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Ice Scours in the Sediments of Glacial Lake Iroquois, Prince Edward County, Eastern Ontario

Sillons glaciels dans les sédiments du Lac glaciaire Iroquois, comté de Prince Edward, dans l'est de l'Ontario

Ледовые борозды в наносах замерзшего ирокезского озра, графство лринц эдвард, вотсочный Онтарио

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Article abstract

Straight or slightly curved ice scours are found in thin glacilacustrine sediment of eastern Lake Iroquois, especially near the crest of an escarpment in Prince Edward County. They are large (to 3.57 km long and 174 m wide), shallow (about 1 m deep) and oriented in a nearly westerly direction. Irregular ridges of sediment have been pushed up along the sides and at the western end of some scours. Bedrock is near the ground surface, but had little influence on the formation of the scours. Based on their shape, location and pattern, we conclude that the scours were most likely formed in shallow water of the short-lived Sydney phase of Lake Iroquois by lake ice driven by prevailing northeasterly winds from the retreating Laurentide Ice Sheet.

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ICE SCOURS IN THE SEDIMENTS OF GLACIAL LAKE IROQUOIS, PRINCE EDWARD COUNTY, EASTERN ONTARIO

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ABSTRACT Straight or slightly curved ice scours are found in thin glacilacustrine sediment of eastern Lake Iroquois, especially near the crest of an escarpment in Prince Edward County. They are large (to 3.57 km long and 174 m wide), shallow (about 1 m deep) and oriented in a nearly westerly direction. Irregular ridges of sediment have been pushed up along the sides and at the western end of some scours. Bedrock is near the ground surface, but had little influence on the formation of the scours. Based on their shape, location and pattern, we conclude that the scours were most likely formed in shallow water of the short-lived Sydney phase of Lake Iroquois by lake ice driven by prevailing northeasterly winds from the retreating Laurentide Ice Sheet.

RÉSUMÉ *Sillons glaciels dans les sédiments du Lac glaciaire Iroquois, comté de Prince Edward, dans l'est de l'Ontario*. On trouve des sillons glaciels, rectilignes ou courbes, dans des sédiments lacustres de l'est du Lac Iroquois, en particulier près du sommet d'un escarpement dans le comté de Prince Edward. Ces sillons sont larges (jusqu'à 3,57 km de longueur et 174 m de largeur), peu profonds (environ 1 m) et orientés vers l'ouest. Des bourrelets irréguliers de sédiments apparaissent en bordure et à l'extrémité ouest de quelques dépressions. Le substratum affleure presque, mais a eu peu d'influence sur la formation des sillons. En se fondant sur leur forme, leur emplacement et leur agencement, on en conclut que les sillons ont été formés dans les eaux peu profondes du Lac Iroquois au cours de la courte phase de Sydney, par les glaces du lac poussées par les vents dominants du nord-est, en provenance de l'Inlandsis laurentidien alors en retrait.

РЕЗЮМЕ ЛЕДОВЫЕ БОРОЗДЫ В НАНОСАХ ЗАМЕРЗШЕГО ИРОКЕЗСКОГО ОЗЕРА, ГРАФСТВО ПРИНЦ ЭДВАРД, ВОСТОЧНЫЙ ОНТАРИО.

В тонких ледовых наносах в восточнои части Ирокезского Озера особенно рядом с гребнем крутого склона графства Принц Эдвард можно наблюдать прямые или слегка извиваюШиеся ледовые борозды. Они имеют большие размеры (до 3.57 км в длину и 174 м в ширину), мелки и ориентированы преимуШественно на запад. Неререгулярные гребни наносов находятся по бокам и в западных окончаниях некоторых борозд. Несмотря на то, что порода находится близко от поверхности грунта, её влияние на формирование этих борозд невелико. На основании формы, расположения и рисунка борозд делается вывод, что они, скорее всего, были сформированы в мелких водах Ирокезского Озера во время короткой фазы Сидней под воздействием озёрного льда, нанесенного доминируюШими северо-восточными ветрами от отступаюШего Лаврентийского материкового ледника.

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INTRODUCTION

Ice scours preserved in the soft sediments of modern and ancient lakes are important indicators of lacustrine processes and environments (Weber, 1958; Dredge, 1982; Grass, 1983). With the exception of work by Berkson and Clay (1973) and Eyles and Clark (1988), these features have not been reported in the glacial Great Lakes. This paper describes scours that formed in a late phase of glacial Lake Iroquois which occupied the Lake Ontario basin during retreat of the Laurentide Ice Sheet (Anderson and Lewis, 1985). We argue that they were created by wind-driven lake ice and possibly icebergs, rather than by a floating ice shelf from the glacier which dammed the lake, and we interpret the palaeoenvironmental conditions at the time of their origin.

THE ICE SCOURS

In southeastern Ontario there are a number of landforms with a southwesterly orientation including drumlins (Chapman and Putnam, 1972), and tunnel channels, escarpment noses and erosion marks created or modified by subglacial fluvial processes (Gilbert, 1990; Shaw and Gilbert, 1990). In some places there are also long, linear depressions in the thin cover of sediment deposited in glacial Lake Iroquois. Most can be distinguished from the true glacial forms on the basis of shape, although they are aligned in nearly the same direction. Each consists of a shallow trench about 1 m deep, tens of metres wide, and from a few hundred metres to several kilometres long, and is flanked by low ridges of sediment. From study of air photographs of the region between Trenton and Kingston, the scours shown on Figure 1 were mapped. Most are small and poorly preserved. They are recognised in farm fields by the darker tone of wetter soil in the depressions. All occur on glacilacustrine sediment at elevations between 90 and 110 m asl.

On the gently undulating top of a limestone escarpment in eastern Prince Edward County many more, larger and better preserved scours were found (Fig. 2). These were mapped in greater detail from large-scale air photographs (Fig. 3) and from observations on the ground, and are the basis of this presentation. Most of the 164 scours mapped on the 93 km² land surface in this detailed study area occur between about 110 and 125 m asl on the south side of slightly higher ground on top of an escarpment which marks the west side of Long Reach and extends westward from Long Reach near the north of the study area (Fig. 2), although a few occur to elevations of 135 m and below 100 m. As other workers report (Dredge, 1982), straight scours predominate (Table I), but 27% had measurable (≥3°) curvature, mainly to the south at the western end. Curvature is generally small (averaging 12°); multiply curved (zig-zag) scours were not found (see also Weber, 1958). Curved scours are significantly longer (Table I), although this may represent only greater opportunity for longer ones to become curved as they formed. The scours reported here are

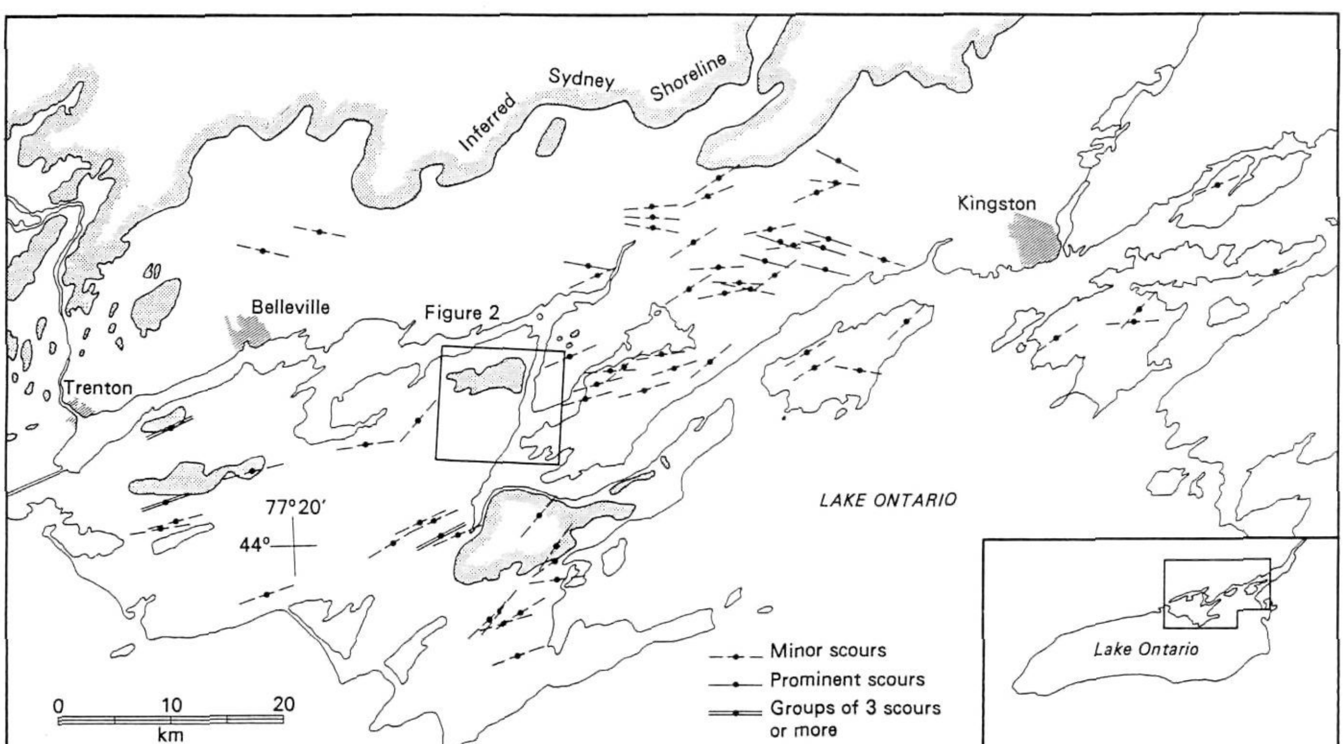

FIGURE 1. Eastern Lake Ontario showing the position of ice scours recorded on air photographs, the study site where scouring is more intensive and the Sydney phase shoreline extended from its mapped location in the Trenton area (Muller and Prest, 1985) using isostatic data of Anderson and Lewis (1985). Lengths of the scours are not in proportion to length on the ground.

Carte de l'est du lac Ontario montrant l'emplacement des sillons glaciels montrés par les photographies aériennes, le site à l'étude où les sillons sont plus nombreux et le tracé du rivage du Lac Iroquois, à la phase de Sydney, à partir de la portion cartographiée de la région de Trenton (Muller et Prest, 1985) à partir des données sur l'isostasie de Anderson et Lewis (1985). La longueur des sillons ne correspond pas à celle des sillons sur le terrain.

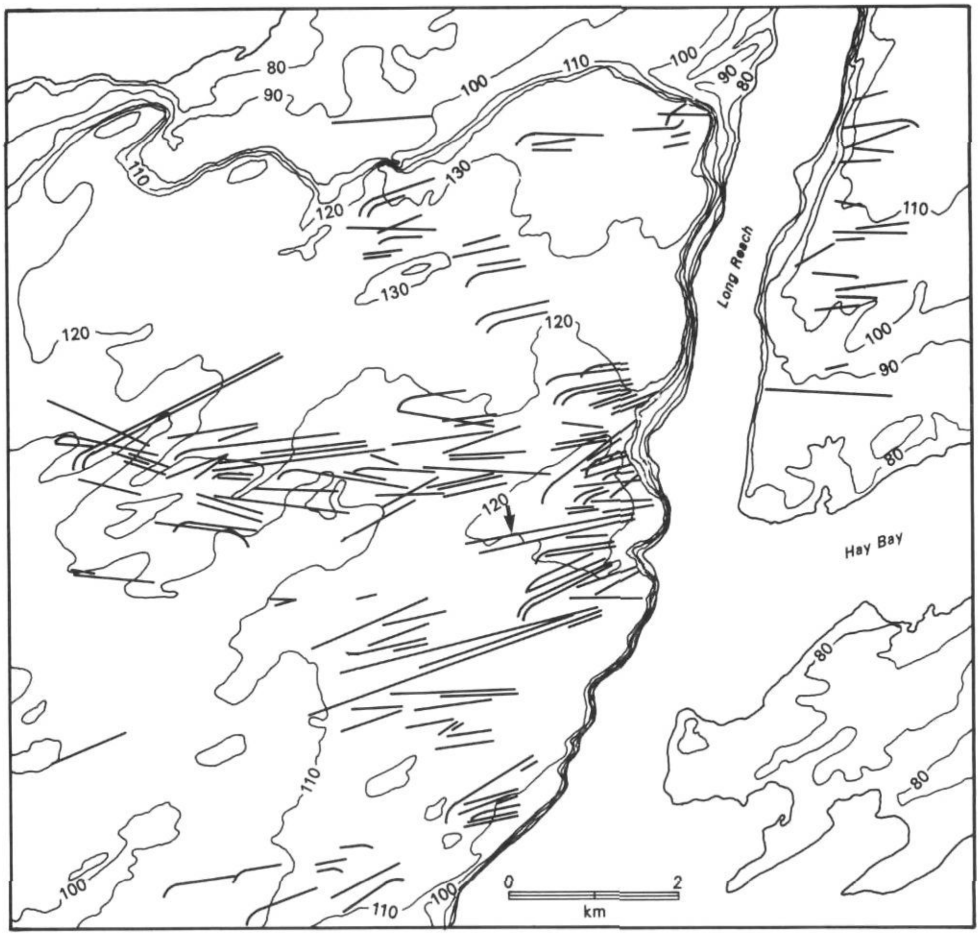

FIGURE 2. Ice scours in the study site. Lengths shown are in proportion to lengths on the ground but curvature of some scours are accentuated to distinguish them from the straight scours. Arrow indicates the scour shown in Figures 5 and 6 (contours from NTS map 31 C/3, 6th ed.).

Les sillons glaciels au site à l'étude. Les longueurs illustrées sont proportionnelles aux longueurs réelles, mais les courbes sont parfois accentuées, afin de bien différencier les sillons droits des sillons courbes. La flèche montre le sillon illustré aux figures 5 et 6 (courbes de niveau à partir de la carte topographique 31 C/3, 6° éd.).

significantly longer and wider than most reported in the literature (Dredge 1982, her Table 1). Orientation of the scours is closely clustered around a mean azimuth of 261° (Fig. 4). There is no statistically significant relation among any of scour length, width, orientation, or elevation.

Scours are incised a maximum of about 1 m. Ridges rising less than 1 m above the ground surface extend irregularly along the sides and there is considerable variation in detail of cross-sectional shape along the scour (Fig. 5). Part of this may be due to subsequent erosion and to agricultural practice (Fig. 6) which appear to have smoothed and muted the scour profile, but only subtle features have been obliterated completely. Some scours still have a small ridge or ridges in the troughs in the orientation of the scour. The scours have formed in a thin cover of glacilacustrine silts and clays on a nearly flat-lying bedrock surface (Fig. 5). In some cases, the sediment has been removed as the scour formed to expose bedrock in the trough of the scour, but there appears to be no control of scour plan form by patterns in the bedrock (see also Clayton *et al.*, 1965). None of the scours contains a large stone at its end (*cf.* Weber, 1958), although at the west end of a few, the lateral ridges wrap around the end of the scour (see also Grass, 1983).

TABLE I

Ice Scours — summary statistics

		Mean	Standard deviation	Range
Straight (n=120)	Length (m)	752	501	134-3568
	Width (m)	73	26	31-174
Curved[1] (n=44)	Length (m)	952	538	191-2756
	Width (m)	72	20	32-126
	Curvature (°)	12	9.1	3-64
All (n=164)	Length (m)	810	518	134-3568
	Width (m)	73	24	31-174

[1] Change in orientation along scour ⩾ 3°

ORIGIN

If we accept that the scours were created as or after the glacilacustrine sediments were deposited (that is, they are not an image of features in the bedrock beneath the thin sediment cover) and that they are not of modern origin (that is, they formed before emergence of the land above lake level), then we may assume that they were created in Lake Iroquois by one or more of three agents: (1) a floating ice shelf extending from the damming glacier and flowing southwestward in response to its mass balance, or (2) icebergs calved from the damming glacier, or (3) seasonal, wind-blown lake ice.

We reject that they originated under a floating ice shelf for the following reasons. Most important is that, even though the

FIGURE 3. Part of air photograph A23662-55 showing ice scours in the study site. Arrow indicates the scour shown in Figures 5 and 6 (aerial photograph reproduced with the permission of Energy, Mines and Resources Canada).

Partie de la photo aérienne A23662-55 montrant les sillons glaciels du site à l'étude. La flèche montre le sillon illustré aux figures 5 et 6 (photo reproduite avec la permission du ministère de l'Énergie, des Mines et des Ressources).

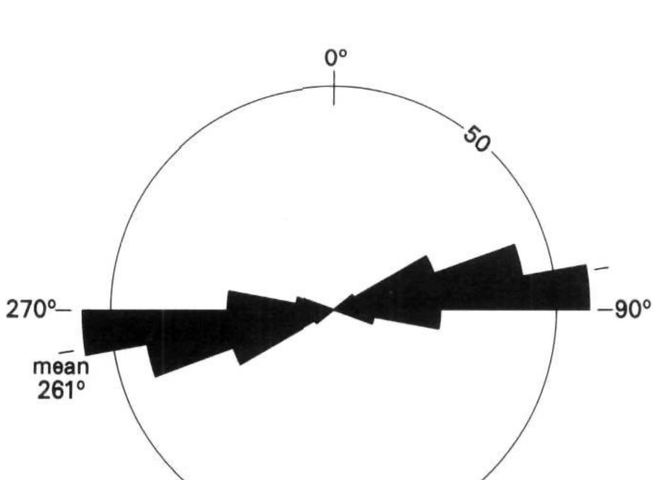

FIGURE 4. Orientation of 164 ice scours in the study site plotted in 10° increments. Data are mirrored across the origin.

Diagramme circulaire donnant l'orientation de 164 sillons glaciels du site à l'étude rapportée par accroissements de 10°.

orientation of the scours is within a narrow band, the cross-cutting relation (Figs. 2 and 3) that many scours exhibit could not be created under an ice shelf unless its flow direction changed. Such a change could only occur over a long time period in response to a difference in the geometry of the ice sheet, and it is likely that earlier scours would be obliterated as the ice grounded along most of its underside on the nearly flat sediment surface. The scours of the study site do not display the large parallel ridge and trough sequence that Woodworth-Lynas and Matile (1988) ascribe to ice shelves in Hudson Bay and Lake Agassiz. The glacilacustrine sediments at the study site are fine-grained with only a few pebbles and cobbles (probably ice rafted) and so were more likely deposited in a distal lake environment, rather than near the margin of a large, active, warm-based ice sheet. Even if they formed under a readvancing ice shelf, more evidence of a high-energy, proximal environment should be found.

If the scours were made by icebergs or lake ice, then consideration of water depth at the time of formation becomes important. Shorelines and water levels of Lake Iroquois about 12 ka BP and its later (before 11.4 ka BP), lower phases have been mapped in the Trenton area by Muller and Prest (1985) among others. From data on orientation and dip of the isostatic surface at the time these lakes existed (Anderson and Lewis

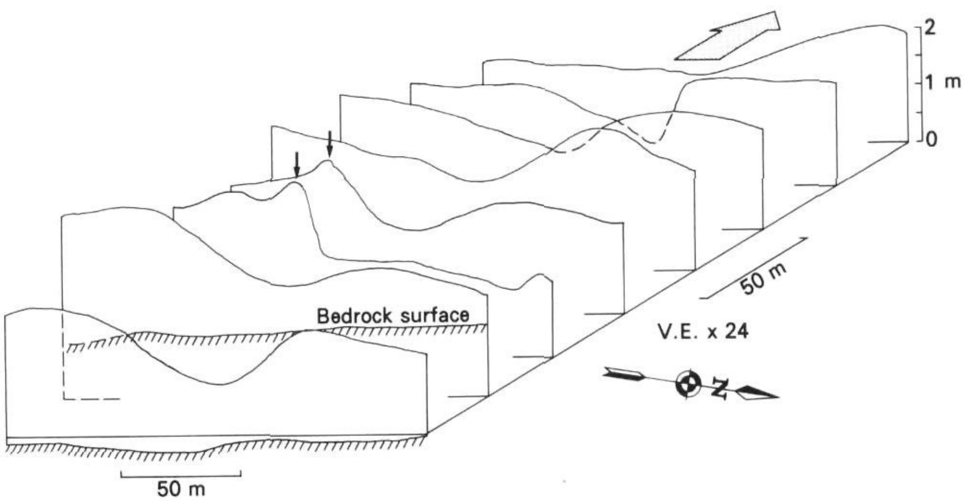

FIGURE 5. View to the southwest showing surveyed profiles across the large (158 m wide, 1.93 km long) scour shown at the arrow in Figures 2 and 3. Peaks at arrows are the result of stone and soil piles made along a fence row. Bedrock surface was determined by electromagnetic survey.

Vue vers le sud-ouest des coupes levées le long du large sillon (158 m de largeur sur 1,93 km de longueur) identifié par une flèche sur les figures 2 et 3. Les pics à l'emplacement des flèches sont le résultat d'un empilement de pierres et de terre le long d'une clôture. La surface du substratum a été déterminée par levé électromagnétique.

FIGURE 6. View to the southwest showing part of the section in Figure 5. Arrows mark the lateral ridges. Automobile near the right hand arrow indicates scale (photo by I. Spooner).

Vue vers le sud-ouest qui montre une partie du sillon de la figure 5. Les flèches montrent les bourrelets latéraux. L'automobile, près de la flèche de droite, donne l'échelle (photo de I. Spooner).

1985), the elevations with respect to present sea level of the water surfaces at the study site may be calculated as follows: 205 m at the highest stage of Lake Iroquois, 182 m in the Frontenac phase, 124 m in the Sydney phase, and 103 m in the Belleville-Sandy Creek phase. These values are subject to an uncertainty of about ±3 m. The average present level of Lake Ontario is 75 m asl. There are few documented raised shorelines in the study area. Leyland (1982) maps one along the east side of Long Reach at about 105 m asl. This suggests that the calculations above are valid and that this shoreline is of the Belleville-Sandy Creek phase when water levels were lower than those in which the scours were created. From these calculations, the position of the shoreline of the Sydney phase may be estimated and extended eastward from its mapped location in the Trenton area and to several islands on high ground in Prince Edward County (Fig. 1).

It can be seen (Fig. 2) that in the study site most of the scours occur between about 110-125 m asl. During the highest Iroquois and Frontenac phases the water depth where the scours occur would have been between 60-90 m. It is possible that even moderate-sized bergs from the nearby calving ice front could have scoured the lake floor, and some of the scours may be of this origin. However, concentration of scours in a narrow range of elevation, their similar orientation (see Helie, 1983), and the absence of large amounts of ice-rafted debris (especially dumped mounds of coarse sediment) suggest that bergs are less likely to have created the scours than lake ice. But it is also unlikely that they were formed by lake ice in deep waters of the Iroquois or Frontenac phases, because although pressure ridges in multiyear sea ice are known to scour the sea floor to 60 m depth (Reimnitz *et al.*, 1984), the known maximum depth of single year lake ice scour is less than 25 m (Grass, 1983).

During the Sydney phase, the site of most of the scours would have been in less than about 9 m water depth on the south side of a low island about 20 km offshore from the north side of the lake (Fig. 1). At this time the ice dam was sufficiently withdrawn to have created a maximum fetch to the east northeast of at least 200 km (Prest 1976; Figs. 16g and h), although the effective fetch (Håkanson and Jansson, 1983) would have been somewhat less due to the presence of the closer shoreline to the north. It is also inferred (Muller and Prest, 1985) that the water level fell rapidly from Frontenac to Belleville-Sandy Creek phases and that, because the Sydney phase beach is weakly developed, the lake level may have stood here for a very short period of years to decades at most.

From this we infer the formation and preservation of ice scours at the study site as follows. Rapid lake level lowering from water depths of about 60 m at the end of the Frontenac phase brought recently deposited, moderately distal, undisturbed glacilacustrine sediment very near to the water surface. These soft sediments were then scoured by wind-driven lake ice in relatively shallow water (less than about 10 m for the most part) around an offshore island where ice ridging and pile-up would be promoted (compare Gilbert, 1991).

Scours are formed instantaneously, and so do not necessarily correspond to the prevailing wind direction (Dionne, 1979). Nevertheless, they are most likely to be best developed in the strongest winds and there is a greater chance that they will be created by the dominant wind. From the sedimentary record in sand dunes, David (1988) records a strong, prevailing wind direction from the northeast and east (orientation toward 230-270°) in southern Québec during the immediate postglacial period. These were katabatic winds draining cold air from the glacier to the northeast. It is probable that the situation in southern Ontario was very similar and that the orientation of the scours (mean 261°) reflects the effect of this wind. The ridges that occur around the western end of some scours supports this interpretation.

Large lake ice scours have formed in water depths from 13-25 m in Lake Erie (Grass, 1983) and in very shallow water (less than about 1 m) in Great Slave Lake (Weber, 1958). This range encompasses the estimated depth of about 9 m at the scour sites in our study area during the Sydney phase. The island at the higher elevation may have acted as a centre for ice jamming, encouraging the pile-up of the moving lake ice sheet and the greater number of scours here (see also Grass, 1983). Some overtopping of the island above the water level by ice pile-up may have occurred, creating the smaller scours on its upper surface. During the open water season, the island may also have protected the scours from erosion by waves in the prevailing northeast winds. Grass (1983) reports that scours in Lake Erie are preserved through the summer only in protected areas.

Ice scouring may have lasted for only one year or a few years before the water level again fell rapidly leaving the land surface well above water level and the possibility of eradication of the scour features by waves (see also Dredge, 1982).

CONCLUSIONS

There is no way of knowing whether the scours all formed at the same time. Scours at higher elevations both in the study area (Fig. 2) and elsewhere (Fig. 1) most likely formed by iceberg keels in water depths of up to 90 m during the Iroquois and Frontenac lake phases. However, based on the form and location of the scours in the study site, we conclude that most were likely formed by rafting lake ice in prevailing katabatic winds blowing from the damming glacier to the east and north, during the short-lived Sydney phase of the lake. Soft sediments were exposed near the water surface for a short period before the lake level fell exposing the scours subaerially and preventing further erosion in the lake. The low island to the north may also have protected the scours from wave erosion.

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