Inuvik to Tuktoyaktuk Highway – Terrain and Permafrost Field Verification Program

FINAL REPORT

August 31, 2012

Prepared for:
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Project Number: 123510689

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1 INTRODUCTION

The Government of the Northwest Territories (GNWT), Department of Transportation (DOT), the Town of Inuvik and the Hamlet of Tuktoyaktuk (the "Developers") are proposing to construct a 140 km all-season highway to connect the Town of Inuvik with the Hamlet of Tuktoyaktuk (the project). The project is wholly within the Inuvialuit Settlement Region, with portions of the highway crossing Inuvialuit 7(1)(a), 7(1)(b) and Crown lands. The project is currently undergoing substituted Panel review by the Environmental Impact Review Board. This report is being submitted on behalf of the Developers and is intended to form part of the record for these proceedings.

1.1 PROJECT BACKGROUND

In early 2012, KAVIK-STANTEC Inc. (K-S), obtained and processed publicly-available 2004-05 digital aerial stereo imagery of the project area, and completed detailed desktop mapping and terrain analysis along the Inuvik to Tuktoyaktuk Highway (ITH). The mapping was completed using Stantec's HD-MAPP 3-dimensional mapping application, at scales ranging from 1:2,500 to 1:7,500 and presented in a 1:10,000 map atlas (KAVIK-STANTEC 2012a).

The associated report, titled Inuvik to Tuktoyaktuk Highway – Baseline Data Acquisition Program Terrain Evaluation Report (Terrain Report), described surficial geology and geoprocesses identified within a 1 km study corridor, and identified 78 locations or segments along Alignments #1 and #3 where terrain features should be taken into consideration during further detailed project design (Terrain Report, Table 3.2). The mapping and analysis presented in the Terrain Report did not take into account project-specific LiDAR imagery, which was not yet available at the time of the analysis. The report recommended that a field program be undertaken to verify the occurrence and extent of identified terrain constraints.

On May 25, the EIRB issued several Information Requests related to the findings and recommendations of the Terrain Report. Specifically, the EIRB requested information about further field verification of some terrain units where the permafrost has a high proportion of ground ice or may contain thick layers of massive ice. The confirmation of terrain-ground ice associations and ground ice distribution contributes to the determination of road embankment thickness and calculations of overall requirements for embankment fill materials.

1.2 STUDY OBJECTIVES

The proposed methodology and workplan is intended to ground-truth the desktop work reported in the Terrain Report. It is also intended to provide information that is pertinent to answering questions raised in two information requests (IRs) issued by the Environmental Impact Review Board (EIRB) on May 25 (#148 and #149.1). The objectives of the proposed work are:

- To verify terrain constraints and sensitive areas along Inuvik to Tuktoyaktuk Highway (ITH) Alignments #1 and #3, as identified in Table 3-2 of the Terrain Report;

- To provide terrain stability information that will assist in identifying further data collection that may be required in support of final design of the embankment roadbed;
- To identify how effective geophysical methods, such as ground penetrating radar (GPR) and resistivity surveys can be for identification of thaw-unstable soils in the Project study area.

2 METHODOLOGY

Two specific tasks were undertaken to complement the original terrain analysis as presented in the Terrain Report (KAVIK-STANTEC 2012a):

1. Additional desktop review of the terrain mapping using LiDAR imagery; and
2. A field program comprising of a visual terrain verification program and geophysical investigations program.

These supplementary terrain and permafrost investigations were led by KAVIK-STANTEC but included sub-contracted discipline experts from Kiggiak-EBA specialized in cold regions sciences and engineering.

2.1 Desktop Review of the Terrain Mapping

The terrain desktop review was conducted by a KAVIK-STANTEC terrain scientist and Kiggiak-EBA permafrost engineer. During this review, special attention was given to review the delineation and attributes of the previously-mapped terrain units as well as any sensitive terrain features that were previously identified in Table 3-2 of the Terrain Report. This review was undertaken using LiDAR data acquired in the summer of 2011. The desktop review work was also undertaken to confirm:

- locations were no field verification of terrain units or constraints is required
- locations or areas that require field observation to confirm and characterize geo-processes or terrain-related constraints, and/or determine next steps
- any other locations not previously identified during original terrain mapping that might require field verification or reconnaissance.

2.2 Terrain Verification Program – Visual

The first phase of the terrain verification program was conducted from June 26th to June 29th, 2012 by the same terrain and permafrost experts that completed the desktop review exercise. The goal of the field verification program was to:

- Confirm surficial geology and geoprocesses identified in the Terrain Report and accompanying map atlas;
- Identify areas where engineered design mitigation techniques or route optimization will likely be required to address confirmed terrain constraints and/or sensitive areas;
- Identify specific locations where further geotechnical/geophysical investigation will assist with identifying ground-ice conditions, particularly the presence of wedge ice observed in the photos as polygonal patterned ground and massive ice that is typically exposed in landslide headscarps common along lakeshores in the region.

As a result of the terrain verification program, seven (7) sites were selected for further investigation using geophysical techniques (GPR and OhmMapper).

2.3 Terrain Verification Program - Geophysical

The geophysical component of the terrain verification program was conducted from July 25th to July 28th, 2012 and consisted of minor subsurface and geophysical investigations of seven (7) sites believed to be representative of characteristic ice-rich landforms along the proposed ITH. The intent of the survey was to collect sufficient data to assess the effectiveness of geophysical techniques (ground penetrating radar and resistivity mapping) in identifying the occurrence of massive ice and/or defining the extent of hazard resulting from ice rich soils. The purpose of the program was to determine the relevance and limitations of the chosen geophysical methods for mapping the occurrence of massive ice and/or defining the extent of hazard resulting from ice rich soils. The geophysical program was led by a Kiggiak-EBA Geophysicist. Field site selection and confirmatory drilling (as described below) was led by the KAVIK-STANTEC terrain scientist.

At each survey location, five (5) shallow boreholes ranging in depth between 1 and 2 meters were drilled in order to sample and characterize the local surface materials as well as to confirm the presence of a concentration of segregated ground ice that is commonly observed at the permafrost table (base of the active layer) in the Mackenzie Valley/Tuktoyaktuk Peninsula.

3 RESULTS

3.1 Desktop Review of Terrain Mapping and Field Verification

During the desktop review of previous terrain mapping, the delineation and attributes of the previously-mapped terrain units were reviewed, as were the sensitive terrain features that were previously identified in Table 3-2 of the Terrain Report. The main conclusions of the desktop review were:

- The terrain mapping scale of 1:2,500 to 1:7,500 is sufficient to precisely characterize the terrain conditions within the project area; the terrain units depicted in the 1:10,000 terrain map atlas included with the Terrain Report have been delineated with only minor modifications needed.
- LiDAR data provides additional accuracy in order to delineate the limits of the various terrain units and has been used to refine the mapping of the ice wedge polygons.
- The terrain related constraints found along the proposed alignments are for the most part, related to: (1) poor drainage conditions; (2) slopes; (3) mass movement processes; and, (4) the presence of ice-rich terrain units.

The outcome of the desktop review was the identificiation of key sites to be visited during the visual field verification program.

Excellent weather conditions during the field program (June 26th to June 29th, 2012) allowed a thorough overview of the route by Bell 206L helicopter. As a result, the following conclusions and comments are supplemental to the Terrain Report:

- The attributes of the various terrain polygons have been correctly identified; the distinction between some of tills and some fine grained glaciofluvial outwash units is complicated in some areas due to the lack of field data and natural material exposures.
- The digital elevation model (DEM) used to generate the 3 dimensional stereo effect used for mapping appears to result in overestimation of slope steepness.
- Several short steep slopes are crossed by the alignments and will likely require emplacement of thick fill.
- The vegetation cover is an excellent indicator of either runoff channels or low-lying bog terrain. The runoff channels are commonly infilled with dwarf birch and willow where the low-lying fields of ice wedge polygonal ground are wet sphagnum-like moss. In the smooth rolling terrain, the vegetation provides an indicative surficial indicator of underlying terrain types.
- The most problematic terrain feature found along the alignments is low-lying terrain characterized by ice-wedge polygons. Several areas along the existing access to borrow source 177 show signs of thaw subsidence at the exact location of the ice wedges.

- A review of the LiDAR data as well as the sites visited along the route made it clear that there are more ice-wedge polygons than were was originally delineated in the terrain atlas.

3.2 Geophysical Field Investigations

Seven (7) geophysical survey sites were visited in the field (Figure 3-1). Sites were selected to be representative of all terrain types (i.e. till, outwash material, lacustrine, fluvial and organic) and all types of terrain related constraints (e.g. high seepage areas, retrogressive thaw flow sides, ice wedge polygons, etc.) along the length of the study area.

Specific radar and resistivity profiles of transects completed at the seven locations are not provided, however the interpretation of results is presented below.

3.2.1 GP1 KP12.5

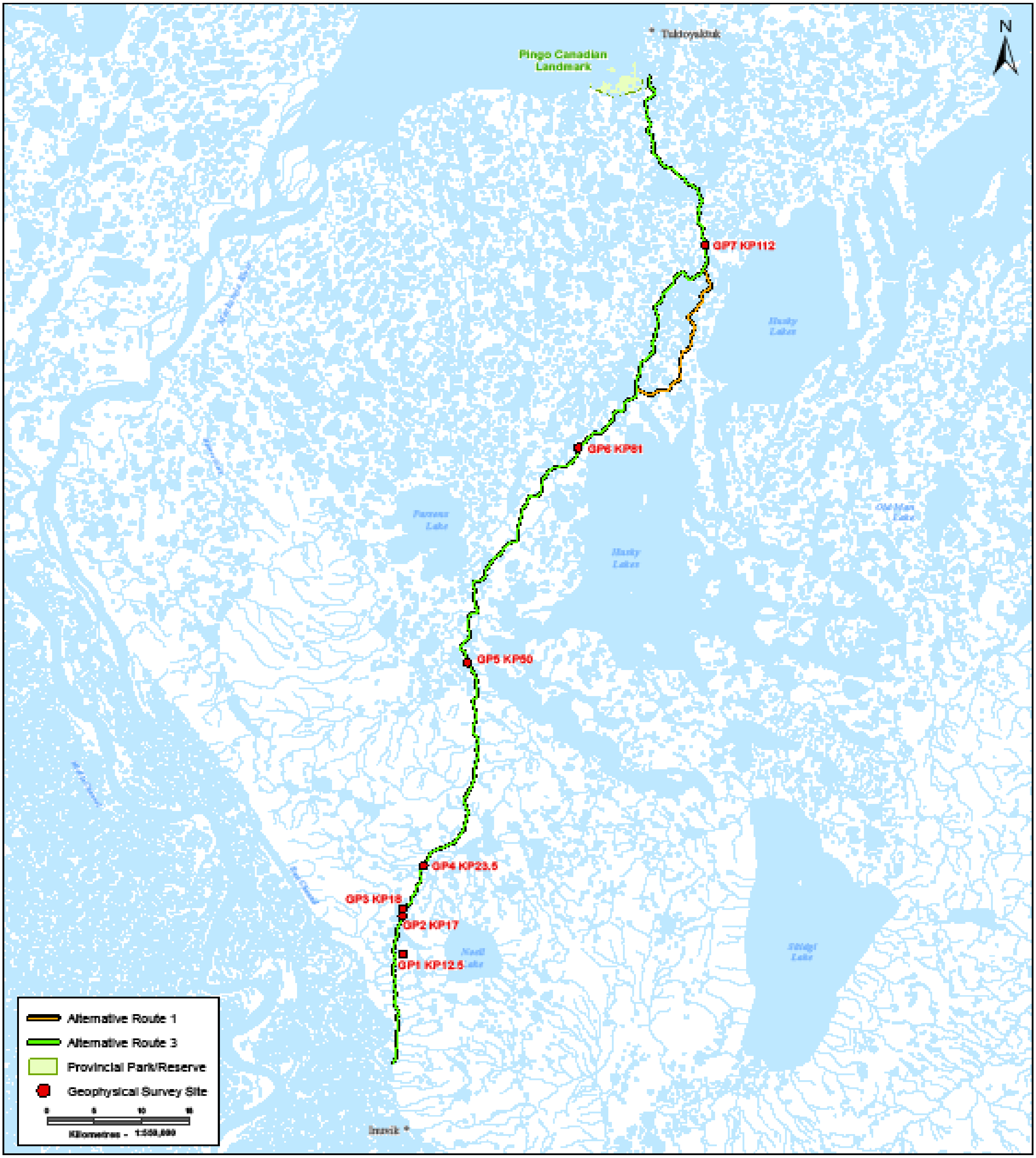
Site GP1 KP12.5 was selected in order to investigate a series of large retrogressive thaw flow slides approximately 800 m east of KP 12.5 (Appendix A, Photo A-1). This type of landslide is typical of fine-grained till material characterized by ice-rich permafrost. The process involves the thermal erosion of [surface] ground ice which leads to successive failures and flow of water saturated sediments (French 2007).

The retrogressive thaw flow slide east of KP12.5 has initiated along the west shore of a small lake in an area characterized by flat to very gently undulating till deposits. Slope gradients along the undisturbed portion of the area average 0 to 5%, with the exception of a short, 3 to 5 m incline along shoreline that can reach up to 60% grade.

The material within the retrogressive thaw flow slide as well as along the scarp face indicates that the till found in the area consists mostly of silt and clay, with only a very minor portion of coarse fragments. The imperfect to poor site drainage and vegetation conditions are typical of the fine texture tills found in the area. Observation of the material along the 3 to 5m high scarp face clearly indicates the presence of massive ice at an approximate depth of 2 m below ground surface (Appendix A, Photo A-2).

Two distinct retrogressive thaw slumps are visible on the 2004 aerial imagery, both slides having an approx. size of 0.4ha. The review of the 2011 LiDAR data indicates that the most northerly thaw slump has growth in size by nearly 8 times over the last 7 years and now covers an approximate area of 3 ha (Figure 3-2).

A series of ground-penetrating radar (GPR) profiles were collected along the crest of the slump area (Figure 3-2). Although visual assessment of the scarp face proposes that there is a sharp contact with massive ice at an approximate depth of 2 m, no strong reflectors corresponding to the top of the massive ice are discernible on the GPR profiles. This seems to suggest that there was little contrast at this site between the soil immediately below the active layer and the massive ice that is thawing out. It also suggests that ice-rich soils are present from the base of the active layer all the way down to the inferred depth of the massive ice between 7 to 10 m depth (based on GPR data).

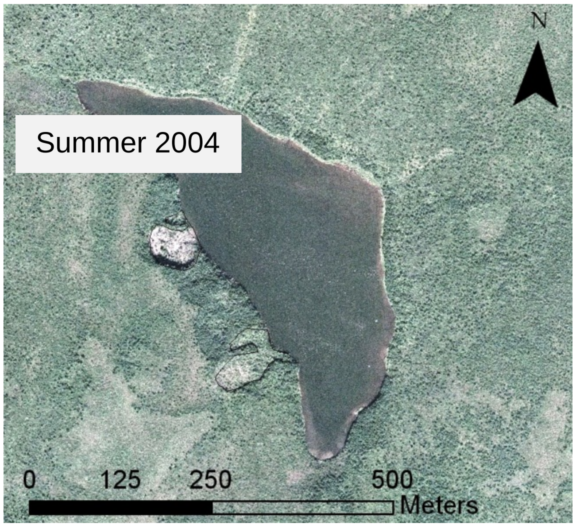


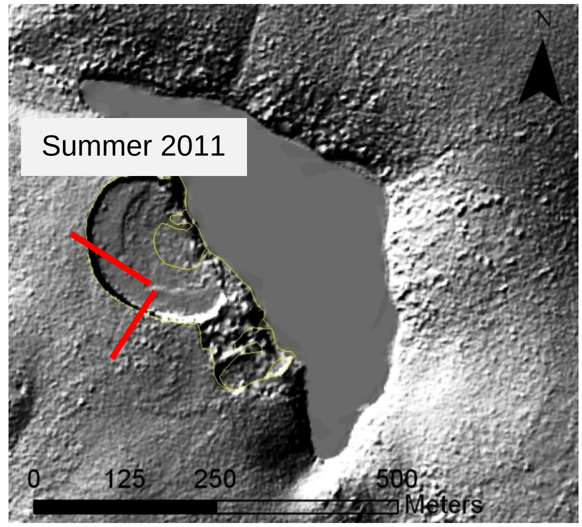
Inuvik to Tuktoyaktuk Highway - Terrain and Permafrost Field Verification

Location of Geophysical Survey Sites

3-1

Figure 3-2 Recent evolution of a retrogressive thaw flow slide located 800m east of KP 12.5





*Approximate locations of the GPR transects in red

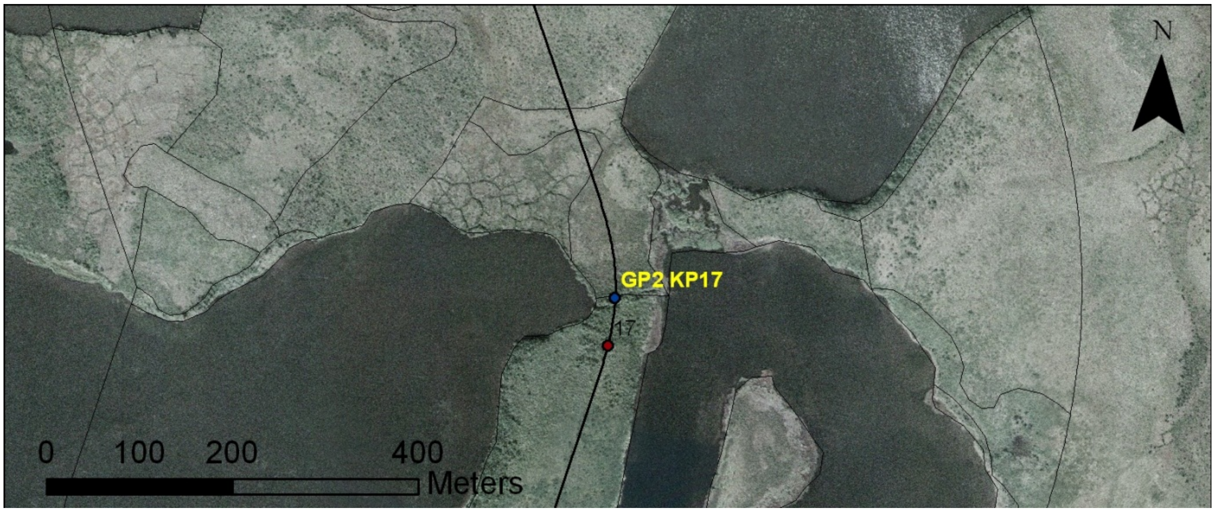
3.2.2 GP2 KP17

At site GP2 KP17, the alignment is located along a narrow, low-lying ridge separating two lakes (Figure 3-3). This site was selected to investigate the local conditions along an area where poor drainage and thermokarst degradation could possibly be an issue in the future.

The site consists of relatively openly vegetated till terrain on either side of a small open creek with thick willow growth (watercourse crossing 13a; Appendix A, Photo A-3). Slopes in the area are very subdued and range from 0 to 2%. Recent evidences of channel migration as well thaw settlement and cracks could be seen on the ground on either side of the creek.

No boreholes were drilled at the site but an active layer transect was completed at the approximate location of the GPR profile. The active layer ranged from 23 cm along the moderately well to well drained till, to a maximum of 166 cm depth at the creek crossing. Active layers depth are directly related to the material texture (i.e. increase thaw depth of the coarse grained material) and material drainage (i.e. increase thaw depth of poorly drained or water saturated materials). Other factors controlling active layer thickness include vegetation and slope aspect (Nixon et al. 2003).

Figure 3-3 Location of site GP2 KP17



The GPR profile collected along the proposed route alignment at the creek crossing provided a relatively good signal penetration on the ground located on either side of the creek, which indicates well frozen, likely ice rich, soils. Within the creek itself the GPR signal is significantly attenuated to the extent that little penetration into the soils is achieved using the GPR. This illustrated the influence temperature and ice content has on the attenuation rate in fine grained soils and this is one of the signatures used in interpreting GPR data for thawed taliks. Another feature of interest that is seen on the GPR profile is the obvious increase in active layer thickness as the creek is approached.

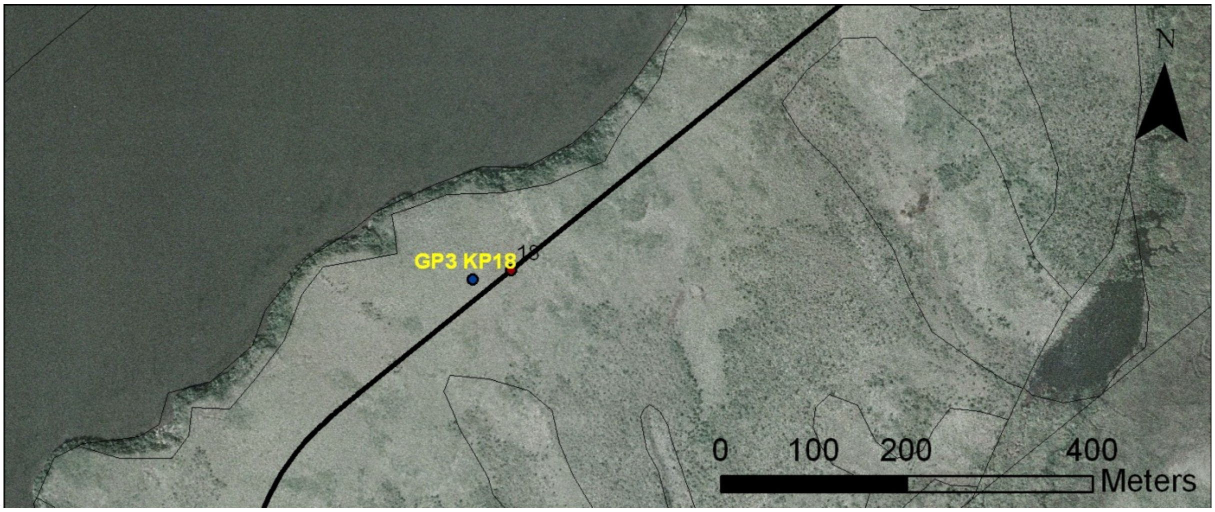
3.2.3 GP3 KP18

Site GP3 KP18 consists of a flat to very gently undulating till deposit. From KP 17.7 to KP 18.5 the proposed alignment is located at close proximity (i.e. from 60 to 120m) to a lake shoreline (Figure 3-4). Airphoto interpretations as well as field observations indicate that the shoreline is characterized by a series of small landslides and therefore is thaw unstable. No exposed soils and fresh landslide scars were identified on site but clear signs of past landslide activity can be observed along the shoreline (Appendix A, Photo A-4).

One GPR profile as well as one OhmMapper (resistivity) profile were collected at this site. Both profiles are oriented perpendicular to the proposed route alignment, from proposed route centerline all the way to the slope break found along the shoreline. The data from both profiles showed relatively low attenuation rates for surficial tills, suggesting that the local materials have relatively coarser grain size distribution than other tills investigated as part of this program.

The OhmMapper data in particular showed very resistive materials in the top 1.5 to 2.75m, suggesting high ice content material immediately below the active layer. This was confirmed by the shallow borehole drilling that was conducted onsite. A very sharp contact between the top soil and ice was encountered at 35 cm below ground level. Clear ice was encountered from 35 cm to approx. 45 cm depth (Appendix A, Photo A-5). Material found between 45 cm and 90 cm showed as much as 60% ice content.

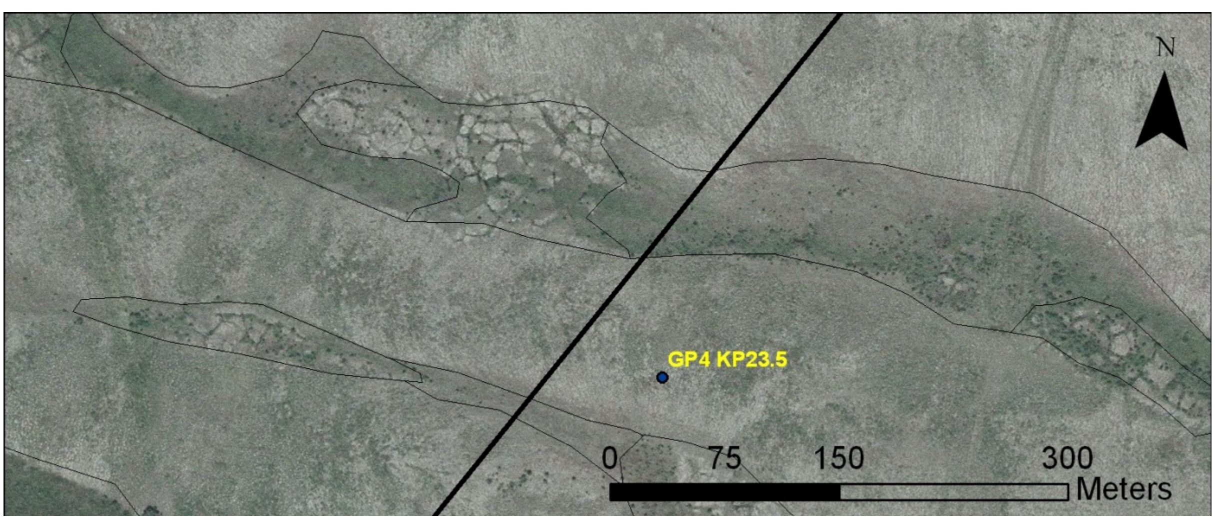
Figure 3-4 Location of site GP3 KP18



3.2.4 GP4 KP23.5

Site GP4 KP23.4 is located on undulating till plain (Figure 3-5). Slopes are very gentle and range from flat to a maximum of 4%. The features of interest at this location are the presence of a series of shallow drainage channels intersecting the proposed route alignment. The channels range in width from a few meters to approximately 125 m. Surface drainage within the channels is generally very poor, with strong seasonal seepage flowing from west to east. The thickness of the organic accumulations is generally thicker with the channels. Some of the larger channels are characterized by well defined, ephemeral creeks but the vast majority of them are characterized by undefined flow path. The distinct vegetation cover found within the drainage paths is as a key indicator of their lateral extent, therefore facilitating the delineation of the channels during the terrain mapping exercise (Appendix A, Photo A-6).

Figure 3-5 Drainage channels at site GP4 KP23.5



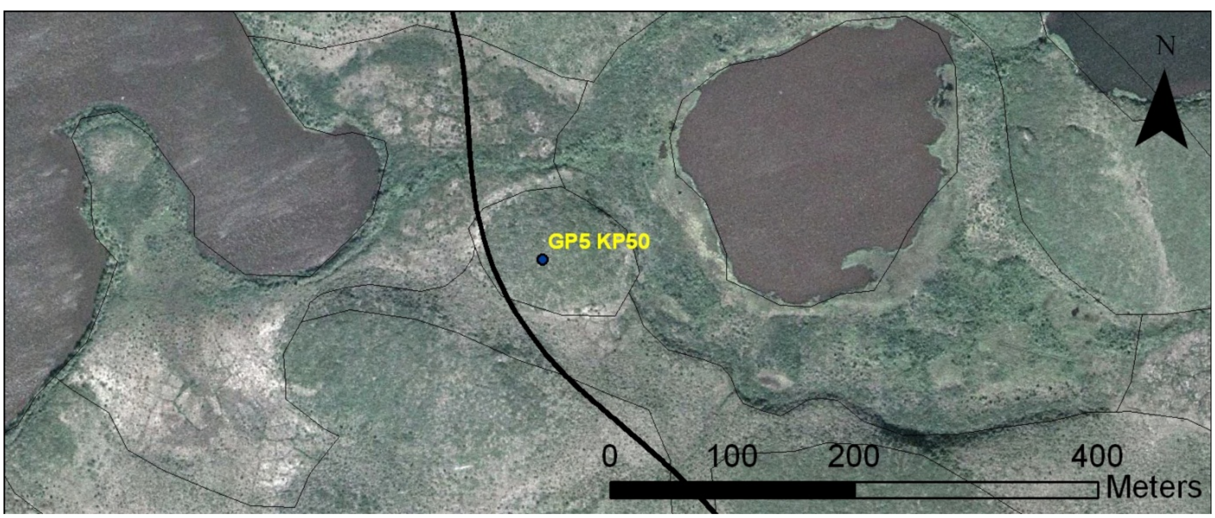
One GPR profile and one OhmMapper profile were collected at this location. The interest in conducting a geophysical survey at this specific site was to assess its utility in refining the mapping of the main drainage path in areas of low topographic relief, knowing that culvert placement is a key factor that could affect the integrity of the road infrastructure. Results of both geophysical methods clearly identify where the low-lying, ice-rich, high moisture materials are located. In addition to identifying concentrations of water, the GPR data showed a series of very narrow reflections that in the field were noted to correlate with surface cracks that could be possible, poorly developed, ice wedge features.

A shallow borehole was drilled in the area separating two of the drainage channels. Sample analysis indicates that the till consist of clayey silt with only a minor fraction of sand and coarse fragments. Ice content in the area immediately below the base of the active layer (i.e. 55cm) was very high, with over 60% ice observed in the samples between 55cm and 1m depth. Visible ice occurred as clear lenses ranging from 3 to 7cm in thickness (Appendix A, Photo A-7).

3.2.5 GP5 KP50

Site GP5 KP50 is characterized by a succession of various terrain types (i.e. till, to glaciofluvial outwash, to lacustrine deposits; Figure 3-6). Slopes are variable and range from 2 to 10% on top of the till and lacustrine deposits, to a maximum of 25% along the edges of the glaciofluvial outwash units (Appendix A, Photo A-8). The drainage of the various parent materials range from moderately well to poor and is directly related to factors such as the various material textures, their topographic positions, slope and aspects.

Figure 3-6 Location of site GP5 KP50



Both a GPR and OhmMapper profiles were collected at this site. The main interest of the geophysical surveys at this location was to see how the geophysics would characterized the changes in the surface materials as the system passes from one terrain unit to another. Neither the GPR nor the OhmMapper data indicate a clear transition between the various terrain units. Although no lateral material transition was interpreted from the geophysical data, rather high ice contents were noted in the in the upper surface materials, as well as in a specific area located at the base of a north facing slope where large ice-wedges were present. In addition, a strong vertical reflector was noted at an approximate depth of two meters below the surface.

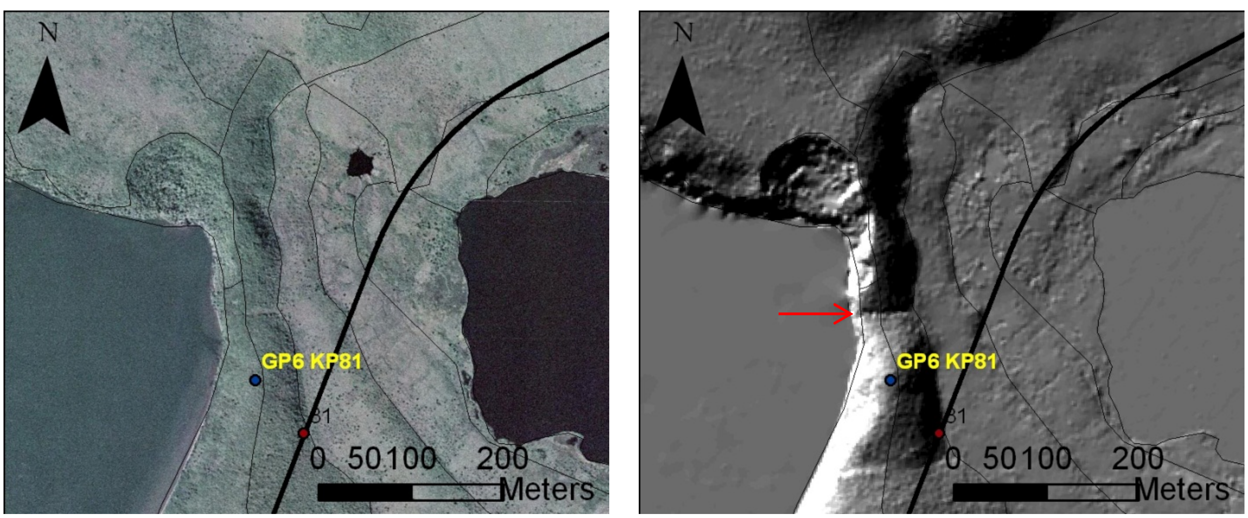
The information collected from a 2 meters deep borehole correlates with the GPR and OhmMapper data. The clayey silt material found at GP5 KP50 is characterized by ice content averaging 50% (Appendix A, Photo A-9) and a sharp contact between clayey silt material and clean sand and gravel was observed at 1.9 meter depth, which correspond to the reflector observed on the GPR profile.

3.2.6 GP6 KP81

At KP81, the proposed alignment crosses from upland till to low-lying lacustrine material. Site GP6 KP81 was selected in relation with the presence of a narrow ridge separating two lakes (Appendix A, Photo A-10). The ridge is approximately 70m wide by 7m high and acts as a natural dam to the lake located on the western side. The transition from till to lacustrine material is located along the eastern side of the ridge, at the very base of the slope. The slope gradients along the surface of the ridge range from 0 to 5%, while the side slopes reach a maximum of 45%.

A retrogressive thaw flow slide is located at the northwestern extremity of the ridge. The landslide has a typical arcuate shape along its crest and covers an area of 100m2(1 ha) Both the field observations and the comparison of the landslide limits between the 2004 airphotos and the 2011 LiDAR data indicates that the landslide is stable and has not increased in size over the last seven years (Figure 3-7). The LiDAR data also indicates that the central portion of the ridge is characterized by a small depression, approximately 2m lower than the surrounding terrain (see the red arrow on Figure 3-7).

Figure 3-7 Airphoto and Lidar data of site GP6 KP81.



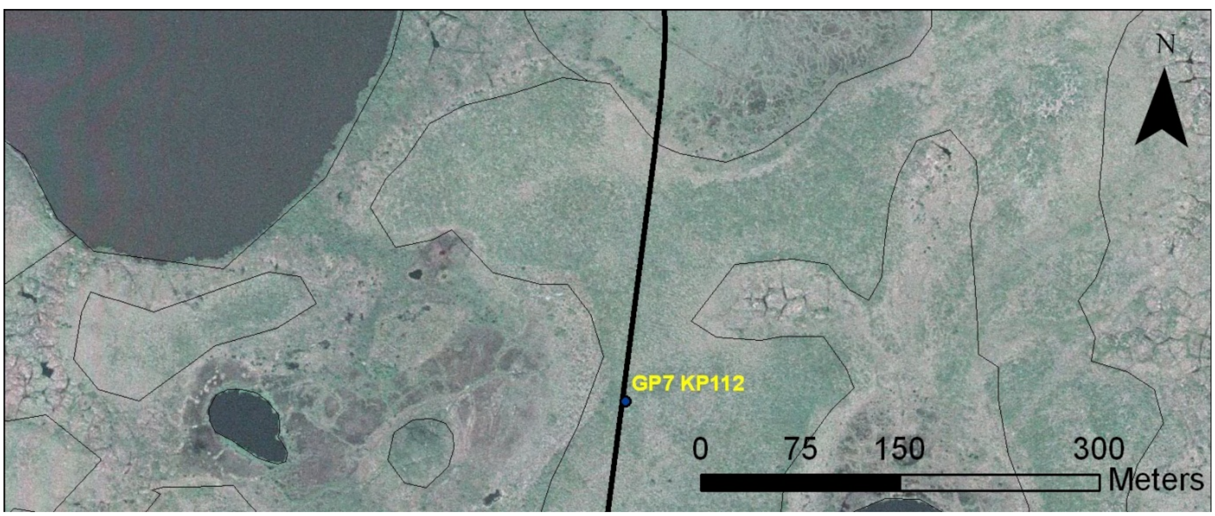
Three GPR profiles were collected at this location. One profile was along the ridge line, one was in the lacustrine material found along the toe of the ridge and the lake to the east, and the third was oriented perpendicular to the ridge, from the top of the rdige to the toe of the slope. The GPR profile along the ridge shows typical variations in active layer thickness and confirms that active drainage and a depressed active layer are present at the depression area noted on the LiDAR data (red arrow). The GPR data in the lacustrine material at base of the ridge show significantly more signal penetration and likely higher ice content. Finally the GPR profile perpendicular to the ridgeline clearly shows that the transition between the till and the lacustrine material is located at the toe of the ridge.

A borehole was drilled on top of the ridge at site GP6 KP81. The core samples indicate that the material in the first meter below ground surface consist dominantly of silt, with minor amounts of clay, sand and gravels. Sand and gravel content increase below one meter depth but silt is still the dominant texture. Active layer measurement average 40 cm on top of the ridge. Ice content was visibly estiamted at 70% in the first 10 cm below the active layer. The ice is present as well defined lenses, ranging in thickness from 1mm to 25mm (Appendix A, Photo A-11). Ice content decrease with depth, averaging 15% at 1.3m depth.

3.2.7 GP7 KP112

Site GP5 KP50 is characterized by a transition between slightly elevated lacustrine deposits and low-lying areas characterized by poor drainage and ice wedge polygons Figure 3-8; Appendix A, Photo A-12). This type of terrain is dominant in the northern portion of the alignment, where extensive areas of ice wedge polygons are crossed by the proposed highway alignment.

Figure 3-8 Lacustrine deposits and ice wedge polygons near KP112



The main interest into conducting geophysical survey at this site was to determine how well the ice wedge polygons could be detected in the GPR records. Two GPR profiles and one OhmMapper profile were collected at the site. The pattern of ice wedges polygons shows up more clearly on the GPR profiles. Evidence of ice wedge formation can be seen along the polygon boundaries, and the center of the ice wedge polygon is also apparent. The OhmMapper (resistivity) data does not show the same level of details and simply shows the ice wedge polygon area as an area of higher resistivity reflecting the higher ice content and standing water.

A shallow borehole was drilled away from the ice wedges in the lacustrine material. The borehole showed an active layer of 30cm immediately underlain by a ice-rich layer of peat and silt. Ice content of the material found between 30cm and 1m depth range from 30% to approx. 55% (Appendix A, Photo A-13).

3.3 Updated Table of Terrain Constraints

One of the main objectives of the present study was to re-examine the terrain constraints and sensitive areas identified along the ITH Alignments #1 and #3, as identified in Table 3-2 of the Terrain Report, in order to determine if those features :

1. Do not require any specific action;
2. Will be addressed through engineered mitigation; or
3. Will be addressed through route optimization during the detail design phase of the project.

As an outcome of this task, an updated table of sensitive areas and terrain constraints is provided in Table 3-1.

Table 3-1 Verified terrain constraints and sensitive areas found along the proposed alignments

Location (KP)	Original comments	Update following field investigation	Proposed Action
Alternate 1 and Alternate 3 (KP 0 to KP 90)			
2 to 6	Visible surface seepage in a series of undefined flow paths. Will require proper management of surface water along the upper side slope	Verified	Will be addressed by engineered mitigation during detailed design
4	Slumping along the shoreline of a thermokarst lake (approximately 400 m west of the alignment)	Verified. The feature is far away from the proposed alignment and therefore not problematic	No action required
5.5 – 6 new	Alignment is very close to lake	Identified	Route optimization will be evaluated in detailed design
11	Recent lake drainage on the east side of the alignment; slumping along the creek exiting the lake (250 m downstream from the creek crossing)	Verified, slump is located downstream from the crossing and is not expected to affect the centerline	Route optimization will be evaluated in detailed design
15 to 15.5	Alignment running along a narrow ridge separating two lakes; route geometry could be improved	Verified, no terrain constraint identified, no terrain issue	Route optimization will be evaluated in detailed design
16	Recently drained lake basin; active thermokarst	Verified	No action required
16.5	Geometry could be improved to stay away from small creek	Verified. Minor undercutting at the creek	Route optimization in effort to move away from the creek will be evaluated in detailed design
17 to 17.3	Low lying, very poorly drained area; presence of ice wedge polygons and signs of recent thermokarst activity	Verified, geophysical investigation confirms ice-rich till; thermokarst confirmed; ridge tops are well-drained	Route optimization in an effort to follow ridge tops and maximize drainage will be evaluated in detailed design
18.1	Alignment less than 30 m from a receding shoreline affected by thermokarst and slumping	Verified. No recent signs of surface erosion or mass movement	Route optimization in an effort to follow ridge tops and maximize drainage will be evaluated in detailed design. Monitoring of shoreline conditions will be conducted.
19 to 19.3	Geometry could be improved to stay away from small creek	Verified	Route optimization in effort to move away from creek will be evaluated in detailed design
19 to 21	Signs of solifluction on several mid to lower slopes in the area	Verified. No solifluction features at proximity to the centerline	No action required
21 to 25	Alignment crosses a series of seven (7) undefined flow paths characterized by seepage, ice wedge polygons and organic accumulations	Verified. Geophysical investigation confirms where the low-lying, ice-rich, high moisture content are	Will be addressed by engineered mitigation during detailed design
27 – 27.5 new	Large area of undefined flow (crossing 20; 20a)	Identified	Route optimization in effort to minimize crossing area will be evaluated in detailed design
31 to 32.5	Alignment runs along a side slope characterized by extensive seepage	Verified. Seepage is not as severe as initially thought	Will be addressed by engineered mitigation during detailed design
35 to 36	Alignment is located approximately 100 m west of a steep escarpment characterized by several gullies and active mass movement	Verified, no evidence of rapid mass movement; slow erosion confirmed	No action required
39	Active mass movement in the area; several solifluction lobes in till material approximately 400 m west of the alignment	Verified but area on alignment is stable	No action required
39.8	Alignment crosses a small colluvial fan; potential debris flow following spring melt or heavy rainfall	Verified, no potential for debris flows	No action required
40.4 to 41	Alignment crosses a 15 to 25% side slope characterized by creep and solifluction	Slight over-evaluation of the slope gradient due to coarse DEM data	Will be addressed by engineered mitigation during detailed design
44	Geometry could be improved to stay further away from a moderately steep slope	Verified, slope is stable	No action required
47.2 to 47.6	Geometry could be improved as the alignment crosses a depression (thermokarst) which has side slopes characterized by creep and solifluction	Verified steep slope, no active movement	Route optimization in effort to avoid crossing depression will be evaluated in detailed design
48.6	Geometry could be improved to stay further away from the short steep slopes of a recently drained lake	Verified, poorly drained area with thermokarst verified; ice rich	Complicated terrain in this area will require evaluation during detailed design
48.8 to 49.4	Poorly drained area; recently drained lake 70 m east; presence of ice wedge polygons and signs of recent thermokarst activity	Verified, poorly drained area with thermokarst verified; ice rich	Complicated terrain in this area will require evaluation during detailed design
49.8	Poorly drained area; recently drained lake 65 m west of the alignment; presence of ice wedge polygons; possible pingo adjacent to the alignment	Verified, poorly drained area with thermokarst verified; ice rich; no pingo	Complicated terrain in this area will require evaluation during detailed design

Location (KP)	Original comments	Update following field investigation	Proposed Action
50.2 to 50.6	Several small retrogressive thaw slumps; the alignment runs along the headscarp of an old slide and is 80 m upslope from an active slide to the east	Verified ice-rich terrain with thermokarst	Complicated terrain in this area will require evaluation during detailed design
51.4	Alignment runs along the edge of a steep slope characterized by active mass movement; geometry could be improved to stay away from the slope	Verified ice-rich terrain with thermokarst	Complicated terrain in this area will require evaluation during detailed design
53.6 to 54.1	Area characterized by a recently (and partially) drained lake as well as an extensive polygonal peatland; possible re-route to the west of the lake	Verified	Route optimization in effort to avoid crossing depression will be evaluated in detailed design
55.4	Alignment crosses a polygonal peat plateau that is characterized by recent thermokarst of ice-wedge polygons due to rapid drainage of a lake	Verified; ice rich	Several crossing options are being evaluated in discussion with regulators and will be confirmed during detailed design
56	Alignment crosses an active colluvial fan (located at the edge of Hans Creek floodplain) characterized by a recent debris flow; the fan is located on top of a fluvial terrace; Hans Creek crossing could be relocated	Verified	Several crossing options are being evaluated in discussion with regulators and will be confirmed during detailed design
57	Alignment crosses a 170 m thermokarst depression characterized by seepage and ice wedge polygons	Verified	Will be addressed by engineered mitigation during detailed design
58.5	Alignment located only a few meters (<10 m) from the headscarp of a stabilized retrogressive thaw slump	Verified	Route optimization in effort to increase distance from thaw flow slumps will be evaluated in detailed design
59.2	Alignment located 100 m from the edge of a small pingo	Verified	No action required
60.6 to 62	Alignment crosses a low-lying are modified by thermokarst; presence of ice wedge polygons	Verified	Route optimization in effort to avoid length of route through ice wedge polygons is being considered and will be determined during detailed design
62.6 to 64	Alignment crosses the headscarp of four (4) stabilized retrogressive thaw slumps; geometry could be improved to avoid the slumps	Verified, retrogressive thaw slumps have stabilized	Route optimization in effort to avoid crossing retrogressive thaw slumps will be evaluated in detailed design
67	Alignment crosses a polygonal peat plateau that is characterized by recent thermokarst of ice-wedge polygons	Verified	A relocation of stream crossing to a more appropriate location is being considered.
68.5 to 72	Area characterized by extensive surface seepage, creep and solifluction	Seepage verified, no creep or solifluction	No action required
76	Alignment located along a narrow ridge (approx. 120 m wide) separating 2 lakes; there is a 10 m elevation change between the two lakes; possibility of rapid lake drainage if thermokarst occurs along the ridge	Verified	Route optimization from km 74-77 in an effort to avoid going between lakes is being considered.
78.8	Alignment is located on top of a narrow ridge (80 m wide) separating a lake (upslope from the alignment) and a moderately steep downslope	Verified, but not problematic	No action
81 to 81.5	Complex area characterized by poorly drained thermokarst lake basin and recently drained lake; with a recent retrogressive thaw slump (200m west from the alignment); possibility for catastrophic lake drainage at KP 81; field assessment is strongly recommended	Verified, the thaw slump is now vegetated and no recent erosion was noted. Geophysical surveys and sampling verify ice-rich terrain	Will be addressed by engineered mitigation during detailed design and ongoing monitoring
81.8 to 82	Alignment crosses 2 solifluction lobes	Verified, features are stable	No action
82.2 to 82.8	Alignments crosses a thermokarst lake basin and a polygonal peatland	Verified	A relocation of the route to the east in an effort to minimize crossing of polygonal terrain is being considered.
83 to 83.7	Alignment crosses a complex area characterized by thermokarst lake basins and ice wedge polygon networks; the area is characterized by recent thermokarst of massive ice (possibly a collapsed pingo) and ice wedge polygons	Verified	A relocation of the route to the east in an effort to minimize crossing of polygonal terrain is being considered.
84 to 85	Alignment crosses two (2) fluvial fans formed from the recent drainage of two small lakes; potential for high seepage	Verified	Will be addressed by engineered mitigation during detailed design and ongoing monitoring
87	Alignment crosses a narrow section (125 m wide) between two (2) lakes; signs of surface seepage	Verified	No action
88.3	Alignment crosses the flow path of an old stabilized slump	Verified	Will be addressed by engineered mitigation during detailed design and ongoing monitoring
89 to 89.2	Alignment crosses a very narrow section (50 m wide) between two lakes; the area is very poorly drained organic and lacustrine deposits and is characterized by the presence of ice-wedge polygons; possible thermokarst of some ice-wedge polygons	Verified	A relocation of the route from 88 to 90.3 to avoid polygonal terrain is being considered
88.8 to 90.5	Alignment crosses a large polygonal peatland characterized by recent thermokarst of ice-wedge polygons due to rapid drainage of a lake	Verified	A relocation of the route from 88 to 90.3 to avoid polygonal terrain is being considered

Location (KP)	Original comments	Update following field investigation	Proposed Action
Route Alternative 1			
91.3 to 92.1	Alignment is located less than 60 m away from the edge of a thermokarst lake characterized by retrogressive thaw slumps; geometry could be improved	Detailed site-specific route evaluation and options will be evaluated if this route is approved. There are no identified terrain constraints that cannot be addressed by engineered mitigation or route optimization.	
93 to 96	Ice-rich deposits; several retrogressive thaw slumps (slumps located 75 to 250 m away from the alignment)		
97.3	Alignment is located at edge of a thermokarst pond characterized by ice wedge polygons, approximately 120 m from the edge of a small pingo		
97.7 to 98	Alignment is located less than 20 m from the edge of a thermokarst lake; geometry could be improved		
98.4	Alignment is located less than 10 m from the edge of a thermokarst lake; geometry could be improved		
100.3 to 101.2	Alignment is located less than 60 m in average (and as close as 20 m) from the edge of a thermokarst lake; geometry could be improved		
105.2 to 105.4	Alignment is located less than 20 m from the edge of a thermokarst lake; geometry could be improved		
106.4	Alignment is located less than 30 m from the edge of a thermokarst lake; geometry could be improved		
107.3	Alignment is located less than 40 m from the edge of a thermokarst lake; geometry could be improved		
107.7 to 108	Alignment is located less than 40 m from the edge of a thermokarst lake; geometry could be improved		
108.8	Alignment passes a narrow (60 m wide) low lying area separating two lakes; small creek crossing; ice-wedge polygons and signs of recent thermokarst		
Route Alternative 3			
93.2 to 93.4	Vast low lying area characterized by polygonal peatlands and poor to very poor drainage	Verified	Will be addressed by engineered mitigation during detailed design
95.3	Alignment located on top of a narrow ridge characterized by retrogressive thaw slumps (approximately 20 m from the alignment)	Verified. Slumps are stabilized	Area will be monitored
96.2 to 96.7	Alignment crosses a poorly drained thermokarst lake basin characterized by ice wedge polygons	Verified	Will be addressed by engineered mitigation during detailed design
97	Alignment passes close (20 m) to the headwalls of two (2) successive thermokarst depressions	Verified	Route optimization in effort to avoid crossing depression will be evaluated in detailed design
98.4	Alignment follows the edge of a recently drained lake basin (less than 40 m from the water); geometry could be improved	Verified	Will be addressed by engineered mitigation during detailed design
101.5 – 110 (combined)	Large area of ice-wedge polygons, thermokarst lakes and organic accumulations	Complex, polygonal terrain verified	A potential relocation of the route to avoid extensive area of polygonal terrain is being considered; alternatively, engineered mitigation will be developed during detailed design
	The two route alternatives join at KP 109.5		
110.5	Alignment passes at the edge of a recently drained lake; geometry could be improved	Verified	Route optimization in effort to increase distance from lake will be evaluated in detailed design
111.5	Alignment follows the edge of a flooded wetland characterized by thermokarst; geometry could be improved	Verified	Route optimization in effort to minimize crossing of wet area and thermokarst terrain will be evaluated in detailed design
112.5 to 113	The alignment crosses a very poorly drained string fen; presence of a pingo approximately 350 m east from the alignment; a re-route could be considered to avoid the fen	Verified	Will be addressed by engineered mitigation during detailed design
114	Alignment passes 30 m from the edge of a thermokarst lake; geometry could be improved	Verified	Will be addressed by engineered mitigation during detailed design
114.1	Alignment passes along the edge of a moderately steep slope characterized by mass movements (debris slide and active layer failures); geometry could be improved	Stabilized. No signs of recent mass movement.	No action
114.5 to 115.5	Alignment passes a complex area characterized by small thermokarst topography, small lakes and moderately steep slopes with susceptible to mass movements; a small re-route could be considered	Verified	Route optimization in effort to avoid thermokarst area will be evaluated in detailed design

Location (KP)	Original comments	Update following field investigation	Proposed Action
116 to 117	Alignment runs along the edge of a steep slope (10 to 20 m away) characterized by active mass movements (small debris slides)	Verified; stable	Route optimization will be considered during detailed design.
119 to 119.7	Alignment runs along the edge of a steep slope (35 to 50 m away) characterized by active mass movements (small debris slides)	Verified; stable	Ongoing monitoring and engineered mitigation
123	Alignment passes along the edge of a recently drained lake characterized by ice-wedge polygons and a pingo (200 m away); area is very poorly drained and shows signs of thermokarst; geometry could be improved	Verified	Ongoing monitoring and engineered mitigation
123.6	Alignment passes a narrow (60 m wide) low lying area separating two lakes; small creek crossing; signs of recent thermokarst	Verified	Ongoing monitoring and engineered mitigation
124.1	Alignment passes 40 m above the headwall of a stabilized retrogressive thaw slump; geometry could be improved	Verified; stable	No action
131.6	Retrogressive thaw slump 35 m west of the alignment	Verified to be active	Will be addressed by engineered mitigation during detailed design.

4 DISCUSSION

The objectives of this terrain and permafrost field verification program were to:

- Refine desktop-based mapping based on field verification and review of LiDAR imagery
- Verify terrain constraints and sensitive areas along Inuvik to Tuktoyaktuk Highway (ITH) Alignments #1 and #3, as identified in Table 3-2 of the Terrain Report
- Provide recommended mitigations or further work required to address verified constraints
- Investigate how geophysical methods can be used to identify massive ice or ice-rich terrain not readily discernable using desktop methods only

The terrain constraints and sensitive areas identified along the proposed alignments correspond mainly to the presence of poorly drained areas as well as the presence of ice rich terrain features. The crossing of poorly drained organic accumulations zones and areas characterized by high surface seepage should be minimized where possible. The areas identified in Table 3-1 are all shown in the terrain map atlas (see Appendix B). Potential route optimizations will be evaluated as part of the detailed engineering design. Areas that cannot be avoided will be addressed by way of engineered mitigations to be considered during detailed design.

Ice-rich terrain features such as ice-wedge polygons are a particular and often unforseen hazard to performance of the road embankment. The initial terrain mapping suggested that up to 17.4 km of Alternative 1, and up to 19 km of Alternative 3 traverse areas of ice-wedge polygons. The latest field visits as well as some additional terrain mapping using recently acquired LiDAR data indicate that there are more ice-wedge polygons than was originally delineated. Similarly to the poorly-drained areas, the crossing of ice-wedge polygons should be minimized in order to prevent possible permafrost degradation and thaw subsidence. A series of minor realignment options have been identified for consideration during final design that could considerably reduce the length of route over terrain containing ice-wedge polygons.

The existing access road to gravel source 177 south of Tuktoyaktuk provided an opportunity to examine a few locations where the embankment was constructed by placing frozen fill directly on a geotextile layer over the surface expression of ice wedge polygons. Aerial and ground examination of sites such as shown in Appendix A, Photo A-14 to A-16, clearly showed subsidence troughs reflecting through the embankment fill. These troughs are an early indication of enhanced thermal erosion where surface water is preferrentially using the ice wedge cavities. The hazard this creates for the embankment is the risk of undermining by thermal erosion followed by sudden collapse of the grade. This has been observed at locations on the Dempster Highway and Alaska Highway (Transportation Association of Canada 2010) and has been known to cause at least one fatality. The application of terrain analyses can identify hazard locations such as the polygon fields in a timely manner for feedback to the engineering design.

Another terrain constraint related to the presence of ice-rich material is the presence of retrogressive thaw flow slides. The review of the terrain mapping as well as the field verification indicates that most of these features are presently stable, suggesting that no recent erosion and mass movement is taking place. A series of active thaw slumps are present in the Inuvik – Tuktoyaktuk corridor but only one is located at close proximity (i.e. KP 131.6) to the alignment. The terrain conditions described at the large retrogressive thaw flow slide describe at site GP1 KP12.5 (i.e. fine-grained material, gently sloping terrain above relatively steep lake shoreline, areas characterized by old landslide scars, etc.) are common and are found at several locations along proposed route. The presences of landslide scars as well as the presence of several older, now stabilized thaw slumps are a very good indicator that this type of rapid mass movement represents a hazard to the proposed highway, especially in areas where the alignment is located at close proximity to water bodies. These known areas of previous instability should be monitored.

The results from the desktop review of the terrain mapping as well as the observations and data gathered during the two phases of the terrain verification program have allowed for a more detailed description of the various terrain landforms as well as their association with the presence of ground ice. The surficial material found along the proposed alignments consists mainly of glacial till while lacustrine deposits are extensive in the northern portion of the study area near Husky Lakes. Glaciofluvial outwash and ice-contact deposits are found locally, especially in the northern portion of the project area. Other surface materials include fluvial, colluvial and organic deposits. Latest field observations as well as a review of the borehole logs from the 2012 geotechnical investigations program (KAVIK-STANTEC 2012b) indicates that ice rich materials are found in all three main terrain types (i.e. till, lacustrine and outwash deposits).

Fine-grained tills observed in southern and central sections of the proposed alignments have showed high concentration of ice (e.g. 40% and above), especially in the first 50 to 100cm underlying the active layer. Segregation ice is visible in the form of individual ice crystals, ice coating on larger particles, randomly or irregularly oriented pattern, or well stratified and oriented lenses. Although only five (5) shallow boreholes have been drilled during this terrain-specific field program, each of these typical forms of visible ice have been observed. Observations made along the head scarp of the large retrogressive thaw flow slide near KP 12.5 indicate that massive ice is present in till deposits along the proposed highway alignments. The outwash deposits found along the alignment are also characterized by high ice content. Drilling conducted during the winter of 2012 showed that ice beds ranging in thicknesses from a few centimeters to several meters were present in the silty to gravely outwash material (KAVIK-STANTEC 2012b). The series of retrogressive thaw slumps as well as the extensive amount of ice wedge polygons found in the lacustrine deposits are strong indicators of the presence ice rich materials.

5 REFERENCES

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APPENDIX A

Site Photographs

Photo A-1 Large retrogressive thaw flow slide located approx. 800m east of the proposed alignment at KP 12.5

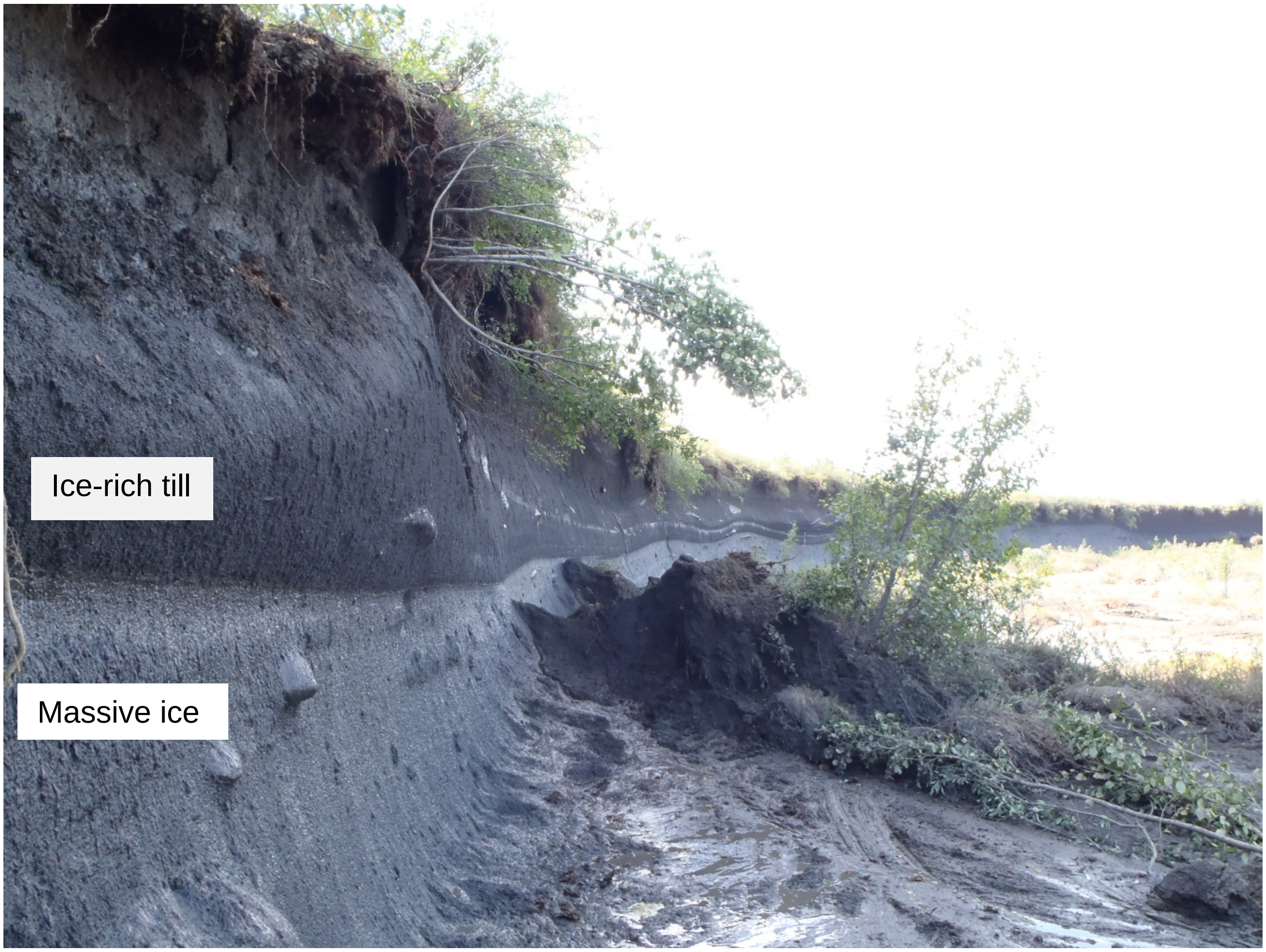

Photo A-2 **Steep headwall of a retrogressive thaw flow slide near KP 12.5. The height of the exposure ranges from 3 to 5m.**

Photo A-3 Low-lying terrain separating two lakes at KP 17.

Photo A-4 **Flat to gently undulating till deposit between KP 17 and KP 18 (route alignment in yellow, landslide scars in red).**

Photo A-5 **Core sample showing sharp contact between the topsoil and ice at 35cm depth. Active layer depth was of 30cm on July 26 (sample depth are in inches).**

Photo A-6 **Gently undulating till topography between KP 23 and KP 25 (route alignment in yellow, drainage channel in black).**

Photo A-7 Core sample of ice-rich till (>60% ice content) at site GP3 KP23.5.

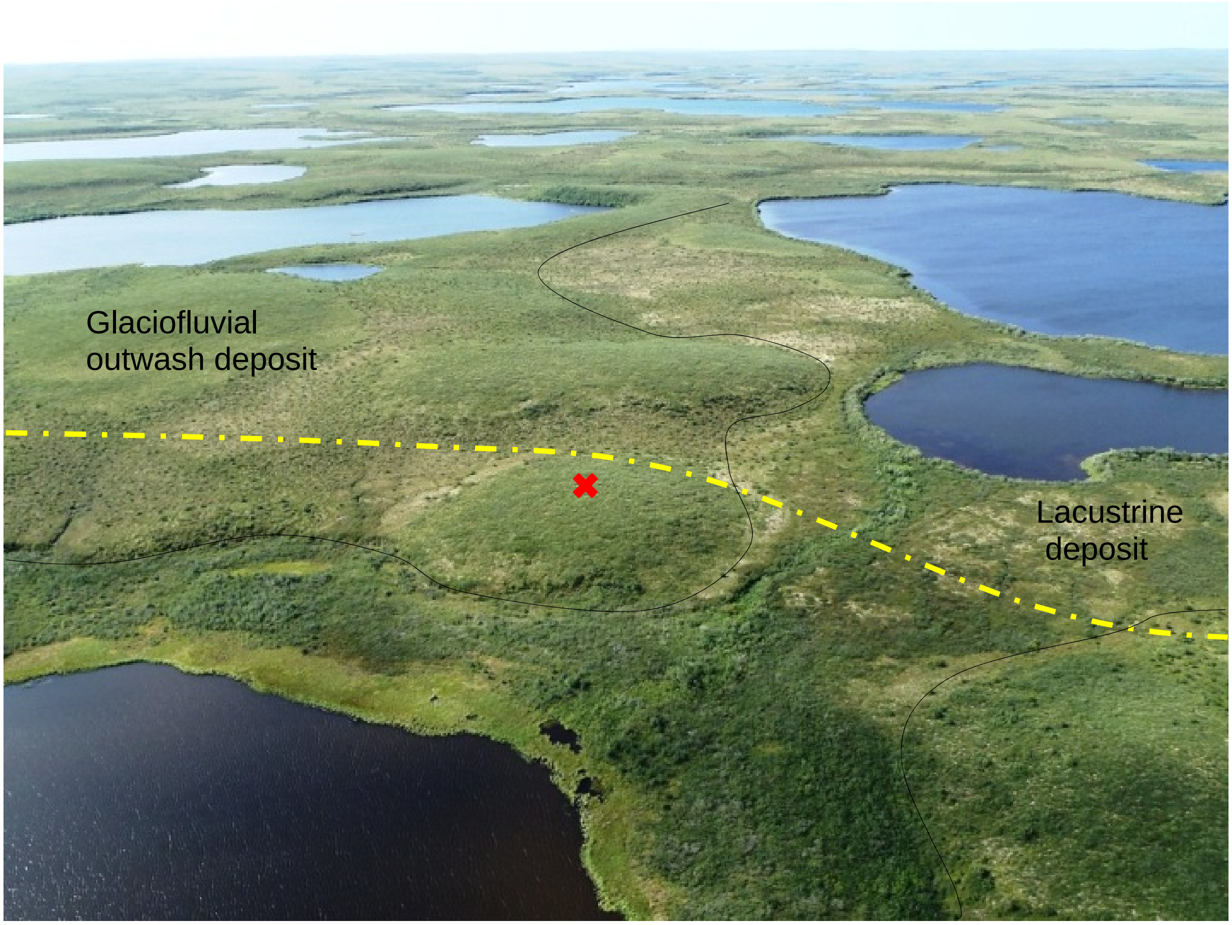

Photo A-8 **Oblique view showing the approximate contact between fine grained glaciofluvial outwash and lacustrine deposits (route alignment in yellow, location of the borehole in red)**

Photo A-9 **Core sample from 140cm to 175 cm depth showing random and irregularly arranged ice formations (approx. 50% ice content)**

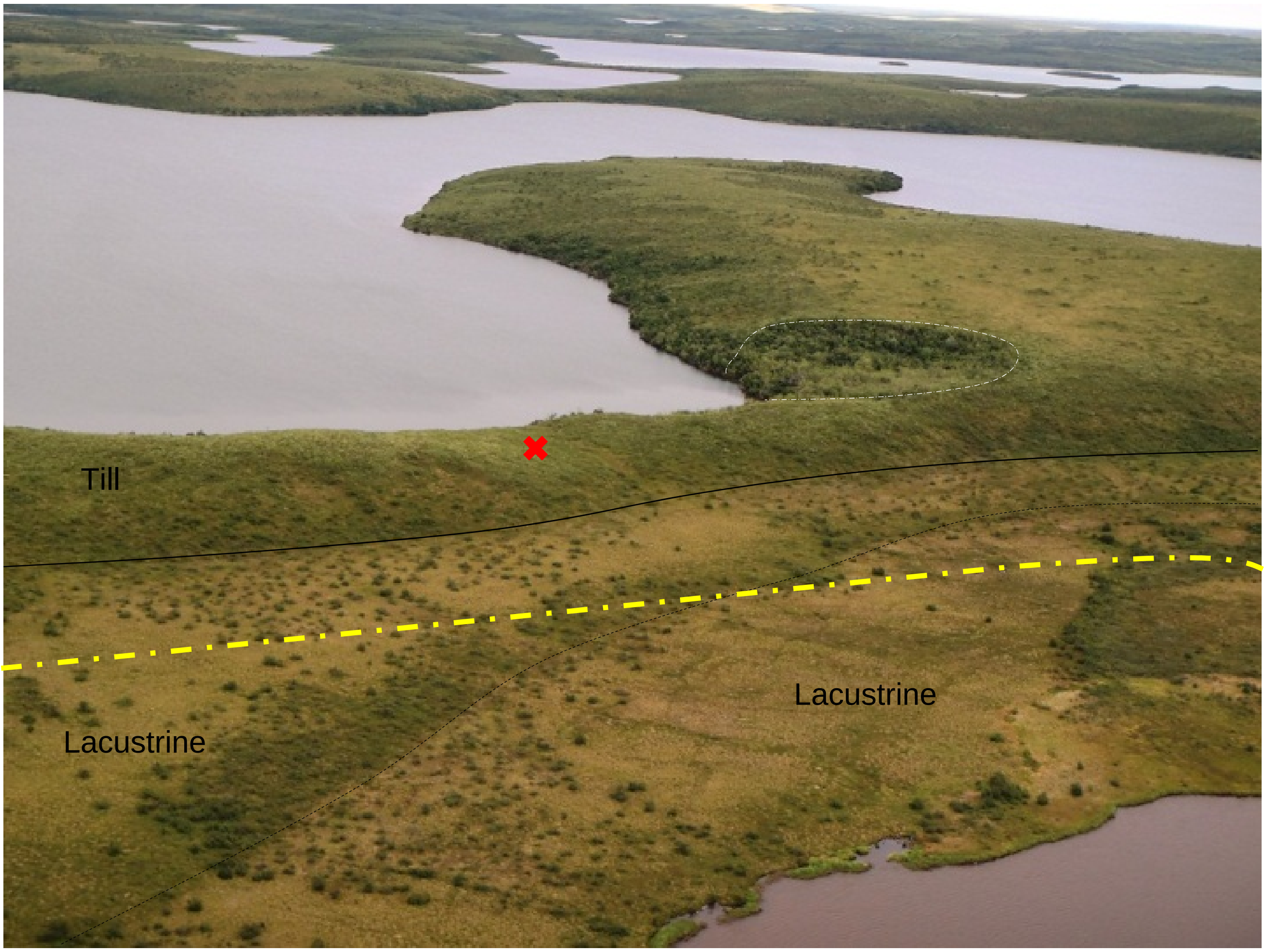

Photo A-10 **Oblique aerial view of a till ridge separating two lakes at KP 81 (route alignment in yellow, limit of a retrogressive thaw flow slide in dashed white, contact between till and lacustrine in solid black, previous lake level in dashed black, location of the borehole in red)**

Photo A-11 Core sample from 50cm to 80cm depth showing silt with thin (1-3mm) horizontally oriented ice lenses (approx. 30% ice content)

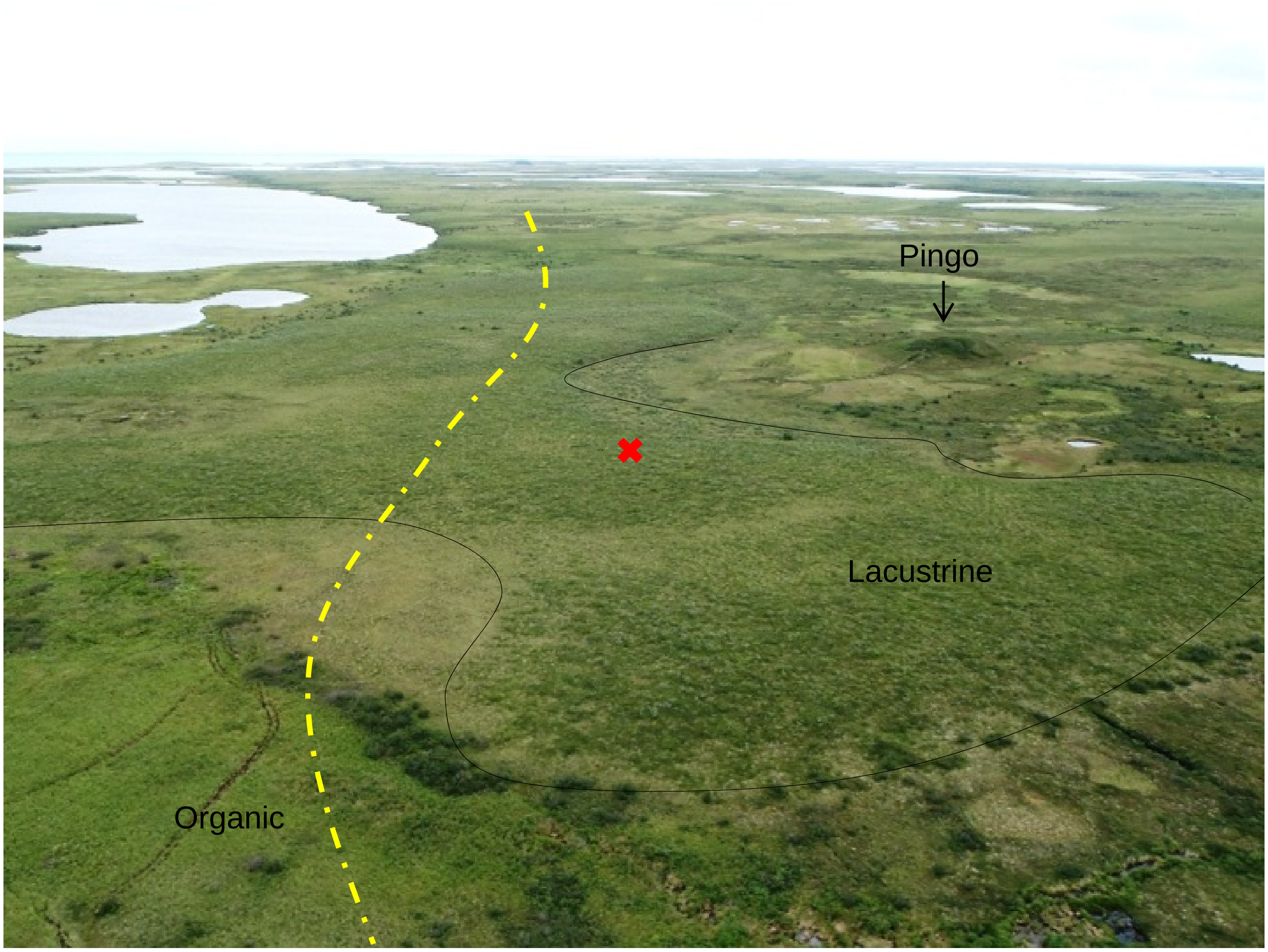

Photo A-12 **Oblique aerial view showing a transition from moderately well drained lacustrine deposits to poorly drained organic terrain characterized by ice-wedge polygons (route alignment in yellow, location of the borehole in red)**

Photo A-13 Core sample from 75cm to 95cm depth showing interbeds of silt and ice lenses (approx. 50% ice content)

Photo A-14 Oblique aerial view of the access road to gravel source 177 near KP 127 of Alternate 3(thaw subsidence along the red dotted lines)

Photo A-15 Thaw subsidence, tension cracks and ponding of surface water along the road bank of the access road to gravel source 177

Photo A-16 Thaw subsidence showing the location of ice wedges under the road bed (black arrows).

APPENDIX B

Map Atlas