Permafrost and surficial materials along a north-south transect: observations from the Norman Wells pipeline

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Abstract: The Norman Wells pipeline, the first completely buried oil pipeline in permafrost in Canada, traverses 869 km of the discontinuous permafrost zone from Norman Wells, Northwest Territories to Zama, Alberta. Observations of permafrost and terrain conditions were recorded during the excavation of the 1.2 m deep pipeline trench. These records provide a unique detailed transect of near-surface permafrost extent, ice content, and sediment characteristics over terrain both newly cleared for the pipeline project as well as previously cleared right-of-ways. Frozen to unfrozen transitions average about two per kilometre, increasing to four or five transitions per kilometre in southern peatlands. Frozen ground distribution ranges from about 80% of right-of-way length at the north end to about 30% at the south end, although locally there is wide variation. Visible ice is present in essentially all permafrost encountered, averaging about 20% by volume but commonly up to 40%.

Résumé : L'oléoduc de Norman Wells, le premier oléoduc enfoui dans le pergélisol au Canada, traverse une zone de pergélisol discontinue sur une distance de 869 km entre Norman Wells (T.N.-O.) et Zama (Alberta). Pendant l'excavation de la tranchée de 1,2 de profondeur pour enfouir l'oléoduc, on a consigné les observations faites sur le pergélisol et les conditions du terrain. Ces observations ont permis d'établir un profil détaillé exceptionnel de l'étendue du pergélisol proche de la surface, de la teneur en glace et des caractéristiques des sédiments dans les terrains qui ont été dégagés récemment pour le projet de l'oléoduc et dans d'autres qui l'ont été plus anciennement pour la construction des emprises de l'oléoduc. On distingue en moyenne deux zones de transition gelées à non gelées par kilomètre; ce nombre passe à 4 ou 5 par kilomètre dans les tourbières méridionales. La proportion de gélisol varie d'environ 80 % dans la partie nord du tracé à environ 30 % dans la partie sud, mais on observe, par endroits, des variations plus grandes. De la glace est visible dans tous les pergélisols traversés, y occupant en moyenne 20 % du volume; il est fréquent qu'elle occupe jusqu'à 40 % du volume.

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INTRODUCTION

The Norman Wells pipeline, the first completely buried oil pipeline in permafrost in Canada, is owned and operated by Enbridge Pipelines (NW) Inc. (Enbridge; formerly Interprovincial Pipe Line (IPL)) and has been in operation since April 1985. The pipeline route provides a unique and detailed north-south transect through the discontinuous permafrost zone in the Mackenzie valley (Fig. 1). Permafrost varies from widespread in the northern portion of the route, to sporadic in the south (*see* Heginbottom, 2000). The underlying sequences of unconsolidated Quaternary deposits are often ice rich and thaw sensitive (*see* Aylsworth et al., 2000). Preconstruction geotechnical investigations and design studies included a continuous geophysical survey along the right-of-way (ROW), mapping of surficial geology at a scale of 1:20 000, thaw-depth and settlement surveys and analyses, drilling of geotechnical boreholes, and geothermal modelling. A summary of the environmental and engineering considerations and a discussion of the novel design features for the pipeline can be found in Nixon et al. (1984), Hanna and McRoberts (1988), and MacInnes et al. (1989).

Research on the thermal regime along the pipeline and geomorphic response of the terrain to construction disturbance was reported in Pilon et al. (1989), Burgess and Harry (1990), MacInnes et al. (1990), Burgess and Riseborough (1990), Burgess (1992), and Burgess et al. (1993, 1995b). Data gathered during all phases of the project are accessible and ultimately archived (Burgess and Naufal, 1991; Burgess, 1993; Burgess et al., 1995a).

A valuable source of data is the observations of the pipeline-trench conditions made during construction, collectively known as the ditchwall logs or the ditchwall database. This database is unique in providing a detailed continuous transect through the discontinuous permafrost zone of terrain and permafrost conditions in the top 1.2 m of the ground.

The database provides base-line geoscience information for the assessment of the impact of climate change on the physical environment. The ditchwall data, along with

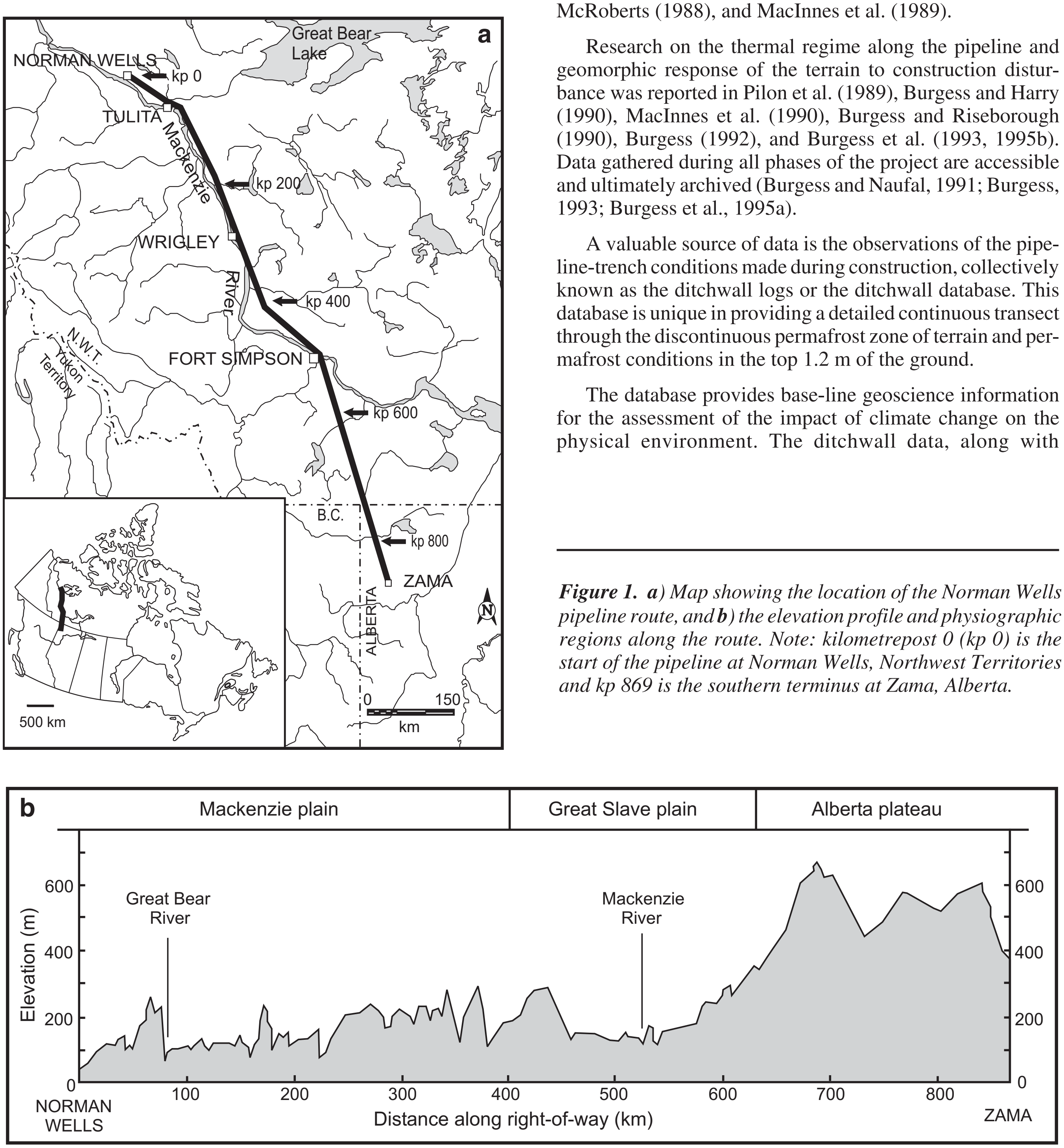

Figure 1. ***a**) Map showing the location of the Norman Wells pipeline route, and **b**) the elevation profile and physiographic regions along the route. Note: kilometrepost 0 (kp 0) is the start of the pipeline at Norman Wells, Northwest Territories and kp 869 is the southern terminus at Zama, Alberta.*

supporting information from pipeline monitoring, form the basis for the following analysis of permafrost and terrain conditions.

DITCHWALL DATABASE

Trenching for the pipeline was undertaken in the months of January, February, and March, when the active layer is refrozen or seasonal frost penetration is thick enough to allow a stable working platform for movement and operation of construction equipment. The trench depth is on average 1.2 m, and the width is generally 1 m. Depending on the segment under construction (there were six) and the nature of the terrain, various trenching methods were used: arctic ditcher (Fig. 2), conventional southern ditcher, and bulldozers and backhoes. During construction of the pipeline, conditions in the open trench were recorded by the pipeline company's inspection personnel at 100 m intervals and at major soil or permafrost interfaces. The observations in the 'ditchwall logs', recorded at 9000 locations, were used to confirm or revise site-specific design or remedial measures.

The ditchwall logs include the following basic geotechnical and permafrost information: thickness of peat, depth of trench, presence of cobbles, frozen/unfrozen condition of trench, and comments regarding soil type and ice conditions. (Note: each record, i.e. location, does not necessarily contain information in all fields.) Figure 3 illustrates soil and permafrost conditions as observed in the trench. The Geological Survey of Canada (GSC) undertook to compile the ditchwall logs into a digital database (Geo-Engineering, 1992a, b, c). Additional relevant information was added to the database, including as-built kilometrepost (kp), location (in UTM co-ordinates), terrain type (based on Enbridge's detailed alignment work (Kay et al., 1983)), and type of right-of-way clearing (previously cleared or newly cleared).

Results and highlights of the ditchwall data analyses are presented below. Some aspects of the ditchwall data have been previously examined by Nixon et al. (1991). General conditions for the whole pipeline route have been summarized using increments of 50 km: i.e. data are presented either as an average or percentage of what was encountered over each 50 km section (kp 0 is located at Norman Wells; *see* Fig. 1 for additional kp locations). A more detailed examination of several components of the database, such as frozen-ground distribution, was made at increments of 5 km, and select examples of these results are also presented. Certain data are presented on the basis of terrain unit or as a function of longer segments of the right-of-way.

TERRAIN CONDITIONS

Terrain units

The terrain classification employed for the Norman Wells pipeline is outlined in MacInnes et al. (1989). The terrain codes were simplified for entry into the digital database, and an initial examination revealed that seven units constituted approximately 85% of the pipeline route. These seven, plus an eighth category encompassing all others, formed the basis for the 50 km interval compilations, and are as follows: Lp — lacustrine landforms, generally plains, including veneers (alluvial, colluvial, eolian, and glaciofluvial) over lacustrine plain units; Mg — moraine, generally ground moraine, including veneers (alluvial, eolian, glaciofluvial) over moraine units; Lp-Mg — composite/complex of lacustrine and moraine units, also includes veneer of one over the other; Ov-Lp — organic veneer over lacustrine units; Ov-Mg — organic veneer over moraine units; Ou-Mg — composite of organic and moraine units; Ou — organic units: fen, bogs, and fen-bog complexes; Other — alluvial, colluvial, eolian, bedrock, and glaciofluvial units.

Figure 2. *Winter construction using an Arctic ditcher for trenching operations (January 1984, kp 0.2). Photograph by K.L. MacInnis. GSC 2000-033A*

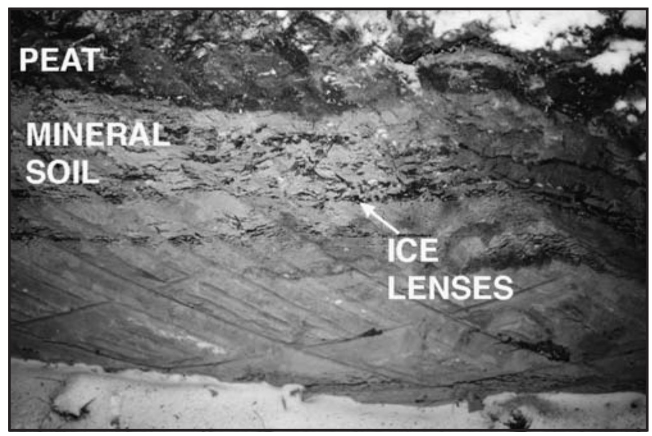

Figure 3. *Soil and permafrost conditions as observed in the trench during construction at kp 0.2. Note the thin peat layer over mineral soil and the ice lenses within the mineral soil. Photograph by D.G. Harry. GSC 2000-033B*

Figure 4a summarizes the percentage occurrence of the dominant terrain units by 50 km intervals. Lacustrine and moraine types dominate in the north (kp 0–550). Organic units or organic veneers dominate from kp 550 to 869 (*see* Aylsworth et al. (2000) for a discussion and maps of the surficial geology of the Mackenzie valley). Figure 4b provides a detailed look by 5 km increments at the first 100 km of the pipeline. At the 5 km interval, the ground is frequently dominated by an individual terrain unit reflecting the local surface geology. For example the high percentage of ‘other’ between kp 60 and 70 is largely bedrock as the pipeline rises in elevation and passes over Bear Rock, north of the Great Bear River. The 50 km interval represents a composite of the terrain units.

Soil groups

Soil type was recorded for all the pipeline route, except the southern section from kp 696 to 869. The thickness of the peat layer was, however, recorded in this southern section. Where peat extends to the bottom of the pipeline trench, the soil type is recorded as organic. Otherwise, soil descriptions entered in the database are, whenever possible, for the mineral soil at the bottom of the trench. Since there were eight ditchwall inspectors (with varying experience in soils identification) soil classifications were not necessarily consistent; for example the use of various terms, i.e. ‘till’ or ‘silt-clay’ may be used more or less often depending on the individual inspector or the terrain being described.

Figure 5a presents soil type summaries by 50 km interval; records with no description of soil type at the bottom of the trench appear as ‘blanks’. Figure 5b links this data to the terrain-unit classification based on airphoto interpretation. The correlation is good with, for example, 65% of the Lp unit composed of clay, silt, and sand, and 60% of the Mg unit described as till.

Peat thickness

Peat thickness is recorded in most ditchwall logs, except for the section from kp 350 to 550, where only 20–30% of the records contain peat data (Fig. 6a). The thickness may be slightly underestimated, due to scraping of the surface by construction equipment to obtain a stable working platform. Figure 6a presents the average peat thickness per 50 km interval along the entire route. The plot reveals that peat thickness increases from an average of 0.3 m in the first 400 km (where lacustrine and moraine units are predominant) to an average of 0.7 in the last 450 km (where organic units/organic veneers are major units). This pattern is consistent with the distribution of organic-rich terrain units (Fig. 4a). Figure 6b provides a more detailed examination of peat thickness as a function of terrain type for three sections of the pipeline route (kp 0–375, 375–675, and 675–869).

It should be noted that in cases where peat extended to the bottom of the trench, the reported thickness may be less than the total thickness of peat, which would lead to an underestimate of the average. This can be of particular importance when examining organic terrain units. The number of observations of peat extending to the bottom of the trench was analyzed by terrain unit for each of the three pipeline route sections. For most nonorganic units, 10% or fewer of the records show peat to the bottom of the trench. In organic terrain, these minimum values for peat thickness represent 30% or more of the Ou and Ou-Mg records (and up to 65% of Ou in the kp 375–675 section), and between 10% and 25% of the Ou-Lp and Ov-Mg records.

The ditchwall database does not provide an indication of the nature of the peatlands. For a discussion of peatlands in the Mackenzie valley, *see* Aylsworth and Kettles (2000), and for a further discussion of peatlands along the pipeline route and their response to pipeline-related environmental change, *see* Burgess and Tarnocai (1997). Boreholes drilled at GSC study sites along the pipeline revealed that the thickness of peat in the frozen peat plateau bogs in northern Alberta can reach up to 7 m.

Cobble occurrence

The occurrence of cobbles and boulders in the trench base was considered a potentially serious problem that could lead to point loading of the pipe when or if settlement occurred. To alleviate this problem, select bedding or sand bags were placed under the pipeline in these areas. The criteria set to flag the presence of cobbles was the occurrence of two or more cobbles, 150 mm or greater in diameter, in 10 m of ditch. The condition was assumed to continue until no such cobbles were present for 50 m of ditch. There is some uncertainty as to how well this recording criteria was adhered to in some sections of the route. In areas where select bedding would have been used in any case (e.g. because native backfill would have been too ice rich) detailed records may not have been kept.

Figures 7a and 7b summarize cobble occurrence by 50 km intervals and by terrain type. The greatest incidence of cobbles is recorded in Lp-Mg, Mg, and Lp units, and in the northern and central portions of the pipeline route where these terrain units predominate; however, cobble occurrence recorded in some segments of the route, for example, from kp 350–450 where the Mg unit covers 50% or more of the terrain (Fig. 4a), seem low. This may reflect either a finer grained moraine in that area, or the possible discrepancies in recording as mentioned above. The high incidence in the northernmost segments may also reflect the greater concern for thaw settlement in the northern section of the route (where the percentage of terrain underlain by permafrost is greater; *see* discussion below).

PERMAFROST

Thermal conditions

The thermal condition of the trench was recorded in the following fashion: F, frozen, either the whole trench or at least the trench bottom; U, unfrozen, either the whole trench or at least the trench bottom; F/U, frozen over unfrozen; normal seasonal freezeback in unfrozen terrain or terrain with an active layer greater than trench bottom; F/U/F, frozen over

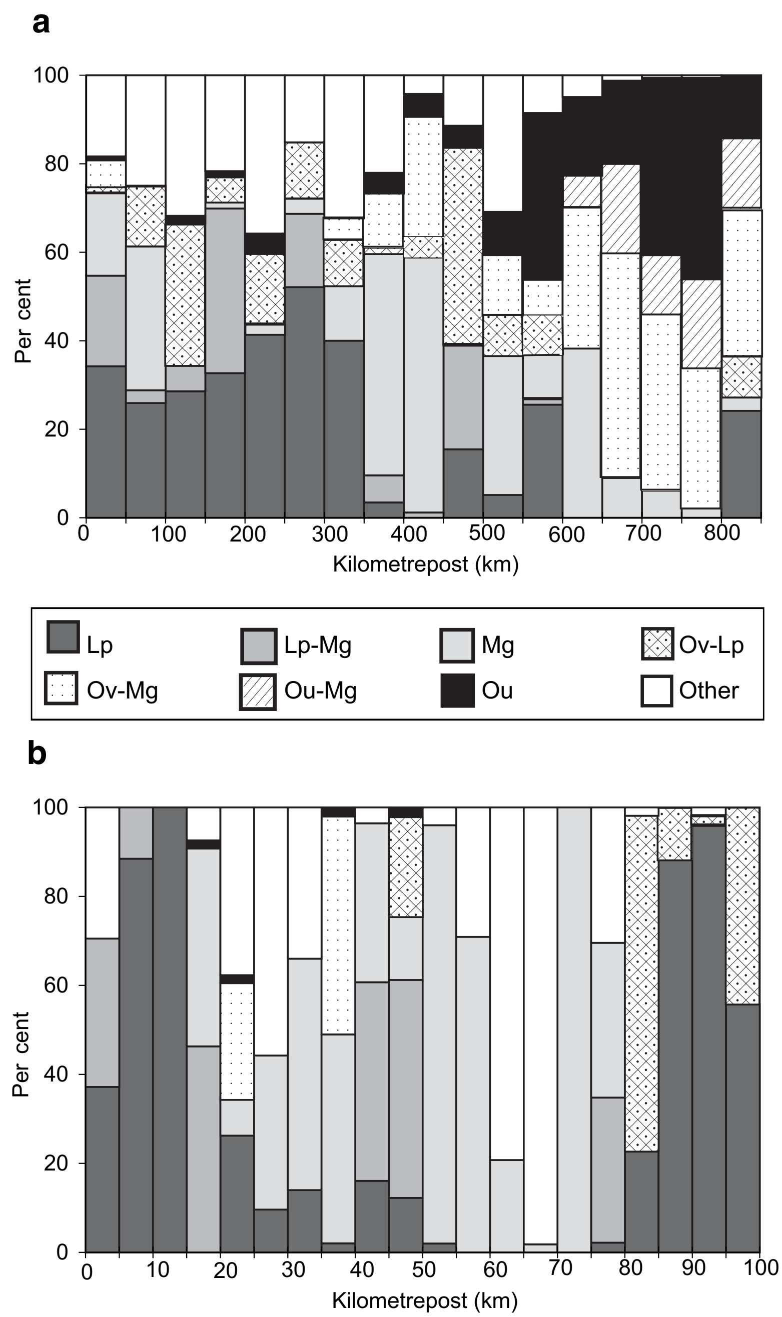

Figure 4. *Distribution of major terrain units.* ***a****) by 50 km intervals along the entire pipeline route, and* ***b****) by 5 km intervals in the first 100 km of the pipeline route. Lp — lacustrine landforms, generally plains, including veneers (alluvial, colluvial, eolian, and glaciofluvial) over lacustrine plain units; Mg — moraine, generally ground moraine, including veneers (alluvial, eolian, glaciofluvial) over moraine units; Lp-Mg — composite/complex of lacustrine and moraine units, also includes veneer of one over the other; Ov-Lp — organic veneer over lacustrine units; Ov-Mg — organic veneer over moraine units; Ou-Mg — composite of organic and moraine units; Ou — organic units: fen, bogs, and fen-bog complexes; Other — alluvial, colluvial, eolian, bedrock, and glaciofluvial units.*

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unfrozen with frozen trench bottom; rare case documented where the seasonal freezeback was incomplete but trench bottom was in permafrost.

The ditchwall logs were analyzed to determine the percentage of terrain that could be interpreted as permafrost (conditions F and F/U/F). It should be noted that observations were at times varying from early January to early March. Some underestimation may have occurred since F/U conditions could in fact represent a case where the active layer is deeper than the trench. Active layer thicknesses observed in undisturbed and uncleared terrain of the central and southern Mackenzie valley are, however, generally less than 120 cm (the depth of the trench); *see*, for example, Table 1 and Figure 5 in Nixon (2000). True underestimation more likely could have occurred in areas where the pipeline occupies a previously cleared right-of-way and some deepening of the permafrost table may have already taken place (as discussed below). Although the newly cleared right-of-way had generally experienced one thaw season before trenching, active layer depths were likely still less than 1 m (based on active layer depths of <1 m measured on the right-of-way at the end of the first thaw season after construction at GSC study sites in newly cleared sections of the northern part of the route).

Figure 8a presents the percentage of permafrost terrain by 50 km interval. There is a general southerly decrease in the percentage of permafrost terrain, from a high of more than

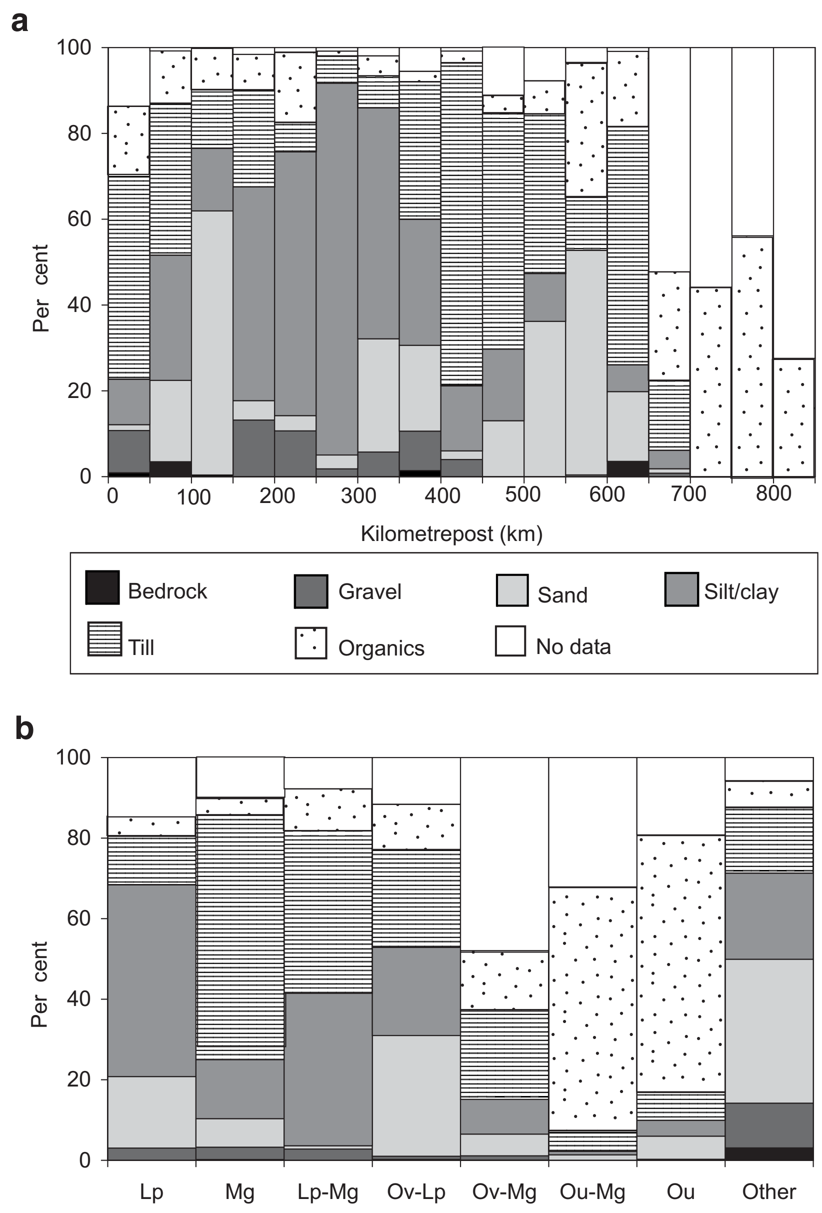

Figure 5. *Distribution of soil groups:* ***a****) by 50 km intervals along the pipeline route, and* ***b****) within major terrain units for the whole route.*

80% in the first 200 km of the route to a low of less than 30% in the kp 550–650 area. This general trend is consistent with the north-south routing of the pipeline through the permafrost zone (*see* Heginbottom, 2000). South of kp 650, the percentage of frozen ground rises as the elevation increases onto the Alberta plateau (*see* physiographic regions in Fig. 1b). The percentage of permafrost between kp 200 and 300 is much lower than elsewhere in the northern part. This low percentage correlates with a high occurrence of clay and silt (*see* Fig. 5) and is perhaps related to high unfrozen water contents of these materials (which may lead to their being described as unfrozen at temperatures slightly below 0°C). Figure 9 provides a detailed look at frozen ground distribution in the 100–300 km region by 5 km intervals.

Part of the pipeline route selection philosophy was to maximize the use of previously cleared right-of-way, in order to minimize the amount of new permafrost thaw and associated settlement that would be initiated by construction clearing. Thus an examination of permafrost occurrence was also undertaken on the basis of type of right-of-way clearing: 1) ‘uncleared’ prior to the pipeline clearing and construction, and 2) ‘previously cleared’: either a) the 20–25 year old CNT

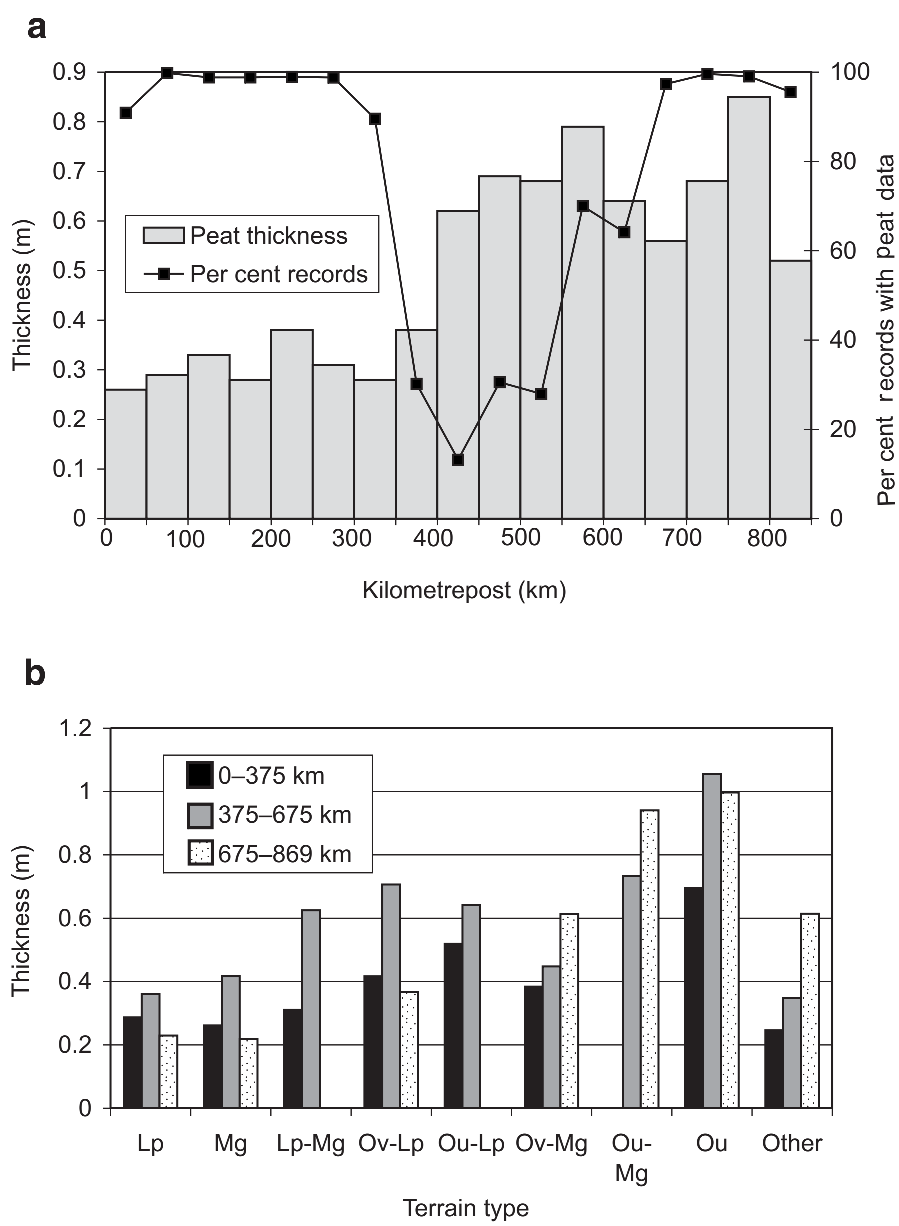

Figure 6. *Average peat thickness:* ***a****) for each 50 km interval along the route; also shown is the percentage of records in each interval with information on peat thickness, and* ***b****) for each major terrain type, dividing the route into three sections: kp 0–375, kp 375–675, and kp 675–869.*

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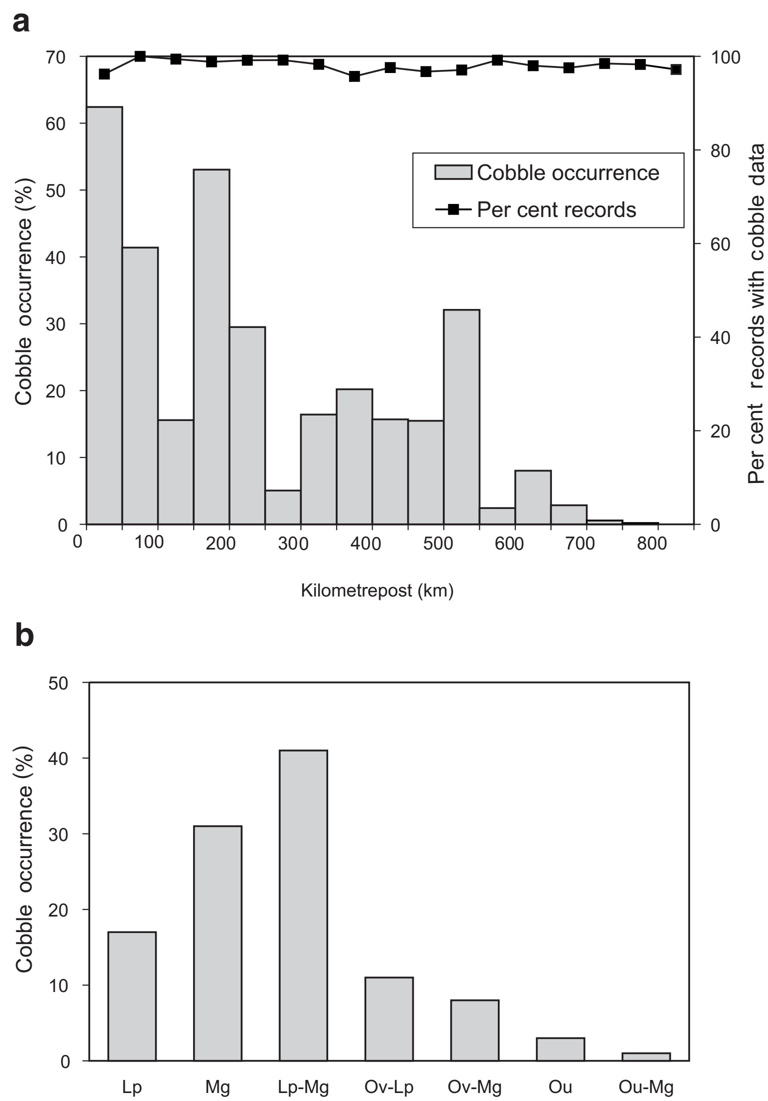

Figure 7. *Summary of cobble occurrence:* ***a****) by 50 km intervals along the pipeline route, and* ***b****) by terrain unit. The percentage of records in each 50 km interval that have information on cobble occurrence is also plotted in a).*

(Canadian National Telecommunications) cutline or b) ‘other’ (such as seismic lines) clearings widened for pipeline construction. Figure 8b shows the distribution of the various types of right-of-way: approximately 60% of the route was previously cleared in the northern section (kp 0–400) compared to 25% in the south (kp 400–869). Figure 8c shows the percentage of frozen ground in previously uncleared right-of-way only, a distribution similar to that for all right-of-way types in Figure 8a. Permafrost occurrences are only a few percent higher in Figure 8c (compared to 8a) suggesting that the extensive use of previous clearing in the north did not have a major impact on the presence or absence of permafrost in the trench.

The distribution of permafrost within previously cleared right-of-way only is shown in Figure 8d (Note: some intervals are blank because they only have newly cleared right-of-way). The general pattern of reduced percentage of frozen ground compared to Figure 8c probably reflects the impact of previous clearing on the degradation of permafrost. The greatest impact has occurred along the southern part of the route (but only a small percentage of the route in the south used previous clearings, and a large percentage of these clearings would have been unfrozen in any case).

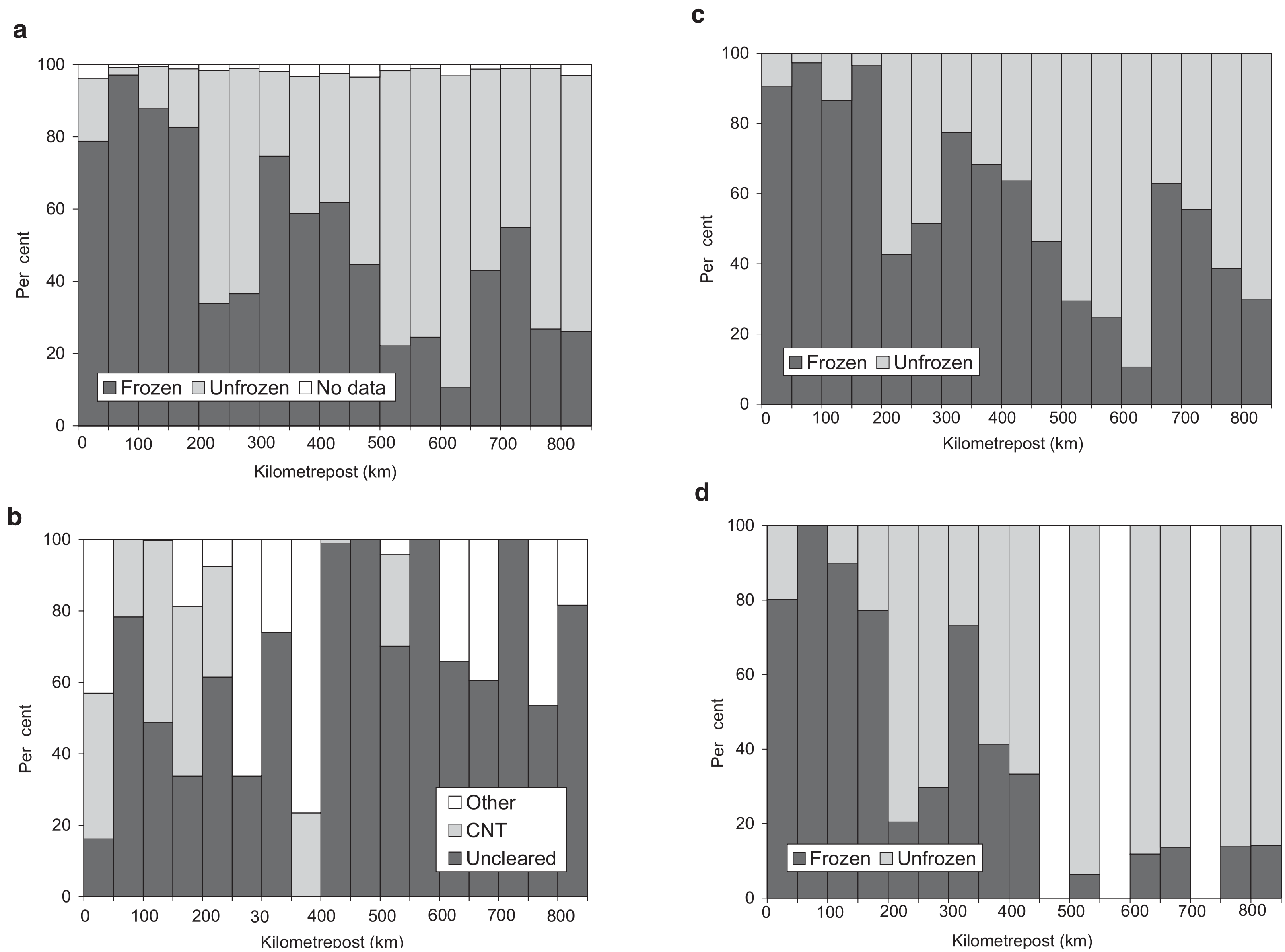

Figure 8. a) *Frozen ground distribution by 50 km intervals for all types of right-of-way;* ***b***) *Distribution of right-of-way types in each 50 km interval along the entire pipeline route. Uncleared = right-of-way that had not been previously cleared, i.e. newly cleared for pipeline construction; CNT = the right-of-way followed the Canadian National Telecommunications clearing that had been made in the 1960s and was originally 12 m wide; OTHER = right-of-way had been cleared, generally to a width of 6 m or less for other purposes such as seismic lines;* ***c***) *Frozen ground distribution in previously uncleared right-of-way, by 50 km intervals.* ***d***) *Frozen ground distribution in all types of previously cleared right-of-way by 50 km intervals. Note: some intervals are blank since they have only newly cleared right-of-way.*

Visible ice distribution

Observations on the type and amount of visible ice in the trench were recorded for the first 335 km of the route. Values entered in the database were those for the trench bottom whenever possible, generally rounded off to the nearest 5%. Figure 10 plots these values as a function of kilometrepost; the data have been separated into observations for ‘new right-of-way’ and ‘old (previously cleared) right-of-way’. In Figure 10, there is considerable scatter in the data, reflecting the different terrain units and soil textures. The scatter is similar for both types of right-of-way. The average of all values is around 20%. A trend line through all the data reveals a slight decrease in percentage of visible ice from north to south.

An examination of the kp 0–335 data, as a function of terrain type and section of the right-of-way was also undertaken. This analysis was based only on those records where the trench bottom was described as frozen (F) and where a description was given for the ice type. These represent a total of 1937 records. Eighty-five per cent of these records contain

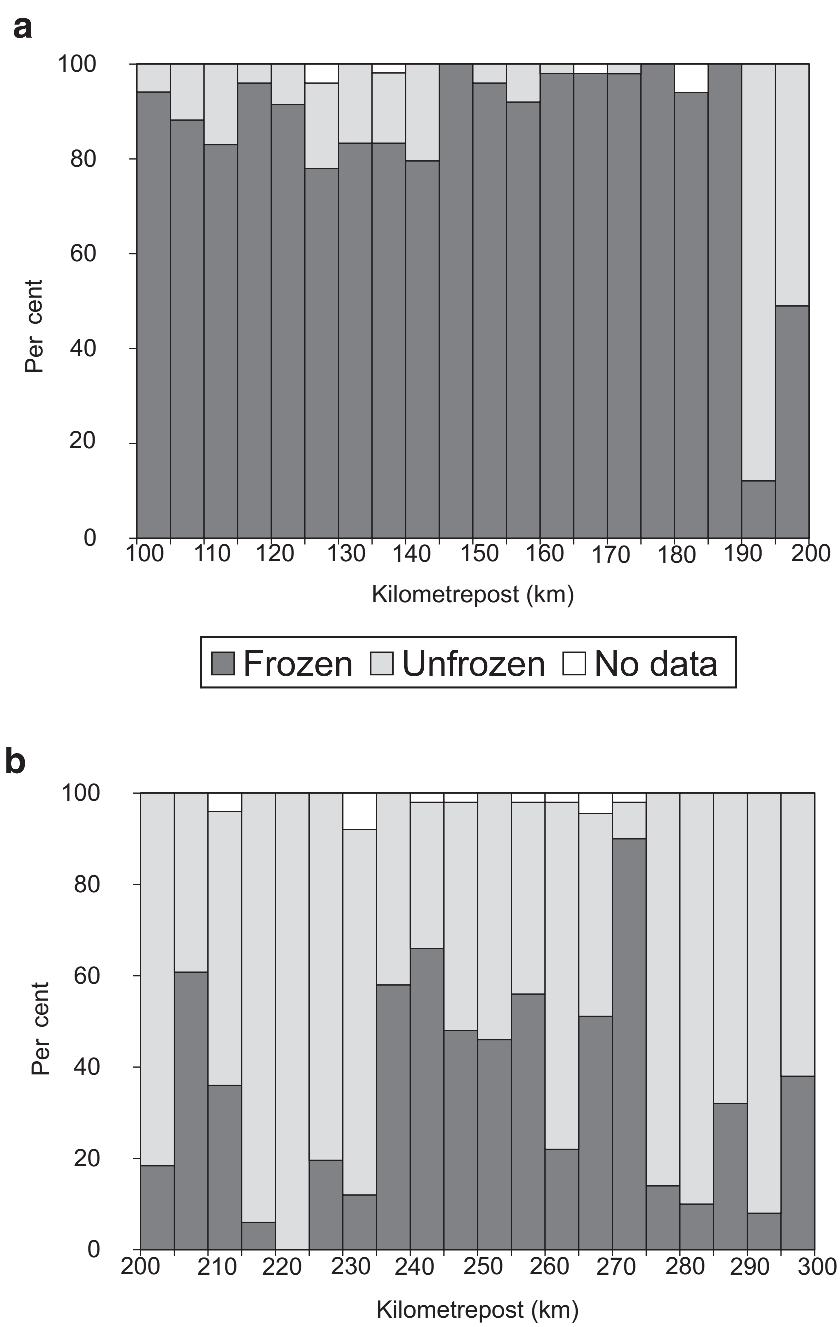

Figure 9. *Frozen ground distribution by 5 km intervals,* ***a****) kp 100–200* ***b****) kp 200–300.*

a percentage value for ice. Thirteen per cent of the records have no value logged but are described as having no visible or excess ice; a value of 0% was therefore assumed for these records. A value of 0% was also assumed for the remaining 2% of the records, although these could represent instances where a per cent ice value was not recorded. The average visible ice content (in per cent) was then calculated for each of the major terrain units, in each of three areas (kp 0–100, 100–200, and 200–335). The results are shown in Figure 11, distinguishing between previously cleared and newly cleared right-of-way. (Note: terrain units which were grouped elsewhere under 'other' have been identified here and are as follows: Go – glaciofluvial, Ed – eolian dune, Cm – colluvial, Af – alluvial fan, Ov-Go – organic veneer over glaciofluvial, Ou-Go – mixture of organic and glaciofluvial, Ou-Lp – composite of organic and lacustrine.)

The ground-ice distribution as a function of terrain type and section of right-of-way reveals that the weak general trend shown in Figure 10 is no longer apparent when examining a specific terrain unit, for example Lp or Lp-Mg. Ice contents are generally lower in the 100–200 kp range than in either the 0–100 kp range or the 200–335 kp range. The average ice content in new clearings is more likely to be higher than that of previously cleared right-of-way in the same terrain unit, but it is often lower or the same. Clearing of the pipeline right-of-way took place one year prior to construction, and the resulting increase in active-layer depth could have decreased the amount of ground ice in the trench, especially for newly cleared portions. Active layer depths measured on the right-of-way at the end of the first thaw season after construction at newly cleared GSC study sites in the northern part of the route were however generally less than 1 m. Thus ground-ice conditions in the base of the trench were likely 'original' for segments of newly cleared right-of-way.

Frozen-unfrozen transitions

The possibility of differential heave or settlement across interfaces between frozen and unfrozen ground is a principal concern for buried pipelines in permafrost terrain. Knowledge of the number of frozen-unfrozen transitions was thus an important consideration in the design of Norman Wells pipeline. Continuous electromagnetic surveys were conducted along the right-of-way prior to construction (Kay et al., 1983)

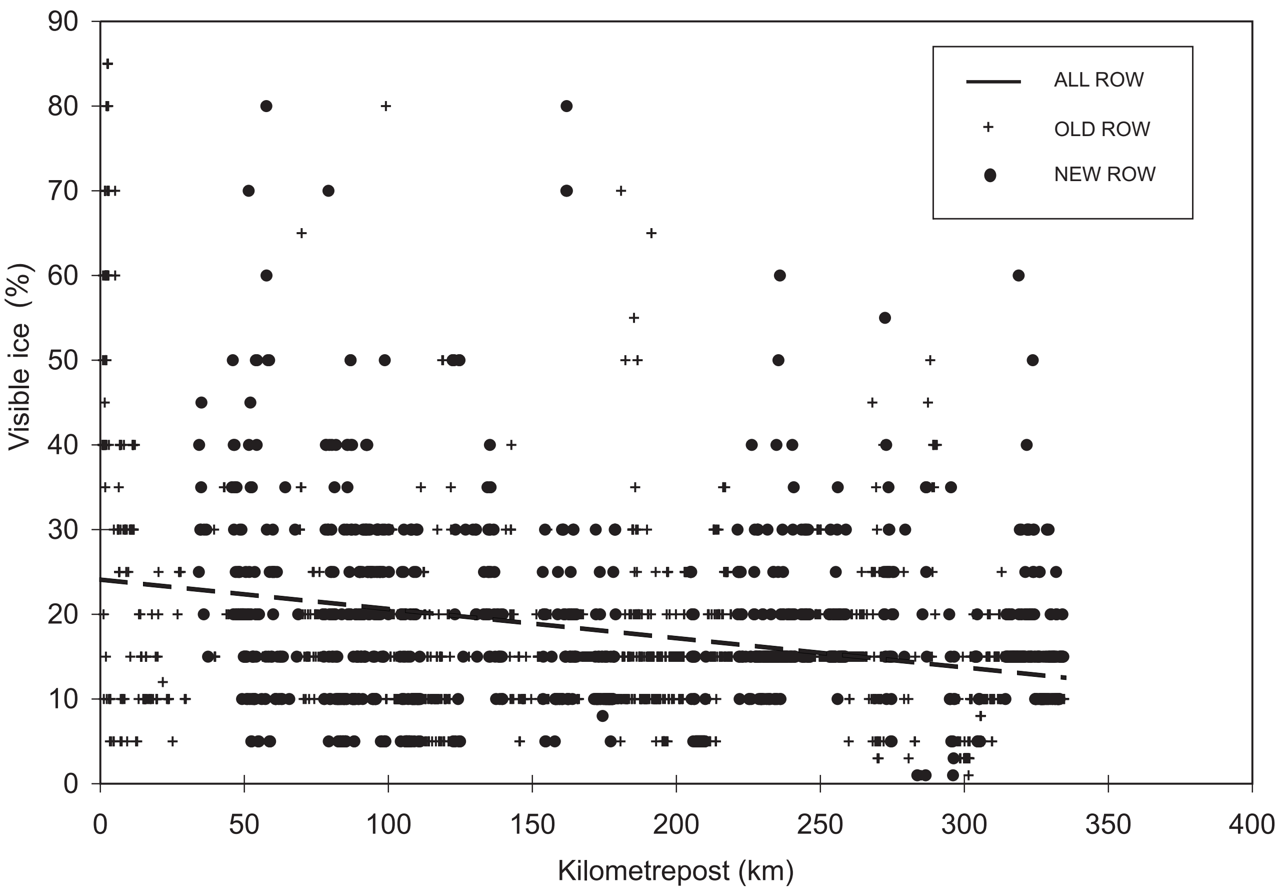

__Figure 10.__ Visible ice content recorded in the trench bottom for the first 335 km of the pipeline route. Observations in newly cleared right-of-way are distinguished from those in previoulsy cleared right-of-way. Trend line is for all data points.

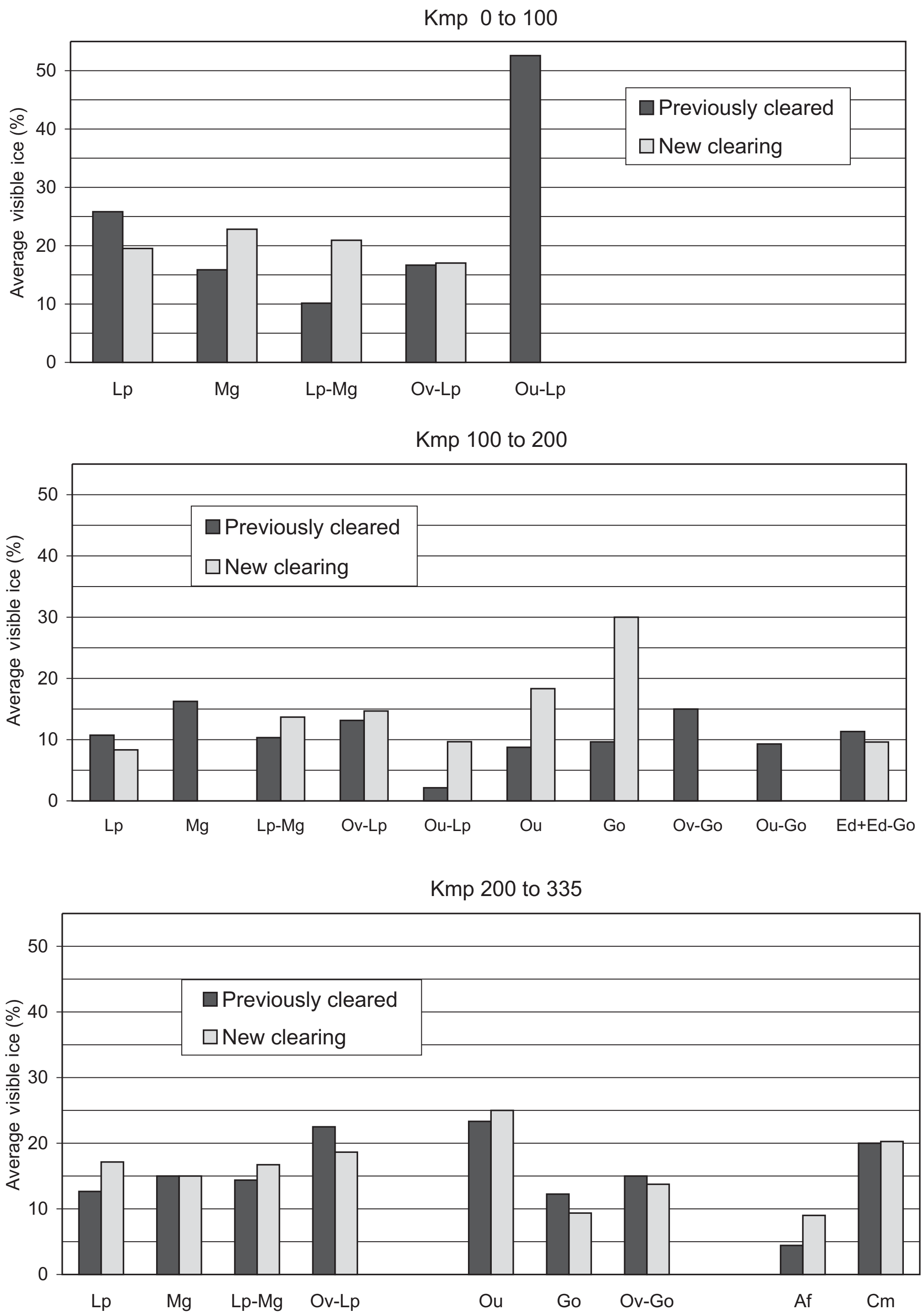

Figure 11. *Average visible ice content for each major terrain unit, shown separately for each of previously cleared and newly cleared right-of-way types. Calculations of the average are based only on those records in the database that have an entry in the ice description field as well as the ice content field.*

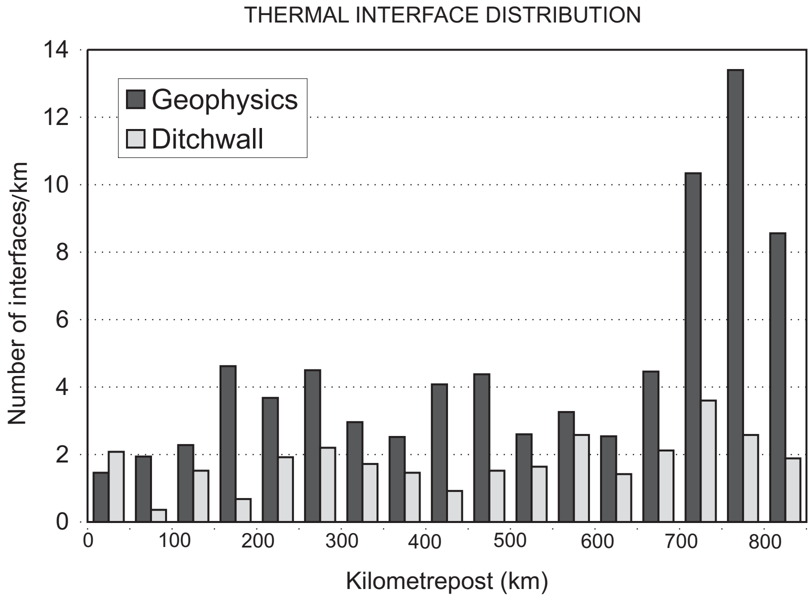

Figure 12.

Average number of frozen/unfrozen interfaces per 50 km interval, as recorded in the ditchwall database and the geophysical surveys (EM).

to determine the presence or absence of frozen conditions in the top 10 m of the ground. The number of interfaces per 50 km interval recorded by the geophysics is compared to the number recorded in the ditchwall database in Figure 12. There is reasonable agreement between the two data sources in the first 700 km; an average of two interfaces per kilometre in the ditchwall data compared to an average of three in the geophysics. South of kp 700, however, the geophysical data show an average of ten interfaces per kilometre while the ditchlogs show only three. Nixon et al. (1991) examined the frozen-unfrozen transitions in the ditchwall database, their frequency along the route, relationship to terrain type, and the length of frozen and unfrozen segments. They also discussed the possible significance of the differences between the ditchwall and geophysical data. The discussion below adds to this analysis and is based on a more complete version of the digital ditchwall database.

Analysis of the ditchlog data, by terrain type, revealed that the average number of interfaces per kilometre is highest in the organic terrain (typically 4–5/km). Lacustrine plains averaged 3/km, while till plains average 1/km. In the northern end, frozen sections are longer, whereas the reverse is true in the south. The lengths of frozen and unfrozen sections were examined in the south, where the number of interfaces was the greatest, using data from kp 500–870 and 5 km intervals. The average length of an unfrozen section is 1 km in the ditchlog data and 0.75 km in the geophysical data. The average length of a frozen section is 0.3 km in the ditchlogs and 0.1 km in the geophysics.

The discrepancies between the geophysical and ditchwall data may be related to several factors:

1) The shallow depth of observations of the ditchlog compared to the geophysics.

2) The geophysical surveys were conducted to obtain information beneath the depth of pipe burial, since this was of greatest importance for pipe design. The condition ‘frozen’ was assigned in the geophysical surveys when at least 3 m of the top 10 m of ground was interpreted as being frozen. If permafrost was thin (<3 m) this would be interpreted as unfrozen, thus giving rise to more interfaces in the geophysical database than in the ditchwall. For example on the Alberta plateau, the total length of unfrozen sections interpreted by geophysics is greater than in the ditchwall logs, which would agree well with the thin permafrost conditions being interpreted as unfrozen. From a pipeline design perspective, these geophysical interfaces in the south between unfrozen or thin (<3 m) permafrost and thick (>3 m) permafrost, have important implications for differential pipe movements.

3) Some of the differences in geophysical response may be related to textural, moisture, or stratigraphic transitions rather than to frozen/unfrozen interfaces; however, these factors were considered in the data interpretation.

The differences were further examined by interpretation of airphotos taken shortly after construction in 1985. The specific sections examined were those south of the Mackenzie River crossing (kp 528–869). This approach focused on identifying fens and other readily recognizable unfrozen areas crossing the right-of-way (i.e. unfrozen and unrelated to construction). The aim was to obtain a minimum for the number of frozen/unfrozen transitions, since no attempt was made to identify transitions in mineral soil or between bogs and mineral soil. The average number of interfaces per kilometre identified from the airphotos was two. Between kp 700–869, where the greatest differences were noted between the ditchwall logs and the geophysics, the average was also 2 interfaces/km. Since the airphoto results represent a minimum number of interfaces, the actual number of interfaces between unfrozen and permafrost terrain (regardless of thickness of permafrost) is likely somewhere between the ditchwall and geophysical values.

SUMMARY

An extensive record of permafrost and terrain conditions in the central and upper Mackenzie valley has been digitized in the ditchwall database from the Norman Wells pipeline construction. This database is unique in providing a detailed continuous transect through the discontinuous permafrost zone of soil types, peat thickness, ground thermal conditions, and visible ice content in the top 1.2 m of the ground. It allows the quantification and analysis of trends along the north-south corridor, as a function of distance, terrain unit, and type of clearing. The database provides base-line geoscience information for the assessment of the impact of climate change on the physical environment. Such detailed data over a wide area are rare, yet important to the validation of regional-scale permafrost prediction models such as that presented later in this volume (*see* Wright et al., 2000).

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