Preliminary assessment of Dempster Highway permafrost conditions:

Mapping to inform the design basis for fibre optic cable installation

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KEY TERMS

The following key terms are commonly used when considering geomorphologic characteristics of permafrost environments and are considered relevant to construction in permafrost. Not all terms listed are explicitly used in this technical memo or in the accompanying maps; they are provided for a convenient reference. Definitions are from the multi-language glossary of permafrost and related ground-ice terms by Everdingen (2005).

Active layer: This is the layer of ground that is subject to annual thawing and freezing in areas underlain by permafrost.

Active layer detachment: A general term referring to several forms of slope failures or failure mechanisms commonly occurring in the active layer overlying permafrost.

Alluvial: This pertains to material or processes associated with transportation and/or subaerial deposition by concentrated running water.

Colluvium: Unsorted, rock fragments and soil materials produced by gravity or mass wasting are called colluvium. Landslides, mudslides and talus are all colluvial deposits. These heterogeneous deposits are generally identifiable in the field and typically lie in a slump at the base of a hill or rock outcrop.

Creep of frozen ground: The slow deformation (or time-dependent shear strain) that results from long-term application of a stress too small to produce failure in the frozen material.

Cryostructure: The structural characteristics of frozen earth materials. The cryostructure is determined by the amount and distribution of pore ice (or ice cement) and lenses of segregated ice. The type and arrangement of ice in the frozen material will depend largely on the initial total water content of the material and the extent of moisture migration during subsequent freezing.

Debris flow: A moving mass of loose mud, sand, soil, rock, water and air that travels down a slope under the influence of gravity. Typically recurrent, on a decadal scale, within a pre-existing gully.

Debris slide: Similar to a debris flow A moving mass of loose mud, sand, soil, rock, water and air that travels down a slope under the influence of gravity. However, typically occurring only once.

Debris slide (active layer detachment): Shallow landslides that develop in permafrost areas, involving reduction in effective stress and strength at the contact between a thawing overburden and underlying frozen material.

Discontinuous permafrost: This occurs between the continuous permafrost zone and the southern latitudinal limit of permafrost in lowlands. Depending on the scale of mapping, several subzones can often be distinguished, based on the percentage of the land surface underlain by permafrost.

Eolian: This means connected with or caused by the action of the wind. Eolian deposits are the result of the accumulation of wind-driven products of the weathering of solid bedrock or unconsolidated alluvial, lacustrine, marine or other deposits.

Excess ice: This the volume of ice in the ground that exceeds the total pore volume that the ground would have under natural unfrozen conditions.

In standard geotechnical terminology, a soil is considered normally consolidated when its total pore volume or its total water content is in equilibrium with the acting gravity stresses. Due to the presence of ground ice, the total water content of a frozen soil may exceed that corresponding to its normally consolidated state when unfrozen. As a result, upon thawing, a soil containing excess ice will settle under its own weight until it attains its consolidated state.

Fluvial: These are very unsorted sediments. Fine-grained sediments are found at the bottom of the stream channel; very coarse sediments, including cobbles and pebbles, can be found along or in the stream. The particle size varies according to the force of the water flow.

Frost heave: This is the upward or outward movement of the ground surface (or objects on or in the ground) caused by the formation of ice in the soil.

Frost action in fine-grained soils increases the volume of the soil not only by freezing of in situ pore water (≈ 9% expansion), but also by drawing water to the freezing front where ice lenses form. Soils that have undergone substantial heaving may consist of alternate layers of ice-saturated soil and relatively clear ice lenses.

The lenses are formed normal to the direction of heat flow and when freezing penetrates from the ground surface (which may be horizontal, sloping or vertical), they form parallel to that surface. When unrestrained, the amount of surface heave may be almost as much as the total thickness of the ice lenses. Frost heave can occur seasonally or continuously if the ground freezes without interruption over a period of years.

Differential, or non-uniform, frost heaving is one of the main detrimental aspects of the frost action process and reflects the heterogeneous nature of most soils, or variations in the heat removal rate and groundwater supply over short distances.

Depending on the degree of restraint, large freezing pressures (up to 1 megapascal) can develop as the ground freezes. These can be transmitted to a foundation, structure or other object placed on the ground surface, or embedded or buried in the ground, as basal (i.e., vertical) forces acting on their underside, or through freezing of the soil to the sides of the foundation, structure or object.

Frost-susceptible ground: This is ground (soil or rock) in which segregated ice will form (causing frost heave) under certain conditions of moisture supply and temperature.

Frost-susceptible ground will eventually become ice-rich, regardless of its initial total water content, if the appropriate moisture supply and temperature conditions persist. By implication, frost-susceptible ground may also be susceptible to thaw weakening effects when it thaws.

Glaciofluvial: These materials are deposited by waters associated with glacial ice that are deposited by a stream or river originating from glacial meltwater.

Glaciolacustrine: Materials that are deposited by waters associated with glacial ice include sediments deposited in lakes that border and/or are supplied by the glacier. Deposits from meltwater exhibit some degree of sorting and are often stratified.

Ice-rich permafrost: Permafrost that contains excess ice is ice-rich. Ice-rich permafrost is thaw-sensitive.

Ice-wedge polygons: A massive, generally wedge-shaped body with its apex pointing downward, composed of foliated or vertically banded, commonly white, ice. Ice wedges are formed in thermal contraction cracks in which hoar frost (see open-cavity ice) forms and into which water from melting snow penetrates in the spring. Repeated annual contraction cracking of the ice in the wedge, followed by freezing of water in the crack, gradually increases the width (and possibly the depth) of the wedge and causes vertical banding of the ice mass. The surface expression of ice wedges is generally a network of polygons. Ice wedges growing as a result of repeated (but not necessarily annual) winter cracking are called active ice wedges. They occur primarily in areas of continuous permafrost when developed in mineral soil.

Lacustrine: These are fine-grained sediments that are deposited in freshwater lakes. Wave action in lakes carries the finer suspended grained silt and clay sized particles towards deeper water. As the water calms, these particles settle out and accumulate at the bottom of the lake to form what is known as lacustrine soil. The lake may no longer exist.

Morainal (Till): This is unstratified and unsorted debris deposited directly from glacial ice without subsequent movement by wind or water. It consists mainly of mechanically broken fragments of bedrock, as well as any soils or earlier glacial deposits that were overridden by the glacier. It commonly includes a mixture of a few large rock fragments within a matrix of fine sand, silt and clay.

Organic: Organic soils contain well-decomposed organic matter with or without plant fibres at various stages of decomposition.

Palsa: A peaty permafrost mound possessing a core of alternating layers of segregated ice and peat or mineral soil material.

Permafrost: This is ground (soil or rock, along with ice and organic material) that remains at or below 0°C for at least two consecutive years.

Permafrost base: The lower boundary surface of permafrost, above which temperatures are perennially below 0°C and below which temperatures are perennially above 0°C.

Permafrost table: This the upper boundary surface of permafrost. The depth of this boundary below the land surface, whether exposed or covered by a water body or glacier ice, varies according to such local factors as topography, exposure to the sun, insulating cover of vegetation and snow, drainage, grain size and degree of sorting of the soil, and thermal properties of the soil and rock.

Permafrost thickness: This the vertical distance between the permafrost table and the permafrost base.

Pore water: This is water that occupies the spaces between sediment particles.

Retrogressive thaw slump: Retrogressive thaw slumps consist of a steep headwall that retreats in a retrogressive fashion due to thawing, and a debris flow formed by the mixture of thawed sediment and meltwater that slides down the face of the headwall and flows away. Such slumps are common in ice-rich glacio-lacustrine sediments and fine grained diamictons.

Rockfall: Free-falling movement of debris from a cliff or steep slope, generally falling straight or bounding downslope.

Segregated ice: This is ice in discrete layers or ice lenses. Segregated ice can range in thickness from a hairline to more than 10 m. It commonly occurs in alternating layers of ice and soil.

Slopewash: A collective term for non-fluvial, incipient alluvial processes (e.g., overland flow, minor rills) that detach, transport, and deposit sediments downhill and mountain slopes. Related sediments (slope alluvium) exhibit nominal sorting or rounding of particles, peds, etc., and lateral sorting downslope on long slopes; stratification is crude and intermittent and readily destroyed by pedoturbation and frost action.

Solifluction: Slow downslope flow of saturated unfrozen earth materials.

Talik: A layer or body of unfrozen ground occurring in a permafrost area due to a local anomaly in thermal, hydrological, hydrogeological, or hydrochemical conditions.

Thaw-sensitive permafrost: This is perennially frozen ground which, when it thaws, will experience significant thaw settlement and lose strength to a value significantly lower than that of similar material in an unfrozen condition. Ice-rich permafrost is thaw-sensitive.

Thawing front: This is the advancing boundary between thawed ground and frozen ground*.* The thawing front may be advancing into either seasonally or perennially frozen ground during progressive thawing. In non-permafrost areas there will be two thawing fronts during the annual thawing period: one moving downward from the surface, the other moving upward from the bottom of the seasonally frozen ground. The thawing front usually coincides more closely with the position of the 0°C isotherm than the freezing front, except in saline permafrost.

Thermal erosion: Thermal erosion is a dynamic process involving the wearing away by thermal means (i.e., the melting of ice), and by mechanical means (i.e., hydraulic transport). Thermal erosion is distinct from the development of thermokarst terrain, which results from thermal melting followed by subsidence of the ground but without hydraulic transport of earth materials.

Thermokarst: This is the process by which characteristic landforms result from the thawing of ice-rich permafrost or the melting of massive ice. Thermal erosion

Till: Drift deposited directly by glacial ice with no sorting action is called till.

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INTRODUCTION

In cold climates such as central and northern Yukon, construction at a site must account for permafrost characteristics and implement design adaptations to ensure the resilience of the infrastructure, or risk costly repairs and interruption to services. The proposed fibre optic link from Inuvik to Dawson City will cross a vast area of permafrost. The challenges associated with construction of this line will be compounded because the cable is buried and because the infrastructure crosses hundreds of kilometres of terrain where there is little known about the nature of the permafrost. Existing highway infrastructure in the region is already affected by permafrost degradation. A buried fibre optic cable may be exposed to numerous permafrost-related hazards in this region including:

- thermokarst processes resulting in ground subsidence o and the formation of depressions and uneven surfaces;
- thermal contraction and cracking of the ground due to large, rapid and differential temperature variation;
- mass movement triggered by seasonal freeze and thaw of the active layer (the layer of soil above permafrost that thaws each summer), and extreme events linked to permafrost thaw.

Several levels of assessment of problematic areas associated with permafrost are required in order to plan, cost, design and build a route of least vulnerability. Recognizing this, NorthwestTel (NWTel) and Ledcor have sought information that will inform their design basis for the Canada North Fibre Loop. This memo and associated maps were produced by Palmer Environmental Consulting Group (PECG) and Northern Climate ExChange (NCE) in order to provide NWTel and Ledcor with a preliminary understanding of the distribution and characteristics of permafrost and related sensitive terrain along the Dempster Highway right-of-way. This insight will help NWTel and Ledcor account for permafrost conditions and sensitivities in their initial estimates of construction and maintenance costs for the fibre optic line.

This was a desktop-based preliminary assessment of permafrost conditions that took full advantage the team’s familiarity with the terrain characteristics, permafrost conditions and related geohazards in both glaciated and unglaciated settings of central to northern Yukon. The tasks performed in this project address potential ground movement linked to changes in permafrost conditions in response to seasonal conditions, climate change, and ground disturbance.

The preliminary assessment of permafrost and mass movement geohazard conditions was completed through three main tasks:

- **Task 1 – Preliminary Mapping and Characterization of Permafrost** – In the context of a desktop assessment, PECG and NCE have created a preliminary map of the permafrost distribution and characteristics based on existing literature, surficial geology mapping (Lipovsky and Bond (compilers), 2014) and aerial/satellite imagery. Mapping and characterization of permafrost extends 50 m on either side of the Dempster Highway (allowing for localized shifting of the alignment away from the highway). Interpretations of general permafrost conditions also considered pertinent associations among landforms, vegetation and permafrost.
- **Task 2 – Mass Movement Geohazard Mapping –** Mass movement geohazard mapping was completed along the portion of the highway within Yukon, based on detailed interpretation of similar spatial data sources identified above in Task 1, with additional reference to pertinent regional reports and publications on landslides and other mass movements. No discrete mass movement geohazards were identified along the portion of the highway in the Northwest Territories due to generally low-relief terrain and poorer quality imagery and elevation data. Within Yukon, each existing or imminent mass movement geohazard with the potential to impact a fibre optic cable buried within the highway shoulder or ditch was delineated and classified according to its type (e.g., active layer detachment, retrogressive thaw slump, debris flow, rockfall, etc.). This task focused only on the hazard posed by geomorphologic mass movement processes, and did not consider the stability of the highway shoulder. Disturbance to the ground thermal regime caused by the highway may create instability that is unrelated to the geomorphologic setting. This is beyond the scope of the current assessment.
- **Task 3 – Final Mapping and Technical Reporting** – In the accompanying geodatabase and PDF files, NCE and PECG provide integrated results of the mapping of permafrost and mass movements (Tasks 1 and 2). The mapping products are accompanied by this technical memo, which summarizes the project objectives, methods, assumptions and limitations.

The tasks above have been completed without fieldwork. Because this project was necessarily completed in early summer, it would have been difficult to collect meaningful field data regarding permafrost characteristics, because the active layer would likely still have been frozen along much of the Dempster Highway corridor.

METHODS

DATA SOURCES

NCE and PECG used and reviewed a wide range of data to complete this desktop analysis. Most data were acquired through public Territorial and Federal geomatics databases (http://mapservices.gov.yk.ca/GeoYukon/, http://www.geomatics.gov.nt.ca/ and http://geogratis.cgdi.gc.ca/, respectively). Additional data were provided by Yukon Highways and Public Works – Transportation Engineering Branch (HPW-TEB) and Yukon Geological Survey (YGS). The eastern two-thirds of the route in NWT has slightly lower-resolution imagery than in Yukon, and no LiDAR-derived elevation/slope models; therefore, our confidence in interpretations in this area is lower than in Yukon. The western third of the NWT portion of the highway was only covered by low-resolution (10 m), black-and-white satellite imagery. Interpretations are accordingly far more approximate and may be unrepresentative of conditions in some areas. A number of important data sources were consulted:

- Surficial geology maps at 1:50,000 (Klondike), 1:125,000 (Klondike, Klondike/Ogilvie, Ogilvie and Eagle Plains; Lipovsky and Bond (compilers), 2014) and 1:250,000 (Fort Mcpherson-Bell River, Arctic Red River, District of Mackenzie; Duk-Rodin and Hughes, 1992a; Duk-Rodin and Hughes, 1992b; and Rampton 1974);
- YGS Open File 2013-15 outlining diagnostic characteristics of permafrost and related mass movement processes in aerial photographs (McKillop et al., 2013);
- National Topographic System (CanVec) GIS base data, accessed from Geomatics Yukon;
- 500 to 600 m-wide corridor of high-resolution, colour orthophotography from 2013/2014, provided by HPW-TEB;
- 600 to 2000 m-wide corridor of LiDAR survey data from 2013/2014, provided by HPW-TEB, and subsequently processed by our team to produce high-resolution, bare-earth hill shade models for the full (variable) width of data coverage available;
- Seamless mosaics covering the entire Yukon portion of the study corridor with high-resolution satellite imagery from August/September 2007 (Quickbird, nearly continuous coverage of Klondike, Klondike/Ogilvie and Ogilvie sections) and September 2010 (GeoEye, continuous coverage of Eagle Plains section), accessed from Geomatics Yukon;
- Colour, 1:45,000-scale aerial photography stereo-pairs along the Yukon portion of the highway corridor from 1977 (archived from the National Air Photo Library); and
- Mackenzie Valley Orthophotos (MVAP), 1:30000 scale aerial photography along the MacKenzie Delta from 2004, provided by NWT Centre for Geomatics.

MAPPING CRITERIA

The data described above were compiled in a GIS database and used to evaluate expected active layer thickness, permafrost-related ground movement potential (following ground disturbance), and periglacial processes or features. Details regarding these criteria are summarized in Table 1.

Table 1. Mapping criteria used to determine permafrost-related ground movement potential.

Criteria	Possible Values	Comments
Active layer thickness (**ALT**)	**Thin** (<1 m) **Thick** (>1 m)	• Based largely on **vegetative/drainage indicators** and experience investigating similar terrain units with soil pits or auger holes • Important indicator of likelihood of encountering permafrost during excavation of the trench for cable installation
Permafrost-related ground movement potential (**PGMP**)	**High** – ground movement *likely* following disturbance **Moderate** – ground movement *possible* following disturbance **Low** – ground movement *unlikely* following disturbance	• Considers predicted **material texture** (e.g., silty/clayey, sandy/gravelly, matrix- vs. clast-supported) and **ground ice potential** (e.g., massive, segregated, pore), based on refined interpretation of surficial geology, hydrogeomorphic setting, etc.
Periglacial processes or features (**PPF**)	Cryoturbation (**C**) Solifluction (**S**) Thermal erosion (**Xe**) Active layer detachment (**Xf**) Retrogressive thaw slump (**Xh**) Palsa (**Xp**) Slopewash (**Xs**) Thermokarst subsidence (**Xt**) Ice-wedge polygons (**Xw**)	• Identification of these processes/features strengthens the "high" classification of ground movement potential within the delineated area, and is intended to draw attention to areas where the greatest challenges and costs may be encountered

Further to the criteria in Table 1, several points warrant further emphasis:

- Polygon boundaries accurately demarcate abrupt to transitional changes in terrain/permafrost conditions. The accuracy of the classifications is assumed to be slightly lower, especially in the continuous zone of permafrost. Field investigation is required to confirm actual ground conditions in representative units.
- Active layer thickness, or depth to permafrost, is considered in determining ground movement potential. Active layer thickness is inferred primarily from ground cover. Active layer thickness is considered “thick” when it is greater than 1 m, which is most common in rocky, gravelly or convex, well-drained terrain.
- The focus was on interpretation of ground ice conditions in the uppermost metre of permafrost (i.e., the first metre below the active layer).
- Where applicable, surface expressions of permafrost-related features and processes have been identified. Confidence of "ground movement potential" conditions is highest in such polygons. For example, visible recognition of ice-wedge polygons (Xw), clearly justifies a "high" ground movement potential rating. Similarly, slopewash (Xs) is deemed unfavourable (high rating) because its presence confirms a thin active layer, typically fine-grained soils, and a significant amount of moisture, which likely accumulates ice in the uppermost layer of permafrost. Construction complexity and maintenance costs are expected to be particularly high where permafrost features/processes have been explicitly identified.
- Finally, it is noted that while a given section of highway may be interpreted as crossing ice-rich permafrost with high ground movement potential, it is unlikely to have excess ground ice throughout its lateral extent. Excess ground ice occurrence commonly ranges from isolated to extensive patches in such areas, meaning that boreholes may or may not intersect ice if drilled. This is one reason why *differential* settlement is commonly associated with ice-rich ground, and why geophysical surveys are a valuable additional to investigative shallow drilling.

The geohazard mapping within the Yukon portion of the highway identifies existing or imminent mass movement geohazards with the potential to impact a fibre optic cable buried within the highway highway shoulder or ditch. Additional unidentified geohazards may exist within the 50 m buffer that was used solely for the purposes of the permafrost mapping. Only generalized delineation of periglacial processes, including some mass movements (e.g., active layer detachments), has been completed within the 50 m buffer area in association with the preliminary permafrost mapping and characterization. The geohazard mapping builds on work recently completed by PECG and Kryotek Arctic Innovation in association with a desktop- and field-based investigation of geohazards for Yukon Government. Importantly, no consideration has been given to potential new mass movement failures on slopes prone to active layer detachments, for example; this exercise has not involved (predictive) terrain stability mapping. As noted above, geohazard mapping was not completed along the NWT portion of the highway due to the lower resolution of available data and the rarity or absence of mass movement processes in the lower-relief terrain.

Table 2 identifies the mass movement geohazards mapped within Yukon.

Table 2. Classification of mapped mass movement geohazards posed to the highway shoulder and ditches.

Abbreviation	Process	Comments
DS	Debris slide	• Typically occur as a single event (unrelated to permafrost)
DF	Debris flow	• Typically recurrent, on a decadal scale, within a pre-existing gully (unrelated to permafrost)
RF	Rockfall	• Typically recurrent, commonly annually, with a severity of impact that depends on the size of blocks (unrelated to permafrost)
DS (ALD)	Debris slide (active layer detachment)	• Typically occur as a single main failure, followed by recurrent, minor sloughing and flows
RTS	Retrogressive thaw slump	• Typically an ongoing or episodic process that can migrate upslope
TKs	Thermokarst subsidence	• Typically an ongoing or episodic process resulting in differential ground settlement
TKg	Thermokarst gully	• Typically an ongoing or episodic process that can migrate upslope

CAVEATS AND KNOWN LIMITATIONS

Because this is only a preliminary assessment of permafrost conditions, based only on desktop analysis, there are a number of noteworthy limitations to this assessment. The assessment considers the area within the highway right of way (i.e., 50 m on either side of centerline). However, the mapping provided does not consider site-specific changes in permafrost conditions that are associated with anthropogenic disturbances such as removal of vegetation, construction of the highway embankment, or excavation. Such interpretations would be unreliable from desktop study. Anthropogenic disturbance significantly changes the ground thermal regime, modifying surface and sub-surface drainage and thermal conductivity properties in such a way that it is not possible to assess permafrost-related ground movement potential below and immediately adjacent to the highway based on the data reviewed. Accordingly, significant anthropogenic disturbance areas have been excluded from the mapping.

The mapping provided does not consider or distinguish potential differences in thickness of ground ice within permafrost. No distinction is made based on the potential magnitude of ground movement (subsidence). Deeper layers can be ice-rich or ice-poor independently of the uppermost layer, in some cases representing a decoupling from current or even recent climatic conditions. Furthermore, the assessment does not explicitly distinguish the nature and origin of ground ice; it only considers the relative likelihood of permafrost-related ground movement. Ice-rich permafrost segments susceptible to subsidence following disturbance could contain excess ice, seams/lenses and/or massive bodies – all of which could result in different magnitudes of ground movement.

Portions of the highway east of Fort McPherson (i.e., Mackenzie lowlands) are mostly morainal plains or blankets, locally overlain by organic materials. Both the morainal and organic materials are characterized as having relatively high ice content and being most sensitive to thaw (Aylsworth et al., 2000; Heginbottom, 2000). Therefore, this terrain is generally classified as having “high” ground movement potential (giving the mapping a lower-resolution appearance than that in the mountainous terrain to the west and south), with exceptions in areas of active fluvial deposits and on better-drained, moderate to steep slopes. Segments of recognizable permafrost processes/features have been distinguished.

Also in the NWT portion, no discrete, existing or imminent geohazards have been mapped. This is because the image/data quality is poorer, so it is difficult to identify discrete mass movement failures, and also because the relief is much lower, so there are likely fewer discrete failures.

Ground temperature data have not been explicitly considered in this interpretation of ground movement potential. However, areas that were unglaciated are likely to have colder ground temperature, thicker permafrost and are more likely to exhibit massive ice features such as ice-wedge polygons. A central section of the highway (km 116 to km 495) was not glaciated during the Wisconsinan period. Areas north and east of Fort McPherson were covered by the Laurentide Ice sheet. Valley glaciers covered sections between km 75 and km 116 (Burn et al., 2015).

RECOMMENDATIONS

The desktop-based analysis described herein has been completed to support Ledcor/NWTel as they develop their design basis and options for construction North Fibre Optic Loop proposed along the Dempster Highway. The reliability of this mapping can be improved through field reconnaissance investigations within representative areas (polygons) along the corridor. Follow-up shallow drilling, potentially combined with geophysical (e.g., electrical resistivity) surveys, would further strengthen the understanding of the distribution of ground ice and support the development of measures to minimize risk of impact to the cable or environment in the most sensitive terrain. The establishment of baseline ground temperature monitoring stations in different terrain/permafrost units would also benefit construction and maintenance planning.

REFERENCES

Aylsworth, J.A., Burgess, M.M., Desrochers, D.T., Duk-Rodkin, A., and Traynor, J.A., 2000. Surficial geology, subsurface materials, and thaw sensitivity of sediments; in The physical environment of the Mackenzie Valley, Northwest Territories: a base line for the assessment of environmental change, (ed.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547, p. 41–48.

Burns, C., Moore, J.L, O'Neill, H.B., Hayley, D.W., Trimble, J.R., Calmels, F., Orban, S.N., Idrees, M., 2015, Permafrost characterization of the Dempster Highway, Yukon and Northwest Territories. Proceedings of 7th Canadian Permafrost Conference, GeoQuebec 2015: Challenges from North to South. Quebec City, Quebec, September 2015.

Duk-Rodkin, A., and Hughes, O.L., 1992a. Surficial geology, Fort McPherson-Bell River, Yukon-Northwest Territories: Geological Survey of Canada, Map 1745A, scale 1:250 000.

Duk-Rodkin, A., and Hughes, O.L., 1992b. Surficial geology, Arctic Red River, District of Mackenzie, Northwest Territories: Geological Survey of Canada, Map 1746A, scale 1:250 000.

Duk-Rodkin, A., 1999. Glacial limits map of Yukon Territory. Geological Survey of Canada Open File 3694; Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Geoscience Map 1999-2, scale 1:1 000 000.

Heginbottom, J.A., 2000. Permafrost and distribution and ground ice in surficial materials; in The physical environment of the Mackenzie Valley, Northwest Territories: a base line for the assessment of environmental change, (ed.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547, p. 31–39.

Lipovsky, P.S., Bond, J.D. (compilers), 2014. Yukon digital surficial geology compilation, digital release 1, 08-Apr-2014. Yukon Geological Survey. Accessed September, 2014.

Rampton, V.N., 1974. Surficial geology, Aklavik, District of Mackenzie, Northwest Territories: Geological Survey of Canada, Map 31-1979, scale 1:250 000.

van Everdingen, R.O., 2005, Multi-language glossary of permafrost and related ground-ice terms. International Permafrost Association, Arctic Institute of North America, University of Calgary, Calgary, Alberta.