LATE WISCONSIN ICE LOBE DYNAMICS: ASSESSMENT THROUGH G.I.S. SUPPORTED THREE DIMENSIONAL MAPPING AND SURFACE PHYSIOGRAPHY

by

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A Thesis

Submitted to the Department of Geography

in Partial Fulfillment of the Requirements

for the Degree

Honours Bachelor of Art

McMaster University

April, 1991

ABSTRACT

The study area is approximately 4,500 km^2 including parts of Hastings, Prince-Edward and Northumberland counties. The area was glaciated during the Late Wisconsin (20-11,800 y.b.p) by the Simcoe Lobe and the Lake Ontario Lobe of the Laurentide ice sheet. Ice activity created subsurface characteristics and surface physiography that can, therefore, be used to suggest patterns of ice flow during the Late Wisconsin.

A computer generated recreation of the bedrock topography within the area revealed two bedrock channels and other characteristics that aid in determination of ice flow patterns. Computer generated drift thickness maps exposed several packages of sediment that were also important in the creation of an ice flow model. Surface features such as drumlins, moraines and eskers provided the final link in suggesting that ice flow was actually contained by bedrock topography.

Evidence suggests, both subsurface and surface, that the Lake Ontario Lobe moved in a southwest direction following bedrock channels. For this reason it is believed that the profile of the ice in this region was thin. At one time the Simcoe Lobes and the Lake Ontario Lobe approached one-another and created the Oak Ridges Moraine. The profile of the Oak Ridges Moraine at this point extended much further than suggested by Chapman and Putnam (1984). There was then a surge of one of the Simcoe Lobes towards the south which ultimately, after ice recession, created the physiography of today.

ACKNOWLEDGEMENTS

I would like to thank several people for their support and friendship. Firstly, Jerry Hibbert for his constant imput whether it be in the form of constructive criticism, knowledge of the subject matter or just to throw in a bad joke once in a while. Secondly, Dr. Carolyn Eyles for her support and use of her office facilities. I would also like to thank Dr. Brian McCann and Ric Hamilton for their support and input towards the completion of this task. Lastly, I would like to thank all my friends, for their moral support, without whom this paper might have not been completed.

Michael
April, 1991

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CHAPTER 1

INTRODUCTION

1.1 Rationale

A relationship between surface physiography (drumlin, moraines and esker orientation) and bedrock channels would imply that the Simcoe and Ontario lobes were constrained by bedrock topography. This relationship would have implications on the nature and dynamics of the ice sheet, implying that the ice sheet was much thinner than previously thought by traditional glaciologists.

1.2 Objectives

1. Define the eastern extent of the Oak Ridges moraine in a subsurface capacity in an attempt to determine exact ice flow patterns.
2. Compare (drumlin, esker and morainal trends) to bedrock channel orientation in order to determine if flow of the Simcoe lobe and the Ontario lobe was highly constrained by bedrock topography.

1.3 Previous Work

1.3.1 Very little work has been done with respect to the study area. According to Duckworth (1979) the Oak Ridges moraine east of Lake Scugog was described briefly by Gravenor (1957) and Mirynech (1962). Chapman and Putnam (1984) give a general view of ice lobe activity based on surface characteristics only. Lack of detailed information reveals the need for an integrated study involving subsurface and surface characteristics.

1.3.2 Subsurface Work

Until recently studies involving the need for subsurface characteristics were based mainly on assumption. Duckworth's (1979) study on the western end of the Oak Ridges Moraine was based "on the assumption that the underlying bedrock is essentially flat...". (p. 1094) With the advent of three-dimensional mapping programs like SURFER (discussed later in the paper) the subsurface can be mapped with some degree of confidence.

It appears to date that only two subsurface studies related to this type of study were completed (Boyce, 1990; Hibbert, 1990). Boyce (1990) used subsurface interpolation to investigate drumlins in the Peterborough Drumlin Field. Hibbert (1990) reveals the importance of increased subsurface knowledge in studying the Halton deformational till: an application of G.I.S. basin analysis. It is apparent that increased knowledge of subsurface characteristics combined with surface physiography may lead to a more accurate interpretation of ice lobe dynamics.

1.3.3 Ice Profile

It has been suggested that glacial ice cover during the late Wisconsin was much thinner than traditional glaciologists have advocated (Boulton et al., 1985). A model developed by Peltier (1981), based on isostatic rebound, implied that the ice cover in the prairies and in Southern Ontario was thinner than previously thought. Models created by Reeh (1982), Fisher et al. (1985), and Boulton et al. (1985) added a significant feature to help establish ice flow patterns - deformable beds. The inclusion of deformable beds, which do occur in the Southern Ontario study area (Boyce, 1990; Hibbert, 1990), produced results similar to Peltier's study. Ice may have been thinner in the prairies because of lobe movement from the Canadian Shield onto the deformable material of the prairies. Deformable beds, according to Fisher et al. (1985) and Boulton et al. (1985), create less yield stress subglacially and would therefore result in increasing ice flow development. Faster movement and directional change of ice flow ultimately results in a thinner ice profile. The same scenario occurs in the Lake Ontario region. In the study area the ice flow movement off the Canadian Shield (a non-deformable precambrian formation) near Kingston would encounter deformable material (drift) on top of the areas deformable bedrock (Verulam Formation) which consists of limestone with alternating shale and claystone around the Belleville and Trenton region.

1.3.4 Ice Flow Constrained by Bedrock Topography.

Mathews (1974) gives examples in the James River valley of South Dakota and the Des Moine valley in Minnesota and Iowa of how the relief of the terrain (scarcely 300m) had topographic control over shape of ice tongues. Mathews came to these conclusions by suggesting methods to determine an estimation of ice lobe slopes from gradients of their margins shown by ice limits, "by contemporaneous recessional moraines, or by lateral melt-water channels, with allowances being made for the dip of an ice lobe laterally, as well as forward toward its extremities." (Mathews 1974, p.37) Mathews suggested that the profile of an glacier can be created by the parabola generated by the equation

$$h=Ax^{1/2}$$

where h = hight above terminus,

x = distance from terminus,

(both in the same units)

A = a coefficient which varies from glacier to glacier.

EXAMPLE OF ICE PROFILE

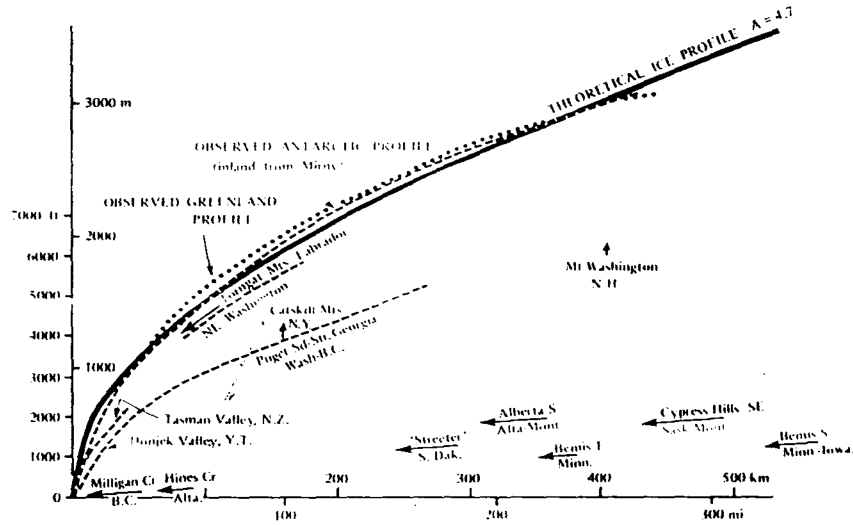

Fig. 1a *Height of present or former ice surfaces at various distances up-stream from the termini. Vertical arrows indicate mountain tops overridden by ice.*

An example created by Mathews (1974) from Hollin (1962) uses this formula with a value of $A = 4.7^{1/2}$ which resulted in a well fit profile of the present Antarctic ice sheet for the first 375 km inland from Mirny (fig. 1a). Mathews therefore suggested that the ice lobes in the prairies were thinner from the presence of moraine profiles and melt-water channels, and that these thinner lobes could be contained by the relief of the land. This situation can be readily applied to the Lake Ontario area.

1.3.5 Ice Surge

Clayton et al. (1985) suggest that areas prone to surging are areas of extreme ice lobation accompanied by gently sloping moraines, abundant supraglacial till flow and large quantities of subglacial water. Mathews (1974) adds that surging is unusually effective at smoothing and fluting resulting in strong fabric orientation in the uppermost sediment sequence.

1.3.6 Drumlins, Eskers and Moraines

Drumlin formation is beyond the scope of this paper. However, the drumlins ellipsoidal form and orientation can be used to define ice flow patterns according to (Smalley and Unwin, 1968; Chapman and Putnam, 1984). Eskers, according to

Chapman and Putnam (1984) are a result of glacio-fluvial sediment transfer within a glacier. Moraines and their suspected formation processes can suggest ice flow limits (Capman and Putnam, 1984).

CHAPTER 2

DATA BASE

2.1 Data Base

Regional water well records were essential in creating subsurface bedrock topography and drift thickness maps for the study area (Fig. 2a). The water well records were provided by the Ministry Of The Environment (MOE) on 1/2 inch magnetic tape which has been converted to a file on the McMaster research VAX. Each record in the file consists of a 256 character sequential file containing a variety of hydrologic, geologic and well installation data. A series of Fortran programs were used (see Appendix) to extract needed well information such as county numbers, UTM co-ordinates, drift thickness, depth to bedrock and surface elevations.

2.2 Data Manipulation

A spatial interpolation package (SURFER) was then used to manipulate the water well data files and create three-dimensional maps of the bedrock topography and drift thickness in the field area. The following Fortran programs, in sequential order, were used to manipulate the (MOE) data.

QUATERNARY GEOLOGY OF SOUTHERN ONTARIO

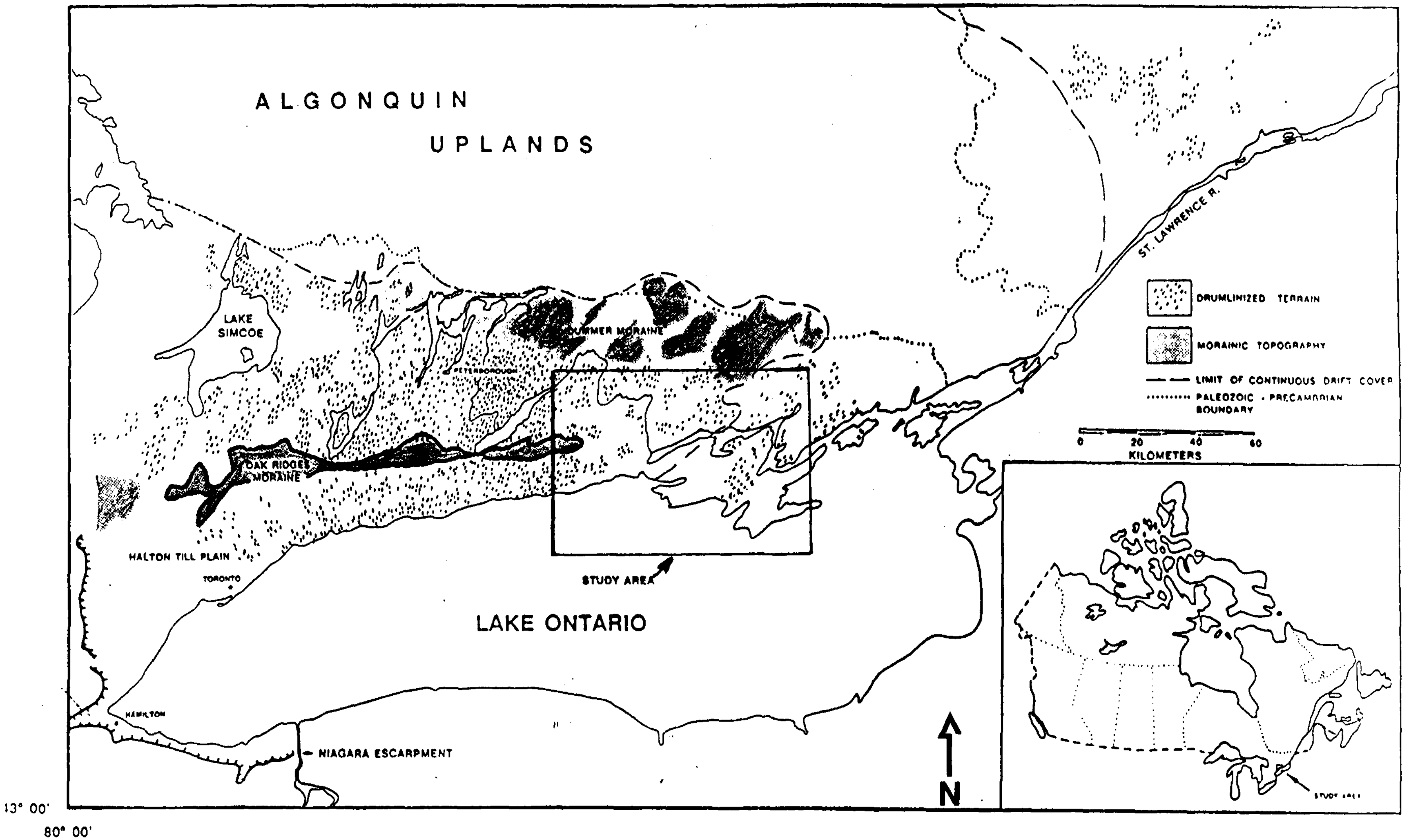

Fig. 2a (modified from Chapman and Putnam 1980)

1.) WELLZONE.FOR is a program that reads and prints to output files all wells and related information (ie. hydrological information) that are categorized by a specific county number in the (MOE) data. In the case of this study Hastings (#29), Northumberland (#45) and Prince-Edward County (#53) were needed. At total of 18,885 wells were on record within the three counties; these wells were then subdivided into separate county files. The files included zone numbers, county numbers, UTM coordinates, depth to bedrock, lithology, elevation and drift thickness.

2.) BEDSORT.FOR reads the files created by WELLZONE and outputs to a data file all wells that reach bedrock within the three counties. Approximately 14,000 wells reach bedrock within the field area. Figure 2b shows the well distribution for each of the three counties. These three files included the same information as WELLZONE.FOR.

3.) BDRKMOD.FOR manipulates the files created by BEDSORT and filters them extracting UTM co-ordinates, zone, easting, northing, surface elevation and depth to bedrock. Overburden thickness and bedrock elevation (above sea level) were also calculated to create drift thickness and bedrock topography maps.

4.) SRCHMOD.FOR uses wells from BDRKMOD that are within a certain perimeter defined by the user. Hastings County extends past the northern extent of the study area requiring the well file to be modified to contain only wells that were

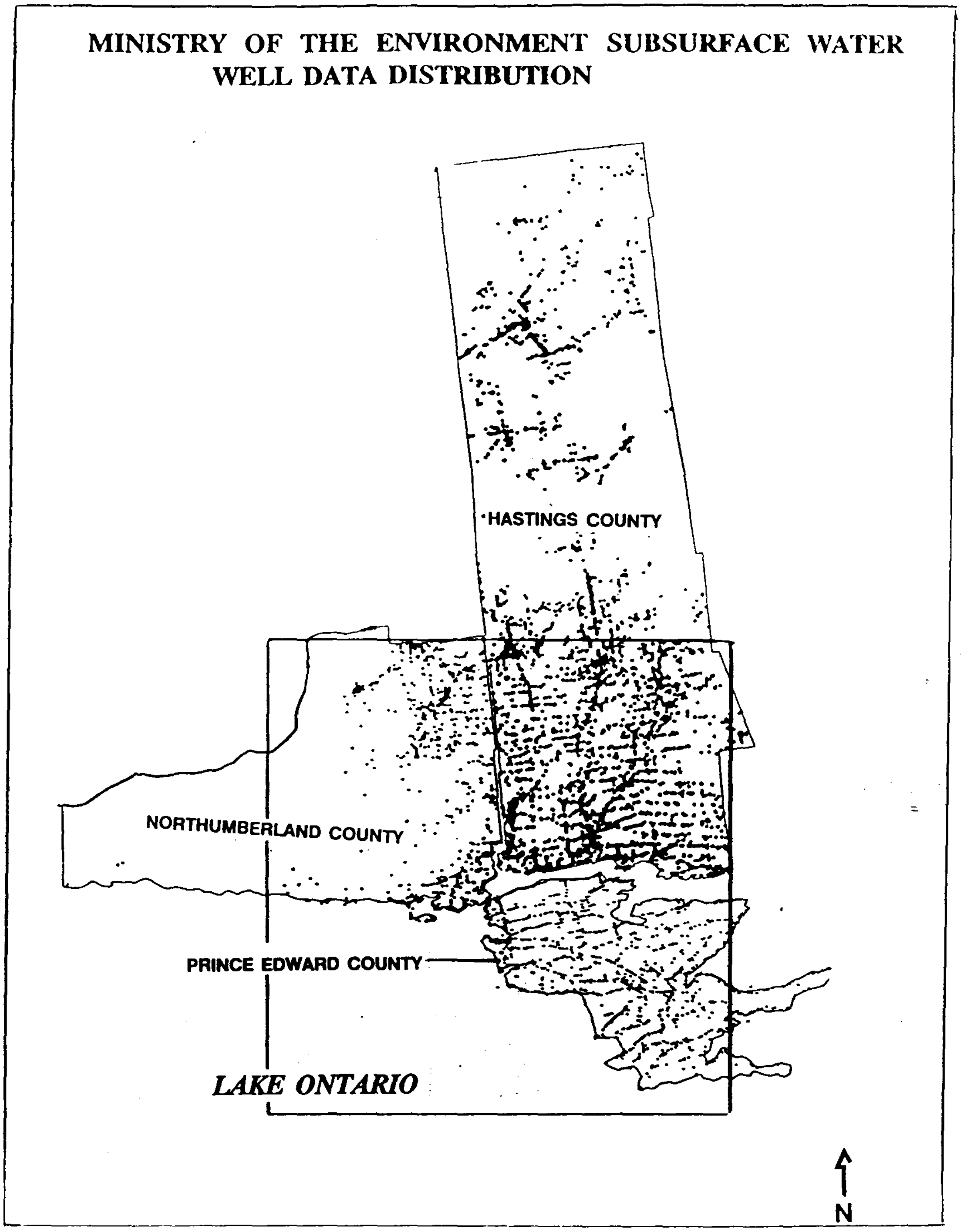
MINISTRY OF THE ENVIRONMENT SUBSURFACE WATER
WELL DATA DISTRIBUTION
HASTINGS COUNTY
NORTHUMBERLAND COUNTY
PRINCE EDWARD COUNTY
LAKE ONTARIO
N

Fig. 2b

below the (UTM) northing co-ordinate of 4,910,000. After running this program there were 4,366 wells that reached bedrock in the southern part of Hastings County. The total number of wells from Hastings, Prince-Edward and Northumberland Counties now numbered (10,161) which exceeded the capability of the SURFER software.

5.) SORTER.FOR is a program that reads a large file, like the file created for South Hastings, counts the total number of entries and allows the user to select a sample of wells. In the case of South Hastings every second well was used. Since the well distribution within the file was unorganized, the sorting procedure was roughly similar to that of a random sort. In doing so, the Hastings file size was reduced to 2,183 wells producing a combined total of 7,978 wells which is within working capacity of SURFER.

2.3 Digitizing

At this point the study required the creation of a boundary file to help define the study area for use with the data compiled for SURFER. To create the boundary file digitizing techniques were employed using the Kurta IS/III digitizer supporting Rockware Inc. Digitize 3.0 software.

Digitizers are machines that are essential for high-volume computer-aided map production that convert elements of an existing map to numerical form. This computer mapping technique relies on having points and lines defined by X-Y coordinates. A map of the study area was placed on the digitizing table and the desired X-Y coordinates were then defined by moving a digitizing puck and clicking a button. The device instantly senses the pucks' position in terms of the table's X and Y coordinates and records the point location in a file (Cuff and Mattson, 1982).

2.4 <u>Subsurface Map Creation</u>

Once the boundary file was created and all the raw water well data files had been manipulated into suitable form then the SURFER interpolation software was used to create three-dimensional bedrock topography maps and drift thickness isopach maps.

The GRID command in SURFER creates a grid system out of the randomly spaced points provided by the user. SURFER interpolates approximate values (during the gridding process) for each intersection point in the grid using the Universal Krigging, Inverse Distance and Minimum Curvature algorithms. This regularly spaced grid, which may be in ASCII or binary format, may then be used in one of two other commands in SURFER; TOPO and SURF. TOPO a menu driven contouring program creates 2-dimensional maps for output.

A contour map is a plot of three values

> of which the first two are (X,Y) co-ordinates and the third (Z) is defined by lines of equal values. The area between two adjacent contours contains only points having values which lie within the range defined by enclosing lines. (SURFER reference manual)

The SURF command takes the grid and creates a three-dimensional figure with the X-Y-Z coordinates. The three dimensional figure created can be viewed through an orthographic or prospective projection. Rotation about the Z axis and tilt after rotation can be used by both projections. Orthographic projection views a plane oriented to the line of sight creating an visual effect similar to that of photography and the human visual system; the size of the surface varies inversely with the distance of the surface from the eye. Rotation about the Z axis specifies the angle of horizontal rotation, up to 360 degrees. Tilt after rotation specifies the angle, above or below the X-Y plane, from which the surface is viewed- up to 90 degrees.(SURFER reference manual)

CHAPTER 3

COMPUTER GENERATED SUBSURFACE

3.1 Bedrock Topography

The computer interpolated reconstruction of the bedrock topography underlying the study area reveals several interesting and distinct characteristics (fig. 3a). There are two bedrock channels that show a northeast-southwest orientation and a plateau located in the northwestern corner of the study area. Further study, on the location of the channels, reveals that they are presently occupied by the Bay of Quinte and by Picton Bay. The plateau is occupied by part of the present day Trent River system.

The bedrock channel presently occupied by the Bay of Quinte is located in the middle of the bedrock topographic map (fig. 3a). The channel is oriented from the northeast to the southwest. The channel width ranges from approximately 12 to 15 km and is approximately 50 km in length. The northern side of the channel has an approximate slope of 10 (m/km) while the southern slope is steeper at an estimated 12 (m/km).

The Picton Bay channel is located at the southeast corner of the bedrock topography map. This channel is also oriented towards the southwest, like its Bay of Quinte

COMPUTER GENERATED BEDROCK TOPOGRAPHY MAP

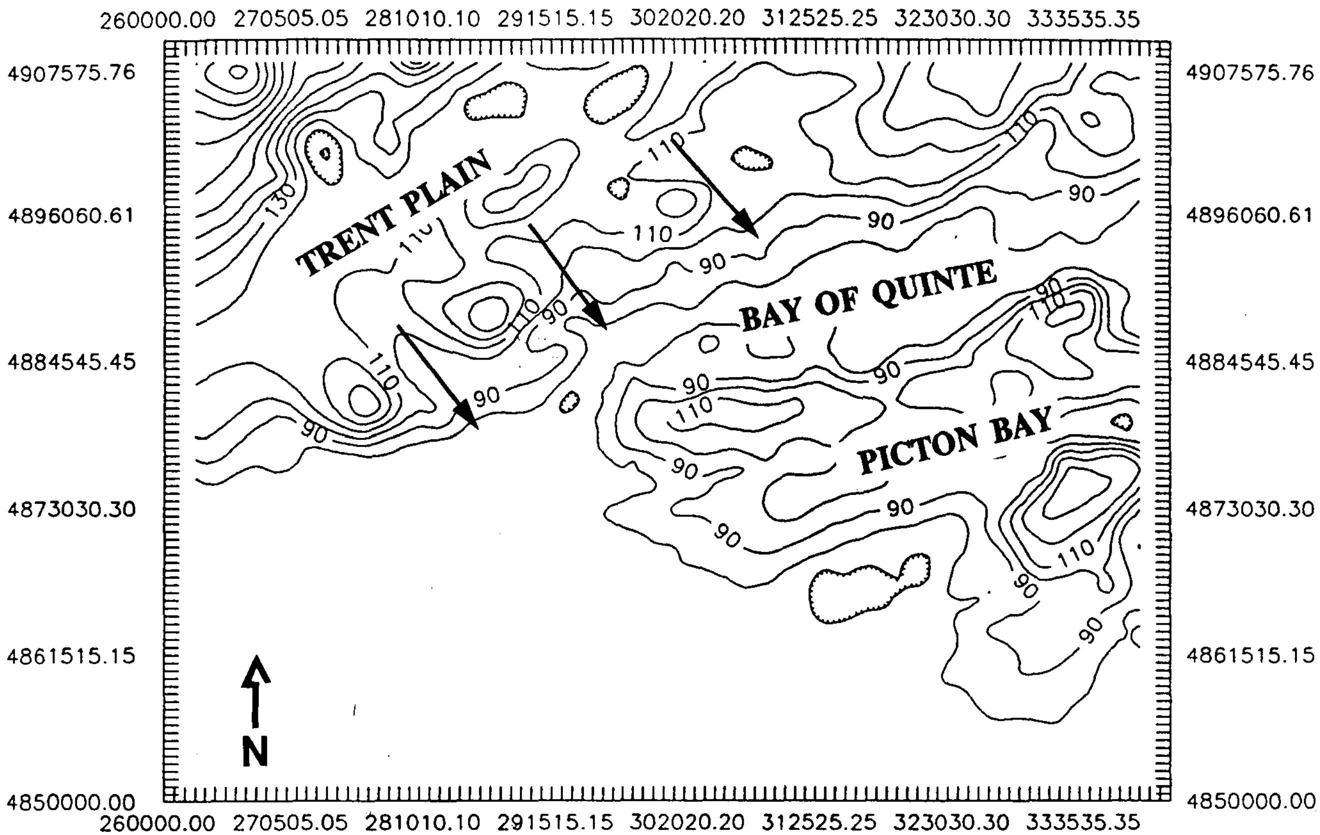

Fig. 3a

Contour Interval 10 m

counterpart. The width of the channel ranges from 5 to 15 km. The northern slope of the channel is approximately 7 (m/km) and its southern slope, which is bounded by the Lake On The Mountain area, is much steeper at 13 (m/km).

The Trent Plain is located in the northwest section of the bedrock topography map with a width ranging from 3 to 17 km. This plain is also oriented northeast to southwest and exhibits several interesting characteristics which should be examined in detail. In the northern part of the plateau there are two depressions and a bedrock high that have rounded shape oriented northeast to southwest. Along the southwestern side of the plateau there are three elongated highs that show a trend towards the southeast. The southern edge of this plateau is dissected by three river channels oriented towards the southeast. These bedrock channels are presently occupied by the Moira and the Trent River systems with the third dissection, located in the south west, infilled with sediment. These river drainage patterns take flow towards the southeast in response to bedrock relief.

The bedrock surface generally dips from the northwest (210 m a.s.l.) towards the Bay of Quinte (70 m a.s.l.) where the trend levels off and from the northwest (210 m a.s.l.) towards the east (80 m a.s.l.). Bedrock within the study area consists of several lithologies (fig. 3b). The bedrock highs on either side of the Picton channel are composed of the Lindsay Formation (lower member) consisting of limestone

BEDROCK LITHOLOGY MAP

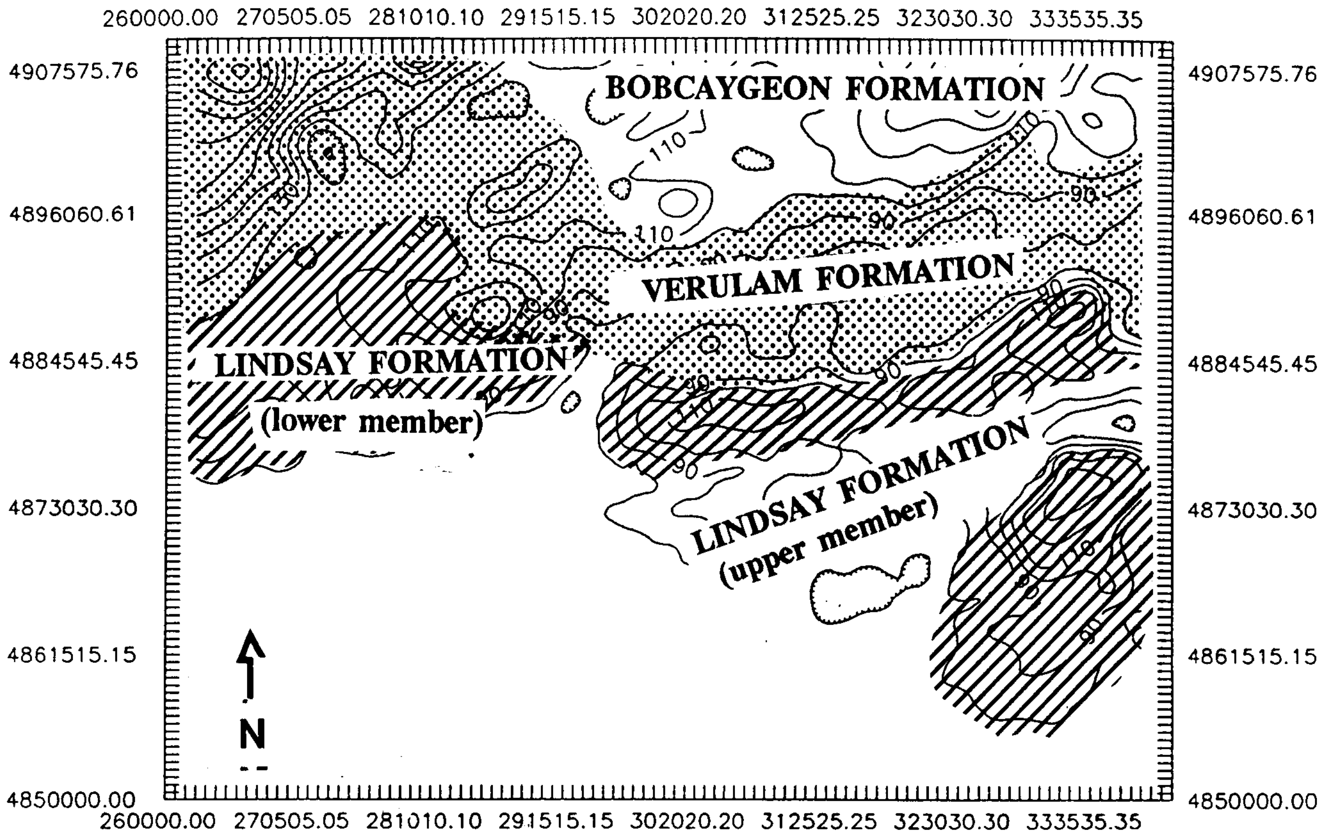

Fig. 3b (Modified from Carson, 1980)

and shale while the channel itself consists of the Lindsay Formation (upper member) which is made up of nodular limestone and shale. The Bay of Quinte channel occupies an area of the Verulam Formation which is largely interbedded limestone and shale (Carson, 1980; 1981a,b,c).

3.2 Drift Thickness

The computer generated drift thickness map (fig. 3c) shows a trend of northwest to southeast oriented packages of thick drift. Drift cover thins dramatically to the south and east to less than 5 m in thickness. Along the western edge of the drift thickness map there are three accumulations of very thick sediment up to 130 m in thickness with northeast to southwest trends. An accumulation of sediment in Prince-Edward County has a rounded shape with its long axis oriented to the southwest.

A comparison of the bedrock topography map and the drift thickness map reveals several interesting points. Thick accumulations of drift occur in the western half of the field area where bedrock topography is highly variable. The eastern section of the study area has a more subdued bedrock topography and very little or intermittent overburden. Minor bedrock channels oriented perpendicular to the major Bay of Quinte and Picton channels are infilled entirely by sediments. The area of maximum drift thickness occurs in the

COMPUTER GENERATED DRIFT THICKNESS MAP

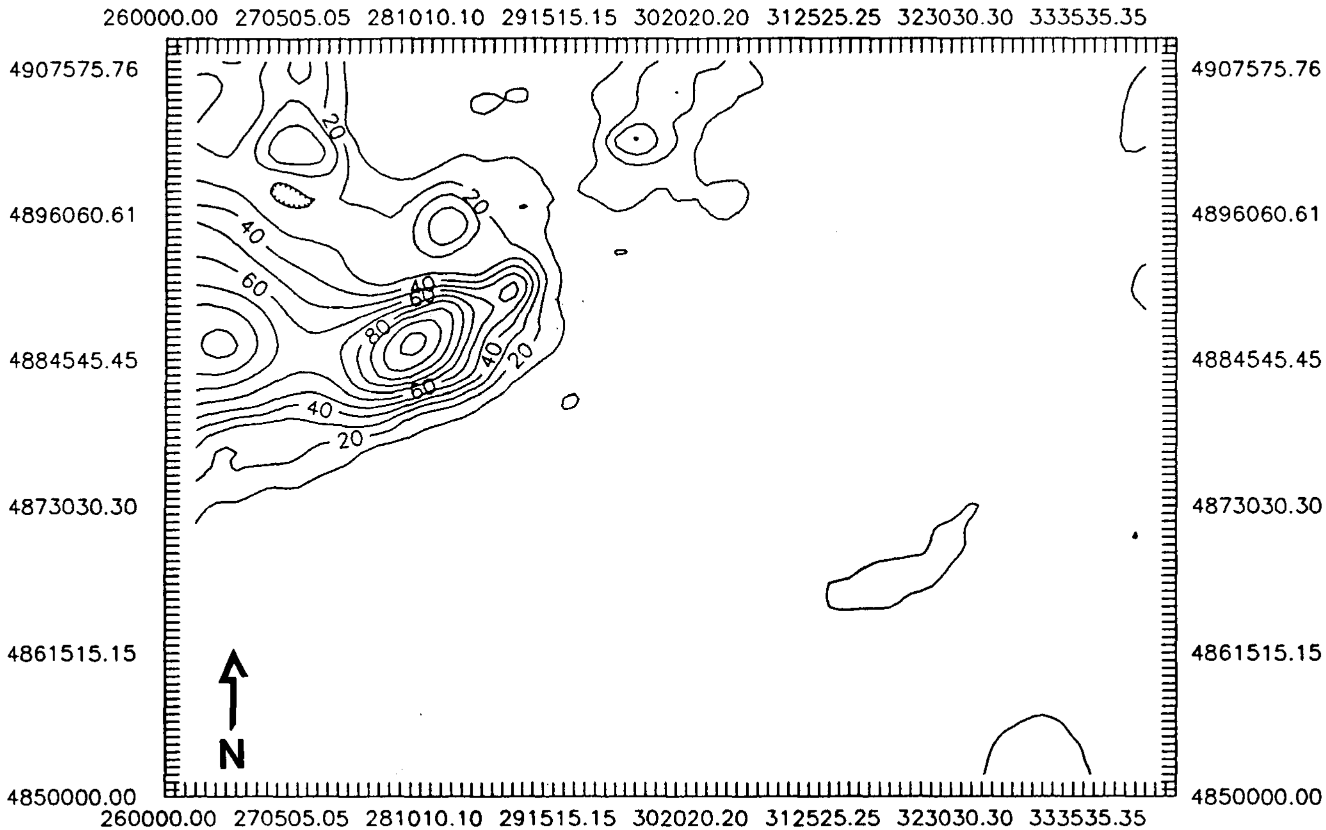

Fig. 3c **Contour Interval 10 m**

bedrock channel now occupied by the Trent River. An estimated 130 m of overburden exists in an area between bedrock highs to the northeast and southwest probably protected the sediment from erosion by ice.

CHAPTER 4

ICE FLOW DYNAMICS

4.1 Bedrock Topography Influence

As proposed earlier in the paper conditions within the study area such as presence of deformable beds, a thinner ice profile and streamlined surface features suggest that the bedrock topography would have great influence on ice flow direction. As stated in the previous chapter there are two large scale bedrock channels in the study area. Each of these channels (the Bay of Quinte channel and the Picton Bay channel) have a northeast to southwest orientation. It can therefore be suggested that the general direction of ice flow, reflects the bedrock topography (created by previous glacial episodes) with the deepening of channels in the late Wisconsin by ice following the same northeast to southwest orientation.

4.2 Drift Thickness: Suggested Extension of the Oak Ridges Moraine.

Further subsurface data in the form of the computer generated drift thickness maps reveal important information other than that which can be related to ice flow direction.

As stated in a previous chapter there are two areas of thick drift occurring at the western end of the study area. An overlay of the Quaternary geology on the regional drift thickness map reveals that the western most accumulation of drift (fig.4a) corresponds directly, in location, to the end of the Oak Ridges Moraine as defined by (Chapman and Putnam 1984). The package of drift, defined by Chapman and Putnam, shows characteristics such as the infilling of bedrock lows and orientation not unlike that of the accumulation of sediment directly to the east and adjoining it. It is therefore suggested that this second package of drift in actuality was the furthest eastern extent of the Oak Ridges Moraine before erosional processes associated with ice surge reduced it to its present hummocky surface expression of 40m in height. The extension of the Oak Ridges Moraine will, from this point on, be referred to as "the extension". It should also be noted that this extension of the Oak Ridges Moraine shows an northeast to southwest orientation.

The eastern half of the study area averages less than 10m of drift. The bedrock surface, in the study area, does not reveal any change in bedrock lithology that would adequately explain this phenomena. However a three-dimensional drift thickness map looking from the southwest to the northwest (fig. 4b) reveals an interesting trend. The two major accumulations of sediment in the west, the Oak Ridges and Extension, and another package to the north are aligned to the

OAK RIDGES MORAINE (EXTENSION)

Fig. 4a

THREE-DIMENSIONAL MAP OF DRIFT THICKNESS

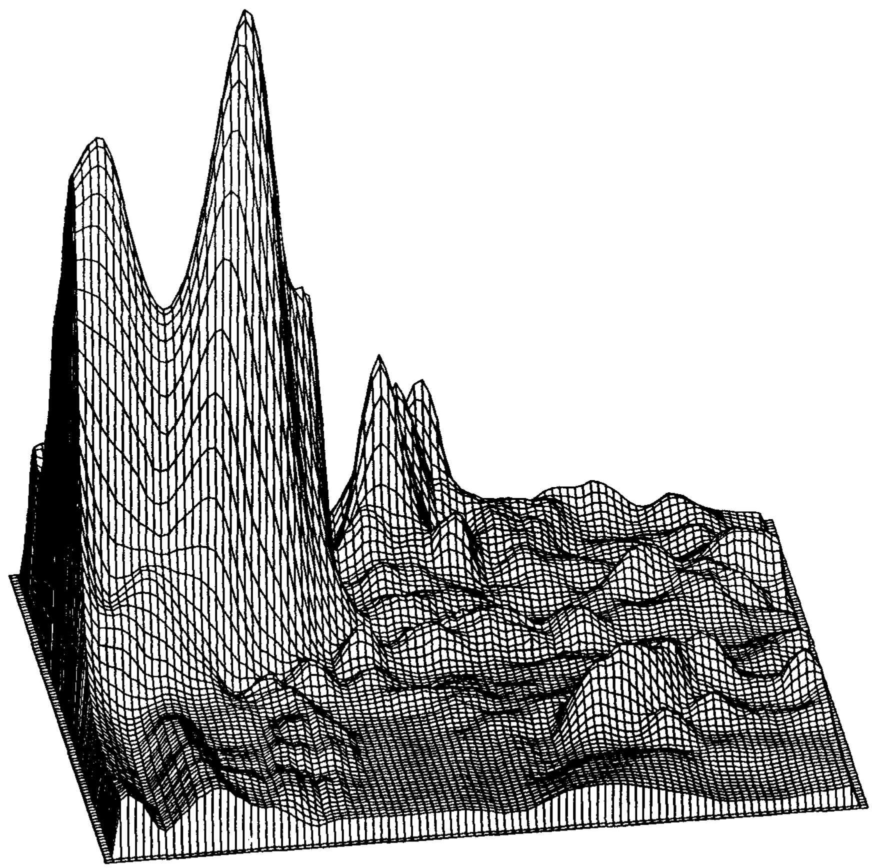

Fig. 4b **View 30 degree and 260 degree about the Z axis**

southwest. A smaller package of sediment corresponding in location to the Picton Bay channel of Prince-Edward county ia also rounded to a southwest trend. It can therefore be suggested that this area was relieved of much of its drift cover during occupation by the Pleistocene ice sheet.

4.3 Drumlins

Streamlined drumlinoid landforms are abundant in the study area and can be used as strong indicators of ice flow dynamics. The origins of drumlins has always been a hotly contested topic and remains so today. There have been several deformational models of drumlin formation (Gravenor, 1953; Flint, 1957; Boulton and Hindmarsh, 1987 ;Boyce, 1990) and erosional theories suggested by (Shaw and Sharpe, 1987). The formation of drumlins is, however, beyond the scope of this paper. Instead this paper is interested in the common conclusion of the papers above (and of Smalley and Unwin, 1968; Chapman and Putnam, 1984) that drumlin ellipsoidal form and orientation can be used to define ice flow patterns of glaciated areas.

4.3.1 Drumlin Orientation

Within the study area there are two distinct trends of drumlin orientation (fig. 4c). Above the hatched line the

DRUMLIN ORIENTATION

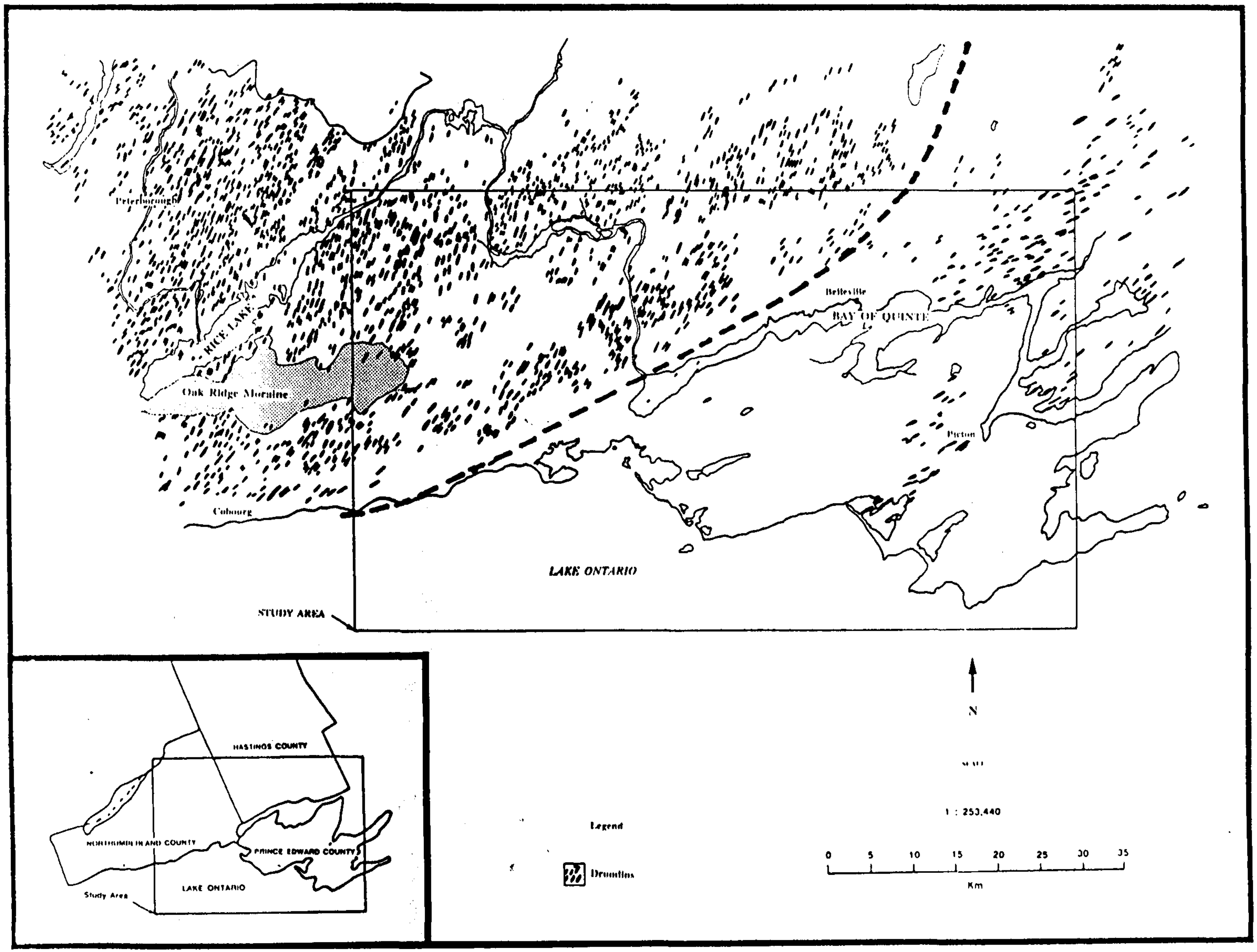

Fig. 4c

drumlin trend is consistent with the orientation of the drumlins in the Peterborough drumlin field. Boyce (1990) examined drumlin orientation in this area concluding a general southwest (190° - 220°) orientation. To the east of the hatched line (fig. 4c) drumlin orientation is 70° west of south (250° azimuth) as suggested by Chapman and Putnam (1984). If drumlin orientation indicates ice flow direction then ice in the area north of the hatched line moved towards the south-southwest and further east the ice movement was to the southwest.

4.4 Moraines

There are two moraines within the area of study: the Oak Ridges Moraine and the Trénton Moraine. The Oak Ridges moraine has been interpreted as being developed as an interlobate moraine between the northward movement of the Lake Ontario lobe and the southward movement of the Lake Simcoe lobes (Chapman and Putnam, 1943; Boyce, 1990) during later stages of the Wisconsin. Strong evidence which support this conclusion are the present drumlin trends in the area. These trends suggest that the Lake Simcoe ice lobes from the north worked their way south to meet the Lake Ontario lobe. In approaching one another the area between the convergence was then the scene of substantial drift accumulation and responsible for the main infrastructure of the Oak Ridges

Moraine.

The Trenton Moraine (Fig. 4d) described by Chapman and Putnam (1984) was created by glacio-fluvial processes. Evidence to support this conclusion includes the irregular bedding of sands and gravels exposed in gravel pits along the moraine. The Trenton Moraine contains large quantities of insitu interbedded glacio fluvial sediments suggesting the landform is not, technically, a moraine (Chapman and Putnam, 1984). The gravel and sandy body is more likely a fluvial landform, possibly part of an outwash plain. The moraine is located along the divide between the drumlins created from the southward moving Lake Simcoe lobe and the northward moving Lake Ontario lobe. The glacio-fluvial nature of the Trenton Moraine and its location at the intersection of two ice lobes suggests that the moraine may have been deposited during meltwater runoff which was channelled to the east between the Lake Ontario and Lake Simcoe lobes.

4.5 Eskers

Eskers (fig. 4d) as defined by Chapman and Putnam (1984) are,

> nobby, sinuous ridges of sand and gravel which are roughly (but not necessarily) parallel to the direction of movement of the glacier. It is believed that they form from the deposition of sediment by meltwater streams confined in tunnels or channels on the surface of, within, or beneath a glacier. p.17

TRENDS IN ESKERS, DRUMLINS AND MORAINES

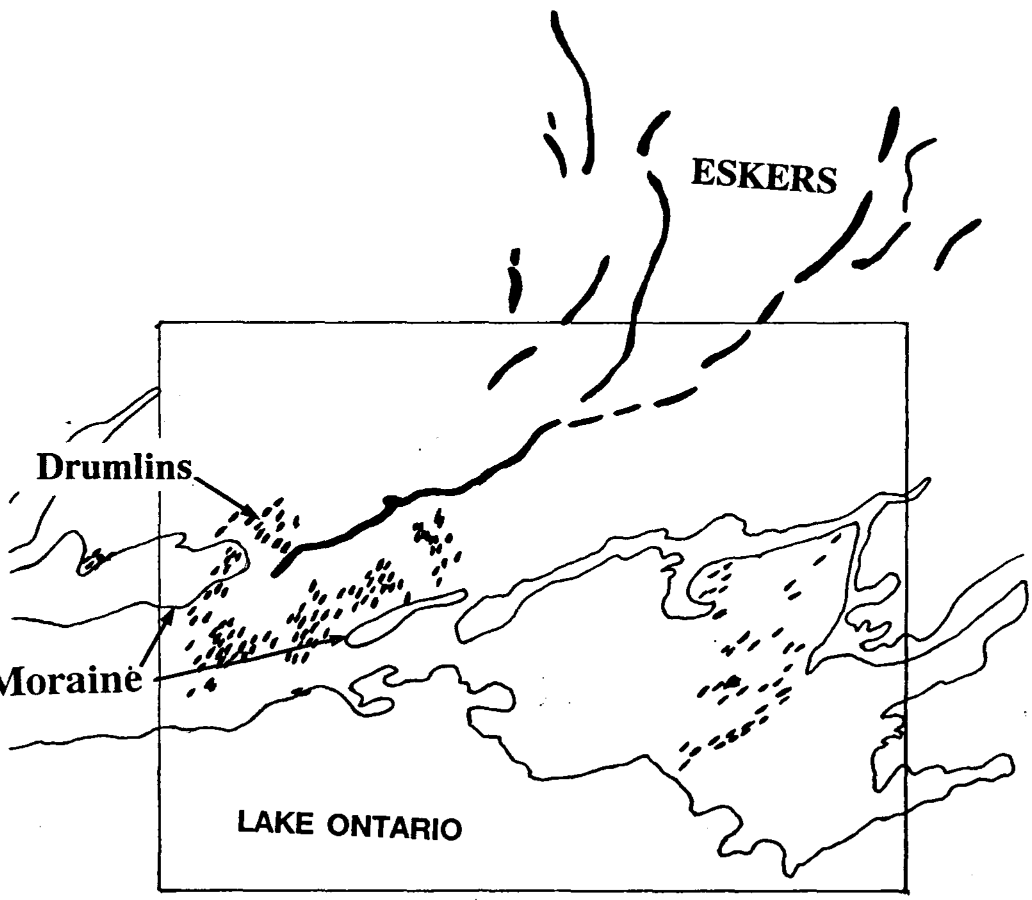

Fig. 4d (MODIFIED FROM CHAPMAN AND PUTNAM, 1984)

1cm = 6km

Figure (4d) shows an very important trend in esker direction. The eskers, north of the study area, extend across an area of approximately 60 km wide. The eskers eventually become more focused towards the southwest, where the extension of the Oak Ridges Moraine use to be. This focus of glacial meltwater in the Trenton area would have acted as a key source of sediment supply to the Oak Ridges Moraine creating conditions suitable for an ice lobe surge.

CHAPTER 5

LATE WISCONSIN ICE LOBE DYNAMICS MODEL

An examination of subsurface information and surface physiography regarding drumlins, moraines (Oak Ridges and Trenton) and eskers can produce a history of late Wisconsin ice lobe activity. The time span (figures 5a-5d) being considered is from approximately 20,000 y.b.p until about 11,800 y.b.p., the time of glacial lake Iroquois (Karrow, 1984).

At some time during this period or during the early part of the Wisconsin, glacial activity removed much of the sediment in the eastern end of the study area. This ice activity reached the deformable beds of the Lindsay and Verulam Formations which created the initial development of the present bedrock channels (Bay of Quinte and Picton).

5.1 <u>The Oak Ridges Moraine</u>

Figure (5a) represents the movement of the Simcoe Lobes towards the south. At the same time, the Lake Ontario lobe moves towards the southwest, following trends resulting from glacial movement over deformable bedrock. The Verulam and Lindsay Formations contain high percentages of deformable shale. These shaley deformable beds are now evident as bedrock channels occupying the Bay of Quinte and Picton Bay.

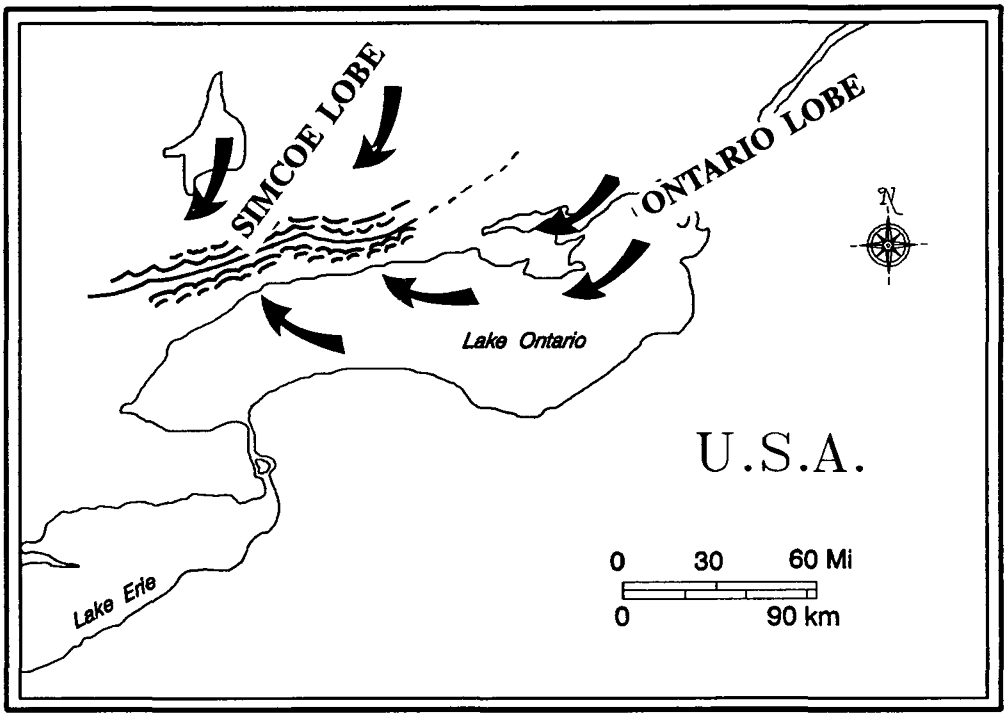

Figure 5a

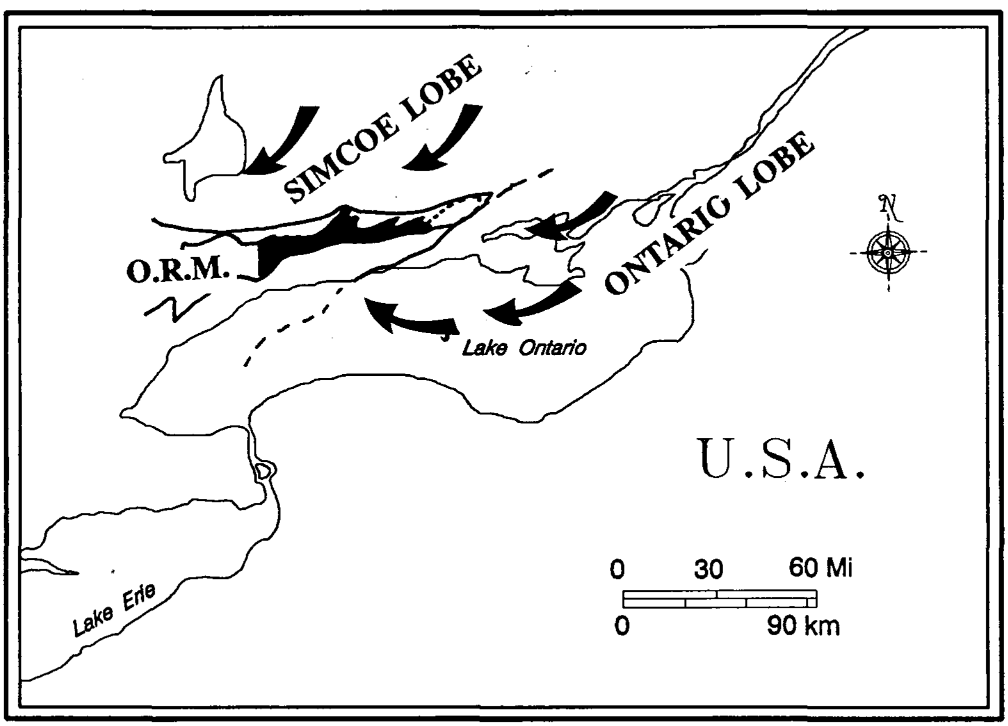

Figure 5b

When the Lake Ontario lobe reached the Lake Ontario basin it expanded towards the north and northwest. Supporting evidence of Ontario lobe movement include the drumlins oriented towards the northwest in the drumlin field occurring from Port Darlington to Toronto. The encroachment of the three lobes, two from the north and one from the south infill bedrock lows with sediment, as shown in the bedrock topography map Figure 5b. At this point the Oak Ridges Moraine is being created between lobal activity (and is therefore considered interlobate).

5.2 Lobe Recession

The maximum length of the Oak Ridges Moraine including "the extension", becomes evident during the recession of the Lake Ontario and Lake Simcoe lobes Figure 5c. In the north the Simcoe lobes retreat enough to make ponding possible between the Simcoe lobes and parts of the Oak Ridges Moraine and the Lake Ontario lobe. During this period large amounts of glacio-fluvial sediment transfer occur as evident by the focusing of esker into the study area. Bedrock topography slopes south and east concentrating all water flow towards the southeast along the edge of the Lake Ontario lobe. Large amounts of flow into this area result in a layer of saturated drift because of the impermeability of the bedrock in the area. Saturation, penetration of the Oak Ridges Moraine and flow through and around the extension begins to occur. These processes act to weaken the already unconsolidated sediments of the Oak Ridges Moraine and increase the speed of retreat of the Ontario lobe reducing any constraints put on the movement of the eastern most Simcoe lobe. The Oak Ridges Moraine's northern boundary at this point is irregular but is smoothed by these processes.

5.3 Simcoe Lobe Surge

According to Clayton et al. 1985 these are perfect conditions (see section 5.2) for basal sliding or surging, of the Simcoe Lobe. According to Clayton et al. 1985 areas prone to surging are: areas where extreme lobation of the ice margin occurs accompanied by gently sloping moraines, abundant supraglacial till flow and large quantities of subglacial water limited to areas of slowly permeable substrate. Mathews (1974) adds by saying surging is unusually effective at smoothing and fluting of terrain resulting in strong fabric orientation in the uppermost sediment sequences. This is evident in the orientation of drift packages, drumlins and bedrock highs within the study area.

The above characteristics create a situation conductive to ice lobe surge (fig. 5c). A thin layer of ice covered the eastern end of the Oak Ridges Moraine extending from Pontypool and to the vicinity of the Lake Ontario lobe in the east. A

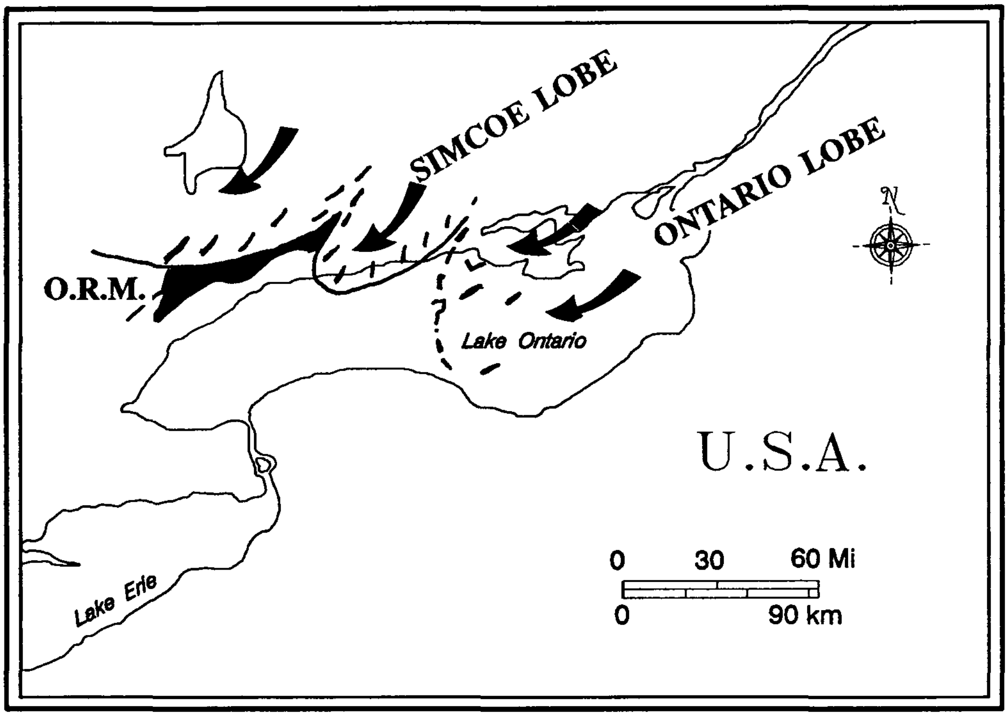

Figure 5c

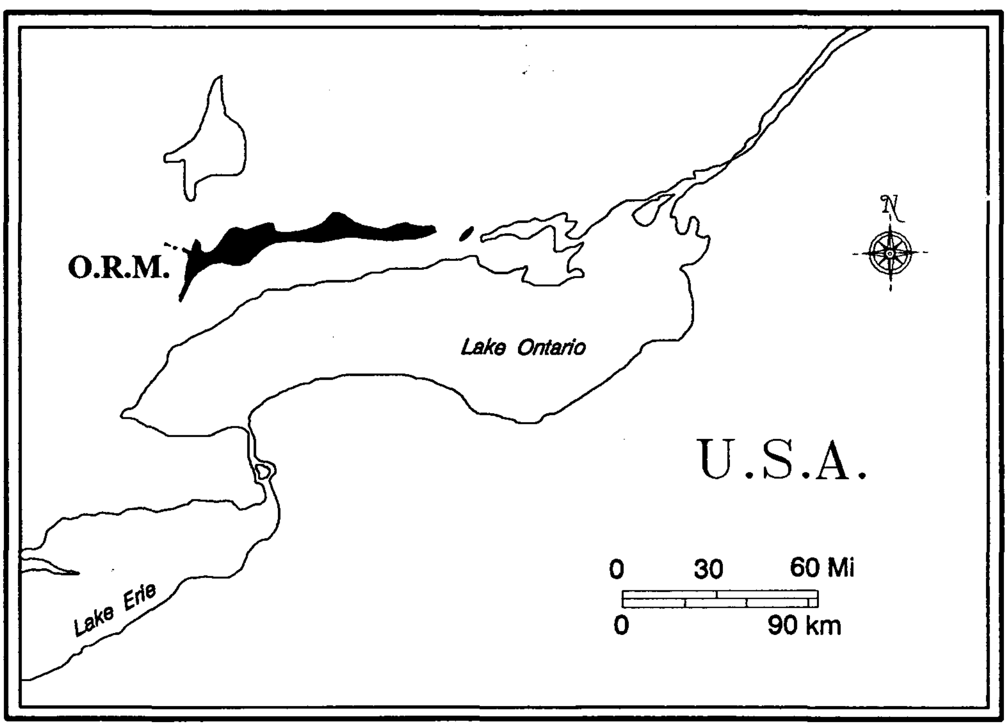

Figure 5d

lower yield stress was created within the Oak Ridges Moraine extension as a result of water penetration into the moraine supplied by glacio-fluvial sediment transfer. This concentration of activity into the area created a situation in which the lobe moved faster along its eastern margin. With increased water pressure and speed, the lobe streamlined the extension of the Oak Ridges Moraine. For this reason the Oak Ridges Moraine at the eastern end averages only 30 to 40m above the surrounding topography while at Pontypool it expresses much greater relief of 115m. The erosion associated with the surge removed most evidence of ponding, and some drumlins created by the Lake Ontario ice lobe (fig. 4d).

CHAPTER 6

CONCLUSIONS

An integrated subsurface and surface physiography approach to ice lobe dynamics can add to the confidence in which actual dynamics of an area can be suggested.

6.1 Bedrock Topography

A computer generated interpretation of the bedrock topography of the area reveals several interesting characteristics. Ice flow of the Late Wisconsin was indeed influenced by bedrock topography. This control could have only been exerted on a thin ice profile. The ice profile was thin due to the influence of deformable beds and of glacio-fluvial sediment transfer which initiated lobation. A thin ice profile allowed the Bay of Quinte and the Picton bedrock channels to bias ice flow direction towards the southwest. Drumlin orientation, creation of moraines and direction of eskers record evidence of how ice and sediment flow was influenced towards the southwest by the bedrock topography.

6.2 Drift Thickness

Drift thickness maps reveal important characteristics that can be related to ice flow direction. In the east of the study area there is very little drift which reveals previous glacial activity removed the overburden by scouring and initiated the development of the Bay of Quinte and Picton bedrock channels while in the west large packages of drift infilled bedrock lows. One of the sediment packages has been interpreted as the maximum eastward extent of the Oak Ridges Moraine. This finding shed light on Chapman and Putnam's 1984 statement of not knowing how far the lobes retreated eastward before another surge.

6.3 The Surge

The profile of the Oak Ridges Moraine and the subdued hummocky topography of "the extension" reveal the extent of the area overridden by a surge of the Simcoe lobe. Conditions within the study area had been conducive to ice surging exacerbated by the presence of deformable beds (the Lindsay and the Verulam Formations), the focusing of large amounts of glacio-fluvial sediment transfer and a release of the restricting force of the Lake Ontario lobe. Following retreat the area was left with remnant features such as southwest oriented bedrock channels, elongated bedrock highs, southwest oriented drift, two drumlin fields oriented in a south-southwest and southwest direction, eskers focusing towards the extension and moraines - Oak Ridges and the Trenton.

6.3 Future Work

Future work in the area of ice lobe dynamics should focus on identifying the age of bedrock channels and the age of the sediment sequences within the area (bottom to top). This work would enable us to produce a more detailed Quaternary history and create a more accurate record of ice sheet flow activity.

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APPENDIX

```
C
*****************************************************************
******
      CHARACTER*11 FILIN,FILOUT
      CHARACTER*2 CIN,CO
      CHARACTER*20 OWN
      CHARACTER*6 DATE
      CHARACTER*15 utm
      CHARACTER*4 ELEV,ZEROD,D(24)
      CHARACTER*11 L(24)
      CHARACTER*1 Y,ANS
      INTEGER KOUNT,COUNT,N
C
*****************************************************************
******
      PRINT*,'            **** PROGRAM  WELLZONE.FOR****'
      PRINT*

PRINT*,'------------------------------------------------------------
----'
      PRINT*,'THIS PROGRAMS READS M.O.E. SEQUENTIAL WATER WELL
RECORDS'
      PRINT*,'(RECL=532   CHAR)   AND   PRODUCES   OUTFILES
CONTAINING'
      PRINT*,'COUNTY#, OWNER, DATE, UTM CO-ORDS, ELEVATION AND
DEPTHS'
      PRINT*,'TO TOP OF FORMATIONS. NOTE: COUNTIES MUST BE
READ IN'
      PRINT*,'ASCENDING ORDER!  UTM ZONES ARE READ IN THIS
VERSION.'

PRINT*,'------------------------------------------------------------
----'
      PRINT*
      PRINT*,'ENTER INPUT FILENAME:'
      READ(*,1)FILIN
      PRINT*,'ENTER OUTPUT FILENAME:'
      READ(*,1) FILOUT
1     FORMAT(A11)
      PRINT*,'ENTER COUNTY NUMBER (2 DIGITS):'
      READ(*,10)CIN
      PRINT*
10    FORMAT(A2)
      N=2
      OPEN(UNIT=1,STATUS='OLD',NAME=FILIN)

OPEN(UNIT=N,STATUS='NEW',NAME=FILOUT,CARRIAGECONTROL='LIST')

      REWIND(UNIT=1)
      ZEROD='0000'
20    KOUNT=-1
30    COUNT=0
```

```
40     DO J = 1, 20000000
       KOUNT=KOUNT+1
50     READ (1,100,ERR=998,END=999) CO,OWN,DATE,UTM,ELEV,
      &(D(I), I=1,24),(L(I), I=1,24)
100   FORMAT(A2,23X,A20,A6,1x,a15,1x,a4,18x,24(a4,7x),t1264,
      &24(4X,A7))
       IF(CO.GT.CIN) THEN
         GO TO 310
       END IF
       IF(CO.EQ.CIN) THEN
         COUNT=COUNT+1
         GO TO 120
       ELSE
         GO TO 40
       END IF
1       2       0               W         R          I          T          E
(N,200)CO,OWN,DATE,UTM,ELEV,ZEROD,L(1),D(1),L(2),D(2),

&L(3),D(3),L(4),D(4),L(5),D(5),L(6),D(6),L(7),D(7),L(8),D(8),

      & L(9),D(9),

&L(10),D(10),L(11),D(11),L(12),D(12),L(13),D(13),L(14),D(14),


&L(15),D(15),L(16),D(16),L(17),D(17),L(18),D(18),L(19),D(19),

      &L(20),D(20),L(21),D(21),L(22),D(22),L(23),D(23),L(24)
200    FORMAT(A2,1X,A20,A6,1X,A15,1x,a4,24(/a4,a7))
300    ENDDO
310    PRINT*
       WRITE(*,400) KOUNT
400   FORMAT(1X'CUMULATIVE NUMBER OF RECORDS READ:[',I6,']')
       PRINT*
       WRITE(*,410) CIN,COUNT
410            FORMAT(1X,'TOTAL     NUMBER     OF     WELLS     IN
COUNTY',1X,A2,1X,'IS:[',
      & I6,']')
       PRINT*
       PRINT*,'READ/WRITE DATA FOR ANOTHER COUNTY?  (Y/N)'
       READ(*,420) ANS
420    FORMAT(A1)
       IF(ANS.EQ.'Y') THEN
         CLOSE(UNIT=N)
         PRINT*,'ENTER OUTPUT FILENAME:'
         READ(*,1) FILOUT
         N=N+1

OPEN(UNIT=N,STATUS='NEW',NAME=FILOUT,CARRIAGECONTROL='LIST')
         PRINT*,'ENTER COUNTY NUMBER (2 DIGITS):'
         READ(*,10) CIN
         PRINT*
```

```
        GOTO 30
      ELSE
        GOTO 999
      END IF
998   PRINT*
      PRINT*,'**** ERROR READING INPUT FILE - PROGRAM ABORTED
****'
999   PRINT*
      WRITE(*,1000) KOUNT
1000  FORMAT(1X,'CUMULATIVE NUMBER OF RECORDS READ:[',I6,']')
      PRINT*
      WRITE(*,1010) CIN,COUNT
1010        FORMAT(1X,'TOTAL    NUMBER    OF    RECORDS    IN
COUNTY',1X,A2,1X,'IS:[',
     &I6,']')
      PRINT*
      PRINT*,'           **** END OF JOB ****'
      PRINT*
      CLOSE(UNIT=1)
      CLOSE(UNIT=N)
      PRINT*
      STOP
      END
```

```
C
************************************************************
******

      CHARACTER*11 FILIN,FILOUT
                              I    N    T    E    G    E    R
CO,EAST,NORTH,ELEV,DEPTH,FORM,COUNT,KOUNT,L(8),ZERO,zone
C
************************************************************
******
      PRINT*
      PRINT*,'              **** BDRKMOD.FOR****'
      PRINT*

PRINT*,'-----------------------------------------------------
----'
      PRINT*,'THIS PROGRAMS READS WELL1 SEQUENTIAL FILES AND
WRITES'
      PRINT*,'TO   A   SECOND   OUTFILE   WELL   POSITION
(EASTING/NORTHING),'
      PRINT*,'SURFACE ELEVATION, DEPTH TO BEDROCK FORMATIONS
AND'
      PRINT*,'BEDROCK  TYPE.  THE  SEARCH  ROUTINE  CURRENTLY
CONTAINS 8'
      PRINT*,'LITHOLOGIES IN THE ARRAY L(I):'
      PRINT*,'    L(1)=LMST, L(2)=DLMT, L(3)=SHLE, L(4)=SNDS'

      PRINT*
      PRINT*,'    L(5)=ROCK, L(6)=GRNT, L(7)=GNSS, L(8)=BSLT'


PRINT*,'-----------------------------------------------------
----'
      PRINT*
      PRINT*,'ENTER INPUT FILENAME:'
      READ(*,1)FILIN
      PRINT*,'ENTER OUTPUT FILENAME:'
      READ(*,1) FILOUT
1     FORMAT(A11)
2     FORMAT(6I2)

OPEN(UNIT=1,STATUS='OLD',NAME=FILIN,CARRIAGECONTROL='LIST')


OPEN(UNIT=2,STATUS='NEW',NAME=FILOUT,CARRIAGECONTROL='LIST')

      L(1)=15
      L(2)=16
      L(3)=17
      L(4)=18
      L(5)=26
```

```
      L(6)=21
      L(7)=41
      L(8)=36
      ZERO=0
      KOUNT=0
      COUNT=-1
5     COUNT=COUNT+1
10    READ(1,20,END=999)CO,zone,east,north,elev
20    FORMAT(T1,I2,28x,i2,i6,i7,1x,i4)
30      DO J = 1,24
35        READ(1,40,END=999) DEPTH,FORM
40        FORMAT(I4,1X,I6)
           DO I = 1,8

IF(L(I).EQ.FORM.AND.EAST.NE.ZERO.AND.NORTH.NE.ZERO.AND.
     &         ELEV.NE.ZERO) THEN
               WRITE(2,50)zone,east,north,elev,depth
50             FORMAT(I2,1x,i6,1x,i7,1x,i4,1x,i4)
               KOUNT=KOUNT+1
            END IF
           END DO
        ENDDO
      GO TO 5
999   PRINT*
      WRITE(*,1000) CO,COUNT
1000        FORMAT(1X,'TOTAL    NUMBER    OF    WELLS    IN
COUNTY#',1X,I2,1X,'IS:[',
     &I6,']')
      PRINT*
      PRINT*
      WRITE(*,1100) KOUNT
1100  FORMAT(1X,'TOTAL RECORDS WRITTEN:[',I6,']')
      CLOSE(UNIT=1)
      CLOSE(UNIT=2)
      PRINT*
      PRINT*
      PRINT*,'          **** END OF JOB ****'
      PRINT*
      STOP
      END
```

```
C
************************************************************
******
      CHARACTER*11 FILIN,FILOUT,Y,ANS
                                   I     N     T     E     G     E     R
COUNT,KOUNT,EAST,NORTH,XH,XL,YH,YL,N,OPT,zone,elev,depth
C
************************************************************
******
      PRINT*
      PRINT*,'              **** PROGRAM SRCHMOD.FOR ****'
      PRINT*

PRINT*,'----------------------------------------------------
----'
      PRINT*,'THIS PROGRAMS LOCATES WELLS FROM A BDRKMOD FILE
AND FINDS'
      PRINT*,'THOSES WITHIN A BOUNDARY DEFINED BY THE USER.'
      PRINT*
      PRINT*,'       OPTION "1" - WRITE DATA TO OUTFILE'
      PRINT*,'       OPTION "2" - WRITE DATA TO SCREEN'

PRINT*,'----------------------------------------------------
----'
      PRINT*
      N=2
      PRINT*,'ENTER OPTION NUMBER:'
      READ(*,1) OPT
1     FORMAT(I)
      PRINT*
      PRINT*,'ENTER XYZ FILENAME:'
      READ(*,4)FILIN
4     FORMAT(A11)
      PRINT*
      IF(OPT.EQ.1) THEN
        PRINT*,'ENTER OUTPUT FILENAME'
        READ(*,4) FILOUT

OPEN(UNIT=N,STATUS='NEW',NAME=FILOUT,CARRIAGECONTROL='LIST')

      END IF
5     PRINT*,'ENTER MAX EASTING (XH):'
      READ(*,6) XH
      PRINT*,'ENTER MIN EASTING (XL):'
      READ(*,6) XL
6     FORMAT(I6)
      IF(XL.GT.XH) THEN
        PRINT*,'XH CANNOT BE < XL - TRY AGAIN!:'
        GOTO 5
      END IF
7     PRINT*,'ENTER MAX NORTHING (YH):'
      READ(*,8) YH
```

```
      PRINT*,'ENTER MIN NORTHING (YL):'
      READ(*,8) YL
8     FORMAT(I7)
      IF(YL.GT.YH) THEN
        PRINT*,'YH CANNOT BE < YL - TRY AGAIN!:'
        GOTO 7
      END IF
      PRINT*
      PRINT*
      OPEN(UNIT=1,STATUS='OLD',NAME=FILIN)
10    REWIND(UNIT=1)
12    KOUNT=0
      COUNT=-1
15    COUNT=COUNT+1
      READ(1,20,END=998)zone,east,north,elev,depth
20    FORMAT(i2,1x,i6,1x,i7,1x,i4,1x,i4)
      IF(EAST.LE.XH.AND.EAST.GE.XL.AND.NORTH.LE.YH.AND.NORTH.

     &GE.YL) THEN
          IF(OPT.EQ.1) THEN
            WRITE(N,30) zone,east,north,elev,depth
30          FORMAT(I2,1x,i6,1x,i7,1x,i4,1x,i4)
            KOUNT=KOUNT+1
          ELSE
            WRITE(*,30) EAST,NORTH,ZB,ZD
            KOUNT=KOUNT+1
          END IF
35    END IF
      GO TO 15
998   PRINT*,'****  END OF FILE! ****'
999   PRINT*
      PRINT*
      WRITE(*,1005) COUNT
1005  FORMAT(1X,'NUMBER OF WELLS READ:[',I6,']')
      PRINT*
      WRITE(*,1006) KOUNT
1006  FORMAT(1X,'NUMBER OF LINES WRITTEN:[',I6,']')
      PRINT*
      PRINT*
      PRINT*,'SEARCH FOR MORE WELLS? (Y/N)'
      READ(*,1100) ANS
1100  FORMAT(1A)
      PRINT*
      IF(ANS.EQ.'Y') THEN
        IF(OPT.EQ.1) THEN
          CLOSE(UNIT=N)
          PRINT*,'ENTER OUTPUT FILENAME:'
          READ(*,4) FILOUT
          N=N+1

OPEN(UNIT=N,STATUS='NEW',NAME=FILOUT,CARRIAGECONTROL='LIST')
```

```
        END IF
        PRINT*
1110    PRINT*,'ENTER MAX EASTING (XH):'
        READ(*,6) XH
        PRINT*,'ENTER MIN EASTING (XL):'
        READ(*,6) XL
        IF(XL.GT.XH) THEN
         PRINT*,'XH CANNOT BE < XL - TRY AGAIN!:'
         GOTO 1110
        END IF
1120    PRINT*,'ENTER MAX NORTHING (YH):'
        READ(*,8) YH
        PRINT*,'ENTER MIN NORTHING (YL):'
        READ(*,8) YL
        IF(YL.GT.YH) THEN
          PRINT*,'YH CANNOT BE < YL - TRY AGAIN!:'
          GOTO 1120
        END IF
        GOTO 10
      END IF
1150  PRINT*
      PRINT*
      PRINT*
      CLOSE(UNIT=1)
      CLOSE(UNIT=2)
      PRINT*
      PRINT*
      PRINT*,'         **** END OF JOB ****'
      PRINT*
      STOP
      END
```

```
C     ********************
      CHARACTER*11 FILIN,FILOUT
      I           N          T          E          G          E          R
COUNT,JOUNT,SELECT,DIVIDE,EAST,NORTH,X,Y,ELEV,DEPTH,ZONE
      REAL ZB,ZD
C     ********************
      PRINT*
      PRINT*,'   *****PROGRAM SORTER.FOR****'
      PRINT*

PRINT*,'--------------------------------------------------'

      PRINT*,'    THIS PROGRAM READS A LARGE FILE, COUNTS THE'

      PRINT*,'TOTAL NUMBER OF ENTRIES AND ALLOWS THE USER TO
SELECT'
      PRINT*,'A SAMPLE OF WELLS.  IMPERIAL UNITS ARE CONVERTED'

      PRINT*,'TO METRIC UNITS AUTOMATICALLY'
      PRINT*
      PRINT*,'ENTER THE NAME OF THE FILE FROM WHICH WELLS WILL
BE'
      PRINT*,'SELECTED:'
      READ(*,1)FILIN
      PRINT*,'ENTER A NAME FOR THE FILE IN WHICH THE SELECTED'
      PRINT*,'WELLS WILL BE SAVED:'
      READ(*,1)FILOUT
1     FORMAT(A11)
      PRINT*,'ENTER A DIVISOR BY WHICH WELLS WILL BE SELECTED.'

      PRINT*,'EG. IF YOU WISH TO PICK EVERY 50TH WELL, ENTER
50.'
      PRINT*,'***WARNING*** THIS VALUE MUST BE AN INTEGER'
      PRINT*,'SUCH AS 50, NOT 50.0'
      READ(*,2)DIVIDE
2     FORMAT(I6)
C
C     ********************
C     OPENING THE FILES
C     ********************
C

OPEN(UNIT=1,STATUS='OLD',NAME=FILIN,CARRIAGECONTROL='LIST')


OPEN(UNIT=2,STATUS='NEW',NAME=FILOUT,CARRIAGECONTROL='LIST')

C
C     ********************
C     THE VARIABLES
C     ********************
C
```

```
C     JOUNT=A COUNTER TO SELECT WELLS AS DEFINED BY THE USER

C     DIVIDE=A VALUE ENTERED BY THE USER EG SELECT EVERY 50TH
WELL
C     COUNT=COUNTS THE NUMBER OF WELLS IN THE ORIGINAL FILE
C     SELECT=COUNTS THE NUMBER OF WELLS SELECTED BY THIS
PROGRAM
C     LITH=READS THE BEDROCK LITHOLOGY IN THE INPUT FILE
C     EAST=UTM CO-ORDINATE
C     NORTH=UTM CO-ORDINATE
C     X=AS EAST
C     Y=AS NORTH
C     ELEV=SURFACE ELEVATION OF WELL SITE
C     DEPTH=DEPTH TO BEDROCK FROM SURFACE
C     ZB=BEDROCK ELEVATION (CALCULATED)
C     ZD=DRIFT THICKNESS (CALCULATED)
C
      COUNT=-1
      JOUNT=0
      SELECT=0
5     X=EAST
      Y=NORTH
      COUNT=COUNT+1
      JOUNT=JOUNT+1
      READ(1,20,END=999)ZONE,EAST,NORTH,ELEV,DEPTH
20    FORMAT(I2,1X,I6,1X,I7,1X,I4,1X,I4)
        IF(JOUNT.NE.DIVIDE) THEN
          GO TO 5
        END IF
C
C     DO THE FOLLOWING ONCE A WELL IS SELECTED
C
      ZB=(ELEV-DEPTH)/3.281
      ZD=DEPTH/3.281
        IF(X.NE.EAST.AND.Y.NE.NORTH) THEN
          WRITE(2,30)ZONE,EAST,NORTH,ZB,ZD
30        FORMAT(I2,1X,I6,1X,I7,1X,F6.1,1X,F5.1)
35      END IF
      JOUNT=0
      SELECT=SELECT+1
      GO TO 5
999   PRINT*
      WRITE(*,1000)COUNT
1000  FORMAT(1X,'TOTAL NUMBER OF WELLS READ:[',I6,']')
      PRINT*
      PRINT*
      WRITE(*,1100)SELECT
1100  FORMAT(1X,'TOTAL NUMBER OF SELECTED WELLS:[',I6,']')
      CLOSE(UNIT=1)
      CLOSE(UNIT=2)
      PRINT*
      PRINT*
```

```
PRINT*,'*****END OF JOB*****'
PRINT*,'NO APPARENT ERRORS'
PRINT*
STOP
END
```