Géographie physique et Quaternaire

The Devil Lake pothole (Ontario): Evidence of subglacial fluvial processes
La marmite de Devil Lake (Ontario) : une forme témoignant d’un processus fluviatile sous-glaciaire

Robert Gilbert

Volume 54, numéro 2, 2000

URI : https://id.erudit.org/iderudit/004823ar
DOI : https://doi.org/10.7202/004823ar

Éditeur(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (imprimé)
1492-143X (numérique)

Citer cet article

Gilbert, R. (2000). The Devil Lake pothole (Ontario): Evidence of subglacial fluvial processes / La marmite de Devil Lake (Ontario) : une forme témoignant d’un processus fluviatile sous-glaciaire. *Géographie physique et Quaternaire*, *54*(2), 245–250. https://doi.org/10.7202/004823ar

Résumé de l'article

Une marmite de 1,93 m de profondeur et d'un diamètre maximal de 1,3 m est située près du sommet d'une crête allongée qui forme un des bras d'un anticlinal érodé dans le paragneiss du socle précambrien, dans le sud de l'Ontario. Sa situation en terrain élevé dans une région de plus de 100 m de relief dans la roche en place montre que sa formation ne s'est pas faite par un courant subaérien moderne ou par des cours d'eau qui auraient pu provenir d'un glacier du Pléistocène supérieur en retrait. La topographie du sub-stratum régional déterminée à partir des cartes topographiques et d'un lever acoustique du soubassement des lacs avoisinants présente un modèle d'érosion sous-glaciaire à grande échelle comme celui d'autres sites de la région. La marmite a été formée par un courant sousglaciaire dont l'écoulement était concentré le long du flanc de l'anticlinal. Pendant que l'eau s'écoulait autour d'une bosse rocheuse, un vortex s'est formé au droit d'une fracture à la surface rocheuse et a provoqué l'érosion qui devait engendrer la marmite. La configuration des lieux a fait en sorte que les écoulements subséquents suivaient le même chemin. La présence de cette marmite constitue une autre preuve de l'importance des eaux sous-glaciaires comme agents d'érosion et de façonnement du relief sous l'Inlandsis laurentidien.

Géographie physique et Quaternaire, 2000, vol. 54, n° 2, p. 245-250, 6 fig.

Note

THE DEVIL LAKE POTHOLE (ONTARIO): EVIDENCE OF SUBGLACIAL FLUVIAL PROCESSES

Robert GILBERT*, Queen's University, Department of Geography, Kingston, Ontario K7L 3N6.

ABSTRACT A pothole 1.93 m deep and 1.3 m maximum diameter is located near the crest of a ridge that forms one arm of an eroded anticline in para-gneiss of the Precambrian Shield in southeastern Ontario. It's position on high ground in a region of more than 100 m relief on the bedrock precludes its formation by modern subaerial stream flow or by streams that could have come from the retreating late Pleistocene glacier. The regional bedrock topography determined from topographic maps and a subbottom acoustic survey of nearby lakes exhibits a pattern of large-scale subglacial fluvial erosion reported for other sites in the region. The pothole formed in subglacial flow where discharge was concentrated along the limb of the anticline. As flow streamed around a small rock knob, a vortex was established at a fracture in the rock surface and initiated the erosion of the pothole. This configuration insured that subsequent flows were similarly focused. The occurrence of this pothole is further evidence of the importance of subglacial water as an agent of erosion and the shaping of landscape beneath the Laurentide Ice Sheet.

RÉSUMÉ *La marmite de Devil Lake (Ontario) : une forme témoignant d'un processus fluviatile sous-glaciaire.* Une marmite de 1,93 m de profondeur et d'un diamètre maximal de 1,3 m est située près du sommet d'une crête allongée qui forme un des bras d'un anticlinal érodé dans le paragneiss du socle précambrien, dans le sud de l'Ontario. Sa situation en terrain élevé dans une région de plus de 100 m de relief dans la roche en place montre que sa formation ne s'est pas faite par un courant subaérien moderne ou par des cours d'eau qui auraient pu provenir d'un glacier du Pléistocène supérieur en retrait. La topographie du substratum régional déterminée à partir des cartes topographiques et d'un lever acoustique du soubassement des lacs avoisinants présente un modèle d'érosion sous-glaciaire à grande échelle comme celui d'autres sites de la région. La marmite a été formée par un courant sousglaciaire dont l'écoulement était concentré le long du flanc de l'anticlinal. Pendant que l'eau s'écoulait autour d'une bosse rocheuse, un vortex s'est formé au droit d'une fracture à la surface rocheuse et a provoqué l'érosion qui devait engendrer la marmite. La configuration des lieux a fait en sorte que les écoulements subséquents suivaient le même chemin. La présence de cette marmite constitue une autre preuve de l'importance des eaux sous-glaciaires comme agents d'érosion et de façonnement du relief sous l'Inlandsis laurentidien.

INTRODUCTION

Evidence mounts that fast-flowing water beneath the Laurentide Ice Sheet significantly shaped landscape by eroding bedrock and creating landforms and landscapes on scales from millimetres to hundreds of kilometres. In the Great Lakes region these features have been documented by, for example, Shaw (1988), Sharpe and Shaw (1989), Gilbert (1990), Shaw and Gilbert (1990), Kor *et al*. (1991), Gilbert and Shaw (1992, 1994), Brennand and Shaw (1994), Pair (1997), Barnett *et al.* (1998), and Kor and Cowell (1998). This paper describes a large pothole on a ridge crest in southeastern Ontario in the context of the regional topography, and proposes its origin by subglacial fluvial processes.

SETTING AND METHODS

The pothole is located 173 m a.s.l. (± 0.5 m determined by altimetry) south of Devil Lake (Figs. 1 and 2) on the northern border of Frontenac Provincial Park. The ridge on which it occurs is the eroded remnant of the northern arm of a prominent northeasterly trending anticline (Fig. 1) in the Frontenac Axis of Precambrian Grenville Supergroup metasedimentary rocks, consisting mainly of para-gneiss and related rocks (Kingston *et al.*, 1985). The bedrock through most of the region is discontinuously covered by a veneer of till less than 1 m thick except in small depressions where up to several metres may be found (Kettles *et al.,* 1992). In small lakes, bogs and poorly drained areas (dark shading on Fig. 2) about 1-5 m of Holocene organic muck have accumulated. Except in these areas, the topography determined from the National Topographic Survey 1:50 000 map 31 C/9 (Fig. 2) approximates the bedrock surface on land.

In order to assess the regional bedrock topography beneath the large lakes, subbottom acoustic surveys were conducted on Devil Lake with a 3.5 kHz subbottom profiling system and on Big Clear Lake with a 50 kHz echo sounder. Positions were determined by GPS transcribed to the analogue record at 1 minute intervals. Penetration to the surface interpreted as bedrock was obtained almost everywhere beneath the lake floors (Fig. 3). The surface shown in Figure 2 was contoured by hand from depths determined on transects 50-100 m apart. The velocity of sound in the sediment (a and b in Fig. 3) was assumed to be as in water (1460 m/s).

The topography in the immediate vicinity of the pothole was determined with a surveying level and chain (Fig. 4) and the surface features at the pothole were sketched (Fig. 5).

Manuscrit reçu le 13 juillet 1999 ; manuscrit révisé accepté le 1er mars 2000

* gilbert@lake.geog.queensu.ca

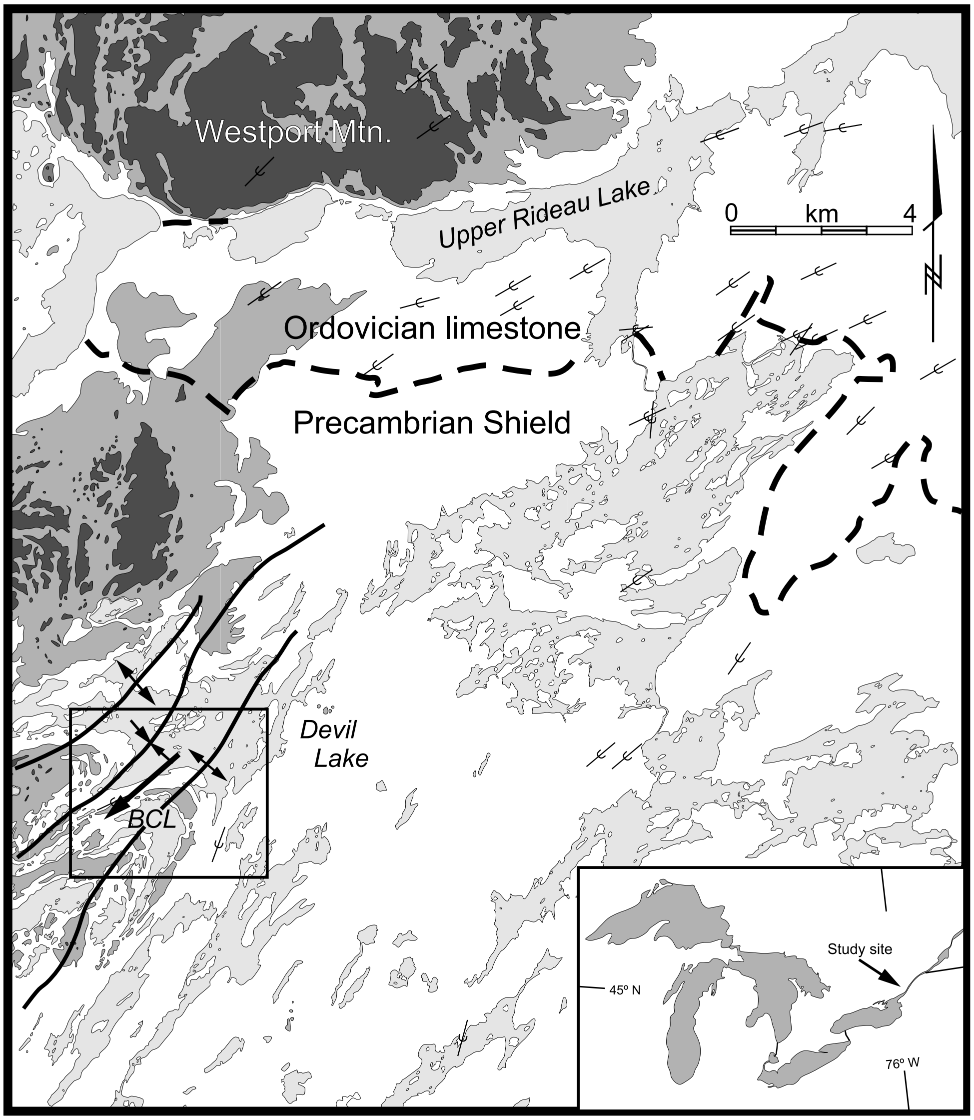

FIGURE 1. Regional map showing the location of the Devil Lake pothole (large arrow), syncline (converging arrows) and anticlines (diverging arrows) in the vicinity of the pothole, glacial striations (U-shaped arrow heads: Kettles *et al.*, 1992) and the southern boundary (dashed line) between Precambrian and Palaeozoic rocks (Kingston *et al.*, 1985). The northern boundary is along the north shore of Upper Rideau Lake. Lakes are lightly shaded; elevations above 170 m (about that of the pothole) and 190 m a.s.l. are shown with mid and dark shading, respectively. BCL is Big Clear Lake. The box outlines Figure 2. The lakes and topography are drawn from National Topographic Survey map 31 C/9 (edition 6).

Carte de la région montrant la localisation de la marmite de Devil Lake (grosse flèche), le synclinal (flèches convergentes) et les anticlinaux (flèches divergentes) dans les environs de la marmite, les stries glaciaires (u traversé d'un trait) ; Kettles et al.*, 1992) et la limite sud (traits discontinus) entre les roches précambriennes et paléozoïques (Kingston* et al.*, 1985). La limite nord se situe le long de la rive nord du Upper Rideau Lake. Les lacs sont en gris pâle ; les altitudes au-dessus de 170 m (à peu près celle de la marmite) et de 190 m sont identifiés par des plages en gris moyen et foncé, respectivement. Les lettres BCL représentent le Big Clear Lake. Le rectangle dessiné autour de la grosse flèche correspond à la figure 2. Les lacs et la topographie sont tirés de la carte topographique nationale 31 C/9 (6^{e} éd.)*

The shape in plan of the pothole was mapped with a small plane table placed in the pothole at the elevations below the rim indicated in Figure 6. Vertical spacing of measured sections was determined by the configuration of the legs beneath the plane table in the confined space of the pothole. A plumb line was used to centre the table over the deepest point in the pothole, 1.93 m below the north rim and radials were measured at 6° increments from the centre. Thus, each section in Figure 6 is correctly placed in relation to those above and below.

RESULTS AND DISCUSSION

Most remarkable is the location of the pothole on the crest of a ridge. Many potholes are described in the literature but most are along past or present river courses or coasts (*e.g.* McKellar, 1890) where their origin is easily related to recognizable patterns in the flow in streams or waves. So-called "glacial potholes" on upland surfaces, of which many have been reported (*e.g.* Upham, 1900) were early-on ascribed to the near vertical movement of supraglacial and englacial water to the bed of the glacier (Elston, 1917; Osborn, 1900). This idea was questioned more than a half century ago (Alexander, 1932; Doll, 1937), and erosion by subglacial meltwater has been invoked for glacial potholes in Scandinavia (Ericsson *et al.*, 1982) and eastern Canada (Sharpe and Shaw, 1989; Kor *et al., 1991*; Shaw, 1996).

REGIONAL EROSIONAL PATTERNS

The location of the Devil Lake pothole on a ridge crest precludes its formation by stream flow. This paper attempts to show that it was created by subglacial fluvial processes as part of a regional pattern of erosion typical of the subglacial fluvial environment described elsewhere.

Although the landscape of southeastern Ontario is subdued, local elements of relief are important in understanding glacial processes and the origin of landforms (Gilbert, 1990;

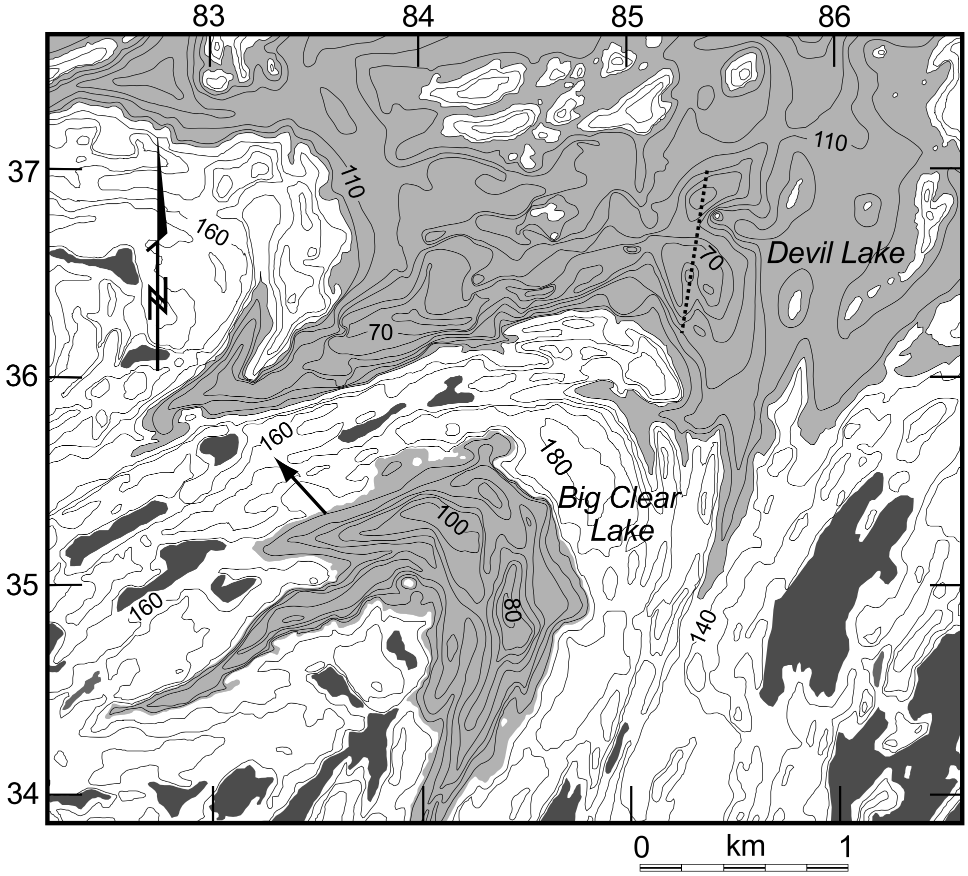

FIGURE 2. Site map of the Devil Lake pothole (arrow). Contours on land at 10 m intervals a.s.l. are from National Topographic Survey map 31 C/9 and represent approximately the bedrock surface. Contours under Devil (131 m a.s.l.) and Big Clear (156 m a.s.l.) lakes (lightly shaded) are of the bedrock surface also at 10 m intervals a.s.l. as determined from acoustic survey with 3.5 kHz subbottom profiling equipment and 50 kHz echo sounding. Ponds, bogs and small lakes not surveyed are darkly shaded. Dashed line shows the position of the transect shown in Figure 3. Positions are UTM grid in Zone 18 3_000E 49_000N.

Carte du site de la marmite de Devil Lake (flèche). Les courbes de niveau terrestres à intervalle de 10 m sont tirées de la carte topographique 31 C/9 et correspondent à peu près à la surface du substratum. Les courbes (trame grise) sous Devil Lake (131 m) et Big Clear Lake (156 m), aussi à 10 m d'intervalle, sont celles du substratum et ont été déterminées à partir d'un profil acoustique à 3,5 kHz et un échosondage à 50 kHz. Les étangs, les tourbières et les petits lacs qui n'ont pas été levés sont en noir. Le tireté correspond au profil de la figure 3. Projection de Mercator transverse (UTM), zone 18 3_000E 49_000N.

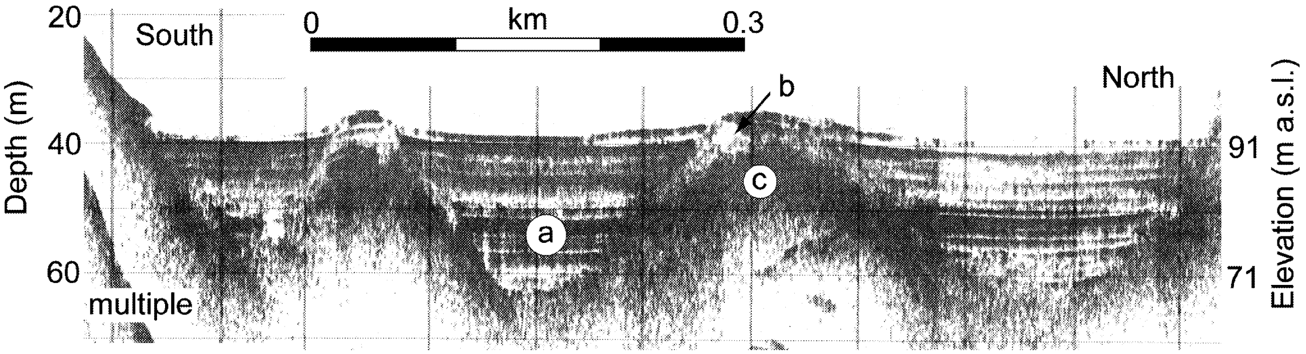

FIGURE 3. A 3.5 kHz acoustic profile from south (at left) to north showing the bedrock surface beneath the lake mapped in Figure 2. The features are interpreted as (a) Holocene sediment fill, (b) conformable late Pleistocene glacial or ice-proximal sediment, and (c) bedrock. The dashed line in Figure 2 locates the profile.

Profil acoustique à 3,5 kHz du sud (à gauche) vers le nord montrant la surface du substratum sous le lac cartographié à la figure 2. Les éléments sont interprétés comme étant (a) un remplissage de sédiments de l'Holocène, (b) un sédiment glaciaire ou de proximité glaciaire conforme du Pléistocène supérieur et (c) le substratum. Le tireté de la figure 2 donne la localisation.

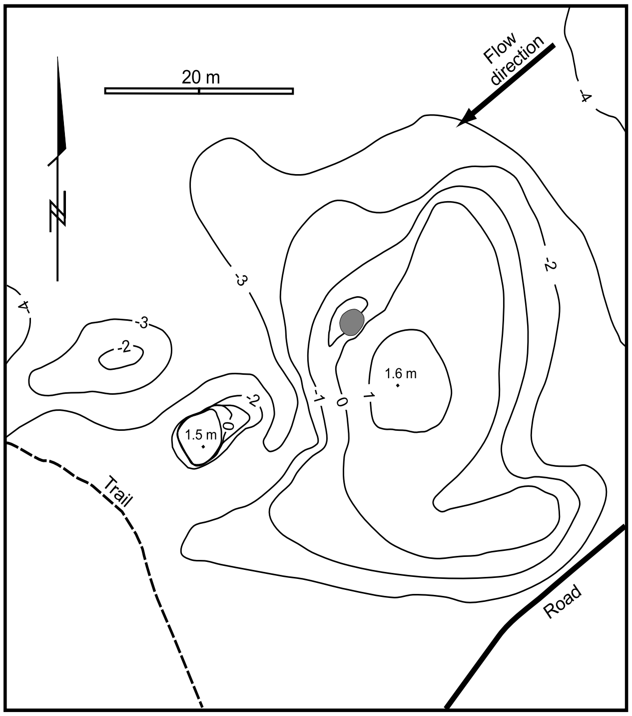

FIGURE 4. Topography in the vicinity of the pothole (shaded oval). Contour interval is 1 m and 0 m elevation is at the north rim of the pothole (173 ± 0.5 m a.s.l.). The proposed direction of flow along the arm of the anticline is marked.

La topographie aux environs de la marmite (ovale tramé). Les courbes sont à intervalle de 1 m et le niveau 0 est situé sur la bordure nord de la marmite (173 ± 0.5 m) La direction de l'écoulement le long de l'anticlinal est suggérée par la flèche.

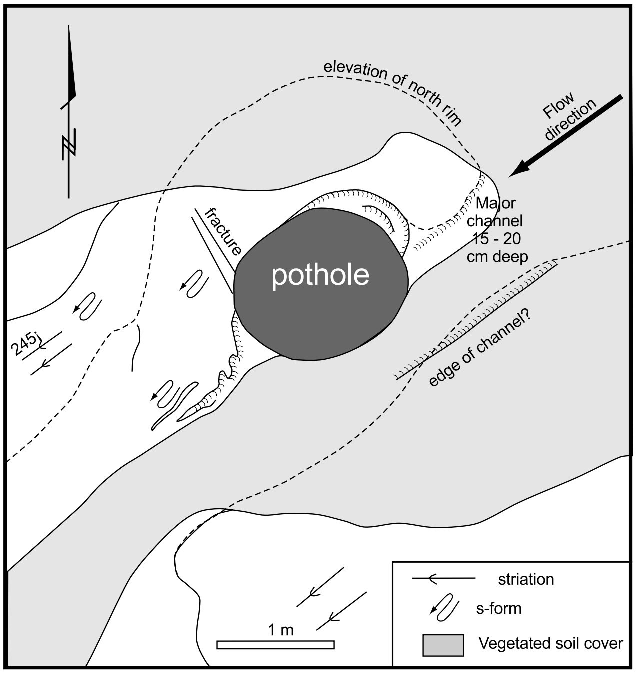

FIGURE 5. Detail of the surface around the pothole.

La surface autour de la marmite.

Shaw and Gilbert, 1990; Gilbert and Shaw, 1992, 1994). Figure 1 shows that an area of higher land referred to as Westport Mountain with elevations in excess of 200 m a.s.l. lies north of a major fault scarp along the north shore of Upper Rideau Lake. Palaeozoic limestone forms a lower surface to the northeast toward the Ottawa Valley and extends west to just north of the study area (Fig. 1). The regional slope in the Precambrian rocks of the study area is to the southeast from areas having elevations in excess of 190 m north and west of the pothole site to 100-130 m in the southeastern part of Figure 1.

This pattern appears to have influenced ice flow, directing west southwesterly flow (230-255°) in the vicinity of Upper Rideau Lake (Kettles *et al.*, 1992) to a more south southwest course at the study site (Fig. 1). The anticline with its axis at 225° diverted flow; striations on the southeastern arm are at 210°, while at the pothole on the northwestern limb they are at 245° (Figs. 1 and 5).

This pattern of flow corresponds with the direction of subglacial water flow proposed during the Ontarian event by Shaw and Gilbert (1990). It is probable that subglacial meltwater discharges would also have been locally diverted southward and concentrated by the somewhat higher land to the north of the study site. Further, the anticlines would themselves concentrate flow, especially into the syncline between them, representing the same type of concentration of flow described by Gilbert and Shaw (1994) as creating lakes at the escarpment that marks the limit of Palaeozoic limestones to the south of the study site.

The bedrock topography in the vicinity of the study site (Fig. 2) reflects both the geometry of the metasedimentary rocks in the anticline and the patterns of subglacial fluvial erosion that have been documented elsewhere. The bedrock surface is below 60 m a.s.l. at several places in Devil Lake. A complicated pattern of small ridges (Fig. 3) on the floor of the lake also occurs on land above the lake and indicates substantial differential erosion of the layered metasedimentary rocks that form the anticline. More importantly, the surface beneath the lake is deeply eroded, so that a relief of almost 130 m occurs along the former crest of the anticline. This pattern corresponds with the horseshoe-shaped scours that are found in front of and beside crag and tail features at a small scale (Shaw, 1994) and indicates the substantial role of subglacial meltwater. It is contended that this topographic pattern is inconsistent with erosion by glacial ice.

The horseshoe shape of the topographic depression at the south of Devil Lake and of the Big Clear Lake (Fig. 2) is identical to the forms described by Kor *et al.* (1991) and ascribed to erosion by water (Gilbert, 1990; Gilbert and Shaw, 1992, 1994) at approximately the same scale as reported here. The relief on the bedrock surface exceeds 100 m downstream along the axis of the anticline through Big Clear Lake. Again, this pattern is inconsistent with erosion directly by glacial ice, but represents the action of larger subglacial flows that initially occupied depressions on the bed beneath the glacier, and at peak flows lifted the glacier from its bed (*cf.* Shaw and Gilbert, 1990; Gilbert and Shaw, 1994).

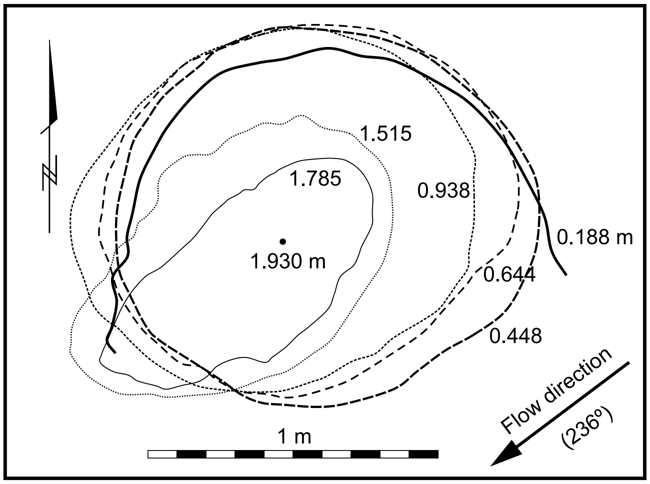

FIGURE 6. Cross sections of the pothole. Depths indicated are in metres below the north rim of the pothole.

Coupe de l'intérieur de la marmite. Les profondeurs (en m) sont données à partir de la bordure nord de la marmite.

The north ridge of the anticline decreases from 186 m a.s.l. at the axis (determined by altimetry) to 165-178 m along the north flank where the pothole is located at 173 m (Fig. 2). Although there are other s-forms (sculptured forms) on a scale of metres along this ridge and throughout the region (*cf.* Kor *et al*., 1991), most are substantially weathered and subdued. The pothole (Fig. 6) is the only feature of its kind that is known in the region. It is located where subglacial flow streamed regionally by the higher land to the north (Fig. 1), and locally by the ridge, especially by the minor depression along it's northerly side. The greater depth of erosion in Devil Lake along the northwestern side of the anticline (Fig. 2) also indicates the concentration of flow along this arm.

EROSIONAL PATTERN AT THE SITE

The topography in the immediate vicinity (Fig. 5) determined where the pothole formed. A small, steep-sided rock knob concentrated and accelerated flow especially along its northwestern flank. A channel was eroded into bedrock at the break in slope about 1.6 m below the top of the knob (Fig. 5), perhaps following an existing weakness in the bedrock.

Experimental data (Alexander, 1932) show that the rotational forces necessary to generate a pothole are greatest from relatively low-angle jets (30-60° from horizontal) flowing across the pothole tangentially to a margin. Such is the case here. The channel is nearly horizontal (Fig. 4) and the pothole is offset to the northwest. It is possible that the transverse fracture (Fig. 5) may have initiated formation by inducing a roller eddy on the right margin of the current which then eroded a progressively larger depression upflow. At the time or times when the pothole was being eroded, it is proposed that glacial ice rested on part of the surface (including the top of the rock knob, 1.6 m above the pothole - Fig. 4) but thin, high-velocity streams of water found their way beneath the ice under substantial hydraulic head.

There is evidence that the pothole developed in two stages. On the northeast side of the pothole is the remnant of part of an elliptical depression, 5-10 cm deep (Fig. 5). Its outer edge forms a sharp crest with the nearly horizontal bedrock surface around and a small secondary crest occurs within part of the depression.

The main pothole developed in this depression, probably as a result of higher velocity flow. The undercut northwest side (Fig. 6) is consistent with the interpretation of a low-angle jet entering along the left and forming a clockwise eddy directed slightly downward to the right. The upper edge forms a sharp crest with the horizontal surface along the north and west sides but is rounded along the east and south where the jet entered the pothole.

The pothole is nearly circular at the top (D_{max}/D_N = 1.10 at 0.45 m, where D_{max} is the maximum diameter and D_N is the greatest dimension normal to D_{max}), becoming more eccentric with depth (D_{max}/D_N = 1.18 at 0.94 m, and 2.15 at 1.78 m. The shape and depth are characteristic of "vertical" potholes created by thin, high-velocity flows (Zen and Prestegaard, 1994). The pothole is progressively undercut downslope, probably as a result of a fault or fractured bedding plane parallel to the flow direction that becomes apparent near the bottom of the pothole. It is this feature that drains the pothole today, so that water does not accumulate in it. Small spiral flutings are still visible on the sides of the pothole (*cf.* Alexander, 1932) but they are badly weathered and individual features cannot be traced for more than a few decimetres. Similar spiral forms were observed in potholes in the Great Lakes region (Sharpe and Shaw, 1989; Kor *et al*., 1991).

The relation of striations, s-forms and glacial sediment to the pothole suggests that the final stage of pothole formation was at the end of glaciation. Downstream of the pothole, the right bank of the channel carries small s-forms and similar weathered forms are found on the horizontal bedrock surface nearby (Fig. 5). Small, poorly preserved striations trending 245° are overlain on these features, but they were not significantly eroded by direct contact with glacial ice. The bottom 0.3 m of the pothole contained a sandy diamicton identical to the thin till over the region (Kettles *et al., .* 1992). All of the fragments larger than 1 cm were angular and showed no evidence of erosion by water. Thus, the sediment was deposited in the pothole probably from the overlying glacial ice after it had been fully formed. The small amount of sediment suggests that the last stage of formation, or at least occupance by subglacial water, was during the final stages of glaciation.

It is probable that water with fine sediment (sand and silt) was the sole mechanism of formation by corrasion of the pothole (*cf.* Alexander, 1932) and that a large stone tool was not required; none was found in the pothole. A clockwise rotating vortex transferred momentum to depth. Mass transport of relatively small amounts of water occurred around the sides, as evidenced by the spirals there, with a relatively weakly rising current in the centre. This focused energy on the sides of the pothole to depth, and transported the eroded rock particles upward and out of the pothole near the axis of rotation (Alexander, 1932).

The time taken to create the pothole is unknown. It is certainly not large (volume, 2.32 m^3) in comparison to the biggest reported (Upham, 1900; Elston, 1917) which are up to several tens of metres in diameter and depth. Lougee (1946) indicated that an almost 2-m diameter pothole formed in gneiss was created in the short time of 6-13 years. Rates of erosion from fluid stress alone indicate that centimetres of erosion may occur in a few hours in a variety of rock types (Houghton *et al.*, 1978). The flow of water draining reservoirs in the Laurentide Ice Sheet was highly episodic (Shoemaker, 1992), as are the jökulhlaups of modern glaciers (Gilbert, 1971; Clague and Mathews, 1973). Individual flow events may have lasted days to weeks and occurred infrequently, perhaps from decades to centuries. The position of the pothole on the flank of the anticline insured that each successive flood created similar conditions of erosion, but it is probable that only a few events were required to create it.

CONCLUSIONS

The Devil Lake pothole provides evidence of subglacial fluvial erosion along ridge crests beneath the Laurentide Ice Sheet in southeastern Ontario. It was created as part of a regional flow pattern that deeply eroded a prominent anticline-syncline complex in the Precambrian rocks of the Frontenac Axis of the Canadian Shield. Its position on the crest of a ridge precludes formation in an existing river. It is also not possible that a subaerial stream existed at this location due to configuration of the ice sheet during deglaciation. At least one, but probably a number of subglacial flow events were diverted by the anticline, eroding it deeply in the present basins of Devil and Big Clear lakes to features similar in form to the smaller scale erosional marks on the bedrock surface elsewhere in the region, and comparable in scale to the larger features reported from the same region. Flow diverted along the flanks of the anticline was locally concentrated and accelerated to create the pothole.

ACKNOWLEDGMENTS

Work was supported with research and equipment grants from the Natural Sciences and Engineering Research Council of Canada. Jaclyn Cockburn assisted in the field and office. Reviews by S. Occhietti, and D.R. Sharpe contributed to the the ideas and presentation.

REFERENCES

Alexander, H. S., 1932. Pothole erosion. Journal of Geology, 40: 305-337.

Barnett, P. J., Sharpe, D. R., Russell, H. A. J., Brennand, T. A., Gorrell, G., Kenny, F. and Pugin, A., 1998. On the origin of the Oak Ridges Moraine. Canadian Journal of Earth Sciences, 35: 1152-1167.

Brennand, T. A. and Shaw, J., 1994. Tunnel channels and associated landforms, south-central Ontario: Their implications for ice-sheet hydrology. Canadian Journal of Earth Sciences, 31: 505-522.

Clague, J. J. and Mathews, W. H., 1973. The magnitude of jökulhlaups. Journal of Glaciology, 12: 501-504.

Doll, C. G., 1937. A glacial pothole on the ridge of the Green Mountains near Fayston, Vermont. Report of State Geologist on the Mineral Industries and Geology of Vermont 1935-36, p. 145-151.

Elston, E. D., 1917. Potholes: Their variety, origin and significance. Scientific Monthly, 5: 554-567.

Ericsson, E., Lidén, E. and Robertsson, A.-M., 1982. New pothole supports reinterpretation of Svea River. Geologiska Foereningen i Stockholm Foerhandlingar, 104: 95-97.

Gilbert, R., 1971. Observations on ice-dammed Summit Lake, British Columbia, Canada. Journal of Glaciology, 10: 351-356.

____ 1990. Evidence for the subglacial meltwater origin and late Quaternary lacustrine environment of Bateau Channel, eastern Lake Ontario. Canadian Journal of Earth Sciences, 27: 939-945.

Gilbert, R. and Shaw, J., 1992. Glacial and early postglacial lacustrine environment of a portion of northeastern Lake Ontario. Canadian Journal of Earth Sciences, 29: 63-75.

____ 1994. Inferred subglacial meltwater origin of lakes on the southern border of the Canadian Shield. Canadian Journal of Earth Sciences, 31: 1630-1637.

Houghton, D. L., Borge, O. E. and Paxton, J. A., 1978. Cavitation resistance of some special concretes. American Concrete Institute Journal, Dec., p. 664-667.

Kettles, I. M., Henderson, P. J. and Henderson, E. P., 1992. Surficial geology, Westport, Ontario. Geological Survey of Canada, Map 1801A. Scale 1:50 000.

Kingston, P. W., Papertzian, V. C. and Williams, D. A., 1985. Geology and mineral deposits of the Kingston area, southern Ontario. Ontario Geological Survey Map P.2611. Scale 1:125 000

Kor, P. S. G. and Cowell, D. W., 1998. Evidence for catastrophic subglacial meltwater sheetfood events on the Bruce Peninsula Ontario. Canadian Journal of Earth Sciences, 35: 1180-1202.

Kor, P. S. G., Shaw, J. and Sharpe, D. R., 1991. Erosion of bedrock by subglacial meltwater, Georgian Bay, Ontario: A regional view. Canadian Journal of Earth Sciences, 27: 623-642.

Lougee, R. J., 1946. Time measurements of pothole development at Westfield, Massachusetts. Geological Society of America, Bulletin, 57: 1282-1283.

McKellar, P., 1890. Potholes north of Lake Superior. Geological Society of America, Bulletin, 1: 568-570.

Osborn, H. F., 1900. A glacial pothole in the Hudson River shales near Catskill, New York. The American Naturalist, 34: 33-36.

Pair, D. L., 1997. Thin film, channelized drainage, or sheetfloods beneath a portion of the Laurentide Ice Sheet: An examination of glacial erosion forms, northern New York State, USA. Sedimentary Geology, 111: 199-215.

Sharpe, D. R. and Shaw, J., 1989. Erosion of bedrock by subglacial meltwater, Cantley, Quebec. Geological Society of America, Bulletin, 101: 1011-1020.

Shaw, J., 1988. Subglacial erosion marks, Wilton Creek, Ontario. Canadian Journal of Earth Sciences, 25: 1256-1267.

____ 1994. Meltwater erosional marks, Marysville, p. 44-45. *In* R. Gilbert, compiler, A field guide to the glacial and postglacial landscape of southeastern Ontario and part of Quebec. Geological Survey of Canada Bulletin 453.

____ 1996. A meltwater model of Laurentide subglacial landscapes, p. 181-236. *In* S. B. McCann and D. C. Ford, eds., Geomorphology Sans Frontieres. John Wiley and Sons.

Shaw, J. and Gilbert, R., 1990. Evidence for large-scale subglacial meltwater flood events in southern Ontario and northern New York State. Geology, 18: 1169-1172.

Shoemaker, E. M., 1992. Water sheet outburst floods from the Laurentide ice sheet. Canadian Journal of Earth Sciences, 29: 1250-1264.

Upham, W., 1900. Giant kettles created by moulin torrents. Geological Society of America, Bulletin, 12: 25-44.

Zen, E. and Prestegaard, K. L., 1994. Possible hydraulic significance of two kinds of potholes; examples from the paleo-Potomac River. Geology, 22: 47-50.