GEOLOGICAL SURVEY OF CANADA
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Predictive Surficial Materials and Surficial Geology Derived from LANDSAT 7, Hearne Lake, NTS 85-I, Northwest Territories

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ABSTRACT

Surficial materials and surficial geology maps provide important geoscience information required for geological reconstructions, mineral exploration and development, and land use planning in northern Canada. In this study, remote predictive mapping was used to derive predictive surficial materials and surficial geology maps for Hearne Lake NTS 85-I, located within the Slave Geological Province. The predictive maps were generated using radiometrically balanced LANDSAT 7 imagery and knowledge gained from airphoto interpretations, field observations and legacy datasets. This Open File contains graphical and digital georeferenced versions of the predictive maps. A printable version of the predictive surficial geology map is provided in pdf format (map scale 1:125 000).

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1. INTRODUCTION

Despite the detailed knowledge of bedrock geology in the mineral-rich Slave Geological Province, knowledge of surficial materials and surficial geology remain rudimentary in the southern Slave. The lack of this geoscience information limits the ability to identify terrain risks associated with various surficial materials along proposed and existing infrastructure corridors (e.g. northern roads). Surficial maps also play a vital role in mineral exploration (e.g. drift prospecting and bedrock mapping), and in the identification of granular aggregate.

The Geological Survey of Canada of Natural Resources Canada has begun to use Remote Predictive Mapping (RPM) to map surficial materials (Grunsky et al., 2006; Brown et al., 2007; Harris, 2008; Stevens et al., 2012) and bedrock (Harris et al., 2010) over large areas where existing geological knowledge is insufficient. These RPM map products provide a first order assessment of surficial materials and bedrock, which can guide traditional field mapping and provide regional information for geotechnical investigations and mineral exploration.

A remote predictive surficial materials map has been derived for the Hearne Lake mapsheet NTS 85-I, as part of research conducted through Great Slave-TRACS (Transportation Risk in the Arctic to Climatic Sensitivity) and GEM (Geo-mapping for Energy and Minerals) (Figure 1). In addition, a predictive surficial geology map that interprets the origin of the sediment deposits has been derived from the surficial materials map. This Open File contains graphical and digital georeferenced versions of the predictive maps for Hearne Lake NTS 85-I. A printable surficial geology map for NTS 85-I is provided in pdf format at a scale of 1:125 000.

1.1. Regional Surficial Geology

The Hearne Lake mapsheet (NTS 85-I) is located within the southern part of the Slave Geological Province of the Northwest Territories (Figure 1). The terrain mainly consists of exposed bedrock, open to dense forests of black spruce, jack pine, and paper birch mixed with marshes, fens and peat bogs in low-lying areas. This region is located within the extensive discountinous zone of permafrost. Forest fires predominately occur across the northern portion of the mapsheet as shown in Figure 1.

The regional geological information indicates the last glacial episode was the Late Wisconsin glaciation, which reached its maximum extent about 18,000 years ago. The Yellowknife region was ice covered to about 11,000 BP and became ice-free by about 10,000 BP (Dyke and Prest, 1987). Paleo ice flow was to the southwest, as evident by striae and fluted bedrock measurements (Kerr, 2006) and the orientation of eskers and drumlinoid features. With the retreat of ice in the region, a large glacial lake (Glacial Lake McConnell) occupied the Great Bear and Great Slave Basins, up to an elevation of 280 m (Craig, 1965; Smith, 1994), resulting in the deposition of fine-grained glaciolacustrine sediments. Wave-washed bedrock and reworked glacial and glaciofluvial sediments are also present.

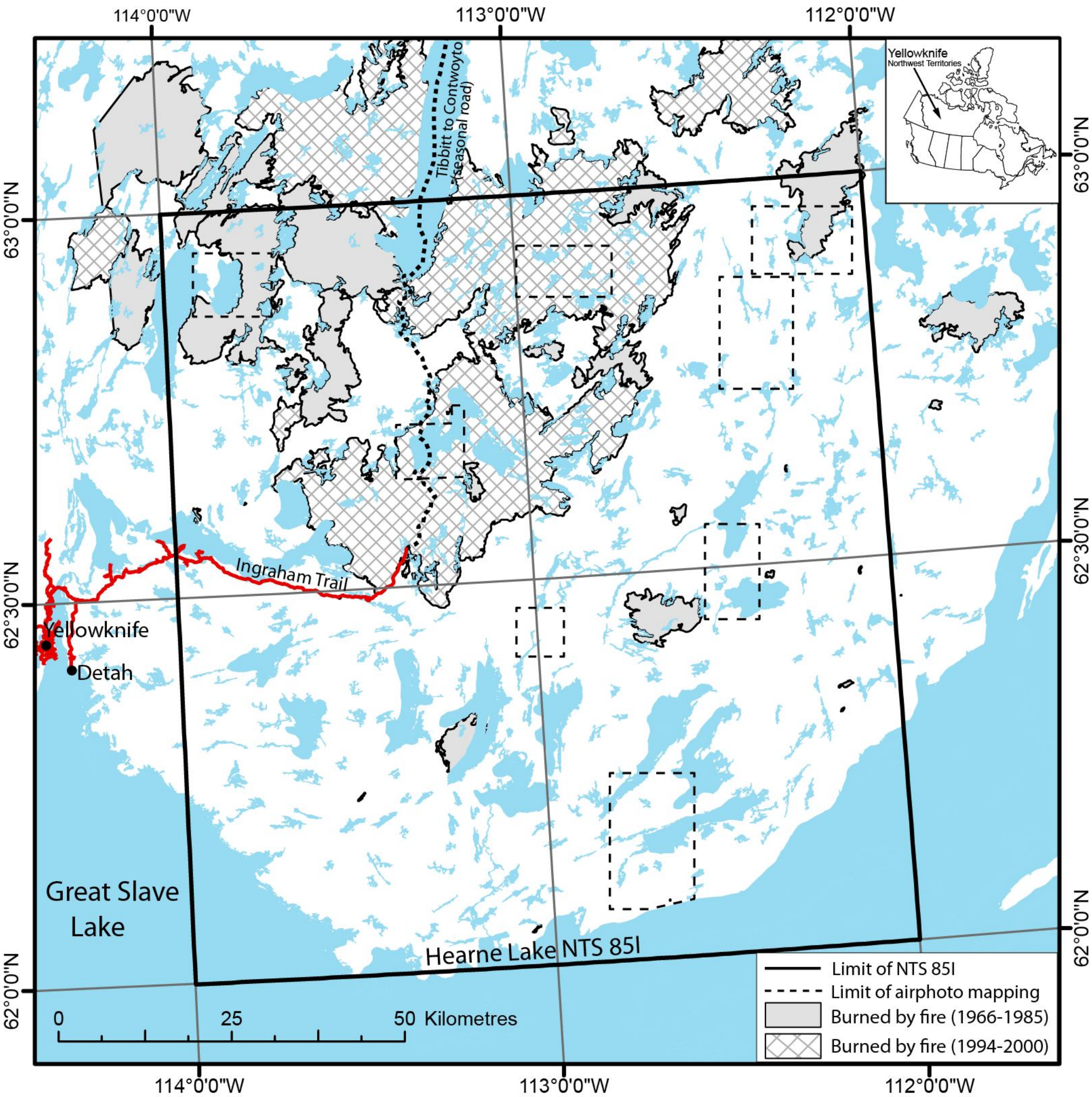

Figure 1. Study area map showing the location of Hearne Lake NTS 85-I (solid back line) and the limit of airphoto mapping used for development of training areas (dashed black line).

Existing surficial maps for this area include information at a national scale 1:5 000 000 (Fulton, 1995), regional scale at 1:1 000 000 (Aylsworth and Shilts, 1989) and local scale at 1:6 000 for the city of Yellowknife (Aspler, 1978). A reconnaissance map of the Yellowknife River basin at 1:250 000 has also been produced for the region (Kerr, 1990). However because of their scale, these maps are inadequate for most applications, such as geological reconstructions, mineral exploration, resource development and government land use planning. A predictvie surficial materials and surficial geology map has been recently published for Yellowknife NTS 85J, located to the west of the present study area (Stevens et al., 2012). Similar mapping techniques are utilized by this study.

1.2. Remote Predictive Mapping (RPM)

Remote predictive mapping (RPM) integrates multiple remote sensing datasets to classify surficial sediment units based on statistically robust models built from user defined training areas (Figure 2). The integration of multiple types of remotely sensed data attempts to improve the accuracy of the mapping by increasing the distinction between each training class (surficial sediment type). From these predictive maps and field data, predictive surficial geology maps can be generated to infer the origin and environment into which the sediment was deposited.

A predictive map does not represent geological truth, but rather an estimate of what may be present on the ground, based on the signatures derived from the interpreted data (geophysical, geochemical, remotely sensed). Traditional geological maps derived from airphoto interpretation are used in this process to construct the classification models and independently validate the resulting map. It should be recognized that all maps, including those based on airphoto interpretations, inherently contain some form of spatial and/or classification error.

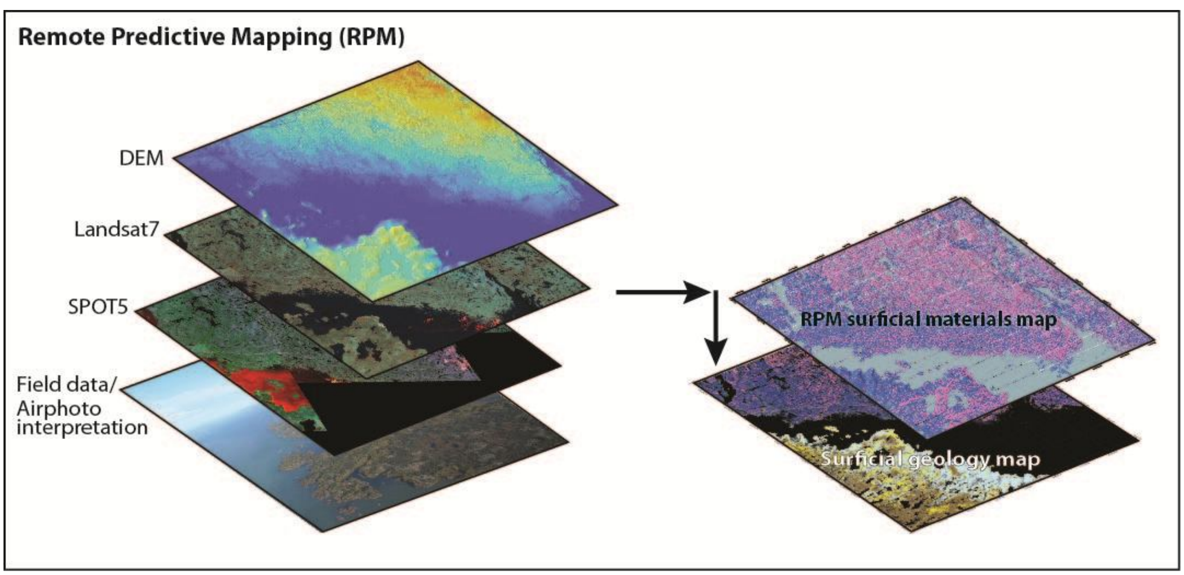

Figure 2. Schematic diagram showing the integrations of multiple remotely sensed datasets used to produce surficial materials and derived surficial geology maps. The data layers used in the analysis are based on the availability and usefulness of various sources of data.

2. REMOTE PREDICTIVE MAPPING APPROACH (NTS 85-I)

The RPM methodology adopted for mapping NTS 85-I was based on the availability of remote sensing data and the authors' field experience of surficial materials and geology found in the region. Figure 3 depicts the general process utilized by this study. Mapping was undertaken using LANDSAT 7 imagery (normalized bands 2,3,4,5 and 7 at 30 m spatial resolution). The LANDSAT 7 imagery was downloaded from Glovis (http://glovis.usgs.gov/) and GeoBase (http://www.geobase.ca/). Each LANDSAT scene was radiometrically normalized by I. Olthof (Canada Centre for Remote Sensing). The normalization procedure is outlined in Olthof et al., (2005). Bands 1 (Blue/Green) was removed, due to its sensitivity to atmospheric contamination. The thermal band 6 was also eliminated from the dataset due to its limited utility in identifying surficial materials.

The data were clipped into three regions due to major difference in spectral reflectance between burned and non-burned terrain. The reflectance values across burned terrain were found to vary with the timing (year) of the burn, which is likely caused by differences in post-burn secession of vegetation. Three separate classification models were created in order minimize classification errors; i) areas not burned by fire since 1966, ii) areas burned between 1966-1985 and iii) areas burned between 1994-2000. These three regions were defined using fire history data downloaded from NWT Centre for Geomatics (http://geomatics.gov.nt.ca/). Figure 1 indicates areas burned by fire over the period of 1966-1985 and 1994-2000.

The robust classification method using maximum likelihood was applied to classify the imagery. This method is based on a randomized and repeated sampling of a training dataset in concert with traditional cross-validation of the classification results (Harris et al., 2012). For each of the 20 repetition, random selections of 40% of the training data were input to produce the classification. Water bodies were masked from the LANDSAT imagery using the near infrared channel (band 4) and with thresholding applied to DN (digital numbers) <40. The derived mask may also included cloud shadows and some wetlands with water at the surface. The overall accuracy of the final majority classification map for the 20 repetitions was compared to the training data. Masked areas of the imagery, such as water bodies, were not used in the accuracy assessment.

A total of 10 bands of data were input to produce the final surficial materials map; normalize bands 2-5+7 and entropy of bands 2-5+7. The entropy of each primary LANDSAT band was calculated of a 7x7 pixel moving window in order to provide local texture of the reflectance values. These additional textural measurements were derived in order to increase the distinction between each surficial materials class.

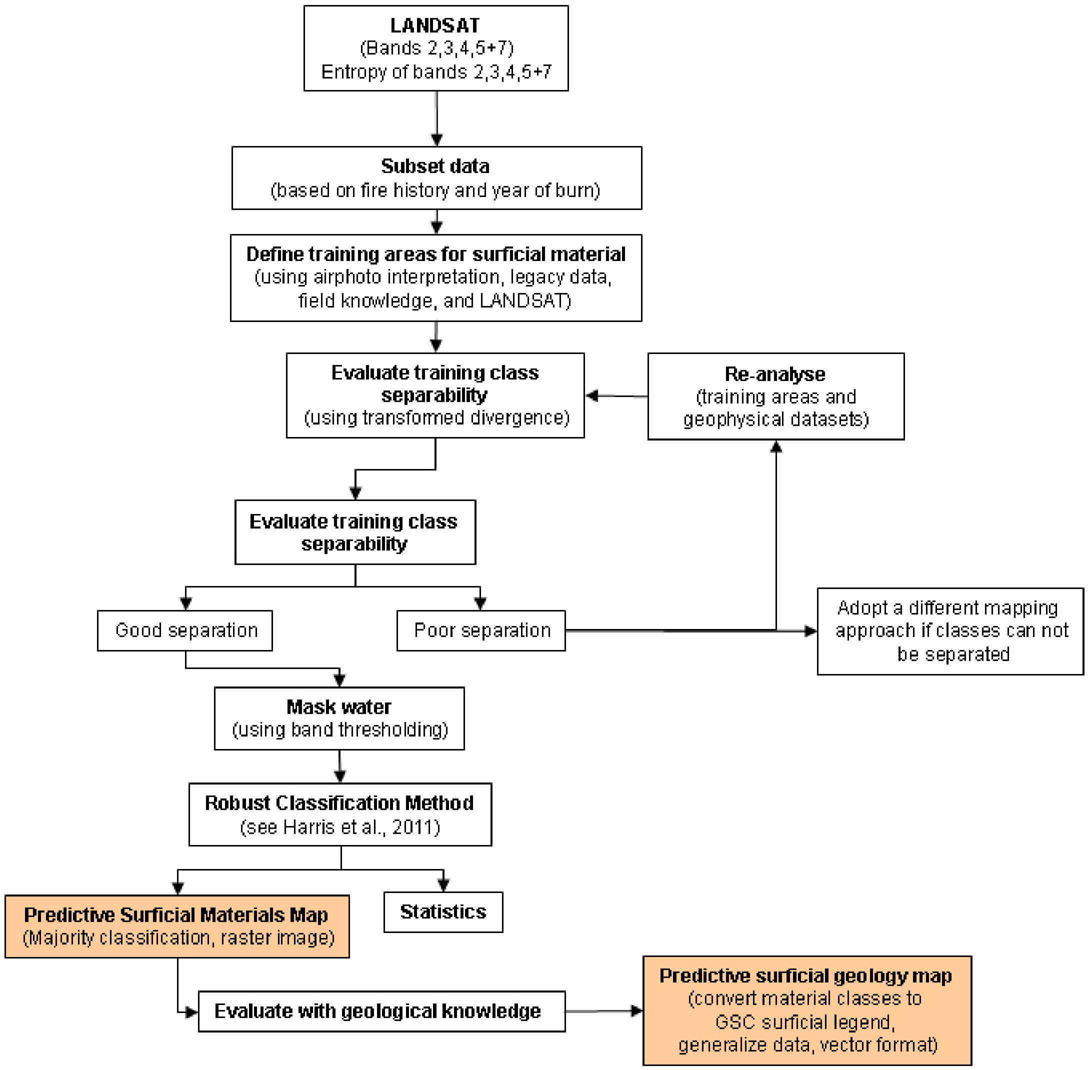

Figure 3. Flow chart describing general remote predictive mapping approach used in this study.

Table 1. Description of LANDSAT bands used to map surficial materials

LANDSAT 7	
Band 2	records reflected green energy (λ=0.52-0.60 microns)
Band 3	records reflected red energy (λ=0.63-0.69 microns)
Band 4	records reflected near infrared energy (λ=0.76-0.90 microns)
Band 5	records short wave infrared energy (λ=1.55-1.75 microns)
Band 7	records short wave infrared energy (λ=2.08-2.35 microns)
LANDSAT texture	
Entropy	Band 2 calculated over a 7x7 pixel moving window
Entropy	Band 3 calculated over a 7x7 pixel moving window
Entropy	Band 4 calculated over a 7x7 pixel moving window
Entropy	Band 5 calculated over a 7x7 pixel moving window
Entropy	Band 7 calculated over a 7x7 pixel moving window

2.1. Training Data

Traditional airphoto interpretation of surface geology was performed by D.E. Kerr, Geological Survey of Canada, to establish representative training classes of surficial materials (Figure 1). The final training classes were based on the outcome of airphoto interpretation, legacy data, and field experience in the region. Field survey of surficial geology was also conducted from helicopter by S.A. Wolfe and C.W. Stevens in August of 2011. Information gained from this field work was used in the development of training areas.

Separate training classes were developed for the three subset regions of NTS 85-I (Table 2). The unequal number and size of training classes for each region is due in part to the limited occurrence of some surficial materials within certain portions of the mapsheet.

The statistical separation between training classes was determined for each surficial material prior to classifying the LANDSAT imagery. The statistical separability of training classes was assessed using transformed divergence (TD), which is determined from the distance between mean reflectance value for each class in the N-dimensional space (Richards, 1986)

$$Dij = \frac{1}{2}tr((Ci - Cj)(Ci^{-1} - Cj^{-1})) + \frac{1}{2}tr((Ci^{-1} - Cj^{-1})(\mu_i - \mu_j)(\mu_i - \mu_j)^T)$$

where *i* and *j* are the two signatures (classes) being compared, *Ci* is the covariance matrix of signature I, μ_i is the mean vector of signature I, *tr* is the trace function (matrix algebra) and *T* is the transposition function. The transformed divergence is expressed as

$$TDij = 2000\left(1 - \exp\left(\frac{-Dij}{8}\right)\right)$$

The TD gives an exponentially decreasing weight to increasing distances between the classes that describes the relative degree of separation (Table 3).

A summary of the transform divergence for surficial materials classes is shown in Table 4. Overall separability between some of the classes was improved by integrating the textural characteristics of the primary LANDSAT bands. Poor separability occurs between silt and clay – till veneer and till veneer – till blanket and moderate separability for silt and clay – till blanket and till veneer - bedrock using the primary LANDSAT bands. This likely reflects similarities in surface vegetation. Statistical distinction between these classes is improved with the addition of the entropy layers (Table 4).

Table 2. Surficial materials classes used as training data for image classification. The GeoCode corresponds to the digital numbers embedded within the digital surficial materials data product accompanying this Open File (*RPM_NTS mapsheet 85I.tif*).

GeoCode	Surficial material classes	Number of polygons	Number of pixels
Unburned by fire (since 1966)			
1	Sand and Gravel	20	1763
2	Silt and Clay	13	1643
3	Till veneer	10	2027
4	Till blanket	7	752
5	Bedrock	30	3270
6	Organic	6	334
Burned by fire (1966-1985)			
1	Sand and Gravel	16	445
2	Silt and Clay	10	527
3	Till veneer	8	775
4	Till blanket	3	187
5	Bedrock	22	2294
Burned by fire (1994-2000)			
1	Sand and Gravel	7	224
4	Till veneer	6	99
4	Till blanket	7	182
5	Bedrock	6	275
7	Mask (NIR band 4, digital numbers DN<40)		

Table 3. Relative degree of separation for transformed divergence between 0.1 and 2.

Transformed divergence	**Relative degree of separation**
0.1 - 1.0	very poor separability
1.0 - 1.5	poor separability (marginal)
1.5 - 1.9	moderate separability
>1.9	good separability

Table 4. Comparison of training classes listed in ascending order of the transformed divergence for LANDSAT bands 2-5+7 and entropy calculated over a 7x7 pixel window for non-burned terrain. Divergence values of greater than 1.98 are not shown.

Training class comparison	**Transformed divergence**	
	LANDSAT	LANDSAT + Entropy
Silt and clay - Till veneer	1.14	1.46
Till veneer - Till blanket	1.35	1.51
Silt and clay - Till blanket	1.74	1.87
Till veneer - Bedrock	1.78	1.88
Sand and gravel - Bedrock	1.93	1.97
Sand and gravel - Till veneer	1.95	1.98

2.2. Classification and Post Processing

The predictive surficial materials map produced in this report was based on 20 repetitions of the robust classification methods using maximum likelihood classification applied to the normalized LANDSAT bands (2-5+7) and entropy (bands 2-5+7). Separate classification models were created for i) areas not burned by fire since 1966, ii) areas burned between 1966-1985 and iii) areas burned between 1994-2000.

The predictive surficial materials map was then generalized in order to conform to cartographic standards for a 1:250 000 mapsheet. The generalization process included 3 iterations of a 3x3 pixel majority filter, conversion the data from raster to vector format and removal of polygons less than 15,300 m^2 (17 pixels). Polygons below this minimum size threshold were replaced with the neighboring classes using the expand tool in ArcGIS. The surficial material classes were expanded by 2 pixels where the minimum size threshold was met.

The classified surficial material classes were then converted into predictive surficial geology units based on knowledge gained from airphoto interpretations, field observations and legacy information. Table 5 indicates the conversion between surficial materials to surficial geology units. In addition, interpreted till veneer below 250 m a.s.l. was reclassified as glaciolacustrine silt and clay as it is not mappable with confidence in this region from airphotos. Sand and gravel mapped adjacent to lakes was also reclassified as modern lacustrine sediments. Exposure of these sediments is inferred to be caused by a decrease in water level.

3. DIGITAL DATA

Digital predictive surficial material data is included in this Open File *NTS_85I_Predictive_Surficial_Material.tif.* The geocode used to define each surficial material is summarized in Table 2. The corresponding generalized surficial geology data has been compiled into a geodatabase (OF7233.gbd). The georeferenced data files include the predictive surficial materials and surficial geology, airphoto interpreted training data and striation measurements compiled from fieldwork in 2011 and from Kerr (2006). Appendix A provides a printable map of the predictive surficial geology (map scale 1: 125 000). Predictive surficial geology units and descriptions are summarized in Table 5. Bedrock outcrops consisting of < 5 pixels were converted to a point feature prior to the generalization process outlined in section 2.2. These features are included in the geodatabase and displayed as “x” in Appendix A.

3.1 Disclaimer

Her Majesty the Queen in right of Canada, as represented by the Minister of Natural Resources (“Canada”), does not warrant or guarantee the accuracy or completeness of the information (“Data”) on this map and does not assume any responsibility or liability with respect to any damage or loss arising from the use or interpretation of the Data.

The Data on this map are intended to convey regional trends and should be used as a guide only. The Data should not be used for design or construction at any specific location, nor are the Data to be used as a replacement for the types of site-specific geotechnical investigations.

Table 5. Surficial materials and equivalent surficial geology units used for mapsheet NTS 85-I.

Surficial Material GeoCode	Surficial Geology Unit	Description of Surficial Geology Unit
6	O	Organic deposits: undifferentiated fen, bog and floating aquatic vegetation
some units were manually reclassified from GeoCode 1	L	Lacustrine sediments: undifferentiated, exposed sediment surrounding modern lakes, variable thickness
2	GL	Glaciolacustrine sediments: undifferentiated silt and clay, may include small outcrops of till veneer, variable thickness
1	GF	Glaciofluvial sediments: undifferentiated sand and gravel to cobbles, forming esker ridges, terraces, outwash plains, may be reworked by wave action forming raised beaches, variable thickness
3	Tv	Till veneer: poorly sorted silt to gravel diamicton, may be modified by glaciolacustrine and meltwater processes, may contain small bedrock outcrops and glaciolacustrine veneer, variable thickness but generally <2 m
4	Tb	Till blanket: poorly sorted silt to gravel diamicton, variable thickness but generally >2 m
5	R	Bedrock: undifferentiated, may be overlain by discontinuous cover of till veneer, glaciolacustrine veneer and isolated glaciofluvial patches

4. REMOTE PREDICTIVE MAPS

The predictive surficial materials map derived from LANDSAT 7 imagery is shown in Figure 4. The overall average accuracy of the surficial materials map over 20 repetitions is 81.7% when compared to the training data. A confusion matrix of the individual accuracies for each surficial materials class is presented in Table 6. Errors in the classification between some surficial material classes are likely the result of similarities in surface vegetation and moisture, such as the confusion between silt and clay and till veneer. The lower than expected accuracy of bedrock reflects is mainly attributed to its confusion with till veneer (25% of the time). The confusion between these two classes is attributed to the presences of vegetated rock outcrops and the high occurrence of isolated bedrock outcrop in till veneer deposits. In addition, changes in surface conditions, from bedrock to vegetated till, may be at or below the resolution of the imagery, resulting in mixed pixel values. Till blanket is also found to be misclassified as till veneer nearly 17% of the time, due to similarities with till veneer.

Table 7 presents the percent coverage of each surficial material within mapsheet NTS 85-I. Surficial materials with the largest coverage include; bedrock (53%), till veneer (17%) and silt and clay (19%). Reclassification of till veneer to silt and clay below the threshold elevation discussed in section 2.2 alters the percent area of these classes to 11% and 24%, respectively. An additional 7% of the area is classified as till blanket and 3% as sand and gravel.

The derived predictive surficial geology map for NTS 85-I is presented in Appendix A. Bedrock (R) outcrops area widespread throughout the mapsheet, whereas glaciolacustrine silt clay (GL) predominately occurs in the lowlands across the southern portion. Glaciolacustrine silt and clay are interpreted to be deposited by Glacial Lake McConnell and former higher water levels of Great Slave Lake. Glaciolacustrine sediments also extend across the adjoining mapsheet NTS 85J, located to the west (Stevens et al., 2012). The northeast region of the mapsheet consists mainly of till veneer (Tv) and bedrock. Bedrock may be more widespread within the region classified as till veneer due to misclassification of small vegetated outcrops. Till blanket (Tb) is mainly restricted to topographically low depressions between bedrock highs. Glaciofluvial (GF) sand and gravels forming eskers and outwash deposits are often reworked by glaciolacustrine and meltwater processes. Raised beach ridges forming from reworking of glaciofluvial sediment deposits are identified at approximately 232, 242, 250, 258, 282, 332 and 374 m asl (Appendix A). Organic deposits (O) representing fen, bog and floating aquatic vegetation and modern lakes sediments (L) exposed from decreased water level were also identified across the mapsheet.

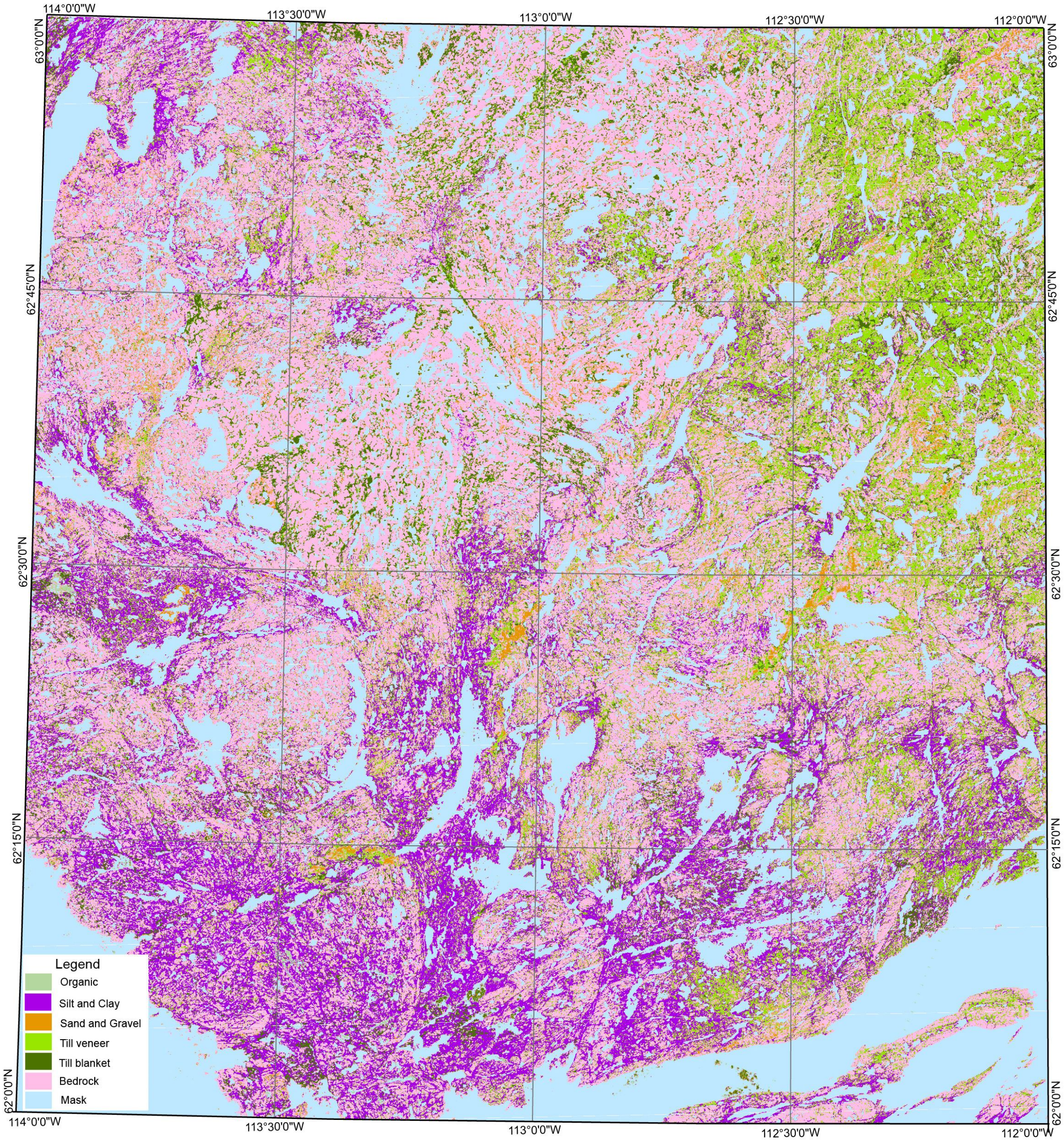

Figure 4. Remote predictive surficial materials map for Hearne Lake NTS 85-I based on LANDSAT data. Numbers shown on the map correspond to the location of field photographs presented in Appendix A. Map scale at 1:125 000.

Table 6. Confusion matrix of accuracy for predictive surficial materials classes (predicted class) compared against training classes (actual class). The individual class accuracy over the 20 repetitions is indicated in bold. The average overall accuracy for the surficial materials map is 81.7%.

	Actual class						
	Material class	Sand and Gravel	Silt and Clay	Till veneer	Till blanket	Bedrock	Organic
Predicted class	Sand and Gravel	**96.6**	0.0	0.3	0.0	0.6	0.0
	Silt and Clay	0.0	**76.1**	13.2	2.1	0.9	0.9
	Till veneer	0.8	20.6	**72.1**	16.9	24.7	0.0
	Till blanket	0.1	1.8	4.3	**75.5**	2.9	0.0
	Bedrock	2.5	1.5	10.0	5.5	**71.0**	0.0
	Organic	0.0	0.0	0.0	0.0	0.0	**99.1**

Table 7. Coverage of surficial materials expressed as the number of pixels and the percent area of land for NTS 85-I. Masked areas representing 27% of the mapsheet were excluded from the analysis.

Surficial material	**Number of pixels**	**Percent area**
Sand and Gravel	298434	3.19%
Silt and Clay	1741215	18.62%
Till veneer	1548919	16.56%
Till blanket	679838	7.27%
Bedrock	4999631	53.46%
Organic	83628	0.89%

5. CONCLUSIONS

This report presents a predictive surficial materials map and derived surficial geology map for the Hearne Lake mapsheet NTS 85-I. These datasets have been generated using a RPM approach in order to provide a first order assessment of surficial materials. This preliminary information is required to assess terrain risks to northern infrastructure and to guide mineral exploration and future mapping within the Slave Geological Province.

6. ACKNOWLEDGEMENTS

This work was conducted under Great Slave - TRACS (Transportation Risk in the Arctic to Climatic Sensitivity) and Geomapping for Energy and Minerals (GEM) Programs of Natural Resources Canada. The authors acknowledge the support of Ian Olthof (Canada Centre for Remote Sensing) for radiometrically balancing the LANDSAT7 data and Jeff Harris (Geological Survey of Canada) for assisting with image classification.

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8. APPENDIX A

Predictive surficial geology map for Hearne Lake, NTS 85-I. A printable version of this surficial geology map is also provided in this Open File as a digital pdf (map scale 1:125 000).

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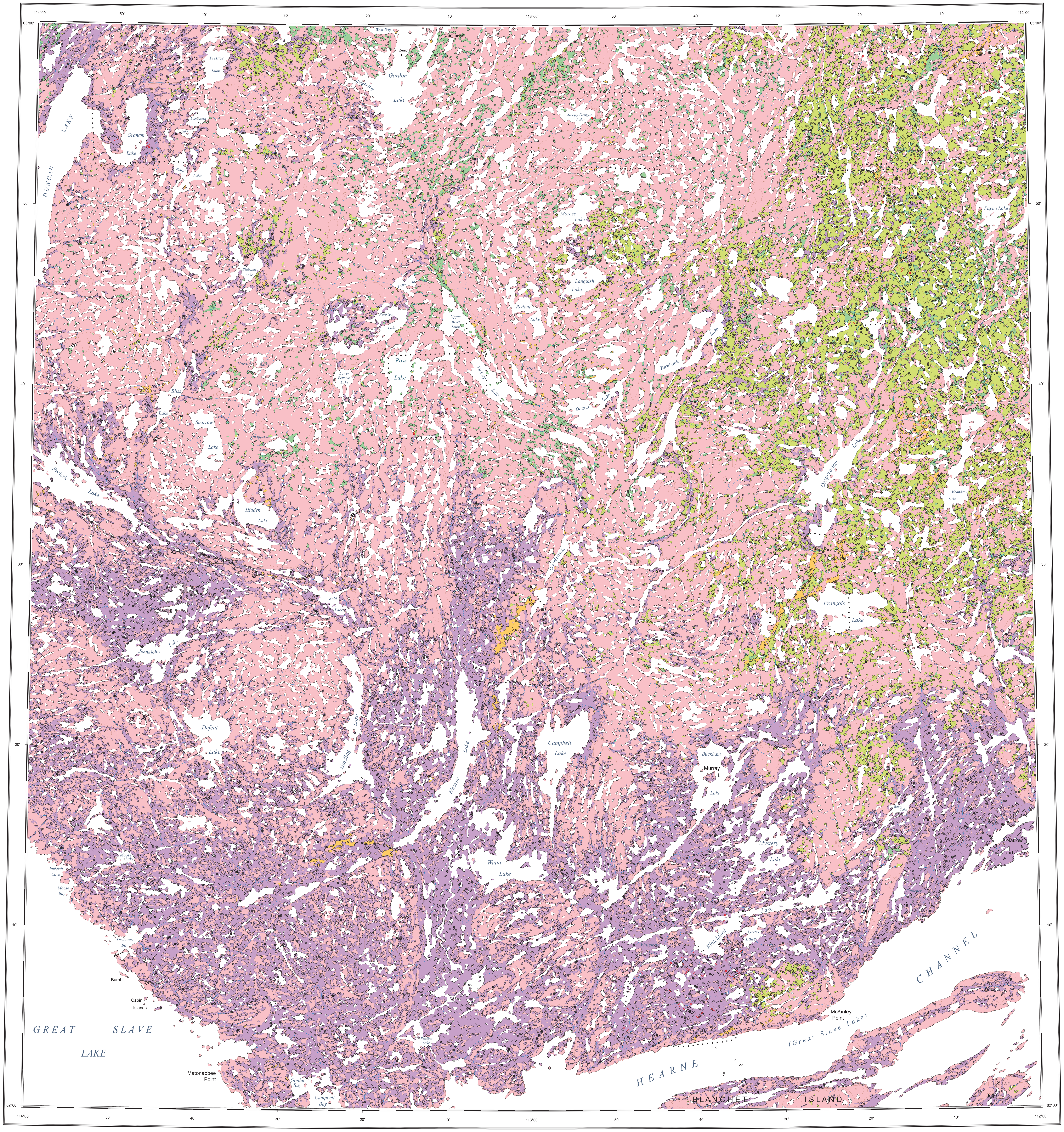


LEGEND

QUATERNARY

HOLOCENE

NONGLACIAL ENVIRONMENT

ORGANIC DEPOSITS: *Undifferentiated fen, bog and floating aquatic vegetation*

LACUSTRINE SEDIMENTS: *Undifferentiated, exposed sediment surrounding modern lakes, variable thickness*

PROGLACIAL AND GLACIAL ENVIRONMENT

GLACIOLACUSTRINE SEDIMENTS: *Undifferentiated silt and clay, may include small outcrops of till veneer, variable thickness*

GLACIOFLUVIAL SEDIMENTS *Undifferentiated sand and gravel to cobbles, forming esker ridges, terraces, outwash plains, may be reworked by wave action forming raised beaches, variable thickness*

TILL VENEER: *Poorly sorted silt to gravel diamicton, may be modified by glaciolacustrine and meltwater processes, may contain small bedrock outcrops and glaciolacustrine veneer, variable thickness but generally < 2 m*

TILL BLANKET: *Poorly sorted silt to gravel diamicton, variable thickness but generally > 2 m*

PRE-QUATERNARY

BEDROCK: *Undifferentiated, may be overlain by discontinuous cover of till veneer, glaciolacustrine veneer and isolated glaciofluvial patches*

Striation (ice flow direction known from Kerr 2006 and 2011)

Small outcrop

Station location (from Kerr 2006)

Limit of airphoto interpretation

The following symbols are derived from airphoto interpretation

Small outcrop

Kame

Geological boundary (confidence defined)

Beach ridge

Esker ridge (sense known)

Esker Ridge (sense unknown)

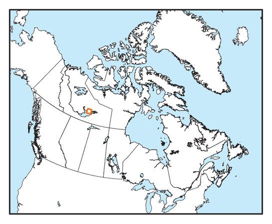
Fluted bedrock (sense known)

Fluted bedrock (sense unknown or unspecified)

Buried drumlinoid ridge or fluting

DESCRIPTIVE NOTES

This predictive surficial geology map is derived from integrating digital datasets of satellite imagery and interpreted airphotos. The limit of airphoto interpretation defines training areas where surficial geology map units and landforms have been identified, and used in the generation of the predictive map. Some of the additional geological features in these areas include small outcrops, kames, beach ridges and eskers. These features may also exist beyond the boundaries of the airphoto interpreted areas. Striations have been compiled from fieldwork in 2011 and Kerr (2006). Lakes may include hydrographic layers and mask areas (see Open File text).



Any revisions or additional geological information known to the user would be welcomed by the Geological Survey of Canada

Digital base from Geomatics Canada, modified by the Geological Survey of Canada

APPENDIX A, TO ACCOMPANY OPEN FILE 7233

PREDICTIVE SURFICIAL GEOLOGY

HEARNE LAKE

NORTHWEST TERRITORIES

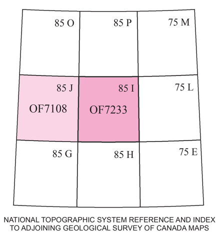
Scale 1:125 000/Échelle 1/125 000

kilometres 2.5 0 2.5 5 7.5 10 kilomètres

Universal Transverse Mercator Projection
North American Datum 1983

Projection transverse universelle de Mercator
Système de référence géodésique nord-américain, 1983

Mean magnetic declination 2013, 17°6'E, decreasing 26' annually
Readings vary from 16°17'E in the SE corner to 17°52'W in the NW corner of the map.



NATIONAL TOPOGRAPHIC SYSTEM REFERENCE AND INDEX TO ADJOINING GEOLOGICAL SURVEY OF CANADA MAPS

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