A VISIT TO THE HOLLEFORD METEOR IMPACT CRATER

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How do you get there? First, find your way to the T-junction of Union Street and Division Street, right in from of the Geology Building, Miller Hall, in which is located the Geology Museum. From this point, there are two ways to go, the direct route, shown as Route A on the map on the following page, and Route B, which is slightly longer, but gives interested parties a chance to see all the rocks associated with the crater except for the sediments deposited in the crater when the crater was filled with water. These lake sediments are only seen in drill cores.

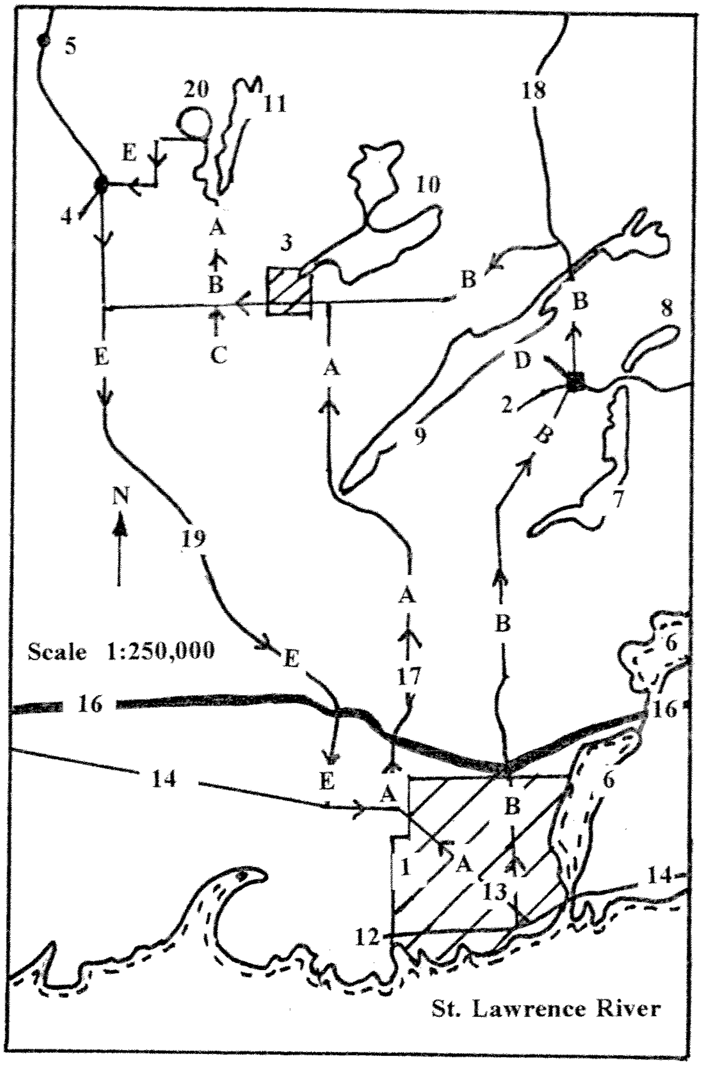
If you choose to take Route A, you go up Division Street to the third stop light. There, you turn left onto Princess Street (Highway 2) and follow it northwest about 5 km to the second stop light after taking a bridge over the railroad tracks. At this light, veer right (north) in the Village of Cataraqui onto the Sydenham Road. Follow Sydenham Road approximately 18 km to a T-junction, where you turn left (west) towards Sydenham. From the T-junction, continue west 3.6 km (through Sydenham) to a secondary road leading north (right). This is Point C on the map. Follow the road north 3.5 km, then westerly 0.2 km, then north again around a gully for 2.7 km. Here, a old church is seen just north of a side road leading west. Follow the side road west 1 km to the best position for viewing the crater, whose centre from this point lies to the northeast.

If you choose route B, follow Division Street about 5 km north to the 401, where it becomes Perth Road. Continue north about 13 km to the south edge of the town of Inverary. This is point D on both maps on the following page. Use the second map to reach outcrops of the type of rocks associated with the Holleford Crater. The third page shows the rock cut on the north side of the road. After examining the rocks, return to point D and continue north for about 4.8 km, then turn west towards Sydenham. After 16 km, you will have passed through the Town of Sydenham and reached Point C on Route A. Use instructions for Route A to reach the crater.

To return to Kingston, you can backtrack along Route A, or choose a faster Route E, shown on the map. For Route E, continue west away from the crater, take the first side road south (left) for 1.3 km, turn west (right) and go 1.8 km to Highway 38 in the Village of Hartington. Turn south (left) onto Highway 38 and follow it back to Kingston.

At the west end of the Inverary section as displayed on page 3, a limestone is shown. Core from the first 67 m of the drill hole within the crater is composed of these beds. Below the limestone, a shale is shown on the section that is equivalent to the next 3.5 m in the drill hole. Below the shale are the Rideau Beds, the lowest members of the Middle Ordovician sequence. These beds are 3.5 m thick in the drill hole. The line marked "Angular Unconformity" on the section can be recognized in the crater drill hole but in the crater, it is underlain by crater lake sediments, whereas, at Inverary, it is underlain by Precambrian rocks. However, another drill hole on the rim of the crater shows the same sequence that is present at Inverary. Place your hand at the angular unconformity and the thickness of your hand will represent a time gap of over 600,000,000 years of missing geologic history. No outcrops of Potsdam Sandstone occur along either route.

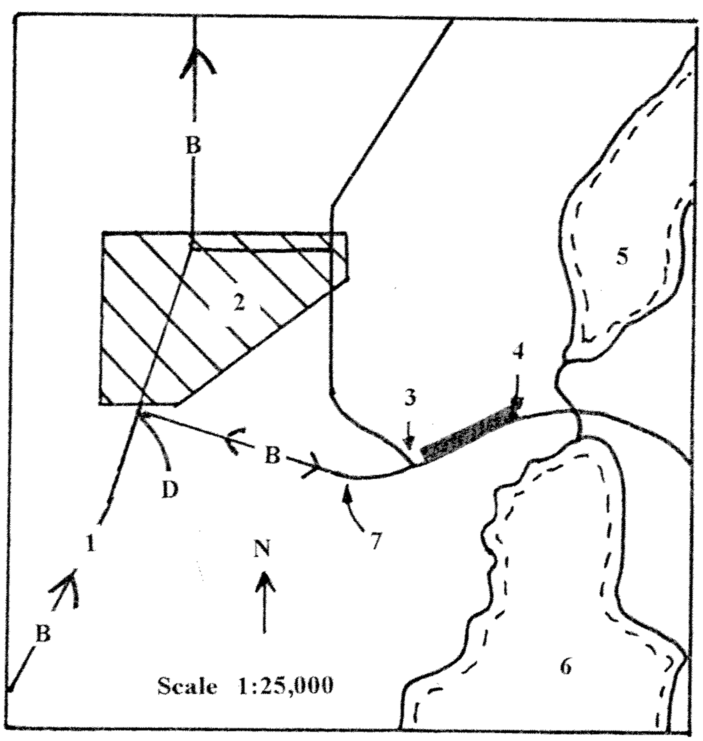
ROUTE TO HOLLEFORD CRATER



LEGEND

1	KINGSTON
2	INVERARY
3	SYDENHAM
4	HARTINGTON
5	VERONA
6	Cataraqui River
7	Collins Lake
8	Inverary Lake
9	Loughboro Lake
10	Sydenham Lake
11	Knowlton Lake
12	Union Street
13	Princess Street
14	Highway 2
16	Highway 401
17	Sydenham Road
18	Perth Road
19	Highway 38
20	Holleford Crater

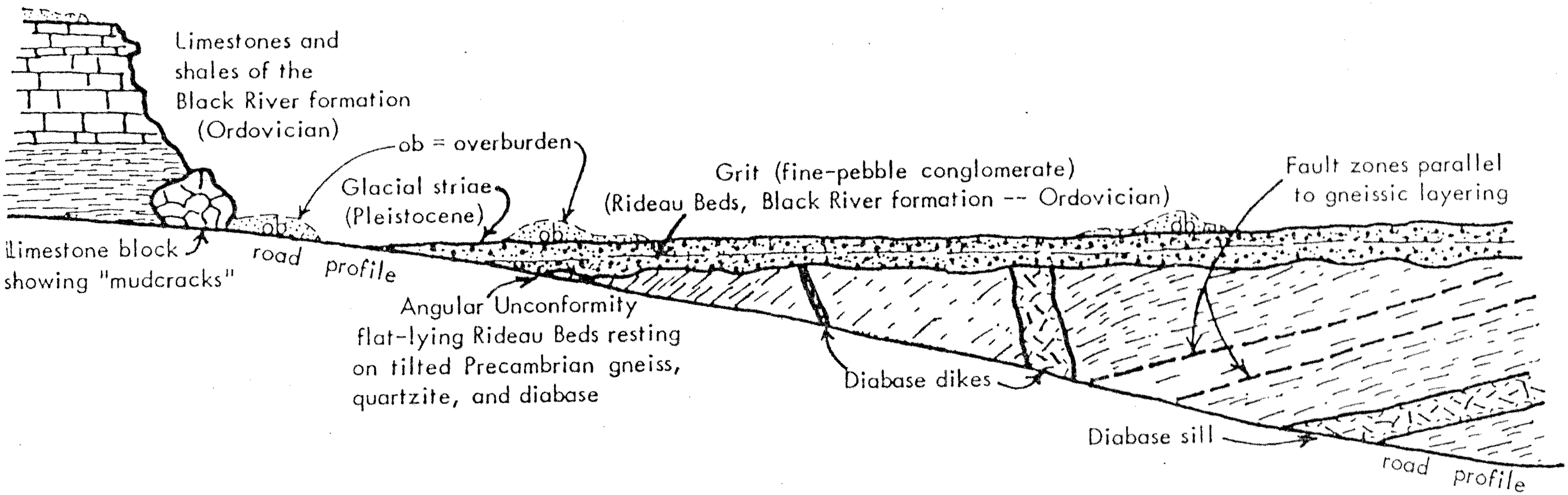
DETAILED MAP OF INVERARY SECTION



LEGEND

1	Perth Road
2	Town of Inverary
3	Old quarry on side road, suitable for parking
4	Inverary rock section showing crater-type rocks.
5	Inverary Lake
6	Collins Lake
7	Road starts down a hill through rock cuts.

EAST OF INVERARY -- GENERALIZED SECTION



Starting at the top (west end) of a rock cut about a mile east of Inverary, the youngest rocks seen are limestones and shales of the Black River Group of Middle Ordovician age -- about 470 mybp (million years before the present). Note the massive bedding in the limestone as contrasted with the thinly-bedded fissile shales. A large loose block of limestone here shows well-developed mud-cracks.

Proceeding east down the hill -- and downwards in the stratigraphic succession -- the Rideau Beds are encountered. This is the lowermost member of the Black River Group and may be termed a "grit" or small-pebble conglomerate. The greenish color is probably due to minor amounts of chlorite $(Mg, Fe, Al)_3(Al, Si)_2O_5(OH)_4$, a mineral related to the micas. Glacial striae are well-preserved on outcrop surfaces of the Rideau Beds.

The flat to gently dipping Rideau Beds are seen to rest in marked angular unconformity on the Precambrian (older than 600 mybp) gneiss, quartzite, and diabase. The diabase dikes cut across the gneiss and quartzite and show fine-grained "chilled" margins against them. In places the diabase shows spheroidal weathering. One diabase body lies parallel to the banding in the gneiss and quartzite, and is termed a "sill". Several gouge zones are present which probably mark minor faults.

The lowermost (eastern) exposures are of marble and a white pegmatite. These are not shown on the sketch above. The marble contains blocks of the pegmatite. Note the relative resistance of these two rock types to weathering and erosion.

awj, 1969

The Age of the Holleford Meteor Impact Crater

The crater is completely covered by the Middle Ordovician Black River Limestone, which started forming about 475 million years ago. Therefore, the impact dates from earlier than 475 million. Rocks fragmented by the impact are about 1,100 million years old and so the impact must have occurred more recently than 1,100 million years ago.

Away from the crater, there is a sandstone formation, the Potsdam, that dates from about 500 million years ago. The crater could not have formed at the time of the formation of the Potsdam Sandstone as this formation is not present in the crater. This leaves two time periods for the impact to have occurred, between 475 and 500 million years ago, and between 510 and 1,100 million years ago. The time scale below shows how these intervals relate to rock types. Note that Montreal was below sea level all through the Lower Ordovician, and has a continuous sedimentary record, whereas Kingston at some time rose above sea level, causing deposition of sediments to stop and erosion to occur.

<table>
<tr><th>Time Frame</th><th>Montreal Section</th><th>Kingston Section</th><th>Crater Section</th></tr>
<tr><td>Middle Ordovician 475 M.</td><td>Trenton Limestone
Black River Limestone</td><td>Trenton Limestone
Black River Limestone</td><td>Trenton Limestone
Black R. Limestone</td></tr>
<tr><td>Lower Ordovician 500 M.</td><td>Chazy Limestone
Beekmantown Dolomite</td><td>Erosion
Deposition</td><td>Window 1. Lacustrine sediments fill crater after meteor impact occurs?</td></tr>
<tr><td>Lower Ord. Upper Camb. 510 M.</td><td>Potsdam Sandstone</td><td>Potsdam Sandstone</td><td>Potsdam Sandstone?</td></tr>
<tr><td>Cambrian 545 M.</td><td>Erosion</td><td>Erosion</td><td rowspan="2">Window 2. Impact of meteor followed by the infilling of crater, then erosion which produced a depression at the crater since sedimentary rock filling the crater is much more easily eroded than metamorphic rocks that form the crater rim.</td></tr>
<tr><td>Late Precambrian 1,100 M.</td><td>Erosion</td><td>Erosion</td></tr>
<tr><td>Precambrian</td><td>Grenville Metamorphic Rocks</td><td>Grenville Metamorphic Rocks</td><td>Grenville Metamorphic Rocks</td></tr>
</table>

Window 1. This time interval assumes that the dip of the Black River Limestone towards the crater centre is dominantly the result of the compaction of sediments within the crater basin. The lake sediments were originally about 420 m thick, but the accumulation of thousands of metres of sedimentary rocks on top of this site during the Ordovician, Silurian and Devonian compacted them by about 60 m. The original near-horizontal base of the Black River stayed at its initial elevation (relative to the rim of the crater) outside the crater area but sank about 60 m at the crater centre, causing the dip seen in this formation all around the crater. The major problem with this impact dating is the time element. There are indications that deposition of marine sediments continued in the Kingston area at least into Beekmantown times, eating up some of the 25 million years assigned to this window. Then, time was needed to remove by erosion any Beekmantown and almost all of the Potsdam that had been deposited in the Late Cambrian and Lower Ordovician. Finally, the site was ready for the impact. Following impact, there is no problem about filling the lake with the sediments reported in the crater drill holes, less than 100,000 years is needed, but before the Black River can be deposited, the lake basin must be drained, for in the two drill holes within the crater, a weathered surface appears just below the base of Black River, indicating exposure to the atmosphere. That means that, at some point on the crater rim (probably on the northeast section), not only did the fall-back eject have to be eroded away, not too serious a problem if it was poorly consolidated, but a notch, possibly twenty metres deep, had to be cut in the crater rim by what was probably a low-gradient, low-volume, near-sea-level stream. This could take more time than we have in this window. Finally, sediments within the basin suggest that the crater lake froze over from time to time. Since this area was at about 20° south latitude during the time span of this window, and near sea level, it is difficult to see how the lake could freeze over. That impact occurred during window 1 is possible but unlikely.

Window 2. This window assumes that a hole existed at the crater site at the time of the deposition of the Black River Limestone, and that the dip of the limestone towards the centre of the crater is a primary dip, that is, the limestone was deposited on a sloping surface. The Precambrian rocks onto which the meteor impacted were formed about 1,100 million years ago at a depth of about 20 km below the surface at the roots of a mountain range. As the mountains eroded away, the land rose isostatically, and these rocks were at the surface at the time of the deposition of the Potsdam Sandstone. That means that the average rate of erosion was about 20 m each million years. However, erosion was faster initially, because the surface rocks were more easily eroded and the gradients were much steeper. The present rate of erosion of Precambrian rocks exposed on the relatively flat Canadian Shield is about 2 m per million years, and that is not an unreasonable rate to assume for the period just before the deposition of the Potsdam. I have assumed that the rate of erosion decayed exponentially between 1,100 and 510 million years, not because I believe this is correct, but merely to illustrate in the accompanying diagram how erosion could reduce the size of the crater that was preserved. No fallback ejecta has been found around the crater, so it was apparently eroded away before the Potsdam was deposited. Also, the rim of the crater was breached at some time so that the lake in the crater could drain. This probably took several tens of millions of years, so I would place the latest date for impact in this window at about 550 million years. If the crater did form at this time, it might have initially been about 200 m (using my estimated rates of erosion) than it appears to be today. If it formed 600 million years ago, it could have been 500 m deeper, and if it formed 650 million years ago, it could have been 1400 m deeper. Although these numbers are highly speculative, they are the best I could come up with, and they do show that the original depth of the crater is dependant on the time of impact. The diagram below illustrates this relationship.

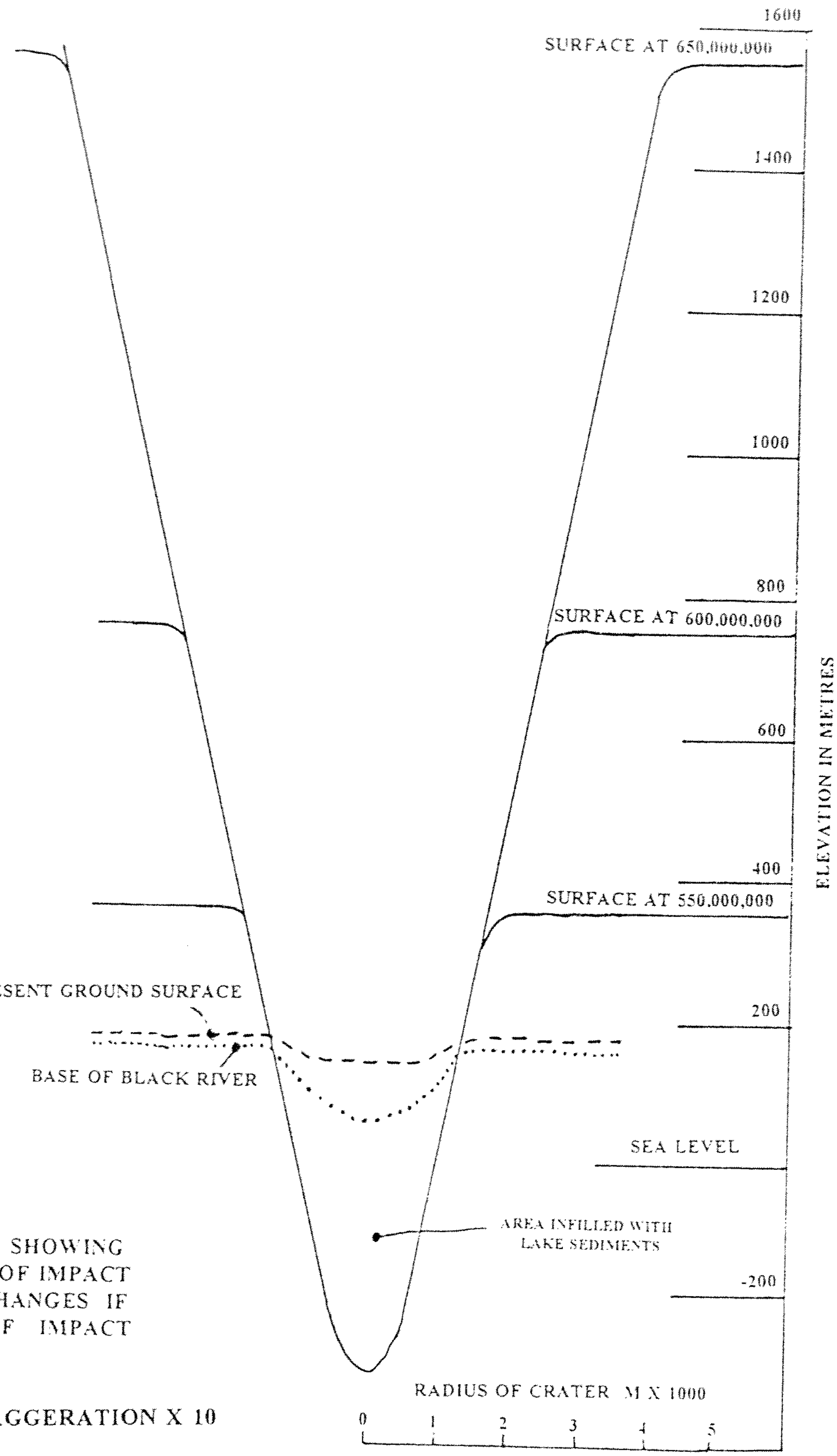


DIAGRAM SHOWING HOW SIZE OF IMPACT CRATER CHANGES IF TIMING OF IMPACT CHANGES

VERTICAL EXAGGERATION X 10