd)

At the top of the cliff face, the blasting operations had caused spreading of the steeply dipping fracture (Photos 6 and 7). At the bottom of the face level with the quarry floor, the confining rock masses on both sides of the fracture, resulted in tight rock to rock contact with no visible broken rock or fault gouge.

The blasting and removal of the rock material in the quarry reveals a discontinuity (offset) of the bedding on both sides of the fracture. On the west side of the structure, a thin shaley interbed was visible in the formation, which did not appear in the rock on the east side of the fracture on the 30-foot high cliff. This confirmed that there was indeed vertical dislocation of the rock along this fracture during folding events in the geological past.

A thorough visual inspection of the north quarry face in the tank T-100 area of the projected fault did not find any trace of this feature. There is a possibility it deviated slightly to the east downriver and this would put the surface trace beyond the quarry face, but because of its dip toward the west, it is still possible it could dissect the bedrock formation below the tank.

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.1 Phase 2: Inclined Borehole BH-4 (cont'd)

The vertical drill holes provide reliable information on the type and quality of the low dipping sandstone beds but, because of their lack of horizontal coverage, are not very effective at locating steeply dipping planar features such as joints, fractures or faults. For this reason and as originally proposed, it was recommended to drill an angle hole, which would cut across all the steeply dipping features below the tank's footprint (Figure 3; Appendix 1). In this manner, the number and location of each bedrock discontinuity would be intercepted and the width, thickness and presence of broken rock could be evaluated. Hence, inclined borehole BH-4 was drilled to a depth of 52.6 between January 24 and January 29, 2006, after which a video camera was used to view the walls of the dry borehole down to the water level at elevation +1.3m. The loss of water during drilling prevented continuing the borehole past the perimeter of the tank. In April 2006 the borehole was grouted to seal the hole preventing water loss and then drilled to its final depth of 65.6m at a point 4m past the tank perimeter. The following table is a summary of the conditions encountered in BH-4:

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.1 Phase 2: Inclined Borehole BH-4 (cont'd)

Table 1: Borehole-4 summary (see Appendix 4 for detailed log)

DEPTH ALONG BOREHOLE m (feet)	ELEVATION (m)*	ROCK TYPE	NOTES
0.84 – 5.49 m (2.75 – 18 feet)	23.12m to 20.25m	Fractured Sandstone	Recovery 51% (surface rock)
5.49 – 22.25 m (18 – 73 feet)	20.25m to 9.94m	Solid Sandstone	Recovery 95% – 100%
22.25 – 23.62 m (73 – 77.5 feet)	9.94m to 9.09m	Solid Microconglomerate	Recovery 96%
23.62 – 27.73 m (77.5 – 91 feet)	9.09m to 6.56m	Solid Sandstone	Recovery 95% – 100%
27.73 – 28.58 m (77.5 – 93.75 feet)	6.56m to 6.04m	Sandy Siltstone	Recovery 98% - 100% (Drill core barrel did not latch; Recovery 63%)
28.58 – 31.70 m (93.75 – 104 feet)	6.04m – 4.12m	Solid Sandstone	Recovery 98% (Future tank level at 5m)
31.70 – 34.14 m (104 – 112 feet)	4.12m to 2.62m	Siltstone	Recovery 83% to 100%. Lower recovery reflects change in material at bedding contact at 4.12m. Slickensides noted on smooth tight fractures at 4.1m to 3.7m (Photo 2; Appendix 3B) with soft grey-green chlorite deposits. No fault gouge observed indicating rock slickenside features are a result of folding rather than faulting.
34.14 – 52.60 m (112 – 172.58 feet)	2.62m to -8.75m	Solid Sandstone	Recovery 96% to 100%. Water elevation at 2.4m (April 14,2006). Water lost after drilling 53m (to elevation -8.75)
52.60 – 65.63 (172.58 – 215.33	-8.75 to -16.70	Solid Sandstone	Recovery 96% to 100%

**Note: Future tank elevation is at 5m. Ground elevations approximate.*

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.1 Phase 2: Inclined Borehole BH-4 (cont'd)

The angle hole did encounter some minor deformation features in the 24.3m (80') to 33.5m (110') depth range (Elevation 2.9m to 8.6m) and drilling water, which was fully recovered to this level, was lost in the last run, at a depth of 53m (173') or within 8 metres of the proposed Tank T-100 perimeter. With no drill water return (because of flow out through a crack or joint in the formation), drill cutting accumulated in the dry upper section of the borehole and the hole could not be continued without cementing the bottom 10 to 15 meters of the borehole (including fractured rock) to re-establish the flow of drill cuttings up the hole to the surface. Without authorisation, this was delayed to allow logging the borehole with a down hole camera, which permitted visual inspection, in the dry section of the rock (to elevation 1.3metres), of discontinuations noted in the core (Photo 1; Appendix 3).

The down hole camera revealed that the condition of the rock in the borehole down to the water level at elevation +1.3 m (Jan 29, 2006) was in the most part solid with minimal open fractures (Photo 1; Appendix 3). The majority of fractures that were observed were small (<5 mm) and were the result of normal hairline thin joints that have been filled over time with calcite mineral deposits. The wider fractures were up to 5 mm wide.

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.1 Phase 2: Inclined Borehole BH-4 (cont'd)

Below the ground water level (approximate elevation 1.3m), the water was extremely cloudy even after flushing with clean water for several hours, and the video camera could not be used to view the rock in the borehole wall.

3.2 Phase 3: Geophysical investigation; 30 m deep HQ core; Boreholes BH-5, BH-6 and BH-7

Boreholes 5, 6 and 7 were drilled to a depth of 16.5m (54’), (16.8) 55’, and 30.8m (101’) respectively (Figure 4; Appendix 1). Boreholes 5 and 6 were cored with an NQ barrel (50mm diameter cores) for the purpose of accommodating the geophysical instruments. Borehole-7 was HQ sized core (75mm diameter) and had the dual purpose of housing the geophysical instruments and providing additional information regarding the bedrock condition to a depth of 30m in the vicinity of Tank T-101. The following table is a summary of the conditions encountered in borehole-7:

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.2 Phase 3: Geophysical investigation; 30 m deep HQ core; Boreholes BH-5, BH-6 and BH-7 (cont'd)

Table 2: HQ Borehole-7 summary (see appendix 4 for detailed log)

DEPTH ALONG BOREHOLE m (feet)	ELEVATION (m)*	ROCK TYPE	NOTES
0 – 0.46 m (0 – 1.5 feet)	3.5m to 3.04	Blasted rock	
0.46 – 2.13 m (1.5 – 4.5 feet)	3.0m to 1.37m	Fractured Sandstone	Blast affected bedrock
2.13 – 3.94 m (4.5 – 12.9 feet)	1.37m to -0.44m	Solid Sandstone	Recovery 97%
3.94 – 5.08 m (12.9 – 16.7 feet)	-0.44m to -1.58m	Silty Sandstone	Recovery 90% Slickensides, striations with more than one strike direction and plunge, and 3cm fracture filled with silt/clay at -0.5m elevation
5.08 – 11.89 m (16.7 – 39 feet)	-1.58m to -8.39	Solid Sandstone	Recovery 98% to 100%
11.89 – 13.59 m (39 – 44.6 feet)	-8.39m to -10.09m	Sandstone	Recovery 95% to 100% Weathered core with slickensides and striations at elevation -8.4m on fracture plane with variable strike and dip. Slickensides and altered rock (chloritized) at elevation -8.9m
13.59 – 17.8 m (44.6 – 58.3 feet)	-10.09m to -14.28m	Solid Sandstone	Recovery 95% to 100%
17.8 – 17.93 m (58.3 -58.8 feet)	-14.28m to -14.43m	Conglomerate and Silty Sandstone	Recovery 93%
17.93 – 23.62 m (58.8 – 77.5 feet)	-14.43m to -20.12m	Solid Sandstone	Recovery 93% to 97%
23.62 – 23.8 m (77.5 – 78.1 feet)	-20.12m to 20.3m	Conglomerate	Recovery 100%
23.8 – 30.76 m (78.1 – 100.9 feet)	-20.3m to -27.26	Solid Sandstone	Recovery 93% to 100%

**Note: Future tank elevation is at 5m. Ground elevations approximate.*

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.2 Phase 3: Geophysical investigation; 30 m deep HQ core; Boreholes BH-5, BH-6 and BH-7 (cont'd)

In general, below the 3m of blast affected rock, BH-7 shows that the solid rock observed in boreholes BH-2 and BH-3 (phase 1) continues to a depth of 30 metres (100’) and will provide a good foundation for the current proposed placements of the tanks.

3.3 Ground Water Observations Summary

Ground water levels in the previous boreholes (Phase 1: BH-1, BH-2, and BH-3; October 2005) and recent boreholes (Phase 2 & 3: BH-4 to BH-7) are summarised in the following table.

WATER LEVELS MEASURED IN THE BOREHOLES

BOREHOLE	WATER DEPTH (m)	APPROXIMATE WATER ELEVATION (m)	DATE
BH-1	0.38	3.60	Oct 22, 2005
BH-2	0.94	2.50	Oct 22, 2005
BH-3	1.12	2.30	Oct 22, 2005
BH-4	36.3*	1.30	Jan 29, 2006
BH-4	34.5*	2.40	April 14, 2006
BH-5	1.65	1.85	Feb 9, 2006
BH-6	1.60	1.90	Feb 9, 2006
BH-7	1.55	1.95	Feb 9, 2006

**Water depth for BH-4 is measured as a distance along an inclined borehole with a plunge of 38%. Actual depth depends on the elevation of the terrain at a point directly above the water table measurement.*

Boreholes BH-1 to BH-3 were measured in the early fall when the tide was high and small water falls were visible on the nearby quarry face.

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.3 Ground Water Observations Summary (cont'd)

Boreholes BH-1 and BH-4 are close to the shoreline and shows more sensitivity to the fluctuating tides than the borehole further inland.

3.4 Hydraulic Conductivity

The thin soil layer encountered at the borehole sites was less than 1m underlain by fractured blast affected rock. Therefore, permeability readings in the soil zone do not apply to the general subsurface conditions.

After completion to the 53-metre (173') depth of Borehole BH-4, water was pumped into the borehole at the maximum rate of the equipment (approximately 12 gpm) over 2 hours with no observed rise in the water elevation (1.3m). Golder performed falling head permeability tests on the monitoring wells drilled in this same zone (quarry floor) for the environmental assessment. They reported k values for the sandstone bedrock range from 1.4×10^{-3} m/s to 6.0×10^{-3} m/s.

3.5 Strength of the Rock Formation

Three (3) rock samples were tested during the first phase of drilling (October 2005) and four (4) during the third phase (Feb 2006) for unconfined uniaxial compression strength.

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.5 Strength of the Rock Formation (cont'd)

The rock samples were representative of the lithology variation of the sandstone. The unconfined uniaxial strength of the bedrock varied between 83.7 and 135.9 MPa, as summarised in the table below.

UNCONFINED UNIAXIAL COMPRESSIVE STRENGTH OF THE SANDSTONE BEDROCK				
SAMPLE NO.	**BOREHOLE**	**DEPTH (m)**	**UNCONFINED UNIAXIAL COMPRESSIVE STRENGTH (MPa)**	**LITHOLOGY**
1	BH-1	13.4	127.1	Silty sandstone
2	BH-2	4.4	104.3	Sandstone
3	BH-3	4.6	83.7	Conglomerate
4	BH-4	32.9	117.7	Silty Sandstone
5	BH-6	14	116.1	Conglomerate
6	BH-7	12.8	99.9	Sandstone
7	BH-7	29.2	135.9	Sandstone

The compressive strength tests done on four (4) hand samples in May 2005 had a similar range of 66MPa to 114MPa indicating an excellent quality rock. The absorption values were usually less than 0.5% for the cemented sandstone fragments but increasing to 1 to 1.5% for the softer sandstone.

3.6 Geophysics

Shear Wave Velocity (Cross-Hole Survey) BH-5, BH-6 and BH-7

As requested in the mandate for tank design, shear wave velocity was measured in the vicinity of tank T-101.

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.6 Geophysics (cont'd)

Shear wave velocity (Vs) was determined by the cross-hole method using the three (3) boreholes drilled in the footprint of the tank (BH-5, BH-6, and BH-7).

Apart from the first 1.5 to 2 metres below the quarry floor, where lower shear velocities were recorded (904 to 1,592 m/sec), the rock between the 2 and 12-metre depth had a consistent regular shear wave velocity varying between 2,000 and 3,000 m/sec.

The bedrock at the site for tank T-101 is covered with a thin layer of blast rock under snow at the time of drilling. A sand and gravel fill was placed over the quarry floor to access the boreholes and provide a working surface for the drill and support vehicles. Three in-line vertical holes were drilled for the cross-hole survey (Figure 1; Appendix 1). The holes had a spacing of 8 metres and a protective casing was used only for the upper portions of the borehole to prevent the quarry fines and the highly fractured blast rock from collapsing into the hole. The remaining depth of each hole was left uncased and bare in order to gain the maximum signal transmission for the geophysical instrument.

The test results show shear wave velocities were in the range of 2000 m/s to 3000 m/s below an approximate elevation of 3m (see Appendix 5A).

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.6 Geophysics (cont'd)

The lower values measured near the surface (904 m/s to 1592 m/s) represents the fractured blast rock. A thin zone of lower shear wave velocity (1744m/s to 1786m/s) was detected at the 13m to 14m depth (approximate elevation: -9m to -10m). The core from borehole BH-6 shows a zone in this range where the rock lithology changes from a sandstone to a microconglomerate with tight near horizontal fractures. This rock type was tested during previous phases and resulted in high compression strengths (83.7 MPa) that will provide excellent support for the specified tank.

No large zones of weakness under the surface blast rock were detected with the cross-hole method. The data also suggests the lack of significant fracture zones that could not be detected below solid bedrock by the surface geophysical method undertaken during the phase 1 geotechnical study. The cross-hole survey work is reported in detail in Appendix 5A.

Electrical Resistivity

On February 10, 2006, electrical resistivity was carried out on the future tank T-101 site to determine grounding criteria for the future tank construction. The survey was limited to the tank T-101 location due to similarity in rock conditions across the site.

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.6 Geophysics (cont'd)

Bedrock is close to the surface in the vicinity of tank T-101 (see borehole logs; Appendix 4) and the results of the electrical resistivity are indicative of the rock rather than the blast rock surface layer. The west to east and north to south seismic traverses shows average resistivities of 2061 ohm-m and 1980 ohm-m respectively. A detailed description of the work is presented in Appendix 5B.

Seismic Refraction Survey (October 2005)

The geophysical surface survey undertaken in October 2005 was carried out to determine if large changes in the overburden existed for the future tank T-101. This method is able to cover a larger aerial extent than the cross-hole survey. It could not, however, detect large fractures that did not continue to the surface of the bedrock (as the cross-hole survey can). In general, this method showed that for each 115m traverse:

- No indication of large fractures at the solid bedrock surface were detected,
- less than 3 metres of fractured bedrock at the surface and no excessive overlying soil or blast rock, and
- bedrock with high compression wave velocities (Vp) (4800m/s to 5200m/s) indicative of strong sandstone was encountered near the surface below the blast affected zone.

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.6 Geophysics (cont'd)

These results, in combination with the boreholes and cross-hole survey, confirm the excellent quality rock conditions at the proposed location of tank T-101. The results of the phase 1 geophysical survey are explained in detail in *Report S-05-1743 phase 1, geotechnical investigation – geology - borings 1, 2 and 3, LNG terminal – Cacouna Energy – November 28, 2005.*

3.7 Water Chemistry

In addition to the results previously reported (*Golder & Assoc., 2005, Environmental Impact Statement*), an additional near surface water sample was taken from BH-5 at approximately 1m elevation. Chemical tests on ground water are summarized in Table 5.2. These tests confirm the following:

- The pH is between 7.3 and 8.2 and has a low corrosion effect on exposed steel
- Chloride concentration in the water is low to moderate and there is a potential corrosion problem.
  f'_c = 35MPa
  w/c ratio < 0.40
  5 to 8% air entrainment for exposed concrete
- Sulphates concentration in the water is very low and is not aggressive to concrete.
- Redox potential in the water is low
- Resistivity of the rock is not a potential corrosion problem for the concrete structure.

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.7 Water Chemistry (cont'd)

TABLE 5.2 CORROSION CONSIDERATIONS

Parameter	Units	Sample location	Media	Value
Resistivity	Ohm – m	Tank T-101 Line SE-1 Line SE-2	Bedrock and overlying blast rock	 2061 1980
pH	----	MW-04-1* MW-04-5* BH-5-060209	Ground water	7.3 8.2 7.9
Chloride (Cl)	ppm	MW-04-1* MW-04-5* BH-5-060209	Ground water	54 490 14.5
Sulphates (SO_4)	ppm	MW-04-1* MW-04-5* BH-5-060209	Ground water	12 46 18.6
Sulphide	ppm	BH-5-060209	Ground water	<0.04
Redox Potential	mV	BH-5-060209	Ground water	463

- *Golder & Assoc., 2005, Environmental Impact Statement (EIS)*

3.8 Previous Test Pits (Future Tank T-102)

No boreholes or geophysics were done in the vicinity of tank T-102 (future) as it was not part of the current mandate. However, based on available information from the provided surveys, there are rock outcrops in a small area on the south perimeter of future tank T-102. The test pits and previous boreholes indicate that bedrock on the northern perimeter is approximately 7m below ground surface, confirming that the bedrock surface slopes downward towards the north and the west.

3.0 SUB-SURFACE EXPLORATION (cont'd)

3.8 Previous Test Pits (Future Tank T-102) (cont'd)

Constructing the tank about one-half diameter towards the southeast would permit founding all foundations on bedrock. The exact location should be determined by future boreholes.

The results of nine (9) test pits provided by Sandwell are summarised in the following table and located in Figure 2; Appendix 1.

TEST PITS		
BOREHOLE	**BEDROCK DEPTH**	**WATER DEPTH**
PT-1	1.2m	No data
PT-2	2.25m	No data
PT-3	2.7m	No data
PT-4	>4m	2.9m
PT-5*	>4m	3m
PT-6*	2.7m	No data
PT-7*	1 to 1.1m	No data
PT-8	>4m	3.2m
PT-9	4.1m	No data

** In area of proposed tank T-102.*

4.0 DESIGN OF FOUNDATIONS, DISCUSSIONS AND RECOMMENDATIONS

The final site elevation or top of tanks foundation is planned to be at 5 metres geodetic. The concrete ring foundation is planned to be 5 metres wide and will be carried below frost depth and into solid rock.

4.0 DESIGN OF FOUNDATIONS, DISCUSSIONS AND RECOMMENTATIONS (cont'd)

This foundation will support the double walled tank consisting of a 1 metre thick prestressed concrete shell 52 metres high applying a loading of about 312 kPa or 378 kPa for a tank filled with liquid (not including roof and snow loads). The bottom of the tank will be carried on engineered fill or reinforced 20MPa lean concrete to bedrock.

The rock cliff on the north half of tank T-100 (Elev. 35 m) will require excavation of the rock (blasting) to a depth of between 20 and 36 metres to reach the current quarry floor. At this level, the solid rock has an allowable design bearing value of 1,000 kPa.

The LNG tanks concrete mat foundation should be placed on solid rock after thin levelling course of lean concrete has been placed to provide a working platform for the formwork.

Any fractured or weak zones should be excavated to a minimum depth of one (1) metre. In the case of large, wide blocks of solid bedrock loosened by the rebound effects of blasting a slightly inclined bedding layer, the corrective action should be determined by a foundation specialist. This will be important to determine what blast affected rock need be removed or can remain in place (provided that the any blast loosened rock that remains is bolted to the underlying undisturbed bedrock). This will be important when a loose block is wedged below a solid block and removal of the loose block would require the removal of the overlying block.

4.0 DESIGN OF FOUNDATIONS, DISCUSSIONS AND RECOMMENTATIONS (cont'd)

Dewatering will be required as the bottom of the foundation is about one metre below the water table. This can be achieved by pumping from sumps installed below the footing level.

At the time of drilling in October 2005, a small waterfall was observed at a location in between the future construction sites of the LNG tanks. Should this water interfere with construction, it should be diverted away through drainage ditches.

4.1 Foundation design parameters

Table 4.1 summarises foundations design parameters for foundations carried on solid bedrock.

4.0 DESIGN OF FOUNDATIONS, DISCUSSIONS AND RECOMMENDATIONS (cont'd)

TABLE 4.1 GEOTECHNICAL DESIGN PARAMETERS		
Parameter	**Units**	**Rock**
Allowable bearing capacity	kPa (tsf)	1000 (10)
Density	kN/m^3	25.5 to 27
Expected settlement	mm	< 10
Design of foundation walls (triangular pressure distribution with depth)		
Modulus of vertical subgrade reaction	Tonnes / m^3	14,000
Allowable rock anchor bond stress	kg / cm^2	11.00
Dynamic design foundation factors (below blast affected bedrock)		
Horizontal design acceleration*	g	0.32 or greater
Design velocity*	v	0.30
Shear wave velocity, Vs	m / s	1765 to 2830 (below blast affected rock)
Dynamic shear modulus, G (sandstone)	kg / cm^2	135 000 – 212 000 (below blast affected rock)
Dynamic shear modulus, G (conglomerate)	kg / cm^2	87 695 – 91 000 (below blast affected rock)
Dynamic Poisson's ratio, ν'	----	0.2872 – 0.3229 (below blast affected rock)
Design foundation factors*		
Poisson's ratio, ν	----	0.31
Modulus of elasticity, E	kg / cm^2	2.99×10^5

*Values suggested by the National Building Code and are not site specific. Values were taken for the Rivière du Loup zone. These values are for stability analysis only. For site specific design criteria, refer to "*Earthquake hazard analysis – Gros Cacouna, Quebec*" (Atkinson, 2006).

**Values estimated from Geotechnical engineering circular No. 5: Evaluation of soil and rock properties. Values are not site specific.

4.0 DESIGN OF FOUNDATIONS, DISCUSSIONS AND RECOMMENDATIONS (cont'd)

4.2 Foundation construction recommendations

- Frost depth is 1.8m in this area
- All shallow foundations on rock must be anchored to prevent uplift due to freezing unless insulation is used.
- Based on the favourable dip of the bedrock formation and the perpendicular jointing pattern, all rock slopes should be cut at 7V:1H using closely spaced preshearing blast holes to minimise overbreak and provide a permanent stable rock face.
- Blast hole drill pattern load factors and delay times should be prepared, keeping in mind the nature of the bedrock formation.
- Foundation excavations should follow standard specifications (CSST, Quebec).
- Rock anchor bond strength must be confirmed by pullout tests. Galvanised anchors should be used for corrosion resistance.
- A lean concrete working platform should be prepared for the foundation formwork.
- For foundations or slabs on grade, remove quarry fines and replace with compacted engineered granular 20 – 00 mm (MG20) crushed stone fill. If more than 300 mm of engineered fill is required, compact in 150 mm lifts to 95% of the modified proctor density.
- Backfill around the foundation to ground level with clean coarse granular material (<5% minus 80µm) to eliminate heaving due to soil freezing.
- Backfill behind retaining walls with compacted crushed stone or clean sand and gravel for drainage. Place a longitudinal drain pipe along the base of the wall.

4.0 DESIGN OF FOUNDATIONS, DISCUSSIONS AND RECOMMENDATIONS (cont'd)

4.2 Foundation Construction Recommendations (cont'd)

- The finished grade surrounding buildings should be sloped away (minimum 1%) from the building to provide for rapid evacuation of surface run-off. The exterior walls of basements, if there are any, should be made impervious using a liner and a perimetric drain.

4.3 Asphalt and Granular Pavements

Light-duty Asphalt Pavement

Suggested cross section for light duty asphalt pavements is:

50 mm asphalt (EB-14)
200 mm 0-35mm crushed stone
100 mm sand-gravel filter or suitable geotextile

Heavy-duty Asphalt Pavement

Suggested cross section for heavy-duty asphalt pavements is:

75 mm asphalt (EB-14)
400 mm 0-35mm crushed stone
100 mm sand-gravel filter or suitable geotextile

Unpaved Road Surfaces

Suggested cross section for granular pavements is:

50 mm 19mm crusher run
400 mm 0-35mm crushed stone
100 mm sand-gravel filter

It is suggested that roads be constructed a minimum of 300 mm above the current ground level to avoid road drainage ditches excavation.

4.0 DESIGN OF FOUNDATIONS, DISCUSSIONS AND RECOMMENDATIONS (cont'd)

4.3 Asphalt and Granular Pavements (cont'd)

The gradations, placement and compaction specifications for the granular bases of the pavements are summarised in Table 4.3.

TABLE 4.3 SPECIFICATIONS FOR PAVEMENT GRANULAR BASES COMPACTED TO 95% OF THE STANDARD PROCTOR IN 150 mm LAYERS USING LIGHT COMPACTION EQUIPMENT

Sieve size	0 – 35 mm crushed stone	Sand-gravel filter
112 mm	----	----
35 mm	100%	80%
31.5 mm	90% - 100%	----
14 mm	68% - 93%	----
5 mm	35% - 60%	35% min.
1.25 mm	19% - 38%	----
0.315 mm	9% - 17%	----
0.080 mm	2% - 7%	0 – 8%

5.0 CONCLUSIONS

Based on the sub-surface exploration (drilling of boreholes, geophysical (seismic) surveys and geological mapping) of the area proposed for the installation of LNG tanks and lighter structures at the LNG Gros Cacouna Terminal, it is concluded that:

- The bedrock observed on site and in boreholes BH-1 to BH-7 consists of solid sandstone and conglomerate adequate for supporting the proposed LNG tanks and smaller structures.

- The structural features of the rock cores (slickensides striations) are a result of the deformation, which took place during structural deformation and folding of the bedrock formation.

5.0 CONCLUSIONS (cont'd)

- Fractures observed are tight and not associated with large zones of fault gouge; in conjunction with the solid rock core observed this supports that the rock conditions based on the field reconnaissance and rock borings are appropriate for the current tank construction.

- Geological literature for the area suggests that fault lines are confined to the water between the north and south shores of the St. Lawrence River, and none are shown on the nearby land masses.

- Seismologists confirm that, although there is continued seismic activity in the St. Lawrence Valley, there are no faults with identifiable movements noted in recorded geologic history (<10,000 years) for the Gros Cacouna area.

- It is also suggested that it is highly unlikely and with an extremely low probability that deep earthquakes many kilometres away would produce movements on the Gros Cacouna site.

- An allowable bearing pressure of 1,000 kPa (10 tsf) may be used in design of foundations on the rock.

- Silt found in boreholes BH-2 and BH-3 are a result of surrounding rock ground up by the drill and do not pose a problem for the tank foundation.

- Dewatering during foundation construction will be minimal, if required.

- Basic chemical analysis of the ground water in the area proposed for the tank construction indicates no immediate concerns. However, the water will be more corrosive to exposed steel and detrimental to concrete in the long term as we advance towards the beach zone.

- Seismic (geophysical) surveys did not detect excessive overlying blast rock or soil or major faults, factures or shear zones in the rock along the three seismic lines under tank T-101.

- Due to the shallow depth of rock at the proposed location, it is recommended that buildings be founded on the rock.

5.0 CONCLUSIONS (cont'd)

The seven (7) boreholes drilled in Phase 1 to 3 (BH-1 to BH-7) indicate good foundation support conditions on the floor of the quarry, however, it is suggested to drill additional boreholes near the eastern perimeter of tank T-101 once the bedrock platform has been prepared. These will help ensure that no anomalies are present that may not have been detected along the geophysical survey lines or the previous boreholes.

A deeper large diameter hole (HQ size – 75 mm in diameter), as completed for tank T-101 (Borehole-7), is necessary at the centreline of each tank to investigate if any soft rock layer is present at greater depth below the 80-metre diameter tanks. The boreholes show that the site is suitable for the construction of the tank farm. The solid sandstone bedrock, located beneath about 2 to 3 metres of quarry fines and blast-fractured rock, offers a good bearing layer with an allowable design bearing value of 1,000 kPa (10 tons per square foot) with settlements limited to less than 10 mm.

We trust that this report answers all your questions. Please do not hesitate to contact us if any further information is required.

JOURNEAUX, BÉDARD & ASSOC. INC.

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