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GEM-2 Mackenzie Project

P.D. Morse, D.E. Kerr, S.A. Wolfe

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Abstract

The Geo-mapping for Energy and Minerals (GEM) program lays the foundation for sustainable economic development in the North, and the Mackenzie Corridor region of interest represents the largest unmapped (bedrock and surficial geology) area of Northwest Territories. The lack of geologic knowledge in this area is a significant detriment to the economic potential of the region. The Rae map (NTS 85-K) identifies surficial geology and associated landforms left by the retreat of the last glaciers which covered the area about 9500 years ago. This preliminary map of surficial geology is based on remote predictive mapping, airphoto interpretation and limited fieldwork. The goal is to develop a timely first-version map, validated in selected areas and reviewed by geological experts, which reasonably depicts the distribution of surficial sediments for northern industry exploration and development purposes.

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Foreword

The Geo-mapping for Energy and Minerals (GEM) program is laying the foundation for sustainable economic development in the North. The Program provides modern public geoscience that will set the stage for long-term decision making related to investment in responsible resource development. Geoscience knowledge produced by GEM supports evidence-based exploration for new energy and mineral resources and enables northern communities to make informed decisions about their land, economy and society. Building upon the success of its first five-years, GEM has been renewed until 2020 to continue producing new, publically available, regional-scale geoscience knowledge in Canada's North.

During the summer 2016, GEM program has successfully carried out 17 research activities that include geological, geochemical and geophysical surveying. These activities have been undertaken in collaboration with provincial and territorial governments, northerners and their institutions, academia and the private sector. GEM will continue to work with these key collaborators as the program advances.

Project Summary

The preliminary Rae map (NTS 85-K) identifies surficial geology left by the retreat of the last glaciers which covered the area about 9500 years ago. The surficial geology is based on remote predictive mapping, extensive airphoto interpretation and limited fieldwork. This work contributes to effective mineral exploration useful in drift prospecting for a variety of commodities including diamonds, precious and base metals, and supports informed decision making for resource development and land use. As part of the Surficial Geology Mapping of the Mackenzie Sedimentary Basin – Bear/Slave Province Boundary activity in the GEM Mackenzie Region Project, this work provides new geological knowledge and improves our understanding of the distribution, nature and glacial history of surficial geology.

Introduction

The Mackenzie Corridor region of interest (Figure 1) represents the largest unmapped (bedrock and surficial) area of Northwest Territories. Nearly one-half of surficial geology of the Northwest Territories remains unmapped, and the bulk of this resides within the Mackenzie Corridor. Given the high mineral potential and realized development within the Bear/Slave Geological Provinces, and the significant energy/mineral potential within the northern Shield to sedimentary basin transect, the lack of geologic knowledge across this boundary is a significant detriment to the economic potential of the region. One of the remaining unmapped areas is Rae River (NTS 85-K) (Figure 1).

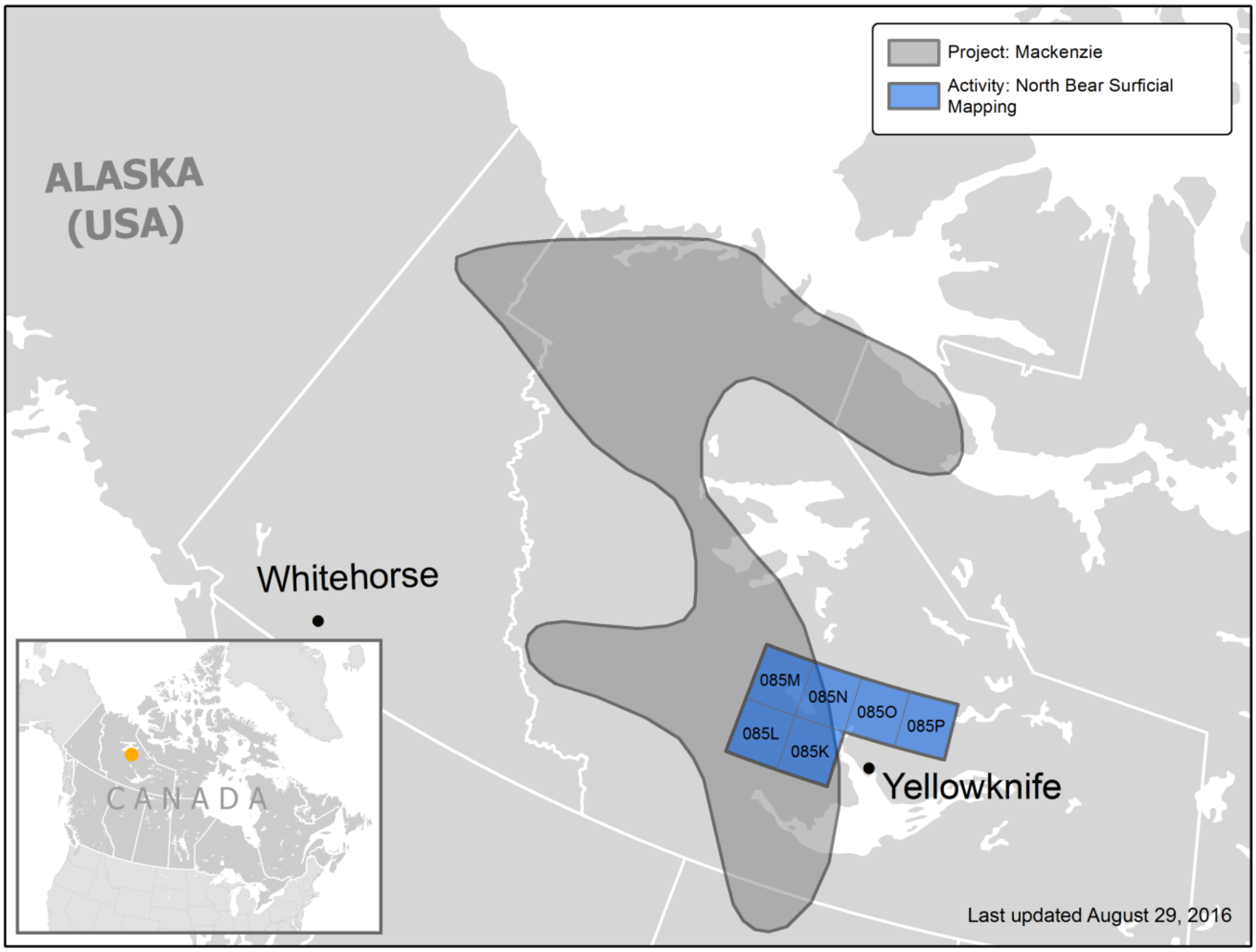

Figure 1. Location of mapping areas: NTS 85-K, 85-O (Morse et al., 2016), 85-N (Ednie et al., 2014), 85-L, and 85-M.

Goal & objective

This activity aims to provide a better understanding of the nature and distribution of surficial geology and glacial history of the southern Mackenzie Corridor. It fills in a major knowledge gap in the NWT, essential for the implementation of successful mineral and petroleum exploration surveys in this poorly-mapped, drift-covered region. Mapping the extent of glacial lake McConnell sediments in the central and southern regions is of particular aid to resource and infrastructure development potential of this region.

Scientific question addressed

The regional framework scientific question being addressed by this research activity is, how can improved surficial mapping facilitate exploration and support resource discovery in the Mackenzie Corridor region (Figure 1).

Methodology

The remote predictive mapping (RPM) methodology adopted for mapping NTS 85-K builds upon experience gained in previous surficial RPM activities in adjoining areas (Ednie et al., 2014; Olthof et al., 2014, Stevens et al., 2012, 2013, 2015), and was based on the availability of remote sensing data, digital elevation and fire history data, extensive aerial photo interpretation (Figure 2), and the authors' field experience of surficial materials and geology found in the region. Surficial materials were converted to surficial geology using expert knowledge and the Geological Survey of Canada's Surficial Data Model (Cocking et al., 2015). The classification approach involved the use of a decision-tree model calibrated on training classes mapped using air photographs. The resulting model was used to predict surficial geology by applying the training classes to satellite imagery and a digital elevation model (DEM) for the 85-K map area. Decision-tree methodology was chosen as the classification algorithm due to its ability to handle large training datasets irrespective of their statistical distributions. Cross validation generates error statistics on a holdout sample from a single trial, and boosting reduces model errors by weighting the incorrectly classified cases more heavily in the subsequent trial runs. This process is repeated for the specified number of trials using a different random holdout sample each time. The final map is generated using the majority prediction from all trials.

Datasets

Mapping was undertaken using multiple LANDSAT 7 imagery taken in 2001 (normalized bands 2,3,4,5, and 7) which was downloaded from Glovis (http://glovis.usgs.gov/). All scenes were pre-screened by Glovis so only minor cloud and cloud shadow were present. Mid-summer acquisition dates were chosen when vegetation is at peak greenness to facilitate normalizing radiometry among scenes and to ensure stable radiometric signatures representing each surficial class. Native projection was Universal Transverse Mercator (UTM) zone 12 with Datum WGS 84 for Glovis. All scenes were projected to the common UTM zone 12 and ellipsoid GRS 1980 to correspond to the mapsheet projection.

Scenes were radiometrically balanced using Thiel-Sen robust regression on each spectral band in adjacent overlap regions between scenes (Olthof et al., 2005). Scenes were mosaiced into the mapsheet extent that included extra data on all four sides. They were first mosaiced east to west and south to north and then again into separate channels in the opposite order to generate two separate mosaics with each one representing one of two overlap regions between scenes. The final mosaic was produced by selecting pixels in overlap regions based on the maximum Normalized Difference Vegetation Index (NDVI = (NIR-Red) / (NIR+Red)) that is used to preferentially select clear-sky pixels over cloud and cloud shadow.

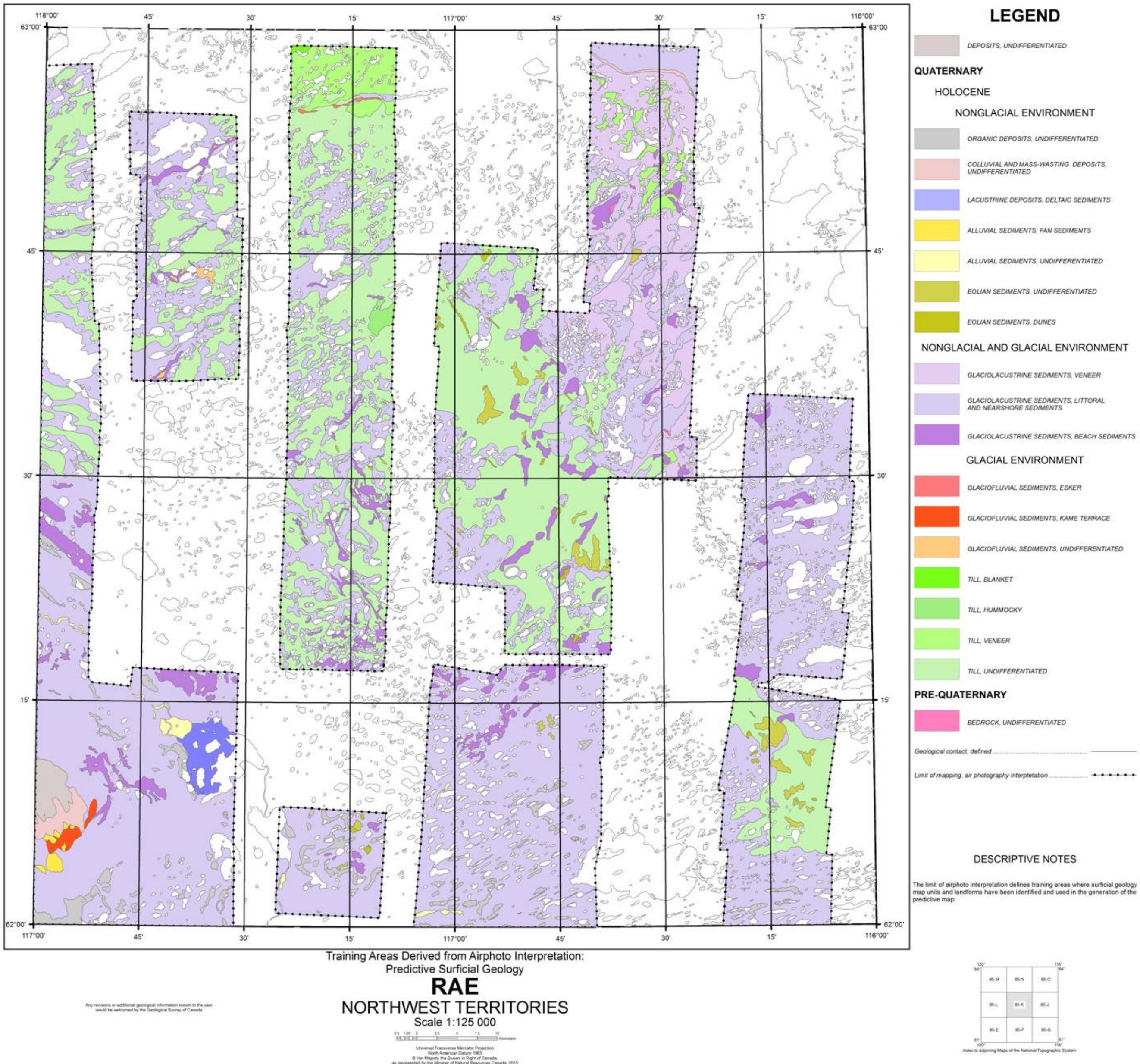

Figure 2. Surficial geology map units determined from expert aerial photography interpretation used to define training areas used in the generation of the remote predictive map.

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 include cloud shadows and some wetlands with water at the surface. The selected mask was then merged to water polygons from the NTDB (Geogratis (http://www.geogratis.gc.ca)) to complete the water mask layer.

Elevation data in the form of a digital elevation model (DEM) was downloaded from Geogratis (http://www.geogratis.gc.ca) as 1:50k NTS grids in lat/long projection with a resolution between 0.75 and 3 arc seconds that was set at 30 m when projected to UTM. Entropy of the elevation data was calculated using a 7x7 pixel moving window in order to provide local texture of the elevation values. The use of entropy data (surface roughness) has been shown to increase the transformed divergence values between surficial materials (Stevens et al. 2012; Ednie et al. 2014).

Fire history (Figure 3) was obtained from the Northwest Territories Centre for Geomatics (http://www.geomatics.gov.nt.ca). Polygons representing forest fires burn areas that preceded the Landsat acquisition dates were gridded at 30 m resolution. Fires dates ranged from 1965 to 2000. A total of 7 bands of data were used to produce the surficial geology map, including normalized bands 2-5+7, a 30 m digital elevation model, and digital elevation entropy.

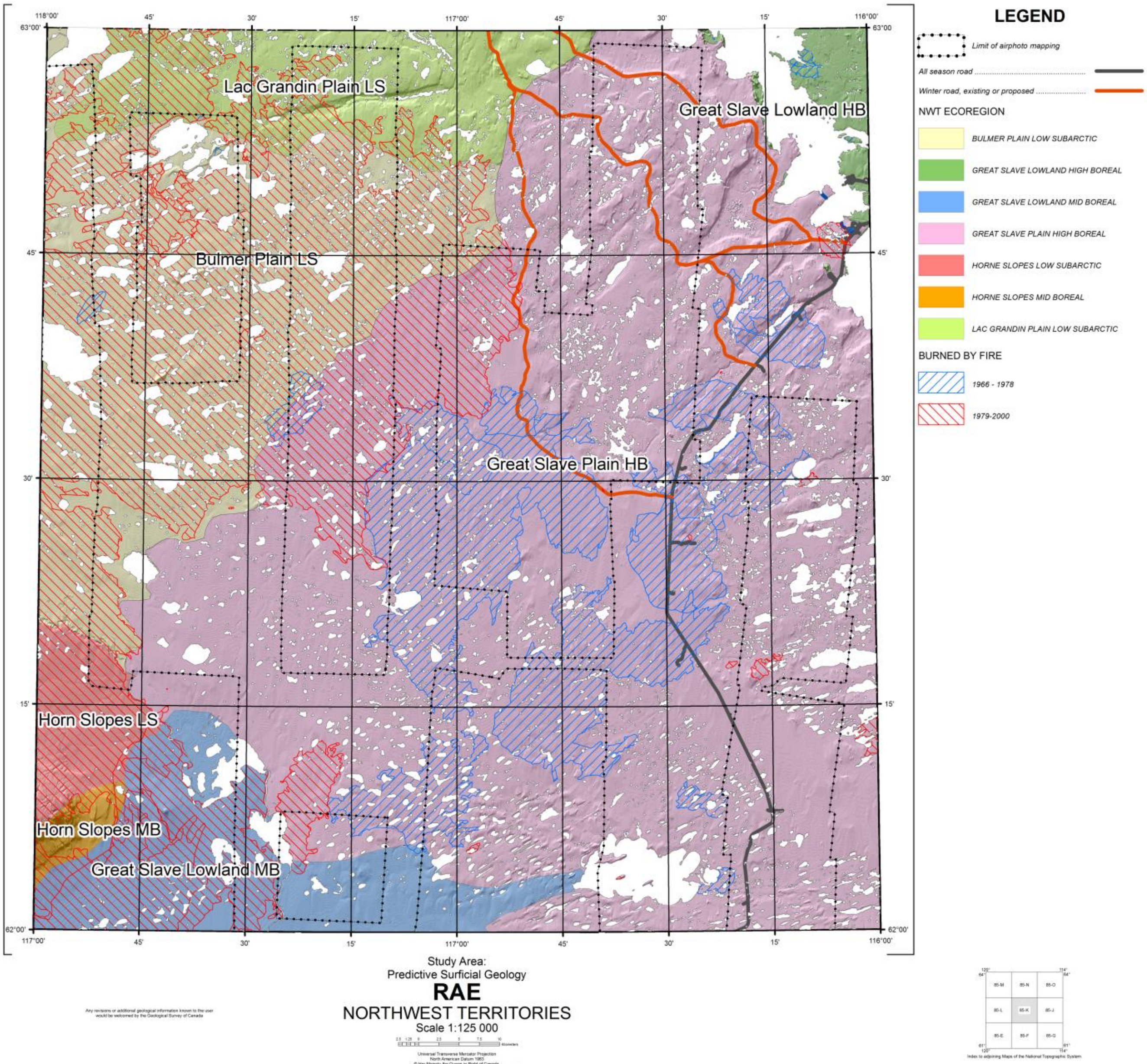

Figure 3. Study area showing the limit of air photography mapping used for training areas, areas burned by fire, and Northwest Territories ecoregions. Fire history and ecoregion data are available from the Northwest Territories Centre for Geomatics (http://www.geomatics.gov.nt.ca).

Training classes of surficial materials were established by performing traditional air photography interpretation over relatively extensive areas (Figure 2). The final training classes were based on the outcome of air photograph interpretation, legacy data, and expert knowledge based on field experience in the region. Field surveys of surficial geology were also conducted from helicopter in 2014. Information gained from this field work was used in the development of the training areas.

Results

The preliminary predictive surficial geology map produced for this report (Figure 4) is based on the Boost mode of the decision-tree methods in See5™. The boost trial incorporates information from the previous 10 trial runs in order to minimize classification errors. All of the trial runs were applied to normalized bands 2-5+7, a 30 m digital elevation model, and digital elevation entropy data. Each repetition was run with a random sample of 75% of the training data for model input while withholding 25% for validation. Nearly 32 000 cases (pixels) were used to calibrate the training classes in the decision-tree model (Table 1). Overall model error is shown in Table 2. The overall error of the surficial geology map using the Boost mode in the decision-tree model is 0.2% when compared to the training data. The boosted accuracy for the surficial geology map is 99.8%. Results from the model runs are presented in Table 3. Results from 100 cross-validations using 75% randomly sampled data for training and the remaining 25% for validation indicate and average overall accuracy of the training areas of over 97%.

The resolution of the Landsat data used in this study is not conducive to identifying the spatial pattern of eskers (GFr). Till blanket and hummocky till (Tb and Th) were not mapped separately and are included in Till (T). Lacustrine deltaic sediments, (Ld) were not discernable in the digital data, but lacustrine sediments, undifferentiated (L) was used to represent shallow lake shores and drained lake basins with marl deposits. Alluvial sediments, undifferentiated (A) were also not discernable. “Burned” classes were merged with the unburned “parent” classes. Glaciofluvial sediments, undifferentiated (GF) was not included in the aerial photography interpreted training data, but was interpreted from the field data and was included in the RPM map. Table 4 provides a description of the final surficial geology classes predicted for NTS 85-K map sheet, and a map of predictive surficial geology based on RPM is shown in Figure 4.

The results show that glaciolacustrine, littoral and nearshore sediments (GLn) predominates the land area throughout the map (27.7% of map area). Till (T) deposits become more prevalent in the northwest (19.1%). Glaciolacustrine veneer and beach deposits (GLv and GLr) make up another 27.6% of the area. Organic deposits (O) are locally common in the south and far northeast, where they have likely developed on GLn sediments. Till veneer (Tv) occurs to the north central portion of the map sheet. Eolian sediments (E) occur in the vicinity of beach deposits (GLr). Lacustrine sedimentsoccur at the margins of some shallow lakes and where such lakes have drained. Glacio-fluvial kame terraces (GFk), alluvial fans (Af), and colluvial deposits (C) all occur in the vicinity of the Horne Plateau to the far southwest of the map area, which is capped by undifferentiated sediments (U). Bedrock (R) is comparatively uncommon within this map sheet. Alluvial floodplain sediments (Ap) and lacustrine beach sediments (Lr) were not included in the RPM training dataset and are therefore not contained within the RPM map. Recognizing these limitations, a subsequent CGM iteration of the NTS 85-K surficial geology map will include more extensive aerial photography interpretation and an improved reconnaissance map.

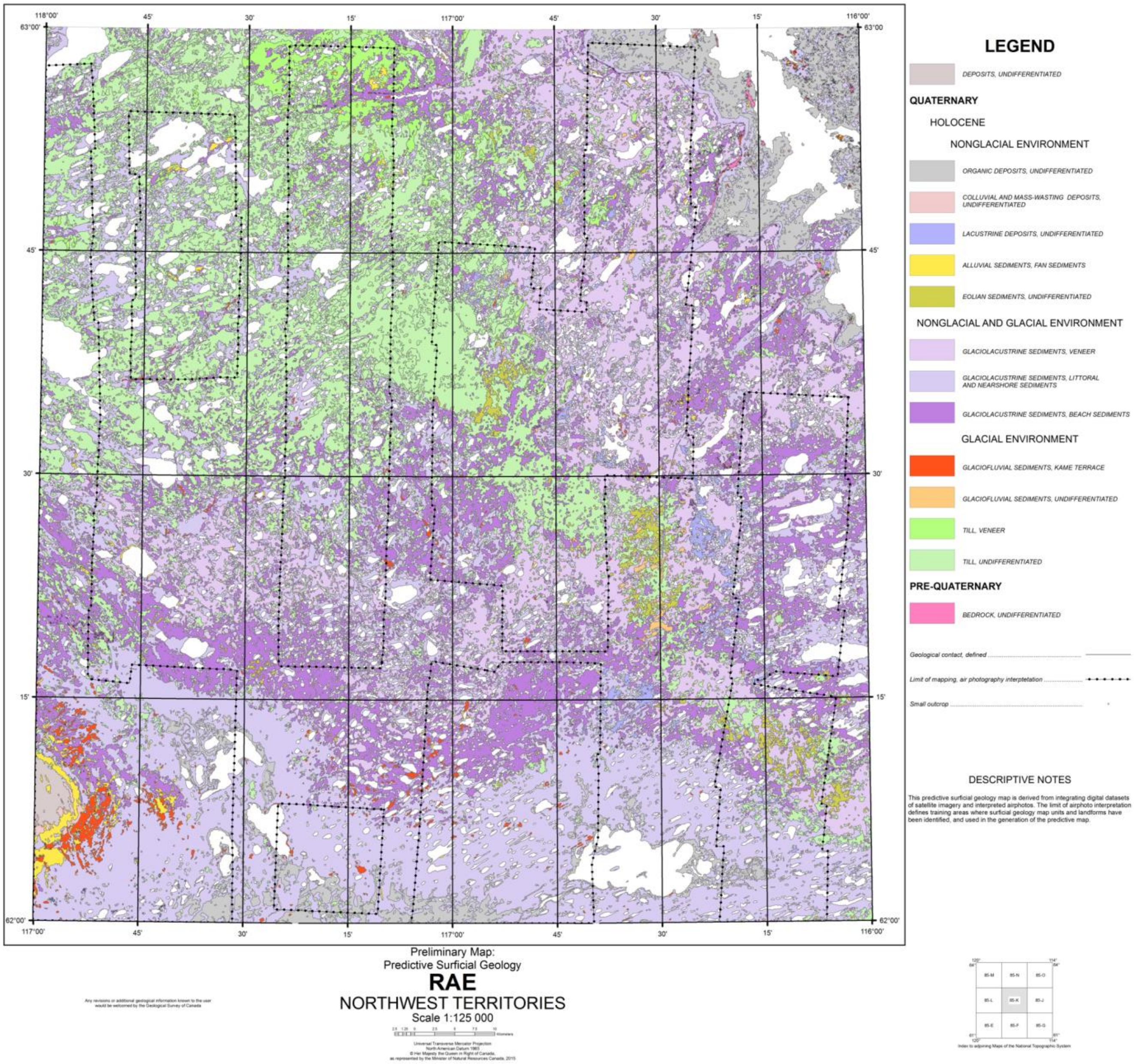

Figure 4. Preliminary results for the remote predictive surficial geology map for Rae NTS 85-K based on LANDSAT, elevation, and fire history data.

Table 1. Surficial geology classes used as training data for image classification for Rae map sheet, NTS 85-K. The GeoCode corresponds to the digital numbers for each class within the classified raster image.

GeoCode	Surficial material classes	Number of pixels
0	Till, undifferentiated (T)	4111
1	Glaciolacustrine sediments, veneer (GLv)	2148
2	Till veneer (Tv)	1033
3	Organic, undifferentiated (O)	2130
4	Water	N/A
5	Lacustrine sediments, undifferentiated (L)	2007
6	Glaciofluvial sediments, kame terrace (GFk)	914
7	Glaciolacustrine sediments, littoral and nearshore sediments (GLn)	7131
8	Till, undifferentiated, burned (TB)	3280
9	Alluvial sediments, fan sediments (Af)	1264
10	Deposits, undifferentiated (U)	2068
11	Eolian sediments, undifferentiated (E)	683
12	Glaciolacustrine sediments, littoral and nearshore sediments (GLr)	1776
13	Glaciofluvial sediments, undifferentiated (GF)	765
14	Glaciolacustrine sediments, littoral and nearshore sediments, burned (GLnB)	542
15	Bedrock, undifferentiated (R)	224
16	Colluvial and mass-wasting deposits, undifferentiated (C)	1764
17	Till veneer, burned (TvB)	153

Table 2. List of all trial runs for the decision-tree model along with errors in cell counts and percentage.

Trial #	Error Pixels	%
0	494	1.5
1	2244	7.0
2	1800	5.6
3	1745	5.5
4	1485	4.6
5	1445	4.5
6	1439	4.5
7	1728	5.6
8	2609	8.2
9	1419	4.4
Boost	77	0.2

Table 3. Confusion matrix evaluated on a random selection of 75% of the training data (23 983 cases) showing accuracy for predictive surficial geology classes (predicted class) compared against 25% of the training classes (actual class).

Reference Class	**Mapped Class**															
	T	GLv	Tv	O	L	GFk	GLn	TB	Af	U	E	GLr	GF	GLnB	R	C	TvB
T	3109	1					1	1			2	1					
GLv		1572					1					3					
Tv		1	771									2					
O				1637			6										
L					1494		1										
GFk						686											
GLn		1					5331					4					
TB	1							2481									3
Af									940							4	
U										1527							
E	2										523						
GLr	1	3	1				2				1	1299					
GF													551	11			
GLnB													7	374			
R															169		
C									1							1348	
TvB																	110

Table 4. RPM surficial geology units and areas mapped, including water, in NTS 85-K.

GeoCode	Surficial Geology Unit	Description of Surficial Geology Unit	Area (km^2)
0	T	Till: undifferentiated	2194.8
1	GLv	Glaciolacustrine sediments: veneer of silt and clay, may include small areas of till veneer, variable thickness	1613.5
2	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	178.3
3	O	Organic deposits: undifferentiated fen, bog and floating aquatic vegetation	712.8
(4)	(Water)	(Water)	1674.5
5	L	Lacustrine deposits: Undifferentiated deposits	78.9
6	GFk	Glaciofluvial sediments: sand and gravel to cobbles, forming kame terraces	72.8
7	GLn	Glaciolacustrine sediments: silts and clays, may overlay bedrock or till	3176.9
9	Af	Alluvial sediments: poorly sorted sediments, forming alluvial fans	72.1
10	U	Undifferentiated sediments	26.3
11	E	Eolian sediments: Undifferentiated sands, forming veneer or dunes	91.7
12	GLr	Glaciolacustrine sediments: sand and gravel to cobbles, forming raised beaches	1548.6
13	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	22.2
15	R	Bedrock: undifferentiated, may be overlain by discontinuous cover of till veneer, glaciolacustrine veneer and isolated glaciofluvial patches	8.5
16	C	Colluvial and mass-wasting deposits: undifferentiated poorly sorted sediments	7.0

Conclusions

Experience has shown that remote predictive mapping can be used for production of preliminary surficial materials and surficial geology maps in the north. For relatively geologically uncomplicated areas, surficial maps can be derived and published using training areas, expert knowledge and the robust classification method. The goal is to develop timely first-version maps, validated in selected areas and reviewed by geological experts, which reasonably depict the distribution of surficial sediments for northern industry exploration and development purposes.

Future work 2016-2017

Production of reconnaissance and predictive surficial geology maps at 1:125,000 scale for NTS 85-K in the Canadian Geoscience Map (CGM) format (in press).
Production of reconnaissance surficial geology maps at 1:125,000 scale for NTS 85-L and NTS 85-M in the Canadian Geoscience Map (CGM) format (both are in preparation).

Acknowledgments

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