Ontario

REPORT

2010 GEOLOGY AND TERRAIN UNIT GEOTECHNICAL DATA REPORT

Canada Chrome Proposed Infrastructure Corridor

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EXECUTIVE SUMMARY

During 2009-2010, Golder Associates Inc. (Golder) conducted preliminary geotechnical studies in support of the proposed 328 km infrastructure corridor. Completed studies include preliminary geotechnical field investigations, terrain unit mapping, laboratory and field testing, geophysical surveys, and hydro-technical support for major river crossings along the proposed corridor. This corridor connects the Ring of Fire mineral prospect in northern Ontario with existing railroad facilities to the south. The purpose of these efforts was to provide the geotechnically-related data to support the engineering design and construction of the proposed embankments, bridges and related structures. The subsurface investigations included the drilling, sampling and testing of 811 drilled boreholes and 188 hand-augered holes. Terrain unit mapping depicting the subsurface conditions in plan and profile for the entire proposed infrastructure corridor was completed using data generated from field explorations, laboratory testing results, and interpretation of LiDAR and aerial imagery.

The following report presents an overall description of the terrain, geology, and seismicity of the study corridor plus the field and laboratory data obtained at over the past 20 months. Part of this information has been conveyed in previous submittals, particularly for major water crossings and material sites, for elements of the project. The terrain unit mapping is presented as a series of 98 alignment sheets showing surficial delineations over a kilometer-wide swath with the corresponding subsurface profile for the length of the infrastructure corridor.

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1.0 INTRODUCTION

Golder Associates Inc. (Golder) was contracted by Canada Chrome Corporation to provide geotechnical engineering services for the proposed 329 km infrastructure corridor that extends from the “Ring of Fire” chromite prospect to the existing railroad at Exton, Ontario. The corridor is undeveloped except for the southern 50 km where logging roads and trails are present. The location of the corridor is shown in Figures 1 and 2.

As part of the geotechnical effort, Golder undertook: the mapping of terrain units along the proposed infrastructure corridor; identification of prospective material sites; the laboratory testing and log preparation of 188 hand-augered boreholes performed by Stares Contracting; a winter drilling program that included the drilling and laboratory testing of 811 boreholes; field testing; geophysical surveys at major water crossings; and hydrologic measurements. The purpose of this report is to present the preliminary terrain unit mapping and interpreted subsurface profile along the infrastructure corridor along with the borehole logs, laboratory and field testing results, geophysical survey results, and hydro-technical data.

This report is a compilation of all the geotechnical data to date along the proposed infrastructure corridor. Some of the data presented here has been included in previously submitted reports for specific elements of the project, particularly hand auger borings, major water crossings, and material sites.

2.0 METHODOLOGY

2.1.1 2009 Hand Auger Boreholes

During 2009, Stares Contracting performed 188 hand augered borings ranging in depth from 1.5 to 6 meters with approximate sample intervals of 1 meter. Golder tested the samples from these borings, classified the soils, and prepared drafted boring logs. In addition, Stares field crews also collected rock samples at 11 locations and these were tested for quality according to AREMA guidelines. A summary report of this investigative effort was submitted in November, 2010 and is also included as Appendix A of this report.

2.1.2 2010 Borehole Drilling

A borehole drilling program was carried out during the winter and spring of 2010. Boreholes targeted the bridge piers and abutments at major water crossings, culvert locations at minor water crossings, potential material sites, and the railroad embankment foundation. The embankment boreholes were drilled at approximate intervals of 400 meters.

Drilling operations were supported by Paddock Drilling (Paddock) who provided drilling personnel and track-mounted and helicopter-portable drill rigs to complete the borings. The drilling method used 99.0 millimeter (3.75 inch) inner diameter (I.D.) hollow-stem auger (HSA) advanced until refusal. After meeting auger refusal at prospective bridge sites, the drilling method was converted to diamond coring into bedrock at selected boreholes. Some holes drilled on prospective material sites in rock were advanced by air hammer after auger refusal to confirm presence and type of bedrock. The railroad embankment boreholes were typically drilled to a depth of 5 meters (16.5 feet) although the depth was increased where soft soils were encountered. The field teams typically consisted of a Golder field technician, geotechnical engineer or geologist as the onsite field supervisor, and a two to three person drill crew.

Field personnel from Golder logged all recovered soil samples and core and directed the drilling operations. Soil characteristics such as frost depth, consistency, moisture, color, texture, density and temperature were recorded. Soils were visually classified in the field according to the Unified Soil Classification System (USCS), which is summarized in Appendix B. Photographs were taken of samples collected, noted on the borehole log, and given appropriate descriptive titles in the photo logs. Each recovered sample was reviewed by the Golder QC/QA personnel before being shipped for laboratory testing. Geotechnical borehole logs are shown in Appendix B, which also includes a table summarizing the location coordinates, depth, drilling date, and elevation of each borehole.

Groundwater observed while drilling (W.D.) is shown on the borehole logs. Borehole locations were determined in the field using a WAAS-enabled handheld GPS receiver. All GPS coordinates were collected in Latitude and Longitude WGS84 (decimal degrees) and ellipsoid heights (US Survey Feet). All lat/long coordinates were converted to UTM zone 16N NAD83, meters. A ground surface model derived from LiDAR datasets was used to determine approximate surface elevations for each borehole.

All borehole locations were marked with a 1.5 meter fiberglass post with a steel tag displaying the borehole number. Photographs were taken of site conditions at each borehole. Photographs at each borehole were noted on the borehole log and given appropriate descriptive titles in the photo logs.

Drive samples were typically collected at 0.8 meter (2.5 foot) intervals to a depth of 4.6 meter (15 feet) below the ground surface, then at 1.5 meter (5 foot) intervals to boring completion or refusal. Drive samples were collected using a 51.0 millimeter (2 inch) outside diameter (O.D.) split-spoon sampler. The sampler was driven using a winch-operated 63.5 kilogram (140 pound) hammer with an approximate 762 millimeter (30 inch) stroke. The sampler was advanced 457.0 millimeters (18 inches) ahead of the HSA or to refusal. The number of blows required to advance the sampler for each 152.0 millimeter (6 inch) interval were recorded on the field log. The N-value is the total number of blows required to drive the sampler the final 305.0 millimeters (12 inch) from the 152.0 to 457.0 millimeter (6 to 18 inch) depth. The blow counts shown are field values that have not been corrected for variables such as overburden, sampler size, or other factors.

In certain locations where soft clays were encountered, undisturbed soil samples were collected by advancing 610 millimeter (24 inch) thin-walled Shelby tube into the soil. In addition, field vane shear tests were completed in soft clays when Shelby tube samples were not recovered.

2.1.3 Soil Laboratory Testing

Laboratory tests were performed to determine index properties of the soil samples collected in the field. These tests included:

- ASTM D-2216-10 - Moisture content
- ASTM D-422-07 - Hydrometer
- ASTM D-4318-10 Atterberg Limits
- ASTM C117-04 – Materials Finer than #200 Sieve
- ASTM C136-06 – Sieve Analysis of Fine and Coarse Aggregates
- ASTM D422-63 (Reapproved 2007) Particle Size Analysis of Soils
- ASTM D-2435-04 - Consolidation
- ASTM D-2974-07 - Organic Content
- ASTM D-7263-09 – Unit Weight and Porosity Determination
- ASTM D-854-10 Method A – Specific Gravity

Vane shear tests were carried out in the field according to ASTM D-2573. Laboratory and field test results for soils are presented in Appendix C and include summary tables and relevant plots.

2.1.4 Rock Laboratory Testing

Bedrock samples from prospective material sites were tested to determine suitability for railroad ballast according to AREMA specifications. These tests and the acceptance criteria for ballast according to the AREMA Manual for Railway Engineering tests or other typical standards included:

- Resistance to Degradation by Abrasion and Impact (by LA Abrasion ASTM C-535 [1000 revs]) – Maximum 35% loss for granite
- Sodium Sulfate Soundness (ASTM C-88) – Maximum 5.0% loss
- Relative Density and Absorption of Coarse Aggregate (ASTM C-127) – Minimum relative density of 2.60 and maximum allowable absorption of 1%
- Clay Lumps and Friable Particles (ASTM C-142) – Maximum 5%
- Evaluation of Durability of Rock for Freeze-Thaw (ASTM 5312 for 30 cycles) – Maximum 5% loss
- Petrographic Analysis (CSA A23.2-15A / ASTM C-295) - No fatal defects and petrographic number not to exceed 125

Bedrock core from bridge sites were point load tested according to ASTM D-5731-08.

The laboratory testing results for rock is presented in Appendix D.

2.1.5 River Crossing Geophysical Surveys

Geophysical surveys were carried out at ten major river crossings during the winter of 2010 using a combination of electrical resistivity imaging (ERI) and ground penetrating radar (GPR). The methods and results of this investigative effort are presented in a technical memorandum previously submitted in April, 2010 and included in Appendix E of this report.

2.1.6 Hydrotechnical Assessments

Golder provided hydrotechnical support for detailed assessments of the 10 largest river crossings and provided general guidance that applies to all the river and stream crossings along the infrastructure corridor. Preliminary assessments of hydrology, hydraulics, ice jam potential, debris jam potential, scour, erosion and bank protection were made for each major crossing. A technical memorandum summarizing this work was submitted in August, 2010 and is also presented in Appendix F of this report. Soundings taken at select water crossings in the winter of 2010 are presented in Appendix G.

2.1.7 Material Site Investigations

Potential material sites were identified by a brief helicopter reconnaissance followed by interpretation of aerial photographs and LIDAR imagery. This was followed by subsurface investigations during the winter 2010 drilling program. The report of the material site investigations is provided as a separate deliverable and is too voluminous to include in this document. However, the borehole logs and laboratory testing data is included in the appendices of this report.

2.1.8 Water Crossing Investigations

Major water crossings were investigated during the winter of 2010 by drilling boreholes at prospective abutments and piers, provided these locations could be accessed. Individual geotechnical reports were prepared for each of these crossings and submitted as separate deliverables. While these reports are not included in this document, the borehole logs and laboratory testing data is included in the appendices of this report.

2.1.9 Terrain Unit Mapping

A terrain unit mapping effort was carried out to characterize the surface and subsurface geologic conditions along the infrastructure corridor (approximately 1 km wide and 329 km long). A terrain unit is a division of the earth's surface which represents a separate and distinct range of soil properties as a result of a common mode of deposition or geologic process. Similar geologic processes tend to result in landforms with common geotechnical properties. They are generally recognizable, through interpretation of imagery, shape, texture, and slope patterns, and the genesis of the material comprising them. By mapping the landforms, the geotechnical conditions in a given area, or along an alignment, can be readily assessed.

The terrain unit mapping effort, using aerial photography and LiDAR imagery, and coupled with data from reconnaissance, field explorations, laboratory testing, and existing geological information, was used to help define the geotechnical conditions for the proposed infrastructure corridor. While stereographic interpretation of aerial photographs has been used for decades, the use of LiDAR in “bare earth” mode now allows a faster and more detailed identification and delineation of landforms because the effects of surface vegetation are removed and the small features of the surface are represented.

Digital mapping programs or Geographic Information Systems (GIS) were used extensively throughout the terrain mapping analysis. Because the LiDAR and aerial imagery were digital geospatial products, they were displayed as overlying layers along with many other data-sets in multiple GIS applications. This type of display was used for both delineating the terrain units and for digitizing and attributing the terrain unit polygons. Using GIS to delineate and digitize terrain units proved to be exceptionally effective and efficient over traditional techniques such as marking up and rubber-sheeting mylar sheets over aerial stereo-pairs.

Once the terrain units were delineated on the surface, a subsurface geologic profile was created by plotting the borehole logs on the preferred alignment profile and interpreting the contacts from the boreholes along this profile within the proposed infrastructure corridor. This strip plan and profile was divided into 98 sheets.

3.0 SITE CONDITIONS

3.1 Topography and Physiography

The topography of the 329 km railroad study corridor is characterized by extensive lowlands with little topographic relief. The most prominent topographic features are low, linear, rounded hills, with a north-south axis. The elevation of the hills rarely exceeds 15 meters above the level of the surrounding swampy terrain. The infrastructure corridor traverses generally northward across the Canadian Shield and then across the Coastal Plain/Hudson Bay Lowlands. The terrain is drained to the northeast by a series of low-gradient rivers that intersect the corridor. The elevation gradually decreases from a maximum of 310 meters, at the southern terminus at Exton, to approximately 165 meters at the northern terminus at the prospective mine site, an overall difference of 145 meters. Selected photographs taken along the infrastructure corridor showing the typical terrain, vegetation, and features of the landscape are presented in Appendix H.

3.2 General Geology

Pre-Cambrian igneous and metamorphic rocks underlie the entire infrastructure corridor at various depths. The region was covered by the Labrador ice sheet during the Last Glacial Maximum in the Pleistocene with ice flow to the southwest. It is in the region of post-glacial rebound. The ice sheet eroded the underlying bedrock into a relatively even surface. The retreat of the ice to the northeast was accompanied by the deposition of till and ice-marginal deposits and the formation of an extensive pro-glacial lake. The lake deposited fine-grained sediments that typically included a small percentage of coarser clasts dropped from ice bergs floating it the lake. As the waters of the lake receded toward Hudson Bay, surficial sediments were locally re-worked by wind and water and plants occupied the surface. Over time, the surficial organic layer developed into a peaty mantle up to several meters thick. A regional geologic map is presented in Figure 3 (Pala and others, 1991).

Permafrost is likely to be sporadically present or in isolated patches in the northern third of the infrastructure corridor (Brown and others, 1997) although none has been encountered in boreholes to date.

The infrastructure corridor can be divided into three sections as follows:

- The southern approximately 90 km is characterized by low topographic relief, dense forests, and numerous lakes. Pre-Cambrian bedrock is intermittently exposed within the corridor and generally consists of competent igneous intrusive rocks of granite and gneiss. These rocks are suitable for production of railroad ballast. The bedrock, where it’s not exposed, is typically overlain by glacially-derived deposits ranging from sandy gravel to clay. A surficial layer of organics 1 to 2m thick typically mantles the surface.

- The central portion of the infrastructure corridor, approximately 150 km long, traverses obliquely across the boundary between the Canadian Shield and Coastal Plain/Hudson Bay Lowlands. Characteristics of this section include crossing both fine-grained glacial till and organic deposits. This section is typically characterized by 1 to 4 meters of peat (or humus) overlying clayey materials that include fine-grained till and lake deposits. Slightly elevated narrow linear ridges of ice marginal materials, likely eskers, occur sporadically. These ice marginal materials are predominately composed of fine sand and silty sands and are typically covered with a meter or less of organics. Bedrock is only exposed at major river crossings and is typically granitic.
- The northern section, approximately 90 km long, lies within the Coastal Plain/Hudson Bay Lowlands. This segment is characterized by low relief, extensive organic deposits with south-southeast-trending drainages and lakes. The infrastructure corridor follows intermittent low ridges of glacial deposits, likely drumlins and eskers, to attempt to stay out of deep organic deposits and soft fine-grained sediments. The lowland terrain has 2-5 meters of organics overlying silty-clayey sediments deposited in an ancient glacial lake. The thickness of the lake sediments is not well defined. Bedrock is known to outcrop at the major river crossings and at the north end of Fish Trap Lake, but is otherwise not generally apparent. The bedrock consists of diorite, a granitic rock. Large deposits of mostly fine sand in low ridges are present near the north terminus of the railroad. This section has been mapped as having sporadic permafrost (Brown and others, 1997).

3.3 Terrain Units

Seven terrain units were identified. For mapping purposes, a terrain unit is shown when the materials characterizing it were present to a thickness equal to or exceeding 1 meter. Each of these units is described below. Due to the importance of identifying the presence of Glacio-lacustrine and Glacio-marine deposits for the engineering effort, this terrain unit is assigned if any of these materials are identified. The anticipated soil profile is designated by listing each anticipated terrain unit from the surface. For example, Qo/Ql/Qt designates Organic deposits equal to or greater than 1 meter in thickness overlying any thickness of Glacio-lacustrine and Glacio-marine deposits and Glacial till.

The terrain unit maps are presented in Appendix I. These maps include the locations and subsurface profiles of all boreholes and hand-auger holes along the preferred alignment.

3.3.1 Organic Deposits (Qo)

This unit is comprised of organic deposits with thickness equal to or greater than 1 meter. Typically, the organic deposits are composed of very soft, moist to wet, peat.

3.3.2 Glacio-lacustrine and Glacio-marine Deposits (Ql)

This unit is commonly referred to as “lake deposits”. This unit typically includes very soft to stiff, moist to wet, clay and silt with minor sand. Organic deposits less than 1 meter thick often overlie this unit.

3.3.3 Undifferentiated Deposits (Qu)

This unit primarily includes loess deposits, colluvium, and floodplain deposits. This unit typically consists of light brown silt and sandy silt, with minor amounts of clay. Soils associated with this unit are generally loose to compact, and dry to wet. Organic deposits less than 1 meter thick often overlie this unit.

3.3.4 Fluvial Deposits (Qf)

This unit typically includes active channel deposits consisting of silty sand and sand with gravel, and may be interbedded with silt and clay. Soils associated with this unit are generally loose and moist to wet. Organic deposits less than 1 meter thickness often overlie this unit.

3.3.5 Glacial Till Deposits (Qt)

Two variations of till deposits occur along the alignment; fine and coarse. Fine till typically consists of firm to hard, moist to wet, silt to silty clay with low content of clasts (cobble and boulders). Coarse till typically consists of compact to very dense, dry to wet, sand to silty sand with high content of clasts. Due to similar engineering properties and limited subsurface data, the till deposits are undifferentiated. Organic deposits less than 1 meter in thickness often overlie this unit.

3.3.6 Ice-Contact and Glaciofluvial Deposits (Qe)

This unit is primarily composed of ice-marginal deposits and includes esker, kame, end moraine, and subaqueous fan deposits, with minor till. Soils are typically compact to very dense, dry to moist, fine to medium sand with minor amounts of silt and gravel. Organic deposits less than 1 meter thick generally overly this unit.

3.3.7 Bedrock (Bx)

Bedrock consists of Pre-Cambrian igneous and metamorphic rock, chiefly granite and gneiss. Organic deposits less than 1 meter thick often overlie this unit.

3.4 Tectonic Setting

Eastern Canada, within which Ontario and the infrastructure corridor are located, is characterized as a stable, intra-plate continental region of the North American tectonic plate, which has a relatively low rate of historical earthquake activity (NRC, 2009c). The region of the corridor is underlain primarily by very old (Archean; ~2.5 to 3.2 billion years old) metamorphic and intrusive igneous bedrock of the Superior Province, which is locally overlain by a mantle of Quaternary (less than 2.6 million years old) glacial till, glacio-laustrine and glacio-marine surficial deposits (OGS, 2008; Reed et al, 2005). The metamorphic and intrusive igneous Archean rocks of the Superior Province exhibit a general east-west structural fabric, which includes major strike-slip faults, and which is cut by ~2 billion-year-old northeast-striking, west-northwest-dipping thrust faults of the Kapuskasing structural zone (Burov et al, 1998; Halls and Zhang, 1998; Leclair et al, 1993; Geis et al, 1990). The Kapuskasing structural zone is located to the east of the proposed infrastructure corridor.

The bedrock faulting, now exposed at the surface in the region of the study corridor, appears to have been confined primarily to the Precambrian time period, at least 2 billion years ago. Evidence of Quaternary-age tectonic surface faulting within the Superior Province does not appear to have been identified or reported in the literature.

3.4.1 Historical Seismicity

The generally tectonically-stable interior of the North American plate of eastern Canada is characterized by a low rate of historical earthquake activity (NRC, 2009c). Nevertheless, a few large and damaging historical earthquakes have occurred, and such earthquakes will continue to do so (NRC, 2009c). The historical seismicity of eastern Canada, including the large earthquakes, is generally concentrated in defined seismic zones (NRC, 2009c), which include:

- Northeastern Ontario Seismic Zone
- Southern Great Lakes Seismic Zone (encompasses Lake Erie and Lake Ontario)
- Western Quebec Seismic Zone (encompasses the Ottawa Valley and Upper St. Lawrence Valley)
- Charlevoix Seismic Zone (encompasses the St. Lawrence Valley just northeast of Quebec City)
- Lower St. Lawrence Seismic Zone

The proposed Canada Chrome Railroad project is located almost entirely within the western part of the Northeastern Ontario Seismic Zone, which is defined by a rectangular area that is approximately 525,000 km^2, and is bounded on the south by approximate Latitude 45 degrees, on the north by Latitude 52 degrees, on the east by approximate Longitude -79 degrees, and on the west by Longitude -89 degrees (NRC, 2009c), as shown in Figure 4. The Northeastern Ontario Seismic Zone has a very low level of earthquake activity in terms of both the frequency of occurrence and the magnitude of the earthquakes (NRC, 2009b; Hayek et al, 2008). The majority of the historical earthquakes which have occurred within the Northeastern Ontario Seismic Zone have been micro earthquakes (< magnitude 3.0) (NRC, 2009b, c). The largest earthquakes to occur in the seismic zone were a magnitude 5.0 earthquake in 1905 in northern Michigan (> 300 km from the southern start of the railroad), and a magnitude 5.0 earthquake in 1928 northeast of Kapuskasing (~400 km east of the project) (NRC, 2009c; Hayek et al, 2008). The majority of the historical seismicity of the Northeastern Ontario Seismic Zone appears to be concentrated in the James Bay area and the Kapuskasing-Cochrane region east of the project, as well as the Pickle Lake, Dryden and Atikokan areas west of the project (Hayek et al, 2008).

The historical earthquake record in the region of the railroad project has been recorded and cataloged by Natural Resources Canada (NRC, 2009b), and by the U.S. Geological Survey (2009). A search of these earthquake catalogs, for the period from 1568 to 2010, and for the area bounded by Latitude 49.0 to 54.0 and Longitude -83.0 to -90.0 (~283,000 km^2 box centered on the proposed corridor), indicates that only 57 earthquakes have occurred, and that they all have been less than magnitude 4.0. The largest recorded earthquake was magnitude 3.9 (NRC, 2009b), and it was located about 150 km west of the proposed railroad. The proposed railroad route is relatively devoid of historical seismicity.

3.4.1.1 Seismic Hazard Mapping

The NRC (2008) has developed seismic hazard maps for Canada, and for the implementation of the 2005 National Building Code of Canada. The focus of the seismic hazard mapping has been on the development of probabilistic seismic hazards map for the 2 percent probability of exceedance ground motions in 50 years. This is equivalent to the 2,475-year return period. The seismic hazard mapping by the NRC (2008) has also resulted in the development of maps for earthquake ground motions for the 100-, 475-, and 1,000-year return periods. The seismic hazard mapping results for the 2,475-year return period indicate that the region of the railroad project is characterized by peak ground accelerations (PGA) of 0.059 g, or less (NRC, 2008).

3.4.1.2 Recommended Seismic Performance Criteria (Peak Ground Acceleration)

The American Railway Engineering and Maintenance-of-Way Association (AREMA) (2010) provides guidelines for the development of seismic performance criteria for design of railway structures (AREMA, 2010). For the Canada Chrome railroad project, the seismic performance criteria for use in structural design are peak horizontal ground accelerations (PGA), or as defined by AREMA (2010), base acceleration coefficients. These seismic performance criteria are input to the development of structural design.

AREMA (2010) identifies three ground motion levels for seismic performance criteria that are associated with three identified performance criteria limit states and three, average return periods for the ground motion levels. These are summarized in Table 1.

TABLE 1
AREMA (2006) SEISMIC PERFORMANCE CRITERIA AND GROUND MOTIONS LEVELS

GROUND MOTION LEVEL	PERFORMANCE CRITERIA STATE	RANGE OF AVERAGE RETURN PERIOD (YEARS)
1	Serviceability	50-100
2	Ultimate	200-500
3	Survivability	1,000-2,400

The Level 1 ground motion (i.e., PGA) is considered an occasional event with a reasonable probability of being exceeded during the life of a structure. The Level 2 PGA is considered a rare event with a low probability of exceedance during the life of a structure, and a Level 3 PGA is a very rare, or maximum credible, event with a very low probability of being exceeded during the life of a structure.

To develop the project-specific PGAs (seismic performance criteria) for use in site seismic design, the project-specific average return periods for each ground motion level were calculated using the methodology of AREMA (2010). The methodology requires the calculation of an Importance Classification Factor based on the assessment of the safety needs of the structure in an earthquake, its immediate value and its replacement value (AREMA, 2010). The Importance Classification Factor derived for the Canada Chrome project is 3.4. The calculated average return periods for each of the ground motion levels, and limit states are listed in Table 2.

TABLE 2
PROJECT-SPECIFIC RETURN PERIODS

GROUND MOTION LEVEL[1]	PERFORMANCE CRITERIA LIMIT STATE[1]	CALCULATED, PROJECT-SPECIFIC RETURN PERIOD (YEARS)[2]
1	Serviceability	93
2	Ultimate	455
3	Survivability	2,190

Notes: [1] The Ground Motion Levels and Limit States are taken from AREMA (2010)
[2] Return period calculated based on the methodology of AREMA (2010) and using a project-specific Importance Classification Factor of 3.4.

The recommended project-specific seismic performance criteria (i.e., PGA) for each ground motion level were developed from the application of the NRC (2009a) online calculation of interpolated seismic hazard values for the proposed bridge sites, and the starting and ending points of the railroad project (7 locations). The calculated values of PGA were for the 100-, 475-, and 2,475-year return periods, for each of these locations, and the results were the same at each location. The 100-, 475-, and 2,475-year return period PGAs at each location were 0.007 g, 0.021 g, and 0.059 g, respectively.

The recommend seismic performance criteria (PGA) for each ground motion level for use in the project are listed in Table 3. These are rounded PGA values for the 100-, 475-, and 2,475-year return periods calculated from the NRC (2009a). Because the return periods of the NRC (2009a) are slightly longer than the respective calculated project-specific return periods, the recommended PGAs in Table 3 are slightly conservative for the respective project-specific return periods.

TABLE 3
RECOMMENDED PROJECT-SPECIFIC SEISMIC PERFORMANCE CRITERIA (PGA)

GROUND MOTION LEVEL	PERFORMANCE CRITERIA LIMIT STATE	CALCULATED, PROJECT-SPECIFIC RETURN PERIOD (YEARS)[1]	RECOMMENDED PGA (G)
1	Serviceability	93	0.01
2	Ultimate	455	0.02
3	Survivability	2,190	0.06

Notes: [1] Taken from Table 2.
[2] Rounded values from the 100-, 475-, and 2,475-year return period PGAs from the NRC (2009a).

4.0 ADDITIONAL INVESTIGATIONS

Investigations to date have been effective in providing the geotechnical information needed to generally characterize the subsurface conditions in the proposed infrastructure corridor and to make preliminary evaluations of potential material sites, proposed embankments, water crossing structures, and other related facilities. Further investigations will be needed for final design of specific structures and to better define the quantity and quality of material sites.

5.0 USE OF REPORT

This report has been prepared for the use of Canada Chrome Corporation and Krech Ojard & Associates in design of the planned infrastructure to connect the proposed mine site in northern Ontario to existing railroad facilities at Exton. The results of the investigations presented in this report are based on interpretation of imagery, a limited number of boreholes, and laboratory tests. There are possible variations in subsurface conditions between explorations, and also with time. Unanticipated soil conditions are commonly encountered and cannot fully be determined by a limited number of explorations or soil samples. The work program followed the standard of care expected of professionals undertaking similar work in Canada under similar conditions. No warranty expressed or implied is made.

6.0 CLOSING

We appreciate the opportunity to prepare this report. Please contact us if you have any questions or require additional information.

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7.0 REFERENCES

American Railway Engineering and Maintenance-of-Way Association (AREMA), 2010. Chapter 9, Seismic Design for Railway Structures.

Brown, J., Ferrians, O.J, Heginbottom, J.A., and Melnikov, E.S., 1997, International Permafrost Association, Circum-Polar Map of Permafrost and Ground Ice Conditions, Circum-Pacific Map Series, Map CP-45, U.S. Geological Survey.

Burov, E., Jaupart, C., and Mareschal, J.C., 1998. Large-scale crustal heterogeneities and lithospheric strength in cratons: Earth and Planetary Science Letters, v. 164, p. 205-219.

Geis, W.T., Cook, F.A., Green, A.G., Milkereit, B., Percival, J.A., and West, G.F., 1990. This thrust sheet formation of the Kapuskasing structural zone revealed by Lithoprobe seismic reflection data: Geology, v. 18, p. 513-516.

Halls, H.C. and Zhang, B., 1998. Uplift structure of the southern Kapuskasing zone from 2.45 Ga dike swarm displacement: Geology, v. 26, n. 1, p. 67-70.

Hayek, S.J., Drysdale, J.A., Adams, J., Lam, T., Halchuk, S., and Peci, V., 2008. Seismicity Studies for Long-Term Seismic Hazard Assessment in the Northern Ontario Part of the Canadian Shield: The 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.

Leclair, A.D., Ernst, R.E., and Hattori, K., 1993. Crustal-scale auriferous shear zones in the central Superior province, Canada: Geology, v. 21, p. 399-402.

Natural Resources Canada (NRC), 2009a. Interpolate 2005 National Building Code of Canada Seismic Hazard Values for Your Site for Lat. 50.186, Long. -86.799; Lat. 50.684, Long. -86.458; Lat. 51.4709, Long. -86.72; Lat. 52.143, Long. -86.619; Lat. 52.377, Long. -86.419; Lat. 52.766, Long. -86.308; and Lat. 52.758, Long. -86.249: http://earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/index-eng.php, date modified 2009-01-07, accessed 1/21/2010.

Natural Resources Canada (NRC), 2009b. Search the Earthquake Database, Lat. 49.0 to 54.0, Long. -83.0 to -90.0: Earthquakes Canada, http://earthquakescanada.nrcan.gc.ca/stndon/NEDB-BNDS/bull-eng.php, date modified 2009-03-27, accessed 1/21/2010.

Natural Resources Canada (NRC), 2009c. Earthquake Zones in Eastern Canada: Earthquakes Canada, http://earthquakescanada.nrcan.gc.ca/zones/eastcan-eng.php, date modified 2009-10-13, accessed 1/21/2010.

Natural Resources Canada (NRC), 2008. 2005 National Building Code of Canada Seismic Hazard Maps: Earthquakes Canada, http://earthquakescanada.nrcan.gc.ca/hazard-alea/zoning/NBCC2005maps-eng.php, date modified 2008-07-09, accessed 1/21/2010.

Pala, S., Barnett, P.J., Babuin, D., Henry, A.P., 1991, Quaternary Geology of Ontario, (Northern and West-Central Sheets), Ontario Geological Survey (OGS), Maps 2553 and 2554, Scale 1:1,000,000,8.

Reed, J.C., Wheeler, J.O., and Tucholke, B.E., 2005. Geologic Map of North America, with Explanatory Notes: Decade of North American Geology, Continent-Scale Map-001, Geological Society of America, Boulder, CO.