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**Ontario Geological Survey
Open File Report 6321**

**Quaternary Geology of the
Lindsay and Peterborough
Areas, Southern Ontario**

2016





ONTARIO GEOLOGICAL SURVEY

Open File Report 6321

Quaternary Geology of the Lindsay and Peterborough Areas, Southern Ontario

by

A.S. Marich

2016



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Miscellaneous Release—Data 333

Results of Till Sample Analyses of the Lindsay and Peterborough Areas, Southern Ontario

by A.S. Marich

This publication can be downloaded from

http://www.geologyontario.mndm.gov.on.ca/mndmaccess/mndm_dir.asp?type=pub&id=MRD333

This digital data release contains grain size, pebble count and carbonate analyses of till samples (Newmarket and Dummer tills) collected in the Lindsay and Peterborough areas, southern Ontario. These data are being released in conjunction with Open File 6321 and Preliminary maps P.3798 and P.3799. This release consists of 3 Microsoft® Excel® (.xls) workbooks.

Abstract

This report discusses the results of a 2 year mapping program aimed at updating and refining the Quaternary geology maps of the Lindsay and Peterborough areas in southern Ontario. Previous mapping of the study area was published by Gravenor in 1957 at a scale of 1:126 720. A more detailed study of the surficial sediments in this area is required for land use planning, aggregate resource mapping and other geoscience-related studies. Two 1:50 000 scale Quaternary geology maps were completed during this program and are discussed in the report. The report includes a descriptive summary of the surficial sedimentary units observed in the field, as well as the associated landforms and their proposed genesis. In addition, a short summary of the economic applications of the various surficial and bedrock units is included. A brief outline of interpreted glacial events involved in the development of the landscape is provided at the end of this report.

Quaternary Geology of the Lindsay and Peterborough Areas, Southern Ontario.

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**Ontario Geological Survey
Open File Report 6321
2016**

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Introduction

This report summarizes the results of Quaternary geology mapping conducted during the summers of 2013 and 2014 in the Lindsay and Peterborough regions of southern Ontario. Previous work by Gravenor (1957) was completed at a scale of 1:126 720. Higher resolution mapping is required in this area to provide baseline geological information for land-use planning, groundwater studies and other geoscience related studies. The aim of the current study is to update the Quaternary geology mapping by identifying and delineating the various surficial geological units using high resolution imagery and elevation models and reconstructing the Quaternary history of the region. Two 1:50 000 scale Quaternary geology maps, of each of the Lindsay and Peterborough areas and covering the National Topographic System (NTS) map sheets 31 D/7 and 31 D/8, respectively, were produced as part of this study (*see* Preliminary maps P.3798 and P.3799, respectively, *in* backpocket; Marich 2016a-b).

The study area comprises approximately 2200 km² and is located northeast of the City of Toronto within the Kawartha Lakes Region of southern Ontario. Access to the study area was via highways 7, 35 and 28 as well as county and municipal roads. Communities in the study area include Manilla, Oakwood, Omemee, Lakefield, Dummer, as well as the cities of Lindsay and Peterborough. The population of Lindsay is approximately 20 000 people (2011 census) and the population of Peterborough is 116 000 (2006 census) (<http://www12.statcan.gc.ca> accessed August 10, 2015).

Land use in the area is primarily agricultural, with several small aggregate operations, and more recently solar power generation facilities. As part of the Kawartha Lakes region, the Lindsay and Peterborough areas are prime destinations for cottages, camping, fishing, and hiking in the summer, and snowmobiling and snowshoeing in the winter. Four conservation areas service the study area. The Lake Simcoe Conservation Area (CA) to the west, the Kawartha Region CA in the Lindsay area, the Ontonabee Region CA in the Peterborough area and the Lower Trent CA south of Rice Lake.

Methodology

FIELDWORK

Fieldwork was conducted during the summers of 2013 and 2014. Observations were made at more than 2500 sites in various types of sediment throughout the study area via auger or soil probe (Figure 1, also in back pocket). Observations were also made at accessible man-made exposures along roadsides as well as in operating and abandoned gravel pits. In addition, observations of freshly tilled fields containing stones and boulders, indicating the likely presence of till, were made early in the field season prior to crop growth. A total of 91 C- horizon till samples were collected and submitted to the Ontario Geological Survey's Geoscience Laboratories in Sudbury for analysis. These samples provide additional data to help determine whether or not the till units may be differentiated geochemically. Pebble counts for lithologic determinations were also undertaken on select samples. Results of the grain size, carbonate analyses, as well as pebble counts are contained in Appendixes 1 to 3.

The Quaternary geology maps portray the distribution of sediments occurring at a metre depth throughout the study area.

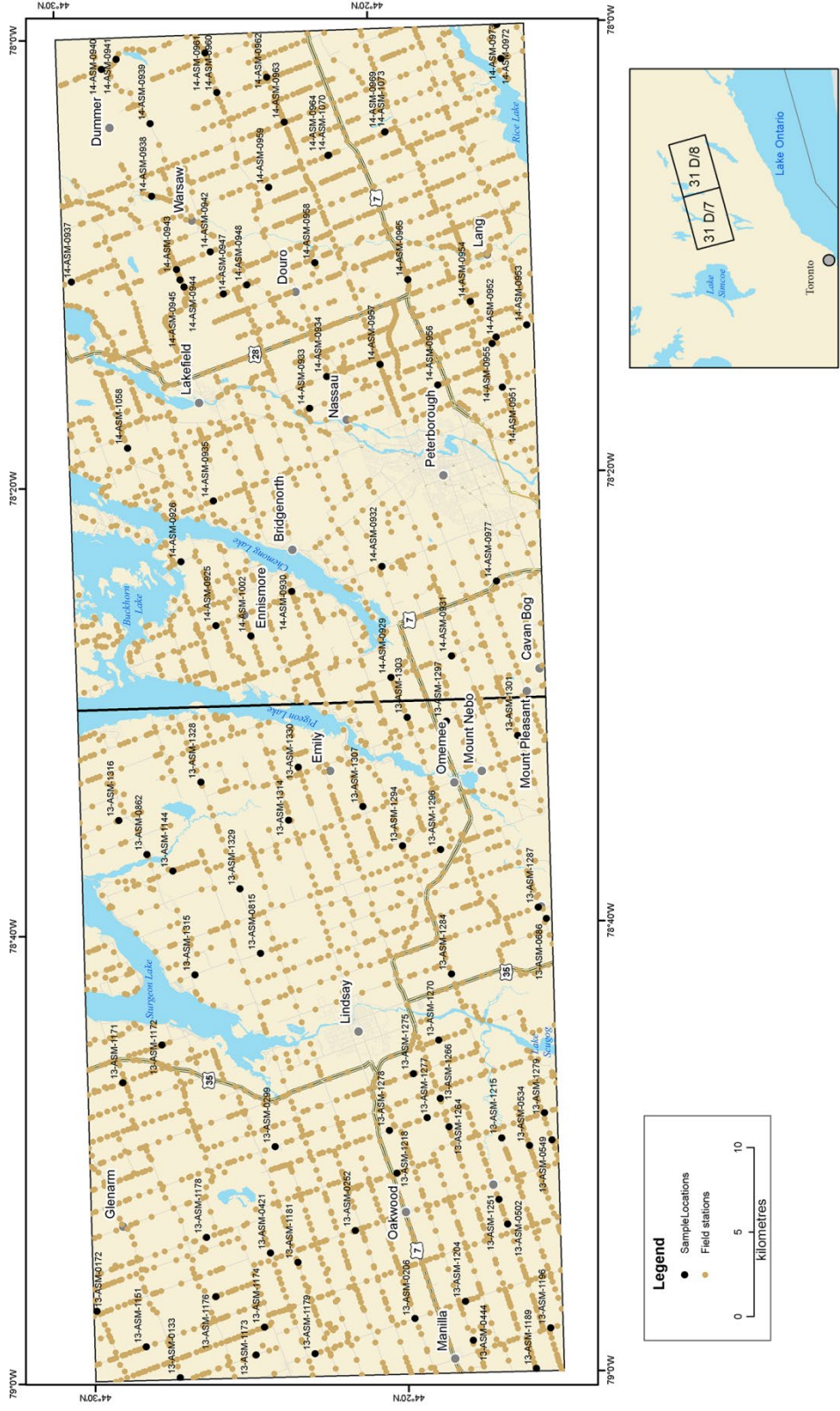


Figure 1. Location of field observations and sampling conducted during the summers of 2013 and 2014, also in back pocket.

INTERPRETATION OF REMOTELY SENSED DATA

The identification of field sites and the interpretation of the aerial extent of the various sedimentary deposits were aided by orthorectified aerial photographs, a 5 m resolution digital elevation model (DEM) and derived hillshaded relief model (Ontario Ministry of Natural Resources and Forestry 2014). Field data and additional baseline data were used to further define the location and extent of surficial units.

Geological Setting

BEDROCK GEOLOGY

The bedrock geology of the Lindsay and Peterborough areas consists of Ordovician limestone and shale of the Gull River, Bobcaygeon, Verulam and Lindsay formations (Figure 2). The unconformable contact between Precambrian granites of the Central Metasedimentary Belt (Grenville Province) and the Bobcaygeon Formation was observed within the north-central portion of the Peterborough NTS area east of Katchewanooka Lake (Photo 1). This was the only observed outcrop of Precambrian bedrock within the study area. Precambrian lithologies north and west of the study area are dominated by the gneisses of the Central Gneiss Belt (Easton 1992) while further to the east lies the Frontenac Terrain which is characterized by a sequence of marbles, quartzite, and quartzofeldspathic gneisses and a lack of volcanic rocks. Marbles observed in till samples may be used as indicators of an ice mass sourced to the east.



Photo 1. Unconformable contact between Precambrian granites of the Central Metasedimentary Belt (Grenville Province) (lower half of the photograph) and overlying limestone of the Ordovician, Bobcaygeon Formation (upper half of the photograph). The pick axe, shown for scale, is approximately 1 m long.

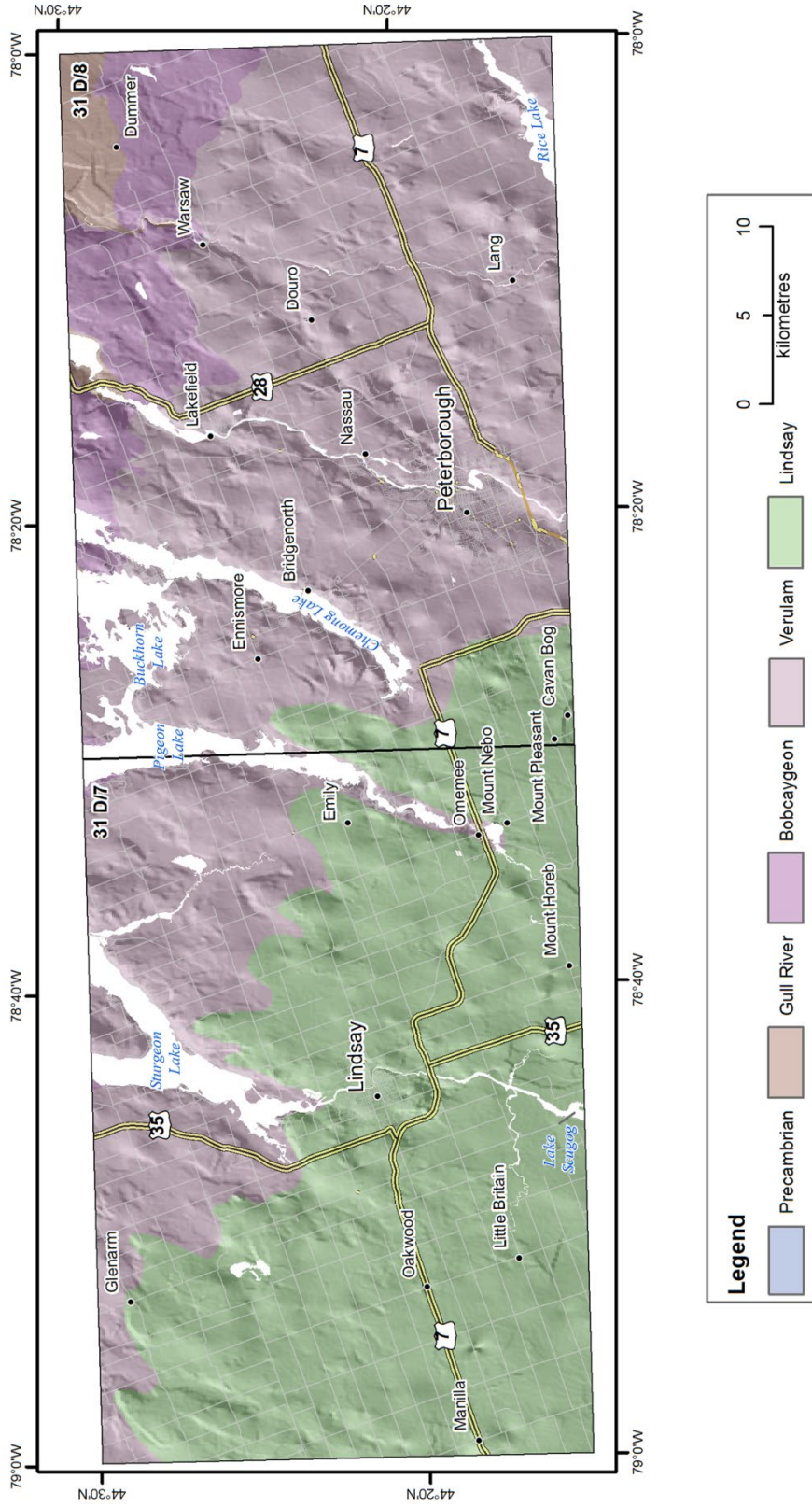


Figure 2. Bedrock geology of the Lindsay and Peterborough areas (modified from Armstrong and Carter 2010) overlain on a shaded-relief image of the interpolated bedrock surface (modified from Gao et al. 2006).

The Paleozoic sequence strikes east-southeast and dips gently southward toward Lake Ontario. Its upper surface is irregular, with gentle undulations punctuated by northeast-southwest-oriented valleys occupied by Sturgeon, Pigeon, Chemong, Katchewanooka and Clear lakes (Gao et al. 2006). The bedrock formations are described, from oldest to youngest, in the following section.

The Gull River Formation occupies a small portion of the northeast corner of the Peterborough NTS map sheet (*see* Figure 2). It consists of light grey to brown, variably fossiliferous, very fine-grained limestone with argillaceous to silty dolostone beds more prevalent toward the base of the formation.

The Bobcaygeon Formation is similarly restricted to the northeast and northern portions of the Peterborough NTS map sheet (*see* Figure 2). It is a light grey-brown to blue-grey to grey-brown, fine- to coarse-textured fossiliferous limestone. Thin shale interbeds and partings increase in abundance upward through the formation; crinoidal grainstones and nodular texture are more common in the lower sequence. Several outcrops of this formation were identified within the study area.

The Verulam Formation occupies the central part of the Peterborough NTS map sheet as well as the northern part of the Lindsay NTS map sheet (*see* Figure 2). It consists of grey, interbedded, bioclastic to very fine-grained limestone and grey-green calcareous shale. The formation crops out in multiple places across the study area.

The Lindsay Formation occupies the southern two-thirds of the Lindsay NTS map sheet and a small portion of the southwest corner of the Peterborough sheet (*see* Figure 2). It is a fine- to coarse-grained, fossiliferous and argillaceous limestone that is commonly nodular. Several outcrops were identified along the formation's northern boundary.

REGIONAL PHYSIOGRAPHY

Chapman and Putnam (1984) recognized 4 physiographic regions in the study area. They include the Carden Plain, Schomberg Clay Plains, Peterborough Drumlin Field and the Dummer Moraine (Figure 3).

The Carden Plain occupies a small portion of the northwest corner of the Lindsay map sheet. The physiographic region is characterized as a limestone plain with a thin drift veneer of either glaciofluvial sediments or till.

The Schomberg Clay Plain is located in the south-central portion of the Lindsay map sheet and consists of a low- to moderate-relief terrain with variable thicknesses of bedded glaciolacustrine clay and silt (Chapman and Putnam 1984). The Schomberg Clay plain contains drumlins as well as sections of hummocky topography. Larger drumlins protrude through the surrounding flat-lying glaciolacustrine sediments whereas smaller drumlins are almost completely buried by these deposits. The height of the drumlin ridges extend above the clay plain and can range from a couple metres to approximately 15 m.

The Peterborough Drumlin Field dominates the study area. The drumlin field comprises drumlins of varying morphologies, including those that are very well developed to drumlinoid hills and surface flutings. The drumlin field is described in greater detail in the following section.

The Dummer Moraine physiographic region occupies the northeast corner of the Peterborough map sheet. The moraines are composed of Dummer Till which is characterized by angular fragments and large boulders of limestone with subordinate Precambrian lithologies. The surface topography is highly irregular, hummocky in places, with the occasional low-relief linear moraines (*see* Figure 3).

Figure 4, in the back pocket of this report, is a shaded relief image of the study area showing the morphology of the landscape. The various landforms described above and in preceding sections of this report can be readily recognized.

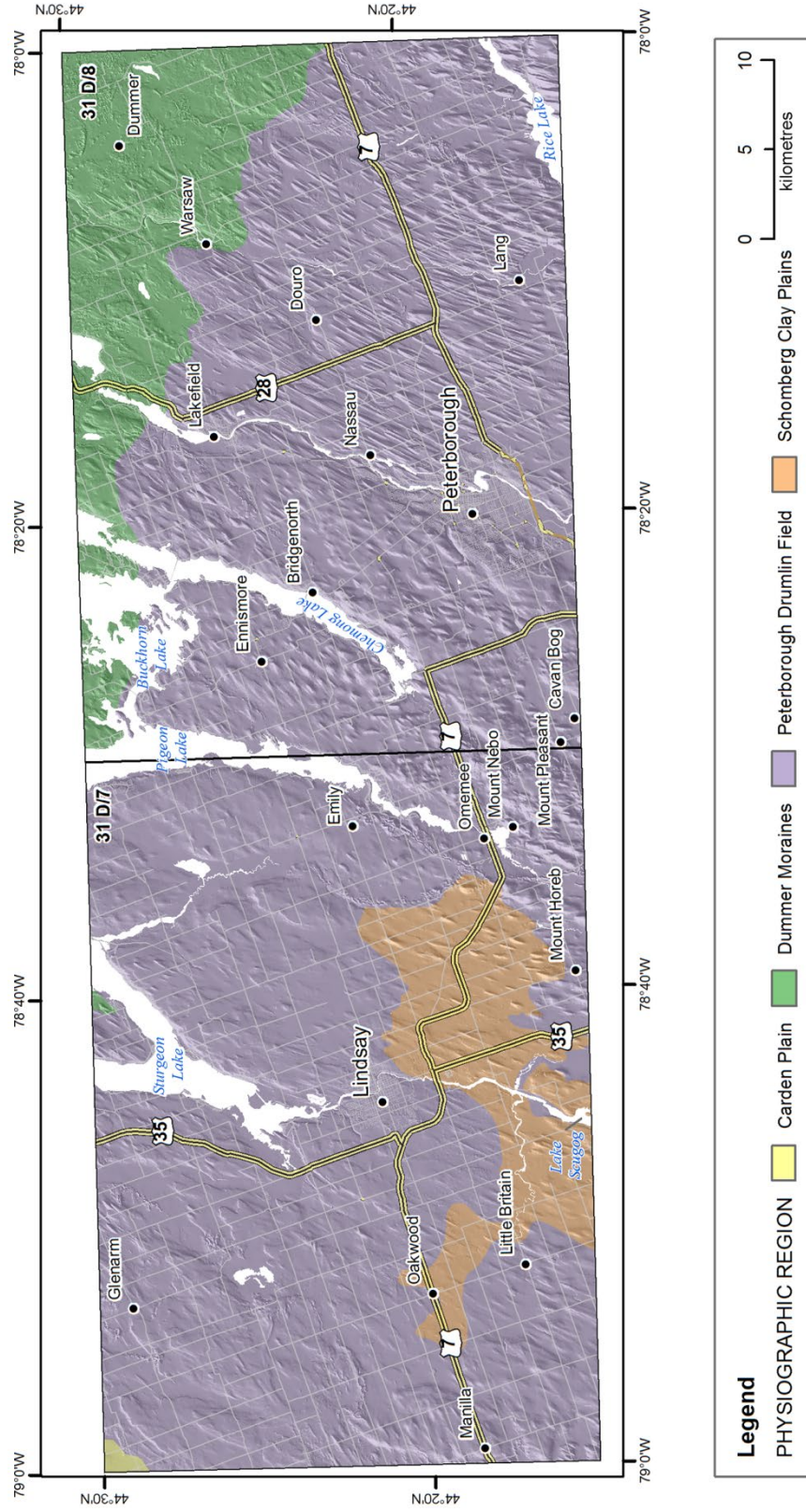


Figure 3. Physiographic regions of the Lindsay and Peterborough areas, *modified from* Chapman and Putnam 1984.

QUATERNARY GEOLOGY

The landscape of the Lindsay and Peterborough map areas was shaped during the last glaciation beginning approximately 20 000 to 25 000 years ago. The landscape was shaped by glacial and deglacial processes. A range of glacial landforms and associated sedimentary deposits have been identified in the study area (*see* maps P.3798 and P.3799, back pocket). Glacial ice (part of the Simcoe Lobe of the Laurentide Ice Sheet (LIS)), originating from the north to northeast, advanced southward across the Lake Ontario basin and extended into the northern United States. The landforms observed in the study area were largely produced subsequent to this advance during ice retreat. No evidence of pre-Late Wisconsinan sediments was observed in this study area, although additional data pertaining to the deep subsurface will determine whether or not older sediments do exist. Past studies have not observed the presence of sediments older than the Newmarket Till in this area. As the Simcoe Lobe retreated northwards and the Ontario Lobe retreated south and eastwards, an interlobate area developed in which the Oak Ridges Moraine formed, as either an ice-contact interlobate feature (Barnett et al. 1998) or subglacially as a massive esker (Sharpe et al. 2013). The final stages of deglaciation saw the development of the Schomberg Ponds, a series of ice- marginal lakes bounded to the south by the Oak Ridges Moraine. The Schomberg Ponds developed as the retreating ice mass stagnated in place (Gravenor 1957). Recessional moraines as well as hummocky topography are also suggestive of ice stagnation. A more thorough discussion of the glacial history of the area is contained in the final section of this report.

Sediment thickness in the study area varies from slightly less than 1 m in the north to approximately 120 m in the south-central and southeast corners of the study area (Gao et al. 2006). Drift is also thin near the communities of Lang and Warsaw (east and northeast of Peterborough, respectively) where bedrock is exposed at several locations (*see* Figure 5).

Although the bedrock surface is commonly highly weathered and fractured, a small number of glacial striae were observed in the northern part of the Lindsay NTS area. Striae measurements captured in this study indicate ice flow to the south and southwest (*see* Figure 2).

The bedrock surface topography is highly irregular, with glacially-sculpted hills and irregular depressions. The drumlin-like ridges are oriented northeast-southwest, are most easily observed in the northern half of the Lindsay NTS area, and are oriented similarly to the till drumlins observed at surface (*see* Figure 5). The bedrock surface slopes downward from northwest to southeast by approximately 200 m. Incised troughs which currently contain the Kawartha Lakes are easily recognized on the bedrock surface, especially that of Sturgeon and Pigeon lake (*see* Figure 5).

Bedrock Escarpments

North-facing bedrock escarpments up to 15 m high occur within the northern half of the Lindsay NTS map sheet within the Verulam and Lindsay formations (Figure 6).

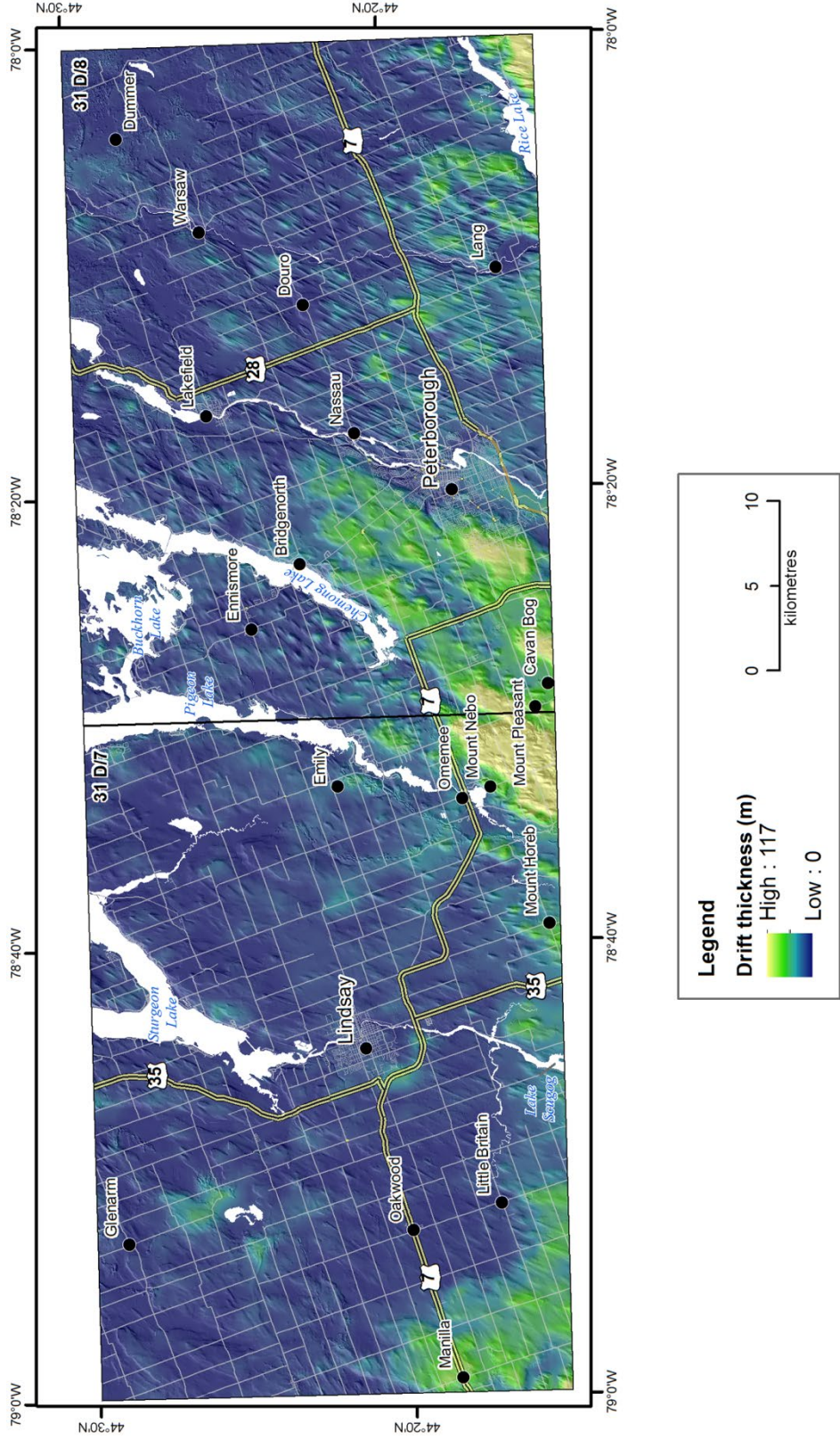


Figure 5. Hillshaded DEM showing drift thickness of the Lindsay and Peterborough areas (after Gao et al. 2006).

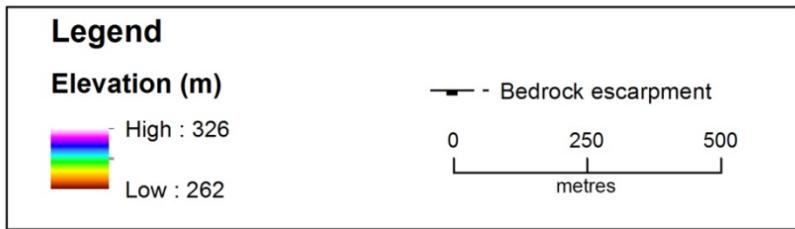
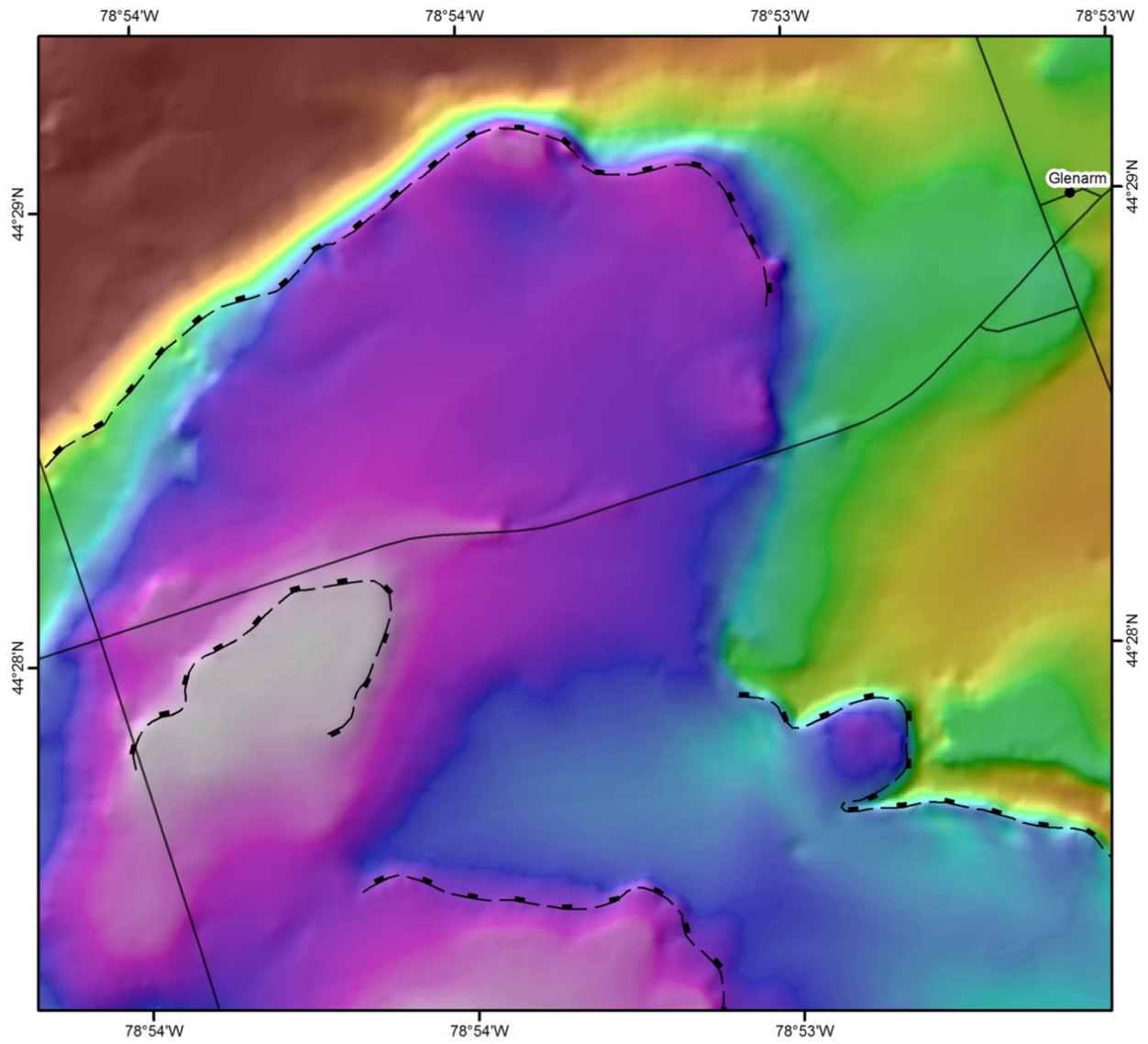


Figure 6. Hillshaded DEM showing several bedrock escarpments.

Bedrock-Drift Complexes

Areas of thin drift over bedrock and exposed bedrock occur primarily in the northern portions of the Lindsay NTS map sheet (*see* map P.3798, back pocket). Thin drift also occurs along modern river valleys at Warsaw and Lang in the Peterborough NTS map sheet (*see* map P.3799, back pocket). The thin drift is most commonly till although glaciofluvial sediments occur on occasion near bedrock escarpments. Limestone boulders commonly litter the surface in areas of thin till. These thin drift-bedrock complexes are likely the result of enhanced glacial erosion with minimal deposition.

SEDIMENTARY DEPOSITS, ASSOCIATED LANDFORMS, AND GENESIS

Till and Associated Landforms

Till is the most dominant sediment type in the study area and 2 distinct till units have been identified. Newmarket Till is the most widespread till deposit occupying two-thirds of the study area. Dummer Till is confined to the northeast corner of the Peterborough NTS area (*see* maps P.3798 and P.3799, back pocket).

Newmarket Till

Newmarket Till is a massive, silty sand diamicton containing an estimated 10 to 15% very coarse sand to pebble gravel (*see* Photo 2). Large boulders, up to 5 m in diameter, have also been observed. Local limestone lithologies dominate the clast component making up on average 98% of the sample, although the occasional Precambrian-derived granite and diorite types are also noted (Table 1, Appendix 3). Clasts within the till are commonly subangular to rounded and are bulleted, faceted, and occasionally striated suggesting subglacial transport.

The matrix of Newmarket Till (82 samples) averages 55% sand, 38% silt and 7% clay in composition (*see* Appendix 1). Figure 7 illustrates the grain size distribution of sand, silt, and clay for Newmarket Till on a ternary diagram.

Newmarket Till occurs in broad, flat to undulating ground moraine, drumlins, hummocks as well as in small morainic ridges. Till thickness is variable, and according to water well records, can exceed 40 m in places. Thin till (<1 m) occurs in the northern part of the Lindsay NTS area. Here the land surface is flat, reflecting the underlying bedrock topography.

This till is interpreted to be subglacially deposited and is extremely compact at depth, especially in exposures through drumlins, and exhibits mild to well-developed fissility. Carbonate content values from till sample analyses show approximately 47% total carbonate, owing to the dominance of Paleozoic limestone and dolostone formations in the area (Table 2).

Newmarket Till was commonly the only sediment type observed in road cuts or in augered holes though it is possible that sand and gravel units interbedded with the till exist at depth. This has been observed in previous studies (Gravenor 1957).



Photo 2. Road cut exposure through Newmarket Till.

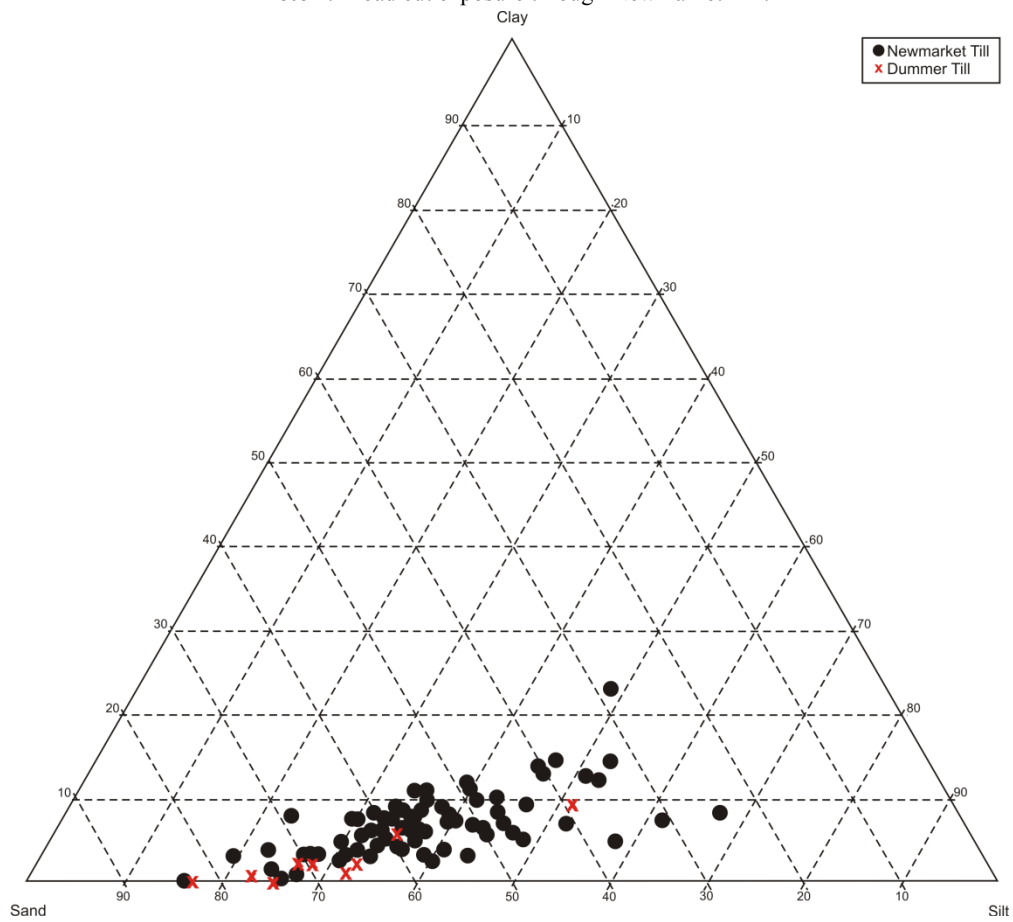


Figure 7. Ternary diagram of sand, silt and clay content of Newmarket and Dummer till samples (*see Appendix 1*).

Table 1. Average content of various lithologies in the pebble fraction of the Dummer and Newmarket tills (Marich 2016c).

	% limestone	% Granite	% Gneiss	% Diorite	% Sandstone	% Quartz	% gabbro	% Other
Dummer Till (n=9)	98.01	1.36	0.00	0.23	0.00	0.00	0.00	0.00
Newmarket Till (n=68)	96.39	3.44	0.05	0.68	0.59	0.04	0.08	0.14

Table 2. Average carbonate content and calcite:dolomite ratios for the Newmarket and Dummer till matrices (Marich 2016c).

Sediment Type	% Calcite	% Dolomite	% Total Carbonate	calcite:dolomite
Newmarket Till (n=82)	44.79	3.00	47.79	34.69
Dummer Till (n=9)	48.70	1.44	50.13	100.81

Dummer Till

Dummer Till is a stony, silty sand diamicton containing an estimated 30 to 40% very coarse sand to cobble gravel and boulder gravel (Photo 3). Clasts within this till are predominantly limestone with occasional to rare Precambrian clasts. The clasts are commonly subangular to angular. In some cases, where the till was observed directly overlying bedrock, it was difficult to differentiate between the till and the underlying highly weathered bedrock surface that was fractured and crushed by subglacial processes. Grain size analyses of 9 samples of Dummer Till matrix returned an average grain size distribution of 67% sand, 30% silt and 3% clay (*see* Appendix 1).

The Dummer Till is most commonly found in irregular hummocks about a metre to 5 m in height in the northeast corner of the study area near the community of Dummer (*see* map P.3799, back pocket). Linear ridges, oriented northwest-southeast, also identified within the area of Dummer Till, may be recessional or terminal moraines. Large areas of thin drift with angular boulders at surface were also observed throughout the study area. Mihychuk (1984) interpreted these as a boulder lag resulting from meltwater washing of the matrix from Dummer Till during deglaciation.

Dummer Till is locally derived, and was likely deposited close to where the sediment became entrained in the ice. The high percentage of clasts of local derivation and their angularity suggest a short transport distance. The hummocks within which the till is found also suggests a stagnating ice mass was involved in deposition of the Dummer Till. There is no preferential alignment of clasts within the Dummer Till (this study, Mihychuk 1984). Small localized deposits of glaciofluvial ice-contact sediment have also been observed in areas of Dummer Till.

Gravenor (1957) suggested that the Dummer Moraine, which is approximately 180 km long and up to 24 km wide (Gravenor 1957; Mihychuk 1984), is an ice-push moraine developed during ice recession. More recently Mihychuk (1984) described the Dummer Moraine as the result of compressive southward flow into north-facing Paleozoic bedrock escarpments, plucking of the bedrock surface causing debris saturation of the ice, followed by mass down wasting and melt out. Terasmae (1980) also interpreted the Dummer Moraine as a stagnant ice disintegration feature.

Differentiating between the Dummer and Newmarket tills using grain size, carbonate analyses of the matrix, and pebble lithologies is difficult. The 2 tills contain similar amounts of sand/silt/clay and carbonate (*see* Figure 7), while the Newmarket Till contains slightly more Precambrian-derived clasts than the Dummer Till, but this was not diagnostic. The 2 till types are easily differentiated where they occur together. The Dummer Till can be recognized by its extreme clast content (mostly angular pebbles

to large boulders), in comparison to the Newmarket Till, which has few clasts and these clasts are commonly subangular to rounded. Figure 7 shows that the grain size of the 2 tills are very similar and both are characterized by a grain size envelope where sand and silt content is high.

Road cuts through several drumlins in the southern portion of the Dummer Moraine showed a unit of poorly consolidated, fine-textured diamicton with notably fewer limestone fragments than expected for Dummer Till underlying a typical Dummer Till bed. The contact between the 2 units is indiscernible and the lower unit may represent a transition into Newmarket Till. All of the drumlins observed within the area dominated by Dummer Till appear to be composed of Newmarket Till.

Drumlins

The Peterborough Drumlin Field is a spectacular example of a drumlin field, containing drumlins of various morphologies and orientations. The drumlin field covers an area approximately 5000 km² (Gravenor 1957; Maclachlan 2011) and is bound to the north by the Dummer Moraine. It extends south of the Oak Ridges Moraine into the Lake Ontario basin, west to Lake Simcoe and east to Hastings County (Chapman and Putnam 1984). More than 3000 well-developed drumlin ridges can be identified within the field (Chapman and Putnam 1984; Boyce and Eyles 1991; Maclachlan 2011) (*see* example Photo 4). Drumlins can range from a few metres to more than 60 m in height, a few metres to half a kilometre wide and can reach up to greater than 5 km in length (Gravenor 1957; Boyce and Eyles 1991; this study). Drumlin length decreases from north to south, and in the southern areas, the drumlins are more ovoid in shape (Boyce and Eyles 1991).

In the current study area, drumlins range in length from approximately 45 m to greater than 5 km, and heights are highly variable, from less than 5 m to greater than 35 m above the surrounding landscape. The higher relief drumlins commonly occur towards the north and near the City of Peterborough, while low-relief drumlins occur within the areas of Schomberg Ponds where they are partially buried by glaciolacustrine sediments (*see* Figure 4, back pocket).

The drumlins are composed primarily of Newmarket Till, but Gravenor (1957) and others (Boyce and Eyles 1991; Shaw and Sharpe 1987) also observed some sorted material as well as bedrock cores. Gravenor (1957) observed stratified sands and gravels which he suggested were a result of the reworking of sediments previously deposited as an interlobate moraine. This suggests the hypothesis that drumlins were formed by advancing ice eroding previously deposited sediments. Similarly, Boyce and Eyles (1991) indicate that the drumlins are composed of deformation till which was derived from the deformation of material at the glacier bed and enhanced erosion of pre-existing sediments from swales. Gravenor (1957) also noted drumlins composed of bedrock in the northernmost portion of the Peterborough Drumlin Field in Victoria County.

Shaw and Sharpe (1987) observed crescentic scour marks around the stoss sides of drumlin, which they suggest is a common observation throughout the drumlin field. Using this observation and the presence of sorted sands and gravels within drumlins, they hypothesized that the drumlin field is a result of sediment being deposited in cavities eroded into the underside of a glacier by a catastrophic meltwater flood.

Neither rock cored drumlins nor stratified sands and gravels were observed in cuts through drumlins in the current study. In addition, the scour marks at the up-ice end of drumlins were not prevalent within the study area. The current study area lies in a small portion of the Peterborough Drumlin Field and the characteristics observed by others may not be present in this part of the drumlin field. It must be noted that complete sections through drumlins were not encountered, and water well records in the area were



Photo 3. Road cut exposure through Dummer Till.



Photo 4. Example of a classically shaped drumlin in the Peterborough Drumlin Field. In this instance, ice flow was northeast to southwest from approximately right to left in the photo. Note barn for scale.

inconclusive for the presence of stratified sediments in the subsurface. Water wells that extend from surface to bedrock in drumlins are nonexistent in the study area. This suggests that water-bearing units (likely sand and gravel) exist at depth within the drumlins.

Although the average orientation of the features in this field is aligned northeast-southwest, at least 4, and possibly 5 flow sets, based on drumlin orientation, have been identified in this study (Figure 8). The boundaries between the flow sets grade into rather than overprint one another. These flow sets represent localized variations in glacier flow dynamics and variations in flow direction and velocity, which affected the morphology of the resulting features.

Flow Set A

Flow Set A is oriented approximately 240° and is located at the west-central edge of the study area. In the area just north of Manilla, the drumlins are narrow and spindle like in morphology (Figure 9). Some of these drumlins have an irregular, almost hummocky surface topography to them, and hummocky terrain exists in the low-lying areas between the drumlins. The hummocks appear to be superimposed on the drumlins and are composed of Newmarket Till.

Flow Set B

Flow Set B contains drumlins oriented approximately 204° and covers the majority of the Lindsay map sheet (Figure 10). The drumlins vary from short, narrow and widely spaced to longer, almost oval mounds spaced further apart than in other parts of the study area (*see* shaded-relief map in Figure 4). This area of drumlins corresponds to the Schomberg Ponds physiographic region (*see* Figure 3), where many of the drumlins are partially to completely buried by deep water glaciolacustrine sediments. There is an area of hummocky topography within this flow set just south of Lindsay, which appears to be superimposed on the drumlins. This zone of hummocks is oriented approximately northwest-southeast and may mark a zone of ice stagnation during deglaciation. The hummocks in this zone consist of Newmarket Till at surface (a minimum of 1.5 m of Newmarket Till was observed) and may be a subglacial facies of Newmarket Till.

Flow Set C

Flow Set C is marked by a series of drumlins oriented approximately 223° (Figure 11). These drumlins, in the eastern half of the Peterborough map sheet, vary from the classic streamlined, or inverted spoon-shaped forms to shorter, more oval-shaped forms (*see* Figure 11).

Flow Set D

Flow Set D comprises drumlins oriented on average at 205° and consists of well-developed, classic drumlin forms that include some highly elongated, narrow features. Some of the drumlins in this area also appear to be superimposed on each other and, in at least one example, a drumlin appears to have 3 tails (Figure 12; Photo 5). Eyles et al. (in press) describe these “composite” drumlins and attribute them to the erosion of pre-existing drumlins by glacial ice, and suggest that the progressive downward erosion of swales between drumlin crests results in these features with multiple tails. They also describe a continuum of subglacial landforms whereby these multi-tailed features are clones of pre-existing features which in turn are intermediate to the longer, lower and narrower streamlined features. All of these landforms are thought to be the result of subglacial deformation of a pre-existing landscape (Eyles et al. in press). The series of highly streamlined and elongated drumlins generally occurs in areas of topographic lows (*see* Figure 4, back pocket). This convergence of flow into low-lying areas may have contributed to increased flow velocities causing enhanced streamlining and elongation of the subglacial bedforms (e.g., Stokes et al. 2011).

Flow Set E

Flow Set E is located in the central portion of the study area, between the southern part of Pigeon Lake and the City of Peterborough. The drumlins consist of asymmetrical mounds that have slight elongation along the axis parallel to ice flow which is approximately 185° (Figure 13). These very poorly developed drumlins are located in an upland area of higher relief. This upland area may have served to impede flow and interrupt or prevent classic-shaped drumlins from being formed. These upland areas are composed predominantly of Newmarket Till with some ice-contact stratified drift. As ice encountered these uplands, it is hypothesised that the ice flow slowed and underwent compressive flow resulting in the shorter, and wider irregular drumlin-like forms. The ice-contact stratified drift draped over portions of the uplands and individual drumlin ridges indicate that meltwater was an important factor in the formation of these drumlins as many of the north-south oriented drumlins appear to be altered by meltwater flow. For example, those drumlins in the southeast corner of Figure 13 appear to have curved southern ends. It suggests that during deglaciation, these drumlins were modified by subglacial and/or proglacial meltwater flow followed by deposition of ice-contact sediments on the drumlin surface.

The well-formed drumlins in the study area all appear to be located in areas of low relief (*see* Figure 4, back pocket), and it is possible that the slope of the land surface played an important role on subglacial flow conditions and the development of drumlins.

Various theories have been proposed for the formation of the Peterborough drumlins, ranging from subglacial deformation and till accretion (Gravenor 1957), the erosion of a pre-existing till sheet by glacial ice (Maclachlan and Eyles 2013; Eyles et al. in press) (commonly evoking an ice-stream mechanism) to formation by subglacial meltwater floods (Shaw and Sharpe 1987). In the current study, it is suggested that the drumlins formed in response to both glacial deformation and erosion of pre-existing sediment, similar to the idea expanded upon by Eyles et al. (in press). Evidence cited for formation by a meltwater flood was not observed within the study area. No boulder lag is present on the surface of the drumlins. Scouring around the stoss ends of drumlins, suggestive of meltwater erosion, is rare. Also, this scouring has also been explained as the result of subglacial deformation and erosion (Eyles et al. in press; Eyles and Doughty in press). Some evidence of debris flow activity in the form of slumped sediments at the surface of drumlins is present, but this is not diagnostic of subglacial meltwater flooding. Deposition by active ice is supported by striated clasts present in the till; and the morphology of the drumlins appears to support variable ice flow velocities with a possible ice-stream acting north and south of the City of Peterborough (Flow Set D; *see* Figure 4; this study; Maclachlan and Eyles 2013; Margold et al. 2015; Eyles and Doughty in press; and others).

Hummocky Moraine

Hummocky moraine occurs in several places throughout the study area. The most extensive area occurs in the northeast corner of the Peterborough map sheet near the village of Dummer (*see* Figure 4 (back pocket), Figure 14; Photo 6). Here the hummocks consist exclusively of Dummer Till. Stratified sand and gravel occurs in localized areas within the hummocky moraine and was only observed in one location in the far northwestern corner of the Peterborough NTS map area. Individual hummocks range from irregular, non-oriented mounds to weakly linear features, oriented roughly perpendicular to ice flow. The linear features within this area may represent various stages of ice retreat and stagnation. The hummocks are products of the irregular melting of clean and debris-laden ice. Depressions developed in areas where clean ice melted in situ, and hummocks where debris-laden ice melted out (Benn and Evans 2010). Flat areas between hummocks are areas of thin drift, where bedrock is occasionally exposed (Figure 14).

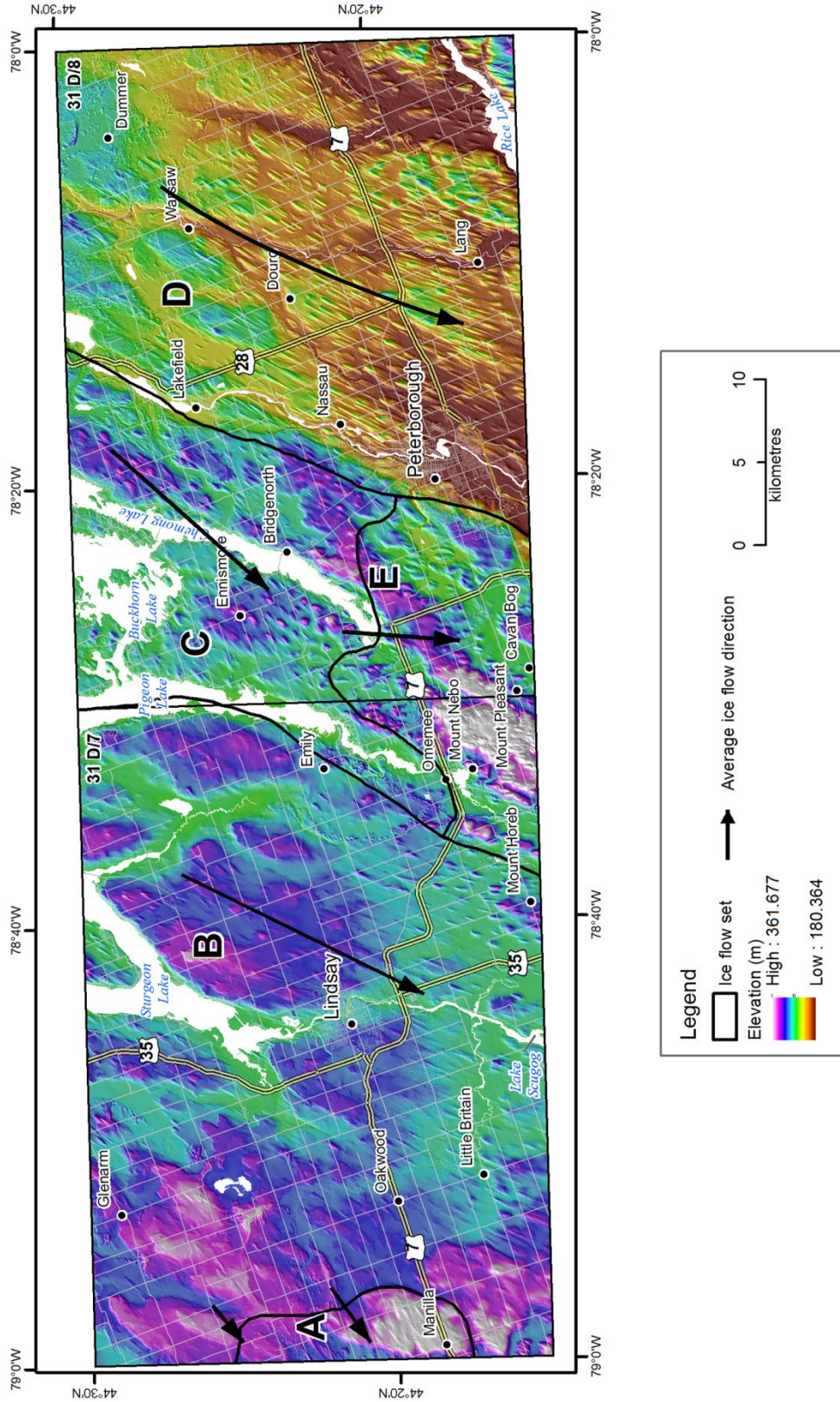


Figure 8. Hillshaded DEM showing various ice-flow sets defined by drumlin orientation within the study area. Flow Set A is approximately 240°; Flow Set B approximately 204°; Flow Set C approximately 223°; Flow Set D approximately 205°; and Flow Set E approximately 185°.

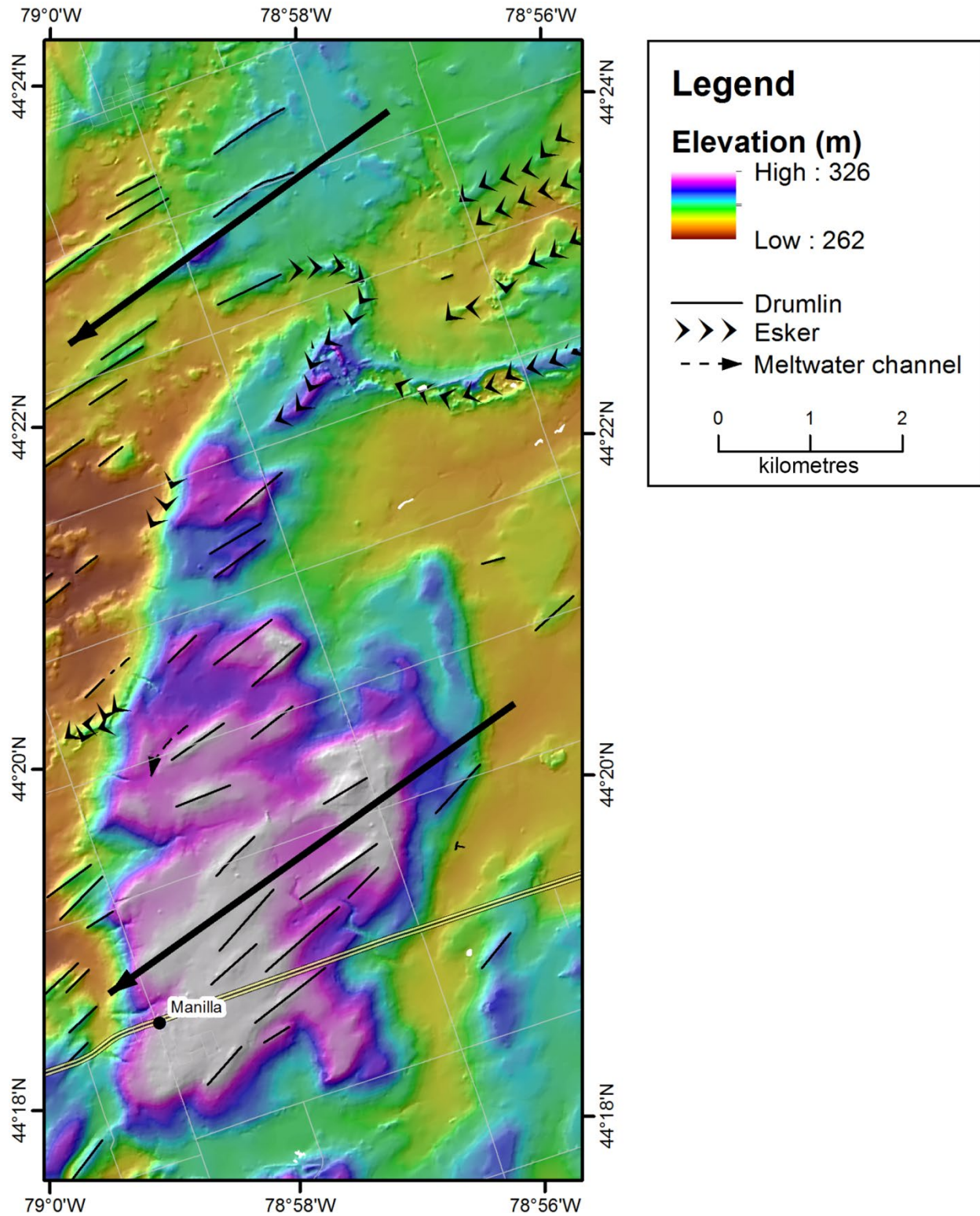


Figure 9. Drumlin Flow Set A. Drumlins and hummocky moraines contained within a narrow valley north of Manila (black arrow depicts ice-flow direction).

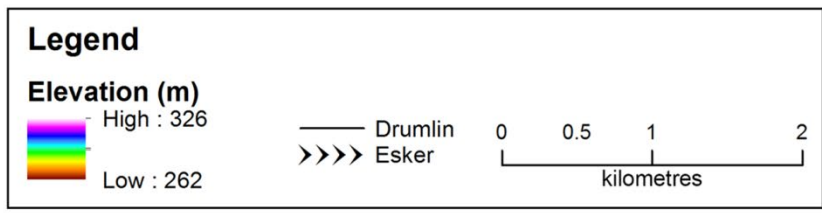
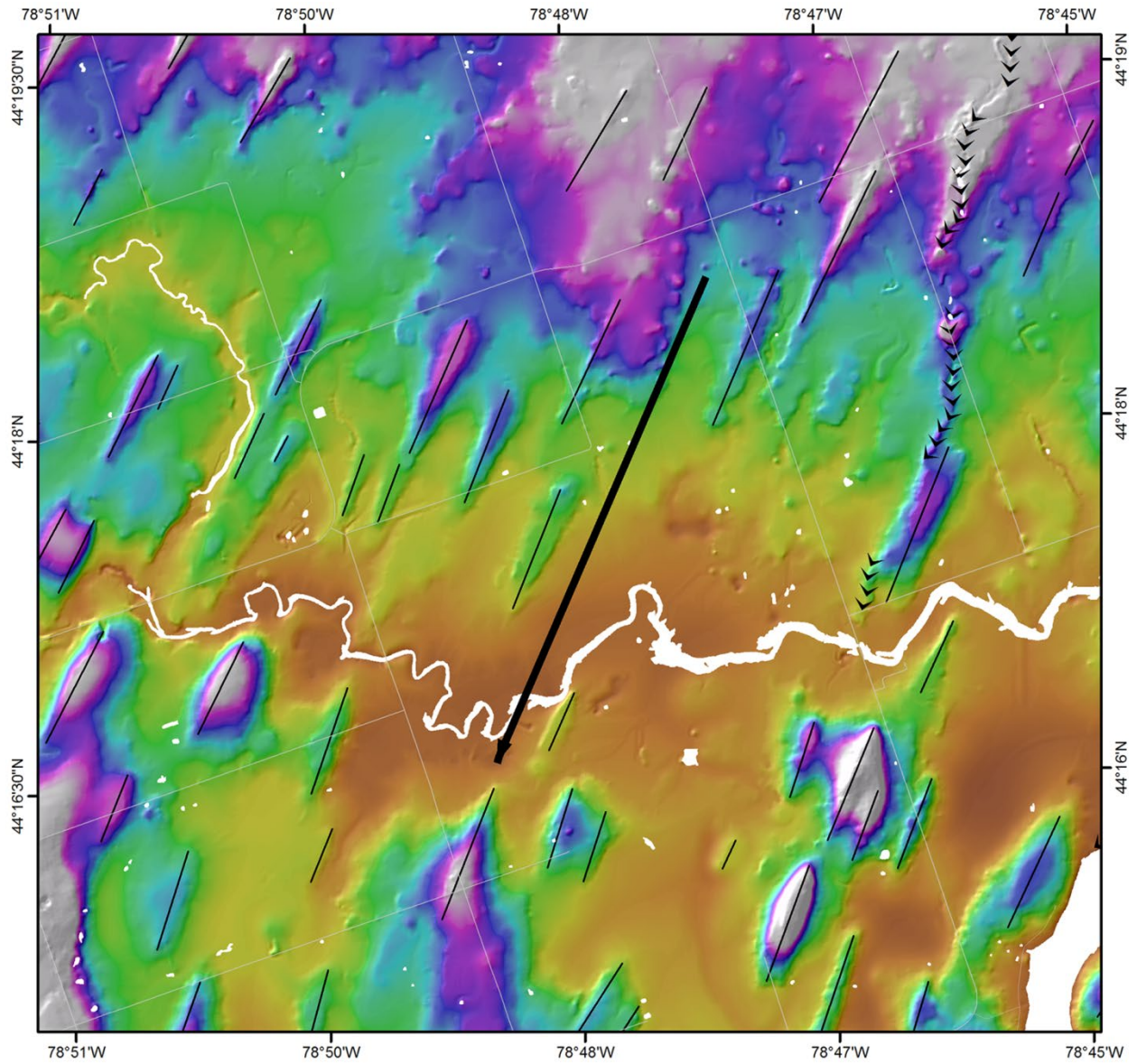


Figure 10. Hillshaded DEM showing features within Flow Set B.

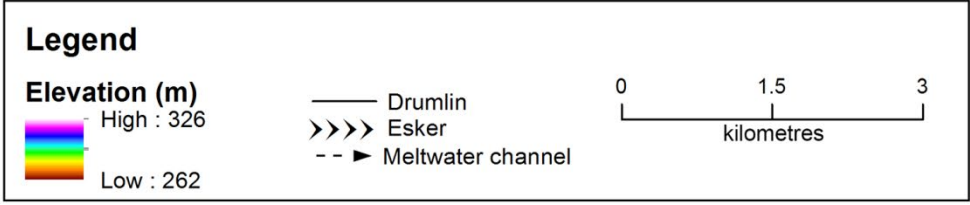
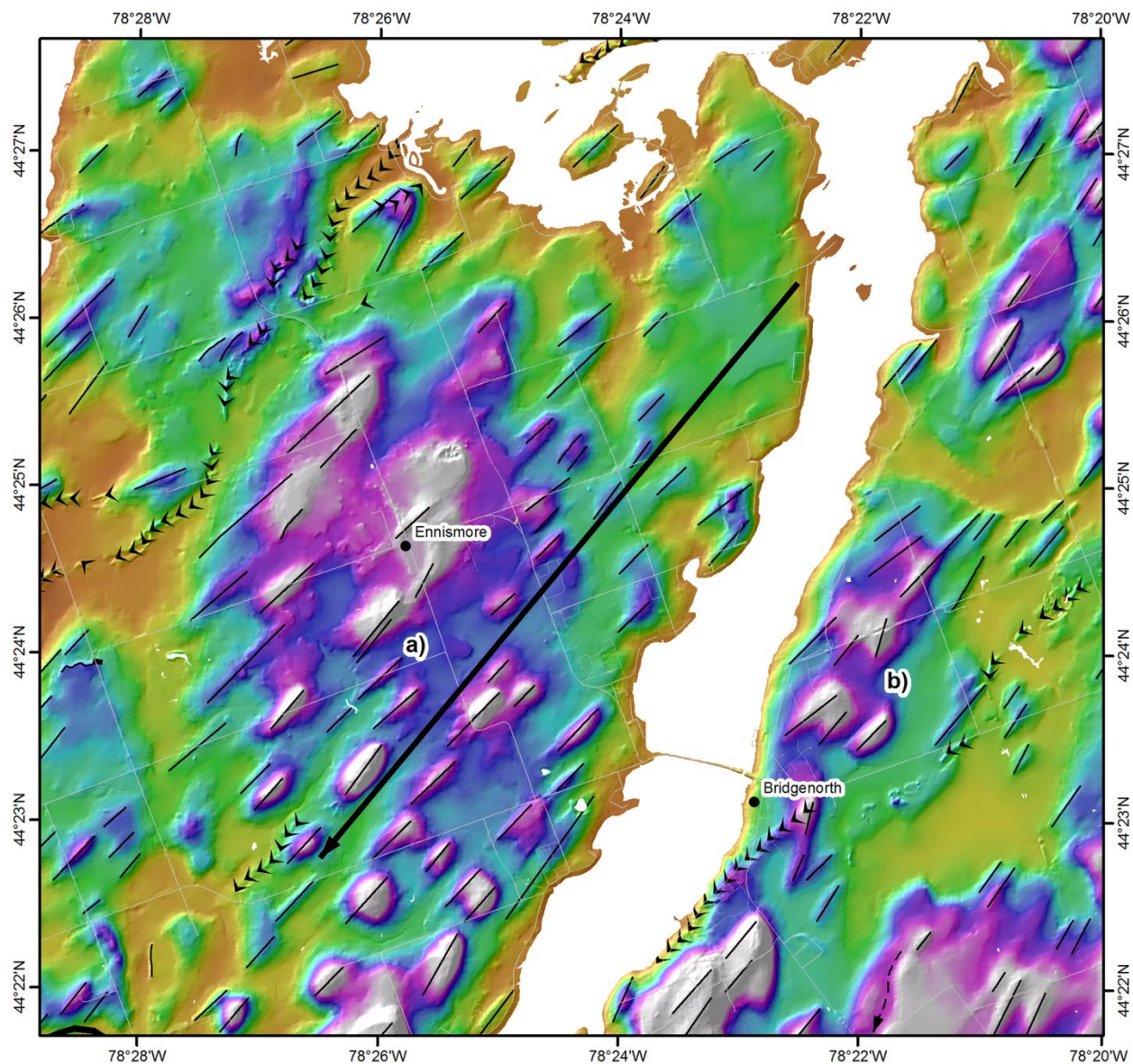


Figure 11. Hillshaded DEM showing features within Flow Set C. Examples of **a)** well-developed, streamlined drumlins and **b)** short, ovoid-shaped drumlins.

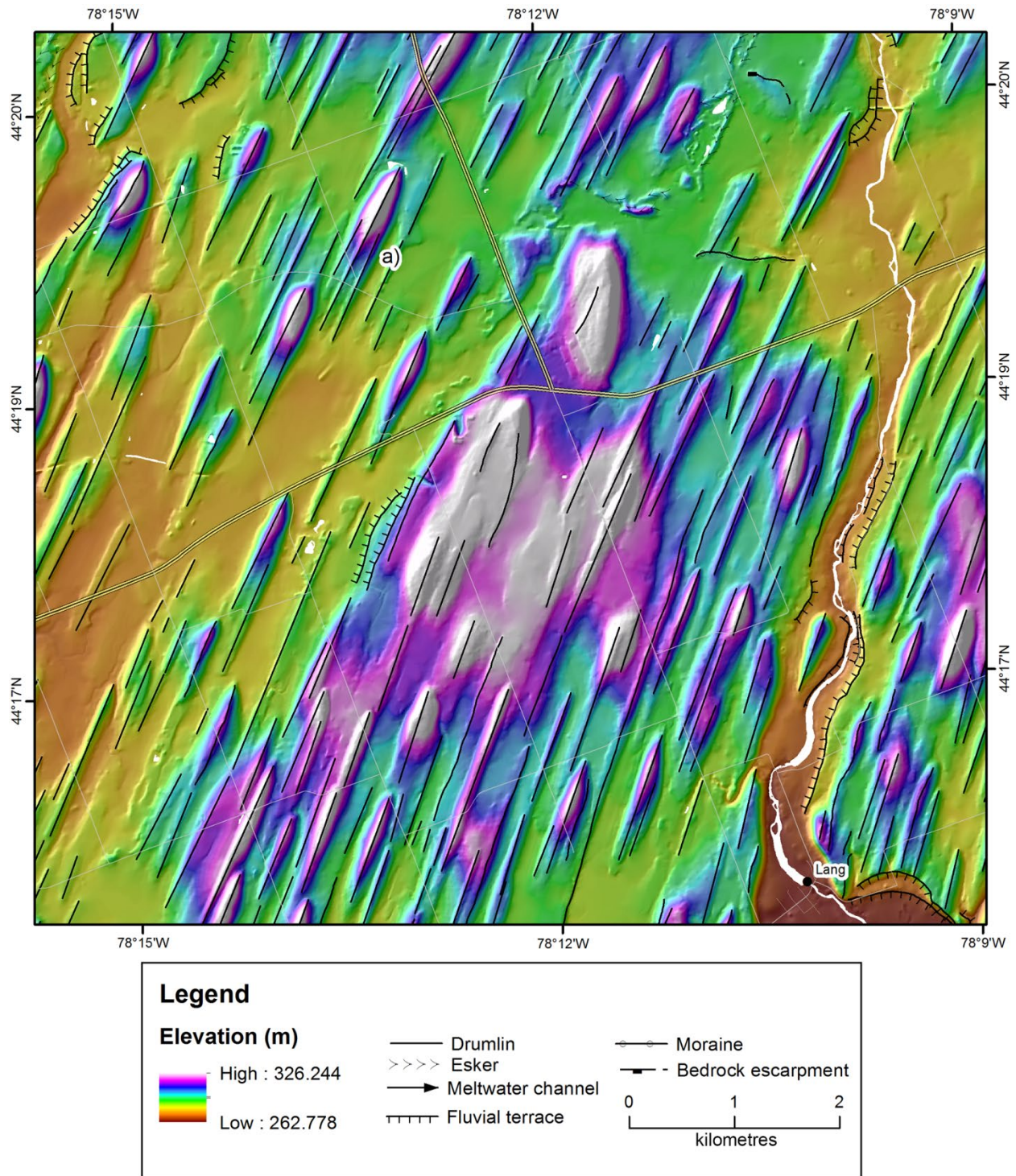


Figure 12. Hillshaded DEM of Flow Set D showing streamlined drumlins **a)** Three-tailed drumlin depicted in Photo 5.

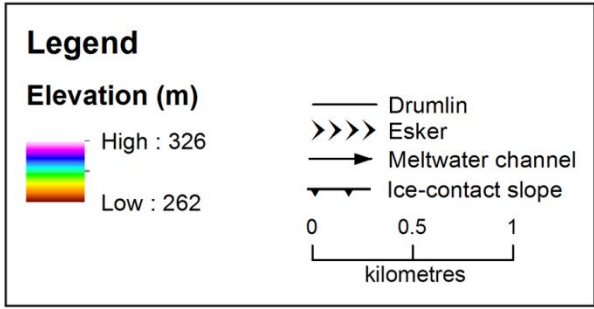
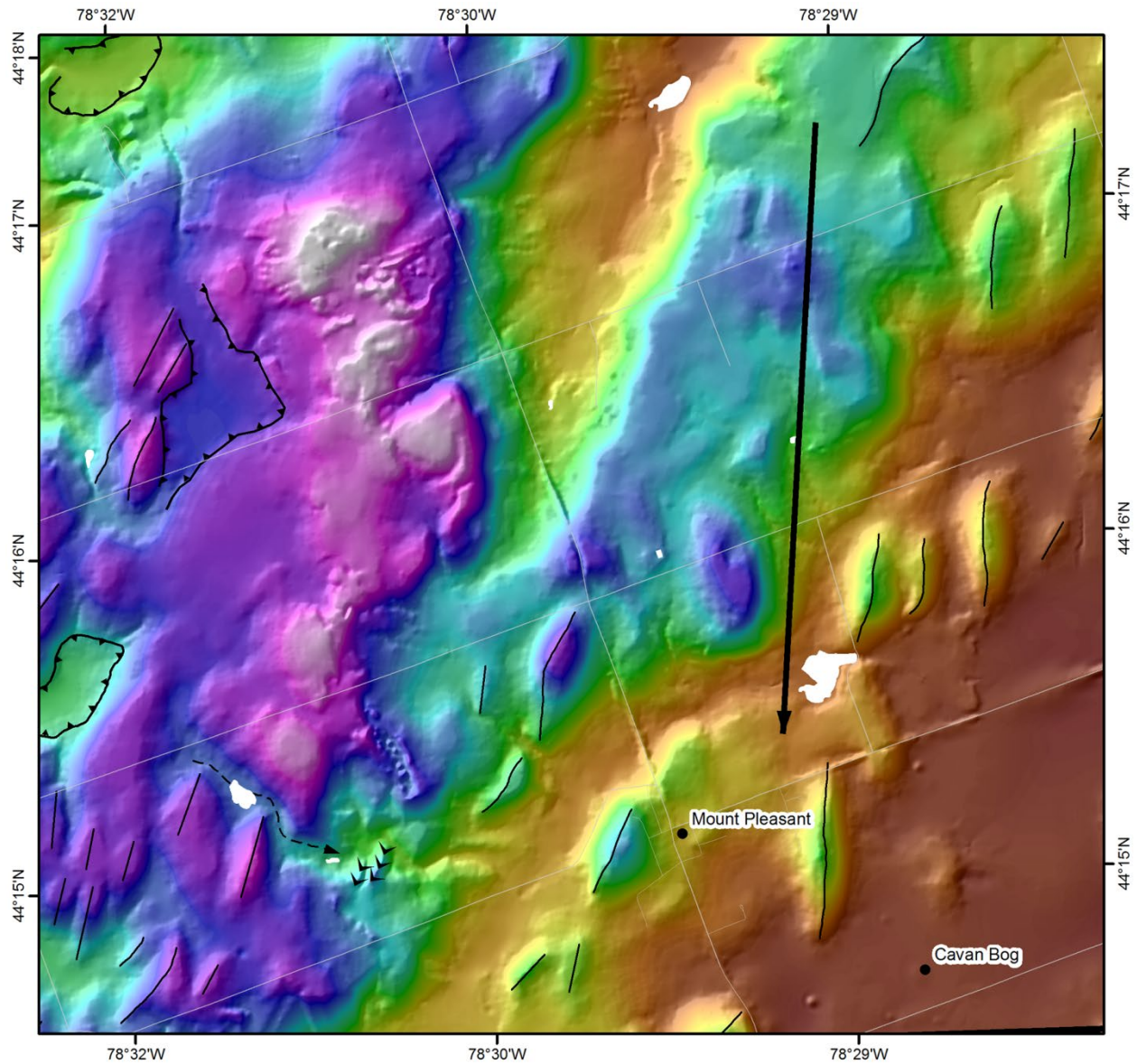


Figure 13. Hillshaded DEM showing irregular hills and poorly-shaped drumlins within Flow Set E.



Photo 5. Oblique aerial photograph of a composite drumlin with 3 tails. The outline of drumlin and tails are in red.



Photo 6. Aerial view of the hummocky topography associated with Dummer Till.

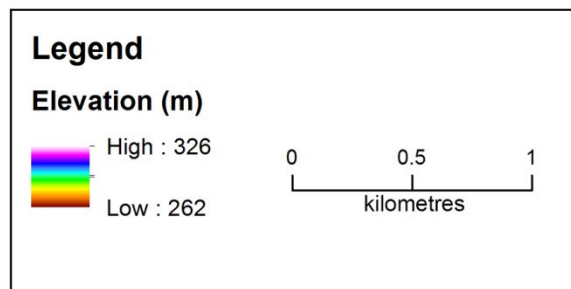
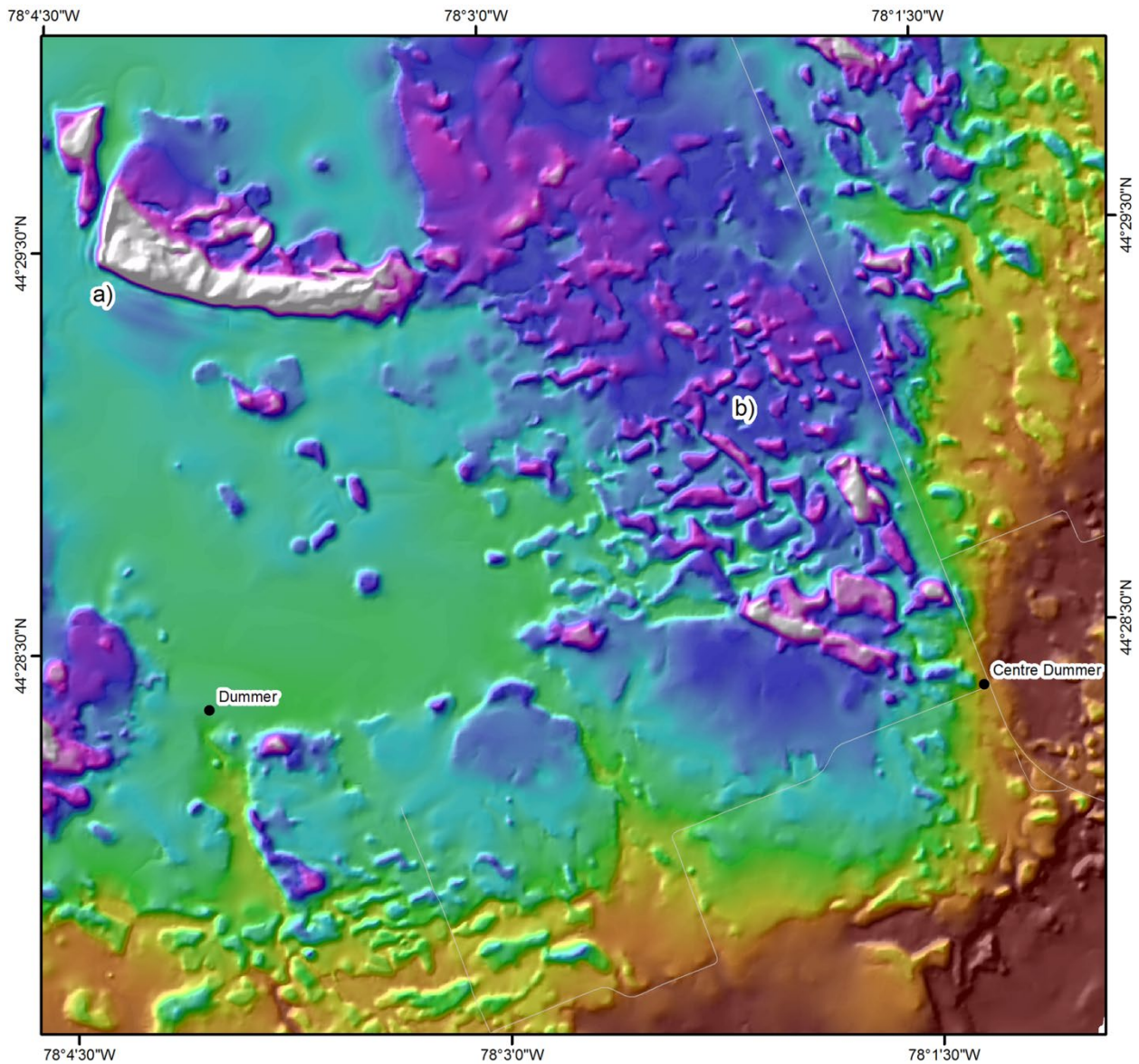


Figure 14. Hillshaded DEM showing the morphology of landforms composed of Dummer Till **a)** prominent moraine segment possibly representing a terminal or recessional moraine, **b)** area of hummocky moraine typical of features composed of Dummer Till.

The southern extent of this area of hummocky topography (and the southern margin of the Dummer Moraine) corresponds roughly to that of the boundary between the Gull River and Verulam formations. Dummer Till is associated with the Gull River Formation in that it is composed primarily of fragmented Gull River bedrock, indicating very short sediment transport distances. The ice mass involved in the deposition of the Dummer Moraine was likely detached from the rest of the Simcoe Ice Lobe in the lee of the Algonquin Highlands (north of the study area) and became stagnant (Mihychuk 1984). It is possible that if ice continued to flow past the Bobcaygeon–Verulam boundary, the Dummer Till would have become finer textured and included a wider range of clast lithologies.

Recessional Moraines

Several moraine ridges have been identified within the study area. The first is located east of Sturgeon Lake in the Lindsay NTS map area (Figure 15). This moraine is just over 2 km long, is oriented northwest-southeast, rises approximately 4 to 6 m above the surrounding land surface and is aligned parallel to a bedrock scarp located just to the east. The moraine is composed of Newmarket Till at surface and possesses an irregular, somewhat hummocky surface.

Additional moraine segments southeast of this ridge may also correspond to the same ice-marginal position. These moraines are located approximately 7 km south of Emily Lake and at the southern end of Pigeon Lake (*see* map P.3798, back pocket). The moraine south of Emily Lake is oriented approximately west-east and is about 1 km long. This is a subtle feature which rises approximately 1 to 4 m above the surrounding land surface and is composed of Newmarket Till at surface. The moraine extending into the southern part of Pigeon Lake is also aligned roughly west-east and is somewhat sinuous along its length with the eastern half curving northward. The surface of this moraine is draped by ice-contact stratified sands and gravels. Water well records suggest till is present at depth in this moraine.

The recessional moraines mapped in this study are aligned predominantly in the west to northwest direction and correlate well with the dominant moraines mapped outside the study area, including the Lake Simcoe Moraine (Chapman and Putnam 1984) and mark local halts in the retreat of the Simcoe Lobe of the Laurentide Ice Sheet (LIS) (Terasmae 1980).

An additional moraine is located in the northeast corner of the study area north of Dummer (*see* Figure 14a). It appears to be a composite of several moraine ridges. The predominant ridge comprising the moraine is approximately 1.5 km long and oriented almost west-east (Photo 7).



Photo 7. East-trending moraine composed of Dummer Till. This moraine corresponds to **a**) in Figure 11, and the black line denotes moraine ridge crest.

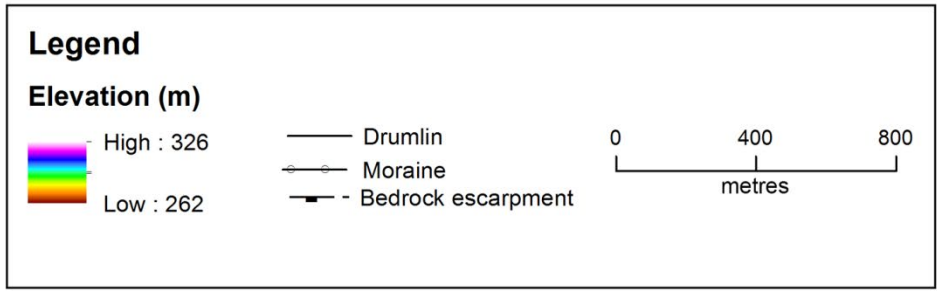
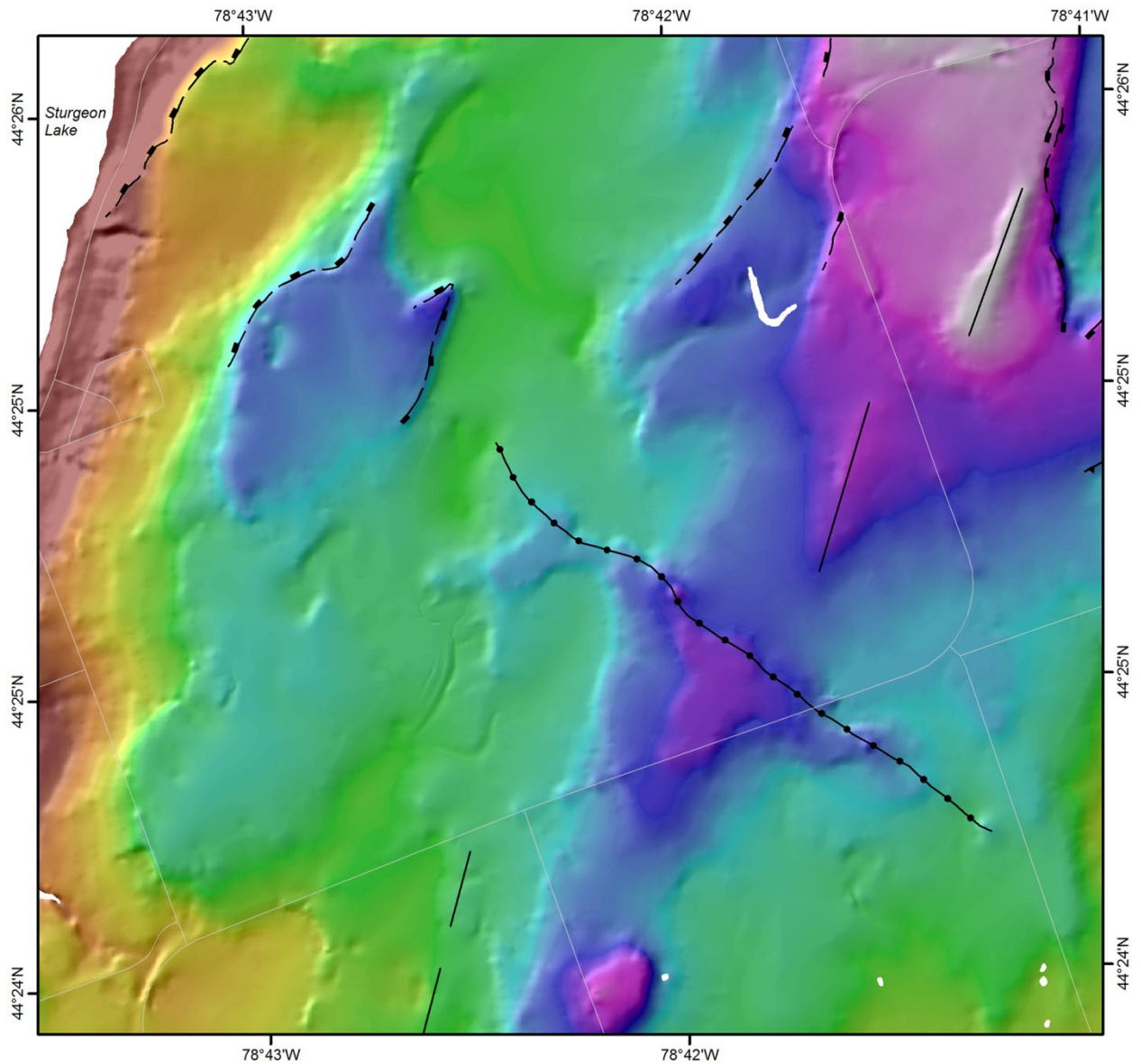


Figure 15. Hillshaded DEM showing a moraine ridge with hummocky surface topography east of Sturgeon Lake.

The southern or lee edge of the moraine is sharp and demarcated by the edge of a wetland. This may be a result of meltwater flow truncating the southern edge of the moraine. The northern (stoss) edge of the moraine is more complex, with several smaller ridges oriented perpendicular, sub-perpendicular and sub-parallel to the dominant ridge. The moraine is composed of Dummer Till and its surface is irregular to hummocky.

In the northeast corner of the study area, where Dummer Till dominates, there are multiple short linear ridges that are perpendicular or sub-perpendicular to the interpreted ice-flow direction in the region. These ridges are found in association with the hummocky terrain described above, and their orientations are not consistent throughout the area although a dominant orientation of northwest-southeast or west-east may be interpreted when looking at the larger area of hummocky moraine. The formation of these moraine ridges may have been the result of processes similar to those suggested above for hummocky moraine; the melt-out of stagnating debris-rich ice.

Irregular hills and associated uplands

In the south-central and southeast portions of the study area, there are a series of irregular hills and knobs located at the highest elevations within the study area (*see* Figure 4, back pocket). These hills appear drumlinized in places, but at most, should only be considered very poorly developed drumlin ridges. Depressions in amongst these irregular hills appear to be the result of melting blocks of glacial ice (Figure 16). For the most part at surface, and at several locations to depths of greater than 15 m, these hills are composed of Newmarket Till. In some instances, there are several metres of glaciofluvial ice-contact stratified deposits draping over the hills, notably the area east of Omemee and west of the Cavan Bog. Deep cuts through these features are rare, though water well records suggest they may be composed of both Newmarket Till and ice-contact stratified deposits at depth. The water well records in this area do not generally reach bedrock therefore making a reasonable estimate of drift thickness difficult. Thicknesses greater than 100 m are inferred.

Glaciofluvial Outwash, Ice-Contact Deposits and Associated Landforms

Glaciofluvial and ice-contact deposits are common throughout the study area. They form some of the most spectacular landforms in the study area including several extensive esker systems. In the Lindsay area, the largest esker system is the Omemee Esker (Figure 17). Esker segments beginning at the southern end of Emily Creek (approximately 11 km in length) and the southern part of Pigeon Lake (approximately 7 km in length) merge just west of Omemee, and extend an additional 7 km to the south to the boundary of the study area. The crest of the esker sits up to 40 m above the surrounding land surface and can exhibit a very sharp crest and steep sides (e.g., the esker ridge at the southern boundary of the Lindsay NTS area). Sediments in the esker vary from clean cobble to boulder gravel to well-bedded, fine-textured sands. Several active aggregate operations are situated along this esker system (Photos 8 and 9).

A series of eskers and ice-contact–stratified deposits oriented northeast-southwest exist on either side of Goose Lake in the west-central part of the Lindsay map area. Goose Lake appears to be a depression caused by the melting of a large block of stagnating ice (Figure 18).

Another set of small eskers and ice-contact deposits exist in the northwest corner of the study area, just north and west of Glenarm. A linear, north-south trending esker system extends south from Sturgeon Lake and is approximately 10 km long, albeit discontinuous along its length (*see* map P. 3798, back pocket).

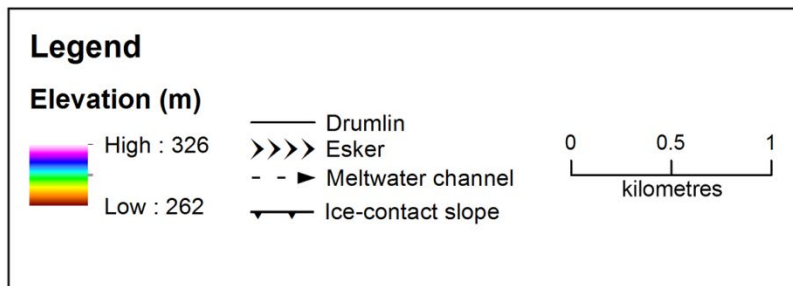
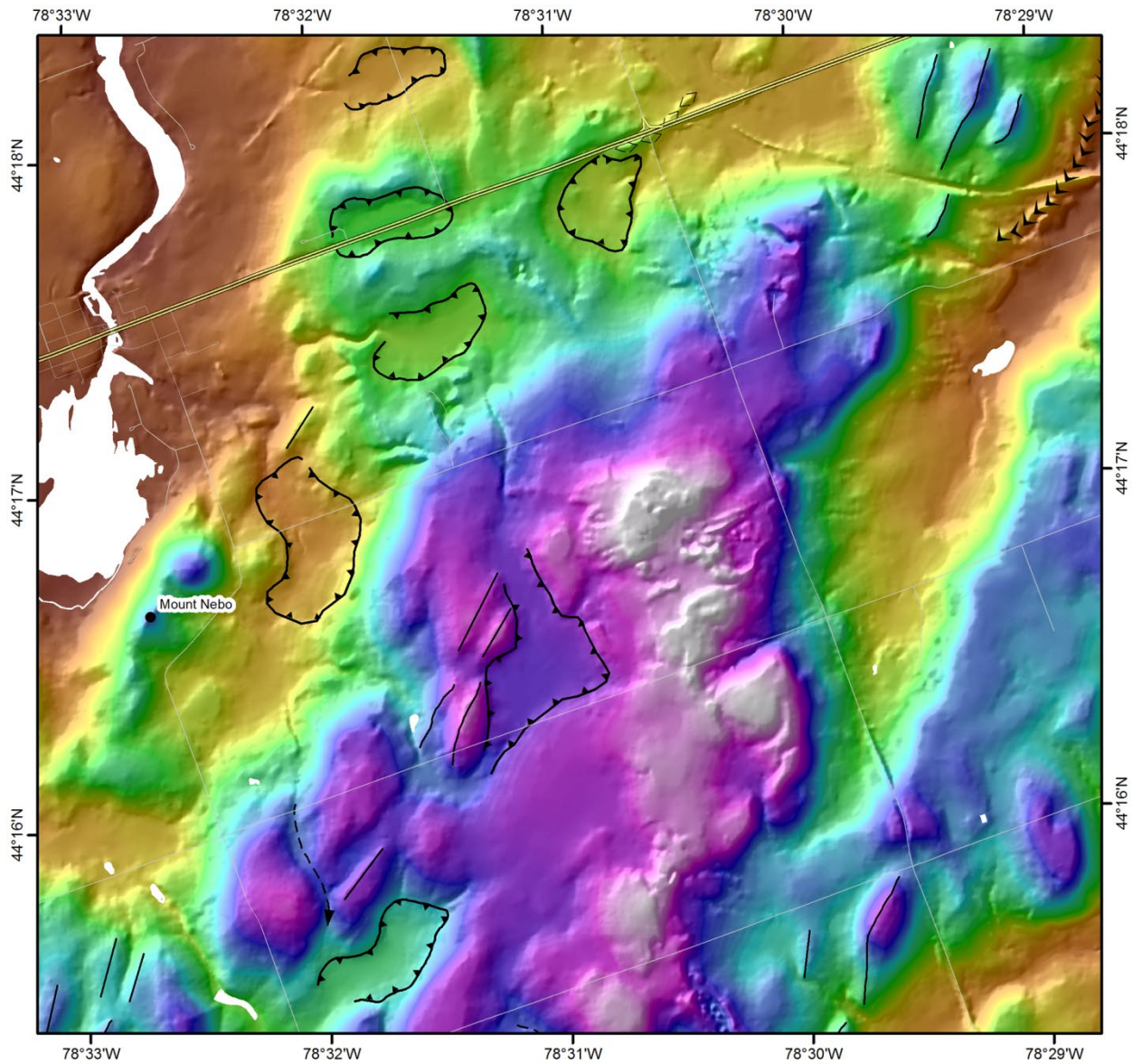


Figure 16. Hillshaded DEM showing irregular hills and ice block depressions.

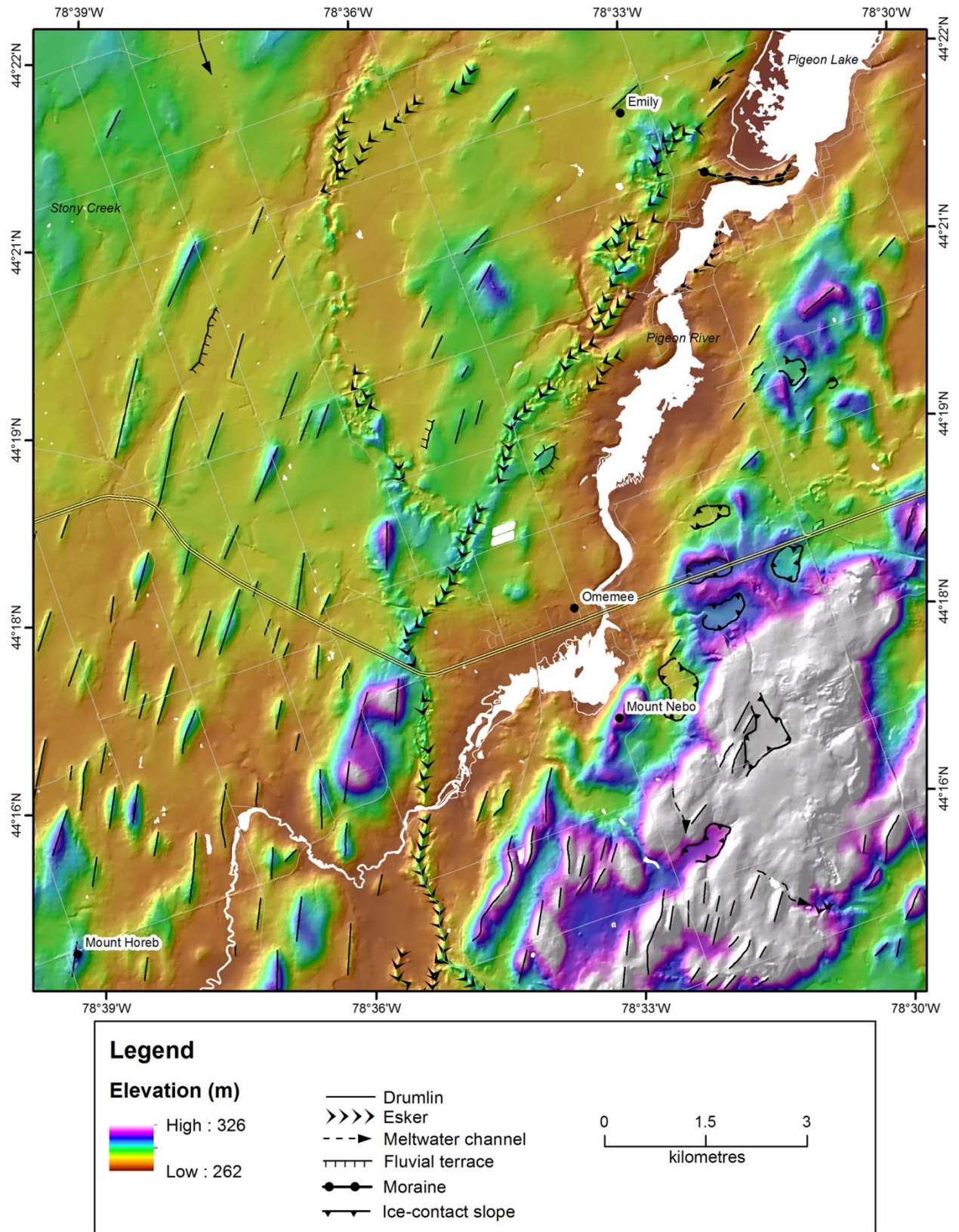


Figure 17. Hillshaded DEM showing the Omemee Esker.



Photo 8. Aerial view of an aggregate operation within the Omeme Esker.



Photo 9. Well-bedded sand and gravel exposed in the Omeme Esker.

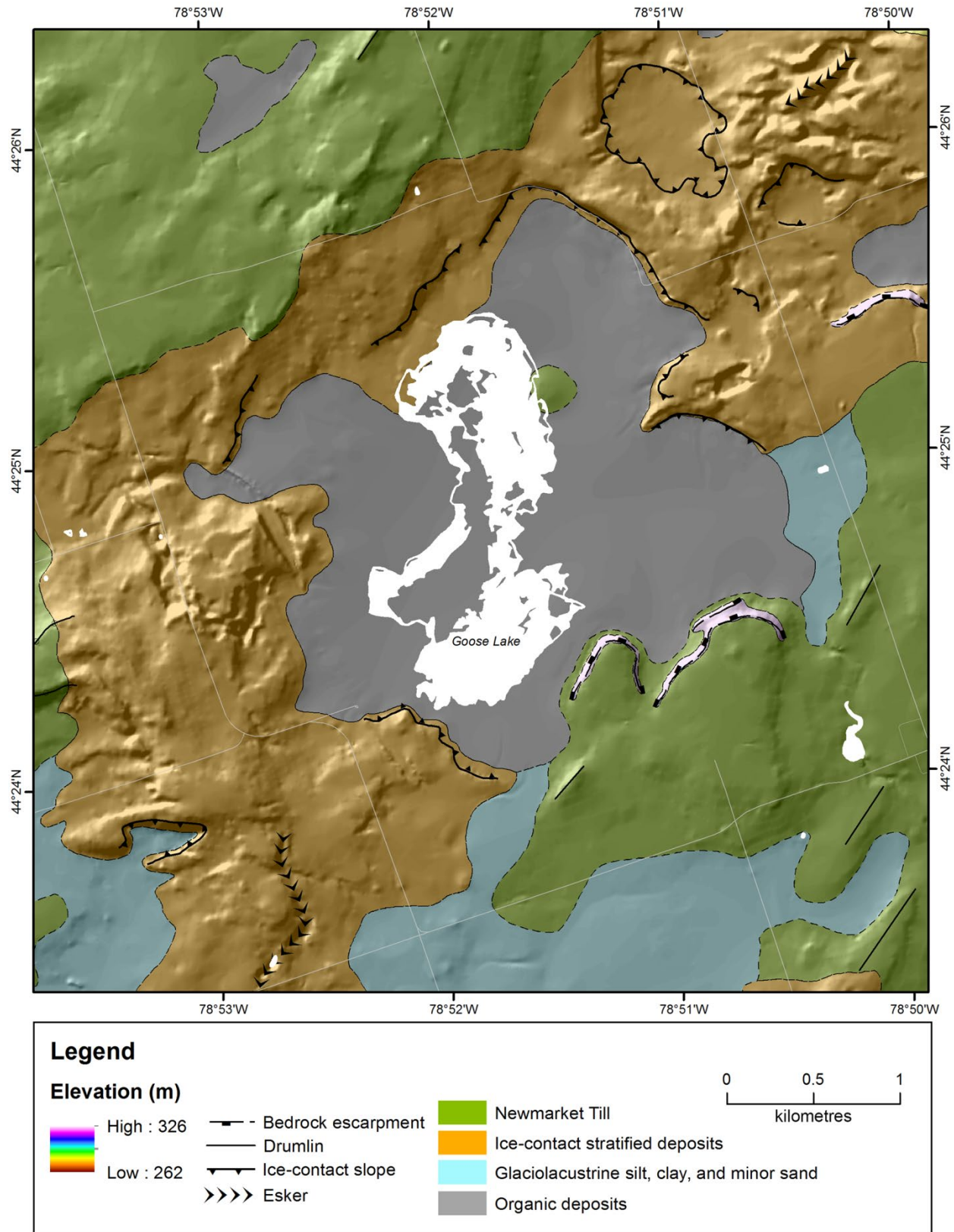


Figure 18. Hillshaded DEM showing ice-contact stratified deposits surrounding Goose Lake west of Sturgeon Lake.

There are more than 5 continuous to semi-continuous eskers in the Peterborough area. The dominant esker ridges in each of these systems are oriented northeast-southwest, aligning well with the orientation of the long axes of nearby drumlins and parallel to broad valleys possibly representing tunnel valleys (this study, Brennand and Shaw 1994; Sharp et al. 2013). The eskers terminate at the Oak Ridges Moraine and may have formed in channels that fed sediment into the moraine (Barnett et al. 1998).

Of these, the Norwood Esker, located on the eastern edge of the map area, is the most prominent, paralleling the northern margin of a tunnel valley (Figure 19). Here, the esker ranges in height from approximately 10 to 25 m above the surrounding landscape and is fairly continuous over a length of approximately 6 km.

A second esker system originating near Katchewanooka Lake and ending at the south end of Chemong Lake near Bridgenorth is also fairly continuous over a length of approximately 14 km (see map P.3799, back pocket). The esker ridges are oriented approximately northeast-southwest and once again align with the orientation of the surrounding drumlins. Several smaller and less continuous esker systems exist within the Peterborough NTS map area, occupying small river valleys. They are commonly diverted around drumlin ridges, suggesting the eskers developed subsequent to the drumlins. These glaciofluvial ice-contact deposits are generally found in association with glaciolacustrine fine-textured sands where eskers terminated in proglacial lakes including the Schomberg Ponds.

All of the glaciofluvial ice-contact deposits contain variably sorted sands and gravels. Clast sizes range from granules to large boulders and are commonly subrounded to rounded in shape. Local Paleozoic lithologies dominate while Precambrian clasts make up approximately 10% of the estimated clast content. Ripples and cross bedding are common within the sandy facies of the eskers.

Glaciofluvial terraces were identified in several areas across the study area, but are most common in the eastern half of the Peterborough NTS area. Several of these truncate the southern ends of drumlins (Figure 20), and many mark multiple levels of meltwater erosion within modern river valleys as well as along the edges of the modern Kawartha Lakes. The elevation of these fluvial terraces range from 200 to 260 m asl and mark a post-glacial drainage event, perhaps the drainage of Lake Peterborough into Lake Iroquois

Significant deltaic sediments were identified in the vicinity of the Norwood Esker as well as the City of Peterborough (see Figure 19; map P. 3799, back pocket). These vary from fine-textured sands to coarse sands at surface. No large exposures were available in these deposits for further examination.

The northward transition within these valleys from glaciolacustrine to glaciofluvial sedimentation is observed in several places, notably at the City of Peterborough and north of Lang (see Figure 20). The 2 sedimentary units were differentiated at surface using grain size and sedimentary structures. The glaciolacustrine sediments are commonly fine-textured sands, horizontally laminated with silts and clay, commonly rhythmically bedded with occasional granules or pea gravel dropstones. Sediments become coarser northward in these valleys where sands with minor gravels become more common. These glaciofluvial sediments can consist of interbedded sands and gravels, but do not exhibit the rhythmites observed in the glaciofluvial deposits. These deposits demonstrate a change from higher energy meltwater flow in the northern, more confined sections of the valleys, to low energy glaciolacustrine environments in the southern parts of the valleys.

Deltas formed within the Schomberg and post-Schomberg meltwater ponds and lakes as the ice retreated further north opening up the valleys containing the modern Kawartha Lakes.

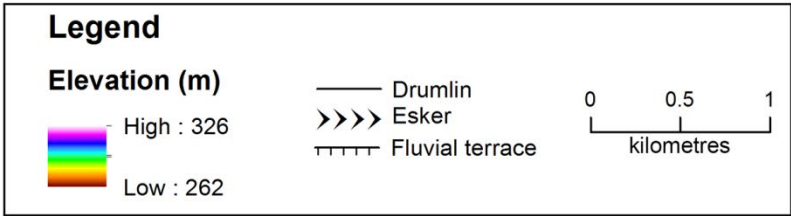
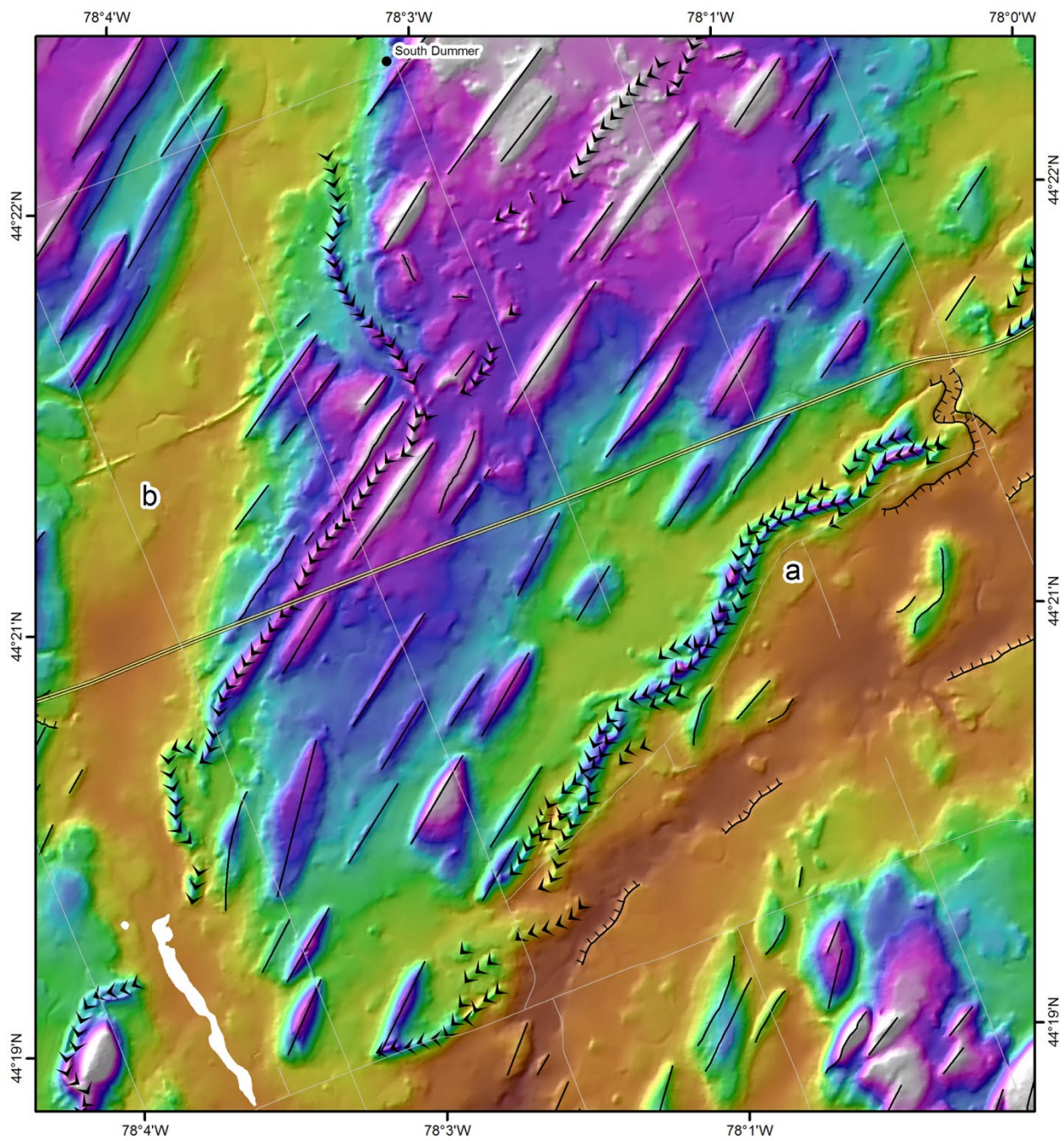


Figure 19. Hillshaded DEM showing the Norwood Esker (a) and tunnel valley (b).

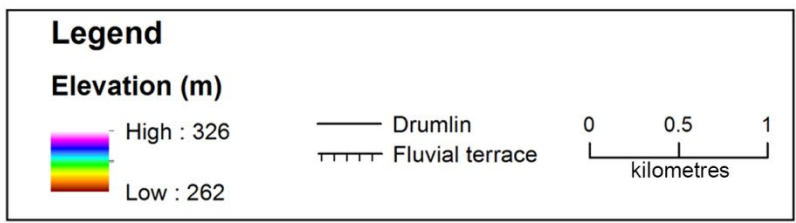
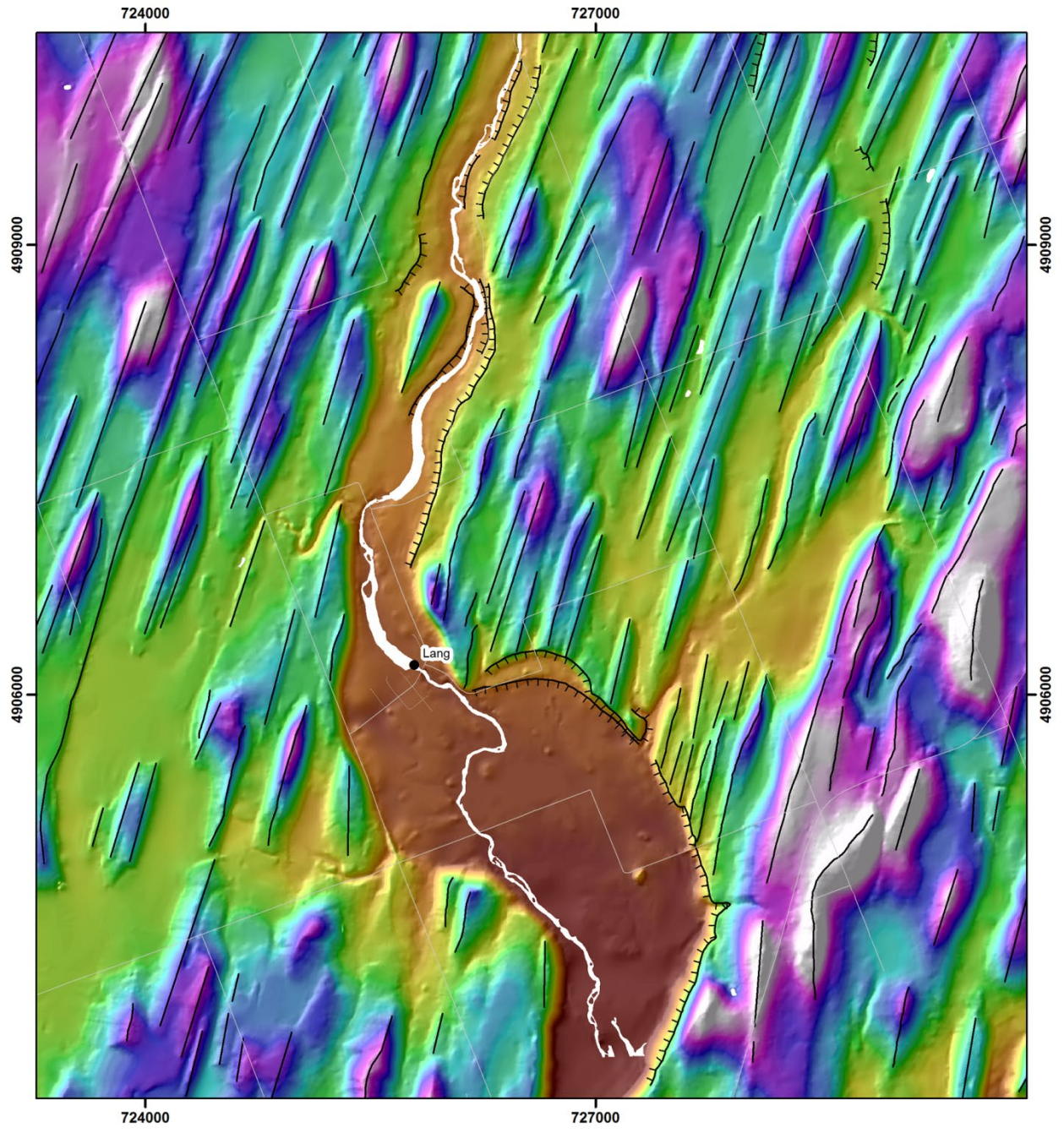


Figure 20. Hillshaded DEM showing glaciofluvial terraces near Lang.

Meltwater Channels and Tunnel Valleys

Meltwater erosional features are also present throughout the study area. In the Lindsay NTS area, several channels occur to the north where the drift cover is thin and easily recognizable on shaded-relief maps (e.g., Figure 21). The largest erosional features identified in this area are tunnel valleys; broad linear valleys with flat bottoms. The tunnel valleys in this study area correspond to those previously identified by the Geological Survey of Canada (Sharpe et al. 2013). These features have been interpreted as tunnel valleys because they are large valleys that are eroded into sediment (Kehew et al. 2013).

A large tunnel valley, oriented northeast to southwest, is located along the valley of the Pigeon River, southwest of Pigeon Lake. In the Peterborough NTS area, several tunnel valleys have been identified. The most prominent of these is located at the eastern edge of the Peterborough NTS area where a tunnel valley intersects the Norwood Esker (*see* Figure 19b). A second tunnel valley begins at Warsaw and extends southward to Rice Lake (*see* Figure 4, back pocket). Additional tunnel valleys occur within southwest-trending valleys currently occupied by Pigeon, Chemong, Katchewanooka and Clear lakes.

It has been suggested by several researchers (e.g., Sharpe et al. 2013; Brennand and Shaw 1994) that the tunnel valleys were formed due to catastrophic outburst floods of subglacial meltwater, a similar mechanism also suggested to explain the formation of the Peterborough Drumlin Field. The evidence cited for this includes the fact that the valleys are incised into regional, drumlinized till, have undulating floors and upslope paths, locally contain eskers, are filled by sandy hyper-concentrated flow deposits (suggesting rapid sedimentation) and contain modern under-fit streams (Sharpe et al. 2013, Brennand and Shaw 1994). Several issues arise when trying to validate this hypothesis. The first, cited by many authors who disagree with the catastrophic flood model, is the question of how and where a large subglacial reservoir could form (e.g., Ó Cofaigh 1996). This issue is never resolved in the literature. A large subglacial lake under the LIS in Hudson's Bay has been hypothesized but no concrete evidence provided (Ó Cofaigh 1996). In addition, there is the question as to why the flood would be catastrophic? What is the reason for catastrophic outbursts of meltwater within the Peterborough area? These questions have also been left unanswered. Ó Cofaigh (1996) also makes the point that often researchers have used the infilling sediments as evidence for the genesis of the tunnel valleys (i.e., depositional evidence for an erosional process). He also concludes that sedimentary infill is not sufficient evidence to hypothesize a mode of valley formation as these sediments may have been deposited at a much later date than the valley formation (Ó Cofaigh 1996).

In this study, it appears that the tunnel valleys post-date the formation of the drumlins and perhaps even some eskers. The valleys clearly truncate portions of the drumlin field, and at the eastern edge of the study area, the Norwood Esker appears to be truncated by a tunnel valley. Post-esker formation of the tunnel valley could explain why the esker is located at the northwest edge of the valley rather than in its bottom as stated often in the literature (e.g., Ó Cofaigh 1996, Brennand and Shaw 1994). The esker may simply be located on the highest point of land in the interfluvium where processes forming the tunnel valley were not active. It is speculated that the tunnel valleys formed by meltwater erosion and subsequent infilling of glaciofluvial and glaciolacustrine sediments. The mechanism of meltwater erosion may be due to steady state meltwater discharge and sediment deformation within channels. Additional subsurface stratigraphic data, beyond the scope of this study, is required to inform this hypothesis. Until the source of a large subglacial meltwater reservoir can be proven, as well as the reasoning behind why meltwater flow should be catastrophic is clarified, it is difficult to suggest that the formation of tunnel valleys was via catastrophic subglacial meltwater sheet floods.

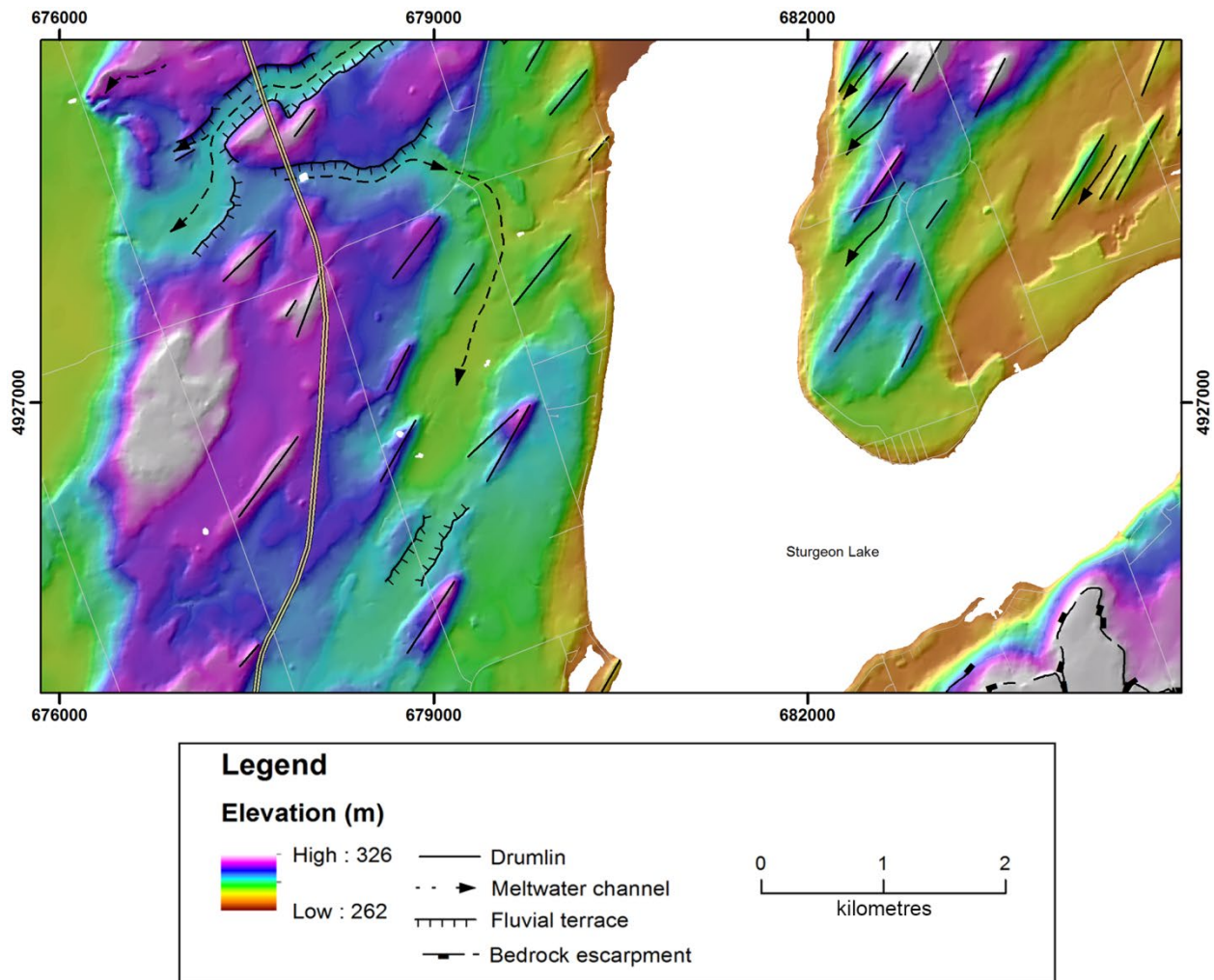


Figure 21. Hillshaded DEM showing meltwater channels.

Glaciolacustrine Deposits and Associated Landforms

Large portions of the study area are covered by fine-textured glaciolacustrine deposits (*see* map P. 3798, back pocket). Gravenor (1957) attributed the laminated silts and sands to the Schomberg Ponds. These sediments occupy low-lying areas in the southern half of the study area, particularly in swales between the higher relief drumlins and hummocks (Figure 22). In places, sandy glaciolacustrine deposits drape the lower slopes of the drumlins and, in other places, there is evidence of fine-textured sediments being winnowed from till on the surface of drumlins by nearshore processes. The glaciolacustrine sediments occupy broad, flat-lying areas that are extensively farmed (Photo 10) and, in places, are capped by variable thicknesses of peat. Deep exposures through these sediments were not observed; however, water well records suggest thicknesses up to 10 m in some locations. Laminated silts and clays as well as interbedded fine- to medium-fine textured sands were observed throughout the areas of glaciolacustrine sedimentation. In many instances, these sediments were rhythmically laminated, with minor deformation structures and ice-rafted debris. Organic material observed in probe samples occurred at surface and relate to modern-day wetland deposition (Photo 11).

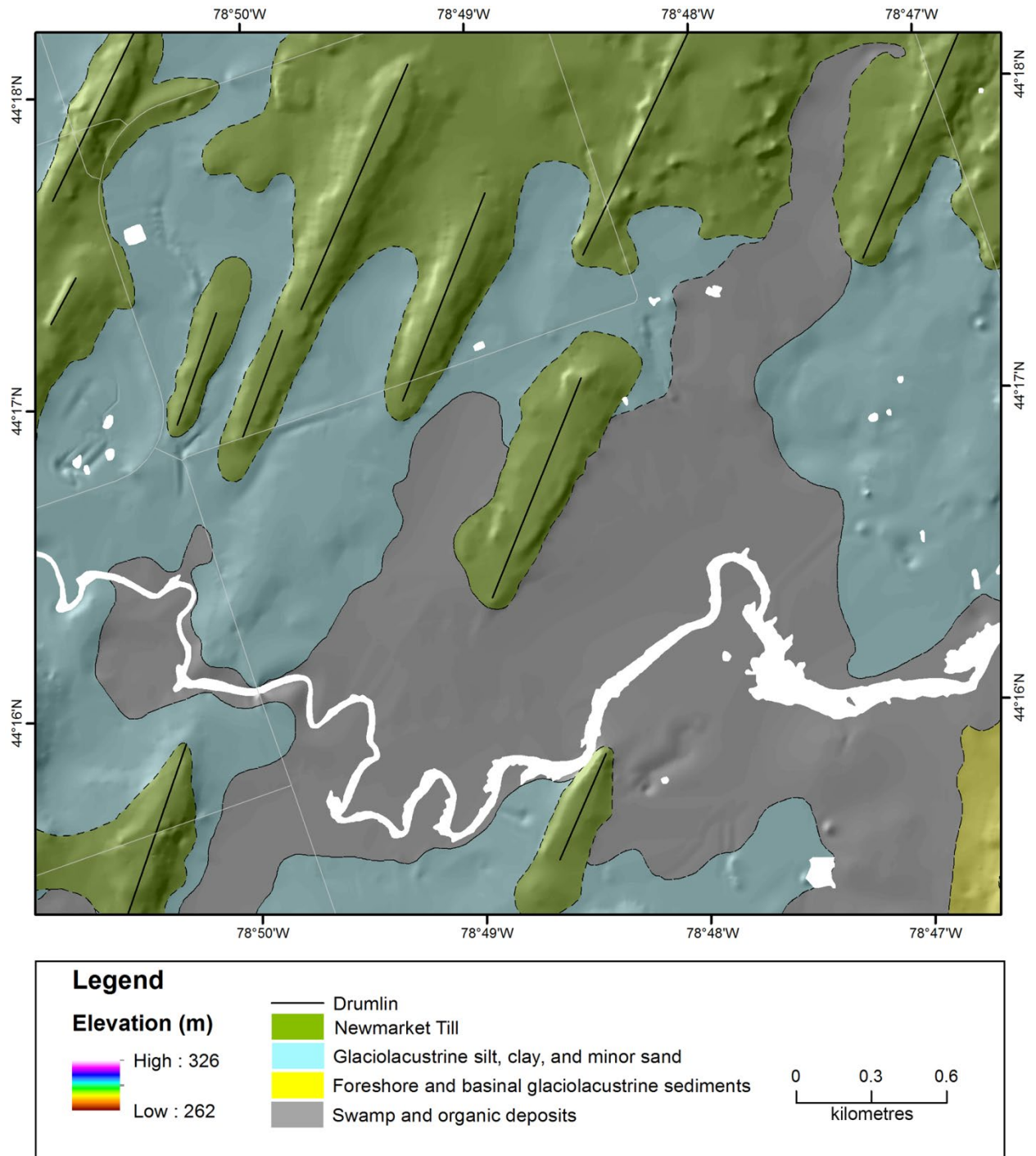


Figure 22. Hillshaded DEM showing the flat-lying areas typical of Schomberg Pond deposits.



Photo 10. Oblique aerial view of the flat-lying topography typically associated with Schomberg Pond deposits.



Photo 11. Wetlands commonly occupy the low-lying areas of Schomberg Pond deposits.

Recent Deposits

Wetlands occur throughout the study area, and in some cases are quite extensive (e.g., the Cavan Bog in the southwest corner of the Peterborough NTS area). The wetlands commonly occur in local depressions between drumlin ridges and peat depths vary from less than 1 m to greater than 3 m in some locations (this study and Riley 1994). The peat is commonly well-humified, with high stump content, and dense tree growth. It is a woody peat with high ash content, limiting its potential use (Riley 1994). Only one example of peat harvesting was observed and consisted of a small operation adjacent to a farm field within the Lindsay NTS area. There was no commercial peat extraction occurring within the study area at the time the study was being conducted.

Glacial History and Relative Timing of Events

The landforms and associated sediments in the Lindsay and Peterborough NTS areas are a result of widespread glaciation followed by ice retreat, stagnation, and final melting of the Simcoe Lobe of the LIS. The following section attempts to describe the relative timing of events that resulted in the landscape that exists in the area today. The timing of these events is reconstructed based on geomorphic interpretations of landforms and sedimentology as well as building on previous work (e.g., Gravenor 1957 and others).

During the last glaciation, the LIS extended well south of the study area into the northern United States and reached its maximum limit during the Port Huron Phase (Terasmae 1980) (Figure 23a). It is suggested here, that while the ice completely covered the study area, the Peterborough Drumlin Field was forming subglacially by deformation and erosion of previously deposited sediments, (i.e., till and glaciofluvial deposits).

As the Simcoe Lobe began to retreat northwards from Lake Ontario, the Ontario Lobe within the Lake Ontario basin retreated eastwards creating an interlobate area in which the Oak Ridges Moraine (ORM) began to form. Two main ideas regarding the formation of the ORM exist. One idea suggests the moraine is an interlobate feature which developed through the melting and subsequent deposition of sands and gravels near the ice fronts (Barnett et al. 1998). A second idea suggests that the ORM may be a very large esker system that formed subglacially with multiple branches feeding into the main west-east trending ridge (Sharpe et al. 2013). The Ontario Lobe of the LIS still occupied much of the Ontario Basin at this point (Figure 23b). The ORM overprints the drumlinized surface (the regional unconformity of Barnett et al. 1998 and others). The drumlin field extends south of the ORM and into Lake Ontario.

As ice retreated from the ORM, the Schomberg Ponds began to form as meltwater was dammed between the ice margin and high ground of the ORM to the south. Glaciolacustrine sediments were deposited over the drumlins in the eastern part of the study area. At about this time, a proglacial lake (Lake Peterborough) had also formed in the basin where the City of Peterborough is currently located (Figure 23b).

As the Simcoe Lobe continued to retreat, it is possible that the ice margin stalled in the area south of Lindsay, producing the broad band of hummocky terrain, and the Ontario Lobe retreated further to the east. At some point, while the Schomberg Ponds were still in existence, water from Glacial Lake Peterborough entered the Rice Lake basin forming a delta below the present level of the lake (Muller and Prest 1985). Lake Peterborough and Lake Iroquois merged as water from Lake Peterborough flowed through Rice Lake and into Lake Iroquois (Figure 23c). There is no evidence that the Schomberg Ponds and Lake Iroquois were connected (Gravenor 1957; Muller and Prest 1985). The extensive fine-textured

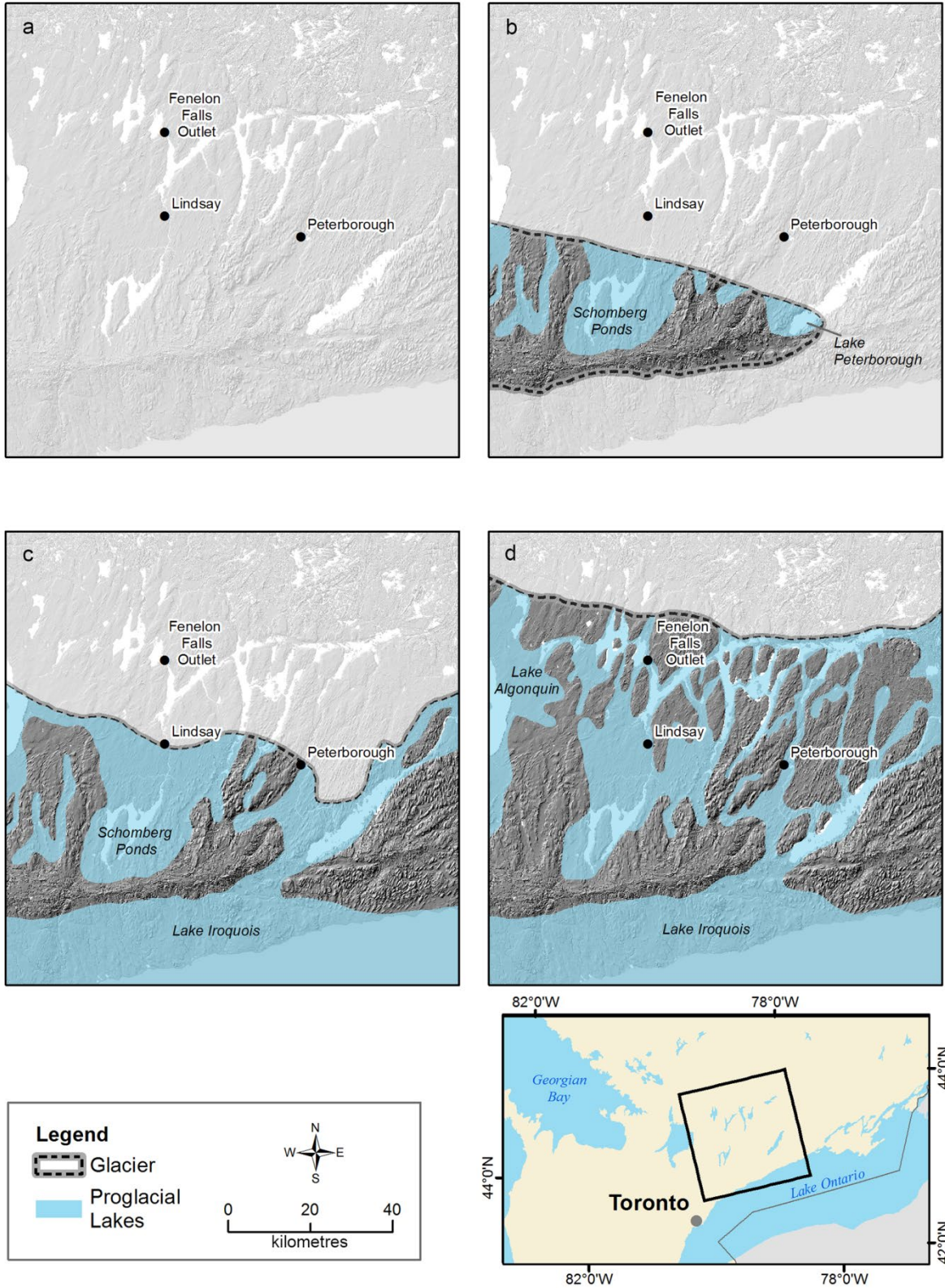


Figure 23. Interpreted location of ice margins, proglacial lakes and meltwater channels responsible for the development of the Lindsay and Peterborough area landscape. **a)** Glacial maximum: ice extended south of the study area and into northern New York State. **b)** Ice retreat to south of Lindsay. Formation of Schomberg Ponds. **c)** Ice retreat to the Dummer Moraine. **d)** Ice retreat to the northern shores of the Kawartha Lakes. Opening of the Fenelon Falls outlet.

glaciolacustrine sediments mapped in the southern portion of the Lindsay NTS area appear to end abruptly at the western edge of the uplands east of Peterborough (*see* map P.3799, back pocket). The uplands and irregular hills in the south-central portion of the study area may have been the boundary/divide between the Schomberg Ponds and Lake Peterborough (Lake Iroquois). A large delta formed at the City of Peterborough where the Algonquin River (modern day Katchewanooka Lake) entered glacial Lake Iroquois (Muller and Prest 1985). The ice margin continued to retreat northeastward until it became stationary and stagnated and melted *in situ* resulting in the deposition of Dummer Till, and associated moraines and hummocks (Figure 23d). The Dummer Moraine formed as the result of compressive flow against the north-facing Paleozoic bedrock escarpments, and plucking of the bedrock surface caused debris saturation of the ice followed by mass down wasting and melt out. Glacial Lake Iroquois was in contact with the Dummer Moraine east of the study area (Mirynech 1962; Muller and Prest 1985). As ice retreated northward from the Dummer Moraine, Lake Iroquois waters flooded the low-lying areas to the north of the moraine. Mirynech (1962) and Henderson (1973) indicate that the Dummer Moraine is contemporaneous with glacial Lake Iroquois and Terasmae (1980) hypothesized that the Dummer Moraine is between 12 500 and 12 000 ¹⁴C years old. This age estimate is based on sediments of Lake Iroquois or post-Lake Iroquois phases extending north of the Dummer Moraine (Terasmae 1980). Lake Iroquois drained shortly after 12 000 ¹⁴C years BP (Terasmae 1980 and Karrow et al. 1975), based on radiocarbon dates and pollen records from Bidy and Ross Lakes north of Belleville.

At about this time, glacial Lake Algonquin had formed north and west of the study area and as the ice continued to retreat northward, the eastern outlet of the lake at Fenelon Falls was uncovered (Figure 23d). Water levels fell as meltwater flowed into basins currently occupied by the Kawartha Lakes and into glacial Lake Iroquois and through current day Rice Lake into Lake Ontario, beginning the Kirkfield low-water Phase (Finamore 1985). It has been suggested that the outlet at Fenelon Falls operated between approximately 12 000 to 11 300 ¹⁴C years BP in this low-water phase (Karrow 1975; Prest 1970). Evidence for this is provided by the oldest organic deposits found in Victoria Bog, approximately 5.5 km northwest of Kirkfield dated at 10 500 ¹⁴C years BP. Deposition of these sediments must have occurred after water stopped flowing through the Kirkfield–Fenelon Falls outlet (Terasmae 1980).

As there are no shorelines identified within the study area, it is extremely difficult to reconstruct water planes. Meltwater flow is marked by the location and pattern of esker ridges, and the scouring/erosion of the lee sides of drumlins is a result of confined subglacial meltwater flow through channels such as those near Lang in the Peterborough NTS area.

ECONOMIC GEOLOGY

AGGREGATE RESOURCES

At the time fieldwork was being conducted, 1 quarry and 116 pits were licenced in the study area. Many of the pits are being used for local aggregate purposes and active extraction was not underway. The larger and more active operations are located within sections of the larger esker systems within the study area (e.g., the Omeemee, Norwood and the esker system south of Warsaw). Other ice-contact deposits have also been extracted for aggregate use. The sand and gravel deposits are highly variable across the study area, with respect to deposit thickness and usefulness for aggregate purposes. There is a high degree of variation in grain size and sorting throughout the study area and even within a single face of a pit. This is due to the variable nature of deposition within the ice-contact glaciofluvial environment. Sand and gravel has been extracted for use in high and low-grade hot-laid asphalt, concrete and cement, although some blending, and selective extraction are required (Ontario Geological Survey 1980a-d, 1985; Geomatics International Limited and Rowell 2000). In some cases the gravels are coated in silts and clays, and some minor cementation of sand grains was observed (Geomatics International Limited and Rowell 2000). Sediments exhibiting these deleterious characteristics must be avoided for construction grade, and road

base materials. Some of the esker deposits are extracted mainly for local use, for example, as road surface material, such as sediments from the esker extending south of Lindsay (Geomatix International Limited and Rowell 2000).

A small quarry is located north of Warsaw where an area, approximately 500 m by 200 m, of bedrock material was removed. The Gull River Formation was quarried here, with faces of 4 to 6 m high, highly irregular bedding, and evidence of water in the pit floor. It is possible that the water table was encountered here and extraction was stopped. The Gull River Formation is suitable for a wide range of crushed material including concrete, asphalt and granular base. Some sections of this formation react poorly with Portland cement (alkali-aggregate reaction), causing the cement to fracture or crumble (Geomatix International Limited and Rowell 2000; Ontario Geological Survey 1980a, 1980b).

In addition to the Gull River Formation, the Bobcaygeon, Verulam and Lindsay formations are located within the study area. The Bobcaygeon Formation may be used for road building and construction, although some beds may be alkali reactive as well (Geomatix International Limited and Rowell, D.J. 2000). The Verulam Formation has been used for lime production in other parts of the province (Gravenor 1957), but has a very low resistance to abrasion and freeze-thaw with some shaly sections, and therefore is not practical for many aggregate uses (Ontario Geological Survey 1980a; Geomatix International Limited and Rowell 2000). The Lindsay Formation may be suitable for cement, but unsuitable for concrete due to its high clay content and expansive properties (Geomatix International Limited and Rowell 2000).

GROUNDWATER RESOURCES

Much of the study area consists of agricultural lands with localized rural housing. Bedrock and overburden-derived groundwater is the primary source of potable water for these dwellings. Overburden wells are commonly used in the southern and south-central portions of the study area where overburden deposits are thickest. The depth of wells is highly variable suggesting the depth and continuity of aquifers in the study area is also highly variable. Bedrock wells serve the majority of residents within the study area. The cities of Peterborough and Lindsay draw water from surface sources.

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Appendix 1.

Grain Size Analyses of Till Samples

This complete data set of grain size analyses is available in Miscellaneous Release—Data 333 (Marich 2016c).

sample site location in Easting and Northing, NAD83, Zone 17
grain size distribution in percent

Sample #	UTM (NAD 83) Easting Northing	Material Type	Summary			% Granules	% Very coarse sand	% Coarse Sand	% Medium sand	% Fine sand	% Very fine sand	% Very coarse silt	% Coarse silt	% Medium silt	% Fine silt	% Very fine Silt	% Clay
			% Sand	% Silt	% Clay												
13-ASM-0133	659302 4924338	Newmarket Till	52.08	40.15	7.77	0	2.73	21.32	14.66	13.37	13.4	6.62	7.86	7.05	5.22	7.77	
13-ASM-0172	663239 4929251	Newmarket Till	57.93	35.6	6.43	0	2.56	31.45	13.74	10.18	10.24	5.3	7.67	7.42	4.97	6.43	
13-ASM-0206	662803 4910456	Newmarket Till	57.1	36.91	6.01	0	1.82	19.21	18.49	17.58	14.89	5.69	6.35	5.65	4.33	6.01	
13-ASM-0252	668022 4913972	Newmarket Till	66.48	30.72	2.8	0	1.92	29.62	19.68	15.26	10.81	5.57	6.51	4.86	2.97	2.8	
13-ASM-0299	672971 4918710	Newmarket Till	68.47	28.09	3.43	0	2.38	29.39	20.01	16.69	12.07	4.41	4.51	3.98	3.12	3.43	
13-ASM-0421	666680 4918998	Newmarket Till	49.78	43.68	6.54	0	1.43	18.34	19	11.01	12.53	7.72	10	8.28	5.15	6.54	
13-ASM-0444	661518 4906993	Newmarket Till	47.52	45.34	7.15	0	1.8	20.16	15.45	10.11	12.59	7.58	9.58	9.18	6.41	7.15	
13-ASM-0502	668407 4904970	Newmarket Till	52.26	40.38	7.36	0	2.15	32.52	12.51	5.08	7.91	6.6	9.97	9.72	6.18	7.36	
13-ASM-0534	673048 4903680	Newmarket Till	52.53	39.35	8.13	0	2.68	21.75	15.89	12.21	11.76	6.44	8.16	7.48	5.51	8.13	
13-ASM-0549	673388 4902346	Newmarket Till	59.59	36.23	4.18	0	1.92	23.13	19.16	15.38	13.33	6.42	7.24	5.61	3.63	4.18	
13-ASM-0686	686500 4902681	Newmarket Till	65.17	32.44	2.39	0	0.53	16.95	26.03	21.66	13.91	5.14	5.55	4.61	3.23	2.39	
13-ASM-0815	684418 4919589	Newmarket Till	58.67	33.85	7.51	0	2.57	27.35	16.38	12.37	10.68	5.67	6.61	6.04	4.85	7.51	
13-ASM-0862	690277 4926304	Newmarket Till	64.31	31.67	4	0	1.32	26.51	22.29	14.19	12.07	5.64	5.97	4.7	3.29	4	
13-ASM-1144	689290 4924771	Newmarket Till	61.43	33.89	4.68	0	2.05	33.97	17.81	7.6	7.44	5.91	8.28	7.53	4.73	4.68	
13-ASM-1151	661132 4926335	Newmarket Till	57.65	37.5	4.83	0	3.16	27.91	14.62	11.96	12.23	6.93	8.15	6.3	3.89	4.83	
13-ASM-1171	676760 4927733	Newmarket Till	55.19	40.75	4.06	0	2.16	26.23	14.86	11.94	14.57	7.83	8.24	6.16	3.95	4.06	
13-ASM-1172	678989 4925416	Newmarket Till	55.95	35.68	8.36	0	1.37	23.93	19.16	11.49	10.4	5.92	7.14	6.8	5.42	8.36	
13-ASM-1173	660650 4919835	Newmarket Till	40.85	52.02	7.15	0	3.32	16.04	10.31	11.18	13.86	9.17	12.55	10.32	6.12	7.15	
13-ASM-1174	662292 4919338	Newmarket Till	32.77	52.77	14.45	0	0.38	9.46	13.92	9.01	11.8	6.97	10.82	13.01	10.17	14.45	
13-ASM-1176	664095 4922226	Newmarket Till	24.55	67.06	8.41	0	0.41	5.6	8.45	10.09	17.24	12.31	16.46	13.28	7.77	8.41	
13-ASM-1178	667615 4922772	Newmarket Till	43.96	46.86	9.2	0	2.07	15.01	13.91	12.97	15.23	7.44	9.06	8.59	6.54	9.2	
13-ASM-1179	660719 4916353	Newmarket Till	57.02	36.38	6.6	0	1.61	23.65	18.73	13.03	11.69	6.2	7.32	6.45	4.72	6.6	
13-ASM-1181	666127 4917373	Newmarket Till	47.07	46.97	5.96	0	0	10.26	26.16	10.65	12.47	7.97	11.53	9.48	5.52	5.96	
13-ASM-1182	658845 4913353	Newmarket Till	69.23	27.23	3.57	0	2.95	35.72	16.44	14.12	10.34	4.38	5.14	4.35	3.02	3.57	
13-ASM-1189	659847 4903266	Newmarket Till	77.28	19.57	3.16	0	1.25	39.15	27.45	9.43	5.76	3.25	4.05	3.65	2.86	3.16	

Sample #	UTM (NAD 83)		Material Type	Summary			% Granules	% Very coarse sand	% Coarse Sand	% Medium sand	% Fine sand	% Very fine sand	% coarse silt	% Coarse silt	% Medium silt	% Fine silt	% Very fine Silt	% Clay
	Eastings	Northing		% Sand	% Silt	% Clay												
13-ASM-1196	662248	4902423	Newmarket Till	28.46	48.54	23	0	0.36	8.86	14.14	5.1	4.69	4.14	8.28	15.78	15.65	23	
13-ASM-1204	663826	4907461	Newmarket Till	60.4	33.02	6.59	0	2.15	26.6	18.01	13.64	11.35	4.69	5.84	6.07	5.07	6.59	
13-ASM-1215	673504	4905310	Newmarket Till	65.49	29.65	4.86	0	2.52	34.8	18.64	9.53	7.19	4.79	6.38	6.08	5.21	4.86	
13-ASM-1218	671417	4911512	Newmarket Till	46.54	48.23	5.24	0	0.35	13.41	19.96	12.82	13.71	8.48	10.94	9.4	5.7	5.24	
13-ASM-1251	669855	4905483	Newmarket Till	74.07	24.31	1.62	0	2.95	41.32	16.89	12.91	8.24	4.08	5.26	4.25	2.48	1.62	
13-ASM-1264	674158	4908438	Newmarket Till	57.55	39.08	3.34	0	2.22	25.39	17.59	12.35	11.95	6.96	8.47	7.2	4.5	3.34	
13-ASM-1266	675832	4908954	Newmarket Till	53.06	43.68	3.26	0	0.32	12.22	22.85	17.67	18.12	7.08	8.35	6.4	3.73	3.26	
13-ASM-1270	679284	4909039	Newmarket Till	57.21	40.35	2.45	0	0	7.58	27.1	22.53	16.92	6.34	7.23	6.13	3.73	2.45	
13-ASM-1275	677304	4910533	Newmarket Till	37.22	58.14	4.64	0	0	5.05	16.35	15.82	17.8	10.04	14.17	10.78	5.35	4.64	
13-ASM-1277	674688	4909724	Newmarket Till	62.72	31.61	5.64	0	2.4	30.3	18.1	11.92	9.81	5.19	6.48	5.9	4.23	5.64	
13-ASM-1278	673943	4911959	Newmarket Till	65.62	31.09	3.3	0	2.64	27.55	18.78	16.65	12.13	4.99	5.82	4.82	3.33	3.3	
13-ASM-1279	674991	4902779	Newmarket Till	40.51	46.56	12.92	0	0.34	9.36	18.6	12.21	12.12	6.43	9.59	10.24	8.18	12.92	
13-ASM-1284	683215	4908288	Newmarket Till	50.62	42.32	7.06	0	2.27	19.61	16.51	12.23	11.95	6.8	9.22	8.57	5.78	7.06	
13-ASM-1287	687157	4903156	Newmarket Till	48.82	40.25	10.93	0	2.76	23.97	13.94	8.15	8.77	6.29	8.99	9.2	7	10.93	
13-ASM-1294	690792	4911193	Newmarket Till	36.12	51.2	12.69	0	0.4	10.17	15.03	10.52	12.05	6.92	10.55	12.29	9.39	12.69	
13-ASM-1296	690570	4908935	Newmarket Till	73.57	25.75	0.68	0	1.95	34.23	20.56	16.83	11.61	4.58	4.63	3.08	1.85	0.68	
13-ASM-1297	698179	4908587	Newmarket Till	56.18	37.6	6.22	0	2.9	23.19	16.18	13.91	13.87	6.28	6.99	6	4.46	6.22	
13-ASM-1301	697326	4904382	Newmarket Till	73.35	22.74	3.92	0	1.77	36.96	22.46	12.16	7.55	3.67	4.3	3.99	3.23	3.92	
13-ASM-1303	698406	4910916	Newmarket Till	57.88	35.97	6.15	0	2.7	25.65	16.28	13.25	11.87	5.69	7.09	6.47	4.85	6.15	
13-ASM-1307	693115	4913522	Newmarket Till	57.63	38.93	3.46	0	1.91	22.07	17.69	15.96	14.43	6.75	7.8	6.18	3.77	3.46	
13-ASM-1314	692306	4917931	Newmarket Till	59.46	35.34	5.19	0	2.4	27.34	17.24	12.48	11.67	5.74	7.21	6.34	4.38	5.19	
13-ASM-1315	693158	4923454	Newmarket Till	62.95	33.84	3.21	0	1.98	27.79	18.06	15.12	13.08	5.56	6.49	5.31	3.4	3.21	
13-ASM-1316	692292	4927963	Newmarket Till	30.77	61.53	7.68	0	0.85	13.34	10.28	6.3	16.12	12.74	14.63	11.35	6.69	7.68	
13-ASM-1328	694558	4923114	Newmarket Till	49.73	44.23	6.05	0	0.31	16.55	24.42	8.45	12.13	8.59	9.9	8.31	5.3	6.05	
13-ASM-1329	688245	4920796	Newmarket Till	59.13	35.25	5.62	0	2.34	26.41	17.33	13.05	11.41	5.71	7.04	6.45	4.64	5.62	
13-ASM-1330	695446	4917357	Newmarket Till	58.76	34.98	6.25	0	2.99	28.38	15.96	11.43	10.13	5.76	7.16	6.9	5.03	6.25	

Sample #	UTM (NAD 83)		Material Type	Summary			% Granules	% Very coarse sand	% Coarse Sand	% Medium sand	% Fine sand	% Very fine sand	% coarse silt	% Coarse silt	% Medium silt	% Fine silt	% Very fine Silt	% Clay
	Eastings	Northing		% Sand	% Silt	% Clay												
14-ASM-0925	703831	4922233	Newmarket Till	57.09	34.31	8.59	0	2.66	25.63	14.97	13.83	12.18	5.24	5.81	5.74	5.34	8.59	
14-ASM-0926	707606	4924292	Newmarket Till	59.99	31.53	8.46	0	2.41	29.23	15.1	13.25	10.62	4.79	5.55	5.48	5.09	8.46	
14-ASM-0929	700759	4911869	Newmarket Till	57.67	33.34	9.01	0	2.84	28.3	14.97	11.56	10.29	5.08	6.23	6.32	5.42	9.01	
14-ASM-0930	705862	4917745	Newmarket Till	59.76	32.63	7.61	0	2.83	31.15	13.26	12.52	11.39	5.23	5.83	5.49	4.69	7.61	
14-ASM-0931	702035	4908292	Newmarket Till	47.29	44.36	8.36	0	2.54	21.94	13.14	9.67	10.88	7.62	10.77	9.09	6	8.36	
14-ASM-0932	707338	4912413	Newmarket Till	69.14	23.15	7.69	0	1.91	24	24.74	18.49	9.53	3.14	3.37	3.5	3.61	7.69	
14-ASM-0933	716687	4916683	Newmarket Till	71.72	27.21	1.07	0	1.97	25.1	25.54	19.11	12.72	4.81	4.75	3.06	1.87	1.07	
14-ASM-0934	718579	4915677	Newmarket Till	48.69	41.53	9.8	0	2.65	20.73	13.63	11.68	12.77	6.62	8.29	7.83	6.02	9.8	
14-ASM-0935	711202	4922369	Newmarket Till	60.39	34.24	5.34	0	3.07	35.35	11.93	10.04	11.18	6.17	7.05	5.71	4.13	5.34	
14-ASM-0937	724168	4930773	Dummer Till	69.57	28.34	2.12	0	2.93	37.25	15.09	14.3	11.32	5.09	5.19	4.07	2.67	2.12	
14-ASM-0938	729246	4926036	Dummer Till	66.58	32.26	1.16	0	3.18	34.63	14.27	14.5	13.96	6.2	5.9	3.93	2.27	1.16	
14-ASM-0939	733542	4926119	Dummer Till	70.83	26.96	2.2	0	4.33	38.22	12.96	9.15	6.17	8.5	5.92	4.67	2.82	2.2	
14-ASM-0940	736756	4928992	Dummer Till	76.56	22.75	0.69	0	3.2	47.24	13.95	12.17	9.53	4.34	4.24	2.87	1.77	0.69	
14-ASM-0941	737352	4928141	Dummer Till	74.65	25.37	0	0	2.55	31.63	22.22	18.25	12.31	4.23	4.15	2.97	1.71	0	
14-ASM-0942	725960	4922560	Newmarket Till	53.57	37.15	9.28	0	1.86	20.02	18.03	13.66	11.62	5.24	6.98	7.4	5.91	9.28	
14-ASM-0943	724913	4924554	Dummer Till	83.09	16.9	0	0	2.33	35.12	23.97	21.67	10.9	2.78	2.14	1.08	0	0	
14-ASM-0944	724305	4924353	Dummer Till - bedrock interface	75.81	21.35	2.85	0	5.86	44.62	11.57	8.32	5.44	6.84	4.34	3.71	2.74	2.85	
14-ASM-0945	723869	4924105	Dummer/Newmarket transition	50.04	40.06	9.93	0	2.49	19.77	15.3	12.48	15.16	7.23	6.75	5.8	5.12	9.93	
14-ASM-0947	723471	4921790	Newmarket Till	56.59	35.27	8.14	0	2.28	25.19	16.56	12.56	11.65	5.81	6.69	6.11	5.01	8.14	
14-ASM-0948	724010	4920391	Newmarket Till	54.51	34.49	11.01	0	3.12	26.26	13.79	11.34	10.01	5.46	6.67	6.61	5.74	11.01	
14-ASM-0951	717943	4905274	Newmarket Till	54.36	36	9.65	0	2.76	25.19	14.26	12.15	11.06	5.61	6.88	6.8	5.65	9.65	
14-ASM-0952	720920	4905645	Newmarket Till	35.08	52.76	12.17	0	0.41	9.87	14.67	10.13	13.35	8.77	11.44	11.13	8.07	12.17	
14-ASM-0953	721638	4903831	Newmarket Till	40.37	45.69	13.91	0	0.37	13.22	16.62	10.16	11.79	6.85	9.29	9.89	7.87	13.91	
14-ASM-0954	723031	4907180	Newmarket Till	53.06	39.47	7.47	0	2.39	22.94	16.08	11.65	12.33	6.95	8.21	6.94	5.04	7.47	
14-ASM-0955	720535	4905894	Newmarket Till	38.17	47.18	14.65	0	0.36	11.24	16.6	9.97	12.23	6.78	9.46	10.44	8.27	14.65	

Sample #	UTM (NAD 83)		Material Type	Summary			% Granules	% Very coarse sand	% Coarse Sand	% Medium sand	% Fine sand	% Very fine sand	% coarse silt	% Coarse silt	% Medium silt	% Fine silt	% Very fine Silt	% Clay
	Eastings	Northings		% Sand	% Silt	% Clay												
14-ASM-0956	718074	4909094	Newmarket Till	47.3	44.13	8.57	0	2.34	18.54	13.89	12.53	13.89	7.31	9.22	8.07	5.64	8.57	
14-ASM-0957	719286	4912521	Newmarket Till	56.17	35.91	7.93	0	2.43	27.43	14.66	11.65	11.1	5.47	6.87	7	5.47	7.93	
14-ASM-0958	725311	4916366	Newmarket Till	54.76	36.09	9.17	0	2.87	27.33	13.21	11.35	11.03	5.48	6.78	6.99	5.81	9.17	
14-ASM-0959	729776	4919108	Newmarket Till	62.43	29.87	7.73	0	2.48	30.4	16.44	13.11	10.22	4.59	5.17	5.15	4.74	7.73	
14-ASM-0960	735397	4922164	Dummer Till	65.1	32.82	2.09	0	2.76	34.89	14.38	13.07	13.29	6.31	6.29	4.36	2.57	2.09	
14-ASM-0961	737729	4922870	Dummer Till	59.08	35.2	5.7	0	3.53	38.21	9.09	8.25	10.07	6.18	7.58	6.64	4.73	5.7	
14-ASM-0962	736297	4919222	Dummer Till	39.24	51.57	9.2	0	0.45	17.3	14.19	7.3	11.64	8.74	12.29	11.33	7.57	9.2	
14-ASM-0963	733642	4918173	Newmarket Till	62.16	30.38	7.46	0	1.84	25.58	18.44	16.3	12.34	4.76	4.8	4.41	4.07	7.46	
14-ASM-0964	731667	4915589	Newmarket Till	53.05	37.43	9.54	0	1.91	21.5	15.9	13.74	12.99	5.83	6.86	6.43	5.32	9.54	
14-ASM-0965	724310	4910867	Newmarket Till	55.42	36.04	8.53	0	2.77	26.17	14.38	12.1	11.21	5.44	6.99	6.95	5.45	8.53	
14-ASM-0969	733059	4912220	Newmarket Till	53.82	35.15	11.04	0	3	24.35	14.45	12.02	11.28	5.2	6.46	6.52	5.69	11.04	
14-ASM-0972	739416	4905608	Newmarket Till	83.83	16.18	0	0	13.99	31.74	23.95	14.15	8.44	2.43	2.22	1.72	1.37	0	
14-ASM-0973	737403	4905368	Newmarket Till	61.57	32.15	6.3	0	1.9	22.95	20.28	16.44	12.73	4.89	5.34	4.96	4.23	6.3	
14-ASM-0977	706456	4905627	Newmarket Till	48.69	39.25	12.06	0	0.34	14.24	20.43	13.68	12.7	5.62	6.94	7.55	6.44	12.06	
14-ASM-1002	703220	4920160	Newmarket Till	59.75	35.82	4.43	0	2.92	26.74	15.99	14.1	13.29	6.12	6.71	5.67	4.03	4.43	
14-ASM-1058	714332	4927451	Newmarket Till	69.91	26.69	3.42	0	2.21	37.01	16.74	13.95	10.84	4.31	4.39	3.89	3.26	3.42	
14-ASM-1070	731676	4915557	Newmarket Till	56.64	35.58	7.79	0	2.89	25.76	14.71	13.28	12.15	6.05	6.83	5.89	4.66	7.79	
14-ASM-1073	733040	4912245	Newmarket Till	46.73	43.15	10.12	0	0.34	12.84	20.37	13.18	13.44	6.82	8.25	8.11	6.53	10.12	

Appendix 2.

Carbonate Analyses of Till Samples

This complete set of carbonate analyses is available in Miscellaneous Release—Data 333 (Marich 2016c).

BDL = below detection limit

N/A = not applicable

Sample ID	Easting	Northing	% Calcite	% Dolomite	% Total Carbonate	Calcite/Dolomite	Sediment Type
13-ASM-0133	659302	4924338	49.04	4.08	53.12	12.02	Newmarket Till
13-ASM-0172	663239	4929251	51.86	4.53	56.39	11.45	Newmarket Till
13-ASM-0206	662803	4910456	36.27	4.08	40.34	8.89	Newmarket Till
13-ASM-0252	668022	4913972	50.12	0.91	51.03	55.08	Newmarket Till
13-ASM-0299	672971	4918710	37.7	3.63	41.33	10.39	Newmarket Till
13-ASM-0421	666680	4918998	48.34	3.85	52.19	12.56	Newmarket Till
13-ASM-0444	661518	4906993	35.39	2.49	37.88	14.21	Newmarket Till
13-ASM-0502	668407	4904970	44.93	0.68	45.61	66.07	Newmarket Till
13-ASM-0534	673048	4903680	55.14	5.44	60.58	10.14	Newmarket Till
13-ASM-0549	673388	4902346	39.97	6.12	46.08	6.53	Newmarket Till
13-ASM-0686	686500	4902681	38.27	1.36	39.63	28.14	Newmarket Till
13-ASM-0815	684418	4919589	53.64	1.59	55.23	33.74	Newmarket Till
13-ASM-0862	690277	4926304	40.02	4.76	44.78	8.41	Newmarket Till
13-ASM-1144	689290	4924771	57.35	3.4	60.75	16.87	Newmarket Till
13-ASM-1151	661132	4926335	39.34	1.25	40.59	31.47	Newmarket Till
13-ASM-1171	676760	4927733	28.63	7.62	36.25	3.76	Newmarket Till
13-ASM-1172	678989	4925416	41.14	3.51	44.65	11.72	Newmarket Till
13-ASM-1173	660650	4919835	50.63	BDL	50.63	N/A	Newmarket Till
13-ASM-1174	662292	4919338	33.98	2.27	36.24	14.97	Newmarket Till
13-ASM-1176	664095	4922226	50.22	4.31	54.52	11.65	Newmarket Till
13-ASM-1178	667615	4922772	35.11	6.66	41.77	5.27	Newmarket Till
13-ASM-1179	660719	4916353	44.08	6.64	50.71	6.64	Newmarket Till
13-ASM-1181	666127	4917373	40.49	2.14	42.63	18.92	Newmarket Till
13-ASM-1182	658845	4913353	41.77	2.49	44.27	16.78	Newmarket Till
13-ASM-1189	659847	4903266	33.26	8.16	41.41	4.08	Newmarket Till
13-ASM-1196	662248	4902423	33.64	4.53	38.18	7.43	Newmarket Till
13-ASM-1204	663826	4907461	43.92	2.14	46.06	20.52	Newmarket Till
13-ASM-1215	673504	4905310	50.39	0.09	50.48	559.89	Newmarket Till
13-ASM-1218	671417	4911512	45.06	3.04	48.1	14.82	Newmarket Till
13-ASM-1251	669855	4905483	57.29	4.81	62.1	11.91	Newmarket Till
13-ASM-1264	674158	4908438	44.56	3.15	47.72	14.15	Newmarket Till
13-ASM-1266	675832	4908954	43.68	1.8	45.48	24.27	Newmarket Till
13-ASM-1270	679284	4909039	14.05	1.58	15.63	8.89	Newmarket Till
13-ASM-1275	677304	4910533	55.58	4.06	59.64	13.69	Newmarket Till
13-ASM-1277	674688	4909724	52.3	3.76	56.06	13.91	Newmarket Till
13-ASM-1278	673943	4911959	44.83	2.38	47.21	18.84	Newmarket Till
13-ASM-1279	674991	4902779	47.42	2.39	49.81	19.84	Newmarket Till
13-ASM-1284	683215	4908288	53.55	1.96	55.51	27.32	Newmarket Till
13-ASM-1287	687157	4903156	49.72	1.44	51.16	34.53	Newmarket Till
13-ASM-1294	690792	4911193	50.74	5.27	56	9.63	Newmarket Till

Sample ID	Easting	Northing	% Calcite	% Dolomite	% Total Carbonate	Calcite/Dolomite	Sediment Type
13-ASM-1296	690570	4908935	49.85	0.45	50.3	110.78	Newmarket Till
13-ASM-1297	698179	4908587	50.43	3.38	53.81	14.92	Newmarket Till
13-ASM-1301	697326	4904382	44.96	4.96	49.91	9.06	Newmarket Till
13-ASM-1303	698406	4910916	49.51	2.93	52.44	16.90	Newmarket Till
13-ASM-1307	693115	4913522	43.73	0.57	44.3	76.72	Newmarket Till
13-ASM-1314	692306	4917931	51.67	1.95	53.62	26.50	Newmarket Till
13-ASM-1315	683158	4923454	40.99	4.18	45.17	9.81	Newmarket Till
13-ASM-1316	692292	4927963	41.79	1.92	43.72	21.77	Newmarket Till
13-ASM-1328	694558	4923114	38.65	1.01	39.66	38.27	Newmarket Till
13-ASM-1329	688245	4920796	49.48	4.83	54.32	10.24	Newmarket Till
13-ASM-1330	695446	4917357	48.48	2.85	51.33	17.01	Newmarket Till
14-ASM-0925	703831	4922233	40.46	2.71	43.18	14.93	Newmarket Till
14-ASM-0926	707606	4924292	36.37	4.74	41.11	7.67	Newmarket Till
14-ASM-0929	700759	4911869	48.13	BDL	48.13	N/A	Newmarket Till
14-ASM-0930	705862	4917745	38.61	1.81	40.42	21.33	Newmarket Till
14-ASM-0931	702035	4908292	46.6	2.71	49.31	17.20	Newmarket Till
14-ASM-0932	707338	4912413	42.8	14.46	57.27	2.96	Newmarket Till
14-ASM-0933	716687	4916683	44.34	0.23	44.57	192.78	Newmarket Till
14-ASM-0934	718579	4915677	52.34	0.9	53.24	58.16	Newmarket Till
14-ASM-0935	711202	4922369	38.88	1.13	40.01	34.41	Newmarket Till
14-ASM-0937	724168	4930773	27.9	0.37	28.28	75.41	Dummer Till
14-ASM-0938	729246	4926036	52.97	0.76	53.72	69.70	Dummer Till
14-ASM-0939	733542	4926119	60.73	1.87	62.59	32.48	Dummer Till
14-ASM-0940	736756	4928992	58.44	1.58	60.02	36.99	Dummer Till
14-ASM-0941	737352	4928141	34.4	1.13	35.53	30.44	Dummer Till
14-ASM-0942	725960	4922560	41.22	1.58	42.8	26.09	Newmarket Till
14-ASM-0943	724913	4924554	19.43	3.62	23.05	5.37	Dummer Till
14-ASM-0944	724305	4924353	54.25	0.23	54.48	235.87	Dummer Till-bedrock interface
14-ASM-0945	723869	4924105	31.59	0.45	32.05	70.20	Dummer/Newmarket transition
14-ASM-0947	723471	4921790	35.37	0.45	35.82	78.60	Newmarket Till
14-ASM-0948	724010	4920391	41.95	1.12	43.08	37.46	Newmarket Till
14-ASM-0951	717943	4905274	60.53	0.96	61.49	63.05	Newmarket Till
14-ASM-0952	720920	4905645	41.27	8.84	50.11	4.67	Newmarket Till
14-ASM-0953	721638	4903831	36.2	5.66	41.86	6.40	Newmarket Till
14-ASM-0954	723031	4907180	43.16	3.4	46.55	12.69	Newmarket Till
14-ASM-0955	720535	4905894	47.36	4.76	52.12	9.95	Newmarket Till
14-ASM-0956	718074	4909094	55.25	2.72	57.97	20.31	Newmarket Till
14-ASM-0957	719286	4912521	47.4	3.85	51.25	12.31	Newmarket Till
14-ASM-0958	725311	4916366	48.49	0.23	48.72	210.83	Newmarket Till
14-ASM-0959	729776	4919108	28.32	1.81	30.13	15.65	Newmarket Till
14-ASM-0960	735397	4922164	62.22	0.23	62.44	270.52	Dummer Till
14-ASM-0961	737729	4922870	70.3	0.19	70.49	370.00	Dummer Till
14-ASM-0962	736297	4919222	51.92	3.17	55.09	16.38	Dummer Till

Sample ID	Easting	Northing	% Calcite	% Dolomite	% Total Carbonate	Calcite/Dolomite	Sediment Type
14-ASM-0963	733642	4918173	41.15	0.45	41.6	91.44	Newmarket Till
14-ASM-0964	731667	4915589	55.36	BDL	55.36	N/A	Newmarket Till
14-ASM-0965	724310	4910867	46.19	4.31	50.5	10.72	Newmarket Till
14-ASM-0969	733059	4912220	52.45	1.81	54.26	28.98	Newmarket Till
14-ASM-0972	739416	4905608	29.26	1.81	31.08	16.17	Newmarket Till
14-ASM-0973	737403	4905368	38.06	0.8	38.86	47.58	Newmarket Till
14-ASM-0977	706456	4905627	51.05	1.21	52.27	42.19	Newmarket Till
14-ASM-1002	703220	4920160	34.64	4.16	38.8	8.33	Newmarket Till
14-ASM-1058	714332	4927451	31.5	2.71	34.21	11.62	Newmarket Till
14-ASM-1070	731676	4915557	50.6	0.76	51.36	66.58	Newmarket Till
14-ASM-1073	733040	4912245	54.16	0.53	54.69	102.19	Newmarket Till

Appendix 3.

Pebble Lithology Analyses of Till Samples

The complete set of pebble lithology data is available in Miscellaneous Release—Data 333 (Marich 2016c).

Composition abbreviations:

% LS = % limestone

% SS = % sandstone

Sample	Easting	Northing	% LS	% Granite	% Gneiss	% Diorite	% SS	% Quartz	% Gabbro	% Other	Comment
14-ASM-0925	703831	4922233	90.8	6.6	0.0	0.0	1.3	1.3	1.7	1.7	Angular to subangular, mode angular; some striated
14-ASM-0926	707606	4924292	91.9	1.6	0.0	3.2	3.2	0.0	0.0	0.0	Subangular to subrounded, mode subangular; some striate, polished, faceted, bulleted.
14-ASM-0929	700759	4911869	91.3	7.2	0.0	0.0	1.4	0.0	0.0	0.0	Angular to subangular, mode angular; calcium carbonate coating on clasts
14-ASM-0930	705862	4917745	91.0	4.5	0.0	0.0	3.0	0.0	0.0	0.0	Subangular to subrounded, mode subrounded; some polished, striated, faceted
14-ASM-0931	702035	4908292	93.9	3.0	0.0	0.0	1.5	0.0	0.0	0.0	Angular to subangular, mode angular
14-ASM-0932	707338	4912413	94.0	3.0	0.0	1.5	1.5	0.0	0.0	0.0	Angular to subangular, mode subangular
14-ASM-0933	716687	4916683	95.3	0.0	0.0	4.7	0.0	0.0	0.0	0.0	Angular to subangular, mode subangular; highly fossiliferous.
14-ASM-0934	718579	4915677	96.6	3.4	0.0	0.0	0.0	0.0	0.0	0.0	Subrounded to rounded; mode subrounded.
14-ASM-0935	711202	4922369	95.9	4.1	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode subangular; some polished, striated.
14-ASM-0937	724168	4930773	93.7	4.8	0.0	0.0	0.0	0.0	0.0	0.0	Angular to subrounded, mode subangular; some polished, striated.
14-ASM-0938	729246	4926036	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded, mode subrounded; some polished, striated, bulleted
14-ASM-0939	733542	4926119	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Angular to subangular; mode subangular
14-ASM-0940	736756	4928992	98.6	1.4	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded; mode subangular; polished, striated
14-ASM-0941	737352	4928141	96.1	2.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode rounded; calcium carbonate cement; polished, striated
14-ASM-0942	725960	4922560	88.4	4.3	0.0	7.2	0.0	0.0	0.0	0.0	Subrounded to rounded, mode subrounded; polished, striated, faceted
14-ASM-0943	724913	4924554	93.8	4.2	0.0	2.1	0.0	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished and striated
14-ASM-0944	724305	4924353	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, striated, faceted; calcium carbonate cement on some clasts
14-ASM-0945	723869	4924105	86.8	3.8	0.0	3.8	1.9	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, striated, faceted
14-ASM-0947	723471	4921790	96.4	0.0	0.0	0.0	1.8	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, faceted, striated
14-ASM-0948	724010	4920391	90.9	7.3	0.0	1.8	0.0	0.0	0.0	0.0	Subangular to subrounded, mode subangular; some polished, faceted, striated
14-ASM-0951	717943	4905274	96.7	1.6	0.0	1.6	0.0	0.0	0.0	0.0	Subangular to subrounded, mode subrounded; some polished, striated, faceted

Sample	Easting	Northing	% LS	% Granite	% Gneiss	% Diorite	% SS	% Quartz	% Gabbro	% Other	Comment
14-ASM-0952	720920	4905645	95.9	2.7	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode subangular; some polished, faceted, striated
14-ASM-0953	721638	4903831	92.2	3.9	0.0	3.9	0.0	0.0	0.0	0.0	Subangular to rounded, mode subangular; some polished, striated, faceted
14-ASM-0954	723031	4907180	91.5	4.3	0.0	4.3	0.0	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, faceted, striated; calcium carbonate
14-ASM-0955	720535	4905894	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Angular to rounded, mode subrounded; some polished, striated, faceted
14-ASM-0956	718074	4909094	92.8	2.9	0.0	4.3	0.0	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, faceted, striated
14-ASM-0957	719286	4912521	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode rounded; some polished, faceted, striated; calcium carbonate cement on surface of some clasts
14-ASM-0958	725311	4916366	96.9	1.5	0.0	1.5	0.0	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, striated, faceted
14-ASM-0959	729776	4919108	95.5	4.5	0.0	0.0	0.0	0.0	0.0	0.0	Angular to subrounded, mode subangular; some polished, faceted, striated, and bulleted
14-ASM-0960	735397	4922164	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Angular to subangular, mode angular; occasional striate, polished and faceted clasts
14-ASM-0961	737729	4922870	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, faceted, striated; some calcium carbonate cement on clasts
14-ASM-0962	736297	4919222	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded; mode subrounded; calcium carbonate cement on some clasts; occasional faceted, polished clasts
14-ASM-0963	733642	4918173	98.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, faceted, striated
14-ASM-0964	731667	4915589	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode subangular; some polished, striated, faceted, bulleted
14-ASM-0965	724310	4910867	94.7	5.3	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, faceted, striated, bulleted
14-ASM-0969	733059	4912220	93.8	4.2	2.1	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, faceted, striated, bulleted
14-ASM-0971	738061	4910041	83.3	9.1	0.0	7.6	0.0	0.0	0.0	0.0	Subangular to rounded, mode rounded; some polished, faceted, striated, bulleted
14-ASM-0972	739416	4905608	90.9	4.5	0.0	0.0	4.5	0.0	0.0	0.0	Subangular to subrounded, mode subangular; some polished, faceted, bulleted, striated
14-ASM-0973	737403	4905368	91.3	2.2	0.0	2.2	4.3	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, faceted, striated, bulleted

Sample	Easting	Northing	% LS	% Granite	% Gneiss	% Diorite	% SS	% Quartz	% Gabbro	% Other	Comment
14-ASM-0977	706456	4905627	92.9	7.1	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, faceted, bulleted, striated
14-ASM-1002	703220	4920160	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to rounded, mode subrounded; some polished, faceted, striated, bulleted
14-ASM-1058	714332	4927451	93.3	6.7	0.0	0.0	0.0	0.0	0.0	0.0	Angular to rounded, mode subangular; some polished, faceted, striated, bulleted
14-ASM-1070	731676	4915557	97.3	1.3	0.0	0.0	1.3	0.0	0.0	0.0	Angular to rounded, mode subrounded; some polished, faceted, bulleted, striated
14-ASM-1073	733040	4912245	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Angular to subrounded, mode subrounded; some polished, faceted, striated, bulleted
13-ASM-1157	665491	4929026	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1171	676760	4927733	94.4	5.6	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1172	678989	4928416	99.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1173	660650	4919835	96.8	3.2	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1174	662292	4919388	99.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1176	664095	4922226	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1178	667615	4922772	94.4	3.3	0.0	0.0	2.2	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1179	660719	4916353	94.9	5.1	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1181	666127	4917373	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1182	658845	4913353	94.6	4.3	0.0	0.0	0.0	0.0	1.1	0.0	Angular to subangular
13-ASM-1189	659847	4903266	81.2	13.0	0.0	0.0	5.8	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1196	662248	4902423	88.5	7.7	0.0	0.0	1.9	0.0	1.9	0.0	Subangular to subrounded
13-ASM-1204	663826	4907461	93.4	6.6	0.0	0.0	0.0	0.0	0.0	0.0	Angular to subangular
13-ASM-1215	673504	4905310	93.3	6.7	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1218	671417	4911512	97.5	1.2	0.0	0.0	0.0	0.0	1.2	0.0	Subangular to subrounded mode subangular
13-ASM-1251	669855	4905483	95.3	4.7	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1264	674158	4908438	96.4	0.0	0.0	1.2	2.4	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1266	675832	4908954	97.6	2.4	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1270	679284	4909039	96.8	3.2	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1275	677304	4910533	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1277	674688	4909724	95.9	2.7	0.0	0.0	1.4	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1278	673943	4911959	96.9	3.1	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded mode subangular
13-ASM-1279	674991	4902779	97.6	1.2	0.0	0.0	0.0	1.2	0.0	0.0	Angular to subangular mode angular

Sample	Easting	Northing	% LS	% Granite	% Gneiss	% Diorite	% SS	% Quartz	% Gabbro	% Other	Comment
13-ASM-1284	683215	4908288	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
13-ASM-1287	687157	4903156	95.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded mode subrounded
13-ASM-1294	690792	4911193	99.1	0.9	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded mode subrounded
13-ASM-1296	690570	4908935	94.7	3.9	0.0	0.0	0.0	0.0	0.0	1.3	Subangular to subrounded
13-ASM-1297	698179	4908587	84.8	10.1	0.0	0.0	0.0	0.0	0.0	5.1	Subangular to subrounded mode subrounded
13-ASM-1301	697326	4904382	89.6	10.4	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded mode subrounded
13-ASM-1303	698406	4910916	92.9	5.7	0.0	1.4	0.0	0.0	0.0	0.0	Subangular to subrounded
13-ASM-1307	693115	4913522	98.9	0.0	0.0	0.0	0.0	0.0	1.1	0.0	Subangular to subrounded mode subangular
13-ASM-1314	692306	4917931	96.8	3.2	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded mode subangular
13-ASM-1315	683158	4923454	91.2	7.7	0.0	0.0	1.1	0.0	0.0	0.0	Subangular to subrounded mode subrounded
13-ASM-1316	692292	4927963	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Subangular to subrounded mode subangular
13-ASM-1328	694558	4923114	96.5	1.2	0.0	0.0	1.2	0.0	0.0	1.2	Subangular to subrounded mode subrounded
13-ASM-1329	688245	4920796	97.8	1.1	1.1	0.0	0.0	0.0	0.0	0.0	Subrounded to rounded mode subrounded

Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	Multiplied by	Gives	Imperial Unit	Multiplied by	Gives
LENGTH					
1 mm	0.039 37	inches	1 inch	25.4	mm
1 cm	0.393 70	inches	1 inch	2.54	cm
1 m	3.280 84	feet	1 foot	0.304 8	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	1.609 344	km
AREA					
1 cm ²	0.155 0	square inches	1 square inch	6.451 6	cm ²
1 m ²	10.763 9	square feet	1 square foot	0.092 903 04	m ²
1 km ²	0.386 10	square miles	1 square mile	2.589 988	km ²
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
VOLUME					
1 cm ³	0.061 023	cubic inches	1 cubic inch	16.387 064	cm ³
1 m ³	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m ³
1 m ³	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m ³
CAPACITY					
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	4.546 090	L
MASS					
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	31.103 476 8	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	0.453 592 37	kg
1 kg	0.001 102 3	tons (short)	1 ton(short)	907.184 74	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	0.907 184 74	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	1016.046 908 8	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	1.016 046 9	t
CONCENTRATION					
1 g/t	0.029 166 6	ounce (troy) / ton (short)	1 ounce (troy) / ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights / ton (short)	1 pennyweight / ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors in **bold** type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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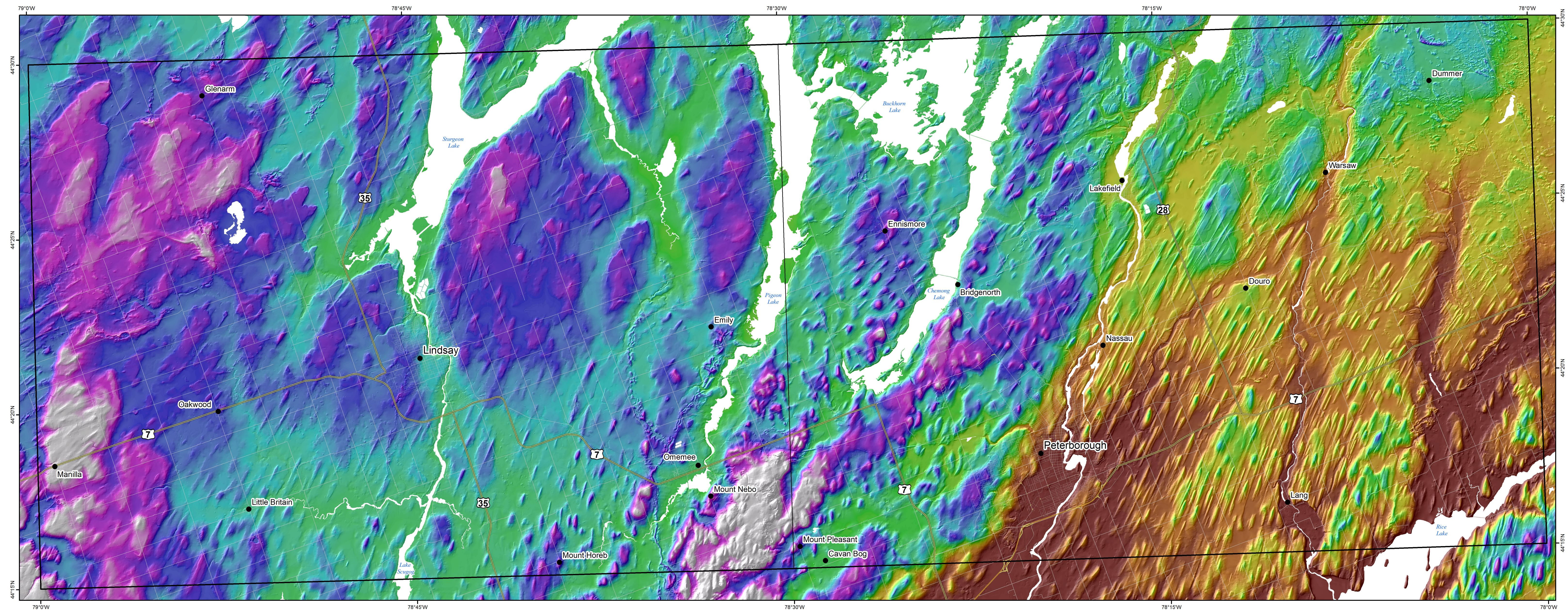
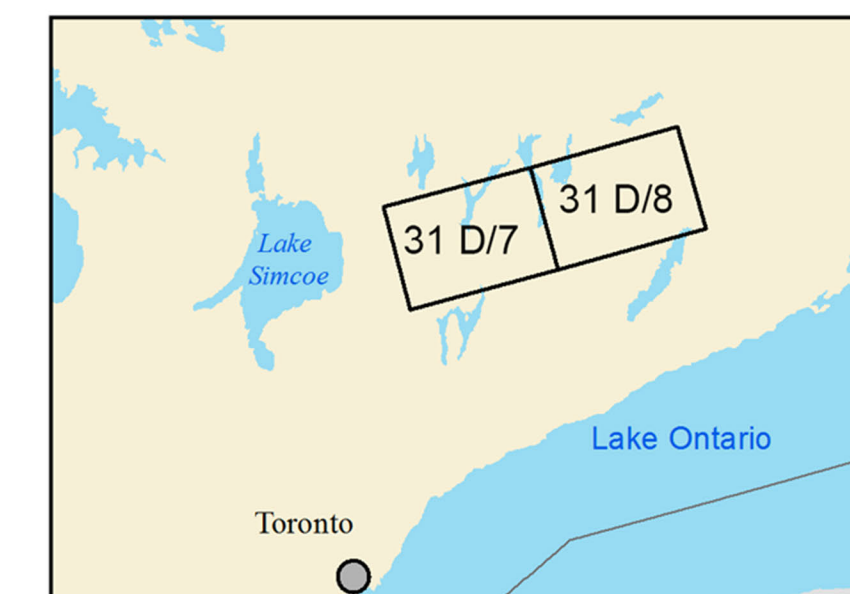
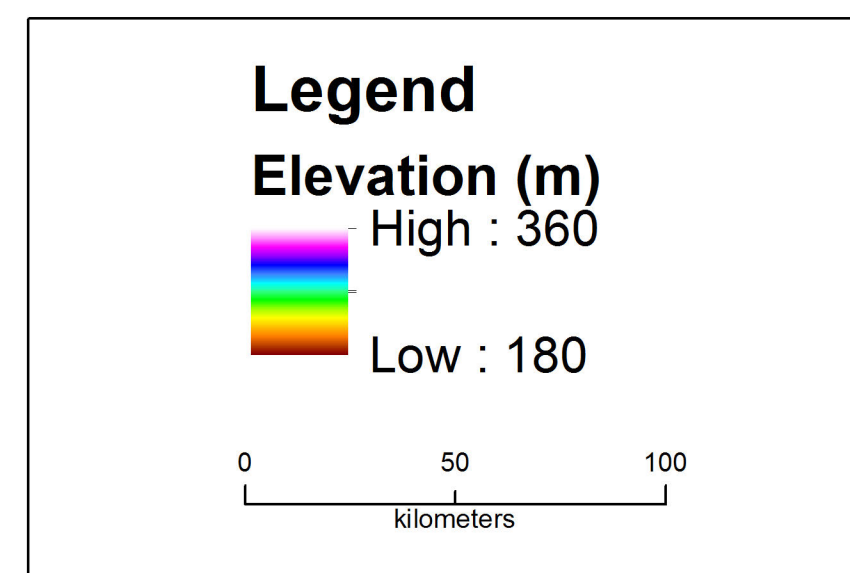
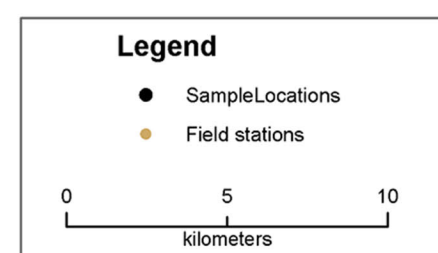
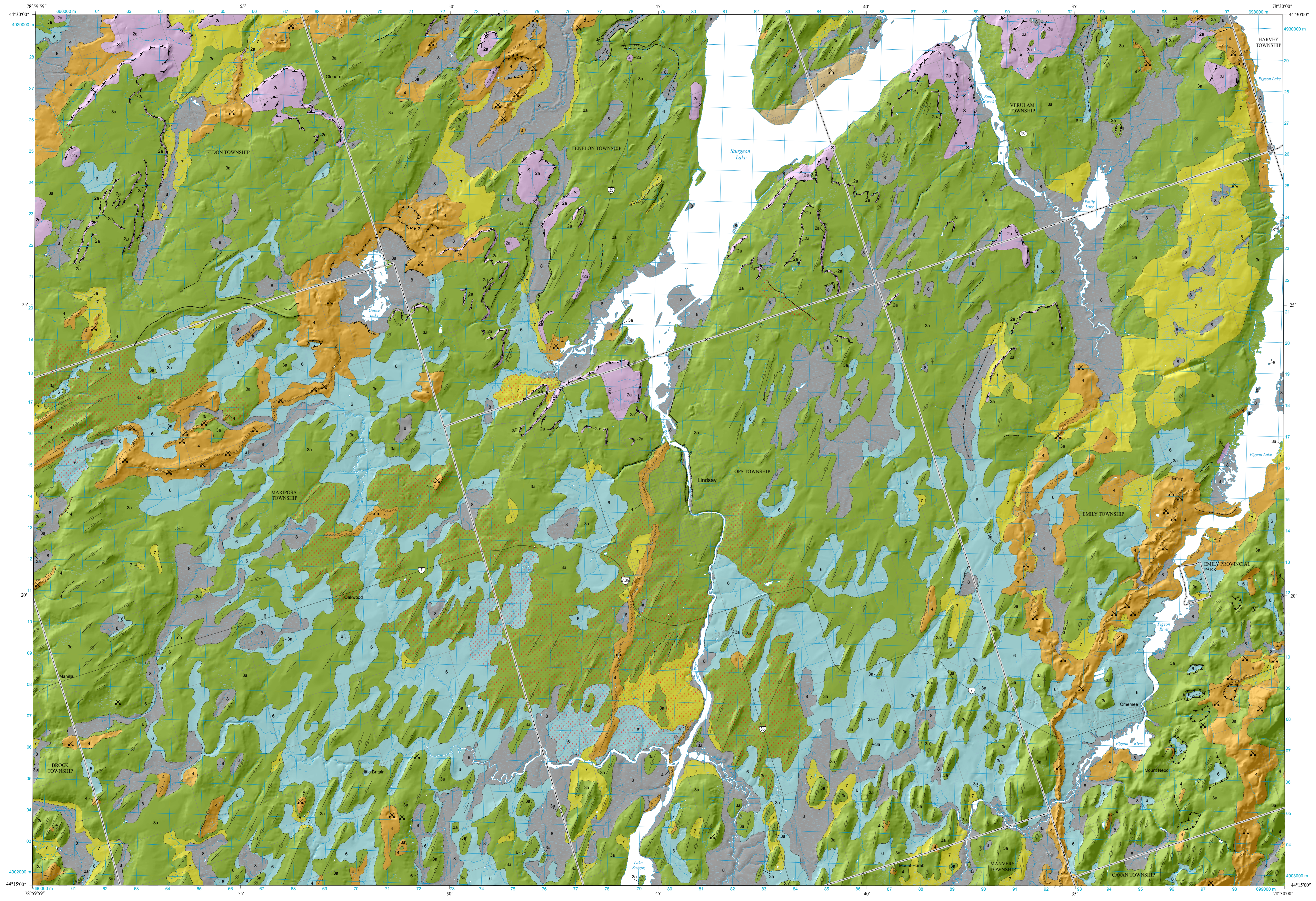


Figure 4. Hillshaded digital elevation model of the Lindsay–Peterborough study area, southern Ontario. This map accompanies OFR 6321.



Figure 1. Map of field and sample locations in the Lindsay–Peterborough mapping area, southern Ontario. This map accompanies OFR 6321.

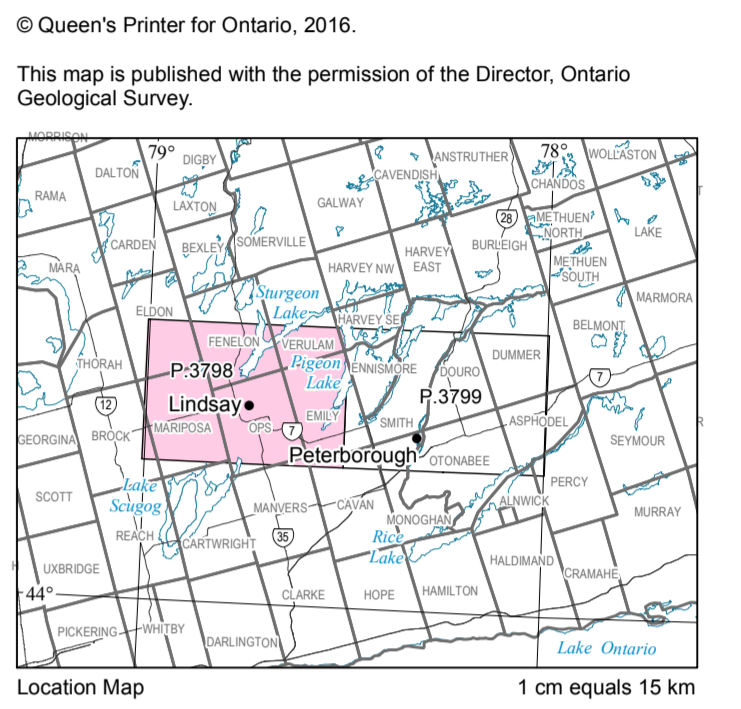




Ontario Geological Survey
MAP P.3798

QUATERNARY GEOLOGY
LINDSAY AREA,
SOUTHERN ONTARIO

Scale 1:50 000
1 000 m 0 1 2 km
NTS Reference: 31 D/7



- LEGEND**
- PHANEROZOIC**
- CENOZOIC**
- QUATERNARY**
- RECENT**
- 8 Organic and Swamp Deposits
Peat and muck
- PLEISTOCENE**
- 7 Foreshore and Basinal Glaciolacustrine Deposits
Very-fine to medium-textured sand, minor silt and gravel
 - 6 Fine-Textured Glaciolacustrine Deposits
Massive to well-laminated, silt and clay, minor sand, minor gravel
 - 5 Glaciofluvial Outwash Deposits
Sand and gravel
5a Mainly sand
5b Mainly sandy gravel and gravel
 - 4 Ice-Contact Stratified Deposits
In moraines, kames, eskers and crevasse fills; fine- to coarse-textured sand, gravel, minor silt and clay
 - 3 Till
Glacial deposit, massive with varying amounts of sand, silt, clay, and gravel
 - 3a Newmarket Till: Stone-poor, carbonate-derived silty to sandy till, may contain beds, lenses and stringers of sand and silt
 - 3b Dummer Till: Stony, carbonate-derived silty to sandy till, may contain beds, lenses and stringers of sand and silt
- PALEOZOIC**
- ORDOVICIAN**
- 1 Bedrock
Undifferentiated bedrock with a very thin discontinuous cover of Quaternary sediment

- SYMBOLS**
- Small bedrock outcrop
 - Geological contact (approximate)
 - Ice-contact slope
 - Minor moraine crest
 - Esker crest (direction of flow known, unknown)
 - Meltwater channel (direction of meltwater flow known, unknown)
 - Terrace
 - Bedrock escarpment
 - Drumlin
 - Hummocky surface topography
 - Glacial striae (direction of ice movement known, unknown)
 - Sand and gravel pit
 - Quarry
 - Administrative boundary (Indian Reserve, provincial park, township)
 - Utilities (pipeline, gas)
 - Roads (primary, secondary, trails)

SOURCES OF INFORMATION

Base map information derived from the Land Information Ontario Data Warehouse, Land Information Ontario, Ministry of Natural Resources and Forestry, scale 1:50 000, with modifications by staff of the Ministry of Northern Development and Mines.

Orthorectified and hillshaded digital elevation model obtained from the Ontario Ministry of Natural Resources and Forestry, 2014.

Mapping conducted using UTM co-ordinates in North American Datum 1983 (NAD83), Zone 17.

This map is associated with the following publications:

Marich, A.S. 2016. Quaternary geology of the Lindsay and Peterborough areas, southern Ontario, Ontario Geological Survey, Open File Report 6321, 59p.

Marich, A.S. 2016. Results of till sample analyses of the Lindsay and Peterborough areas, southern Ontario, Ontario Geological Survey, Miscellaneous Release—Data 333.

Compiled geology derived from:

Armstrong, D.K. and Dodge, J.E.P. 2007. Paleozoic geology of southern Ontario, Ontario Geological Survey, Miscellaneous Release—Data 219.

Gravenor, C.P. 1957. Surficial geology of the Lindsay—Peterborough area, Ontario: Victoria, Peterborough, Durham and Northumberland counties; Geological Survey of Canada, Memoir 288, 61p.

Ontario Geological Survey 2010. Surficial geology of southern Ontario, Ontario Geological Survey, Miscellaneous Release—Data 128—Revised.

Water well records by the Ontario Ministry of the Environment and Climate Change.

Geology is not tied to survey lines.

Magnetic declination for centre of map area, approximately 11°7.56'W in 2016.

Metric conversion factor 1 foot = 0.3048 m.

CREDITS

Geological mapping by A.S. Marich, 2013 and 2014.
Field assistance provided by J.G. Vervaeke and M.A. Robinson.
Digital drafting by S. Evers.
Cartographic production by R. Corcoran.

Every possible effort has been made to ensure the accuracy of the information presented on this map; however, the Ontario Ministry of Northern Development and Mines does not assume liability for errors that may occur. Users should verify critical information.

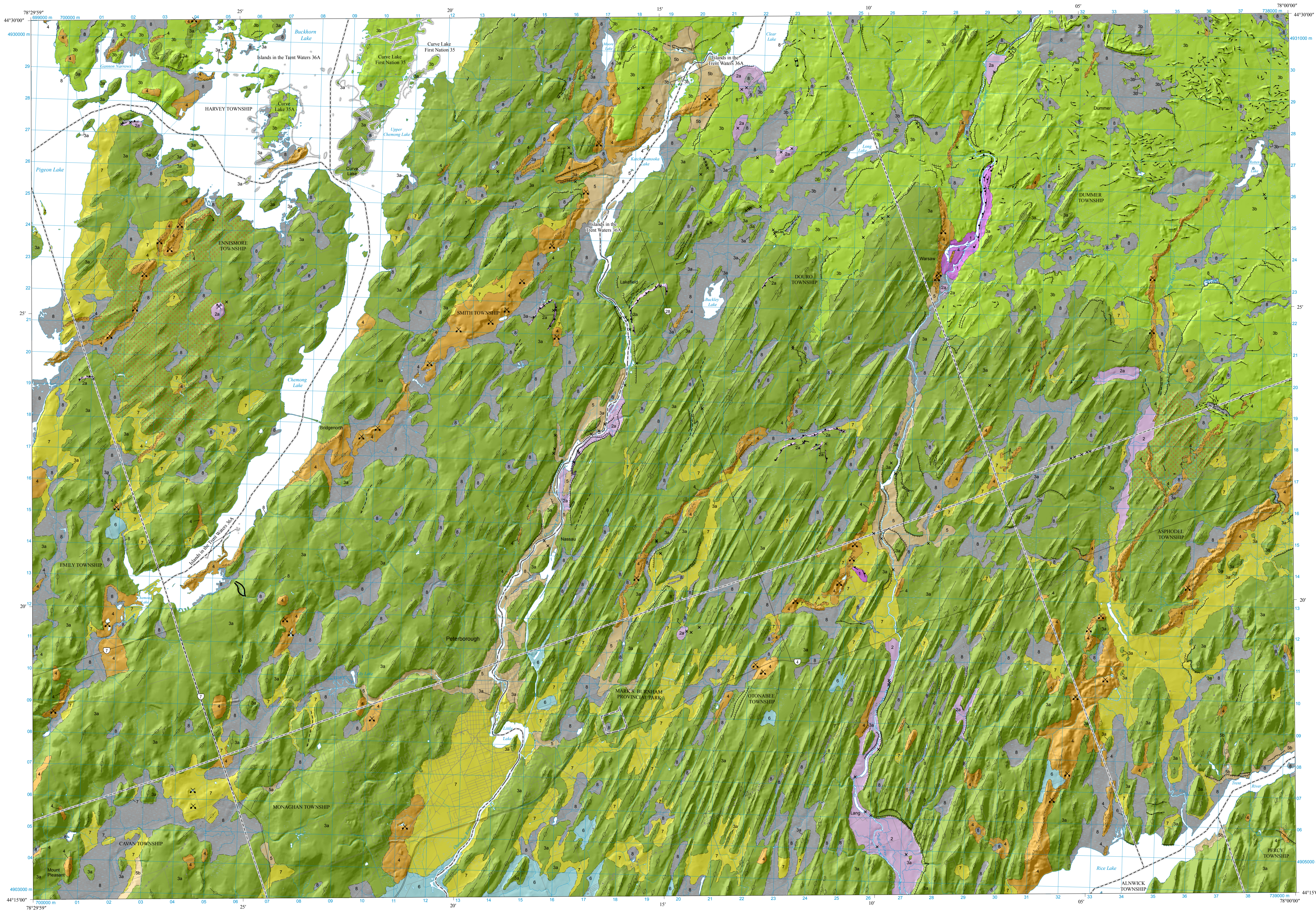
Issued 2016.

Information from this publication may be quoted if credit is given. It is recommended that reference to this map be made in the following form.

Marich, A.S. 2016. Quaternary geology, Lindsay area, southern Ontario, Ontario Geological Survey, Preliminary Map P.3798, scale 1:50 000.



Users of OGS products are encouraged to contact those Aboriginal communities whose traditional territories may be located in the mineral exploration area to discuss their project.

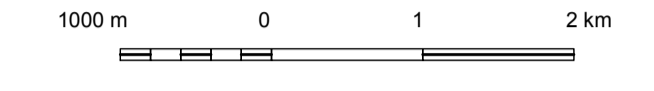


Ontario Geological Survey

MAP P.3799

QUATERNARY GEOLOGY PETERBOROUGH AREA, SOUTHERN ONTARIO

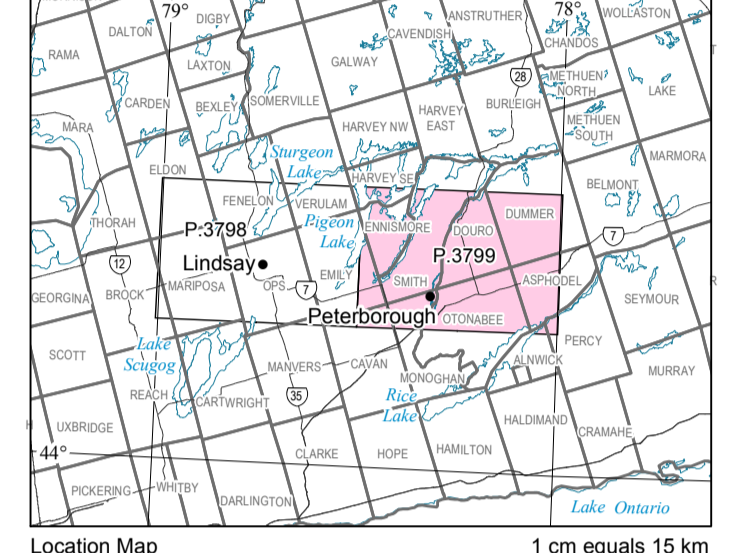
Scale 1:50 000



NTS Reference: 31 D/8

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Location Map 1 cm equals 15 km

LEGEND

PHANEROZOIC

CENOZOIC

QUATERNARY

RECENT

8 Organic and Swamp Deposits
Peat and muck

PLEISTOCENE

7 Foreshore and Basinal Glaciolacustrine Deposits
Very-fine to medium-textured sand, minor silt and gravel

6 Fine-Textured Glaciolacustrine Deposits
Massive to well-laminated, silt and clay, minor sand, minor gravel

5 Glaciolacustrine Outwash Deposits
Sand and gravel
5a Mainly sand
5b Mainly stratified gravel and gravel

4 Ice-Contact Stratified Deposits
In moraines, kames, eskers and crevasse fills; fine- to coarse-textured sand, gravel, minor silt and clay

TILL

3a Newmarket Till: stone-poor, carbonate-derived silt to sandy till; may contain beds, lenses and stringers of sand and silt

3b Dummer Till: stony, carbonate-derived silt to sandy till; may contain beds, lenses and stringers of sand and silt

Bedrock-Drift Complex

2a Minor to moderate Paleozoic bedrock exposure
2a Mainly till veneer
2b Mainly stratified veneer

PALEOZOIC

ORDOVICIAN

Bedrock
Undifferentiated bedrock with a very thin discontinuous cover of Quaternary sediment

SYMBOLS

- Small bedrock outcrop
- Geological contact (approximate)
- Slump
- Ice-contact slope
- Minor moraine crest
- Esker crest (direction of flow known, unknown)
- Meltwater channel (direction of meltwater flow known, unknown)
- Terrace
- Bedrock escarpment
- Drumlin
- Hummocky surface topography
- Glacial striae (direction of ice movement known, unknown)
- Sand and gravel pit
- Quarry
- Administrative boundary (Indian Reserve, provincial park, township)
- Utilities (pipeline, gas)
- Roads (primary, secondary)
- Railways

SOURCES OF INFORMATION

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Ontario Geological Survey 2010. Surficial geology of southern Ontario. Ontario Geological Survey, Miscellaneous Release—Data 128—Revised.

Water well records by the Ontario Ministry of the Environment and Climate Change.

Geology is not tied to survey lines.

Magnetic declination for centre of map area, approximately 11°26.6' E in 2016.

Metric conversion factor 1 foot = 0.3048 m.

CREDITS

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