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PRELIMINARY FOUNDATION INVESTIGATION AND DESIGN REPORT DETROIT RIVER INTERNATIONAL CROSSING

EVALUATION OF ALTERNATIVE BRIDGE SITES

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REPORT

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EXECUTIVE SUMMARY

Purpose and Scope of Work

This report presents the results of geotechnical explorations and testing related to the bridge crossing portion of the Area of Continued Analysis (ACA) associated with the Detroit River International Crossing (DRIC) between Windsor, Ontario, and Detroit, Michigan. This work was undertaken as part of an on-going study for a joint partnership between the Ministry of Transportation Ontario, Transport Canada, the Michigan Department of Transportation (MDOT), and the US Federal Highway Administration (FHWA).

Three locations for a new bridge crossing of the Detroit River are under consideration and two of these are close to historic salt mining facilities. In 1954, a sinkhole developed on a solution mining site operated by Canadian Industries Limited (now Windsor Salt) that is within the overall DRIC ACA study area. The sinkhole and concerns related to the overall stability of the rock mass adjacent to the sinkhole prompted an evaluation of the solution mining activities and to define boundaries around the former solution mining site beyond which the ground would be suitable for the proposed bridge.

The work completed for the geologic and geotechnical evaluation of alternative crossing locations for the DRIC project consisted of a program of deep drilling, down-hole geophysical logging, cross-well seismic surveys, surface seismic reflection surveys, numerical analysis, and historical research. This study included the following tasks:

- literature review of research regarding solution mining practices and subsidence issues as applicable to the geology of Windsor, Ontario, and Detroit, Michigan;
- critical review of available historical documents related to solution mining and subsidence in the greater Windsor and Detroit areas;
- completion of a surface seismic reflection survey in early 2006, as an initial means to identify potential areas affected by solution mining;
- drilling of 12 exploratory wells (boreholes) to depths of nearly 500 m in areas being considered for the proposed crossing locations and in areas relevant to defining the potential influences of nearby solution mining on the rock mass;
- use of down-hole geophysical tools to characterise the rock mass near the exploratory wells;
- laboratory testing of rock core specimens;
- use of cross-well geophysical methods, typically used for resource (oil) exploration, to assess the condition of the rock mass between the wells along nineteen profiles;
- computer simulation of the rock mass and various subsurface solution mining conditions to calibrate this study to field conditions that precipitated a sinkhole on a nearby site in 1954; and
- geological and engineering evaluations to define the boundaries of solution mining influence and the future performance of the rock mass beneath the potential bridge sites.

On the basis of this work, a number of conclusions have been drawn and recommendations made to assist with selection of an appropriate bridge site.

Summary of Field Explorations and Testing

Field drilling investigations in most of the explored areas encountered bedrock conditions in the upper rock formations that are considered typical of the Windsor-Detroit region. These formations (Detroit River Group) in the top approximately 110 to 120 m of rock exhibited fractures and open joints that produce artesian water flows and hydrogen sulphide gas when this water is exposed to atmospheric pressures. The water pressures and flow volumes caused difficulties during drilling and construction of the well casings. In two of the exploratory wells, the conditions in the upper formations appear to have been influenced by subsidence over solution mined areas. In the salt-bearing Salina Formation, where salt beds were encountered between about 290 to 301 m below the ground surface, the explorations did not encounter any solution mining cavities, though some wells near the former solution mining site encountered rock and salt masses that have likely been influenced by solution mining. Measurements of fluid pressures during and subsequent to drilling activities assisted in defining the groundwater conditions at the subject sites.

Down-hole geophysical logging provided detailed measurements of the geology and character of the rock mass immediately surrounding each of the well holes. Data from this logging indicated that those wells that were drilled in close proximity to the former solution mining site exhibited thinned salt beds and horizontal fractures or open joints and bedding planes within the rock masses above the salt beds.

The cross-well seismic survey data, when combined with the down-hole data at each well location, provided evidence defining areas in which the rock mass remains in its natural state and other areas where the rock mass has been disturbed. The cross-well surveys also revealed several areas suspected of being near solution mining cavities with two surveys indicating evidence of potential brine-filled zones and cavity remnants.

Summary of Geology and Engineering Evaluations

Down-hole logging data was used to develop a three-dimensional model of the subsurface geology in which interfaces between rock formations were interpolated between wells to develop a number of topographic surfaces for these layers. This model included details of rock layer interface elevations, rock fracture data, groundwater and drilling fluid information, and well hole wall characteristics. Interpreted geologic interfaces between rock types were also developed based on the cross-well seismic data and these were used to build a second series of topographic rock formation surfaces. Four of the surface seismic profiles were used within the model to examine the conditions around the northern edge of the former solution mining site. Historical data related to former solution mining wells was also incorporated into this three-dimensional model. Information related to solution mining operations, from the former Canadian Industries Limited site and nearby facilities, coupled with a number of simplifying assumptions was used to develop three-dimensional representations of areas from which salt was likely removed since the available information was limited in detail. This model permitted spatial correlation between all forms of subsurface and historical information.

In addition to the three-dimensional computer model of the site subsurface conditions, a series of computer simulations (models) of the mechanical rock mass behaviour were completed to assess past and potential future performance of the ground near the bridge sites. Several simulations were compared to the estimated field conditions immediately preceding development of the sinkhole in 1954 and the resulting ground settlement. Other simulations were compared to conditions at nearby and existing solution-mined cavities now used for underground storage of petroleum products. After achieving reasonable correspondence between the computer simulations and observed behaviour, additional work was completed to define zones of rock that could have been disturbed by subsidence of the rock mass over and adjacent to solution mined zone. The results of all simulations were used to assess the potential for future rock mass displacements and for defining areas that could be considered to be suitable for support of bridge foundations from a geotechnical perspective.

Summary of Conclusions

A detailed review of historical evidence, coupled with the evidence from field investigations has assisted in defining the limit of mass salt dissolution from the former Canadian Industries Limited solution mining operation, defined for this study as the Limit of Primary Solution Mining Influence. Field evidence, historical data, and numerical modelling have also formed the basis of defining limits within which the rock mass has been altered to some degree by displacements associated with the nearby solution mining, defined for this study as the Limit of Secondary Solution Mining Influence. These limits are shown on Figure ES-1 and summarized in geographical coordinate form in Section 9 of this report. These limits are considered reasonable and prudent for this project since:

- the limit of primary solution mining influence, being zones where salt was directly removed by the mining, is based on inferred extents of former dissolution based on thinned salt beds, even though rock-on-rock (salt) contact was observed in all exploratory well locations.
- the limit of secondary solution mining influence, being zones where the rock mass outside the area of primary influence experienced a degree of displacement or disturbance, is based on reasonable numerical analyses coupled with settlement observations on a nearby site, and this limit is projected beyond the primary zone of influence described above;
- the limits of primary and secondary solution mining influence are consistent among several different methods of processing and interpretation of the geophysical data; and

- the limits of primary and secondary influence, as defined for this project, fall outside of other boundaries that could be defined using a variety of alternative interpretations of subsurface conditions and different geology and engineering analysis approaches.

The existing and future rock mass conditions in the vicinity of Crossing A are expected to be no different than in other areas of western Windsor that have been unaffected by solution mining. Crossing A is outside the Limits of Primary and Secondary Solution Mining Influence.

The proposed Crossing B alignment falls outside the Limits of Primary and Secondary Solution Mining Influence, and the rock mass performance for this crossing is expected to be no different than in other areas of western Windsor that have been unaffected by solution mining.

The main bridge pier locations for Crossing C, are outside the Limits of Primary and Secondary Solution Mining influence and future rock mass conditions in an area where the rock mass conditions are expected to be no different than in other areas of western Windsor that have been unaffected by solution mining. However, the proposed approach to Crossing C passes over the eastern end of the former solution mining well field and a subsurface anomaly that is suspected to be a brine-filled cavity, rubble zone, and disturbed rock mass. Initial estimates suggest that the rock mass above this anomaly might experience subsidence ranging up to values on the order of 2 m. The proportion of such subsidence that has already occurred or may occur in the future cannot be quantified at this time because of uncertainties associated with the nature and position of the identified anomaly. Should this crossing alignment be considered further, additional study will be required to refine the range of risks and orders of magnitude of future settlement that should be accommodated by design. The field exploration and testing program and historical data are not sufficient to clearly assess the three-dimensional extent, specific location, or potential limits of influence of this subsurface anomaly. The level of effort (investigation, testing, and analysis) that may be required to further refine these issues relative to the Crossing C approach alignment is extensive and, if undertaken, may still be insufficient to consider supporting structures on the rock within and adjacent to the identified limits of solution mining influence within an acceptable degree of risk.

Regardless of the bridge site selected, all bridge foundations will likely derive their support from the rock of the Dundee and Lucas Formations (approximately the top 50 m of rock). These rock formations exhibit natural open joints, fractures, and other features, typical to these formations throughout the region. During conventional investigations for detail design, particular attention should be given to these features through a combination of angled and vertical cored holes to ascertain whether or not a program of foundation rock improvement may be required during construction. Provided that the bridge structures are located outside the limits described in this report, it is considered that issues associated with these natural features, artesian groundwater conditions, and hydrogen sulphide within the groundwater, may be the most significant geologic issues for foundation design and construction.

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PART A - PRELIMINARY FOUNDATION INVESTIGATION REPORT

DETROIT RIVER INTERNATIONAL CROSSING
EVALUATION OF ALTERNATIVE BRIDGE SITES

1.0 INTRODUCTION

This report presents the results of geotechnical explorations and testing related to the bridge crossing portion of the Area of Continued Analysis (ACA) associated with the Detroit River International Crossing (DRIC) between Windsor, Ontario, and Detroit, Michigan as illustrated on Figure 1.1. This work was undertaken at the request of URS Corporation as part of an on-going study for a joint partnership between the Ministry of Transportation Ontario, Transport Canada, the Michigan Department of Transportation (MDOT), and the US Federal Highway Administration (FHWA). In keeping with conventional MTO format for foundation investigation reports, this report is prepared in two parts. Part A of this report, Sections 1 to 5, provides all data collected during field and laboratory work completed for the bridge site aspects of the DRIC project. Part B of this report, Sections 6 through 11, provides geologic and geotechnical evaluations to assist with selecting the bridge location.

The terms of reference for the original scope of work issued during the proposal period are outlined in the Ministry of Transportation, Ontario's (MTO's) Request for Proposal (RFP), dated September 2004, and in the scope of geotechnical work prepared by Golder Associates included in the revised URS proposal dated January, 2005. Scope changes related to completing borehole exploration and testing work are outlined in Golder Associates Ltd. letters to the MTO dated June 9, 2006 and July 18, 2007.

Three locations for a new bridge crossing of the Detroit River are under consideration and two of these are close to historic salt extraction facilities. In 1954, a sinkhole developed on a solution mining site that is within the overall DRIC ACA study area. The sinkhole and concerns related to the overall stability of the rock mass adjacent to the sinkhole prompted an evaluation of the solution mining activities and how these might or might not affect potential bridge crossing locations.

The subject of the work described in this report has been to evaluate the subsurface conditions associated with the potential Practical Alternative Crossings, designated Crossings A, B, and C, as shown on Figure 1.1. Two potential bridge sites, Crossings B and C, are located in areas that are near or adjacent to properties that have been subjected to extraction of salt by solution mining methods. The work carried out for this report addresses the overall suitability of these two crossing sites with respect to the stability of the rock mass underlying the sites. During early work for the Environmental Assessment carried out under the original terms of reference for this project, the potential bridge crossing sites were numbered X1 through X15, and the X10 crossing location included a southerly (X10S) and a northerly (X10N)alignment. In keeping with the original crossing designations, the two crossing locations subjected to deep drilling, geophysical testing, and site suitability analyses were named X10N and X11. These two sites correspond with the DRIC Practical Alternatives crossing options designated Crossing B and Crossing C, respectively. Within this report, reference numbering systems are related to the original X10N and X11 crossing location designations, though the crossings themselves are discussed within the report with respect to the Crossing B and C identification.

2.0 SITE DESCRIPTION

Three potential bridge sites, Crossings A, B and C, have been selected as potential Practical Alternatives for the Detroit River International Crossing (DRIC) between Windsor, Ontario, and Detroit, Michigan. These sites and the crossing alignments are illustrated on Figures 1.1 and 2.1.

The potential crossing sites are located near or adjacent to industrial property along the Detroit River waterfront. Crossing A, located to the south of the existing Brighton Beach Power Plant, crosses through areas that, although they are zoned as industrial areas, have largely been unaffected by previous salt mining activities. Crossings B and C, however, are near areas where salt was extracted using solution mining methods between 1901 and 1954. A total of 12 new deep exploratory wells have been completed using salt and oil well drilling techniques at the potential bridge sites. Six wells were allocated to each of the crossings. The area of Crossing B that may include the main bridge piers, anchor blocks (should a suspension bridge design be selected), and sections of the approach structures is near the southern side of the former Canada-Industries Ltd. brine well field. Since the potential Crossing C traverses the eastern end of properties subjected to solution mining, two of the wells for this crossing have been located to the south of the main bridge pier and anchor block location. A description of each of the crossing sites and 12 drill sites follows. The locations of all wells completed for this report are illustrated on Figure 3.1.

2.1 Crossing A

Crossing A traverses a number of undeveloped parcels of land between the intersection of Ojibway Parkway, Sandwich Street, and E.C. Row Expressway as shown on Figure 2.1. The alignment for Crossing A passes through the Brighton Beach Industrial Area, between the existing Nemak Plant and Broadway Street, before crossing the river immediately south of the existing Brighton Beach Power Plant. Existing subsurface information was utilised for this crossing location and no new explorations were completed in this area as part of this report.

2.2 Crossing B

The portion of Crossing B investigated as part of this work includes properties owned by Southwest Sales Inc. (SWS) and Ontario Power Generation (OPG). Figure 2.1 illustrates the general locations of the Crossing B alignment option. Both properties are bound to the north by Prospect Avenue and to the south by the largely unfinished right-of-way for McKee Street.

The SWS property is on the waterfront of the Detroit River, and the OPG property abuts the eastern side of the SWS property. Currently, the SWS property is used for an aggregate shipping and transfer depot and is occupied by numerous piles of various grades of sand and gravel.

The OPG property is bound on the west by the SWS property and on the east by a number of small commercial/industrial and municipal properties that front on Sandwich Street. The OPG property was formerly part of the J. Clark Keith Generating Station, originally constructed between 1951 and 1953, ceased operation in 1984, and was demolished in 1997. The portion of the generating station site on which the explorations were conducted was used for coal and ash storage before it was decommissioned.

Wells X10N-1, X10N-2, and X10N-6 are located on the SWS property as shown on Figure 3.1. Well X10N-1 is situated on the shoreline of Detroit River, on the northwestern edge of the SWS property; Well X10N-2 is located on the northeastern corner of the SWS property, directly across from the entrance to the current offices of Windsor Salt (Canadian Salt Company Ltd.) at the end of Prospect Avenue; and Well X10N-6 is located on the south-western side of the SWS property, bordering the OPG property. All three sites are surrounded by piles of various grades of sand and gravel. Electricity transmission towers exist along Prospect Avenue, which borders Well X10N-2. The topography of all three areas are generally flat.

Wells X10N-3, X10N-4, and X10N-5 are located on the OPG property as shown on Figure 3.1. Well X10N-3 is located on the north-eastern side of the OPG property, along Prospect Avenue; Well X10N-4 is located on the central-western side of the OPG property; and Well X10N-5 is located on the southwestern side of the OPG property. These wells are located such that they form a line that runs near perpendicular to Prospect Avenue and the presumed edge of the former solution mining site. The OPG property is wooded, containing small trees and shrubs. The OPG site includes old containment berms, ditches, and abandoned pipes from its former uses, but the immediate well areas are generally flat. The ground surface elevation drops east of Well X10N-3 towards Prospect Avenue. High voltage electricity transmission line towers exist along the east side of the property.

The northing, easting and elevation coordinates of the as-drilled well locations were surveyed by Brisco and O'Rourke surveyors in accordance with the Ontario Ministry of Natural Resources (MNR) regulations and are summarized below. The well locations are based on the UTM NAD83 (Zone 17) coordinate system, and the ground surface elevations at the well locations are referenced to the geodetic datum.

Table 2.1: Surveyed Coordinates And Elevations of X10N Wells

Well Number	Northing (m)	Easting (m)	Ground Surface Elevation (m)
X10N-1	4683554.59	327337.73	176.79
X10N-2	4683653.23	327497.41	176.57
X10N-3	4683541.96	327734.95	177.89
X10N-4	4683469.02	327624.88	178.09
X10N-5	4683332.98	327594.76	178.45
X10N-6	4683380.87	327430.39	178.45

2.3 Crossing C

Crossing C traverses or borders many properties along Sandwich Street between Ojibway Parkway and Prince Road as shown on Figure 2.1. Of these properties, several are of key importance to this crossing option.

Windsor Salt (Canadian Salt Company Ltd. and its predecessor Canadian-Industries Ltd.) formerly occupied most of the land located between Prospect Avenue to the south, a shipping and drainage channel opposite Chappell Avenue to the north, the Detroit River to the west, and Sandwich Street to the East. In addition, the former extent of the Windsor Salt facility crossed Sandwich Street where the lands are now bordered by the Essex Terminal Railway to the north and east, and the City of Windsor Lou Romano Water Reclamation Plant to the south. These lands were subject to solution mining between 1901 and 1954. Following the closure of the solution mining operations at the site ca. 1954 to 1957, the property has since been subdivided into a number of parcels used for aggregate shipping, transfer, and stockpiling, or for truck freight operations. Elevated approach structures for Crossing C may cross over this eastern part of the former solution mining site.

Located to the north of the former Windsor Salt facility lands, the property occupied by the Van De Hogan Group is used as a shipping terminal. Bridge piers for potential Crossing C may be located on the property occupied by the Sterling Marine Fuels depot. This land, owned by the Windsor Port Authority, is used for off-loading, storage, and transfer of various fuel and asphalt products.

City of Windsor properties, including a parcel immediately to the south of the Police Training Centre on Sandwich Street, and the Lou Romano Water Reclamation Plant were also sites for drilling activity as these may abut the approach structures for Crossing C.

Wells X11-1, X11-5, and X11-6 are located on the Sterling Marine Fuels depot property. Wells X11-1 and X11-6 are located along the western side of the property close to the Detroit River shoreline; Well X11-5 is located on the southeastern corner of the property. Wells X11-1 and X11-6 are surrounded by small trees and shrubs, while the immediate area of the well locations is grassy. The western side of Well X11-5 also contains trees and shrubs, while the remainder of the area has been cleared of vegetation. The location of Well X11-5 is within an area occupied by asphalt storage and distribution facilities, with two asphalt tanks to the east of Well X11-5, that are surrounded by a containment berm. In general, the topography of the Sterling Marine Fuels depot is slightly undulating, but the ground surface elevation does not change appreciably within the immediate hole areas. The one exception is the approximate 1.5 m ground surface elevation rise associated with the height of the containment berm that surrounds the asphalt tanks area.

Well X11-2 is located on the northern edge of the Van De Hogan Group property. A row of trees borders the property on the northern side, while the remainder of the site has been cleared of vegetation. A railway track passes through the property, which, along with the various buildings, is used as a shipping terminal. The Van De Hogan Group property is generally flat.

Well X11-3 is located immediately to the south of the Police Training Centre on Sandwich Street. Originally, the area was vegetated with trees, shrubs and grass, however, the site was cleared of vegetation and gravel berms were constructed around the site. Vegetation still surrounds the site on the east and south sides of the site. Electricity transmission towers exist along Sandwich Street, located to the west of the site. The site is generally flat.

Well X11-4 is located on the northwestern corner of the Lou Romano Water Reclamation Plant property, within the lawn area between the Plant's front entrance and Sandwich Street. The site was vegetated with grass and landscaping plantings. Electricity transmission towers exist along Sandwich Street, located on the west side of the site. The site is generally flat.

The northing, easting, and elevation coordinates of the as-drilled well locations were surveyed by Brisco and O'Rourke surveyors in accordance with MNR regulations, and the location data are summarized below. The well locations are based on the UTM NAD83 (Zone 17) coordinate system, and the ground surface elevations at the well locations are referenced to the geodetic datum.

Table 2.2: Surveyed Coordinates and Elevations of X11 Wells

Well Number	Northing (m)	Easting (m)	Ground Surface Elevation (m)
X11-1	4684641.84	328007.99	177.39
X11-2	4684273.85	327924.54	176.95
X11-3	4683697.05	328123.88	177.42
X11-4	4683412.27	328025.60	177.25
X11-5	4684408.98	328137.89	177.62
X11-6	4684527.67	327918.73	179.35

3.0 GEOTECHNICAL INVESTIGATION METHODS

Three phases of geotechnical investigation were carried out to examine the subsurface conditions near and at the potential bridge crossing locations. The first phase of work, undertaken between August, 2005 and June, 2006, consisted of reviewing available subsurface data and historical information regarding the nearby salt mining operations. The second phase of work consisted of a surface seismic reflection survey completed in February, 2006. The third and final phase of investigation work, conducted between September, 2006 and August, 2007, included drilling twelve wells to approximately 500 m deep each, conducting down-hole logging of rock characteristics in each well, and conducting a series of cross-well seismic surveys between selected wells.

The exploratory well locations were chosen to examine the conditions in the vicinity of the potential main bridge pier locations and to assist in defining the limits of solution mining where the possible alignments approach properties subjected to the mining. The final number of wells and their field positions were selected to balance issues associated with proximity to areas of concern, property access, physical or operational obstructions to drilling and well-to-well distances compatible with the cross-well testing.

The results of all of these phases are presented in this report with the details of the field investigation methods (second and third phases) described below. The data from the surface seismic reflection work was reprocessed following acquisition of site-specific rock formation data and is therefore described following the drilling and down-hole methods. All field exploration locations are illustrated on Figure 3.1. Logs of the encountered subsurface conditions are included in Appendix A. For the cored wells, two logs have been produced for each well. The first log provides detailed geologic descriptions along with conventional geotechnical rock core data. The second log includes these detailed geologic descriptions along with the down-hole logging data for comparison to the remaining rotary drilled wells.

3.1 Drilling Program

In accordance with the MNR regulations, a drilling program was set out for the wells based on the requirements outlined in the Oil, Gas and Salt Resources of Ontario (OGSRA) Provincial Operating Standards, Version 2.0.

The initial drilling program as approved by MNR specified the installation and cementing in place of three sets of casing in order to prevent cross contamination of any underground aquifers. The use of down-hole geophysical testing was completed prior to the installation of the bottom two casing sections. Following each casing installation and cementing event each hole was "bond-logged" to check the continuity of the cement bond between the casing and rock. In some cases, it was also necessary to use temperature logging techniques to identify where the top of cement could be expected if cement did not return to surface during casing installation cementing events. In such cases, cementing was carried out by either addition of cement through the annular spaces between the casing and rock, or between the casings, from the top, or by perforation of the casing from inside near the anticipated top of cement (based on the temperature logging) and forcing cement through the perforation into the annular space.

The top or surface casing, also called the “conductor casing”, consisted of a 340 mm diameter steel casing installed through the overburden to the surface of the bedrock at approximate depths of 27.8 to 32.8 m. Class ‘G’ 0-1-0% cement plus 2% $CaCl_2$, with a minimum of 100% excess cement (in excess of the theoretical or calculated volume), was initially specified in order to ensure that the 340 mm casing was cemented to the ground surface and through the annular space between the casing and rock and overburden soil.

The first well casing of 244 mm diameter, was initially planned to be installed to a depth of approximately 100 m within the Lucas Formation. Due to the artesian water conditions encountered within the first well, X10N-5, the drilling program was modified for the remainder of the holes, changing the depth of the first casing from 100 m to 50 m. Class ‘G’ 0-1-0% cement plus 2% $CaCl_2$, with a minimum of 100% excess cement, was initially specified in order to ensure that the 244 mm casing would be cemented to the ground surface through the annular space between the casing and rock or to at least 25 m above the tip of the casing above. A Class A “blow-out-protection”, or BOP, device was installed and fitted onto the second casing, following which pressure testing of the casing and annular seal was completed using a low initial pressure of 700 kPa and a subsequent high pressure of 3,500 kPa for 10 minutes each.

The second steel well casing was 178 mm in diameter and was installed to depths between approximately 188 and 215 m. Class ‘G’ 0-1-0% cement plus 2% $CaCl_2$, with a minimum of 100% excess cement, was initially specified in order to ensure that the 178 mm casing would be cemented to the ground surface and through the annular space between the casing and rock or to at least 25 m above the tip of the casing above. A Class B BOP device was installed and fitted onto the third set of casing, following which pressure testing of the equipment was conducted.

In Well X10N-2, due to drilling difficulties encountered below the 178 mm casing two subsequent casings were installed, a 138 mm casing to 316.5 m, and a 118 mm (HW size) casing to the full depth of the well, 491.4 m. The wells were advanced to approximate total depths of 500 m each. The details of the casing depths and the total depth for each well are provided in the table below.

Table 3.1: Casing Installation Summary

Well Number	340 mm Casing Depth (m)	244 mm Casing Depth (m)	178 mm Casing Depth (m)	138 mm Casing Depth (m)	118 mm Casing Depth (m)	Total Depth (m)
X10N-1	28.32	46.47	205.07	-	-	492.54
X10N-2	29.02	45.90	188.90	316.46	491.40	491.40
X10N-3	29.17	47.46	205.51	-	-	495.53
X10N-4	31.39	47.68	214.78	-	-	492.78

Well Number	340 mm Casing Depth (m)	244 mm Casing Depth (m)	178 mm Casing Depth (m)	138 mm Casing Depth (m)	118 mm Casing Depth (m)	Total Depth (m)
X10N-5	30.30	47.98	212.50	-	-	496.50
X10N-6	30.30	49.39	205.99	-	-	492.39
X11-1	32.30	49.36	205.21	-	-	500.12
X11-2	31.57	48.43	204.51	-	-	496.93
X11-3	29.83	46.93	204.93	-	-	500.16
X11-4	29.08	47.60	205.87	-	-	489.38
X11-5	31.18	95.80	215.00	-	-	496.05
X11-6	33.32	45.68	204.42	-	-	500.18

In accordance with the OGSRA Provincial Operating Standards, Version 2.0, Section 3.1 and discussions with MNR, drilling fluids were restricted to fresh water within horizons containing fresh water aquifers and brine for drilling in saline aquifers. The wells were advanced using four drilling rigs, one used to obtain rock cores, a cable tool rig, and two rotary rigs. Upon completion of drilling, down-hole and cross-hole geophysics surveys were conducted in each hole. Descriptions of the drilling and geophysics methods and equipment are provided below.

3.2 Rock Coring

Two Wells, X10N-2 and X11-5, were cored between October 31, 2006 and May 14, 2007. Well X10-2 is located within the SWS property along Crossing B, while Well X11-5 is located within the Sterling Marine Fuels depot property along Crossing C. The wells were drilled using a Gardner Denver 15W drilling rig supplied and operated by Davidson Well Drilling Ltd. of Wingham, Ontario. This drilling rig was also used to install the conductor casing for this well. Coring was accomplished using Davidson’s LD wire-line coring system with a double-tube core barrel that recovered 75 mm diameter cores.

X11-5 was cored between November 10, 2006 and January 21, 2007, during which time the well was advanced to a depth of 496.05 m below ground surface. Well X10N-2 was cored between February 8, 2007 and May 14, 2007, during which time the well was advanced from 28.52 m to 346.1 m below ground surface. Bedrock was cored from a depth of 31.18 m and 28.52 m below ground surface in X11-5 and X10N-2 respectively.

All rock core samples were identified in the field, placed in labelled core boxes, photographed, and transported to a warehouse for storage and further classification.

3.3 Cable Tool Drilling

With the exception of X11-5, the Bucyrus Erie 36L cable tool rig supplied and operated by Bradco Drilling Inc. of Merlin, Ontario was used to drill through the overburden in all wells for the installation of the conductor casings. The conductor casing for Well X11-5 was installed using the coring rig. In addition, the cable tool drilling rig was used for the installation of the surface casing (to 50 m depth) in Wells X11-1, X11-2, X11-3, X11-4 and X11-6, though completion of drilling for the 50 m casings using the cable tool drilling rig was prevented in Well X11-6 by artesian water flow, and at the location of Well X11-1 due to fractured rock near the top of the bedrock. Due to difficulties in completion of coring for Well X10N-2, the cable tool drilling rig was used to clean the well of debris, install and cement the fourth well casing to 316.46 m below ground surface, and clear cement and debris from 316.5 m deep to the depth previously achieved during coring operations. Due to subsequent difficulties drilling within the Salina Formation E-Unit, the cable tool rig was not able to complete the drilling. Well X10N-2 was replaced by the PortaDrill TLT 474 rotary drilling rig.

The cable tool rig operates by raising and dropping heavy, hardened steel bits to the bottom of the well, crushing the soil and/or rock beneath to create the hole. Once the bottom of the well becomes clogged due to loose soil and/or rock chips, the bit is raised and a bailer is used to remove the debris from inside the hole. Once the hole is bailed, the bit is lowered into the hole, and the process is repeated until the desired depth is reached. The 340 mm conductor casing was advanced simultaneously with drilling.

No soil samples were retrieved for storage or testing during drilling through the overburden material because of the significant degree of mixing and disturbance that takes place during such drilling with the cable tool rig. Soil conditions were inferred and described from the materials removed by the bailer. Rock samples were obtained from the bailer during all subsequent drilling for classification purposes. The rock samples were examined and tested on-site as described in Section 3.4.

3.4 Rotary Drilling

Two rotary drill rigs, a PortaDrill TLT 474 and an Ingersoll-Rand 780, both supplied and operated by Bradco Drilling Inc. of Merlin, Ontario, were used to advance all the other wells to their final depths with the exceptions of the top section of Well X10N-2 and the entirety of Well X11-5. The dates during which the wells were advanced using the rotary rigs are shown below.

Table 3.2: Rotary Drilled Wells Start and End Dates

Well Number	Start Date	End Date
X10N-1	March 12, 2007	April 2, 2007
X10N-2	June 7, 2007	July 6, 2007
X10N-3	April 26, 2007	May 17, 2007
X10N-4	February 9, 2007	March 9, 2007
X10N-5	December 2, 2006	January 24, 2007
X10N-6	April 9, 2007	April 19, 2007
X11-1	August 10, 2007	August 24, 2007
X11-2	June 21, 2007	July 15, 2007
X11-3	May 23, 2007	June 14, 2007
X11-4	May 21, 2007	June 23, 2007
X11-6	July 10, 2007	August 6, 2007

The wells were advanced using three different bits. A 311 mm (12 ¼ inch) bit was used to advance the wells through the 340 mm conductor casing to approximately 50 m, prior to the installation of the 244 mm casing. A 222 mm (8 ¾ inch) bit was then used to advance the wells through the 244 mm casing to approximately 210 m, prior to the installation of the 178 mm casing. A 159 mm (6 ¼ inch) bit was then used to advance the wells to the final depths.

Chip samples were obtained from the flow of drilling fluids returned to the surface at 3 m intervals of bit depth so long as drilling fluid circulation was possible. The chip samples were identified in the field, placed in labelled containers and transported to Golder's on-site laboratory for further examination.

The chip logging procedure, developed based on the Shell Oil Company Sample Examination Manual (Shell, 1981), was used to identify the rock types. The chip samples were washed, dried, and placed in labelled containers. Each dried sample was examined under a binocular microscope and divided based on the colour of the chips. The percentage of each chip colour category as visually compared to the total volume of chips, chip size, roundness, sphericity, porosity, and any other notes such as the presence of stylolites[1] were described. Hydrochloric acid (HCl) and Alizarin Red were added to the different coloured samples in order to classify the rock type.

3.5 Down-Hole Geophysical Logging

All wells were subjected to down-hole testing and logging with a suite of tools consisting of a mechanical calliper, natural gamma radiation measuring device, a device for measuring apparent conductivity, an acoustic televiewer (ATV), and a full waveform sonic (FWS) impulse emitter

[1] A stylolite is an irregular surface or contact, often with an "interlocking" appearance, usually in carbonate rocks, formed by differential movement under pressure.

and receiver. These tools are described in more detail below. Logs associated with these tools are provided in Appendix B for each of the wells.

3.5.1 Mechanical Calliper

The mechanical calliper measures the physical diameter of the well created during drilling using three 1.59 m long, spring-loaded measurement arms located at 120^{o} intervals around the circumference of the 39 mm diameter. Each measurement arm is linked to a central displacement transducer that provides a means to calculate a measurement of the well or well diameter. The device used for this project was the 2PCA-1000 3-Arm Calliper manufactured by Mount Sopris Instrument Company, Inc., of Denver, CO, USA. This device measures well diameters between 57 and 736 mm with an accuracy of about 0.5 mm and a resolution of 0.08 mm.

3.5.2 Natural Gamma Radiation Tool

The natural gamma radiation tool measures naturally occurring gamma radiation found in different geological formations and is useful for defining marker beds with unique gamma radiation signatures. These electromagnetic emissions are released by nuclei of unstable elements as they decay to a more stable state. In rock formations, the decaying elements are usually Potassium (40), Uranium (238 and 235), and Thorium (232). Potassium 40 is found in potassium bearing minerals including potassium feldspars, biotite, orthoclase and several clay minerals rendering detection of these minerals possible using natural gamma radiation logging. These logs thus indicate decreasing response levels in order from shale and clays, to siltstones, to sandy siltstones to clean sandstones and gravels, and in this particular case, evaporites such as salt and gypsum (or anhydrite). This tool does not use an active source of radioactive materials but instead uses a radioactive sensor, in this case a scintillation sodium crystal that emits a light pulse proportional to the strength of the gamma radiation. A photo multiplier tube converts the light pulse to electrical current read by the collection and processing computers. The tool used for this project was the 2PGA-1000 Natural Gamma, SP, Single Point Resistance device manufactured by Mount Sopris Instrument Company, Inc., of Denver, CO, USA.

3.5.3 Apparent Conductivity Tool

The apparent conductivity device measures the ability of the formation to conduct electrical current by using magnetic induction coils. The apparent conductivity of the formation can be used to correlate the type of formation (shale/salt/limestone, etc) when used in conjunction with other data types. A Geonics Canada Ltd., of Mississauga, Ontario, EM39 model was used for this project (sold by Mount Sopris Instrument Company, Inc. as the 2PIA-1000 Electromagnetic Induction tool) with field coils spaced at 250 mm and 500 mm intervals.

3.5.4 Acoustic Televiewer

The character of the well walls was examined on this project using a 1.6 m long, 40 mm diameter, ABI 40 Slim-Line Acoustic Televiewer (ATV) manufactured by Advanced Logic Technology, of Luxembourg. The acoustic televiewer measures the travel time required to bounce an acoustic signal off the well wall and its return to the probe and produces 360 degree images of the well wall. The travel time correlates to the diameter of the well and the strength of the returning signal correlates to the density of the formation. This tool is capable of detecting and measuring fractures, joints, or other openings and their orientation within the well and is suitable for measuring and imaging these features through cloudy or muddy drilling fluids when optical televiewers are not. This instrument is typically capable of measuring well characteristics for wells ranging in diameter from 50 to 533 mm, with a resolution of 0.08 mm. In addition, this instrument is used to measure well inclination and the azimuth of the measured features to an accuracy of ±0.5 and ±1.0 degrees, respectively.

3.5.5 Full Waveform Sonic Tool

The FWS 50/68 Full Waveform Sonic probe, manufactured by Advanced Logic Technology, of Luxembourg, was used to record the velocity of soundwaves (at 20 kHz) travelling through the formations parallel to the well wall. The soundwave velocity can be correlated to the density of the formation. Data from this probe was used to assist with interpretation of formation properties necessary for processing and interpreting other seismic measuring techniques (e.g. surface seismic reflection surveys and cross-well seismic imaging).

3.5.6 Optical Televiewer

The optical televiewer produces a continuous and oriented 360° image of the well wall "unwrapped" using a camera that views a reflection of the well wall in a conic mirror. Image orientation is achieved using a precision 3-axis magnetometer and two accelerometers so that the north-south orientation of the well wall features can be identified. The optical televiewer can only be used when the well or borehole fluids are clear enough to permit use of the camera. For the DRIC project, the optical televiewer was used in Well X10N-2 in an attempt to identify features that may have been associated with blockage of the well during and subsequent to drilling. Images were obtained for a portion of the well where the fluids were sufficiently clear. Attempts were made to use this tool in other wells but the fluids remaining in the wells were not sufficiently clear.

3.6 Cross-Well Seismic Imaging

Cross-well seismic imaging techniques use a piezoelectric sonic signal source in one well to send acoustic (sound) vibration waves through bedrock formations to a string of receivers in another well. By measuring the signal travel times between known distances using different positions of the source and receivers, direct and reflected signals can provide information regarding the position characteristics of reflection surfaces within the bedrock formations. These reflection surfaces can include fractures, bedrock formation contacts, and boundaries between or zones of material of different densities (wave transmission properties). Through mathematical processing and mapping of the signals, an image of the ground between the wells can be generated. The images can be created in terms of 2-dimensional spatial coordinates and contours of seismic velocity (tomogram) or of P-wave (compression wave) reflectivity. For this project, Z-Seis Reservoir Seismic (Calgary, AB, and Houston, TX) were subcontracted to complete 19 cross-well seismic surveys between the wells as shown on Figure 3.1. In general, the surveys were completed using a single source in one well and strings of receivers in adjacent wells such that data for two profiles could be collected using a single set-up event ("dual profile" operation). Due to the geometry of the well locations and profiles, a few single profiles were also surveyed. For the DRIC work, the receivers consisted of a string of 20 hydrophones linearly spaced 1.5 m apart along a 36 m long, 42 mm diameter cable. Sources included 89 mm and 105 mm diameter, 5.15 m long, piezoelectric transmitters operating within the general range of 100 to 2,000 Hz. Signals were transmitted and received at 1.5 m intervals throughout the well depths from about 50 m to the well bottom, near 500 m. Data collection and processing reports for the cross-well seismic surveys are included in Appendix C.

3.7 Surface Seismic Reflection Survey

A seismic reflection survey covering a portion of the area of the Sandwich West solution mining field and the portions of the land immediately to the south was undertaken in February, 2006. The study area and seismic reflection survey line locations are presented on Figure 3.1. This survey was conducted using the seismic sources of truck-mounted vibration-inducing equipment ("vibroseis") and small charges in boreholes and strings of geophones laid in patterns on the ground surface to receive seismic signals. In the northern part of the study area, four 2D seismic reflection lines (06-DRIC-01 to 06-DRIC-04) were acquired using the vibroseis trucks. In the southern part of the study area, eight parallel lines of data were acquired with the borehole charges in which two lines of data were recorded simultaneously. This arrangement of seismic survey lines and the surveying approach, which is typically called a geophysical "swath" survey, allows pseudo three-dimensional coverage to be acquired for an area.

There were difficulties inherent in collecting data at the site. High levels of ambient noise were present from industrial operations, shipping traffic, and vehicle traffic. The thick overburden containing loose sediments, fill (including unknown quantities and types of debris) and peat resulted in difficulties with coupling of the geophones and ground. Furthermore, portions of the land within the planned survey area were inaccessible due to land use or landowner restrictions, which constrained the length of lines to less than that desired for the depth of imaging being sought. Initial processing of the data in 2006 was also constrained by the lack of local drill hole geophysical data, requiring the use of sonic logs from a hole 10 km from the site. Reprocessing of the data was completed in June through August of 2007 using full waveform sonic data supplemented by selected bedrock formation tops interpreted using the natural gamma radiation data acquired for the new exploratory Wells X10N-3, X10N-4, and X10N-5 that were drilled in and through the seismic survey “swath” area. The data collection report for the surface seismic reflection survey is included in Appendix D of this report.

3.8 Laboratory Testing

Laboratory testing of recovered rock was carried out on selected core samples. The testing was completed by Queen’s University, in Kingston, Ontario. Rock core samples were selected for testing considering their stratigraphic position and with the purpose of obtaining a number of specimens to be able to make comparisons to published strength and deformation characteristics for the rock formations of interest. A total of sixteen uniaxial compression tests and seven Brazilian tensile strength tests were completed and the results of these tests are included in Appendix E.

4.0 SUBSURFACE CONDITIONS

This section of the report presents a summary of the regional geology, site geology, site hydrogeology, and the conditions encountered during drilling. Although the site geologic conditions were defined by drilling as well as field and laboratory testing, details regarding the conditions encountered during the drilling follow this summary so as to associate the conditions directly with the interpreted geologic formations and boundaries.

4.1 Regional Geology

Above the oldest Precambrian bedrock and within the depths or elevations of interest for this project, Southwestern Ontario is underlain by relatively flat-lying sedimentary bedrock of Paleozoic age. These sedimentary rock formations were formed in shallow marine environments within what is now geologically referred to as the Michigan Basin, a regional bowl-shaped depression with shallow relief centred on south-central Michigan. The Silurian and Devonian formations, found in the top 500 m of bedrock, are those of primary interest for the work described in this report. The Salina Formation, the deepest and oldest of the explored formations, is typically subdivided into seven units, labelled A through G, oldest to youngest. The youngest member (or unit) of the Salina formation (G member) is conformably overlain by primarily carbonate strata (dolostone and limestone) of the Silurian Bass Islands Formation. The carbonate Bois Blanc Formation, of Devonian age, unconformably overlies the Bass Islands Formation as the early Devonian was characterized by a period of erosion. In Southwestern Ontario, the Bois Blanc formation is overlain by the Sylvania, Amherstburg, Lucas, and, in some areas, the Dundee Formations of the Detroit River group.

As part of this study, available information on outcrops and quarries within these formations was reviewed. Within south-western Ontario, outcrops of these formations are rare, particularly for the deeper Salina Formation units. For this work it was considered important to identify potential vertical joint patterns as these may affect the mechanical behaviour of the bedrock mass. There is, however, little detailed information available on the vertical joint patterns within the Devonian and Silurian Formation at depths on the order of 100 to 500 m in southern Ontario. Work by Sanford et al. (1985) and Boyce and Morris (2002) indicate that the faulting/fracture patterns in these formations is a reflection of basement rock characteristics ("reactivation of basement structures is suspected to control the location of Paleozoic fault and fracture systems" Boyce and Morris, 2002). These authors show that at least on a regional scale, there is a fracture framework that includes these Paleozoic formations (Devonian and Silurian). How these regional scale fracture networks relate to smaller-scale fracturing or jointing between these regional fractures is unclear. In addition, regional isostatic post-glacial rebound and temperature changes during and post-deposition and lithification also provide mechanisms that could induce mechanical and structural features such as incipient vertical jointing, cracking, or weak planes in the bedrock formations. Discussion of such features is provided in Section 4.3, below, as appropriate for each of the formations.

Mapping of the upper-most formation in the Windsor-Detroit area is shown on Figure 4.1 along with a simplified geologic section of the bedrock in the western areas of Windsor. A system of geologic abbreviations is used within this report to identify the geologic units as follows, from oldest to youngest:

- Silurian Salina Formation, SsA through SsG;
- Silurian Bass Islands Formation, Sbi;
- Devonian Bois Blanc Formation, Dbb;
- Devonian Amherstburg Formation (Detroit River Group of Formations), Sylvania Member[2], Das;
- Devonian Amherstburg Formation (Detroit River Group of Formations), Da;
- Devonian Lucas Formation (Detroit River Group of Formations), Dl; and
- Devonian Dundee Formation (Detroit River Group of Formations), Dd.

The study area is located in the physiographic region of Southwestern Ontario known as the St. Clair Clay Plains. Within this region, Essex County and the southwestern part of Kent County are normally discussed as a subregion known as the Essex Clay Plain. Late-Pleistocene era unconsolidated sedimentary (soil) deposits were deposited over the Dundee Formation in the Windsor area during the last period of continental deglaciation, about 14,000 to 10,000 years ago. These sediments largely consist of basal till in some areas, deposited at the contact between the bedrock and either moving or grounded ice (resting on and eroding the rock surface), and a sequence of sediments deposited in a large glacial lake environment. In some locations, this sequence includes sand and gravel overlying the bedrock or basal till, though the majority of these deposits in the project area consist of a 20 to 30 m thick, primarily fine-grained layer of silt and clay materials. These sediments often have a grain size distribution similar to fine-grained glacial till, though the consistency of the deposits is significantly softer than typical basal tills elsewhere in Ontario. It has been interpreted that these materials are the result of large volumes of sediments being deposited from the base of floating ice sheets through a relatively shallow column of water such that segregation (sedimentary sorting) of materials was limited.

4.2 Correlation of Rock Cores and Natural Gamma Measurements

After completion of rock coring in the two cored wells, X10N-2 and X11-5, the results of the down-hole logging of natural gamma radiation measurements were correlated to detailed geologic evaluations and descriptions of the core samples. Clear and distinct relationships were established between the formation boundaries evident in the core samples and the natural gamma logs. These relationships permitted identification of formation boundaries in wells that were drilled using rotary methods from which only chip samples were obtained. A total of 112 individual and characteristic geologic beds (“marker beds”), including interpreted formation tops, were identified within the bedrock column based on their distinct natural gamma log signature as illustrated on Figures 4.2 and 4.3. Beds numbered 1 through 72 indicate identifiable peaks in the

[2] The Sylvania Member of the Amherstburg Formation has distinctly different characteristics that separate it from the rest of the Amherstburg Formation, and therefore, the Sylvania Member will be referred to as the Sylvania Formation throughout this report.

gamma signature in regions otherwise typified by lower values, thus indicating shale beds. Those marker positions numbered 100 through 120 indicate identifiable low values within regions otherwise typified by higher natural gamma readings, indicated beds of sandstone, dolostone, limestone, or evaporite minerals (salt, anhydrite, gypsum). These marker beds were used for this study to define geologic boundaries and to permit a comparison of bed elevations among the wells.

4.3 Bedrock Stratigraphy Summary

General descriptions of the site geology derived from the literature review and from explorations completed on the potential bridge sites are provided below. The descriptions are presented in order from the ground surface to the maximum explored depth, to be in keeping with the progress of drilling rather than in depositional age, though the deposits and formation labelling follows a typical geological sequence. Two tables are presented below that summarize the depths and elevations of the geologic boundaries identified by the on-site drilling, testing, and detailed geologic examination of rock cores obtained from two of the twelve drilled wells.

Table 4.1 – Top Elevations of Geologic Formation Boundaries, X10N Series Wells

	X10N-1 (m)	X10N-2 (m)	X10N-3 (m)	X10N-4 (m)	X10N-5 (m)	X10N-6 (m)
Ground Level	176.79	176.57	177.89	178.09	178.45	178.45
Dundee Formation	148.97	148.05	149.22	147.70	148.65	148.65
Lucas Formation	132.24	132.78	132.89	133.01	135.60	134.02
Amherstburg Formation	66.91	64.61	68.61	68.82	71.66	70.25
Sylvania Formation	42.78	42.43	43.97	44.99	46.40	45.88
Bois Blanc Formation	18.41	17.61	20.28	21.41	22.89	21.97
Bass Islands Formation	-19.51	-17.48	-17.82	-16.56	-19.63	-19.37
Salina Formation:						
G-unit Shale & Dolostone	-54.16	-55.73	-54.69	-52.21	-52.81	-52.78
F-unit Shale	-77.70	-79.13	-78.18	-75.88	-75.61	-74.61
F-unit Salt	-115.93	-119.80	-116.69	-115.30	-114.71	-113.57
E-unit Dolostone	-162.48	-161.34	-160.89	-161.24	-161.35	-161.39
D-unit Salt	-192.36	-193.23	-193.11	-192.59	-191.60	-191.97
C-unit Shale	-201.59	-201.20	-200.55	-200.62	-199.88	-201.68
B-unit Salt	-241.11	-241.50	-239.75	-241.06	-238.47	-238.85
A-unit Carbonate	-306.99	-307.19	-308.02	-306.30	-303.87	-305.34

Table 4.2 – Top Elevations of Geologic Formation Boundaries, X11 Series Wells

	X11-1 (m)	X11-2 (m)	X11-3 (m)	X11-4 (m)	X11-5 (m)	X11-6 (m)
Ground Level	177.39	176.95	177.42	177.25	177.62	179.35
Dundee Formation	145.59	145.88	148.09	148.67	146.94	146.53
Lucas Formation	124.38	128.57	134.42	137.07	126.9	125.02
Amherstburg Formation	58.39	61.67	71.08	72.76	61.29	60.25
Sylvania Formation	34.12	37.1	45.52	48.76	36.02	35.35
Bois Blanc Formation	8.62	12.49	21.75	25.07	11.12	10.35
Bass Islands Formation	-24.06	-22.05	-19.23	-14.15	-23.38	-22.65
Salina Formation:						
G-unit Shale & Dolostone	-63.71	-63.05	-59.58	-54.13	-62.58	-61.89

	X11-1 (m)	X11-2 (m)	X11-3 (m)	X11-4 (m)	X11-5 (m)	X11-6 (m)
F-unit Shale	-88.05	-85.78	-79.58	-76.83	-85.53	-86.12
F-unit Salt	-126.45	-123.57	-119.28	-115.37	-123.85	-124.99
E-unit Dolostone	-170.41	-166.95	-161.21	-158.52	-166.38	-169.65
D-unit Salt	-200.66	-197.73	-192.35	-188.81	-196.58	-199.65
C-unit Shale	-209.86	-206.43	-201.03	-197.26	-205.68	-209.02
B-unit Salt	-258.90	-250.70	-246.83	-237.74	-250.48	-254.96
A-unit Carbonate	-317.61	-313.69	-308.53	-307.29	-308.18	-314.65

Regional dip of the strata is to the north at about 0.5% to 1%. Marker bed elevations within the upper Dundee and Lucas Formations are difficult to discern in some wells, making the comparisons in these two formations somewhat uncertain.

The table below summarizes salt bed thickness comparisons for wells that either likely experienced little or no solution mining in the southern and northern groups of wells. The southern group of wells in this category include X10N-1, X10N-4 through X10N-6. The northern group of wells in this category include X11-1, X11-2, X11-5, and X11-6. Well X11-3 is not included in this group because of the comparatively large geographical separation between this well and others in the northern group and the potential that this may have been influenced by solution mining wells in the north-east quadrant of the former Windsor Salt brine field. Wells X10N-2, X10N-3 and X11-4 are not included in the southern group of wells (for this comparison) as these are closest to the abandoned solution mining area. In this table, comparisons are made between the cumulative thickness of evaporites in the D and F units, and the total thickness of the B unit is used as a comparison since salt constitutes the majority of this unit.

Table 4.3 – Regional Trends of Cumulative Evaporite Bed Thickness in Salina Formation

Formation	X10N Well Group	X11 Well Group
Salina Formation F-unit Salt - Combined Salt Bed Thickness		
Average Thickness (m)	33.4	30.9
Salina Formation D-unit Salt - Combined Salt Bed Thickness		
Average Thickness (m)	5.5	5.9
Salina Formation B-unit Salt – Total Formation Member Thickness		
Average Thickness (m)	65.8	61.1

Comparing bed thicknesses and elevations using these groups indicates that there is a regional trend of thinning of the B and F evaporites towards the north whereas the D salt bed remains relatively consistent in cumulative thickness.

4.3.1 Detroit River Group

4.3.1.1 Detroit River Group – Dundee Formation

The Dundee Formation is a light grey, medium strong, petroliferous (containing natural petroleum), thinly to medium-bedded, stylolitic, vuggy[3], dolomitic limestone based on the recovered rock core samples. From a geological report on mining activities in south western Ontario, it is stated of the Detroit River Group formation that "The limestone from a drilling and blasting perspective is almost ideal with uniform horizontal bedding and regularly spaced vertical joints. The natural blocky texture of the rock allows it to be drilled on an unusually large 7 m x 8 m pattern, producing a shot with a maximum 760 mm lump size and only a small percentage of finely sized material (MNDM 2003)." At a quarry in St. Mary's, Ontario, within the Dundee Formation (Armstrong and Carter 2006) some vertical joints persist for more than several metres and have a horizontal spacing of 2 or 3 m. Most joint sets have a vertical persistence of less than 1 or 2 m and have a spacing of 0.5 to 1 m typically. Data from the acoustic televiewer indicated vertical features (either joints or vertical features filled with evaporite minerals) ranging in vertical length between 0.2 to 5.9 m with an average of about 1.8 m. A total of 14 such features were evident in 8 of the 12 exploratory wells. Uniaxial compressive strengths (UCS) of this bedrock as reported in literature and local test data reviewed during preparation of this report are on the order of 30 to over 100 MPa, but typically between about 50 and 90 MPa. Four tests carried out nearby this project site exhibited UCS values of 33.3, 36.4, 49.2 and 55.4 MPa. RQD values for the cores obtained using NQ coring techniques during nearby investigations typically were near 80 %, though values as low as 10 % are often encountered in the top 2 m of rock. RQD values of core recovered from Well X10N-2 ranged from 0 to 71%, with an average of about 26%. From Well X11-5, RQD values ranged between about 19 and 82 % with an average of about 44 %.

4.3.1.2 Detroit River Group – Lucas Formation

The Lucas Formation is a light tan/grey to medium brown, medium strong, laminated to thinly bedded, petroliferous dolostone with white, weak gypsum beds and bituminous partings. At a quarry in Amherstberg, Ontario, within the Lucas Formation (Armstrong and Carter 2006) most vertical joint sets persist for 1 to 2 m and are spaced at 0.5 to 1 m typically, but some joints persist for 3 to 5 m with spacing on the order of 2 to 3 m or more. Data from the acoustic televiewer indicated vertical features ranging in vertical length between 0.2 to about 8.1 m with an average of about 1.9 m. A total of 22 such features were evident in 10 of the 12 exploratory wells. Uniaxial compressive strengths of this bedrock formation as reported in literature reviewed during preparation of this report are on the order of 50 to 100 MPa. Two tests completed as part of the US DRIC study exhibited UCS values of about 51 and 85 MPa. Data from Russell (1993) indicated uniaxial compression strengths ranging from about 22 to 55 MPa, with an average of about 37 MPa. Measured elastic compression modulus values ranged from 31

[3] A small cavity often with a mineral lining of different composition from that of the surrounding rock.

to 45 GPa. From Well X10N-2, RQD values ranged between 0 and 100% with an average of about 25% and core from Well X11-5 exhibited RQD values between 0 and 38% with an average of about 15 %.

4.3.1.3 Detroit River Group – Amherstburg Formation

Below the Lucas formation, the Amherstburg Formation consists of medium brown, moderately strong to strong, porous, thinly bedded, petroliferous dolostone, with some laminar bituminous[4] partings. At a quarry in Amherstberg, Ontario, within the Amherstburg Formation (Armstrong and Carter 2006) most joint sets persist for 1 to 2 m and are spaced at 0.5 to 1 m typically, but some joints persist for 3 to 5 m with spacing on the order of 2 to 3 m or more. Data from the acoustic televiewer indicated vertical features ranging in vertical length between 0.5 to about 5.6 m with an average of about 2.0 m. A total of 5 such features were evident in 3 of the 12 exploratory wells. Uniaxial compressive strengths of this bedrock as reported in literature reviewed during preparation of this report are on the order of 70 to 120 MPa for the dolostone and as low as 40 MPa for interbedded sandstone layers. One test from the US DRIC testing program exhibited a UCS value of about 85 MPa and an elastic modulus of about 35 GPa. From Well X10N-2, RQD values ranged between 0 and 100% with an average of about 43% and core from Well X11-5 exhibited RQD values between about 9 and 55 % with an average of about 22 %.

4.3.1.4 Detroit River Group – Amherstburg Formation Sylvania Member

The Amherstburg Formation Sylvania Member is typically pale grey, moderately strong to strong, fine to medium grained, thinly bedded, porous silica sandstone based on the recovered rock core samples. Photos or sites of exposures of this formation in quarries or natural outcrops were not available. It has been reported (Russell 1993) that the grains are well-sorted, medium-grained and densely packed with planar or concave-convex grain contacts. Data from the acoustic televiewer indicated two vertical features with vertical lengths of about 0.7 to about 1.9 m found in Wells X10N-3 and X11-3. Cementation is highly variable and strength has also been reported in the literature to vary from near 10 MPa to over 100 MPa. Of 30 tests reported by Russell (1993) the average uniaxial compression strength was about 55 MPa, with a standard deviation of about 5 MPa. One test completed for the US DRIC study indicated a UCS of about 45 MPa and an elastic modulus of about 29 GPa. RQD values for rock core recovered from Well X10N-2 ranged from 0 to about 52%, with an average of about 12%. From Well X11-5, RQD values ranged between about 6 and 48 % with an average of about 17 %.

4.3.2 Bois Blanc Formation

Directly below the Sylvania Formation is the Bois Blanc Formation that consists of light grey to medium brown, interbedded, medium strong, porous, fine-grained, cherty[5] dolostone with

[4] Containing bitumen or tarry hydrocarbon compounds.
[5] Containing granular cryptocrystalline silica, similar to flint.

sandstone interbeds. Exposures of the Bois Blanc, Bass Islands, and Salina Formation E unit, likely the more competent of the formations, are rare in this region. Upper Silurian carbonates as found in quarries near the north-western margin of the Michigan Basin (e.g. Underwood et al. 2003) exhibited vertical fracture patterns on the order of 1 to 2 m in vertical and horizontal directions. A review of photos taken of a quarry within these formations in the Niagara peninsula region of Ontario suggest similar vertical jointing characteristics. Laboratory testing carried out as part of the US DRIC program indicated UCS values ranging between 67 and 193 MPa, with an average of about 104 MPa. Elastic modulus values ranged from about 28 to 48 GPa, with an average for the six tests of about 38 GPa. Data from the acoustic televiewer indicated vertical features ranging in vertical length between 0.7 to about 6.6 m with an average of about 2.4 m. A total of 7 such features were evident in 3 of the 12 exploratory wells. Uniaxial compressive strengths of this bedrock are about 80 to 200 MPa for the dolostone and as low as 40 MPa for the interbedded sandstone layers. RQD values for rock core recovered from Well X10N-2 ranged from 0 to about 20% with an average of less than 5%. From Well X11-5, RQD values ranged between about 0 and 47 % with an average of about 7 %.

4.3.3 Bass Islands Formation

The Bass Islands Formation, underlying the Bois Blanc Formation, consists of tan to beige, strong to very strong, friable, porous, thinly to medium-bedded dolostone with a brecciated texture and some zones of gypsum. As indicated above, vertical joints are on the order of 1 to 2 m in vertical and horizontal directions in quarries of similar Silurian carbonate formations near the north-western margin of the Michigan Basin and in the Bass Islands formation in the Niagara peninsula. Data from the acoustic televiewer indicated vertical features ranging in vertical length between 0.3 to about 14.7 m with an average of about 2.9 m. A total of 11 such features were evident in 5 of the 12 exploratory wells. Uniaxial compression strengths of similar dolostone typically range between about 80 and 200 MPa. The result of one test completed for the US DRIC study indicated a UCS value of about 81 MPa and an elastic modulus of about 56 GPa. RQD values of rock core recovered from Well X10N-2 ranged from 0 to about 20% with an average of less than 5%. RQD values for rock core recovered from Well X10N-2 ranged from 0 to about 100% with an average of about 35%. From Well X11-5, RQD values ranged between 0 and 78 % with an average of about 24 %.

4.3.4 Salina Formation

4.3.4.1 Salina Formation, G-unit, Shale and Dolostone

The Salina Formation is made up of seven discrete units, the top layer (G-unit) of which includes light brown-grey, bedded dolostone and white, weak gypsum/anhydrite[6] with layers of calcareous shale and shaley dolostone. It should be noted that there are differences in the geologic criteria

[6] Anhydrite is defined as anhydrous (without water) calcium sulphate $CaSO_4$, whereas gypsum is hydrated calcium sulphate $CaSO_4 2H_2O$. Anhydrite transforms to gypsum in the presence of water.

and naming conventions used for defining the Salina G and F Unit shale and dolostone strata in the US and Canada. Data from the acoustic televiewer indicated vertical features ranging in vertical length between 0.9 to about 1.7 m with an average of about 1.3 m. A total of 4 such features were evident in 3 of the 12 exploratory wells. Uniaxial compression strengths as indicated by four tests carried out for this project (one from the US DRIC investigation and three from the Canadian study) ranged between 85 to 180 MPa with corresponding elastic modulus values ranging from about 24 to 77 GPa. RQD values of rock core recovered from Well X10N-2 ranged from 0 to about 85% with an average of about 30%. From Well X11-5, RQD values ranged between 32 and 89 % with an average of about 54%.

4.3.4.2 Salina Formation, F-unit, Shale

Below the G-unit is the uppermost portion of the Salina F-unit that consists primarily of shale and dolostone. For the purposes of this report, this is identified as the Salina F Shale in keeping with local nomenclature. Within the wells completed for this project, the Salina F Shale consists of grey to dark grey, strong, fine-grained, shaley dolostone and dolomitic shale interbedded with white to grey, weak gypsum/anhydrite. Data from the acoustic televiewer indicated vertical features ranging in vertical length between 0.9 to about 2.7 m with an average of about 1.5 m. A total of 4 such features were evident in Wells X10N-2 and X11-6 with 3 of these being in X10N-2. A total of eight uniaxial compression strength tests (3 from the US DRIC program, 5 from the Canadian DRIC program) indicated strengths ranging from about 55 to 130 MPa and elastic modulus values ranging from about 16 to 48 GPa. RQD values of rock core recovered from Well X10N-2 ranged from 0 to about 85% with an average of about 25%. From Well X11-5, RQD values ranged between 0 and 100 % with an average of about 76 %.

4.3.4.3 Salina Formation, F-unit, Salt

Beneath the Salina F Shale is the Salina F Salt. Based on a review of the cores and natural gamma logs, five evaporite beds were clearly identified within the Salina F Salt, being divided by dolostone layers; These evaporites are numbered SsF-1 through SsF-5 from lowest elevation to highest elevation, consistent with their depositional sequence. The uppermost portions (approximately 2 m) of the salt in this unit are shaley, whereas the remainder of the salt is clear to light grey. The third evaporite bed consists of gypsum/anhydrite. The separating interbeds consist of grey to brown, medium strong to strong, fine-grained, porous, shaley dolostone. The thickest of these interbeds includes salt nodules (eyes) within the dolostone. Data from the acoustic televiewer indicated vertical features ranging in vertical length between 0.2 to about 1.5 m with an average of about 0.6 m. A total of 7 such features were evident in 5 of the 12 exploratory wells. Uniaxial compression strengths for the dolomitic shale/dolostone stringers in the salt are estimated to range between about 86 to 188 MPa based on six tests carried out for this project (3 tests each US and Canadian DRIC programs) and values typical for similar salt deposits. Elastic modulus values ranged from about 9 to 71 GPa.. In 1980, an exploratory well (E-5) was drilled by BP and rock core through this unit exhibited average RQD values of 85 to 90 %. Within this formation, well X10N-2 was advanced using rotary drilling methods and core was not recovered from which to estimate the RQD of the rock at this location and depth. From Well X11-5, RQD values ranged between 0 and 97 % over the Salina F Salt with an average of about 62 %.

4.3.4.4 Salina Formation, E-unit, Dolostone

As a massive layer of grey-brown, strong, fine-grained, dolomitic limestone and dolostone, the Salina Formation E-unit underlies the Salina F Salt. This Formation also includes relatively thin interbeds of gypsum/anhydrite. One exposure of the Salina Formation exists in the Niagara peninsula area of Ontario in a rock cut near Welland (Armstrong and Carter 2006). About 5.3 m of interbedded dolostone and shale are exposed that likely represent part of the Camillus Formation, upper Salina Group, and this formation is approximately equivalent to the E Unit (Armstrong and Carter 2006). The dolostones are thin bedded and contain large gypsum nodules. This exposure may illustrate the general character of the Salina Formation E Unit, but there is uncertainty with respect to it being directly analogous. This formation is medium to thinly bedded with interbedded shales. Most joint sets evident persist for less than 1 m with a spacing of 0.5 to 1.5 m and more persistent joints are not evident in the photographs. Data from the acoustic televiewer indicated vertical features ranging in vertical length between 0.2 to about 1.9 m with an average of about 0.8 m. A total of 15 such features were evident in 7 of the 12 exploratory wells. Uniaxial compression strengths are estimated to range between about 74 to 214 MPa based on testing carried out for this project (US and Canadian DRIC programs) with corresponding elastic modulus values ranging between 21 and 69 GPa. The rock cores obtained by the nearby explorations completed in 1980 on the BP site (Well E-5) exhibited a typical RQD of 100 %. Within this formation, well X10N-2 was advanced using rotary drilling methods and core was not recovered from which to estimate the RQD of the rock at this location and depth. From Well X11-5, RQD values ranged between 92 and 100 % with an average of about 96 %.

4.3.4.5 Salina Formation, D-unit, Salt

There are two clearly identifiable salt beds within the Salina D Salt (SsD-1 and SsD-2), separated by a dolostone interbed. The salt is clear to grey and weak, and the dolostone is grey to brown, strong, and fine-grained. No vertical features were evident within the D-unit salt. Uniaxial compression strengths for the stringers in the salt are estimated to range between about 70 and 100 MPa. One test indicated a UCS of 155 MPa and an elastic modulus of 33 GPa. Rock core through the Salina D Salt in the 1980 BP explorations revealed an average RQD value of 67 % in the lower salt bed and 100 % in the upper salt bed (low RQD values are most likely to be associated with weak bedding planes). Within this formation, well X10N-2 was advanced using rotary drilling methods and core was not recovered from which to estimate the RQD of the rock at this location and depth. From Well X11-5, RQD values from the three core runs taken from this layer were 100, 98, and 100 %.

4.3.4.6 Salina Formation, C-unit, Shale

A layer of grey, strong, fine-grained, thinly to medium-bedded, gypsiferous, shaley dolostone and dolomitic shale and mudstone underlies the Salina D Salt. Data from the acoustic televiewer indicated vertical features ranging in vertical length between 0.1 to about 3.0 m with an average of about 0.9 m. A total of 24 such features were evident in 3 of the 12 exploratory wells. Uniaxial compression strengths for the dolomitic shale and dolostone ranged between about 27 and 194 MPa (81 MPa for average of 8 tests) based on US and Canadian testing completed for this project while corresponding elastic modulus values ranged between 4 and 70 GPa (28 GPa for average of 8 tests). In 1980, rock core from exploratory Well E-5 (location shown on Figure 7.1) was found to have an average RQD value of 90 % (ranging between 72 and 100%). Within this formation, well X10N-2 was advanced using rotary drilling methods and core was not recovered from which to estimate the RQD of the rock at this location and depth. From Well X11-5, RQD values ranged between about 92 and 100 % with an average close to 100 %.

4.3.4.7 Salina Formation, B-unit, Salt

A third salt unit is beneath the Salina C Shale that consists primarily of clear to grey, weak salt. This massive salt layer includes a number of relatively thin (up to about 2 m) interbeds (or "stringers") of shaley dolostone or dolomitic shale. One vertical feature of about 0.4 m length was indicated by the acoustic televiewer data within this formation at Well X10N-2. Two uniaxial compression tests completed on the shaley dolostone/dolomitic shale within this unit exhibited UCS values of 48 and 72 MPa and elastic modulus values of about 8 and 67 GPa. Within this formation, well X10N-2 was advanced using rotary drilling methods and core was not recovered from which to estimate the RQD of the rock at this location and depth. From Well X11-5, RQD values ranged between about 83 and 98 % with an average of about 92 %.

4.3.4.8 Salina Formation, A-unit, Carbonate

Underlying the Salina B Salt is the Salina A Carbonate layer, which is technically classified as having two components, A2 and the underlying A1. During this investigation, only the Salina A2 Carbonate was encountered and characterized by dense dolostone, limestone and dolomitic shale. This stratum was encountered at the base of the wells and was only cored in X11-5 for 1 run that exhibited an RQD of about 93 %.

4.4 Groundwater and Hydrogeology

The rock formations over the entire area are overlain by 25 to 35 m of soft to firm, clayey silt/silty clay with static water levels measured within the upper horizons of this overburden between 0 and 2 m below the ground surface.

Artesian water pressures were encountered at the interface between the soil and bedrock at a depth of about 28.3 to 31.5 m below ground surface. The static pressure head of the water at this interface is about 2 m above ground surface (approximately Elevation 179 m) based on nearby conventional boreholes and observation wells. Significant artesian water flows were encountered in all wells while drilling in the Lucas Formation between Elevations of 130 and 70 m, or approximate depths of 50 and 110 m below the ground surface. These artesian water flows varied in pressure head between about 11 and 14 m as measured by pressure gauges at two locations (X10N-1 and X10N-5). Flows through the 244 mm casing varied up to about 2,500 litres per minute (lpm) based on approximate measured time rates of filling the on-site tanks. The water contained hydrogen sulphide gas and stained equipment black upon exposure to atmospheric pressure. Depending on the flow rates, containment capability, and the distance or anticipated time required to reach the next casing level, cement was forced into these zones to attempt to seal off the flow. Success of such sealing attempts was variable, but sufficient after one to two attempts to permit continued drilling. All artesian water flows contained hydrogen sulphide (at the soil bedrock interface through to the base of the Bass Islands Formation).

During drilling of some wells, circulation was either partially or completely lost (no return of drilling fluids) while drilling in the Lucas Formation near the interface with the Amherstburg Formation or in the Sylvania sandstone. Artesian pressures were again encountered in some wells near the top of the Bass Islands Formation.

Upon reaching the Bass Islands Formation, a third casing was installed measuring 178 mm diameter. The tip of this casing was typically set at about 190 to 210 m below ground surface and cemented into place. Cement was pumped until it returned through the annulus to near the ground surface. Some cementing attempts required that the casing be perforated and cement injected through the perforated well to fully seal off artesian flows between the casings. All such perforations were sealed by consequent cementing operations. Brine was used as the drilling fluid below this point.

During subsequent drilling through the Bass Islands Formation, Salina Formation G-unit, and the shale of the Salina Formation F-unit, circulation of drilling fluids was largely maintained in most wells, though some gradual losses occurred over these zones. Upon reaching the Salina F Salt at or near depths of about 300 m below ground surface, all circulation was lost in Wells X10N-2 (though circulation was also lost above this formation in this well), X10N-3, X10N-4, and X11-4. Minor losses of circulation were also noted in Wells X10N-1 and X11-3.

Artesian water flows were exhibited while coring in Well X10N-2 in the Salina F Shale at about 260 m below ground surface when the drillers erroneously started using fresh water instead of brine and mud. The lower fluid density thus likely permitted upward flow. Upon learning of this mistake, Golder site personnel had the drillers immediately switch to brine (as they were to be using brine upon encountering the Salina Formation).

Static fluid levels in these wells measured more than one month after completion of the wells typically ranged from 15 to 30 m below ground surface except for Well X10N-4 that had a fluid level of 0.1 m below ground surface. Fluid levels were measured on September 27, 2007 and these measurements are summarized in the table below.

Table 4.4 – Post-Drilling Well Fluid Levels

Well No.	Depth Below Ground to Fluid Surface (m)	Well No.	Depth Below Ground to Fluid Surface (m)
X10N-1	14.8	X11-1	28.8
X10N-2	25.9	X11-2	26.0
X10N-3	15.2	X11-3	18.3
X10N-4	0.1	X11-4	19.7
X10N-5	28.2	X11-5	30.7
X10N-6	20.6	X11-6	30.5

Well X10N-4 was the first well to lose circulation and significant volumes of cement were introduced into the formation at the top of the Salina F Salt to curb fluid losses. Following completion of drilling, an attempt was also made by a member of the drilling crew to dispose of some of the formation water (from artesian flows) into this well, but after filling the well to the surface (from an initial fluid surface of about 30 m below ground), no more water could be added to the well, likely due to the density differences of the brine (below) and fresh water (added).

4.5 Subsurface Conditions Encountered During Drilling - Crossing B

4.5.1 X10N-1 (Southwest Sales Site)

Overburden materials in X10N-1 consisted of surficial fill extending to a depth of about 10.3 m below ground surface. The fill contained concrete rubble, and red brick and wood fragments. A 17.1 m deposit of grey clayey-silt/silty-clay was encountered underlying the fill. The top 8 m of this deposit contained some gravel, and was generally harder. The silty-clay deposit was underlain by a 1.1 m thick sand and gravel basal till containing some silt and clay. Bedrock was encountered at 27.82 m below ground surface.

The conductor casing (340 mm diameter casing) was installed through the overburden to the top of bedrock using a cable-tool drilling rig for a the total depth of 28.32 m into the top of rock. Following installation, artesian water with a flow of approximately 25 to 45 lpm was observed flowing up, around the outside of and within the casing. The casing was therefore perforated and 13.1 m^3 of cement was used to seal off artesian water flows.

At a depth of approximately 45.5 m, artesian water was encountered with a flow of about 40 lpm. The installation of the 244 mm casing to a depth of 46.4 m using 3.0 m^3 of cement sealed off the artesian water flows until they were encountered again at a depth of 48.9 m with the flow ranging from about 10 to 40 lpm.

The artesian water flow continued through 58 m below ground surface with flows ranging from 20 to 40 lpm. At a depth of about 61 m below ground surface, the artesian flow increased to 500 lpm. In an attempt to control the flow, brine (1080 kg/m^3) was pumped into the well. At an approximate depth of 64 m, a 1 m drop was noted by the driller. As drilling continued between depths of 65 and 75 m, several 10 cm drops were observed in the drilling, and the water flow increased.

At a depth of about 80 m, the artesian flow rapidly increased to rates between 2000 and 2500 lpm, at which point brine (1,200 kg/m^3) was used in an attempt to balance the hydrostatic pressure of the formation. The brine was unsuccessful in stopping the flow, and the well was sealed using the BOP device. A gauge was attached to the BOP and a water pressure of about 138 kPa (20 psi). Subsequently, 13.5 m^3 of cement was pumped to a depth of 81.5 m to seal off the flow. The water flow only decreased to about 450 lpm, at which point a further 16.0 m^3 of cement was pumped into the well to seal off the flow once more. The water flow decreased to about 50 lpm, and at a depth of about 88 m the flow decreased further to about 10 lpm.

Between the depths of 90 and 120 m, artesian flows ranging from 90 to 140 lpm were encountered. Between the depths of 123 and 163 m, drilling fluids were lost at a rate of about 1.5 to 2.5 lpm. Near a depth of 185 m, flows ranging from about 10 lpm to 30 lpm were encountered with enough hydrostatic pressure that the flow were returning to surface. At about 197 m, artesian flow was estimated to be about 100 lpm.

Drilling stopped at about 205 m below ground surface to install the 178 mm casing. The artesian flow increased to 240 lpm during the down-hole geophysical logging, and brine (1110 kg/m^3) was used in an attempt to control the flow. During the casing installation, 7.9 m^3 of cement was used to seal off the artesian water flow, but no cement was returned to the surface and a flow of approximately 110 lpm was observed exiting through the annulus between the two casings. The 178 mm casing was perforated between 56 and 57 m and 3.5 m^3 of cement was pumped into the well, successfully stopping the artesian flow. Drilling was resumed using brine with a density of about 1200 kg/m^3 drawn from the BP brine lagoons.

At a depth of about 280 m, white bubbles of an unknown origin where observed in the return water. As drilling continued to 285 m below ground surface, near the top of the Salina F Salt, drilling fluids were lost at rates between about 40 to 50 lpm. Also, circulation decreased to about 75% of full circulation, after which point circulation varied significantly but was capable of being maintained sufficiently to recover chip samples. Fluid losses at rates of approximately 25 lpm were encountered between depths of about 345.5 and 363.5 m and between 375.5 and 402.5 m. Artesian flow of approximately 25 lpm was encountered in between the two fluid loss zones. Drilling was completed to a final hole depth of 492.54 m, and down-hole logging was completed from the bottom of the 178 mm casing to the bottom of the well.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary - X10N-1 (3rd well drilled in X10N series):

- Top of rock at Elev. 149.0 m (27.8 m below ground surface [bgs])
- Water level in overburden observed at Elev. 174.8 m (2 metres below ground surface (m bgs)) - *Overburden*
- Conductor casing set to Elev. 148.5 m (28.3 m bgs), artesian water flow of 25 to 45 lpm (H_2S odour), casing perforated and 13.1 m^3 cement used to seal flow – *Dundee Formation*
- Artesian water (H_2S odour) flow of 20 to 40 lpm at Elev. 131.3 m (45.5 m bgs)
- 1st well casing set to Elev. 130.4 m (46.4 m bgs), 2.6 m above bottom of hole, and cemented in place with 3.0 m^3 cement – *Lucas Formation.*
- Artesian water flow continued between 20 to 40 lpm at Elev. 118.8 m (58 m bgs) – *Lucas Formation.*
- 1 m "bit drop" noted by drillers at Elev. 112.8 m (64 m bgs) with increase in artesian flow rate to 500 lpm – *Lucas Formation*
- Several 10 cm "drops" noted by drillers between Elevs. 111.8 to 101.8 m (65 to 75 m bgs) – *Lucas Formation*
- Artesian water flow increased significantly (factor of 50) to about 2,000 to 2,500 lpm at Elev. 96.8 m (80 m bgs), measured pressure head of 138 kPa (14 m above ground surface), well cemented twice - flow controlled to 450 lpm for first cementing, then to 50 lpm from second cementing – *Lucas Formation*
- Artesian flow increased to between 90 and 140 lpm at Elev. 86.8 to 56.8 m (90 to 120 m bgs) – *Lucas and Amherstburg Formations*
- Minor drilling fluid losses observed between Elev. 33.8 to 3.8 m (143 to 163 m bgs) – *Sylvania Formation.*
- Artesian water flow to surface of 20 lpm at Elev. -5.2 m (185 m bgs) – *Bois Blanc Formation*
- Artesian water flow of about 100 lpm at Elev. -21.2 m (198 m bgs) – *Bois Blanc Formation*
- Artesian water flow of 240 lpm at Elev. -30.2 m (207 m bgs), brine (1110 kg/m^3) used to slow flow and permit geophysical logging of well – *Bass Islands Formation*
- 2nd well casing set at Elev. -28.2 m (205 m bgs), cemented in place, two cementing jobs required, with the second one at Elev. 116.8 m (60 m bgs) by perforation of the casing to seal off artesian flow between casings, drilling recommenced using light brine – *Bass Islands Formation (perforation and cementation in Lucas Formation)*
- Bubbles in drilling fluid (brine) noted at Elev. -103.2 m (280 m bgs) – *Salina F-Unit Shale Formation*
- Drilling fluid losses of 40 to 50 lpm observed at Elev. -108.2 m (285 m bgs) – *top of Salina Formation F-Unit Shale*
- Switched to heavy brine at Elev. -113.2 m (290 m bgs) – *Salina Formation F-Unit Shale*
- Drilling fluid surging at Elev. -123.2 m (300 m bgs) – *Salina Formation F-Unit Salt*
- Drilling fluid losses of about 30 lpm between Elev. -173.2 and -315.7 m (350 and 492.5 m bgs) – *Salina Formation D-Unit Salt*
- Sufficient circulation maintained to recover chip samples for entire well.
- End of well at Elev. -315.7 (492.5 m bgs) – *Salina Formation A-Unit Carbonate*

Note that the calliper logs were obtained following cementing events completed between 60 and 84 m and prior to setting of 2nd casing. Calliper logs indicate washout zones between 65 and 71 m bgs.

4.5.2 X10N-2 (Cored Well, Southwest Sales Site)

The overburden in Well X10N-2 consisted of fill composed of brown sand and gravel extending from the ground surface to a depth of 2.24 m. The fill was underlain by 26.0 m of brown to grey, clayey silt/silty clay containing trace amounts of sand and gravel. The silty clay deposit is further underlain by 0.28 m of till composed of grey silty clay with cobbles. Bedrock was encountered at 28.52 m below ground surface.

The conductor casing (340 mm diameter casing) was installed through the overburden into the top of bedrock using the cable-tool drilling rig operated by Bradco Drilling Inc. The total depth of the conductor casing installed was 29.02 m with the top of rock at 28.52 m. No artesian water flow was observed following installation.

Fractured rock is believed to have been encountered past a depth of 33.8 m due to the loss of core samples. The first artesian water flow zone was encountered below the fractured rock at a depth of about 42 m. Artesian flow was controlled by switching to a barite-polymer and mud mixture drilling fluid used to balance the hydrostatic pressure of the formation. The 244 mm casing was installed using 4.0 m^3 of cement, with the tip at a depth of 45.9 m in accordance with MNR approval of the program change for this well.

Artesian water, which returned black with a sulphurous odour, was encountered at a depth of 47.4 m with a flow rate of approximately 500 lpm. This artesian zone was controlled using a xanthan gum polymer mixture to balance the hydrostatic pressures of the formation.

At approximately 121 m below ground surface, a fluid loss zone was encountered with a water loss of about 1,000 lpm and a loss of the polymer drilling fluids. The core barrel was sheared off in the well at 123.5 m depth. After repairs, coring was resumed, but no core was recovered from 138.5 to 141.5 m. Another fluid loss zone was encountered between 142.6 and 157.9 m, with partial to no core recovery from 147.7 to 153.8 m. A lower fluid loss zone was then encountered at a depth of about 177.0 m.

No core was recovered from 178.17 to 180.12 m, 181.22 to 185.2 m, and 187.3 to 188.3 m. At 188.4 m, the inner core barrel broke and had to be extracted from the well. Between 181.22 and 183.5 m, 50 to 76 mm bit drops were observed during drilling. Fracture zones were present from 187.3 to 189.3 m, with minor artesian water flow observed in the last 0.2 m of the fracture zone.

Significant artesian flow was experienced while reaming, using a freshwater drilling fluid, installed to install the 178 mm casing to a tip depth of 188.9 m. The well was installed with 6.8 m^3 of cement and the cement surface between the casings was found at 51.9 m using temperature logging. The hole was cemented a second time between the casings with 5.8 m^3 of cement, bringing the surface of the cement in the annulus between the casings to 14.9m below the ground surface.

No core was recovered from 189.4 to 189.9 m. At a depth of 195.1 m, it was determined through down hole testing that the hole was being drilled 1.2 degrees off-center. The hole was drilled with the tricone bit from 195.1 to 198.4 m in order to realign the well. At approximately 196 m circulation of drilling fluids was partially lost.

Small, but unmeasured and unrecorded, drops in the drill bit were observed by the drillers between the depths of 210.6 and 213.0 m and no core was recovered from 210.6 to 216.3 m, and from 219.1 to 223.0 m. At 226.8 m bgs circulation was entirely lost, and the core barrel was sheared and had to be extracted from the well. During this period, the drillers considered that the hole was experiencing caving and the hole was therefore drilled with a tricone bit from 226.27 to 232.8 m. To regain circulation, 11.5 m^3 of cement was pumped into the well to seal it off. Upon resuming drilling through the cement within the well, a zone in which no cement was encountered was found between the depths of 167.9 to 234.75 m, and circulation was entirely lost again at 238.5 m. The well was cemented a second time with 16 m^3 of cement, and the cement surface found upon resumption of drilling was at 110.9 m; however, no cement was encountered between 170.9 and 230.9 m, and between 233.4 and 234.9 m. The hole was advanced using the tricone bit from 244.7 to 255.9 m. The well was cemented a third time using 1.5 m^3 of cement at 245.1 m bgs. Circulation was poor once more at 246.3 m, with a fluid loss of approximately 300 lpm. Consequently, at a depth of 248.7 m, it was cemented a fourth time with 12 m^3 of cement as a plug. The surface of the cement was found at 147.9 m upon resumption of drilling. In order to avoid damaging coring equipment again due to losses of circulation, the hole was advanced with the tricone bit from 255.9 to 260.6 m; coring was resumed past this depth. Drilling fluid losses were experienced past a depth of 266.9 m, and circulation was lost completely by 295.2 m, at which point the drill pipes were sheared at about 36 m below ground surface. The drilling equipment was recovered, and the well was drilled “blind” without return of cuttings or fluids using the tricone bit to a depth of 337.55 m. It is estimated that that the approximately 889 lpm of brine was being lost down well. At 337.55 m, 13.3 m^3 of cement was pumped in as a plug, and the cement surface was found to be at 134.3 m bgs once it had cured. Drilling using the tricone bit was continued to a depth of 346.1 m, at which point difficulties with the equipment prompted a change of drilling methods. Down-hole logging was completed to the bottom of the well at this time.

The cable tool rig was mobilized to the site and commenced clearing the hole of debris as the tool could not reach the previous well depth. It was intended that a 138 mm casing be installed through the Salina F Salt to the Salina E Dolostone to protect the well from caving materials through the salt formation. While attempting to install the casing, it became jammed in the well above the F salt. It was then raised and lowered again, and during subsequent installation dropped suddenly to a tip depth of about 319 m where it jammed in the well again. The debris within and below the casing was cleared to a depth of about 322 m and the casing was cemented in place. During subsequent redrilling, the cable tool cleared through the cement within the casing and through the softer debris below, but could not advance into the Salina E Dolostone.

As a result, the PortaDrill TLT474 was mobilized to the site and drilling resumed to the bottom of the well, a final depth of about 491.4 m. Down-hole logging was completed and cross-well seismic testing began. During one testing run, the equipment became jammed in the well and after multiple recovery attempts was successfully brought to the surface. The PortaDrill TLT474 rig was subsequently remobilized to the well, and the well was cleared again to the bottom. After several attempts, HW flush-joint drill casing (118 mm diameter) was successfully installed to the bottom of the well. This casing was not cemented in place with the intent that it may be possible to recover the casing in the future during well abandonment.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary - X10N-2 (6th well drilled in X10N series):

- Top of rock at Elev. 148.1 m (28.5 m bgs) – *Dundee Formation*
- Conductor casing set to Elev. 147.6 m (29.0 m bgs) – *Dundee Formation*
- Artesian flow at Elev. 134.6 m (42 m bgs) adequately controlled with mud –*Lucas Formation*
- Fractured zones noted
- 1st well casing set at Elev. 130.7 m (45.9 m bgs) and cemented in place – *Lucas Formation.*
- Drilling fluid losses of 1,000 lpm at Elev. 54.6 m (121 m bgs) – *Amherstburg Formation*
- Core barrel sheared off Elev. 53.1 m (123.5 m bgs)
- Drilling fluid losses between Elev. 34.6 and 18.6 m to (142 and 158 m bgs) – *Sylvania Formation*
- Drilling fluid losses at Elev. -0.4 m (177 m bgs) – *Bois Blanc Formation*
- Inner core barrel broke and had to be fished from well at Elev. -11.8 m (188.4 m bgs) – *Bois Blanc Formation*
- 2nd well casing set at Elev. -12.4 m (189 m bgs) and cemented in place – *Bois Blanc Formation*
- Drilling fluid losses at Elev. -19.4 m (196 m bgs) – *Bass Islands Formation*
- Well cemented at Elev. -58.1 m (234.7 m bgs) – *Salina Formation G-Unit Shale and Dolostone*
- Lost all drilling fluid at Elev. -61.9 m (238.5 m bgs) – *Salina Formation G-Unit Shale and Dolostone*
- Well cemented at Elev. -68.5 m (245.1 m bgs) – *Salina Formation G-Unit Shale Dolostone*
- Switched to rotary tricone drilling at Elev. -68.1 m (244.7 m bgs) – *Salina Formation G-Unit Shale and Dolostone*
- Drilling fluid losses at Elev. -70.3 m (246.3 m bgs) – *Salina Formation G-Unit Shale and Dolostone*
- Well cemented at Elev. -72.1 m (248.7 m bgs) – *Salina Formation F-Unit Shale*

- Drillers switched to coring and use of fresh water at Elev. -84 m (260.6 m bgs) – *Salina Formation F-Unit Shale*
- Drilling fluid losses encountered between Elev. -90.3 and -118.6 m (266.9 and 295.2 m bgs)
- Drilling fluid losses and drillers note suspected fracture zone at Elev. -106.4 to -108.4 m (283 to 285 m bgs) – *Salina Formation F-Unit Shale*
- Coring halted at Elev. -118.6 m (295.2 m bgs) and rotary drilling with brine recommenced – *Salina Formation F-Unit Shale*
- Coring recommenced at Elev. -117.1 (293.7 bgs) with brine, 0.7 m core recovered, twisted off drill string, drill string recovered, rotary drilled blind below – *Salina Formation F-Unit Shale*
- Rotary drilled blind to Elev. -161 m (337.6 m bgs), well cemented, upon redrilling found no cement between Elev. -23.4 and -73.4 m (200 and 250 m bgs), and again between -88.4 and -133.4 m (265 and 310 m bgs) – *Salina Formation F-Unit*
- Davidson Drilling Inc. off site, cable tool mobilized to hole, 138 mm casing installed to Elev. -139.9 m (316.5 m bgs) and cemented in place, cable tool cleared cuttings between bottom of casing and previously drilled hole but could proceed no further - *Salina Formation F-Unit Salt*
- Rotary drilling commenced with PortaDrill TLT474 using heavy brine and continued drilling blind (no circulation) to bottom of well - *Salina Formation F-Unit Salt to end of hole*
- Caving of debris above Elev. -195.4 m (372 m bgs) required the well be redrilled and HW casing (118 mm diameter) was installed to bottom of well - *Salina Formation*
- End of well at Elev. -314.8 m (491.4 m bgs) – *Salina Formation, A2 Member*

4.5.3 X10N-3 (OPG Site)

Overburden materials found in X10N-3 consists of a greenish grey clayey-silt containing trace amounts of sand and gravel. This deposit has been considered to be possible fill material. This material was encountered between 1.3 m and 4.9 m below ground surface and was underlain by a 23.6 m thick deposit of grey clayey silt/silty clay containing some sand and occasional gravel. The clayey silt/silty clay deposit is underlain by a 0.2 m thick deposit of sand and gravel. Bedrock was encountered at 28.67 m below ground surface.

The conductor casing (340 mm diameter casing) was installed through the overburden into the top of bedrock using a cable-tool drilling rig. The total depth of the conductor casing installed was 29.17 m and top of rock was at 28.67 m. No artesian water flows were observed at this location after conductor installation until drilling within the bedrock formations.

Flowing water conditions were first encountered at about 39.6 m below ground surface with a flow of about 75.7 lpm of black water with a sulphurous odour. Drilling was continued to a depth of about 48 m. Down-hole logging was completed while the groundwater flows were contained. The 244 mm casing was installed in this hole at a tip depth of 47.6 m, in accordance with MNR approval of the program change for this well, using 2.81 m^3 of cement with the cement surface found at 36 m below ground surface during bond logging.

At depths between about 50 and 61 m, artesian water flows ranging between about 65 and 320 lpm were encountered. At 61 m bgs, the hydrogen sulphide (H_2S) alarms on personal protective equipment were triggered, and site personnel cleared the area until safety precautions were in place and flows were controlled. The flow decreased to between about 50 and 110 lpm when drilling reached approximately 67 m depth, and did not release sufficient H_2S to trigger alarms. Artesian water flow subsequently increased to about 400 lpm between depths of 75 and 95 m bgs. At a depth of 95.6 m, 13.8 m^3 of cement were used to seal off the water flows.

However below approximately 105.5 m, water losses and water gains were observed intermittently until approximately 147.6 m when artesian water started to flow steadily, increasing in rate with increasing depth.

Following down-hole logging, the 178 mm casing was installed in this hole to a tip depth of 205.51 m using 13.8 m^3 of cement. At a depth of 210 m, circulation was lost while drilling with light brine (1,010 kg/m^3) and the 178 mm casing was perforated at an approximate depth of 62 m bgs to pump 2.5 m^3 of cement into the well to control losses.

At approximately 217.5 m, an artesian zone with a flow rate of approximately 50 lpm was encountered returning milky-coloured fluid. At a depth of 247.46 m the drilling fluid was changed to heavy brine (1,200 kg/m^3). At a depth of 256.46 m, brine was lost into the formation at a rate of about 190 lpm.

Circulation was entirely lost at a depth of 296.95 m and drilling continued 'blind' below this depth. From a depth of 366.5 m to the bottom of the hole, 495.53 m, 500 lpm of brine was pumped into the well to flush the cuttings up to the loss zone with no return of circulation. Drilling was completed to the final hole depth of 495.53 m and geophysical testing was completed.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary X10N-3 (5th well drilled in X10N Series):

- Top of rock at Elev. 149.2 m (28.7 m bgs) – *Dundee Formation*
- Conductor casing set to Elev. 149.7 m (29.2 m bgs) – *Dundee Formation*
- Artesian water flow of 76 lpm at Elev. 138.3 m (39.6 m bgs) – *Dundee Formation*
- 1st well casing set at Elev. 130.3 m (47.6 m bgs) – *Lucas Formation*
- Artesian water flow of 60 lpm at Elev. 126.3 m (51.6 m bgs) – *Lucas Formation*
- Artesian water flow of 320 lpm at Elev. 117.3 m (60.6 m bgs) H_2S alarm triggered – *Lucas Formation*

- Artesian water flow of about 400 lpm between Elev. 102.9 and 82.9 m (75 and 95 m bgs) - *Lucas Formation*
- Well cemented at Elev. 82.3 m (95.6 m bgs) – *Lucas Formation*
- Intermittent artesian water flow and drilling fluid losses near Elev. 72.3 m (105.6 m bgs) – *Lucas Formation immediately above Amherstburg Formation*
- Artesian water flow increasing with depth starting at Elev. 30.3 m (147.6 m bgs) – *Amherstburg Formation to Bass Islands Formation*
- 2nd well casing set at Elev. -27.6 (205.5 m bgs) drilling with light brine for remainder of well – *Bass Islands Formation*
- Artesian flow of 50 lpm at Elev. -39.6 m (217.5 m bgs) – *Bass Islands Formation*
- Lost all drilling fluids at Elev. -119.1 m (297 m bgs) – *Salina Formation F-Unit Salt*
- Drilled remaining depth of well "blind" using up to 500 lpm of brine between Elev. -188.6 m (366.5 m bgs) and bottom of well - *Salina Formation E-Unit Dolostone to end of hole*
- Bottom of well at Elev. -317.6 m (495.5 m bgs) – *Salina Formation A-Unit Carbonate*

4.5.4 X10N-4 (OPG Site)

The overburden in X10N-4 consists of dark grey clayey silt containing trace amounts of sand and gravel. This deposit has been considered to be possible fill material. This material was encountered between 1.0 and 3.8 m and was underlain by a 26.2 m thick deposit of grey clayey silt/silty clay containing some sand and occasional gravel. The clayey silt/silty clay deposit was underlain by a 0.9 m thick deposit of sand and gravel. Bedrock was encountered at 30.89 m below ground surface.

The conductor casing (340 mm diameter casing) was installed through the overburden into the top of bedrock using a cable-tool drilling rig. The total depth of the conductor casing installed was 31.4 m to the top of rock. No artesian water flows were observed at this location after conductor casing installation until drilling within the bedrock formations. A top up of 2.3 m^3 of cement was pumped into the annular spacing to secure the casing to the surrounding subsurface material.

The 244 mm casing was installed in this hole to a tip depth of 47.68 m in accordance with the MNR approved program change for this well, using 2.3 m^3 of cement. Artesian flow of water with a sulphurous odour was encountered between 56 and 74 m bgs flowing at approximately 45 lpm. Further, artesian flows were encountered between 86 and 94 m, with flow rates of up to 1,500 lpm with a strong sulphurous odour. With the first section of casing in place, the artesian flows were readily halted and controlled with the BOP in place. Water pressure was measured at about 115 kPa (16 psi) using a gauge attached to the BOP about 1.0 m above ground. The well was cemented at a depth of 95 m with 12 m^3 of cement in order to seal off the water flow. The flow was not stopped, and an additional 3.85 m^3 of cement was pumped in at a depth of 74 m in an attempt to seal off/reduce water flows. During subsequent redrilling, water flows between approximately 60 and 380 lpm were measured at 52.6 and 55.6 m respectively. The flow rates then decreased to less than 5 lpm at 56.6 m.

Drilling fluid losses were experienced between depths of 108 and 118 m and between 124 and 129 m artesian water inflows were observed. Between 146 and 162 m, the artesian water exhibited a hydrocarbon odour. Drilling fluid losses were once more observed between 195 and 216 m.

The 178 mm casing was installed at 215.89 m, and was cemented twice, the first time using 7.0 m^3 of cement, and the second time using 0.8 m^3 of cement to raise the top of cement in the annular spacing to surface. Drilling was resumed using brine (1,200 kg/m^3) drawn from the BP brine lagoons. At approximately 288 m drilling fluid losses were experienced, and circulation was entirely lost suddenly at 301.3 m. As this was the first well drilled, two cementing operations were undertaken in accordance with the MNR approved drilling program. The first operation required approximately 7.2 m^3 of cement in which cement was returned to 4.85 m bgs. Upon drilling through the bottom of the cement again at about 304 m, circulation was entirely lost again. Cementing was undertaken once again with 12.0 m^3 pumped into the well and cement did not return to the surface. The top of cement was measured at about 136 m depth. Upon curing of the cement, drilling was resumed and circulation was again entirely lost at the bottom of the hole at about 304 m depth.

Down-hole geophysics was performed at a depth of 306 m to ascertain the condition of the hole and possible reasons for the lost circulation. No cavities were evident. Drilling was resumed 'blind' to a depth of 309.8 m, at which point 17.5 m^3 of cement was pumped down the hole to stop losses. The top of cement was measured at 296.3 m depth with the water level at 31.5 m depth. Drilling recommenced to a depth of 312.5 m, where circulation was lost again. Drilling continued 'blind' for the remainder of the hole using up to 770 lpm of brine, subsequent to MNR approval of the "blind" drilling methods for the remainder of the wells. Drilling was completed to the final hole depth of 492.78 m and down-hole logging was completed at the conclusion of drilling.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary X10N-4 (2nd well drilled in X10N series):

- Top of rock at Elev. 147.2 m (30.9 m bgs) – *Dundee Formation*
- Conductor casing set to Elev. 146.7 m (31.4 m bgs) – *Dundee Formation*
- 1st well casing set at Elev. 130.4 m (47.7 m bgs) – *Lucas Formation*
- Artesian water flow about 450 lpm between Elev. 122.1 and 104.1 m (56 to 74 m bgs) – *Lucas Formation*
- Well cemented at Elev. 83.1 m (95 m bgs) – *Lucas Formation*
- 2nd well cementing during redrilling at Elev. 104.1 m (74 m bgs) - *Lucas Formation*
- Drilling fluid losses between Elev. 70.1 and 60.1 m (108 and 118 m bgs) – *Lucas Formation to Amherstburg Formation*

- Artesian water flow between Elev. 54.1 and 49.1 m (124 and 129 m bgs) – *Amherstburg Formation*
- Hydrocarbon odour observed between Elev. 32.1 and 16.1 m (146 to 162 m bgs) – *Sylvania Formation to Bois Blanc Formation*
- Drilling fluid losses between Elevs. -16.9 and -37.9 m (195 and 216 m bgs) – *Bass Islands Formation*
- 2nd well casing set at Elev. -37.9 m (216 m bgs) and cemented in place – *Bass Islands Formation*
- Drilling fluid losses at Elev. -109.9 m (288 m bgs) – *Salina Formation F-Unit Shale*
- Lost all drilling fluids at Elev. -121.9 m (300 m bgs), total of 19.2 m^3 cement used to seal well, circulation regained – *Salina Formation F-Unit Salt*
- Lost all drilling fluids at Elev. -131.7 m (309.8 m bgs), 17.5 m^3 cement used to seal well, circulation regained – *Salina Formation F-Unit Salt*
- Drilling fluids progressively lost until no circulation at Elev. -134.4 m (312.5 m bgs) drilled remaining depth "blind" using up to 770 lpm of brine - *Saline Formation F-Unit Salt to end of hole*
- Bottom of well at Elev. -314.7 m (492.8 m bgs) – *Salina Formation, A-Unit Carbonate*

4.5.5 X10N-5 (OPG Site)

The overburden in X10N-5 consisted of dark to light grey, clayey silt containing some fine sand, and was encountered from surface to 11 m bgs. The clayey silt deposit is underlain by 16.5 m deposit of light grey, silty clay containing some fine sand and trace amounts to some gravel with occasional pebbles and cobbles at the bottom of the deposit. This deposit is underlain by a 2.3 m thick deposit of fine to coarse sand containing some pebbles. Bedrock was encountered at 29.8 m below ground surface.

The conductor casing (340 mm diameter casing) was installed through the overburden into the top of bedrock using a cable-tool drilling rig. The total depth of the conductor casing installed was 30.3 m. No artesian water flows were observed at this location after conductor installation until drilling within the bedrock formations.

The 244 mm casing was installed to a tip depth of 47.98 m in accordance with the MNR approved program change for this well. Artesian water was first encountered at a depth of about 58.5 m. Flow rates were relatively small being less than 10 lpm, but the rates increased with depth. At a depth of about 70 m, the flow rate was near 380 lpm, and by a depth of 74 m, the flow had increased to about 400 lpm. To seal off the flow, 5.5 m^3 of cement was pumped into the well. During redrilling of the cement, it was observed that the cement was washed out or missing between 22 and 45 m depths. An additional 3.55 m^3 of cement was pumped into the well in an attempt to fill the void.

At approximately 85 m depth, a drilling fluid loss of about 80 lpm was measured, which increased to 96 lpm and 100 lpm at 96 and 105 m, respectively. Between 120 and 130 m, water losses and water gains were observed intermittently. Following this zone, water losses continued to increase until approximately 160 m where losses were estimated at 185 lpm. At a depth of 197.5 m, drilling fluids were lost into the well at a rate of approximately 760 lpm. At 212 m, an artesian flow rate of about 265 lpm was measured. The second steel casing (178 mm diameter) was successfully set to a depth of about 212.5 m using 7 m^3 of cement. From the bond log, the top of the cement was at a depth of 87.5 m which failed MNR requirements by not overlapping the 244 mm casing. Consequently, 11.7 m^3 of cement was pumped into the well raising the top of the cement to 11.5 m bgs. Following down-hole logging, drilling was completed to the final depth of 496.5 m maintaining good circulation of drilling fluids for the remainder of the well.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary X10N-5 (1st well drilled in X10N series):

- Top of rock at Elev. 148.7 m (29.8 m bgs) – *Dundee Formation*
- Conductor casing set to Elev. 148.2 m (30.3 m bgs) – *Dundee Formation*
- 1st well casing set to Elev. 130.5 m (48.0 m bgs) - *Lucas Formation*
- Artesian water flow of 0 to 10 lpm at Elev. 120 m (58.5 m bgs) gradually increasing with depth – *Lucas Formation*
- Artesian water flow of 380 lpm at Elev. 108.5 m (70 m bgs) – *Lucas Formation*
- Artesian water flow of 400 lpm at Elev. 104.5 m (74 m bgs) – *Lucas Formation*
- Well cemented at Elev. 104.5 m (74 m bgs), during redrilling the cement was washed out or missing between Elevs. 156.5 and 133.5 m (22 and 45 m bgs), well cemented again to fill voids - *Lucas Formation and Dundee Formation*
- Drilling fluid losses increasing to 100 lpm between Elevs. 93.5 and 73.5 m (85 and 105 m bgs) – *Lucas Formation*
- Intermittent artesian water flow and drilling fluid losses between Elev. 68.5 and 58.5 m (120 and 130 m bgs) - *Amherstburg Formation*
- Drilling fluid losses of 185 lpm between Elevs. 19 m (159.5 m bgs) – *Bois Blanc Formation*
- Drilling fluid losses of 760 lpm at Elev. -19 m (197.5 m bgs) – *Bois Blanc Formation immediately above Bass Islands Formation*
- Drilling fluid losses of 265 lpm at Elev. -19.5 m (212 m bgs) - *Bass Islands Formation*
- 2nd well casing set at Elev. -33 m (212.5 m bgs) and cemented in place, second cementing required to top up annulus between casings, switched to brine – *Bass Islands Formation*
- Bottom of well at Elev. -318 m (496.5 m bgs) – *Salina Formation A-Unit Carbonate*

4.5.6 X10N-6 (Southwest Sales Site)

The overburden in X10N-6 is fill consisting of grey, silty clay containing trace amounts of sand, gravel and metal. The fill layer extends to a depth of 7.0 m. The fill layer is underlain by 20.0 m of grey, silty clay containing trace amounts of sand, gravel and cobbles. The silty clay deposit is further underlain by 2.8 m of a grey silty clay till deposit containing trace amounts of sand and gravel. Bedrock was encountered at 29.8 m below ground surface.

The conductor casing (340 mm diameter casing) was installed through the overburden into the top of bedrock using the cable-tool drilling rig. The total depth of the conductor casing installed was 30.3 m. Artesian water flows were observed at this location after conductor installation and the conductor casing was cemented.

During subsequent drilling, a fracture zone was encountered between 47 and 48 m depths. The 244 millimetre casing was installed with the tip at 49.39 m below ground surface using 3.05 m^3 of cement.

Drilling fluid losses of about 40 lpm, 200 lpm, and 125 lpm were measured at depths of 71.4, 77.4 m, and 79.4 m respectively. At about 165.5 m the drill bit was changed, at which time artesian flow of less than 5 lpm was observed while no drilling took place, but a fluid loss of approximately 65 lpm was observed at the same depth while drilling took place. At a depth of 172.4 m, artesian water flow of about 15 lpm was measured, while at 174.4 m, a water loss of about 75 lpm was measured.

Following down-hole logging, the 244 mm casing was installed with the tip at 206 m below ground surface using 12.3 m^3 of cement. The cement surface was encountered during redrilling at a depth of approximately 27.5 m. At a depth of 206.4 m, an artesian water flow of 75 lpm was measured, but this diminished and drilling was completed to the final hole depth of 492.39 m. Down-hole logging was completed following the conclusion of drilling.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary X10N-6 (4th well drilled in X10N series):

- Top of rock at Elev. 148.6 m (29.8 m bgs) – *Dundee Formation*
- Conductor casing set to Elev. 148.1 m (30.3 m bgs) and cemented in place – *Dundee Formation*
- Fractures noted between Elevs. 131.4 and 130.4 m (47 and 48 m bgs) – *Lucas Formation*
- 1st well casing set at Elev. 129.0 m (49.4 m bgs) – *Lucas Formation*
- Drilling fluid losses ranging from 40 to 200 lpm between Elevs. 108.4 and 98.4 m (70 and 80 m bgs) – *Lucas Formation*
- Drilling fluid losses ranging from 15 to 75 lpm between Elevs. 12.4 and 3.4 m (166 to 175 m bgs) – *Bois Blanc Formation*
- 2nd well casing set at Elev. -27.6 m (206 m bgs) – *Bass Islands Formation*
- Artesian water flow of 75 lpm Elev. -28 m (206.4 m bgs) – *Bass Islands Formation*
- Bottom of well at Elev. -314 (492.4 m bgs) – *Salina Formation A-Unit Carbonate*

4.6 Subsurface Conditions Encountered During Drilling - Crossing C

4.6.1 X11-1 (Sterling Fuels Site)

Overburden materials in X11-1 consisted of fill extending to a depth of 5.0 m below ground surface. The fill was brown and grey, to black, clayey silt, containing some sand and gravel, metal, wood, and concrete debris. A 20 m thick deposit of grey, clayey silt/silty clay containing trace amounts to some gravel and cobbles was encountered underlying the fill. The clayey silt/silty clay deposit was underlain by a 6.8 m thick grey, silty clay, basal till. Bedrock was encountered at 31.8 m below ground surface.

The conductor casing (340 mm diameter casing) was installed through the overburden into the top of bedrock using the cable-tool drilling rig. The top of bedrock was encountered at a depth of 31.8 m. During the installation of the conductor casing through the bedrock, flowing sand conditions were encountered at a depth of 28.34 m. The conductor casing was installed to a total depth of 32.3 m and was cemented with 1.1 m^3 of cement. Flowing sand conditions continued, affecting the conductor casing, subsequently, a 1 m steel pipe was welded to casing providing additional support at a depth of 28.34 m. A second 4 m long steel pipe was added at a depth of 28.86 m to stop collapsing.

Artesian water with a sulphurous odour was encountered at depths between about 34.9 and 35.9 m during drilling following the conductor installation. The 244 mm casing was installed with the tip at 49.36 m, in accordance with MNR approval, using 4.2 m^3 of cement. At a depth of 61.9 m artesian water was encountered and continued until about 206 m depth with flow rates varying from less than 10 lpm to about 100 lpm. The 178 mm casing was installed with the tip at 205.2 m using 14.1 m^3 of cement, at which point the artesian water flow was sealed off. No further water losses or gains were observed during the remainder of the drilling and the well was completed using brine for drilling fluids to a depth of 500.12 m. Down-hole logging was completed following the conclusion of drilling.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary X11-1 (6th well drilled in X11 series):

- Flowing sand encountered at Elev. 149.1 m (28.3 m bgs) – *Overburden*
- Top of rock Elev. 145.6 m (31.8 m bgs) – *Dundee Formation*
- Conductor casing set to Elev. 145.1 m (32.3 m bgs) and cemented in place – *Dundee Formation*
- Artesian water flow (low flow rates) encountered between Elevs. 142.4 and 141.4 m (35 and 36 m bgs) – *Dundee Formation*
- 1st well casing set at Elev. 128.04 m (49.36 m bgs) and cemented in place – *Lucas Formation*

- Artesian water flow ranging from 10 to 100 lpm between Elevs. 115.5 and -28.6 m (61.9 and 206 m bgs) – *Lucas, Amherstburg, Sylvania, and Bois Blanc Formations*
- 2nd well casing set at Elev. -28.6 m (206 m bgs) and cemented in place – *Bass Islands Formation*
- Bottom of well at Elev. -322.72 m (500.12 m bgs) – *Salina Formation A-Unit Carbonate*

4.6.2 X11-2 (Van De Hogan Group Site)

The overburden in X11-2 encountered fill extending to a depth of 5.5 m below ground surface. The fill consisted of brown and grey, to black, clayey silt containing some sand and gravel, and trace amounts of wood and brick fragments. The fill deposit was underlain by 20.7 m of grey, clayey silt/silty clay, with trace amounts of sand and gravel. The clayey silt/silty clay deposit is further underlain by 4.87 m of grey sand and gravel, with weathered rock being present in the bottom 2.17 m of the deposit. Bedrock was encountered at 31.07 m below ground surface.

The conductor casing (340 mm diameter casing) was installed through the overburden into the top of bedrock using the cable-tool drilling rig. The total depth of the conductor casing installed was 31.57 m. Following the conductor cementation, artesian flow was pouring out of the casing at the surface. The flow was successfully stopped by pumping 10 m^3 of cement into the well to a depth of 32.5 m, completely isolating the conductor casing.

The 244 mm casing was installed to a depth of 48.43 m, using 3.9 m^3 of cement, subsequent down-hole logging was completed. At a depth of about 71 m, artesian flow with a sulphurous odour was encountered flowing at approximately 350 lpm. At a depth of 72 m, 3.7 m^3 of cement was pumped into the well in an attempt to seal off the water flow. Artesian water flows of 150 lpm continued, increasing with depth to 90.93 m bgs, with flow rates increasing to 500 lpm. The well was once more cemented using 12.5 m^3 of cement in an attempt to seal off the water flow. During redrilling through the cement, artesian water flows of about 80 lpm and 115 lpm were observed at depths of between 81 and 82 m. The artesian water flow then decreased, and was sporadic to a depth of about 109 m at which point flows were less than 10 lpm. Near a depth of about 181 m, artesian water flows began to increase with depth flowing at 30 to 50 lpm by 198 m bgs and continued at these approximate rates to a depth of about 206 m, at which point down-hole logging was completed and the 178 mm casing was installed with the tip at a depth of 204.51 m. No further losses or gains of the brine drilling fluids were observed below this depth. Drilling was completed to the final hole depth of 496.93 m and down-hole logging was completed at the conclusion of drilling.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary X11-2 (4th well drilled in X11 series):

- Top of rock Elev. 145.83 m (31.7 m bgs) – *Dundee Formation*
- Conductor casing set to Elev. 145.33 m (31.5 m bgs) and cemented in place – *Dundee Formation*
- Artesian water flowing out of casing at surface - *Dundee Formation*
- 1st well casing set at Elev. 128.47 m (48.43 m bgs) and cemented in place – *Lucas Formation*
- Artesian water flow at 350 lpm between Elevs. 105.9 and 104.9 m (71 and 72 m bgs), well cemented, flows reduced to 150 lpm and increased to 500 lpm by Elev. 85.97 m (90.93 m bgs), – *Lucas Formation*
- Artesian water flow at 80 to 115 lpm encountered during redrilling near Elev. 95.9 m (81 m bgs) – *Lucas Formation*
- Artesian water flow at 10 lpm at Elev. 67.9 m (109 m bgs), increasing to 50 lpm by Elev. -29.1 m (206 m bgs) - *Lucas, Amherstburg, Sylvania, Bois Blanc and Bass Islands Formations*
- 2nd well casing set at Elev. -27.6 m (204.5 m bgs) and cemented in place – *Bass Islands Formation*
- Bottom of well at Elev. -320.03 m (496.93 m bgs) – *Salina Formation A-Unit Carbonate*

4.6.3 X11-3 (City of Windsor Site)

The overburden materials in X11-3 consisted of a sand and gravel fill extending to a depth of 0.3 m below ground surface. The sand and gravel deposit was underlain by a 26 m thick deposit of gray clayey silt/silty clay. A 2.99 m thick granular deposit consisting of gravel, cobbles and large boulders was encountered underlying the silty clay deposit. Bedrock was encountered at 29.33 m below ground surface.

The conductor casing (340 mm diameter casing) was installed through the overburden to the top of bedrock using a cable-tool drilling rig. The total depth of the conductor casing installed was 29.83 m.

Artesian water was encountered during drilling at depths of about 32 m and 44.5 m, with flows of approximately 300 and 30 lpm respectively. Following down-hole logging, the 244 mm casing was installed to a depth of 46.93 m using 4.2 m^3 of cement.

Following installation of the casing, artesian water was encountered again at about 62 m with a flow of 20 lpm. The artesian water flow zone continued to a depth of about 87 m, with the flow increasing to about 40 lpm. Artesian water flows continually observed between 40 to 50 lpm to a depth of 204 m with localized low flow losses between 123 and 125 m bgs, and between 151 and 153 m bgs. Drilling was stopped at a depth of 205.93 m to permit down-hole logging and to install casing. Water flow at this depth was measured at about 50 lpm. The 178 mm casing was installed with the tip at 204.93 m using 13.5 m^3 of cement.

Between depths of 245 and 248 m surrounding formation was collapsing into well obstructing logging tools and the well had to be redrilled to a depth of 317 m.

Upon resuming drilling using brine, a minor water loss zone was encountered at a depth of 312 m, with a fluid loss rates of less than 5 lpm. No further loss of drilling fluids or artesian water flows were encountered during the drilling to the final bottom of the well at 500.16 m. Down-hole logging was completed at the conclusion of drilling.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary X11-3 (2nd well drilled in X11 series):

- Top of rock Elev. 148.07 m (29.33 m bgs) – *Dundee Formation*
- Conductor casing set to Elev. 147.57 m (29.83 m bgs) and cemented in place – *Dundee Formation*
- Artesian water flow at 30 to 300 lpm between Elevs. 145.37 and 132.87 m (32 and 44.5 m bgs) – *Dundee Formation to Lucas Formation*
- 1st well casing set at Elev. 130.47 m (46.93 m bgs) and cemented in place – *Lucas Formation*
- Artesian water flow at 20 to 40 lpm between Elev. 115.4 and 90.4 m (62 and 87 m bgs) – *Lucas Formation*
- Artesian water flow at 40 to 50 lpm from Elev. 90.4 to -26.6 m (87 to 204 m bgs)
- Minor water loss at Elev. 54.4 m (123 m bgs) – *Amherstburg Formation*
- Minor water loss at Elev. 26.4 m (151 m bgs) - *Sylvania Formation*
- 2nd well casing set at Elev. -27.53 m (204.93 m bgs) and cemented in place – *Bass Islands Formation*
- Surrounding formation collapsing into well at Elev. -67.6 (245 m bgs) - *Salina Formation G-Unit Shale and Dolostone*
- Minor fluid loss at Elev. -134.6 m (312 m bgs) – *Salina Formation F-Unit Salt*
- Bottom of well at Elev. -322.76 m (500.16 m bgs) – *Salina Formation A-Unit Carbonate*

4.6.4 X11-4 (Lou Romano Water Reclamation Plant Site)

Overburden materials in X11-4 consisted of clayey silt extending to a depth of 23.92 m. This deposit is underlain by a 4.04 m thick deposit of soft clayey silt to silt deposit. A 0.62 m thick clayey silt to silt, basal till containing some gravel and cobbles was encountered immediately overlying the bedrock found at 28.58 m below ground surface.

The conductor casing (340 mm diameter casing) was installed through the overburden into the top of bedrock using the cable-tool drilling rig. The total depth of the conductor casing installed was 29.08 m.

During subsequent drilling, artesian water was encountered between the depths of about 31 and 48 m with a flow rate of less than 15 lpm. The 244 mm casing was installed to a depth of 47.6 m using 4.5 m^3 of cement. A bit drop of 1.5 m was observed by the driller at a depth of 48.21 m. To prevent collapse in this void, 4.9 m^3 of cement was pumped into the well. Artesian water flows were encountered between the depths of about 56.5 and 205.9 m where drilling was stopped for down-hole logging and the installation of the 178 mm casing. The water flow rates ranged from approximately 20 lpm to 150 lpm over this 149.4 m interval. Hydrogen sulphide readings were measured at 60 parts per million (ppm) adjacent to the well head when the drilling was at a depth of about 110 m. The 178 mm casing was installed with the tip at a depth of 205.87 m using 14.3 m^3 of cement. Artesian water flow continued at about 150 lpm after the casing installation. Subsequently, the casing was perforated at 78 m bgs and 13.2 m^3 of cement was pumped into the annual spacing.

Drilling continued to 209.84 m bgs, circulation was lost.

The top of the Salina F salt was encountered at a depth of about 296 m, shortly after which brine drilling fluid losses were observed at a depth of 311 m. The brine loss zone continued to a depth of about 388 m, with water losses ranging from about 40 lpm near the top of the zone until at the bottom of the zone circulation was entirely lost. Blind drilling was completed to the final hole depth of 489.38 m after which down-hole logging was completed.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary X11-4 (3^rd^ well drilled in X11 series):

- Top of rock Elev. 148.68 m (28.52 m bgs) – *Dundee Formation*
- Conductor casing set to Elev. 148.18 m (29.02 m bgs) and cemented in place – *Dundee Formation*
- Artesian water flow of less than 15 lpm between Elevs. 146.2 and 129.2 m (31 and 48 m bgs) – *Dundee Formation*
- 1st well casing set at Elev. m (47.6 m bgs) and cemented in place – *Lucas Formation*
- Bit drop of 1.5 m and hole collapse at Elev. 128.99 m (48.21 m bgs) well cemented - *Lucas Formation*
- H_2S measured at 60 ppm at well head with depth at Elev. 67.2 m (110 m bgs) - *Amherstburg Formation*

- Artesian water flow at 20 to 150 lpm between Elev. 120.7 and -28.7 m (56.5 and 205.9 m bgs) – *Lucas, Amherstburg, Sylvania, Bois Blanc and Bass Islands Formations*
- 2nd well casing set at Elev. -28.67 m (205.87 m bgs) and cemented in place – *Bass Islands Formation*
- Artesian water flow of 150 lpm at Elev. -28.7 m (205.9 m bgs), casing perforated at Elev. 99.2 m (78 m bgs), well recemented - *Bass Islands Formation and Lucas Formation*
- Circulation lost at Elev. -32-64 m (209.84 m bgs) - *Bass Islands Formation*
- Drilling fluid losses from Elev. -133.8 to -210.8 m (311 to 388 m bgs) – *Salina Formation F-Unit Salt to C-Unit Shale*
- Drilling circulation entirely lost at Elev. -210.8 m (388 m bgs) – *Salina Formation C-Unit Shale*
- Bottom of well at Elev. -312.18 m (489.38 m bgs) – *Salina Formation A-Unit Carbonate*

X11-5 (Cored Well, Sterling Fuels Site)

The overburden materials in X11-5 consisted of black fill extending to a depth of 4.57 m bgs. Underlying the fill is 2.75 m of grey sand grading to 23.06 m grey sand and gravel. Bedrock was encountered at 30.68 m bgs.

The conductor casing (340 mm diameter casing) was installed through the overburden into the top of bedrock using the well drilling rig. The total depth of the conductor casing installed was 31.18 m.

Artesian water pressure was encountered during coring at a depth of about 90 m and was controlled by increasing the density of the drilling fluids. Artesian flow rates or pressures were not measured. Coring, reaming, geophysical testing, and casing installation were completed according to the planned program. The 244 and 178 mm casings were installed to depths of 95.8 and 215 m using 5.1 m^3 and 5.8 m^3 of cement, respectively. No unusual water flow conditions were encountered during subsequent coring operations using brine as the drilling fluid. The well was completed to a total depth of 496.05 m and down-hole logging was completed following conclusion of drilling work.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary X11-5 (1st well drilled in X11 series):

- Top of rock Elev. 146.92 m (30.68 m bgs) – *Dundee Formation*
- Conductor casing set to Elev. 146.42 m (31.18 m bgs) and cemented in place – *Dundee Formation*
- Artesian water flow at Elev. 87.6 m (90 m bgs) – *Lucas Formation*

- 1st well casing set at Elev. 81.8 m (95.8 m bgs) and cemented in place – *Lucas Formation*
- 2nd well casing set at Elev. -37.4 m (215.0 m bgs) and cemented in place – *Bass Islands Formation*
- Bottom of well at Elev. - 318.45 (496.05 m bgs) – *Salina Formation A-Unit Carbonate*

4.6.5 X11-6 (Sterling Fuels Site)

The overburden in X11-6 consisted of fill extending to a depth of 18 m. The fill deposit is underlain by a 10.0 m thick clayey silt deposit. A 4.82 m thick sand and gravel deposit with some clay was encountered underlying the clayey silt deposit. Bedrock was encountered at 32.82 m below ground surface.

The conductor casing (340 mm diameter casing) was installed through the overburden into the top of bedrock using the well drilling rig. The total depth of the conductor casing installed was 33.32 m. No artesian water conditions have been observed at this location.

After completing down-hole logging, the 244 mm casing was installed with the tip at 45.68 m using 3.98 m^3 of cement. Following the installation of the 244 mm, the PortaDrill TLT474 was moved to Well X10N-2 and the Ingersoll Rand completed the drilling of Well X11-6. The first water loss zone was encountered at a depth of about 84.6 m and with the water loss of 60 litres over the night shift. Water loss at rates of 10 lpm were encountered between 131.3 and 149.3 m.

After down-hole logging, the 178 mm casing was installed to a tip depth of 204.42 m using 15.0 m^3 of cement. No further gains or losses in drilling fluids were observed throughout the remainder of drilling to the bottom of the well at 500.18 m bgs. Down-hole logging was completed at the conclusion of drilling.

The conditions encountered in the well are described in short summary form below along with annotation related to the formation in which the conditions were observed.

Well Drilling Summary X11-6 (5th well drilled in X11 series):

- Top of rock Elev. 146.58 m (32.82 m bgs) – *Dundee Formation*
- Conductor casing set to Elev. 146.08 m (33.32 m bgs) – *Dundee Formation*
- 1st well casing set at Elev. 133.72 m (45.68 m bgs) and cemented in place – *Lucas Formation*
- Switched drilling rig to Ingersoll Rand at Elev. 132.07 m (47.33 m bgs) - *Lucas Formation*
- Drilling fluid losses of 60 litres over night shift at Elev. 94.77 m (84.63 m bgs) – *Lucas Formation*
- 2nd well casing set at Elev. -25.02 m (204.42 m bgs) and cemented in place – *Bass Islands Formation*
- Bottom of well at Elev. -316.65 (496.05 m bgs) – *Salina Formation A-Unit Carbonate*

5.0 CLOSURE

The senior technician supervising the field work was Mr. David Mitchell from the Golder Windsor office. The drilling companies were Bradco Drilling Inc., of Merlin, Ontario, and Davidson Drilling, Inc., of Wingham, Ontario. The laboratory testing of rock core samples was performed by Queen's University, Kingston, Ontario. The Foundation Investigation Report was prepared by Dr. Storer Boone, P.Eng., an Associate with Golder, with the assistance of Mrs. Cathy Pitman, P.Geol., Ms. Nikol Kochmanova, P.Eng., and Mr. Mark Monier-Williams. Mr. Fintan Heffernan, P.Eng., Golder's Designated MTO Contact for this project, conducted an independent quality review of the report.

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PART B - PRELIMINARY FOUNDATION DESIGN REPORT

DETROIT RIVER INTERNATIONAL CROSSING
EVALUATION OF ALTERNATIVE BRIDGE SITES

6.0 DISCUSSION AND ENGINEERING EVALUATIONS

6.1 Introduction

This report presents the results of geotechnical explorations and testing related to the bridge crossing portion of the Area of Continued Analysis (ACA) associated with the Detroit River International Crossing (DRIC) between Windsor, Ontario, and Detroit, Michigan as illustrated on Figure 1.1. This work was undertaken at the request of URS Corporation as part of an on-going study for a joint partnership between the Ministry of Transportation Ontario, Transport Canada, the Michigan Department of Transportation (MDOT), and the US Federal Highway Administration (FHWA). Part A of this report, Sections 1 to 4, provides all data collected during field and laboratory work completed for the bridge site aspects of the DRIC project. Part B of this report, Sections 6 through 10, provides geologic and geotechnical evaluations to assist with selecting the bridge location.

The terms of reference for the original scope of work issued during the proposal period are outlined in the Ministry of Transportation, Ontario's (MTO's) Request for Proposal (RFP), dated September 2004, and in the scope of geotechnical work prepared by Golder included in the revised URS proposal dated January, 2005. Scope changes related to completing borehole exploration, testing, and evaluation work are outlined in Golder letters to the MTO dated June 9, 2006 and July 18, 2007.

Three options for locating a new bridge crossing of the Detroit River are under consideration and two of these are close to historic salt extraction facilities. In 1954 a sinkhole developed on a solution mining site that is within the overall DRIC ACA study area. The sinkhole and concerns related to the overall stability of the rock mass adjacent to the sinkhole prompted an evaluation of the solution mining activities and how these might or might not affect potential bridge crossing locations.

The subject of the work described in this report has been to evaluate the subsurface conditions associated with the potential Practical Alternative Crossings, designated Crossings A, B, and C, as shown on Figure 1.1. Two potential bridge sites, Crossings B and C, are located in areas that are near or adjacent to properties that have been subjected to extraction of salt by solution mining methods. The work carried out for this report addresses the overall suitability of these two crossing sites with respect to the stability of the rock mass underlying the sites. During early work for the Environmental Assessment carried out under the original terms of reference for this project, the potential bridge crossing sites were numbered X1 through X15, and the X10 crossing location included a southerly (X10S) and a northerly alignment (X10N) on the Canadian side of the Detroit River. In keeping with the original crossing designations, the two crossing locations subjected to deep drilling, geophysical testing, and site suitability analyses were named X10N and X11. These two sites correspond with the DRIC Practical Alternatives crossing options designated Crossing B and Crossing C, respectively. Within this report, reference numbering systems are related to the original X10N and X11 crossing location designations, though the crossings themselves are discussed within the report with respect to the Crossing B and C identification.

The interpretation and recommendations provided in this Part B of the report are intended only to provide the planners and designers with sufficient information to assess the feasible project alternatives and to assist with site selection. The information provided in this report is not sufficient for final design and additional investigations will be required for foundation design and construction at the selected site.

6.2 Project Description

The Detroit River International Crossing project will consist of constructing a new bridge to cross the Detroit River, between Windsor, Ontario, and Detroit, Michigan. The overall project will also include new access roads to the bridge, and associated customs, immigration, and toll plazas. Three potential bridge sites, Crossings A, B and C, have been selected as potential Practical Alternatives for the DRIC. These sites and the crossing alignments are illustrated on Figures 1.1 and 2.1. This report is focused on engineering and geology concerns related to selection of the most suitable site for the bridge. Other aspects of the DRIC project are addressed in separate reports.

At the time this report was prepared, the type and specific location of the bridge structural units had not been determined and only general alignments were available, with further detailing of alignments and locations awaiting confirmation of a suitable site. The bridge design is currently under study and both suspension and cable-stay bridges are under consideration.

The potential crossing sites are located near or adjacent to industrial property along the Detroit River waterfront. Crossing A, located to the south of the existing Brighton Beach power plant, crosses through areas that, although they are zoned as industrial areas, have largely been unaffected by previous salt mining activities. Crossings B and C, however, are near areas where salt was extracted using solution mining methods between 1901 and 1957. A total of 12 deep wells have been completed using salt and oil well drilling techniques at the potential bridge sites. Six wells were allocated to each of the crossings. The area of Crossing B that may include the main bridge piers, anchor blocks (should a suspension bridge design be selected), and sections of the approach structures is bound by Prospect, Sandwich, and McKee Streets and the Detroit River. Crossing C traverses a number of properties with the main bridge pier and anchor block structures potentially located in an area bound by Russell Street, the undeveloped westward extensions of South and Prince Streets, and the Detroit River.

7.0 INFLUENCES OF SALT EXTRACTION

7.1 Introduction

The present and historical practice of salt extraction by solution mining has had diverse effects on the subsurface condition of portions of the land along the banks of the Detroit River. Understanding the methods of extraction, the history of the salt extraction operations and the past observed effects on land surface stability is fundamental to any choices regarding the location of a new river crossing. The following sections provide both a broad review of solution mining practices and a historical account of the principal solution mining activities in the area being considered for the crossing. The report describes salt mining activity only on the Canadian side of the proposed crossing. Documents describing salt production, ground subsidence and cavern formation have been reviewed to assess the adequacy of the available information for a determination of surface subsidence risk on and adjacent to the undermined lands. Information has been requested from the salt production companies and cavern operators in order to verify and enhance information contained in the public literature, however gaps in the available information remain and site investigations have been directed towards filling these gaps where possible.

Solution mining activity has occurred in three distinct well fields. These are referenced in this report as Sandwich West, the location of the earliest activity and now abandoned as a salt mining site, the BP site, an area of completed solution mining now used for petrochemical storage, and the Sandwich East site, an area of current solution mining activity. These fields are shown on Figure 7.1 and 7.2.

7.2 Salt Extraction By Solution Mining

Salt extraction by solution mining was first practiced in pre-historic times as natural saline springs were exploited as sources of salt. Roman towns in Europe grew up around natural salt springs and salt was a highly valued commodity. Drilling techniques were first developed by the Chinese almost 1,000 years ago, and were employed to drill wells for the injection of water and production of man-made brine. In North America, brine wells were first drilled at the time of the American Civil war when America had to abandon its forced dependence on colonial Britain as its sole source of salt. Thereafter, salt production using solution mining methods grew rapidly across the salt deposits of North America, with one of the most important being in the Michigan Basin in southern Ontario, Michigan, and Ohio.

Brine production is a simple process and has only changed in comparatively minor ways over centuries of practice. A well is drilled through a salt stratum, with preference given to the thickest of the available strata. The well is usually cased to isolate it from natural groundwater overlying the salt, although earlier wells would often not take this step. Modern wells use casings grouted into the hole some distance below the top of the salt stratum. Once the well is completed, a tubing is suspended to the bottom of the well. Water is either forced down the tubing or down the annulus between the tubing and hole or casing, displacing brine from the bottom of the hole up the annulus or tubing. Some wells can be operated without a well casing if compressed air is blown down the tubing through a hose extending part way down the well. The rising bubbles reduce the weight of the water column in the tubing allowing it to rise to surface and be replaced by water drawn down from natural aquifers. In one of these two ways, water is brought into contact with salt at the bottom of the hole and the saline water is withdrawn. A cavity or cavern is developed within the salt stratum as a result.

In modern solution mining practice a drill hole is advanced to the bottom of the proposed vertical extent of the cavern, and a casing is cemented into the hole some distance above (often at the planned top of cavern but sometimes substantially above this and sometimes, in thick salt strata, lower). Initial cavern development still uses a tubing suspended inside the casing through which water is injected near to the bottom of the hole and brine is recovered through the annulus between the casing and the tubing. This creates a generally cylindrical cavity (see “Direct Injection” or “Detroit Method” on Figure 7.2c). After creating a sump in which insoluble minerals can collect, it is common to inject a control fluid such as air, diesel fuel or food-grade oil that will float on brine (Figure 7.2b). Air is rarely used in modern salt mining due to the safety risks associated with controlling the high pressures at the well head. The control fluid prevents upward migration of the cavern (fresh water rises in brine and tends to preferentially leach or dissolve the roof), allowing control of the cavern shape. From this point onwards, it is possible to create a cavern of predictable shape by varying the location of the tubing, cutting the casing to raise the roof level, and injecting or removing the control fluid. It is normal today to maintain some salt in the roof of the cavern to ensure that the cavern maintains its pressure integrity and stability though this has not been the case historically. Salt, being essentially impermeable provides an ideal cavern roof.

Where more than one brine well is operated in one locale, it is often operationally convenient to join the resulting caverns together and use one or more well for injection and others for withdrawal. Caverns can be joined together by enlarging them through normal operation until they connect (sometimes this might occur accidentally). Commonly this is achieved early in the life of the wells by hydrofracturing[7] the salt or by using directed jets of air and water to preferentially dissolve salt in a particular direction. In the last ten to twenty years it has become more common to use directional drilling to create interconnected caverns since there is a much greater degree of control over the location of the interconnection. Cavern galleries comprising several aligned wells are created in this way, allowing operating efficiencies and a much greater degree of control of cavern shape than was possible historically.

In some areas of the world, single well caverns can be on the order of more than 200 to 300 m in diameter and more than 50 m (and sometimes hundreds of metres) in height. Caverns may be interconnected in rows as long as 1,000 m or more. Caverns created by a single brine well can be in the range of a few thousand to as much as 1 million cubic metres in volume and interconnected

[7] Use of fluid pressure to expand and split or fracture the formation.

brine well caverns may be on the order of 1 million cubic metres in volume or more. Caverns in the Windsor area are known to vary widely in size and some groups of caverns are interconnected while others are not.

Periodically, at intervals identified by regulations or to meet the operators design requirements, the cavern is surveyed by sonar techniques so that its dimensions are accurately known. Sonar tools produce a three-dimensional image of the cavern which has a high degree of accuracy except in cases where the cavern roof migrates high above the bottom of the well casing or where a wide "pancake" is preferentially washed out at or near the roof, in which case the tool experiences blind zones in its scanning range. Until the 1970's, these techniques were not available and cavern shape was largely unknown.

It was not unusual for cavities surrounding older wells, being those drilled before the advent of modern sonar logging tools around 1970 and particularly those drilled in the 19^{th} and early 20^{th} century before the dangers of uncontrolled solution mining became widely known, to become unintentionally interconnected. This may have occurred by overlap of gradually enlarging caverns, enlargement of natural solution features or fractures, poor roof elevation control, or migration of fluid along hydrofractures that extended beyond their intended range. As caverns became interconnected it then became possible to pump water down into the salt formation through one well and extract the resulting brine from one or several wells some distance away, thereby improving the productivity of the solution mining operation. When operated in this way, particularly if a single well is used for injecting fresh water, there is uncertainty in the size of individual caverns and the nature of the interconnections, both in plan and in vertical section. As cavern spans increase it is also common for roof falls of increasing size to take place. Sometimes the operator may be aware of these from evidence of broken casings and pressure surges in the brine, and sometimes there may be little evidence. As roof falls progress upwards, well casings and the cement bonds between the casings and surrounding rock formations become compromised, interconnections with overlying aquifers sometimes occur, and the caverns lose their pressure integrity. If it is then no longer possible to apply pressure to the injection well head to lift brine through the production well then pumps must be installed to maintain production. The simplest pumps are airlift pumps, in which a compressed air line is inserted into the production well to inject air and reduce the density of the fluid to less than that in the injection well. Submersed mechanical and electrical pumps may also be installed.

Once the injection well and production well become decoupled as a result of the interconnection with an overlying aquifer as described above, it becomes more difficult to match injection and production fluid quantities. It becomes possible to inject excess fresh water and dissolve more salt than is produced or to produce more brine than the quantity of water injected. In the latter case water must be drawn from a connected aquifer. In the case of excess injection, most of the salt will be dissolved near to the injection well or along the pathway to the connected aquifer, which will normally be above an area of large roof span. Since a large proportion of the salt is probably removed around the area of collapsed roof it is probable that water leaves the cavern system at low saturation and carries relatively small amounts of dissolved salt with it. By contrast, when more brine is produced than the quantity of water injected, the path followed by the inflowing water is more difficult to predict and examples exist of dissolution occurring well outside the nominal extents of the brine well field. This phenomenon accounts for extensive surface collapses in some historic solution mining districts such as Cheshire in northwestern England where surface effects have occurred several kilometres from known extraction wells (e.g. Whittaker and Reddish 1989).

In modern practice, once caverns have reached their predicted limiting diameter they are either abandoned or are converted to some type of storage facility. Storage of waste products or of petrochemicals are common uses.

7.3 Overview Of Solution Mining Practices In Windsor

Within the Windsor-Detroit area, salt has been extracted from beneath the ground surface since the mid- to late 1800s using two different methods: solution mining and underground rock salt mining. Salt extraction by solution mining was started in Windsor in the early 1900s from single cavity wells that rapidly developed into a gallery system where fresh water was injected into the salt beds through one well and brine pumped from one or several other wells.

The Canadian Salt Company Limited was founded in 1893 under the name of the Windsor Salt Company. The company owned many brine wells in the township of Sandwich West. The rest of the brine wells located in the general area are, or have been, owned by Canadian Industries Ltd., Canadian Salt Company, Wyandotte Chemicals Corporation, BP Canada Energy Company, Dome Petroleum Limited, Allied General Chemical Canada Limited, and Canadian Steel Corporation. Ownership of some wells has been transferred between several of these companies and their respective subsidiaries or parent companies a number of times over the years since the wells were first installed. A total of 73 wells are known to have been drilled in the Windsor area. Most were originally used for solution cavern development to produce food-grade salt and chemical feedstock and many of the resulting caverns are now used for storage purposes.

Figure 7.3 illustrates an isometric three-dimensional view of the known caverns and wells in the study area and the development sites with which they are associated. The fields were developed in the order of Sandwich West, BP Field, and Sandwich East, and only the Sandwich East field is currently producing salt, while the BP field is used for petrochemical storage. Figure 7.3 illustrates the relative size of the known caverns, the corresponding well depths, and the distances between the edges of the caverns. Depths of the wells installed on the Sandwich West site are not completely known and no size or depth data exist for any of the developed caverns. Several of the wells and caverns on the BP site were developed as part of the initial Sandwich West site and these are shown on Figures 7.4, 7.5, and 7.6. Figure 7.7 illustrates caverns more carefully developed as storage caverns and Figures 7.8 illustrates caverns carefully developed for production of salt in the Sandwich East brine well field. Some caverns in the BP and Sandwich East fields were intentionally interconnected by hydrofracturing to form cavern galleries and are still operated by injecting or withdrawing from more than one well.

Wells drilled in the first half of the 20th century were typically drilled to the presumed base of the B Salt unit of the Salina formation (402 - 488m depth) and cased to some point between the top of the formation and the top of the target salt stratum. The earliest few wells were drilled only to the F or D salt (290 - 340m depth). Packers (mechanical or inflatable seals around the well tubing) were used in some wells to control the location of brine circulation in uncased portions of wells. Initial development of individual caverns in the Sandwich West field rapidly resulted in interconnections between wells and from the mid-1920's onwards the wells were operated as a connected group. By the late 1920s the caverns lost pressure integrity (due to interconnection with overlying aquifers as described in the previous section) and wells had to be drilled as pumping wells. Through the 1930s and 1940s numerous wells were drilled as both injection and pumping wells. No documentation available for review indicates any use of control fluids, so upward migration of caverns around the wells from the B Salt up to the D and F salt most likely occurred. Records indicate that injection of water exceeded production of brine, suggesting both uncertainty in total salt dissolution but also that most of the excess salt would have been extracted within the cavern field or immediately surrounding the main injection wells. Subsidence of the cavern field was observed in the 1940's and rapid surface settlements culminating in a sinkhole forming in 1954 resulted in the wells being plugged and the field abandoned.

Production of salt moved to the east (into the BP Field and the Sandwich East field) where new wells were drilled to create independent caverns and holes were cased to the target cavern depth so that the location of dissolution was effectively controlled. Wells 32 to 35 in the BP field became interconnected at some point later in their development, and wells in the C and Y series of the Canadian Salt Sandwich east field were intentionally interconnected by hydrofracturing so that they could be operated as galleries. All caverns mined from the late 1950s onwards continue to be in use today and have maintained their pressure integrity. While some of the caverns are connected to their immediate neighbours as noted above, records of the size and shape of the caverns and the salt produced from them appear to be complete.

Well development and operational histories are discussed in further detail for each of these sites in the report sections below.

7.4 Available Information on Well Drilling and Cavern Development

There has been extensive study of historical solution mining in the Windsor area, much of it resulting from interest in a surface collapse in the Sandwich West field in 1954. Information has also been obtained from cavern operators and from public records. A full bibliographic list is provided at the conclusion of this report. The main sources relied upon in this assessment of salt cavern development are listed below:

- The Canadian Brine Limited Brine Field at Windsor, Ontario (Mair, 1962)
- Brinefield Subsidence at Windsor, Ontario (Terzaghi, 1970)
- J. Clark Keith Generating Station Assessment of Foundation Stability (Ontario Hydro, 1978)

- An Alternate Hypothesis for the Craters at the Windsor/Detroit Area (Nieto and Stump, 1979)
- A Re-examination of the Processes of Sinkhole Formation, Windsor (Canada) Brinefield (Russell, 1981)
- A mechanism for Sinkhole Development above Brine Cavities in the Windsor-Detroit Area (Nieto et. al., 1983)
- A Methodology for Rock Mechanics Design of Brine Fields based on Case Histories of Sinkhole Formation in Windsor-Detroit Area (Rothenburg and Dusseault, 2002)
- Well historical data, well history reports and well status reports, BP storage wells (provided to Golder by BP)
- Evaluation of Roof Stability of BP Caverns 32/33 Windsor Storage Field, Windsor, Ontario (Fernandez and Castro, 2002)
- Assessment of Hydraulic Connection Mechanisms between BP Storage site and Canadian Brinefield at Windsor, Ontario (Fernandez, 2003)
- Role of the Sylvania Formation in Sinkhole Development, Essex County. Ontario Geologic Survey, Open File Report 5861, D. J. Russel, 1993.
- Ontario Department of Natural Resources drilling and completion records.
- Drawing: "Well Sites & Well Properties, Canadian Industries Limited, Salt and Alkali Divisions, Windsor Ontario," February 5, 1941, revised multiple dates 1948, 1949, 1950, 1952, 1953, 1955, 1963

The locations of brine wells within the study area are shown on Figures 7.1, 7.4, 7.8, and 7.10 and the following table summarizes available information for these wells.

Table 7.1: Well Data Available

Well No.	Date Drilled	Sonar Records	Drilling and Completion Reports	Subsidence Data
Canadian Salt Brinefield (Sandwich East)				
C1	1958	X	X	X
C2	1957	X	X	X
C3	1957	X	X	X
C4	1958	X	X	X
C5	1957	X	X	X
C6	1957	X	X	X
Y1	1957	X	X	X
Y2	1957	X	X	X
Y3	1957	X	X	X
Y4	1957	X	X	X
Y5	1957	X	X	X
Y6	1957	X	X	X
Y7	1957	X	X	X

Well No.	Date Drilled	Sonar Records	Drilling and Completion Reports	Subsidence Data
Canadian Salt Brinefield (Sandwich East)				
Y8	1957	X	X	X
Y9	1957	X	X	X
Y10	1957	X	X	X
Y11	1957	X	X	X
Y12	1957	X	X	X
BP Canada Storage Caverns (BP Field)				
A32	1972	X	X	X
A33	1972	X	X	X
A35	1972	X	X	X
B7		X		X
B32		X		X
B33		X		X
B35		X		X
E1/ E01	1977	X	X	X
E2/ E02	1977	X	X	X
E3/E03	1977	X	X	X
E5/ E05	1997	X	X	X
I4/ I04	1978	X	X	X
P8		X		X
Canadian Salt Brinefield (Sandwich West)				
1 to 22	1902 to 1946	Records exist only for drilling and abandonment dates along with some casing and operational information. These wells were all interconnected as discussed in detail below		
23	1946	Plugged in 1958		
24	1946	Plugged in 1957		
25	1946	Plugged in 1957		
26	1949	Plugged in 1957		
27	1949	Plugged in 1957		
28	1948	Not completed		
29	1953	Plugged in 1957		
30	1953	Plugged in 1958		
31	1955	Not completed		
32	1956	Became part of BP storage caverns (BP field)		
33	1956	Became part of BP storage caverns (BP field)		
34	1957	Became part of BP storage caverns (BP field)		
35	1959	Became part of BP storage caverns (BP field)		

During operation, data commonly collected includes volume of water pumped in and volume and salinity of brine extracted. In recent years, annual sonar surveys of caverns have been completed and subsidence measurements of well heads and subsidence pins have been collected. Unfortunately, most of these data are not available for key wells, particularly for the wells in the Sandwich West field.

7.5 Detailed History of Brine and Storage Fields

7.5.1 Sandwich West Site

Salt was produced from the Sandwich West site for over 50 years at a variety of rates and using a number of different methods. For the first few brine wells, the D and F salts were the primary production horizons, while the remaining wells targeted the B salt. However, due to leakage of water from faulty packers, dissolution of salt veins, opening of cracks in strata between salt beds and collapse of cavern roof strata, it is likely that considerable quantities of salt came from all three salt horizons. The locations and well identification numbers are illustrated on Figures 7.1 and 7.10.

The producing life of Wells 1-16 generally progressed from single-cavern water forcing wells, to water injection or deep pumping wells for a group of caverns to eventual plugging. Wells 17, 18 and 21 were drilled for deep well pumps, and Well 19 was drilled as the main injection well for the last decade of the life of the field. Figure 7.11 illustrates the operating mode and life span of each well. Note that on Figure 7.10, some wells are given prefixes related to their MNR well licence numbers while others are not, and in the following discussion the prefixes are not used. There is limited information on the depths of the wells and the depths to which they were cased. The first few wells, possibly only 1 to 3, were drilled into the F salt (290 to 330 m) and were cased to about 235 m (Russell 1981). Later wells were drilled into the B salt and there is record of Wells 13 onwards being cased to depths of between 380 m to 390 m. However, drilling logs have not been available for review and this information is substantiated only by a summary survey of the wells produced by Canadian Industries Ltd. (and later the Canadian Salt Company) in 1948 and updated through 1955, summaries produced by Russell (1981 and 1993), and MNR files where available. A general summary of well histories is provided below.

Well 1: Drilled in 1902 as a single water force well (see Figure 7.2a), became hydraulically connected to Well 3 in 1920, and was part of a gallery of connected wells including Wells 2, 3, 6 and 11 by 1930. Well 1 was abandoned in 1922.

Well 2: Drilled in 1906 and plugged with cement (abandoned) in 1928 due to rockfalls in the F salt that were probably caused by leaky casings. This well became part of interconnected gallery of Wells 1, 3, 6 and 11 by 1930.

Well 3: Drilled in 1917 as a single water force well, Well 3 became hydraulically connected to Well 1 in 1920, requiring conversion to an air-lift well. The casing for this well extended to 236 m depth (Russell 1981) so that production was most likely from the top of the Salina Formation F Member salt, found at a depth of about 295 m (based on nearby Well X10N-2). By 1930, this well was connected to Wells 1, 2, 6 and 11. Well 3 was repeatedly plugged between 1920 to 1930. Poor plugging probably resulted in Well 3 acting as a conduit between all three salt beds.

Well 4: Drilled in 1921, Well 4 was cased to 349 m below ground surface, to about 11 m into the Salina Formation E Member based on data from Well X11-3. This became progressively connected to the main gallery that included Wells 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 17 by the end of 1940. Well 4 then became a water injection well before it was plugged in 1950 due to damage from rock falls between 350 m and 316 m. Well 4 was used by Russell (1981) as an example of what was considered a typical operation for the Windsor Sandwich West Brinefield and this history is summarized here. When drilled in 1921, Well 4 encountered what were thought of as natural solution cavities in the F salt, but which may have been caused by fluids injected through other wells. The well was cased to 349 m to enable production from the D salt, which caused undermining of the overlying E-unit and resulted in rockfalls that interrupted production. These rockfalls required the casing to be lowered to 384 m in 1929 to enable production from the B salt. Well 4 continued as a single water force well until 1935, during which time occasional rockfalls at the D salt level were attributed to leaky packers that enabled unsaturated brine to access the D salt. A number of other wells were drilled nearby and in July of 1935 it was noticed that Well 4 was hydraulically connected to Well 17, most likely through either the B or D salt cavities. In the 1930s, there was extensive interconnection between several wells, and by the early 1940s, all wells on the main site were connected, which required new methods of brine recovery. As such, Well 4 was used intermittently in the 1930s as an air-lift well, then as a water injection well between 1940 and 1942. In 1942 it was converted to a deep well pump, and then was plugged in 1950 due to damage from rockfalls.

Well 4 produced 484,000 tons of salt as brine until 1946 and very little after this, however this figure cannot be directly used to calculate cavern size because production during the first 7 years was likely split between the B and D salts (though the proportion from each remains unknown), and after conversion to a deep well pump, it was producing brine from an unknown source. Additionally, 50 to 100% more water was pumped into the ground than was recovered as brine (Russell, 1981). Excess water seems to have leaked to other stratigraphic units, or to have produced brine of variable saturation that would have resulted in a cavern of different dimensions than what would be calculated solely from salt production records.

Well 5: Drilled in 1923, Well 5 encountered brine at the D salt level in connection with other wells. It was plugged in 1929 due to rockfalls in F salt that were probably caused by leaky casings, and by 1935, this well became connected to the gallery that included Wells 1, 2, 3, 5, 6, 7, 8, 9, 11, 12, 13 and 14. Well 5 is at the centre of the surface sinkhole that formed in 1954 (Figure 7.10).

Well 6: Well 6 was drilled in 1924, plugged in 1929, and was connected to Wells 1, 2, 3 and 11 by 1930.

Well 7: This well was drilled as an air lift pump well in 1926. In 1935, this well became connected to the gallery that included Wells 1, 2, 3, 5, 6, 7, 8, 9, 11, 12, 13 and 14, and was then converted to a water injection well in 1937. Well 7 was plugged in 1945.

Well 8: This well was drilled in 1927 and became connected to the gallery that included Wells 1, 2, 3, 5, 6, 7, 8, 9, 11, 12, 13 and 14, by 1930. It was plugged in 1931.

Well 9: Drilled in 1928, Well 9 was used as a water injection well until 1939. In 1935, this well became connected to the gallery that included Wells 1, 2, 3, 5, 6, 7, 8, 9, 11, 12, 13 and 14. Well 9 was plugged in 1940.

Well 10: Drilled in 1929, this well became part of the main gallery that included Wells 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 17 by the end of 1940. Well 10 was then converted to a water injection well, and was plugged in 1949.

Well 11: Well 11 was drilled 1930 and became connected to Wells 1, 2, 3 and 6 in that same year. It was plugged in 1938.

Well 12: During drilling of Well 12 in 1929, a cavity at 335 m was discovered. This well was plugged in 1931 as a result of damage from rock falls, but became connected to the gallery that included Wells 1, 2, 3, 5, 6, 7, 8, 9, 11, 12, 13 and 14 by 1935. Well 12 directly underlies the 1954 sinkhole.

Well 13: Well 13 was drilled in December of 1929, at about the time that the casing was lowered to near the top of the B salt in Well 4 because of rock falls. Cavities in the D salt were discovered during drilling of Well 13. This is the first well within the records reviewed as part of this work that specifically indicates a casing depth. This casing was installed to a depth of 387 m, consistent with the new “lowered” casing in Well 4. In 1935, this well, used as a pumping well, became connected to the gallery that included Wells 1, 2, 3, 5, 6, 7, 8, 9, 11, 12, 13 and 14. Well 13 was used to extract brine between 1936-1954 and was plugged in 1955.

Well 14: Well 14 was drilled as a water forcing well in 1930. It was plugged in 1933 and became subsequently connected to the gallery that included Wells 1, 2, 3, 5, 6, 7, 8, 9, 11, 12, 13 and 14 by 1935. The reviewed records do not provide a specific depth of the casing for this well, but it is anticipated that it was likely set at about 387 m, consistent with Well 13 installed a few months before.

Well 15: Drilled as a water forcing well in 1931, Well 15 became connected to the main gallery in 1947 when it was converted to a deep well pump. Well 15 was the main producer of brine for the years 1950 to 1954, and was plugged in 1955. The reviewed records note that the casing was installed to a depth of 393 m.

Well 16: Well 16 was drilled in 1930 and plugged in 1948. The reviewed records do not provide a specific depth of the casing for this well, but it is anticipated that it was likely set at about 393 m, consistent with Well 15 installed a few months before.

Well 17: Well 17 was drilled as a pump well in 1935 and became part of the main gallery that included Wells 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, and 14 by the end of 1940. Between 1936-1940, Well 17 was used to extract brine. It was plugged in 1949. The reviewed records do not provide a specific depth of the casing for this well, but it is anticipated that it was likely set at about 387 m, consistent with Well 13.

Well 18: Drilled as a pump well in 1941, Well 18 was plugged in 1944. The reviewed records do not provide a specific depth of the casing for this well, but it is anticipated that it was likely set at about 387 m, consistent with Well 13.

Well 19: In 1943, Well 19 was drilled as a water injection well. The reviewed indicate that the casing for this well was installed to a depth of about 388 m. In 1945, rockfalls in the D or F salts caused breaks in the casing, so the casing was lowered 45 cm, presumably only to close the gap that had developed in the uncemented portion. The casing could not be repaired, so it was 'picked up' and injection continued, allowing free access of water into the D and/or F salts. Between 1950 and 1954, all of the production water was injected through this well before it was plugged in 1955.

Well 20: Drilling of Well 20 was attempted in late 1944. Cavities were found at 305 m (F salt) and in the Sylvania sandstone at 156 m. The well was never completed and its depth at abandonment is not known.

Well 21: Well 21 was drilled as a well pump in 1947. Caving occurred between 361 m and 434 m and a crevice in the Sylvania was noticed. Well 21 produced a substantial amount of brine between 1950 and 1952, at which time it was plugged. The reviewed records do not provide a specific depth of the casing for this well, but it is anticipated that it was likely set at about 388 m, consistent with Well 19.

Well 22: Well 22 was drilled as a pump well in 1948, was cased to a depth of 391 m, and was plugged in 1958.

Wells 23 to 25 were drilled into the B salt in 1946 to unknown depth and cased to 391 m (the middle of the C unit). They were operated as water forcing wells until 1957. The mode of operation indicates that they were not interconnected to other caverns, but production from them is unknown. The spacing of these wells was about 125 m, as was the spacing of 26 and 27, so the average span of the caverns would have been less than 125 m to avoid interconnection.

Wells 26 and 27 were drilled into the B Salt to a depth of 488 m in 1949 and cased to the top of the B Salt at 411 m. They were also operated until 1958 as water forcing wells.

Wells 28 and 31 were started but never completed. The reasons for this are not known.

Wells 29 and 30 were drilled in 1953 to unknown depths and abandoned in 1957 and 1958 respectively and these were operated as water forcing wells and did not become interconnected with other caverns based on the reviewed information.

The available records and research reports suggest that a total of about 4.6 million cubic metres of salt was removed from the Sandwich West site. Initial production in the early 1900s was in the F Salt from Wells 1, 2, and 3. As early as 1921 wells intersected brine when they were drilled, and this was usually in the F or D salt. Well 4, far to the east of producing wells at the time, intersected brine in the F Salt. Well 5 intersected brine in the D Salt in 1923 and was damaged by collapse in the F Salt in 1929. Production from wells installed through to the late 1920s was likely from the D salt, given that the casings were likely uncemented and directly above the D salt horizon, though there was also likely some continued production from the F salt. Following rock fall damages to multiple wells in the late 1920s, casings were likely lowered, in the case of Well 4, or installed to greater depths, as for Well 13 and subsequent wells. The majority of subsequent production after 1929 was likely from the B salt.

The wells became progressively interconnected to a single gallery that progressed eastwards across the well field and by 1947 had reached as far as Well 15 (see Figure 7.12). From 1945 Well 19 on the west edge of the field was the main water injector well and the main brine production wells were 13 and 21 on the north edge of the field until Well 15 on the east edge became connected. Operating procedures for the field from 1950 to 1954 likely created substantial enlargement of the cavern extending outwards from Well 19 and allowed a general flow of fresh water through the centre of the field to replace brine being withdrawn from Well 15.

It is unclear when the general cavern field lost pressure integrity but it may have been as early as 1920 when the first airlift well was required following interconnection with Well 1. It is probable that poor casing bond was the cause of the initial loss of integrity and this may have been the conduit for injected water loss throughout the remaining life of the field. According to Bays (1962) early wells of the type used at the Sandwich West site were rarely cemented except to shut out water from other formations, thus leaving annular space between the drilled hole and the casing.

This well history illustrates that there was extensive lateral interconnection of wells at the D and F Salt level, as well as vertical connections to other aquifers in the bedrock system, probably due initially to uncemented casings, poorly plugged wells, and also potentially due to caving above the F Salt. Russell (1981) notes that the area around Wells 5 and 12 was probably deteriorating as soon as they were drilled, and that salt production throughout their operation was most likely from the F and D horizons. Figure 7.13 summarizes the repair events for the wells according to dates and depths at which the damages occurred

7.5.2 BP Site

The BP hydrocarbon storage site is located approximately 1 km east of the Detroit River, and includes nine storage caverns and two inactive caverns that were dissolved into the B salt during the last stage of development of the Sandwich West site between 1956 and 1971. After solution mining ended, Dome Petroleum (now BP) acquired the rights to use the caverns for liquefied petroleum gas (LPG) storage.

These petroleum product storage caverns are now operated by pumping brine to displace the stored liquid gas, or by injecting product to displace brine, which maintains virtually constant cavern pressures (Fernandez, 2003).

Cavern 32: Cavern 32 was developed at Well 32, which was drilled to a depth of 485 m, the roof of which was in the B salt. When Dome took ownership of the property in about 1971, a decision was made to drill two more wells into cavern 32 (32A-brine which was drilled to a depth of about 437m, and 32B-product which was drilled to a similar but unknown depth). Both wells were cased into the top of the B Salt at 411 m. During this drilling it became evident that cavern 32 was connected to caverns 33 and 35 through a 30 m thick pile of rubble at the bottom of the cavern. Storage operations started in 1972, and in late 1979 or early 1980, a major roof collapse occurred, which raised the top of the cavern by about 18m into the dolomitic shale above salt B. This collapse was attributed to a large and sudden change in cavern pressure. Studies conducted after the collapse concluded that, despite the collapse, the caverns remained safe for continued storage, provided that rapid pressure fluctuations were avoided (Fernandez and Castro 2002). In 1997 this cavern was converted from storage of natural gas liquids (NGL) to propane and at this time Wells 32 and 32A were abandoned. Sonar completed in 2002 determined the capacity of the cavern to be 184,039 m^3. Figure 7.14 illustrates an isometric view of this cavern showing the propagation upward of the cavern into the Salina Formation C Member horizon. As with other caverns discussed here, its total volume cannot be directly inferred from this measurement due to the rubble layer lying in the bottom of the cavern.

Cavern 33: Cavern 33 was developed at Well 33 which was drilled to a depth of 480m, the roof of which is into the B salt. When Dome took ownership of the cavern, two more wells were drilled (33A-brine and 33B-product, both of which were cased into the top of the B Salt and had tubing suspended to 469 m), and cavern 33 was shown to be connected to caverns 32 and 35 through a 30 m thick pile of rubble at the bottom of the caverns. Well 33 was abandoned in 1997, the year in which this cavern was converted from storage of natural gas liquids (NGL) to propane. Sonar completed in 2002 determined the capacity of the cavern to be 164,888 m^3.

Cavern 34: Cavern 34 was developed at Well 34 which was drilled to a depth of 487 m. Cavern 34 was not converted for storage of petroleum products, and was permanently decommissioned.

Cavern 35: Cavern 35 was developed at Well 35 which was drilled to a depth of 471 m, the roof of which is into the B salt. When Dome took ownership of the cavern, two more wells were drilled into the cavern (A35A-brine, drilled to 442 m ,and B35-product,). Cavern 35 was again shown to be connected to caverns 32 and 33 through a 30 m thick pile of rubble at the bottom of the caverns. In 1972, cavern 35 was fitted for LPG storage. Well 35 was abandoned in 1997, when cavern 35 was converted from storage of NGL to propane.

Cavern B-7: Cavern B-7 was developed at Well B-7, the roof of which is below the roof of the B salt. This cavern was developed in the mid 1970s and early 1980s specifically for petroleum product storage purposes. Sonar completed in 2002 determined the capacity of the cavern to be 54,533 m^3.

Cavern P-8: Cavern P-8 was developed at Well P-8, the roof of which is below the top of the B salt. This cavern was developed in the mid 1970s and early 1980s specifically for petroleum product storage purposes. Sonar completed in 2002 determined the capacity of the cavern to be 66,502 m^3.

Cavern E-1 and EO-1: Cavern E-1/EO-1 were developed at Wells E-1 and EO-1 which were drilled to a depth of 478m, and the roof of this cavern is below the top of the B salt. This cavern was developed in the mid 1970s and early 1980s specifically for storage purposes. Sonar surveys completed in 2002 determined the capacity of the cavern to be 2,531 and 82,563 m^3 respectively.

Cavern E-2: Cavern E-2 was developed at Well E-2 and the roof of this cavern is below the top of the B salt. Cavern E-2 was withdrawn from service in 1977 when hydraulic communication with adjacent brine caverns was detected by hydrocarbon contamination. Sonar completed in 2002 determined the capacity of the cavern to be 11,530 m^3.

Cavern E-3/EO-3: Cavern E-3/EO-3 was developed at Wells E-3 and EO-3 which were drilled to a depth of 481 m and the roof of this cavern is below the top of the B salt. This cavern was developed in the mid 1970s and early 1980s specifically for storage purposes. Sonar completed in 2002 determined the capacity of this joined cavern to be 57,134 m^3 .

Cavern E-5/EO-5-2: Cavern E-5/EO-5-2 was developed at Well E-5 (an exploratory hole drilled in 1980) and later EO-5-2 was drilled in 1997 to the bottom of the B salt at about 440 m to assist with operations. The roof of this cavern is below the top of the B salt. This cavern was developed in the early 1980s specifically for storage purposes. Sonar completed in 2002 determined the capacity of this joined cavern to be 50,501 m^3.

Cavern I-4/IO-4: Cavern I-4/IO-4 was developed at Wells I-4 and IO-4 drilled in 1978 to a depth of 460m. The roof of this cavern is below the top of the B salt. This cavern was developed in the late 1970s and early 1980s specifically for storage purposes. Sonar completed in 2002 determined the capacity of this joined cavern to be 56,055 m^3.

BP caverns 32, 33, 34 and 35 operated as an interconnected group and were connected by hydrofracturing and pumping/washing between wells early in their development. The top of the

BP storage caverns is below the top of the B salt in all caverns except 32 and E3. In cavern 32, the top of the cavern is well above the top of the B salt as a result of major roof collapse in 1980, which was attributed to a rapid and large change in fluid pressure (Fernandez and Castro, 2002). However, the D and F salt remain in place above the caverns and they continue to operate under pressure

Sonar data has been collected for most of the active caverns since 1987. The table below summarizes pertinent cavern information determined by the most recent sonar surveys.

Table 7.2: Sonar Survey and Estimated Cavern Volume Summary BP Site

Well ID	Cavern roof elevation (m)	Top of salt B elevation (m)	Cavern volume (m^3)	Maximum Diameter (m)	Minimum Diameter (m)
B32/A32	-211.53	-227.1	184,039	84	122
B33/A33	-235.64	-227.4	164,888	84	122
A35[1]	-247.96	-229.5	160,622	107	114
B35[1]	-240.94		152,585		
P8	-238.66		66,502	76	76
E5[2]	-241.74		50,501	61	61
E01[2]	-243.93		82,536		
E1[2]	N/A		309	91	91
I4	-243.84		56,055	76	107
B7	-245.36		54,533	61	91
E2	-247.508		11,530	31	31
E3	-232.72		57,134	76	76
		Total	**1,041,034**	**747**	**892**

[1] Wells A35 and B35 form one cavern (Fernandez)
[2] Wells E1 and E01 form one cavern (Fernandez)

7.5.3 Sandwich East Site

Construction of the Canadian Salt East Brinefield started in 1957, following the loss of the Sandwich West site due to the sinkhole. Production of brine began in 1958. The brinefield consists of 18 wells laid out in 3 north/south rows of 6 wells each (Figure 7.8). Brine from these wells is exclusively produced from the B salt. Wells in each row were interconnected by hydrofracturing, during which fluid was injected at sufficient pressures to cause a fracture. Fractures are typically assumed to be oriented horizontally in this situation, although they may sometimes deviate from horizontal if one of the horizontal principal stresses is less than the vertical stress.

Well C-1: Well C-1 was drilled in 1958 to a depth of 478 m, through salt B and a cement plug was installed from the bottom of the well to the top of the hydrofracturing zone at 465 m depth. A casing was set and cemented on top of the plug. The cement plug was then drilled through the intended hydrofracturing zone and cemented casings were extended down to the bottom of the hole, then perforated towards the bottom of the salt layer,. During the early stages of production, this well was connected to Wells C-2, C-3, C-4, C-5 and Y-4. Well C-1 was plugged in 1986.

Well C-2: Well C-2 was drilled and cased to a depth of 480 m in 1957 through salt B and perforated at the hydrofracturing zone at 462 m, was located near the bottom of the salt bed. During the early stages of production, this well was connected to Wells C-1, C-3, C-4, C-5 and Y-4. Well C-2 was plugged in 1986.

Well C-3: Well C-3 was drilled in 1957 to a depth of 484 m. A cement plug was installed by filling the hole with stone and cement from the bottom up to a short distance above the hydrofracturing zone at 464 m depth after a hydraulic connection with Well Y-2 was noticed. Casing was then set on this plug and cemented, and the cement plug was then drilled out to the original bottom. During the early stages of production, this well was connected to Wells C-1, C-2, C-4, C-5 and Y-4. Well C-3 was plugged in 1986.

Well C-4: Well C-4 was drilled in 1958 to a depth of 477 m, through salt B and a cement plug was installed from the bottom of the well to the top of the hydrofracturing zone at 464 m depth, after which the casing was set and cemented on top of the plug. The cement plug was also drilled through the intended hydrofracturing zone and cemented casings were extended down to the bottom of the hole, then perforated towards the bottom of the salt layer. During the early stages of production, this well was connected to Wells C-1, C-2, C-3, C-5 and Y-4. Between 1977 and the early 1990s, production was concentrated in Wells C-4, C-5, C-6, and Wells Y-1 to Y-6.

Wells C-5 and C-6: These wells were drilled and cased to depths of 480m to 486 m in 1957 through salt B and perforated at the hydrofracturing zone at 466 m to 472 m , near the bottom of the salt bed. During the early stages of production, Well C-5 was connected to Wells C-1, C-2, C-3, C-4, and Y-4. Well C-6 was connected to Y-6. Between 1977 and the early 1990s, production was concentrated in Wells C-4, C-5, C-6, and Wells Y-1 to Y-6.

Wells Y-1 to Y-8: In 1957, these wells were drilled and cased through salt B to depths varying from 480 m to 493 m and perforated at the hydrofracturing zone located near the bottom of the salt bed (465 m to 470 m). During the early stages of production, Y-4 was connected to Wells C-1, C-2, C-3, C-4, and C-5, and Wells Y-1, Y-2, Y-3, Y-5, Y-7, Y-8 and Y-9 were interconnected. Well Y-6 was connected to C-6. Production from Wells Y-7 and Y-8 was discontinued in 1977 after hydraulic connection with BP cavern E-2 was noticed. Between 1977 and the early 1990s, brine production was concentrated in Wells Y-1 to Y-6 and Wells C-4 to C-6.

Well Y-9: Well Y-9 was drilled to a depth of 487 m in 1957. A cement plug was installed at a depth of 467 m by filling the hole with stone and cement from the bottom up to a short distance above the hydrofracturing zone (near the bottom of the casing) after a hydraulic connection with Well Y-2 was noticed. Casing was then set on this plug and cemented, and the cement plug was drilled to the original bottom. During the early stages of production, this well was connected to Wells Y-1, Y-2, Y-3, Y-5, Y-7, and Y-8. In late 1977, production in this well was discontinued after it was discovered to be in hydraulic connection with BP cavern E-2.

Wells Y-10 to Y-12: All of these wells were drilled to a depth of 486 to 492 m, cased and cemented in 1957 to total depth through salt B and perforated at the hydrofracturing zone at a depth of 470 to 476 m which was located near the bottom of the salt bed. During the early stages of production, these wells were interconnected. In late 1977, production in these wells was discontinued after they were discovered to be in hydraulic connection with BP cavern E-2.

Based on data abstracted from Fernandez (2002 and 2003), Canadian Salt (east) cavern volumes, and maximum and minimum diameters are summarized in the table below.

Table 7.3: Sonar Survey and Estimated Cavern Volume Summary Sandwich East Site

CANADIAN SALT EAST BRINEFIELD			
Well ID	Volume (m^3)	Minimum Diameter (m)	Maximum Diameter (m)
Y7	19,124	31	152
Y8	40,024	46	244
Y9	684	15	31
Y10	39,937	76	145
Y11	58,558	76	198
Y12	41,457	85	95
Y1	36,039	61	91
Y2[3]	420,883	137	183
Y3	11,726	61	152
Y4	23,766	61	152
Y5	179,234	91	259
Y6	5,007	31	31
C1	69,874	107	122
C2	49,957	61	183
C3	150,609	191	198
C4	5,098	23	23
C5	108,518	152	244
C6	83,968	76	76
Total	**1,344,463**		

In the early stages of brine production, wells were connected in four groups (Fernandez, 2003):

Group 1: Y-1, Y-2, Y-3, Y-5; and Y-7, Y-8, Y-9 which include wells in the southern half of the central and western rows. Y2, at up to 50 m height, is considerably higher than all other caverns, most of which are less than 20 m high.

Group 2: C-1, C-2, C-3, C-4, C-5; and Y-4, which includes the 5 wells in the eastern row and the middle well in the centre row.

Group 3: Y-10, Y-11 and Y-12, which include the northern half of the western row

Group 4: Y-6 and C-6, which includes the northern end of the central and eastern row.

Caverns have since been enlarged and additional hydraulic connections have been established. In 1977, Wells Y-7 to Y-12 were detected to be in hydraulic connection with BP cavern Well E-2.

7.5.4 Former Ontario Hydro Lands

There are no known wells or caverns and, in theory, no solution mining of salt beneath the former lands of Ontario Hydro. Figure 7.15 illustrates aerial photos taken in 1931 and 1947 showing the former lands of Ontario Hydro being used as a coal shipping and storage facilities owned by the Empire Hanna Coal Co. and the Mullen Coal Co., or as undeveloped lands. In these photos, the progression of development at the Sandwich West site and several of the well head structures are visible for active and recently closed wells.

7.6 Historical Subsidence Resulting From Salt Mining

7.6.1 Factors Controlling Cavern Development and Stability

Cavern development is controlled by the location of well casings, the continuity and purity of salt beds, the presence of insoluble layers within the salt strata and the rock mass quality of the rock strata between and above the salt beds. The salt strata in the Salina formation are all horizontally bedded and all contain thin mudstone and shale beds. The rock separating the salt beds is of variable quality, but is capable of supporting significant spans if caverns are developed carefully. Observed jointing in the F and G units is vertical and widely spaced. Though NW and NE trending joint sets are expected based upon regional trends, more than one or two joints have been observed in the few 10 m to 15 m exposures visible in the Ojibway rock-salt mine, making it difficult to estimate average joint spacing. The C and E beds are assumed to be relatively competent based upon the high values of RQD and descriptions given by Fernandez (2002) and thus large spans (in excess of 200 m) can probably be sustained, particularly if some salt is maintained in the cavern roof so that the water pressure in the cavern is higher than that in the bedding or joints of the overlying shales. Many wells at the Sandwich West site are known or presumed to have been cased only to the F or D salt (or somewhat above these formations) despite being drilled as deep as, and presumably to exploit, the thicker B salt (Russell, 1981). As a result, dissolution occurred in several beds rather than only at the intended injection horizon.

The presence of claystone or shale layers (stringers) within the salts of the Salina Formation, and massive dolostone and dolomitic shale beds between salt units exert a stratigraphic control on the shape of the brinefield caverns by controlling the vertical leaching path. Because the stringers can be over 1 m thick, the exposed insoluble slab at the cavern roof can remain intact for long periods even for relatively large cavern spans (many tens of metres). The extension of the resulting thin dissolution zones is difficult to control and can result in hydraulic connections, such as those interpreted at the BP storage site noted in this report. Controlled cavern development relies upon these thin beds collapsing after salt has been mined above and below them over a limited height. Sometimes this may not happen and extensive lateral enlargement of the cavern occurs below the stringer. In historical cavern development this was probably not viewed as a problem since the interconnection of caverns over large areas allowed higher production to be achieved with fewer injection and production holes. However, in the absence of sonar surveys, this created a situation where it is now almost impossible to interpret the shape and height of these older caverns from production records.

At the Sandwich West site, a number of wells completed into the B salt appear to have also experienced casing damage in or above the D salt, as reported by Russell (1981) suggesting that dissolution occurred in the D salt and that large roof spans were able to develop in that stratum.

Overlying the topmost salt in the Salina Formation (F salt), the dolomitic shale of unit G is typically weak and friable. The tendency of weak beds to sag and separate is likely to cause damage to well casings and allow access of brine to fractures, thereby contributing to progressive caving. Older wells were not cased below about 236 m, which would have allowed brine to readily enter any bed separations above the F salt. Solution mining caverns in the nearby Amherstburg area have exhibited progressive caving through this shaly unit and it is probable that any large historic caverns that exploited the F salt would have experienced extensive roof failure when the cavern diameter exceeded about 100 m and possibly less. Individual caverns developed in the B Salt have been observed in Amherstburg to cause caving through the E unit when their diameter was in the range of 200 to 300 m and to have caved up through the F and G units with progressively smaller diameter, stabilizing in the base of the more massive and competent Bass Islands dolostone with a final diameter as little as 50 m. Based on observations in the Ojibway rock salt mine and reviewed sonar data caving through the Salina appears to develop in the form of a dome or truncated cone with its sides at an angle of about 30^{o} to the vertical, consistent with the shape of caving observed in the immediate roof of underground mines in similar rock types. The Bass Islands formation has been reported to be the most important stratum responsible for large unsupported spans over cavities in underlying salt units (Rothenburg, 2002). Nevertheless, based upon experience with rock salt mining in equivalent geology in New York State (Retsof Salt mine, Golder files), it is estimated that isolated caverns in excess of about 300 m diameter have the potential to cause caving through the Bass Islands dolostone.

If large caverns are separated by pillars of small size (for example where the extraction of salt exceeds 90% of the plan area of the cavern field, with a height of 10 m and over an area extending several hundred metres in each plan dimension) it is conceivable that the pillars deform rapidly but without failure. The span of the group of caverns may exceed the spanning capacity of the Bass Islands Formation rocks but the presence of small pillars within the salt may allow the Bass Islands Formation to sag rather than fracture catastrophically. This can result in damaging surface subsidence.

In the event that sag is sufficient to create open vertical fractures and induce stress changes in the overlying strata, the Sylvania Sandstone has been interpreted by some investigators to shear and flow as a running sand. Voids identified at the top of the Sylvania in a well drilled in the Grosse

Isle field were interpreted by Russell (1981) to be the result of sag and material loss from this horizon. However, none of the literature reviewed as part of this study records Sylvania sand actually being found in the debris filling caverns at greater depth and no voids were noted in the Sylvania sandstone during the drilling investigations carried out for this report.

Interconnection between the caverns and overlying aquifers has the potential to significantly alter the course of cavern development. Although dry rock salt mining in the F salt in Windsor has demonstrated that there is no connection to water sources in the lower part of the G unit shale immediately overlying the salt, it has been shown by current drilling investigations that the Bass Islands dolostone and shallower strata are aquifers. If fluids in the brine wells have been injected into and withdrawn from these aquifers then the quantity of salt dissolved becomes impossible to estimate accurately. Furthermore the direction of cavern development may not be possible to predict, as it may follow the direction of the fractures creating the interconnection, rather than the flow paths intended due to the well layout. Withdrawal or injection of fluids into the Sylvania sandstone (either water drawn from this aquifer into the caverns or brine escaping from the caverns) may also cause migration of solids within the fluid.

7.6.2 Overview of Ground Subsidence Mechanisms

Removal of salt from within the solution mined "caverns" allows the caverns to widen laterally and vertically, which reduces the pillar width between one cavern and the next adjacent cavern. This causes greater stresses to be carried by the pillars of salt that remain between the caverns. This in turn causes the salt pillars to deform by creep and as the size of pillars decreases creep occurs at an accelerated rate and, in extreme circumstances, pillars may fail in a catastrophic manner. These processes allow overlying rock strata to also deform downwards. In addition, large roof spans tend to sag and spans in excess of about 200 m created in the process of solution mining may also initiate progressive collapse of the immediate roof and initiate sag of the overlying strata. These two effects in combination cause downward movement of the rock around the caverns and result in subsidence of the ground surface.

Subsidence rates can vary substantially but rates on the order of a few millimetres per year have been recorded over large (>200m span) abandoned caverns, while rates of up to 10 mm per year have been recorded over stable operating solution mined caverns nearby in Amherstburg. Intense extraction of the salt may cause time-dependent subsidence at higher rates (often in excess of 50 mm per year, although generalizations are difficult) as the small remaining salt pillars deform. In some cases portions of caverns collapse such that the cavern becomes filled with broken rock and debris. "Bulking" of broken rock as it fills these caverns can limit the ultimate magnitude of surface subsidence since loose assemblages of broken rock occupy more volume than a comparable mass of intact rock. Thus the broken rock can eventually fill the cavern, preventing further collapse. Where such collapses occur in caverns with very large spans, particularly those in horizontally bedded strata, large block failures may reduce the amount of bulking and allow discrete sinkhole features to migrate to surface. Such problems are of concern in that sinkholes caused by failure of large spans in individual caverns may not be "predated" by significant subsidence developing at the surface.

Subsidence due to mining has been widely researched and summarized (e.g. Jeremic, 1994, Whittaker and Reddish, 1989). It is commonly found that subsidence due to extensive mine workings in seams of limited height when compared to their depth, such as for longwall mining in coal, results in measurable subsidence within an area extending some distance outside the footprint of mining. The exact extent outside of the plan area of mining depends upon a number of factors including the depth and the type of rock overlying the mined seam. Values in the literature of estimates for the width of the influence zone outside the mined area vary from 0.3D depth to 0.7D (where D is the depth to the mined seam), with wider effects being typical for weaker and less competent overlying rock masses. With the high proportion of strong rock in the sequence above the Windsor area salt caverns, an influence zone width in the lower part of this range would be expected, consistent with experience common to the US Appalachian coal fields.

7.6.3 Subsidence of the Sandwich West Site

One of the most dramatic incidents of sinkhole development and ground subsidence to have taken place in the Windsor area occurred in 1954 at the Canadian Industries Limited facilities (Sandwich West site). In this instance, an approximately 300 m diameter bowl-shaped depression developed slowly over the course of a number of years (see Figure 7.10). By the late 1940s, recognizable differential settlement had occurred resulting in cracks in several of the plant buildings on the site. Eighty reference points were established, and between 1951 and 1953, settlement was observed to increase at an accelerated rate. Subsidence measurements showed that maximum settlement was occurring along a line approximately between Well 19 and Well 5 (see Figure 7.10). Over the period from 1948 and 1954 movements along this line varied from a few millimetres over the 6 years at Well 19 to up to 500 mm near Well 5. Then, within a period of a few hours in February 1954, the ground collapsed into a sinkhole about 8 m deep at the centre, 150 m in diameter near Wells 5 and 12 (see Figures 7.10 and 7.16). Several buildings and railroad facilities were irreparably damaged during this incident. The sinkhole was later filled and the area has since been reused for open storage and rail yards. Subsidence of the property following the sinkhole, measured at the ground surface, ranged from about 25 mm to over 1.5 m between 1954 and 1968.

The operational sequencing of well development, discussed earlier, which undoubtedly contributed significantly to the deterioration of the strata overlying the solution cavern zone, appears not to have been particularly pre-planned; rather the wells just appear to have been laid out on a grid pattern around the periphery of the property. In particular, the use of Well 19 as the primary injector with the primary extraction wells (13 and 15) being located much farther to the east likely promoted migration of brine over significantly greater distances than would be encompassed by a single stable cavern geometry. The well history described earlier indicates that the solution mining was performed in a way that allowed little control over the elevation at which dissolution occurred. Wells were sometimes cased to depths considerably above the intended dissolution target, permitting more extensive dissolution into thinner beds above the B salt horizon than would have allowed good control of the cavity development. Little or no cementing of casings also likely permitted flow of freshwater to upper reaches of the salt beds. Injection and extraction records show a surplus of water being injected when compared to the brine that was extracted, indicating that injection water was leaking out of the brine cavity system and migrating into existing groundwater aquifers outside the brinefield. Some reports place the excess injection at 50% of the total injection (e.g. Terzaghi, 1970). It is now not possible to estimate how much of the lost water caused additional dissolution since actual location(s) of interconnections to higher bedrock aquifer(s) are not known.

Based upon the well history summarized above, the mechanism causing subsidence was most likely the progressive failure of pillars between a series of closely spaced, irregular caverns dissolved in the F salt. It is possible but less likely that a single large cavern formed below the location of the sinkhole and that the roof of that cavern collapsed to surface. Other subtly different mechanisms may also be responsible for the observed subsidence, depending on the specific geological setting. In the Windsor area several researchers have postulated a combination of collapse, sag and solids transport in water to explain the observed sinkholes. Stump (1980) and later, Nieto (1987) described the following general sinkhole formation mechanics for the geology of the Windsor area:

- *"Upon formation of a sufficiently large cavity within salt deposits, the bedrock forming the "roof" of the caverns begins to sag.*
- *Natural fractures in the overlying bedrock formations open and new fractures develop as the result of increased stresses caused by the sagging and lack of support underneath.*
- *Portions of the bedrock formations may fracture and cave into the salt caverns.*
- *The sagging and caving of the bedrock formations propagates upwards to the Sylvania Sandstone formation. The Sylvania Sandstone formation is known to be sufficiently weak that upon stressing past its yield strength due to sagging stresses, the bedrock disintegrates into fragments consistent with the sand of its original sedimentary formation.*
- *When in the presence of groundwater, the resulting disintegrated Sylvania Sandstone can flow through the fractures in the underlying bedrock to fill void spaces in the solution mined caverns, the broken rock debris within the caverns, and the space within the fractures themselves.*
- *The void space then produced by the lost Sylvania Sandstone leaves the overlying Detroit River dolomite unsupported. Although this formation is often "stronger" than the underlying formations, the resulting spans across the void space may be too great for the formation to maintain and the rock mass may collapse in a "plug"-type failure, carrying with it the overburden soils, thus producing the steep-walled sinkholes that have been observed in the Windsor and Detroit areas."*

A schematic diagram of this process is illustrated on Figure 7.17. Given the history of well drilling and operation described earlier, Russell (1981) considered it possible that the operations in the Sandwich West field resulted in removal of sand from the Sylvania Sandstone prior to any extensive sagging and collapse of the underlying strata, although this cannot be confirmed. Russell (1981) notes voids found at the top of the sandstone during well drilling in the Grosse Ile field, south of the study area, even though all underlying beds were present and contained no other voids. This suggests that removal of sand is possible even when the underlying salt beds are intact. However, investigation holes drilled as part of Russell's work encountered difficult drilling but no voids within the Sylvania Formation at a site adjacent to and southwest of the Sandwich West sinkhole (Well W1 on Figure 3). His work identified discrete zones within the Sylvania sandstone that are weak and lost all cohesion upon failure in uniaxial compression tests but shows the majority of the rock to be stronger and more competent, thus probably capable of withstanding substantial sagging stresses.

Russell (1993) noted that "it is unlikely that a sufficient volume of sand would be able to pass through the underlying Bois Blanc formation" to create the upward sinkhole propagation mechanism proposed by Stump. Yet, Russell provides the following summary of his postulated combination of collapse mechanisms:

"As dissolution of the F salt continued, the overlying beds would have subsided, as an increasing area of rock above the F salt was undermined. It is at this stage that compressive failure of the Sylvania sandstone would have occurred and sand may have started to migrate slowly downwards, grain by grain through joints. Eventually, the unsupported roof overlying the brine began to stope. The style and rate of stoping may have been such that the bulking ratio was low. Whatever the case, this conventional stoping needed to migrate only 106.7 m (i.e., until it reaches the base of the sandstone). Granular stoping would then be permitted at a greatly accelerated rate as the sand grains drained through a rubble column filling in voids created by dry stoping. This stage probably occurred in 1952 – 1953 as signalled by the increased rate of surface subsidence. When granular stoping was complete, the void was about 106.7 m from the rockhead. Conventional dry stoping would then account for void migration to the base of the glacial clays."

Russell also neglected the fact that there was a net outflow of water from the caverns (injected water volume greater than recovered brine volume) rather than a net inflow that might have transported fines into rubble-filled voids though some transport along flow paths may have occurred. The likelihood of this mechanism contributing to historical or future subsidence will be discussed further in subsequent sections of this report.

Only limited subsidence data were collected after the 1954 event (see Figure 7.10) and most of these data were in the form of surface measurements taken directly above the cavern field, where consolidation of the overburden soils may have masked absolute bedrock movements. Measurements were however taken on adjacent Ontario Hydro lands, and these provide the best record of actual ground behaviour (see Figure 7.18). These measurements are described more fully in Section 7.6.6, below. There is though some published data that partially fills in this gap. Ground surface settlement records within the well field quoted by Terzaghi (1970) indicate that movements in the most critical zones decayed to relatively low rates within a few years and over the subsequent 20 years totalled only a few inches.

7.6.4 Subsidence of the BP Site

Subsidence data for wellheads within the BP area has been collected intermittently since 1973 by John B. Smeeton, Ontario Inc. This data indicates fluctuations in elevations of varying amounts with no discernible trends within the error of the surveying measurements. Continued operation of the caverns at a pressure greater than the head of brine in the wells is likely to ensure that subsidence does not occur as these wells and caverns continue to operate with pressure integrity.

7.6.5 Subsidence of the Sandwich East Site

Subsidence data for wells within the Canadian Salt Company Ltd. (Sandwich East site) study area has been collected intermittently since 1973 by John B. Smeeton Ontario Inc. As for the BP site, this data indicates fluctuations in elevations of varying small magnitudes with no discernible trends.

7.6.6 Former Ontario Hydro Lands

Settlement was noted over a number of years on the former Ontario Hydro lands south of Prospect Avenue, immediately adjacent to the sandwich west field. Reports presenting the results of stability studies carried out for the J. Clark Keith generating station indicate a direct relationship of movement trends with groundwater aquifer pressure and soil subsidence (Ontario Hydro, 1978) rather than any clear link to activities in the brine field. Subsidence of the structures and foundations of the Keith station, located some 500 m south of Prospect Avenue, was monitored between 1952 and 1978. The 1954 sinkhole at the Sandwich West site raised concerns about the stability of the generating station, and several additional benchmarks were added.

Ground surface subsidence between 1952 and 1978 (most recent available data) at the most proximal location to the Sandwich West field (immediately south of Prospect Avenue adjacent to Well 8) stabilized at about 120 mm, and the timing and pattern of settlement measured elsewhere on the generating station site 500 m to the south suggests that it was not related to the 1954 sinkhole, but to settlements associated with structural loads on the foundation of the building (Ontario Hydro, 1978).

On the south side of Prospect Avenue, adjacent to Well 8 (see Figure 7.18), subsidence surveys performed for Ontario Hydro indicate that from 1962 to 1973 subsidence at the top of bedrock was about 1 mm per year (benchmark 10A on Figure 7.18). At locations further from the Sandwich West field property boundary (benchmarks 6, 9, 12 on Figure 7.18) movements were variable but indicated no net settlement within the margin of error of survey readings. The measured subsidence is consistent with expectations for the long term settlement at the edge of a stable area of salt extraction, with the closest point to the extracted area settling at about 1 mm per year (Figure 7.18). Subsidence monitoring point 10A/10B was installed onto bedrock in 1962, after some subsidence had already occurred. Ontario Hydro extrapolated the trends observed in the surface displacement to rock displacement patterns as there seemed to be some similarity in the trends (as shown in Figure 7.18). Other settlement points exhibited little discernable displacement, considering the accuracy of the readings. Though in 1962 the surveys were conducted with equipment with an accuracy of about 4 mm, there was some dispute about the stability of the reference benchmark and it appears that the readings are accurate to within only plus or minus 10 mm.

The inferred cause of the ground subsidence in these charts is due to a variety of interpreted causes. At rock/surface settlement point 10/10A/10B the displacement is likely mainly due to the undermining of the rock as a result of solution mining. In this area, the total displacement trends may be associated with the time-rate of settlement due to both rock block displacement as well as secondary creep of the underlying salt.

The ground surface subsidence (points installed in overburden) of about 100 mm at this point is considered to be the combined result of several factors including:

- Subsidence of the underlying rock mass (including rock creep displacements);
- Displacement of the overburden mass toward the area of large displacements (horizontal “squeezing” of the soft soils);
- Pore water pressure changes induced by the adjacent ground subsidence in 1954 and subsequent consolidation settlement of the overburden;
- Use of the land as an ash storage facility (ash loads inducing consolidation settlement of the overburden);
- Expansion and heightening of the ash storage dykes in 1967 very near point 10/10A/10B inducing some initial heave (as noted in one of the OPG reports) and subsequent consolidation settlement.

Discerning which of these factors may be the principle cause of the observed settlement magnitudes and trends is difficult based on the available data.

7.6.7 Subsidence at Other Neighbouring Sites

Several large sinkholes also developed on Grosse Ile, in the Detroit River about 11 km south of the study area, similar to the Sandwich West sinkhole. These sinkholes ranged in diameter between 100 and 300 m and were over 30 m deep.

Based on an anecdotal report from a site operator, there may have been a sinkhole in Amherstburg that did not fully develop and remained as a localized but distinct depression over a now-abandoned brine well field, but the details of this report are not well documented. Caverns which have been surveyed in the Amherstburg area indicated that individual caverns up to 300 m in diameter have experienced upward roof migration as a result of caving but this has been arrested in or below the Bass Islands dolostone formation (Golder files). Local subsidence troughs have not been observed over caverns of this size. It appears that cavern spans larger than 300 m are required to cause discrete subsidence collapse although sinkhole development over the very long term cannot be ruled out for single caverns with spans in the range of 250 m to 300 m.

It is also understood that facilities on the Wyandotte Chemical Corporation site, formerly owned by Detroit Edison Company, located on the western shore of the Detroit River in Wyandotte, MI, near Grosse Ile, settled by as much as 300 mm or more. This settlement has been attributed to the solution mining that has occurred beneath the property.

Another suspected sinkhole may have occurred on the property of the Detroit Marine Terminal in the early 1960’s, though the details of this incident were not well documented and it has been interpreted by others that the event was indicative of causes unrelated to salt extraction. In the Windsor area, numerous subsidence and ground failure events have occurred along the riverfront, particularly at aggregate storage and handling facilities (Golder files). These events are largely associated with overloading the relatively weak soils near the river and are unrelated to solution mining activities.

It is noteworthy that sinkholes reported in the literature have been similar in size (beginning as depressions around 300 m in diameter) according to a review by Re/Spec (1981). Given the consistent geological conditions across the region, this provides a basis for qualitative assessment of cavern stability, and suggests that an area on the order of 300 m diameter, depending on depth, must be undermined in order to initiate instability.

7.7 Previous Numerical Analyses of Cavern Stability

7.7.1 Study of BP Caverns 32/33 Roof Collapse

In 2002, Fernandez and Castro completed a study of the stability of BP cavern 32/33 that had experienced a roof collapse in 1980, resulting in propagation of the cavern up in to the Salina Formation C unit. This cavern was approximately 100 m across at its smallest “arching span” distance and the total length of the cavern 32/35 was about 215 m, though these two caverns were separated by a pillar of salt but interconnected through an estimated 30 m thick pile of rubble at the bottom of the caverns. Fernandez and Castro judged the future stability of the cavern roof based on comparison of the maximum shear stresses in the vicinity of the cavern walls calculated using finite element computer modelling techniques with the shear strength of salt under confining stress conditions consistent with the field conditions. In addition, they evaluated the likely magnitudes of horizontal stress in the cavern roof, considering that tensile or low compressive stresses may trigger cracking or joint opening within the rock mass that could, in turn, isolate large rock wedges or blocks that may then become unstable during cavern operations. Based on multiple finite element models, they concluded that the maximum shear stresses induced in the cavern walls were well within an acceptable margin of the shear strength of the salt. They also concluded that, as cavern spans exceed about 100 m, localized zones of low horizontal stress may develop but that these zones would have limited vertical extent and the pressure integrity of the cavern would likely not be compromised. Referencing work completed by Hendron and Fernandez (1980) regarding the critical mechanism of roof development, Fernandez and Castro (2002) report that horizontal joints spaced at 0.3 to 1 m within the rock mass above the cavern roof likely controls the local stability and shape of the cavern roof. It was considered that sudden changes in cavern pressure could induce pressure differentials within the roof mass high enough to trigger separation along the flat-lying geometry of these joints or "poorly bonded beds." This report concluded that, provided operating conditions were well controlled, the caverns should remain stable, though some long-term minor upward propagation and widening of the cavern roofs may be expected and a monitoring program was recommended.

7.7.2 U.S. DRIC Study by E. Cording

During early work conducted to assist in selecting potential field investigation methods for the U.S. DRIC study team, Dr. Edward Cording (Cording 2006) completed a three-dimensional (3-D) parametric analysis of single caverns using the 3-D Universal Distinct Element Code (3DEC, Itasca 2006). The analyses completed by Dr. Cording used information available at the time based on previous studies and was intended to derive a guideline for the critical sizes that would need to be detected by the field work.

The parametric study undertaken by Dr. Cording considered four sizes of caverns that were square in plan shape with side dimensions of 30.5 (100 ft), 91.5 (300 ft), 122 (400 ft), and 152.5 m (500 ft). It was considered that the square cavern shape would produce more conservative results than if the modelled cavern was circular in plan shape (i.e., the square cavern model may indicate roof failure with smaller dimensions than a circular cavern model). The model geometry considered bedding planes at a 0.6 m vertical spacing in the first 15.2 m of rock overlying the cavern and 3.3 m spacing thereafter above this to the top of the model. Bedding thicknesses and vertical joint spacing was varied using discrete values to evaluate the influence of the spacing on roof stability. Vertical joints were assumed to be vertically continuous in both cross-directions and ranged in horizontal spacing from 7.6 to 15.2 m. Table 7.4, below, summarizes the properties of the rock used within the UDEC model. Table 7.5, below, summaries the parametric cases evaluated in Dr. Cording's study.

Table 7.4: Summary of Numerical Modelling Engineering Parameters (Cording, 2006)

Condition/Parameter	Value or Range
Bedding joints (shale), 1st 6.1 m above roof	$\phi'_{peak} = 25^o$, $\phi'_{residual} = 20^o$
Bedding joints above 6.1 m	$\phi'_{peak} = 40^o$, $\phi'_{residual} = 35^o$
Young's modulus of rock above roof, E	12.6 GPa
Normal joint stiffness, K_n	8.5 GPa

Table 7.5: Summary of Numerical Model Cases and Results (Cording, 2006)

Case	Cavern Width (m)	Horizontal Bedding Joint Spacing (m)		Vertical Joint Spacing (m)	Other	Extent of Failure (Y, Slight, N), Maximum Displacement (m)		
		0 to 15.2 m above roof	15.2 to 30.5 m above roof			Roof	6.1 m above roof	15.2 m above roof
3	91.5	0.6	3	15.2		Y	Y, 1.5	N, 0.15
3	30.5	0.6	3	15.2	E= 1/3	Y	Y, 1.1	N, <0.1
3	152.5	0.6	3	15.2		Y	Y, 3.2	Y, 1.43
4	91.5	0.6	1.5	15.2		N, 0.15	N, 0.15	N, <0.1
4	91.5	0.6	1.5	15.2		SL, 0.37	SL, 0.15	N, <0.1
5	91.5	1.5	3	7.6		SL, 0.58	N, 0.12	N, <0.1
5	30.5	1.5	3	7.6		SL, 0.30	N, <0.1	N, <0.1
5	121.5	1.5	3	7.6	$K_o = 2$, $\phi'_{shale} =$ 35/30	N, 0.24	N, 0.21	N, 0.15
8	152.5	6.1, 9.2	12.5	7.6		N, 0.21	N, 0.21	N, 0.12
9	91.5	0.6	3	7.6				
9	121.5	0.6	3	7.6		Y	Y, 2.38	SL, 0.4

Dr. Cording drew a number of conclusions from this numerical study and reviews of historical data, that fallout of rock and loosening above cavern roofs will terminate against the stiffer, more massively bedded rock, including shales, that are in the rock profile above the Salt units, for caverns with widths in the range of 30.5 m (100 ft) to 91.5 m (300 ft). These caverns would thus remain stable and would not propagate to the surface, consistent with the findings of Ferndandez and Castro (2002) and Hendron and Fernandez (1980).

8.0 INTERPRETED CURRENT ROCK MASS CONDITIONS

Investigations and testing conducted for this project were specifically targeted toward acquiring as useful as possible a range of data allowing multiple means of interpreting the subsurface conditions at and between wells with respect to the solution mining activities near the project sites and the overall condition of the rock mass at the potential bridge locations. In addition to the information obtained directly from drilling, the suite of down-hole logging data and the cross-well seismic tomography provided useful additional information for quantitatively and qualitatively judging the character of the rock mass. Of the available site-specific geological and geotechnical data, the direct drilling and down-hole testing was judged the most direct and reliable and hence was ranked of first importance in the interpretations, followed by the cross-well seismic imaging, and lastly, the surface seismic reflection survey. All of the data was also compared to historical records of the nearby solution mining operations.

Information from the down-hole logging and conditions encountered during drilling as summarized on well "pairs" illustrated on Figures 8.1a to 8.1w. These pairs were set up to be consistent with the cross-well seismic image pairs to facilitate direct comparison of the data. In addition, "fence" diagrams were prepared that summarize the subsurface stratigraphy for a number of key cross-sections through the new wells and the Sandwich West solution mining. The location of these sections is shown on Figure 8.2 with the sections A through F illustrated on Figures 8.3 through 8.8.

The methods used in interpreting the subsurface data and developing these sections are discussed in greater detail below. Following the discussion of the interpretive methods, interpreted conditions for each crossing location are addressed in detail.

8.1 Methods And Bases of Interpretation

8.1.1 Stratigraphic Analysis

A comparison of elevations of 112 marker beds (including interpreted formation tops) was completed for all wells. The marker beds as identified by their distinct natural gamma log signature (as illustrated on Figures 4.2 and 4.3) in combination with deflections on the caliper and apparent conductivity logs are summarized in Table I following the text of this report. It was considered that anomalous thicknesses or elevations of the marker beds could be indicative of salt removal and settlement of overlying layers. Comparisons were made between those wells that were least likely to have been influenced by solution mining, to those that were most likely to have been influenced by the past activities in the Sandwich West brine field. The group of wells least likely to have been influenced was considered to be X10N-1, X10N-4, X10N-5, and X10N-6 in the south, and X11-1, X11-2, X11-5, and X11-6 in the north. Although the numbers of data points in the comparison is small, limited to four potentially unaffected wells in each of the southern and northern groups, these two groups provide a reasonable indication of possible natural variation in stratigraphy.

The cumulative thickness of evaporites was examined for each of the Salina Formation B, D, and F members, and the thicknesses of all other formations were compared as well. Particular consideration was given to possible natural variation in the base of the B salt bed as the depositional elevations of beds above this level were hypothesized as potentially being influenced by such elevation differences and thereby masking any variations likely due to salt extraction within or above the B salt. The results of this evaluation suggest that solution mining has affected the thickness of the salt beds in those wells closest to the Sandwich West brine field as shown in the table below.

Table 8.1: Summary of Cumulative Evaporite Bed Thickness, Southern Well Group

Southern Well Group Average Cumulative Salt Bed Thicknesses (X10N-1, X10N-5, X10N-6, X10N-4)		Thickness Difference from Mean		
		X10N-2	X10N-3	X11-4
F Salt (mean excluding X10N-2, X10N-3)	33.38	-13.8%	-5.4%	-10.9%
Standard Deviation	0.63 (1.9%)			
D Salt (mean excluding X10N-2, X10N-3)	5.47	-14.1%	-29.2%	0.5%
Standard Deviation	0.50 (9.2%)			
B Salt (mean excluding X10N-2, X10N-3)	65.81	-0.2%	0.3%	-0.5%
Standard Deviation	0.45 (0.7%)			

Table 8.2: Summary of Cumulative Evaporite Bed Thickness, Northern Well Group

Northern Group of Wells Average Cumulative Salt Bed Thicknesses (X11-1, X11-2, X11-5, X11-6)		Thickness Difference from Mean
		X11-3
F Salt (mean excluding X10N-2, X10N-3)	30.88	-10.9%
Standard Deviation	0.39 (1.3%)	
D Salt (mean excluding X10N-2, X10N-3)	5.93	0.5%
Standard Deviation	0.36 (6.1%)	
B Salt (mean excluding X10N-2, X10N-3)	61.14	-0.5%
Standard Deviation	1.31 (0.9%)	

8.1.2 Fracture Characteristics

Fracture characteristics were identified within the drilled wells using data from the acoustic televiewer and the calliper logs. These data were interpreted for each well according to a set of criteria described below, and fracture characteristics were then summarized with respect to depth, dip, and aperture, and subsequently statistically evaluated to ascertain differences that may exist between wells, formations, or both.

Prior to interpretation, the televiewer image is rotated to a common reference direction, being magnetic north in this case. Planar features which intersect the borehole wall produce sinusoidal traces in the “unwrapped” televiewer image. Using the reference direction recorded during logging, sinusoids can be analyzed to produce dip and dip directions of structural features. A three-dimensional schematic of a fracture with aperture and the appearance of the same fracture within the televiewer log is shown in Figure 8.9.

Features on the televiewer logs were then identified and analyzed for azimuth and dip. Sinusoidal features on the amplitude and travel time logs were interpreted according to the following system of classification.

1. Major Open Joint / Fracture: Continuous televiewer sinusoids with aperture greater than 0.01 m and associated calliper or travel time anomalies. Where these features exhibited apertures greater than about 0.1 m an estimate was made of the actual aperture width (height).
2. Minor Open Joint / Fracture: Continuous televiewer sinusoids with less than 0.01 m of aperture but with associated calliper or travel time anomalies.
3. Partially Open Joint / Fracture: Continuous televiewer sinusoid with discontinuous aperture.
4. Filled Fracture / Joint: Continuous or discontinuous sinusoids with no apparent aperture that are parallel or at an angle to the bedding.
5. Bedding / Banding / Foliation: Generally appear as a series of parallel or sub-parallel sinusoids. These can be misinterpreted as Filled Fractures / Joints and vice-versa.
6. Geological Contact: These are interpreted from review of the televiewer data together with the stratigraphic logs (natural gamma and apparent conductivity) and marked if there is no obvious associated mechanical structure.

These structure features (“Structure and Tadpoles” column on the televiewer log plots) were digitized by hand and referenced to the north-oriented borehole images.

The features identified as major, minor, and partially open joints/fractures were grouped together, counted, and categorized by formation as illustrated in the frequency diagrams of Figures 8.10 and 8.11. It was considered that formations overlying salt that had been subjected to solution mining may exhibit a greater degree of such features. The dip angle of these fractures/joints is summarized on Figure 8.12. On Figures 8.1a to 8.1w, a representation of fracture frequency per 0.3 m is indicated as an aid to comparison with rock core logs. While this is labelled “fracture frequency” the data includes all major, minor, and partial open joints/fractures as well as all bedding/banding/foliation indicators as well as these may be planes of weakness that could be prone to breakage in cores.

In addition, features that did not exhibit sinusoidal characteristics were also interpreted and logged. A summary of these features is provided in Table II at the conclusion of this text. These features included vertical fractures/joints, vugs, cement, or other evident characteristics of the well wall.

As well as fractures and other features, data from the down-hole logging was interpreted to provide indications of apparent Rock Hardness (RH). The Apparent RH log is a representation of apparent rock hardness as a percentile as compared to a selected base value.

This magnitude of the reflected acoustic signal is primarily dependent on the impedance contrast between the borehole fluid and the formation. The relationship is based on the reflection coefficient:

$$\text{reflection coefficient} = \frac{(\text{formation density x Formation Vp}) - (\text{fluid Density x Fluid Vp})}{(\text{formation density x Formation Vp}) + (\text{fluid Density x Fluid Vp})}$$

Software is used to extract a mean amplitude log from the amplitude image log; thus providing a single mean amplitude value (the mean of the 144 points recorded at a given depth sample) for each depth sample. The mean amplitude log is the basis for the apparent rock hardness log. The Apparent RH is produced by dividing the mean amplitude by a normalizing factor. This factor is defined based on data available from the site; with the intent to developing a site-specific normalizing factor. The normalizing factor can be the highest value (in dB) recorded at a given site for a given borehole diameter, or it can be a value selected to relate one site to another, hence the “percentile” rating of the apparent RH.

The Apparent RH is related to the geotechnical rock quality indices of Rock Quality Designation (RQD) – shown as “pseudo RQD” on Figures 8.1a through 8.1w and 8.3 through 8.8, Total Core Recovery (TCR), solid core recovery (SCR), and the Fracture Index (FI), but there is no quantitative correlation among these parameters. The geotechnical rock quality indices are, at best, a rough measurement made on a disturbed core sample and the apparent RH log is an estimate from an in situ measurement of the borehole wall conditions.

While a qualitative correlation between the apparent RH log and the various geotechnical indices is intuitively attractive, there are some notable exceptions. The apparent RH log will deviate significantly when derived from decentralized acoustic televiewer logs (due to washouts or other borehole enlargements). Also, certain geologic conditions such as the presence of gypsum layers which will likely core well (high RQD, TCR , SCR and low FI), but are soft, will likely have low apparent RH values. These limitations must be considered when evaluating these apparent rock quality indices between formations, other laboratory and field data, and between sites.

8.1.3 Hydrogeology

To assist with interpreting the past, current and future rock mass conditions and the potential for continued salt dissolution, an assessment of the site hydrogeology was made based on the zones of artesian flow and measured pressures, losses of drilling fluids, density of the drilling fluids, and measured static fluid levels in the wells. Figure 8.13 illustrates the interpreted fluid pressure profile through the formations encountered during drilling. Within this figure, two plots are provided. The first plot indicates hydrostatic fresh water pressures from the maximum measured pressure head encountered during drilling. This pressure profile provides a reference from which the field conditions may be judged. The second plot indicates the fluid pressures indicated by artesian flow and subsequent fluid losses when drilling fluid densities were changed as well as a range of pressures approaching the bottom of the wells based on the static fluid levels.

Increased conductivity was measured in the wells where they passed through the permeable Sylvania Formation sandstone. These conductivity measurements do not appear to be associated with changes in well hole diameter, drilling fluids (as fresh water was used within this horizon), or variability in porosity. There appears to be a trend that suggests the measured conductivities within the formation fluids are greater or less depending on proximity to the Sandwich West brine field. This interpretation is consistent with the long-term problems with broken, repaired, and poorly abandoned brine wells on the nearby solution mining site as well as potential aquifer mixing during the sinkhole collapse event and it is considered that the relative changes in conductivity reflect brine permeation of the Sylvania Formation sandstone.

It is considered that in the area of the Sandwich West brine field and crossing areas, the fresh water and saline water aquifers are hydraulically connected as a result of the solution mining and the subsequent subsidence and disturbance of the rock mass underlying this brine well field. The fluid pressure profile further indicates that there should be little, if any, potential for future dissolution of the natural salt beds through migration of fresh water through these horizons, regardless of the aquifer hydraulic interconnection.

8.1.4 Cross-Well Seismic Profiles

Initial evaluation of the cross-well seismic data processed and prepared by Z-Seis (see Appendix C) was completed by Dr. Roger Turpening, of Michigan Technological University and a report covering his work is provided in Appendix F. Two example cross-well profiles are provided in Figure 8.14 that illustrate composite reflection images and seismic velocity tomograms (coloured background in these images) in areas undisturbed by solution mining. Cross-well profiles that exhibited seismic testing anomalies are illustrated in Figures 8.15 through 8.23. General discussion regarding the methods used for interpretation of these images are included below and detailed discussions of the individual anomalies, their classification (with respect to interpreted physical meaning) and their relevance to specific areas of the project are provided in Sections 8.2 and 8.3.

For this project, it has been considered that the primary criteria required to interpret a potential brine-filled cavity within the rock mass between wells must include a clearly identified area of low seismic velocity coupled with low-amplitude seismic reflection data. Since the seismic reflection energy may be influenced by vertical or horizontal fractures within the rock, either caused by natural or solution mining influences, it was considered that this type of feature must be accompanied by a low-velocity zone to indicate brine-filled cavities. Brine will exhibit velocities substantially less than the surrounding rock, regardless of rock formation or type. Where reflection amplitudes are relatively low in comparison to surrounding areas, it was considered that this condition may indicate rock that is more fractured or jointed than in other areas. Where seismic compression wave velocities are low, yet reflection amplitudes remain relatively consistent with other areas, it was considered that these areas may represent low-height brine filled joints, fractures, or separated bedding planes.

During interpretation, the following broad issues associated with the cross-well geophysical testing were considered:

1. the amplitude and frequency content of the received signals is a function of the quality of the rock through which the signals pass and anisotropy resulting from open joints or bedding may influence the resulting images (through scatter or attenuation of reflected signals – see Section 8.1.4.1, below for additional discussion);
2. each of the "reflectors" may or may not be representative of a geologic boundary in that the reflectors are defined by boundaries of significantly different acoustic impedance (acoustic impedance is the product of velocity and density), rather than geologic age or mineralogy, though changes in these may also be consistent with formational contacts;
3. the level of energy and frequency content transmitted from source to receiver well may diminish with increasing distance between the wells; and
4. features inferred from the apparent shape or time-depth positions of reflectors may be the result of natural processes, (see Figure 8.24), solution mining, or the estimated seismic velocity model upon which the reflector positions are based.

The anomalies were categorized under four classifications as follows, in order of least concern to most concern with respect to this project:

Class 1 - Reflector anomaly (geologic structure) without significant velocity anomaly.

Class 2 - Low amplitude reflectors without significant velocity anomalies

Class 3 - Obscured or displaced reflectors without significant velocity anomalies

Class 4 - Class 3 with significant velocity anomaly

Additional discussions of these anomalies as pertinent to each of the crossings and cross-well profiles are presented in the report Sections 8.2 and 8.3, below. A summary of the conditions considered responsible for the anomalous characteristics evident in some of the cross-well seismic images (signal strength or energy losses) and apparent attenuation of reflectors are described in more detail in Section 8.1.4.1 provided by Dr. Turpening.

The standard method used by Z-Seis for processing the cross-well profiles is to use the first arrival data to fit a 3rd order Chbyshev polynomial to describe the velocity variation within layers with a thickness of 1 to 2 m. This reduces the number of parameters used to describe the velocity model to a few thousand where any one profile may include 20,000 to 100,000 traces with associated seismic wave travel time picks. This approach is used since artefacts may be generated by under-constrained tomographic velocity inversions in which the number of parameters may be similar to the number of observations, making computations problematic. To examine the effect that this fundamental processing tool may have on the interpreted results, a hybrid inversion process was used so that where zones of greater resolution were needed, the velocity model was described by small blocks (“pixels”), while using the more stable polynomial approach for the remainder of the model. This “Pixelized” inversion process was used to evaluate the velocity tomogram for nine of the DRIC profiles. The images included in Appendix C and Figures 8.15 to 8.23 are based on the standard layered model and polynomial methods applied by Z-Seis for defining the velocity model and ray tracing method. Figures 8.25 to 8.33 illustrate comparisons between a number of seismic velocity profiles developed using both the layered model and “pixelized” inversion processes. Composite images illustrating both the “pixelized” velocity tomogram as a basis for reflector ray tracing have not been generated since a hybrid polynomial/“pixelized” ray tracer has not yet been developed and is a subject for future applied research.

In general, the differences between the standard layered model and the “pixelized” tomographic velocity inversions are minor in areas where it is anticipated that the rock mass has not been subject to solution mining processes (see Figures 8.25 and 8.26). In areas closer to and within the former solution mining site the differences between these two approaches is apparent. Figures 8.27 through 8.33 illustrate these differences.

In light of the differences in velocity model indicated by the two different approaches for processing, the cross-well seismic data was also examined in detail in comparison to the down-hole natural gamma logs to ascertain the degree to which “ties” could be made between corresponding natural gamma signatures in the wells at either end of a cross-well profile by tracing cross-well reflectors from one well to the other. In addition, because of the relative flat-lying nature of the bedrock formations, it was considered that the apparent geometry of the seismic reflectors may lend insight into which areas of ground had been influenced by the solution mining. Since the reflection images are based on an estimated seismic velocity model, changes in the seismic velocity will also have an influence on the apparent position of the identified reflectors, with the reflectors potentially being inferred to exist either above or below its true spatial position because of a lack of definition of the velocity model. The difference between the inferred position and true position depends on the direction (“up-going” or “down-going” seismic reflection waves). Therefore, it can be interpreted that where the ground has been disturbed, the reflector positions will differ from the expected natural and nearly horizontal positions according to the character of velocity model change (as an indicator of rock mass disturbance).

This approach has been used to rank the inferred quality of the ground in a semi-quantitative manner on the basis of individual cross-well profiles. For all profiles, a total of 6 key indicator reflectors were selected, these being the reflectors associated with (from deep to shallow) the Salina Formation A2 carbonate, a particularly strong reflection from a carbonate “stringer” within the Salina Formation B unit salt, the top of the Salina Formation B, D, and F unit salt beds, and the top of the Salina Formation F unit shale. In all cases, there was sufficient data within the processed images to link natural gamma signatures from one well to the corresponding signature in the opposite well of the profile. The elevation and horizontal position of the reflectors, however, departed from a straight-line interpolation between the two wells in a number of cases.

Each of these six reflectors was traced with respect to elevation and horizontal distance between the wells for all profiles at evenly spaced increments (ranging from 5 m to 10 m) along the line of the reflector. These points were then correlated to the 3-dimensional geographic coordinate system for the site. Two surfaces were created for each of the six stratigraphic marker positions described above. One surface was created based solely on a straight-line fit between corresponding natural gamma signatures at each of the well positions. The second surface was created using the data generated through tracing and digitizing the cross-well seismic reflectors. The topography of surfaces created using the seismic reflector elevations are illustrated in Figures 8.34 to 8.39. Figure 8.34 illustrates the lowest of these reflectors, representative of the top of the Salina Formation A2 unit. The interpolated topography indicates two relatively high positions, one in the southern group of wells between X10N-6 and X10N-2, and a second in the northern group of wells centred on well X11-5. It is interpreted that these represent potential natural variation in this particular surface. Comparing Figures 8.35 through 8.39 it is evident that the number of areas and magnitude of the apparent topographic relief increase from the top of the Salina Formation D salt unit up to the F shale unit. These areas, most prevalently associated with the profiles between exploratory wells X10N-2, X10N-3, X11-3, and X11-4, are also consistent with the areas that were subject to solution mining.

A second comparison was also made in which the distance was calculated between the reflector position and the linear interpolation between the wells at each of the incremental distances along the reflector traces. The standard deviation of these distances, being either positive or negative around the linear interpolation, was used as a semi-quantitative measure for each reflector of the departure from the expected natural near-horizontal stratigraphy. Table 8.3, below, summarizes the results of this comparison, exclusive of the Salina Formation A2 reflector as this is below the level of any former solution mining and is considered representative of natural variation. This summary indicates that, like the differences between the methods used to define the seismic velocity models, those profiles that are closer to or within the former solution mining site exhibited greater degrees of apparent elevation difference between the seismic reflectors and the linear interpolation between the natural gamma signatures at the opposing wells (larger standard deviation).

Table 8.3 Comparison of Apparent Cross-Well Seismic Reflector and Interpreted Geologic Interface Elevations

Cross-Well Profile		Standard Deviation of Reflector Elevation Comparison (m)
X10N-5	10N-6	1.2
X10N-1	10N-6	1.2
X11-6	11-1	1.3
X11-5	11-2	1.6
X11-5	11-6	1.6
X11-5	11-1	1.8

Cross-Well Profile		Standard Deviation of Reflector Elevation Comparison (m)
X11-6	11-2	1.8
X10N-6	10N-4	2.0
X10N-5	10N-4	2.6
X10N-3	10N-4	2.6
X10N-1	10N-2	2.8
X11-4	11-3	3.0
X10N-1	10N-4	3.0
X11-3	10N-2	3.1
X11-4	10N-3	3.2
X10N-6	10N-2	3.7
X10N-4	10N-2	3.8
X10N-3	10N-2	4.4
X10N-3	11-3	5.8

8.1.4.1 Geophysical Conditions Responsible for Reflector Amplitude Variability

In the X10N-2 to X10N-3, X11-3 to X10N-2, X11-3 to X10N-3, and X11-3 to X11-4 profiles, zones of weak reflections and sections of the reflectors associated with major stringers are of such low relative amplitude as to appear missing (Figures 8.15 through 8.23). Other features, such as the arch-like structures in the C-Shale (descending from left to right in Figure 8.23), the missing reflectors indicative of the A2 carbonate, and the borehole televiewer images (Figure 8.40) suggest a need for a single seismic wave propagation model that would satisfy all of these observations. It is likely that an anisotropic, effective-medium model is the correct model. Some of the fundamental principles for such a model and the observations that support such an approach are described below.

The cross-well reflection images taken together with the borehole televiewer logs display anomalies in the categories described below. A seismic wave propagation model must satisfy all of these constraints.

Reflection Images

1. Reflection wavelets— weak, smeared, discontinuous
2. Entire images—weak
3. Reflectors associated with major stringers in B-Salt — missing, and/or poorly connected
4. A2 Carbonate marker reflectors — sometimes missing
5. Background tomographic velocities
6. Arch-like features

Borehole Televiewer Images

1. *Delamination of bedding planes*
2. *Few (2 or 3) per meter*
3. *3-D nature unknown*

Reflection events exhibit anomalous characteristics in three manners. First, within several images weak amplitudes reflections exist over a portion of a reflector and yet the same reflector is strong a short distance away. Second, the reflection amplitude in the images X10N-2 to X10N-3 and X10N-2 to X11-3 are weak with respect to other images (see Figures 8.41 and 8.42) . Third, within the profile X10N-2 to X10N-3 the entire image above the B-Salt is very low in signal amplitude and the reflections are sometimes sinuous with a broad, "smeared" wavelet. The most dramatic example occurs in the lower portion of the B-Salt in the X11-3 to X11-4 image where over one hundred meters of reflections are absent from three or four major stringers. Although some weak events do exist in this gap they are so sinuous and weak that they do not necessarily connect the remaining segments of the stringers on each side of the image. The A2 reflection exists at the base of all images except a major portion of it is missing in the X11-3 to X11-4 image (and large segments of this interface are in place and strong).

In the background of all of the reflection images is a display of the compression wave velocities obtained from the first arrival times of the seismic waves. Those velocities show little or no change in many of the areas mentioned above where weak, discontinuous reflectors now exist. However, local cases of velocity change do exist, as indicated in several of the profiles. When the seismic properties of the medium are a function of direction of propagation of the seismic waves (P and S) and the polarization of the waves (S) the medium is anisotropic. For shale formations, the compression wave (P wave) velocity is slightly faster in the direction along the bedding planes than it is perpendicular to the bedding planes (transverse isotropy). Measurements in the Utica Shale in the Michigan Basin have shown the P wave anisotropy to range from 12% to 27%. In fractured media the compression wave velocity is faster parallel to the fractures than it is perpendicular to those fractures. It is common for vertical sets of fractures to occur in horizontal beds, further complicating conditions of anisotropy, particularly when different sets of orthogonal fractures exist (e.g. MacBeth and Lynn, 2000; Hornby, et. al. 1994).

Figure 8.40 illustrates that the delamination of the bedding planes produces a horizontal stack of a few, new, thin, beds separated by brine-filled gaps. The thickness of each, new, thin bed is an order of magnitude smaller (approx. 0.3m) than a wavelength in the previous intact formation (for the E-Dolostone the wavelength is approximately 5 to 6 m). This new formation is clearly transversely isotropic, i.e. the horizontal velocity is nearly unchanged but the vertical velocity has now been reduced. The 3-dimensional nature of these bed openings is unknown. In some areas, broad, low amplitude reflectors appear to arch over and through some of the zones of weak reflections (see Figure 8.23). These are considered to be an interface created by a step-wise connection of delaminations.

For a seismic wave propagation model to be constructed that satisfies all of the constraints discussed above it must:

1. "attenuate" the seismic reflections;
2. broaden/smear the wavelet;
3. leave the compression wave velocities relatively unaltered;
4. "eliminate or mask" the A2 reflection in some images; and
5. allow for arch-like reflections

New interfaces produced by the delamination of the bedding planes likely create large reflection coefficients in places where no (seismic) interface previously existed. It is clear that if a given "gap" is thick and has a spatial extent that is a significant portion of a Fresnel zone then the reflection coefficient, for normal incidence, will be very large:

$$R = (\rho_1 v_1 - \rho_2 v_2)/(\rho_1 v_1 + \rho_2 v_2)$$

where: ρ_1 = density of medium #1
v_1 = compression wave velocity in medium #1
ρ_2 = density of medium #2
v_2 = compression wave velocity in medium #2

Given that medium #2 is brine then R is large no matter the properties of medium #1. The Zeoppritz equations give the correct reflection coefficients, R, for non-normal incidence and they too will be large if medium #2 is brine. Since the transmitted energy, T, is simply:

$$T = 1 - R$$

Given a stack of a few bed delaminations, the transmitted energy is small. Note that this does not involve or make any statement concerning the intrinsic attenuation of the intact media between the delaminations. The transmitted energy will always be small no matter the nature of the intrinsic attenuation. This discussion does not address scattering and assumes that all delaminations are flat.

The approach described above is not valid when the aerial extent of each delamination is smaller than the Fresnel zone. When the delamination is much thinner than a wavelength the reflection from the top of the delamination can not be treated as a reflection isolated completely from the reflection at the bottom of the delamination. All of the bed openings in Figure 8.39 are relatively thin. As the delaminations become thin they approach the common definition of fractures that can be described in terms of the aspect ratio of an individual fracture and the fracture density of a large volume of fractures.

To theoretically describe a complex medium, such as a fractured solid, effective medium theory or replacement media approaches may be used (e.g. O'Connell and Budiansky, 1974, 1977; Hudson, 1981, 1990, 1996, Walsh, 1966). These approaches use simple velocity parameters and an expression for intrinsic seismic attenuation from the compression and shear wave velocities, V_p and V_s; attenuation coefficients or quality factors (α's or Q's) for the matrix and the fluid filling the fractures. The parameters of the fractures are, as mentioned above, given by their orientation, size, aspect ratio, shape, and density. In all cases these dimensions are given in reference to the wavelength of the illuminating seismic waves. In the literature cited above the wavelengths are assumed to be long (a hundred meters and up) to very long (kilometers). Such wavelengths are not applicable to the testing carried out for the DRIC project.

Several factors cause seismic waves to lose amplitude along the propagation path. Some of them, such as the partitioning of energy upon reflection and refraction are not strictly speaking losses in amplitude but merely a partitioning and repartitioning of energy (reflection coefficients applied multiple times*)* at every interface. The spreading of energy away from the source (1/r for spherical spreading or $1/r^{½}$ for cylindrical spreading) is only an apparent loss of energy. Scattering is yet another apparent loss of seismic energy. In this case, perturbations in the medium cause the seismic energy to reflect and refract out of the plane of propagation (Turpening, 1984) in a manner that is frequency dependent (i.e. the size of the perturbation compared to the wavelength of the impinging wave is important). The energy appears to be lost, frequently being called "apparent attenuation" only because it is scattered away from the receivers. Only intrinsic attenuation, which coverts the particle motion of the seismic wave to heat, is a true loss of energy.

The mechanism of intrinsic attenuation has been investigated and debated for many decades, especially the role of fractures (e.g. Savage, 1966, Walsh, 1966). For example, the variation of intrinsic attenuation as a function of frequency might produce a measure of permeability (Pride, et. al. 2003). In like manner, the frequency dependency seen in scattering can indicate something about the size of the scatterers. However, first scattering must be separated from intrinsic attenuation. Furthermore, the mechanism of intrinsic attenuation is unclear and therefore the precise relationship, if any exists, between permeability and intrinsic attenuation has not been established. Empirical evidence has been reported (e.g. Carrillo, et. al. 2007) of a connection between apparent attenuation (scattering plus intrinsic attenuation) and permeability. Therefore, the frequency shift method employed by Quan and Harris (1999) has been used as a method of identifying the mechanism that creates the zones of weak reflections seen in the DRIC images.

If the medium is homogeneous, isotropic, and composed of particles much smaller than a wavelength then the intrinsic attenuation can be described with an attenuation coefficient (α) in the following manner:

$$A_1 = A_0\,(1/x)\,e^{-x\alpha}$$

where: A_0 = amplitude "at" the source and x = distance

Given the attenuation coefficient a quality factor Q, for the medium can be defined as:

$$1/Q = \alpha v/\pi f$$

where: α = attenuation coefficient
v = velocity
f = frequency

In 1982 Kietti Aki stated that "it is not easy to define precisely what is meant by scattering", however he went on to impose the following three features on the elusive concept:

1. It is a wave phenomena that exists in a medium of three dimensional heterogeneity
2. It implies rough heterogeneity
3. It implies (one is observing) an incoherent signal

The dimensions involved are given in terms of the lengths of the impinging seismic waves. Scale and scale-length are terms that are especially important for evaluating the DRIC data in this context. It is difficult to separate the effects of scattering from the effects of intrinsic attenuation. The term apparent attenuation is therefore used to lump the two phenomena together. However, in numerical forward modeling (e.g., Prange, 1988, 1989; Greaves 1998, Sato and Fehler, 1999) and in solid, physical model modeling (Scheimer, 1978) the effects of scattering alone can be observed. The computational load in numerical modeling of scattering is severe and therefore there many approximations that make the task manageable in a research context. Aki and Chouet (1975), Aki (1982), and Sato and Fehler, (1999) and others have looked at the *coda* as the seismic "signal" of scattering. The *coda* is that portion of a seismogram, usually a long, slowly decaying, wave train that immediately follows a known signal (compression or shear wave). These investigators have shown that most of that "signal" results from the forward scattering of the known signal as it propagates toward the receiver.

The above discussions summarize some of the geophysics involved in this area of study and have illustrated that the ground mass between some of the X10N wells and X11-3 to X11-4 are unique seismic wave imaging areas. The new features, namely the bed openings, do not fit the conventional scales of effective modeling theory nor the scales of numerical modeling of scattering. The challenges related to different scale effects are the result of simultaneously occurring phenomena. First, the seismic imaging is being produced by sonic waves in the kilohertz frequency band and, second, the density of the delaminations is relatively low, being three or four per wavelength. In this case, the wavelengths are not long compared to the "fracture size" nor the "fracture density" as required by existing effective modeling theories and scattering theories. In general, however, it is considered based on the aforementioned principles that seismic wave scattering conceptually can satisfy all of the amplitude related constraints identified above.

8.1.5 Surface Seismic Reflection Data

The surface seismic reflection data, collected at the locations illustrated on Figure 3.1, were interpreted by comparison to the down-hole full waveform sonic and natural gamma logs. Reflectors were judged based on consideration of the relative acoustic impedance indicated by significant changes in either formation material type, as this may influence density, and evident changes in sonic velocity.

During acquisition, the surface seismic reflection data were adversely influenced by a relatively high degree of background seismic noise and, for the southern "swath" data, poor coupling between the geophone receivers and the soft ground surface conditions. Surface interference with geophone and source positioning also significantly inhibited the numbers of and distances covered by the acquisition lines, thus limiting the effective depth of the surveys. Therefore, the data is considered to be of lower quality and reliability with increasing depth. Even after reprocessing the data and completing depth migration following acquisition of the site-specific sonic data, these conditions influenced the southern "swath" data to such a degree that it was not used for any further interpretation. While the 2D data acquisition lines across the northern part of the Sandwich West field and the abutting properties also exhibited significant degrees of noise (poor signal to noise ratio), following comparison with the down-hole logging data and the higher resolution cross-well work conducted immediately to the north of these profiles, it was considered that the reflection data provided useful indicators of physical changes that may have occurred in the surveyed areas.

Figures 8.43 through 8.46 illustrate the interpretations showing areas of relatively continuous reflectors, areas in which the data was considered of low quality (due to depth and signal limitations), seismically disturbed areas, and interpreted vertical off-set planes, and the tops of potential structural features (seismic anomalies). In these figures, the reflectors were not considered direct indicators of geologic boundaries but represented changes in acoustic impedance that may produce a reflected signal. This information was subsequently used to assist with evaluating potential changes in geologic boundary elevation as discussed subsequently in this report. Given that the areas within the Sandwich West field have likely been disturbed to some degree, it was difficult to follow reflectors through the seismically disturbed zones with any degree of confidence. However, it was considered that identification of seismically disturbed zones would assist in delineating the areas influenced by solution mining and disturbed rock formations.

8.1.6 Three-Dimensional Model of Solution Mining and Crossing Sites

To assist with interpretation of field data in comparison with historical information, simplified three-dimensional representations of the solution mining activities were incorporated into the GoCAD (Earth Decision, 2007) model. As noted by Russell (1983, 1993), extrapolation of the volume of salt removed to the individual size of caverns at each well location is extremely difficult and problematic, given the limitations of available records and the mixed methods of working each well. Given these fundamental limitations, however, an exercise was completed in which a number of simplifying assumptions were made in order to derive some indication of which salt horizons may have been exploited and the potential lateral extent of such mining.

It was assumed that the cavities created by the methods used at the Sandwich West brine operations may be either of idealized inverted cone shape or of idealized cylindrical shape. However, given the tendency for brine stratification to preferentially remove salt at the highest levels, the idealized cone shape was used as the basis for assessing the lateral extent of dissolution since, for a given volume, the inverted cone assumption results in a greater lateral extent. Figure 8.47 illustrates an example of a solution void created at the bottom of a salt mine shaft sump in which fresh water from seepage through formations above was allowed to pool for a significant period of time. During the time that the sump operated, pumping conditions resulted in two apparent water levels creating different dissolution voids. This void illustrates the preferential dissolution of salt from the upper levels of the created cavities and the resulting wedge-shaped cross section when low brine flow velocities occur. Within the upper salt beds, it was assumed that the cavities in each of the individual salt beds would take the shape of a series of inverted cones, with cross sections much like the example in Figure 8.47, at each salt horizon based on interpreted changes in salt thickness at Wells X10N-2 and X10N-3. At each of these locations, the following assumptions were made:

- thinning of salt beds at X10N-2 and X10N-3 may be indicative of the direct result of solution mining;
- prior to rock subsidence, the former cavity emanating from the nearest solution mining well occupied a space now represented by the difference in current salt bed thicknesses at X10N-2 and X10N-3 and typical salt bed thicknesses as measured in other exploratory wells more distant from the solution mining wells;
  - at the locations of the nearest solution mining wells, being Well 3 for X10N-2, and Wells 9 and 18 near X10N-3, the solution mining removed all salt from the subject salt bed; and
  - the shape of the former cavity wall could be inferred based on a straight-line slope from the base of the salt bed at the solution mining well to the top of the thinned salt bed at the exploratory well, and extrapolated to a distance and height consistent with the typical salt bed thickness identified at more distant exploratory wells (e.g., X10N-1,X10N-4, X10N-5, X10N-6).

Figures 8.48 through 8.50 illustrate these assumptions and the inferred lateral extent of salt dissolution near exploratory wells X10N-2 and X10N-3.

It was further assumed that the total volume of salt extracted from near well locations might be proportional to the operating life of the individual well (though water injection wells will likely dissolve more nearby salt than airlift or deep wells that were used primarily to extract the brine). Using this approach and the geometry assumptions listed above, a volume of about 212,000 m^3 of salt is estimated to have been removed from Well 4. Russell reported that approximately 484,000 tons of salt was removed from this well, corresponding to a volume of approximately 203,000 m^3.

These assumptions result in an estimated annual average production rate of about 14,000 to 16,000 m^3 of salt. Annual rates of salt extraction from the cluster of wells first developed as part of the Sandwich West site (Wells 32 through 35) may have been on the order of 10,000 to 12,000 m^3 based on sonar measurements of volume and the total number of years these wells were in operation as salt production wells. These comparisons suggest that while this approach is a gross simplification, it may be reasonably useful for assisting interpretation.

The total volume of salt removed near individual wells, however, was influenced by the well operating mode and cross-field flow of water and brine between wells. Figure 8.51 illustrates a reassessment of the historical development of the brine wells and their potential influence on the salt beds based on the available records, field evidence, and the simplifying assumptions described above. Within Figure 8.51, the development of production from individual wells is illustrated by circular areas, representative of the plan view of the inverted cone idealized cavity shapes within the beds from which salt was likely extracted based on the historical records. Through until about 1929 the salt was primarily taken from the F salt bed in Wells 1, 2, and 3, and from the D salt in Wells 4 through 13. After 1929, it is likely that the majority of production may have been from the B salt, though with substantial communication and salt dissolution within the upper salt beds due to progressive subsidence and opening of beds and the conditions of the water forcing wells. Considering the operational modes of the solution mining wells, potential flow paths between water injection and air-lift or deep pumping wells are also illustrated in Figure 8.51. For the 1954 case (Figure 8.51d), all potential flow paths are superposed on the hypothetical zones of solution mining. Where paths overlap from year to year, the colour is darker so as to qualitatively illustrate the potential duration and severity of dissolution relative to other areas of the site. This figure illustrates a likely reason why the sinkhole developed at the location it did even though Wells 5 and 12 produced relatively small volumes of salt and were in operation for short periods in comparison to other wells. Figure 8.52 illustrates the hypothetical influence area of individual wells as measured by the top radius of the assumed cavity shape in relation to the Sandwich West site surface features.

8.1.7 Numerical Modelling

8.1.7.1 Model Development

A series of numerical model analyses were completed to assist in assessing the potential lateral and vertical extent of the influences of both the collapse that occurred on the Sandwich West site and those areas near the collapse that have been subjected to solution mining. It was considered that, provided an appropriate model was developed that could be reasonably calibrated to the field collapse that occurred in 1954, and the performance of BP cavern 32/33, the model results would be sufficiently credible to lend insight into interpreting the mechanisms of rock mass behaviour, distress, and displacement that may be evident in the field data.

Based on a review of the solution mining history and practices at the Sandwich West site, a numerical analysis was conducted to examine the potential behaviour and collapse mechanisms of the overlying rock formations when subject to solution mining in relatively low-height but laterally extensive chambers. The cavity formation mechanisms considered within these analyses differ from those considered by Dr. Cording (2006b) since his works was largely concerned with the minimum cavern size that might be of concern as related to the detection limits of the proposed (at that time) cross-well seismic testing and imaging methods. Although collapse of individual caverns is of some importance for the Canadian investigations, the extensive interconnection of wells, relative thickness of the upper salt formations from which large volumes of salt may have been removed, and the subsequent sinkhole development suggest alternative mechanisms of rock and surface displacement may have occurred and may be of more relevance to the future stability of the rock underlying the potential DRIC bridge sites. This numerical modelling work was focused on the initial mechanical behaviour of the overlying rock masses when subject to undermining by salt removal and did not examine or include the long-term creep displacement of salt.

The two-dimensional (2-D) Universal Distinct Element Code (Itasca 2007) was used to model a variety of cavern scenarios. This software was chosen because of its ability to reasonably replicate detailed rock formation characteristics and provide appropriate and suitable modelling of horizontally extensive mining of salt. The particular advantage of UDEC for this modelling is that it allows good replication of the blocky geometry of a jointed rock mass subjected to quasi-static or dynamic loading conditions. This software is capable of simulating large displacements (slip and opening) along distinct surfaces in a discontinuous medium treated as an assemblage of discrete (convex or concave) polygonal blocks with rounded corners. Discontinuities are treated as boundaries between the blocks. Relative motion along the discontinuities is governed by linear and non-linear force-displacement relations for movement in both the normal and shear directions.

Fifteen UDEC models were set up with different solution cavity geometries to examine the potential effects of cavity geometry as well as assumptions regarding vertical jointing in the bedrock mass. Four of the models were set up with a 10 metre thick solution cavity at the top of the F-member Salt (just under the F-member shale). The horizontal extents of the cavities were 150 m, 200 m, 300 m and 400 m. Three models were set up with a 60 m thick solution cavity in the B-Salt (full height of the unit), and one considered a 20 m thick solution cavity, similar to the dimensions of the existing BP cavern 32/33. The horizontal extents of the cavities in the B-member Salt were 100 m, 200 m, 300 m, and 500 m wide. Two models considered a trapezoidal shape of the solution cavity where the top was wider than the bottom to examine what effects a tapering cavity shape may have on the resulting disturbance of the rock mass. All models were 500 m in depth, with the last layer being the A2 Member dolostone of the Salina formation. The lateral extent of the models with cavities in the F Member salt was 500 metres for the 150 m and 200 m wide cavities. All other models were 1,000 m in horizontal extent to avoid boundary effects, mainly because of the greater lateral extent or the greater depth of the cavity. The cases also varied the assumptions regarding the relationship between block height (bedding thickness) and block width (distance between vertical joints). Table 8.4 below summarizes the model geometry and jointing cases examined in this study.

The models mainly consist of blocks formed by horizontal continuous "joints" (bedding) and discontinuous vertical jointing (cross joints). The bedding spacing in each stratigraphic unit reflects the measurements in the core logs. A bedding thickness larger than that measured was used to permit practicable completion of numerical calculations. However, the relative thickness of all the units was respected to maintain the same stiffness ratios between the beds. In addition, the properties of the blocks were downgraded to account for the fact that larger blocks than the actual blocks were used. The strength and stiffness reduction that was used was based on assessing the equivalent Rock Mass Rating (RMR) for each bedded zone of the overall rock mass to reflect small-scale variation in bed thickness and jointing intensity pertinent to each geologic formation. The RMR is a function of the intact strength, RQD, spacing of joints, condition of joints and water. The relationships developed by Hoek and Brown (1980, 1988, 1997) that relate intact properties to rock mass properties were then applied to each layer. The downgrading of rock mass properties considered the explicitly defined joints in each model (as described below) and, therefore, did not apply the same degree of downgrading of properties as might otherwise be applied if the rock mass were modelled as a continuum. All horizontal jointing (bedding) was generated randomly using the standard deviation of the spacing measured for each unit. Three conditions of vertical cross joints were considered.

- *Discontinuous Joint Model:* The first set of models considered a mean horizontal spacing of vertical joints of 10 m with a standard deviation of 3 m in which these joints passed only through individual beds. This model was considered to be reasonably consistent with the overall character of Dr. Cording's analysis but the positions of the vertical joints were permitted to vary throughout the layer, thus creating a brick-work like array of joints that did not pass fully through all layers (discontinuous joint model). The cross jointing was more intense in the layers above the Salina (mean 5 m spacing with a standard deviation of 2 m), again to reflect lower RQD's (8 to 44) in comparison to that of the Salina formation (53 to 98). While Dr. Cording's (2006b) analysis used continuous vertical joints of about 7.6 and 15.2 m spacing, these analyses varied the conditions to ascertain the effect that different joint characteristics may have on the modelled behaviour.
- *Large Continuous Joint Model:* The second set of models used the bedding spacing logic as described above and considered vertical joints existing at 20 m mean horizontal spacing (standard deviation of 5 m), a vertical length of 100 m (standard deviation of 20 m), and a minimum vertical distance between any two adjacent joints of 20 m (standard deviation of 5 m).
- *Block Joint Model:* The third, and considered most realistic, model (approximately square blocks model) implemented a randomized joint pattern that created block patterns (spacing between joints as related to their length) with an aspect ratio on the order of 1.0 ± 0.2, consistent with the research of Huang and Angelier (1989), Underwood et al. (2003), Cooke et al. (2006), and Bakun et al. (2008). It has also been observed that within sedimentary rock

formations, longer, more vertically persistent joints may be found at a correspondingly greater horizontal spacing (e.g. Bakun et al. 2008). It was recognised that for the outcrops and quarry exposures reviewed for this work vertical and horizontal stress relief, weathering, and blast damage may have influenced the visible jointing and fractures. Therefore, the numerical model incorporated vertical joints, potentially composed of closely related sets of joints with smaller vertical persistence, that were typically 25±5 m long and distributed randomly throughout the rock mass with a second set of longer joints up to 100±20 m at greater horizontal spacing. This joint spacing is about one half to one order of magnitude greater than the joint spacing visible in the reviewed outcrop and quarry information. Because the UDEC code permits use of only uniform distributions for randomizing the joint sets, these two different uniform distributions were used to approximate negative exponential distributions of joint length and spacing that would be more consistent with observations in natural formations. With the combination of vertical joints overlapping bedding planes produced a rock mass that included persistent vertical joints as well as blocks with an aspect ratio consistent with field observations and research studies. The vertical bedding thickness was increased slightly to achieve reasonable computational times and demands, and the properties of the blocks were downgraded as appropriate for such modelling such that bedding thicknesses varied between about 4 m and 8 m, proportional to field evidence of bedding thickness within the respective strata.

The geometric parameters for each unit in the model are shown in Table 8.4. Table 8.5 summarize selected descriptive statistics for each of the models. Figure 8.53 illustrates the geometry of the three different assumptions regarding horizontal bedding and vertical joint/fracture characteristics.

Table 8.4: Model Geometric Data, Model Sets 1 and 2

Formation	From (m)	To (m)	Bedding Thickness (m)		Average RQD
			Mean	St. Dev.	
Dundee	29	44	0.88	0.126	44
Lucas	44	118	1.40	0.204	13
Amherstburg	118	134	1.66	0.239	22
Sylvania Member	134	159	1.00	0.143	8
Bois Blanc	159	192	1.14	0.164	14
Brass Island	192	239	2.16	0.312	20
G Member Dolostone	239	259	2.55	0.368	53
F Member Shale	259	303	1.51	0.218	76
F Member Salt	303	344	1.71	0.246	63
E Member Dolostone	344	374	3.08	0.445	96
D Member Salt	374	383	1.94	0.280	98
C Member Shale	383	428	3.12	0.451	97
B Member Salt	428	486	2.24	0.323	85
A Member Dolostone	486	500	1.95	0.282	63

Table 8.5: Model Statistics

Case No.	Salt Unit	Cavity Width, Height (Shape)[1]	Vertical Joint Pattern[2]	No. Blocks	Total No. Contacts
1	F	150, 10 m (R)	D	6,415	168,359
2	F	200, 10 m (R)	D	6,410	187,082
3	F	300, 10 m (R)	D	13,061	353,395
4	F	400, 10 m (R)	D	13,044	548,924
5	B	100, 60 m (R)	D	13,073	548,344
6	B	200, 60 m (R)	D	12,965	320,860
7	B	300, 60 m (R)	D	12,965	324,225
8	F	400, 10 m (R)	L	23914	316436
9	F	500, 30 m (T)	L	23,223	308,872
10	F	400, 10 m (R)	B	29,229	253,288
11	F	500, 30 m (T 3:1))	B	27,887	248,664
12	F	500, 30 m (T 6:1)	B	27,887	248,664
13	B	100, 20 m (R)	B	27,887	248,664
14	B, D, F	500, 30 m (T 3:1) in F 250, 5 m (R) in D, 60, 30 m (T) in B	B	27,887	248,664
15 (K_o=2)	F	500, 30 m (T 3:1)	B	27,887	248,664

Notes: 1) R = rectangular, T = trapezoid with top width shown, bottom width 300 m with side slope vertical:horizontal distance ratio shown, width of cavity shown first, height second; 2) D = discontinuous vertical joints passing through discrete beds only, L = large vertical joints passing through multiple beds; B = block-type model with aspect ratio of length to height near 1.

The bedding was modelled with a peak friction angle of 25° and a residual friction angle of 15°. The cross joints were modelled with a friction angle of 35° and a residual friction angle of 20°.

A comparison of laboratory testing results suggests that the Formations at the Detroit DRIC sites generally exhibit higher strengths than the Windsor site for the dolomitic shale units as illustrated on Figure 8.54. Rock mechanics parameter values for modelling the geologic formations were based upon the laboratory test results, published values for similar rock formations, geophysical logs, and core inspection, recognizing the variability of the mineralogy and mechanical properties within each formation. These values have also been downgraded to appropriate rock mass strength within the discrete element blocks using rock mass quality estimates based upon core logging and geophysical log interpretation as described above. Table 8.6, below, summarizes the parameters used within the numerical modelling completed for this study.

Table 8.6: Model Parameters for Block Model

Unit	ρ (kg/m^3)	E_{rm} (GPa)	ν	σ_{trm} (kPa)	C_{rm} (MPa)	ϕ'_{rm}
Overburden	1,800	0.02	0.30	2	0.005	25
Dundee	2,530	22	0.35	500	5.130	58.4
Lucas	2,230	18	0.29	200	2.280	52.8
Amherstburg	2,230	18	0.29	250	2.550	50.0
Sylvania	2,310	13	0.30	200	2.210	52.8
Bois Blanc	2,487	18	0.25	400	4.400	50.9
Bass Islands	2,230	19	0.29	300	3.570	47.2
G Dolostone	2,757	25	0.15	1000	10.220	50.4
F Shale	2,577	7	0.13	400	4.070	38.8
F Salt	2,670	3	0.20	600	3.100	43.6
E Dolostone	2,643	33	0.25	1600	15.790	48.2
D Salt	2,670	3	0.20	600	3.100	43.3
C Shale	2,590	3	0.18	400	3.630	30.6
B Salt	2,670	3	0.20	600	3.100	41.5
A Dolostone	2,757	28	0.25	1200	12.090	46.0

Within the models used for this study, the ratio of horizontal to vertical stress, k_o, within the bedrock was set equal to 1.0 to establish the initial in situ conditions. Earlier work on sinkhole development mechanisms (e.g., Stump et al. 1982, Neito 1987) assign unusually high values to in situ horizontal stresses for the near-surface sedimentary rock formations (0 to 160 m depth) as these are postulated to be contributing to the destruction of the Sylvania Formation sandstone. However, the work used in support of this high horizontal stress argument (Herget 1973, Herget, et al. 1975) was for depths on the order of 1,000 m, rather than the 0 to 500 m depths for the investigated conditions. The use of this approach resulted in k_o values on the order of 4 to 10 at the depths of the Sylvania Formation sandstone and formations above. For sedimentary formations of relatively low horizontal stiffness (on the order of E_h = 25 to 40 GPa), Sheorey (1994) and Arjang (2006) indicate that for preliminary purposes, k_o can be approximated using the following equation:

$$k_o = 0.25 + 7E_h(0.001 + 1/Z)$$

This is similar to but above the lower bound of trends in measured data suggested by Brown and Hoek (1978), near the estimates indicated by Brown and Hoek (1978) of data published by Haimson (1978), and below values associated with Canadian shield metamorphic rock formations. Using Sheorey's approach and the laboratory values of elastic modulus, values of estimated k_o varied between about 2 and 3.6, at depths on the order of 70 to 130 m, decreasing to about 0.4 to 1.8 near the top of the B salt (380 to 400 m), with an average k_o of about 1.2 to 1.8, depending on the range of E_h used as illustrated in Figure 8.54. It was considered that a k_o value of about 1 was a suitable value to choose for the parametric study. This approach is also consistent with that of Fernandez and Castro (2002) in their analysis of the BP caverns, RESPEC (2005) in studies of hydrocarbon storage facilities in the Silurian salt formations in the Appalachian basin (analogous to the Michigan basin salt formations), and the numerical work described in Dr. Cording's May 2006 report. Higher values of k_o may increase the stability of the rock mass within the models by providing greater confining stresses and frictional constraint on any vertical joints. However, in this particular analysis problem, there are two competing issues to consider. On the one hand, higher horizontal stresses may tend to increase stability and decrease settlements, and perhaps increase the time required for settlement to occur, thereby suggesting our numerical model results are conservative. On the other hand, higher horizontal stresses might inhibit the formation of the sinkhole as actually occurred on the nearby property and our analysis might then not develop the similar magnitudes of settlements compared to those observed, suggesting the numerical model might not be conservative. Therefore, an additional numerical model trial was completed in which the conditions assumed included the "block" rock mass joint model, a $k_o = 2.0$, and a large trapezoidal cavity in the F Salt.

In addition to modelling the rock mass beneath the sites, the numerical UDEC modelling also considered the potential behaviour of the overburden soil. Within the models, the overburden soils were considered an elastic-plastic medium defined by a Mohr-Coulomb yield criterion with an angle of internal friction, ϕ', of 25^o and an effective cohesion intercept of 5 to 10 kPa, consistent with drained strength parameters for the relatively soft silty clay overburden based on testing completed nearby for other aspects of the DRIC project. An initial elastic modulus of 20 MPa was used to simulate the stress-strain properties of this overburden. In situ horizontal stresses were allowed to come to equilibrium using the simplified approach of $k_o = 1\text{-}\sin \phi'$.

8.1.7.2 Numerical Model Results

Figure 8.55 summarizes the displacement profiles at the model bedrock surface (top of the Dundee Formation) for all of the cases examined.

Settlement values and other geometric values of interest for each of the cases are also summarized in Table 8.7, below. The numerical modelling estimates of maximum settlement differ greatly depending on the assumptions regarding vertical joint patterns. The discontinuous joint model that limited vertical jointing to within the bed thickness exhibited interlocking between the beam-like beds and did not result in displacements that approached the order of magnitude of settlements observed at the Sandwich West site, even with very large subsurface cavities. All of these cases produced maximum settlements of less than 200 mm. This model was therefore rejected as an appropriate simulation of the field conditions. The large continuous vertical joint model produced the most severe maximum settlements, with cases for full removal of the F salt indicating over 3.5 m of settlement. The prevalence and vertical length of joints within this model may be too great, however, considering that vertical joints tend to terminate, then propagate horizontally along weaker beds (Underwood et al. 2003, Cooke et al. 2006). Settlements estimated using the block model of joint patterns were similar to those using the large continuous joint model with the maximum rock surface settlement for the full-height removal of the F salt being about 3 m. These results, when compared with the many metres of settlement that occurred over the Sandwich West brine field suggest that the discontinuous block model is not a reasonable approximation of the actual conditions for numerical modelling purposes. The large continuous joint or block models likely represent more realistic rock mass responses to undermining in this particular case. Both these models exhibited plastic failure to the rock surface of magnitudes that are similar to the behaviour experienced at the Sandwich West site (settlements preceding sinkhole development on the order of 500 mm to sinkhole depths of 6 to 8 m).

Figures 8.56 through 8.59 illustrate displacement patterns, shear displacements, joint openings, and changes in horizontal stresses surrounding the simulated trapezoidal cavity in the F salt using the block model. These suggest that within a zone beyond the edge of the simulated cavity the modelled rock mass exhibits some changes relative to these criteria, though these changes diminish with increasing distance from the cavity edge.

Figure 8.60 illustrates the numerical analysis of the BP 32/33 cavern using the block bedding and jointing model. This model indicates that assuming that the cavity does not have pressure integrity and the internal pressure is permitted to drop to near hydrostatic pressures, collapse of the roof could be expected, yet surface settlement would be nominal. With internal pressure integrity and an internal pressure consistent with a pressure head of brine from the cavity bottom to the ground surface, extensive roof collapse would not be expected. Given the inherent overestimation of settlement behaviour since the 2D UDEC model considers the cavity to be infinitely long, perpendicular to the plane of the model, it is considered that this analysis represents a reasonable validation of the modelling approach.

Table 8.7: Summary of Numerical Model Results

Case	Salt Unit	Cavity Width	Cavity Height	Model[1]	Shape[2]	Depth to Top	Max Settlement (mm)	Offset Distance (m)[3]	Angle of Draw (degrees)[3]
1	F	150	10	D	R	300	67	-28	-5.3
2	F	200	10	D	R	300	133	-27	-5.1
3	F	300	10	D	R	300	93	-39	-7.4
4	F	400	10	D	R	300	158	-27	-5.1
5	B	100	60	D	R	420	14	NA	NA
6	B	200	60	D	R	420	42	3	<1
7	B	300	60	D	R	420	124	71	9.6
8	F	400	10	L	R	300	1890	28	5.2
9	F	500	30	L	T	300	3660	20	3.7
10	F	400	10	B	R	300	526	52	9.7
11	F	500	30	B	T (3:1)	300	2974	46	8.6
12	F	500	30	B	T (6:1)	300	2487	42	7.9
13	F	500	30	B	T (3:1)	300	4142	83	12.7
	D	250	5	B	R	370			
	B	500	30	B	T (1:1)	420			
14 (k_o=2)	F	500	30	B	T (3:1)	300	3698	64	12.0
15	B	120	20	B	R	420	45	91	12.3

Case	Salt Unit	Cavity Width	Cavity Height	Model[1]	Shape[2]	Depth to Top	Max Settlement (mm)	Offset Distance (m)[3]	Angle of Draw (degrees)[3]

NOTES: 1. D = discontinuous joints; L = large continuous joints, B = block joint model; 2. R = rectangular, T = trapezoid with top width shown; 3. Off-set distance and angle of draw defined based on closest point to cavern edge with estimated 25 mm settlement or less at rock surface (see Figure 8.62 and Section 8.1.9, below).

Previous studies of the collapse at the Sandwich West brine well field have attributed considerable importance to unusually high in situ horizontal stresses and the properties and performance under stress of the Sylvania sandstone. The results of these numerical simulations support one notion proposed by Russell (1993) that the unusual properties of the Sylvania sandstone were unlikely to be the primary mechanism for propagation of large settlements to the surface. The magnitude of the horizontal stresses play a minor role in the principal failure/deformation mechanisms of the larger solution mined cavities. While high horizontal stresses have a stabilizing effect on cavities of limited span, once the spans become wide, higher horizontal stresses drive the strata to buckling earlier than for conditions with lower horizontal stresses (this applies to all formations including the Sylvania Sandstone). This phenomena also increases the magnitudes of the maximum settlement at the surface of the rock and, given the range of k_o values suggested by the approach of Sheorey (1994), may be one of the compounding effects that produces field settlements greater than those shown by the results of the series of numerical analyses conducted for this study. Further, these numerical results clearly suggest that many metres of surface settlement may occur from cavities created in the F, D, or B salt beds or a combination of these. By exploiting natural jointing, relatively low “bulking” of the bedrock may occur during a more orderly collapse of the bedrock formations, leading to the formation of a “sinkhole” at the surface.

The numerical modelling results also indicate that where the underlying rock displacements are on the order of 25 to 30 mm or less, ground surface settlements are nearly identical to those of the underlying rock. Within the range of rock surface settlements between about 30 and 300 mm, the soil surface exhibited greater settlement than the underlying rock due to lateral and vertical displacements of the overburden mass toward the zone of maximum settlement (sinkhole area). This behaviour is summarized in Figure 8.55 illustrating the relationship between ground surface settlement and underlying rock displacement magnitudes.

8.1.8 Re-evaluation of 1954 Sinkhole Formation

Based on these numerical results and consideration of the site history, as illustrated by Figure 8.51 that the combination of mining partially from the F salt (near the first 3 wells) and later extraction of the D salt and portions of the B salt caused opening of joints and beds in the formations above (see Figure 8.61) that resulted in dissolution of the F salt through cross-field pumping of water and brine, and finally formation of a large cavity that precipitated the development of the observed sinkhole. A sequence of events, conditions and mechanisms is provided below as a plausible scenario for development of the sinkhole observed at the Sandwich West site in 1954.

Initial solution mining in Wells 1 through 3 removed salt primarily from the F salt beds (hence the discovery of "brine" and "cavities" when drilling nearby solution mining wells). Some salt may have also been removed from the D salt beds as well, but these may not have been the primary target of the mining. Wells 4 through 7 were drilled to target the D salt and production likely removed significant quantities from this bed through until about 1928 or 1929 when rock falls and damage to the wells (casings and brine recovery pipes) made production from this bed appear impractical. Since well casings may have been poorly sealed between formations, or likely not sealed at all, there was likely opportunity for stratification of the brine to result in dissolution of salt at higher levels. Casings for Well 4 and 7 were then likely extended deeper to target the B salt and to assist in protecting the brine pipes from damage. Subsequent wells were deliberately drilled and cased to the deeper depths to target the B salt in an effort to avoid the problems that beset Wells 4 through 7. Wells 5 and 6 were abandoned by 1929 and 1930, respectively. Again, poor or non-existent sealing of well casings likely permitted dissolution of salt at higher levels.

Mining from the D salt in and around Wells 4, 5, 6 and 7 likely resulted in subsidence of the overlying E and F units of the Salina Formation. This subsidence would have probably opened up joints and bedding planes permitting free movement of fluids (brine and water) and the "discovery of natural brine" and cavities found during drilling of subsequent wells. During later operation, site history information clearly indicates the cross-field pumping of water and brine while removing significant volumes of salt. Because of brine stratification, the cross-field flow of fluids likely exploited the upper salt beds, creating cavity enlargements where previous subsidence and joint or bed openings provided the opportunity for flow. Continued cross-field flow could have removed sufficient salt to result in large unsupported spans in the rock mass above the top of the F salt, particularly in the centre of the site, immediately below the 1954 sinkhole location (see Figure 8.51).

Horizontal stresses, consistent with the observations of Brown and Hoek (1978) and (Sheorey (1994), at first may have inhibited subsidence and sinkhole formation while the span of the likely cavities in the F salt were relatively limited in size or while pillars of salt remained to assist in supporting the formations above. These same horizontal stresses, however, likely exacerbated buckling behaviour once the combination of displacements and span length reached critical values, and the displacements exploited natural incipient vertical joint features within the bedrock formations to result in the observed rapid formation of the sinkhole.

8.1.9 Generalized Zones of Mining Influence ("Angle of Draw")

In mining engineering, a number of empirical and convenient geometric constructions are used to assess the influence of a subsurface mine on the ground surface. Definitions of the various angles and conditions are illustrated on Figure 8.62. As a mine is opened up underground, the rock will tend to respond in a zone immediately above the opening. A characteristic angle that bounds the rock most influenced by this opening is referred to as the "caving angle," measured between the plane of the mine roof and the bounds of the responding rock. Above this angle, or the point at which the “caving angle” lines intersect when drawn from opposite sides of the mine opening roof, the rock mass responds only minimally, with the corresponding caving angles often classified as “subcritical”. As the mine is further opened, there may come a point at which the “caving angle” intercepts the ground surface and this condition is often classified as “critical”. With further opening of the mine, the “caving angle” opens further and, once beyond vertical, is called the “angle of draw”. This “angle of draw”, measured from a vertical line, represents the ground mass outside of the limits of the underground opening that is influenced by this opening and exhibits displacements at the ground or rock surface.

The “angle of draw”, therefore, is a convenient geometric construction used to define the limit beyond the edge of a mined area at which the ground surface settlement becomes “small”. Defining the point at which surface settlement is “zero” is impractical and, when using numerical or manual calculation methods, can be beyond the limit of reasonable accuracy given the variability in ground and mining parameters. The definition of “small”, therefore, can be somewhat arbitrary and subjective. Typically for mining problems (outside of urban areas) the angle of draw is based upon the point at which the surface settlement is about 5% of the maximum settlement (see Figure 8.62). For the DRIC case, however, 5% of maximum settlement values of 2 to 5 m or more would be on the order of 100 to 200 mm or more. These values of bedrock settlement were considered unacceptable for this project. In soft ground tunnelling in urban environments, for example, this defined angle of draw may be set based on surface settlements near “zero” – an impractical limit with respect to settlement tolerances but a mathematically convenient term for describing the outer limit of the settlement trough. In this case, the “angle of draw” may be on the order of 20 to 45 degrees, again, depending on how the surface displacement limit is defined. For many urban situations, settlement tolerances are commonly set equal to a value on the order of 12 to 25 mm depending on the sensitivity of the surrounding structures. For this project the point defining the angle of draw was deliberately chosen to be consistent with values of settlement typically considered acceptable for new construction or underground work in urban areas. Therefore, a bounding value of estimated displacement of 25 mm or less was considered appropriate for defining the angle of draw.

The discontinuous vertical joint models produced results somewhat consistent with analytical and empirical estimates suggesting that the “angle of draw” for low-height, horizontally wide cavities is in the range of 15^o to 18^o from vertical when the point defining the angle is taken as 5% of the maximum settlement. However, the maximum settlement values in these discontinuous block models were less than 150 mm and entirely inconsistent with the field observations of large displacements and the eventual formation of the sinkhole.

Based on early empirical work from other case histories, an “angle of draw” of about 15^o was used for the US DRIC study (Cording, May 2006) and this was defined based on the distance to points where the settlements at the perimeter of the solution mine well field ranged between about 12 and 100 mm. For cavities with vertical walls, the UDEC modelling carried out for this study indicated “angles of draw” between about 9^o and 12^o. For cavities with thin edges, with side slopes on the order of 9^o to 18^o, the corresponding “angles of draw” were about 8^o to 9^o, respectively. By rational extension, a cavity with a side slope of near 0^o (near horizontal edge of a cavity of nearly zero thickness at the edge) representing a hypothetical and lower limit of what may constitute a "cavity", may be taken as an asymptote of the angle of draw where the angle of draw becomes meaningless (i.e., vertical settlement above the threshold limit does not occur at the rock surface beyond the edge of the cavity). Figure 8.63 illustrates the resulting relationship between cavity wall shape (side slope) and the corresponding "angle of draw".

Above the rock surface, displacements are expected to occur within the overburden depending on distance from the source of the underlying rock displacement, rock displacement magnitudes, and the nature of the overburden soil (cohesive silty clay and clayey silt in the DRIC case). Near the edge of an underground opening or depression in the rock surface, overburden soil will tend to displace toward the opening or depression in both vertical and lateral directions. This behaviour, as modelled for the DRIC study, is illustrated by the patterns of displacement shown in Figure 8.53 where in areas of large displacement (greater than approximately 300 mm), the ground surface displaces somewhat less than the underlying rock as soil mass also displaces laterally from outside the immediate zone of settlement toward the point of maximum displacement and the overburden mass fails in shear. At greater distances and smaller vertical rock surface displacement magnitudes (on the order of 30 mm to 300 mm, in this case), the ground surface exhibits a zone of influence that is greater than for the underlying rock (at similar displacement magnitudes), arising from the displacement of soil toward the point of maximum vertical rock displacement, again as it fails in shear and also exhibits lateral and vertical elastic and plastic deformations. It is from this behaviour that an "angle of draw" could be inferred extending from the bedrock surface to the ground surface. This behaviour is consistent with the field monitoring conducted by OPG illustrated in Figure 7.18. However, at small values of rock surface displacement, the ground surface displacement also is reduced and the influence of lateral soil displacements diminishes as the overburden is no longer failing. At the point where "angle of draw" for the bedrock is defined (25 mm settlement or less) the ground surface settlement is equal to the underlying rock displacement and, thus, the "angles of draw" for the two materials converge to the same point. Above the point used for defining the "angle of draw" within the rock for the DRIC project, therefore, the "angle of draw: within the overburden can be effectively considered equal to zero.

Based on the numerical modelling results, two zones of mining influence are defined for this project as follows:

- Primary Influence Zone: The primary influence zone represents the likely limit of mass salt dissolution outside the boundaries of the former solution mining operation. Within this zone, it is expected that solution mining may have directly removed salt from the B, D, or F salt beds. This zone is analogous to the edges of an underground opening used for defining the "angles of draw" discussed above.
- Secondary Influence Zone: The secondary influence zone represents the likely plan view limit (limit at the rock and ground surface) of rock disturbance, for example opening of joints or bedding, or hydraulic connection through joints and open bedding, and is defined at the point

where displacements estimated by the numerical modelling are anticipated to be 25 mm or less (at time of major subsidence ca. late 1950s). This limit is defined based on an "angle of draw" chosen to be consistent with the estimated general shape of the subsurface cavity walls and edge.

These two zones, also illustrated in Figure 8.62, are used in combination with the historical and field information to appropriately define specific zones and limits of influence for each of the potential crossing locations as discussed in Sections 8.2 and 8.3, below.

8.2 Interpreted Rock Mass Conditions For Crossing B

The interpreted rock mass conditions at the Crossing B location are summarized below with respect to individual wells first, a discussion of the interpreted conditions between wells second, and then third, a summary for the crossing location addressing all conditions. For Crossing B reference is also made to the X11-3 and X11-4 wells as these assist in defining the extent of solution mining activities and the effects that they had on the overall rock mass in the area. Within the report sections below, most of the discussions related to the rock mass mainly focus on the conditions encountered within the formations below the 2nd well casing, in the Silurian Bass Islands and Salina Formations, unless particularly notable conditions were encountered within the upper formations. Above this level, the losses of drilling fluids and artesian water conditions are well documented in previous sections of this report, but are considered to be primarily associated with the natural conditions, with the exception of the influences of brine on groundwater conditions.

8.2.1 Interpreted Conditions at Crossing B Well Locations

8.2.1.1 Well X10N-1

Well X10N-1 exhibited a 1 m drop in the bit and drill string while drilling through the Lucas formation. Based on a review of available literature, and discussions with local well drillers, such bit drops have been encountered in other areas of south-western Ontario within the Lucas formation. Measurements of the space into which the bit dropped were not made at the time of drilling due to the high rate of sulphurous and artesian flows and it is unknown whether this was a vertical or horizontal feature. A comparison of the fracture features among all of the wells drilled for this study indicates that the Lucas formation is consistently more fractured than any of the other formations, regardless of the location of the well within the study area. This formation is also known to be one of the more productive bedrock aquifers within the region (MOE 2003) in which the mean hydraulic transmissivity of this formation has been estimated to be on the order of 30 m^2/day with specific capacities between 5 and 50 lpm per metre for wells installed within the upper portions of the Detroit River Group of formations (Dundee and Lucas Formations). The specific capacity is consistent with values of artesian flows emanating from the wells during explorations conducted for this project. The Lucas formation is a laminated to thinly bedded dolostone with weak gypsum beds, and may have been subjected to some natural dissolution of carbonate and gypsum minerals along the beds and horizontal and vertical joints and fractures. It is therefore considered that this bit drop is consistent with the natural formation conditions.

Following installation of the two bedrock well casings, Well X10N-1 also exhibited partial losses of circulation near the top of the Salina F salt and Salina D salt formations. These fluid losses, however, were not sufficient to prevent maintaining circulation throughout the remainder of the well. No bit drops or other drilling behaviour indicative of fractured zones were encountered within these same zones. Though the calliper and acoustic televiewer logs indicated hole enlargement at these elevations, and some fracture openings, these were of apertures less than 10 cm. It is therefore considered that these drilling fluid losses (hydraulic connection) are evidence of some minor influence of salt dissolution, likely the result of brine stratification in the nearby solution mining and preferential leaching along networks of pure salt near the upper boundary of these salt formations, and that the overlying strata rest directly on the salt beds beneath.

The other data obtained from this well during drilling and down-hole logging are unremarkable in comparison to other wells completed at this site.

8.2.1.2 Well X10N-2

Of all the wells drilled for this project, Well X10N-2 was the most difficult to complete as a result of subsurface conditions. Fractured rock was encountered between about 34 and 42 m below the ground surface in the Dundee formation. Overall, however, the Lucas formation was somewhat less fractured in Well X10N-2 than in the other wells within the X10N cluster and, consequently, the artesian flow conditions were less severe than in other wells.

Following installation of the second casing in the Bass Islands Formation, circulation was partially lost within the Salina Formation G Member, and fully lost once drilling neared the top of the F salt unit from about 283 m below ground surface to the bottom of the well. Cementing was unable to limit losses of drilling fluids and several drilling methods had to be used to advance through fractured zones and to overcome loss of drilling fluids and clearing of cuttings returning into the well.

Well X10N-2 exhibits thinner F and D salt layers than in most other wells. The cumulative thickness of salt within the F unit was about 28.8 m, nearly 4.6 m or about 14% less than the mean thickness, or thinner by more than 7 times the 1.9% standard deviation of the mean cumulative thickness. The most significant changes in thickness were noted within the top two salt beds, the SsF-4 and SsF-5. At this location, the thickness of the D salt was also about 14% less than the mean salt thickness of those wells least likely to have been affected by solution mining. No evidence of solution mining removal of the B salt was found in the comparison of strata thicknesses and elevations for this location.

Horizontal fractures/open joints were prevalent throughout Well X10N-2 above the Salina Formation C Member. Major aperture fractures/open joints were apparent in the Salina Formation G shale, F shale, and E dolostone beds. Figure 8.58 illustrates a section of the optical televiewer log in this well within the Salina Formation E Member dolostone. The sum of directly measured apertures of fractures/open joints within the Salina Formation units is approximately 2.5 m, whereas on consideration of those considered “major” in classification (being greater than 0.01 m in aperture) but not directly measured (being less than 0.1 m in aperture) the sum of the openings is on the order of 4.2 m. Below the base of the D salt unit, the C unit exhibited about twice the number of minor or partially open fractures/joints compared to all other wells except X11-4. Only one fracture within the B salt was noted as “major” and the aperture was less than about 50 mm. For comparative purposes, open fractures and joints within the Detroit River Group, Bois Blanc, and Bass Islands Formations were not included in the summation of total aperture due to the prevalence of such features in these formations and the Lucas Formation in particular.

8.2.1.3 Well X10N-3

Following installation of the second casing in Well X10N-3, drilling was unremarkable until a depth of about 297 m below ground surface at the top of the Salina Formation F Member salt at which point circulation of drilling fluids was entirely lost.

Well X10N-3 exhibits thinner F and D salt layers than in most other wells except X10N-2. The cumulative thickness of evaporites within the F unit was about 31.6 m, about 5.5% less than the mean thickness of this unit for all potentially unaffected wells. Based on the available data it appears that the changes in thickness were noted within the top two salt beds, the SsF-4 and SsF-5 layers, and the bottom salt bed, SsF-1. As much as 1 m may have been removed from each of these salt beds based on the thickness comparisons to other wells. At this location, the thickness of the D salt was also about 29% less than the mean salt thickness of those wells least likely to have been affected by solution mining, with around 1.6 m potentially having been removed. At the X10N-3 location, the cumulative thickness of the B salt was comparable to all other locations and was nominally equal to the mean thickness in comparison to well locations least likely to have been affected by solution mining.

Horizontal fractures/open joints were evident in Well X10N-3 above the Salina Formation C Member. Major aperture fractures/open joints were apparent in the Salina Formation G shale, F shale, and E dolostone beds, as well as those above the Salina Formation (notably the Bass Islands and Bois Blanc Formations). The sum of directly measured apertures of fractures/open joints is approximately 0.7 m within the Salina Formation, whereas on consideration of those considered “major” in classification (being greater than 0.01 m in aperture) but not directly measured (being less than 0.1 m in aperture) the sum of all the openings in the Salina Formation is on the order of 0.9 m. Below the base of the D salt unit, few minor or partially open fractures/joints were noted. For comparative purposes, open fractures and joints within the Detroit River Group, Bois Blanc, and Bass Islands Formations were not included in these summations of total aperture due to the prevalence of such features in these formations and the Lucas Formation in particular. However, it is notable that the Bass Islands and Bois Blanc Formations exhibited a greater number of “major” fractures than most other wells within these formations with a total cumulative aperture on the order of 0.5 m.

8.2.1.4 Well X10N-4

Following installation of the two bedrock well casings, Well X10N-4 exhibited partial losses of circulation near the base of the Salina F shale unit. Total losses of circulation were experienced below this near the top of the Salina F salt unit (SsF-4 and SsF-5). As this was the first well drilled, attempts were made to seal off the well using cement. A total of about 36 m^3 of cement was introduced into the well and circulation was partially regained before being entirely lost again. Prior to introducing cement into the well, down-hole logging was used to identify the zones through which circulation was being lost as no bit drops or other unusual conditions were encountered during the drilling.

At the location of Well X10N-4 the cumulative thickness of the F, D and B evaporite beds were near the mean thickness of the wells least likely to have been affected by solution mining in the Crossing B vicinity. There is little if any evidence of solution mining influence on any of the major salt horizons at this well location based on comparisons of bed elevations or thicknesses. The only evidence of salt dissolution is the loss of drilling fluids near the top of the F salt. This may be associated with limited preferential dissolution of salt along networks of very pure salt that can be found near the top of the F salt evaporites. These networks are likely the geological result of prior erosion of the salt soon after its deposition, then redeposition of salt, infilling the old erosion channel.

The analysis of fractures indicates that the rock mass at Well X10N-4 exhibits numbers and sizes of open joints or fractures that are typical of all wells drilled in areas unaffected by solution mining. Other data obtained from the drilling and down-hole logging are unremarkable in comparison to other wells drilled for this project.

8.2.1.5 Wells X10N-5 and X10N-6

Once the 2nd well casings were installed in these two wells, the drilling and down-hole logging was unremarkable and it is considered that these two wells provide a suitable comparison to all others as exhibiting the typical characteristics of the rock formations in the area. It is also noted that the base of the B salt is at its highest elevation at these two holes in comparison to all others.

8.2.1.6 Well X11-3

Following the measures necessary to control artesian flows while drilling through the upper formations and installation of the 2nd well casing, drilling in X11-3 was largely unremarkable, except for partial losses of circulation encountered near the top of the F salt at about 312 m below the ground surface. Circulation was sufficiently maintained to permit return of chip samples throughout drilling. During down-hole logging, small pieces of rock were dislodged from the well wall inhibiting progress until the debris was cleared with the cable tool drill rig. All other down-hole logging data is unremarkable. At this well, the cumulative thickness of salt in the D unit was less in comparison to mean cumulative evaporite thickness in the northern group of wells, but nearly identical to the mean cumulative evaporite thickness of the southern well group. The data does not provide conclusive evidence of whether or not solution mining may have influenced salt bed thickness at this location.

8.2.1.7 Well X11-4

After setting the 2nd well casing in place, partial drilling fluid losses were encountered to varying degrees between the depths of about 311 m and 388 m below the ground surface, extending through the F, E, D, and C units of the Salina Formation. Drilling circulation was entirely lost within the C unit at a depth of about 388 m. Drilling continued “blind” for the remainder of this well.

Well X11-4 exhibited a nominally thinner F salt unit in comparison to those wells considered least likely to have been influenced by solution mining in the southern group of wells. If salt was removed from the F unit, it may have been removed from the uppermost salt bed (SsF-5). Comparisons of the cumulative evaporite thicknesses in the D and B units suggest that salt has not been removed by solution mining directly at this well location.

Horizontal fractures/open joints were evident in Well X11-4 above the Salina Formation, though these were not of note in comparison to other wells. Of particular interest, however, the Salina Formation C Member exhibited more than 3 times the number of open joints/fractures in comparison to most other wells, including about 40% more in number than X10N-2. These open joints/fractures were typically of an aperture less than 10 cm, and more commonly closer to about 3 cm. The sum of those considered “major” in classification (being greater than 0.01 m in aperture) but not directly measured (being less than 0.1 m in aperture) the sum of all the openings in the Salina Formation C Member is on the order of 0.5 m to 0.8 m. For comparative purposes, open fractures and joints within the Detroit River Group, Bois Blanc, and Bass Islands Formations were not included in these summations of total aperture due to the prevalence of such features in these formations and the Lucas Formation in particular.

8.2.2 Interpreted Conditions Along Crossing B Cross-Well Profiles

A number of the cross-well surveys in the Crossing B area (X10N) exhibited conditions that are consistent with the Michigan Basin geology. These are discussed first with reference made to characteristic features and with particular emphasis on those features notable in the salt beds. Examples of these images are shown on Figure 8.14. Others in this group are included in Appendix C for reference. In large measure, these are unremarkable as compared to those areas in which anomalous survey features are imaged or solution mining may have occurred. Those images in which features of note were specifically identified are described in greater detail in subsequent report sections below. The images that are good indicators of typical stratigraphy in the Crossing B vicinity include:

X10N1 to X10N6	X10N-4 to X10N-6
X10N1 to X10N4	X10N-5 to X10N-6
X10N-4 to X10N-5	

In general, the images are consistent with relatively flat formation stratigraphy. The descriptions of the images and their correlation to the stratigraphy provided below are presented in order from deepest to most shallow since any anomalies that are potentially indicative of solution mining activity may propagate upwards from the source location at the mining depth.

In many images, especially in X10N-1 to X10N-6 and X10N-5 to X10N-6 at the base of the B-Salt around the 490m depth, a strong, flat wavelet with two positive amplitude reflectors is visible and indicates the presence of the Salina Formation A2 Member carbonate. More specifically it is the tuned event from the A2 Carbonate and the underlying A2 evaporite. In some surveys (e.g. X10N-1 to X10N-4, X10N-2 to X10N-6, and X11-6 to X11-1) a perturbation exists on top of the A2 layer indicating a carbonate growth on the A2 member. In the X10N-2 to X10N-6 images a thickening of the top of the A2 is present in the middle of the survey (see Figure 8.34). Gentle unconformities do exist and small carbonate mounds are present on the A2 Carbonate, however, major faults, large anticlines and synclines do not occur within the study areas.

Directly above the A2, at about 480 m depth, as many as three, clear, flat stringers can be observed in the B salt. Carbonate stringers are also present and indicated in the B salt and above them are shale stringers in the 450 m to 430 m depth interval. Some of the stringers are very strong and clear all the way across the image while others become weak in places, but nonetheless go all the way across the survey. Some of these stringers exhibit broad, low relief, undulating surfaces (see Figure 8.35) and areas of comparatively low reflector elevation are exhibited in the X10N-2 to X11-3 profile.

The top of the B-Salt is apparent as a nearly continuous reflection event, but at times not as strong a reflector as some of the stringers in the B-Salt. Although the lower half of the C shale is often high in velocity and provides a second reflector above the top of the B-Salt, the boundary between the B salt and C shale is sometimes difficult to discern in the composite cross-well images due to the variable thickness of anhydrite and salt interbeds in the lower portion of the C shale. Within the C-Shale, at approximately 400 m depth, three or four nearly continuous and strong reflectors are commonly evident. The interpreted top of the B-Salt exhibits broad, low relief, undulating surfaces (see Figure 8.36) and is generally unremarkable.

The bottom of the D-Salt, at approximately 380m, is a very strong and clear reflector with the top of the D-Salt the same, though these are probably not specifically the top and bottom of the D-Salt, but rather a tuned wavelet caused by the D-Salt and the stringer in the middle of this unit.

Because of the low compression wave velocity within the D-Salt, the interface with the overlying high velocity E member dolostone is a very strong reflector, a much better reflector than the top of the E dolostone at approximately 340 m. The interpreted topography of this interface is illustrated in Figure 8.37 in which a notable comparatively low reflector elevation is evident in the profile between X11-3 and X10N-2. Within the E dolostone there are one or two undulating reflectors internal to the E dolostone that are stronger reflectors than the top even though the F-Salt overlies the E dolostone.

The F-Salt is composed of four salt layers with clear, high compression wave velocity stringers between them. One major stringer at an approximate depth of 310m is so thick that it produces distinct reflections from its top and bottom (at kilohertz frequencies). In some areas, the SsF-3 anhydrite layer produces an apparent merging or diverging of these reflectors or, in some instances where this layer is of sufficient thickness, a third reflector. The top of the F-Salt is at approximately 300m and it is expressed as a strong, flat reflector, with a thin, parallel stringer immediately below it. The interpreted topography of this interface is illustrated in Figure 8.38 in which comparatively low reflector elevations are evident in the cross-well profiles X10N-2 to X11-3 and X10N-2 to X10N-3.

The interpreted topography of the F-Shale is illustrated in Figure 8.39. This figure illustrates a number of comparatively low reflector elevations, exhibiting greater relief than similar undulations in the formation interfaces below (up to 8.4 m of apparent reflector sag in some areas).

8.2.2.1 Cross-Well Profile X10N-1 to X10N-2

In this survey, illustrated on Figure 8.15, the reflectors identified near the top of the B salt (Zone "A"), were weak in comparison to the clear and typical images described above. However, the base of the B-Salt is intact and a strong reflection is seen from the A2 Carbonate. Zone "B", in the F-Salt near X10N-2 displays a broad arch-shaped feature that appears to involve more than one stringer. Zones "C" and "D" are significant because they are along the borehole where a gain has been applied to the data. Despite this gain the reflections in Zones "C" and "D" are weak, indicating that the reflectors in this region may have been altered in some manner. Strong and clear reflections are evident within the E dolostone and the top of the F-Salt. Zone "B" is also notable because the stringers in the F-Salt are interrupted and discontinuous, especially the thick stringer in the middle of the F-Salt near X10N-2. However, the top of the F-Salt is strong across the image. All anomaly zones in this image are classified as Class 2 anomalies. The "pixelized" velocity tomogram, shown in Figure 8.27, indicates that, in general, the seismic velocity model values are lower near Well X10N-2. The velocities estimated for the E dolostone are also higher near the centre and X10N-1 than in the layered velocity model. These differences in the velocity model interpretations suggest that the apparent elevation differences in the arch-shaped features may be associated with the differences in velocity models when generating the reflection ray traces. In addition, the "pixelized" inversion indicates that the physical features generating the anomalies within this profile are more associated with the conditions near Well X10N-2.

8.2.2.2 Cross-Well Profile X10N-2 to X10N-3

The profile X10N-2 to X10N-3, illustrated on Figure 8.16, exhibits significant disturbance of the seismic reflectors. During field acquisition, the signal strength was also relatively weak in Zone “E” (also see Figure 8.41). As a result, this profile is difficult to interpret. In this image it appears that there is a relatively large zone of sagging or slumping of reflectors in the middle of the survey (see Figure 8.38). All formations above the F-Salt exhibit significant disturbance of the reflectors, particularly in the middle of the profile (see Figures 8.38 and 8.39). The top of the F salt is somewhat difficult to discern across much of the profile. Within the F salt, a number of the reflectors appear to converge, suggesting solution mining within this horizon. The stringers in the F-Salt (Zone “F”) are present but rather weak and disjointed. The top of the D salt is difficult to discern and appears to have possibly converged onto the top of the E unit, though the resolution in the reflectors combined with the limited thickness of the D salt inhibit a conclusive interpretation. The strong reflectors that delineate the E dolostone, especially the base of the dolostone are weak, suggesting that this reflector may be either obscured by materials above the reflector that dissipate and diffuse the seismic energy or the formation itself has been altered. The top of the B salt is present and the stringers in the B-Salt are present, but, again, not as clear and strong as in many of the profiles, but the reflectors suggest only small relief in the inferred topography of these formations (see Figure 8.35 and 8.36). The large-amplitude, flat A2 Carbonate reflection, tuned with the underlying A2 evaporite is present. All anomaly zones in this image are Class 2 anomalies. The “pixelized” velocity tomogram, shown in Figure 8.28, indicates that, in general, the seismic velocity model values are lower near Well X10N-2. These differences in the velocity model interpretations suggest that the apparent elevation differences in the arch-shaped features may be associated with the differences in velocity models when generating the reflection ray traces. In addition, the “pixelized” inversion indicates that the physical features generating the anomalies within this profile are more associated with the conditions near Well X10N-2.

8.2.2.3 Cross-Well Profile X10N-2 to X10N-4

Cross-well profile X10N-2 to X10N-4, illustrated on Figure 8.17, exhibits a number of areas of disturbance between the wells. Overall, the reflections throughout the profile are relatively low amplitude (weak) and are not as clear as in many other profiles, particularly in the “up going” image. Zones "G" and "H" exhibit weak reflectors, particularly in the E Member and above the mid-height of the B Member. Considering the relatively weak reflectors, however, a number of features may be gleaned from this profile. The D salt appears to thin toward X10N-2, though it is somewhat difficult to distinguish in this image. Two zones of comparatively high compression wave velocity were noted adjacent to X10N-4 at the depths of about 260 m and about 305 m. It is considered that these may be indicative of the cement introduced into this well in attempts to seal off lost circulation zones during drilling. This conclusion is supported by the difference in the sonic log completed prior to introducing the cement into the well that does not indicate a substantial increase in sonic velocity characteristics while the trace through the tomographic image completed after the cement event that shows this increase. All the anomalies in this image are considered Class 2 anomalies with the exception of the relatively high seismic velocity anomalies. These are unclassified and are considered the result of cementing operations. The “pixelized” velocity tomogram, shown in Figure 8.30, indicates that, in general, the seismic velocity model values are significantly lower near Well X10N-2, especially near the base of the F salt, and higher near X10N-4, particularly in the E dolostone unit. These differences in the velocity model interpretations suggest that the difficulties in resolving reflectors through this image may be associated with the differences in velocity models when generating the reflection ray traces. In addition, the “pixelized” inversion indicates that the physical features generating the anomalies within this profile are more associated with the conditions near Well X10N-2.

8.2.2.4 Cross-Well Profile X10N-2 to X10N-6

In this survey, illustrated on Figure 8.18, the F salt near borehole X10N-6 is intact and the reflectors are strong and clear, especially the thick stringer in the middle of the F-Salt formation. However, the very top of the F salt near X10N-6 and all of the F salt near X10-2 (Zone “I”) exhibits weak reflectors. The reflectors at the top of the B salt are weak in zones “J” and “K” while the stringers in the base of the B-Salt are strong, clear, and in place. Furthermore, the A2 carbonate reflection is good except for one apparent fault with a small offset. In the middle of the profile, the G shale and Bass Islands formations appear to sag toward borehole X10N-2 (Zone "L"). The “pixelized” velocity tomogram, shown in Figure 8.31, indicates that, in general, the seismic velocity model values are generally lower near Well X10N-2, especially near the base of the D salt, and higher throughout the profile in the E dolostone unit. These differences in the velocity model interpretations suggest that the apparent sag in the reflectors through this image may be associated with the differences in velocity models when generating the reflection ray traces. In addition, the “pixelized” inversion indicates that the physical features generating the anomalies within this profile are more associated with the conditions near Well X10N-2.

8.2.2.5 Cross-Well Profile X10N-2 to X11-3

Between Wells X10N-2 and X11-3, the seismic reflections are distorted, discontinuous and weak in many areas, as illustrated on Figures 8.19 and 8.42. During processing, significant gain was applied to the field data to develop this image. The resolution is relatively low as well, due to signal loss in the higher frequencies. Given these issues, however, a number of general trends can be observed in this profile. Within the B salt, the lower stringers are more clear and consistent near X11-3, with the upper part of the B salt exhibiting very weak reflectors near both X11-3 and X10N-2 (Zones "M" and “N”). The major carbonate interbed (stringer) in the B salt illustrated in Figure 8.35 appears to sag toward the middle of this image. Reflectors within the lower part of the C unit also appear to decline toward the centre of the profile with the most significant change in elevation being near the middle of the profile. Reflectors around the boundaries of the D salt, however, exhibit a trend of declining somewhat toward X11-3, again with the most significant change near the centre of the profile. The up-going and down-going profiles exhibit differences in this profile in which the reflectors in the up-going image suggest some sagging of the discontinuous upper reflectors (above the F salt) in the middle of the profile, whereas the down-going image suggests arched reflectors in this same area. Although the reflectors are poorly resolved and discontinuous, the reflectors in the upper-most formations appear to be more somewhat more horizontally ordered. Two relatively low velocity zones are also indicated by the velocity tomogram near X11-3 at the depths of about 400 m and 440 m in the C and B units respectively. Zones "M" is considered a Class 4 anomaly because of both weak reflectors and significantly lower seismic velocities through this area. Zone "N" is considered a Class 2 anomaly. Because of the relatively low signal strength and disordered reflectors much of this profile is considered to be within the Class 3 range of anomaly categorization. A “pixelized” tomogram of this profile could not be generated due to the comparatively small number of seismic wave first-arrival events. Thus, greater resolution of the velocity model beyond the layered model could not be achieved.

8.2.2.6 Cross-Well Profile X10N-3 to X10N-4

Cross-well profile X10N-3 to X10N-4, illustrated on Figure 8.20, is largely unremarkable except for a few features of note. A low seismic velocity zone is evident near X10N-3 at a depth of about 308 m. All circulation was lost at this level in X10N-3 and it is considered that this zone likely represents a low-height brine-filled feature. In this same area, it appears that the upper reflectors in the F salt also decline toward X10N-3.

8.2.2.7 Cross-Well Profile X10N-3 to X11-3

As with the profile X10N-2 to X11-3, between Wells X10N-3 and X11-3 the seismic reflections are distorted, discontinuous and weak in many areas, as illustrated on Figure 8.21. During processing, significant gain was applied to the field data to develop this image. The resolution is relatively low as well, due to signal loss in the higher frequencies. Given these issues, however, a number of general trends can be observed in this profile. Within the B salt, the stringers are discontinuous and distorted, however, the reflectors suggest two zones of distortion. These two zones, Zones “O” and “P”, exhibit some sagging and uncharacteristic reflections. In some areas, these reflectors appear somewhat overlapped though the resolution is not sufficient to be conclusive in this regard. Of note, the sag at the top of the B salt in Figure 8.36 is close to the former solution mining Well 4. Progressing upward within the profile, these zones appear to merge and, by the D salt, it appears that the top of the D salt has converged with the top of the E unit and top of the F unit has sagged significantly in the centre. Near the top of the down-going image, the reflectors within the Lucas and Amherstburg Formations appear somewhat more ordered and horizontal. The two relatively low velocity zones evident in the X10N-2 to X11-3 profile are not evident near X11-3 in this profile and velocities appear reasonably consistent with other profiles. Because of the relatively low signal strength and disordered reflectors, much of this profile is considered to be within the Class 3 range of anomaly categorization. In the comparison of the velocity tomograms generated for this profile using the different processing models, the “pixelized” inversion provided in Figure 8.29 indicates significant changes within the middle of the profile where the resolution should be the best (numbers of ray paths passing through individual processing “pixels”). This image suggests that the ground above the D-Salt has been altered such that the seismic velocities through this zone are lower than those that would be indicated using a layered model, thus further suggesting rock damage patterns consistent with the formation of the nearby sinkhole from solution mining within the D and F salt beds (see Figure 8.21).

8.2.2.8 Cross-Well Profile X10N-3 to X11-4

In this image, illustrated on Figure 8.22, the reflectors in the B salt unit are weak over the majority of the image, though the alteration is more evident closer to Well X11-4 (Zone "Q"). The entire A2 carbonate reflection (Zone "R") in this image also exhibits a comparatively very low amplitude. It is not considered that the A2 carbonate has been dissolved or removed, but rather of the stringers and formations above it have been disturbed or the presence of nearby cavities within the Fresnel zone have scattered the seismic energy such that no reflection or a very weak reflection occurs at the A2 carbonate interface. In Zone “Q” the phenomena that has altered the B salt reflectors has extended slightly into the C shale, but may not have penetrated up into the overlying D unit. This feature also exhibits relatively low seismic velocity. This low seismic velocity feature near the interface of the D and C Members appears to extend across the image but is less evident near Well X10N-3 and X11-4. A low “arching” relief is apparent in the C shale in this profile as well as a reduction in seismic velocity near the X11-4 well, indicative of a significant change in material properties in this vicinity. Zone 5, near the top of the F Member salt near X11-4 exhibits weak reflectors. Zone "Q" is considered a Class 4 anomaly in its upper reaches, and the lower part of this zone and Zone "R" are considered Class 3 anomalies. Zone "S" is considered a Class 2 anomaly. The “pixelized” inversion of the seismic velocity suggests that the low velocity zone (near the top of Zone Q) may be smaller in dimension but with a greater change (lower) velocity than the layered velocity model. In addition, the “pixelized” inversion indicates that the physical features generating the anomalies within this profile are more associated with the conditions near Well X10N-3.

8.2.2.9 Cross-Well Profile X11N-3 to X11-4

In this survey, illustrated on Figure 8.23, the reflectors in the B salt have been disturbed in Zones “T” and “U”. Zones “T” and “U” taken together, show that the top of the B-Salt has been altered across the entire image and the entire thickness of the B salt has been changed in the center of this image. Moreover, the A2 Carbonate reflection at the base of the B salt is not readily apparent over the central portion of the image. It is not considered that the A2 carbonate has been dissolved or removed, but rather the stringers and formations above it may have been disturbed and the seismic energy was scattered such that no reflection or a very weak reflection occurs at the A2 carbonate interface. Two features make Zone “U” significant. First, the reflectors at the top of the B salt are very weak and this feature extends into the C shale. Secondly, the seismic velocity tomogram indicates a zone of significantly low velocity compared to the surrounding materials. There is some indication that this feature may extend into the D salt unit as well. The E dolostone and the F salt appear to have not been affected. As with the X10N-3 to X11-4 profile, the C shale exhibits a low-relief arch shape in some areas. Zone "T" is considered a Class

3 anomaly and Zone "U" a Class 4 anomaly. Note that these zones are similar in shape and position to Zone "Q" and "P" in the Wells X10N-3 to X11-4 profile and the actual features that create these anomalies may lie partially within the Fresnel zones of both profiles. The “pixelized” velocity inversion of this profile is only somewhat different than the layered velocity model, suggesting that the apparent positions and character of the reflectors in the composite image (Figure 8.23) have not been shifted by velocity anomalies not otherwise identified. The notable difference between the two velocity tomograms is an increase in the overall size of the velocity anomaly (Zone “U”) and a reduction of the intensity of the velocity change (average velocities within this zone are somewhat higher).

8.2.3 Synthesis and Summary of Interpretations For Crossing B

The drilling, testing, and subsequent analyses and comparisons to historical information, lead to a number of conclusions regarding the interpreted current rock mass conditions for Crossing B.

In all wells, the drilling did not encounter large voids or cavities within any of the formations except the Lucas Formation and the one cavity that was encountered is considered to be a natural feature. All wells encountered rock resting directly on the salt deposits.

The characteristics and prevalence of open or partially open joints/fractures suggest that some bed delamination and separation has occurred as a result of the solution mining. In the areas of wells X10N-2, X10N-3, and X11-4, these predominantly horizontal openings are associated largely in strata overlying salt deposits that exhibit some evidence of solution mining. In these areas, the beds likely separated during the mining and, later, subsidence of progressively higher strata. The joints/fractures remain open likely due to the bridging effects of the intact blocks of rock above and beside the well area, thus exemplifying a “bulking” of the rock mass during and due to subsidence or removal of underlying materials. It is expected that the open joints/fractures are not laterally continuous but represent a connected network of fractures and openings along horizontal and vertical shear surfaces. At X10N-2, there is some indication that the Salina C Member formation that exists beneath the salt deposits most likely to have been mined (F and D salt) also exhibits a relatively small degree of bedding opening. Near X10N-2 it is considered that this may be the combined result of stress relief during mining of the F and D units compounded by deeper solution mining in the B salt in nearby Well 8 (though early dissolution likely occurred in the D salt) Wells 5 and 12, and the collapse (sinkhole), the centre of which was less than about 200 m from Well X10N-2. The distinct element numerical modelling completed as part of this study provides further indication that such mechanisms are reasonable as illustrated on Figures 8.56 to 8.59.

Where the wells exhibited a full to partial loss of circulation during drilling, it is considered that the bedding delamination or opening of joints/fractures has led to hydraulic connection between these wells and the rock mass closer to the brine well field. Some hydraulic communication may have also developed along the interface between overlying rock beds and nearly pure salt infill zones via small networks of preferential salt dissolution from fresh water at the top of stratified brine from solution mining at a great distance away. Though this hydraulic communication exists, there is little to suggest that the overall rock mass at and near the locations of X10N-1 and X10N-4 has been meaningfully altered by displacement or undermined by salt dissolution.

The opening of horizontal bedding and vertical joints is considered to be one of the fundamental reasons for the attenuation of seismic energy and loss of reflector amplitude in the Class 2 anomalies present in the cross-well profiles. The velocity tomograms appear largely unaffected through these regions, indicating that the openings of the bedding and joints is of sufficiently small magnitude to not influence the average velocity across the mass and the calculated velocities are reasonably consistent with typical seismic velocity characteristics of an intact mass in these formations. It is of note that the influence of open fractures is evident in the velocity tomograms where they are within the Lucas Formation, Amherstburg Formation, and Sylvania Member of the Amherstburg Formation. All of these formations exhibit lower seismic velocities than one might expect for massive (unfractured) formations with similar limestone and dolostone mineralogy, though these formations did not have the same degree of suitable coverage of seismic testing as those within the middle of the profiles due to the wider seismic wave incidence angles.

The Class 3 anomalies present in the X10N-3 to X11-4 and X11-3 to X11-4 profiles are considered representative of zones in which the rock is more substantially influenced by the opening of joints and where the seismic energy may be further scattered by the presence of nearby cavities and rubble within the Fresnel zone. In particular, cross-well profile X11-3 to X11-4, running parallel and immediately east of Sandwich Street, crosses between a set of four former solution mining wells that includes Wells 4, 10, 15, and 22 and the anomaly is consistent with the historical evidence of solution mining within the B salt in this area (see Figures 7.11 and 8.51). Historical evidence indicates that Well 10, located to the west of the profile was operated as a water injection well for a period of about 8 years, and that Well 15, located on the opposite side of Sandwich Street operated as a deep pumping well for about two years of this time (1947 and 1948) when Well 15 was one of the most productive wells on the site. After Well 10 was abandoned, Wells 15 and 22 operated as deep brine extraction wells when only Well 19 was injecting freshwater. These injection and pumping conditions likely created preferential dissolution of salt between these wells and crossing beneath Sandwich Street. Profile X10N-3 to X11-4 crosses immediately to the south of solution mining Well 10 parallel to Prospect Avenue. In addition, these profiles exhibit significant zones of reduced seismic velocity in comparison with the surrounding materials within the Salina Formation C unit near Well X11-4. This zone (in both profiles) is considered to represent a Class 4 anomaly and may be indicative of a nearby brine filled cavity or a former cavity filled with brine and rubble. At the location of Well X11-4, no cavities or voids were encountered, though circulation was lost entirely in the C unit at this level at a depth of 388 m. This feature may be larger but analogous to the solution mining and subsequent upward propagation of the storage caverns at Wells 32 through 35 formed by Canadian Industries Ltd. and later assumed by Dome Petroleum and BP as illustrated on Figures 7.14 and 8.60. The dimensions and spatial position of these Class 3 and Class 4 anomalies off the profile lines can not be directly established. However, given that these anomalies are evident on both profiles suggests that the anomalies likely lie in the region bound by these profiles and Wells

10 and 4, though the deeper and more northerly end of the Class 3 anomaly in profile X11-3 to X11-4 may be more directly associated with the solution mining at Wells 4 and 15. Based on the results of the cross-well testing, the drilling, and down-hole testing, it is anticipated that the solution mining has had a direct influence on the rock mass in the immediate vicinity of Well X11-4, though this well lies beyond direct impingement on any cavities or zones of significant salt removal as the overlying rock beds rest directly on the salt deposits.

Based on the evidence and interpretations of the drilling and testing, the maximum extent of meaningful or significant solution mining activity along the southern boundary of the Sandwich West brine well field, along Prospect Avenue, has likely been limited to an area of about 100 m to 120 m extending from the solution mining wells. Figures 8.64 to 8.69 illustrate the limits of direct (primary) influence of solution mining from individual mining wells using the inferred limits of the former cavities as illustrated in Figure 8.48 through 8.50 and the edges of the seismic anomaly identified in cross-well profile X11-3 to X11-4.

Beyond the limits of direct influence of solution mining, it is considered that the rock mass exhibits secondary effects from the solution mining activities and subsidence that occurred within the brine well field. These secondary effects are interpreted to include some minor evidence of hydraulic communication between opened joints/fractures, opened joints/fractures that disturb the seismic energy transmission through these regions, and ground surface subsidence. Based on early empirical work from other case histories, an “angle of draw” of about 15^o was used for the US study (Cording, May 2006) and this was defined based on the distance to points where the settlements ranged between about 12 and 100 mm. The numerical modelling completed for the detailed analyses discussed in the draft report prepared for the Canadian DRIC site indicated angles of draw ranging from about 8^o to 12^o, depending on the shape of the edge of the subsurface cavity used in the model (see Figure 8.63). In this case, the “angle of draw” was defined to the furthest distance (since the modelled subsidence of the surface was asymmetrical) at which the rock surface settlement was estimated to be 25 mm or less (see Figure 8.60). For cavities with thin edges, with side slopes on the order of 9^o to 18^o, the corresponding “angles of draw” were about 8^o to 9^o, respectively. For cavities with vertical walls, the modelling indicated “angles of draw” between about 9^o and 12^o. Therefore, for defining the limit of secondary influence, an “angle of draw” of 9^o was used in areas where the former edges of the cavities were inferred to be thin based on salt bed thickness, and, in the area of the identified seismic anomaly between X11-3 and X11-4, an “angle of draw” of 12^o was also used as a guide because of the irregular anomaly shape.

For each of the former solution mining wells, a radius of influence was defined based on field evidence at the new exploration wells (e.g., thinning of salt beds) and the hypothetical maximum primary influence zones based on historical evidence, as discussed in Section 8.1.6 and shown in Figures 8.48 to 8.50. Using the assessed “angles of draw” described above, additional radii of influence were extended from these wells to the estimated maximum limit of secondary solution mining influence. This approach was also compared to the settlement monitoring data from OPG (Figure 7.18) and the results of the numerical analyses (Figure 8.55), where the position of maximum estimated settlement was centred on the known sinkhole location. Based on this logic, line segments were drawn based on tangent points to the influence radii and bounds of primary and secondary solution mining influence were defined for the entire DRIC project and these are shown on Figure 8.69.

The assumptions and analyses underlying the definition of these zones of primary and secondary influence have also been examined in comparison to three other potential interpretations of the subsurface conditions to gauge whether other assumptions may lead to greater off-set distances between the proposed bridge and the former solution mining site.

Alternative Hypothesis A – Thinning of Salt Beds by Natural Causes: In contrast to the conclusions made in this report, it could be inferred that thinning of the salt beds at the locations of exploratory wells X10N-2 and X10N-3 is the result of natural processes due to geologic peculiarities in these areas during the genesis of these formations. Given that the exploratory wells at the locations also exhibited the greatest number of open fractures in the overlying formations (except for the Lucas Formation), it is difficult to justify these being solely of natural origin, and this hypothesis has been largely rejected in our evaluation (except as described below).

Alternative Hypothesis B – Thinning of Salt Beds by Creep Displacements: If the salt bed thinning is inferred to be related to creep displacements toward a nearby cavity, and the measured fractures are a secondary result of solution mining, this assumption may lead to the conclusion that the ground closer to the former brine wells is suitable for the bridge location. However, residual uncertainty remains regarding the degree to which the open fractures/joints may close in the future. Some of the monitoring data from the OPG site (see Figure 7.18) suggests that there may be continued long term displacement associated with this mechanism. Defining the magnitude and rate of this displacement with a defined degree of certainty is difficult, however, given the limited available data.

Alternative Hypothesis C – Large Steep-Walled Cavity: Recognising that rock-on-rock (salt) contact was observed in all exploratory wells, it could be presumed that the salt beds at particular wells (X10N-2, X10N-3, and X11-4) were thinner as a result of the processes outlined in either Alternative Hypotheses A or B. In this case, the cavity or cavities caused by solution mining may have been near, but not encountered by, the new exploratory wells. Assuming that the cavities approached no closer than 5 m from the exploratory wells (so as to leave the salt mass relatively intact), angles of draw defining the extent of secondary influence were projected from these locations to the ground surface (see Figures 8.64 through 8.68). The angles of draw for this alternative hypothesis were selected to be consistent with the preliminary angle of draw used for the US study in defining the corridors within which to conduct explorations, and the angle of draw resulting from numerical modelling of cavities with vertical walls. In all cases, these limits were within the boundaries drawn using the approach that forms the basis of this study as described above.

The pixelized" seismic tomograms (Figures 8.25 through 8.33) and interpolated topography of key reflector surfaces (Figures 8.34 through 8.39) support these defined boundaries and conclusions. South of exploratory Wells X10N-1 and X10N-3 the interpolated surface topography of the key reflector surfaces is unremarkable and exhibits low-relief undulations consistent with the expected natural geologic conditions. North of these wells, the undulations of the surface becomes progressively more pronounced, particularly in the formations above the D and F salt beds. The most significant features observed in these interpolated reflector surfaces are within those profiles that cross the former solution mining site where rock damage is known to have occurred. The "pixelized" seismic velocity tomograms further suggest, through a different data processing and interpretation approach, that those areas outside the defined limit of secondary solution mining influence exhibit unremarkable conditions consistent with native formation conditions. The changes in the velocity model indicated by the alternative data processing approach are more pronounced at and within the area defined as subjected to primary solution mining influence. Therefore, regardless of the approach used for the cross-well seismic data processing and interpretation, the areas of altered rock are evident and these fall within the defined boundaries.

Considering these alternative hypotheses and alternative methods for data processing and interpretation, the defined boundaries of primary and secondary influence represent a prudent and reasonable approach to defining the suitable areas for a life-line structure that must be in service for more than half a century.

8.3 Interpreted Rock Mass Conditions For Crossing C

8.3.1 Interpreted Conditions at Crossing C Well Locations

With the exception of Wells X11-3 and X11-4, as discussed in Section 8.2, above, all the remaining Crossing C wells (X11 Series) exhibited conditions during drilling and down-hole logging consistent with conditions that may be expected elsewhere in the Windsor-Detroit area where solution mining has not occurred. Other than difficulties associated with control of artesian water flows from the Lucas, Amherstburg, and Bois Blanc Formations, the conditions encountered during drilling were unremarkable in these wells.

8.3.2 Interpreted Conditions Along Crossing C Cross-Well Profiles

Cross-well seismic profiles radiating around Wells X11-3 and X11-4 are discussed above in Section 8.2 as related to Crossing B as these profiles cross the known solution mined areas. Within the remaining five profiles between Wells X11-1, X11-2, X11-5, and X11-6 exhibited conditions that exemplify the consistent and generally flat-lying formations of the Michigan Basin geology. Other than features that may be geologically interesting, there were no anomalies of note in these profiles.

8.3.3 Synthesis and Summary of Interpretations For Crossing C

The interpreted current conditions of the rock formations along the Crossing C alignment indicate that no solution mining has occurred or has influenced the area proposed for the main span bridge foundations. However, the current rock conditions along the southern reaches of the potential Crossing C alignment have been significantly influenced by solution mining in the area of the Sandwich West brine well field, as described under Section 8.2, above, parallel to Sandwich Street, along the X11-3 and X11-4 profile.

The Class 3 anomalies present in the X10N-3 to X11-4 and X11-3 to X11-4 profiles are considered representative of zones in which the rock is more substantially influenced by the opening of joints and where the seismic energy may be further scattered by the presence of nearby cavities and rubble within the Fresnel zone. In particular, cross-well profile X11-3 to X11-4, running parallel and immediately east of Sandwich Street, crosses between a set of four former solution mining wells that includes Wells 4, 10, 15, and 22 and the anomaly is consistent with the historical evidence of solution mining within the B salt in this area (see Figures 7.11 and 8.51). Historical evidence indicates that Well 10, located to the west of the profile was operated as a water injection well for a period of about 8 years, and that Well 15, located on the opposite side of Sandwich Street operated as a deep pumping well for about two years of this time (1947 and 1948) when Well 15 was one of the most productive wells on the site. After Well 10 was abandoned, Wells 15 and 22 operated as deep brine extraction wells when only Well 19 was injecting freshwater. These injection and pumping conditions likely created preferential dissolution of salt between these wells and crossing beneath Sandwich Street. Profile X10N-3 to X11-4 crosses immediately to the south of solution mining Well 10 parallel to Prospect Avenue. In addition, these profiles exhibit significant zones of reduced seismic velocity in comparison with the surrounding materials within the Salina Formation C unit near Well X11-4. This zone (in both profiles) is considered to represent a Class 4 anomaly and may be indicative of a nearby brine filled cavity or a former cavity filled with brine and rubble. At the location of Well X11-4, no cavities or voids were encountered, though circulation was lost entirely in the C unit at this level at a depth of 388 m. This feature may be larger but analogous to the solution mining and subsequent upward propagation of the storage caverns at Wells 32 through 35 formed by Canadian Industries Ltd. and later assumed by Dome Petroleum and BP as illustrated on Figures 7.14 and 8.60. The dimensions and spatial position of these Class 3 and Class 4 anomalies off the profile lines can not be directly established. However, given that these anomalies are evident on both profiles suggests that the anomalies likely lie in the region bound by these profiles and Wells 10 and 4, though the deeper and more northerly end of the Class 3 anomaly in profile X11-3 to X11-4 may be more directly associated with the solution mining at Wells 15 and 22. Based on the results of the cross-well testing, the drilling, and down-hole testing, it is anticipated that the solution mining has had a direct influence on the rock mass in the immediate vicinity of Well X11-4, though this well lies beyond direct impingement on any cavities or zones of significant salt removal as the overlying rock beds rest directly on the salt deposits.

Along the north side of the Sandwich West brine field, the surface seismic reflection survey provides some evidence that disturbance of the seismic response of the rock mass may have extended as far as about 170 m from Wells 7, 13, and 21, where significant mining of the D and B salt deposits occurred, though the degree and influence distance of disturbance appears to be somewhat less near Well 13. A number of subsurface seismic anomalies were identified and, though these have not been classified due to the low resolution and high signal to noise ratio of the data and results, suggest that areas of significant disturbance may be concentrated within a region to the north of Wells 7, 13, and 21 radiating about 100 m distant from the wells, similar to the conditions along the southern boundary of the former solution mining site.

The conditions encountered in Well X11-3, coupled with the broad indications of solution mining influence provided by the surface seismic reflection survey, and the extents of solution mining as judged under Section 8.2 for areas near and south of Prospect Avenue, suggest that a similar radius of direct influence may be applicable for solution mining wells near the northeastern boundary of the Sandwich West brine field. Historical information, however, suggests that Well 4 may have had a greater radius of influence in the D salt than in these other areas. Therefore, it is considered that a more prudent radius of influence of about 120 to 150 m is an appropriate limit of direct (primary) influence of solution mining considering the residual uncertainty in this area. Beyond the limits of primary influence of solution mining, the rock mass is expected exhibits secondary effects from the solution mining activities and subsidence that occurred within the brine well field. These secondary effects are interpreted to include some minor evidence of hydraulic communication between opened joints/fractures, and opened joints/fractures that disturb the seismic energy through these regions. Based on the cross-well seismic imaging, the condition of the rock mass evident at Wells X10N-3, X10N-4, X11-3, and X11-4, and the results of the numerical modelling, it is anticipated that these secondary effects exist to diminishing degrees away from the edge of the solution mined areas. North of X11-3, along Sandwich Street, it is considered that these secondary effects diminish to negligible degrees at a distance of about 60 m to 90 m north of Well X11-3 and 60 m to 70 m south of Well X11-4. Figures 8.67 and 8.68 illustrate the limits of primary and secondary influences of the solution mining near these wells.

As discussed in Section 8.2 for Crossing B, for each of the former solution mining wells, radii of influence for primary and secondary effects of the solution mining were defined based on field evidence, historical information, settlement monitoring at the OPG site, and numerical modelling. Based on this logic, line segments were drawn based on tangent points to the influence radii and bounds of primary and secondary solution mining influence were defined for the entire DRIC project and these are shown on Figure 8.69.

9.0 ASSESSMENT OF FUTURE ROCK MASS STABILITY

Outside of the areas of primary and secondary influences from solution mining as defined in Section 8 of this report, it is anticipated that the future stability and performance of the rock mass will be typical of the rock formations elsewhere in the Windsor-Detroit vicinity. It is considered that long-term displacements of the rock mass that occur outside the limits of secondary influences of solution mining will be of small magnitudes and a wide-spread nature such that they will be unimportant to the bridge foundations. In this regard, the most critical element for the future performance of the bridge foundations will be addressing the conditions within the Lucas Formation. Based on the conditions encountered during drilling and the down-hole logging of bedrock features, it is anticipated that a bedrock grouting or improvement program may be necessary to provide additional assurance of long-term satisfactory performance. Characterisation of bedrock fracture and opening patterns and magnitudes should be addressed during final design investigations, regardless of which of the three potential crossing sites is selected for the bridge location.

9.1 Crossing A (X10 South)

For Crossing A, located well outside of the areas of solution mining, it is anticipated that the future stability and performance of the rock mass within the alignment will be typical of the rock formations elsewhere in the Windsor-Detroit vicinity.

9.2 Crossing B (X10 North)

Within the areas defined by the limits of the primary and secondary solution mining influence defined in Section 8, there remains some residual risk of long-term displacement. The results of the UDEC modelling indicate that near the edge of primary dissolution and removal of salt surrounding the perimeter well locations (primary influence zone and edge of brine well field), settlements may be on the order of 100 mm, consistent with historical data. The proportion of this displacement that has already occurred is unknown. For prudent planning and site evaluation purposes, however, the full ranges of settlement identified by the UDEC modelling should be considered within the zone of secondary influence as illustrated on Figure 9.1. Geographic coordinates of the southern boundaries of each of these limits are provided in the table below. Based on the interpreted extent of solution mining influence, the UDEC modelling results, and the historical evidence, the potential future rock mass displacements are considered to be negligible south of the defined limits of secondary solution mining influence for Crossing B (X10N) and should be within limits compatible with those expected for rock conditions unaltered by solution mining elsewhere in the region.

Table 9.1 Limits of Primary and Secondary Solution Mining Geographic Coordinates (Southern)

Limit of Primary Solution Mining Influence		Limit of Primary Solution Mining Influence	
Easting	**Northing**	**Easting**	**Northing**
328,117	4,683,399	328,121	4,683,319
328,060	4,683,419	328,009	4,683,355
327,837	4,683,445	327,935	4,683,362
327,366	4,683,670	327,813	4,683,385
		327,335	4,683,602

NOTE: Coordinates NAD 83 Projection UTM Zone 17N

9.3 Crossing C (X11)

Although the location for the main pier of Crossing C is planned to be within the northern group of wells drilled for this project that are considered unaffected by solution mining, the approaches to this area pass close to and over portions of the Sandwich West brine field. Two areas of concern are identified for the future performance of the rock mass in this vicinity, the first being the lands bordering the north eastern edge, and the second being the area of Sandwich Street that passes across the eastern section of the Sandwich West brine field.

Within the areas defined by the limits of the primary and secondary solution mining influence defined in Section 8, there remains some residual risk of long-term displacement. The results of the UDEC modelling indicate that near the edge of primary dissolution and removal of salt surrounding the perimeter well locations (primary influence zone and edge of brine well field), settlements may be on the order of 100 mm, consistent with historical data. The proportion of this displacement that has already occurred is unknown. For prudent planning and site evaluation purposes, however, the full ranges of settlement identified by the UDEC modelling should be considered within the zone of secondary influence as illustrated on Figure 9.1. Geographic coordinates of the southern and northern boundaries of each of these limits are provided in the tables below. Based on the interpreted extent of solution mining influence, the UDEC modelling results, and the historical evidence, the potential future rock mass displacements are considered to be negligible outside the defined limits of secondary solution mining influence and should be within limits compatible with those expected for rock conditions unaltered by solution mining elsewhere in the region.

Table 9.2 Limits of Primary and Secondary Solution Mining Geographic Coordinates (Crossing C – Southern)

Limit of Primary Solution Mining Influence		Limit of Secondary Solution Mining Influence	
Easting	**Northing**	**Easting**	**Northing**
328,117	4,683,399	328,121	4,683,319
328,060	4,683,419	328,009	4,683,355
327,837	4,683,445	327,935	4,683,362
327,366	4,683,670	327,813	4,683,385
		327,335	4,683,602

NOTE: Coordinates NAD 83 Projection UTM Zone 17N

Table 9.3 Limits of Primary and Secondary Solution Mining Geographic Coordinates (Crossing C – Northern)

Limit of Primary Solution Mining Influence		Limit of Secondary Solution Mining Influence	
Easting	**Northing**	**Easting**	**Northing**
327644	4684226	327706	4684273
327976	4684068	328013	4684128
328086	4683974	328123	4684043
328102	4683937	328163	4683981
328102	4683877	328173	4683940
328092	4683820	328172	4683872
328079	4683766	328150	4683764
328078	4683712	328190	4683708
328107	4683670		
328154	4683646		

NOTE: Coordinates NAD 83 Projection UTM Zone 17N

The reach of Crossing C alignment that passes over the eastern end of the Sandwich West brine well field is of primary concern for this alignment. The character of the seismic anomaly found between wells X11-3 and X11-4 (significant low-velocity zones coupled with relatively large decreases in relative reflection amplitude) is of concern in this case. This anomaly is also consistent in depth and horizontal position with the nearby solution mining at Wells #4, #10, #15, and #22 (particularly these latter two wells). For a period of eight years, there was flow from the brine field west of Sandwich Street to Wells #22 and #15, as well as flow between these to wells. Figure 9.2 illustrates the spatial position of this anomaly in comparison to the hypothetical areas of solution mining based on historical data and the assumptions described in Section 8.1.6. There also appears to be a relationship between this anomaly and one evident between exploratory wells X10N-3 and X11-4, potentially confirming a flow link between the wells and a merging of cavities. Several different interpretations of this anomaly may be made:

- The upper portion of this anomaly clearly exhibits zones of significantly lower seismic velocity. This may be interpreted as open fractures or spaces within the rock filled with brine resulting from dissolution near the top of the salt beds as a result of the cross-field flow or at the top of the interconnected cavities.
- The lower portion of the identified anomaly, where only reflector amplitude differences are observed, might be representative of one of two conditions:
    - The lower portion of the anomaly may represent a former cavity now filled with sufficient amounts of subsided material with an aggregate density in the horizontal direction (so as to have only a small influence on the 1st arrival time seismic wave energy and thus the velocity tomogram) similar to the surrounding salt and rock mass with sufficient horizontal bed or joint openings to significantly scatter reflection energy; or
    - The lower portion of the anomaly may represent the influence of nearby cavities (closer to the former brine wells) where the first arrival times of the seismic waves are not influenced as they pass through intact formations between wells X11-3 and X11-4, but the seismic reflection energy is scattered by cavities impinging within the Fresnel zone

of the testing along this profile (the upper part of the anomaly, being the low velocity zones, may then represent the edges of cavities that are larger at their tops than at greater depths).

Which of these two interpretations is correct can not be determined based on available data. In addition, the seismic anomaly may be the composite result of many features that influence the seismic energy. The three-dimensional position of the features that produce the seismic anomaly can also not be identified.

Should the identified anomaly be representative of large open cavities associated with Wells #15 and #22, but with the cavities largely only within the Fresnel zone of the cross-well profile, such cavities are likely of a size that may result in propagation of settlements to the surface, based on a combination of inferred size from the cross-well testing and the historical data. The time-rate of propagation is uncertain, but based on the solution mining well locations the propagation would likely influence the ground above the anomaly (though to what degree is uncertain). In the vicinity of this anomaly, there is little available evidence to suggest that relatively large magnitudes of subsidence have taken place. Furthermore, changes in ground surface topography or features that have taken place over the past 54 years may have obscured settlements of lesser magnitudes that have already taken place. Such changes may have included:

- Construction of the high-pressure pipeline crossing the site;
- Construction of small industrial/commercial buildings, a fuel station, and a sandblasting operation along Sandwich Street in this vicinity;
- Adjustments to railway alignments and grades for the spur lines crossing Sandwich Street; and
- Changes to the roadway widths, paving, and drainage associated with Sandwich Street.

In order to evaluate the potential future behaviour of the ground in this area, an additional UDEC model analysis was completed. This model considered the worst case that the anomaly evident along profile X11-3 to X11-4 represented the remains of a solution mined cavity. In the model, the anomaly area within the B salt was assumed to be fully dissolved, discounting the rubble that would result from collapse of the dolostone and shale stringers and the impurities left after salt dissolution (gypsum, shale, and other mineral deposits). It was assumed that the model cavity was hydraulically unconfined as the pressure integrity of this area was breached in the 1940s. This model further considered that the roof of the cavity started intact at the base of the C member, though the anomaly suggests that this feature has propagated upward into the base of the C member.

The results of the UDEC model suggest that the ground surface may subside substantially in the future, as illustrated on Figure 9.3. The degree of subsidence that has already occurred is not quantifiable at this time. Furthermore, it must be noted that the UDEC model is a two dimensional representation of the ground responses, thus assuming the modelled conditions extend infinitely in directions perpendicular to the model profile (east and west in the case of this anomaly). The assumptions made for this UDEC model are therefore considered conservative should the anomaly represent a cavity that is limited in dimensions along these perpendicular directions. The position of the anomaly in the east and west directions and its true three-dimensional shape can not be quantified based on the information available at the time this report was prepared. There is, however, historical evidence to suggest that the anomaly may represent features on either or both sides of this profile that affect the image through the Fresnel zone of the seismic reflections as well as directly through this profile. For prudent planning purposes, it is recommended that any alignments that pass along Sandwich Street, exclude use of structures that are founded on the rock within the boundaries of the primary and secondary solution mining influence areas as defined in Section 8 and illustrated in Figure 9.1. Furthermore, as conditions to the east of Wells 15 and 22 and exploratory Wells X11-3 and X11-3 have not been explored or analysed in detail, alignments should not be considered east of the defined boundaries until further explorations, testing, and analyses are completed. Should further consideration of structures within these areas be necessary, it is recommended that further testing and analyses include (in no particular order):

- Investigations to determine whether the existing well casings for solution mining Wells 4, 10, 15, and 22 might still be found and, if so, determining whether or not these might be reopened (drilling through cement plugs) to permit additional geophysical testing;
- Potential drilling of new exploratory wells (perhaps up to 5) in vicinity of anomalies with one of these preferably centred on the anomaly (though physical site constraints may prevent this ideal location);
- Additional cross-well seismic surveys between new and existing wells;
- Cross-well shear wave testing may also be a suitable technique for examining other characteristics of the rock mass that can not be elucidated using the cross-well seismic (sonic) testing that has been completed in the program of work already undertaken;
- Borehole gravity surveys in Wells X11-3, X11-4, any existing solution mining wells that can be exhumed and reopened, and new exploratory wells;
- Parametric 2- and 3-dimensional numerical modelling of various plausible opening geometries as identified/inferred from field exploration and testing.
- Parametric 3-dimensional seismic modelling to better understand the characteristic ground conditions that produce the apparent attenuation (seismic energy loss) of the seismic reflectors and low velocity zones would be recommended.
- Detailed site topographic surveys, potential test pits, and further research in City of Windsor, BP, Essex Terminal Railway, and Canadian Salt records to identify whether or not a subsidence zone occurred in the area that has been subsequently masked, and the magnitude of such historical settlement;
- Potential use of InSAR (Interferometric Synthetic Aperture Radar) satellite data to examine what movements may have occurred since the initial data was collected in 1992; and
- Close coordination of parametric geological/geotechnical studies with parametric analyses of structure performance to ascertain limits of acceptable displacement.

Though the additional work described above may assist in refining the estimates of potential future rock mass behaviour, this work may still not lead to a conclusion that the risks to structures founded in this area are tolerable.

10.0 SUMMARY AND CONCLUSIONS

The work completed for the geologic and geotechnical evaluation of alternative crossing locations for the DRIC project consisted of a program of deep drilling, down-hole geophysical logging, cross-well seismic surveys, surface seismic reflection surveys, numerical analysis, and historical research. On the basis of this work, a number of conclusions have been drawn and recommendations made to assist with selection of an appropriate bridge site as discussed below.

Field drilling investigations did not encounter solution mining cavities, though some wells encountered rock and salt masses that have likely been influenced by solution mining. The cross-well seismic surveys revealed several areas suspected of being near solution mining cavities with two surveys indicating evidence of potential brine-filled zones and cavity remnants. Surveys conducted across the former solution mining site have assisted in identifying areas of disturbed rock as a comparison to and validation of other surveys that indicate undisturbed rock.

A detailed review of historical evidence, coupled with the evidence from field investigations has assisted in defining the limit of mass salt dissolution from the former Canadian Industries Limited solution mining operation, defined for this study as the Limit of Primary Solution Mining Influence. Field evidence, historical data, and numerical modelling have also formed the basis of defining limits within which the rock mass has been altered to some degree by displacements associated with the nearby solution mining, defined for this study as the Limit of Secondary Solution Mining Influence. These limits are shown on Figure 9.1 and summarized in the tables provided in Section 9. These limits are considered reasonable and prudent in that:

- the limit of primary solution mining influence, being zones where salt was directly removed by the mining, is based on inferred extents of former dissolution based on thinned salt beds, even though rock-on-rock (salt) contact was observed in all exploratory well locations.
- the limit of secondary solution mining influence, being zones where the rock mass outside the area of primary interest experienced a degree of displacement or disturbance, is based on reasonable numerical analyses coupled with settlement observations on a nearby site, and this limit is projected beyond the primary zone of influence described above;
- the limits of primary and secondary solution mining influence are consistent among several different methods of processing and interpretation of the geophysical data; and
- the limits of primary and secondary influence fall outside of boundaries that may be defined for a variety of alternative interpretations of the nature of former solution mining cavities and empirical mining engineering approaches to defining distances from mines to ground largely unaffected by underground works.

The existing and future rock mass conditions in the vicinity of Crossing A are expected to be no different than in other areas of western Windsor that have been unaffected by solution mining. Crossing A is outside the Limits of Primary and Secondary Solution Mining Influence.

The proposed Crossing B alignment falls outside the Limits of Primary and Secondary Solution Mining Influence, and the rock mass performance for this crossing is expected to be no different than in other areas of western Windsor that have been unaffected by solution mining.

The main span bridge foundation locations for Crossing C are outside the Limits of Primary and Secondary Solution Mining influence and future rock mass conditions in an area where the rock mass conditions are expected to be no different than in other areas of western Windsor that have been unaffected by solution mining. However, the proposed approach to Crossing C passes over the eastern end of the former solution mining well field and a subsurface anomaly that is suspected to be a brine-filled cavity, rubble zone, and disturbed rock mass. Initial estimates suggest that the rock mass above this anomaly might experience subsidence ranging up to values on the order of 2 m. The proportion of such subsidence that has already occurred or may occur in the future cannot be quantified at this time because of uncertainties associated with the nature and position of the identified anomaly. Should this crossing alignment be considered further, additional study will be required to refine the range of risks and orders of magnitude of future settlement that should be accommodated by design. The field exploration and testing program and historical data are not sufficient to clearly assess the three-dimensional extent, specific location, or potential limits of influence of this subsurface anomaly. The level of effort (investigation, testing, and analysis) that may be required to further refine these issues relative to the Crossing C approach alignment is extensive and, if undertaken, may still be insufficient to consider supporting structures on the rock within and adjacent to the identified limits of solution mining influence within an acceptable degree of risk.

Regardless of the bridge site selected, all bridge foundations will likely derive their support from the rock of the Dundee and Lucas Formations. These rock formations exhibit natural open joints, fractures, and other features, typical to these formations throughout the region. During conventional investigations for detail design, particular attention should be given to these features through a combination of angled and vertical cored holes to ascertain whether or not a program of foundation rock improvement may be required during construction. Provided that the bridge structures are located outside the limits described in this report, it is considered that issues associated with these natural features, artesian groundwater conditions, and hydrogen sulphide within the groundwater, may be the most significant geologic issues for foundation design and construction.

11.0 CLOSURE

This report has been prepared to assist the Detroit River International Crossing project team with evaluating conceptual alignment alternatives and bridge site selection for the Detroit River crossing. The work undertaken in preparation of this report and the resulting conclusions and recommendations are intended as guides to selecting a bridge site that will be suitable for long-term bridge performance. Additional geotechnical investigations and analyses must be completed during final design, regardless of the site(s) selected for the crossing.

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TABLE I
SUMMARY OF MARKER BED ELEVATIONS AND EVAPORITE THICKNESS

FORMATION TOP AND MARKER BED ELEVATION DATA

Legend
- Minimum Value in X10N + X11-4 cluster
- Difference Between Minimum and Next Lowest Value
- Difference Between Minimum and Maximum Value
- Formation Boundary Elevations
- Salt/Evaporite Beds

	X10N-1		X10N-2		X10N-3		X10N-4		X10N-5		X10N-6		X11-4		X11-3		X11-2		X11-5		X11-6		X11-1	
Marker Bed Number/Formation Top	Elev (m)		Elev (m)		Elev (m)		Elev (m)		Elev (m)		Elev (m)		Elev (m)		Elev (m)		Elev (m)		Elev (m)		Elev (m)		Elev (m)	
Ground Surface Elevation	176.8		176.6		177.9		178.1		178.5		178.4		177.2		177.4		176.9		177.6		179.4		177.4	
	28.3		29.1		29.2		31.4		30.4		30.3		28.5		29.3		31.0				32.9		31.8	
Bedrock/Dundee Formation	148.5		147.6		148.7		146.7		148.2		148.2		148.7		148.1		145.9		147.3		146.5		145.6	
Lucas Formation	132.2		132.8		132.9		133.0		135.6		134.0		137.1		134.4		128.6		126.9		125.0		124.4	
1	115.6		114.4		115.6		116.0		116.2		117.1		118.2		116.3				116.5		114.8		115.0	
100	108.0		104.0		105.5		106.6		107.6		111.3		107.3		101.2		98.6				101.2		100.2	
2	98.9		98.9		100.2		100.2		100.8		101.1		99.6		97.5		97.4		97.9		97.2		99.7	
3	88.1		86.0		87.7		89.1		90.3		89.9		92.6		92.3		82.5		84.5		82.1		81.2	
4	84.9		82.8		85.2		86.2		87.3		87.0		90.2		90.5		78.1		78.7		80.1		77.1	
101	81.5		79.6		81.9		83.1		83.6		83.5		85.2		89.2		75.2		76.2		74.8		73.4	
5	70.4		69.0		71.8		72.5		74.0		73.0		77.6		75.6		65.8		65.3		64.3		63.0	
Amherstburg Formation	66.9		64.6		68.6		68.8		71.7		70.3		72.8		71.1		61.7		60.6		60.3		58.4	
6	66.6		66.0		68.1		68.5		70.5		69.8		73.2		71.5		62.5		62.1		61.1		59.3	
Sylvania Formation	42.8		42.4		44.0		45.0		46.4		45.9		48.8		45.5		37.1		36.0		35.4		34.1	
Bois Blanc Formation	18.4		17.6		20.3		21.4		22.9		22.0		25.1		21.8		12.5		11.1		10.4		8.6	
7	17.6		16.5		19.0		20.4		21.7		20.9		23.9		21.6		11.1		9.8		8.6		7.6	
8	14.4		13.4		16.2		17.5		18.6		17.9		21.1		18.7		9.7		8.3		7.4		5.7	
9	13.0		10.9		12.8		16.4		17.3		16.6		19.5		17.4		7.4		6.4		5.2		4.5	
10	11.1		9.9		12.2		14.2		15.5		14.0		16.4		14.9		5.2		4.8		3.8		3.4	
11	5.8		6.6		9.8		10.0		11.4		12.1		13.2		11.1		1.6		1.2		0.4		-1.1	
101a	-0.7		-1.9		1.9		4.0		4.7		4.5		10.1		2.7		-8.6		-7.4		-11.8		-13.2	
101b	-5.1		-6.8		-5.6		-3.3		-3.4		-3.6		-4.7		-8.6		-12.5		-12.9		-12.8		-14.5	
12	-5.7		-7.8		-6.7		-4.8		-4.0		-4.3		-6.3		-9.8		-13.4		-13.8		-13.5		-15.1	
13	-9.0		-11.5		-9.8		-8.4		-7.3		-7.6		-9.6		-13.2		-17.0		-18.1		-18.3		-19.6	
Bass island	-19.5		-17.5		-17.8		-16.6		-19.6		-19.4		-14.2		-19.2		-22.1		-23.4		-22.7		-24.1	
14	-29.7		-31.3		-29.1		-28.0		-28.1		-28.1		-28.3		-33.8		-36.3		-36.7		-37.8		-38.8	
15	-38.1		-39.5		-37.7		-36.0		-36.1		-36.1		-36.2		-42.3		-45.3		-46.2		-46.7		-48.2	
16	-45.6		-46.7		-45.6		-43.7		-43.8		-43.5		-44.0		-50.0		-52.9		-53.3		-53.7		-55.3	
17	-48.4		-49.5		-48.4		-46.4		-46.7		-46.4		-46.9		-52.4		-55.7		-56.0		-56.5		-58.2	
18	-51.8		-53.3		-52.0		-50.0		-50.3		-50.1		-50.4		-56.1		-59.4		-59.8		-60.2		-61.9	
G-Member Shale & Dolostone	-54.2		-55.7		-54.7		-52.2		-52.8		-52.8		-54.1		-59.6		-63.1		-62.6		-61.7		-63.2	
19	-58.3		-59.8		-58.7		-56.8		-57.1		-57.6		-57.3		-62.6		-65.8		-66.0		-66.7		-68.1	
20	-64.2		-66.1		-64.7		-62.0		-61.8		-62.2		-63.0		-67.4		-72.0		-72.2		-74.0		-74.4	
21	-67.8		-69.9		-68.6		-65.7		-66.0		-66.1		-66.4		-71.1		-75.6		-75.6		-77.9		-78.0	
22	-72.5		-74.1		-73.1		-70.4		-70.4		-69.2		-71.7		-74.5		-80.5		-80.4		-81.1		-82.9	
23	-74.9		-76.1		-75.4		-73.5		-72.4		-71.8		-73.8		-77.2		-82.9		-82.6		-83.2		-85.0	
F-Member Shale	-77.7		-79.1		-78.2		-75.9		-75.6		-74.6		-76.8		-79.6		-85.8		-85.5		-86.1		-88.1	
24	-78.0		-79.5		-78.5		-76.2		-75.9		-75.0		-77.1		-79.9		-86.1		-85.9		-86.5		-88.2	
25	-80.5		-82.4		-80.9		-78.7		-78.7		-78.1		-79.8		-83.3		-88.5		-88.9		-89.0		-91.2	
102	-82.3		-83.6		-82.4		-80.4		-80.6		-79.6		-81.4		-85.1		-89.9		-90.1		-90.2		-92.2	
26	-83.3		-84.8		-83.6		-81.2		-81.8		-80.8		-82.6		-86.4		-91.1		-91.7		-91.5		-93.3	
27	-85.5		-86.9		-86.1		-84.6		-83.9		-83.4		-85.3		-88.5		-93.6		-94.3		-94.4		-95.8	
103	-86.9		-88.4		-87.7		-85.4		-85.4		-84.6		-86.5		-89.9		-95.1		-95.2		-95.7		-97.3	
28	-88.1		-89.2		-88.2		-86.2		-86.0		-85.2		-87.2		-90.6		-95.9		-95.9		-96.2		-98.3	
29	-96.8		-98.8		-96.8		-94.9		-94.6		-93.8		-95.8		-99.3		-104.2		-105.2		-105.0		-106.9	
30	-103.4		-106.7		-104.6		-102.4		-101.7		-101.2		-103.0		-106.9		-111.8		-111.8		-112.5		-113.9	
104	-104.5		-107.6		-105.2		-103.2		-102.8		-102.1		-104.1		-107.9		-112.7		-112.7		-113.5		-114.9	
31	-105.8		-109.1		-106.7		-104.5		-104.1		-103.5		-105.2		-109.2		-114.2		-113.9		-114.8		-116.2	
105	-106.5		-109.6		-107.5		-105.3		-104.9		-104.1		-105.9		-110.0		-114.8		-114.5		-115.3		-116.6	
32	-107.6		-110.9		-108.8		-106.8		-105.7		-105.2		-107.1		-111.2		-116.2		-115.5		-116.7		-117.5	
106	-109.4		-112.5		-110.4		-108.4		-108.2		-107.1		-109.1		-113.0		-117.7		-117.5		-118.5		-119.6	
33	-110.7		-113.1		-111.1		-109.1		-109.0		-108.5		-109.8		-114.2		-118.9		-118.2		-119.8		-121.2	
34	-112.4		-115.9		-113.6		-111.4		-111.4		-110.3		-112.2		-116.0		-120.6		-120.4		-121.7		-122.8	
35	-113.8		-117.3		-115.1		-112.9		-113.0		-111.8		-113.7		-117.5		-122.1		-122.3		-123.1		-124.4	
36	-114.8		-119.5		-116.0		-114.1		-114.1		-113.0		-114.6		-118.3		-123.0		-123.0		-124.2		-125.4	
F-Member salt	-115.9		-119.8		-116.7		-115.3		-114.7		-113.6		-115.4		-119.3		-123.6		-123.9		-125.0		-126.5	
107	-116.3		-120.1		-116.7		-115.4		-114.8		-114.1		-115.7		-119.7		-124.1		-124.0		-125.0		-126.6	
108	-119.0	2.6	-121.4	1.4	-118.1	1.4	-116.7	1.3	-115.8	1.0	-118.1	4.0	-116.2	0.5	-120.1	0.4	-124.6	0.5	-124.8	0.8	-125.9	0.9	-127.3	0.7
37	-119.6		-122.6		-118.5		-117.0		-116.8		-118.9		-117.0		-120.9		-125.4		-125.1		-126.3		-127.8	
38	-120.6		-123.1		-120.0		-118.3		-117.7		-119.9		-118.0		-121.7		-126.4		-126.5		-127.7		-129.1	
109	-121.4		-123.8		-120.5		-118.8		-118.5		-120.5		-118.7		-122.3		-126.8		-127.1		-128.0		-129.6	
110	-129.3	8.0	-127.9	4.2	-128.4	7.9	-127.8	9.0	-127.4	9.0	-129.1	8.6	-125.2	6.5	-129.1	6.8	-134.3	7.4	-133.1	6.0	-136.2	8.2	-137.0	7.4
39	-131.2		-129.4		-130.1		-129.7		-129.1		-130.4		-126.9		-130.8		-135.9		-135.2		-138.3		-139.1	
40	-132.8		-131.0		-131.5		-131.4		-131.0		-132.2		-128.6		-132.3		-137.7		-136.7		-140.0		-140.7	
41	-134.6		-132.2		-133.1		-133.1		-134.0		-135.2		-130.6		-134.9		-138.7		-138.0		-141.2		-141.8	
110a	-135.1		-132.5		-133.4		-133.5		-135.1		-136.0		-131.0		-135.5		-139.1		-138.4		-142.7		-142.7	
110b	-136.2	1.2	-134.8	2.3	-134.9	1.4	-134.9	1.4	-135.2	0.1	-136.1	0.1	-132.0	1.0	-136.9	1.4	-141.0	1.9	-139.7	1.3	-143.9	1.2	-144.2	1.5
42	-137.4		-136.2		-136.4		-136.3		-135.4		-136.6		-133.1		-137.3		-142.7		-141.8		-145.2		-145.8	
111	-138.5		-137.3		-137.2		-137.4		-136.6		-137.8		-134.4		-138.5		-143.9		-142.5		-146.3		-146.6	
112	-145.9	7.3	-143.4	6.1	-144.7	7.5	-144.2	6.8	-143.8	7.3	-145.2	7.4	-141.4	7.0	-145.3	6.8	-150.6	6.7	-149.8	7.3	-152.8	6.5	-153.7	7.1
43	-146.9		-145.2		-146.1		-145.5		-144.8		-146.3		-142.3		-146.1		-151.6		-150.9		-153.4		-154.8	
113	-147.9		-146.4		-147.0		-146.1		-145.7		-147.1		-143.6		-147.1		-152.3		-151.4		-154.8		-155.4	
44	-160.3		-158.9		-156.7		-159.2		-158.5		-159.3		-153.2		-159.5		-164.4		-163.6		-166.4		-168.0	
45	-161.8		-160.8		-159.1		-160.7		-160.6		-160.8		-156.0		-161.6		-166.0		-165.5		-168.7		-169.7	
114	-162.1	14.2	-161.2	14.8	-160.3	13.3	-161.0	14.9	-161.2	15.4	-161.2	14.1	-158.3	14.7	-162.0	14.9	-166.6	14.2	-166.2	14.8	-169.2	14.4	-170.1	14.7

TABLE I
SUMMARY OF MARKER BED ELEVATIONS AND EVAPORITE THICKNESS

FORMATION TOP AND MARKER BED ELEVATION DATA

Legend	
Minimum Value in X10N + X11-4 cluster	(red)
Difference Between Minimum and Next Lowest Value	(orange)
Difference Between Minimum and Maximum Value	(light orange)
Formation Boundary Elevations	(tan)
Salt/Evaporite Beds	(yellow)

Marker Bed Number/Formation Top	X10N-1 Elev (m)		X10N-2 Elev (m)		X10N-3 Elev (m)		X10N-4 Elev (m)		X10N-5 Elev (m)		X10N-6 Elev (m)		X11-4 Elev (m)		X11-3 Elev (m)		X11-2 Elev (m)		X11-5 Elev (m)		X11-6 Elev (m)		X11-1 Elev (m)	
E-Member Dolostone	-162.5		-161.3		-160.9		-161.2		-161.4		-161.4		-158.5		-161.2		-167.0		-166.4		-169.7		-170.4	
46	-164.7		-163.9		-164.1		-163.7		-163.4		-163.7		-161.4		-164.2		-169.7		-169.2		-171.6		-172.9	
47	-166.7		-165.7		-166.1		-165.9		-165.3		-166.5		-163.5		-165.8		-171.4		-170.7		-173.2		-174.6	
48	-171.1		-170.5		-170.7		-170.7		-169.9		-170.6		-167.8		-170.6		-176.1		-175.5		-178.0		-179.7	
49	-172.6		-172.0		-172.3		-171.9		-171.2		-171.9		-168.9		-171.7		-177.3		-176.8		-179.5		-181.0	
50	-174.4		-174.2		-174.6		-174.4		-173.6		-173.9		-170.9		-174.4		-179.7		-178.6		-182.2		-183.3	
51	-175.1		-174.9		-175.4		-175.2		-174.3		-174.6		-171.7		-175.0		-180.4		-179.5		-183.0		-183.9	
52	-176.3		-176.1		-176.4		-176.3		-175.4		-175.7		-172.7		-176.3		-181.6		-180.8		-184.0		-185.1	
53	-177.6		-177.4		-177.9		-177.8		-176.6		-177.2		-174.3		-177.4		-183.0		-181.9		-185.2		-186.4	
54	-180.0		-179.6		-180.0		-179.8		-179.0		-179.4		-176.5		-179.7		-185.0		-184.0		-187.2		-188.4	
55	-187.8		-187.9		-188.3		-187.6		-186.9		-187.2		-184.3		-187.8		-192.4		-191.9		-195.1		-196.2	
56	-189.0		-189.3		-189.4		-188.7		-188.2		-188.4		-185.3		-189.2		-194.0		-193.2		-196.5		-197.2	
57	-191.2	28.7	-192.1	30.7	-192.6	31.7	-191.9	30.7	-190.6	29.3	-190.7	29.3	-188.1		-192.1		-196.5		-195.7		-198.7		-199.9	
D-Member salt	-192.4		-193.2		-193.1		-192.6		-191.6		-192.0		-188.8		-192.4		197.7		-196.6		-199.7		-200.7	
115	-192.7		-193.4		-194.1		-192.6		-191.7		-192.2		-188.9		-192.8		-198.1		-196.8		-200.0		-201.0	
116	-195.9	3.3	-194.9	1.4	-195.7	1.6	-195.4	2.8	-194.2	2.4	-194.1	1.9	-192.6	3.6	-195.3	2.5	-201.0	2.9	-199.9	3.1	-203.5	3.5	-204.6	3.6
58	-197.4		-196.7		-196.7		-196.6		-196.0		-196.7		-194.5		-197.3		-202.6		-201.6		-205.5		-206.1	
117	-198.5		-197.7		-197.7		-197.8		-197.2		-197.9		-195.2		-198.2		-203.6		-202.5		-206.1		-207.3	
118	-201.4	2.9	-201.0	3.3	-200.0	2.3	-200.2	2.4	-199.8	2.5	-201.5	3.6	-197.1	1.9	-200.8	2.6	-206.1	2.5	-205.5	2.9	-208.9	2.7	-209.8	2.5
C-Member Shale	-201.6		-201.2		-200.6		-200.6		-199.9		-201.7		-197.1		-201.0		-206.1		-205.7		-209.0		-209.9	
119	-216.6		-216.7		-215.6		-215.2		-213.5		-213.9		-210.3		-213.1		-225.4		-225.1		-229.1		-230.4	
120	-220.3		-220.2		-219.6		-219.0		-217.2		-217.7		-214.6		-220.1		-229.9		-228.5		-232.8		-234.0	
59	-225.7		-226.1		-225.7		-225.0		-223.2		-223.0		-221.5		-223.3		-231.7		-233.9		-238.1		-239.4	
60	-227.4		-227.0		-226.4		-225.9		-224.1		-224.6		-222.4		-224.2		-237.6		-236.1		-240.7		-241.6	
60a	-229.3		-229.3		-228.6		-228.2		-226.4		-227.6		-224.5		-226.3		-239.7		-238.0		-242.9		-243.8	
61	-231.6		-231.0		-230.8		-230.1		-228.0		-229.6		-226.6		-228.2		-241.5		-240.4		-245.2		-246.0	
62	-233.5		-233.7		-232.8		-232.2		-230.4		-231.4		-229.3		-231.1		-244.1		-242.5		-247.3		-248.5	
63	-235.9		-236.1		-235.5		-235.0		-232.9		-233.9		-232.3		-233.7		-246.5		-244.9		-249.7		-250.8	
64	-239.0		-239.3		-238.9		-238.3		-236.1		-236.9		-237.4		-239.6		-249.6		-247.9		-252.7		-253.9	
65	-240.6	39.0	-240.9	39.7	-242.1	41.5	-240.8	40.2	-238.0	38.1	-238.3	36.6	-240.7	43.7	-243.5	42.4	-250.6	44.5	-249.2	43.5	-253.7	44.7	-255.2	45.3
B-Member salt	-241.1		-241.5		-242.0		-241.1		-238.5		-238.9		-241.8		-246.8		-250.8		-249.4		-254.4		-255.4	
65a	-245.3		-245.8		-248.3		-246.7		-243.9		-242.7		-245.3		-247.5		-251.2		-250.1		-254.9		-256.2	
66	-253.0		-253.9		-255.4		-253.4		-250.3		-249.7		-256.0		-258.2		-251.9		-251.6		-255.1		-259.5	
67	-258.2		-259.1		-260.4		-258.5		-255.3		-254.9		-260.9		-263.0		-257.8		-257.6		-260.4		-266.1	
68	-262.9		-263.9		-264.7		-263.1		-259.9		-259.5		-264.9		-267.1		-263.5		-264.0		-266.7		-272.8	
69	-267.7		-268.7		-269.6		-267.7		-264.5		-264.1		-269.4		-271.7		-271.7		-270.4		-274.1		-279.0	
70	-273.4		-274.2		-275.2		-273.0		-270.3		-270.1		-275.1		-276.9		-279.2		-276.2		-281.1		-284.7	
71	-284.9		-285.4		-286.2		-284.3		-282.0		-283.1								-287.6					
72	-300.1	65.9	-300.5	65.7	-301.1	66.0	-299.1	65.2	-296.9	65.4	-298.4	66.5		65.5		61.7		62.9	-301.3	60.0		60.3		61.4
Base of B-Member salt	-307.0		-307.2		-308.0		-306.3		-303.9		-305.3		-307.3		-308.5		-313.7		-309.4		-314.7		-317.6	

SUMMARY

	X10N-1	X10N-2		X10N-3		X10N-4	X10N-5	X10N-6	X11-4	X11-3	X11-2	X11-5	X11-6	X11-1
Total Thickness of Salt in F	33.3	28.8	2.8	31.6		33.3	32.7	34.2	29.8	30.3	30.7	30.1	31.2	31.5
			5.5											
Total Thickness of Salt in D	6.2	4.7		3.9	0.8	5.2	5.0	5.5	5.5	5.1	5.4	6.0	6.2	6.1
					2.3									
Total Thickness of Salt in B	65.9	65.7		66.0		65.2 / 0.2	65.4	66.5	65.5	61.7	62.9	60.0	60.3	61.4
						1.2								

X10N Cumulative Salt Bed Thicknesses				Difference from Mean			
					X10N-2	X10N-3	X11-4
Average Thickness of Salt in F (excluding X10N-2)		33.38 m					
	Stdev	0.63 m		1.9%	-13.8%	-5.4%	-10.9%
Average Thickness of Salt in D (excl X10N-2, X10N-3)		5.47 m					
	Stdev	0.50 m		9.2%	-14.1%	-29.2%	0.5%
Average Thickness of Salt in B		65.81 m					
	Stdev	0.45 m		0.7%	-0.2%	0.3%	-0.5%

X11 Cumulative Salt Bed Thicknesses - Excluding X11-4			Difference from Mean	
				X11-3
Average Thickness of Salt in F (excl X11-3 and X11-4)		30.88 m		
	Stdev	0.39 m	1.3%	-1.9%
Average Thickness of Salt in D (excl X11-3 and X11-4)		5.93 m		
	Stdev	0.36 m	6.1%	-13.5%
Average Thickness of Salt in B (excl X11-3 and X11-4)		61.14 m		
	Stdev	1.31 m	2.1%	0.9%

VERTICAL FRACTURE TABLE (X10N SERIES)

Geologic Formation	X10N-1				X10N-2				X10N-3				X10N-4				X10N-5				X10N-6			
	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note
Dundee	29.6	30.0		Broken Zone	31.3	32.0		Vugs	33.0	33.7		Broken Zone	37.9	38.6	0.7	Vertical	30.1	30.3		Cement	30.2	30.3		Cement
	32.7	33.1		Broken Zone									38.8	39.1	0.3	Vertical	30.3	36.2	5.9	Vertical	30.7	30.9	0.2	Vertical
	38.9	39.1		Vugs									42.9	43.1		Vugs	36.2	36.6		Broken Zone				
	40.5	41.9	1.4	Vertical													36.6	37.0	0.4	Vertical				
	44.4	44.6		Broken Zone													39.4	40.5	1.1	Vertical				
	47.6	48.0		Broken Zone													41.5	42.4	0.9	Vertical				
																	42.4	42.7		Broken Zone				
																	42.7	47.2	4.5	Vertical				
Lucas	53.8	57.6	3.8	Vertical	46.0	46.2		Vugs	45.7	46.1	0.4	Vertical	45.8	46.0		Vugs	47.2	47.6		Broken Zone	48.5	4902		Cement
	61.7	61.9		Vugs	52.3	53.8		Vugs	46.9	48.3		Broken Zone	60.9	61.3		Broken Zone	47.4	47.5		Cement	51.5	52.0		Vugs
	69.5	70.6		Broken Zone	54.5	54.9		Vugs	48.0	49.0		Cement	64.9	65.8		Vugs	89.0	89.3		Vugs	55.7	56.3		Broken Zone
					56.2	56.7		Vugs	52.1	52.7		Vugs	69.8	71.1		Broken Zone	91.0	91.5	0.5	Vertical	61.5	62.4	0.9	Vertical
					57.0	58.0		Broken Zone	55.2	55.3		Vugs					106.1	106.7		Vugs	66.8	68.0		Broken Zone
					58.3	58.7		Vugs	56.5	57.9		Broken Zone									76.2	77.6	1.4	Vertical
					59.1	59.7		Vugs	63.6	63.8		Vugs												
					61.4	61.6		Vugs	64.8	65.3		Vugs												
					63.8	66.1		Vugs	99.1	99.6		Broken Zone												
					85.8	86.4		Vugs																
					91.2	91.7	0.5	Vertical																
Amherstburg	-	-		-	121.7	122.0		Broken Zone	-	-		-	-	-		-	123.2	123.9		Broken Zone	109.7	110.5		Broken Zone
					122.4	122.9		Broken Zone																
					123.2	124.0		Vugs																
					125.5	126.0		Vugs																
Sylvania	156.3	158.2		Vugs	-	-		-	134.0	134.7	0.7	Vertical	143.1	143.4		Vugs	152.3	153.6		Vugs	-	-		-
									142.4	142.5		Vugs					154.5	155.0		Vugs				
																	155.5	156.3		Vugs				
Bois Blanc	162.6	162.8		Vugs	160.6	162.5		Vugs	158.6	160.9		Vugs	158.2	158.7		Vugs	-	-		-	-	-		-
					164.2	165.1		Broken Zone	188.9	189.0		Vugs	159.1	159.9		Vugs								
					166.9	167.3		Vugs					170.3	170.9		Vugs								
					179.1	179.8	0.7	Vertical																
					186.6	186.9		Broken Zone																
Bass Islands	209.2	211.0	1.8	Vertical	194.6	195.3	0.7	Vertical	204.5	204.6		Cement	229.3	229.7	0.4	Vertical	209.1	210.1		Vugs	200.6	202.6		Unknown
	220.4	223.4	3.0	Vertical	196.2	201.4	5.2	Vertical	210.6	211.0		Vugs					212.0	212.1		Cement				
					202.5	205.0	2.5	Vertical									215.0	215.3	0.3	Vertical				
					206.4	207.1	0.7	Vertical									217.1	218.1	1.0	Vertical				
					207.8	222.5	14.7	Vertical									219.6	220.5		Broken Zone				
					222.7	223.1		Vugs									221.6	221.8		Vugs				
																	225.2	226.2		Broken Zone				

VERTICAL FRACTURE TABLE (X10N SERIES)

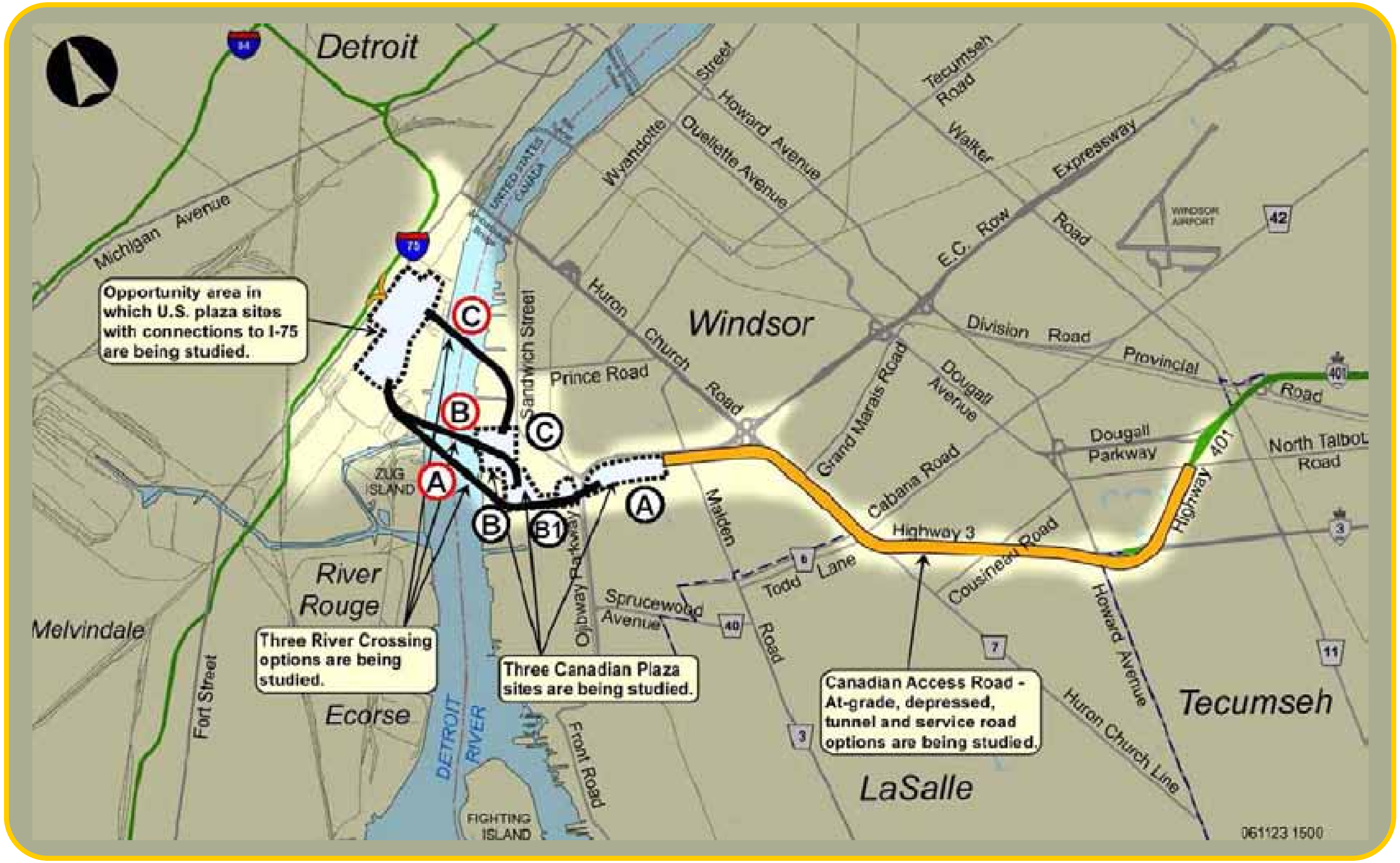
Geologic Formation	X10N-1				X10N-2				X10N-3				X10N-4				X10N-5				X10N-6			
	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note
Salina G-					244.8	245.7	0.9	Vertical													243.4	244.6		Broken Zone
unit Shale &	-	-		-	250.7	252.0	1.3	Vertical	-	-		-	-	-		-	-	-		-	245.4	245.8		Broken Zone
Dolostone					255.1	255.9		Broken Zone																
Salina F-unit					256.3	257.0		Broken Zone													289.4	290.0		Vugs
Shale					270.0	270.9	0.9	Vertical																
	-	-		-	276.5	277.4	0.9	Vertical	-	-		-	-	-		-	-	-		-				
					283.2	284.6	1.4	Vertical																
					293.3	293.8		Broken Zone																
Salina F-unit					305.0	305.7		Vugs					314.1	314.4	0.3	Vertical					307.8	309.1		Vugs
Salt	-	-		-					-	-		-					-	-		-	311.4	312.9	1.5	Vertical
																					314.3	315.2	0.9	Vertical
Salina E-unit	339.5	340.9		Vugs					338.9	341.1		Broken Zone	341.9	342.2	0.3	Vertical	361.2	361.6		Broken Zone	340.0	341.3		Broken Zone
Dolostone	341.5	341.9	0.4	Vertical	-	-		-	343.3	343.9		Broken Zone	344.6	345.9		Vugs					342.4	342.8	0.4	Vertical
	344.0	344.6	0.6	Vertical									347.1	347.5	0.4	Vertical					346.3	347.0	0.7	Vertical
													360.5	361.3	0.8	Vertical								
Salina D-	373.8	374.2		Broken Zone																				
unit Salt					-	-		-	-	-		-	-	-		-	-	-		-	-	-		-
Salina C-	378.5	378.8		Broken Zone	379.5	382.3		Broken Zone	378.6	385.9		Broken Zone	379.9	381.2		Broken Zone					391.0	391.7	0.7	Vertical
unit Shale	379.9	380.1		Broken Zone	387.1	388.2	1.1	Vertical	390.5	391.2	0.7	Vertical	393.0	393.5		Broken Zone								
	383.4	383.8	0.4	Vertical	395.0	395.6	0.6	Vertical	393.7	394.2	0.5	Vertical												
	385.4	388.4	3.0	Vertical	396.2	397.1	0.9	Vertical																
	402.1	403.2	1.1	Vertical	400.4	400.7	0.3	Vertical									-	-		-				
					404.8	405.0	0.2	Vertical																
					409.0	409.5	0.5	Vertical																
					413.0	413.7		Vugs																
					416.0	416.1	0.1	Vertical																
Salina B-													474.1	474.5		Unknown								
unit Salt	-	-		-	-	-		-	-	-		-					-	-		-	-	-		-
Salina A-					485.6	486.0	0.4	Vertical																
unit Salt	-	-		-					-	-		-	-	-		-	-	-		-	-	-		-

VERTICAL FRACTURE TABLE (X11 SERIES)

Geologic Formation	X11-1				X11-2				X11-3				X11-4				X11-5				X11-6			
	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note
Dundee	32.2	32.3		Cement	32.6	33.2		Vugs	29.8	30.7	0.9	Vertical	29.0	29.1		Cement	35.4	39.4	4.0	Vertical	34.4	37.2	2.8	Vertical
	49.8	49.8		Vugs	38.9	49.3		Slurry	42.8	43.3	0.5	Vertical	29.5	30.4	0.9	Vertical	45.1	45.4		Vugs	46.0	47.5		Cement
	48.0	48.6		Unknown									34.9	48.8		Slurry								
	48.6	48.7		Cement																				
	50.6	51.0		Cement																				
Lucas	63.5	66.0	2.5	Vertical	50.5	53.3		Cement	43.3	43.8		Broken Zone	55.1	55.5		Vugs	51.5	52.8		Broken Zone	58.7	58.9		Vugs
	66.0	66.1		Vugs	54.5	58.9	4.4	Vertical	48.4	48.7		Vugs	57.3	58.9	1.6	Vertical	53.0	54.0	1.0	Vertical	64.7	64.9	0.2	Vertical
	66.6	66.9		Vugs	60.3	60.4		Vugs	46.5	48.5		Unknown	75.1	75.7	0.6	Vertical	58.8	59.3	0.5	Vertical	72.0	73.6	1.6	Vertical
	70.1	70.2		Vugs	65.1	65.3		Cement	57.2	58.1		Vugs	80.6	82.0		Vugs	59.3	60.7		Vugs	74.1	76.2		Vugs
	72.2	73.0		Vugs	65.4	65.6		Cement	58.9	60.4		Vugs	82.4	84.4		Vugs	62.4	62.5		Vugs				
	84.7	84.8		Vugs	68.1	69.7		Vugs	62.8	63.3		Vugs	85.9	86.2		Vugs	67.4	68.3		Vugs				
					70.8	71.9		Vugs	67.4	73.3	5.9	Vertical	90.6	91.5	0.9	Vertical	71.0	71.8		Vugs				
					78.8	79.3		Cement	75.5	83.6	8.1	Vertical					74.9	76.1		Broken Zone				
					104.2	105.1	0.9	Vertical	84.5	85.1		Vugs					77.6	78.3		Broken Zone				
									86.3	87.6	1.3	Vertical					81.0	82.6		Vugs				
									88.5	89.7		Broken Zone					101.1	102.4		Cement				
									89.7	90.6	0.9	Vertical												
									91.0	91.4	0.4	Vertical												
									92.9	95.6	2.7	Vertical												
									96.1	96.9	0.8	Vertical												
Amherstburg	130.3	131.3		Broken Zone	116.7	117.0		Vugs	113.8	119.4	5.6	Vertical	114.1	115.5	1.4	Vertical	117.8	130.7		Vugs				
	132.2	133.2		Broken Zone	117.8	118.6		Vugs	120.0	121.5	1.5	Vertical									-	-		-
	133.9	135.2		Broken Zone				Vugs	130.5	131.5	1.0	Vertical												
Sylvania	-	-		-	161.1	162.0		Vugs	146.3	148.6		Vugs	140.7	141.1		Vugs	149.8	152.5		Vugs	-	-		-
									150.5	152.4	1.9	Vertical	149.7	150.3		Vugs	162.9	165.8		Vugs				
Bois Blanc	170.7	171.9		Vugs	166.4	168.7		Vugs	160.7	161.3		Vugs					186.9	188.7		Vugs	171.1	173.5		Vugs
	183.7	185.2		Broken Zone					166.2	170.6	4.4	Vertical					189.9	192.2		Broken Zone	193.6	194.5	0.9	Vertical
	187.1	187.4		Broken Zone					171.0	171.7	0.7	Vertical					194.1	196.9		Broken Zone				
	196.6	197.6		Broken Zone					174.1	176.2	2.1	Vertical	-	-		-								
	200.9	202.8		Unknown					177.1	178.2	1.1	Vertical												
		6							179.5	186.1	6.6	Vertical												
									192.5	194.6		Broken Zone												
Bass Islands	203.9	204.0		Cement	203.3	203.5		Cement	203.0	203.6		Cement	211.6	212.0		Vugs	206.0	206.7		Vugs	204.5	205.6		Cement
	206.8	207.0		Cement					203.6	203.7		Cement									233.3	236.3		Broken Zone
	208.8	209.5		Broken Zone					204.9	205.3		Cement												
	233.2	234.9	1.7	Vertical					214.1	215.1		Vugs												

VERTICAL FRACTURE TABLE (X11 SERIES)

Geologic Formation	X11-1				X11-2				X11-3				X11-4				X11-5				X11-6			
	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note	From	To	Length	Note
Salina G-unit Shale & Dolostone	253.0	254.3	1.3	Vertical	-	-		-	-			-	-	-		-	-	-		-	260.4 265.1	262.1 266.2	1.7 	Vertical Broken Zone
Salina F-unit Shale	-	-		-	-	-		-	-			-	-	-		-	-	-		-	295.1	297.8	2.7	Vertical
Salina F-unit Salt	-	-		-	313.8	314.2	0.4	Vertical	310.6 311.2 313.7	310.8 311.6 314.3	0.2 0.4 	Vertical Vertical Broken Zone	304.1 309.3	304.3 310.3		Vugs Vugs	-	-		-	317.8 323.8	318.1 324.4	0.3 	Vertical Broken Zone
Salina E-unit Dolostone	348.0 352.9 368.3	349.5 353.9 370.0	 1.7	Broken Zone Vugs Vertical	344.3 347.0 348.0 349.3 365.9	345.6 347.2 348.8 350.6 367.3	 0.2 0.8 1.3 	Broken Zone Vertical Vertical Vertical Broken Zone	339.4 343.1 346.1 350.2 352.6 359.3	341.8 343.3 348.0 351.2 353.0 361.7	 1.9 	Broken Zone Vugs Vertical Vugs Vugs Vugs	-	-		-	347.9 350.8 357.4 360.6 363.8	348.4 352.3 357.7 361.2 366.5		Vugs Vugs Vugs Vugs Vugs	352.5 356.1 360.2 361.1 368.8	352.8 357.1 360.5 361.8 371.5	0.3 1.0 0.7 	Vertical Vertical Broken Zone Vertical Broken Zone
Salina D-unit Salt	-	-		-	-	-		-	-	-		-	-	-		-	383.2	387.3		Broken Zone	-	-		-
Salina C-unit Shale	-	-		-	422.9 426.8	423.1 427.0	0.2 0.4	Vertical Vertical	379.0 383.8 387.2 390.6 391.1 410.4 420.6	383.2 386.5 388.1 390.9 391.3 411.3 421.3	 2.7 0.9 0.9 	Broken Zone Vertical Vertical Vugs Vugs Vertical Broken Zone	392.3 408.9	394.4 409.9		Broken Zone Broken Zone	388.8 391.2 397.2 399.9 403.1 405.0 425.4 426.5	390.9 392.0 397.6 401.4 404.4 405.4 425.6 427.0	 0.8 0.4 1.5 1.3 0.5	Broken Zone Vertical Vertical Vertical Vertical Vugs Vugs Vertical	407.5	408.3	0.8	Vertical
Salina B-unit Salt	-	-		-	-	-		-	-	-		-	-	-		-	453.7	454.3		Broken Zone	-	-		-
Salina A-unit Salt	-	-		-	-	-		-	-	-		-	-	-		-	-	-		-	-	-		-



Notes:
1. This figure is to be read with the accompanying report.
2. Site plan of area provided by URS Corporation.

PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

TITLE
AREA OF CONTINUED ANALYSIS

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 1.1**	
GIS	JFC	19 Dec. 2007		
CHECK	JM	19 Dec. 2007		
REVIEW	SB	19 Dec. 2007		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\Nov2007_Edits\Figure1.1_Area_of_ContinuedAnalysis.mxd

LEGEND

- Other Wells or Boreholes
- Cavern Storage Well
- Solution Mining Well
- F013199_15 MNR Well Licence Number (where mapped and available)
- Expressway
- Major Road
- Local Road
- Railway
- Sinkhole, 1954
- Water

Notes:
1. Crossing location data provided by URS Corporation.

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Wells from AMEC and Ontario Ministry of Natural Resources, Oil Salt and Gas Resources Library.
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

0 125 250 500 750
Metres

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

CROSSING LOCATIONS

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE 1:15,000	REV. 1
DESIGN	CC	24 May 2006		
GIS	JFC	21 Feb. 2008		
CHECK	JM	21 Feb. 2008		
REVIEW	SB	21 Feb. 2008		

FIGURE: 2.1

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure2.1_Crossing_Locations.mxd

LEGEND

- Drilled Holes
- Other Wells or Boreholes
- Cavern Storage Well
- Solution Mining Well
- Surface Seismic 2D Reflection Survey Lines
- Cross Well Profiles
- Surface Seismic "Swath" Survey Lines
- Major Road
- Local Road
- Sinkhole, 1954
- Water

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Orthophotos - URS, obtained 2004 and 2005
Wells from AMEC and the Ontario Ministry of Natural Resources, Oil Salt and Gas Resources Library.
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2007
Datum: NAD 83 Projection: UTM Zone 17N

0 100 200 400 600
Metres

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

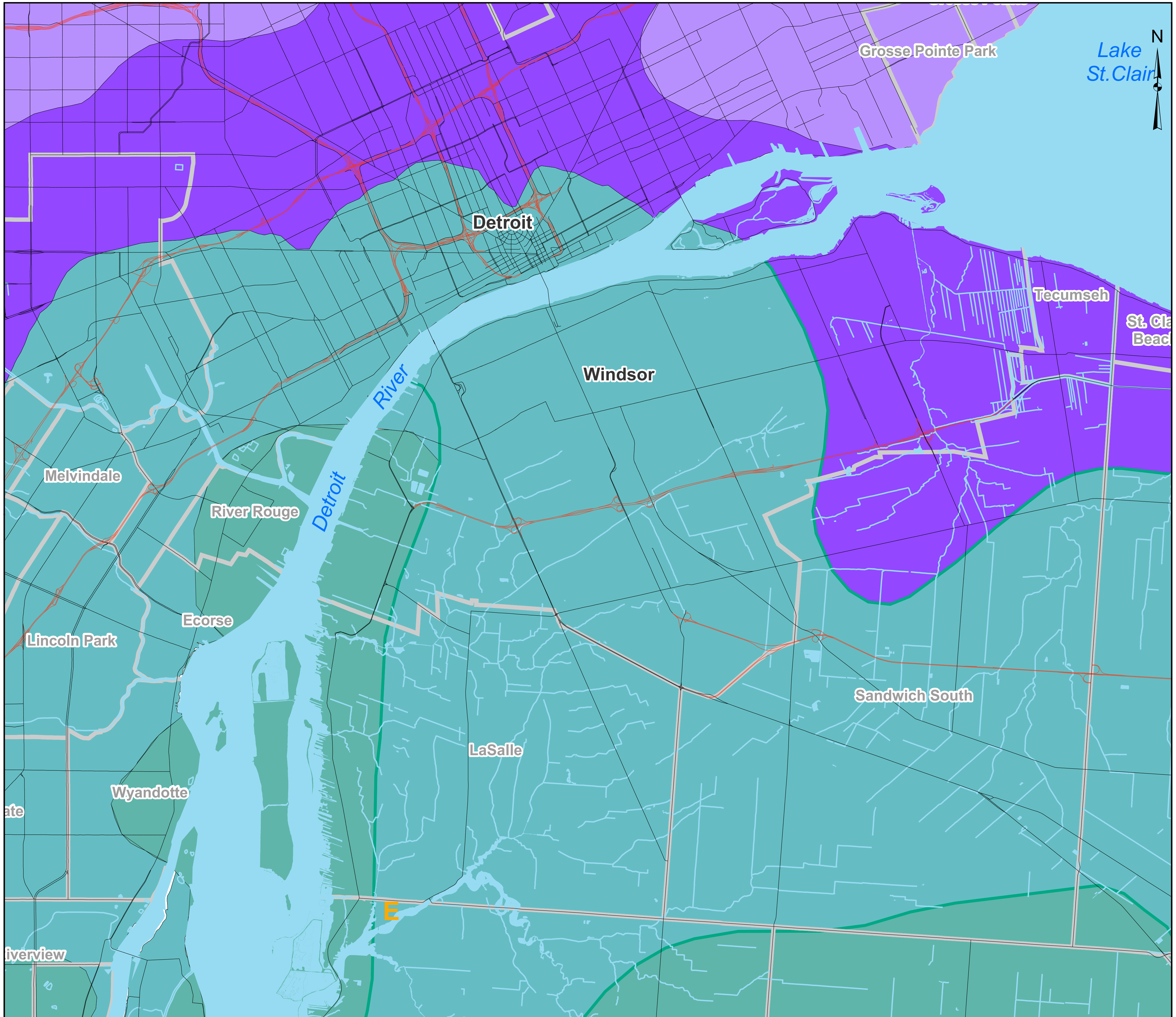
TITLE

SITE AND EXPLORATION LOCATION PLAN

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE 1:7,500	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 3.1**	
GIS	JFC	29 Jan. 2008		
CHECK	JM	29 Jan. 2008		
REVIEW	SB	29 Jan. 2008		

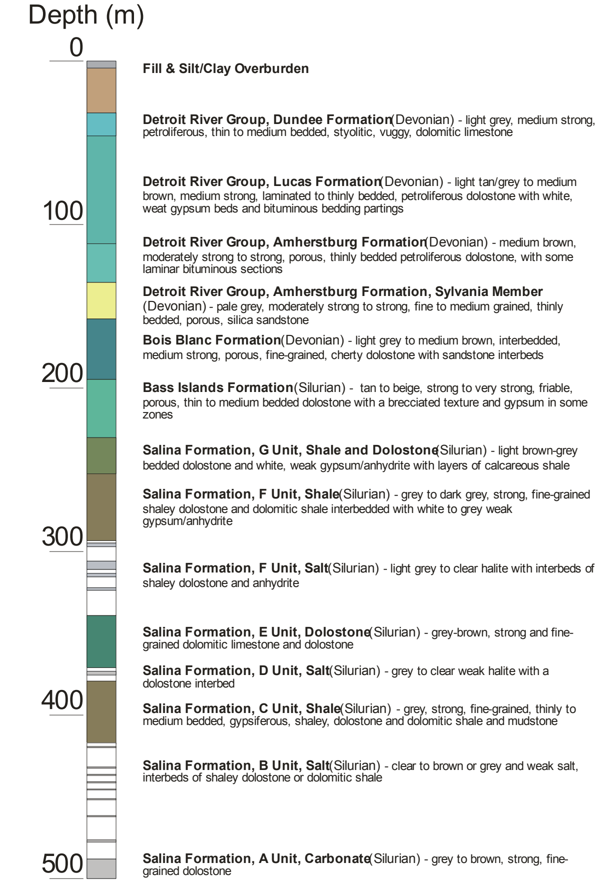
G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure3.1_Siteand ExplorationLocationPlan.mxd



LEGEND

- Expressway
- Major Road
- Municipal Boundary
- Bedford Shale
- Antrim Shale
- Traverse Group
- Dundee Limestone
- Detroit River Group
- Water

Simplified Bedrock Geology Profile for Western Windsor



REFERENCE

Base Data - MNR NRVIS, obtained 2004 and CANMAP v7.3 obtained 2003,
Ontario Geology - OGS digital 1:250 000, obtained 2003.
Michigan Geology - downloaded from MI Geographic Data Library - 1:500000, obtained Feb. 2004.
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

0 0.5 1 2 3 4
Kilometers

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

REGIONAL BEDROCK GEOLOGY AND GEOLOGICAL PROFILE

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE 1:100,000	REV. 1
DESIGN	AW	16 Feb. 2005	**FIGURE: 4.1**	
GIS	JFC	17 Jan. 2008		
CHECK	JM	17 Jan. 2008		
REVIEW	SB	17 Jan. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure4.1_RegionalGeologyandGeologicProfile_v2.mxd

LEGEND

FORMATION MARKER BEDS

NOTES

THIS DRAWING IS SCHEMATIC ONLY AND IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING TEXT.
ALL LOCATIONS ARE APPROXIMATE.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

BEDROCK STRATIGRAPHY
X10N SERIES WELLS

Golder Associates
LONDON, ONTARIO

PROJECT No. 04-1111-060B			FILE No.	041111060B-G01042
DESIGN			SCALE AS SHOWN	REV.
CADD	DCH	2 Nov 2007	**FIGURE 4.2**	
CHECK	JM	13 Dec 2007		
REVIEW	SB	13 Dec 2007		

LEGEND

FORMATION MARKER BEDS

NOTES

THIS DRAWING IS SCHEMATIC ONLY AND IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING TEXT.
ALL LOCATIONS ARE APPROXIMATE.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

BEDROCK STRATIGRAPHY X11_ SERIES WELLS

Golder Associates
LONDON, ONTARIO

PROJECT No. 04-1111-060B			FILE No. 041111060B-G01043
DESIGN			SCALE AS SHOWN REV.
CADD	DCH	7 Nov 2007	**FIGURE 4.3**
CHECK	JM	13 Dec 2007	
REVIEW	SB	13 Dec 2007	

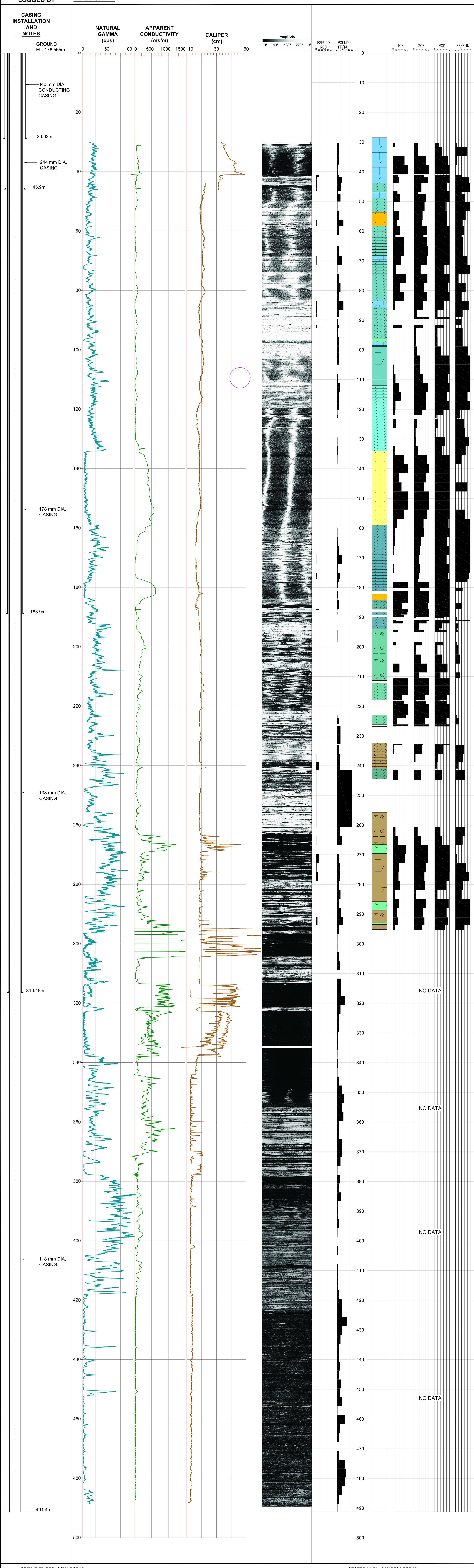
Drawing file: 041111060B-G01043.dwg Jan 15, 2008 - 9:15am

FILENAME: T:\Projects\2004\04-1111-060B (URS, Detroit, Michigan)\-AE-\041111060B04.4.dwg

RECORD OF BOREHOLE BH X10N-2

PROJECT REF.	04-1111-060B	LOG REF. DATUM	GROUND ELEVATION 176.565 m
LOCATION	WINDSOR N 4 683 653 E 327 497 (NAD 83)	INCLINATION	-90°
LOG DATE	FEB. 8, 2007 to MAY 14, 2007	AZIMUTH	NA
LOGGED BY	MK,LK,RC,AH	DRILL EQUIP. & METHOD	GARDNER DENVER 15W ROTARY CORING & TRICONE ROLLER BIT

Golder Associates
Mississauga, Ontario, Canada



STRATIGRAPHY (DEPTH IN METERS BELOW GROUND SURFACE)

GROUND SURFACE

0 to 28.52 **OVERBURDEN**.
(NOT CHARACTERIZED, NOT RECOVERED).

DUNDEE FORMATION (28.52 m to 43.79 m)

28.52 to 43.79 Light grey to pale brown, medium strong, thinly to medium-bedded, vuggy, stylolitic, petroliferous, **DOLOMITIC LIMESTONE.**

LUCAS FORMATION (43.79 m to 111.96 m)

43.79 to 46.90 Pale brown, laminated, medium strong, **petroliferous DOLOMITIC SHALE** with bituminous partings.
46.90 to 48.88 Very pale grey, laminated, **DOLOMITIC LIMESTONE**.
48.88 to 53.65 Pale brown to brown, laminated, porous, weak, **SANDY DOLOSTONE**.
53.65 to 58.20 Pale brown, moderately porous, **CALCIFEROUS SANDSTONE** with occasional bituminous partings.
58.20 to 68.37 Pale brown to pale grey, laminated, moderately porous, weak to medium strong, **SILTY DOLOSTONE**.
68.37 to 70.20 Pale brown, **fossiliferous**, **SANDY LIMESTONE** with occasional vuggy bands.
70.20 to 83.60 Pale brown to pale grey, laminated, moderately porous, weak to medium strong, **SILTY DOLOSTONE**.
83.60 to 85.60 Pale brown, **fossiliferous LIMESTONE** grading down to dense pseudomorphs of **GYPSUM**.
85.60 to 96.30 Light brown to light grey, laminated to thinly bedded, **GYPSIFEROUS DOLOSTONE** with nodules of **GYPSUM** and stylolites.
96.30 to 97.30 White, weak **GYPSUM** and **ANHYDRITE**.
97.30 to 98.85 Very pale grey, **petroliferous LIMESTONE**.
98.85 to 109.87 Pale grey to pale brown, **fossiliferous DOLOMITIC SHALE** with bituminous partings.
109.87 to 111.96 Pale grey to dark brown, massive grading down to intensely laminated, stylolitic, **DOLOMITIC SHALE**.

AMHERSTBURG FORMATION (111.96 m to 134.14 m)

111.96 to 134.14 Pale to medium brown, moderately strong to strong, porous, thinly bedded, bioclastic, **petroliferous DOLOSTONE** with some laminar bituminous sections.

SYLVANIA FORMATION (134.14 m to 158.96 m)

134.14 to 158.96 Pale grey, moderately strong to strong, fine to medium-grained, thinly bedded, porous, **silica SANDSTONE**.

BOIS BLANC FORMATION (158.96 m to 194.05 m)

158.96 to 181.22 Light grey to grey, interbedded, medium strong, porous, fine-grained, **CHERTY DOLOSTONE**.
181.22 to 182.20 Lost core.
182.20 to 184.27 White, porous **SANDSTONE**.
184.27 to 187.32 Grey, banded, **GYPSIFEROUS DOLOSTONE**.
187.32 to 188.30 Lost core.
188.30 to 189.30 Grey, banded **DOLOSTONE**.
189.30 to 189.90 Lost core.
189.90 to 190.37 Grey, massive, **petroliferous DOLOSTONE**.
190.37 to 193.10 Light grey, interbedded, medium strong, porous, fine-grained, **BRECCIATED DOLOSTONE**.
193.10 to 193.25 Light brown, **GYPSIFEROUS**, **SHALEY DOLOSTONE**.
193.25 to 194.05 Grey, massive, strong to very strong **DOLOSTONE**.

BASS ISLANDS FORMATION (194.05 m to 232.30 m)

194.05 to 210.15 Pale grey to brown, **DOLOSTONE BRECCIA** interbedded with **GYPSIFEROUS**, **DOLOMITIC SHALE**. Bituminous partings and numerous healed vertical fractures.
210.15 to 211.30 Grey to black, **DOLOMITIC SILTSTONE**.
211.30 to 212.15 Lost core.
212.15 to 217.85 Pale grey, moderately porous, strong, fine-grained **DOLOSTONE**. Gypsum-free.
217.85 to 223.00 Lost core.
223.00 to 226.10 Interbedded grey, crystalline **DOLOSTONE** and pale brown, **DOLOMITIC SILTSTONE** with bituminous partings.
226.10 to 226.70 Lost core.
226.70 to 226.80 Laminated, **DOLOMITIC SILT** with **ANHYDRITE** bands.
226.80 to 232.30 Lost core.

SALINA FORMATION (232.30 m to 491.40 m, End of Hole)
G-UNIT SHALE AND DOLOSTONE (232.30 m to 255.70 m)

232.30 to 240.86 Pale brown to grey, **DOLOMITIC SILTSTONE** with **ANHYDRITE** inclusions and stylolites.
240.86 to 244.55 Pale grey to brown, **GYPSIFEROUS DOLOSTONE** with **ANHYDRITE** bands and inclusions.
244.55 to 255.70 Lost core.

F-UNIT SHALE and SALT (255.70 m to 337.91 m)

255.70 to 266.60 Brown to grey, strong to weak, **GYPSIFEROUS**, **DOLOMITIC SHALE** with bands of **ANHYDRITE**.
266.60 to 269.60 White, weak **ANHYDRITE**.
269.60 to 285.80 Grey, laminated, **DOLOMITIC SHALE**.
285.80 to 288.70 White, weak, clean **ANHYDRITE**.
288.70 to 292.97 Alternating grey, strong, fine-grained **DOLOSTONE** with **GYPSIFEROUS**, **DOLOMITIC SHALE**.
292.97 to 293.50 White, weak **ANHYDRITE**.
293.50 to 295.20 Alternating grey, strong, fine-grained **DOLOSTONE** with **GYPSIFEROUS**, **DOLOMITIC SHALE**.

295.20 End of Coring.

E-UNIT DOLOSTONE (337.91 m to 369.80 m)

337.91 to 369.80 NO SAMPLE RECOVERY

D-UNIT SALT (369.80 m to 377.77 m)

369.80 to 377.77 NO SAMPLE RECOVERY

C-UNIT SHALE (377.77 m to 418.07 m)

377.77 to 418.07 NO SAMPLE RECOVERY

B-UNIT SALT (418.07 m to 483.76 m)

418.07 to 483.76 NO SAMPLE RECOVERY

A-UNIT CARBONATE (483.76 m to 491.40 m)

483.76 to 491.40 NO SAMPLE RECOVERY

491.40 End of Hole.

SIMPLIFIED GEOLOGY LEGEND:

- LIMESTONE
- DOLOMITIC LIMESTONE
- DOLOSTONE
- GYPSUM/ANHYDRITE IN LIMESTONE
- GYPSUM/ANHYDRITE IN DOLOSTONE
- GYPSUM / ANHYDRITE
- SANDSTONE
- CHERTY DOLOSTONE
- GYPSUM / ANHYDRITE IN DOLOMITE SHALE
- DOLOMITIC SHALE
- HALITE (SALT)

GEOTECHNICAL INDICES LEGEND:

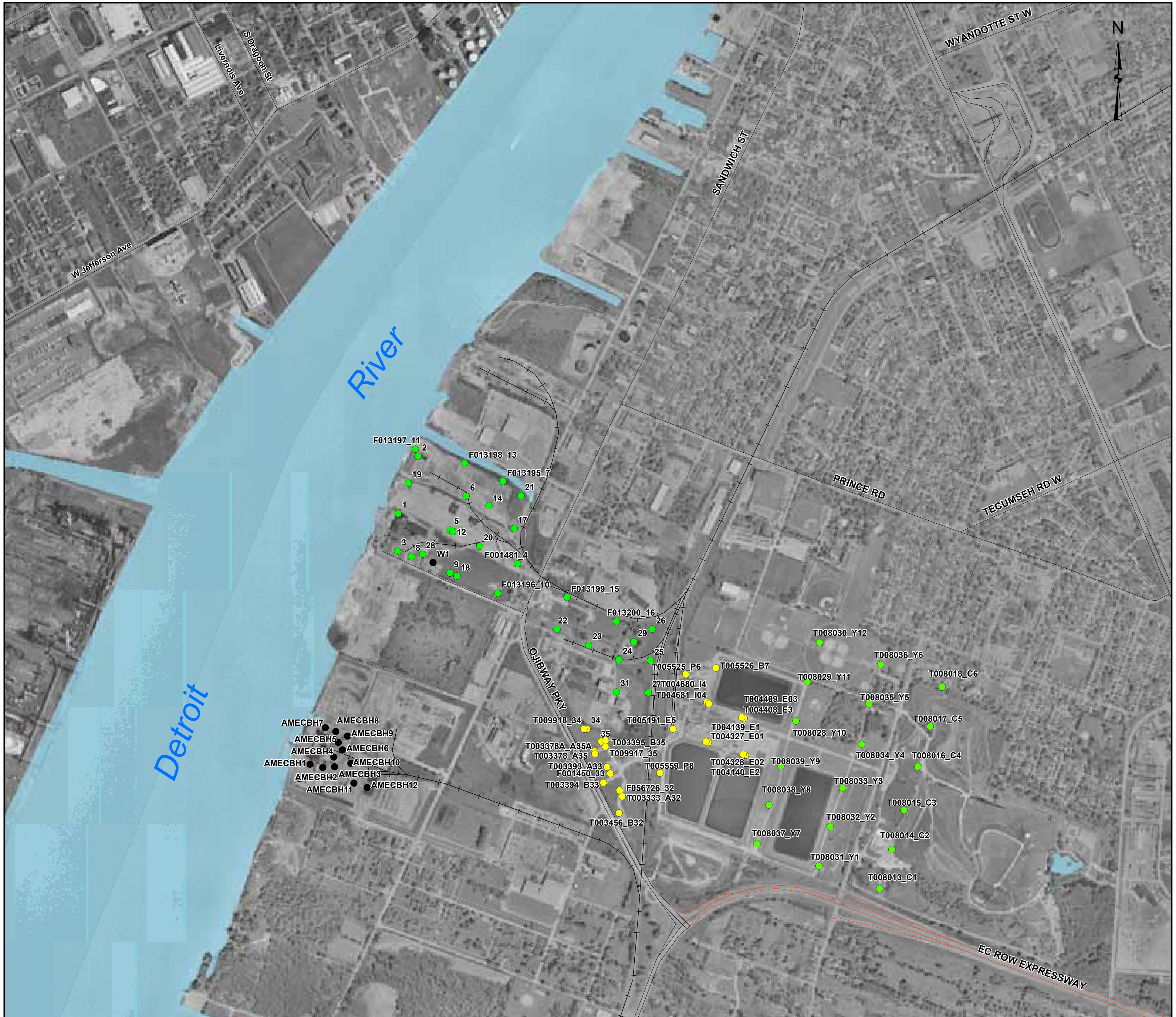
TCR - % TOTAL CORE RECOVERY / RUN
SCR - % SOLID CORE RECOVERY / RUN
RQD - % ROCK QUALITY DESIGNATION / RUN
FF/RUN - NUMBER OF FRACTURES / RUN
PSEUDO RQD - INTERPRETED % ROCK QUALITY DESIGNATION / RUN
PSEUDO FF/RUN - INTERPRETED NUMBER OF FRACTURES / RUN

NOTE:

1. LEGEND IDENTIFIES ROCK MINERALOGY AND IS NOT INTENDED TO INDICATE GEOLOGIC FORMATIONS.

10 0 10 20
VERTICAL SCALE METRES

FIGURE
4.4



LEGEND

- ● Other Wells or Boreholes
- ● Cavern Storage Well
- ● Solution Mining Well
- F013199_15 MNR Well License Number (where mapped and available)
- Expressway
- Major Road
- Local Road
- Railway
- Water

NOTES:
1. Well locations as shown obtained from multiple sources. See report text for full references.
2. Wells shown with alpha-numeric label, such as the series beginning F013xxx_xx, F0014xx_xx, T00xxxx_xx are based on location and well licence data provided by the Ontario Ministry of Natural Resources, Oil Salt and Gas Resources Library.
3. Geotechnical boreholes labelled AMECBH7 from report prepared by AMEC for Brighton Beach power station construction. See report for full reference.

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

0 125 250 500 750
Metres

PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

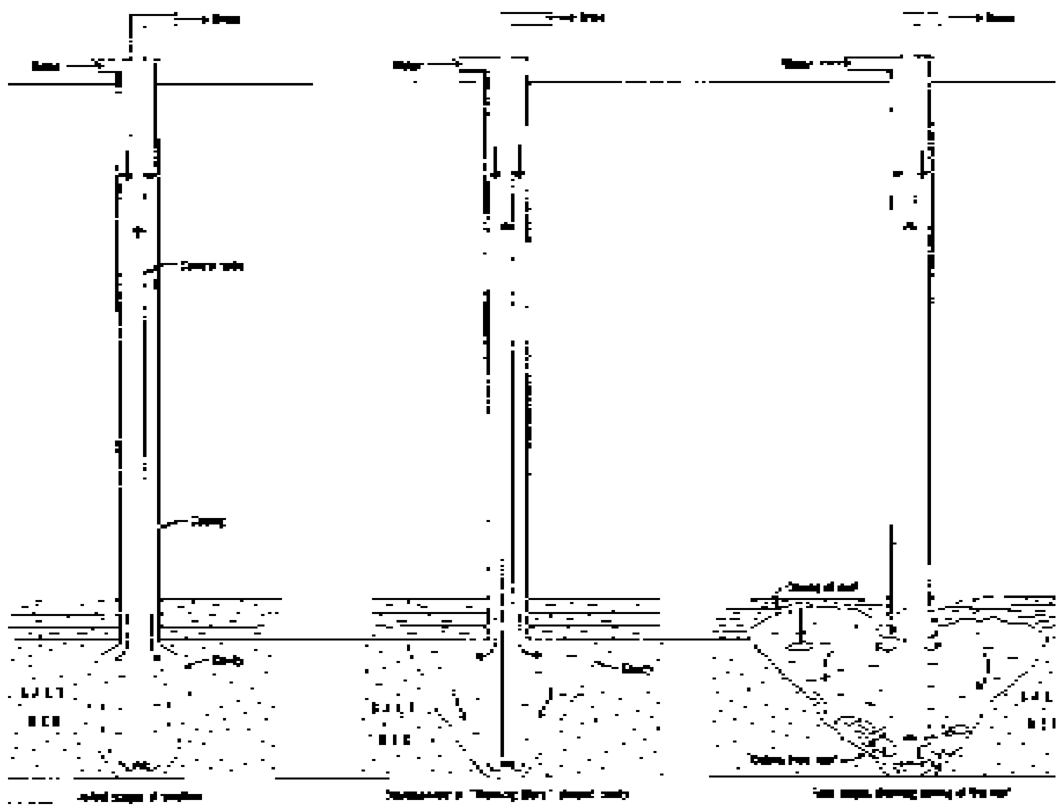
TITLE
LOCATION OF BRINE WELLS

Golder Associates
Mississauga, Ontario

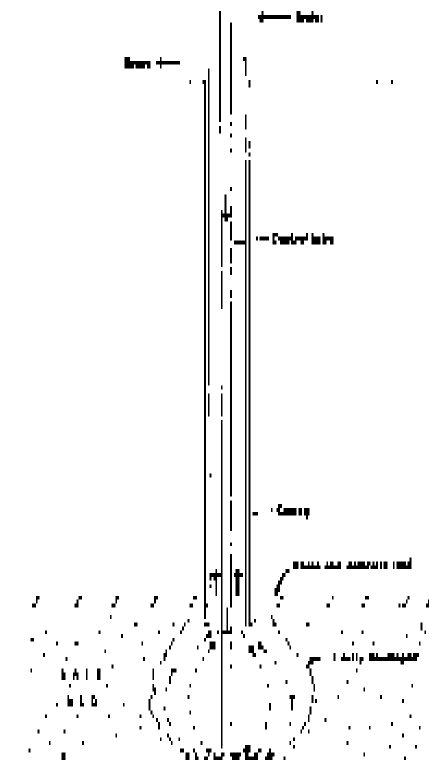
PROJECT No. 04-1111-060			SCALE 1:15,000	REV. 1
DESIGN	CC	24 May 2006		
GIS	JFC	21 Feb. 2008		
CHECK	JM	21 Feb. 2008		
REVIEW	SB	21 Feb. 2008		

FIGURE: 7.1

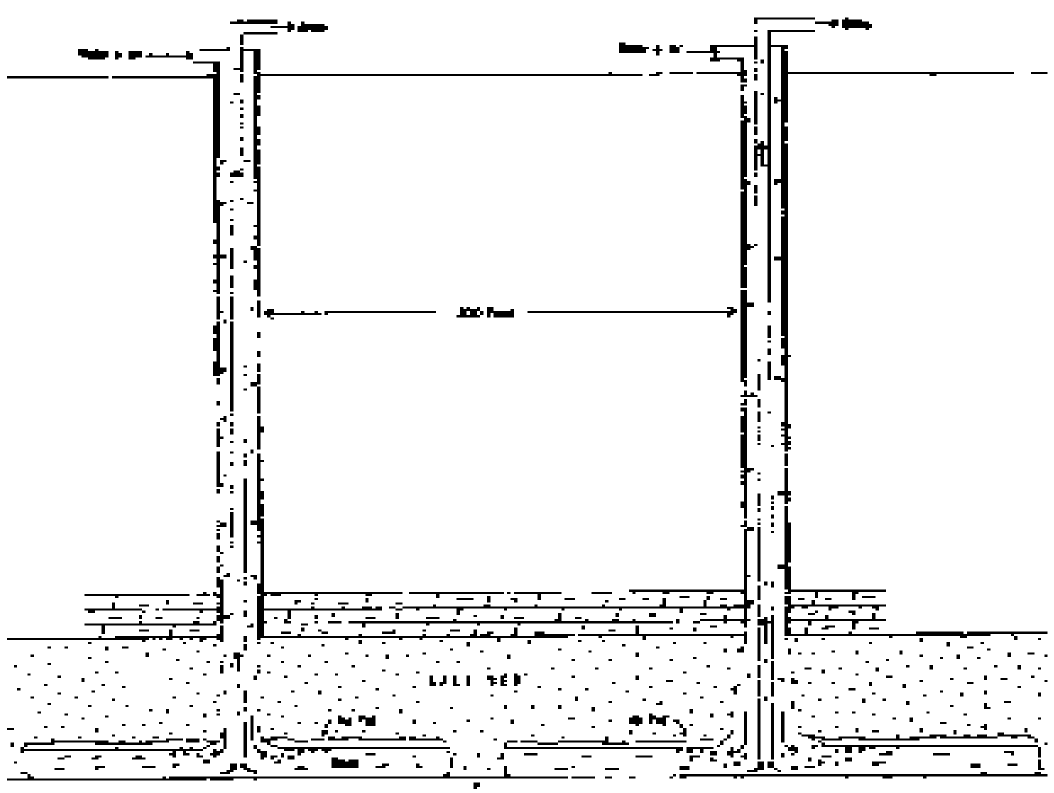
G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure7.1_Location_of_Brine_Wells.mxd



a) - Tully method of brine-well operation
(Reverse circulation)



c) - Detroit method of brine-well operation
(Direct circulation)



b) - Use of air pad method of joining two nearby wells
(Immiscible fluids normally used for roof protection)

REFERENCE

BY: D.F. HEWITT (1962)
ENTITLED: SALT IN ONTARIO, INDUSTRIAL MINERAL REPORT No. 6
ONTARIO DEPARTMENT OF MINES

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

SOLUTION MINING METHODS

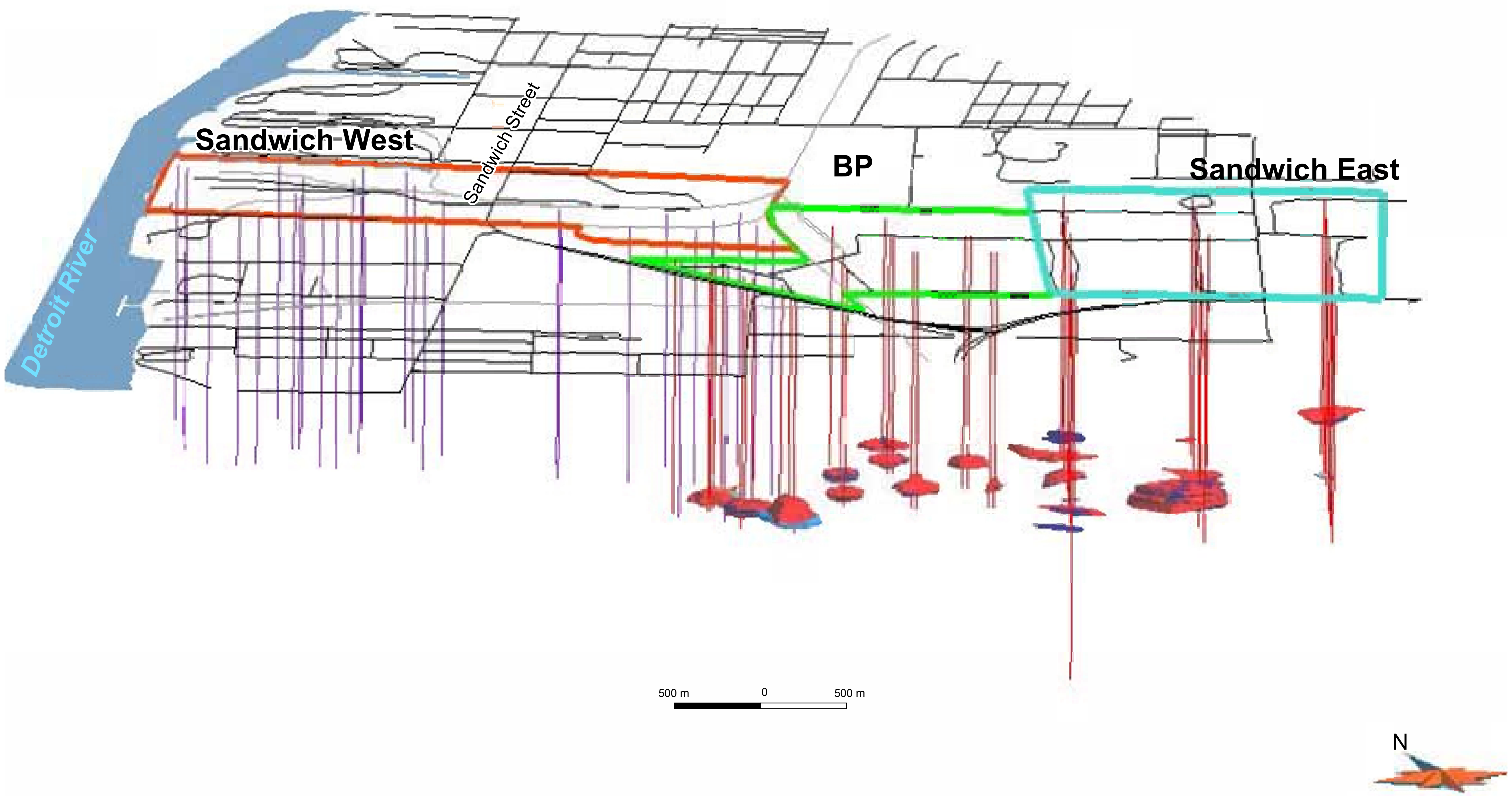
Golder Associates
LONDON, ONTARIO

PROJECT No.	04-1111-060B		FILE No.	041111060-R01-7_2
DESIGN			SCALE AS SHOWN	REV. 1
CADD	BG/WDF	10 Nov 2007		
CHECK	JM	13 Dec 2007	**FIGURE 7.2**	
REVIEW	SB	13 Dec 2007		

Drawing file: 04111060-R01-7_2.dwg Jan 15, 2008 - 10:01am

LEGEND

- Approximate Boundaries of former Sandwich West Site (Canadian Industries Ltd., Canadian Salt Co. Ltd., Windsor Salt)
- Approximate Boundaries of BP Site
- Approximate Boundaries of Sandwich East Site
- Surface Roads
- Railway
- Well Borehole
- Approximate dimensions of cavern where sonar survey data is available



REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

NOTES:

1. Well depths for Sandwich West brine field are approximated. No cavern data is available for solution mining activities in the Sandwich West brine field. See report text for full discussion.
2. Caverns as shown are based on preliminary sonar survey data provided by BP.
3. Vertical exaggeration is 1x. Horizontal distance measured along Prospect Ave between Euclid Ave and Ojibway Parkway. Horizontal scale is approximate.

PROJECT

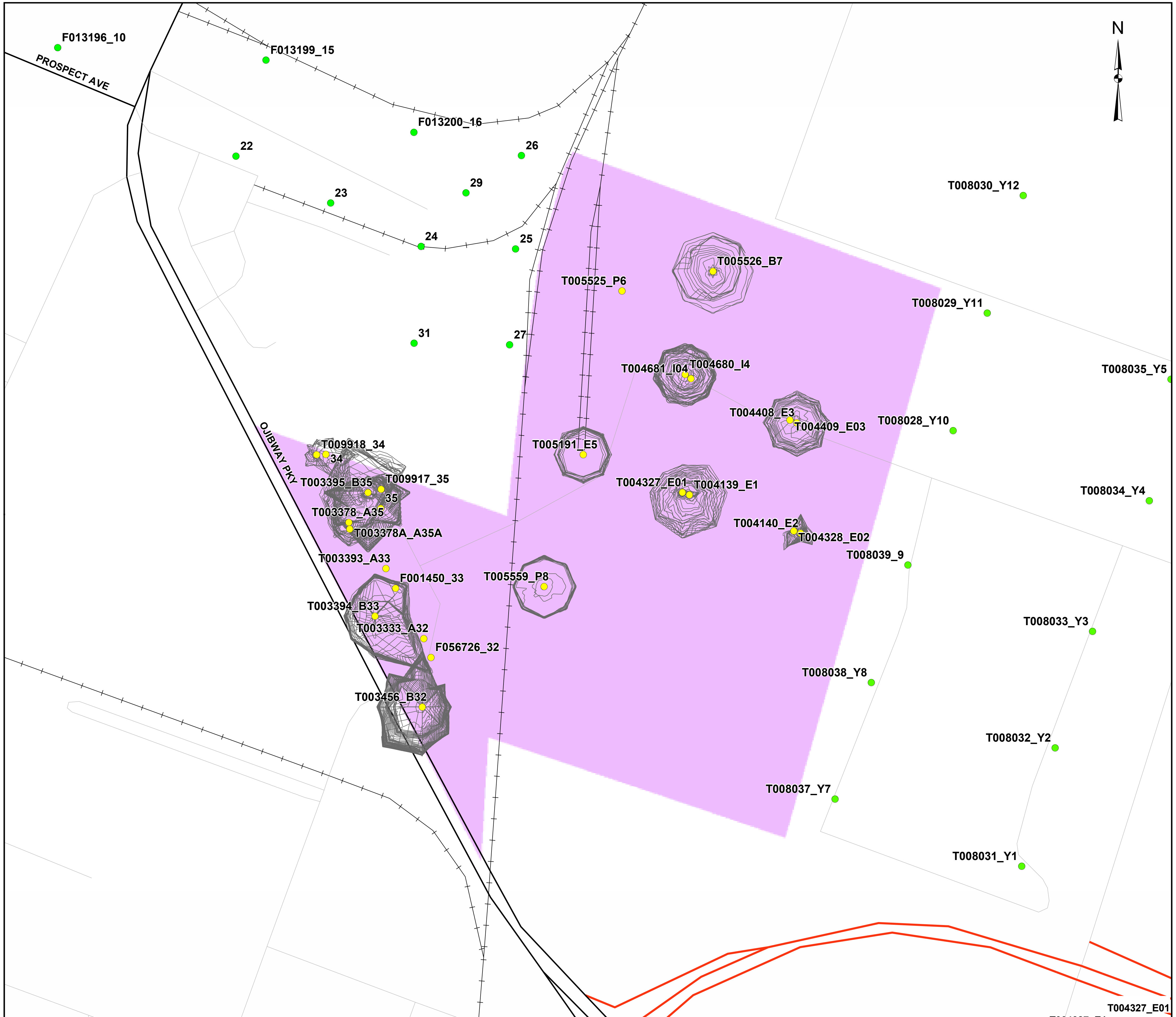
DETROIT RIVER INTERNATIONAL CROSSING

TITLE

ISOMETRIC VIEW OF KNOWN WELLS AND SALT CAVERNS

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE See scalebar	REV. 1
DESIGN	CC	24 May 2006	FIGURE: 7.3	
GIS	JFC	17 Jan. 2008		
CHECK	JM	17 Jan. 2008		
REVIEW	SB	17 Jan. 2008		



LEGEND

- Other Wells
- Cavern Storage Well
- Solution Mining Well
- Expressway
- Major Road
- Local Road
- Railway
- Salt Cavern Contours
- Water
- Approximate Boundaries of BP Cavern Field

NOTES:
Caverns as shown are based on preliminary data provided by BP.

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

0 50 100 200 300
Metres

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

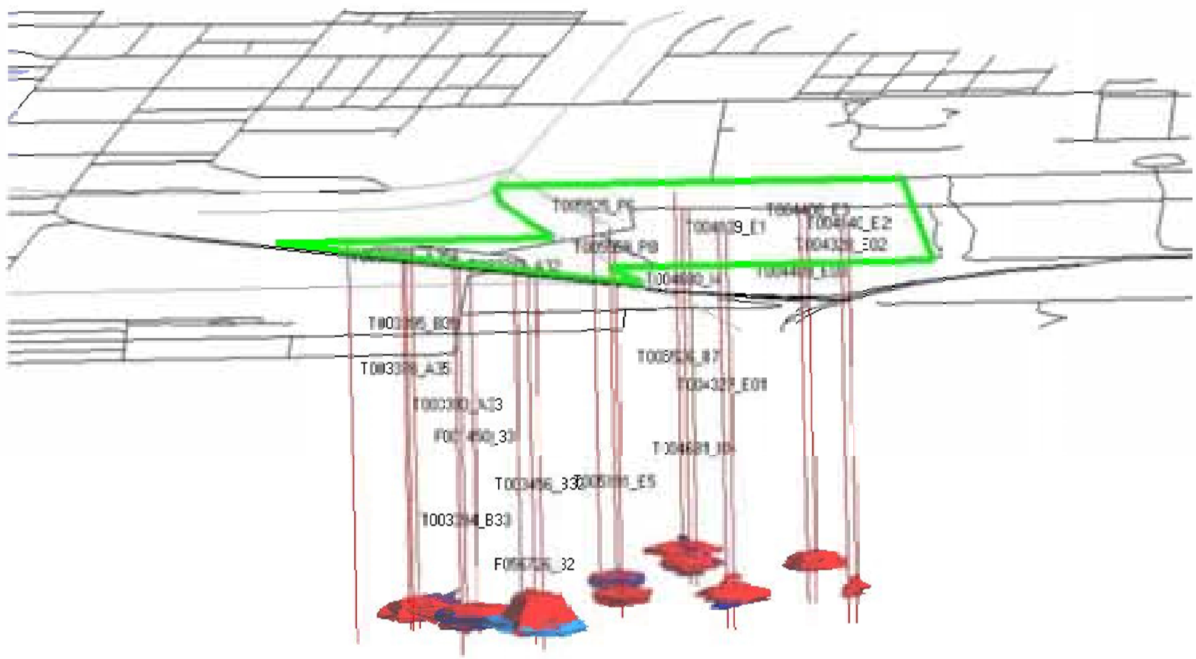
SALT CAVERNS IN BP FIELD

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE 1:5,000	REV. 1
DESIGN	CC	24 May 2006		
GIS	JFC	17 Jan. 2008		
CHECK	JM	17 Jan. 2008		
REVIEW	SB	17 Jan. 2008		

FIGURE: 7.4

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure7.4_Caverns_BP.mxd



500 0 500 m

LEGEND

- Approximate Boundaries of BP Site
- Surface Roads
- Railway
- Well Borehole
- Approximate dimensions of Cavern

NOTE:
1. Caverns as shown are based on preliminary sonar survey data provided by BP.
2. Vertical exaggeration 1x. Horizontal distance measured along Linsell Ave between Chappus and Healy Street. Horizontal distance is approximate.

PROJECT

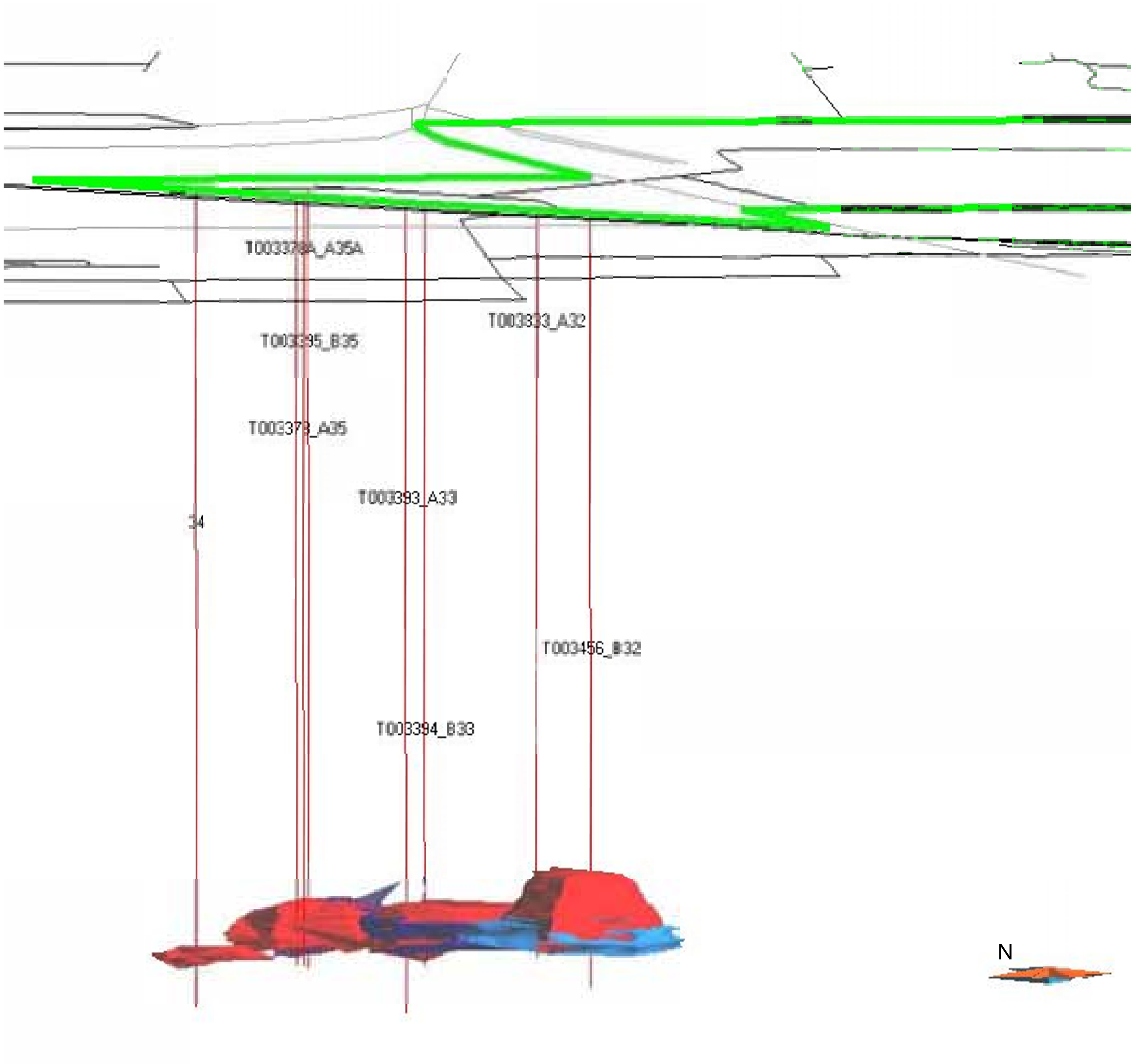
DETROIT RIVER INTERNATIONAL CROSSING

TITLE

ISOMETRIC VIEW OF WELLS AND SALT CAVERNS IN BP FIELD

Golder Associates, Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE See note	REV. 1
DESIGN	CC	21 Sept. 2004	**FIGURE: 7.5**	
GIS	JFC	17 Jan. 2008		
CHECK	JM	17 Jan. 2008		
REVIEW	SB	17 Jan. 2008		



LEGEND

- Approximate Boundaries of BP Site
- Surface Roads
- Railway
- Well Borehole
- Approximate dimensions of cavern, most recent sonar survey
- Well Borehole
- Approximate dimensions of cavern, first sonar survey

NOTE:
1. Caverns as shown are based on preliminary sonar survey data provided by BP.
2. Vertical exaggeration 1x. Horizontal distance measured along Linsell Ave between Chappus and Healy Street. Horizontal distance is approximate.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

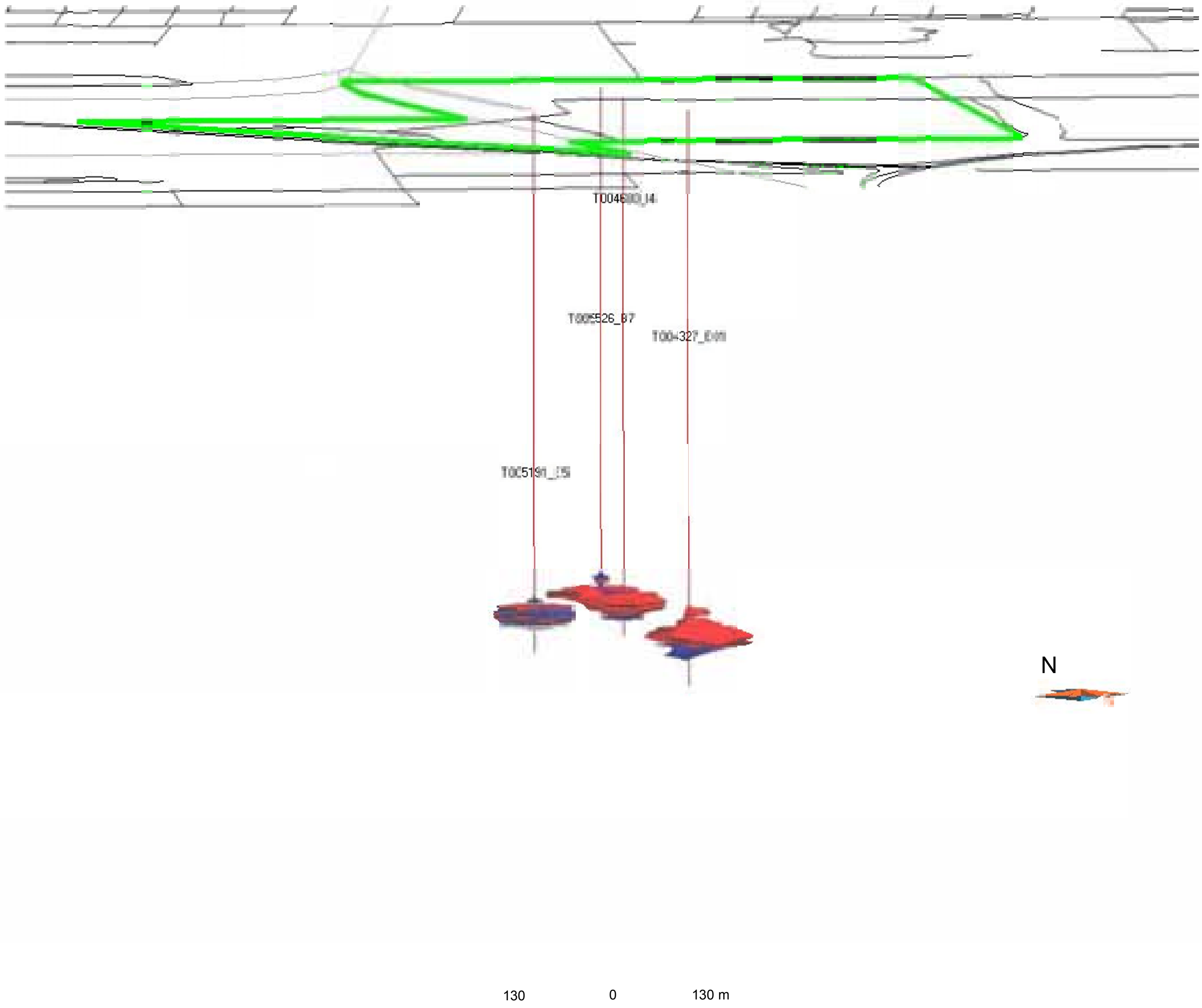
TITLE

ISOMETRIC VIEW OF WELLS AND SALT CAVERNS 32 - 35 IN BP FIELD

PROJECT No. 04-1111-060			SCALE See note	REV. 1
DESIGN	CC	21 Sept. 2004	FIGURE: 7.6	
GIS	JFC	17 Jan. 2008		
CHECK	JM	17 Jan. 2008		
REVIEW	SB	17 Jan. 2008		

Golder Associates
Mississauga, Ontario

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure7.6_Isometric_View_Wells_Caverns_32to35_BP_Field_v2.mxd



LEGEND

- Approximate Boundaries of BP Site
- Surface Roads
- Railway
- Well Borehole
- Approximate dimensions of cavern, most recent sonar survey
- Well Borehole
- Approximate dimensions of cavern, first sonar survey

NOTE:
1. Caverns as shown are based on preliminary sonar survey data provided by BP.
2. Vertical exaggeration 1x. Horizontal distance measured along Linsell Ave between Chappus and Healy Street. Horizontal distance is approximate.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

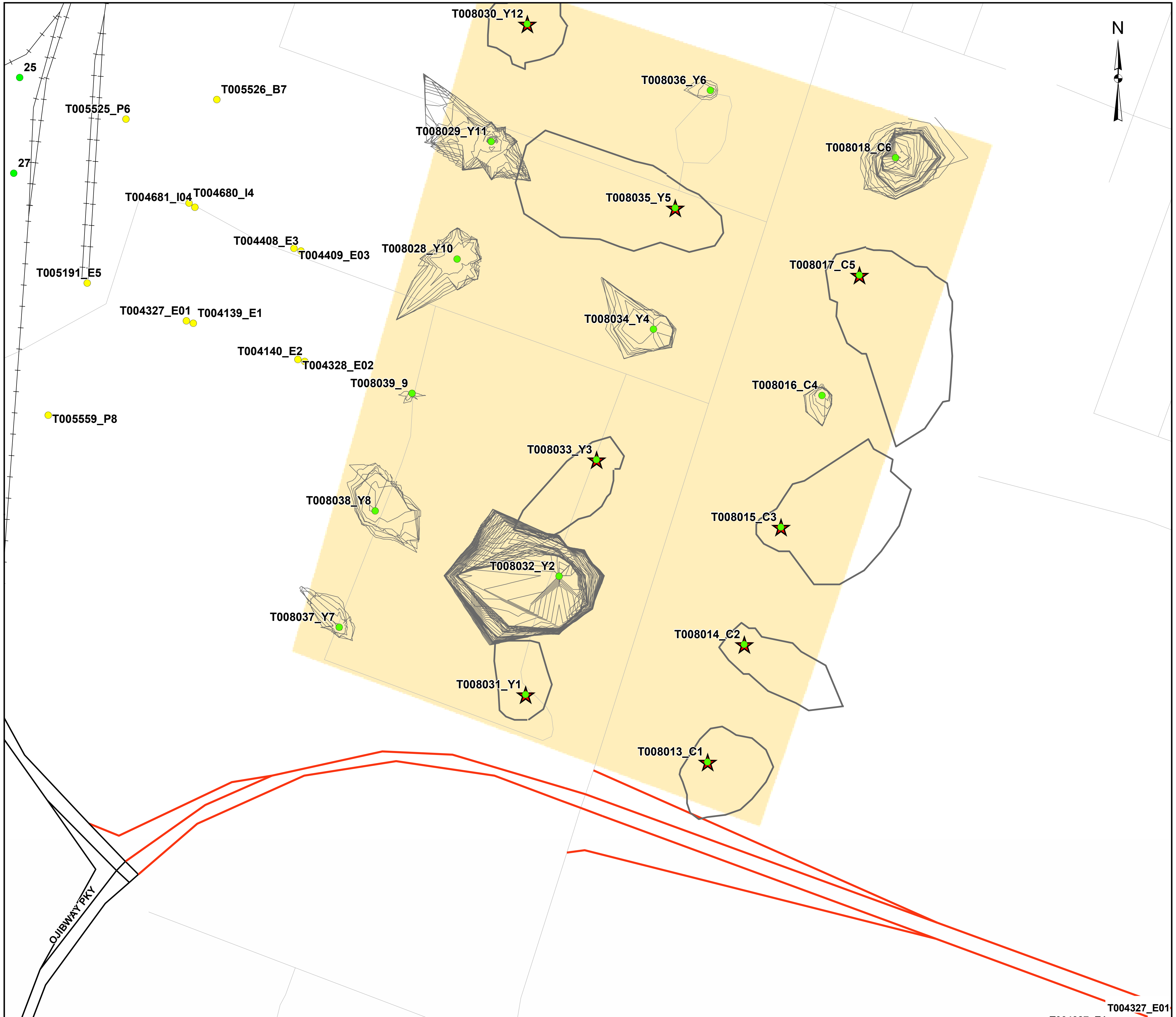
TITLE

ISOMETRIC VIEW OF WELLS AND SALT CAVERNS E04 - B7 IN BP FIELD

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE See note	REV. 1
DESIGN	CC	21 Sept. 2004	**FIGURE: 7.7**	
GIS	JFC	17 Jan. 2008		
CHECK	JM	17 Jan. 2008		
REVIEW	SB	17 Jan. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure7.7_Isometric_View_Wells_Caverns_E04_B7_BP_Field.mxd



LEGEND

- Cavern Storage Well
- Solution Mining Well
- No Sonar Data Available
- Expressway
- Major Road
- Local Road
- Railway
- Salt Cavern Contours
- Water
- Approximate Boundaries of Sandwich East Brine Field

NOTES:
1. Caverns as shown are based on preliminary sonar survey data provided by BP.
2. Records provided may be incomplete.

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

0 50 100 200 300
Metres

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

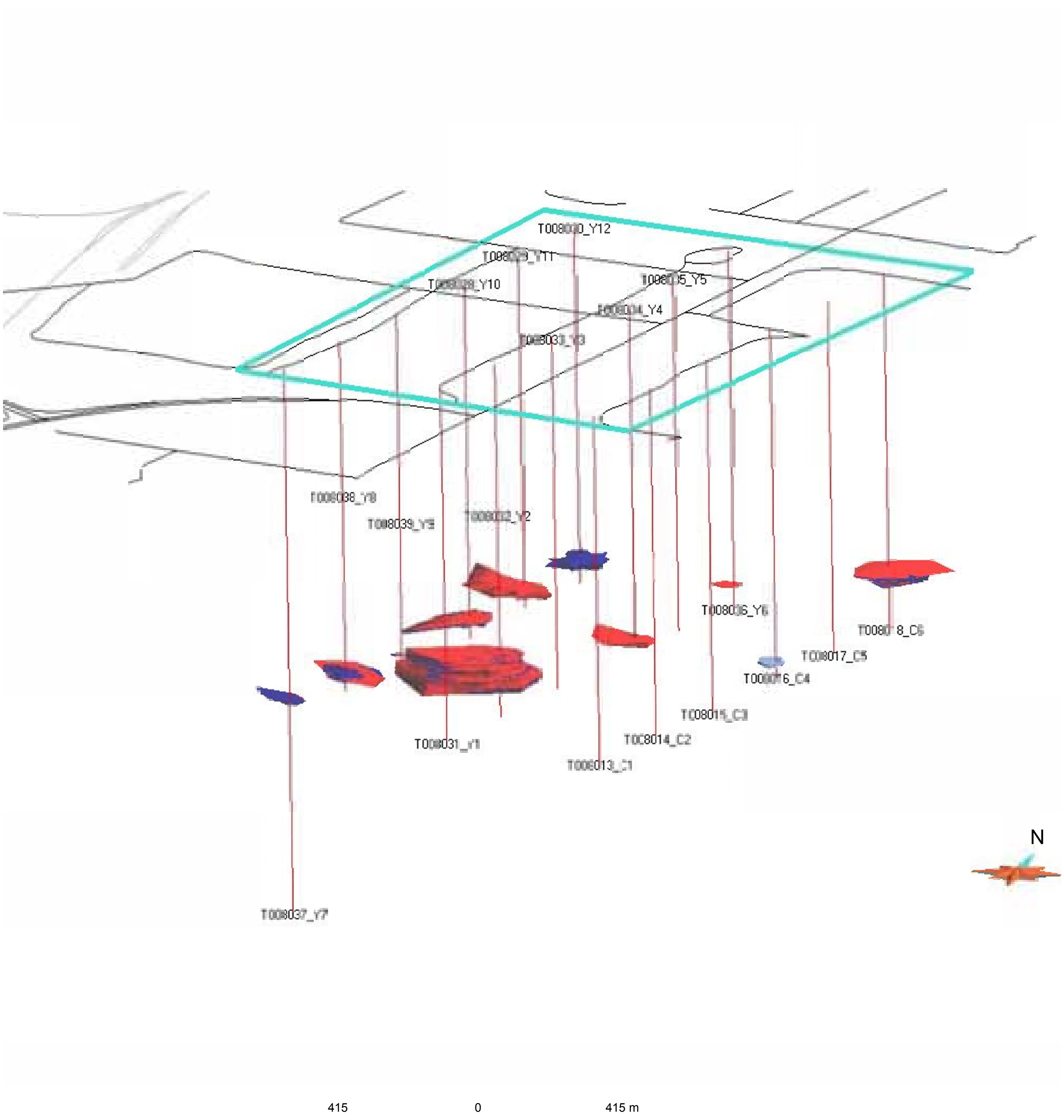
TITLE

SALT CAVERNS IN CANADIAN SALT SANDWICH EAST FIELD

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE 1:5,000	REV. 1
DESIGN	CC	24 May 2006	FIGURE: 7.8	
GIS	JFC	17 Jan. 2008		
CHECK	JM	17 Jan. 2008		
REVIEW	SB	17 Jan. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure7.8_Caverns_Canadian_Salt_Sandwich_East.mxd



LEGEND

- Approximate Boundaries of Sandwich East Brine Field
- Surface Roads
- Railway
- Well Borehole
- Approximate Dimensions of Cavern for Available Data

NOTE:
1. Caverns as shown are based on preliminary sonar survey data provided by BP.
2. Vertical exaggeration 1x. Horizontal distance measured along Vaughan St. Horizontal distance is approximate.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

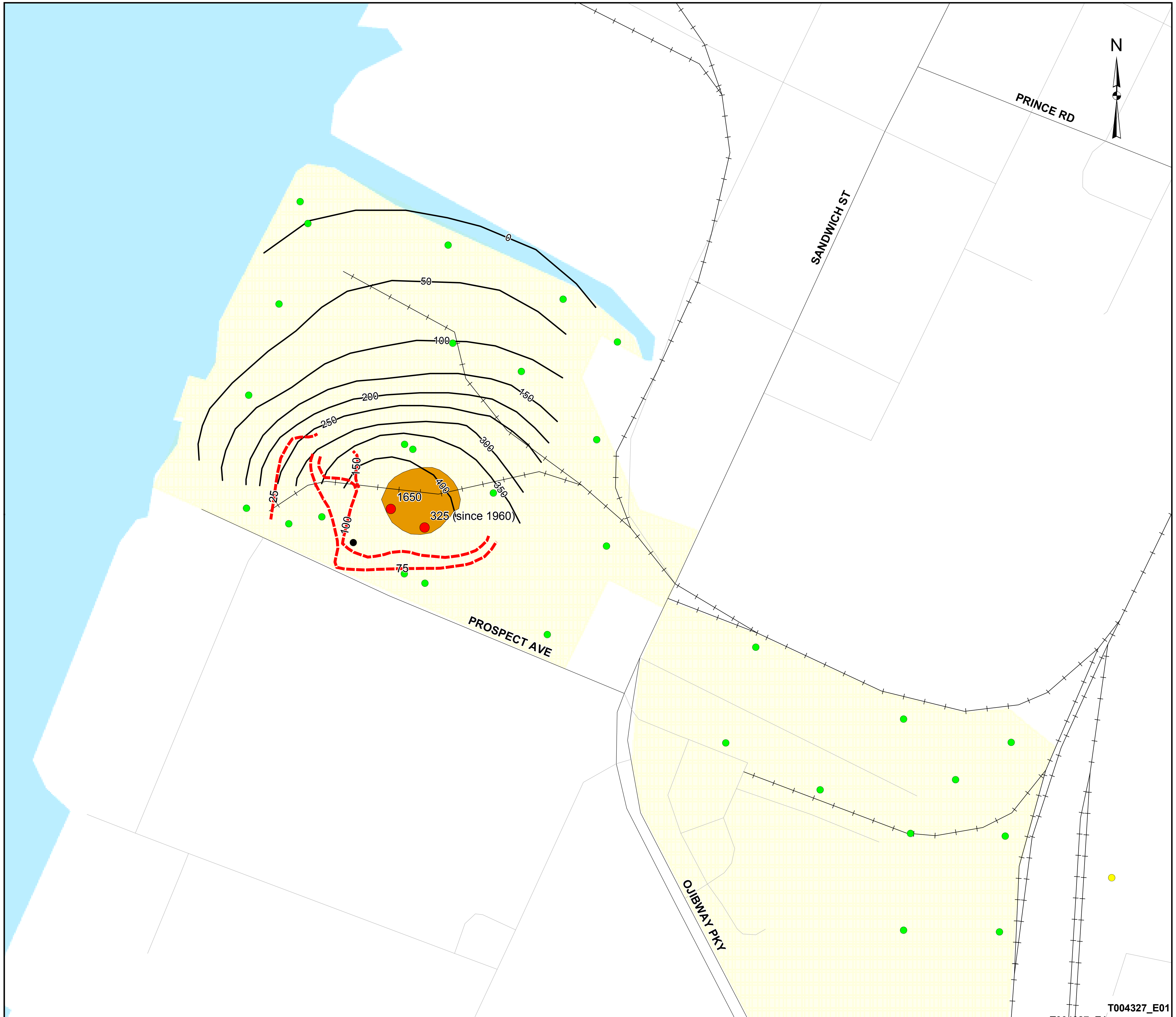
TITLE

ISOMETRIC VIEW OF WELLS AND SALT CAVERNS IN CANADIAN SALT SANDWICH EAST FIELD

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE As Shown	REV. 1
DESIGN	CC	21 Sept. 2004	**FIGURE: 7.9**	
GIS	JFC	17 Jan. 2008		
CHECK	JM	17 Jan. 2008		
REVIEW	SB	17 Jan. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure7.9_Isometric_View_Wells_Salt_Caverns_Canadian_Salt_Sandwich_East.mxd



LEGEND

- Other Wells or Boreholes
- Cavern Storage Well
- Solution Mining Well
- Approximate Ground Subsidence Contours (mm) 1954-1968
- Approximate Ground Subsidence Contours (mm) 1948-1954
- Major Road
- Local Road
- Railway
- Sinkhole, 1954
- Water
- Approximate Boundaries of former Sandwich West Brine Field

NOTES:

1. Approximate subsidence contours based on Russel, (1973) and Terzaghi (1970)
2. Well locations as shown obtained from multiple sources. See report text for full references.

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

0 50 100 200 300
Metres

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

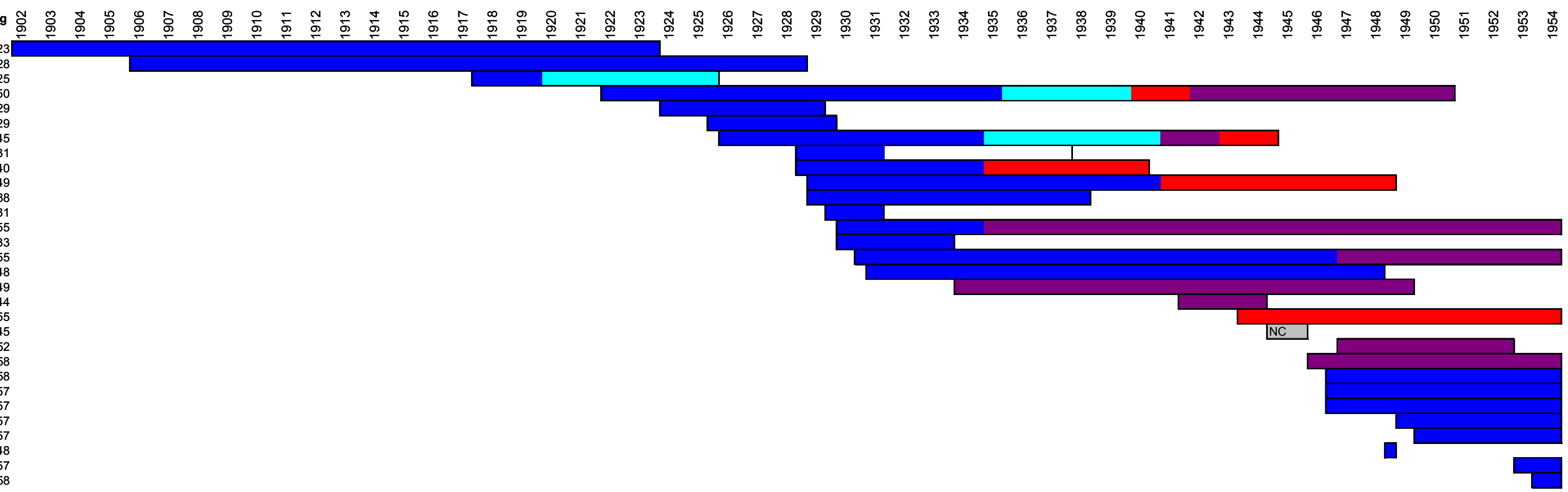
TITLE

WELL LOCATIONS, SUBSIDENCE CONTOURS AND SINKHOLE IN SANDWICH WEST FIELD

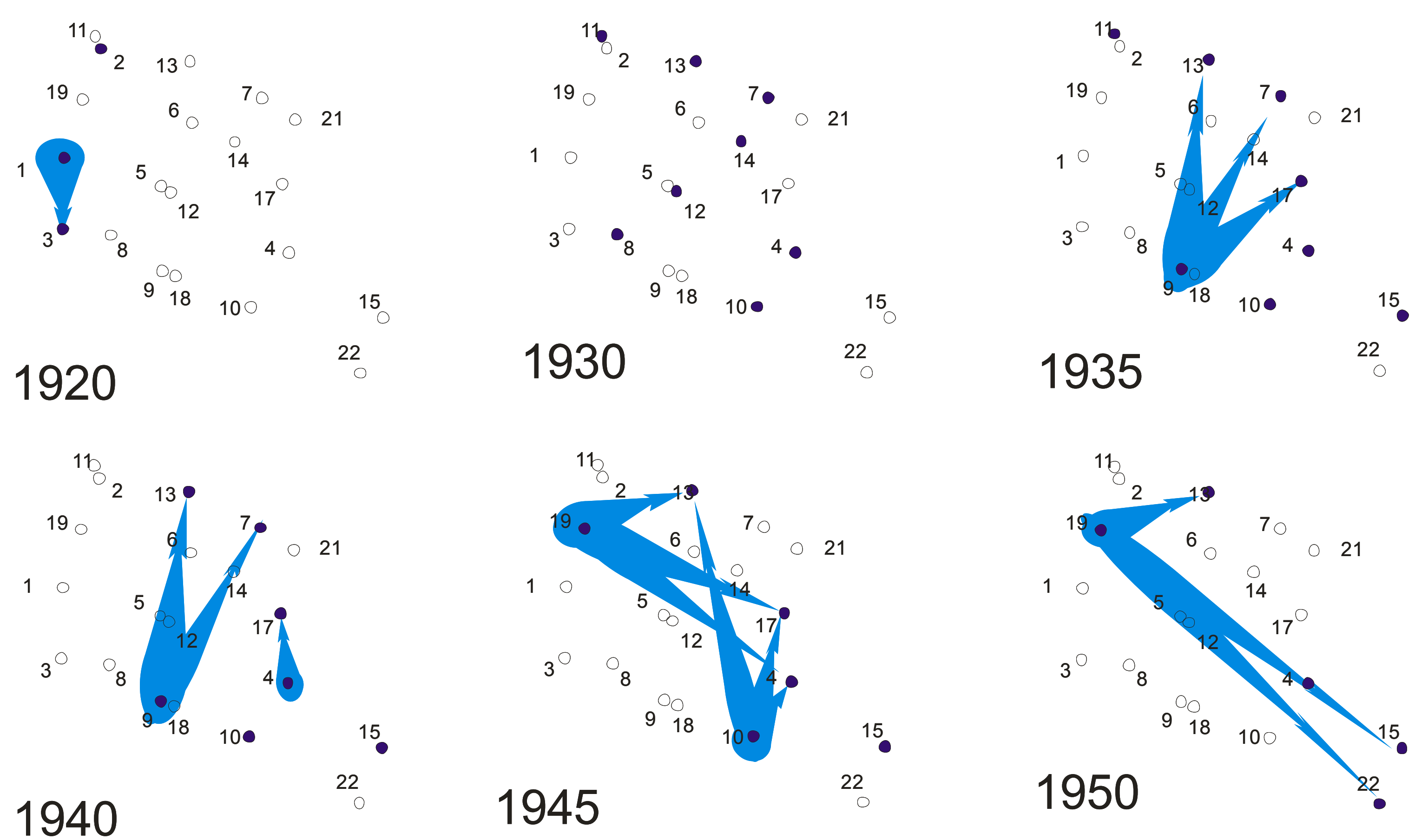
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE 1:5,000	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 7.10**	
GIS	JFC	13 Dec. 2007		
CHECK	JM	13 Dec. 2007		
REVIEW	SB	13 Dec. 2007		

Well No.	Drilling Date	Plugging Date
#1	Mar-02	Jun-23
#2	Apr-06	Dec-28
#3	Jun-17	Jun-25
#4	Mar-22	Sep-50
#5	Dec-23	Feb-29
#6	Mar-25	Oct-29
#7	Jan-26	Jan-45
#8	Apr-28	Apr-31
#9	Sep-28	Aug-40
#10	Dec-28	Nov-49
#11	Apr-29	Mar-38
#12	Aug-29	Apr-31
#13	Dec-29	Oct-55
#14	Apr-30	Nov-33
#15	Nov-30	Aug-55
#16	Dec-30	Jun-48
#17	Feb-34	Apr-49
#18	Jun-41	Jun-44
#19	Nov-43	Nov-55
#20	Sep-44	Nov-45
#21	Feb-47	Dec-52
#22	May-46	Feb-58
#23	Jun-46	Feb-58
#24	Jul-46	Jun-57
#25	Aug-46	Jun-57
#26	Mar-49	Jun-57
#27	Jul-49	Jul-57
#28	Jun-48	Oct-48
#29	Apr-53	May-57
#30	Jun-53	Feb-58



FLOW ACROSS WELL FIELD FOR SELECTED YEARS



LEGEND

- Operating Well
- Non-operational Well (plugged, not drilled)
- Potential flow direction from injection well to deep well or airlift well
- Conventional brine well operation
- Operation as air-lift well
- Operation as fresh water injection only well
- Operation as deep well for pumping of brine
- NC — Not completed

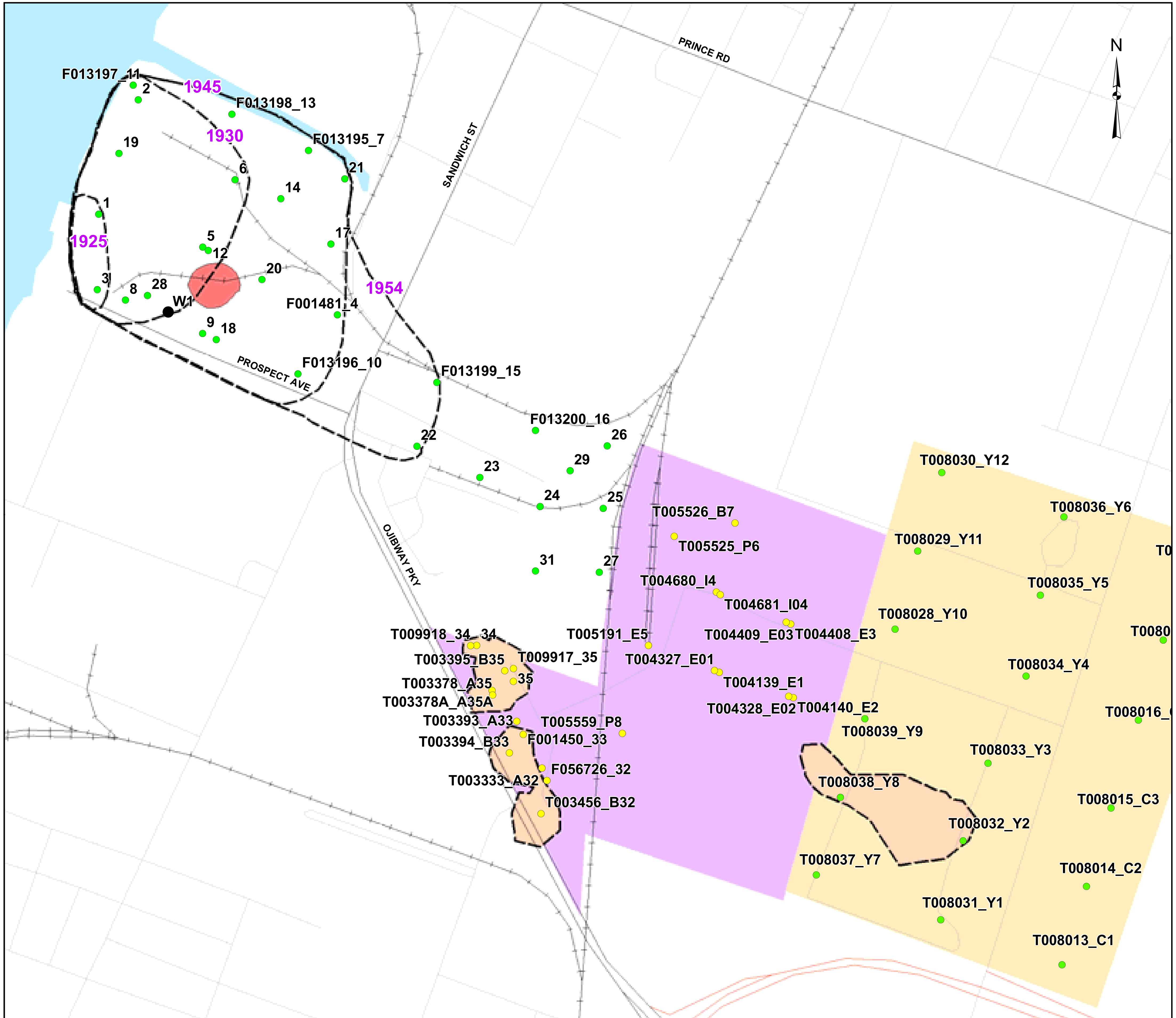
Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. Data and correlations used for development of this figure are discussed in the above referenced reports.

PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

TITLE
OPERATING MODE AND LIFESPAN OF INDIVIDUAL WELLS IN SANDWICH WEST FIELD

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	CC	24 May 2006	FIGURE: 7.11	
GIS	JFC	13 Dec. 2007		
CHECK	JM	13 Dec. 2007		
REVIEW	SB	13 Dec. 2007		



LEGEND

- Cavern Storage Well
- Solution Mining Well
- Other Wells or Boreholes
- Expressway
- Major Road
- Local Road
- Railway
- 1954 Approximate Date of Interconnection (Russell,1993)
- Interconnected Caverns Interpreted from Brine Well Records
- Sinkhole 1954
- Water
- Joined Salt Caverns
- Approximate Boundaries of Canadian Salt Sandwich East Field
- Approximate Boundaries of BP Cavern Field

Note:

1. Wells shown with alpha-numeric label, such as the series beginning F013xxx_xx, F0014xx_xx, T00xxxx_xx are based on location and well licence data provided by the Ontario Ministry of Natural Resources, Oil Salt and Gas Resources Library.

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

0 100 200 400 600
Metres

PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

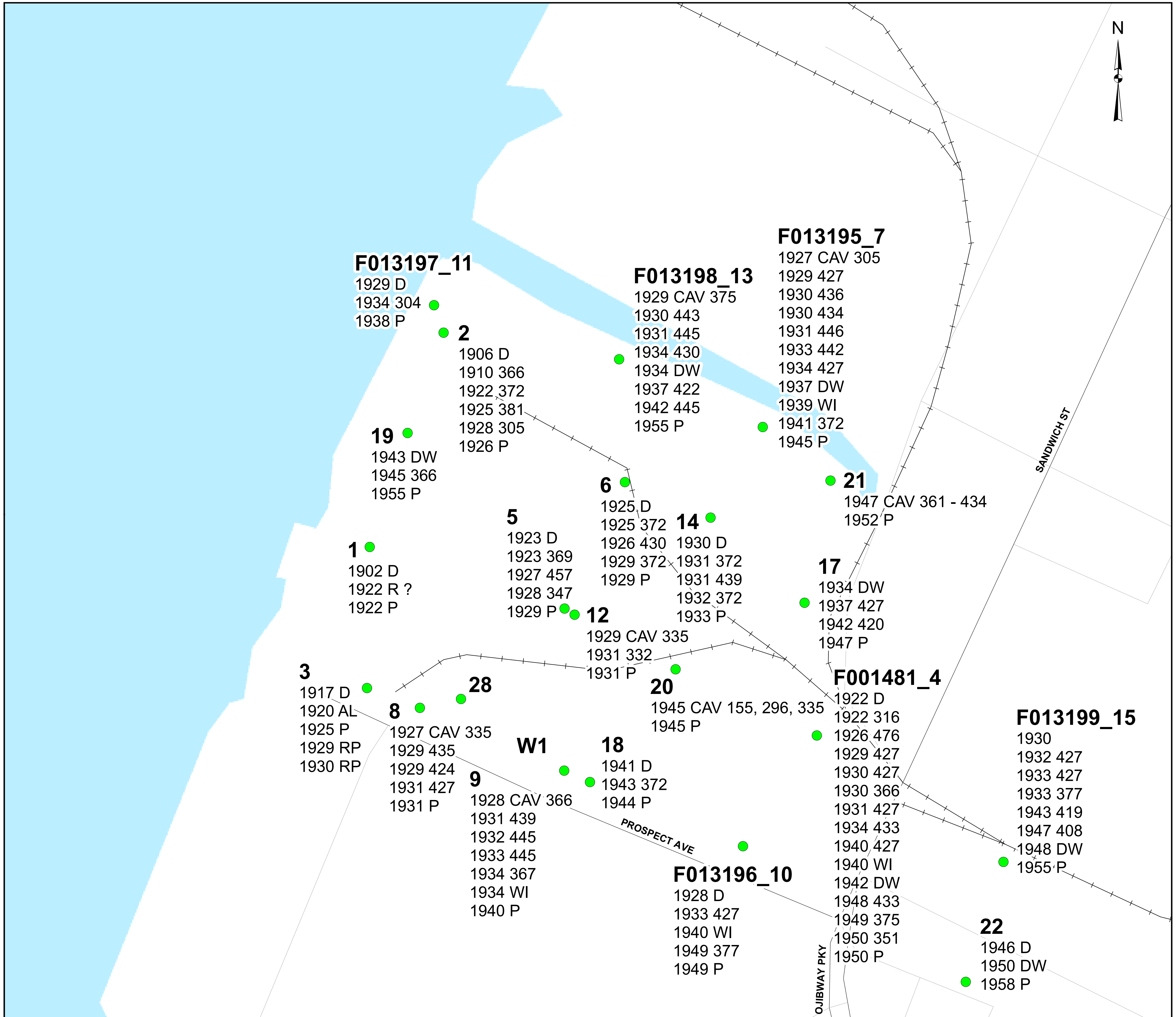
TITLE
INTERCONNECTION OF WELLS IN SANDWICH WEST FIELD

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060		SCALE 1:7,500	REV. 1
DESIGN	CC	24 May 2006	
GIS	JFC	13 Dec. 2007	
CHECK	JM	13 Dec. 2007	
REVIEW	SB	13 Dec. 2007	

FIGURE: 7.12

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\Nov2007_Edits\Figure7.12_Interconnection_of_Wells_Sandwich_WestField.mxd



LEGEND

- Solution Mining Well
- F013199_15 MNR Well License Number (where mapped and available)
- Expressway
- Major Road
- Local Road
- Railway
- Water

NOTES:

1. History of Repairs, Sandwich West Brine Field, 1902-1954 from Russell (1993). The first date gives the date of drilling, usually as a single well injection system. If drilled as any other type of well it is shown thus; AL-air lift; D-drilling date; DW-deep pump well; WI-water injection. If caving or cavities were encountered, CAV is shown, with the depth in metres. The dates below the first one are those when repairs were needed at the depth in metres shown. If the well was converted to a different type (AL, WI, DW), plugged (P) or replugged (RP), the date for that work is also shown.
2. Wells shown with alpha-numeric label, such as the series begining F013xxx_xx, F0014xx_xx, T00xxx_xx are based on location and well licence data provided by the Ontario Ministry of Natural Resources, Oil Salt and Gas Resources Library.

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

0 50 100 200 300
Metres

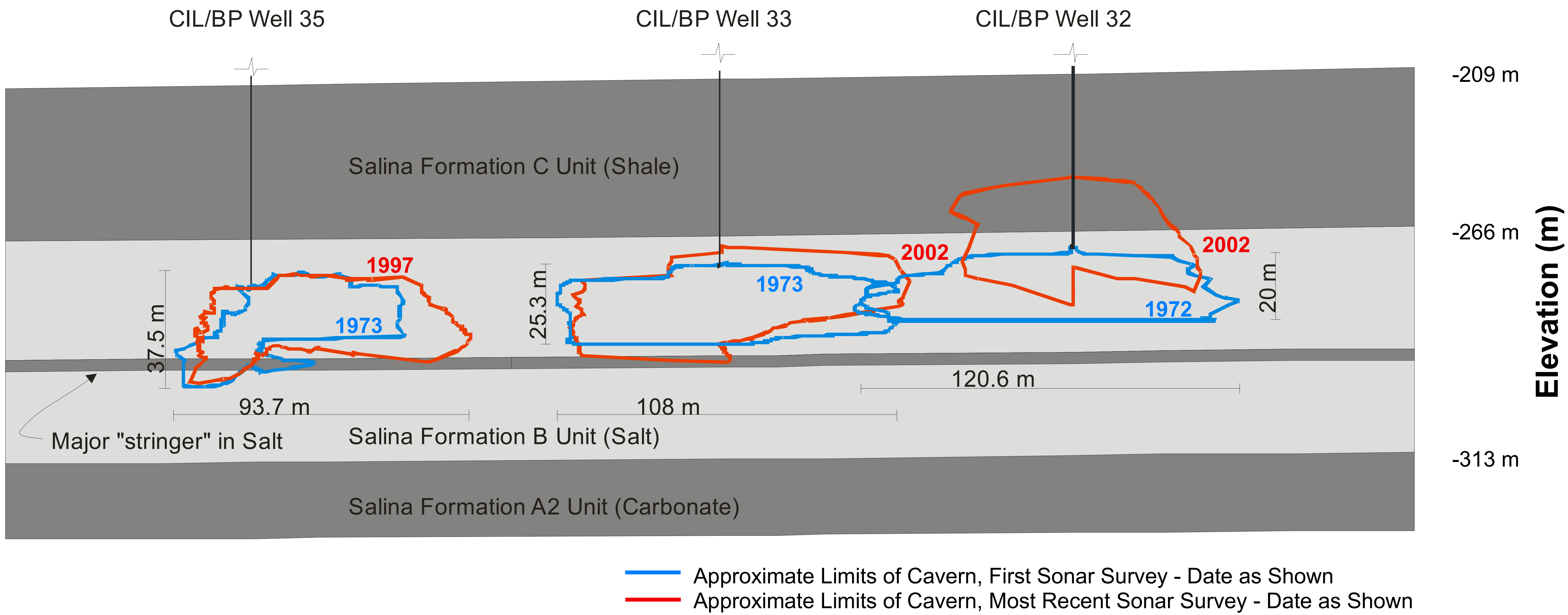
PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

TITLE
DAMAGES TO WELL PIPES DURING OPERATIONAL LIFE IN SANDWICH WEST FIELD

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE 1:4,000	REV. 1
DESIGN	CC	24 May 2006	FIGURE: 7.13	
GIS	CC	13 Dec. 2007		
CHECK	JM	13 Dec. 2007		
REVIEW	SB	13 Dec. 2007		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure7.13_Damages_to_WellsPipes_During_OperationalLife_Sandwich_West_Field.mxd



NOTE:
1. Geologic formation boundaries based on surfaces and regional bed topography interpreted using recent well gamma log data from X10N and X11 series wells.
2. Caverns as shown are based on sonar survey data provided by BP.

PROJECT	DETROIT RIVER INTERNATIONAL CROSSING			
TITLE	**ROOF FALL AT BP CAVERN 32 IN BP FIELD**			
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE NTS	REV. 1
	DESIGN	CC	24 May 2006	**FIGURE: 7.14**
	GIS	JFC	13 Dec. 2007	
	CHECK	JM	13 Dec. 2007	
	REVIEW	SB	13 Dec. 2007	

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\Nov2007_Edits\Figure7.14_Roof_Collapse_BPCavern 32.mxd

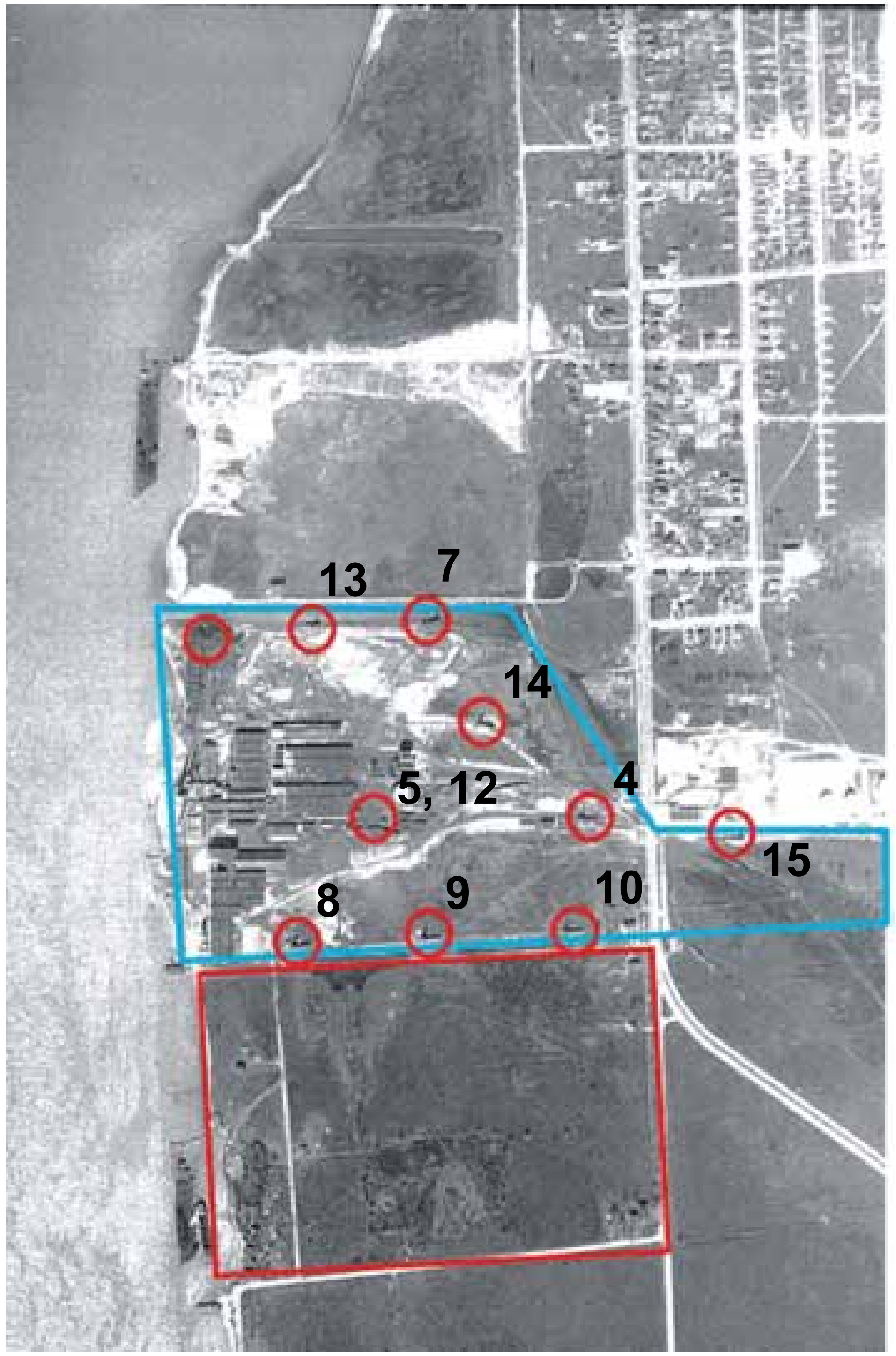


Photo 1: Aerial photo taken April, 1931, showing Canadian Industries Ltd. facility (blue outlines) and early expansion of the brine wells east of Sandwich Street. Visible well heads indicated by red circles. Mullen Coal Co. docks and open lands shown to south of CIL properties. (red outlines)

Photo 2: Aerial photo taken May, 1947, showing Canadian Industries Ltd. facility (blue outlines) and continued expansion of the brine wells east of Sandwich Street. Expanded Mullen Coal Co. coal handling facility, docks and open lands shown to south of CIL properties. (red outlines)

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

AERIAL PHOTOS OF SANDWICH WEST SITE AND NEIGHBOURING PROPERTIES

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 7.15**	
GIS	JFC	13 Dec. 2007		
CHECK	JM	13 Dec. 2007		
REVIEW	SB	13 Dec. 2007		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\Nov2007_Edits\Figure7.15_Aerial Photos of Sandwich West Site and Neighbouring Properties.mxd

Photo 1. Looking northeast from near well #3, north of present Windsor Salt offices, showing start of major subsidence.

Photo 2. Looking west-northwest from between wells #10 and #20, in present open field showing loss of high compressor building (centre).

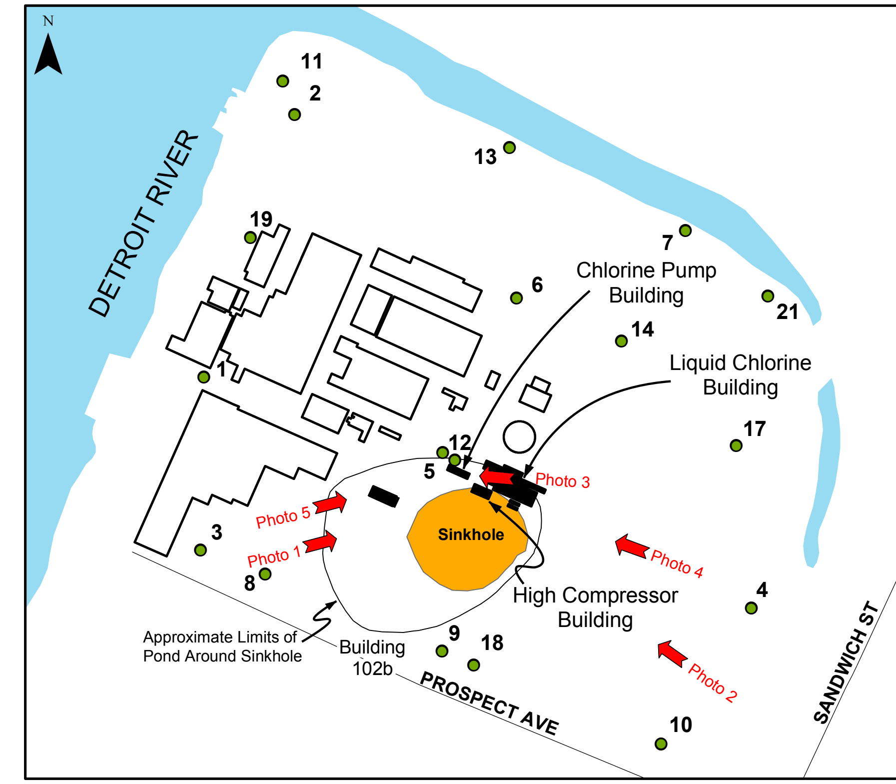


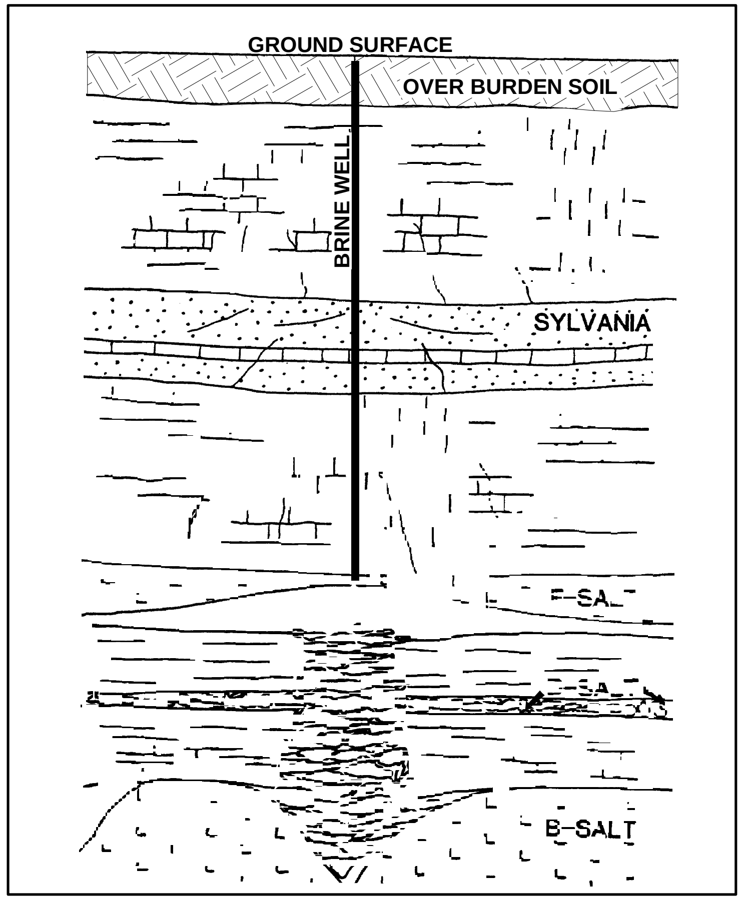
Photo 3. Looking west from between wells #20 and #14 on liquid chlorine building showing loss of chlorine pump building.

Photo 4. Looking west from near wells #20 and #4, south of liquid chlorine building, showing loss of high compressor building (middle ground) and shed 102b (background).

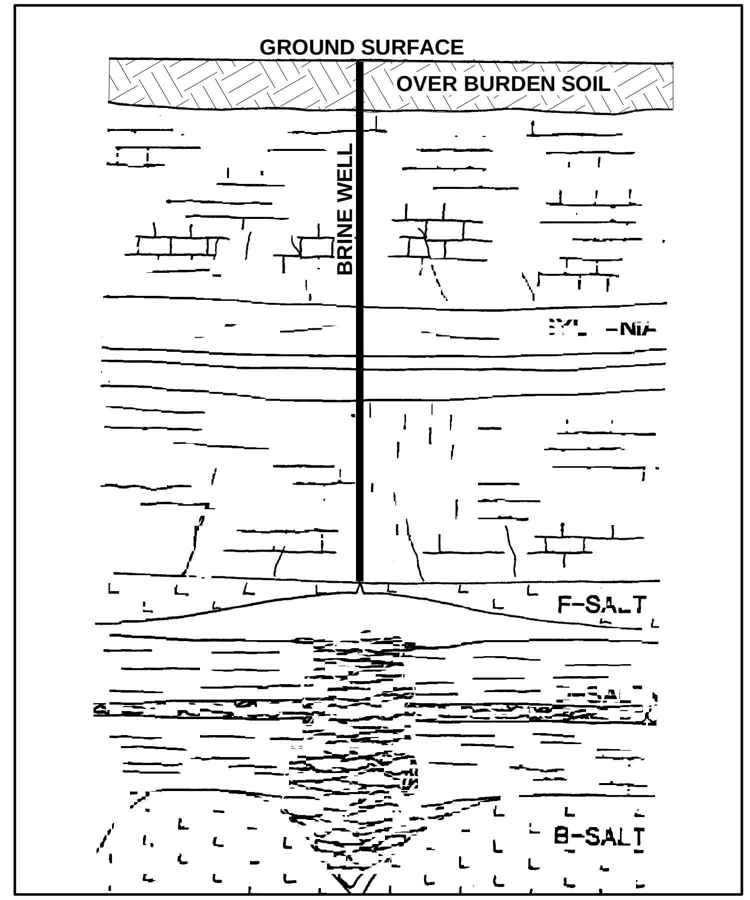
Photo 5. Looking northeast from near well #28, north of present Windsor Salt offices, showing loss of shed 102b.

Notes:
1. This figure is to be read with the accompanying report.
2. Photographer unknown

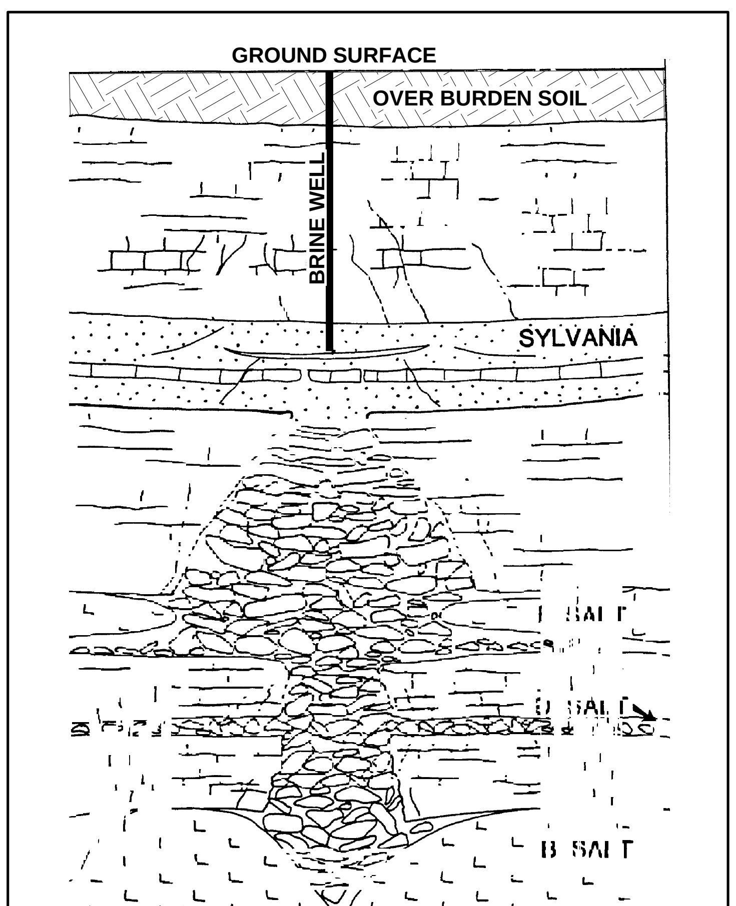
PROJECT	DETROIT RIVER INTERNATIONAL CROSSING			
TITLE	**SINKHOLE AT CANADIAN INDUSTRIES LIMITED, FEBRUARY 1954**			
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE NTS	REV. 1
	DESIGN	CC	24 May 2006	**FIGURE: 7.16**
	GIS	JFC	13 Dec. 2007	
	CHECK	JM	13 Dec. 2007	
	REVIEW	SB	13 Dec. 2007	



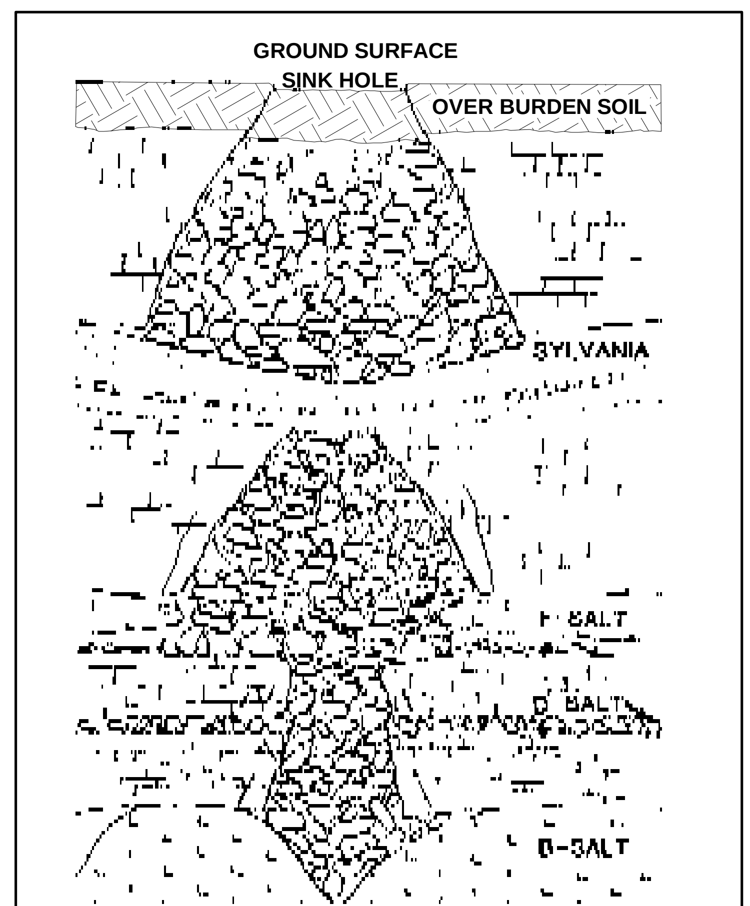
a) Initial dissolution of B, D, and F salt beds



b) Enlargement of cavities and caving of roof rock into openings in B, D, and F salt beds



c) Continued enlargement of cavities and collapse of material into openings, loss of brine well



d) Crushing and decompositon of Sylvania Sandstone, loss of sand into void spaces below, and collapse of dolostone above forming surface sink hole.

REFERENCE

1) - Russel, D.J. (1993). Role of the sylvania formation in sinkhole development, Essex County, Ontario Geological Survey, open file report 5861. Ministry of Northern Development and Mines, 122p.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

SUGGESTED MECHANISM FOR SURFACE SUBSIDENCE OVER SOLUTION MINING

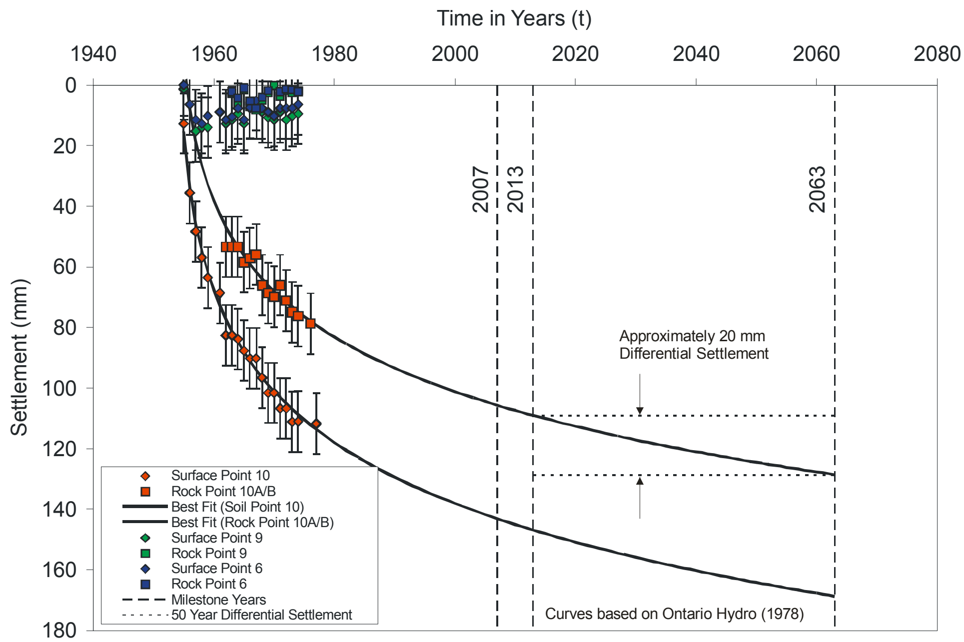
Golder Associates
LONDON, ONTARIO

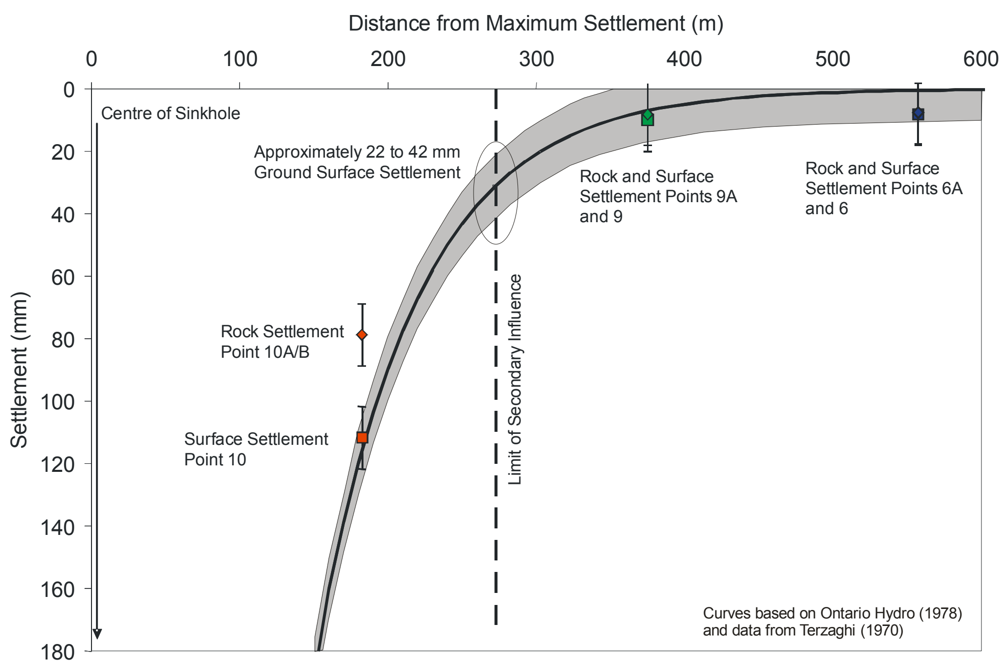
PROJECT No.	04-1111-060B	
DESIGN		
CADD	BG/WDF	3 Jan 2008
CHECK	JM	10 Jan 2008
REVIEW	SB	10 Jan 2008

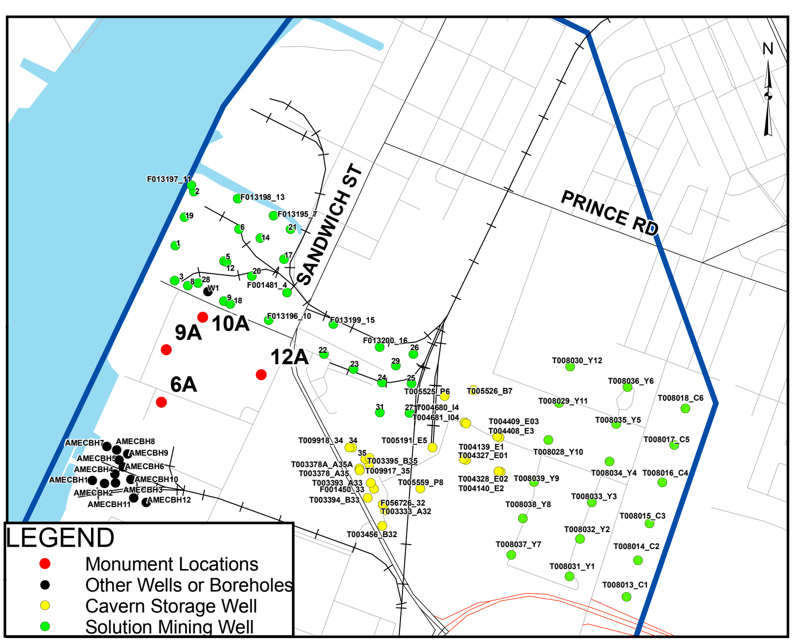
FILE No. 041111060-R01-7_17
SCALE AS SHOWN REV. 1

FIGURE 7.17

Drawing file: 041111060-R01-7_17.dwg Jan 15, 2008 - 2:18pm







PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

SUBSIDENCE MONITORING ON FORMER ONTARIO HYDRO LANDS

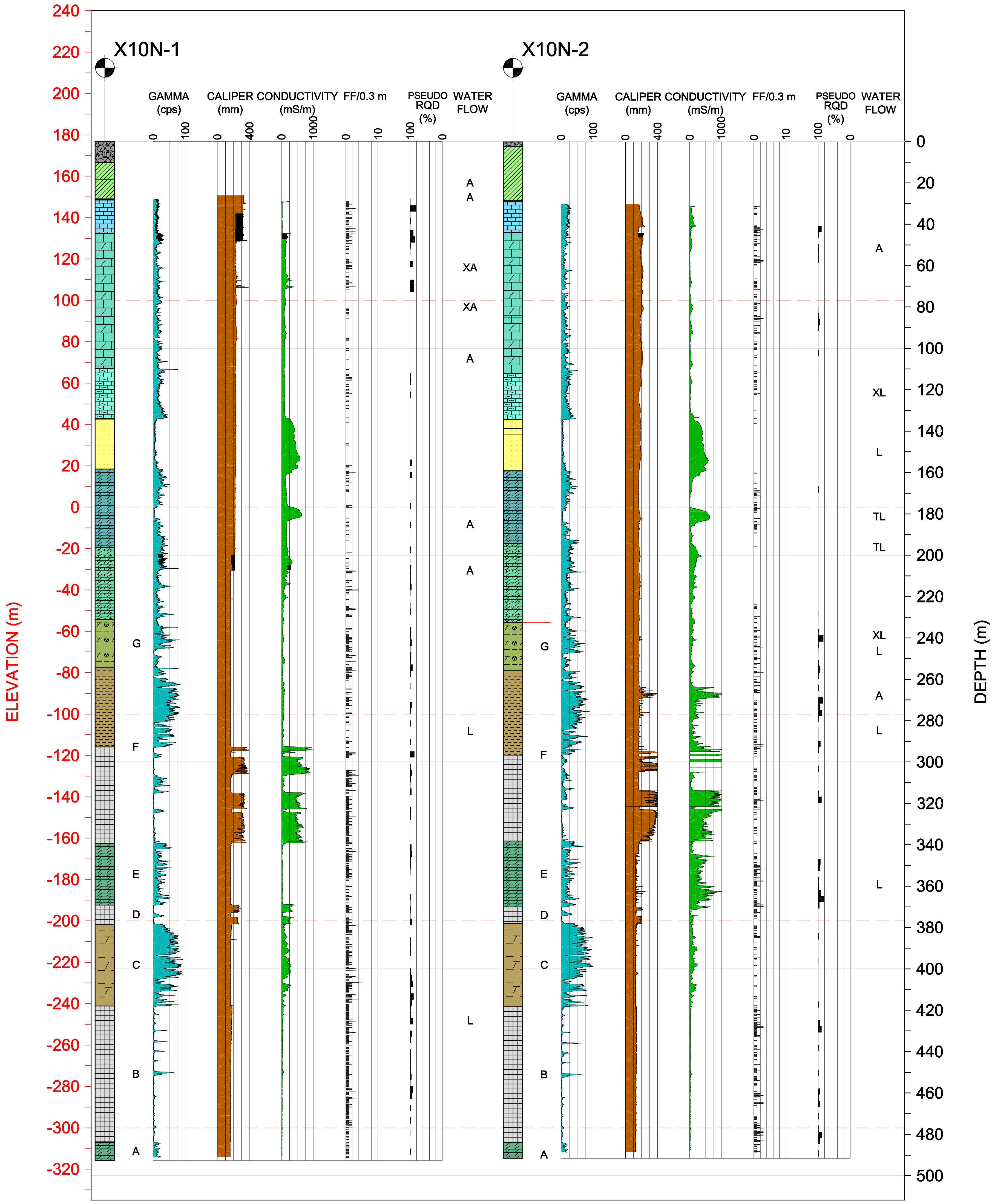
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE As shown	REV. 1
DESIGN	CC	21 Sept. 2004		
GIS	PB	13 Dec. 2007		
CHECK	PB	13 Dec. 2007		
REVIEW	PB	13 Dec. 2007		

FIGURE: 7.18

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure7.18_Subsidence_monitoring_Former_Ontario_lands.mxd

PLOT DATE: January 22, 2008
FILENAME: T:\Projects\2004\04-1111-060B (URS, Detroit, Michigan)\-AE-\041111060BAE08.1a.dwg



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES
SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-1.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

Golder Associates
Mississauga, Ontario, Canada

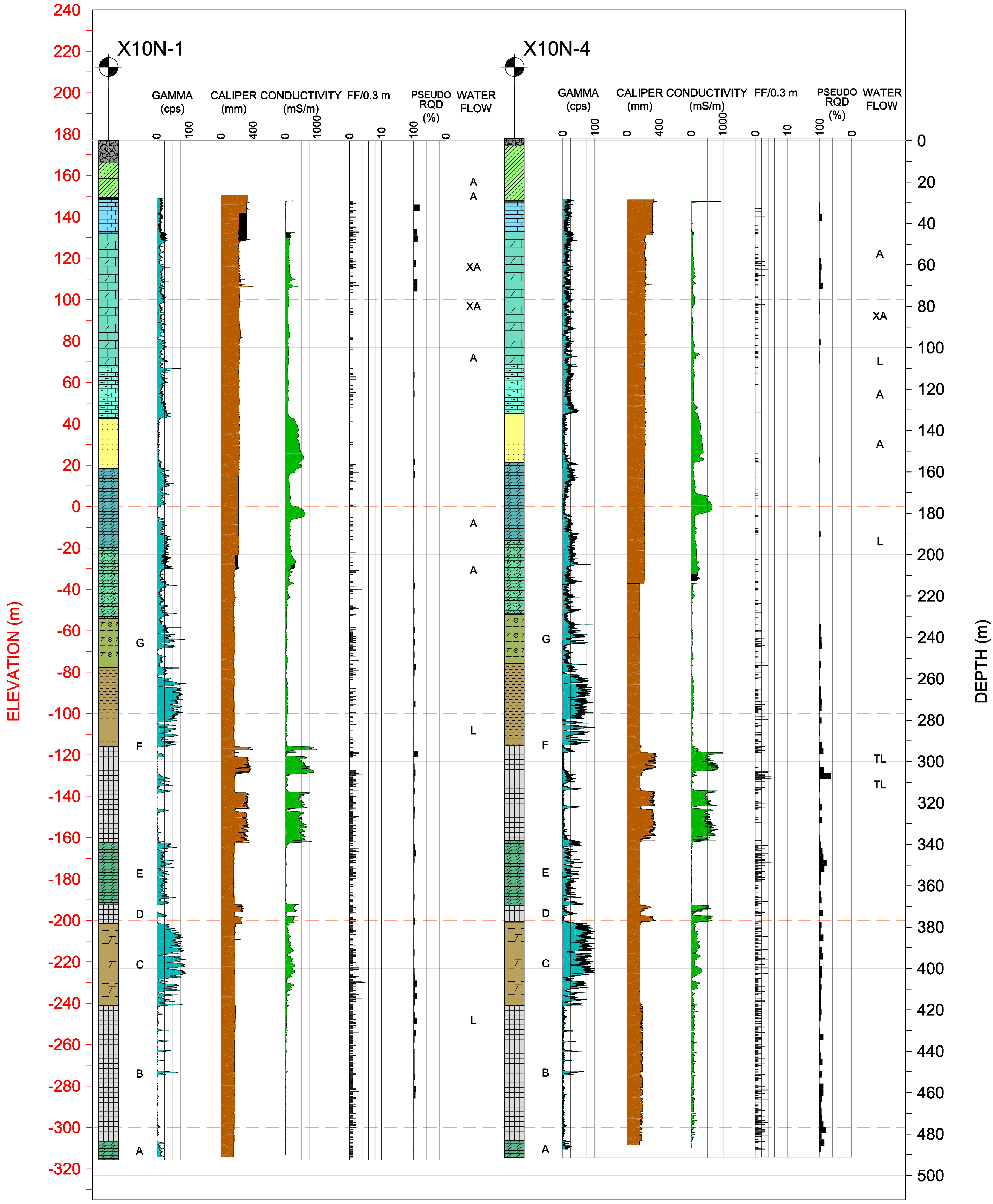
SCALE	AS SHOWN
DATE	16 Jan. 2008
DESIGN	
CAD	JFC
CHECK	JM/CP
REVIEW	TGC
FILE No.	041111060BAE08.1a.dwg
PROJECT No.	04-1111-060B
REV.	A

TITLE

SUBSURFACE LOG SUMMARIES X10N-1 AND X10N-2

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1a



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-1.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

Golder Associates
Mississauga, Ontario, Canada

SCALE	AS SHOWN
DATE	16 Jan. 2008
DESIGN	
CAD	JFC
CHECK	JM/CP
REVIEW	TGC

FILE No. 041111060BAE08.1b.dwg

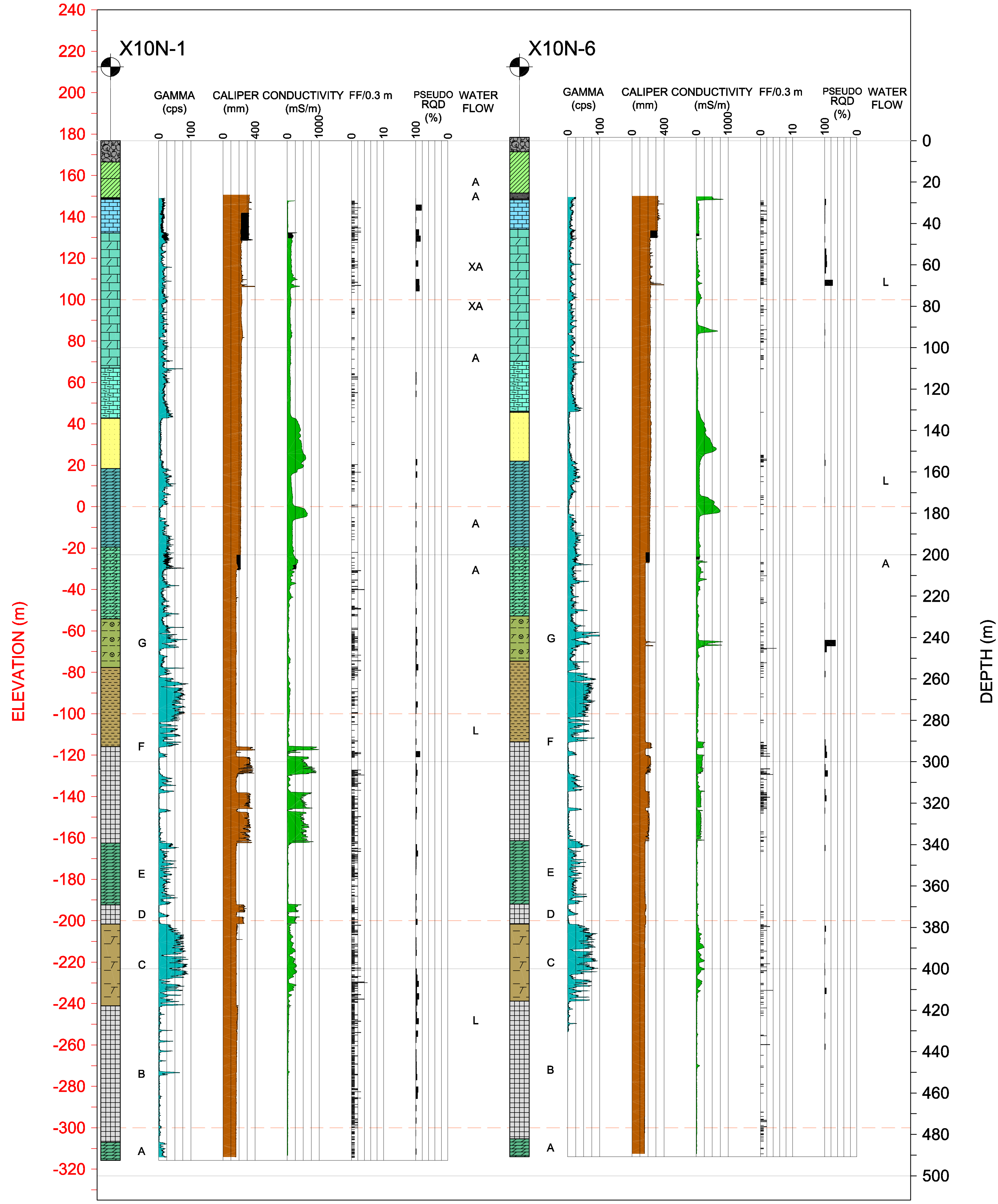
PROJECT No. 04-1111-060B REV. A

TITLE

SUBSURFACE LOG SUMMARIES X10N-1 AND X10N-4

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1b



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

SCALE VERT. 1:2000 METRES (40 0 40 80)
SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-1.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

Golder Associates
Mississauga, Ontario, Canada

SCALE	AS SHOWN
DATE	16 Jan. 2008
DESIGN	
CAD	JFC
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SUBSURFACE LOG SUMMARIES X10N-1 AND X10N-6

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1c

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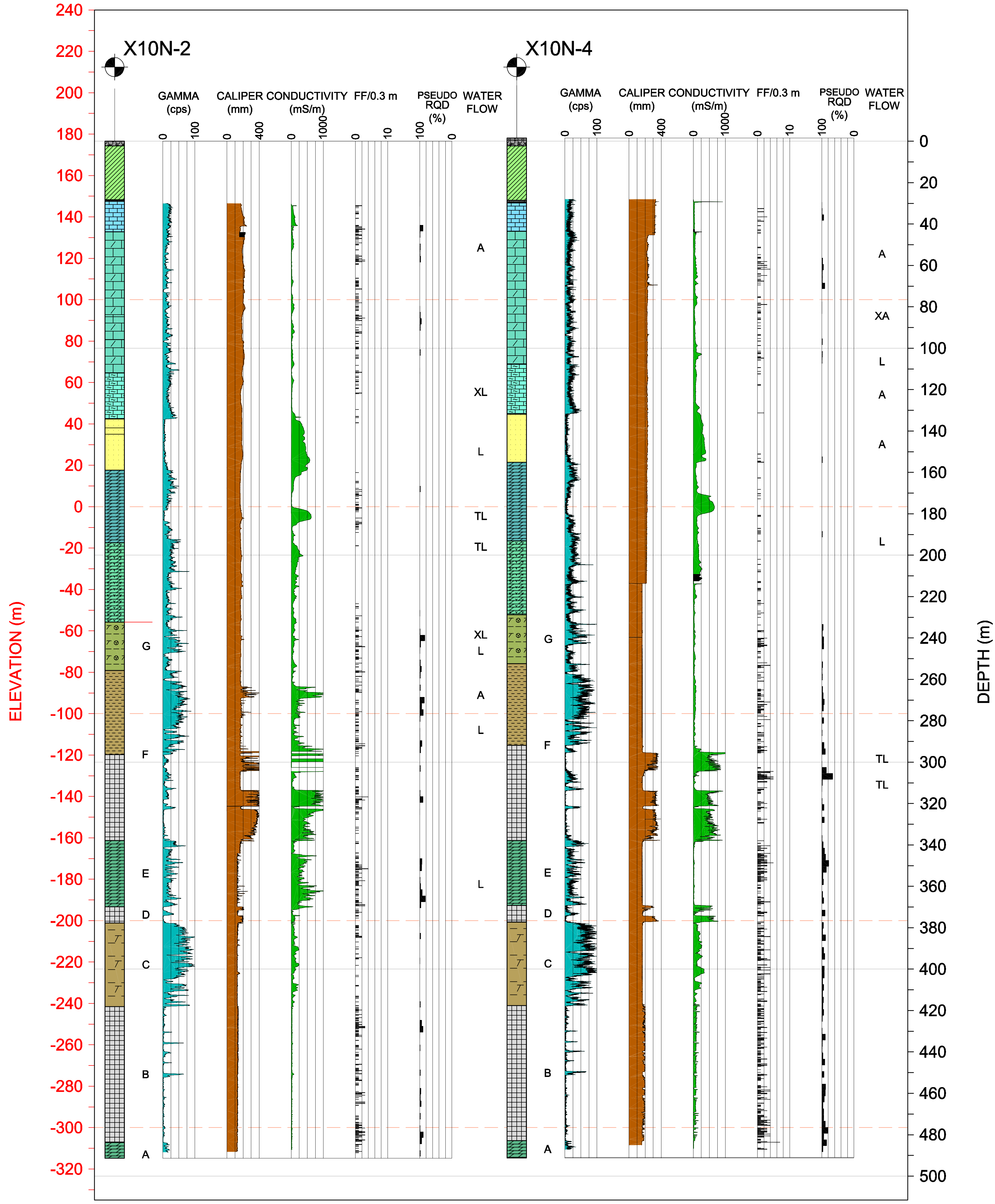

LEGEND:

FILL
SILTY CLAY
TILL
DUNDEE FORMATION
LUCAS FORMATION
AMHERSTBURG FORMATION
SYLVANIA FORMATION
BOIS BLANC FORMATION
BASS ISLANDS FORMATION
SALINA LIMESTONE
SALINA SHALE
SALINA DOLOSTONE
SALINA DOLOMITIC SHALE
SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES
SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-2.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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SUBSURFACE LOG SUMMARIES X10N-2 AND X10N-4

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1d

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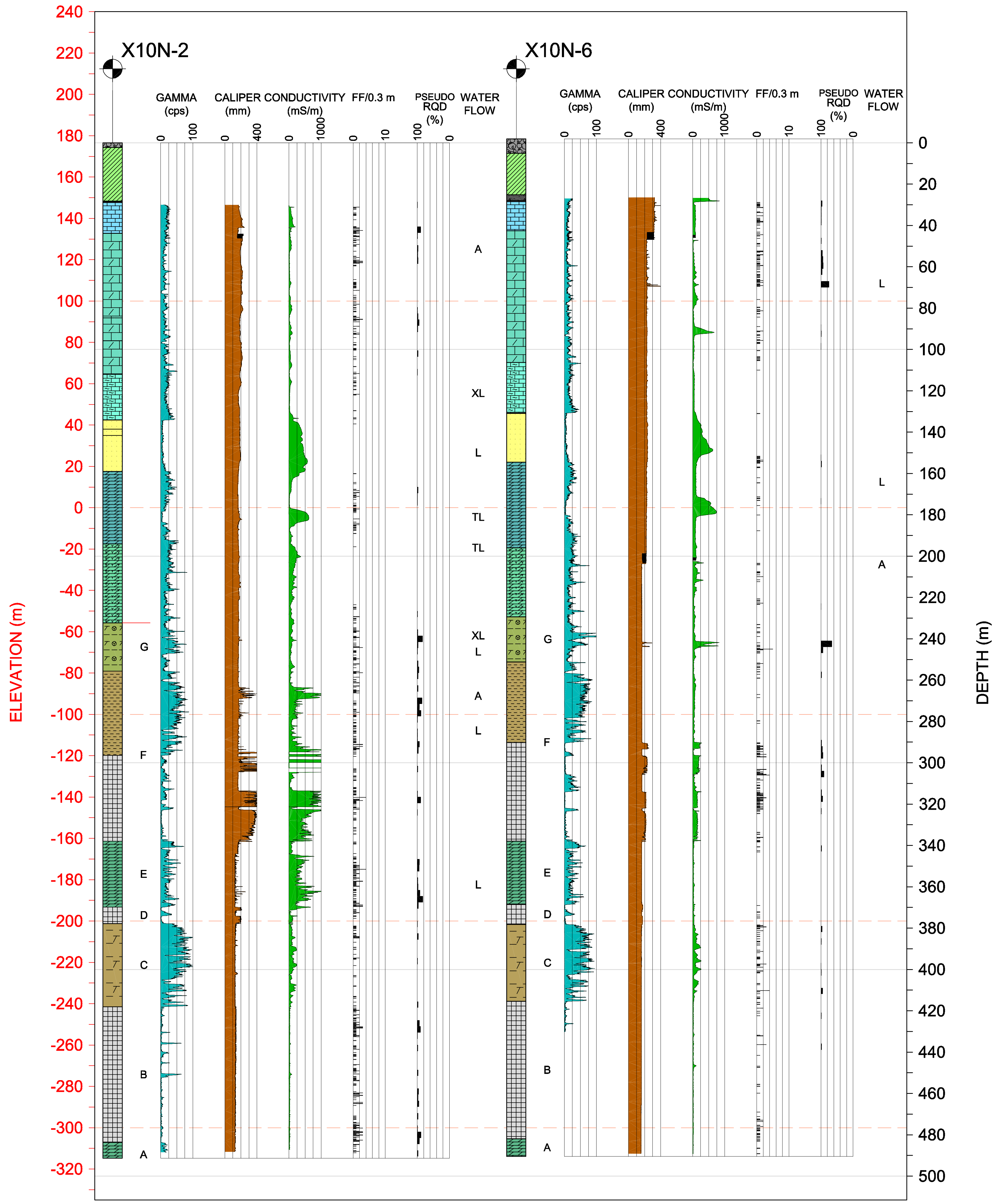
FILENAME: T:\Projects\2004\04-1111-060B (URS, Detroit, Michigan)\-AE-\041111060BAE08.1e.dwg



LEGEND:

FILL	BOIS BLANC FORMATION
SILTY CLAY	BASS ISLANDS FORMATION
TILL	SALINA LIMESTONE
DUNDEE FORMATION	SALINA SHALE
LUCAS FORMATION	SALINA DOLOSTONE
AMHERSTBURG FORMATION	SALINA DOLOMITIC SHALE
SYLVANIA FORMATION	SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-2.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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SUBSURFACE LOG SUMMARIES X10N-2 AND X10N-6

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1e

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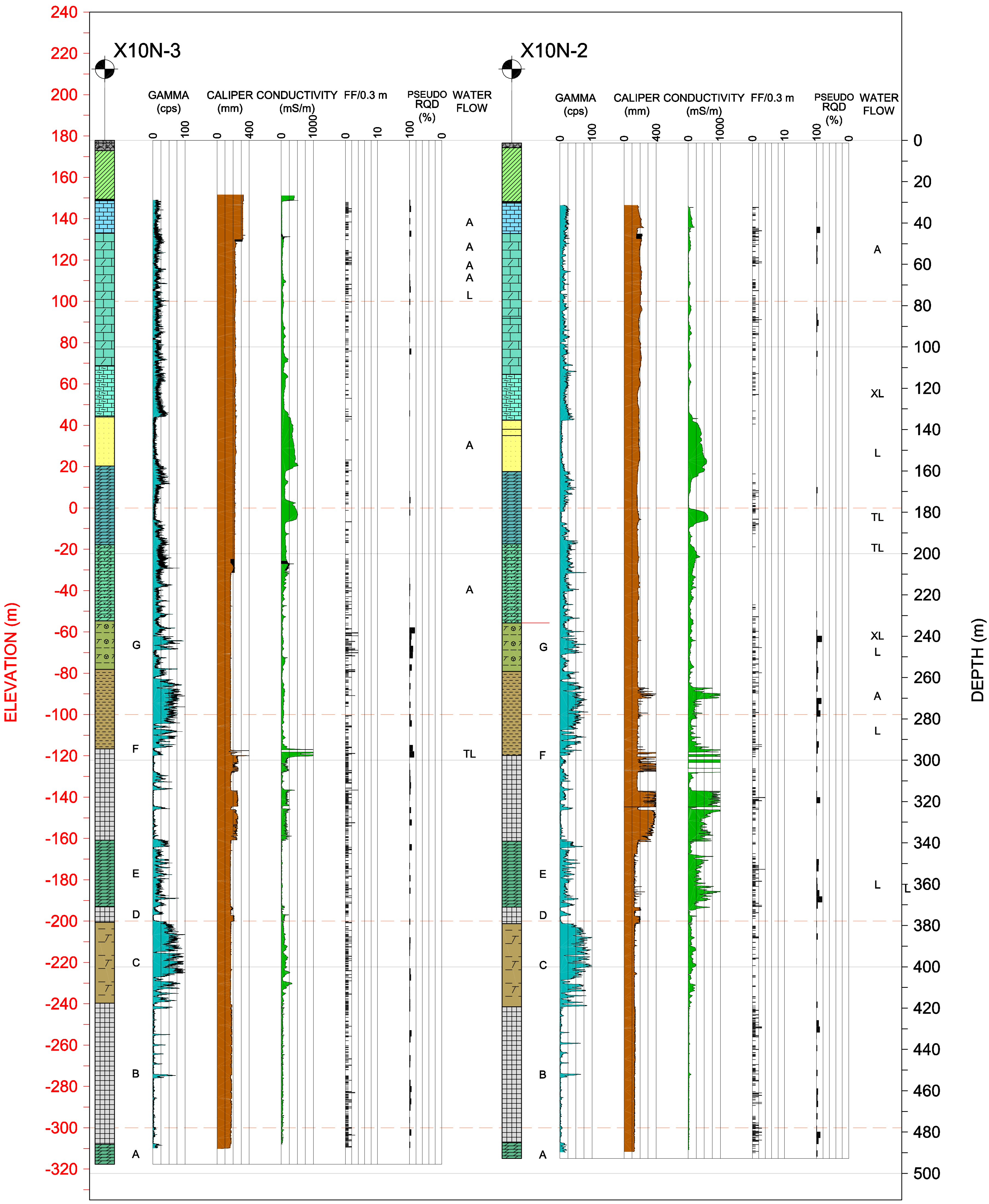
FILENAME: T:\Projects\2004\04-1111-060B (URS, Detroit, Michigan)\-AE-\041111060BAE08.1f.dwg



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-3.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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SUBSURFACE LOG SUMMARIES X10N-3 AND X10N-2

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1f

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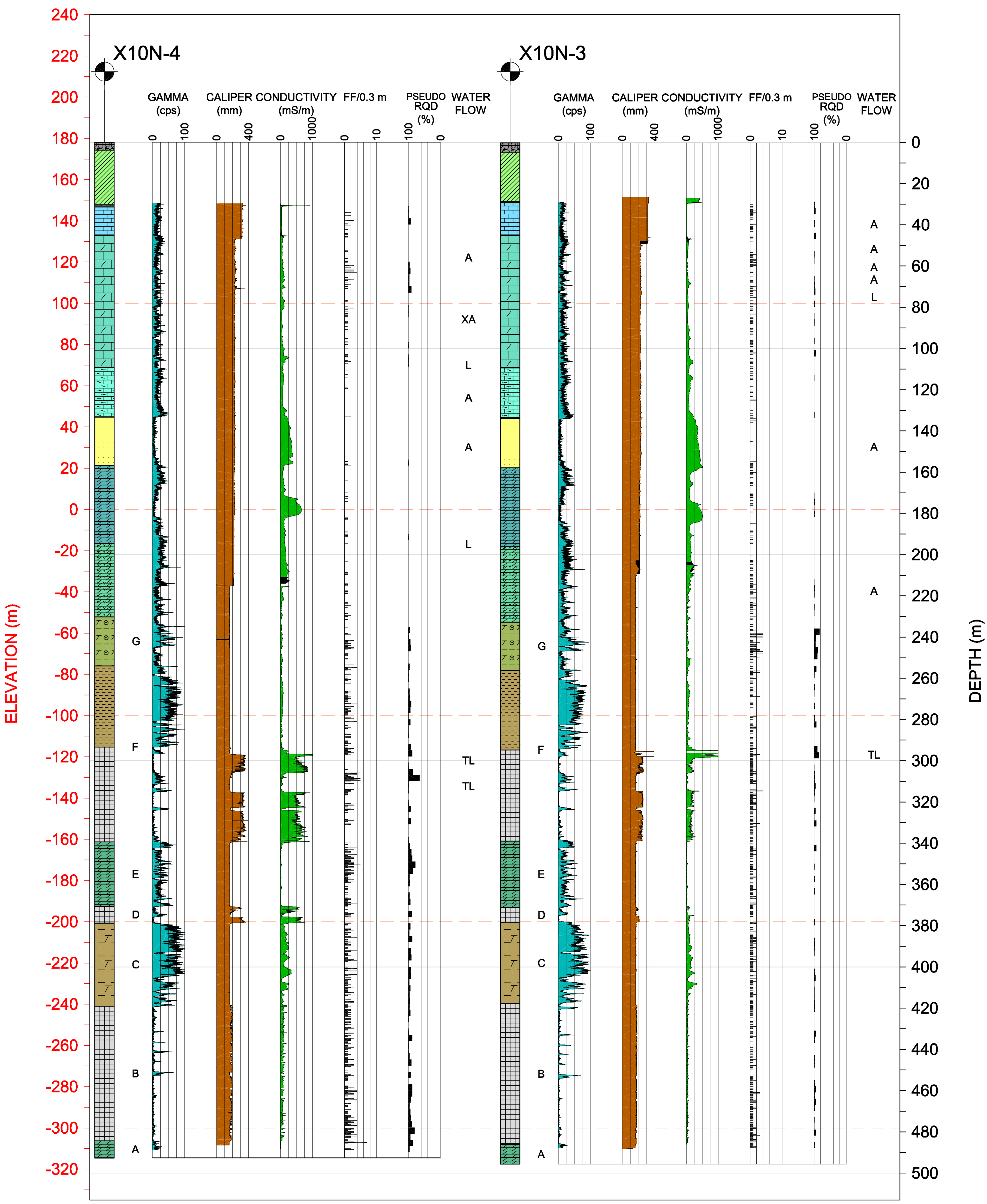

LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-3.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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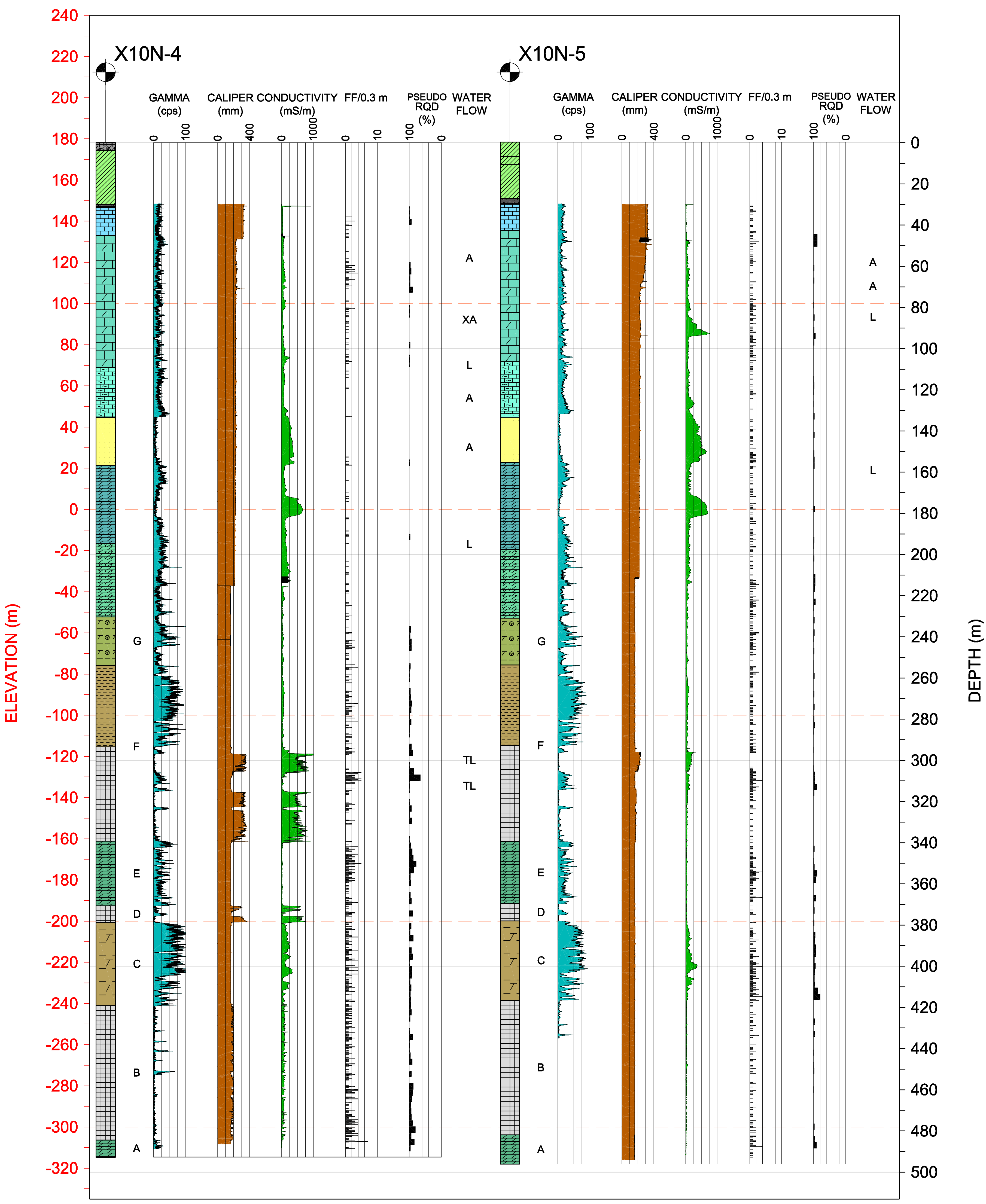
SUBSURFACE LOG SUMMARIES X10N-4 AND X10N-3

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1g



LEGEND:

FILL	BOIS BLANC FORMATION
SILTY CLAY	BASS ISLANDS FORMATION
TILL	SALINA LIMESTONE
DUNDEE FORMATION	SALINA SHALE
LUCAS FORMATION	SALINA DOLOSTONE
AMHERSTBURG FORMATION	SALINA DOLOMITIC SHALE
SYLVANIA FORMATION	SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-4.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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SUBSURFACE LOG SUMMARIES X10N-4 AND X10N-5

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1h

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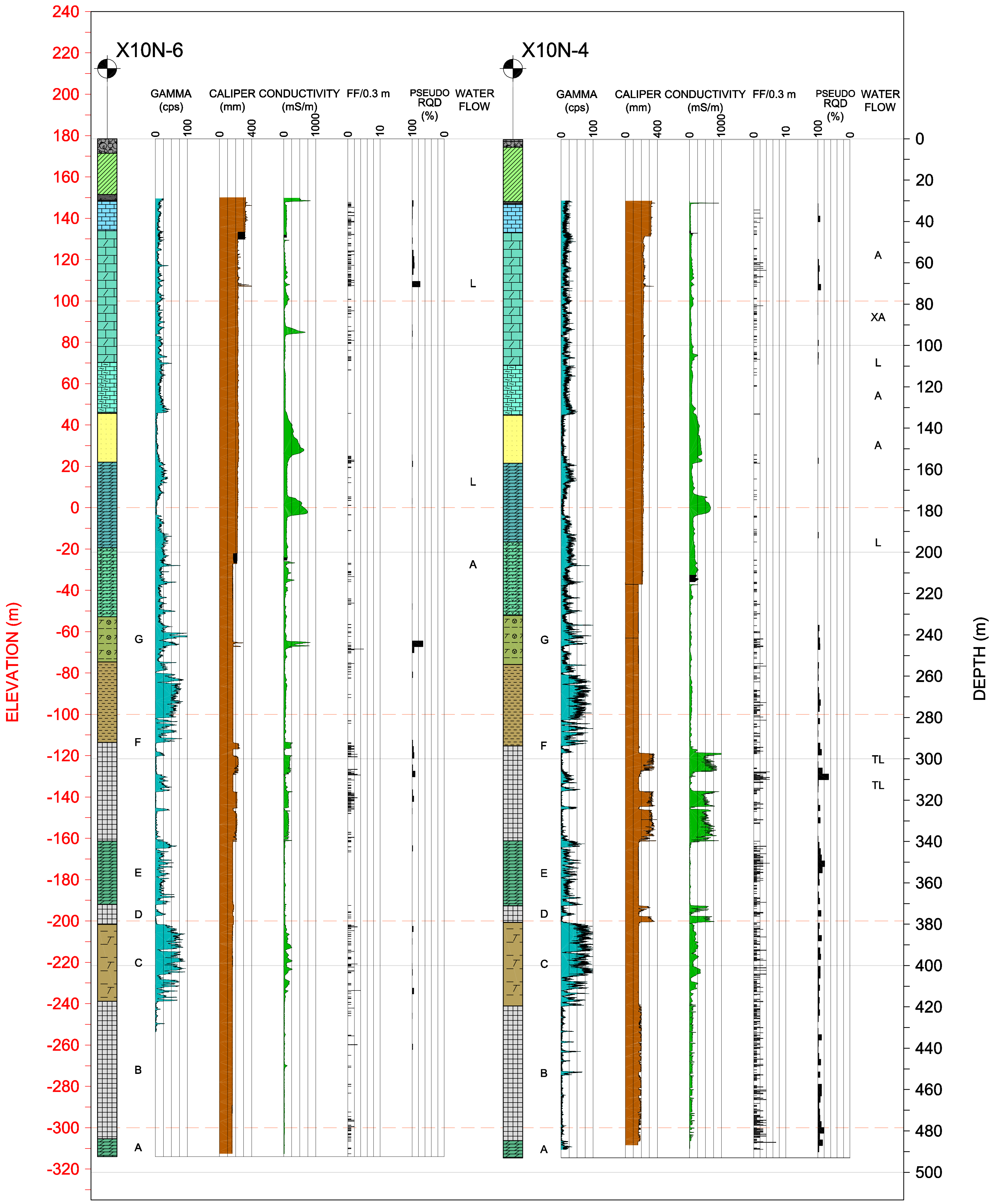

LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-6.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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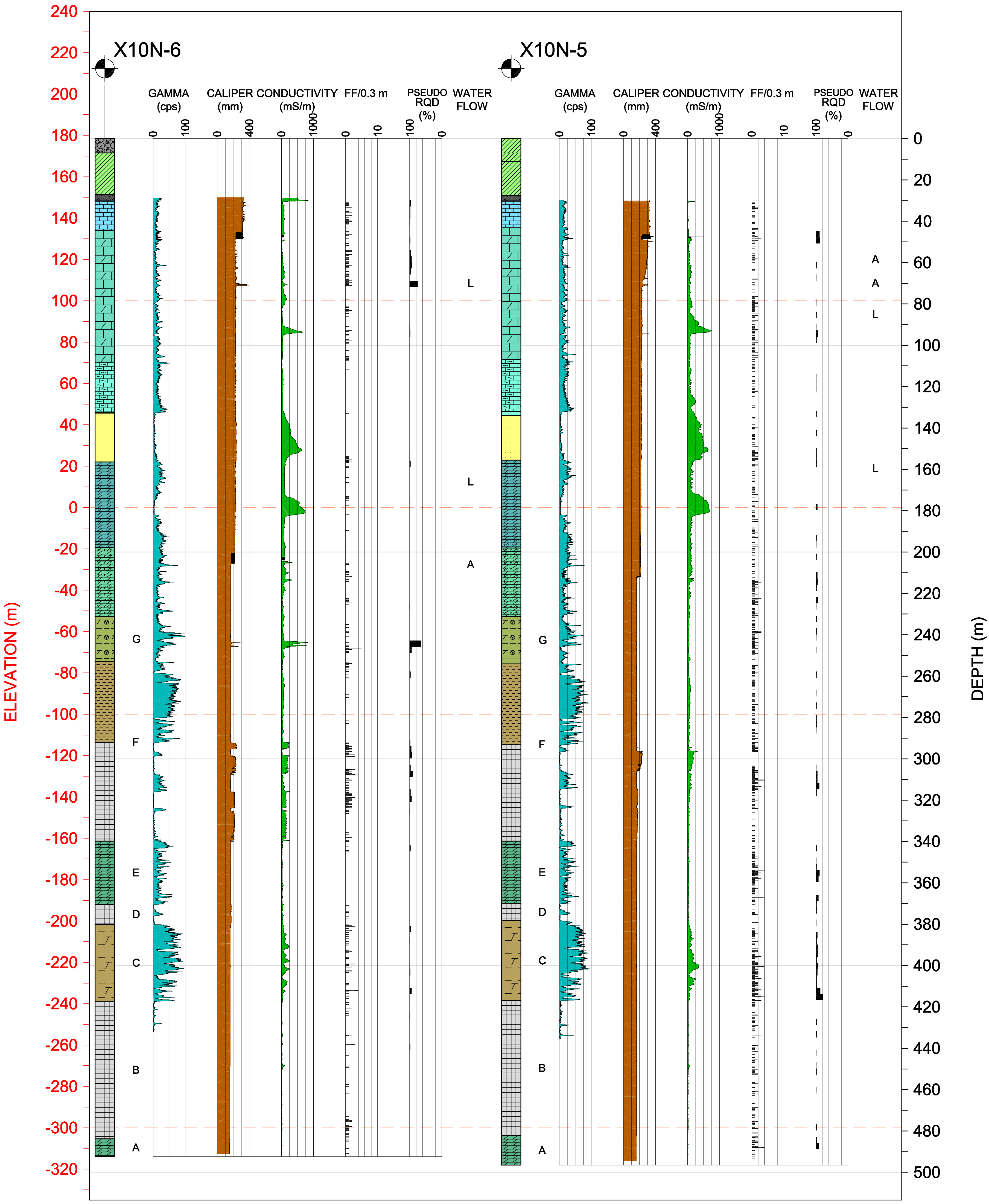
SUBSURFACE LOG SUMMARIES X10N-6 AND X10N-4

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1i



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-6.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
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SUBSURFACE LOG SUMMARIES X10N-6 AND X10N-5

DETRIOT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1j

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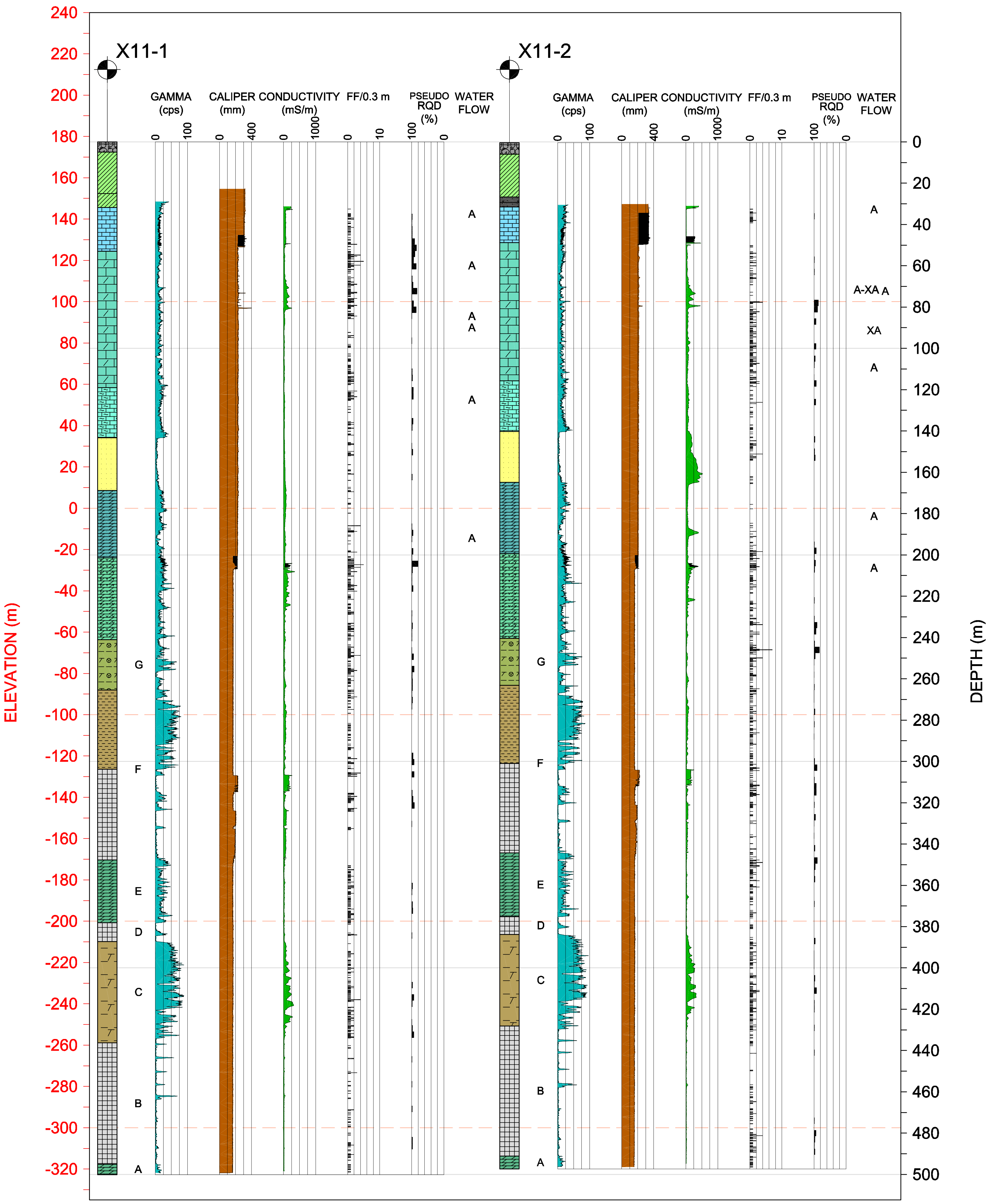

LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-6.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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SUBSURFACE LOG SUMMARIES X11-1 AND X11-2

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1k

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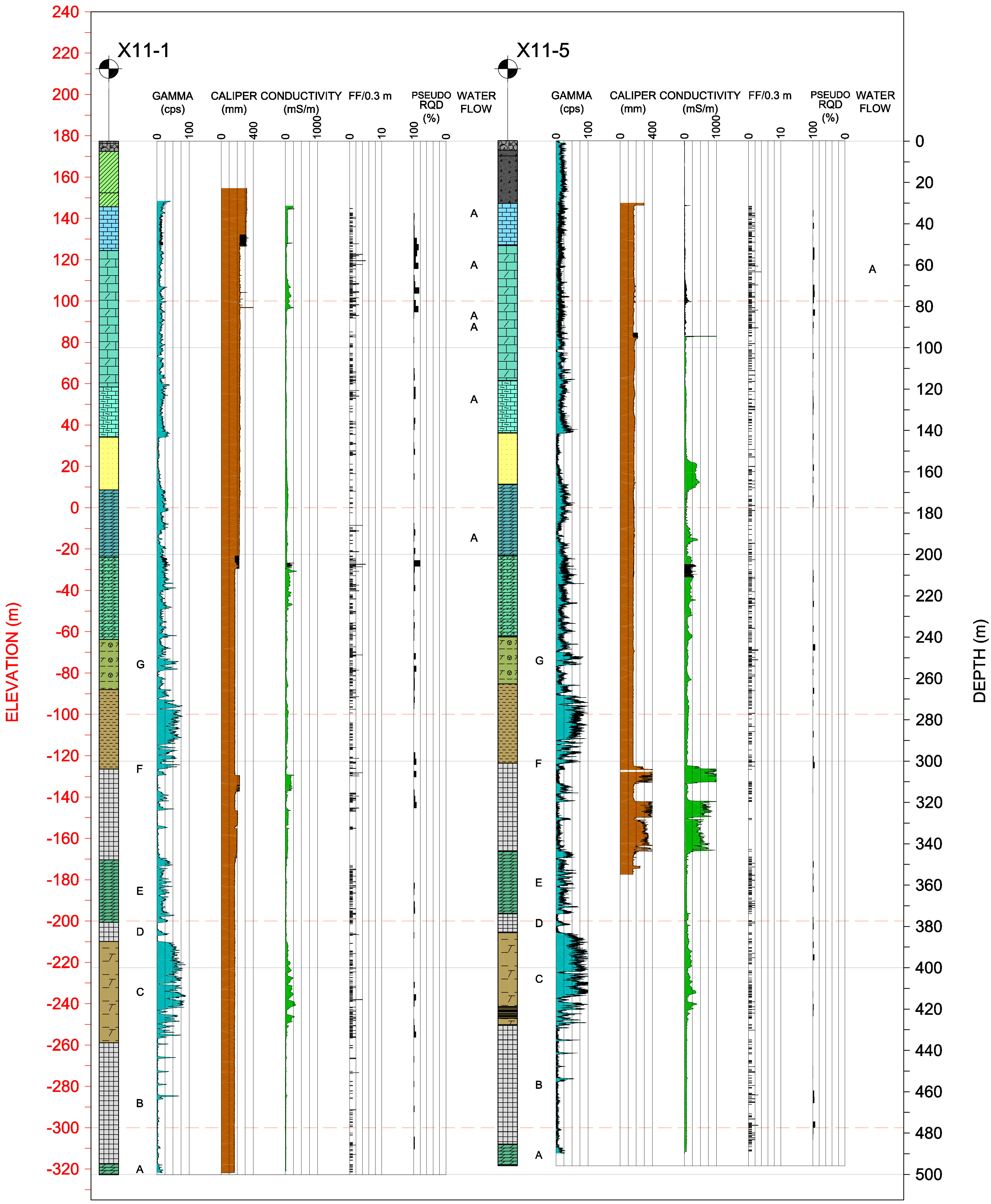

LEGEND:

	FILL		BOIS BLANC FORMATION
	SILTY CLAY		BASS ISLANDS FORMATION
	TILL		SALINA LIMESTONE
	DUNDEE FORMATION		SALINA SHALE
	LUCAS FORMATION		SALINA DOLOSTONE
	AMHERSTBURG FORMATION		SALINA DOLOMITIC SHALE
	SYLVANIA FORMATION		SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X11-1.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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TITLE

SUBSURFACE LOG SUMMARIES X11-1 AND X11-5

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE **8.1I**

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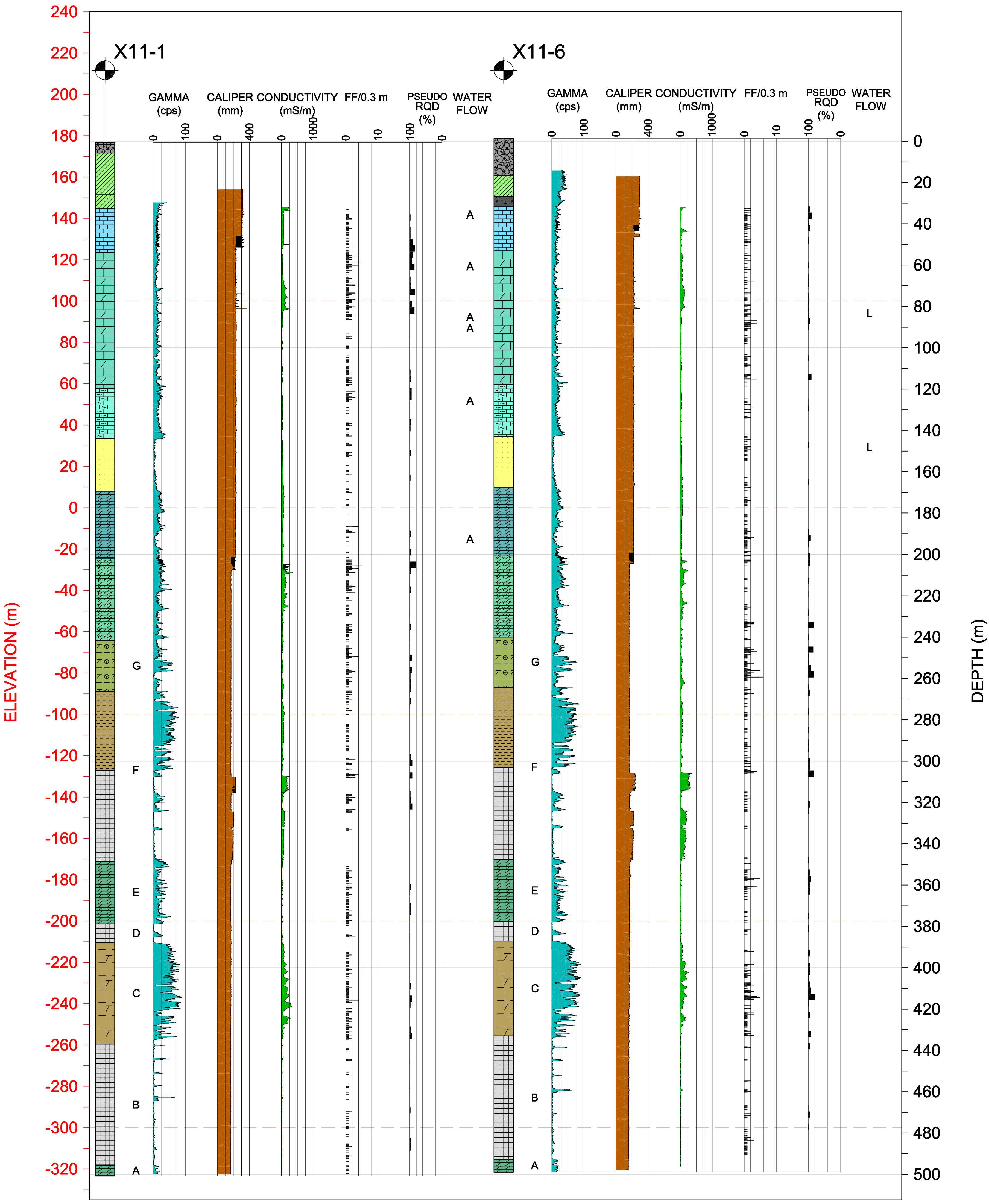

LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X11-1.
2. INTERBEDS NOT SHOWN.
3. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

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CAD	JFC		
FILE No. 041111060BAE08.1m.dwg	CHECK JM/CP	DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE	FIGURE 8.1m
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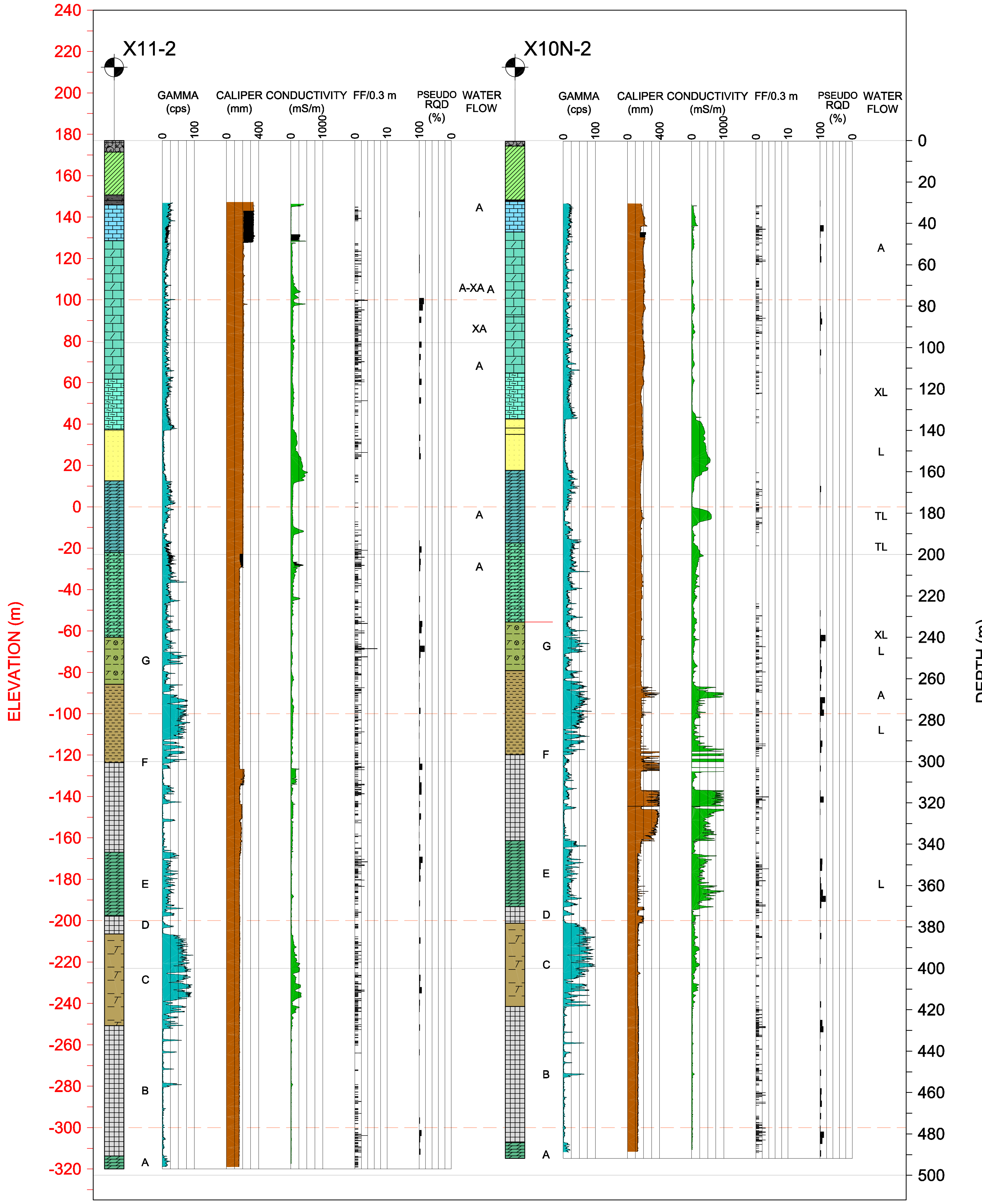

LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES
SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X11-2.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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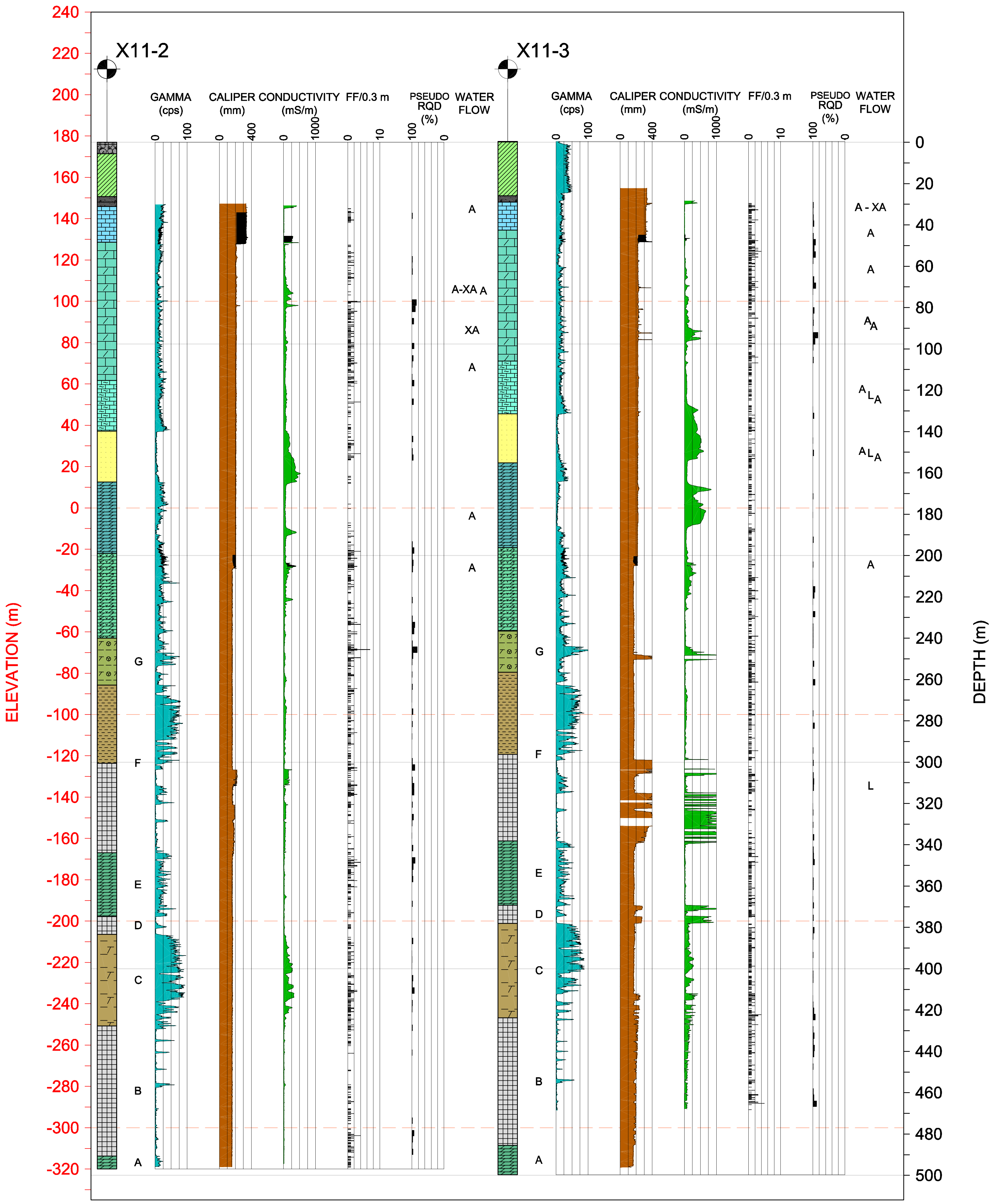
PROJECT No. 04-1111-060B REV. A

TITLE

SUBSURFACE LOG SUMMARIES X11-2 AND X10N-2

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1n



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

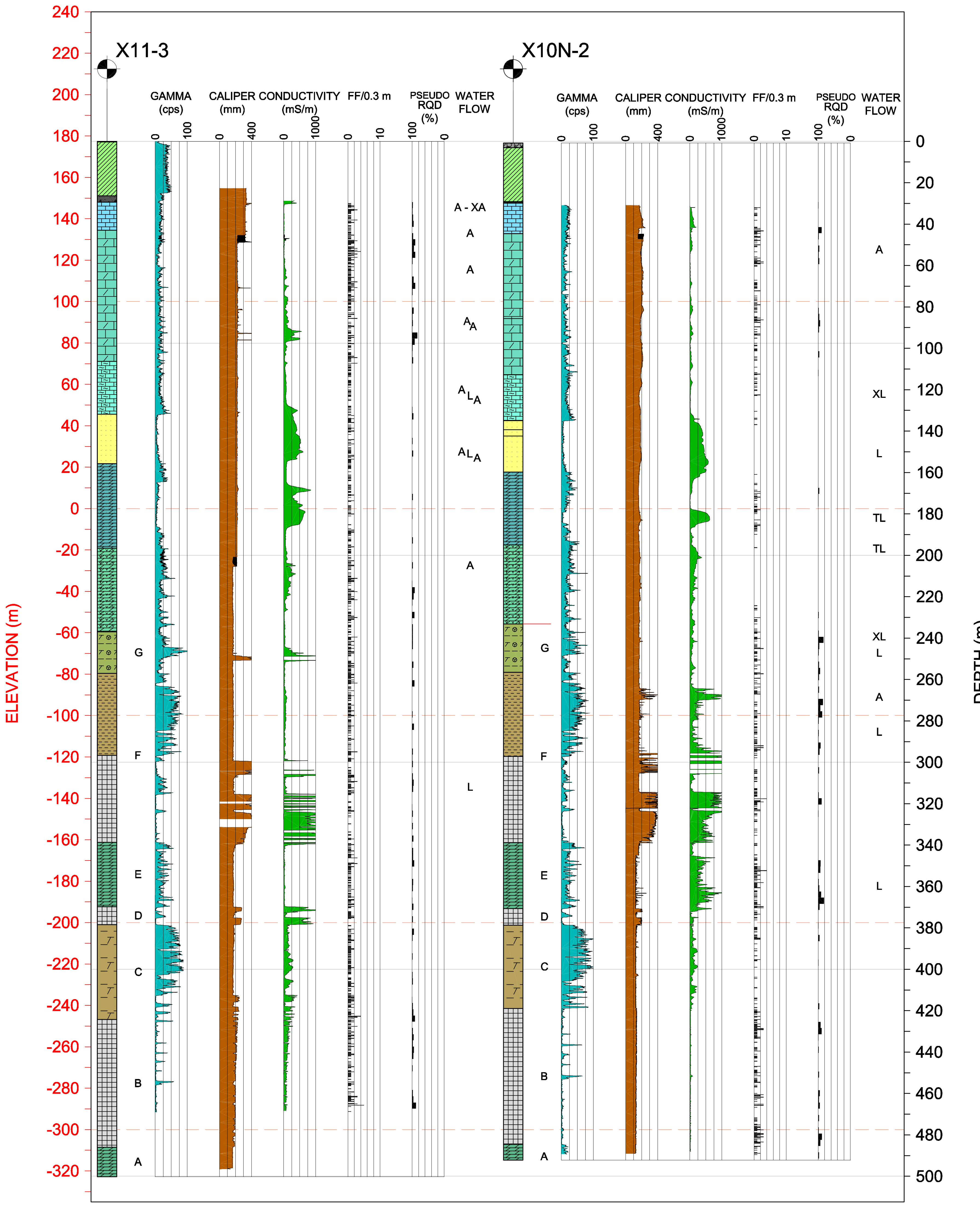
NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X10N-6.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

Golder Associates
Mississauga, Ontario, Canada

SCALE	AS SHOWN	TITLE	**SUBSURFACE LOG SUMMARIES X11-2 AND X11-3**
DATE	16 Jan. 2008		
DESIGN			
CAD	JFC		
FILE No. 041111060BAE08.1o.dwg	CHECK JM/CP	DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE	FIGURE **8.1o**
PROJECT No. 04-1111-060B REV. A	REVIEW TGC		

PLOT DATE: January 22, 2008
FILENAME: T:\Projects\2004\04-1111-060B (URS, Detroit, Michigan)\-AE-\041111060BAE08.1p.dwg



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X11-3.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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Mississauga, Ontario, Canada

SCALE	AS SHOWN
DATE	16 Jan. 2008
DESIGN	
CAD	JFC
CHECK	JM/CP
REVIEW	TGC

FILE No. 041111060BAE08.1p.dwg

PROJECT No. 04-1111-060B REV. A

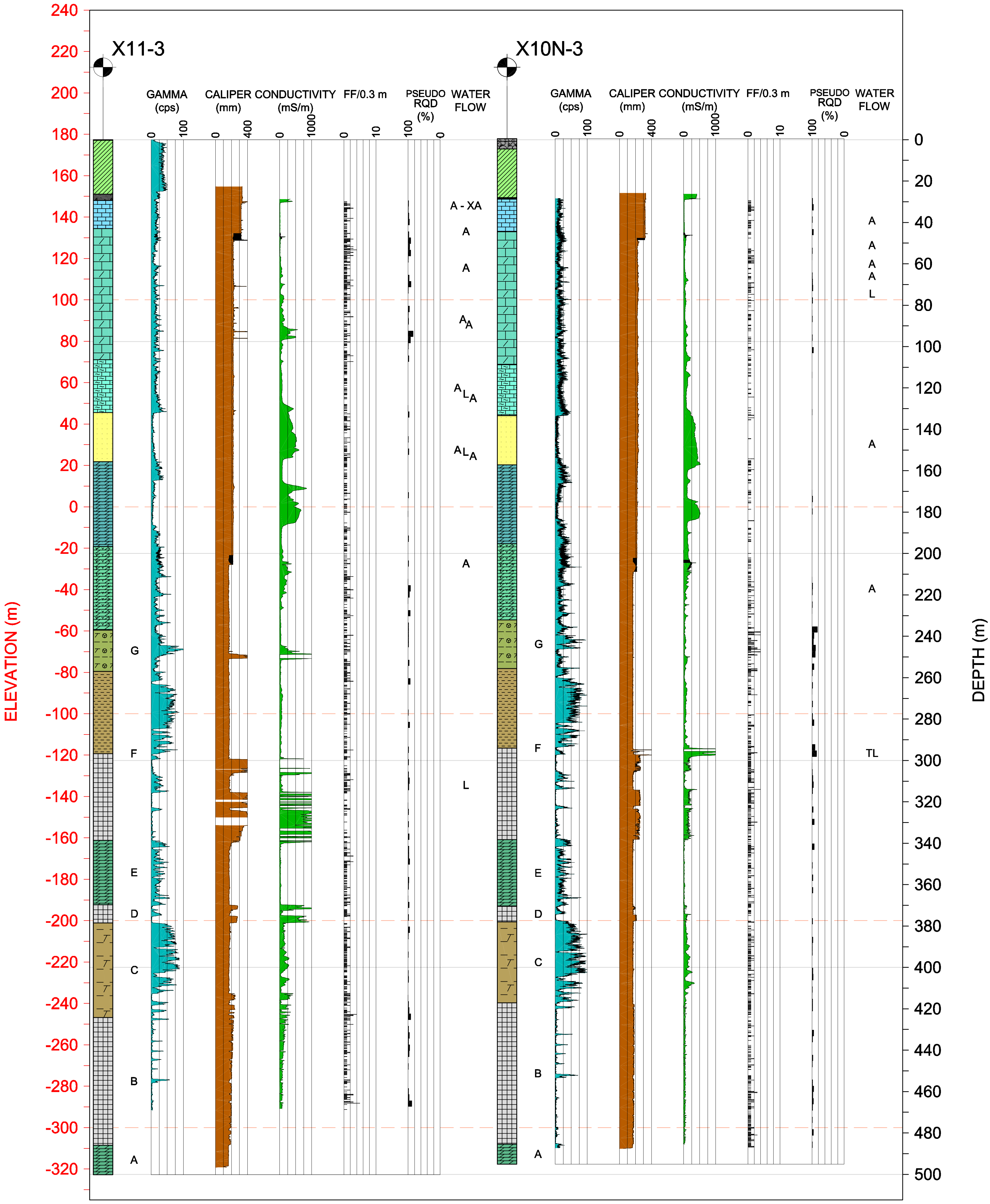
TITLE

SUBSURFACE LOG SUMMARIES X11-3 AND X10N-2

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1p

PLOT DATE: January 22, 2008
FILENAME: T:\Projects\2004\04-1111-060B (URS, Detroit, Michigan)\-AE-\041111060BAE08.1q.dwg



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES
SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

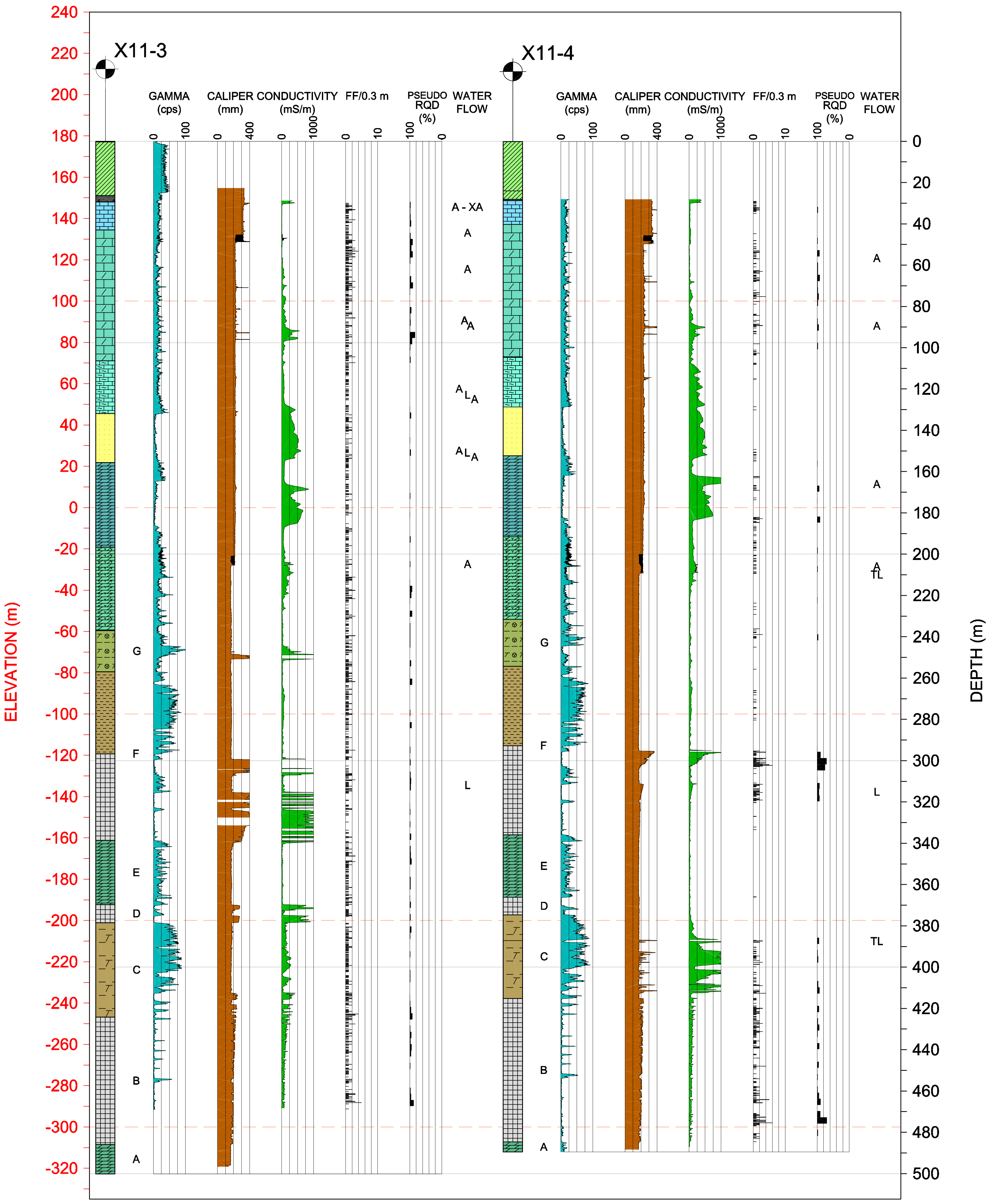
1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X11-3.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

Golder Associates
Mississauga, Ontario, Canada

SCALE	AS SHOWN	TITLE	**SUBSURFACE LOG SUMMARIES X11-3 AND X10N-3**
DATE	16 Jan. 2008		
DESIGN			
CAD	JFC		
CHECK	JM/CP		DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE
REVIEW	TGC	FIGURE	**8.1q**

FILE No. 041111060BAE08.1q.dwg
PROJECT No. 04-1111-060B REV. A

PLOT DATE: January 22, 2008
FILENAME: T:\Projects\2004\04-1111-060B (URS, Detroit, Michigan)\-AE-\041111060BAE08.1r.dwg



LEGEND:

FILL	BOIS BLANC FORMATION
SILTY CLAY	BASS ISLANDS FORMATION
TILL	SALINA LIMESTONE
DUNDEE FORMATION	SALINA SHALE
LUCAS FORMATION	SALINA DOLOSTONE
AMHERSTBURG FORMATION	SALINA DOLOMITIC SHALE
SYLVANIA FORMATION	SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X11-3.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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SCALE	AS SHOWN
DATE	16 Jan. 2008
DESIGN	
CAD	JFC
CHECK	JM/CP
REVIEW	TGC

FILE No. 041111060BAE08.1r.dwg

PROJECT No. 04-1111-060B REV. A

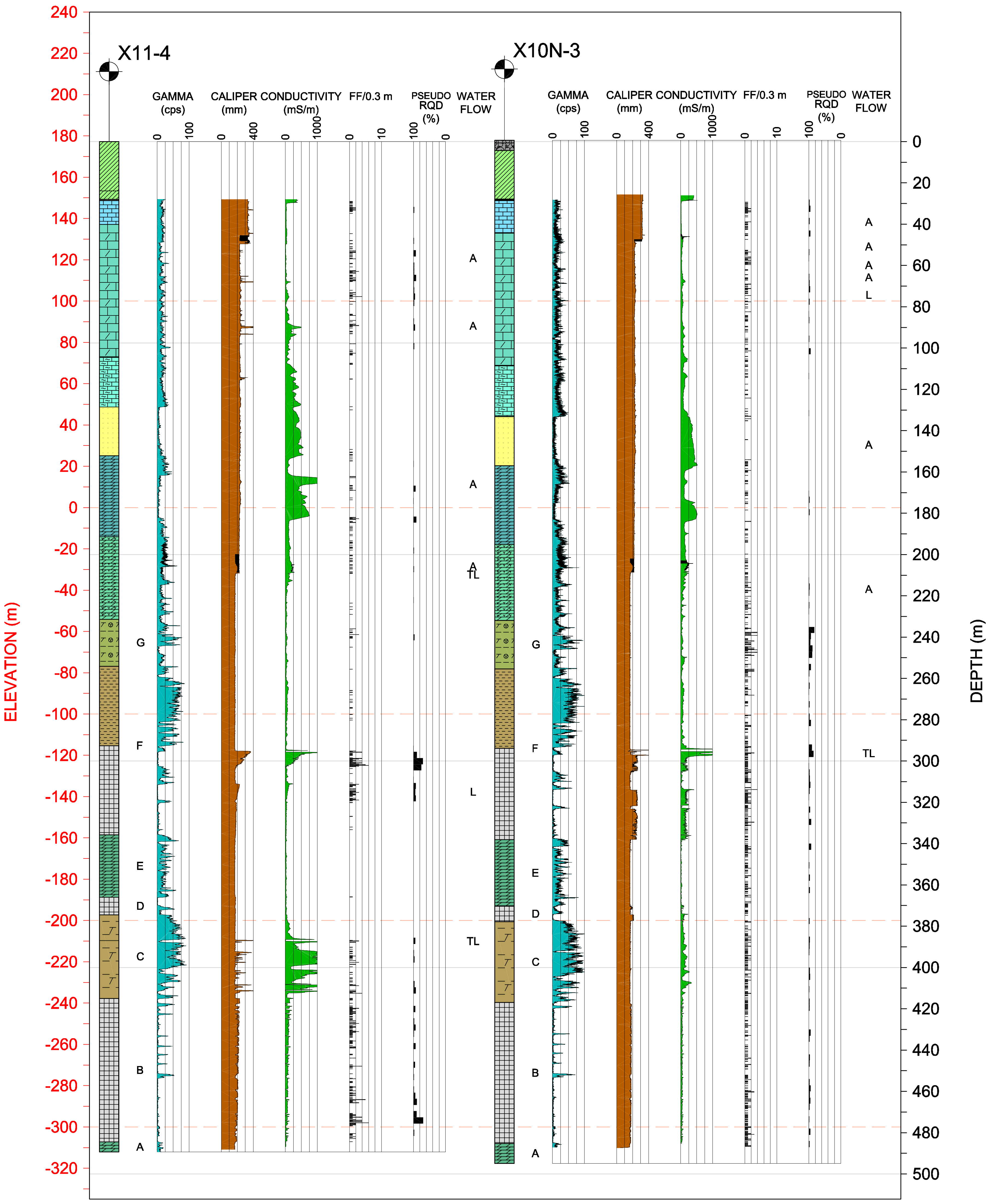
TITLE

SUBSURFACE LOG SUMMARIES X11-3 AND X11-4

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE **8.1r**

PLOT DATE: January 22, 2008
FILENAME: T:\Projects\2004\04-1111-060B (URS, Detroit, Michigan)\-AE-\041111060BAE08.1s.dwg



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X11-4.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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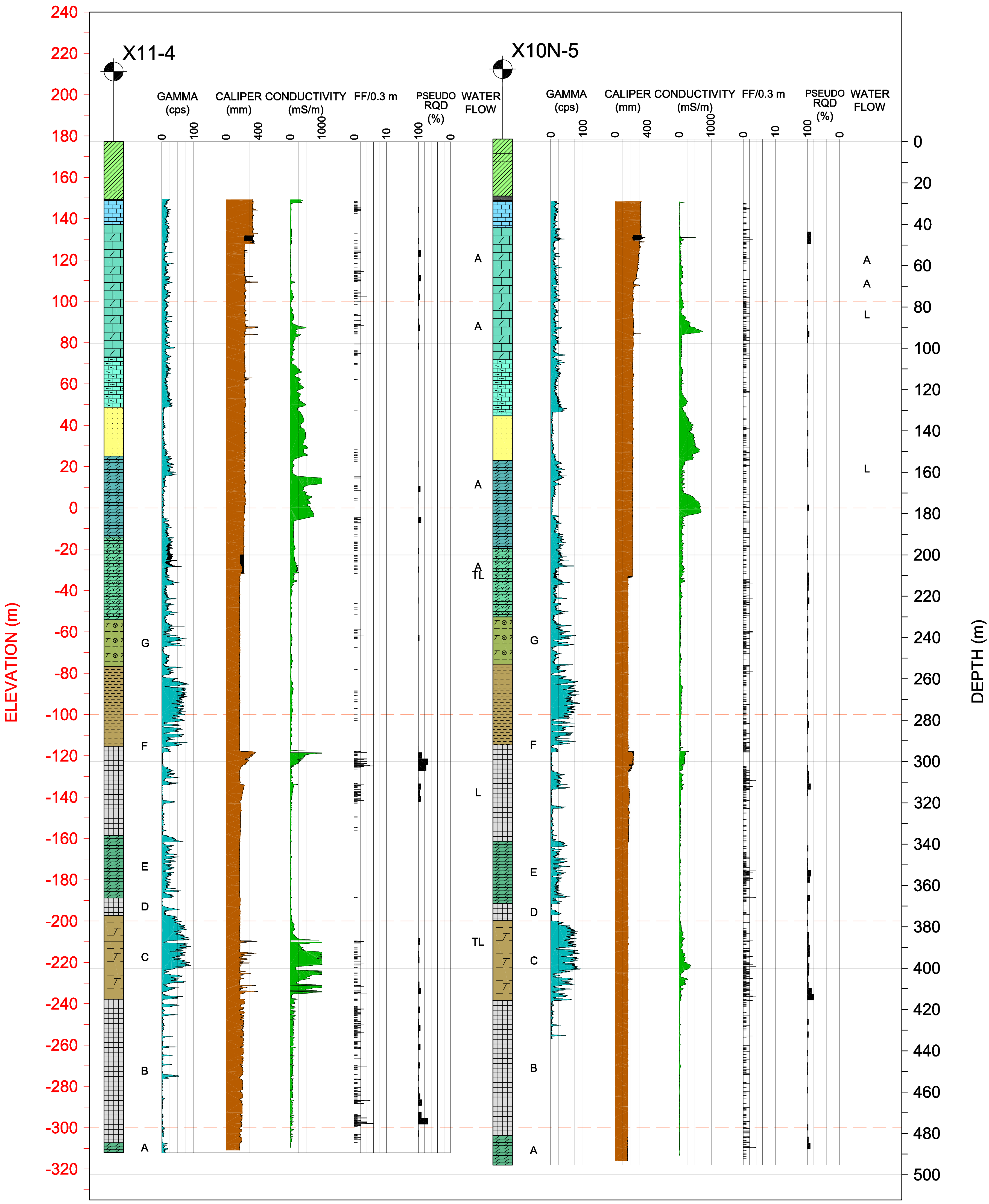
FILE No.	041111060BAE08.1s.dwg
PROJECT No.	04-1111-060B
REV.	A
SCALE	AS SHOWN
DATE	16 Jan. 2008
DESIGN	
CAD	JFC
CHECK	JM/CP
REVIEW	TGC

TITLE

SUBSURFACE LOG SUMMARIES X11-4 AND X10N-3

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1s



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES
SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X11-4.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

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SCALE	AS SHOWN
DATE	16 Jan. 2008
DESIGN	
CAD	JFC
CHECK	JM/CP
REVIEW	TGC
FILE No.	041111060BAE08.1t.dwg
PROJECT No.	04-1111-060B
REV.	A

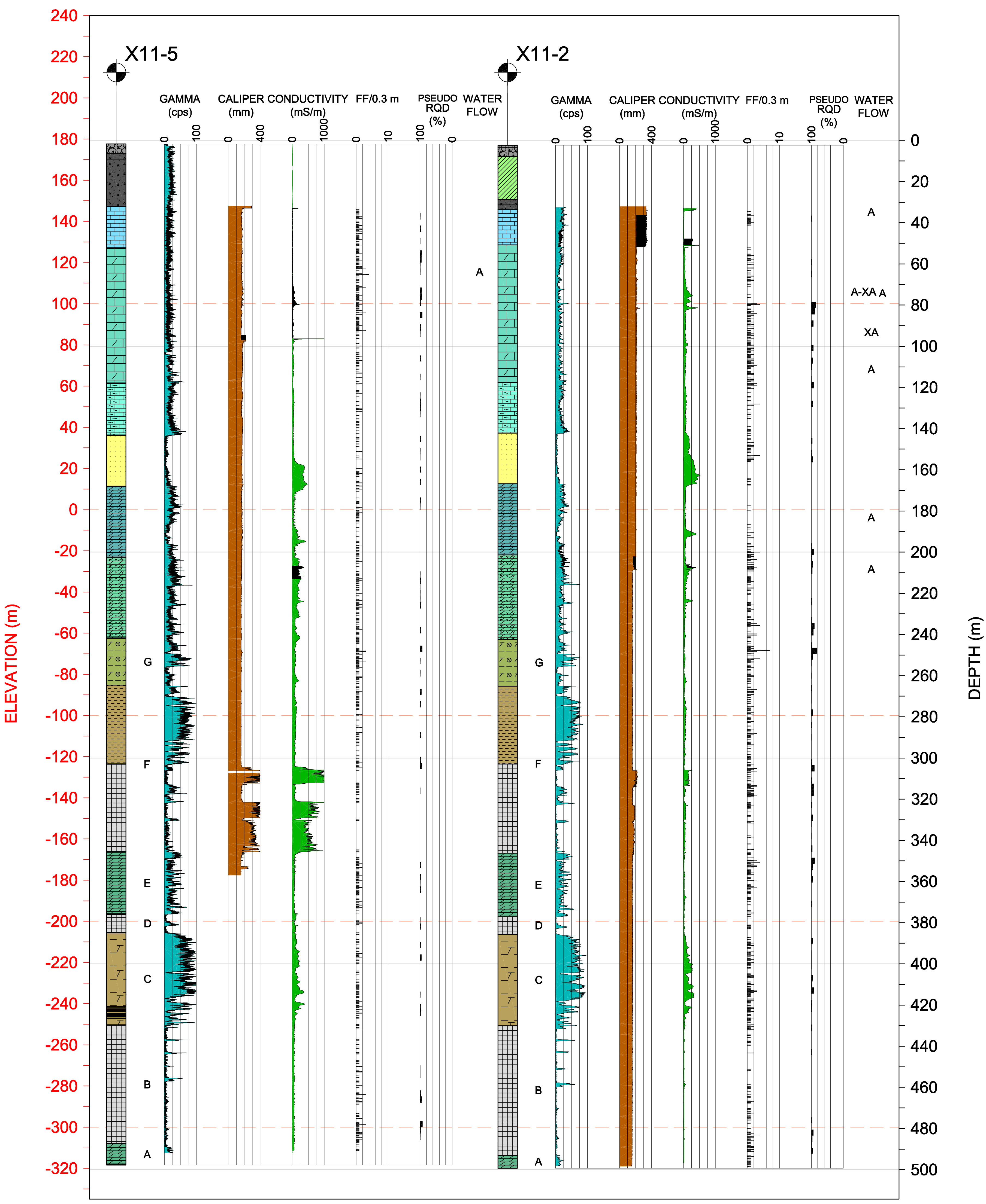
TITLE

SUBSURFACE LOG SUMMARIES X11-4 AND X10N-5

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1t

PLOT DATE: January 22, 2008
FILENAME: T:\Projects\2004\04-1111-060B (URS, Detroit, Michigan)\-AE-\041111060BAE08.1u.dwg



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X11-5.
2. INTERBEDS NOT SHOWN.
3. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.

40 0 40 80

SCALE VERT. 1:2000 METRES

SCALE HORIZONTAL NOT TO SCALE

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Mississauga, Ontario, Canada

SCALE	AS SHOWN	DATE	16 Jan. 2008
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CHECK	JM/CP	REVIEW	TGC
FILE No.	041111060BAE08.1u.dwg		
PROJECT No.	04-1111-060B	REV.	A

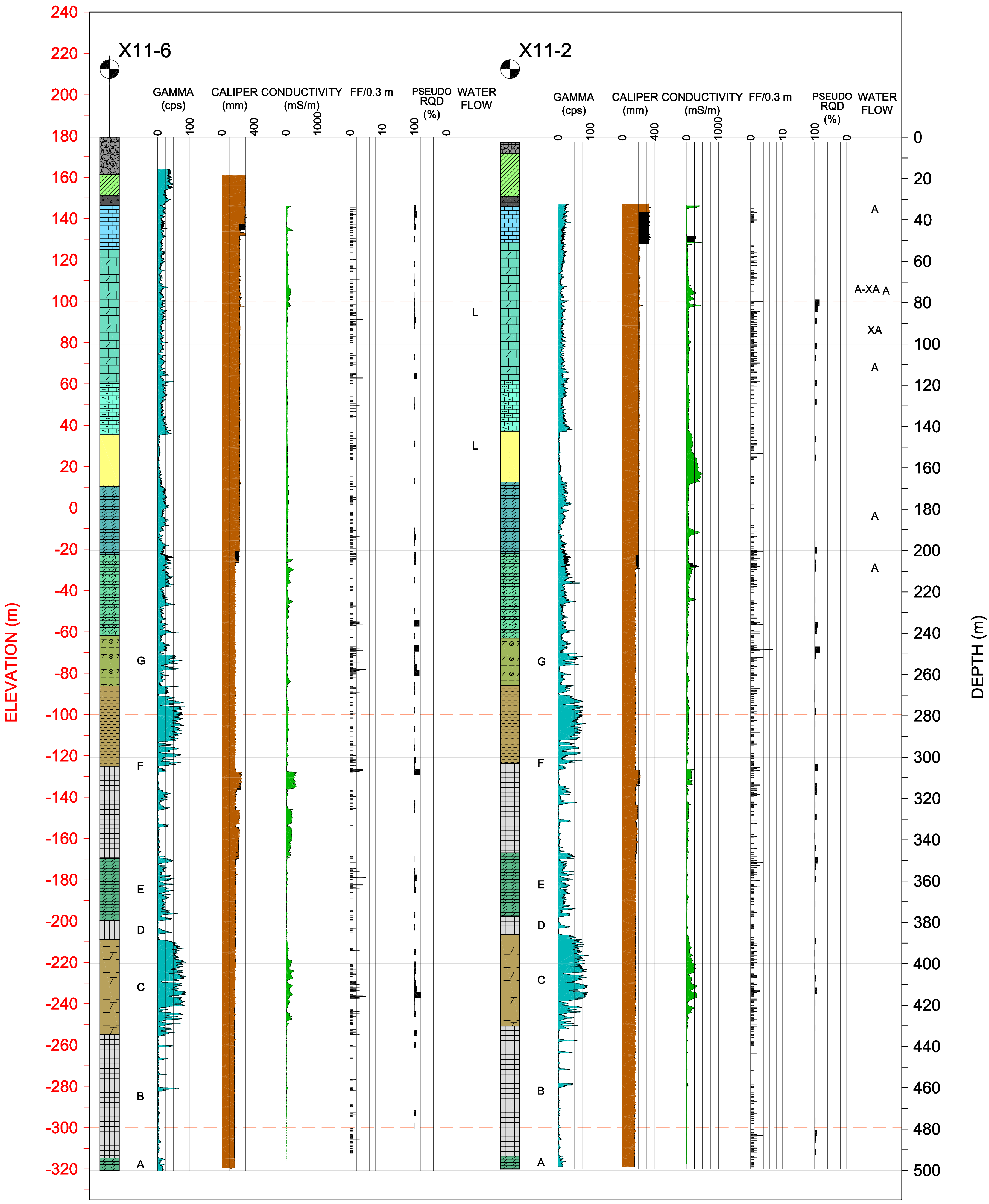
TITLE

SUBSURFACE LOG SUMMARIES
X11-5 AND X11-2

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1u

PLOT DATE: January 22, 2008
FILENAME: T:\Projects\2004\04-1111-060B (URS, Detroit, Michigan)\-AE-\041111060BAE08.1v.dwg



LEGEND:

FILL	BOIS BLANC FORMATION
SILTY CLAY	BASS ISLANDS FORMATION
TILL	SALINA LIMESTONE
DUNDEE FORMATION	SALINA SHALE
LUCAS FORMATION	SALINA DOLOSTONE
AMHERSTBURG FORMATION	SALINA DOLOMITIC SHALE
SYLVANIA FORMATION	SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES
SCALE HORIZONTAL NOT TO SCALE

LEGEND:

- XA ARTESIAN FLOW >500 L/min
- A ARTESIAN FLOW <500 L/min
- XL WATER LOSS >500 L/min
- L WATER LOSS <500 L/min
- TL TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X11-6.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

Golder Associates
Mississauga, Ontario, Canada

SCALE	AS SHOWN
DATE	16 Jan. 2008
DESIGN	
CAD	JFC
CHECK	JM/CP
REVIEW	TGC

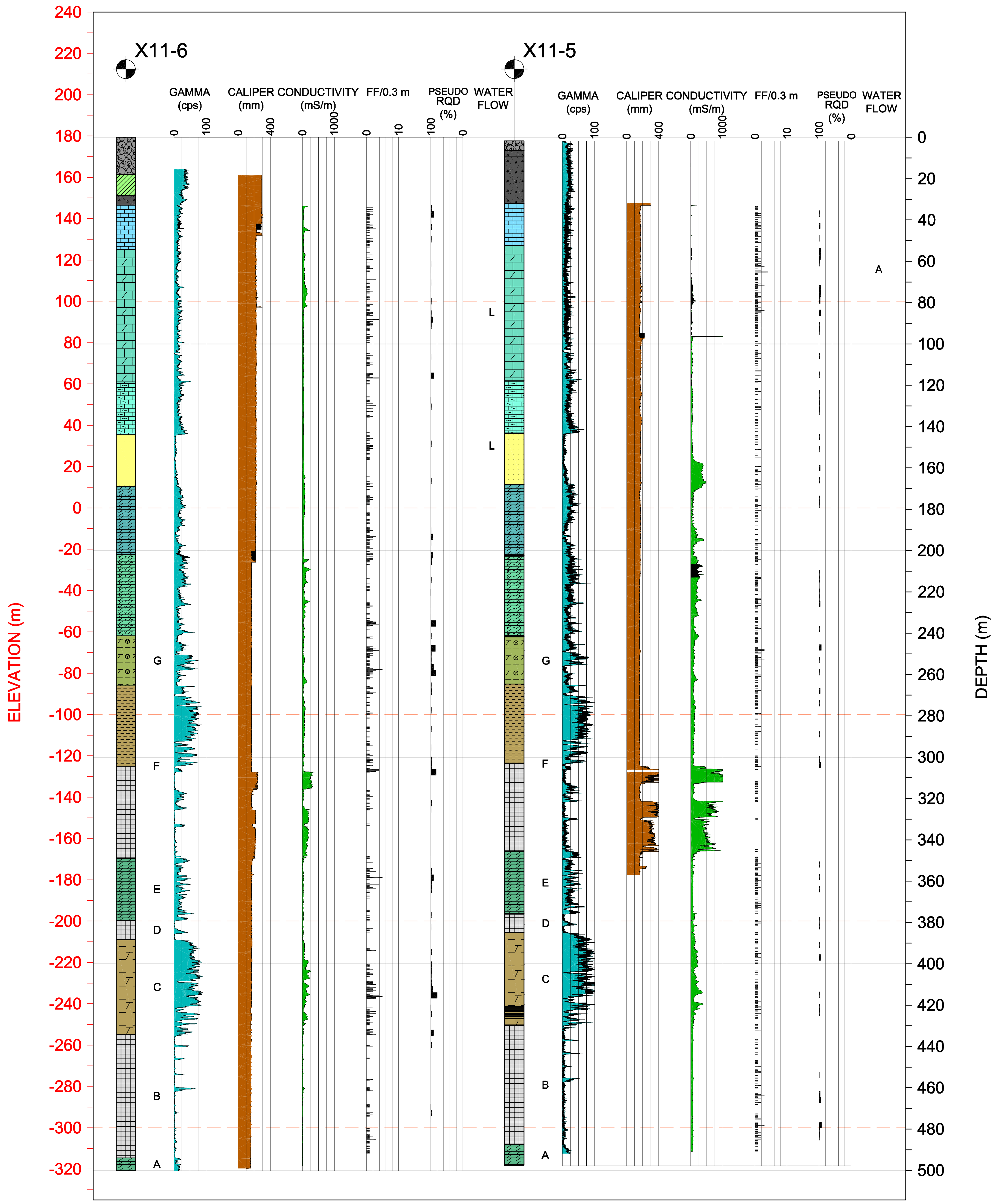
FILE No. 041111060BAE08.1v.dwg
PROJECT No. 04-1111-060B REV. A

TITLE

SUBSURFACE LOG SUMMARIES X11-6 AND X11-2

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1v



LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA SHALE
- SALINA DOLOSTONE
- SALINA DOLOMITIC SHALE
- SALINA SALTS & EVAPORITES

40 0 40 80

SCALE VERT. 1:2000 METRES
SCALE HORIZONTAL NOT TO SCALE

LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

NOTES:

1. DEPTH SCALE IS ESTABLISHED FROM BOREHOLE X11-6.
2. FF INCLUDES ALL MAJOR-OPEN, MINOR-OPEN, PARTIALLY-OPEN AND FILLED FRACTURES/JOINTS; BEDDINGS; AND GEOLOGICAL CONTACTS.
3. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY, INTERBEDS NOT SHOWN. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
4. PSEUDO RQD IS AN INTERPRETED QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

Golder Associates
Mississauga, Ontario, Canada

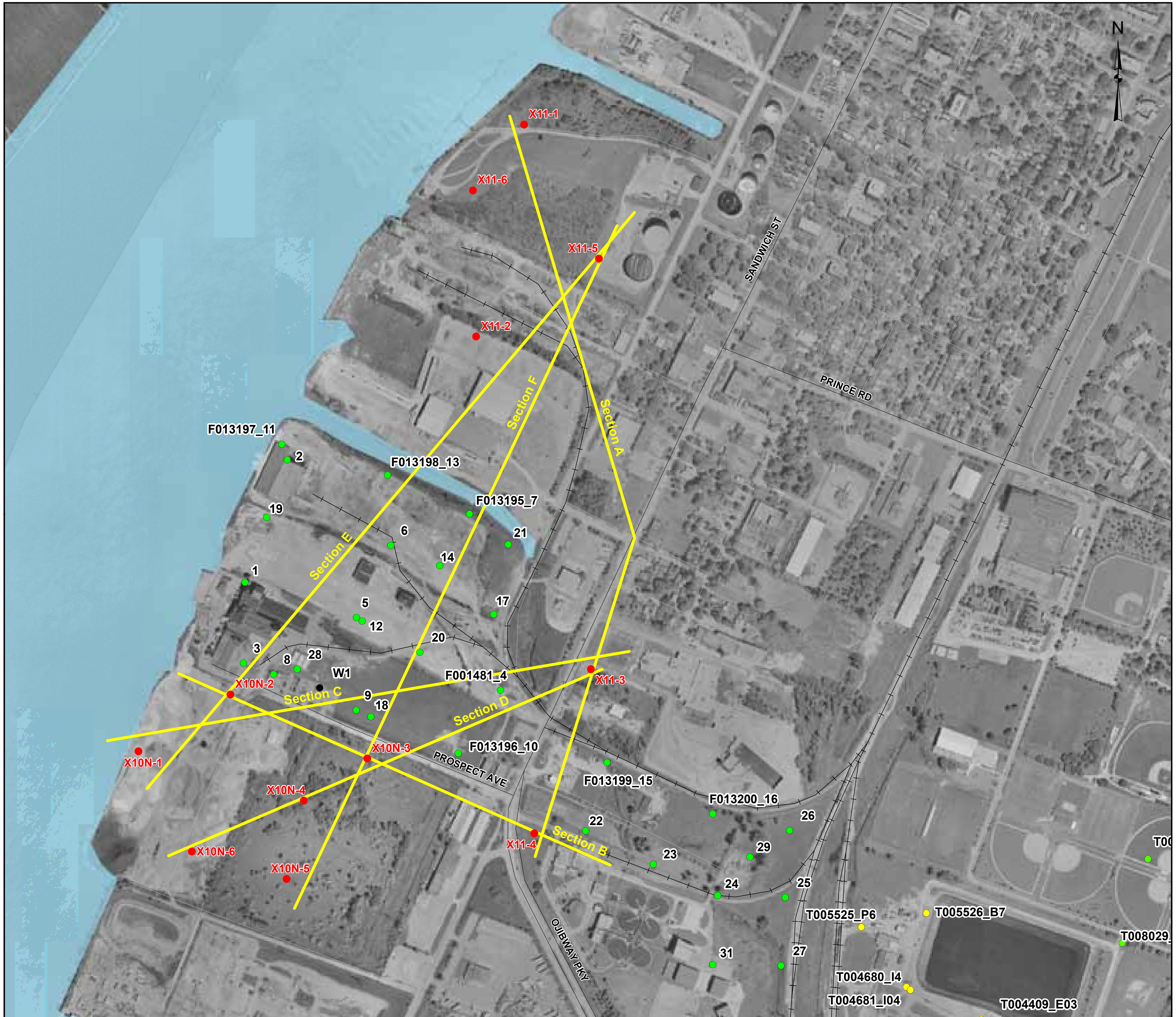
FILE No. 041111060BAE08.1w.dwg		SCALE	AS SHOWN
PROJECT No. 04-1111-060B	REV. A	DATE	16 Jan. 2008
		DESIGN	
		CAD	JFC
		CHECK	JM/CP
		REVIEW	TGC

TITLE

SUBSURFACE LOG SUMMARIES X11-6 AND X11-5

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.1w



LEGEND

- New Exploratory Wells
- Other Wells or Boreholes
- Cavern Storage Well
- Solution Mining Well
- F013199_15 MNR Well Licence Number (where mapped and available)
- Major Road
- Local Road
- Railway
- Cross Section Lines
- Water

NOTES:

1. Well locations as shown obtained from multiple sources. See report text for full references.
2. Wells shown with alpha-numeric label, such as the series beginning F013xxx_xx, F0014xx_xx, T00xxxx_xx are based on location and well licence data provided by the Ontario Ministry of Natural Resources, Oil Salt and Gas Resources Library.
3. Geotechnical boreholes labelled AMECBH7 from report prepared by AMEC for Brighton Beach power station construction. See report for full reference.

DRAFT

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

0 100 200 400 600
Metres

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

SECTION LOCATION PLAN

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE 1:7,000	REV. 0
DESIGN	CC	24 May 2006		
GIS	JFC	21 Feb. 2008		
CHECK	JM	21 Feb. 2008		
REVIEW	SB	21 Feb. 2008		

FIGURE: 8.2

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.2_Section_Location_Plan.mxd

A
1
CROSS SECTION A-A'

LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA DOLOSTONE
- SALINA SHALES
- SALINA SALINA SALTS
- EXPLORATORY WELL DRILLED FOR DRIC PROJECT. DEPTH AS SHOWN
- FORMER SOLUTION MINING WELL TOTAL DEPTH UNKNOWN
- O/S OFF-SET DISTANCE FROM SECTION LINE
- MAJOR OPEN FRACTURES/JOINTS
- MINOR OPEN FRACTURES/JOINTS
- PARTIALLY OPEN FRACTURES/JOINTS
- FILLED FRACTURES/JOINTS

WATER FLOW LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

SOLUTION MINING WELL RECORDS:

CAV	CAVITY ENCOUNTERED DURING DRILLING
C	ESTIMATED / RECORDED CASING DEPTH
R	REPAIR OF DAMAGE TO CASING OR INTERVAL (DEEPER) BRINE TUBING / PIPE
(1931)	DATE OF REPAIR OR OCCURRENCE

NOTES:

1. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
2. INTERPRETED INTERFACES BETWEEN GEOLOGIC FORMATIONS ARE SHOWN BY SOLID LINES. THESE INTERPRETED INTERFACES ARE APPROXIMATE AND CONDITIONS BETWEEN THE EXPLORED LOCATIONS WILL VARY FROM THOSE CONDITIONS AND INTERFACE ELEVATIONS SHOWN.
3. SEISMIC ANOMALIES, WHERE SHOWN, INDICATE GENERAL AREAS OF CHANGES IN SEISMIC CHARACTER AND ARE ASSOCIATED WITH DIFFERENT INFERRED CAUSES OF THE ANOMALOUS TEST RESULTS. REFERENCE MUST BE MADE TO THE DESCRIPTIONS PROVIDED IN THE REPORT TEXT REGARDING THE INTERPRETED CONDITIONS AT THESE LOCATIONS.
4. FRACTURE FREQUENCY ILLUSTRATED AS FF/0.3 m INCLUDES MAJOR, MINOR, AND PARTIALLY OPEN FRACTURES/JOINTS AS IDENTIFIED SEPARATELY AS WELL AS BEDDING, FILLED FRACTURES/JOINTS, GEOLOGIC CONTACTS, AND INDICATIONS OF BEDDING/BANDING/FOLIATION, WHERE THIS LATTER CATEGORY IS TYPICALLY THE MOST PREVALENT FEATURE. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.
5. PSEUDO RQD IS AN QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

SCALE HORIZ. 1:1000 METRES (20 0 20 40)

SCALE VERT. 1:2500 METRES (50 0 50 100)

Golder Associates, Mississauga, Ontario, Canada	SCALE: AS SHOWN	TITLE: **SECTION A-A'**	
	DATE: 22 Jan. 2008		
	DESIGN:		
	CAD: JFC		
FILE No. 041111060BAE08.3.dwg	CHECK: JM/CP	DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE	FIGURE 8.3
PROJECT No. 04-1111-060B REV. A	REVIEW: SJB/TGC		

B
1

CROSS SECTION B-B'

LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA DOLOSTONE
- SALINA SHALES
- SALINA SALINA SALTS
- EXPLORATORY WELL DRILLED FOR DRIC PROJECT. DEPTH AS SHOWN
- FORMER SOLUTION MINING WELL TOTAL DEPTH UNKNOWN
- O/S OFF-SET DISTANCE FROM SECTION LINE
- MAJOR OPEN FRACTURES/JOINTS
- MINOR OPEN FRACTURES/JOINTS
- PARTIALLY OPEN FRACTURES/JOINTS
- FILLED FRACTURES/JOINTS

WATER FLOW LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

SOLUTION MINING WELL RECORDS:

CAV	CAVITY ENCOUNTERED DURING DRILLING
C	ESTIMATED / RECORDED CASING DEPTH
R	REPAIR OF DAMAGE TO CASING OR INTERVAL (DEEPER) BRINE TUBING / PIPE
(1931)	DATE OF REPAIR OR OCCURRENCE

NOTES:

1. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
2. INTERPRETED INTERFACES BETWEEN GEOLOGIC FORMATIONS ARE SHOWN BY SOLID LINES. THESE INTERPRETED INTERFACES ARE APPROXIMATE AND CONDITIONS BETWEEN THE EXPLORED LOCATIONS WILL VARY FROM THOSE CONDITIONS AND INTERFACE ELEVATIONS SHOWN.
3. SEISMIC ANOMALIES, WHERE SHOWN, INDICATE GENERAL AREAS OF CHANGES IN SEISMIC CHARACTER AND ARE ASSOCIATED WITH DIFFERENT INFERRED CAUSES OF THE ANOMALOUS TEST RESULTS. REFERENCE MUST BE MADE TO THE DESCRIPTIONS PROVIDED IN THE REPORT TEXT REGARDING THE INTERPRETED CONDITIONS AT THESE LOCATIONS.
4. FRACTURE FREQUENCY ILLUSTRATED AS FF/0.3 m INCLUDES MAJOR, MINOR, AND PARTIALLY OPEN FRACTURES/JOINTS AS IDENTIFIED SEPARATELY AS WELL AS BEDDING, FILLED FRACTURES/JOINTS, GEOLOGIC CONTACTS, AND INDICATIONS OF BEDDING/BANDING/FOLIATION, WHERE THIS LATTER CATEGORY IS TYPICALLY THE MOST PREVALENT FEATURE. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.
5. PSEUDO RQD IS AN QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

20 0 20 40
SCALE HORIZ. 1:1000 METRES

50 0 50 100
SCALE VERT. 1:2500 METRES

Golder Associates
Mississauga, Ontario, Canada

FILE No.	041111060BAE08.4.dwg	SCALE	AS SHOWN
PROJECT No.	04-1111-060B	DATE	22 Jan. 2008
REV.	A	DESIGN	
		CAD	JFC
		CHECK	JM/CP
		REVIEW	SJB/TGC

TITLE

SECTION B-B'

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.4

LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA DOLOSTONE
- SALINA SHALES
- SALINA SALINA SALTS
- EXPLORATORY WELL DRILLED FOR DRIC PROJECT. DEPTH AS SHOWN
- FORMER SOLUTION MINING WELL TOTAL DEPTH UNKNOWN
- EXPLORATORY WELL AS DESCRIBED BY RUSSELL (1993)
- O/S OFF-SET DISTANCE FROM SECTION LINE
- MAJOR OPEN FRACTURES/JOINTS
- MINOR OPEN FRACTURES/JOINTS
- PARTIALLY OPEN FRACTURES/JOINTS
- FILLED FRACTURES/JOINTS

WATER FLOW LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

SOLUTION MINING WELL RECORDS:

CAV	CAVITY ENCOUNTERED DURING DRILLING
C	ESTIMATED / RECORDED CASING DEPTH
R	REPAIR OF DAMAGE TO CASING OR INTERVAL (DEEPER) BRINE TUBING / PIPE
(1931)	DATE OF REPAIR OR OCCURRENCE

NOTES:

1. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
2. INTERPRETED INTERFACES BETWEEN GEOLOGIC FORMATIONS ARE SHOWN BY SOLID LINES. THESE INTERPRETED INTERFACES ARE APPROXIMATE AND CONDITIONS BETWEEN THE EXPLORED LOCATIONS WILL VARY FROM THOSE CONDITIONS AND INTERFACE ELEVATIONS SHOWN.
3. SEISMIC ANOMALIES, WHERE SHOWN, INDICATE GENERAL AREAS OF CHANGES IN SEISMIC CHARACTER AND ARE ASSOCIATED WITH DIFFERENT INFERRED CAUSES OF THE ANOMALOUS TEST RESULTS. REFERENCE MUST BE MADE TO THE DESCRIPTIONS PROVIDED IN THE REPORT TEXT REGARDING THE INTERPRETED CONDITIONS AT THESE LOCATIONS.
4. FRACTURE FREQUENCY ILLUSTRATED AS FF/0.3 m INCLUDES MAJOR, MINOR, AND PARTIALLY OPEN FRACTURES/JOINTS AS IDENTIFIED SEPARATELY AS WELL AS BEDDING, FILLED FRACTURES/JOINTS, GEOLOGIC CONTACTS, AND INDICATIONS OF BEDDING/BANDING/FOLIATION, WHERE THIS LATTER CATEGORY IS TYPICALLY THE MOST PREVALENT FEATURE. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.
5. PSEUDO RQD IS AN QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

SCALE HORIZ. 1:1000 METRES

SCALE VERT. 1:2500 METRES

Golder Associates, Mississauga, Ontario, Canada	SCALE: AS SHOWN	TITLE: **SECTION C-C'**	
	DATE: 22 Jan. 2008		
	DESIGN:		
	CAD: JFC		
FILE No. 041111060BAE08.5.dwg	CHECK: JM/CP	DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE	FIGURE 8.5
PROJECT No. 04-1111-060B REV. A	REVIEW: SJB/TGC		

D
1
CROSS SECTION D-D'

LEGEND:

FILL	SYLVANIA FORMATION	EXPLORATORY WELL DRILLED FOR DRIC PROJECT. DEPTH AS SHOWN
SILTY CLAY	BOIS BLANC FORMATION	FORMER SOLUTION MINING WELL TOTAL DEPTH UNKNOWN
TILL	BASS ISLANDS FORMATION	O/S OFF-SET DISTANCE FROM SECTION LINE
DUNDEE FORMATION	SALINA LIMESTONE	MAJOR OPEN FRACTURES/JOINTS
LUCAS FORMATION	SALINA DOLOSTONE	MINOR OPEN FRACTURES/JOINTS
AMHERSTBURG FORMATION	SALINA SHALES	PARTIALLY OPEN FRACTURES/JOINTS
	SALINA SALINA SALTS	FILLED FRACTURES/JOINTS

WATER FLOW LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

SOLUTION MINING WELL RECORDS:

CAV	CAVITY ENCOUNTERED DURING DRILLING
C	ESTIMATED / RECORDED CASING DEPTH
R	REPAIR OF DAMAGE TO CASING OR INTERVAL (DEEPER) BRINE TUBING / PIPE
(1931)	DATE OF REPAIR OR OCCURRENCE

NOTES:

1. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
2. INTERPRETED INTERFACES BETWEEN GEOLOGIC FORMATIONS ARE SHOWN BY SOLID LINES. THESE INTERPRETED INTERFACES ARE APPROXIMATE AND CONDITIONS BETWEEN THE EXPLORED LOCATIONS WILL VARY FROM THOSE CONDITIONS AND INTERFACE ELEVATIONS SHOWN.
3. SEISMIC ANOMALIES, WHERE SHOWN, INDICATE GENERAL AREAS OF CHANGES IN SEISMIC CHARACTER AND ARE ASSOCIATED WITH DIFFERENT INFERRED CAUSES OF THE ANOMALOUS TEST RESULTS. REFERENCE MUST BE MADE TO THE DESCRIPTIONS PROVIDED IN THE REPORT TEXT REGARDING THE INTERPRETED CONDITIONS AT THESE LOCATIONS.
4. FRACTURE FREQUENCY ILLUSTRATED AS FF/0.3 m INCLUDES MAJOR, MINOR, AND PARTIALLY OPEN FRACTURES/JOINTS AS IDENTIFIED SEPARATELY AS WELL AS BEDDING, FILLED FRACTURES/JOINTS, GEOLOGIC CONTACTS, AND INDICATIONS OF BEDDING/BANDING/FOLIATION, WHERE THIS LATTER CATEGORY IS TYPICALLY THE MOST PREVALENT FEATURE. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.
5. PSEUDO RQD IS AN QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

20 0 20 40
SCALE HORIZ. 1:1000 METRES

50 0 50 100
SCALE VERT. 1:2500 METRES

Golder Associates, Mississauga, Ontario, Canada	SCALE: AS SHOWN	TITLE: **SECTION D-D'**
	DATE: 22 Jan. 2008	
	DESIGN	
	CAD: JFC	
FILE No. 041111060BAE08.6.dwg	CHECK: JM/CP	DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE
PROJECT No. 04-1111-060B; REV. A	REVIEW: SJB/TGC	FIGURE 8.6

LEGEND:

- FILL
- SILTY CLAY
- TILL
- DUNDEE FORMATION
- LUCAS FORMATION
- AMHERSTBURG FORMATION
- SYLVANIA FORMATION
- BOIS BLANC FORMATION
- BASS ISLANDS FORMATION
- SALINA LIMESTONE
- SALINA DOLOSTONE
- SALINA SHALES
- SALINA SALINA SALTS
- EXPLORATORY WELL DRILLED FOR DRIC PROJECT. DEPTH AS SHOWN
- FORMER SOLUTION MINING WELL TOTAL DEPTH UNKNOWN
- O/S OFF-SET DISTANCE FROM SECTION LINE
- MAJOR OPEN FRACTURES/JOINTS
- MINOR OPEN FRACTURES/JOINTS
- PARTIALLY OPEN FRACTURES/JOINTS
- FILLED FRACTURES/JOINTS

WATER FLOW LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

SOLUTION MINING WELL RECORDS:

CAV	CAVITY ENCOUNTERED DURING DRILLING
C	ESTIMATED / RECORDED CASING DEPTH
R	REPAIR OF DAMAGE TO CASING OR INTERVAL (DEEPER) BRINE TUBING / PIPE
(1931)	DATE OF REPAIR OR OCCURRENCE

NOTES:

1. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
2. INTERPRETED INTERFACES BETWEEN GEOLOGIC FORMATIONS ARE SHOWN BY SOLID LINES. THESE INTERPRETED INTERFACES ARE APPROXIMATE AND CONDITIONS BETWEEN THE EXPLORED LOCATIONS WILL VARY FROM THOSE CONDITIONS AND INTERFACE ELEVATIONS SHOWN.
3. SEISMIC ANOMALIES, WHERE SHOWN, INDICATE GENERAL AREAS OF CHANGES IN SEISMIC CHARACTER AND ARE ASSOCIATED WITH DIFFERENT INFERRED CAUSES OF THE ANOMALOUS TEST RESULTS. REFERENCE MUST BE MADE TO THE DESCRIPTIONS PROVIDED IN THE REPORT TEXT REGARDING THE INTERPRETED CONDITIONS AT THESE LOCATIONS.
4. FRACTURE FREQUENCY ILLUSTRATED AS FF/0.3 m INCLUDES MAJOR, MINOR, AND PARTIALLY OPEN FRACTURES/JOINTS AS IDENTIFIED SEPARATELY AS WELL AS BEDDING, FILLED FRACTURES/JOINTS, GEOLOGIC CONTACTS, AND INDICATIONS OF BEDDING/BANDING/FOLIATION, WHERE THIS LATTER CATEGORY IS TYPICALLY THE MOST PREVALENT FEATURE. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.
5. PSEUDO RQD IS AN QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

SCALE HORIZ. 1:1000 METRES (20 0 20 40)

SCALE VERT. 1:2500 METRES (50 0 50 100)

Golder Associates, Mississauga, Ontario, Canada	SCALE: AS SHOWN	TITLE: **SECTION E-E'**	
	DATE: 22 Jan. 2008		
	DESIGN:		
	CAD: JFC		
FILE No. 041111060BAE08.7.dwg	CHECK: JM/CP	DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE	FIGURE 8.7
PROJECT No. 04-1111-060B REV. A	REVIEW: SJB/TGC		

F
1

CROSS SECTION F-F'

LEGEND:

FILL	SYLVANIA FORMATION	EXPLORATORY WELL DRILLED FOR DRIC PROJECT. DEPTH AS SHOWN
SILTY CLAY	BOIS BLANC FORMATION	FORMER SOLUTION MINING WELL TOTAL DEPTH UNKNOWN
TILL	BASS ISLANDS FORMATION	O/S OFF-SET DISTANCE FROM SECTION LINE
DUNDEE FORMATION	SALINA LIMESTONE	MAJOR OPEN FRACTURES/JOINTS
LUCAS FORMATION	SALINA DOLOSTONE	MINOR OPEN FRACTURES/JOINTS
AMHERSTBURG FORMATION	SALINA SHALES	PARTIALLY OPEN FRACTURES/JOINTS
	SALINA SALINA SALTS	FILLED FRACTURES/JOINTS

WATER FLOW LEGEND:

XA	ARTESIAN FLOW >500 L/min
A	ARTESIAN FLOW <500 L/min
XL	WATER LOSS >500 L/min
L	WATER LOSS <500 L/min
TL	TOTAL LOSS OF CIRCULATION

SOLUTION MINING WELL RECORDS:

CAV	CAVITY ENCOUNTERED DURING DRILLING
C	ESTIMATED / RECORDED CASING DEPTH
R	REPAIR OF DAMAGE TO CASING OR INTERVAL (DEEPER) BRINE TUBING / PIPE
(1931)	DATE OF REPAIR OR OCCURRENCE

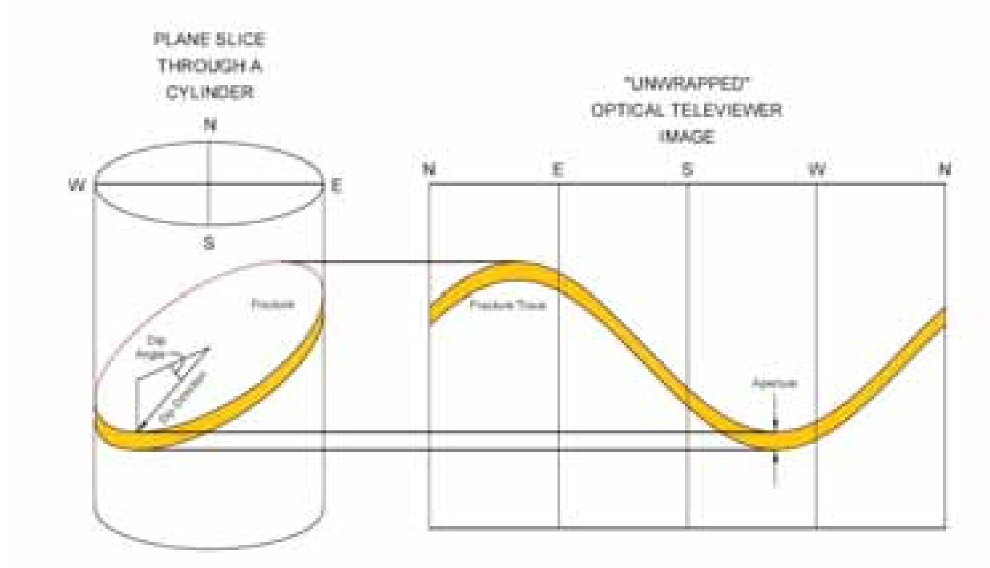
NOTES:

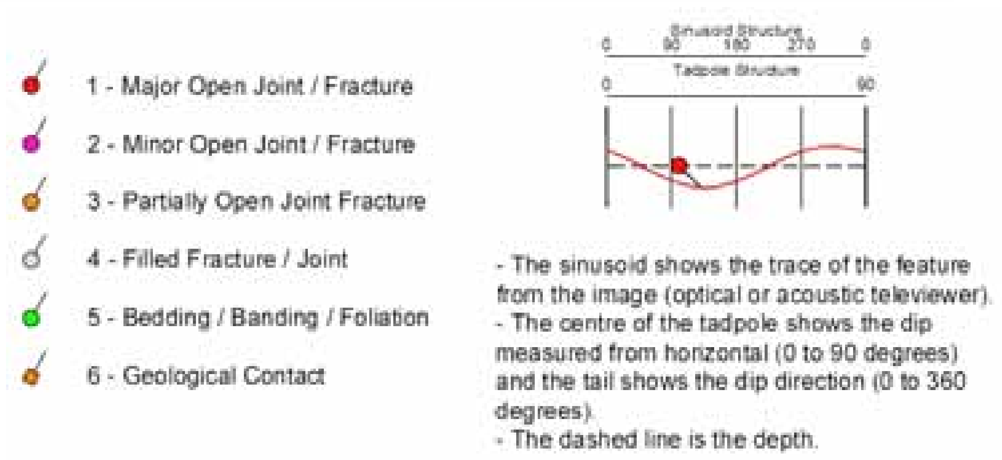
1. GRAPHICAL REPRESENTATION OF ROCK FORMATIONS AT WELL LOCATIONS AND IN LEGEND INDICATES GENERAL ROCK TYPE AND GEOLOGIC FORMATION ONLY. FOR DETAILED ROCK TYPE DESCRIPTIONS REFER TO FIGURES 4.4 AND 4.5 AND TO RECORD OF DRILLHOLE SHEETS IN APPENDIX A.
2. INTERPRETED INTERFACES BETWEEN GEOLOGIC FORMATIONS ARE SHOWN BY SOLID LINES. THESE INTERPRETED INTERFACES ARE APPROXIMATE AND CONDITIONS BETWEEN THE EXPLORED LOCATIONS WILL VARY FROM THOSE CONDITIONS AND INTERFACE ELEVATIONS SHOWN.
3. SEISMIC ANOMALIES, WHERE SHOWN, INDICATE GENERAL AREAS OF CHANGES IN SEISMIC CHARACTER AND ARE ASSOCIATED WITH DIFFERENT INFERRED CAUSES OF THE ANOMALOUS TEST RESULTS. REFERENCE MUST BE MADE TO THE DESCRIPTIONS PROVIDED IN THE REPORT TEXT REGARDING THE INTERPRETED CONDITIONS AT THESE LOCATIONS.
4. FRACTURE FREQUENCY ILLUSTRATED AS FF/0.3 m INCLUDES MAJOR, MINOR, AND PARTIALLY OPEN FRACTURES/JOINTS AS IDENTIFIED SEPARATELY AS WELL AS BEDDING, FILLED FRACTURES/JOINTS, GEOLOGIC CONTACTS, AND INDICATIONS OF BEDDING/BANDING/FOLIATION, WHERE THIS LATTER CATEGORY IS TYPICALLY THE MOST PREVALENT FEATURE. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.
5. PSEUDO RQD IS AN QUALITATIVE ESTIMATE OF THE OVERALL ROCK QUALITY BASED ON THE ACOUSTIC TELEVIEWER DATA. SEE REPORT TEXT FOR ADDITIONAL DISCUSSION.

SCALE HORIZ. 1:1000 METRES

SCALE VERT. 1:2500 METRES

Golder Associates, Mississauga, Ontario, Canada	SCALE: AS SHOWN	TITLE: SECTION F-F'
	DATE: 22 Jan. 2008	
	DESIGN:	
	CAD: JFC	
FILE No. 041111060BAE08.8.dwg	CHECK: JM/CP	DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE
PROJECT No. 04-1111-060B REV. A	REVIEW: SJB/TGC	FIGURE 8.8





Sinusoidal features on amplitude and travel time logs are interpreted according to the following classifications:

- Major Open Joint / Fracture: Continuous televiewer sinusoids with aperture greater than 0.01 m and associated caliper or travel time anomalies. Where these features exhibited apertures greater than about 0.1 m an estimate was made of the actual aperture width (height).

- Minor Open Joint / Fracture: Continuous televiewer sinusoids with less than 0.01 m of aperture but with associated caliper or travel time anomalies.

- Partially Open Joint / Fracture: Continuous televiewer sinusoid with discontinuous aperture.

- Filled Fracture / Joint: Continuous or discontinuous sinusoids with no aperture that are parallel or at an angle to the bedding.

- Bedding / Banding / Foliation: Generally appear as a series of parallel or sub-parallel sinusoids. These can be misinterpreted as Filled Fractures / Joints and vice-versa.

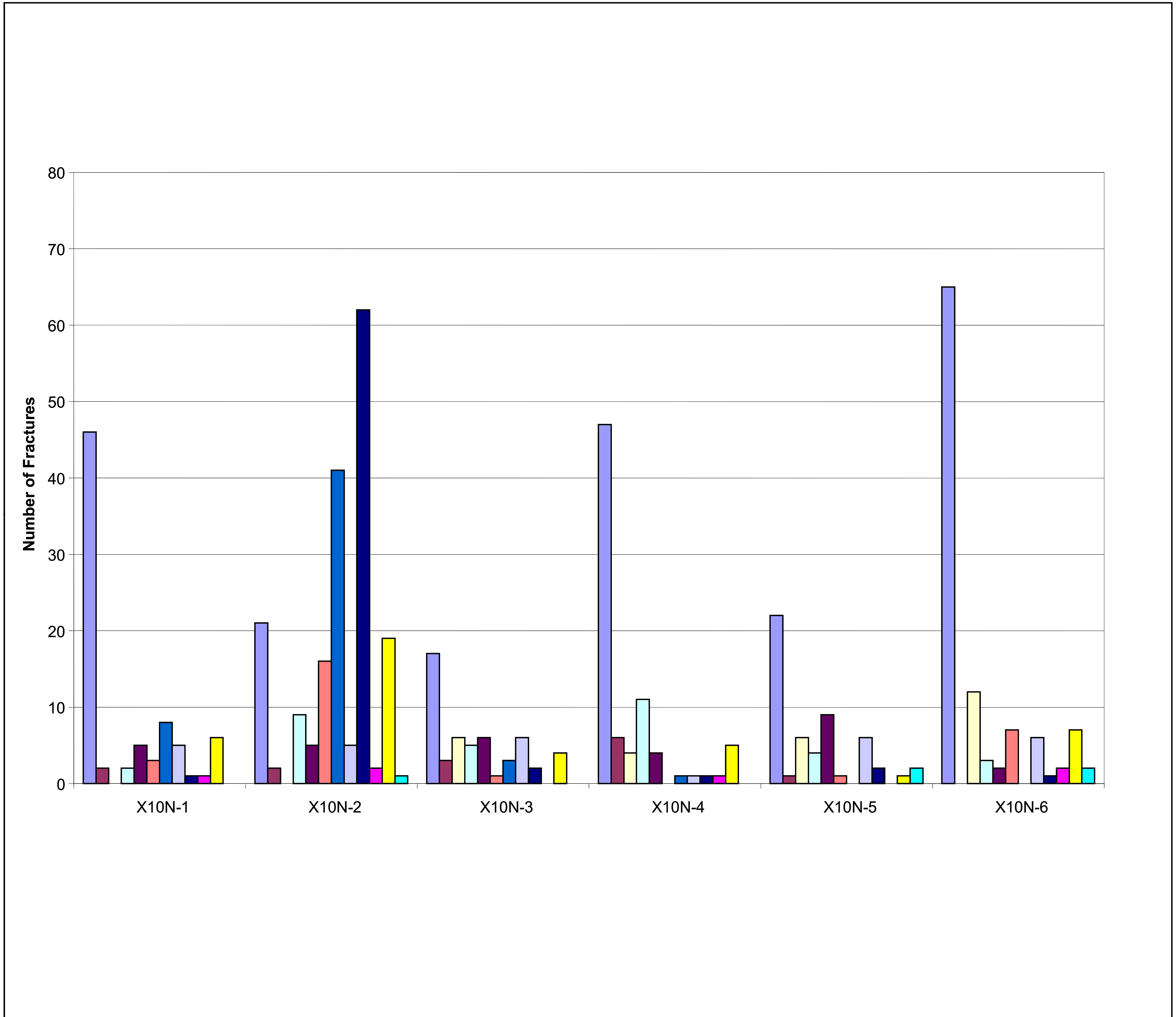
- Geological Contact: These are interpreted from review of the televiewer data together with the stratigraphic logs (natural gamma and apparent conductivity) and marked if there is no obvious associated mechanical structure.

PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

TITLE
INTERPRETATION OF FRACTURE CHARACTERISTICS

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE As Shown	REV. 1
DESIGN	CC	21 Sept. 2004	**FIGURE: 8.9**	
GIS	CC	19 Dec. 2007		
CHECK	JM	19 Dec. 2007		
REVIEW	SB	19 Dec. 2007		



LEGEND

- Detroit River Group Lucas Formation
- Detroit River Group Amherstburg Formation
- Detroit River Group Amherstburg Formation, Sylvania Member
- Bois Blanc Formation
- Bass Islands Formation
- Salina Formation - G Unit Shale
- Salina Formation - F Unit Shale
- Salina Formation - F Unit Salt
- Salina Formation - E Unit Dolostone
- Salina Formation - D Unit Salt
- Salina Formation - C Unit Shale
- Salina Formation - B Unit Salt

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. Data and correlations used for development of this figure are discussed in the above referenced reports.
3. Fracture data interpreted from acoustic televiewer and caliper data according to the following criteria:
   a) Major Open Joint / Fracture: Continuous televiewer sinusoids with aperture greater than 0.01 m and associated caliper or travel time anomalies.
   b) Minor Open Joint / Fracture: Continuous televiewer sinusoids with less than 0.01 m of aperture but with associated caliper or travel time anomalies.
   c) Partially Open Joint / Fracture: Continuous televiewer sinusoid with discontinuous aperture.
4. Number of fractures presented in histogram represents sum of Major, Minor, and Partially Open Joint/Fracture categories.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

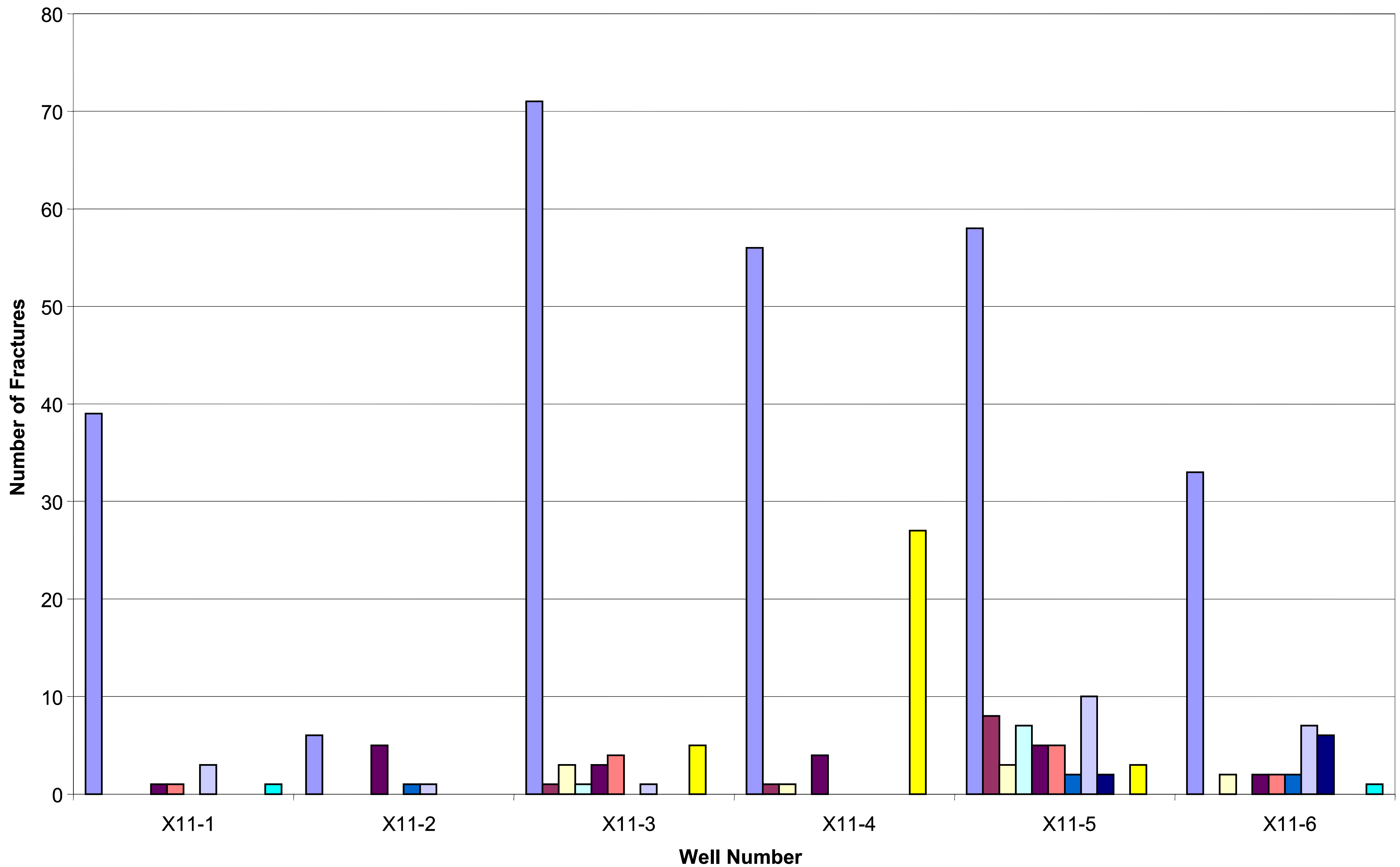
TITLE

FRACTURE SUMMARY – X10N SERIES WELLS

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	CC	24 May 2006	FIGURE: 8.10	
GIS	JFC	13 Dec. 2007		
CHECK	JM	13 Dec. 2007		
REVIEW	SB	13 Dec. 2007		

Golder Associates
Mississauga, Ontario

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.10_FRACTURE SUMMARY – X10N SERIES WELLS.mxd



LEGEND

- Detroit River Group Lucas Formation
- Detroit River Group Amherstburg Formation
- Detroit River Group Amherstburg Formation, Sylvania Member
- Bois Blanc Formation
- Bass Islands Formation
- Salina Formation - G Unit Shale
- Salina Formation - F Unit Shale
- Salina Formation - F Unit Salt
- Salina Formation - E Unit Dolostone
- Salina Formation - D Unit Salt
- Salina Formation - C Unit Shale
- Salina Formation - B Unit Salt

Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. Data and correlations used for development of this figure are discussed in the above referenced reports.
3. Fracture data interpreted from acoustic televiewer and caliper data according to the following criteria:
   a) Major Open Joint / Fracture: Continuous televiewer sinusoids with aperture greater than 0.01 m and associated caliper or travel time anomalies.
   b) Minor Open Joint / Fracture: Continuous televiewer sinusoids with less than 0.01 m of aperture but with associated caliper or travel time anomalies.
   c) Partially Open Joint / Fracture: Continuous televiewer sinusoid with discontinuous aperture.
4. Number of fractures presented in histogram above represents sum of Major, Minor, and Partially Open Joint/Fracture categories.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

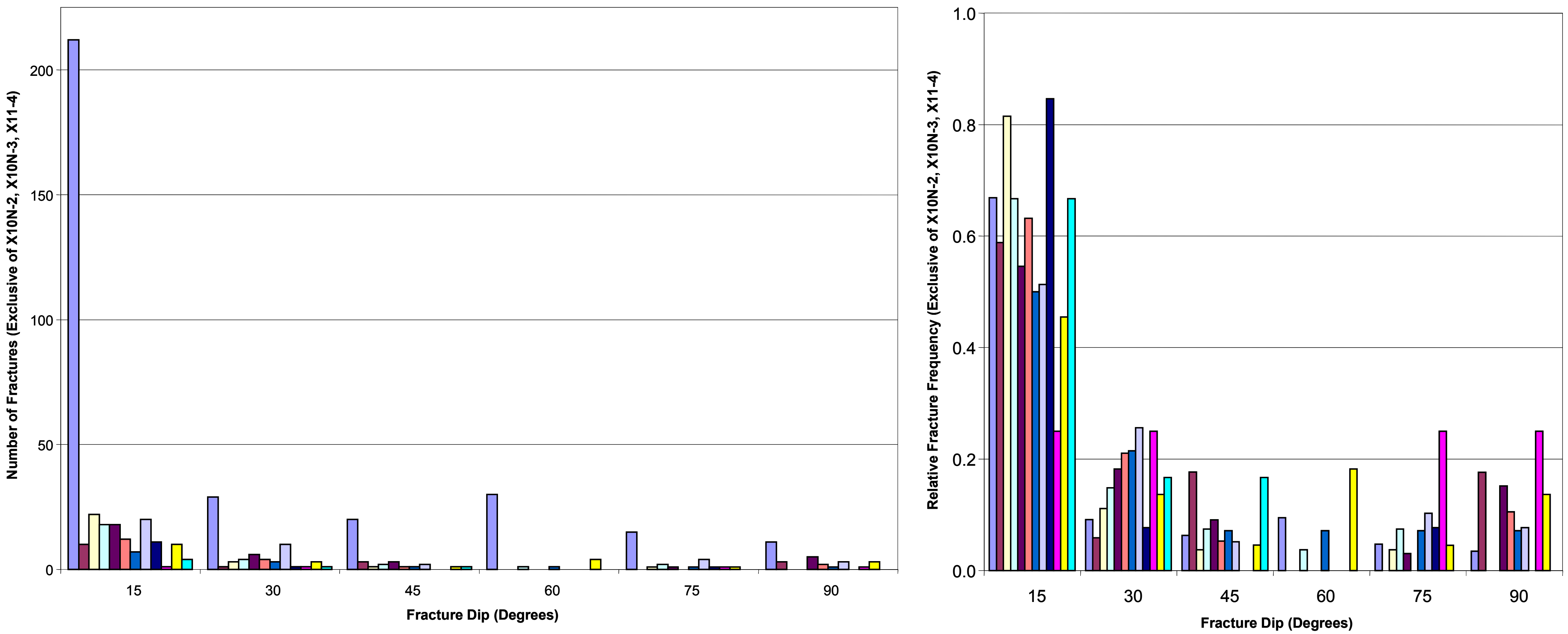
TITLE

FRACTURE SUMMARY – X11 SERIES WELLS

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.11**	
GIS	JFC	13 Dec. 2007		
CHECK	JM	13 Dec. 2007		
REVIEW	SB	13 Dec. 2007		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.11_FRACTURE SUMMARY – X11 SERIES WELLS.mxd



LEGEND

- Detroit River Group Lucas Formation
- Detroit River Group Amherstburg Formation
- Detroit River Group Amherstburg Formation, Sylvania Member
- Bois Blanc Formation
- Bass Islands Formation
- Salina Formation - G Unit Shale
- Salina Formation - F Unit Shale
- Salina Formation - F Unit Salt
- Salina Formation - E Unit Dolostone
- Salina Formation - D Unit Salt
- Salina Formation - C Unit Shale
- Salina Formation - B Unit Salt

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. Data and correlations used for development of this figure are discussed in the above referenced reports.
3. Fracture data interpreted from acoustic televiewer and caliper data according to the following criteria:
   a) Major Open Joint / Fracture: Continuous televiewer sinusoids with aperture greater than 0.01 m and associated caliper or travel time anomalies.
   b) Minor Open Joint / Fracture: Continuous televiewer sinusoids with less than 0.01 m of aperture but with associated caliper or travel time anomalies.
   c) Partially Open Joint / Fracture: Continuous televiewer sinusoid with discontinuous aperture.
4. Number of fractures presented in histogram above represents sum of Major, Minor, and Partially Open Joint/Fracture categories.

PROJECT

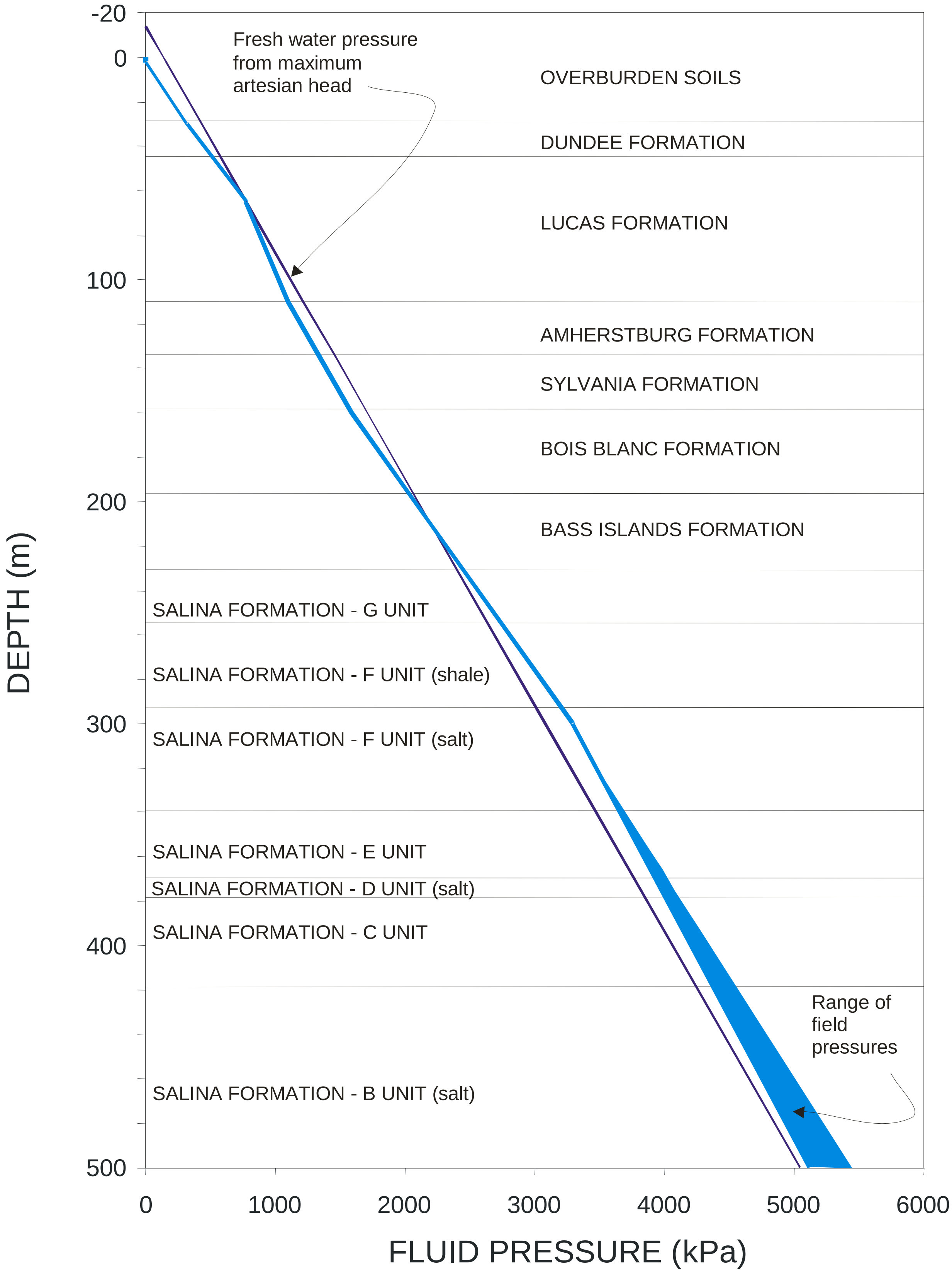
DETROIT RIVER INTERNATIONAL CROSSING

TITLE

FRACTURE SUMMARY – DIP ANGLE

Golder Associates
Mississauga, Ontario

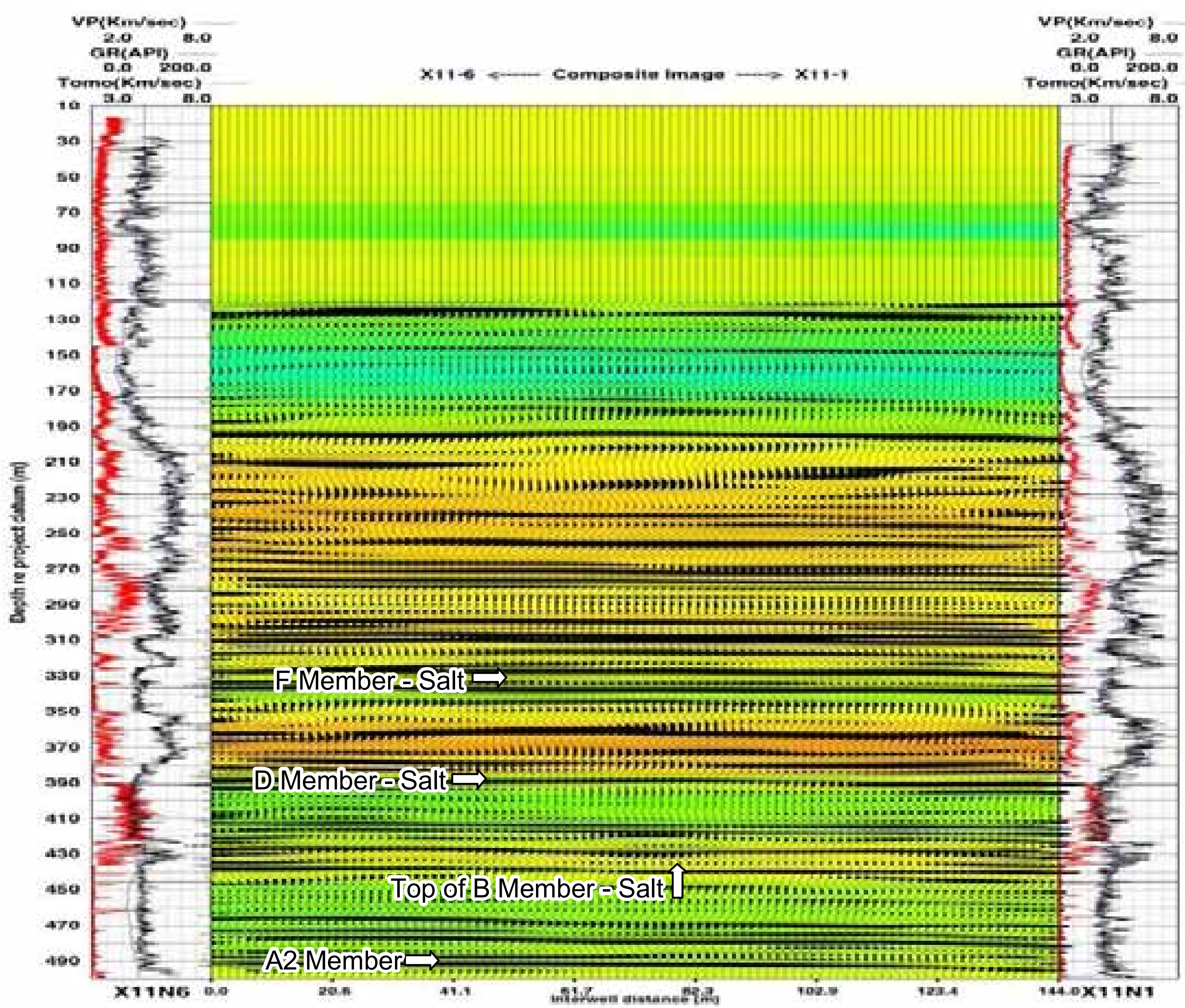
PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.12**	
GIS	JFC	13 Dec. 2007		
CHECK	JM	13 Dec. 2007		
REVIEW	SB	13 Dec. 2007		



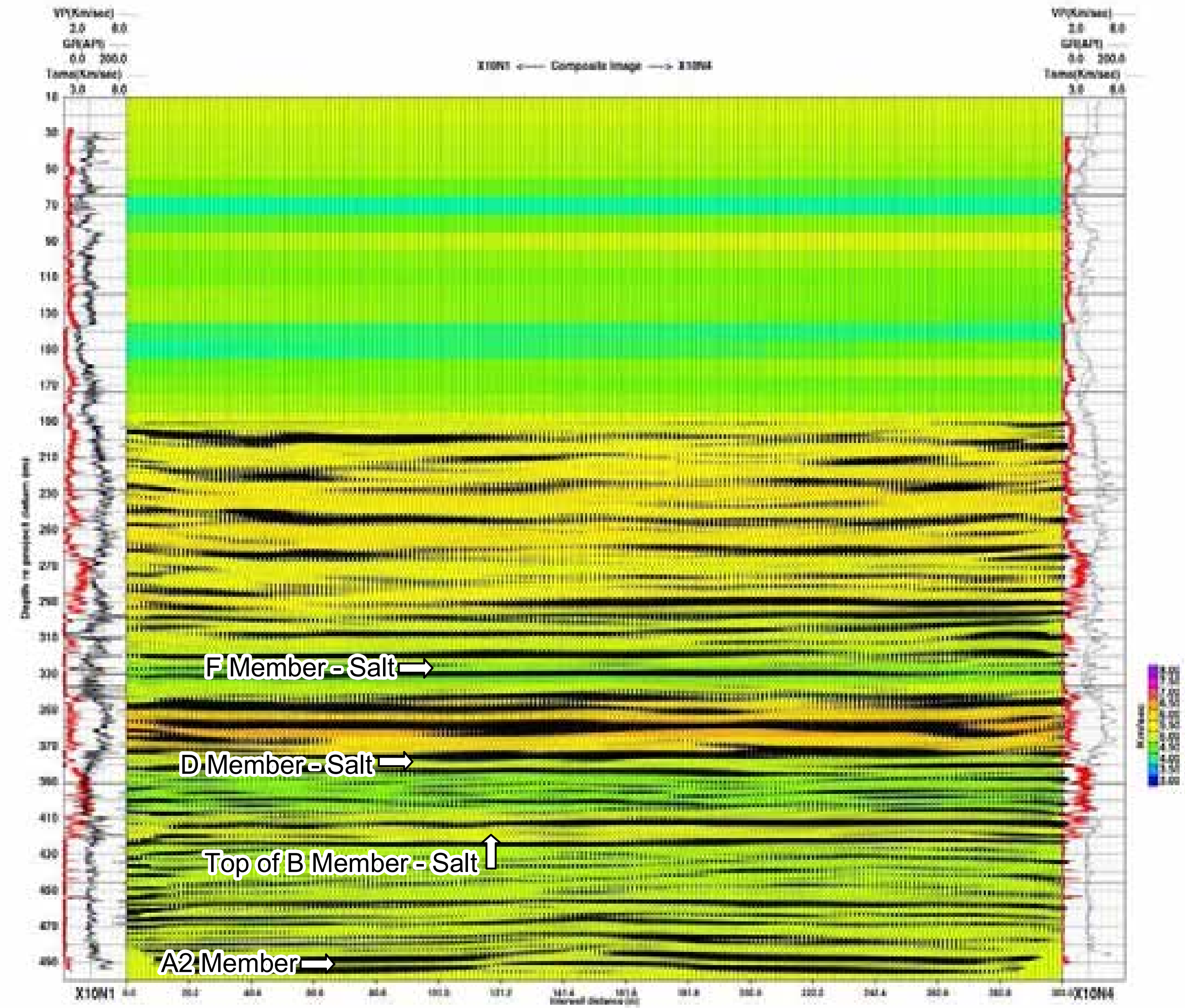
NOTE:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

PROJECT DETROIT RIVER INTERNATIONAL CROSSING					
TITLE INTERPRETED SUBSURFACE FLUID PRESSURE PROFILE					
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060			SCALE NTS	REV. 1
	DESIGN	CC	21 Sept. 2004	FIGURE: 8.13	
	GIS	JFC	20 Feb. 2008		
	CHECK	JM	20 Feb. 2008		
	REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.13_INTERPRETED SUBSURFACE FLUID PRESSURE PROFILE.mxd



Example 1: Cross-Well Seismic Imaging Profile (Up-Going) X11-1 to X11-6, illustrating clearly defined and relatively flat reflectors shown as overlapping black peaks in the reflection traces creating black lines against the coloured velocity tomogram.



Example 2: Cross-Well Seismic Imaging Profile (Up-Going) X10N-1 to X10N-4, illustrating clearly defined and relatively flat reflectors shown as overlapping black peaks in the reflection traces creating black lines against the coloured velocity tomogram.

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Appendix C.
3. “Up-Going” refers to the direction of the reflected seismic energy. Only up-going images are shown in this Figure. Comparison to the down-going images may be made by reference to Appendix C and Appendix F.

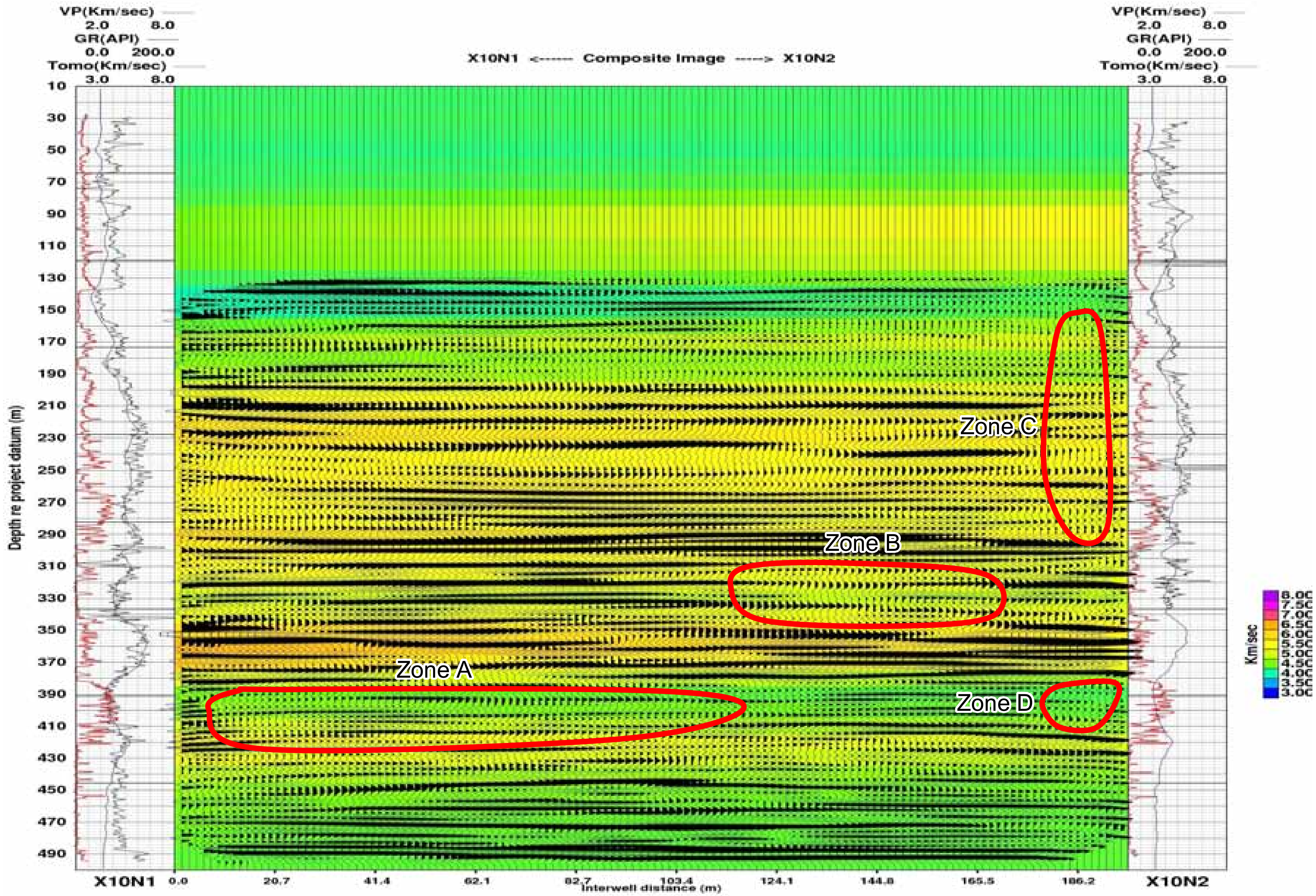
PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

TITLE
EXAMPLE CROSS-WELL PROFILES

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.14**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.14_EXAMPLE CROSS-WELL PROFILES.mxd

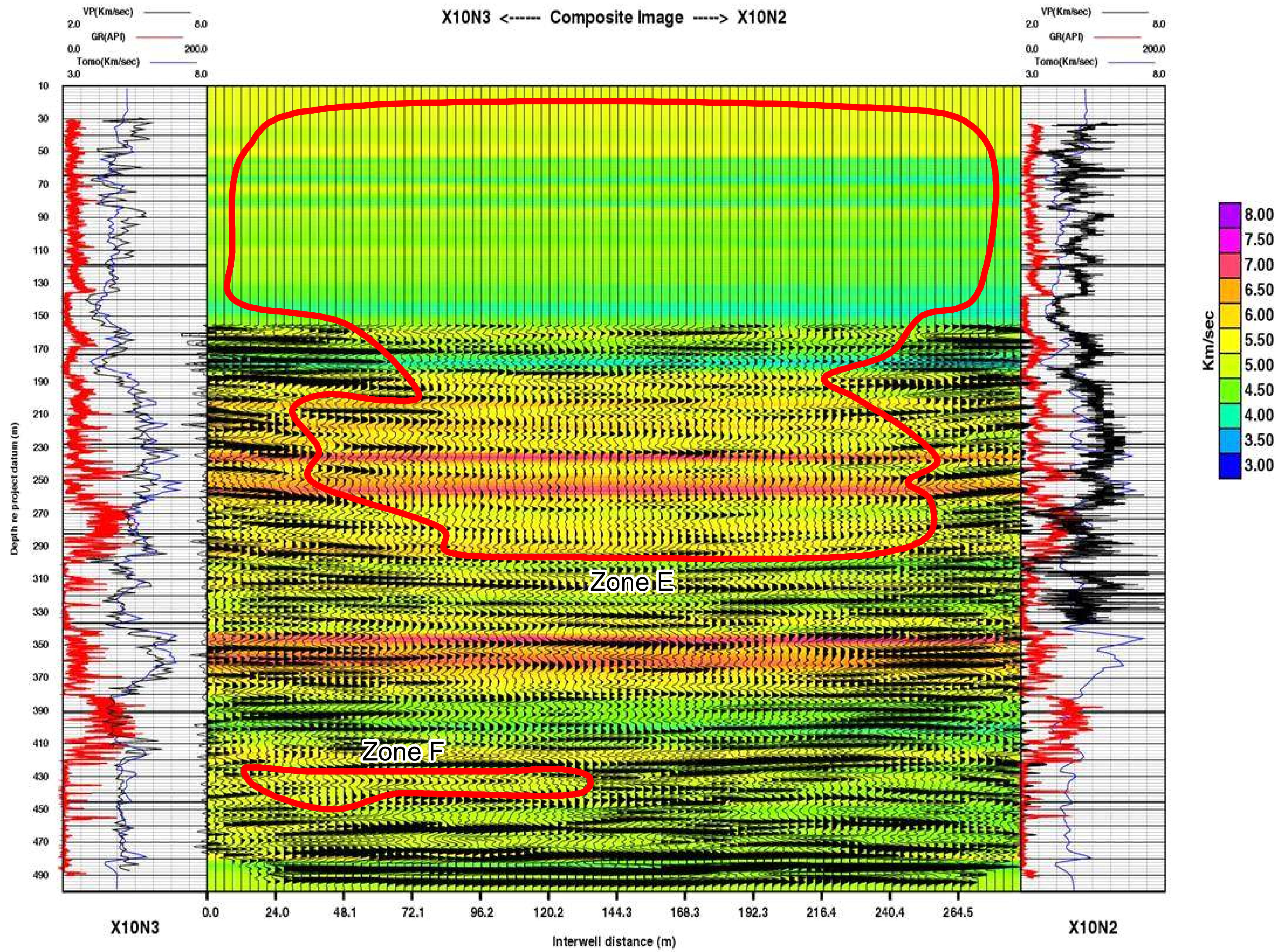


Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Appendix C.
3. "Up-Going" refers to the direction of the reflected seismic energy. Only up-going images are shown in this Figure. Comparison to the down-going images may be made by reference to Appendix C and Appendix F.
4. Anomaly Zones based on up-going and down-going images. Interpretation of these anomaly zones is included in the report text.

PROJECT			
DETROIT RIVER INTERNATIONAL CROSSING			
TITLE: **SUBSURFACE SEISMIC ANOMALIES CROSS-WELL PROFILE X10N-1 TO X10N-2**			
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060	SCALE	REV. 1
	DESIGN CC 24 May 2006		
	GIS JFC 20 Feb. 2008	**FIGURE: 8.15**	
	CHECK JM 20 Feb. 2008		
	REVIEW SB 20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.15_SUBSURFACE SEISMIC ANOMALIES_CROSS-WELL PROFILE X10N-1 TO X10N-2.mxd



Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Appendix C.
3. "Up-Going" refers to the direction of the reflected seismic energy. Only up-going images are shown in this Figure. Comparison to the down-going images may be made by reference to Appendix C and Appendix F.
4. Anomaly Zones based on up-going and down-going images. Interpretation of these anomaly zones is included in the report text.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

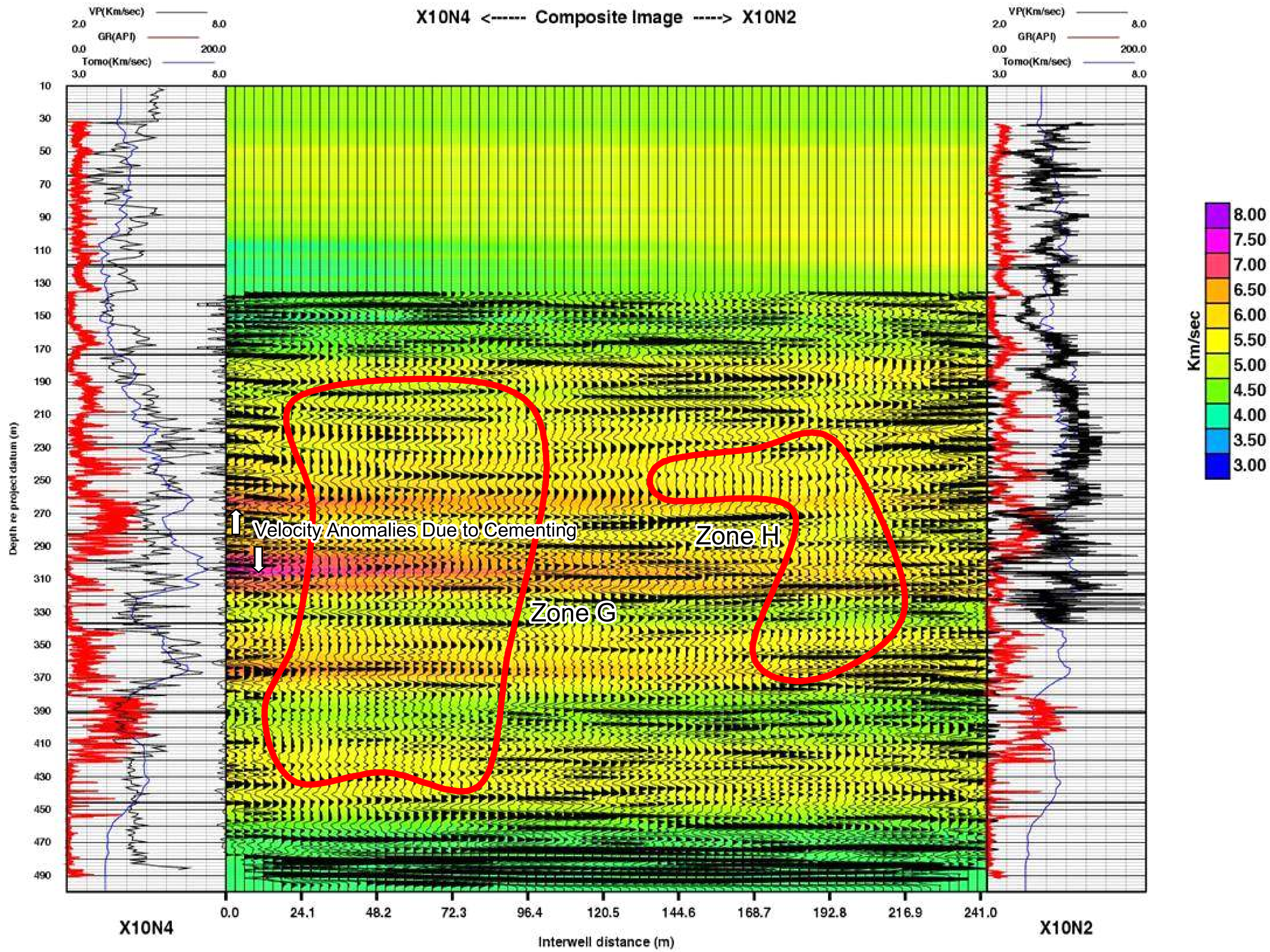
TITLE

SUBSURFACE SEISMIC ANOMALIES CROSS-WELL PROFILE X10N-2 TO X10N-3

Golder Associates, Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.16**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.16_SUBSURFACE SEISMIC ANOMALIES_CROSS-WELL PROFILE X10N-2 TO X10N-3.mxd



Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Appendix C.
3. "Up-Going" refers to the direction of the reflected seismic energy. Only up-going images are shown in this Figure. Comparison to the down-going images may be made by reference to Appendix C and Appendix F.
4. Anomaly Zones based on up-going and down-going images. Interpretation of these anomaly zones is included in the report text.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

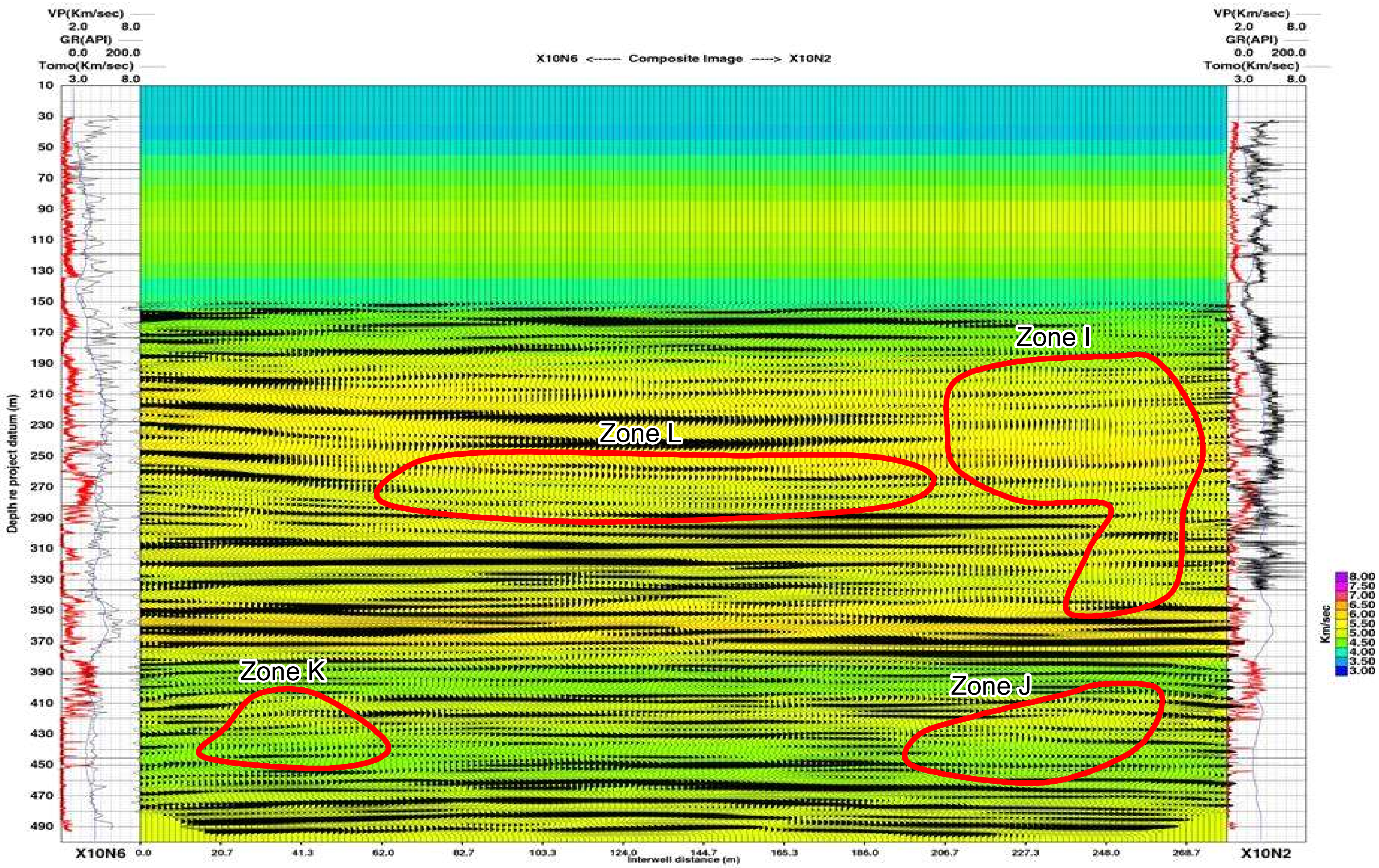
SUBSURFACE SEISMIC ANOMALIES
CROSS-WELL PROFILE X10N-2 TO X10N-4

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006		
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

FIGURE: 8.17

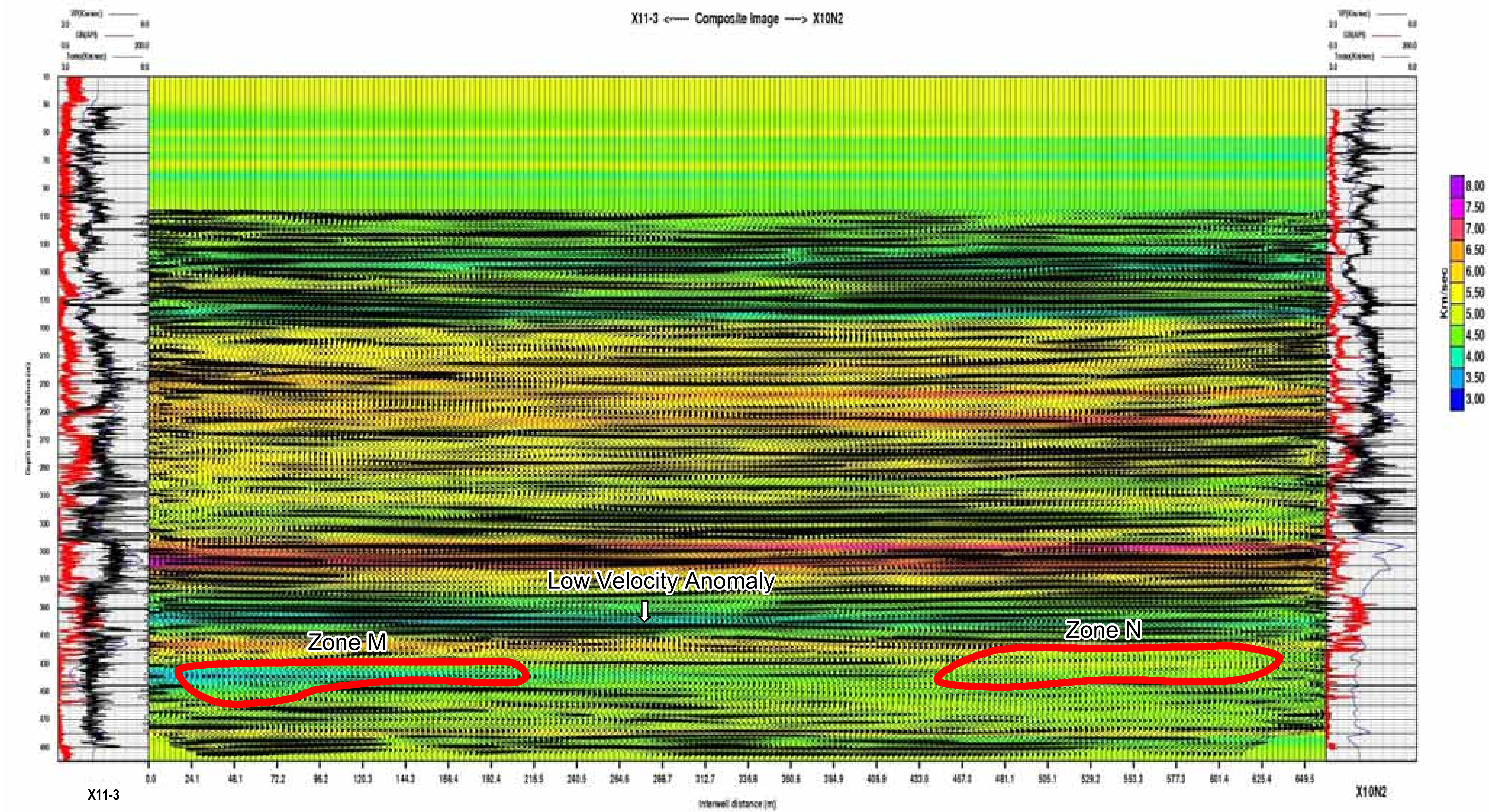
G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.17_SUBSURFACE SEISMIC ANOMALIES_CROSS-WELL PROFILE X10N-2 TO X10N-4.mxd



Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Appendix C.
3. "Up-Going" refers to the direction of the reflected seismic energy. Only up-going images are shown in this Figure. Comparison to the down-going images may be made by reference to Appendix C and Appendix F.
4. Anomaly Zones based on up-going and down-going images. Interpretation of these anomaly zones is included in the report text.

PROJECT				
DETROIT RIVER INTERNATIONAL CROSSING				
TITLE: SUBSURFACE SEISMIC ANOMALIES CROSS-WELL PROFILE X10N-2 TO X10N-6				
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE	REV. 1
	DESIGN	CC	24 May 2006	FIGURE: 8.18
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.18_SUBSURFACE SEISMIC ANOMALIES_CROSS-WELL PROFILE X10N-2 TO X10N-6.mxd



Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Appendix C.
3. “Up-Going” refers to the direction of the reflected seismic energy. Only up-going images are shown in this Figure. Comparison to the down-going images may be made by reference to Appendix C and Appendix F.
4. Anomaly Zones based on up-going and down-going images. Interpretation of these anomaly zones is included in the report text.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

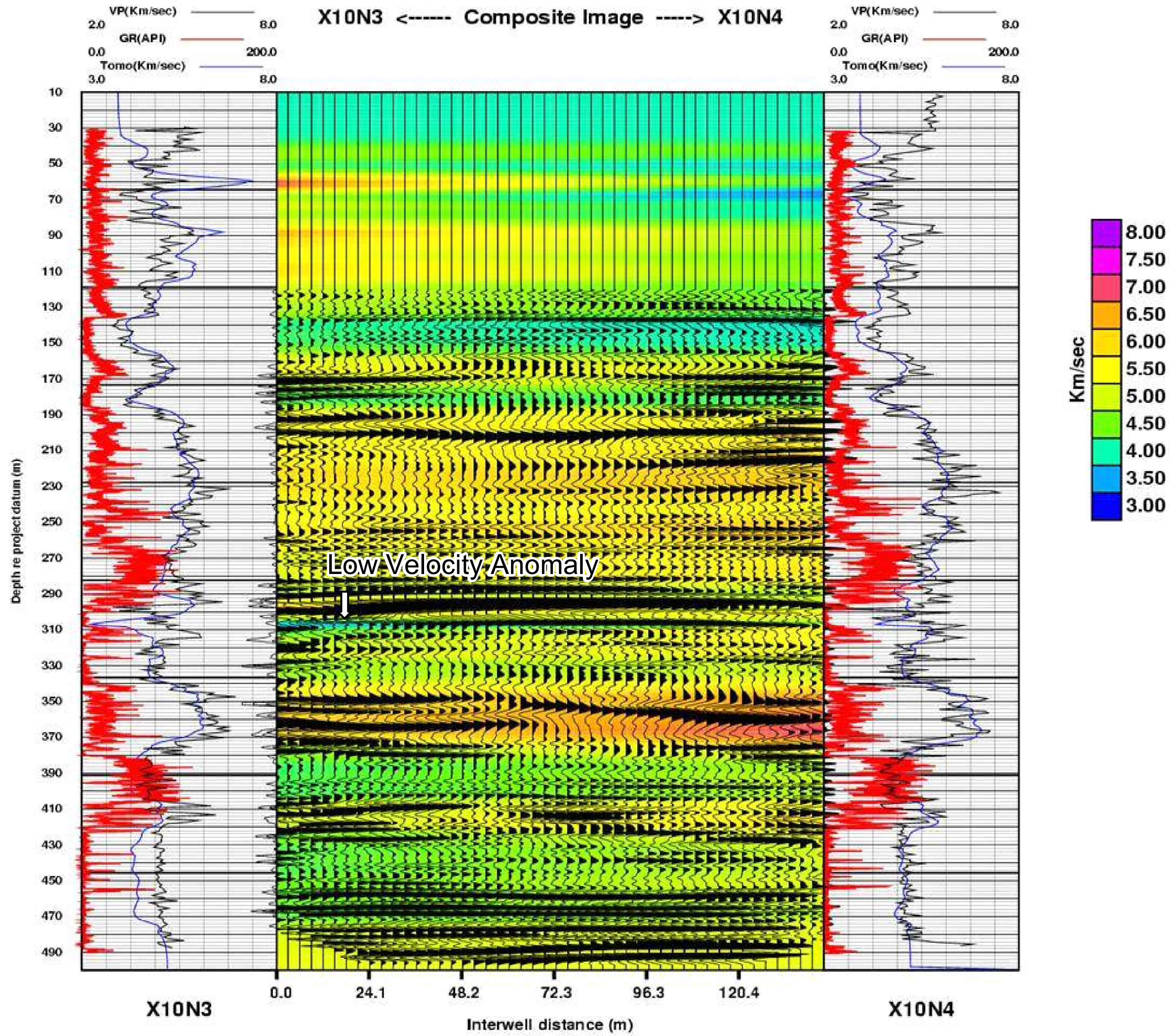
TITLE

SUBSURFACE SEISMIC ANOMALIES
CROSS-WELL PROFILE X10N-2 TO X11-3

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.19**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.19_SUBSURFACE SEISMIC ANOMALIES_CROSS-WELL PROFILE X10N-2 TO X11-3.mxd



Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Appendix C.
3. "Up-Going" refers to the direction of the reflected seismic energy. Only up-going images are shown in this Figure. Comparison to the down-going images may be made by reference to Appendix C and Appendix F.
4. Anomaly Zones based on up-going and down-going images. Interpretation of these anomaly zones is included in the report text.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

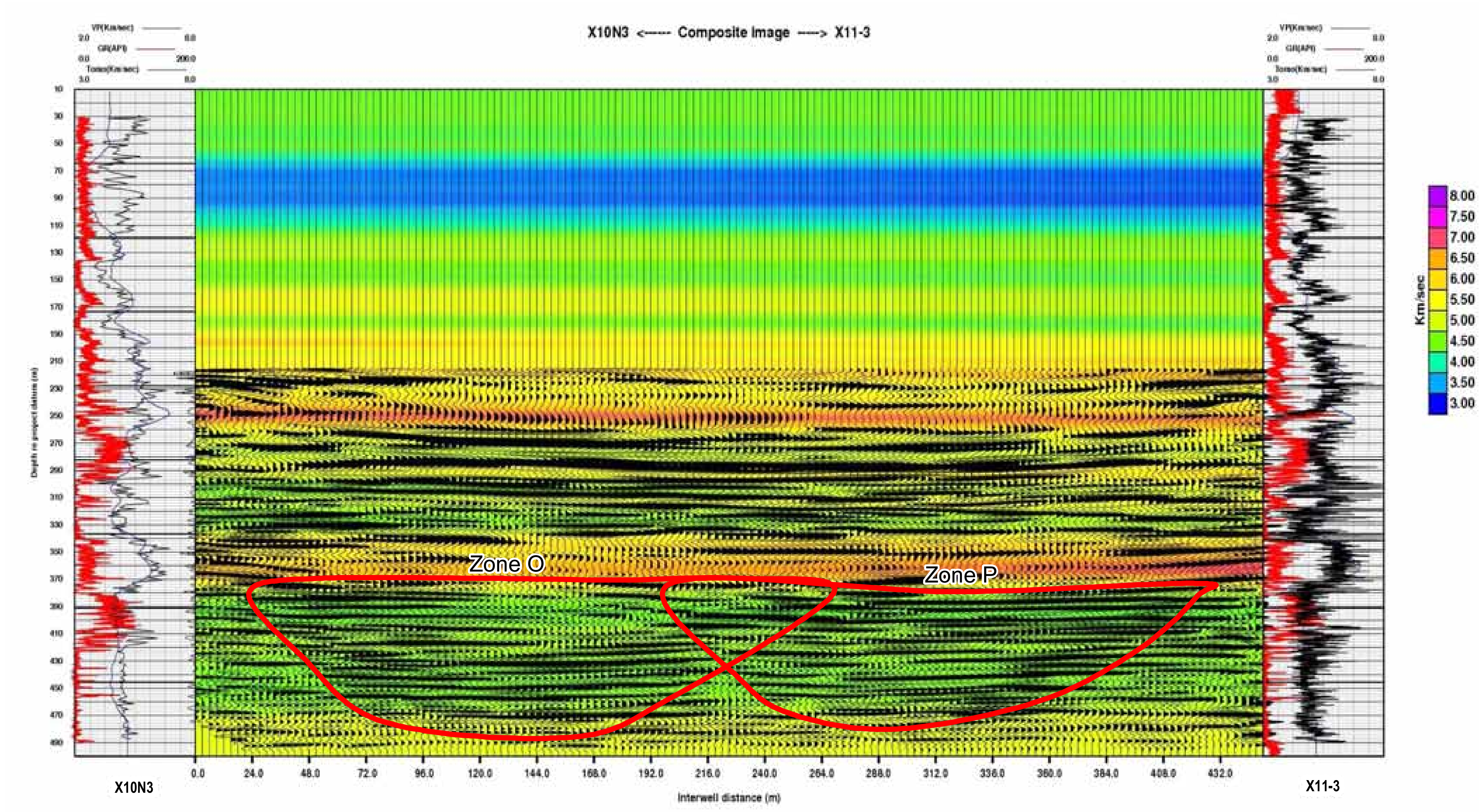
TITLE

SUBSURFACE SEISMIC ANOMALIES CROSS-WELL PROFILE X10N-3 TO X10N-4

Golder Associates, Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.20**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.20_SUBSURFACE SEISMIC ANOMALIES_CROSS-WELL PROFILE X10N-3 TO X10N-4.mxd

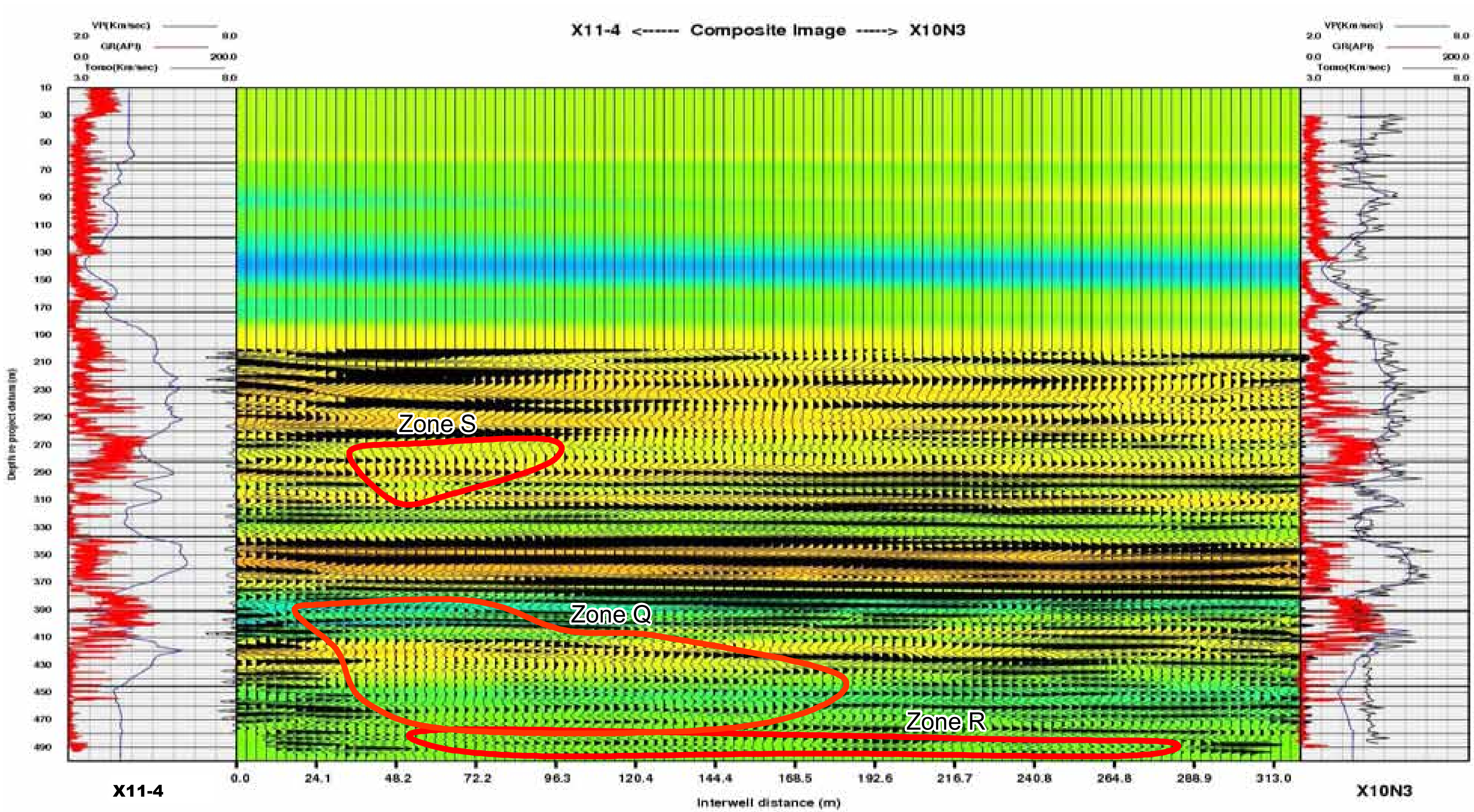


Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Appendix C.
3. "Up-Going" refers to the direction of the reflected seismic energy. Only up-going images are shown in this Figure. Comparison to the down-going images may be made by reference to Appendix C and Appendix F.
4. Anomaly Zones based on up-going and down-going images. Interpretation of these anomaly zones is included in the report text.

PROJECT				
DETROIT RIVER INTERNATIONAL CROSSING				
TITLE: SUBSURFACE SEISMIC ANOMALIES CROSS-WELL PROFILE X10N-3 TO X11-3				
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE	REV. 1
	DESIGN	CC	24 May 2006	FIGURE: 8.21
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	

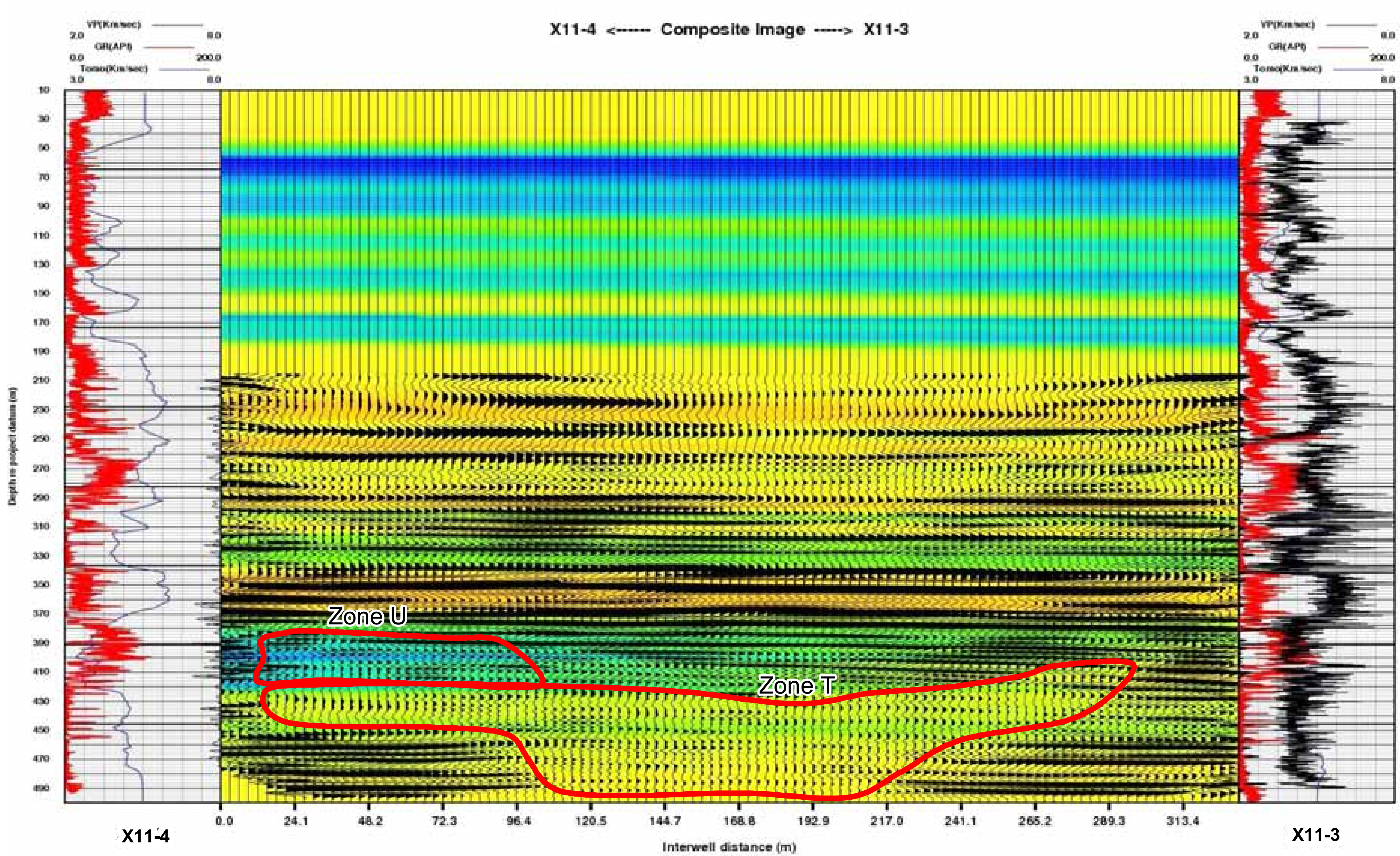
G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.21_SUBSURFACE SEISMIC ANOMALIES_CROSS-WELL PROFILE X10N-3 TO X11-3.mxd



Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Appendix C.
3. “Up-Going” refers to the direction of the reflected seismic energy. Only up-going images are shown in this Figure. Comparison to the down-going images may be made by reference to Appendix C and Appendix F.
4. Anomaly Zones based on up-going and down-going images. Interpretation of these anomaly zones is included in the report text.

PROJECT				
DETROIT RIVER INTERNATIONAL CROSSING				
TITLE				
SUBSURFACE SEISMIC ANOMALIES CROSS-WELL PROFILE X10N-3 TO X11-4				
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE	REV. 1
	DESIGN	CC	24 May 2006	**FIGURE: 8.22**
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	

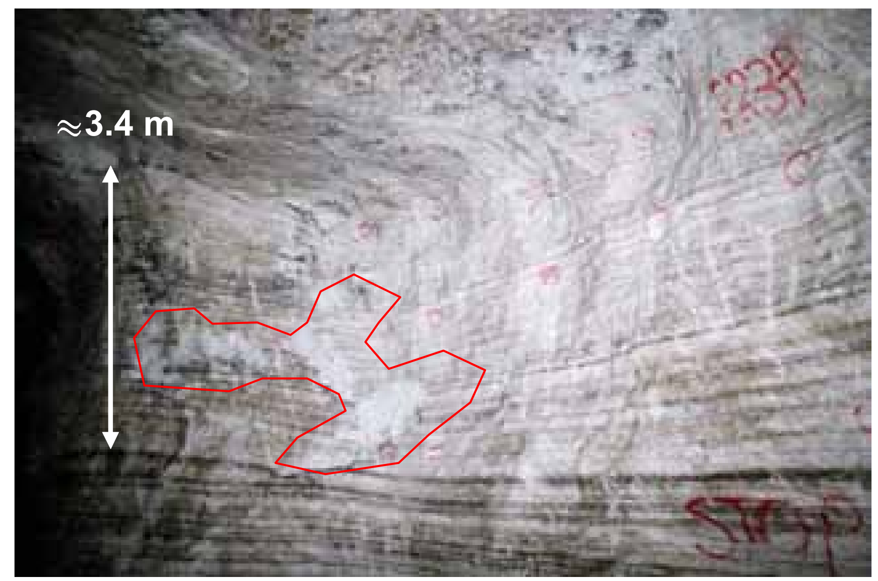
G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.22_SUBSURFACE SEISMIC ANOMALIES_CROSS-WELL PROFILE X10N-3 TO X11-4.mxd

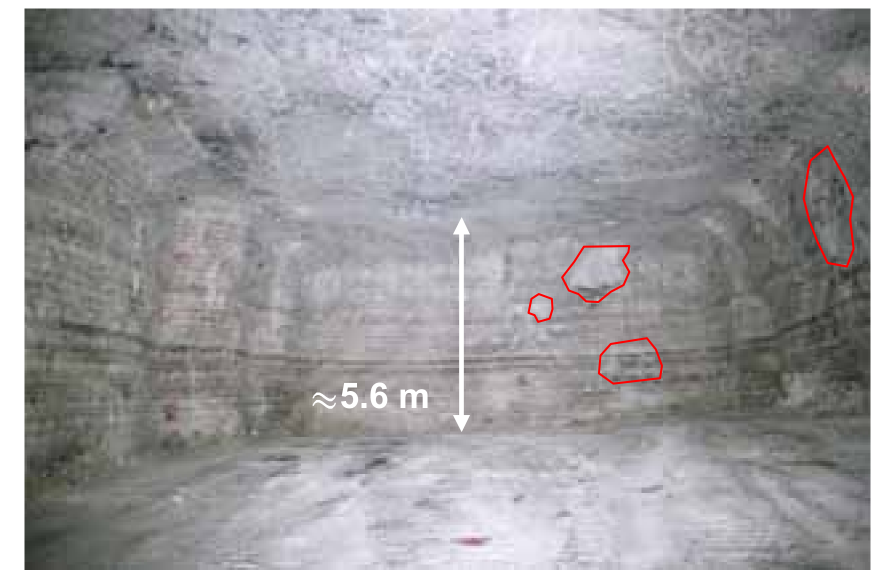


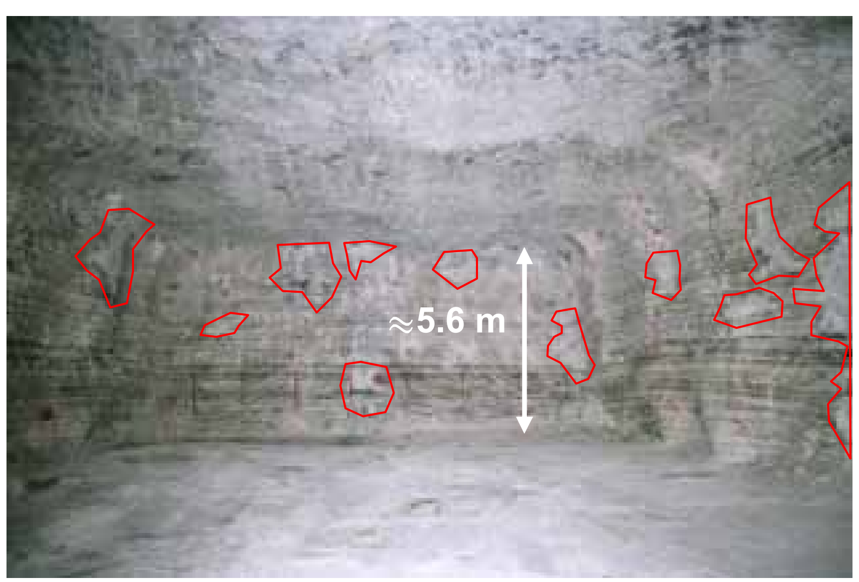
Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Appendix C.
3. "Up-Going" refers to the direction of the reflected seismic energy. Only up-going images are shown in this Figure. Comparison to the down-going images may be made by reference to Appendix C and Appendix F.
4. Anomaly Zones based on up-going and down-going images. Interpretation of these anomaly zones is included in the report text.

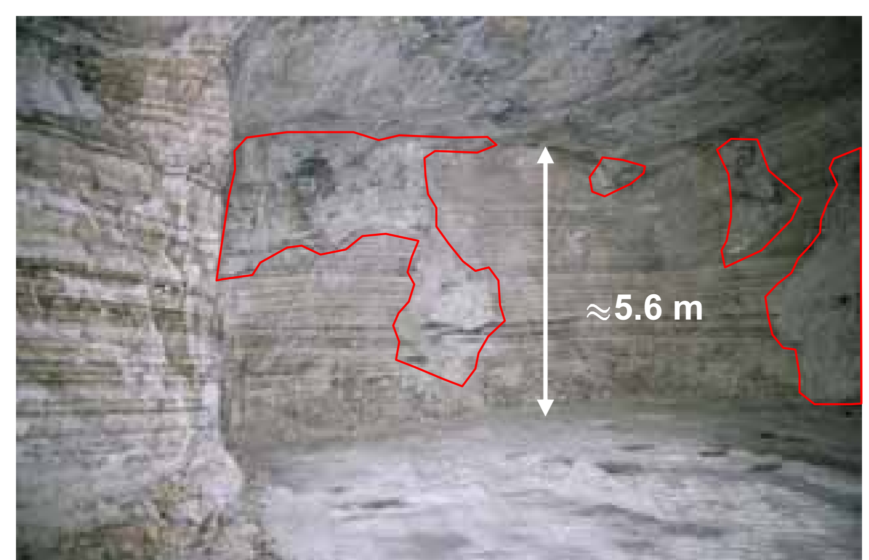
PROJECT	DETROIT RIVER INTERNATIONAL CROSSING			
TITLE	**SUBSURFACE SEISMIC ANOMALIES CROSS-WELL PROFILE X11-3 TO X11-4**			
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE	REV. 1
	DESIGN	CC	24 May 2006	**FIGURE: 8.23**
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.23_SUBSURFACE SEISMIC ANOMALIES_CROSS-WELL PROFILE X11-3 TO X11-4.mxd









Zones of natural dissolution and recrystallisation of salt outlined in red. Photos taken in Salina Formation F salt.

Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

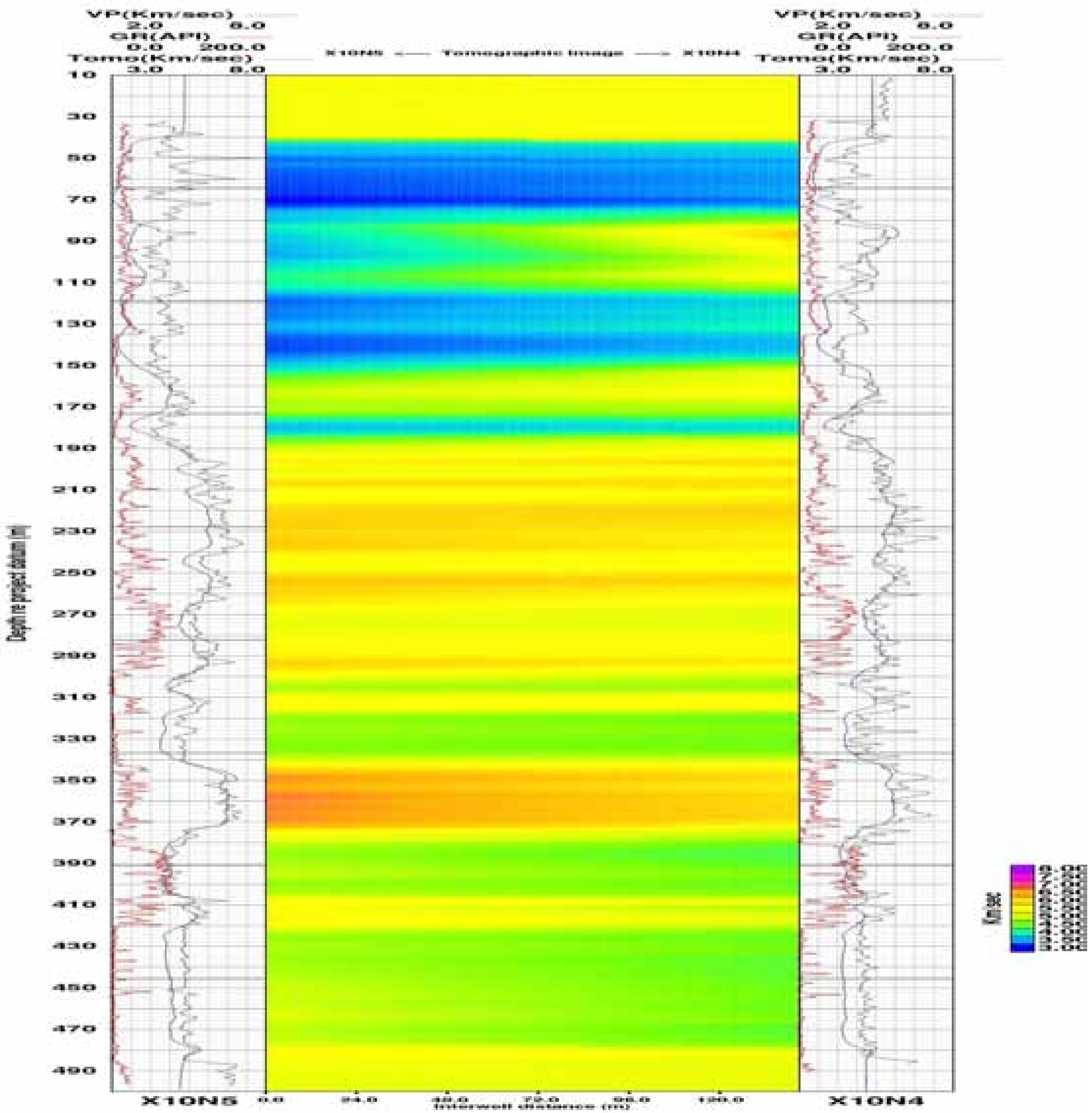
TITLE

NATURAL FEATURES IN SALT BEDS

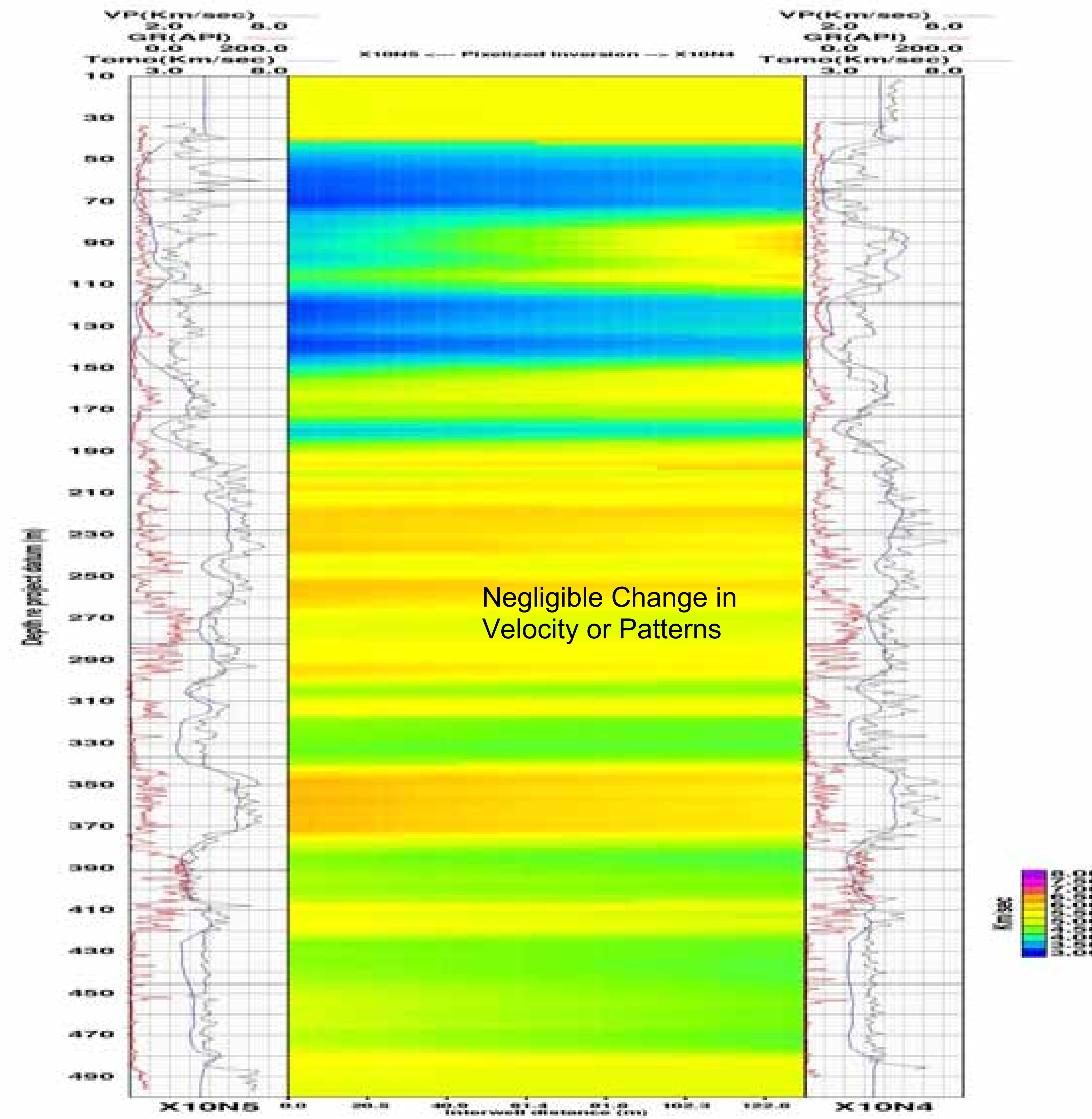
Golder Associates, Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006		
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

FIGURE: 8.24



Original Tomographic Image (Layered Velocity Model)



"Pixelized" Inversion

Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

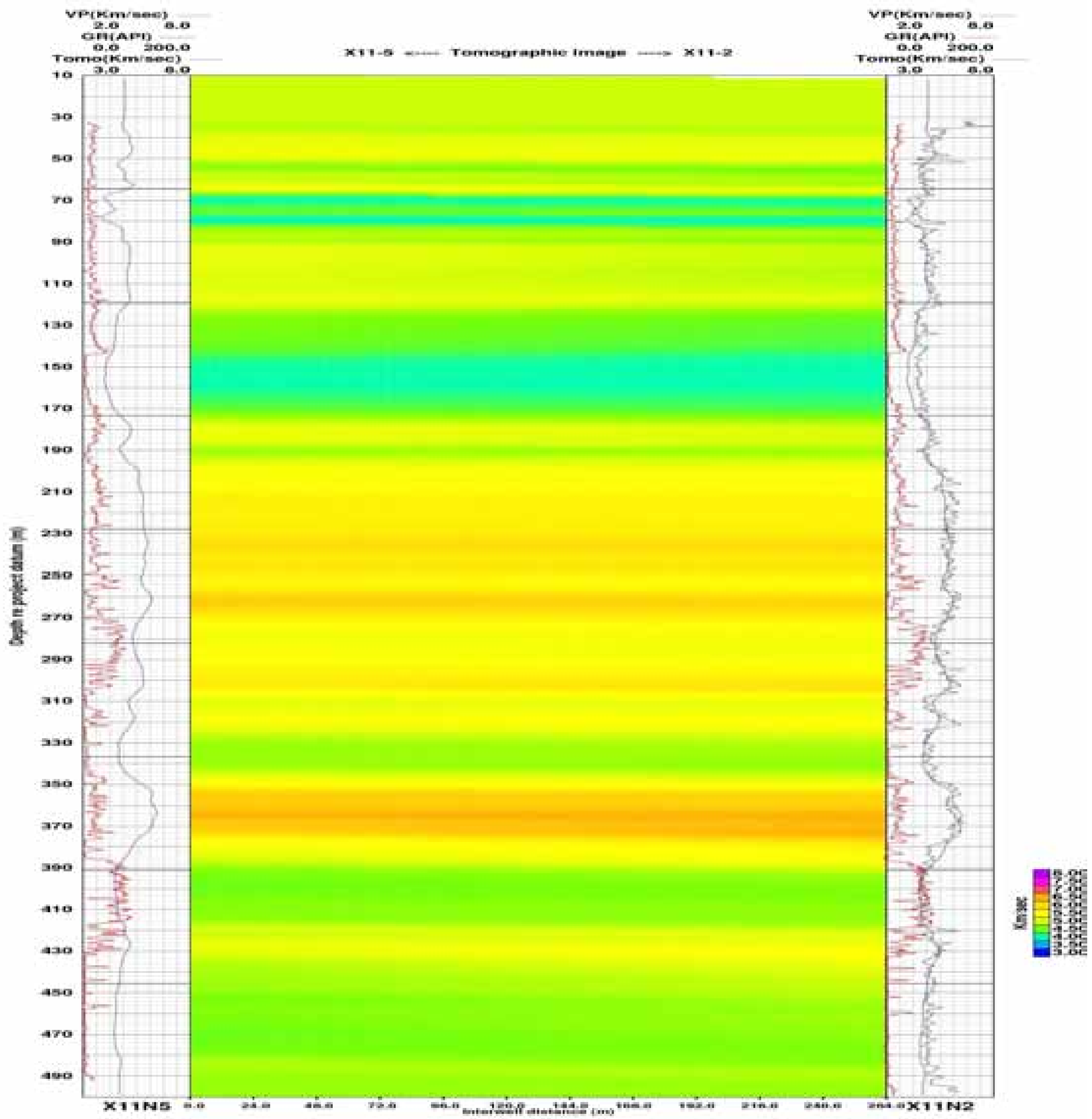
TITLE

COMPARISON OF VELOCITY TOMOGRAMS PROFILE X10N-5 TO X10N-4

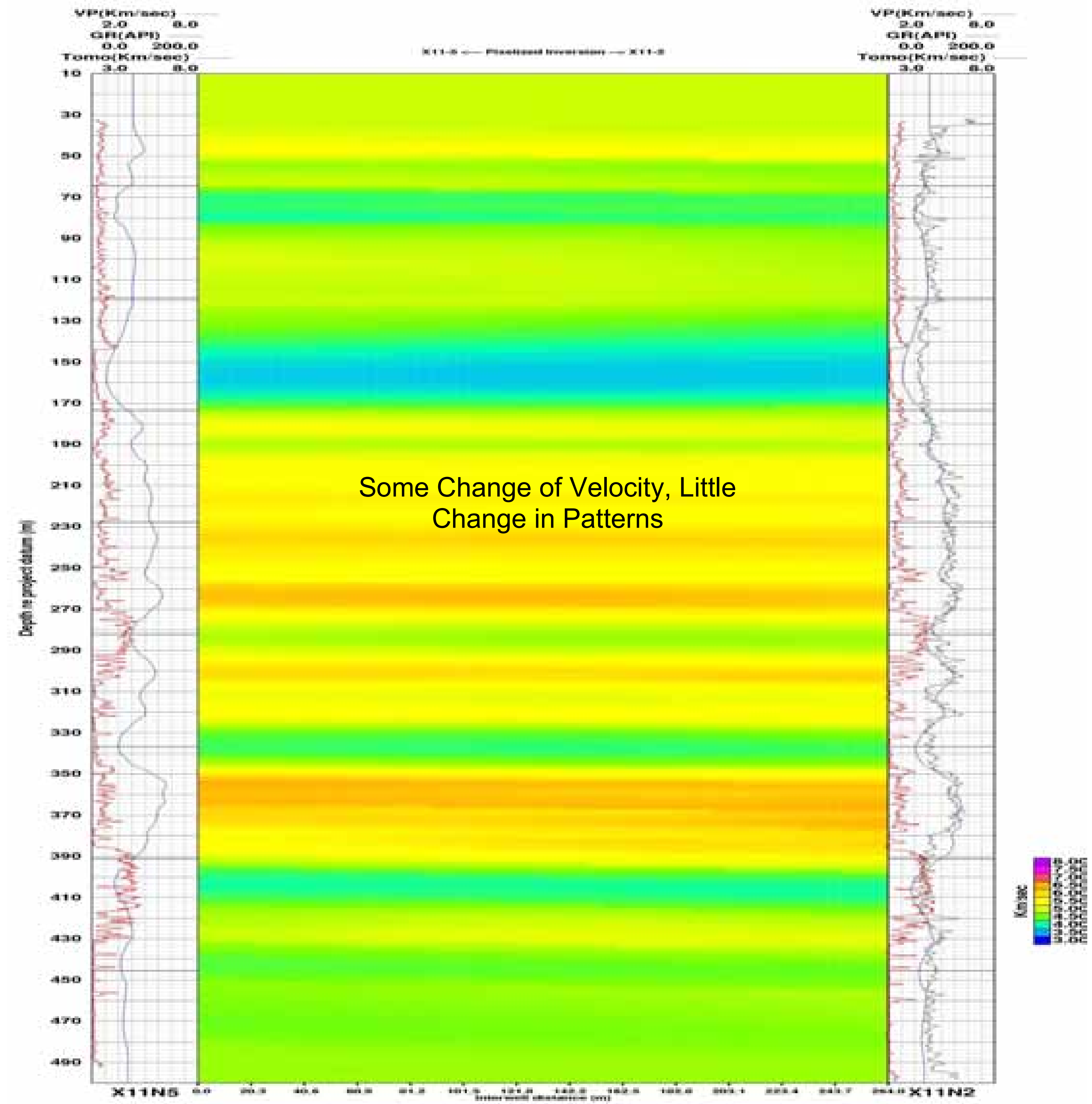
PROJECT No. 04-1111-060			SCALE / REV. 1
DESIGN	CC	24 May 2006	
GIS	JFC	20 Feb. 2008	**FIGURE: 8.25**
CHECK	JM	20 Feb. 2008	
REVIEW	SB	20 Feb. 2008	

Golder Associates
Mississauga, Ontario

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.25_COMPARISON OF VELOCITY TOMOGRAMS_ PROFILE X10N-5 TO X10N-4.mxd



Original Tomographic Image (Layered Velocity Model)



“Pixelized” Inversion

Notes:

1. This figure is to be read with the accompanying reports “Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites”.
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

PROJECT

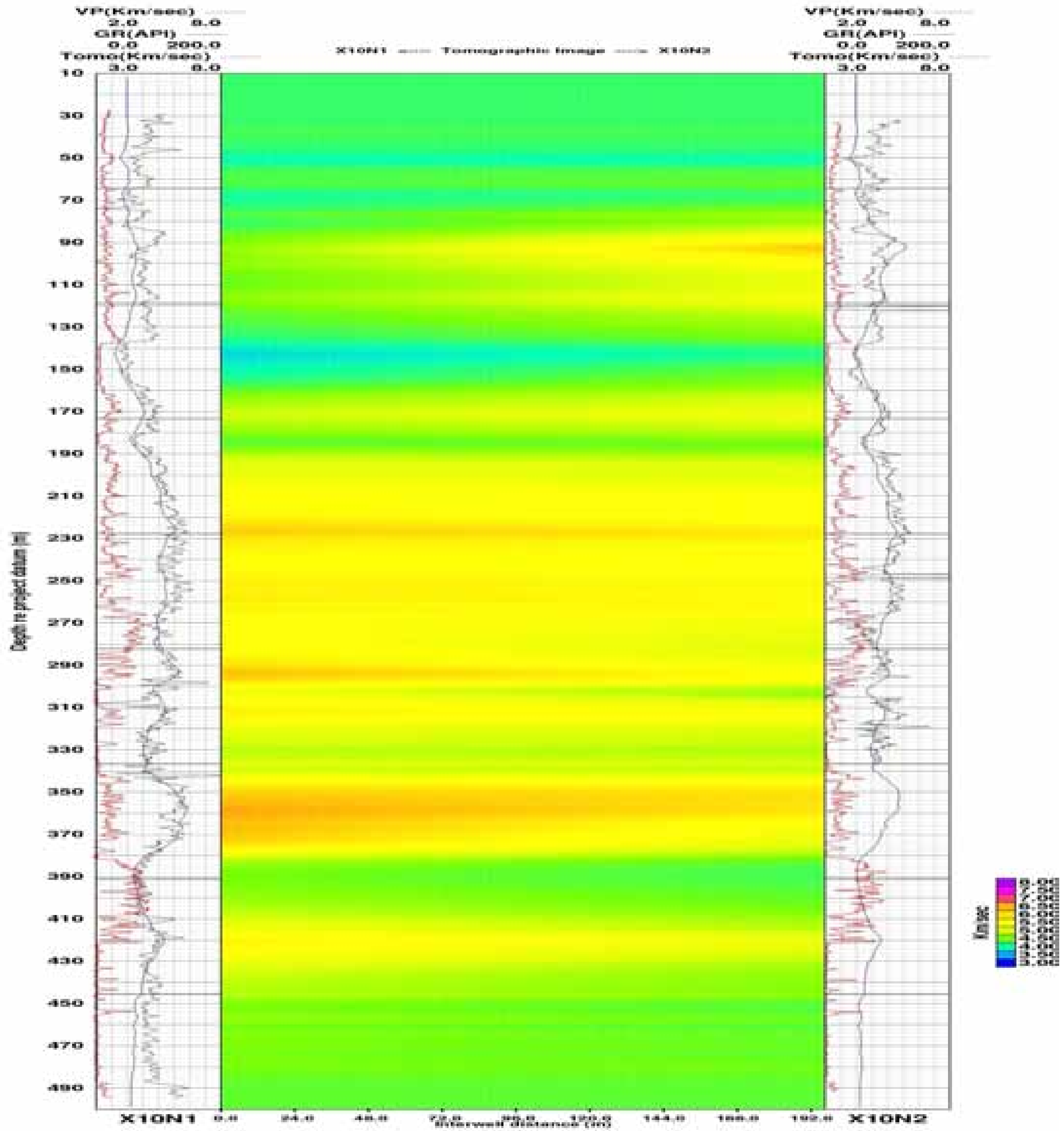
DETROIT RIVER INTERNATIONAL CROSSING

TITLE

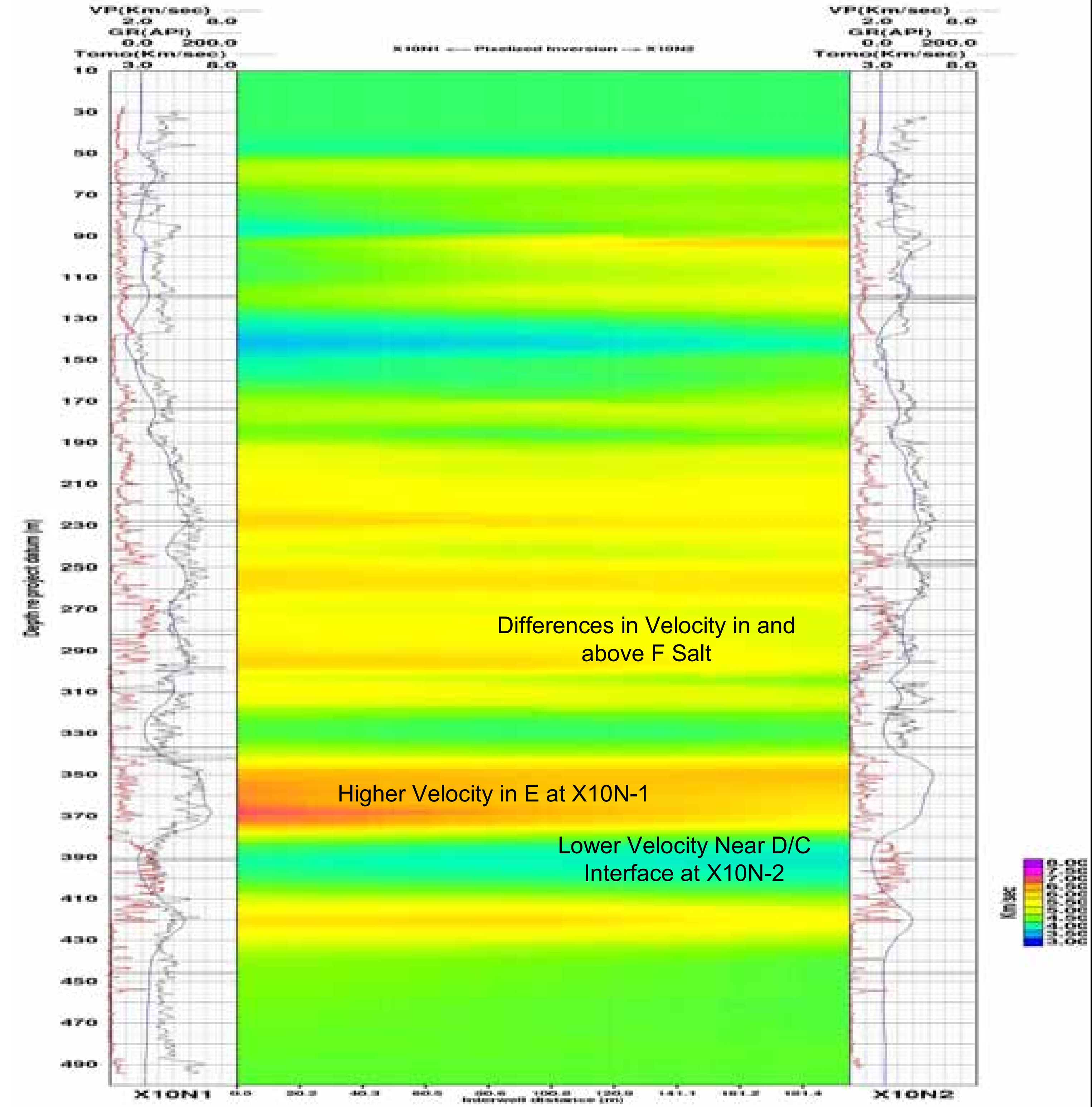
COMPARISON OF VELOCITY TOMOGRAMS
PROFILE X11-5 TO X11-2

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.26**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		



Original Tomographic Image (Layered Velocity Model)



"Pixelized" Inversion

Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

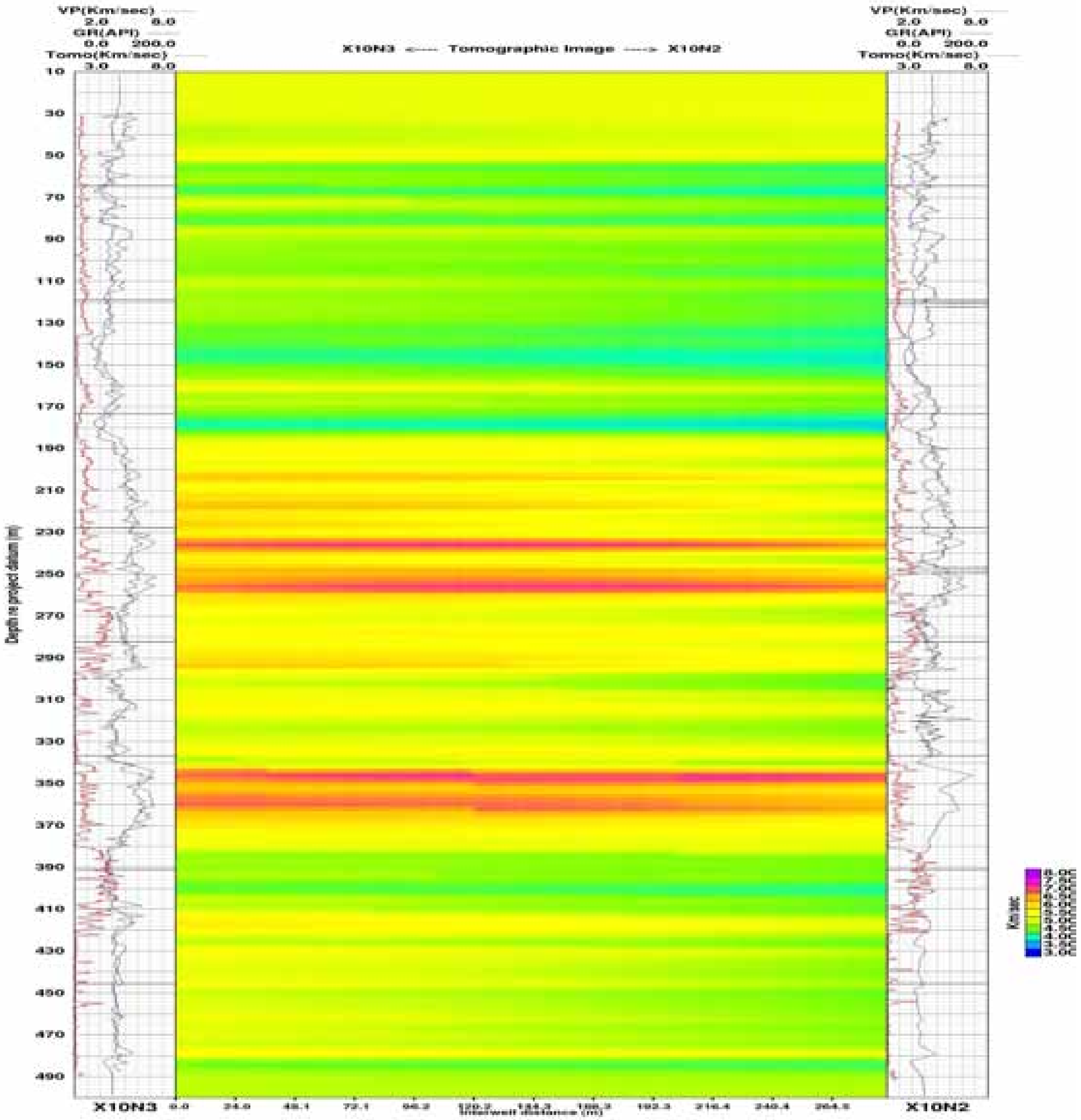
TITLE

COMPARISON OF VELOCITY TOMOGRAMS PROFILE X10N-1 TO X10N-2

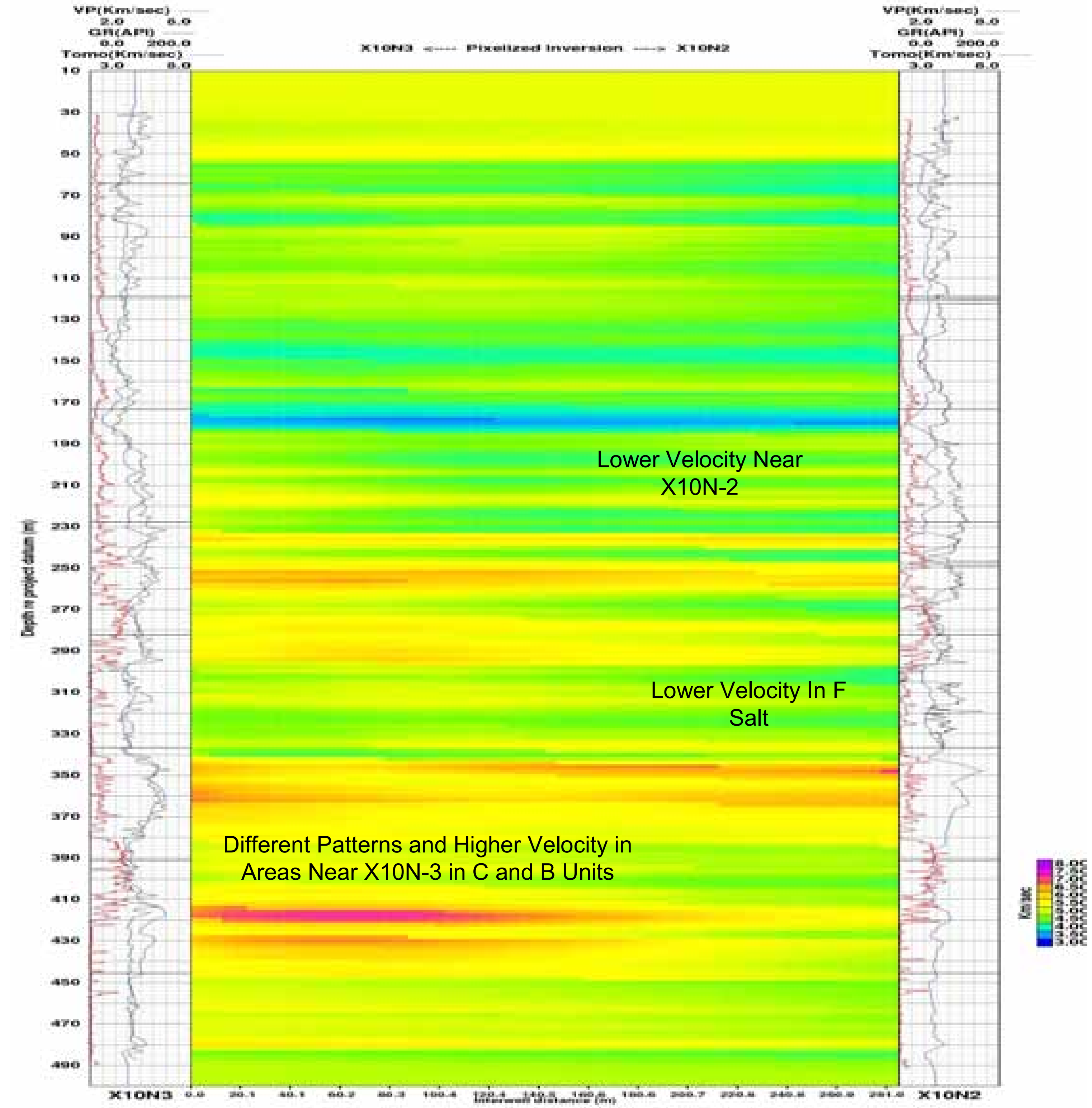
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.27**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.27_COMPARISON OF VELOCITY TOMOGRAMS_ PROFILE X10N-1 TO X10N-2.mxd



Original Tomographic Image (Layered Velocity Model)



"Pixelized" Inversion

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

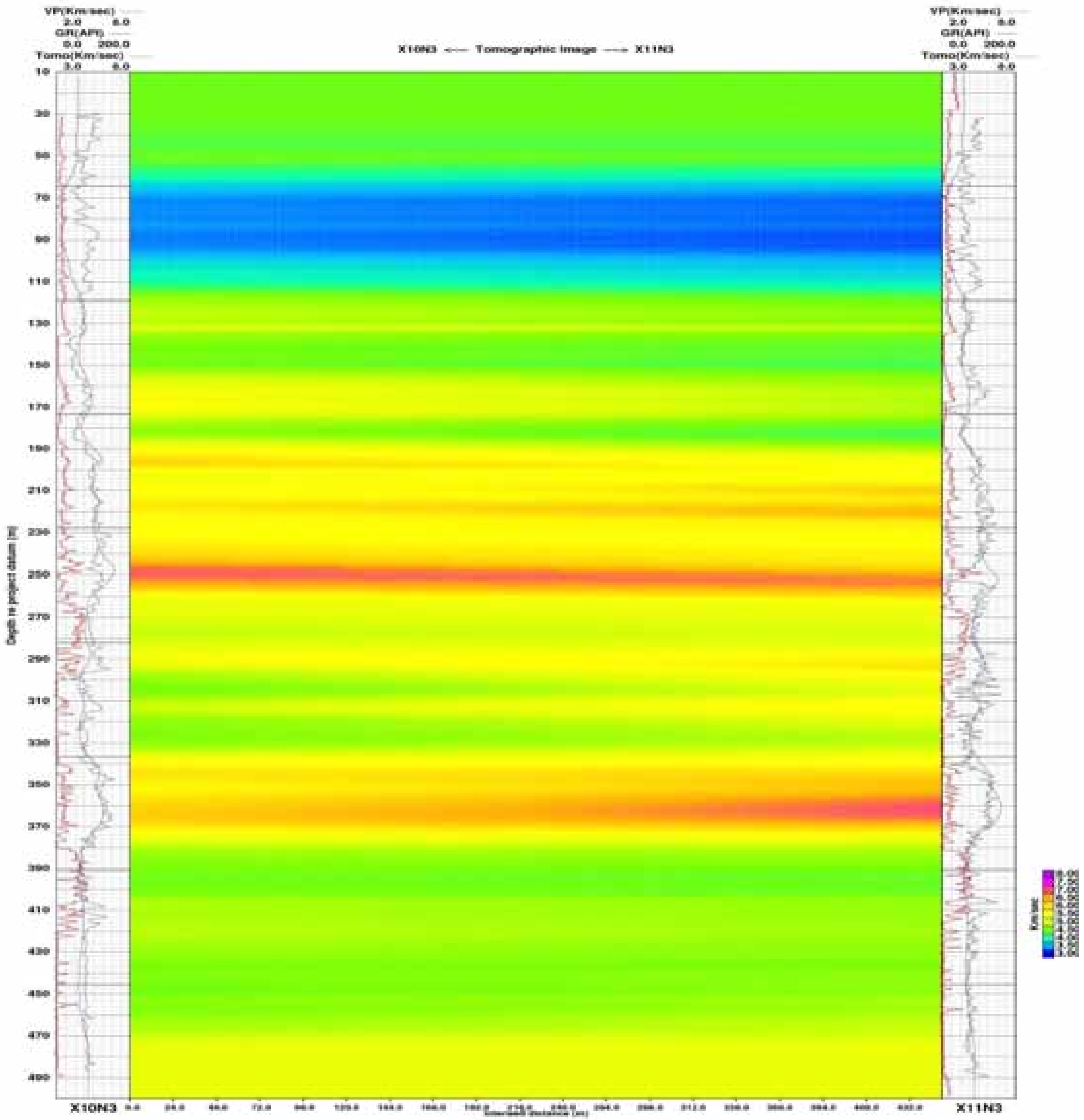
COMPARISON OF VELOCITY TOMOGRAMS PROFILE X10N-3 TO X10N-2

PROJECT No. 04-1111-060			SCALE / REV. 1
DESIGN	CC	24 May 2006	
GIS	JFC	20 Feb. 2008	
CHECK	JM	20 Feb. 2008	
REVIEW	SB	20 Feb. 2008	

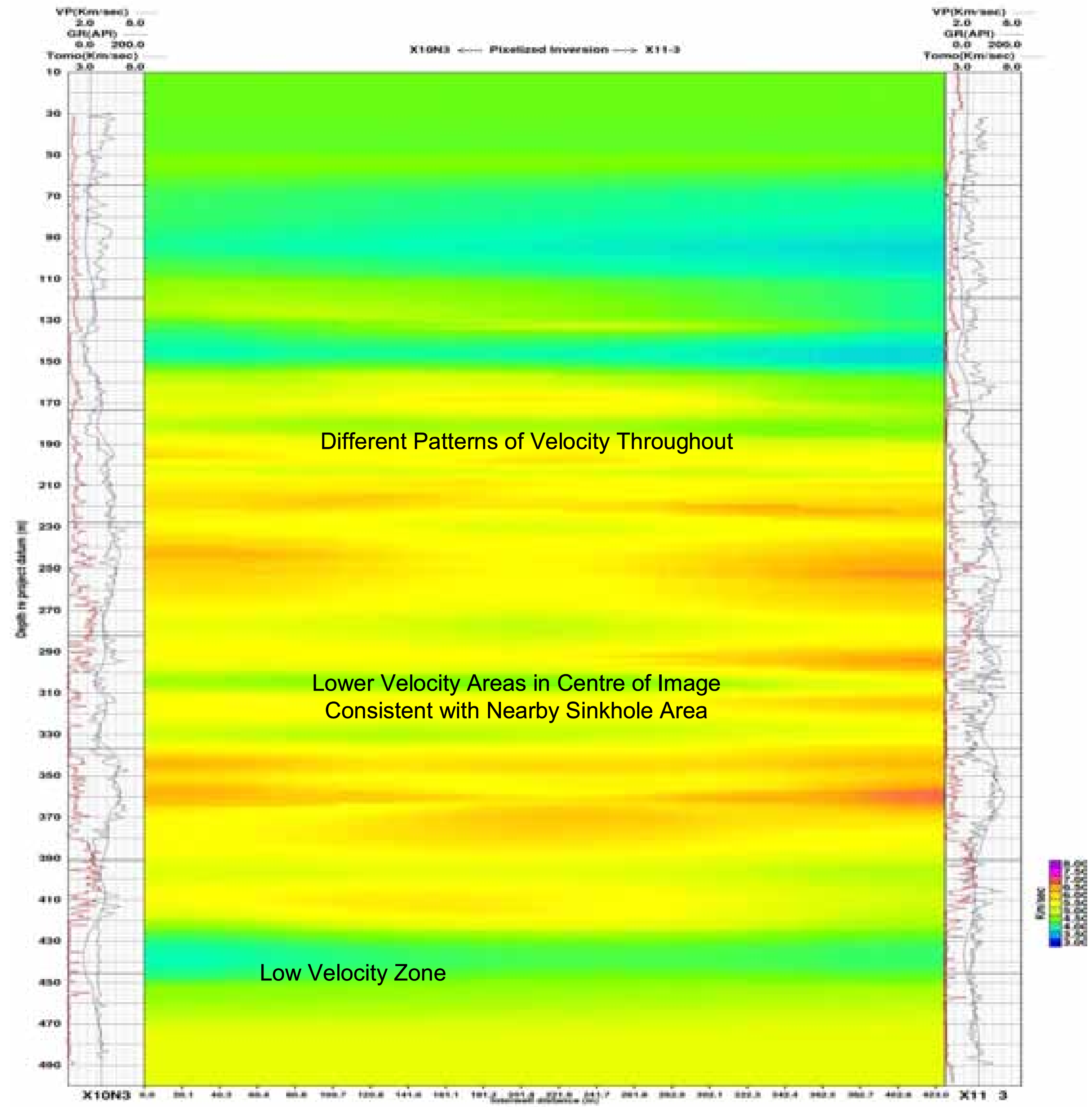
Golder Associates
Mississauga, Ontario

FIGURE: 8.28

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.28_COMPARISON OF VELOCITY TOMOGRAMS_ PROFILE X10N-2 TO X10N-3.mxd



Original Tomographic Image (Layered Velocity Model)



"Pixelized" Inversion

Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

PROJECT

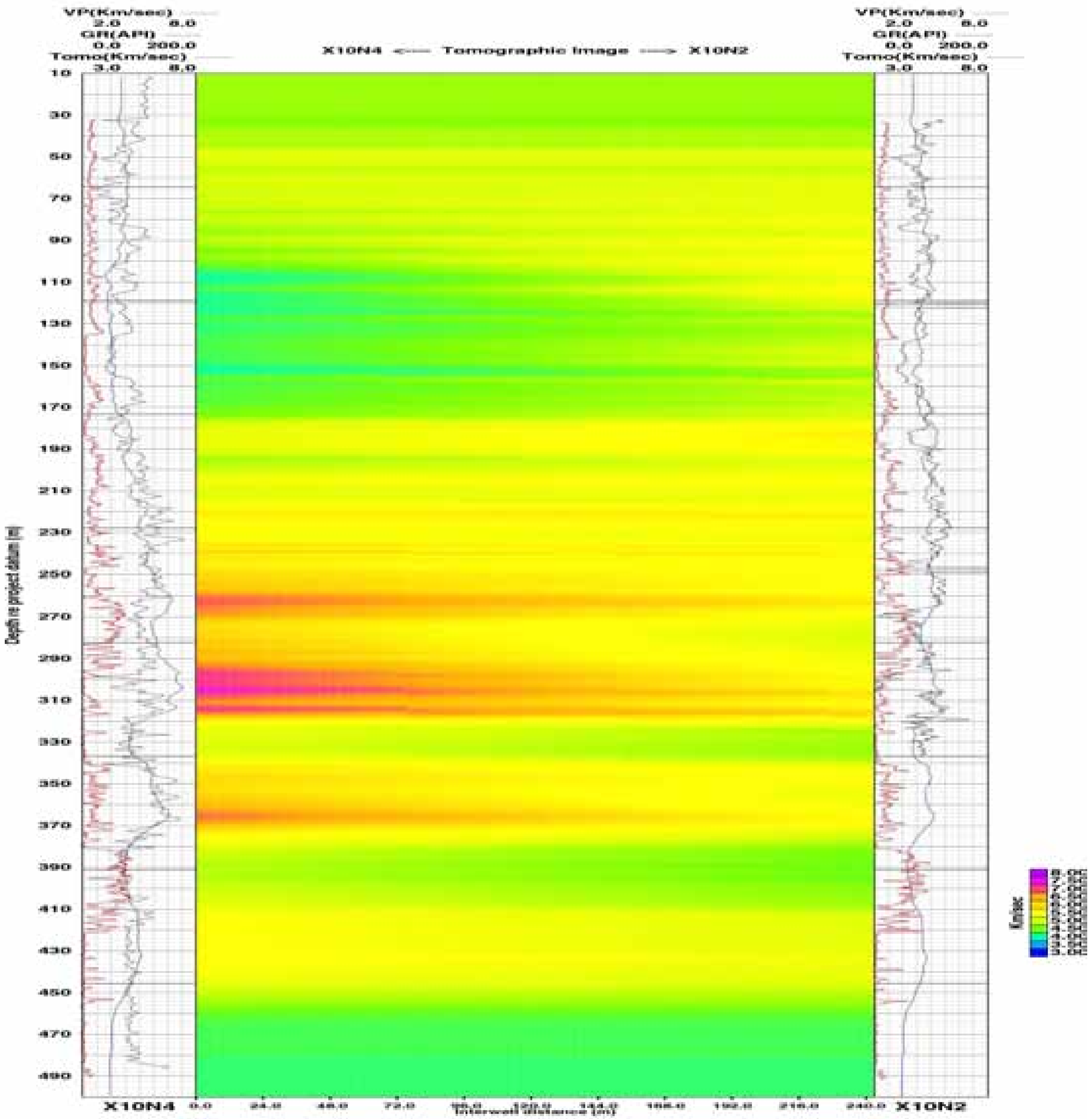
DETROIT RIVER INTERNATIONAL CROSSING

TITLE

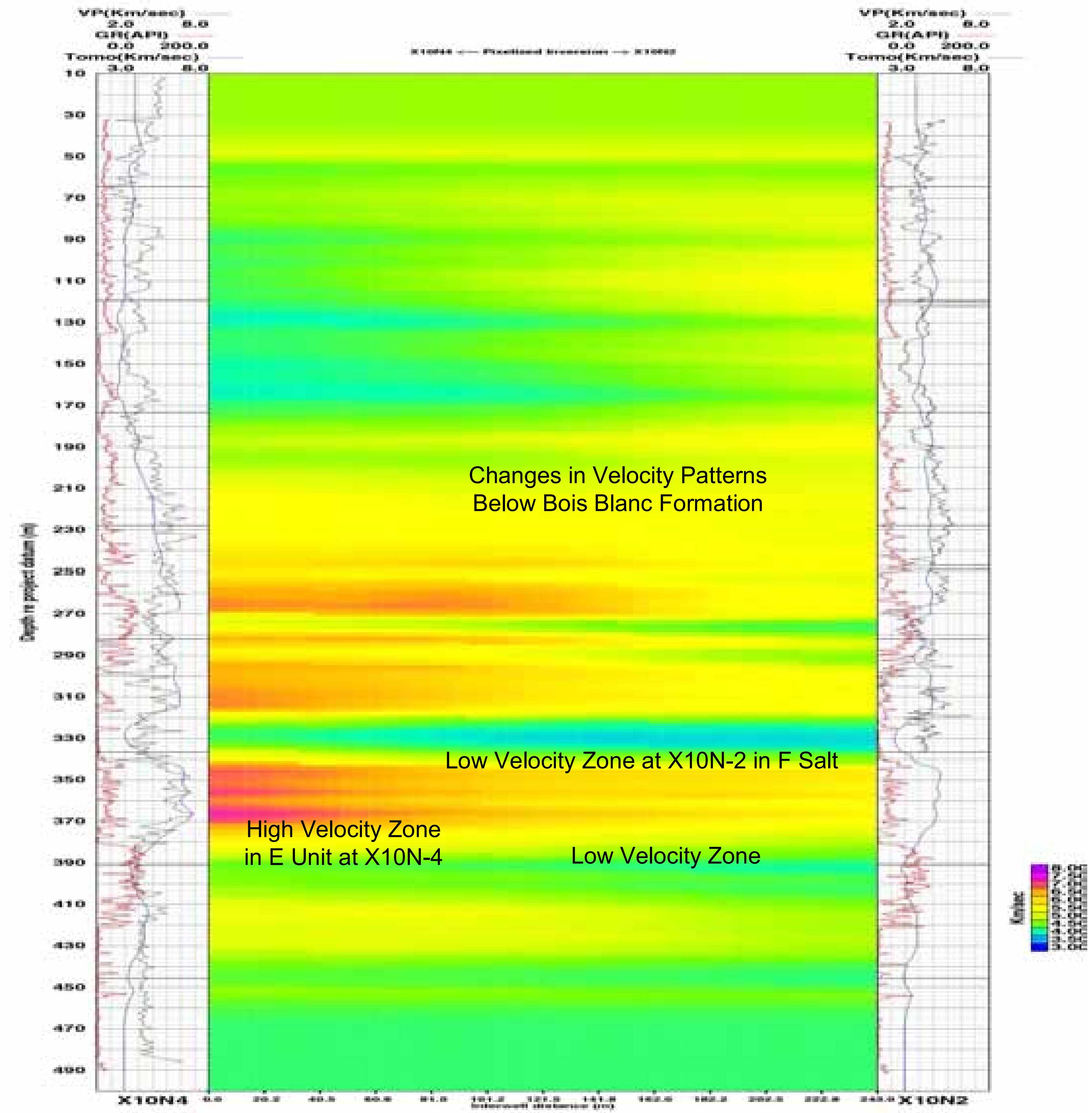
COMPARISON OF VELOCITY TOMOGRAMS
PROFILE X10N-3 TO X11-3

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.29**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		



Original Tomographic Image (Layered Velocity Model)

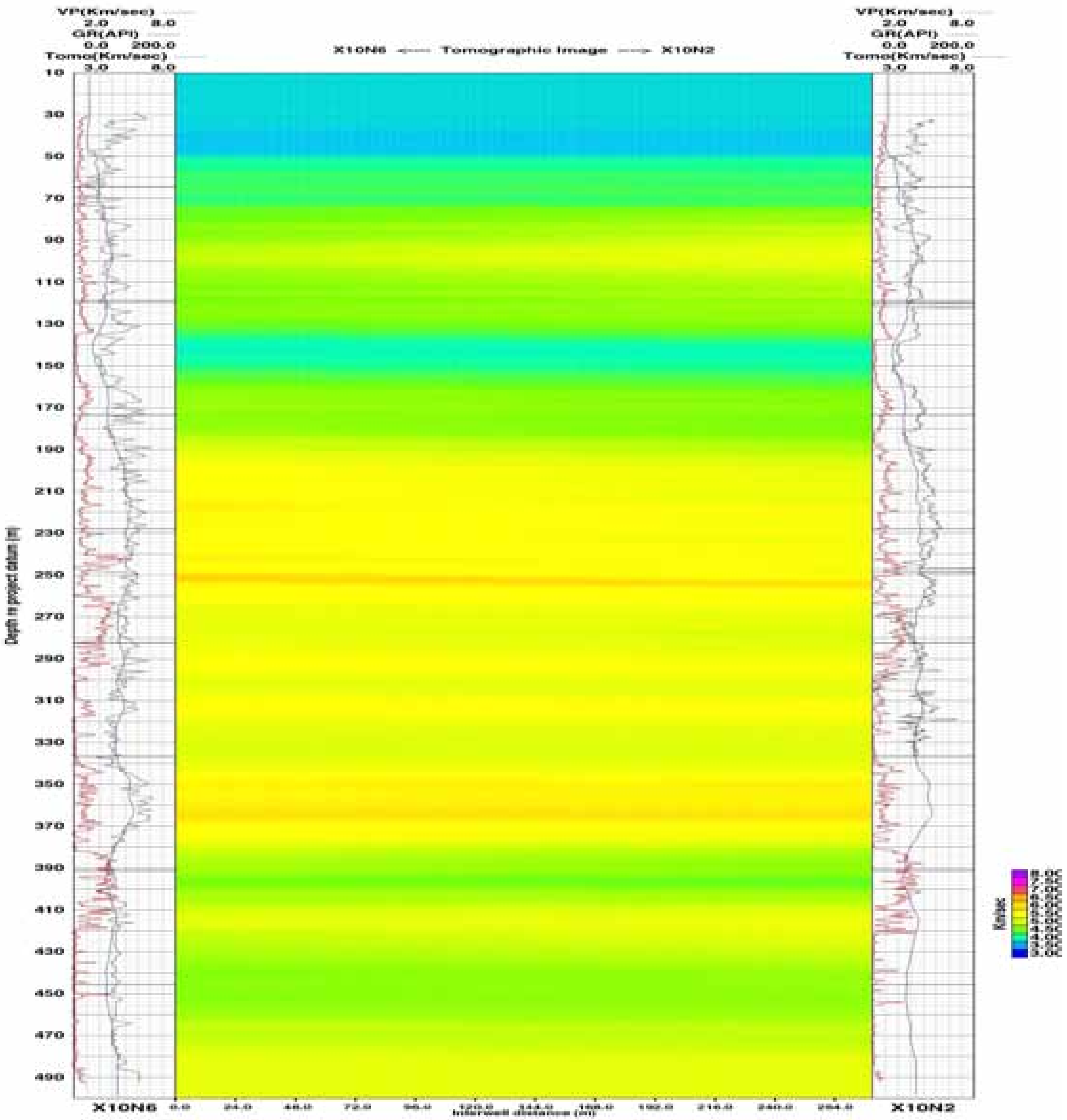


"Pixelized" Inversion

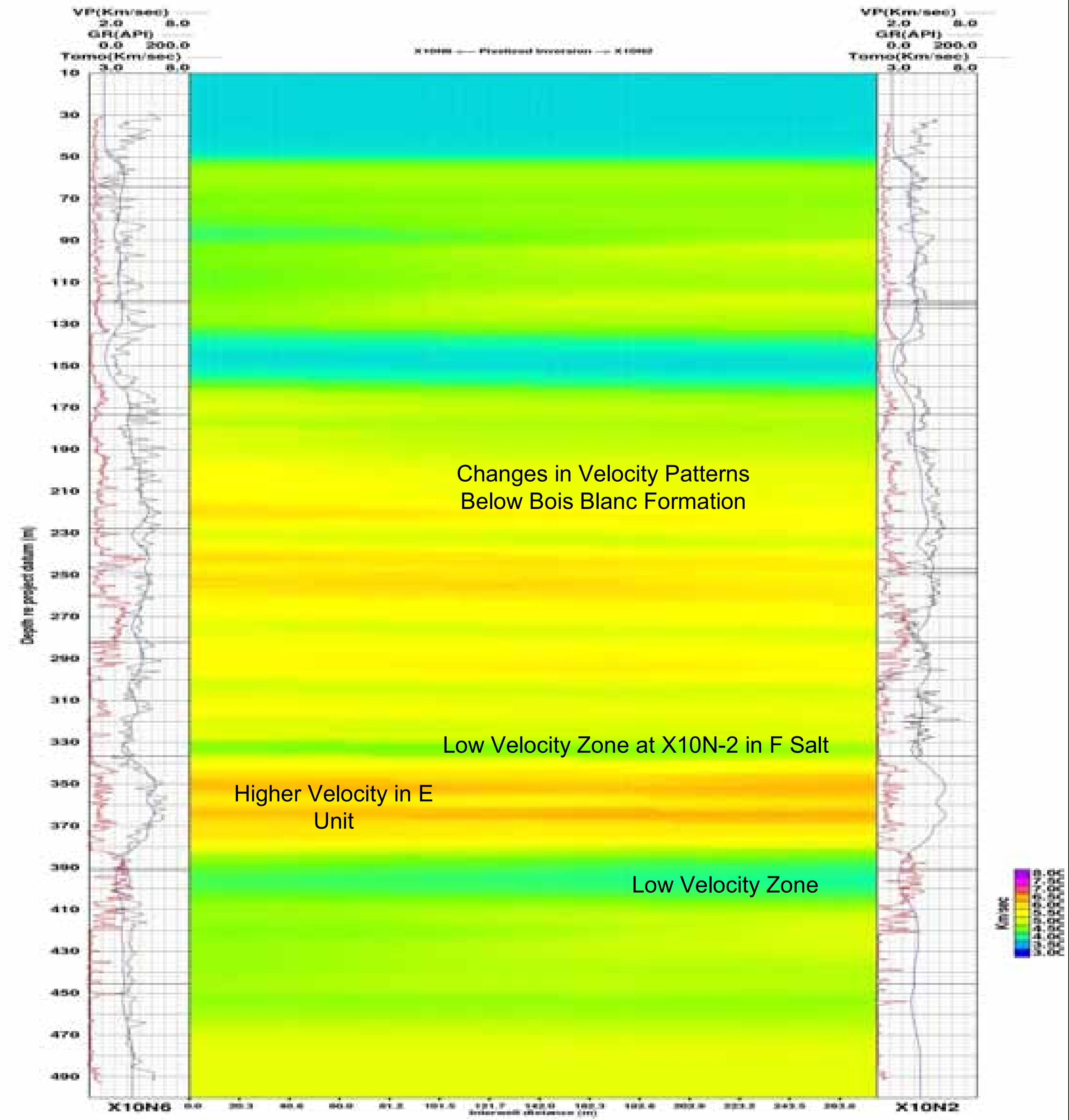
Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

PROJECT: DETROIT RIVER INTERNATIONAL CROSSING				
TITLE: **COMPARISON OF VELOCITY TOMOGRAMS PROFILE X10N-4 TO X10N-2**				
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE	REV. 1
	DESIGN CC	24 May 2006	**FIGURE: 8.30**	
	GIS JFC	20 Feb. 2008		
	CHECK JM	20 Feb. 2008		
	REVIEW SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.30_COMPARISON OF VELOCITY TOMOGRAMS_ PROFILE X10N-4 TO X10N-2.mxd



Original Tomographic Image (Layered Velocity Model)



"Pixelized" Inversion

Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

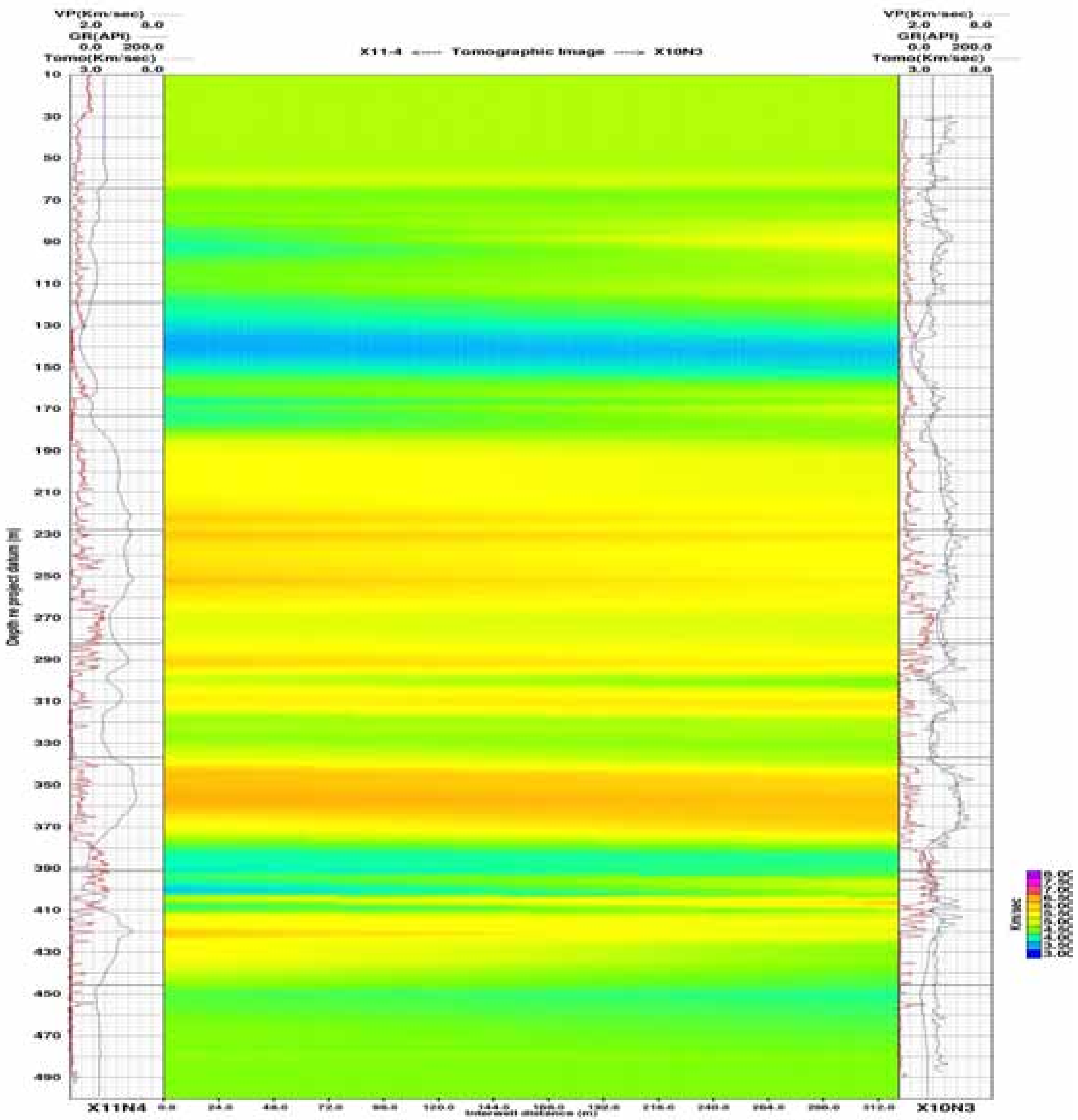
TITLE

COMPARISON OF VELOCITY TOMOGRAMS
PROFILE X10N-6 TO X10N-2

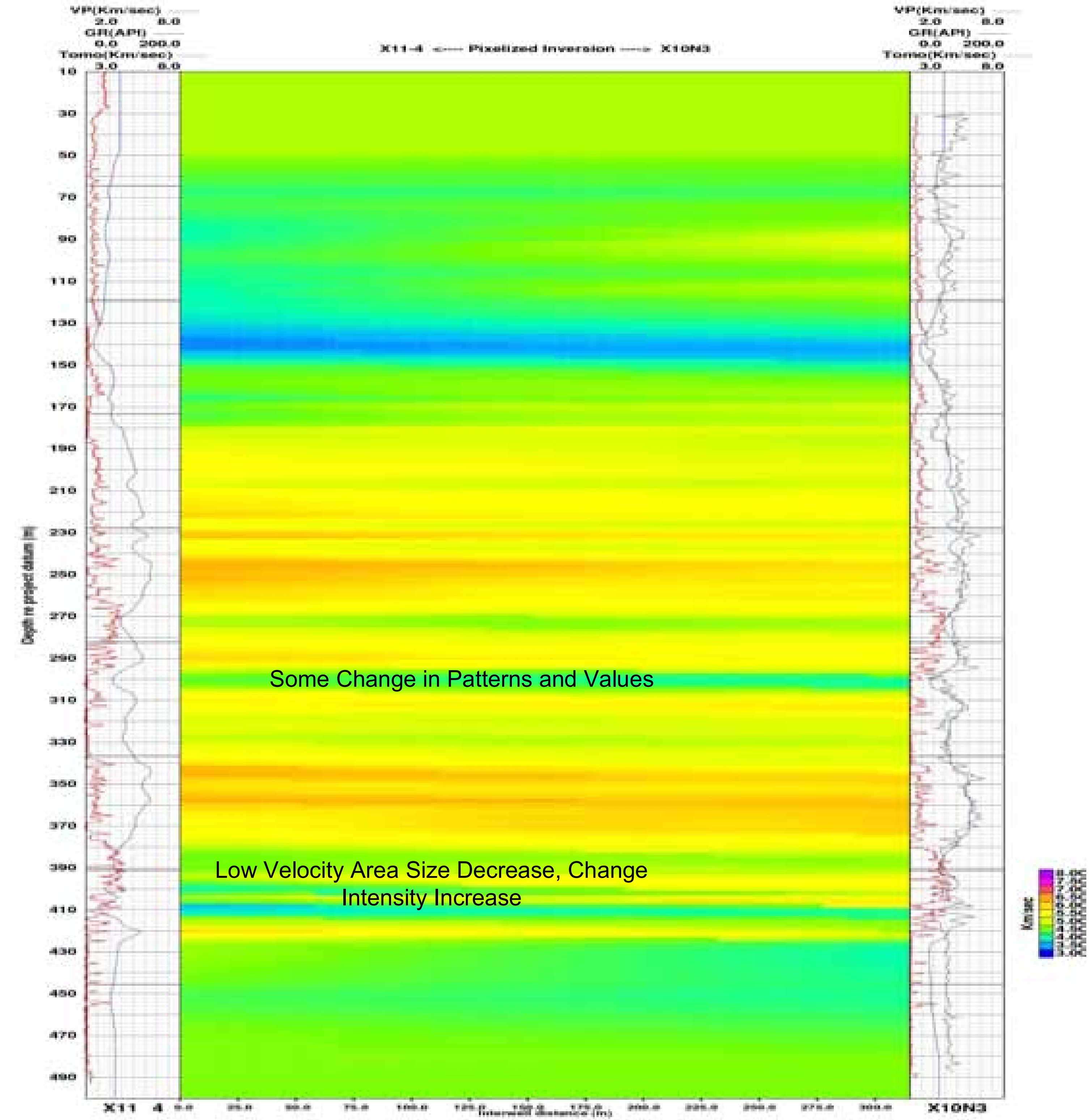
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.31**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.31_COMPARISON OF VELOCITY TOMOGRAMS_ PROFILE X10N-6 TO X10N-2.mxd



Original Tomographic Image (Layered Velocity Model)



"Pixelized" Inversion

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

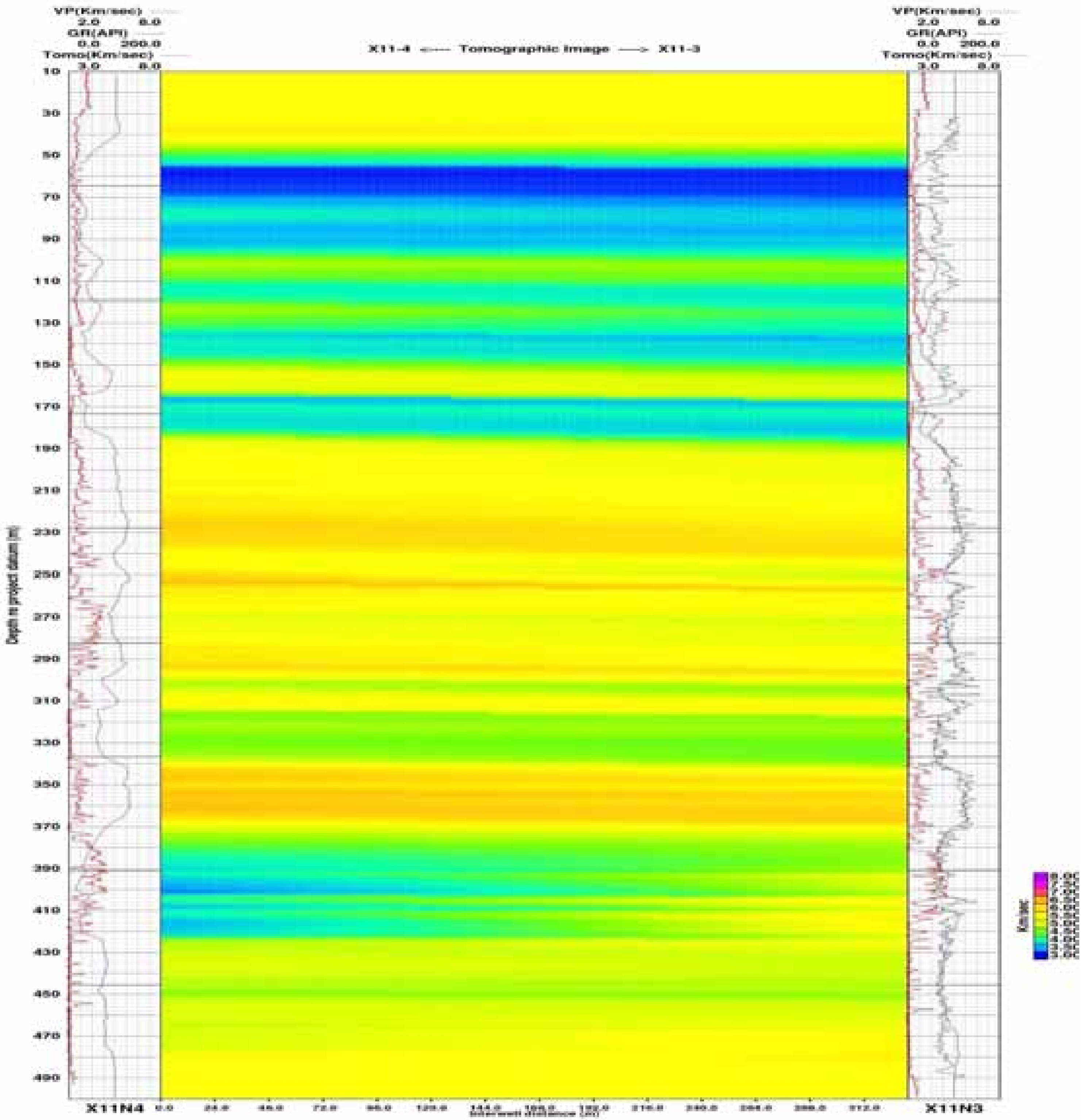
PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

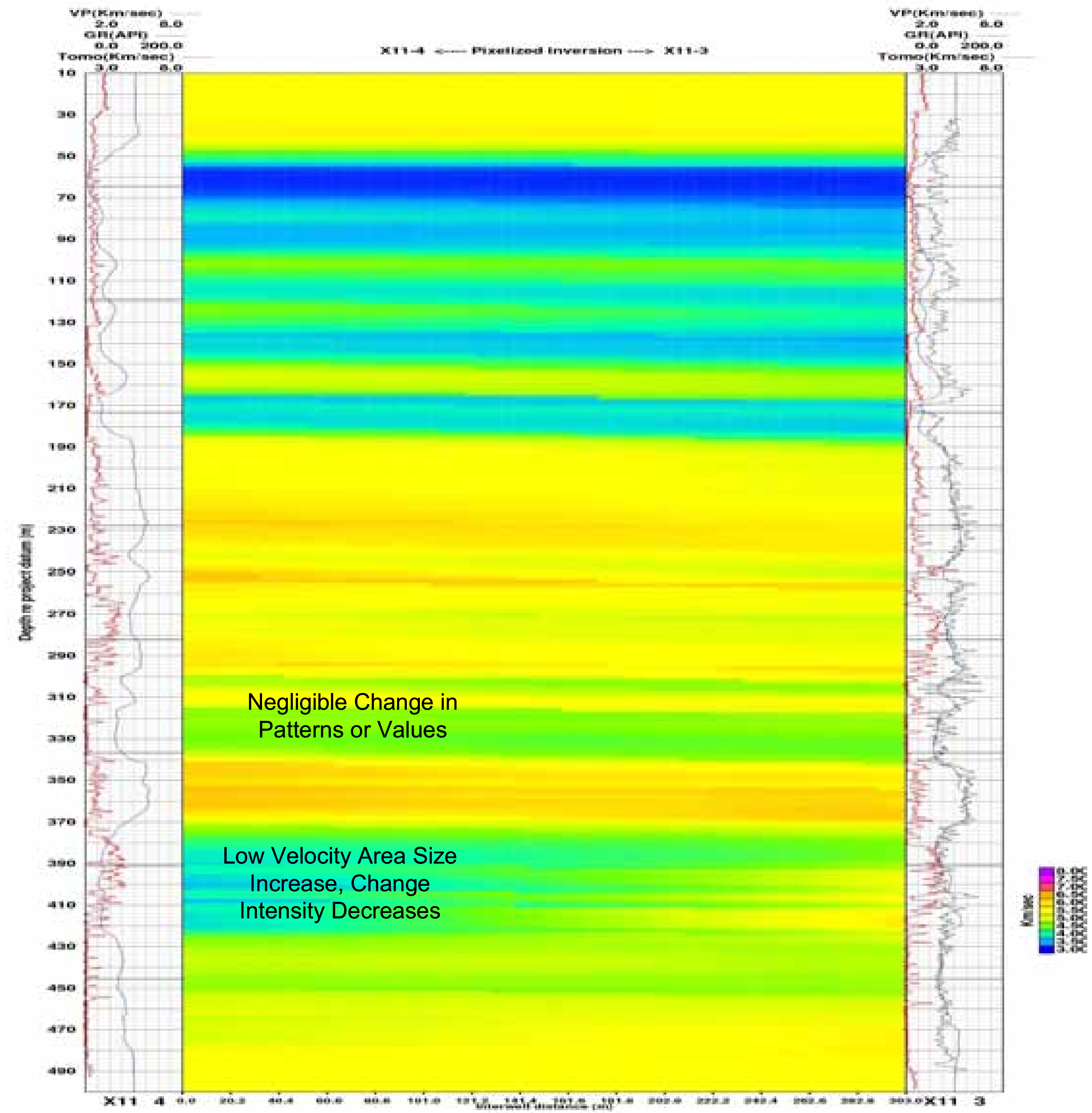
TITLE

COMPARISON OF VELOCITY TOMOGRAMS PROFILE X11-4 TO X10N-3

Golder Associates Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE	REV. 1
	DESIGN	CC	24 May 2006	**FIGURE: 8.32**
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	



Original Tomographic Image (Layered Velocity Model)

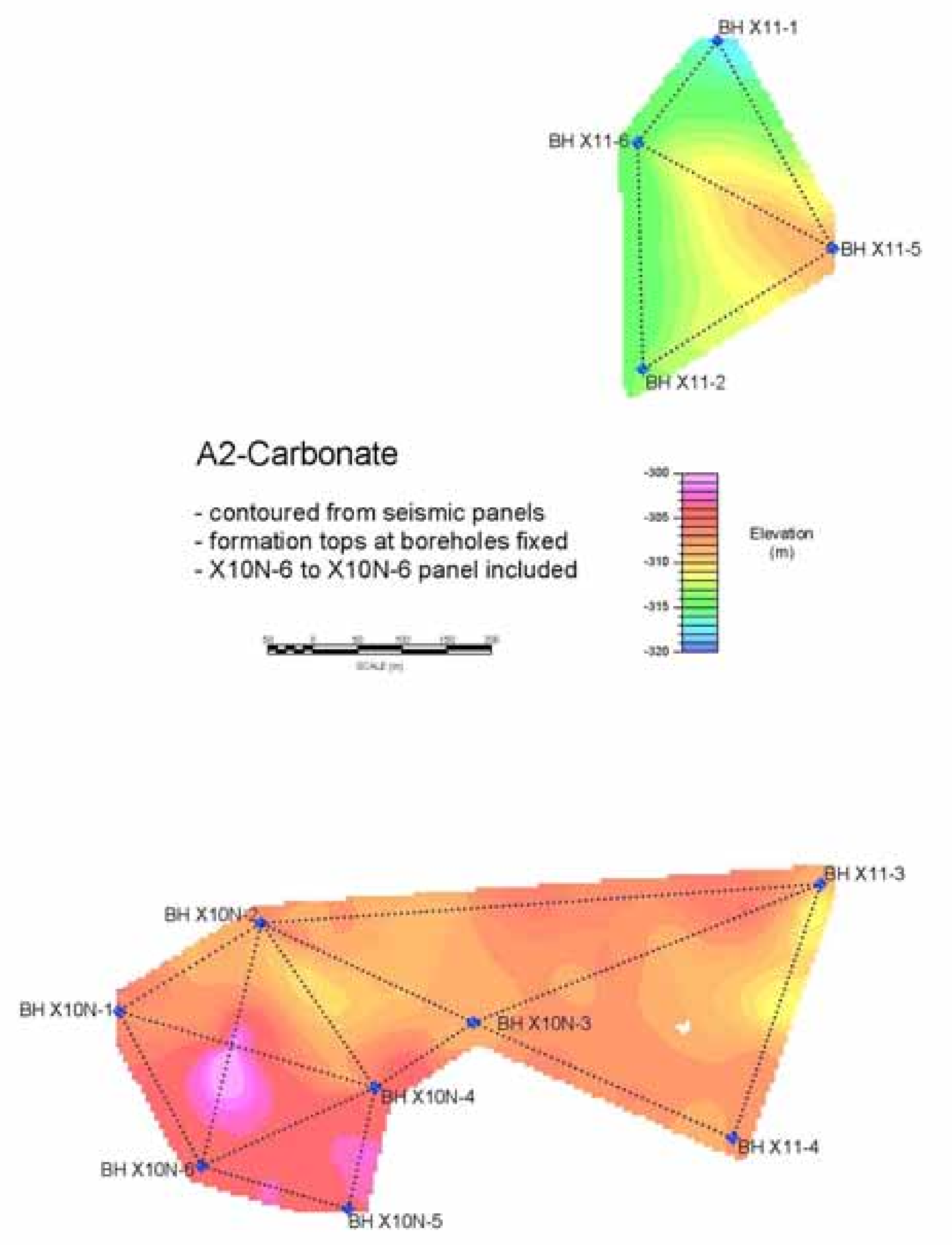


"Pixelized" Inversion

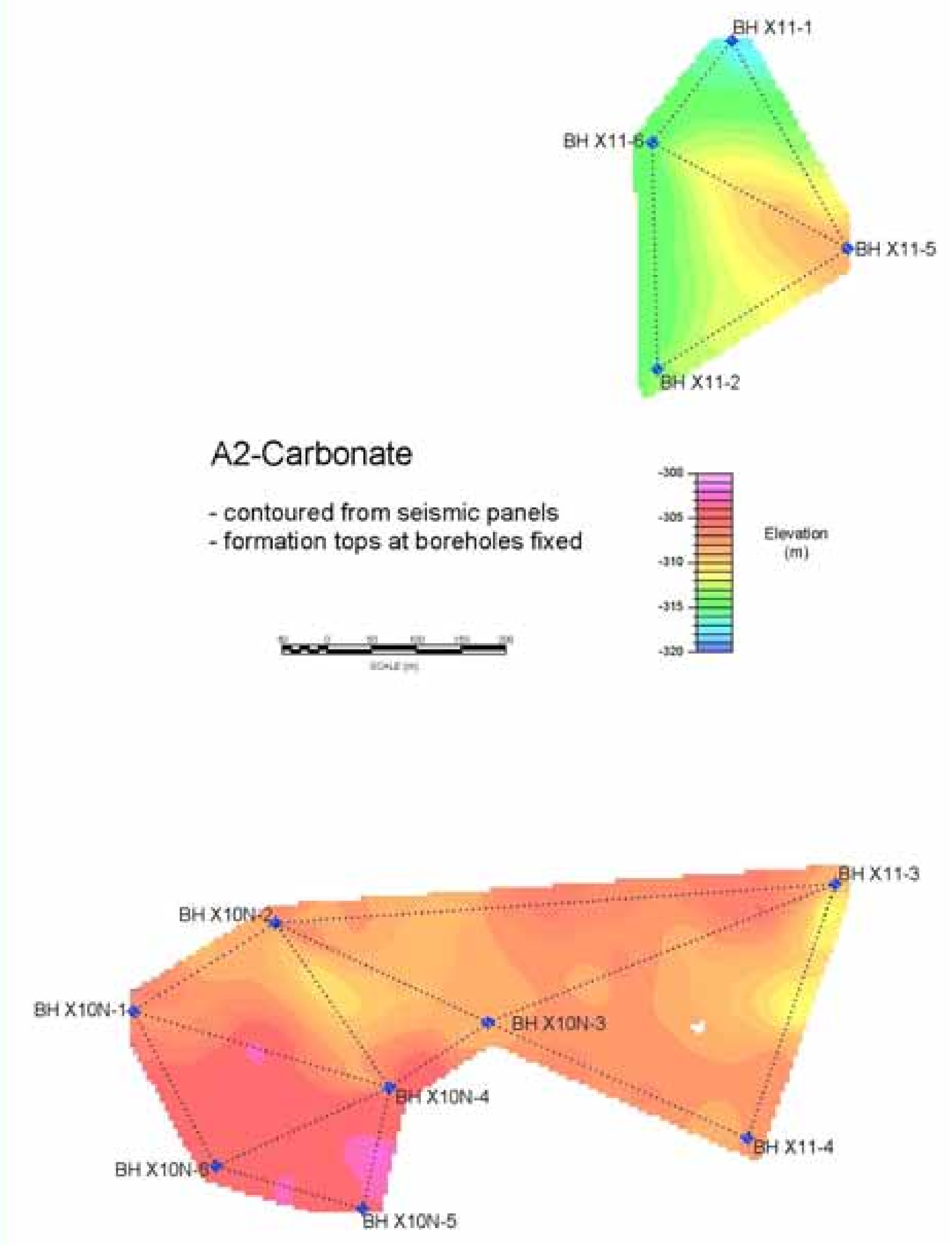
Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.33_COMPARISON OF VELOCITY TOMOGRAMS_ PROFILE X11-4 TO X11-3.mxd

PROJECT				
DETROIT RIVER INTERNATIONAL CROSSING				
TITLE				
COMPARISON OF VELOCITY TOMOGRAMS PROFILE X11-4 TO X11-3				
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE	REV. 1
	DESIGN	CC	24 May 2006	FIGURE: 8.33
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	



Interpolated Topography With Profile
X10N-6 to X10N-2



Interpolated Topography Without Profile
X10N-6 to X10N-2

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

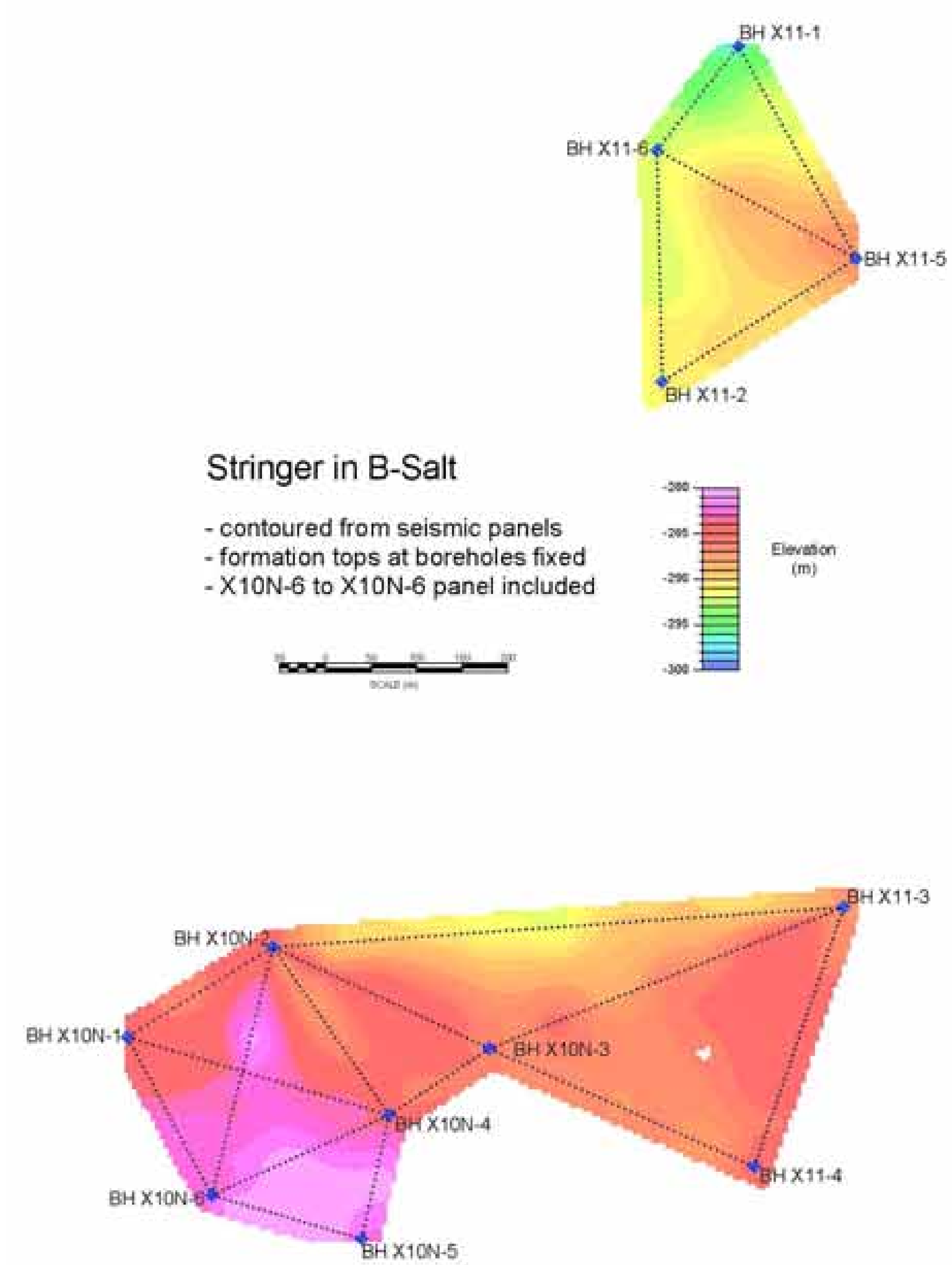
PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

TITLE
INTERPOLATED TOPOGRAPHY
TOP OF SALINA FORMATION A2 UNIT

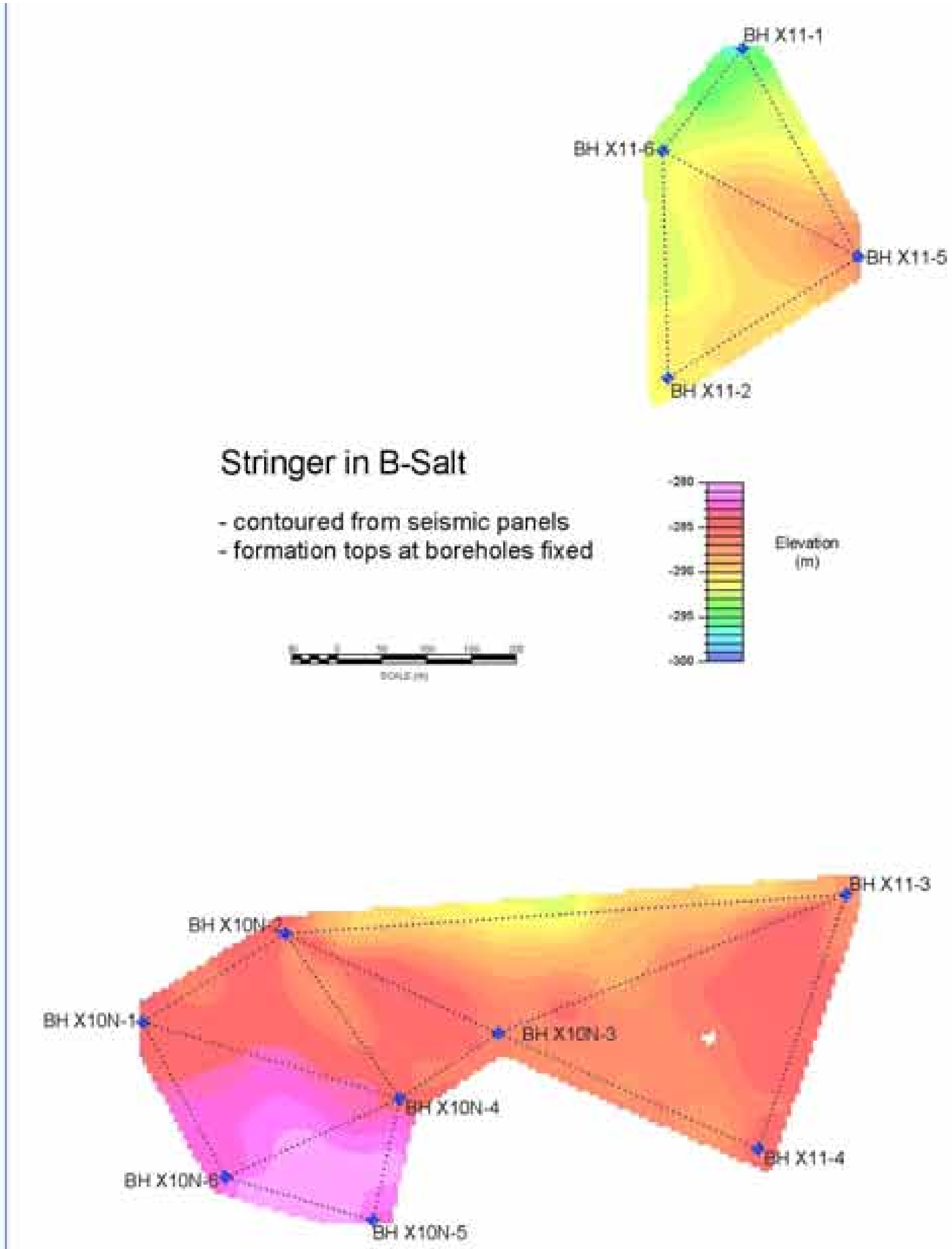
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.34**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.34_INTERPOLATED TOPOGRAPHY_TOP OF SALINA FORMATION A2 UNIT.mxd



Interpolated Topography With Profile
X10N-6 to X10N-2



Interpolated Topography Without Profile
X10N-6 to X10N-2

Notes:

1. This figure is to be read with the accompanying reports “Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites”.
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

PROJECT

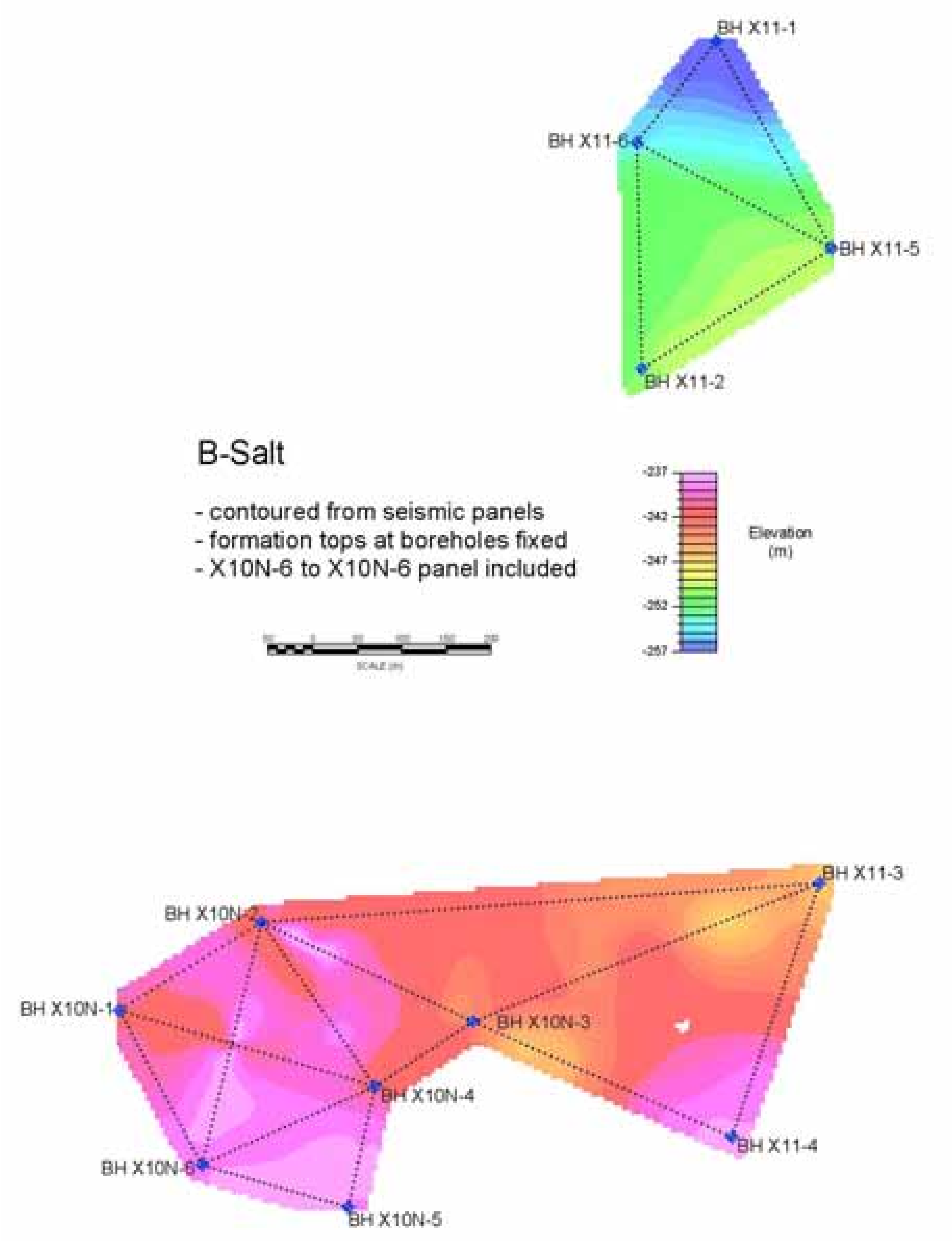
DETROIT RIVER INTERNATIONAL CROSSING

TITLE

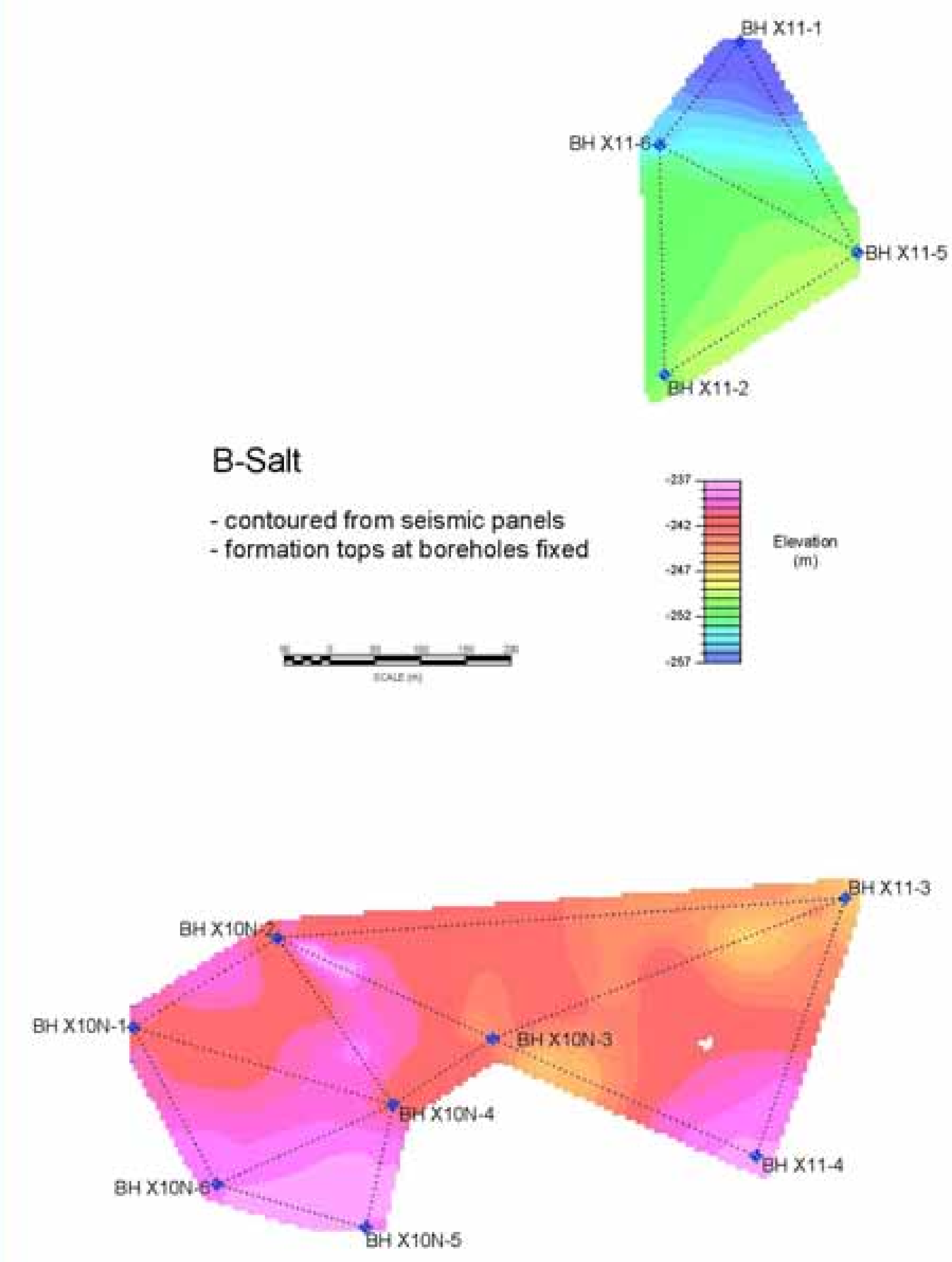
INTERPOLATED TOPOGRAPHY TOP OF SALINA FORMATION B UNIT CARBONATE INTERBED

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.35**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		



Interpolated Topography With Profile
X10N-6 to X10N-2



Interpolated Topography Without Profile
X10N-6 to X10N-2

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

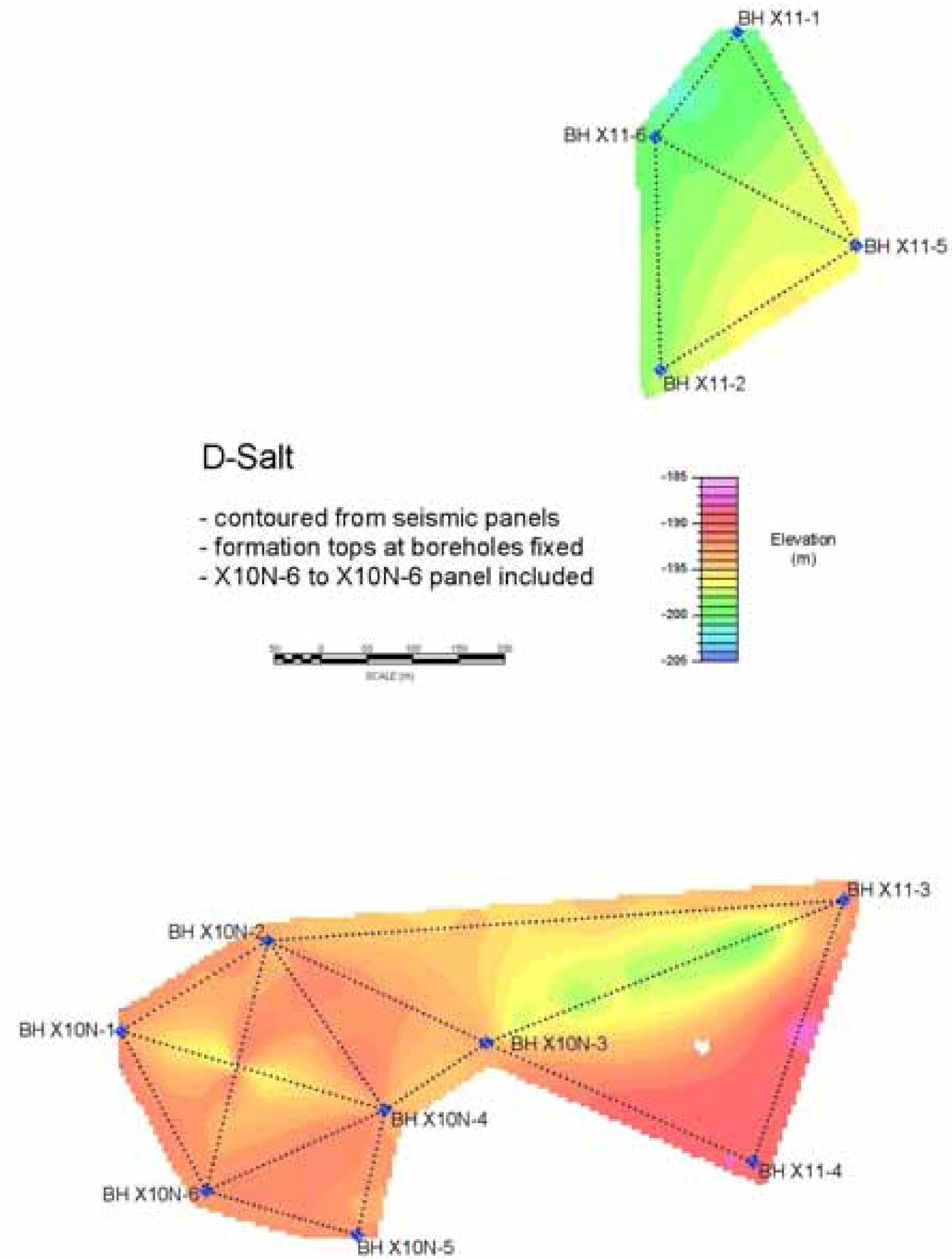
PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

TITLE
INTERPOLATED TOPOGRAPHY
TOP OF SALINA FORMATION B UNIT SALT

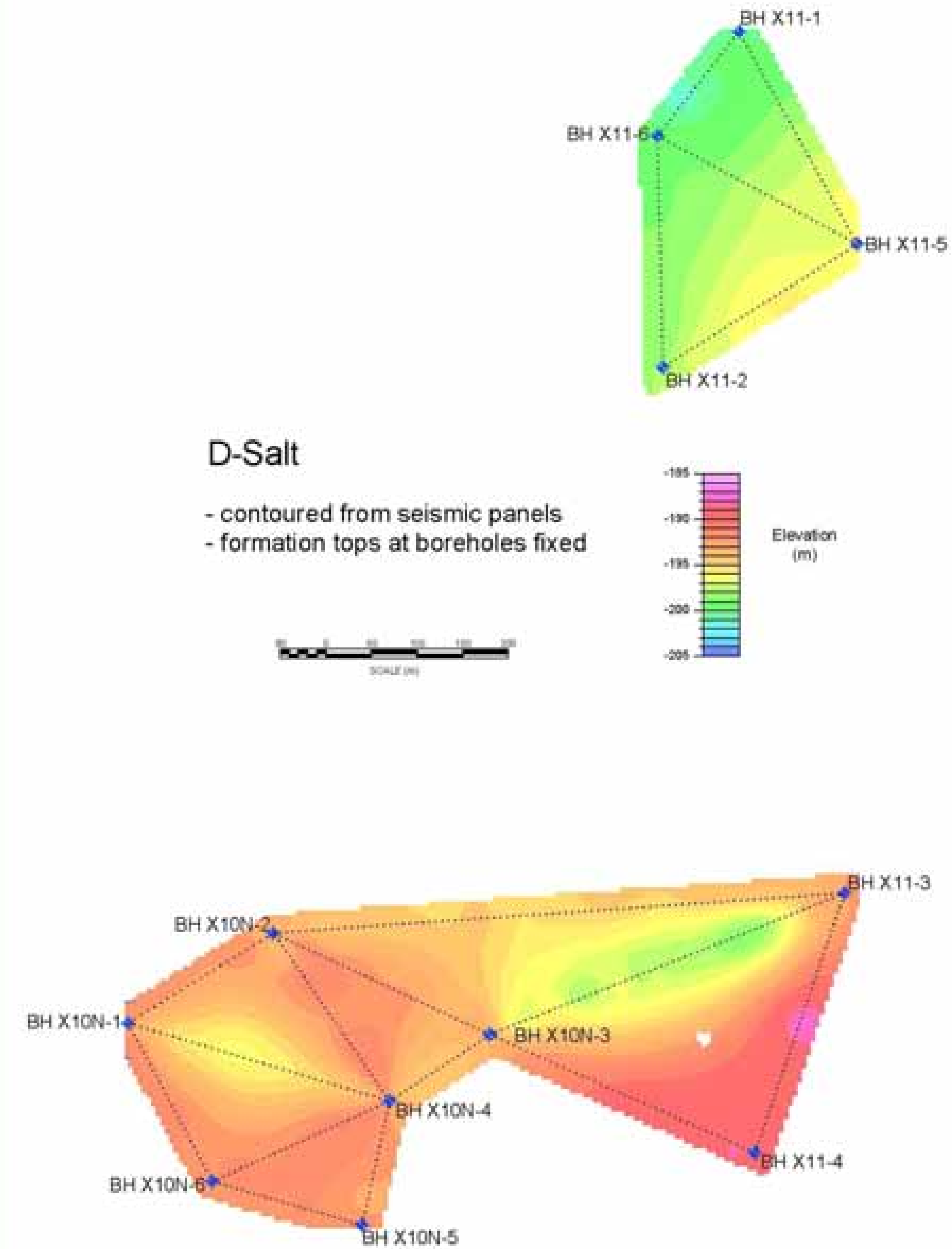
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.36**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.36_INTERPOLATED TOPOGRAPHY_TOP OF SALINA FORMATION B UNIT SALT.mxd



Interpolated Topography With Profile
X10N-6 to X10N-2



Interpolated Topography Without Profile
X10N-6 to X10N-2

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

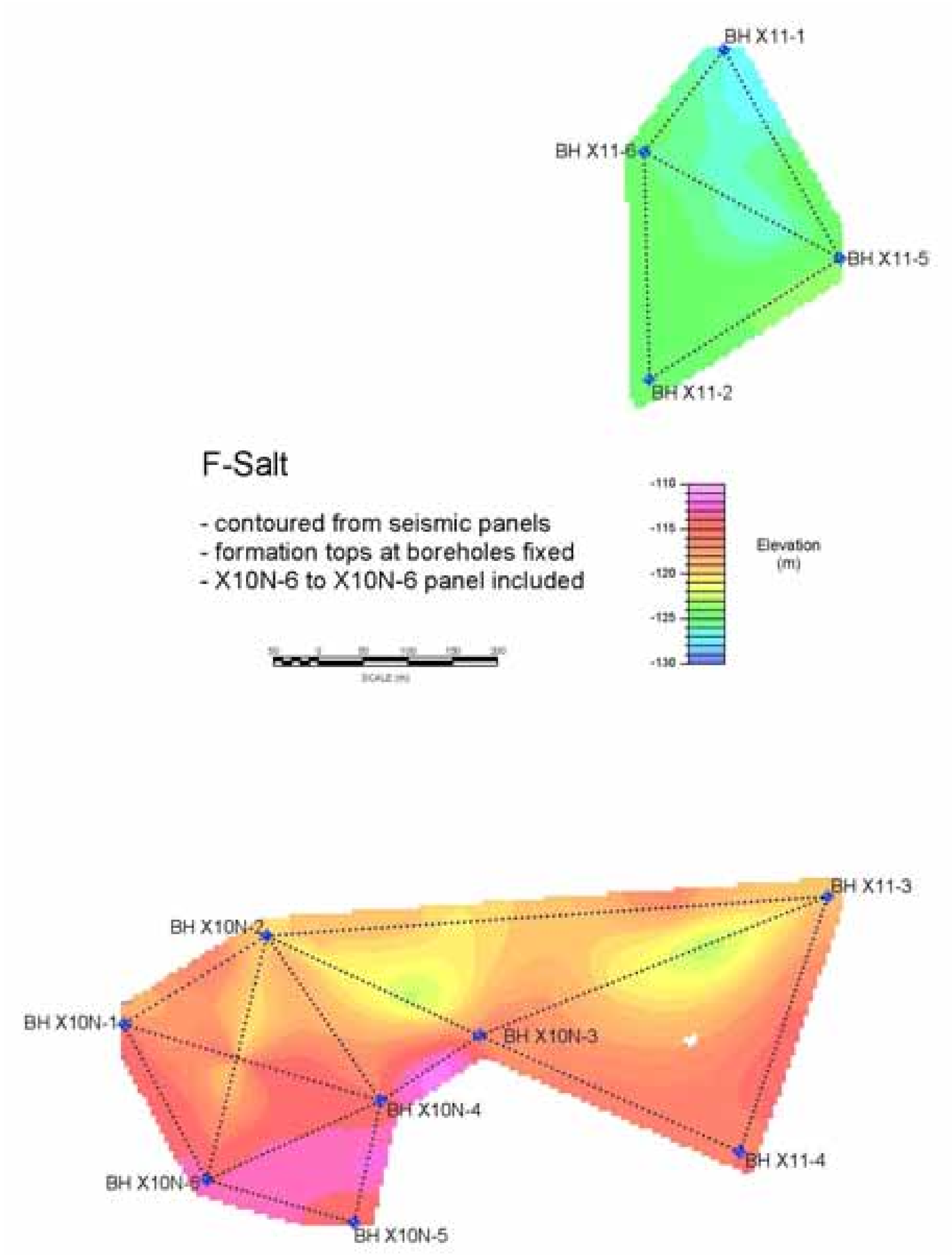
PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

TITLE
INTERPOLATED TOPOGRAPHY
TOP OF SALINA FORMATION D UNIT SALT

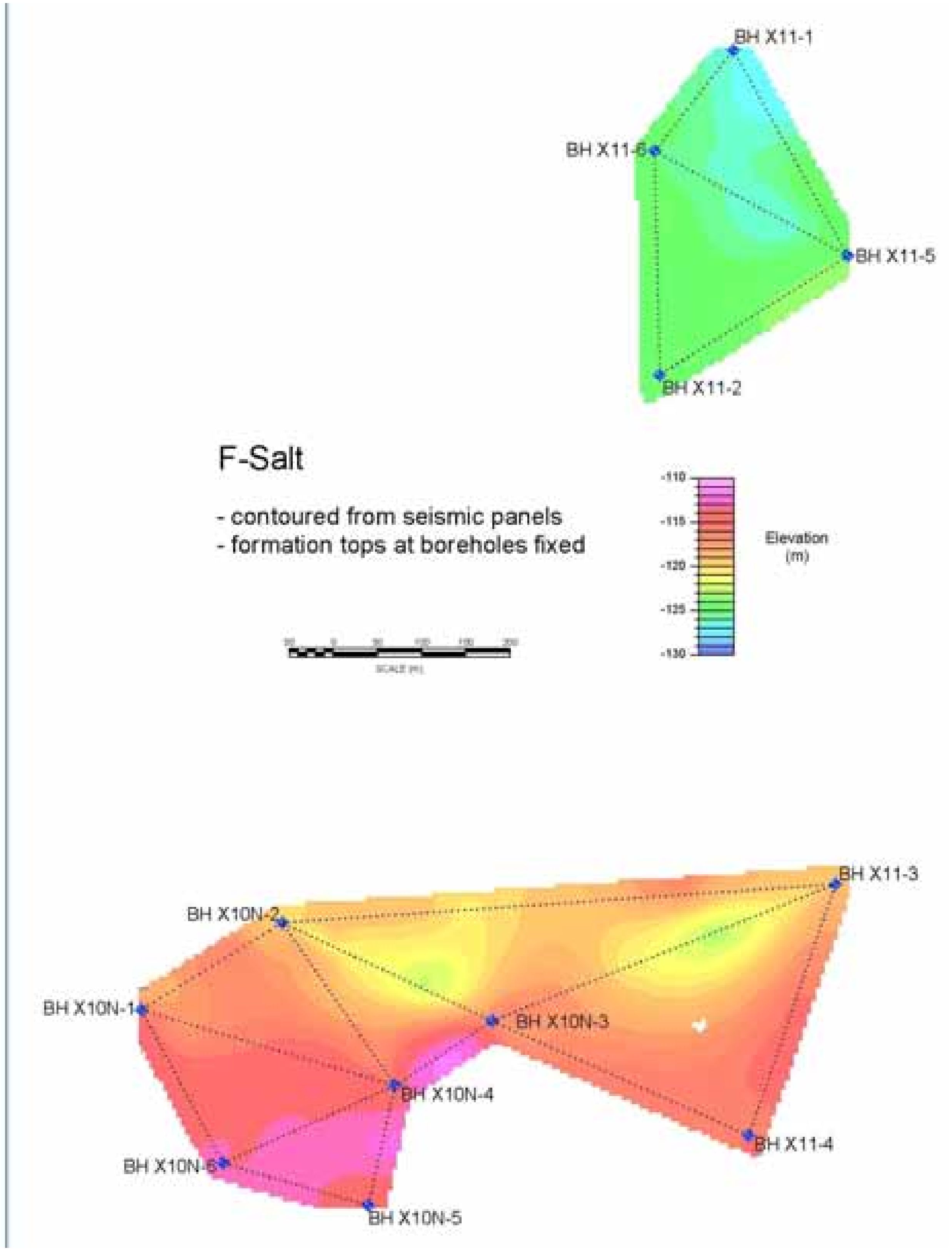
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.37**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.36_INTERPOLATED TOPOGRAPHY_TOP OF SALINA FORMATION B UNIT SALT.mxd



Interpolated Topography With Profile
X10N-6 to X10N-2



Interpolated Topography Without Profile
X10N-6 to X10N-2

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

PROJECT

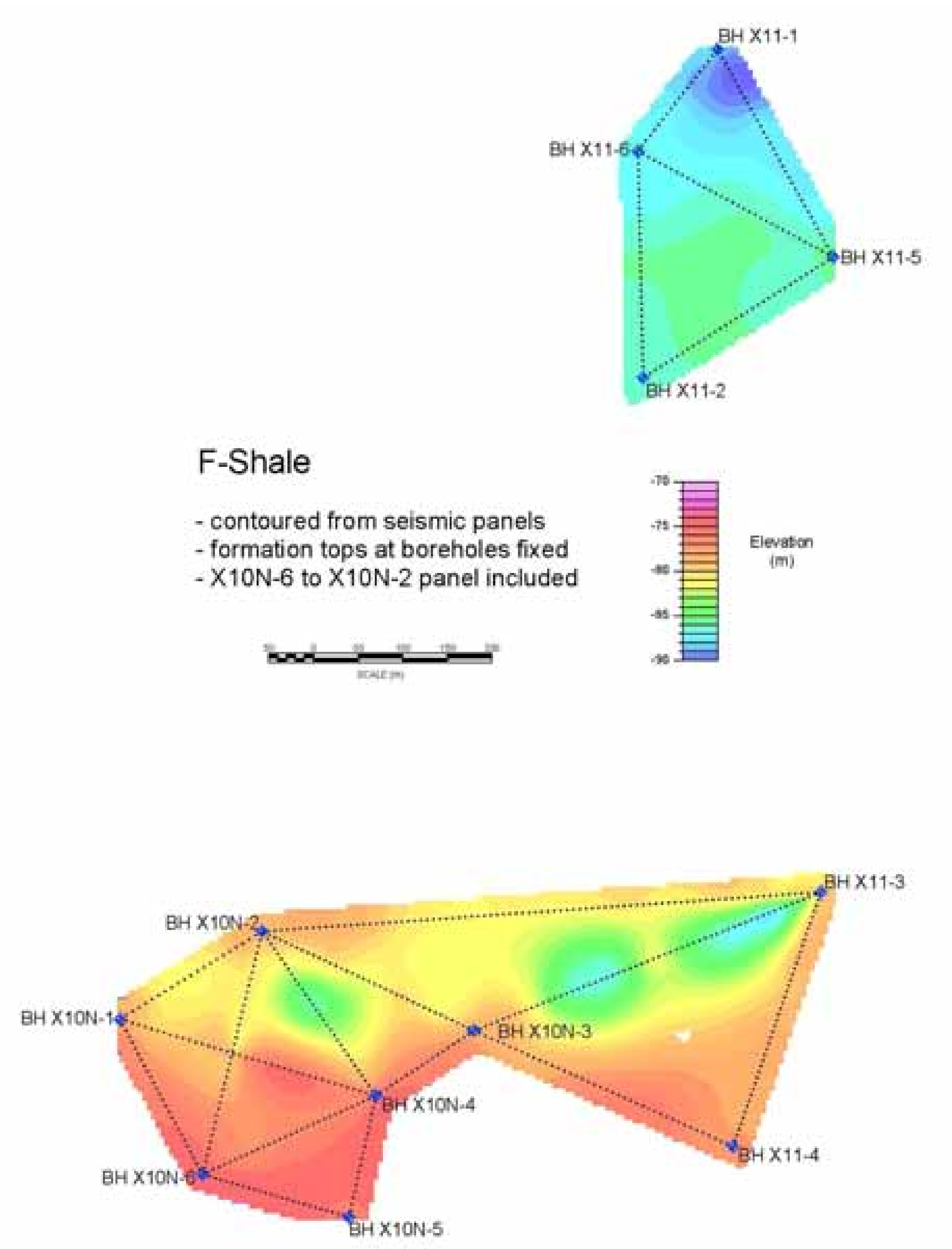
DETROIT RIVER INTERNATIONAL CROSSING

TITLE

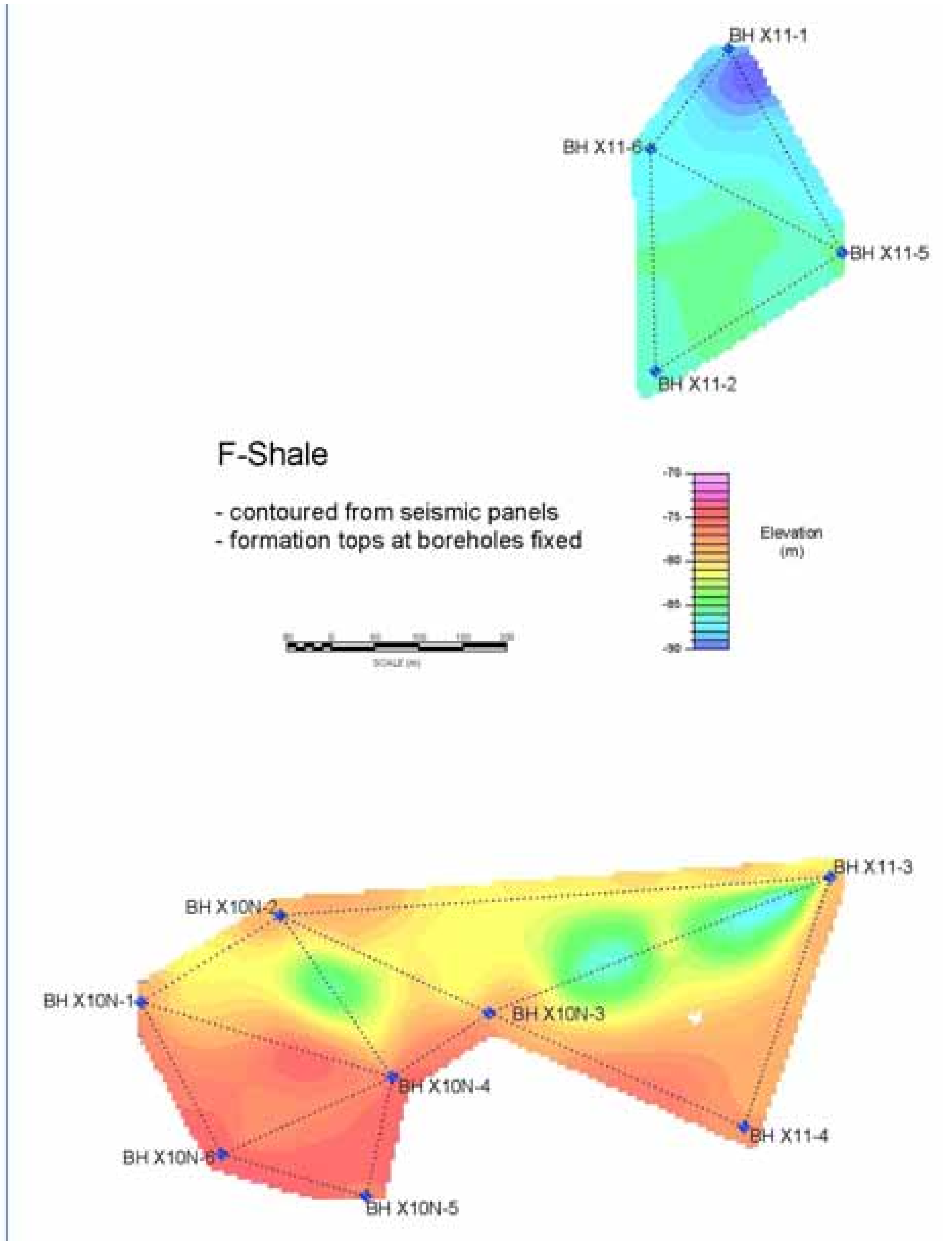
INTERPOLATED TOPOGRAPHY
TOP OF SALINA FORMATION F UNIT SALT

Golder Associates Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE	REV. 1
	DESIGN	CC	24 May 2006	**FIGURE: 8.38**
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.38_INTERPOLATED TOPOGRAPHY_TOP OF SALINA FORMATION F UNIT SALT.mxd



Interpolated Topography With Profile
X10N-6 to X10N-2



Interpolated Topography Without Profile
X10N-6 to X10N-2

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

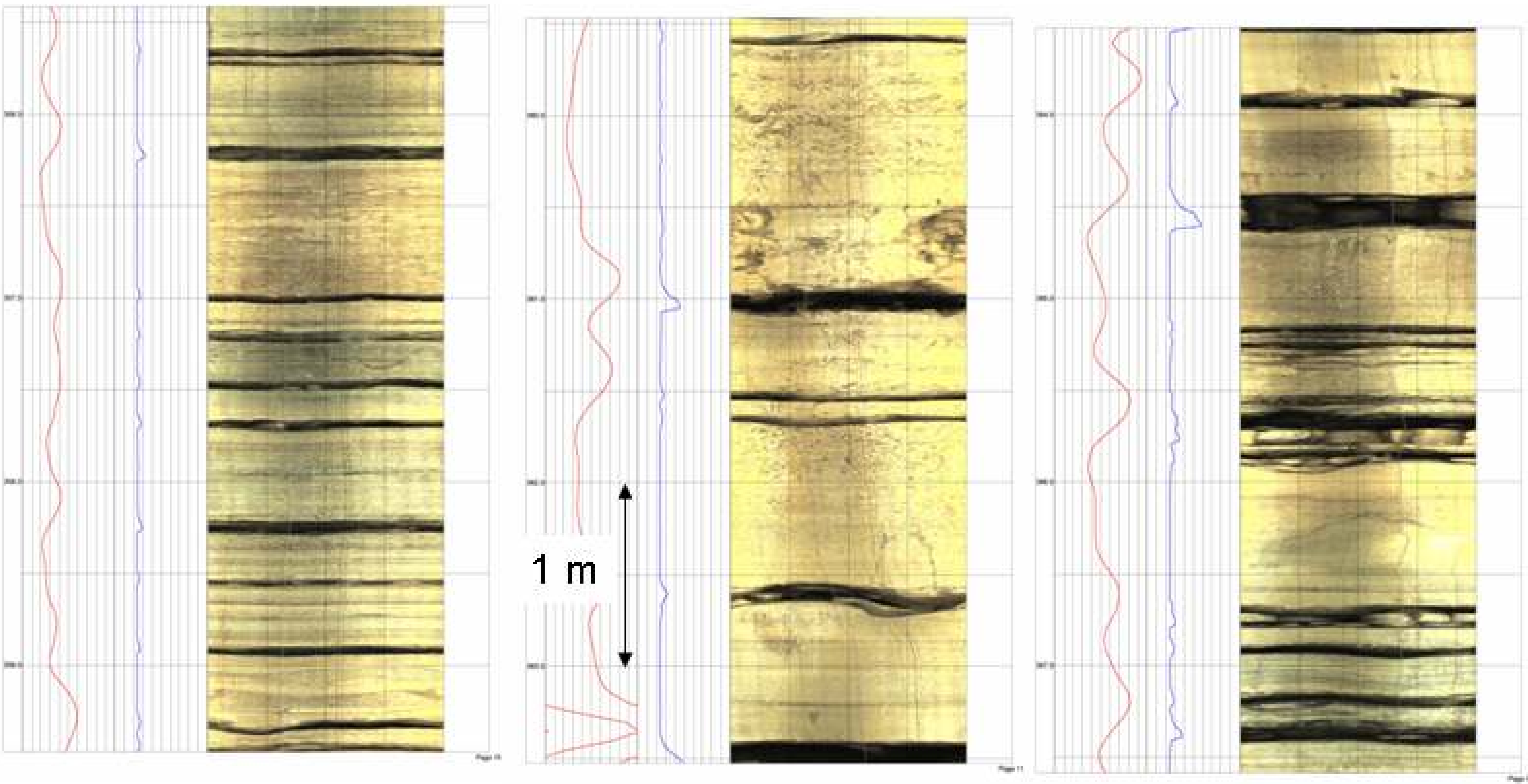
PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

INTERPOLATED TOPOGRAPHY
TOP OF SALINA FORMATION F UNIT SHALE

Golder Associates Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE	REV. 1
	DESIGN	CC	24 May 2006	**FIGURE: 8.39**
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	



Note:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

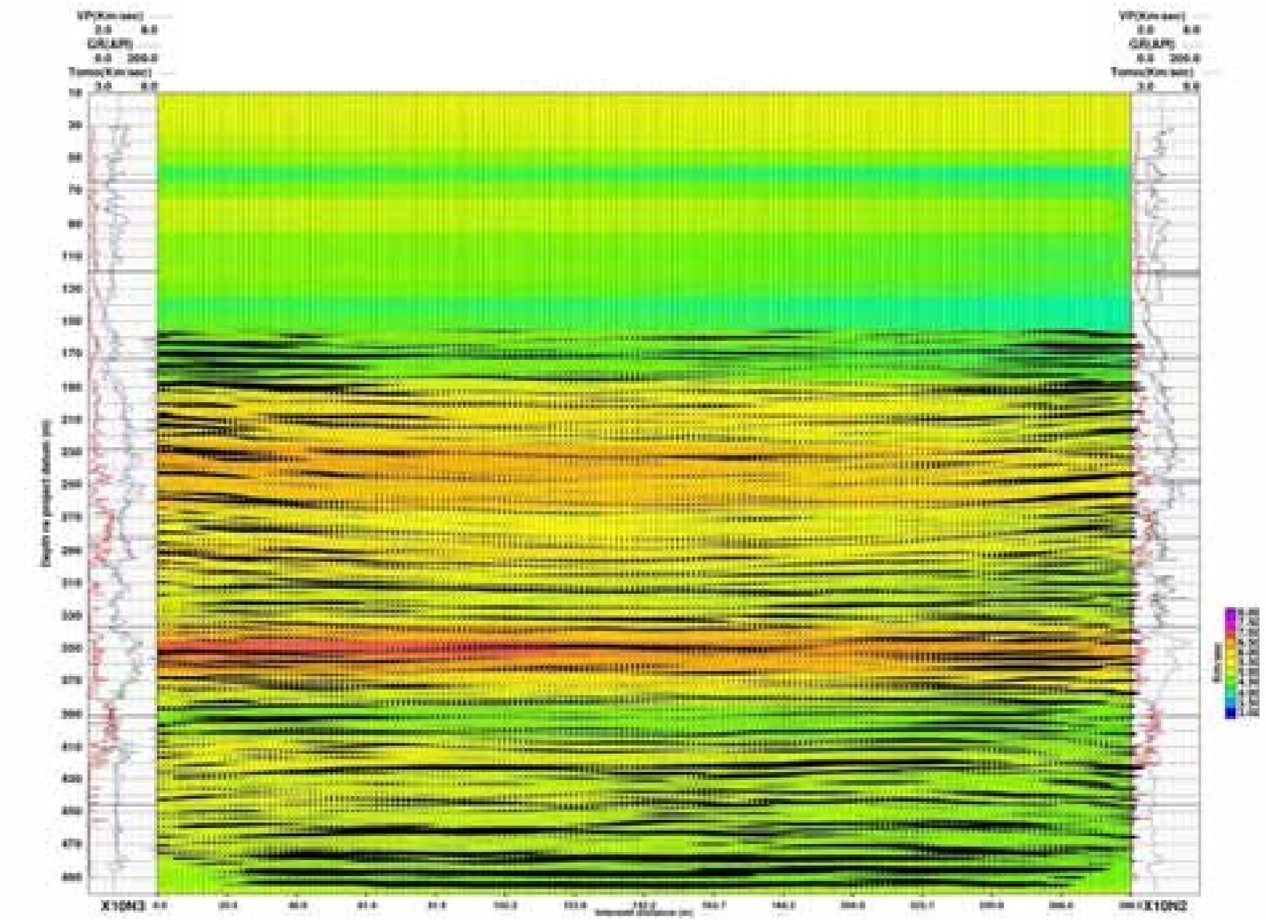
PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

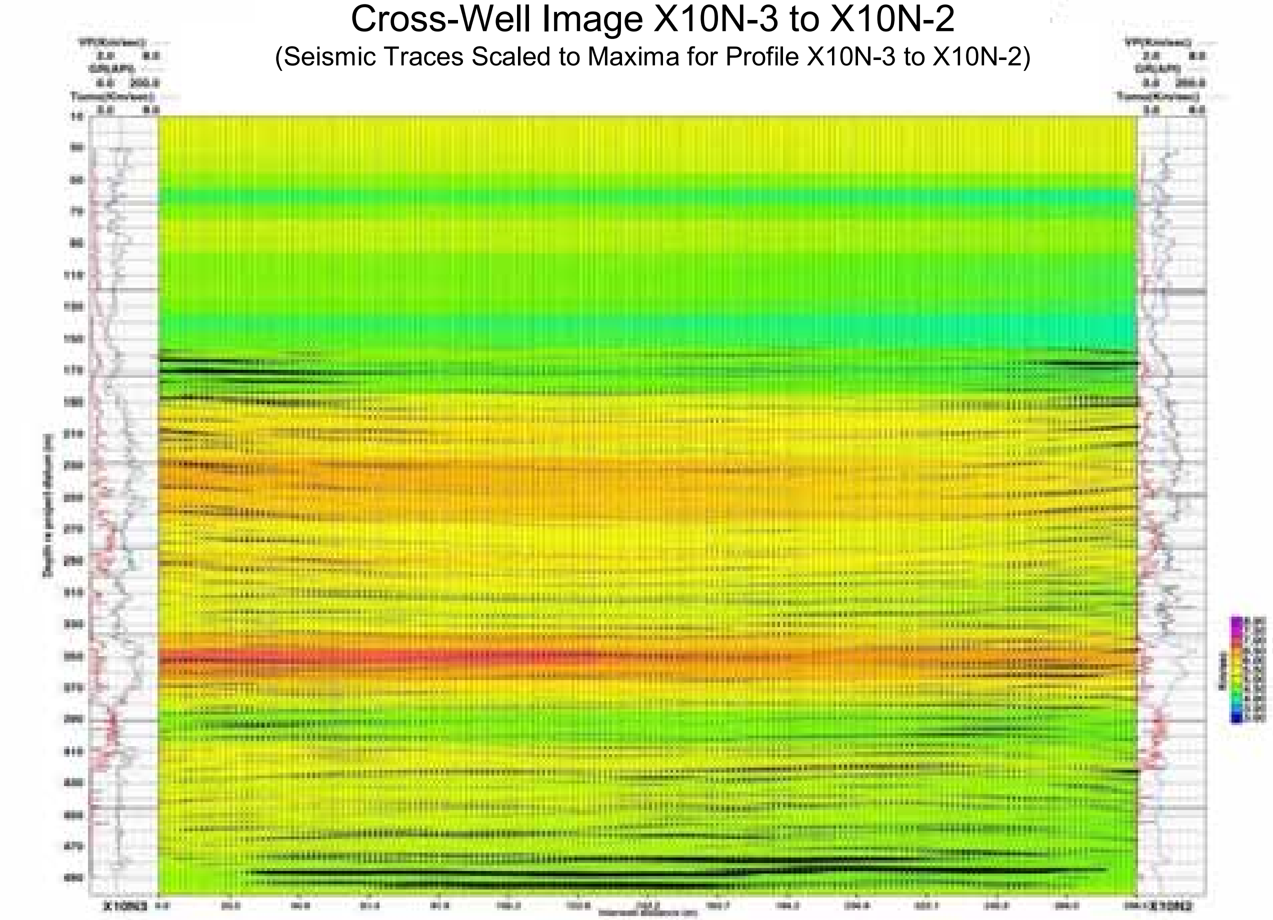
TITLE

OPENINGS IN SALINA FORMATION E UNIT
PARTIAL OPTICAL TELEVIEWER LOG

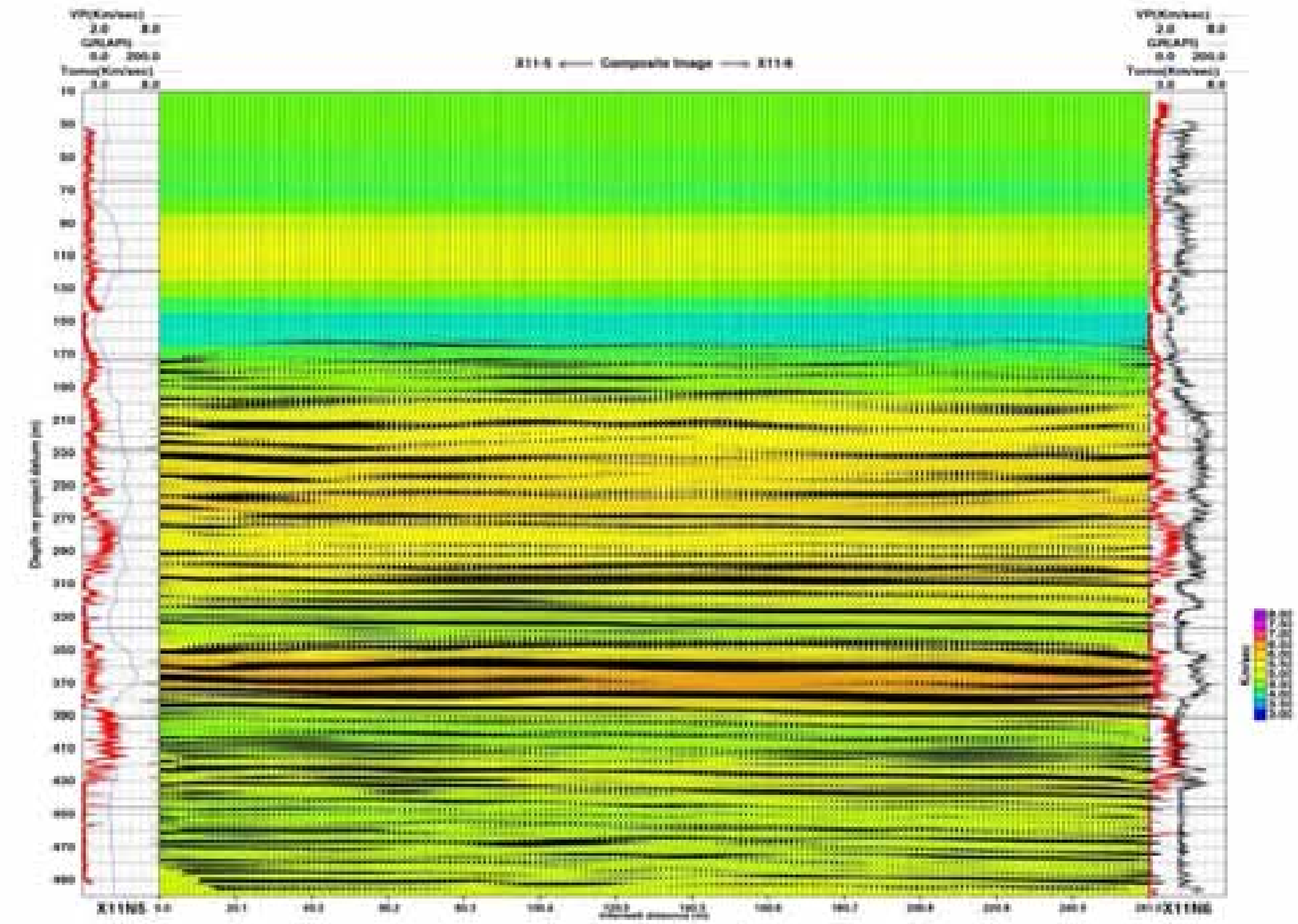
Golder Associates Mississauga, Ontario	PROJECT No. 04-1111-060			SCALE	REV. 0
	DESIGN	CC	24 May 2006	**FIGURE: 8.40**	
	GIS	JFC	20 Feb. 2008		
	CHECK	JM	20 Feb. 2008		
	REVIEW	SB	20 Feb. 2008		



Cross-Well Image X10N-3 to X10N-2
(Seismic Traces Scaled to Maxima for Profile X10N-3 to X10N-2)



Cross-Well Image X10N-3 to X10N-2
(Seismic Traces Scaled to Maxima for Profile X11-5 to X11-6)



Cross-Well Image X11-5 to X11-6
(Scaled to Maxima for Profile X11-5 to X11-6)

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

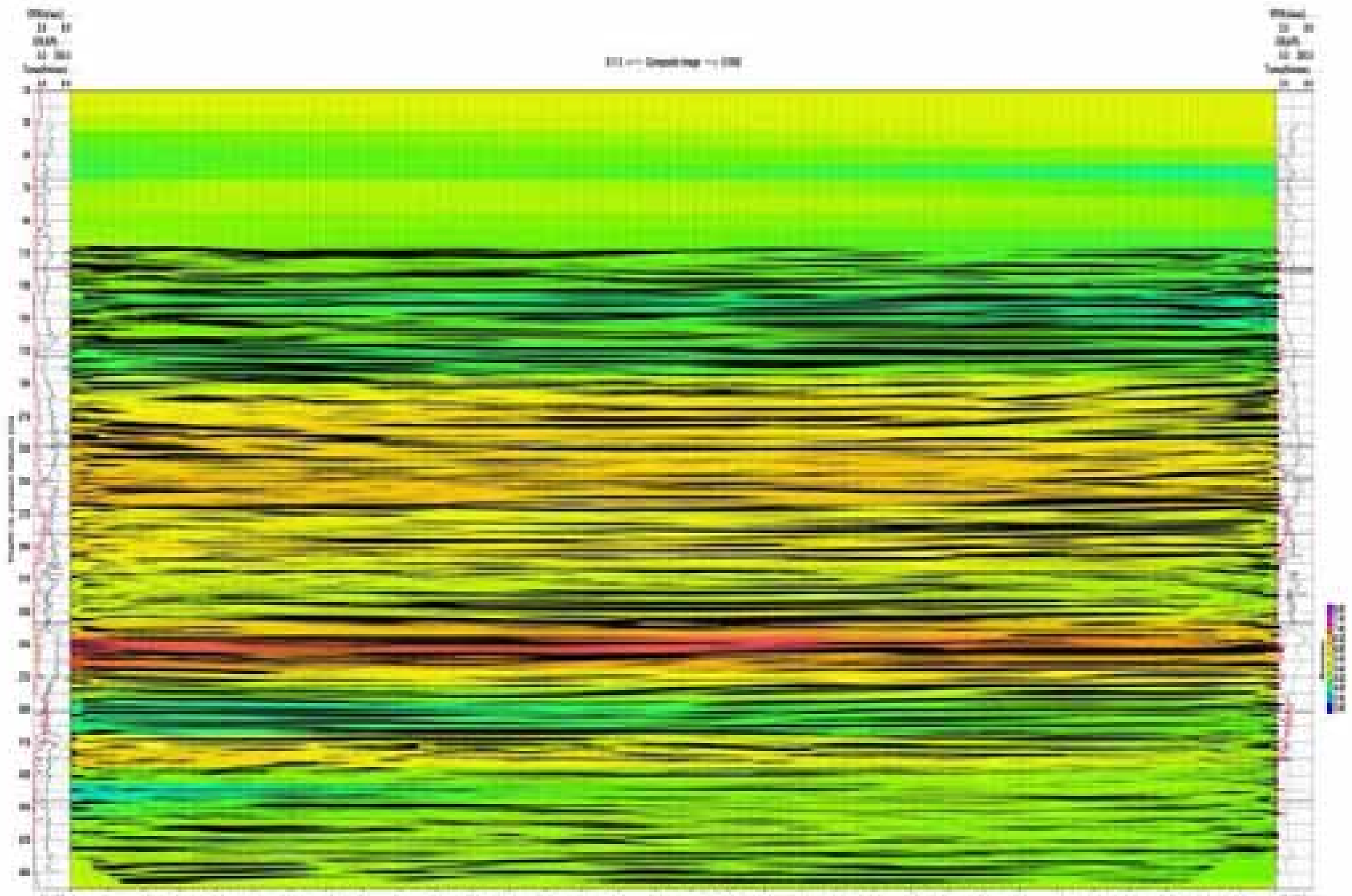
TITLE

AMPLITUDE SCALING OF SEISMIC IMAGES PROFILE X10N-2 TO X10N-3

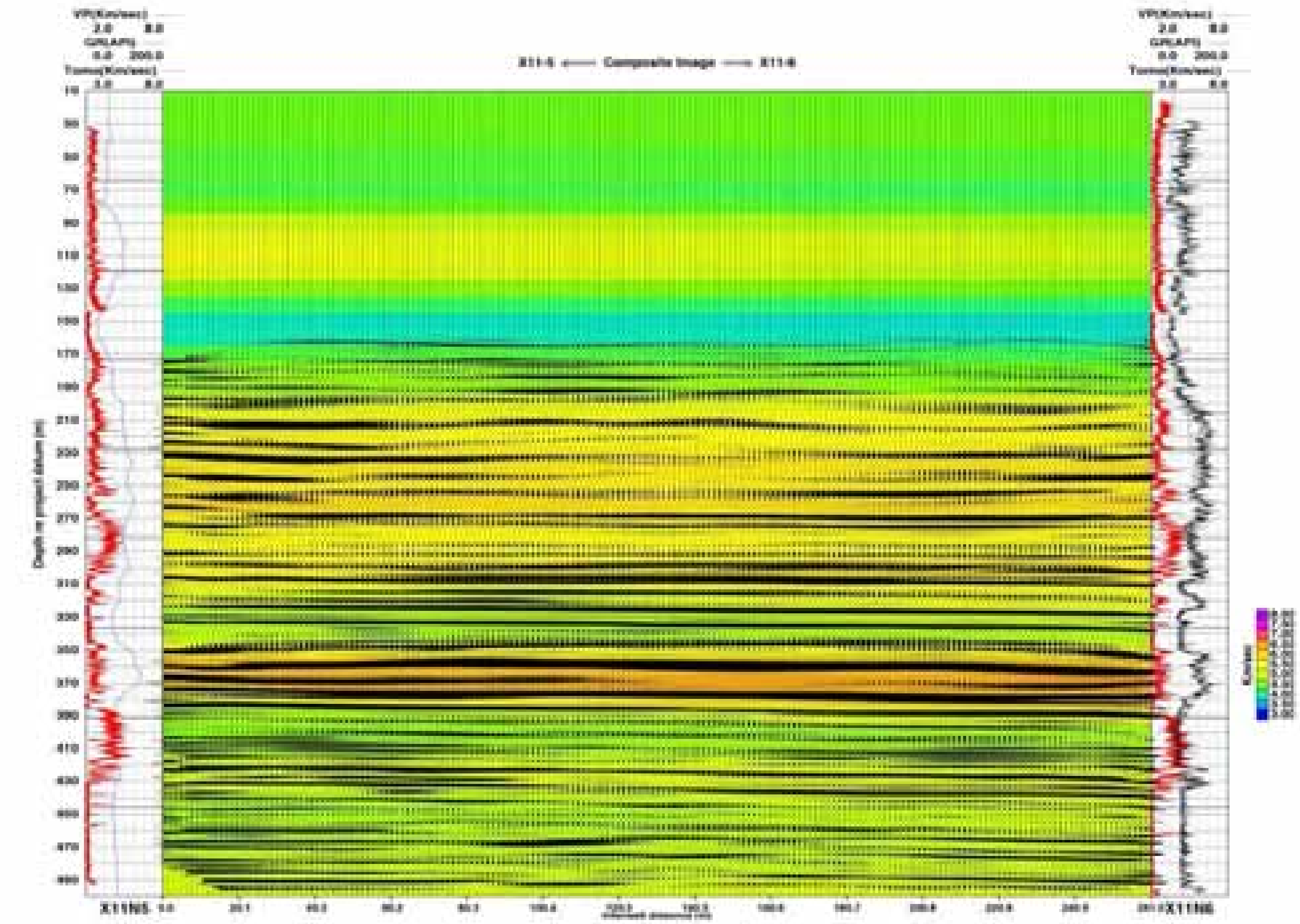
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.41**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

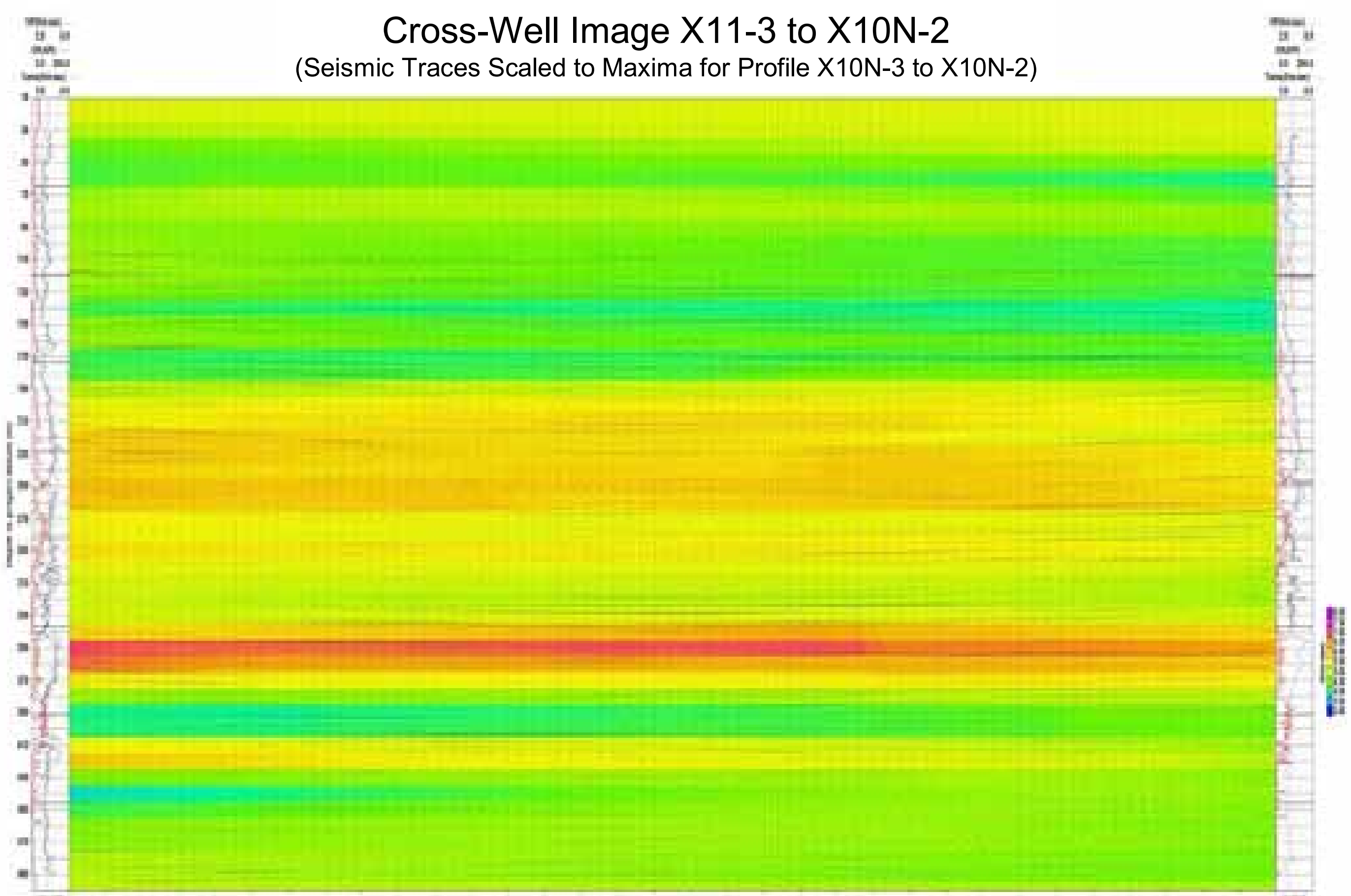
G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.41_AMPLITUDE SCALING OF SEISMIC IMAGES_ PROFILE X10N-2 TO X10N-3.mxd



Cross-Well Image X11-3 to X10N-2
(Seismic Traces Scaled to Maxima for Profile X10N-3 to X10N-2)



Cross-Well Image X11-5 to X11-6
(Scaled to Maxima for Profile X11-5 to X11-6)



Cross-Well Image X11-3 to X10N-2
(Seismic Traces Scaled to Maxima for Profile X11-5 to X11-6)

Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. For discussion of data processing and plotting of reflection traces seismic velocity tomogram, see Section 8 and Appendix C of this report.

PROJECT

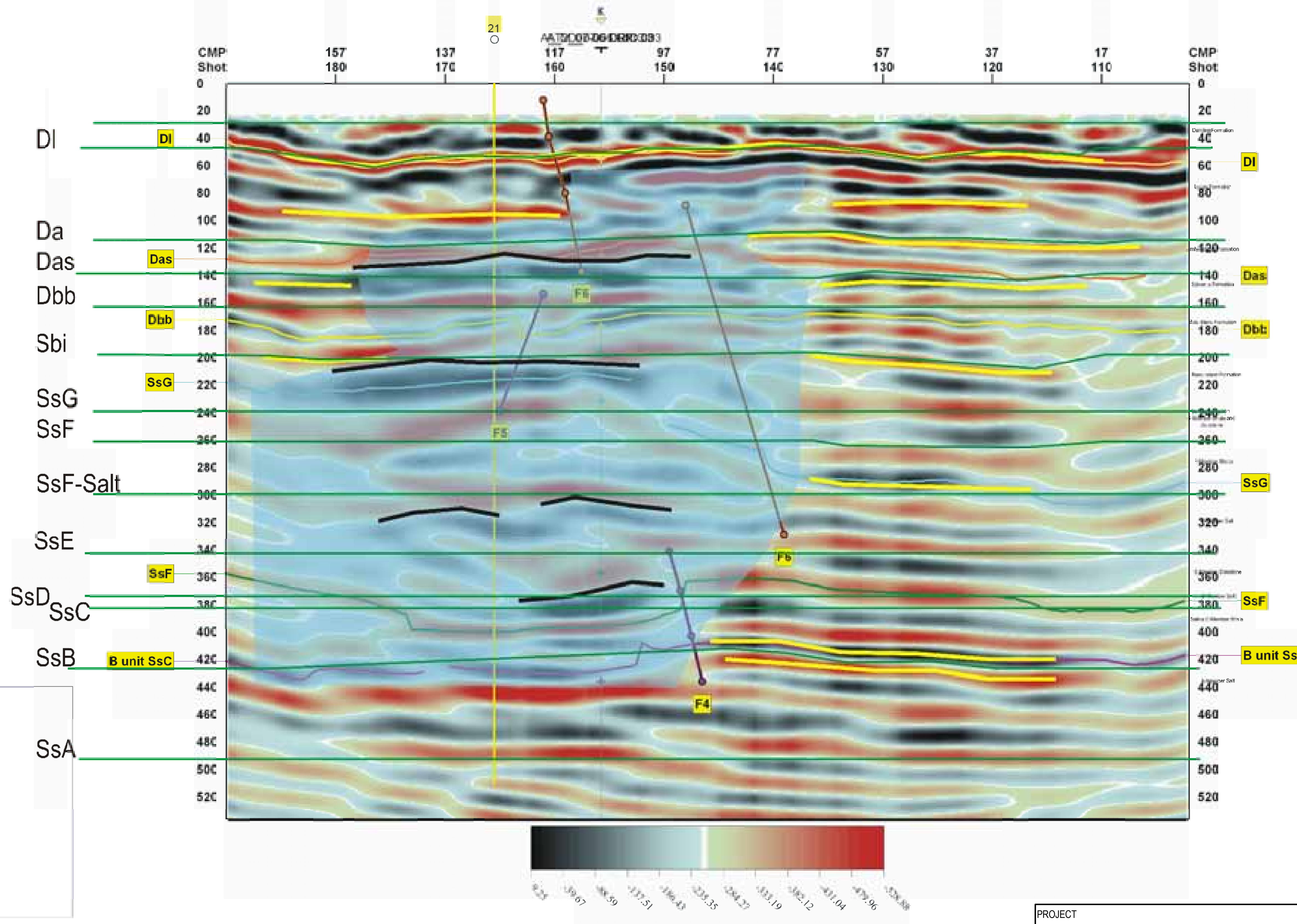
DETROIT RIVER INTERNATIONAL CROSSING

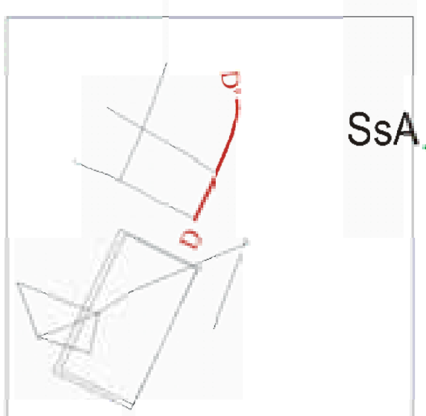
TITLE

AMPLITUDE SCALING OF SEISMIC IMAGES PROFILE X10N-2 TO X11-3

Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE	REV. 1
	DESIGN	CC	24 May 2006	FIGURE: 8.42
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.42_AMPLITUDE SCALING OF SEISMIC IMAGES_ PROFILE X10N-2 TO X11-3.mxd





LEGEND

- Seismic Reflector Suitable for Interpretation
- Interpreted Formation Top Elevations
- Top of Seismic Anomaly
- Zone of Reflection Disturbance
- Zone of Uninterpreted Data

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

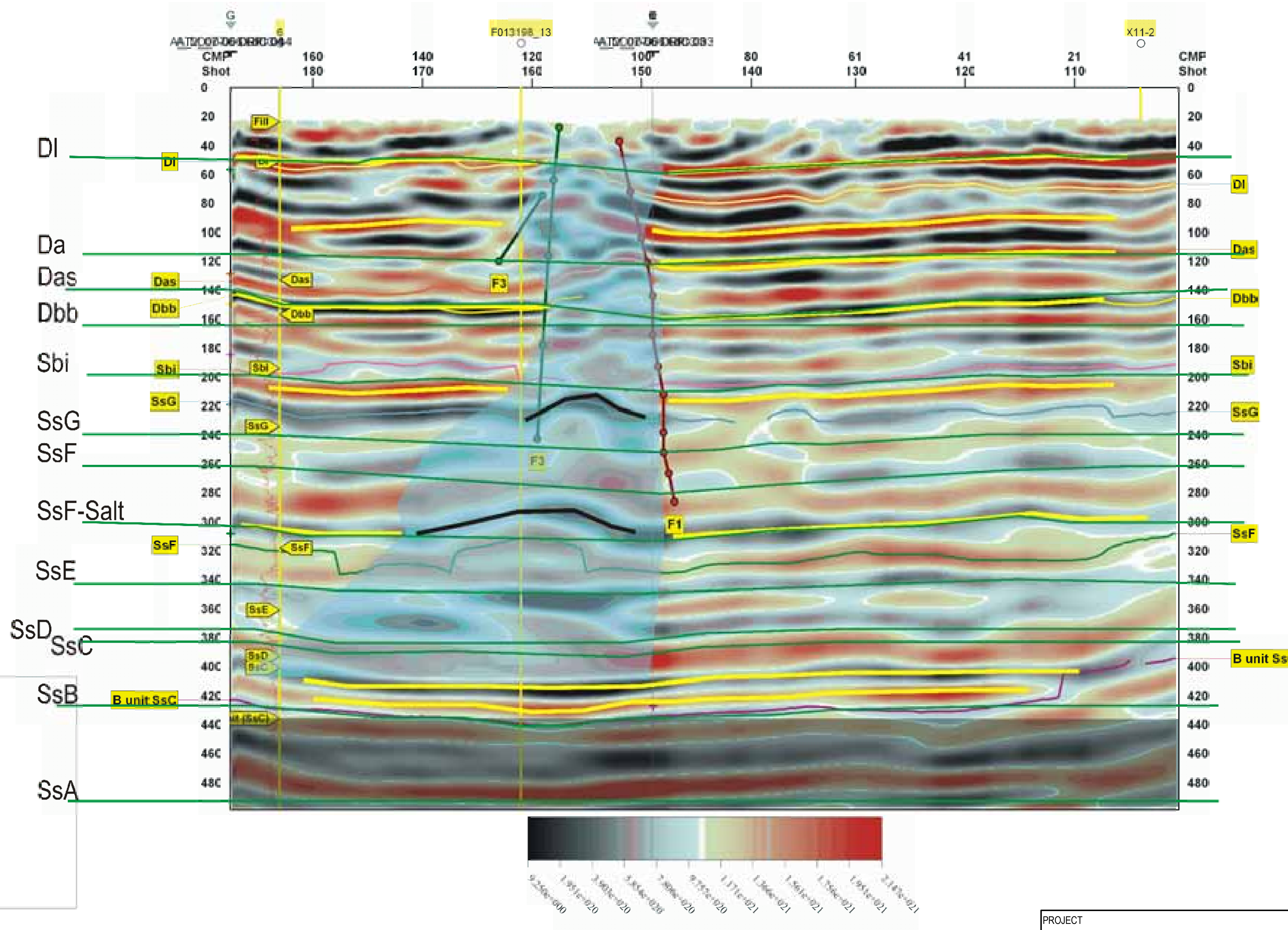
INTERPRETATION OF REPROCESSED SURFACE SEISMIC SURVEY LINE DRIC01

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.43**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.43_Interpretation of Reprocessed Surface Seismic Survey Line DRIC01.mxd

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.44_Interpretation of Reprocessed Surface Seismic Survey Line DRIC02.mxd



LEGEND

- Seismic Reflector Suitable for Interpretation
- Interpreted Formation Top Elevations
- Top of Seismic Anomaly
- Zone of Reflection Disturbance
- Zone of Uninterpreted Data

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

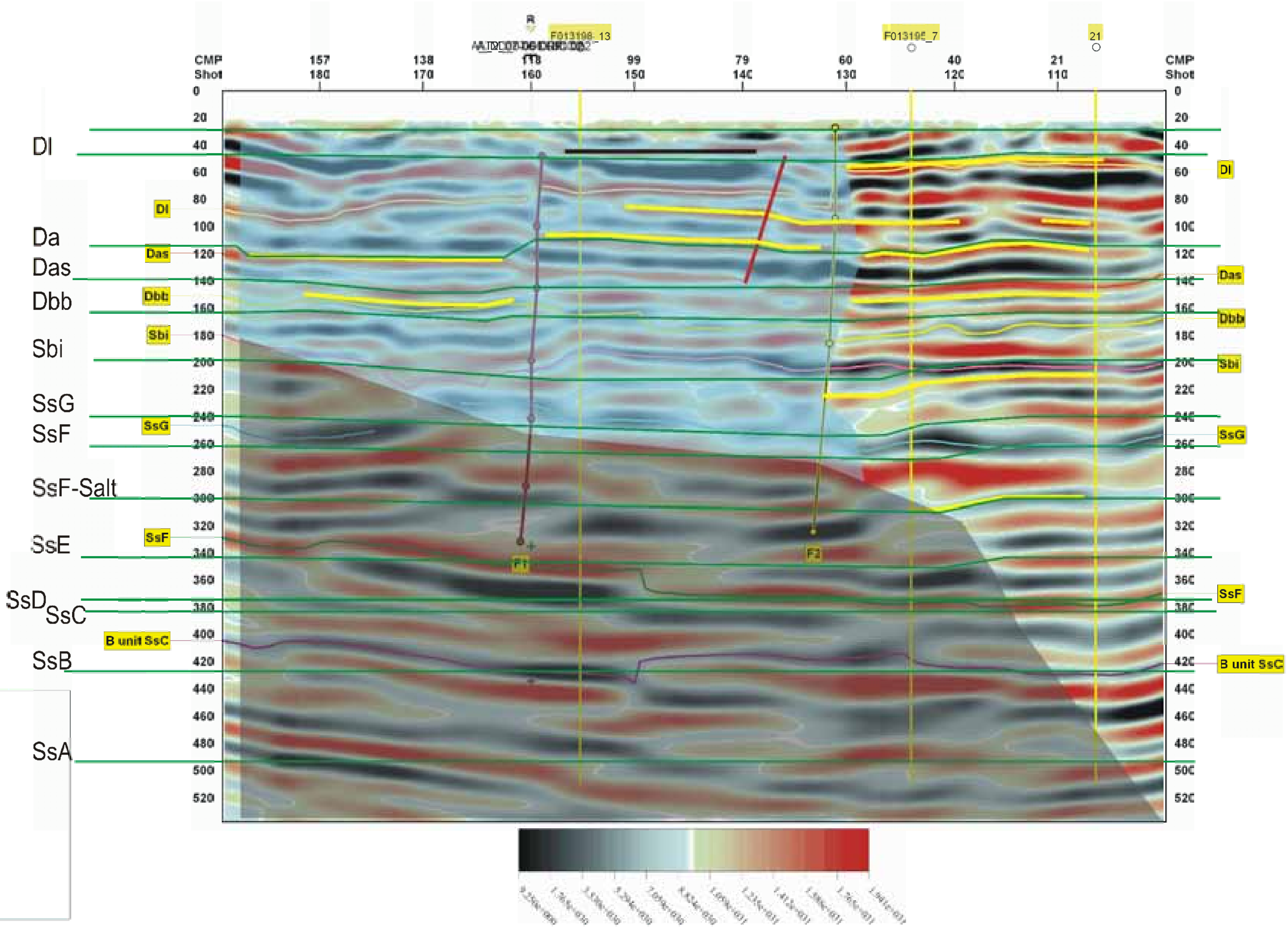
TITLE

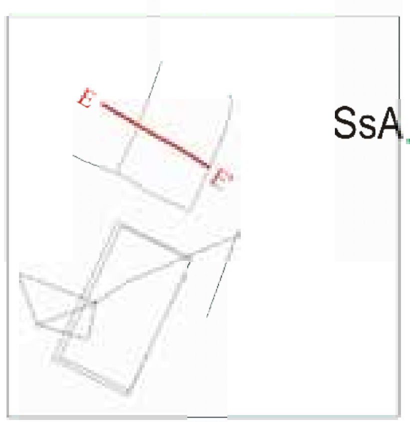
INTERPRETATION OF REPROCESSED SURFACE SEISMIC SURVEY LINE DRIC02

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	CC	24 May 2006		
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

FIGURE: 8.44





LEGEND

- Seismic Reflector Suitable for Interpretation
- Interpreted Formation Top Elevations
- Top of Seismic Anomaly
- Zone of Reflection Disturbance
- Zone of Uninterpreted Data

PROJECT

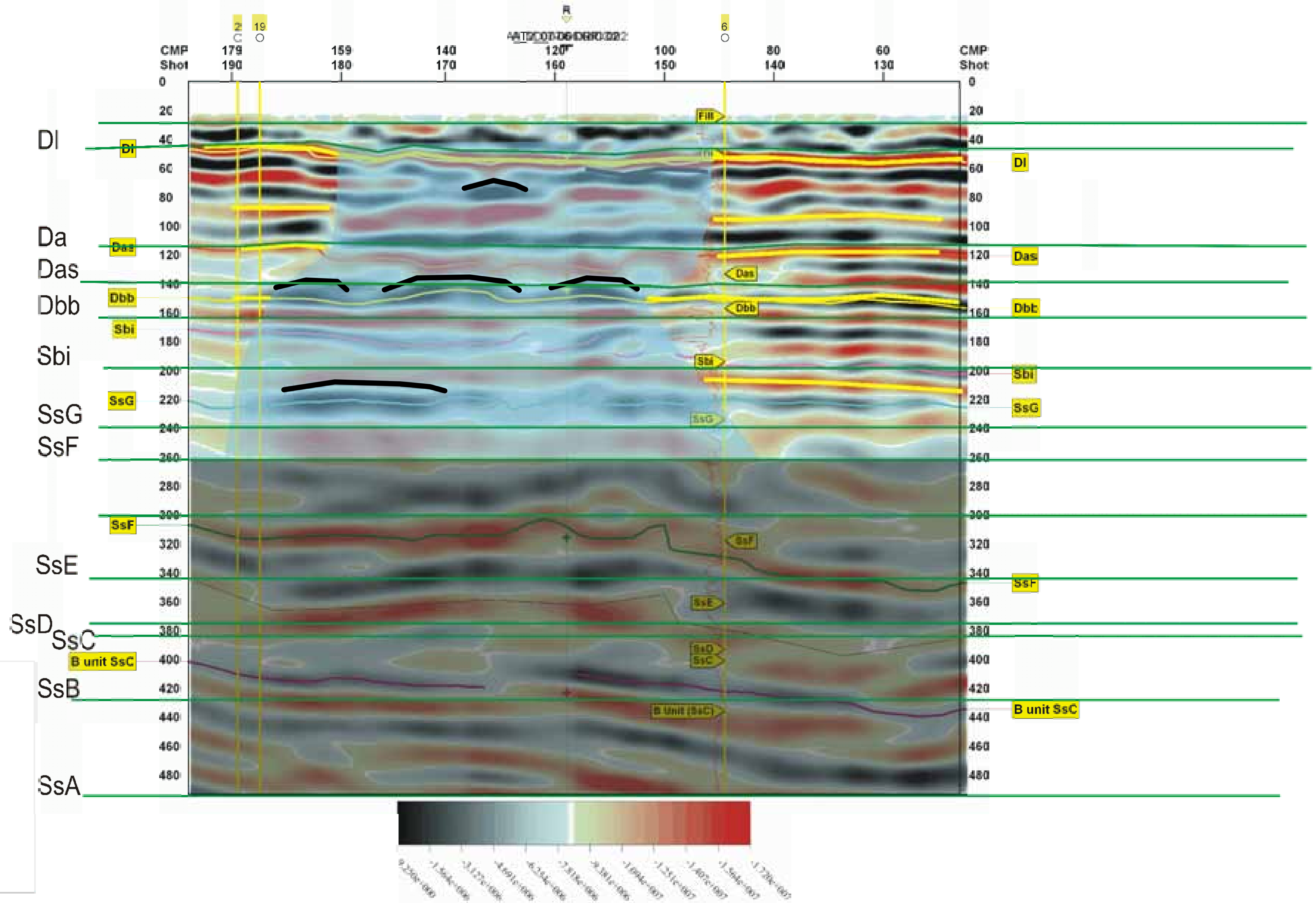
DETROIT RIVER INTERNATIONAL CROSSING

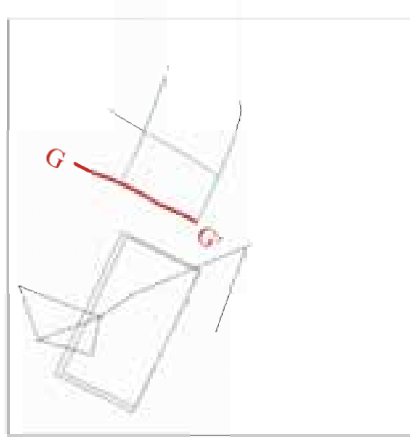
TITLE

INTERPRETATION OF REPROCESSED SURFACE SEISMIC SURVEY LINE DRIC03

Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE NTS	REV. 1
	DESIGN	CC	24 May 2006	**FIGURE: 8.45**
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.45_Interpretation of Reprocessed Surface Seismic Survey Line DRIC03.mxd





LEGEND

- Seismic Reflector Suitable for Interpretation
- Interpreted Formation Top Elevations
- Top of Seismic Anomaly
- Zone of Significant Reflection Disturbance
- Zone of Uninterpreted Data

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

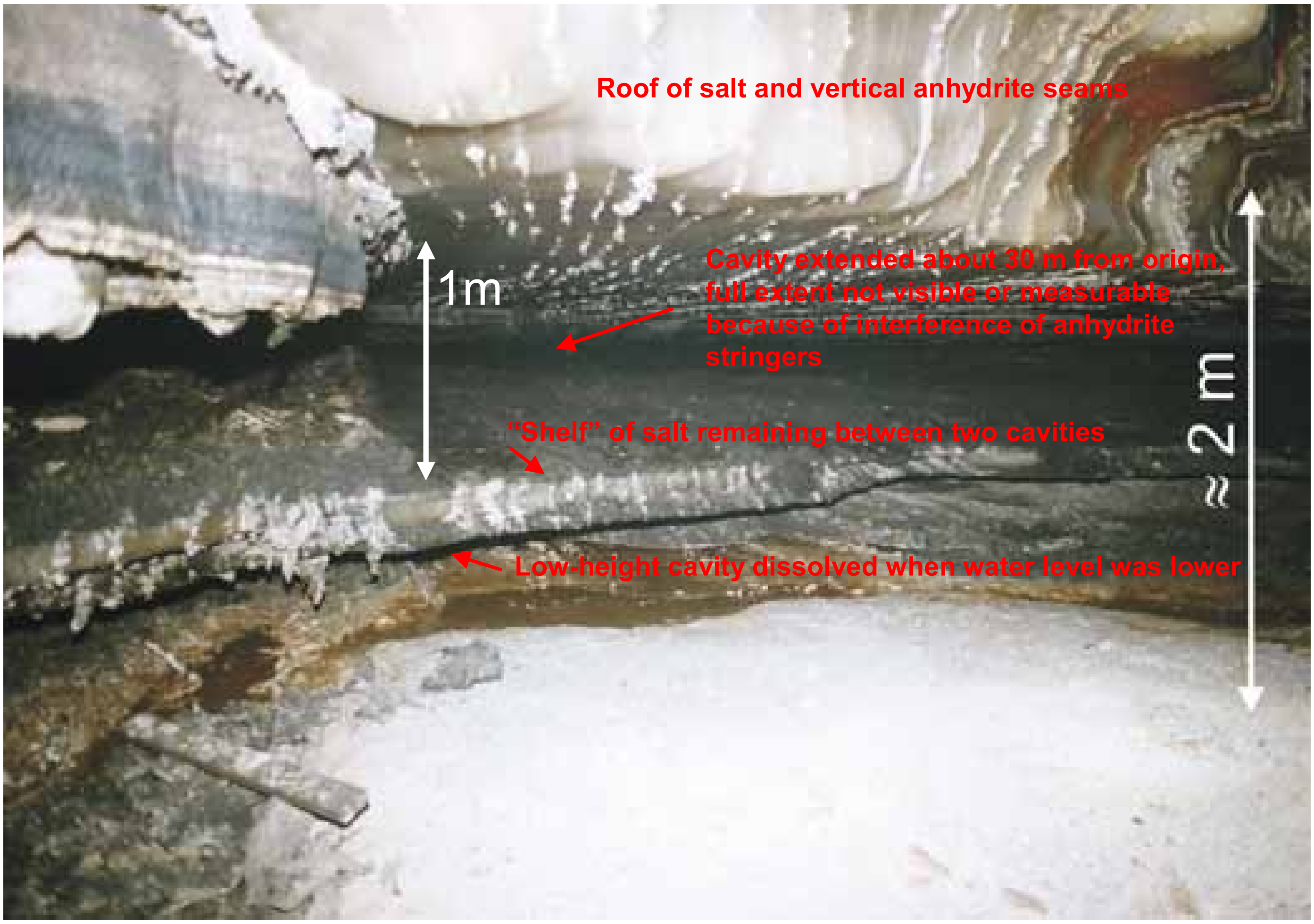
TITLE

INTERPRETATION OF REPROCESSED SURFACE SEISMIC SURVEY LINE DRIC04

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.46**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.46_Interpretation of Reprocessed Surface Seismic Survey Line DRIC04.mxd



Example of salt dissolution cavity created by a pool of fresh water in the base of a salt mine shaft. Preferential dissolution of salt at top of water/brine column created a "wedge-shaped" cavity radiating out from the shaft centre that pinched out about 30 m from the shaft wall. Cavity developed and was undetected for a period of about 30 years. Different sump pump changes resulted in two identifiably different water levels and cavity formations.

NOTE:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

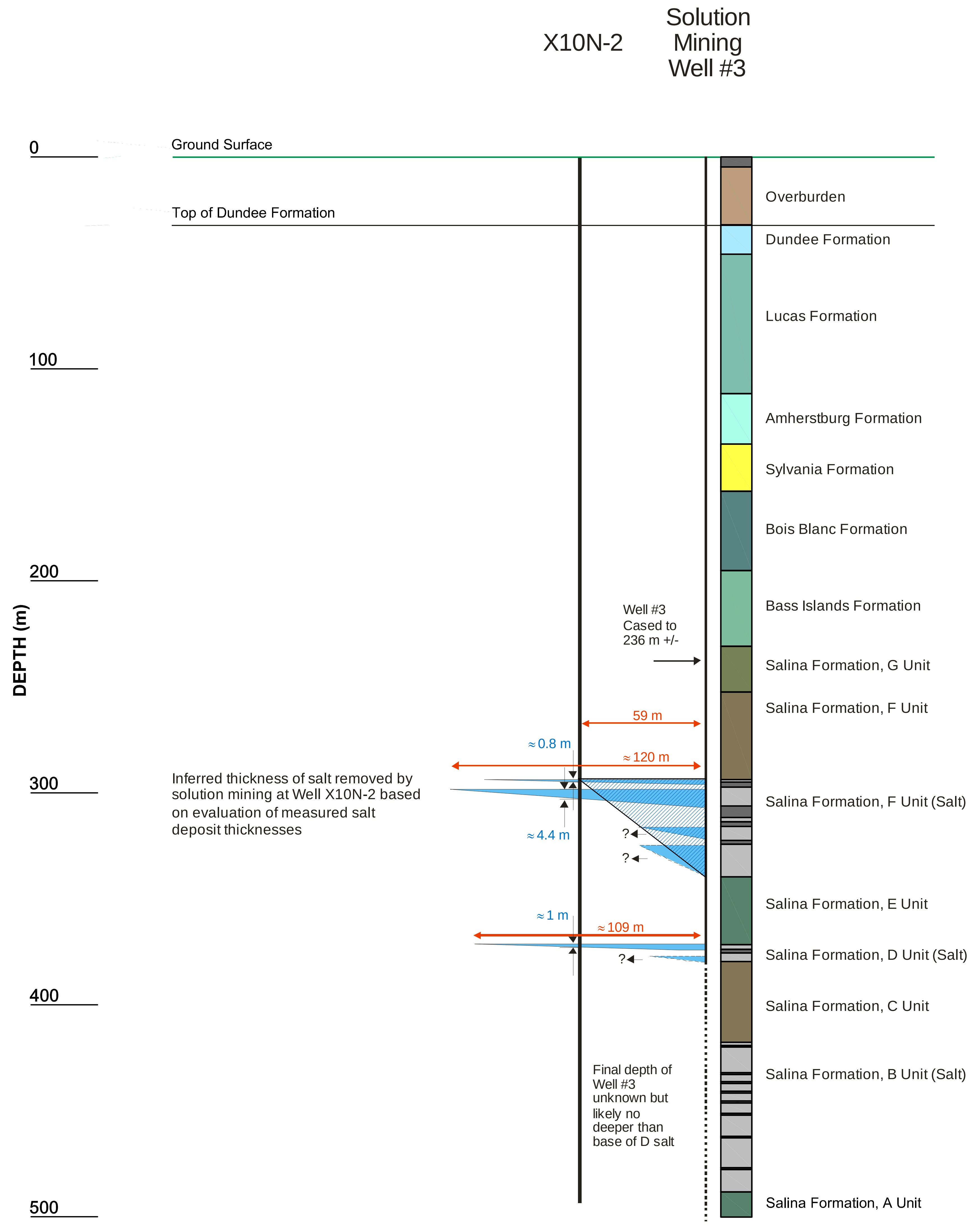
TITLE
EXAMPLE OF SALT DISSOLUTION VOID

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	PB	10 Jan. 2008	**FIGURE: 8.47**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

Golder Associates
Mississauga, Ontario

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.47_EXAMPLE_OF_SALT_DISSOLUTION_VOID.mxd

PLOT DATE: February 21, 2008
FILENAME: N:\active\projects - other offices\Mississauga\2004\04-1111-060 URS Detroit River International Crossing\04-1111-060B Report Figures\041111060-R01-8_4.dwg



LEGEND

(blue solid wedge)	ESTIMATED EXTENT OF FORMER CAVITY BASED ON SALT BED THICKNESS DATA ("STACKED CONE HYPOTHESIS")
≈ 0.6 m	INFERRED MAXIMUM AMOUNT OF SALT POSSIBLY REMOVED BY SOLUTION MINING BASED ON COMPARISON OF ENCOUNTERED SALT THICKNESS TO THICKNESS AT WELLS X10N-1, X10N-4, X10N-5, X10N-6
(hatched wedge)	ESTIMATED EXTENT OF FORMER CAVITY BASED ON SIMPLE CONE HYPOTHESIS

ESTIMATED CONDITIONS PRIOR TO 1954 SUBSIDENCE

Golder Associates
London, Ontario, Canada

SCALE	AS SHOWN
DATE	21 Feb 2008
DESIGN	
CAD	WDF
CHECK	JM
REVIEW	SB

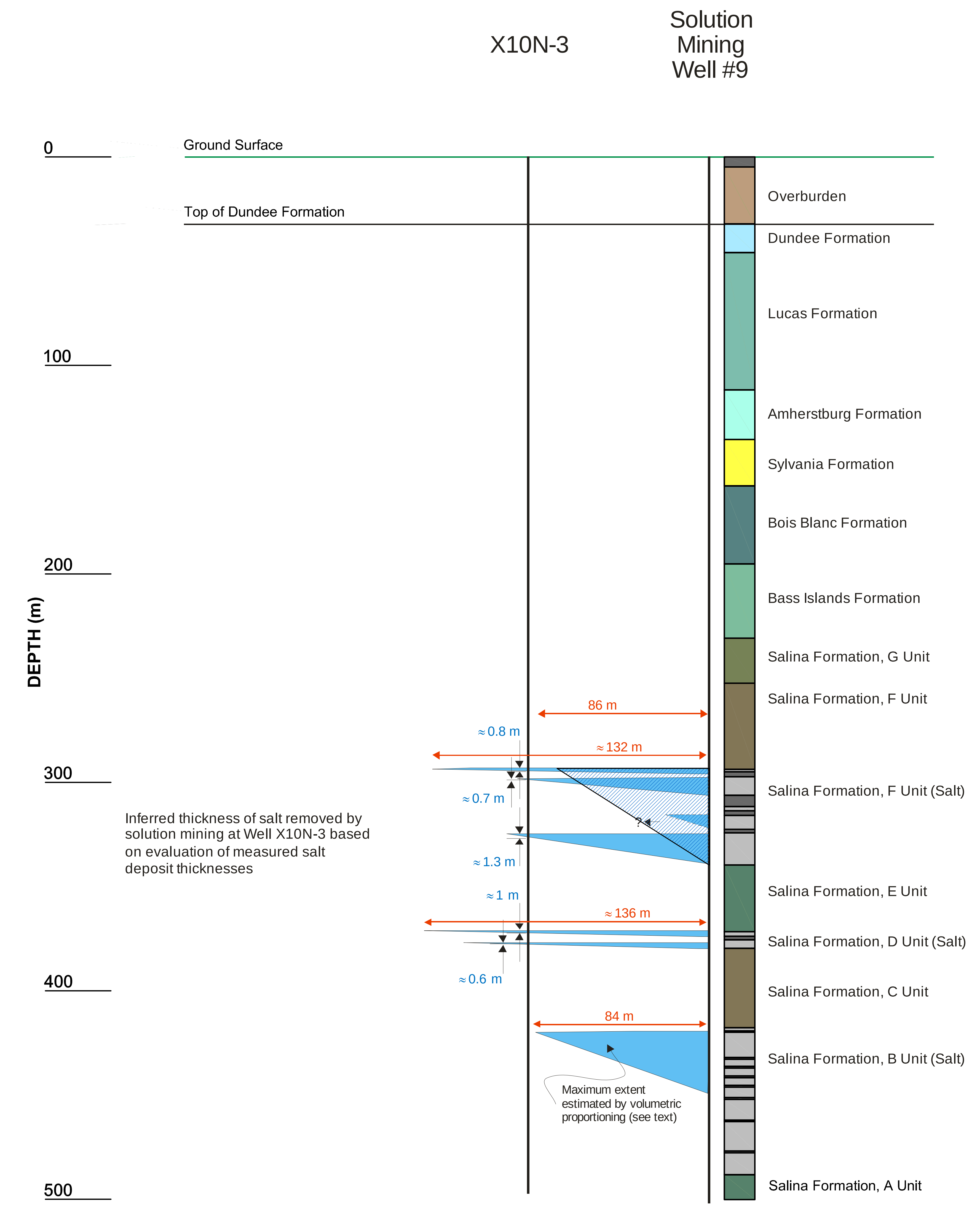
FILE No. 041111060-R01-8_4.DWG
PROJECT No. 04-1111-060B REV. 0

TITLE

INFERRED SALT DISSOLUTION NEAR SOLUTION MINING WELL #3

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.48



LEGEND

(blue wedge symbol)	ESTIMATED EXTENT OF FORMER CAVITY BASED ON SALT BED THICKNESS DATA ("STACKED CONE HYPOTHESIS")
≈ 0.6 m	INFERRED MAXIMUM AMOUNT OF SALT POSSIBLY REMOVED BY SOLUTION MINING BASED ON COMPARISON OF ENCOUNTERED SALT THICKNESS TO THICKNESS AT WELLS X10N-1, X10N-4, X10N-5, X10N-6
(hatched triangle symbol)	ESTIMATED EXTENT OF FORMER CAVITY BASED ON SIMPLE CONE HYPOTHESIS

ESTIMATED CONDITIONS PRIOR TO 1954 SUBSIDENCE

Golder Associates
London, Ontario, Canada

SCALE	AS SHOWN
DATE	21 Feb 2008
DESIGN	
CAD	WDF
CHECK	JM
REVIEW	SB
FILE No.	041111060-R01-8_4.DWG
PROJECT No.	04-1111-060B
REV.	0

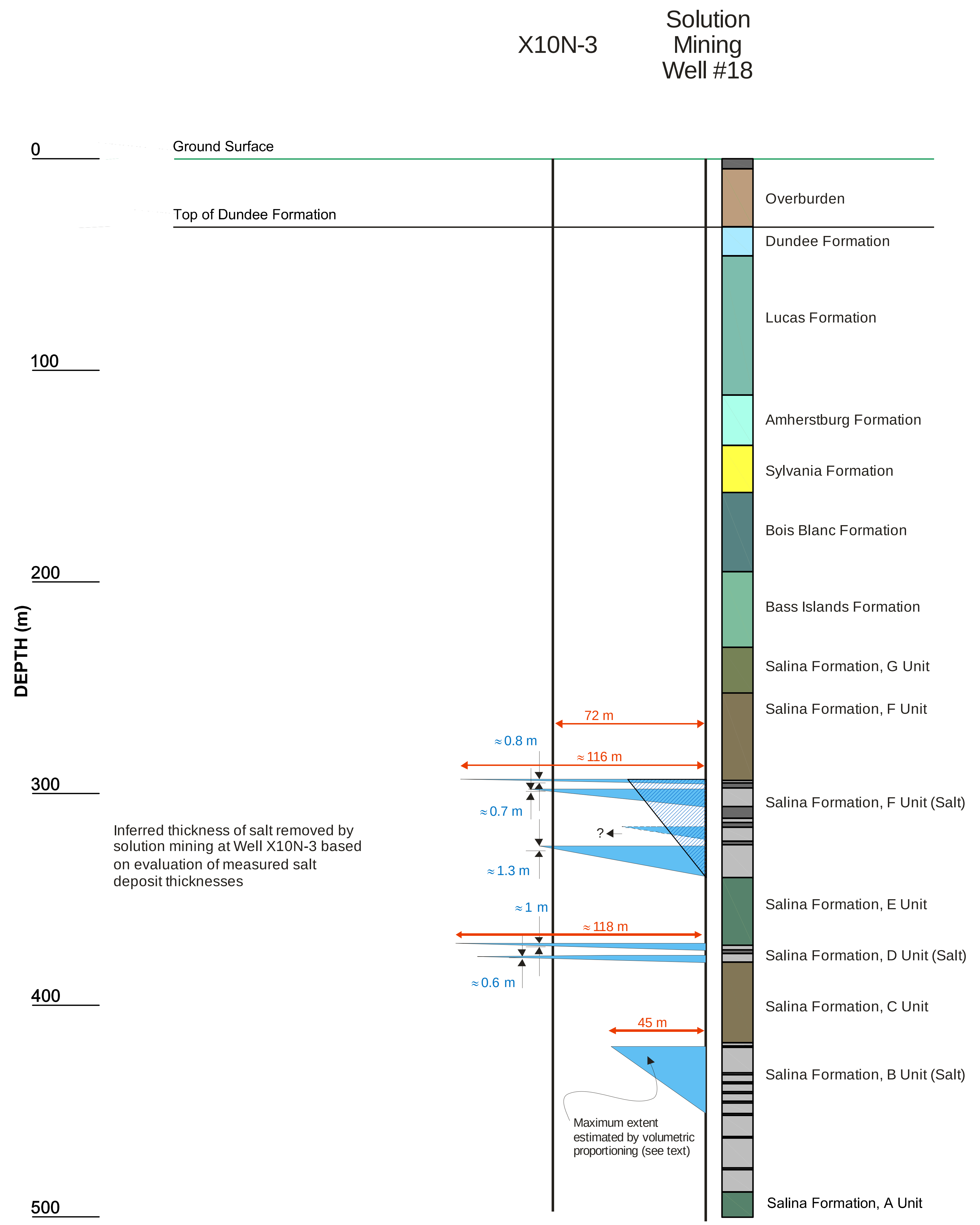
TITLE

INFERRED SALT DISSOLUTION NEAR SOLUTION MINING WELL #9

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.49

PLOT DATE: February 21, 2008
FILENAME: N:\active\projects - other offices\Mississauga\2004\04-1111-060 URS Detroit River International Crossing\04-1111-060B Report Figures\041111060-R01-8_4.dwg



LEGEND

(blue wedge symbol)	ESTIMATED EXTENT OF FORMER CAVITY BASED ON SALT BED THICKNESS DATA ("STACKED CONE HYPOTHESIS")
≈ 0.6 m	INFERRED MAXIMUM AMOUNT OF SALT POSSIBLY REMOVED BY SOLUTION MINING BASED ON COMPARISON OF ENCOUNTERED SALT THICKNESS TO THICKNESS AT WELLS X10N-1, X10N-4, X10N-5, X10N-6
(hatched triangle symbol)	ESTIMATED EXTENT OF FORMER CAVITY BASED ON SIMPLE CONE HYPOTHESIS

ESTIMATED CONDITIONS PRIOR TO 1954 SUBSIDENCE

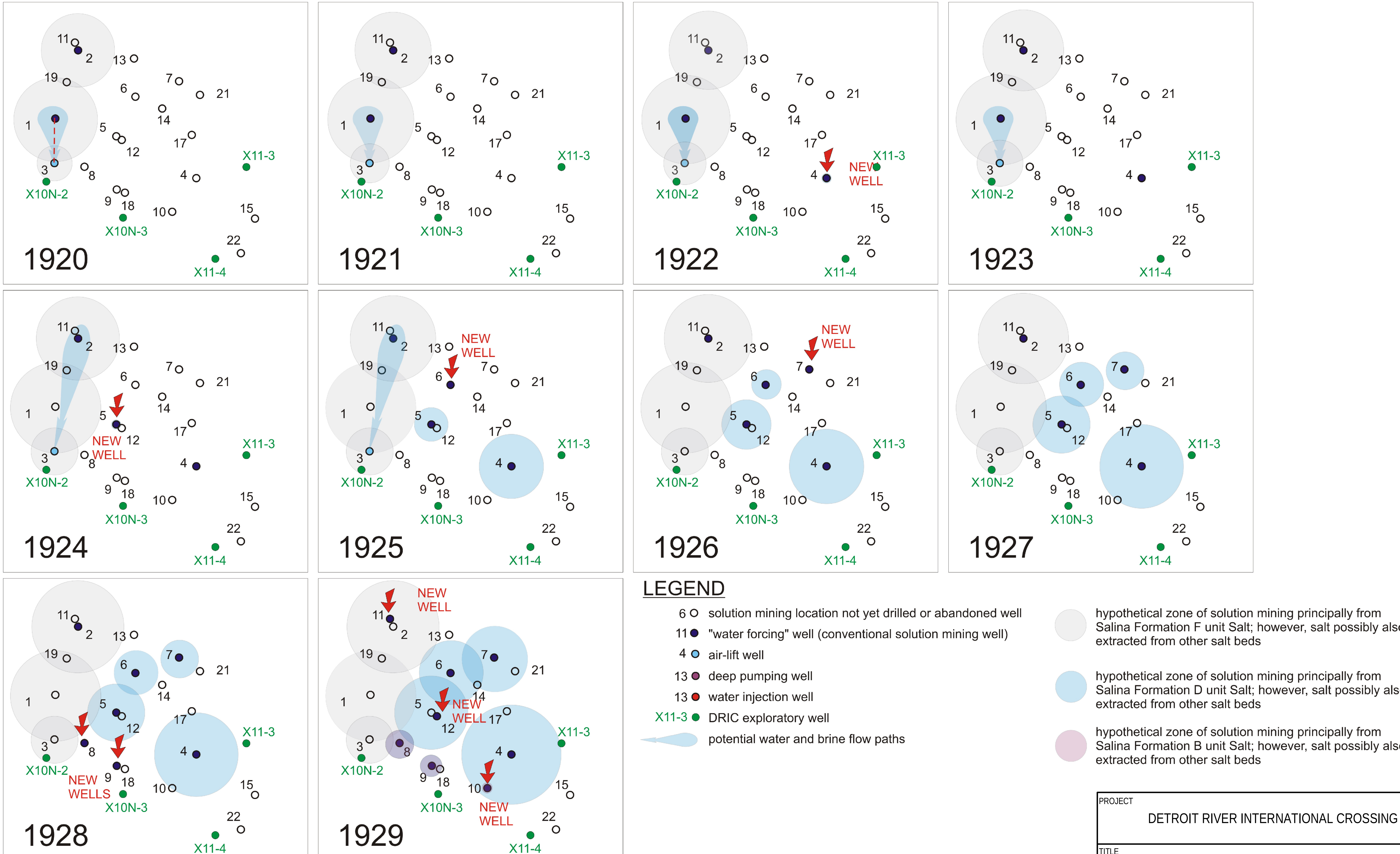
Golder Associates
London, Ontario, Canada

SCALE	AS SHOWN	TITLE	
DATE	21 Feb 2008		
DESIGN			
CAD	WDF		
CHECK	JM		
REVIEW	SB		
FILE No.	041111060-R01-8_4.DWG		
PROJECT No.	04-1111-060B	REV.	0

INFERRED SALT DISSOLUTION NEAR SOLUTION MINING WELL #18

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.50



Note: This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

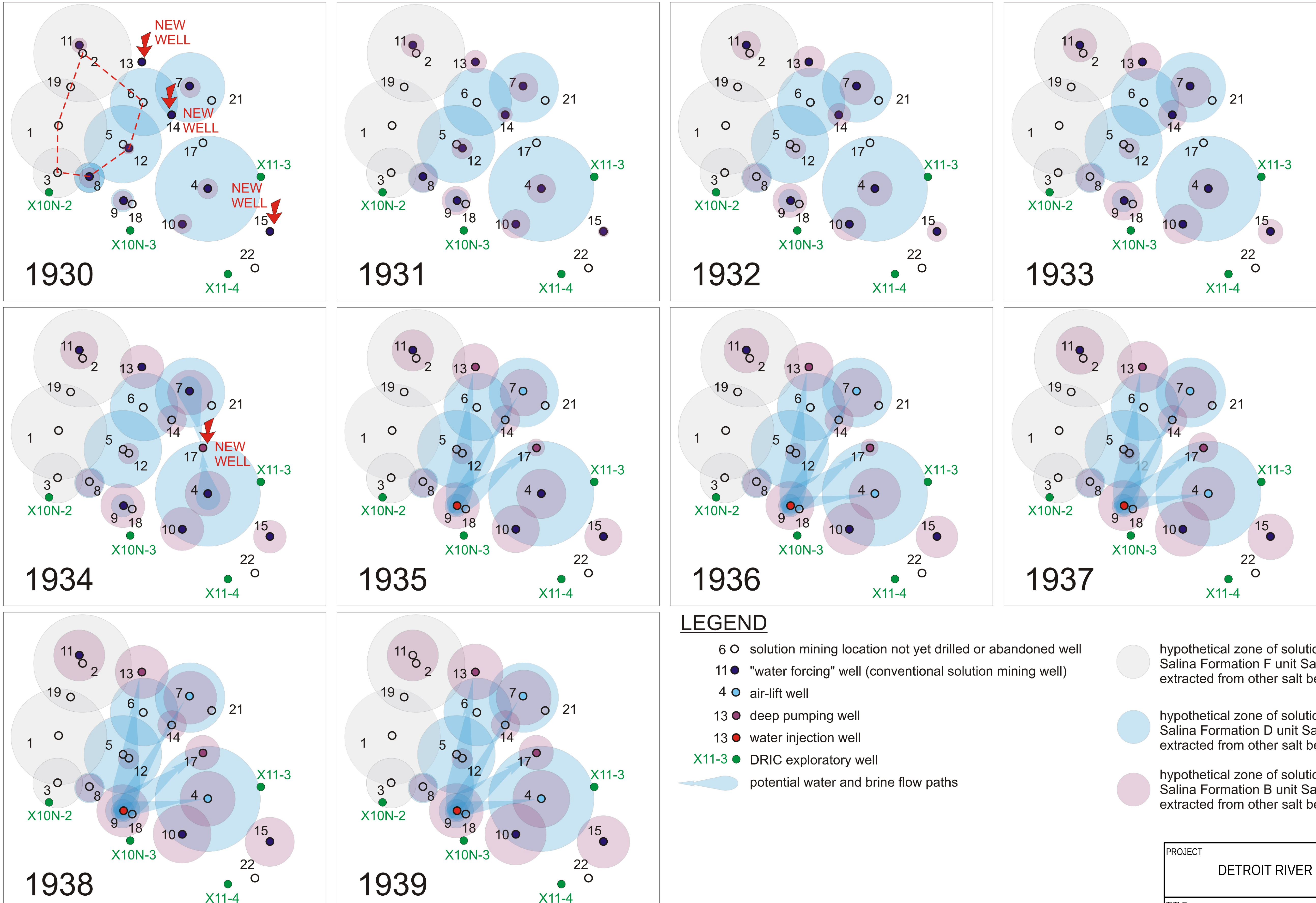
PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

TITLE
REASSESSMENT OF SANDWICH WEST SITE HISTORY

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 0
DESIGN	CC	24 May 2006	FIGURE: 8.51a	
GIS	JFC	21 Feb. 2008		
CHECK	JM	21 Feb. 2008		
REVIEW	SB	21 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.51a Re-Assessment of Sandwich West Site History.mxd



LEGEND

6 solution mining location not yet drilled or abandoned well
11 "water forcing" well (conventional solution mining well)
4 air-lift well
13 deep pumping well
13 water injection well
X11-3 DRIC exploratory well
potential water and brine flow paths

hypothetical zone of solution mining principally from Salina Formation F unit Salt; however, salt possibly also extracted from other salt beds

hypothetical zone of solution mining principally from Salina Formation D unit Salt; however, salt possibly also extracted from other salt beds

hypothetical zone of solution mining principally from Salina Formation B unit Salt; however, salt possibly also extracted from other salt beds

Note: This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

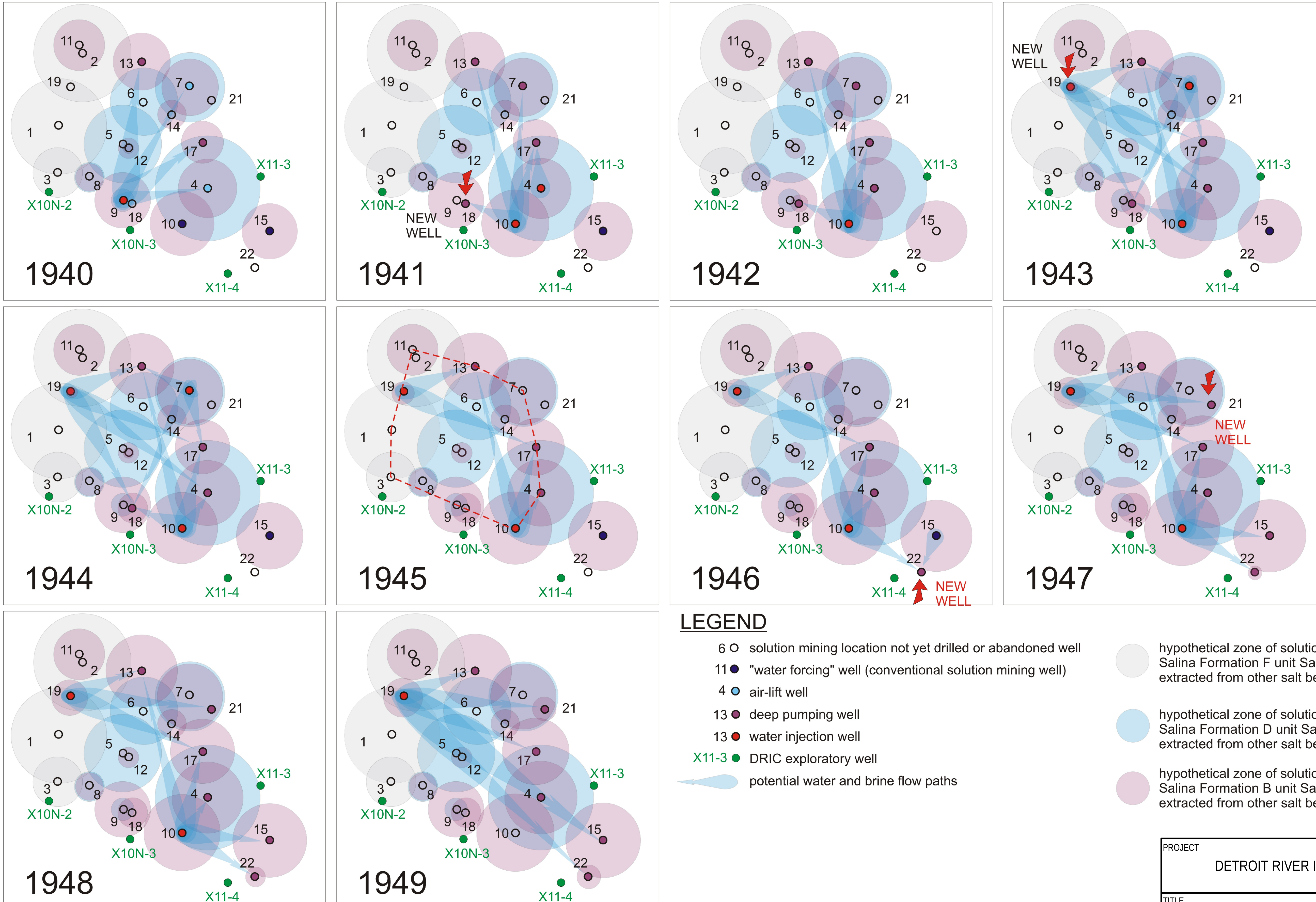
PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

TITLE
REASSESSMENT OF SANDWICH WEST SITE HISTORY

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 0
DESIGN	CC	24 May 2006	FIGURE: 8.51b	
GIS	JFC	21 Feb. 2008		
CHECK	JM	21 Feb. 2008		
REVIEW	SB	21 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.51b Re-Assessment of Sandwich West Site History.mxd



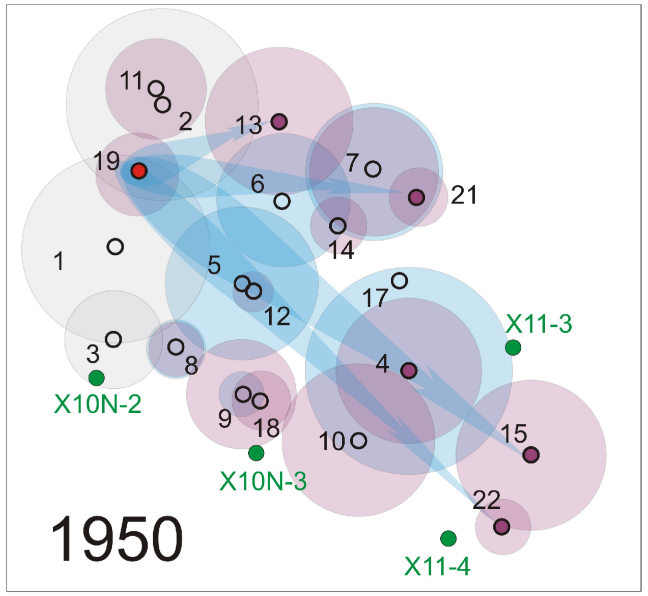
LEGEND

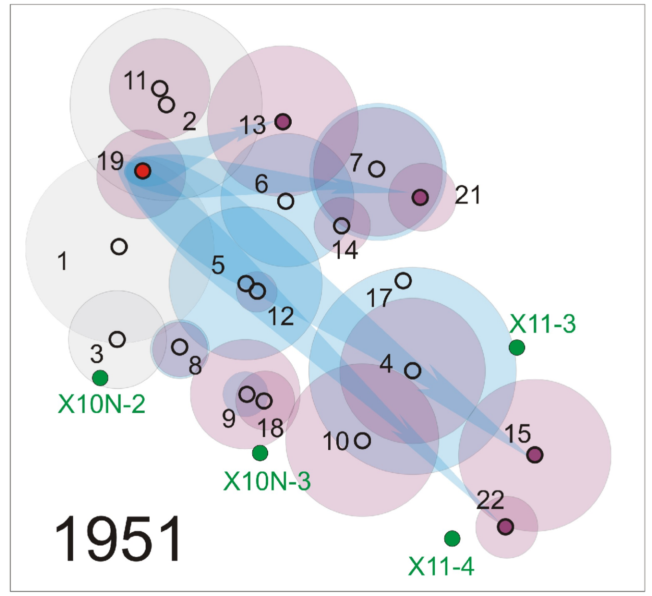
- 6 ○ solution mining location not yet drilled or abandoned well
- 11 ● "water forcing" well (conventional solution mining well)
- 4 ● air-lift well
- 13 ● deep pumping well
- 13 ● water injection well
- X11-3 ● DRIC exploratory well
- potential water and brine flow paths

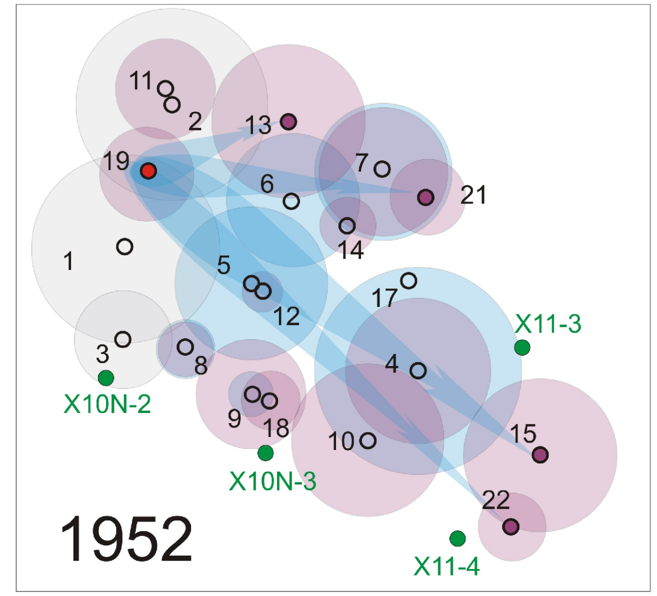
- hypothetical zone of solution mining principally from Salina Formation F unit Salt; however, salt possibly also extracted from other salt beds
- hypothetical zone of solution mining principally from Salina Formation D unit Salt; however, salt possibly also extracted from other salt beds
- hypothetical zone of solution mining principally from Salina Formation B unit Salt; however, salt possibly also extracted from other salt beds

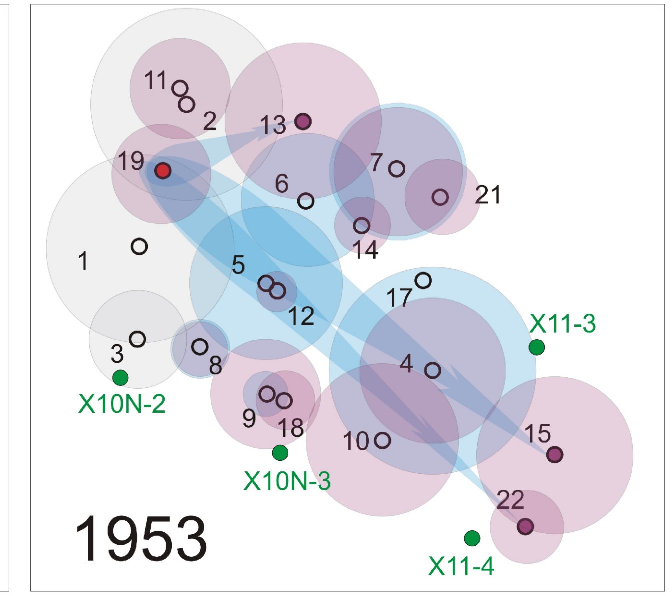
Note: This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

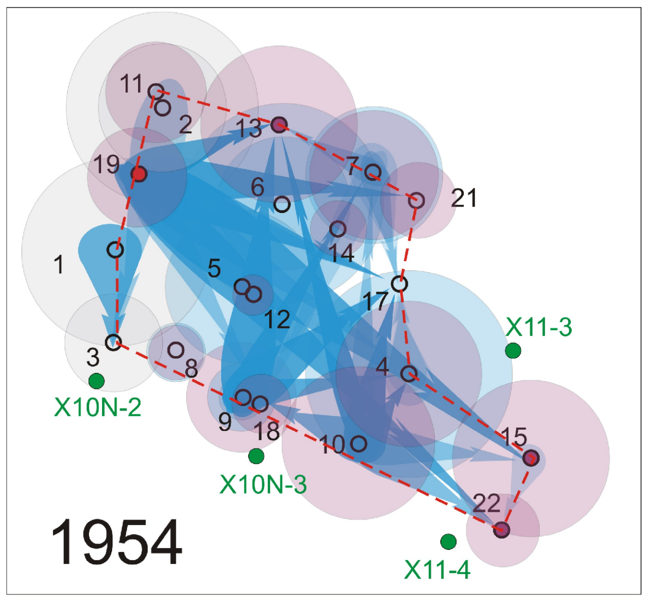
PROJECT	DETROIT RIVER INTERNATIONAL CROSSING			
TITLE	REASSESSMENT OF SANDWICH WEST SITE HISTORY			
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE NTS	REV. 0
	DESIGN	CC	24 May 2006	FIGURE: 8.51c
	GIS	JFC	21 Feb. 2008	
	CHECK	JM	21 Feb. 2008	
	REVIEW	SB	21 Feb. 2008	











1954:

For the 1954 case, all potential flow paths are superposed on the hypothetical zones of solution mining. Where paths overlap from year to year, the colour is darker so as to qualitatively and illustrate the potential duration and severity of dissolution relative to other areas of the site.

LEGEND

- 6 ○ solution mining location not yet drilled or abandoned well
- 11 ● "water forcing" well (conventional solution mining well)
- 4 ● air-lift well
- 13 ● deep pumping well
- 13 ● water injection well
- X11-3 ● DRIC exploratory well
- potential water and brine flow paths

- hypothetical zone of solution mining principally from Salina Formation F unit Salt; however, salt possibly also extracted from other salt beds
- hypothetical zone of solution mining principally from Salina Formation D unit Salt; however, salt possibly also extracted from other salt beds
- hypothetical zone of solution mining principally from Salina Formation B unit Salt; however, salt possibly also extracted from other salt beds

Note: This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

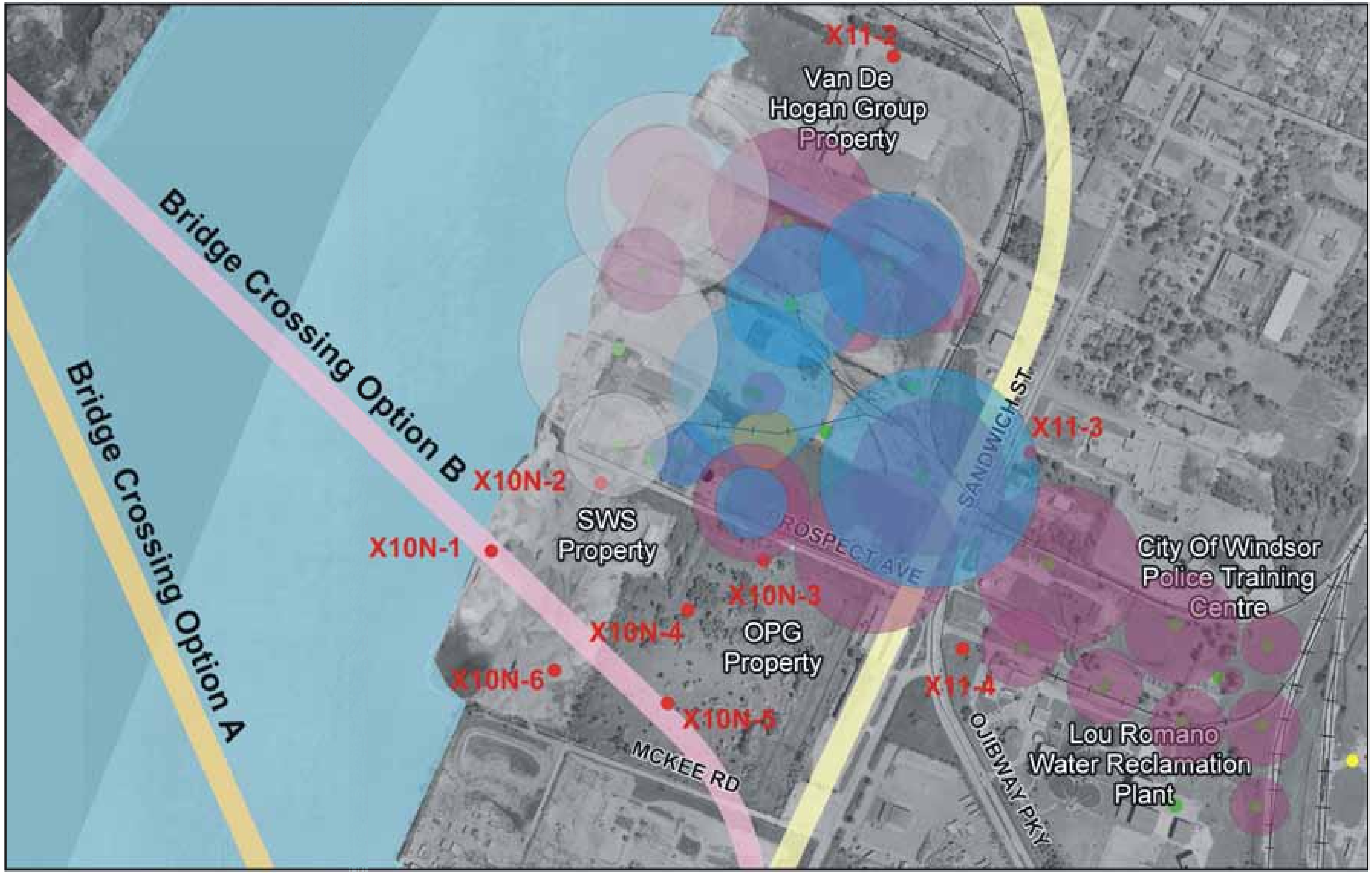
TITLE

REASSESSMENT OF SANDWICH WEST SITE HISTORY

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 0
DESIGN	CC	24 May 2006	FIGURE: 8.51d	
GIS	JFC	21 Feb. 2008		
CHECK	JM	21 Feb. 2008		
REVIEW	SB	21 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.51d Re-Assessment of Sandwich West Site History.mxd



LEGEND

- New Exploratory Wells
- Other Wells or Boreholes
- Cavern Storage Well
- Solution Mining Well
- Major Road
- Local Road
- Railway
- Sinkhole, 1954
- Water
- Hypothetical zone of solution mining principally from Salina Formation F unit Salt; however, salt possibly also extracted from D Member.
- Hypothetical zone of solution mining principally from Salina Formation D unit Salt through ca. 1930. Salt also removed from F and B units.
- Hypothetical zone of solution mining principally from Salina Formation B unit Salt after ca. 1930. Salt also possibly removed from F and D units in some areas.

NOTE:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. Zones of solution mining as shown are based on a number of simplifying assumptions and are intended only as an indicator of potential salt removal areas based on historical information. Salt was removed from areas within the brine well field between wells and these areas are not shown.

PROJECT

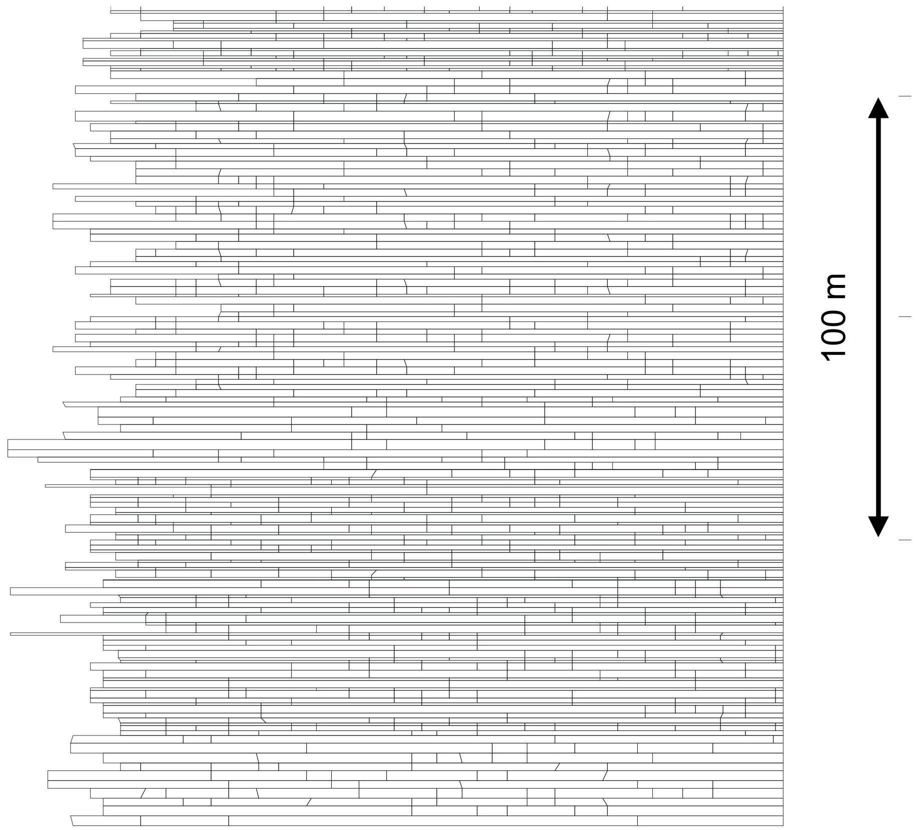
DETROIT RIVER INTERNATIONAL CROSSING

TITLE

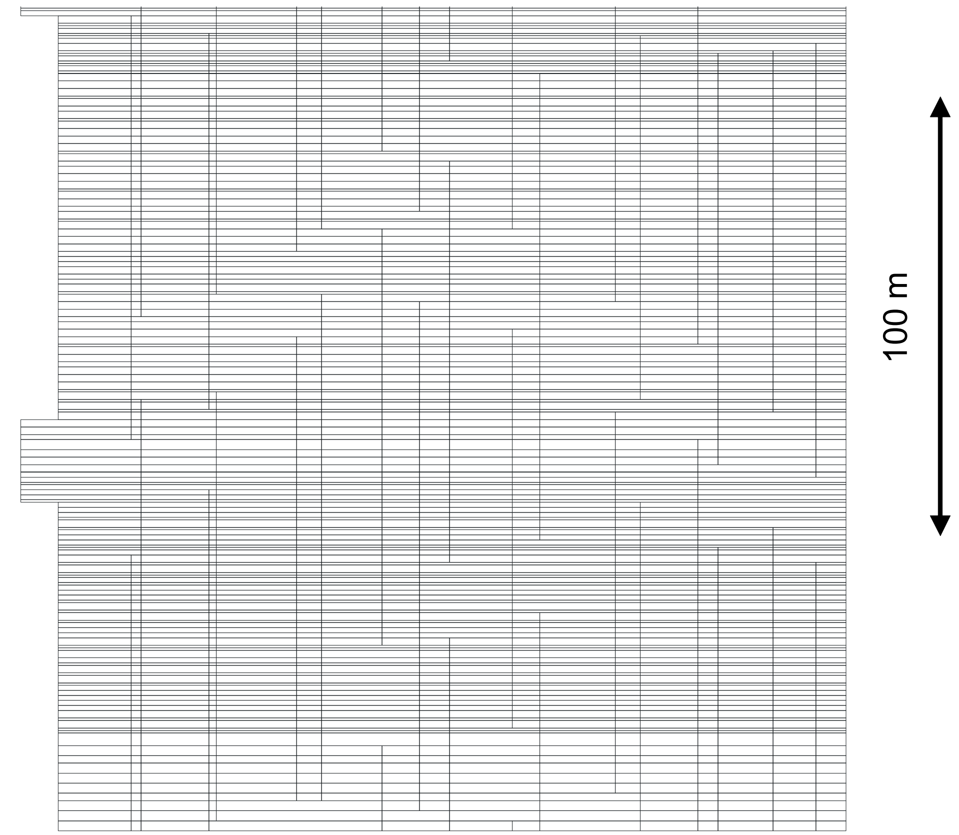
HYPOTHETICAL INFLUENCE OF INDIVIDUAL SOLUTION MINING WELLS

Golder Associates
Mississauga, Ontario

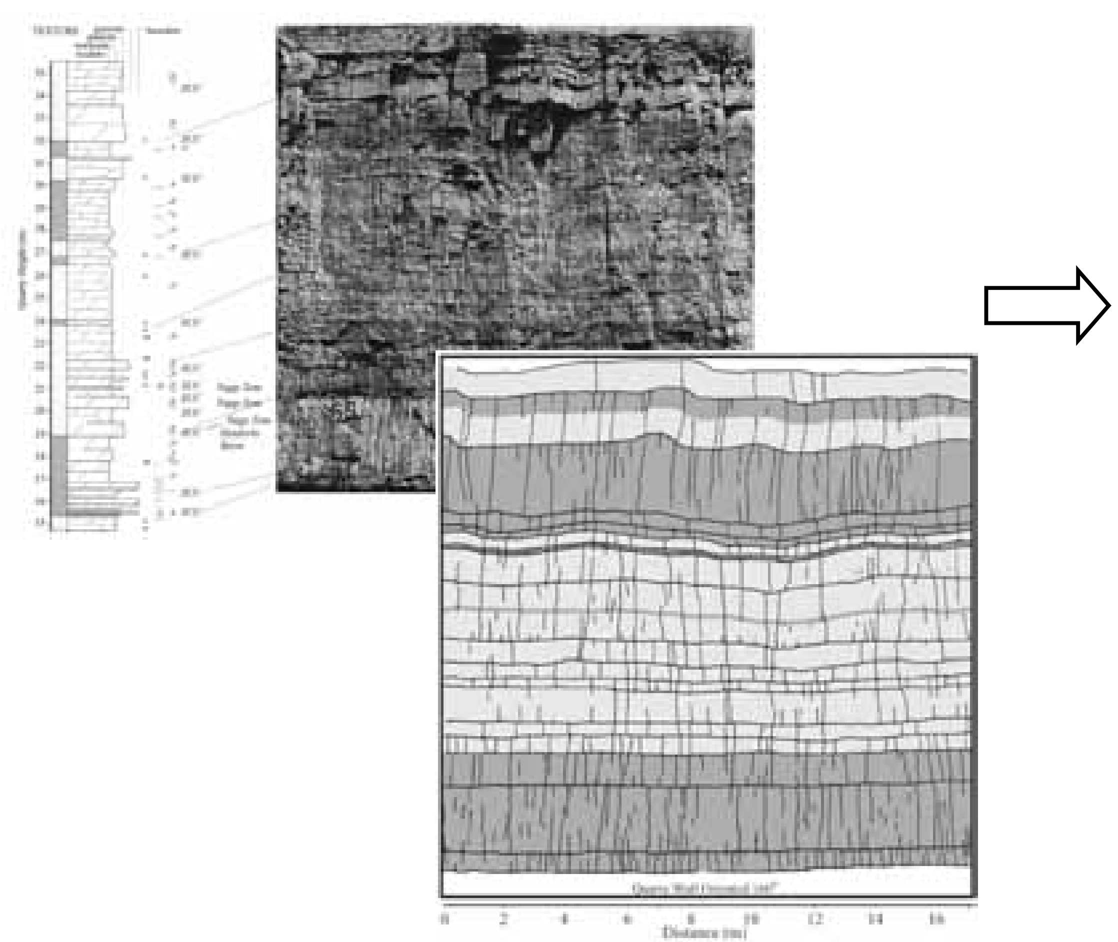
PROJECT No. 04-1111-060			SCALE NTS	REV. 0
DESIGN	CC	21 Sept. 2004	**FIGURE: 8.52**	
GIS	JFC	22 Feb. 2008		
CHECK	JM	22 Feb. 2008		
REVIEW	SB	22 Feb. 2008		

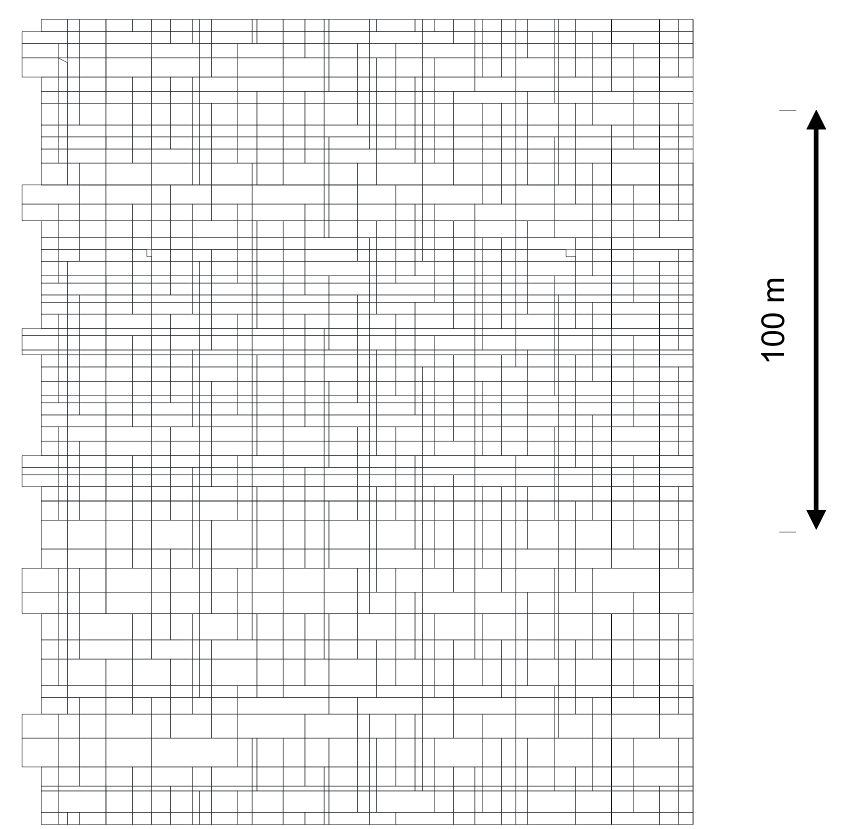


Discontinuous Vertical Joint Model Mesh



Large Vertical Joint Model Mesh





"Block" Joint Model Mesh

Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. Images and diagram of vertical jointing patterns from Underwood, C.A., Cooke, M.L., Simo, J.A. and Muldoon, M.A. (2003) Stratigraphic controls on vertical fracture patterns in Silurian dolomite, northeastern Wisconsin. American Association of Petroleum Geologists, Bulletin, Vol. 87, No. 1, 121–142.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

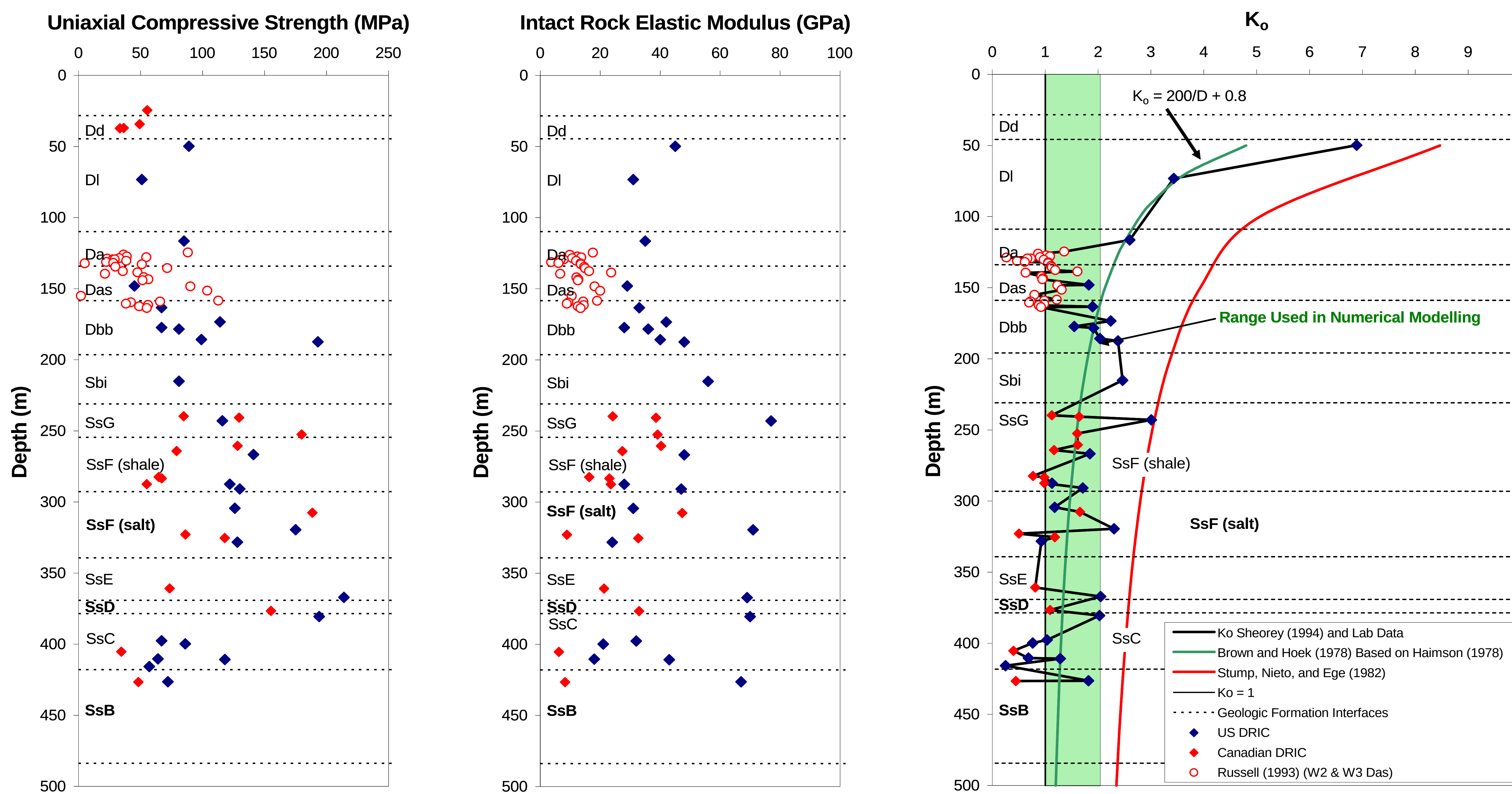
TITLE

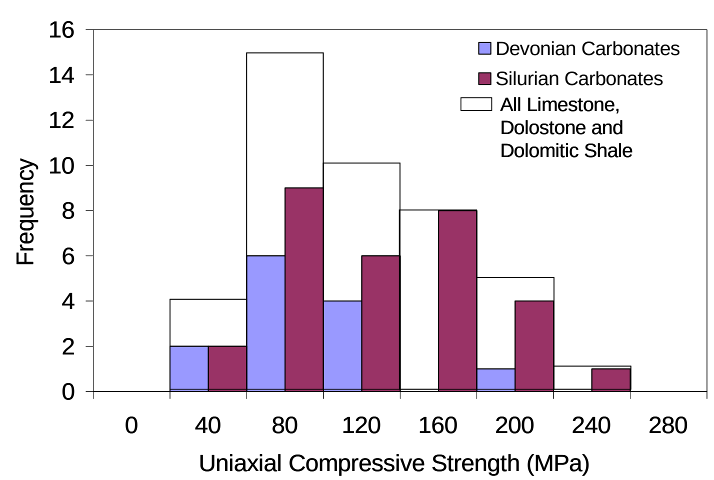
HORIZONTAL AND VERTICAL BEDDING/JOINT PATTERNS FOR UDEC MODELLING

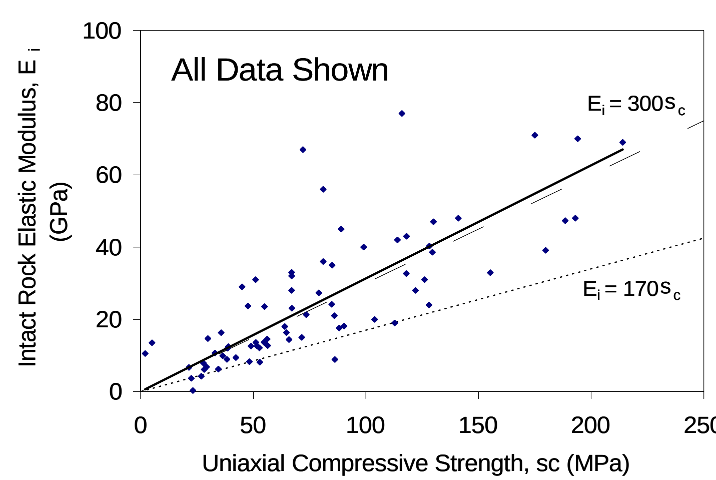
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.53**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.53_HORIZONTAL AND VERTICAL BEDDING_JOINT PATTERNS FOR UDEC MODELLING.mxd







Notes:

1. Data from Russell (1993) exploration locations W2 and W3 and US DRIC data from TB -7 and TB-11 adjusted in elevation to match geologic profile elevations at location of Sandwich West solution mining site.
2. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites ".

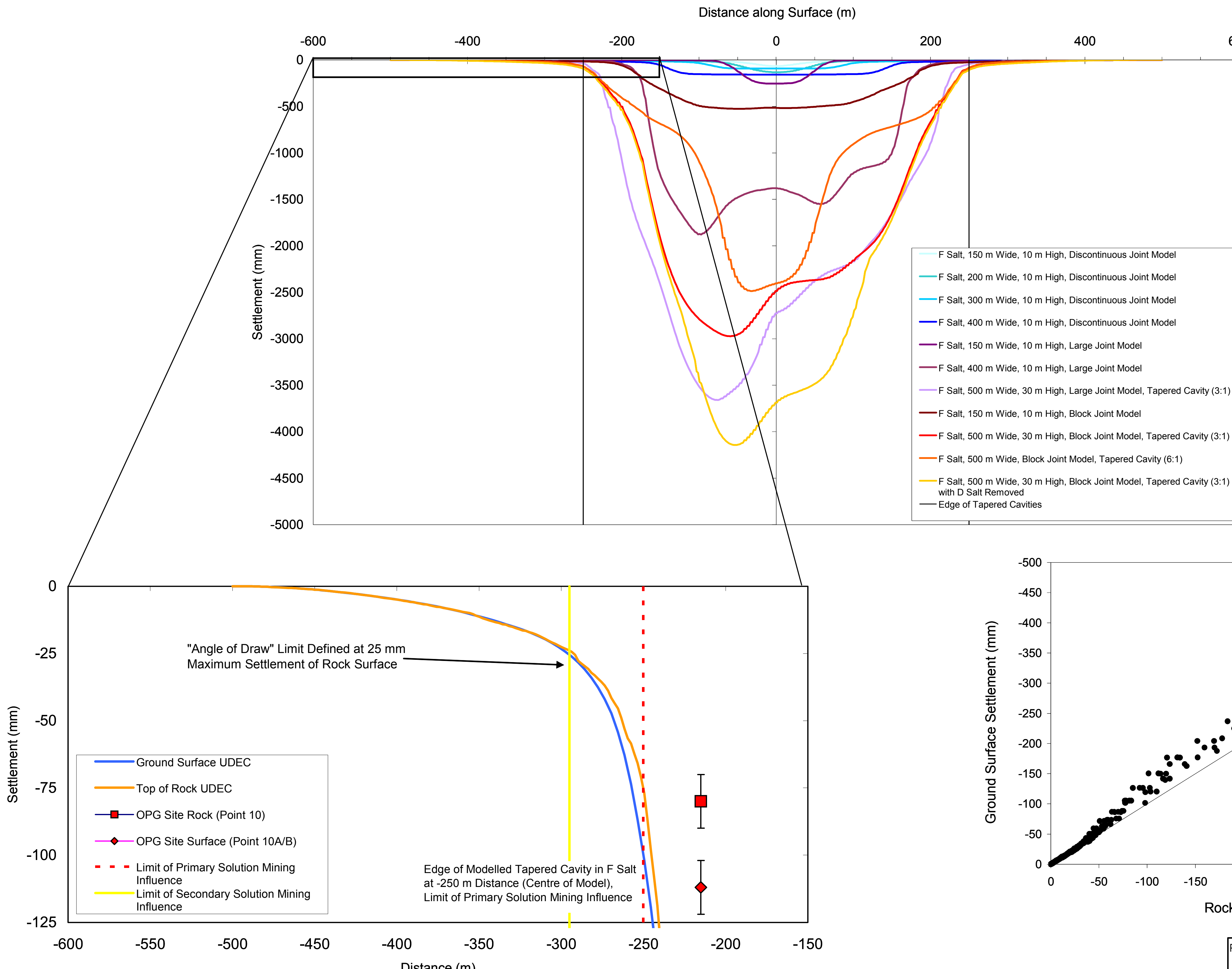
PROJECT	DETROIT RIVER INTERNATIONAL CROSSING
TITLE	PROFILE OF LABORATORY TEST DATA AND ESTIMATED K_o

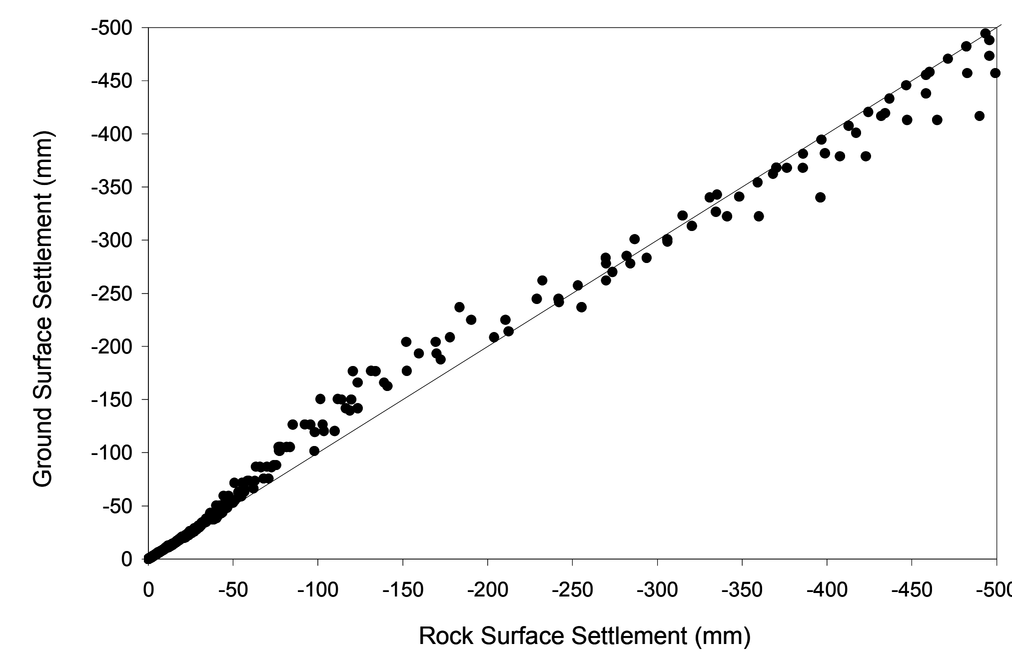
Golder Associates, Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS
DESIGN	CC	24 May 2006	REV. 1
GIS	JFC	22 Feb. 2008	
CHECK	JM	22 Feb. 2008	
REVIEW	SB	22 Feb. 2008	

FIGURE: 8.54

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.54_Estimated Ko Profile.mxd





Notes:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

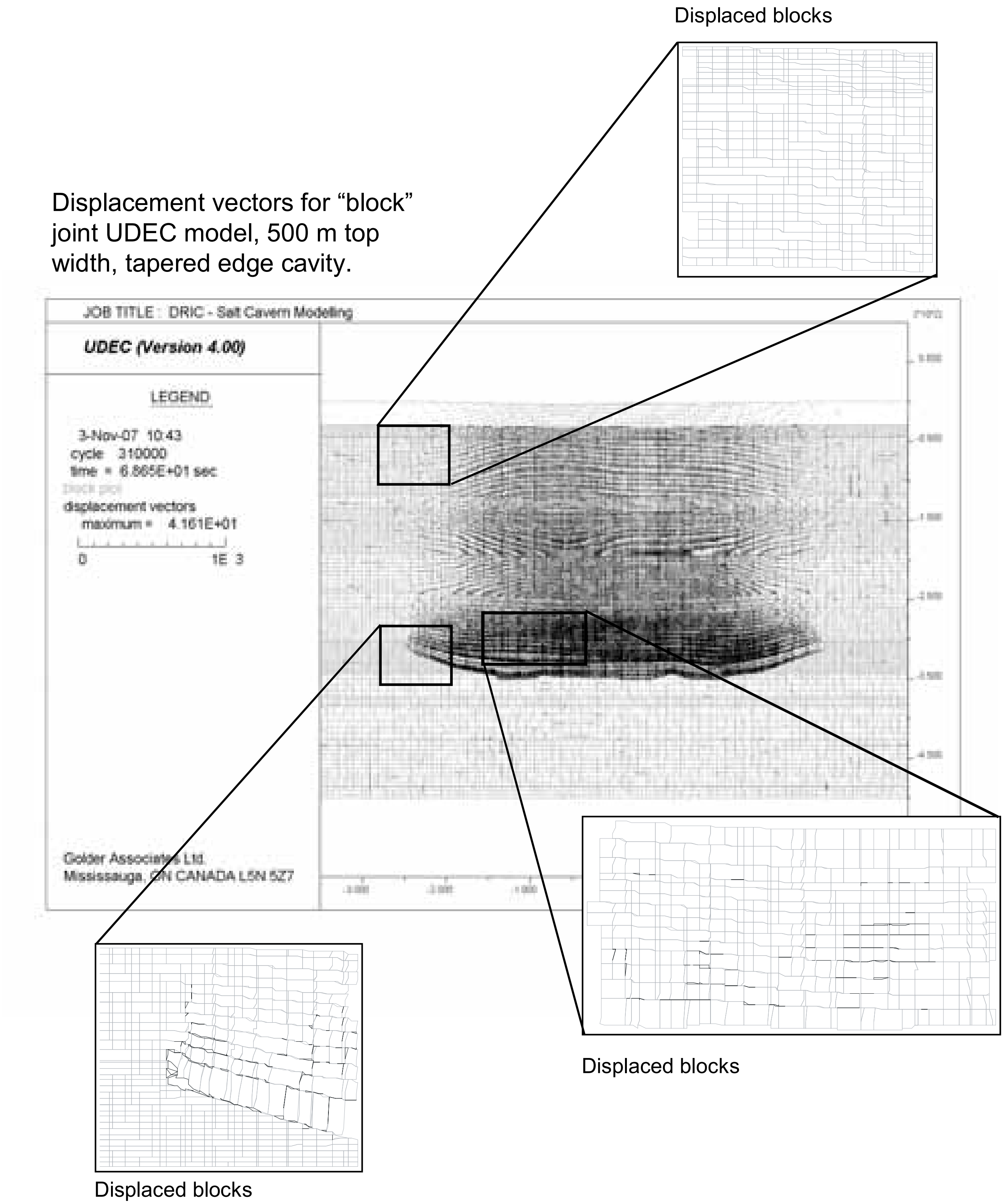
TITLE
SURFACE DISPLACEMENT PROFILES UDEC RESULTS

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 0
DESIGN	CC	24 May 2006	**FIGURE: 8.55**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.55_SURFACE DISPLACEMENT PROFILES_UDEC RESULTS.mxd

Displacement vectors for “block” joint UDEC model, 500 m top width, tapered edge cavity.

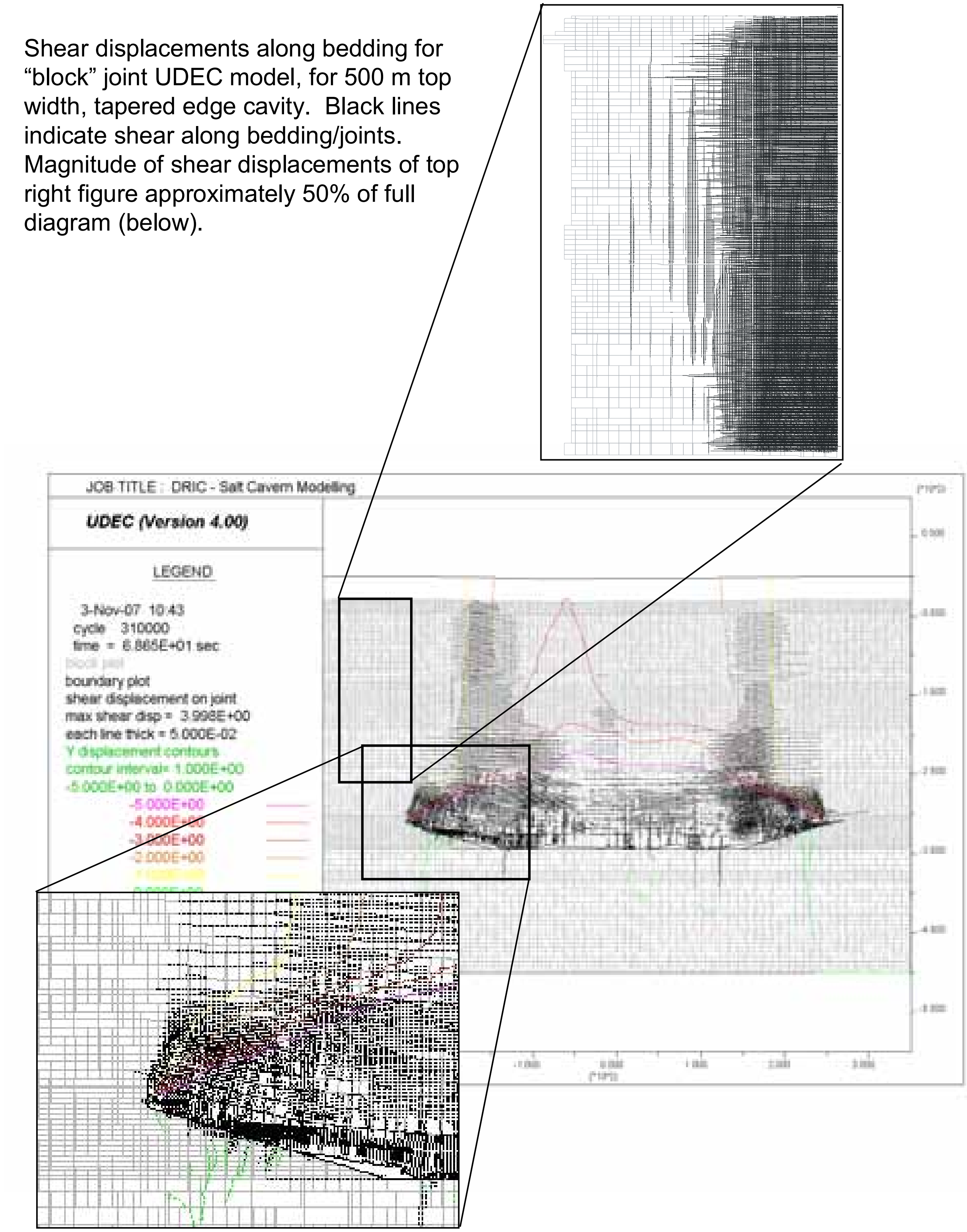


NOTE:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

PROJECT	DETROIT RIVER INTERNATIONAL CROSSING				
TITLE	**PATTERNS OF DISPLACEMENT UDEC RESULTS**				
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060			SCALE NTS	REV. 1
	DESIGN	CC	21 Sept. 2004	**FIGURE: 8.56**	
	GIS	JFC	20 Feb. 2008		
	CHECK	JM	20 Feb. 2008		
	REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.56_PATTERNS OF DISPLACEMENT_UDEC RESULTS.mxd

Shear displacements along bedding for "block" joint UDEC model, for 500 m top width, tapered edge cavity. Black lines indicate shear along bedding/joints. Magnitude of shear displacements of top right figure approximately 50% of full diagram (below).



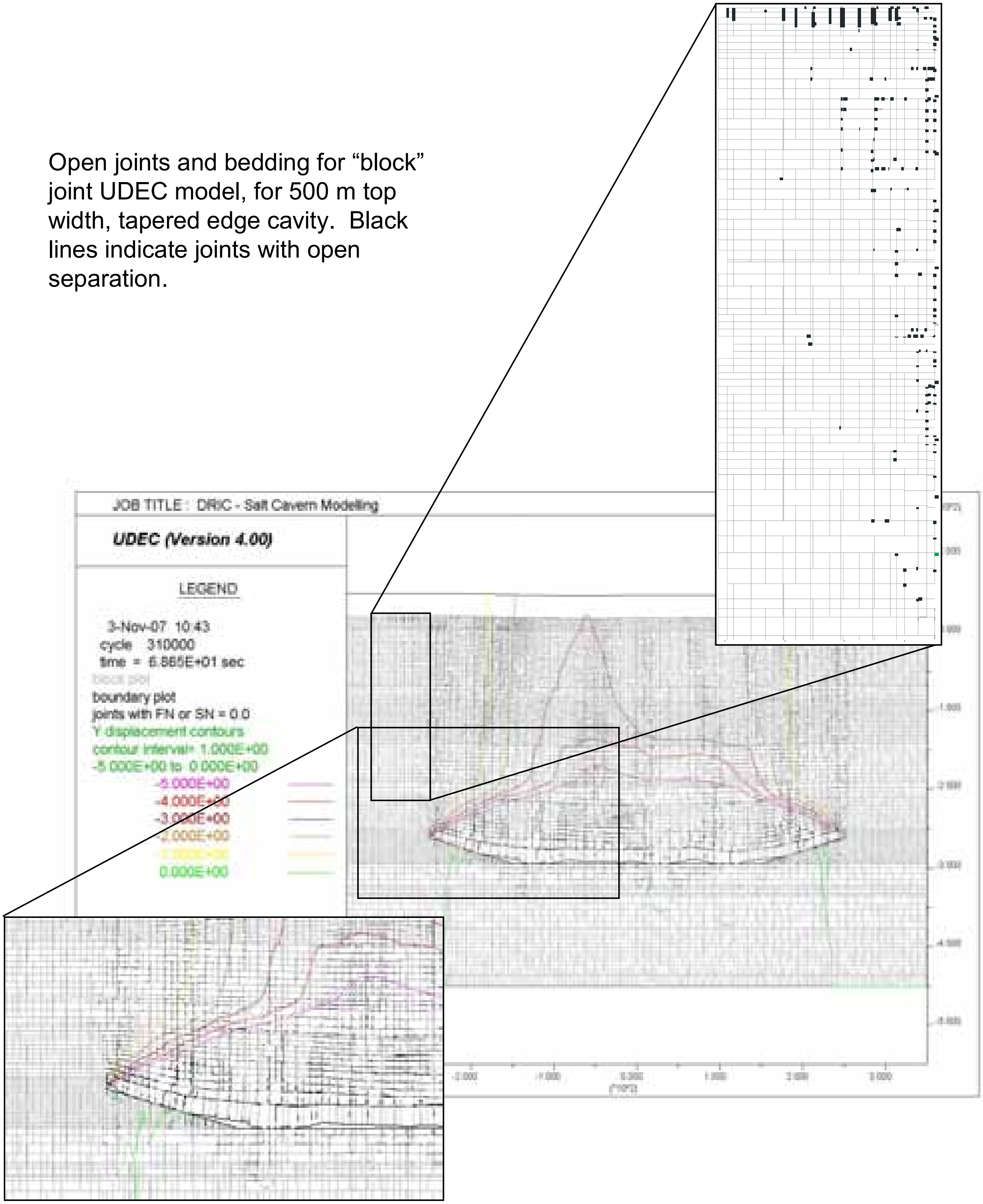
NOTE:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

PROJECT				
DETROIT RIVER INTERNATIONAL CROSSING				
TITLE: **SHEAR DISPLACEMENTS SURROUNDING TRAPEZOIDAL CAVITY IN F SALT, UDEC RESULTS**				
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060			SCALE NTS / REV. 1
	DESIGN	CC	21 Sept. 2004	**FIGURE: 8.57**
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.57_SHEAR DISPLACEMENTS SURROUNDING TRAPEZOIDAL CAVITY IN F SALT_UDEC RESULTS.mxd

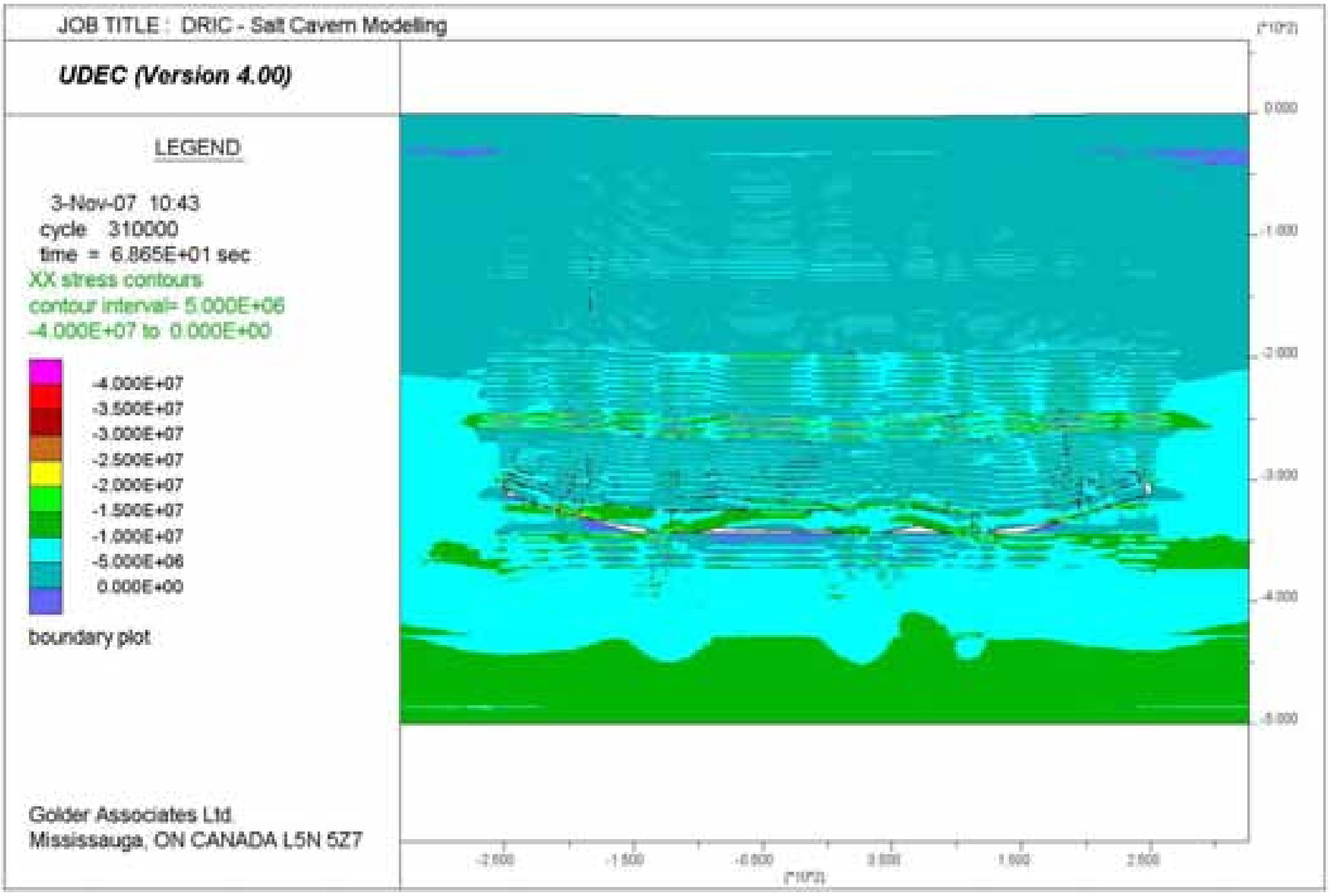
G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.58_JOINT OPENINGS SURROUNDINGTRAPEZOIDAL CAVITY IN F SALT_UDEC RESULTS .mxd

Open joints and bedding for "block" joint UDEC model, for 500 m top width, tapered edge cavity. Black lines indicate joints with open separation.



NOTE:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

PROJECT	DETROIT RIVER INTERNATIONAL CROSSING			
TITLE	JOINT OPENINGS SURROUNDING TRAPEZOIDAL CAVITY IN F SALT, UDEC RESULTS			
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE NTS	REV. 1
	DESIGN	CC	21 Sept. 2004	FIGURE: 8.58
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	



NOTE:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

PROJECT

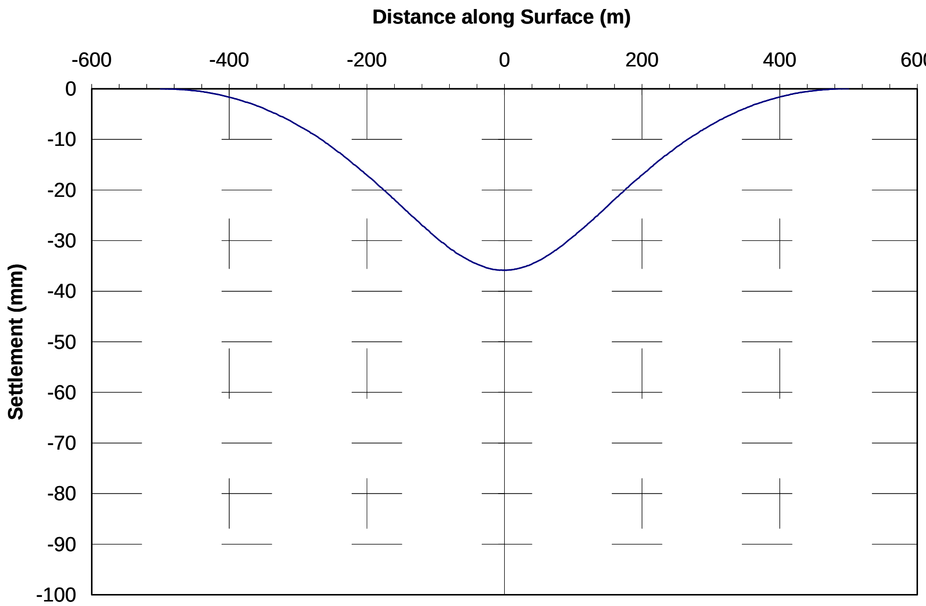
DETROIT RIVER INTERNATIONAL CROSSING

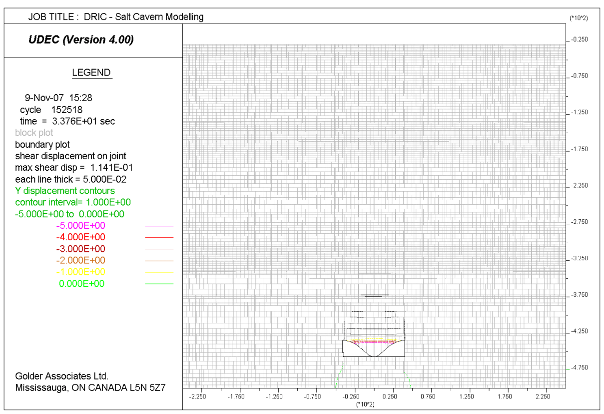
TITLE

HORIZONTAL STRESS SURROUNDING TRAPEZOIDAL CAVITY IN F SALT, UDEC RESULTS

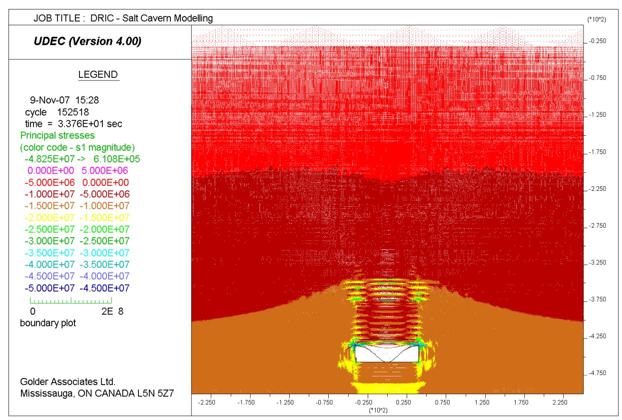
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE NTS	REV. 1
	DESIGN	CC	21 Sept. 2004	**FIGURE: 8.59**
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.59_HORIZONTAL STRESS SURROUNDINGTRAPEZOIDAL CAVITY IN F SALT UDEC RESULTS.mxd

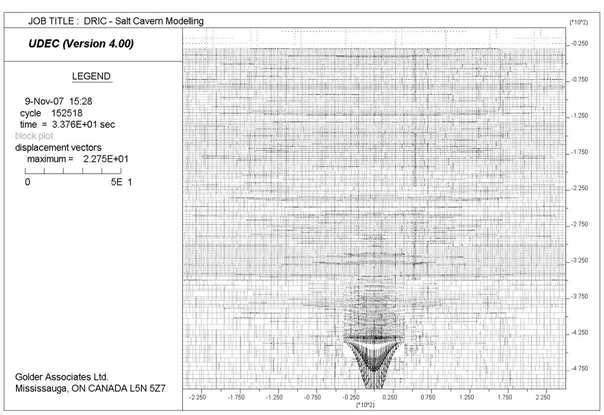




Shear Displacements



Major Principal Stress



Displacement Vectors

NOTE:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

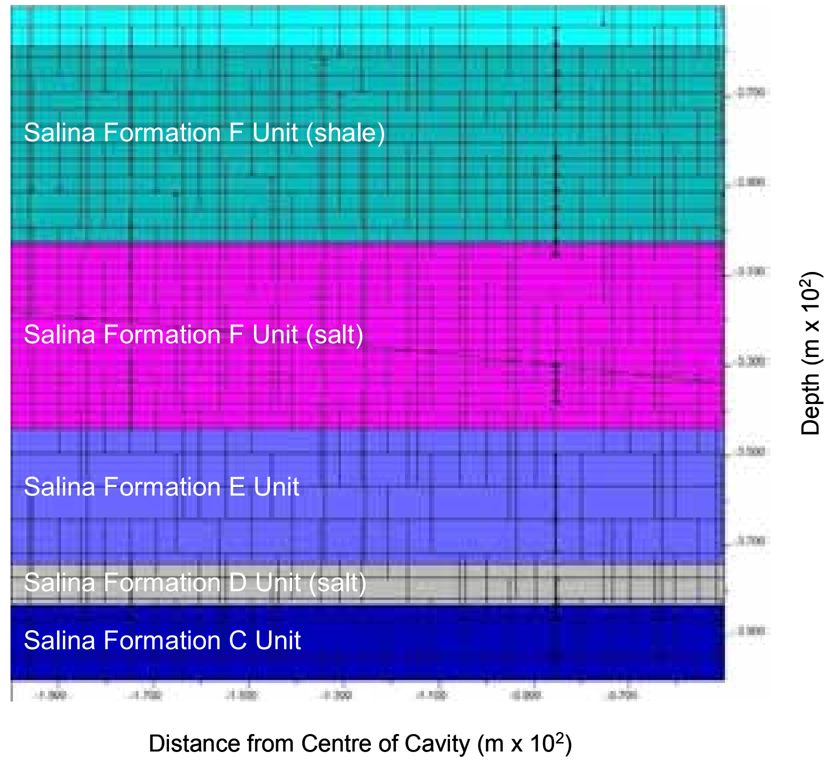
TITLE

DISPLACEMENTS AT BP CAVERN 32/33
UDEC RESULTS

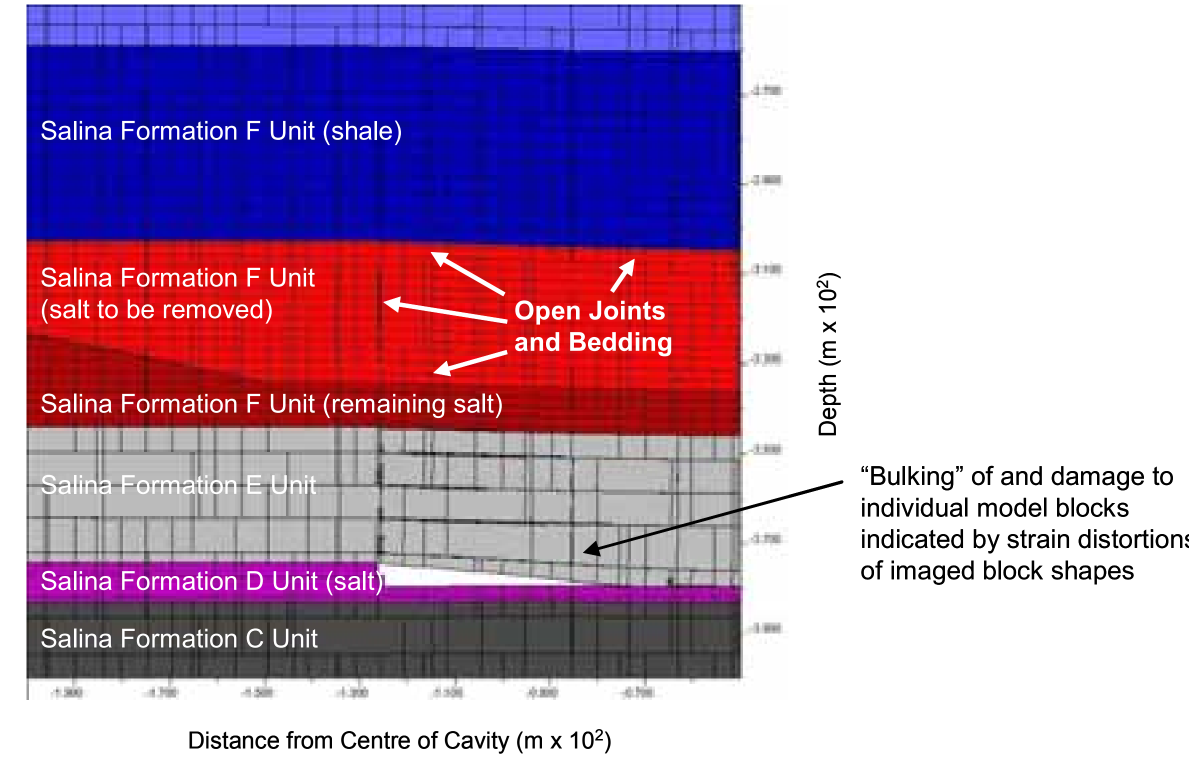
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	CC	21 Sept. 2004	FIGURE: 8.60	
GIS	JFC	22 Feb. 2008		
CHECK	JM	22 Feb. 2008		
REVIEW	SB	22 Feb. 2008		

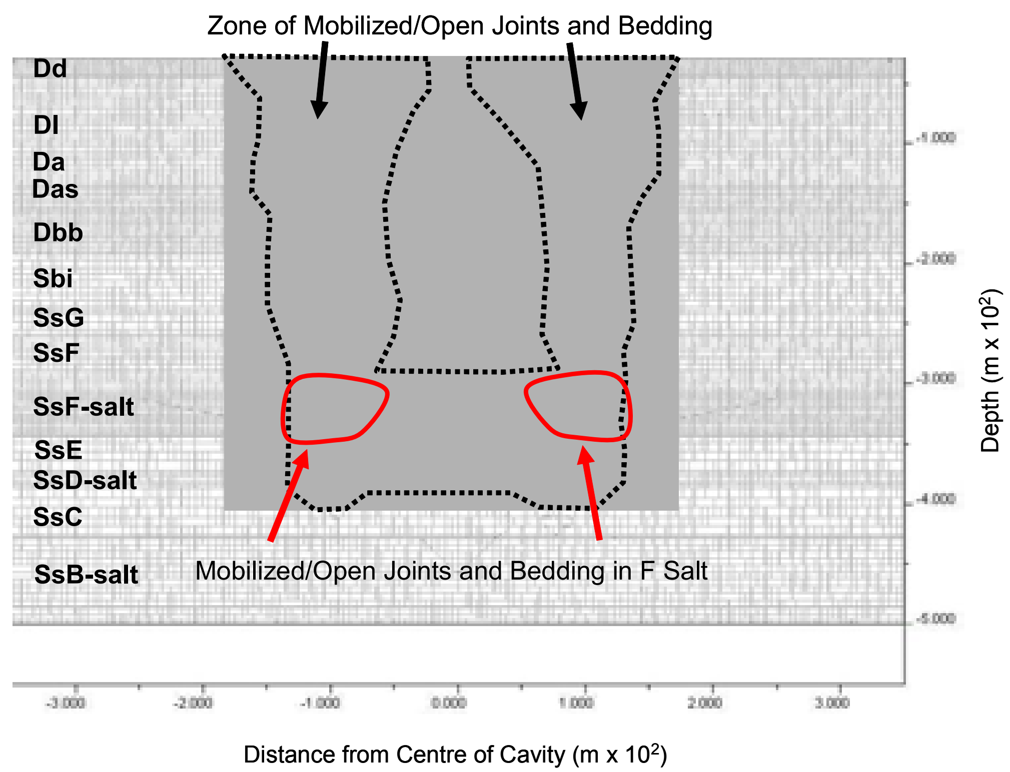
INITIAL CONDITIONS



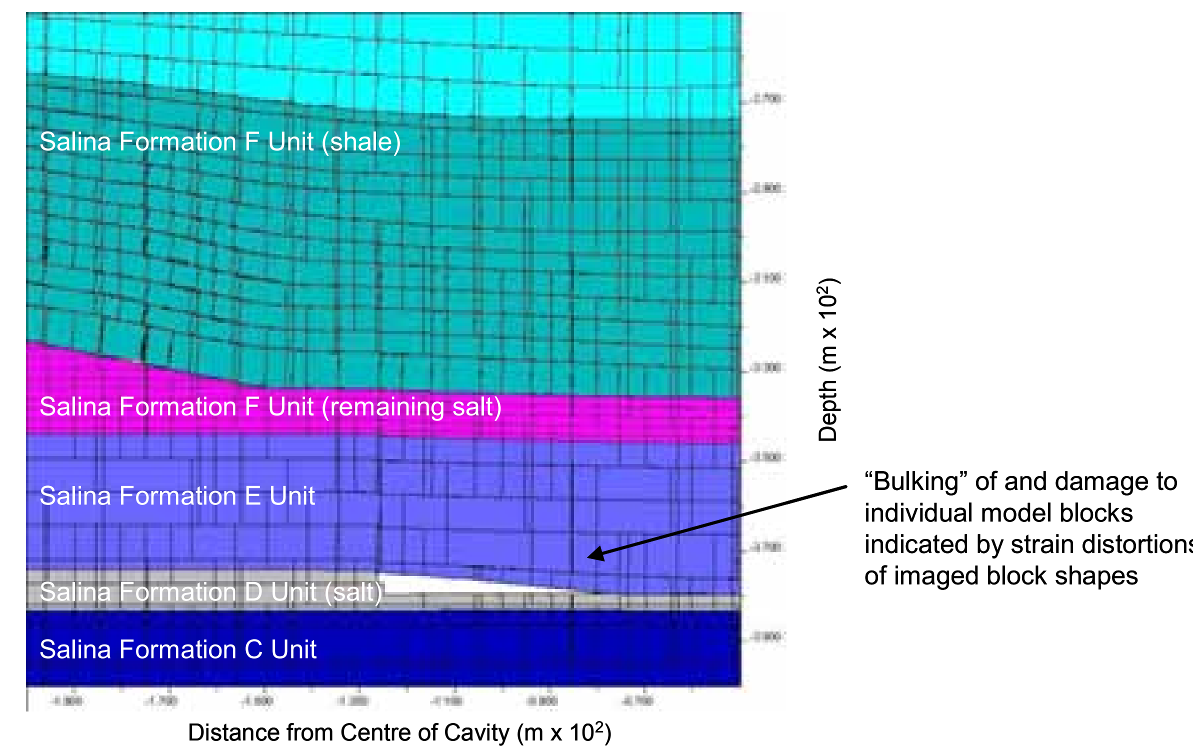
AFTER REMOVAL OF D SALT



AFTER REMOVAL OF D SALT



AFTER REMOVAL OF F SALT



Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. Colours of formations determined by computational step and are not representative of formation legend in other figures.
3. Removed thickness of salt is representative of cumulative thickness of salt beds and not of formation thickness. Individual salt beds within formation are not shown and were not modelled separately.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

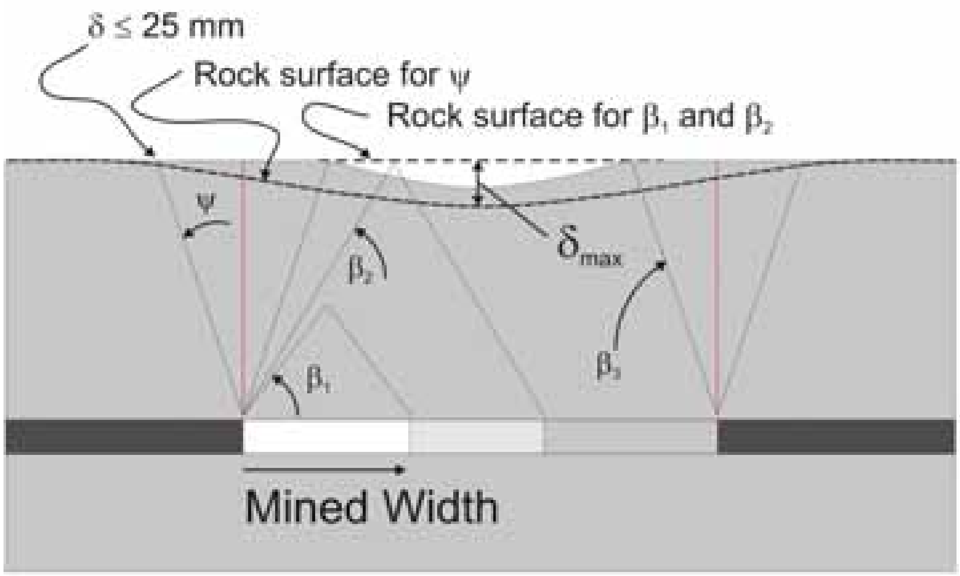
TITLE

MECHANISM FOR SINKHOLE FORMATION SANDWICH WEST SITE

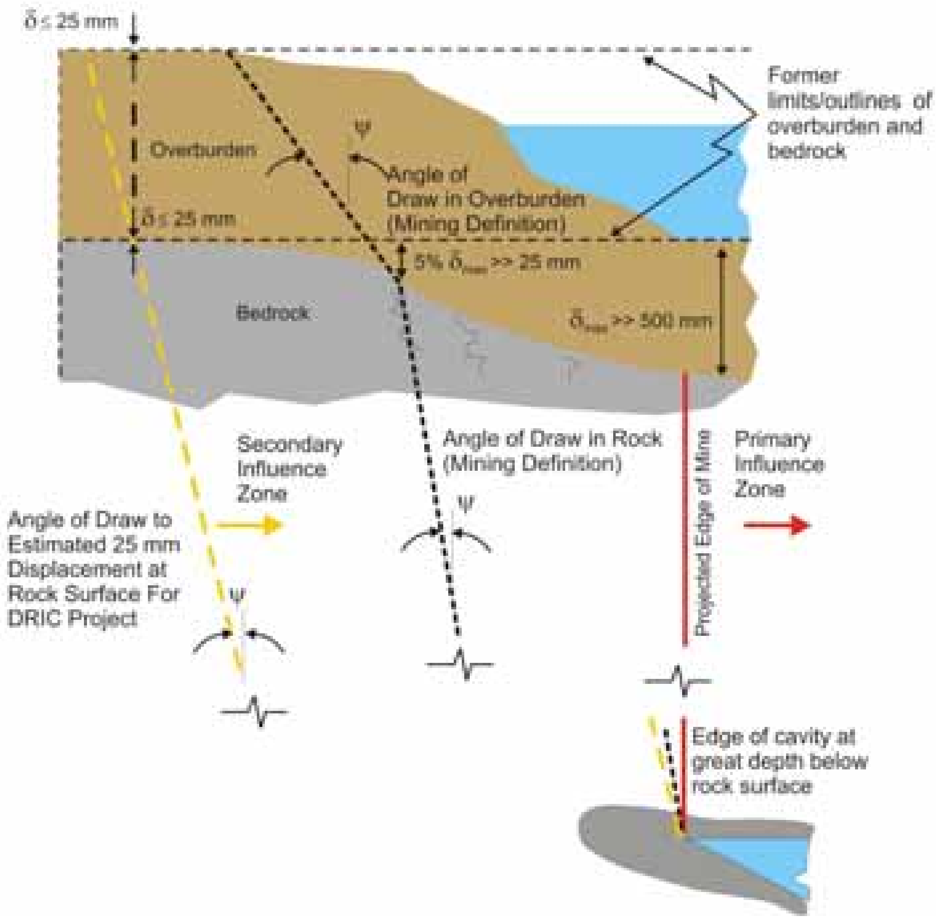
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 8.61**	
GIS	JFC	22 Feb. 2008		
CHECK	JM	22 Feb. 2008		
REVIEW	SB	22 Feb. 2008		

General Mining Case with DRIC Criteria



Application of "Angle of Draw" Concept to DRIC Project



β = caving angle: 1 sub-critical, 2 critical, 3 supercritical
ψ = angle of draw
δ = settlement

NOTE:
1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

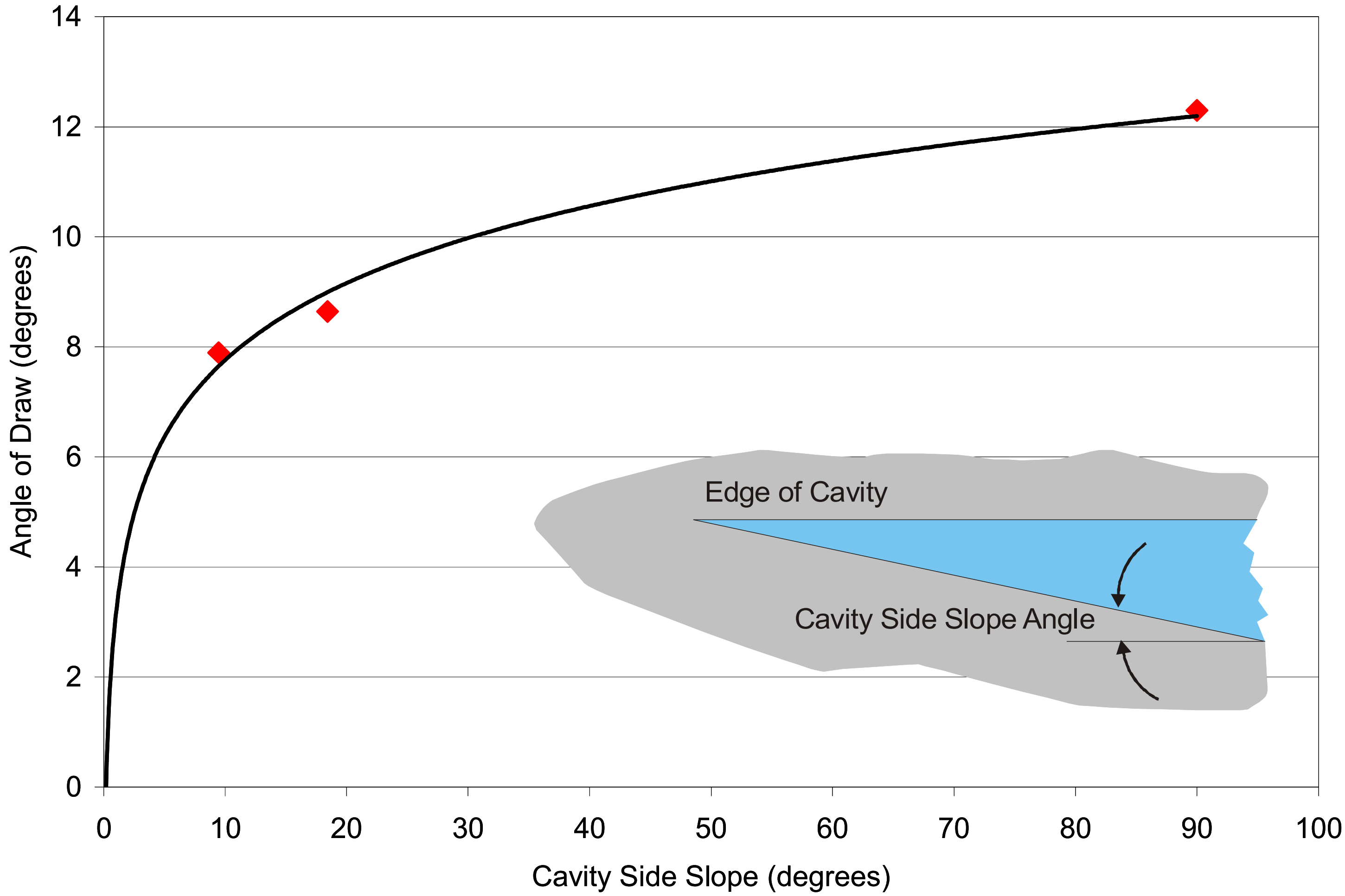
PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

TITLE
ANGLE OF DRAW DEFINITION

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 1
DESIGN	PB	10 Jan. 2008	**FIGURE: 8.62**	
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.62_ANGLE_OF_DRAW_DEFINITION.mxd



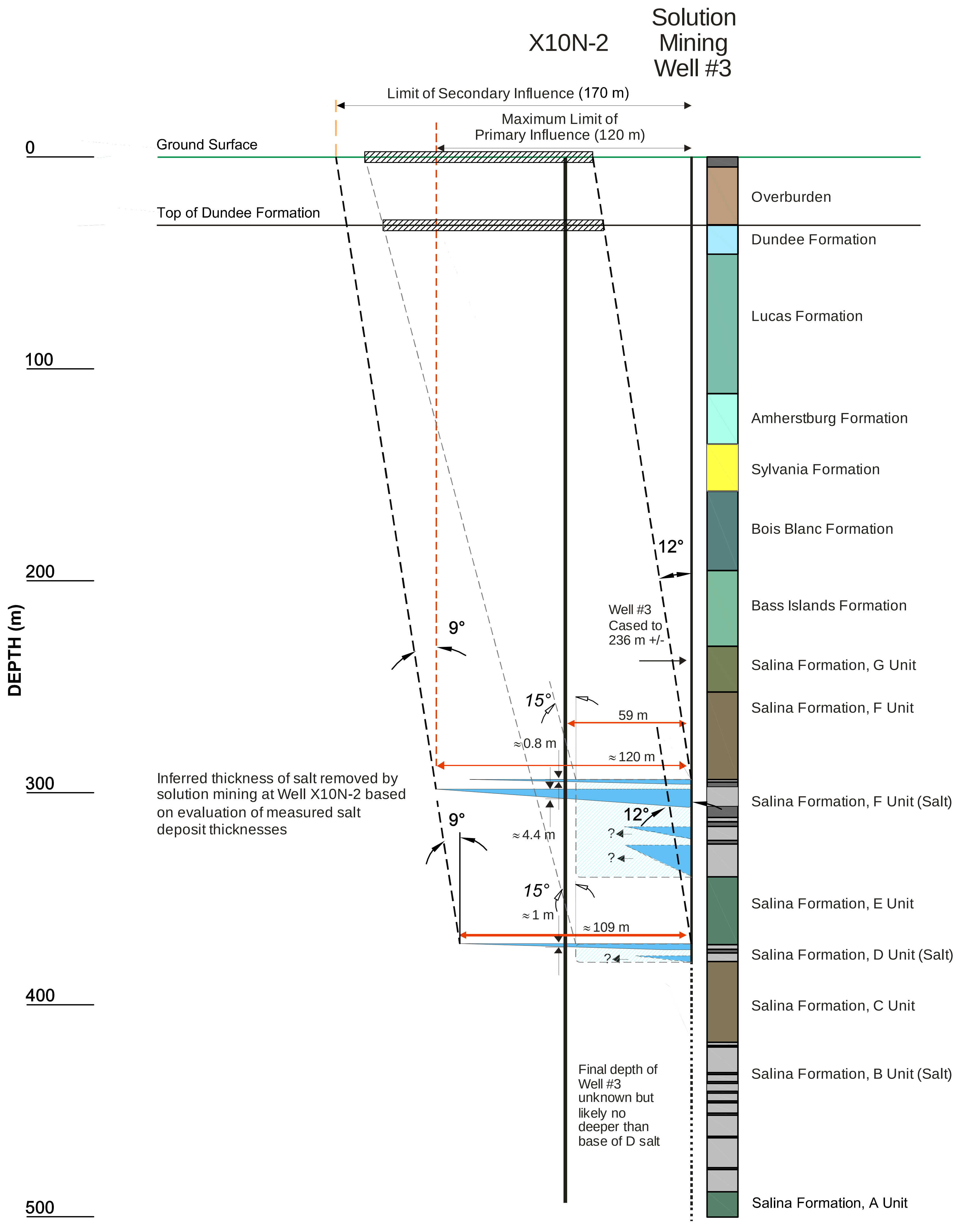
Notes:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".
2. Angle of draw defined based on the distance from cavity edge to the point on rock surface where numerical modelling indicated displacements on the order of 25 mm or less
3. Data points derived from UDEC numerical modelling using "block" joint model. See report text for discussion of assumptions and modelling results.

PROJECT				
DETROIT RIVER INTERNATIONAL CROSSING				
TITLE				
ANGLE OF DRAW AND CAVITY SHAPE				
Golder Associates, Mississauga, Ontario	PROJECT No. 04-1111-060		SCALE NTS	REV. 1
	DESIGN	PB	10 Jan. 2008	**FIGURE: 8.63**
	GIS	JFC	20 Feb. 2008	
	CHECK	JM	20 Feb. 2008	
	REVIEW	SB	20 Feb. 2008	

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.63_ANGLE_OF_DRAW_AND_CAVITY_SHAPE.mxd

PLOT DATE: February 21, 2008
FILENAME: N:\active\projects - other offices\Mississauga\2004\04-1111-060 URS Detroit River International Crossing\04-1111-060B Report Figures\041111060-R01-8_6.dwg



LEGEND

ESTIMATED EXTENT OF FORMER CAVITY BASED ON SALT BED THICKNESS DATA

ALTERNATIVE LARGE SINGLE CAVITY HYPOTHESIS

RANGE OF SECONDARY INFLUENCE LIMITS AT ROCK AND GROUND SURFACE USING ALTERNATIVE LARGE SINGLE CAVITY HYPOTHESIS

ESTIMATED CONDITIONS PRIOR TO 1954 SUBSIDENCE

Golder Associates
London, Ontario, Canada

SCALE	AS SHOWN	TITLE	
DATE	21 Feb 2008		
DESIGN			
CAD	WDF		
CHECK	JM		
REVIEW	SB		

FILE No. 041111060-R01-8_6.DWG

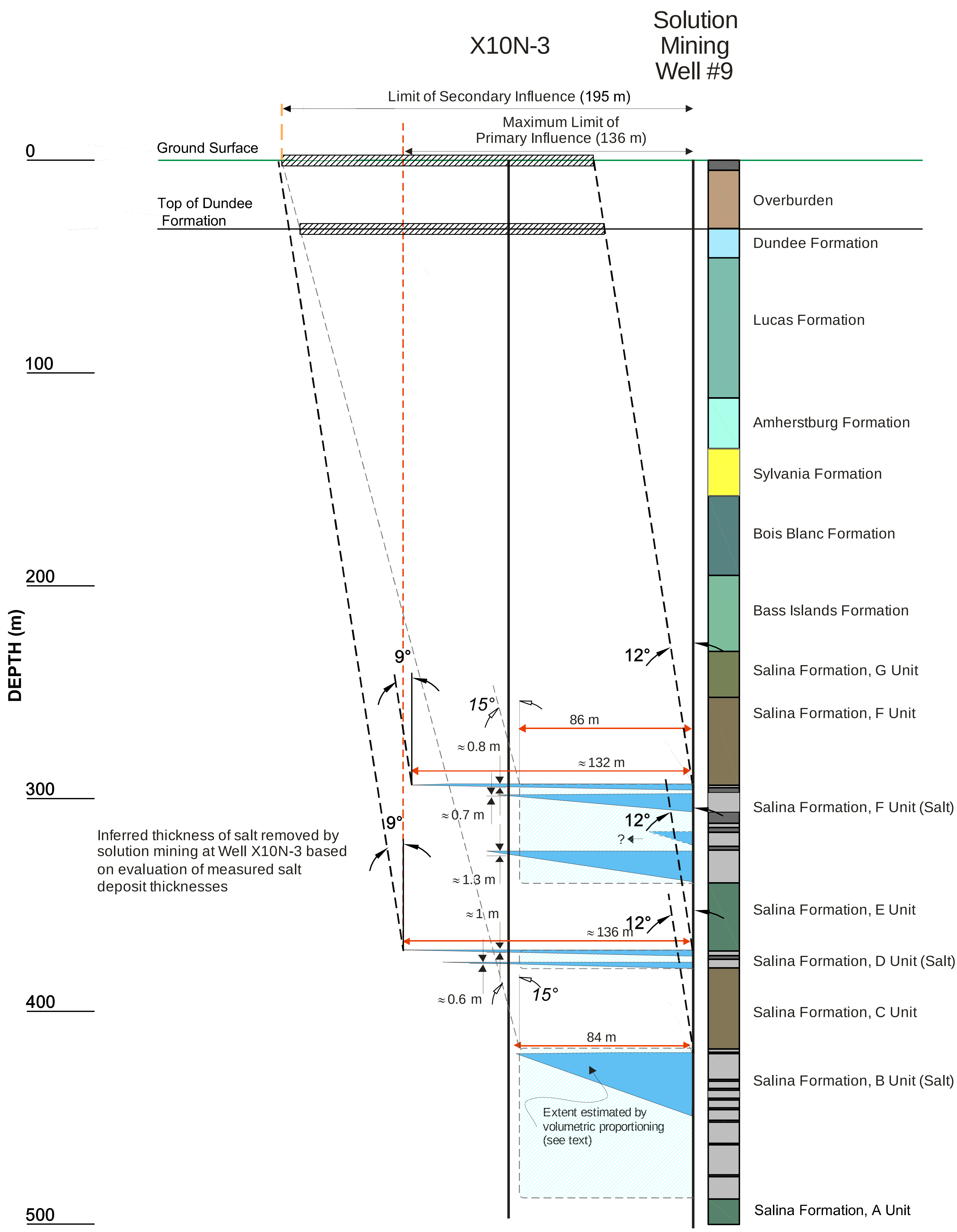
PROJECT No. 04-1111-060B REV. 0

PRIMARY AND SECONDARY INFLUENCE OF SOLUTION MINING NEAR WELL #3 (X10N-2)

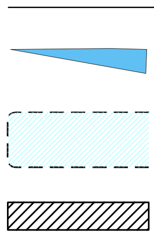
DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.64

PLOT DATE: February 21, 2008
FILENAME: N:\active\projects – other offices\Mississauga\2004\04-1111-060 URS Detroit River International Crossing\04-1111-060B Report Figures\041111060-R01-8_6.dwg



LEGEND



ESTIMATED EXTENT OF FORMER CAVITY BASED ON SALT BED THICKNESS DATA

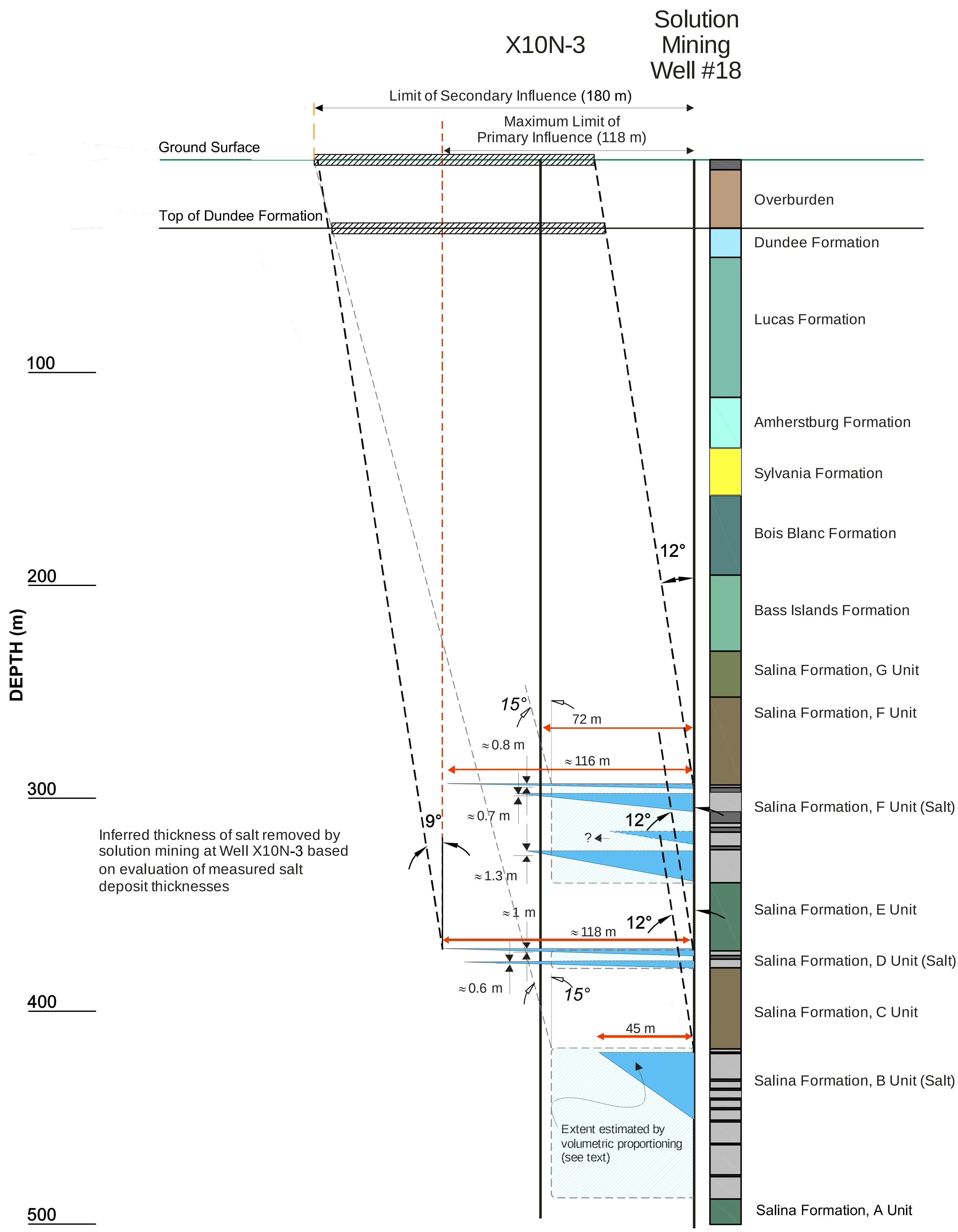
ALTERNATIVE LARGE SINGLE CAVITY HYPOTHESIS

RANGE OF SECONDARY INFLUENCE LIMITS AT ROCK AND GROUND SURFACE USING ALTERNATIVE LARGE SINGLE CAVITY HYPOTHESIS

ESTIMATED CONDITIONS PRIOR TO 1954 SUBSIDENCE

Golder Associates, London, Ontario, Canada	SCALE: AS SHOWN	TITLE: PRIMARY AND SECONDARY INFLUENCE OF SOLUTION MINING NEAR WELL #9 (X10N-3)
	DATE: 21 Feb 2008	
	DESIGN:	
	CAD: WDF	
FILE No. 041111060-R01-8_6.DWG	CHECK: JM	DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE
PROJECT No. 04-1111-060B REV. 0	REVIEW: SB	FIGURE 8.65

PLOT DATE: February 21, 2008
FILENAME: N:\active\projects - other offices\Mississauga\2004\04-1111-060 URS Detroit River International Crossing\04-1111-060B Report Figures\041111060-R01-8_6.dwg



LEGEND

ESTIMATED EXTENT OF FORMER CAVITY BASED ON SALT BED THICKNESS DATA

ALTERNATIVE LARGE SINGLE CAVITY HYPOTHESIS

RANGE OF SECONDARY INFLUENCE LIMITS AT ROCK AND GROUND SURFACE USING ALTERNATIVE LARGE SINGLE CAVITY HYPOTHESIS

ESTIMATED CONDITIONS PRIOR TO 1954 SUBSIDENCE

Golder Associates
London, Ontario, Canada

SCALE	AS SHOWN
DATE	21 Feb 2008
DESIGN	
CAD	WDF
CHECK	JM
REVIEW	SB

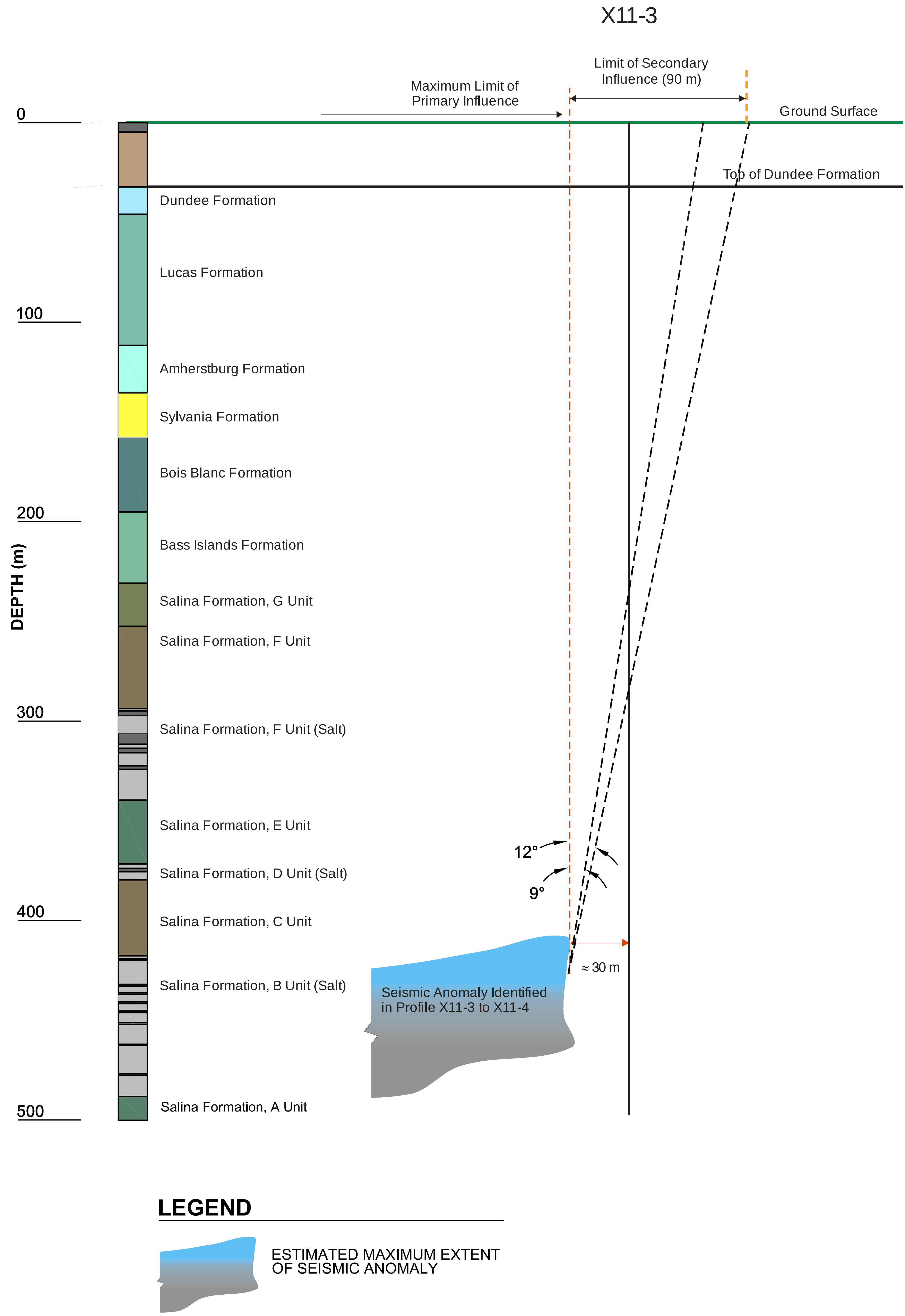
FILE No. 041111060-R01-8_6.DWG
PROJECT No. 04-1111-060B REV. 0

TITLE

PRIMARY AND SECONDARY INFLUENCE OF SOLUTION MINING NEAR WELL #18 (X10N-3)

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.66

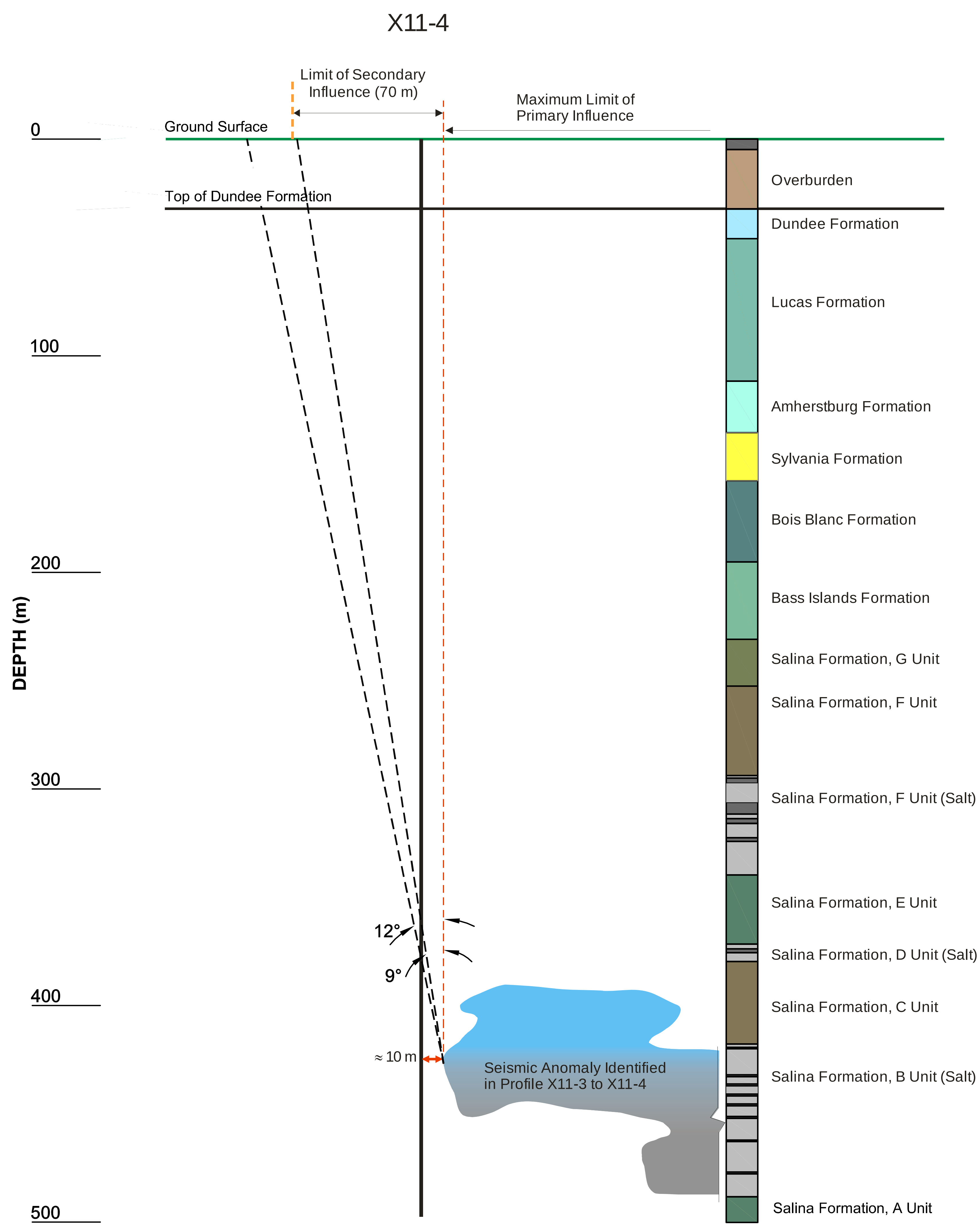


Golder Associates
London, Ontario, Canada

SCALE	AS SHOWN	TITLE	PRIMARY AND SECONDARY INFLUENCE OF SOLUTION MINING NEAR WELL X11-3
DATE	21 Feb 2008		
DESIGN			
CAD	WDF		
CHECK	JM		DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE
REVIEW	SB	FIGURE	8.67

FILE No. 041111060-R01-8_6.DWG
PROJECT No. 04-1111-060B REV. 0

PLOT DATE: February 21, 2008
FILENAME: N:\active\projects – other offices\Mississauga\2004\04-1111-060 URS Detroit River International Crossing\04-1111-060B Report Figures\041111060-R01-8_6.dwg



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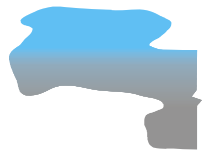


ESTIMATED MAXIMUM EXTENT OF SEISMIC ANOMALY

Golder Associates
London, Ontario, Canada

FILE No. 041111060-R01-8_6.DWG		
PROJECT No. 04-1111-060B	REV. 0	
SCALE	AS SHOWN	
DATE	21 Feb 2008	
DESIGN		
CAD	WDF	
CHECK	JM	
REVIEW	SB	

TITLE

PRIMARY AND SECONDARY INFLUENCE OF SOLUTION MINING NEAR WELL X11-4

DETROIT RIVER INTERNATIONAL CROSSING CANADA SIDE

FIGURE 8.68

LEGEND

- Rock Surface Settlement Monitoring Point (OPG)
- New Exploratory Well
- Other Wells or Boreholes
- Solution Mining Well
- Numerical Analysis Section
- Boundary of Primary Solution Mining Influence
- Boundary of Secondary Solution Mining Influence
- Radii of Secondary Infuence of Solution Mining from Wells
- Range of Radii from Maximum Settlement at Sinkhole to Estimated 25mm Settlement Position Based on Numerical Modelling
- Major Road
- Local Road
- Railway
- Sinkhole, 1954
- Water

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Orthophotos - URS, obtained 2004 and 2005
Wells from AMEC and the Ontario Ministry of Natural Resources, Oil Salt and Gas Resources Library.
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2007
Datum: NAD 83 Projection: UTM Zone 17N

0 100 200 400
Metres

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

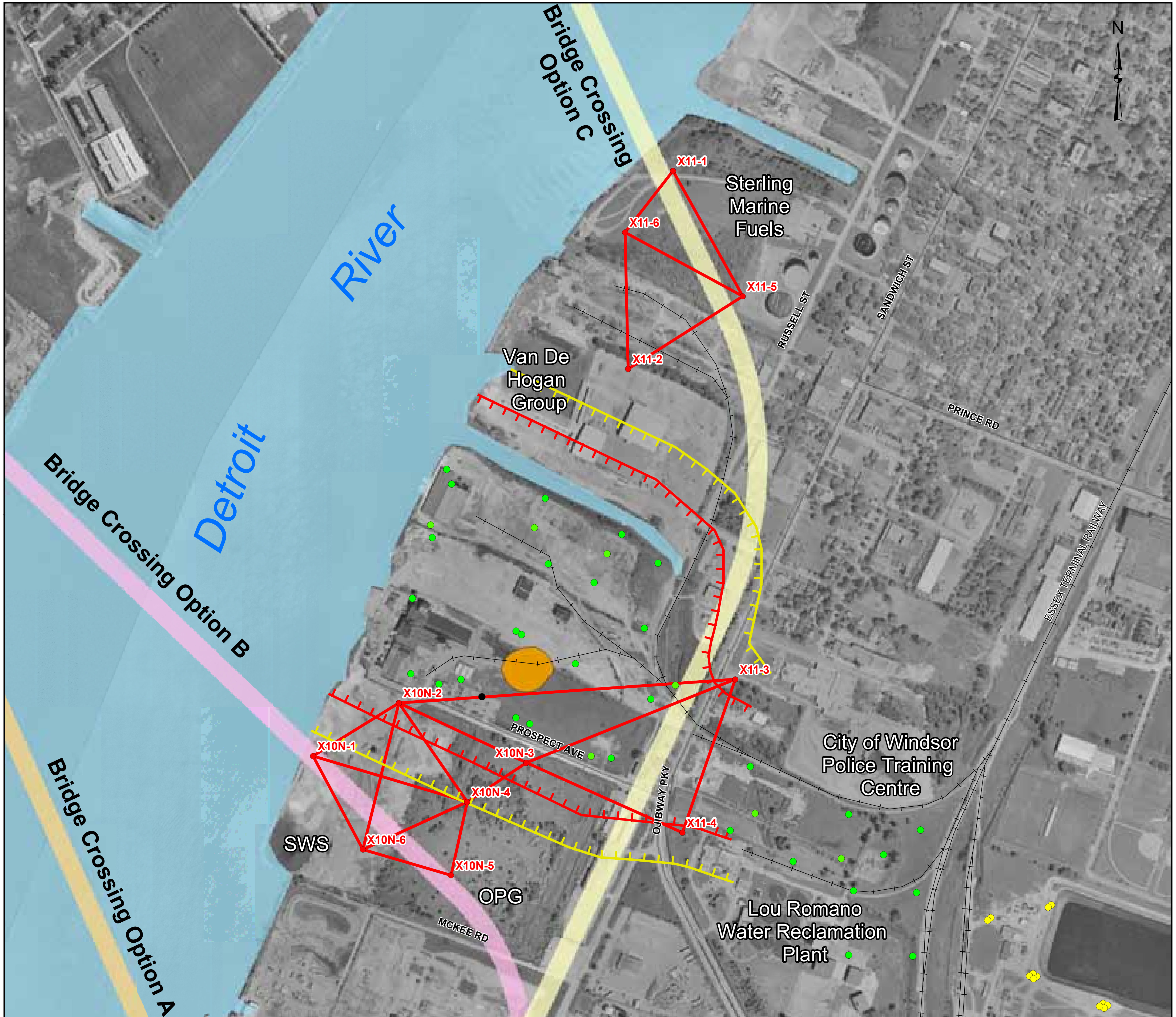
INTERPRETED LIMITS OF SOLUTION MINING INFLUENCES

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE 1:6,000	REV. 1
DESIGN	CC	24 May 2006		
GIS	JFC	20 Feb. 2008		
CHECK	JM	20 Feb. 2008		
REVIEW	SB	20 Feb. 2008		

FIGURE: 8.69

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure8.69_Interpreted_Limits_of_Solution_Mining_Influences.mxd



LEGEND

- Drilled Holes
- Other Wells or Boreholes
- Cavern Storage Well
- Solution Mining Well
- Boundary of Primary Solution Mining Influence
- Boundary of Secondary Solution Mining Influence
- Cross Well Profiles
- Major Road
- Local Road
- Sinkhole, 1954
- Water

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Orthophotos - URS, obtained 2004 and 2005
Wells from AMEC and the Ontario Ministry of Natural Resources, Oil Salt and Gas Resources Library.
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2007
Datum: NAD 83 Projection: UTM Zone 17N

0 100 200 400 600
Metres

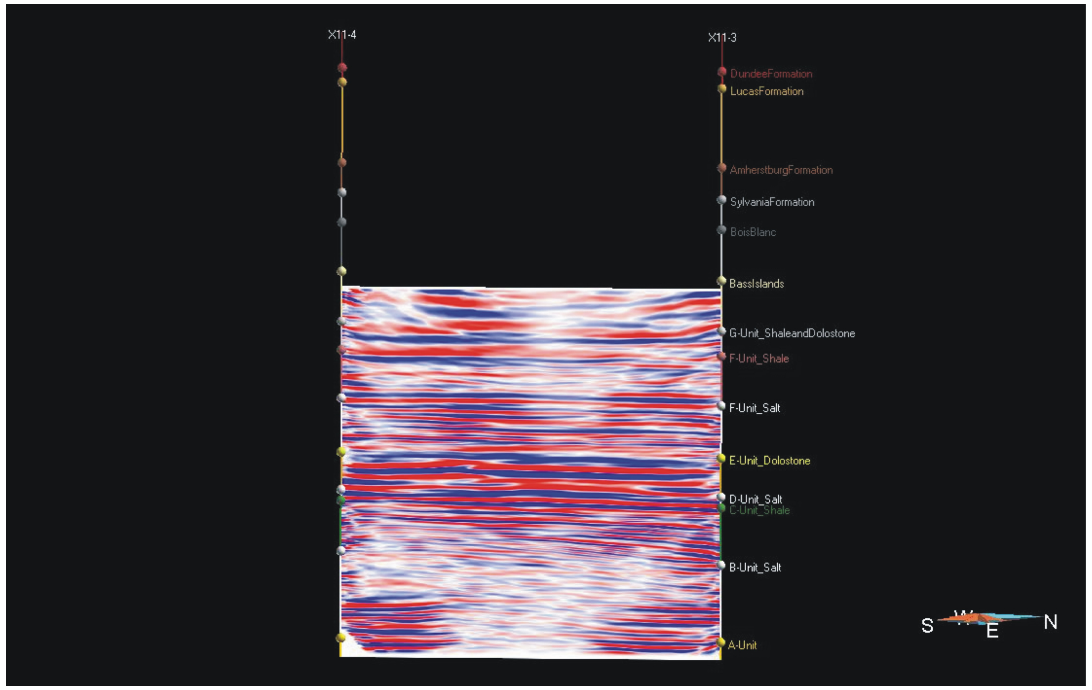
PROJECT
DETROIT RIVER INTERNATIONAL CROSSING

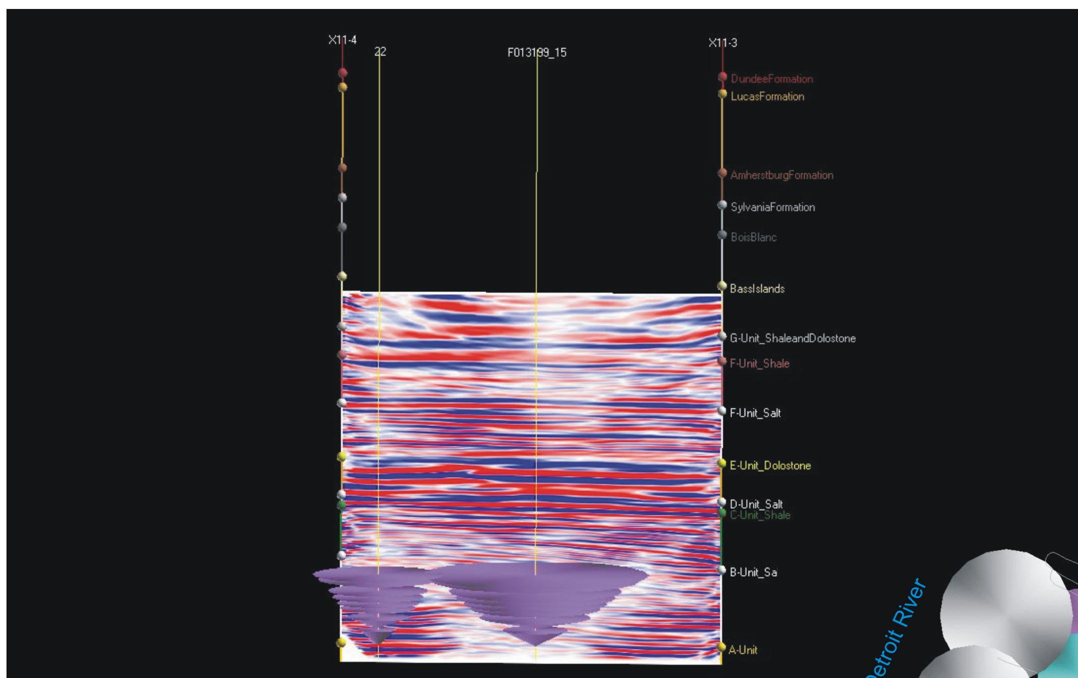
TITLE
BOUNDARIES OF PRIMARY AND SECONDARY SOLUTION MINING INFLUENCES

Golder Associates
Mississauga, Ontario

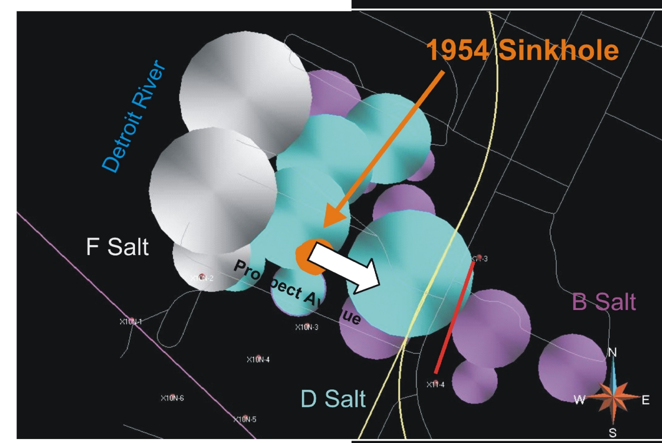
PROJECT No. 04-1111-060			SCALE 1:7,500	REV. 1
DESIGN	CC	24 May 2006	**FIGURE: 9.1**	
GIS	PB	08 Feb. 2008		
CHECK	JM	08 Feb. 2008		
REVIEW	SB	08 Feb. 2008		

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure9.1_Boundaries_for_Bridge_Structure_Locations.mxd

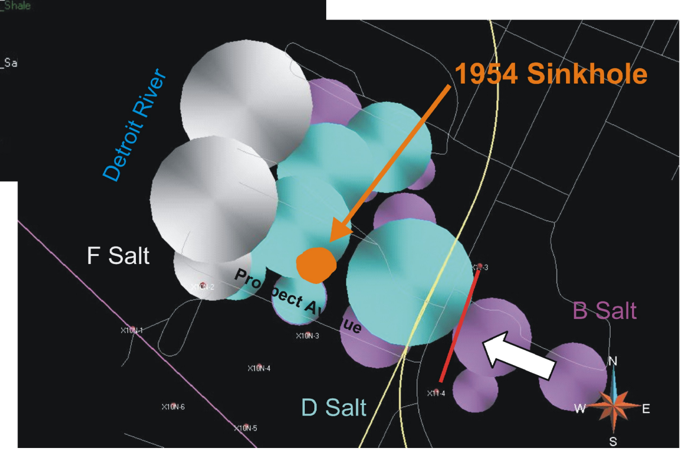




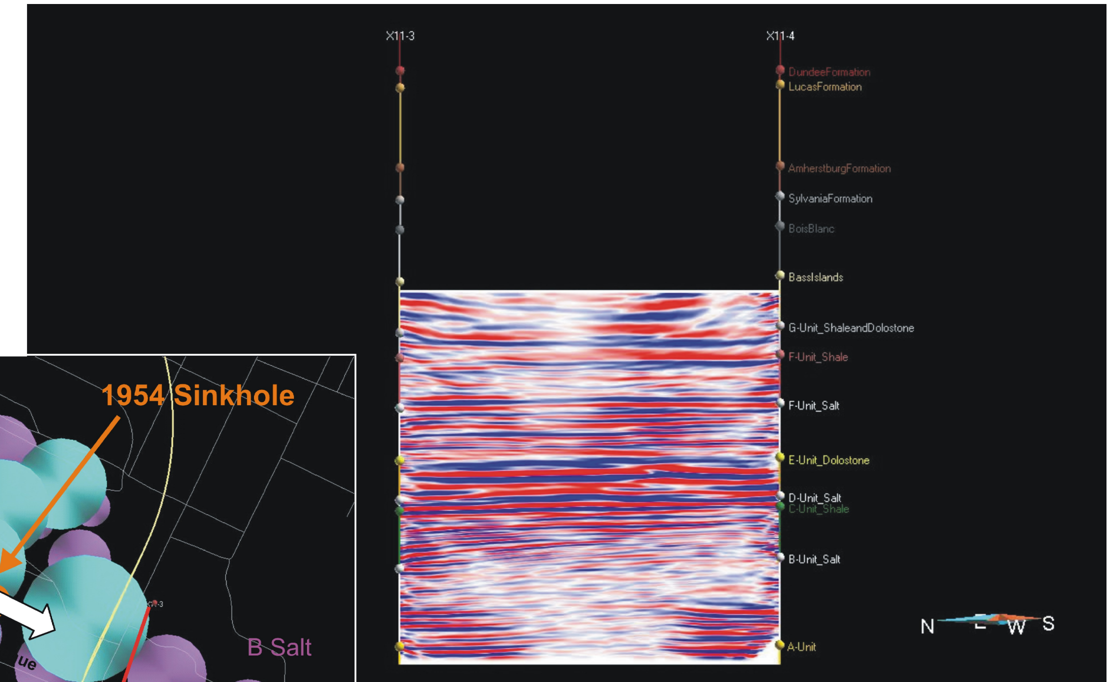
View of subsurface seismic anomaly between wells X11-3 (right) and X11-4 (left) looking west. Top image shows seismic anomaly only. Bottom image illustrates anomaly with hypothetical solution mining volumes for solution mining wells 15 (right) and 22 (left) superposed on seismic anomaly.

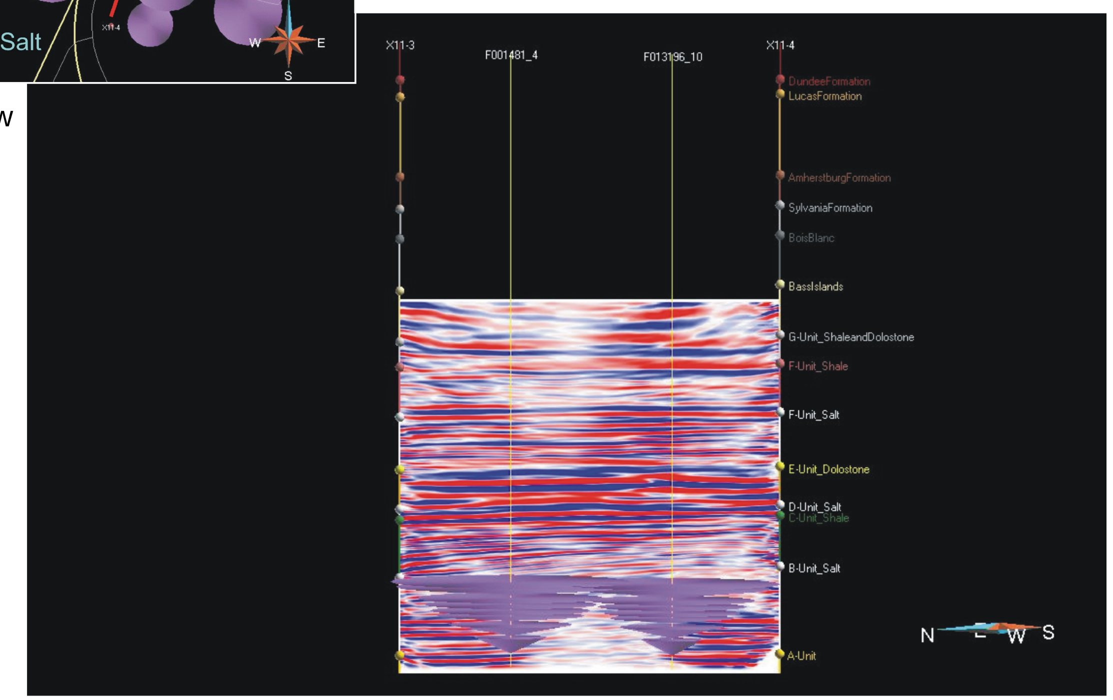


Plan showing direction of view and hypothetical influence areas of individual solution mining wells.



Plan showing direction of view and hypothetical influence areas of individual solution mining wells.





View of subsurface seismic anomaly between wells X11-3 (left) and X11-4 (right) looking east. Top image shows anomaly only. Bottom image illustrates seismic anomaly with hypothetical solution mining volumes for solution mining wells 4 (left) and 10 (right) superposed on seismic anomaly.

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

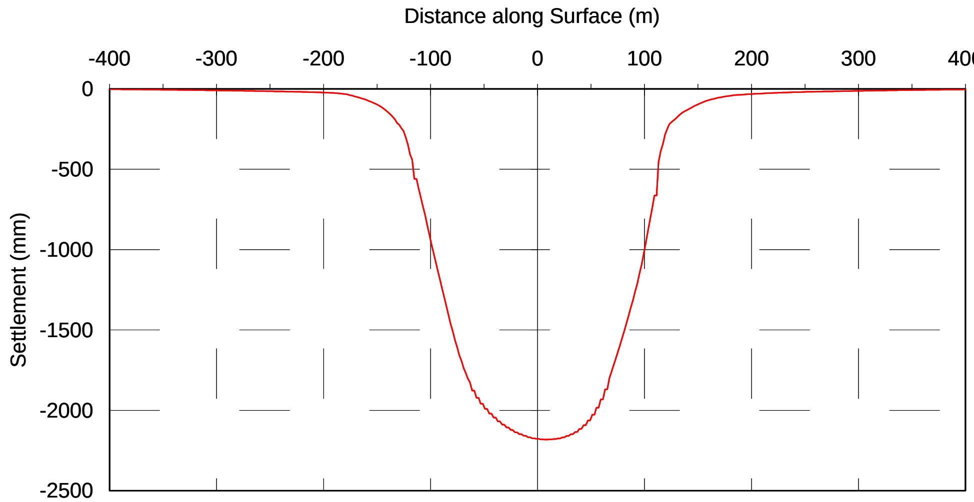
SUBSURFACE ANOMALY CROSSING C
THREE DIMENSIONAL MODEL
WELLS X11-3 TO X11-4

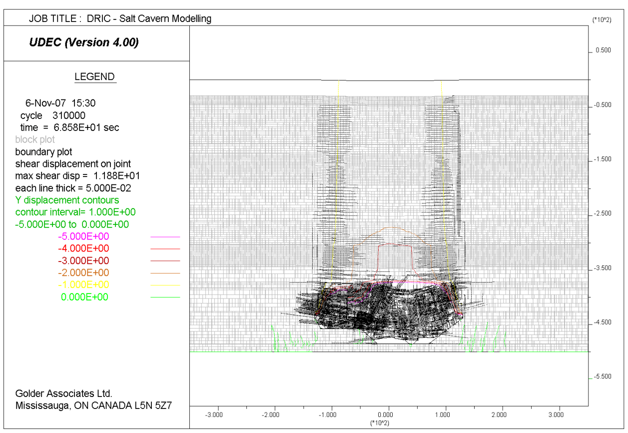
Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 0
DESIGN	CC	24 May 2006	FIGURE: 9.2	
GIS	JFC	28 Feb. 2008		
CHECK	JM	28 Feb. 2008		
REVIEW	SB	28 Feb. 2008		

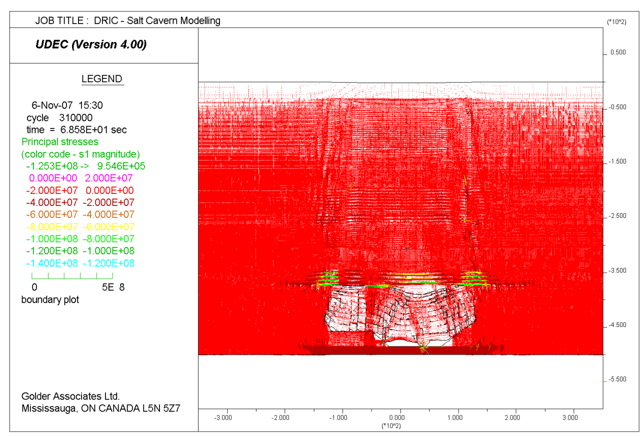
Note: This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure9.2_SUBSURFACE ANOMALY_CROSSING C_THREE_DIMENSIONAL MODEL.mxd

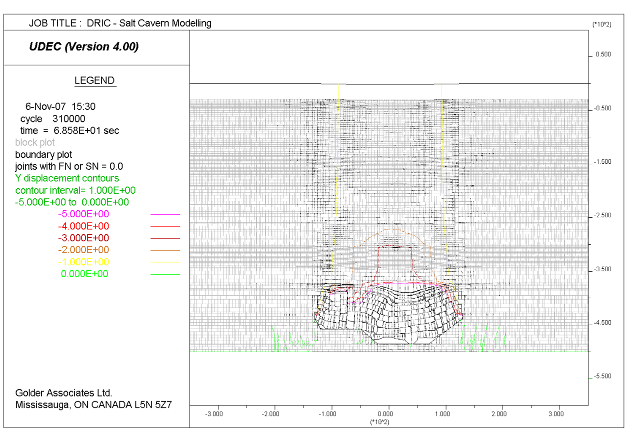




Shear displacements



Major Principal Stress



Open joints and bedding

PROJECT

DETROIT RIVER INTERNATIONAL CROSSING

TITLE

SUBSURFACE ANOMALY, CROSSING C
UDEC RESULTS

Golder Associates
Mississauga, Ontario

PROJECT No. 04-1111-060			SCALE NTS	REV. 0
DESIGN	CC	21 Sept. 2004	FIGURE: 9.3	
GIS	CC	22 Feb. 2008		
CHECK	JM	22 Feb. 2008		
REVIEW	SB	22 Feb. 2008		

NOTE:

1. This figure is to be read with the accompanying reports "Preliminary Foundation Design Report, Detroit River International Crossing, Evaluation Of Alternative Bridge Sites".

G:\Projects\2004\04-1111-060_Windsor_tunnel\GIS\MXDs\Draft\December_2007_Edits_PB\Figure9.3_SUBSURFACE ANOMALY_CROSSING C_UDEC RESULTSfinal.mxd