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2022

Canada

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2022

Permanent link: https://doi.org/10.4095/329969

This publication is available for free download through GEOSCAN (https://geoscan.nrcan.gc.ca/).

Recommended citation
Sladen, W.E., Parker, R.J.H., Morse, P.D., Kokelj, S.V., and Smith, S.L., 2022. Geomorphic feature inventory along the Dempster and Inuvik to Tuktoyaktuk highway corridor, Yukon and Northwest Territories; Geological Survey of Canada, Open File 8885, 1 .zip file. https://doi.org/10.4095/329969

Publications in this series have not been edited; they are released as submitted by the author.

ABSTRACT

Thaw of permafrost and associated ground ice melt can reduce ground stability, modify terrain, and reconfigure drainage patterns affecting terrestrial and aquatic ecosystems and presenting challenges to northern infrastructure and societies. The integrity of ground-based transportation infrastructure is critical to northern communities. Geomorphic features can indicate ground ice presence and thaw susceptibility. This Geological Survey of Canada Open File presents the digital georeferenced database of landforms identified in continuous permafrost terrain using high-resolution satellite imagery. The database is for a 10 km-wide corridor centered on the Dempster and Inuvik-Tuktoyaktuk highways. This 875 km-long transect traverses a variety of geological and physiographic terrain types, including glaciated and non-glaciated terrain, in the northcentral Yukon and northwestern Northwest Territories, where variation in climate, relief, ecology, and disturbance have produced a variety of periglacial conditions. We identified geomorphic features in high-resolution (0.6 m) satellite imagery visualized in 3D, and digitized them in ArcGIS. We used custom Python scripts to populate the attributes for each geomorphic feature. A total of 8746 features were mapped by type and categorized within three main classes: hydrological (n = 1188), mass movement (n = 2435), and periglacial (n = 5123). Features were identified at 1:10 000 and mapped at 1:5000. This report presents the geospatial database in ESRI® shapefile, Keyhole Markup Language (KML), and comma-delineated formats.

DISCLAIMER

1 INTRODUCTION

This Open File is a key product associated with the Geological Survey of Canada's (GSC) efforts in collaboration with the Northwest Territories Geological Survey (NTGS) to improve mapping of permafrost-affected terrain. Climate change and disturbance due to forest fire and infrastructure development are causing permafrost to warm and thaw. Thaw of permafrost that contains ice can lead to changes in hydrology and affect ground instability, which have implications for natural systems and infrastructure integrity. Since the western Canadian Arctic is warming at more than double the global average rate (Bush and Lemmen, 2019), permafrost thaw may present significant societal and economic challenges. Knowledge of permafrost conditions and sensitivity to warming is essential for making informed decisions regarding land management, resource development, and infrastructure design, maintenance, and adaptation strategies.

Sladen *et al.* (2021) previously co-developed a methodological protocol to classify and digitize geomorphic features of permafrost terrain using high-resolution (0.6 m) satellite imagery. Geomorphic features are identified in a 3-D visualization at 1:10 000 scale and digitized at 1:5 000 in ArcGIS. Customized Python® scripts populate the attributes for each geomorphic feature. Using the protocol described in Sladen *et al.* (2021), high-resolution WorldView-2, WorldView-3, and GeoEye-1 imagery, spanning the period from 2004 to 2018, were used to develop an inventory of features in the periglacial terrain of northwestern Canada. This multi-component Open File presents the digital geodatabase of landforms observed within a 10 km-wide corridor centered on the Dempster Highway and the Inuvik to Tuktoyaktuk Highway (DH-ITH) (Figure 1).

2 STUDY REGION

The DH-ITH is an all-season route that connects the rest of Canada to the Beaufort Sea at Tuktoyaktuk, NWT (Figure 1). The Dempster Highway (completed in 1978) is a gravel road that starts in west-central Yukon at 64°N (near Dawson), traverses northward through the mountainous terrain of the Northern Cordillera, and crosses the territorial border into the NWT at 67°N where it then traverses the subdued relief of the Interior Plains to Inuvik (68.4°N). Completed in 2017, the Inuvik-Tuktoyaktuk Highway continues northward from Inuvik across the Arctic Coastal Plain to the Beaufort Sea coast at 69.4°N, extending the all-season connection to the Arctic Ocean. The 875-km-long corridor traverses a variety of geological and physiographic terrain types (Figure 1), including glaciated and non-glaciated terrain (Bostock, 2014; Matthews, 1986; Rampton, 1988; Roots and Hart, 2004). The southern ~100 km of the DH-ITH is in extensive discontinuous permafrost, but for the remainder of the corridor permafrost is continuous (Figure 1 inset; Heginbottom *et al.*, 1995). Ground ice is present as buried glacial ice, wedge ice, segregated ice, and intrusive ice (Burn *et al.*, 2015; O'Neill *et al.*, 2019). There is a diverse range in periglacial conditions throughout the corridor that results from variations in climate, relief, ecology, disturbance, and glacial history (Burn, 2004; Burn and Kokelj, 2009; Burn *et al.*, 2015; Kokelj *et al.*, 2017; O'Neill *et al.*, 2019).

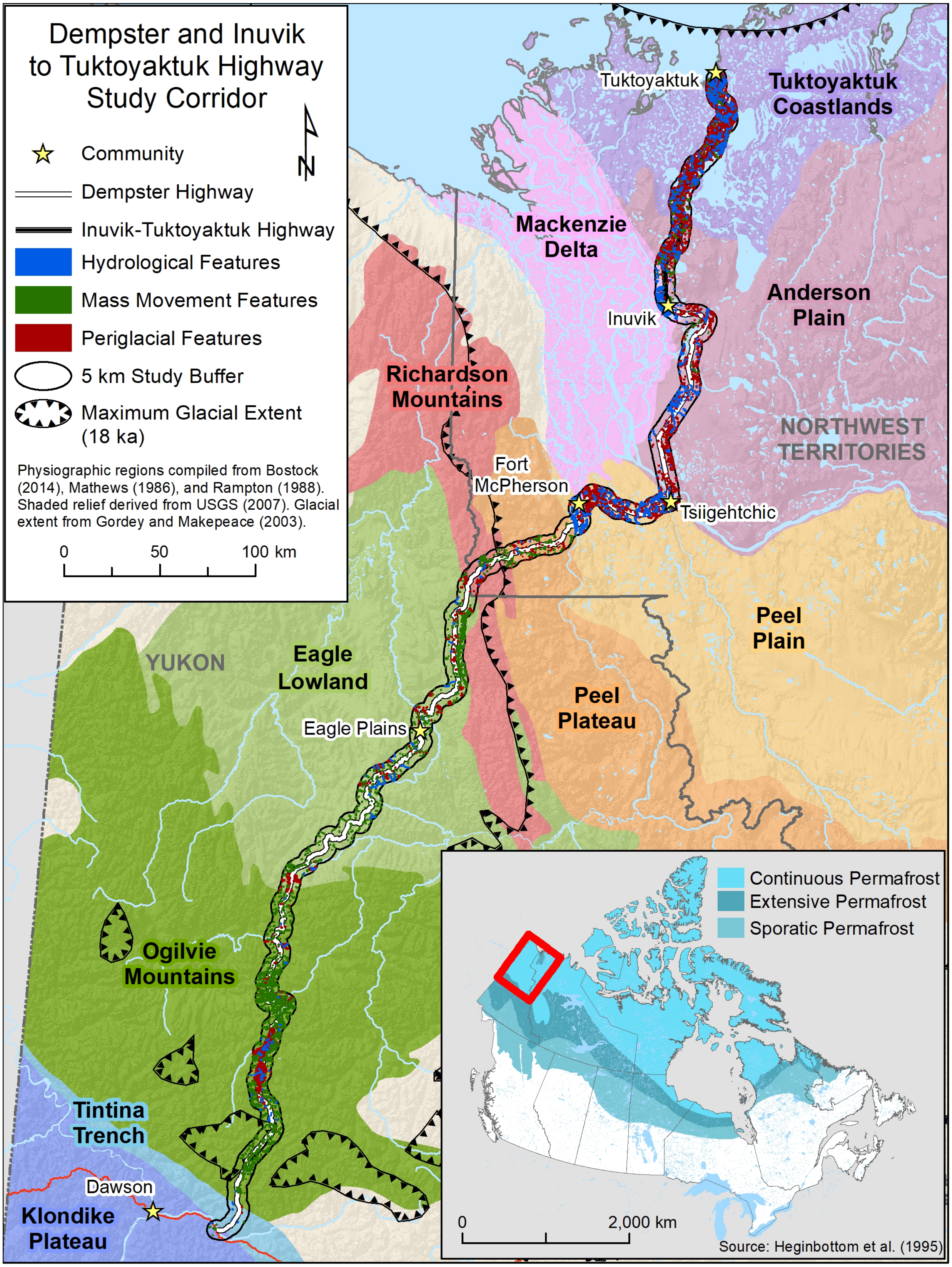

Figure 1. The DH-ITH corridor and physiographic regions, extent of mapping, and feature class distribution. Inset shows study area location and extent of continuous and discontinuous permafrost in Canada.

3 DESCRIPTION OF PRODUCT

The inventory is grouped into three main feature classes: periglacial, hydrological, and mass movement. The features are polygons with a combination of attributes assigned according to the protocol or derived from supplementary data sources that include surficial geology, physiographic region, and permafrost extent. A full description of the feature attributes can be found in Sladen *et al.* (2021).

The database file descriptions, attribute field names and associated codes for coded attributes, if applicable, are listed below. Figures 2 to 8 show the variability in distribution of periglacial terrain features identified in this geodatabase for different physiographic regions.

3.1 Database File Descriptions

\Data\CSV	Comma-delineated feature attribute values
\Data\KML	Keyhole Markup Language geographic data files for expressing geographic feature annotation and visualization
\Data\SHP	Shapefile (polygon) geographic data files for storing the geometric location and attribute information of geographic features

Filename convention: Designated by feature class code

3.2 Feature Attribute Fields

OBJECTID	Unique identification number
Shape	Feature class type and geometric properties, generated automatically in ArcMap (polygon centroid (x,y in m) in CSV files)
Shape_Length	Polygon perimeter length (m), generated automatically in ArcMap
Shape_Area	Polygon area (m^2), generated automatically in ArcMap
LAT	Latitude of feature centroid in decimal degrees
LONG	Longitude of feature centroid in decimal degrees
NTS_50K	National Topographic System map (Government of Canada, 2018)
CLASS	Feature class
TYPE	Feature type
SUBTYPE	Feature subtype
SUBTYPE_DESC	Feature subtype description, MASS features only
IND_MUL	Individual vs. multiple features
ACTIVITY	Active vs. inactive, MASS features only
MATERIAL	Feature material, MASS features only
ORIENTED	Similar orientation as surrounding features, HYDRO features only
COMMENTS	Mapper comments
SURF_GEO	Surficial geology unit code, assigned (Duk-Rodkin and Hughes, 1992a,b; Rampton, 1988; Thomas and Rampton, 1982a,b,c,d,e,f)
PHYS_REG	Physiographic region/division, assigned (Bostock, 2014; Mathews, 1986; Rampton, 1988)
PF_DESC	Permafrost zone and ground ice content, assigned (Heginbottom *et al.*, 1995)
IMG_SET	Number of the image set, assigned (DigitalGlobe, 2018)
IMG_NUM	Number of the input image within an image set, assigned (DigitalGlobe, 2018)
IMG_SOURCE	Satellite sensor, assigned (DigitalGlobe, 2018)
IMG_DATE	Date the input image was acquired (YYYY-MM-DD), assigned (DigitalGlobe, 2018)

3.3 Attribute Codes

CLASS

HYDRO	Hydrological
MASS	Mass movement
PERI	Periglacial

TYPE

(Hydrological features)

BS	Beaded stream
DLB	Drained-lake basin
ICE	Icing
TL	Lake/pond affected by thermokarst
TG	Thermokarst gully
UN	Unclassified

(Mass movement features)

FA	Fall
FL	Flow
SL	Slide
TO	Topple
CX	Complex
UN	Unclassified

(Periglacial features)

PALSA	Palsa
PINGO	Pingo
LITH	Lithalsa
MOUND	Mounds – Badlands
POLY	Ice-wedge polygon
PEATP	Peat plateau complex
SNF	String / net fen
UN	Unclassified

SUBTYPE

(Hydrological features)

FULL	Fully drained
PART	Partly drained
NA	Not applicable
UN	Unclassified

(Mass movement features)

ALD	Active-layer detachment
DF	Debris flow
RTS	Retrogressive thaw slump
SO	Solifluction
RG	Rock glacier

RS	Rotational slide
TS	Translational slide
SS	Shoreline slump
BF	Block failure
UN	Unclassified

(Periglacial features)

HIGH	High centre
LOW	Low centre
NA	Not applicable
UN	Unclassified
UNDIF	Undifferentiated

SUBTYPE_DESC
(Pertains to mass wasting features only)

LO	Lobes
SH	Sheets (stripes)
TE	Terraces
NA	Not applicable
UN	Unclassified

IND_MUL

IND	Individual features
MUL	Multiple features
NA	Not applicable
UN	Unclassified

ACTIVITY
(Pertains to mass wasting features only)

ACT	Active
INACT	Inactive
UN	Unclassified

MATERIAL
(Pertains to mass wasting features only)

Q	Quaternary sediments
R	Bedrock
UN	Unclassified

ORIENTED
(Pertains to hydrological features only)

N	No
Y	Yes
NA	Not applicable
UN	Unclassified

SURF_GEO
(Combination of genetic category and morphologic descriptor from Duk-Rodkin and Hughes, 1992a,b; Rampton, 1988; Thomas and Rampton, 1982a,b,c,d,e,f).

Genetic category

A	Alluvial deposits
C	Colluvial deposits
GF	Glaciofluvial
GL	Glaciolacustrine
L	Lacustrine
O	Organic
M	Morainal
R	Bedrock
R1	Sedimentary
T	Till

Morphologic descriptor

a	Apron or talus deposits
b	Blanket
c	Ice-contact
f	Fan
f1	Outwash fan deposits
h	Hummocky
p	Plain or outwash plain deposits
r	Rolling
t	Terrace
v	Veneer
wb	Bog
wf	Fen
z	Landslide deposits

* Code example: GFt = Glaciofluvial terrace.

PF_DESC
(Combination of permafrost extent and ground ice content based on Heginbottom *et al.*, 1995)

Permafrost Extent (% land underlain by permafrost)

C	Continuous (90-100%)
E	Extensive discontinuous (50-90%)

Ground Ice Content (% by volume of visible ice based on Heginbottom *et al.*, 1995)

L	Low (<10%)
M	Medium (10-20%)
H	High (>20%)

*Code example: CL-M = continuous permafrost extent with low to medium ground ice content.

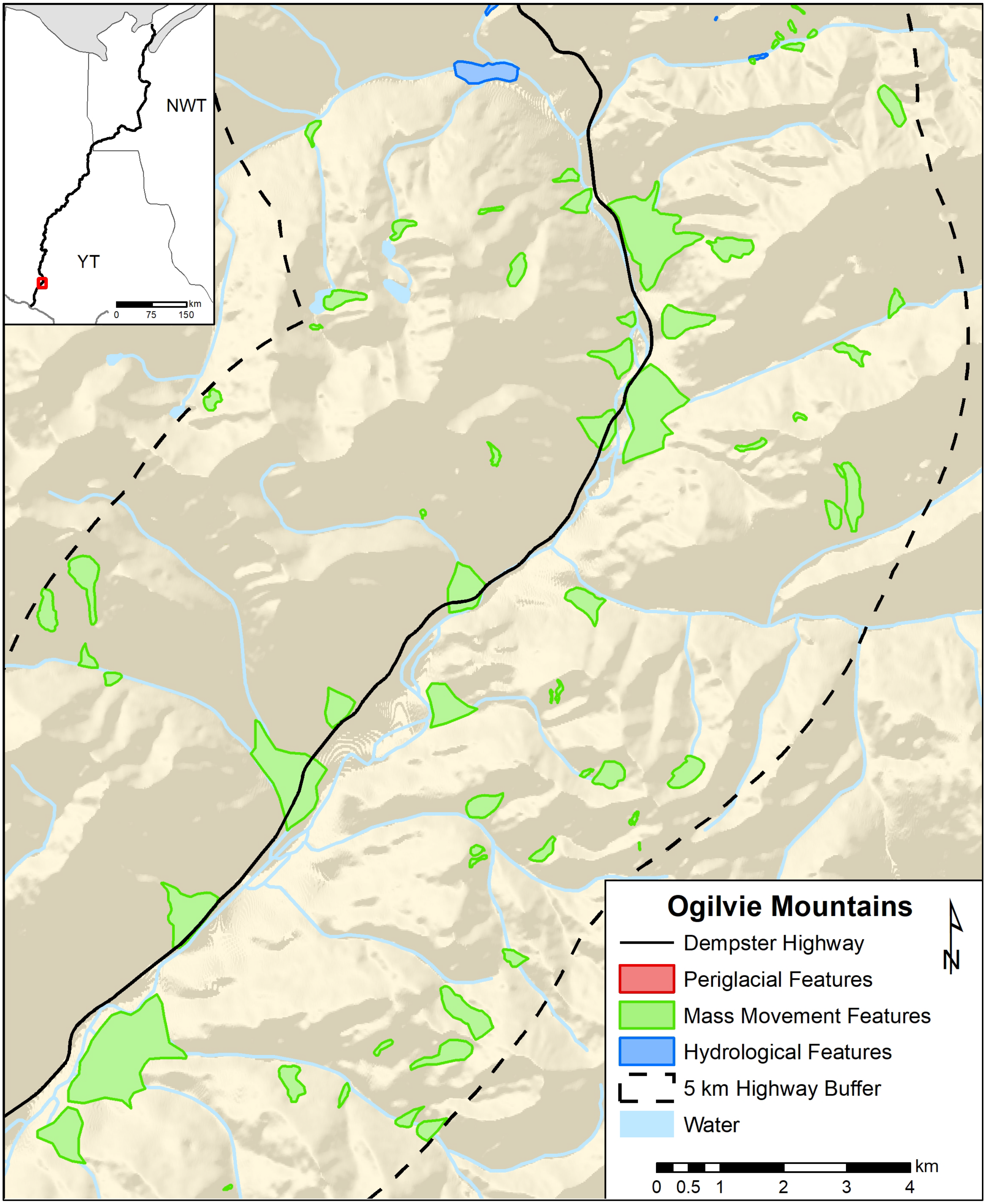

Figure 2. Geomorphic feature class distribution for a portion of the corridor in the Ogilvie Mountains. See inset for location.

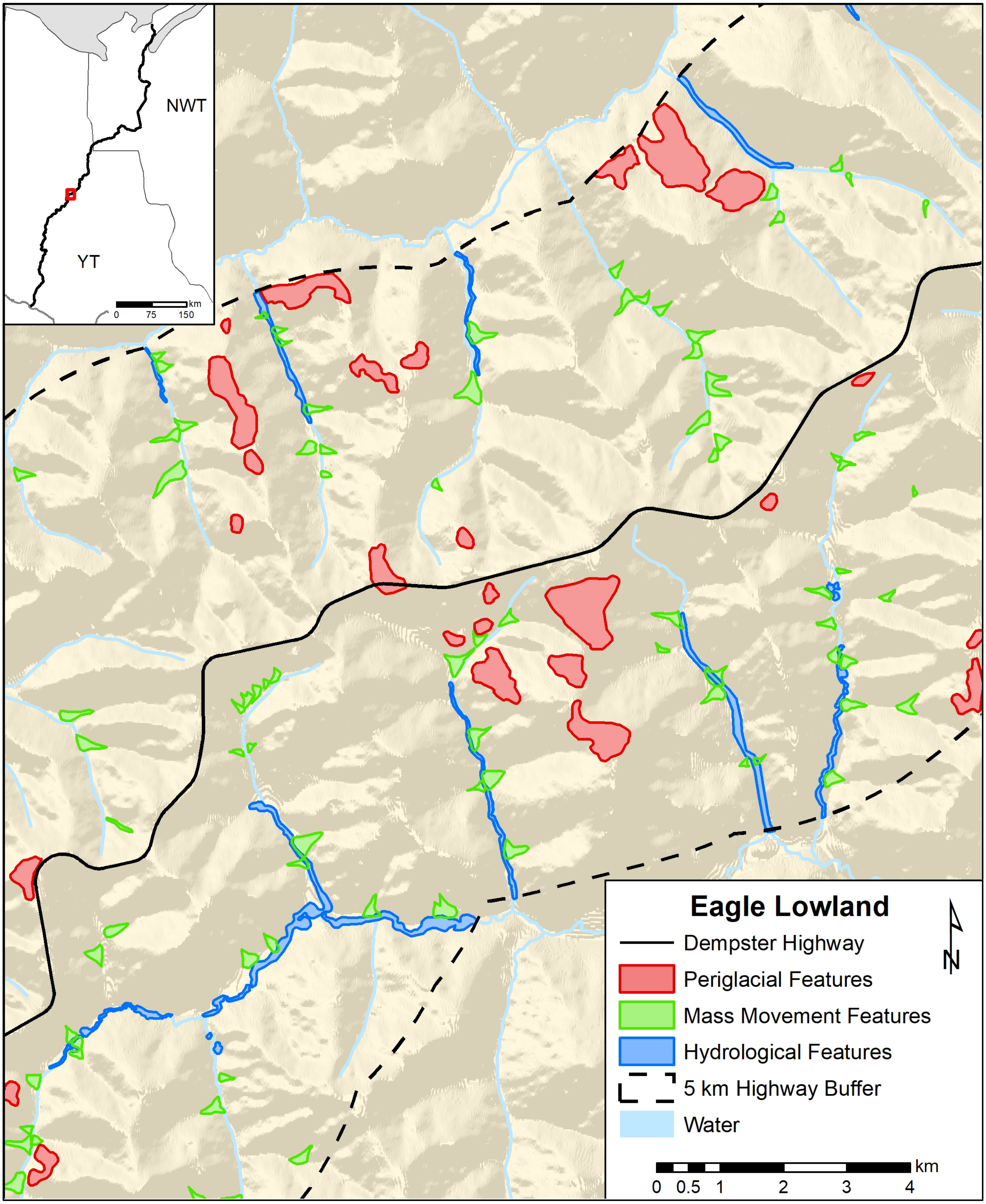

Figure 3. Geomorphic feature class distribution for a portion of the corridor in the Eagle Lowland. See inset for location.

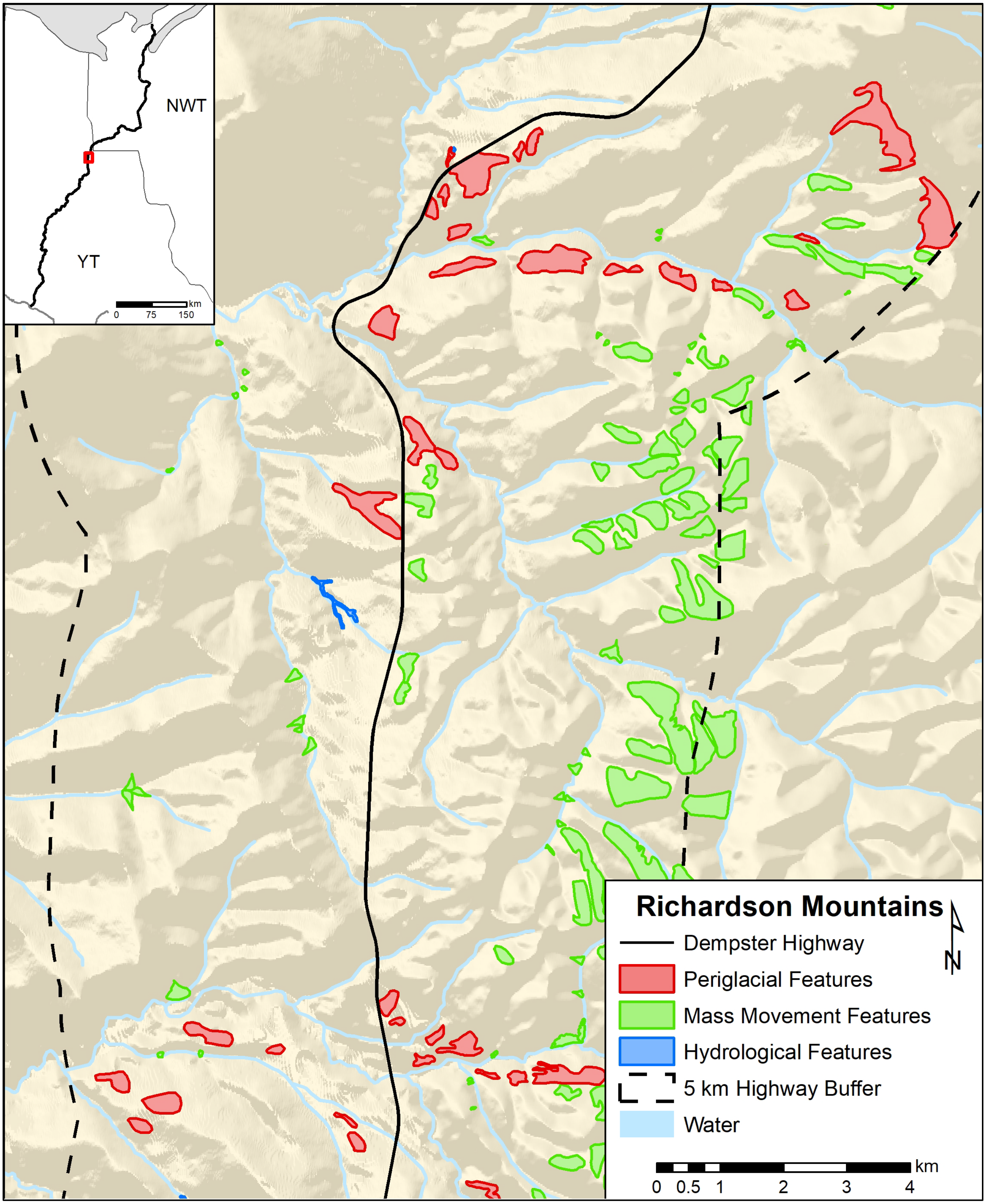

Figure 4. Geomorphic feature class distribution for a portion of the corridor in the Richardson Mountains. See inset for location.

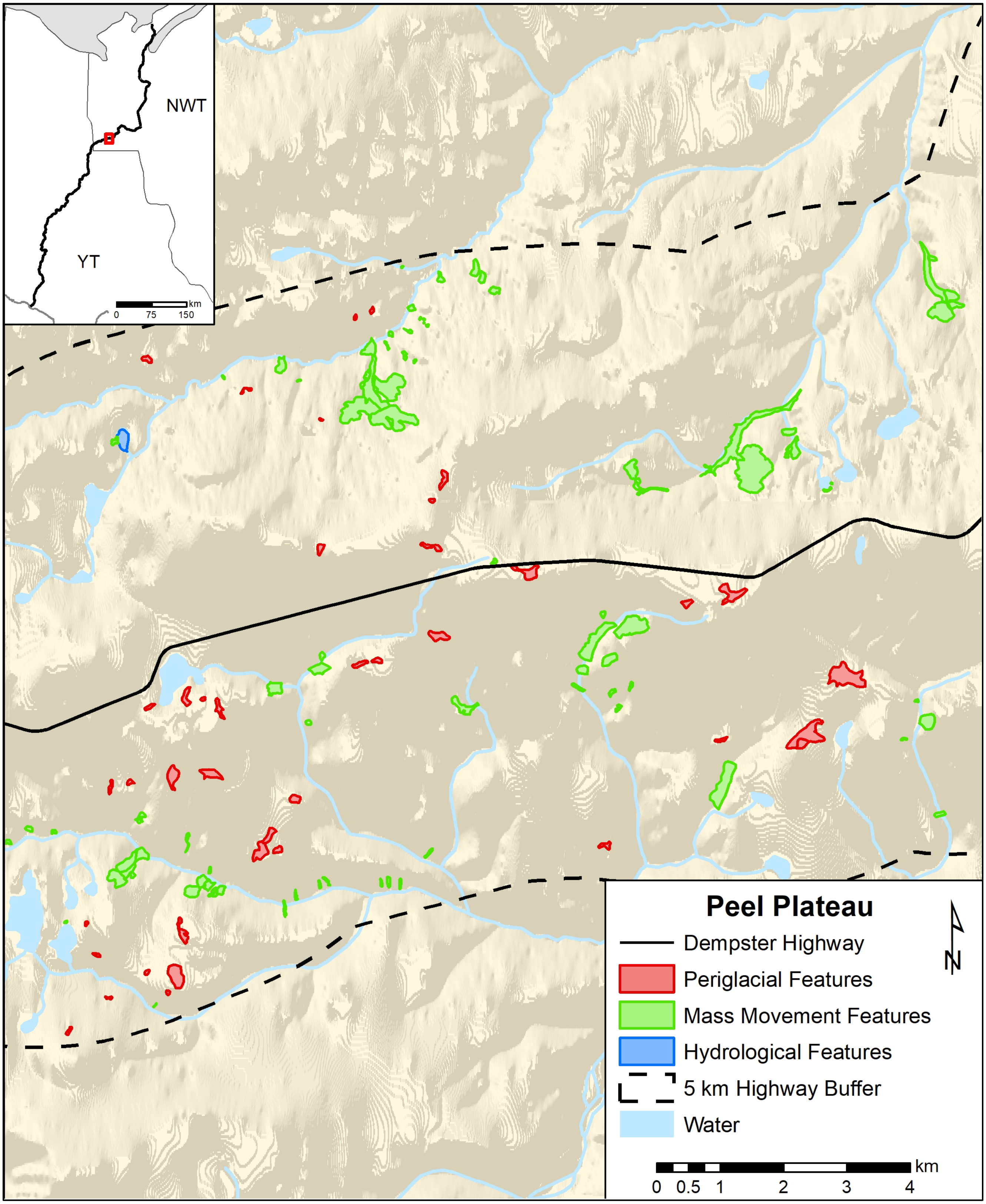

Figure 5. Geomorphic feature class distribution for a portion of the corridor in the Peel Plateau. See inset for location.

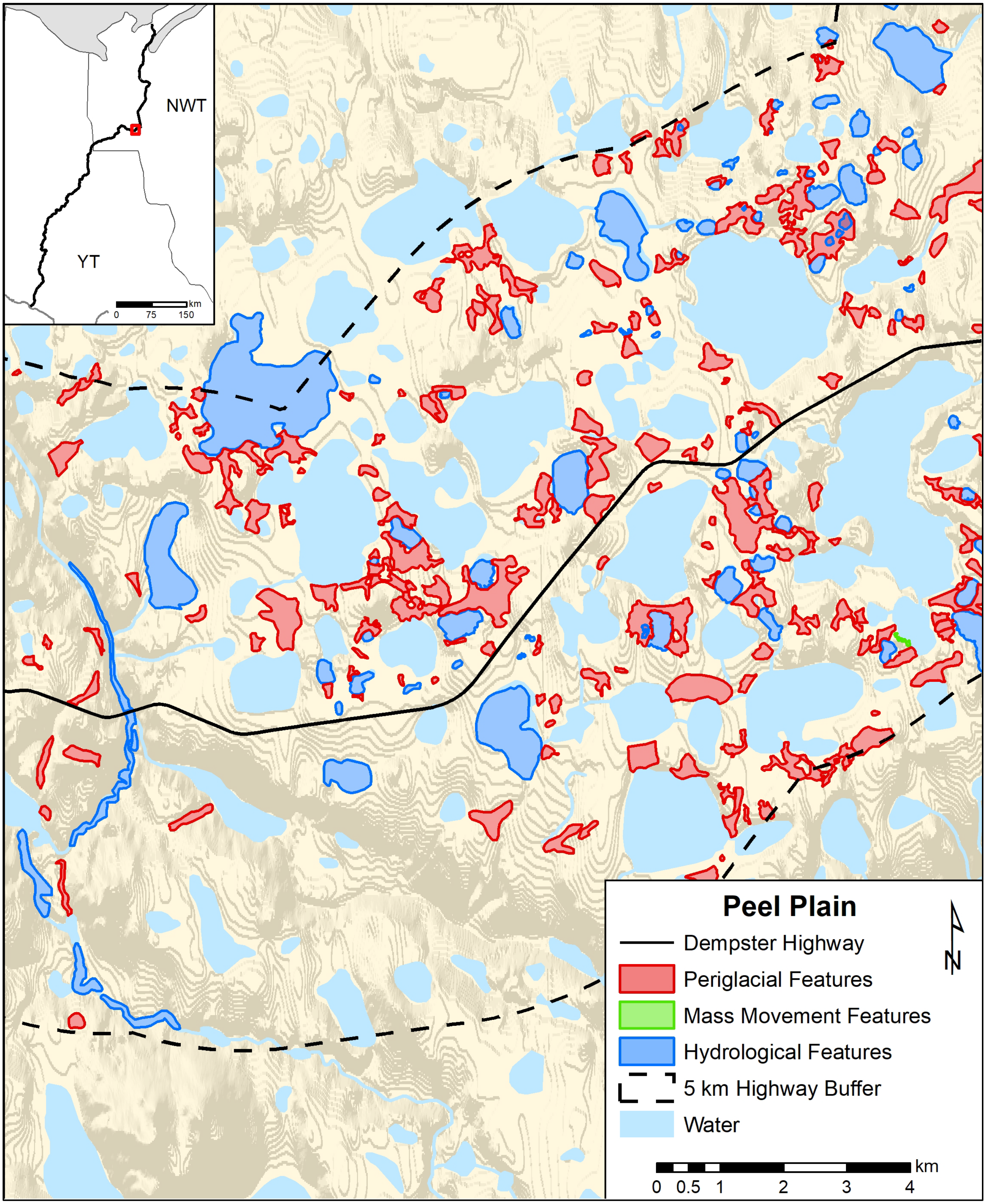

Figure 6. Geomorphic feature class distribution for a portion of the corridor in the Peel Plain. See inset for location.

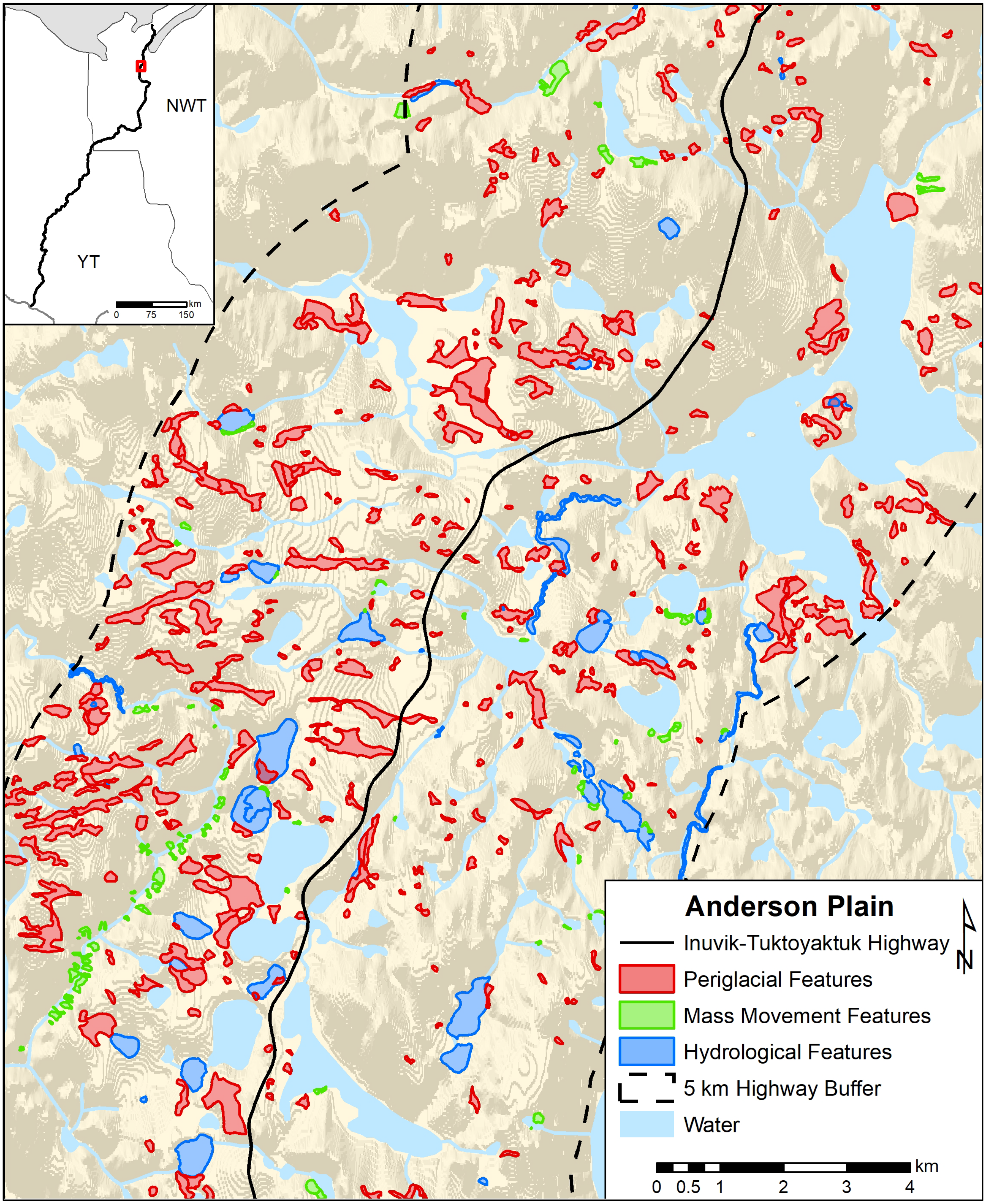

Figure 7. Geomorphic feature class distribution for a portion of the corridor in the Anderson Plain. See inset for location.

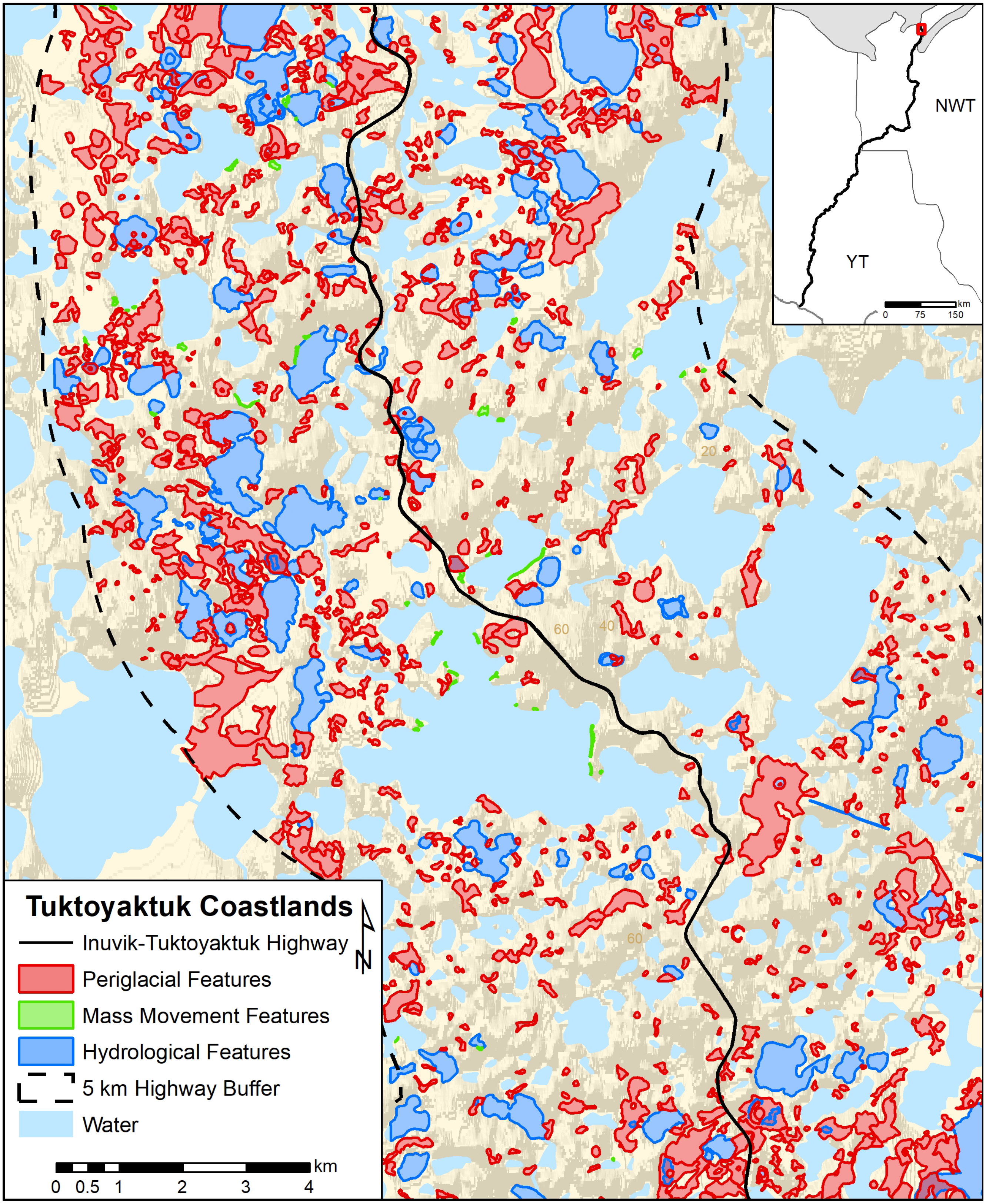

Figure 8. Geomorphic feature class distribution for a portion of the corridor in the Tuktoyaktuk Coastlands. See inset for location.

4 LIMITATIONS

This work is primarily a desktop study. The identification of landscape features relies heavily on digital and optical datasets with limited field validation. One of the main data limitations is that the best available elevation dataset that covers the entire DH-ITH corridor is the Canadian Digital Elevation Model (CDEM; Government of Canada, 2018). The CDEM has a pixel size of approximately 20 m and the high-resolution imagery has a pixel size of 0.6 m. The mismatched resolution of the two datasets results in a number of issues for feature identification when the data are combined to generate the stereo pairs for 3D mapping. Features with local relief but with footprints at the same scale as the resolution of the CDEM data, such as pingos or palsas, do not appear in 3D, and therefore these features are more difficult to identify unless supplementary high resolution elevation data, such as Light Detection and Ranging (LiDAR) (van der Sluijs *et al.*, 2018), are available for the same area. In areas of low relief, such as along the ITH, the CDEM does not capture small-scale variation in elevation such as slightly elevated plateaus or shorelines. Lastly, several sections of the CDEM dataset are shifted by multiple pixels resulting in an offset between contours and features in the 3D imagery, such as streams that appear to run along the ridges beside valleys and hills in the middle of lakes. These issues result in difficulty identifying and/or delineating features. To compensate for the relatively coarse resolution of the CDEM, LiDAR data are consulted wherever available. Additional limitations include cloud cover and shadows, especially in areas of high relief, that obstructed view and made it difficult to delineate features.

The bare earth LiDAR provides an excellent data set for delineating features that are obscured by vegetation. However, the extent of the LiDAR data is limited and does not cover the entire study corridor. As a result, it is used as supplementary reference data but was not used to generate the 3D imagery. Permafrost extent and ground ice content is based on national-scale mapping and therefore may not reflect local conditions.

5 SUMMARY

This database comprises a total of 8746 landforms identified over the 8419 km^2 Dempster and Inuvik-Tuktoyaktuk highway corridor, including 5123 periglacial features, 2435 mass movement features, and 1188 hydrological features. The average density of the features is 696 ha·100 km^{-2} for the corridor, but this varies from 17 ha·100 km^{-2} in the Tintina Trench to 1714 ha·100 km^{-2} in the Tuktoyaktuk Coastlands. Periglacial and hydrological features are concentrated in the northernmost 39% of the corridor, whereas slope and mass wasting features dominate the southern 61% of the corridor, where the physiographic regions have high relative relief. These densities may vary slightly if waterbodies are taken into consideration.

Geomorphic inventories such as this can provide a basis for identifying potential geohazards to the natural environment, infrastructure, and society. This database can be used to determine the extent and diversity of features in this region and to establish relationships between geomorphic landforms, landscape characteristics, and surficial geology. For example, the distribution of periglacial and hydrological features indicates the comparatively high areal extent of ice-rich permafrost that is thaw sensitive in the northern regions of the DH-ITH. The high density of lakes affected by thermokarst suggests a high magnitude of contemporary thaw activity, which is expected to continue under a warming climate. The concentration of these features in organic, fine-grained, and glacially-derived sediments highlights the presence of ground ice and thaw sensitivity of these deposits. These data can provide a basis of developing spatial models of landscape-thaw susceptibility (e.g. Rudy *et al.*, 2019), which can inform risk assessment and improve decision making regarding public safety and environmental management.

ACKNOWLEDGEMENTS

Support was provided by Natural Resources Canada, Transport Canada, and NTGS. The authors would like to highlight the significant contribution of Erik Duncan, Samuel Jardine, and Andrew Branson for meticulous identification and digitization of features. This work benefitted from discussions with Andrée Blais-Stevens, Janet Campbell, Dan Kerr, Alain Plouffe, and Louis Robertson of the GSC, and Panya Lipovsky at the Yukon Geological Survey. Jurjen van der Sluijs at the NWT Centre for Geomatics provided bare earth LiDAR for sections of the corridor. Brendan O'Neill provided helpful comments on the report.

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