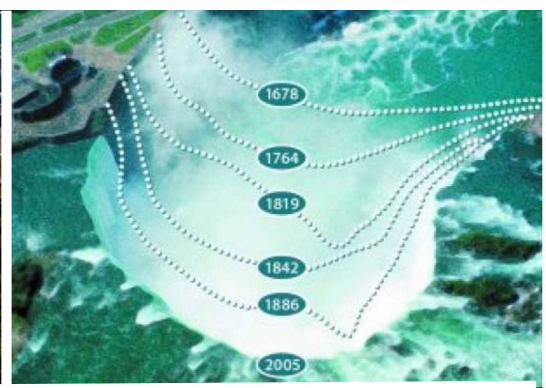
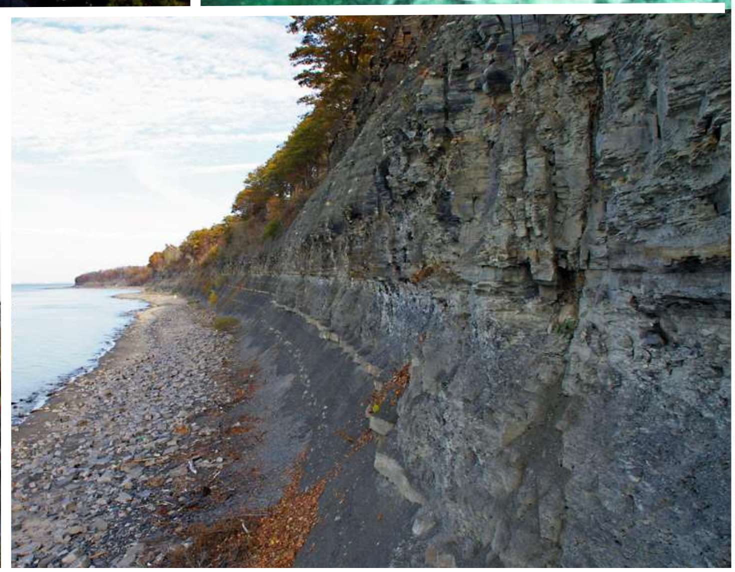
THE UPPER ORDOVICIAN–DEVONIAN AND PLEISTOCENE GEOLOGIC HISTORY OF WESTERN YORK: A GUIDE TO THE GEOLOGY OF THE NIAGARA FRONTIER

Field Trip 2 – Monday - July 31, 2023

International Commission on Stratigraphy Subcommission on Devonian Stratigraphy Geneseo, New York





International Commission on Stratigraphy
Subcommission on Devonian Stratigraphy

..

THE UPPER ORDOVICIAN–DEVONIAN AND PLEISTOCENE GEOLOGIC HISTORY OF WESTERN YORK: A GUIDE TO THE GEOLOGY OF THE NIAGARA FRONTIER

Carlton E. Brett and Betty-Lou Brett
Editors

Field Trip 2 – Monday - July 31, 2023
Geneseo, New York

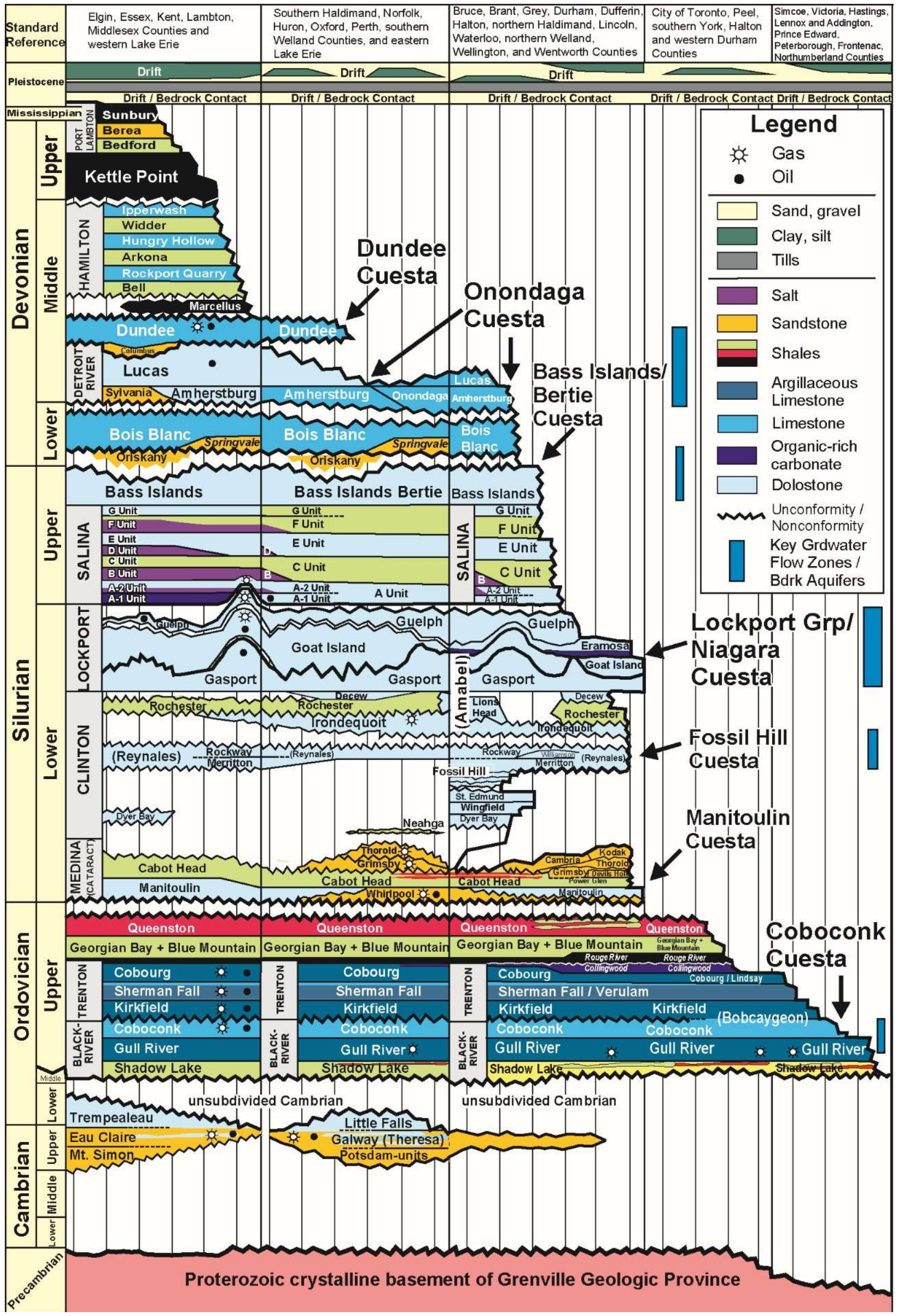


Figure A. Revised terminology of Paleozoic strata for south-central and southwestern Ontario (*modified after* Winder 1961; Beards 1967; Winder and Sanford 1972; Armstrong and Carter 2010; Brunton et al. 2017; Carter et al. 2017). Group names are in capitals, members in italics, and abandoned or geographically restricted formation names in brackets (e.g., Amabel Formation, which comprises: Irondequoit and Rochester/Lions Head fms of Clinton Group and Gasport Fm and lower member of Goat Island Fm of Lockport Group, and Reynales which is older than Rockway and Merritton fms, but has been used for these terms away from Niagara region; Brunton and Brintnell 2011; Brunton et al. 2012). The change in position of the Ordovician–Silurian boundary is discussed in Bergström et al (2011) and Schröer et al. (2016). Relative thicknesses of rock units are not to scale (courtesy of Frank Brunton)

THE UPPER ORDOVICIAN-DEVONIAN AND PLEISTOCENE GEOLOGIC HISTORY OF WESTERN YORK: A GUIDE TO THE GEOLOGY OF THE NAGARA FRONTIER

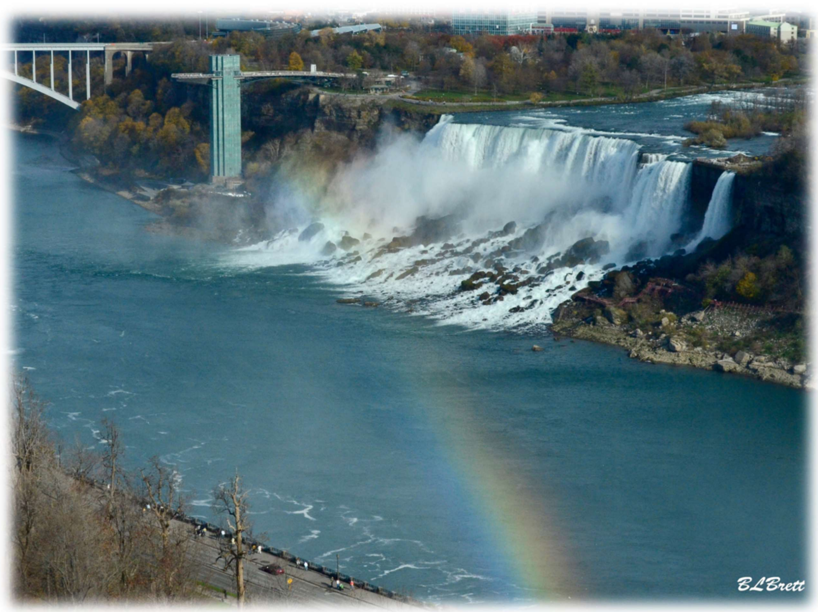
by Carlton E. Brett

Table of Contents

PART I GENERAL GEOLOGY, GEOMORPHOLOGY, STRUCTURE, AND QUATERNARY HISTORY OF THE NIAGARA FRONTIER

CARLTON E. BRETT

View of Horseshoe Falls from Canada



View of Niagara Falls from Canada

GENERAL GEOLOGY, GEOMORPHOLOGY, STRUCTURE, AND QUATERNARY HISTORY OF THE NIAGARA FRONTIER

CARLTON E. BRETT

1 Department of Geology, University of Cincinnati, Cincinnati, Ohio 45221-0013
(carlton.brett@uc.edu)

INTRODUCTION

Western New York State and adjacent southern Ontario, Canada, lie between two of the Great Lakes, Lake Erie to the southwest and Lake Ontario to the north. The Niagara River, which connects the two lakes flows northward separates the United States (New York) and Ontario, Canada. The river has an enormous flow (average: ~57020m^3/second) as it carries water from the four upper Great Lakes- but is relatively short 57.3 km (35.6 mi) and drops 99 m (326') in elevation, with 51 m (167') of the drop being at the iconic Niagara Falls (see Tesmer, 1981). The mean natural flow is about 202,000 ft^3 (5,721 m^3/sec) and can be increased temporarily by as much as 50 percent due to water surface set up during storms along Lake Erie. However, it is otherwise very stable. Since about 1905, the flow over the Falls itself has been markedly limited by water diversion for hydroelectric power generation. Presently, and by an international agreement in 1953, it carries 50 percent of the river's natural flow or about 100,000 ft^3/sec (2,800 m^3/sec) during tourist hours (day hours in summer) and only about 25 percent 50,000 ft^3/sec (1,400 m^3 /sec) at other times. About 92 percent of undiverted flow passes over the Horseshoe Falls, 8 percent over the American Falls, and this percentage may have been the average even under pre-control discharges (Tesmer, 1981; American Falls International Board 1974).

The western New York portion this region, proximal to the Niagara River, including Niagara, Orleans, Erie, and Genesee counties, is historically called the Niagara Frontier, a term dating from the War of 1812, when the northern border was contested between the United States and Canada. The Niagara Frontier was long a strategic area in eastern North America because with a portage road around the falls and subsequently the Erie Canal with its locks at Lockport to allow passage up and down the Niagara Escarpment it was possible to transport goods from Lake Erie and the upper Great Lakes to and from Lake Ontario or the Hudson River and New York ports.

Buffalo in Erie County lies along the western end of Lake Erie at the head of the Niagara River. Niagara Falls, NY in Niagara County and its sister city, Niagara Falls, Ontario are separated by the great falls and Upper Great Gorge of the Niagara River. The waterpower of this falls long inspired the development of mills and other industries, especially chemical industry, and is today one of the most important sources of hydroelectric power generation in both the US and Canada.

GEOMORPHOLOGY AND PHYSIOGRAPHIC REGIONS

Elevations in the Niagara Frontier increase in a southerly direction range from ~74m (243') at the shore of Lake Ontario to about 590m (1940) in the Boston Hills southern Erie

County. The geomorphology-physiography of the Niagara Frontier is dominated by two major north-facing, east-west cuestas or escarpments the Niagara or Lockport escarpment in the north and the Onondaga escarpment. These scarps separate regions of relatively low relief and with subtle glacial features including a series of moraines produced during recession of late Pleistocene.

These parallel the east-west outcrop belts of mid Paleozoic bedrock which have developed perpendicular to the gentle southward dip. This physiography reflects a combination of tectonics and variations in bedrock resistance to erosion developed over some 300 million years of erosion since the rocks were uplifted and tilted gently (0.25-to-0.5-degree dip) to the south during the Carboniferous-Permian Alleghenian Orogeny. The bedrock and glacial geology of western New York were mapped by Fisher et al. (1970).

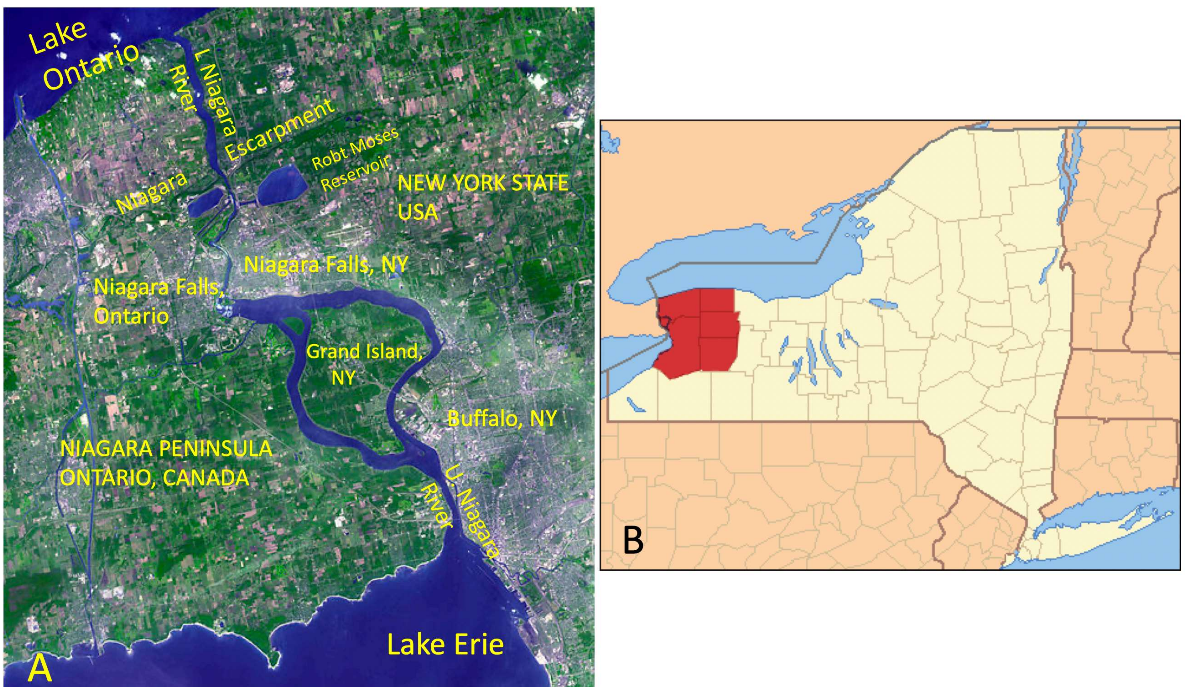


Figure 1. The Niagara region of western New York State and Ontario, Canada. A) Satellite image showing major landmarks referred to in the text. L: lower (near the mouth); U: upper (near the head) of the Niagara River. B) Map of New York State, showing the extent of the Niagara Frontier as defined by US weather Bureau. Counties shown (clockwise from northwest): Niagara, Orleans, Genesee, Wyoming, Erie.

Lake Ontario Plain: The area immediately south of Lake Ontario is a lake plain which was formerly a wave swashed floor of the preceding Lake Iroquois, a proglacial lake in the Ontario basin which was held on the north side by the wasting Laurentide icesheet. The lake plain is underlain by brick red mudstone and siltstone of the Upper Ordovician Queenston Formation.

A prominent gravel ridge which formed a woodland road for early native Americans and presently hosts NY Rte. 104 (Ridge Road), represents a beach ridge developed at the former shoreline of Lake Iroquois (Figs.2, 3). The Lake Ontario Plain is notable area for orchard and vineyard agriculture because of the temperature moderating effect of Lake Ontario.

Niagara Escarpment: The Niagara (also called Lakes or Lockport) Escarpment is a prominent erosional cuesta with no evidence for fault offset. The scarp (commonly referred to as a "mountain") rises about 76 m (250') above the Lake Ontario plain to the north. The escarpment can be traced from western New York westward to near Hamilton, Ontario and thence in an almost north-south into the Bruce Peninsula between Lake Huron and the Georgian Bay and thence across Manitoulin Island into the upper Peninsula of Michigan and finally to the Door Peninsula of Wisconsin in Lake Michigan, a distance of more than 1050 km (650 miles). Throughout this length the escarpment represents the erosional edge of the resistant Silurian Lockport Group (Wenlock, Sheinwoodian to lower Homerian) dolostones. In places in western New York, separate narrow terraces are developed on the hard mid Clinton Group Irondequoit Limestone and, locally on the Medina Sandstone. The knickpoint of the Niagara Escarpment produces numerous waterfalls on small north flowing streams and of course in the Niagara River. Much of the lower Silurian outcrop belt discussed in this guide lies within the narrow (commonly <1 mile wide) ribbon of terrane from the base to the top of the escarpment.

Lake Tonawanda lowland: The upper Lockport Group and Salina Group dip gently to the south forming a tableland, which following the last glacial stage (Wisconsin) was occupied by a shallow lake, referred to as Lake Tonawanda (d'Agostino, 1958) which was essentially overflow from ancestral Lake Erie. Today this region is flat land with local swamps and bogs, especially over the position of the Salina Group which has almost no exposures.

Onondaga and Portage Escarpments: To the south, in central Erie County, a second and less prominent escarpment is formed at the erosional edge of the upper Silurian Bertie and Akron dolostone and the unconformably overlying Lower-Middle Devonian Bois Blanc (upper Emsian) and Onondaga limestones (uppermost Emsian to Eifelian). Again, a number of waterfalls occur here on minor streams, e.g., Indian Falls at Akron. However, the Niagara River has cut through the escarpment with only rapids at the Black Rock Channel. Here the Bertie Group forms a small island in the river termed Squaw Island.

South of the Onondaga Escarpment in Erie County the topography changes from tableland to hilly, a series of large northwest flowing creeks (or small rivers) Buffalo, Cazenovia and Cayuga, and Tonawanda and their many tributaries cut into the Middle Upper Devonian gray and black shales and thin limestones in central Erie County.

Somewhat harder black shales and siltstones hold up a Lake or Portage Escarpment south of Buffalo where the topography becomes notably more rugged. A broad planar region extends along Lake Erie inward to the Portage Escarpment. This flatland was formerly the bed of late Pleistocene predecessor lakes Dana and Whittlesey when water in the Erie basin was at higher elevations formerly the bed of late Pleistocene predecessor lakes Dana and Whittlesey when water in the Erie basin was at higher elevations.

STRUCTURAL GEOLOGY

The structure of western New York is relatively simple, rocks dip gently at. 0.25 to 0.5 degrees to the southwest. This tilt, imparted by the Carboniferous-Permian Alleghenian Orogeny has very strongly influenced the development of the prominent west-east outcrop belts which display successively older rocks to the north, and the development of the

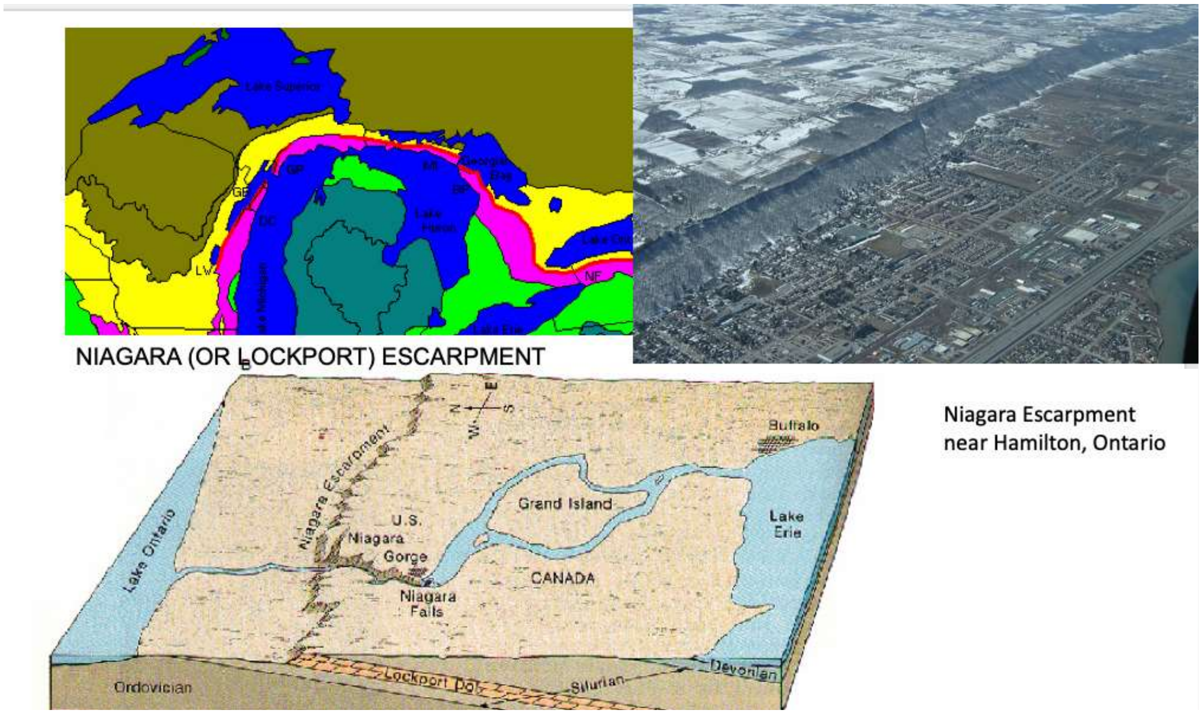


Figure 2. The Niagara Escarpment and outcrop belt of Silurian Lockport Group and equivalents. Upper left figure, extent of the Escarpment (in magenta) in the Great Lakes area, segments going clockwise: Door Peninsula starting near Lake Winnebago (LW) and near Green By (GB) and continuing into Door County (DC), Wisconsin, continuing into the Garden Peninsula (GP) in Michigan, and thence into Manitoulin Island (MI) and the Bruce Peninsula (BP) in Ontario between Lake Huron and Georgian Bay and finally, extending to Niagara Falls, NY (NF); upper right: aerial view of Niagara Escarpment near Hamilton, Ontario (relief is about 90m); lower view; schematic view of the Niagara Escarpment in the Niagara Frontier area.

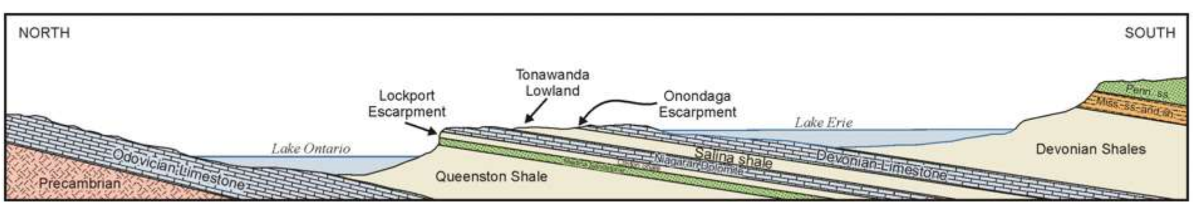


Figure 2B. Regional north to south cross section through the Niagara Frontier showing the three major escarpments: Niagara (Lockport), Onondaga, and Portage. Note lake basins and low relief table lands in areas of soft shale outcrop.

escarpments at the leading erosional edges of more resistant rock layers softer shales and evaporites have eroded to the flat tableland stretches. In addition, there are apparently a series of minor folds and possibly small faults including a minor syncline oblique to the Niagara River that may have helped focus drainage of both the Niagara River and an earlier St. Davids River (Liberty, 1981).

Finally, most rocks in western New York show a series of sharply defined vertical to slightly oblique fractures or joints in particular sets that help to control erosion and keep the walls of Niagara Gorge near vertical and permit the collapse of large blocks of bed rock during falls recession. These joints are also a product of the regional stresses during the Alleghenian Orogeny. Recent studies by Lash (2006) and Lash and Blood (2006), suggest that these joints may have formed by the release of pressure from natural gas/petroleum buildup along zones of slight extension perpendicular to major stress directions during the Alleghenian Orogeny analogous to hydrofracking.

PLEISTOCENE HISTORY OF THE NIAGARA FRONTIER AND NIAGARA GORGE

The Niagara Falls and vicinity have been subject to many classic studies. Early authoritative accounts of the Falls include Hall (1838, 1842, 1844; Lyell, 1838-1842, 1860; Gilbert, 1891,1907; Grabau, 1901, Kindle and Taylor, 1913; see Tinkler 19887 for excellent review of early views). For a more modern synthesis see Tesmer (ed.) (1981) and papers therein. The latter volume is presently being updated. Excellent and detailed roadlogs and descriptions of sections include Krajewski and Terasmae (1981),

Wisconsin Glaciation: The Niagara Frontier area was subject to repeated glaciations although the details of older episodes has been largely obliterated by the erosion and reworking in the final Wisconsin glacial advance. These glacial advances had preferentially scoured out the soft Ordovician and Devonian shales in the valleys of the older, pre-glacial northeast-flowing Erian and Ontarian Rivers. Glacial deposits including end and ground moraine, drumlins, eskers, and glacially related lake deposits, in western New York originated during one or more pre-Wisconsin glaciations and three or more successively less-extensive Wisconsin stades (Dreimanis and Karrow, 1972; Muller and Calkin, 1993; Terasmae, 1981).

Ice- margin retreat about 14,000 B.P. from positions in the mid-western United States initiated lake deposits, succession of moraines and ice-dammed lake in the Great Lakes basins. Hough, 1958; Prest, 1970; Calkin and Feenstra, 1985; Muller and Prest, 1985). Both ice recession and glacial-lake events were repeatedly interrupted by glacial readvances and complicated by crustal warping and erosion of lake outlets. The following account is excerpted and modified from earlier guidebooks by Brett and Calkin, 1987, 1996)

Evidently, during earlier interglacials, there were strong flows from the (later) Lake Erie Basin over the Niagara Escarpment. Former major outlets cut across the Niagara Escarpment west of Niagara Falls, such as the Erigan Valley (Karrow, 1973; Flint and Lolcama, 1986) and the pre-Late Wisconsin, St. Davids Gorge (Hobson and Terasmae, 1969; Karrow and Terasmae, 1970; Terasmae, 1981) were drift- filled prior to the last glacial retreat. they may have influenced the later drainage and in places, as at the Whirlpool of the Niagara River, were re-excavated by chance intersections.

During the last major ice readvance into New York State, the Port Huron stade dating from about 13,000 B.P. (Calkin and Muller, 1993), the ice sheet spread radially out of the Lake Ontario basin. Glacial Lake Whittlesey, which was initiated in the Erie basin by this advance, was succeeded by three phases of glacial Lake Warren, as well as very brief phases termed Lake Grassmere, Lake Lundy, and possibly two yet shorter glacial lake intervals during subsequent general ice recession from western New York.

Lakes Erie, Iroquois, and Tonawanda: The receding Wisconsin glacial front was stalled at the crest of the Niagara Escarpment until after ~1300 B.P. year BP forming the Barre-Albion moraine along of just in front of the escarpment. Retreat of the ice front north of the Niagara Escarpment by at least 12,400 B.P. created ice dammed Lake Iroquois in the southern part of the old Ontarian River Valley (subsequently Lake Ontario basin) and allowed waters from the predecessor lakes (Lundy, Grassmere) to flow over the Niagara Escarpment in several spillways, the westernmost being the ancestral Niagara River (Muller and Prest, 1985). Nonglacial early Lake Erie came into existence in the Erie basin with removal of glacial waters to the north of the Niagara Escarpment, presumably simultaneously with formation of Lake Iroquois. Radiocarbon ages for the inception of early Lake Erie are as old as 12,650 B.P. or as young as 12,000 B.P. (Coakley and Lewis, 1985). these waters, they spilled into the Tonawanda Lowland between Onondaga and Lockport cuestas (Fig. 2B) forming the river-lake, known as Lake Tonawanda, with initial outlets to Lake Dawson in the west end of the Ontario basin (Fig. 3).

The lowering of glacially dammed lake waters below the Niagara Escarpment for the last time and consequent formation of early Lake Erie, initiated the Niagara drainage system as we know it today and the first Niagara Falls came into existence ~12,300 years BP when water from the Erie basin/Lake Tonawanda first poured over the escarpment and into Lake Iroquois near the present town of Lewiston (Fig. 3). The 11.2 km (~7mi) canyon or Niagara gorge has been cut by headward erosion of the falls in the past 12,000 years. A complex history of changing outlets to the upper Great Lakes owing to glacial retreat past thresholds and isostatic uplifts produced periods of greater or lesser flows through the ancestral Niagara River. This led to periods or slow or nearly stalled erosional retreat of the falls and other intervals when narrow deep stretches of the Niagara Gorge were formed.

The swift-moving catastrophic waters of final lowering (Forsyth, 1973) must have first incised a channel across the Buffalo-Fort Erie Moraine and Niagara Falls Moraine; however, this incipient Niagara River may have quickly cut down to the underlying Onondaga Limestone surface at Buffalo (Barnett, 1979). This surface now forms the Lake Erie's threshold.

Lake Tonawanda was a shallow river-lake extension of the upper Niagara River and at high flows, of early Lake Erie itself (d'Agostino, 1958). During its highest stand, perhaps at about 590 ft (179.9 m) near Niagara Fails, the lake stretched 58 mi (93 km) eastward and averaged about 30 ft (9.1) m) in depth. At this stage outflow was via spillways cut through the Niagara Escarpment at Lewiston, and farther east at Lockport, Gasport, Medina, and Holly, New York (Kindle and Taylor, 1913). At least one of these bedrock spillways may have been cut prior to this outflow: clayey sand and gravel described from borings in the lower reaches of the Lockport spillway (see Stop 1 in road log) is interpreted as till (Calkin and Brett, 1978).

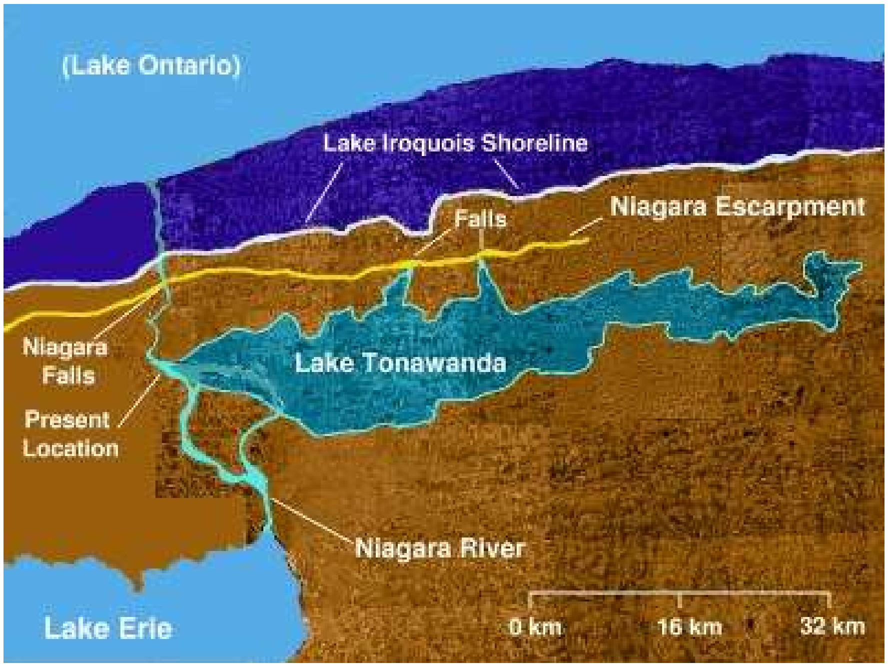


Figure 3. Lake Tonawanda and Lake Iroquois at about 12,000 BP; pale blue area north of Lake Iroquois represents the receding late Wisconsin glacial front. Note the several spillways over the Niagara Escarpment.

The Lewiston spillway eventually became the main Niagara River channel as differential isostatic uplift toward the northeast caused the eastern outlets to give way successively to those in the west closer to Lake Erie outflows. A series of regularly decreasing radiocarbon ages on spruce wood collected at the lower end of the main Lockport spillway suggests that major sediment and water discharge here had ceased by about 10,920 ± 160 B.P. and moved to the Ontario basin only via Lewiston/ Niagara Falls outlets (see Stop 1). Lake Tonawanda had probably drained to a series of marshes in its eastern portions by this time.

Gorge formation probably involved headward recession of one major falls line from the escarpment at Lewiston through most of the gorge length, except through portions resurrected from the buried St. Davids Gorge (Stop 8). Here, the cutting and re-excavation may have involved a series of rapids and stepped falls, as Pohlman (1889) had envisioned for excavation of the whole Gorge. However, the rate of back- cutting was erratic, perhaps because of drainage diversions or additions (above). The banks of this ancestral Niagara left abandoned above the gorge wa11s by Falls recession are terraced in places along the gorge and outline a channel broader than the present gorge. Remnant sand and gravel along this channel have revealed, at selected locations, a well-preserved mollusk assemblage. This is, in part, like that of the present assemblage of Niagara River mollusks (Letson *in* Grabau, 1901; Calkin and Brett, 1978; Brett, 1981a).

St. Davids Gorge and Whirlpool: The broad Whirlpool Basin, occurring at a sharp "elbow bend" in the Niagara Gorge is one of the most dramatic features of the river (Fig. 4). It is the result of the accidental intersection of the modern Niagara River and falls with an old glacial drift-filled gorge and partial re-excavation of that pre-late Wisconsin gorge. The buried St. Davids Gorge has been known since the time of Lyell and Hall; its stratigraphy south of the Whirlpool was outlined at the turn of the century by Upham (1898) and Spencer (1894). Hobson and Terasmae (1969) obtained a ^{14}C age of 22,800 ± 450 yr B.P. (GSC-816) on wood of interstadial deposits sandwiched between multiple till sequences within the buried portion from a drill core through the fill of the St. Davids Gorge.

The reach of the Niagara Gorge between the Niagara Glen and the Whirlpool, the so-called "Ongiara Gorge" of Antevs (1931) was considered to have been cut after about 9800 B.P. (Calkin and Brett, 1978), based on ages of mollusks obtained from riverbanks just north of the Niagara Glen and at the Whirlpool mol1usk succession (Fig. 4) A suite of bivalves *Pisidium* and unionids, and gastropods especially *Goniobasis* (Brett, 1981a), was found in sands in the terrace at Whirlpool Points indicating that this area was part of the ancient upper (above the falls) Niagara River bed and was preserved here because headward erosion caused the river to shift westward into the soft drift fill of the ancient St. Davids Gorge. The Niagara Glen data suggest that the intersection of the receding falls with the buried St. Davids Gorge may not have occurred fully until about 4500 B.P.; furthermore, it is likely to have been associated with increased discharge due to the return of upper Great Lakes discharge through Lake Erie started during the Nipissing phase of the upper Great Lakes.

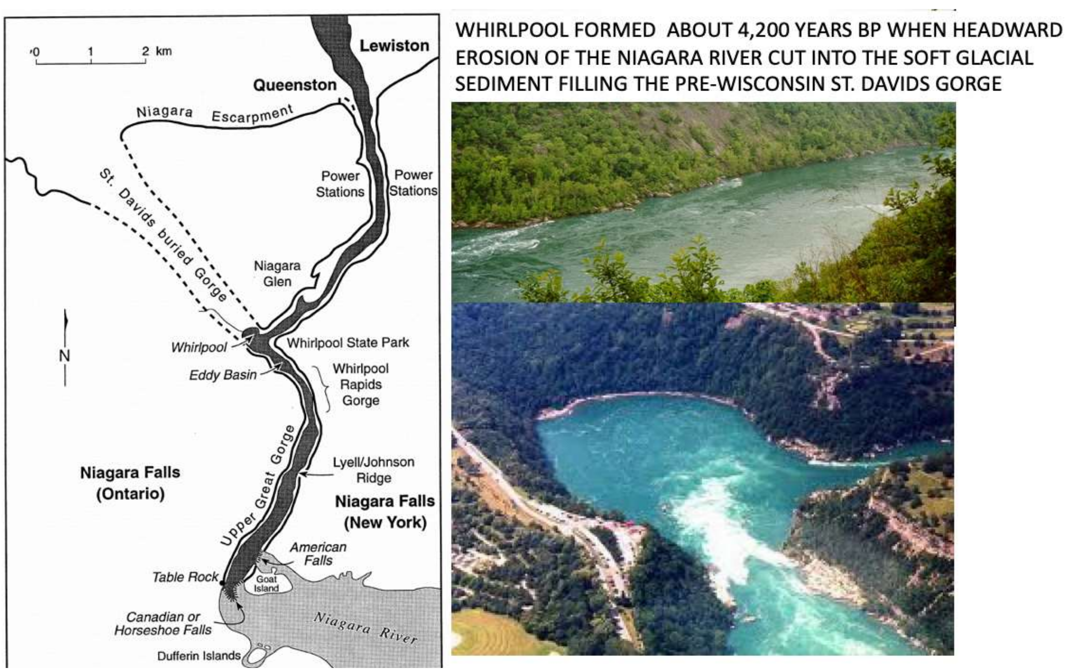


Figure 4. Sketch map of the Niagara Gorge, showing the position of the Falls and Whirlpool. Upper right photo of the lower Gorge; lower aerial view of the Eddy Basin (base of view) and Whirlpool; note that the modern Niagara. River exit from the Whirlpool is to the middle right while the Whirlpool Basin occupies an exhumed of the late Wisconsin St. Davids Gorge

Once the Falls reached the buried St. Davids Gorge at the Whirlpool, it rapidly exhumed the drift, following the path of the pre-Late Wisconsin gorge (Fig.4; see Stop 8) through the wide section of the Whirlpool, turning southeastward into the equally wide Eddy Basin and then back to the southern end of the narrower Whirlpool Rapids gorge section (Fig. 5). Correlation of the upper end of the Whirlpool Rapids with the head of the buried St. Davids Gorge was suggested by Johnson (1928), based on borehole data that showed the footings for the nearby Cantilever Bridge over the Gorge were situated in till.

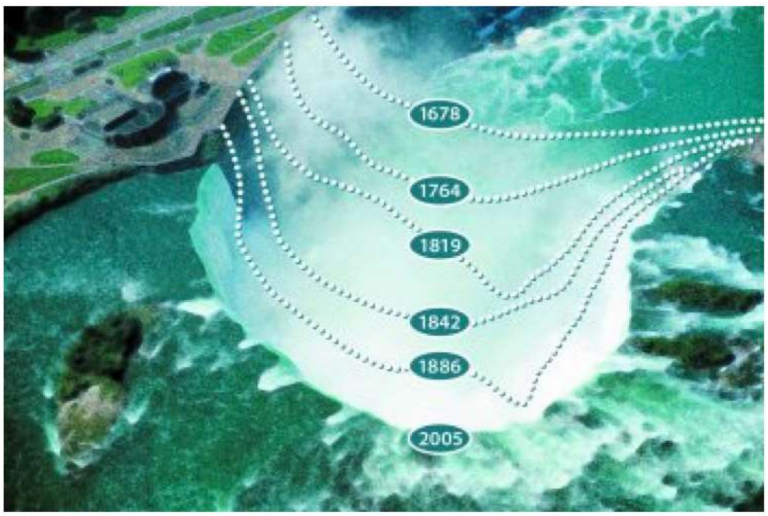
The narrow Whirlpool Rapids gorge within the pre-Late Wisconsin St. Davids Gorge may reflect cutting by the older St. Davids River under lower discharges. Tinkler and others (1994) speculate that such conditions may have occurred with a readvancing ice margin that would have raised base levels in the Ontario basin and eventually filled the St. Davids Gorge with drift. Such conditions could have occurred during the Late Wisconsin advance (Hobson and Terasmae, 1969).

Rates of Cutting of the Upper Great Gorge and modern falls: The Upper Great Gorge upstream from the Whirlpool is 3700 m long and as suggested by Taylor (1933) appears to be the product of the full Great Lakes outflow like that of the present. This may be supported at least in part by comparison of its mean rate of cutting with that from historic data (Fig. 5). The mean recession rate must have been on the order of 3.2 ft/yr (0.8 -1.0 m/yr) for the historic period 1842 through 1905 (International Joint Commission, 1953, p. 14) before major man-made water diversions. However, a rate of 3.6 ft/yr (1.1 m/yr) has been determined for the total years of record (1670 through 1969, American Falls International Board, 1974). Projection of these rates indicates that recession past the American Falls and separation of flow into the two channels may have occurred about 600 years ago.

Analysis of the historic rates of recession by the International Joint Commission (1953) suggested that the average recession of the Horseshoe Falls had decreased from 4.2 ft yr-1 (1.28 m yr-1) between 1842 and 1906, to 3.2 ft yr-1 (0.98 m/yr) between 1906 and 1927, and to 2.2 ft./feet (0.67.m/year) from 1927 to 1950. They initially attributed this to three main causes including:(1) the southerly dip of the Lockport Formation; (2) the southward thickening of the Lockport cap rock from 20 ft (6 m) at. Lewiston to 80 ft (24 m) at the Falls; and (3) diminishing discharge of the river as a result of increased diversion for hydroelectric power. However, more detailed analysis of historic data (Philbrick, 1970) and that from soundings in the Upper Great Gorge indicate that the rate of retreat has been much more variable than this suggests, despite nearly uniform flows and continuous bedrock materials. Furthermore, Philbrick (1970, 1974) has argued that the planimetric configuration of the Falls may be as great or of greater control on recession than factors mentioned above. His ideas relative to retreat of the Horseshoe Falls are summarized below.

Philbrick maintains that there are three stages of the horizontal configuration of the Falls. The vertical cross wall is an unstable form that progresses to the horizontal arch, the most stable form (Fig. 5). Recession will be slow during the arch stage and deep plunge pools will be produced. This stage, in turn, may be subdivided into the notched stage (Fig. 5) when the highest stresses and greatest strains are generated and a more stable arch phase. The notch stage coincides with the highest rates of recession and with shallow plunge pools. Model studies (Philbrick, 1970) show that stresses during the notch configuration may be three times those that occur during times when the crest is arched. Depths of the plunge pools are therefore inversely related to the rate of retreat with major deep plunge pools recording times of stasis within the retreat, presumably when the falls crest had achieved an arch configuration as is approached by the present Horseshoe Falls.

PROFILES OF THE HORSESHOE FALLS THROUGH TIME



EROSION OF THE CANADIAN FALLS WAS ABOUT 1M/YEAR PRIOR TO POWER PLANTS

Figure 5. View of the crest of the Canadian or Horseshoe Falls taken in 2005 comparing estimated crestline positions for 1678 to 1886; earlier configurations are based on relatively crude drawings; note the decreasing rate of erosion following the late 19th century and development of power plants as well as the increasingly arcuate and more stable configurations of the crestline through time.

Future of the Falls: In his "Principles of Geology," Lyell (1860, p. 181) suggested that, on the basis of contemporary rates, of recession, the Falls would eventually reach Lake Erie in about 30,000 years (see also Lyell, 1838). Projections of the twentieth century rate of about 2 ft/ yr (0.6 m/yr) via the shortest (West or Chippewa) channel (Fig. 6) yields about 48,000 years for the 18 mi (29 km) distance. Such projections are based on fallacious assumptions, but the results may be as good as any number that could be generated considering the complicated scenario of retreat (Philbrick, 1974). Philbrick suggests the following sequence of events during progressive recession of the Falls and Gorge to Lake Erie (see Fig. 6):

(1) Retreat at 2 ft/ yr (0.6 m/yr) causes capture of the American channel above Goat Island about 2000 years AP (After Present) and with 7000 years AP, a lowering of the Chippewa-Grass Island Pool above the Falls with consequent slight lowering of Lake Erie levels.

(2) Splitting of the Horseshoe Falls into first, two falls, then three, and subsequently two falls again as recession causes the channel to split at Navy Island and again around the north end of Grand Island.

(3) Headward migration of Chippewa Horseshoe Falls down south dip of the Lockport Formation to a height of 50 ft (15m) at which point recession is so retarded as to make it a quasi-stationary waterfall (similar to present American Falls).

(4) Rapid erosion to form a broad, gentle gorge and stepped rapids in the Salina Group rocks. Eventual capture of slower-eroding Tonawanda (east) Channel by Chippewa Channel near upstream end of Grand Island.

(5) Marked slowing of recession to Lake Erie and Niagara River mouth as gorge develops in Bertie dolomite and single Falls on overlying tough Onondaga Limestone.

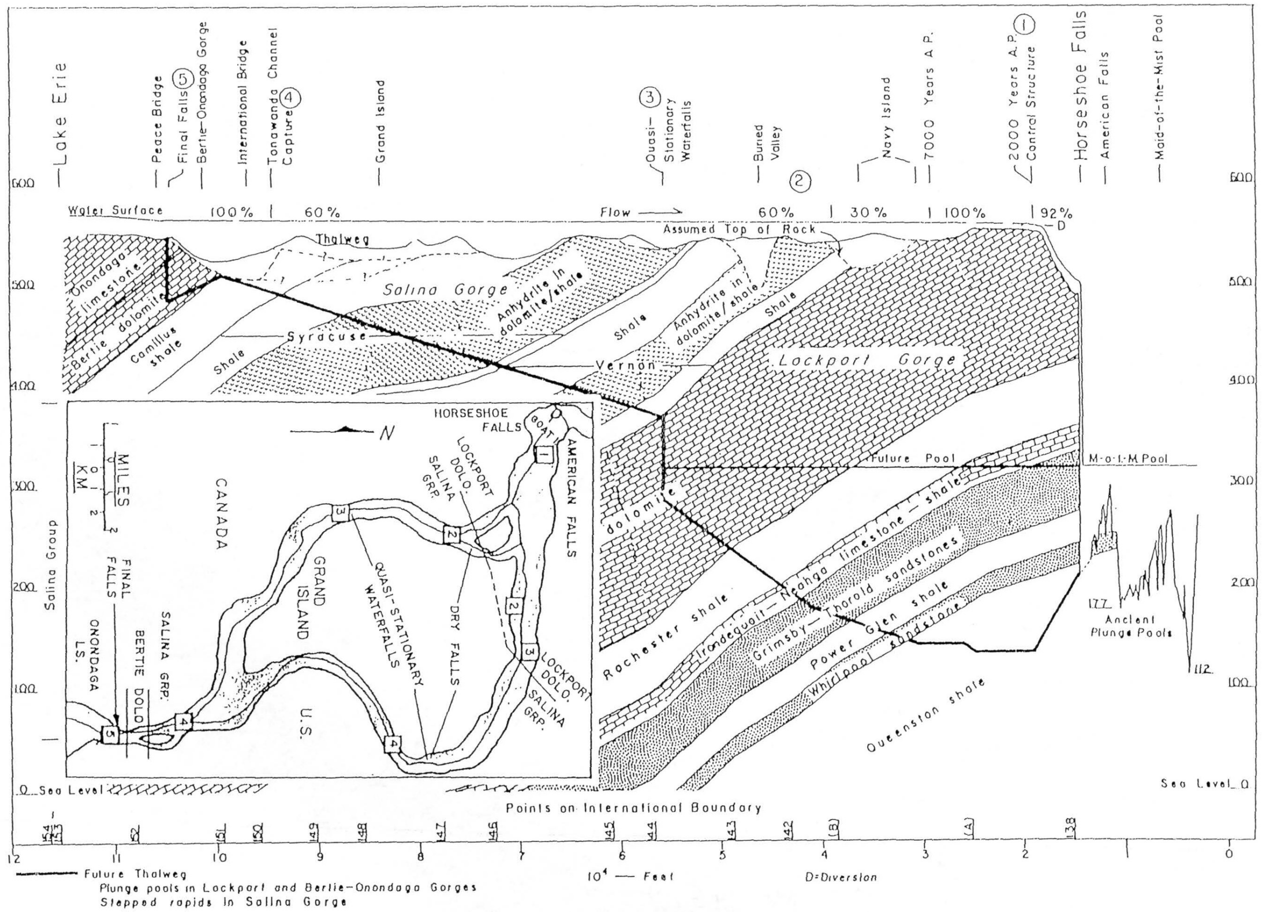


Figure 6. Geologic cross section along the Thruway of the Chippewa Channel (west branch) Niagara River, Lake Erie to Horseshoe Falls. Numbers on top of profile correspond with those on inset map (with equivalent numbers having equivalent dates on both channels) and events in text. Percentages refer to the share of undiverted flow carried during recession of the Falls. From Calkin and Barnett (1990).

BRIEF HISTORY OF HUMAN SETTLEMENT IN THE NIAGARA FRONTIER

A brief discussion of the human history of the Niagara region is provided in Tesmer (ed.) (1981); also see Conlin, 1986 and https://www.oldfortniagara.org.

There is evidence for human presence in the Niagara Frontier as long ago as ~12,000 BP nearly the same time that the falls themselves were forming at the escarpment near present Lewiston. Natives of the Clovis culture in the so-called Paleo-Indian period inhabited the area of the Lake Erie shore up to about 9,000 BP, as evidenced by fluted tool. This culture was succeeded by hunter-gatherer peoples of the Archaic Period. (9,000-3,000 yrs BP) and the more agrarian culture of the Woodland period (3000 to 300 yrs BP). Members of the Iroquois league occupied villages within stockades. Local tribes in the Niagara Frontier, included the so-called Five Nations of the Iroquois League, the Seneca, Cayuga, Onondaga, Oneida, and Mohawk (later the Tuscarora nation was incorporated in the League forming the Six Nations, as well as the non-affiliated Hurons and Neutrals. At the time of European intrusion into the area there were local tribal conflicts, and these were enhanced by the foreigners and at various times different tribes were allied with the French, British or later Colonists.

There is some debate as to which European first saw the falls. Neither Jacques Cartier 1535 nor Samuel de Champlain (1608) saw the falls, but they brought back stories of a colossal cataract in the forests, related by natives. Etiene Brule who first studied the Great lakes may or may not have seen the Falls in 1615, the Jesuits Father Gabriel Lalemont and Father Louis Hennepin clearly did see the falls and transcribed the native Iroquois term, Onghiara in their notes and sketches. Hennepin (1683) produced an account and engraving of the falls; he was very impressed and overestimated the height of the cataract by about three times. A more reasonable early account was given by Dudley (1722).

During the ensuing two centuries the strategic importance of the Niagara River became clear: despite the major obstacle of Niagara Falls and Escarpment, this river provided a natural highway to allow transport of goods, especially furs from the interior of North America to Lake Ontario and then out to the St. Lawrence. But the Falls necessitated the development of a portage road along which goods could be transported by wagons up or down the escarpment and around the great falls. The portage road began near the present site of Lewiston, NY, the “lower landing”. Hence the lower Niagara River and its mouth on Lake Ontario became a critical area and this guaranteed that there would be conflict. The portage road led through the heart of country controlled by America’s most powerful native alliance, the Iroquois league. The French had allied themselves early with the Hurons, bitter enemies of the Iroquois league, and this led to major animosity. Nonetheless, in the 1670s relationships with the Iroquois improved to the point that trader Rene Cavelier, Sieur de La Salle was able to obtain permission to use the portage road. French settlers were thus the first to attempt to control this natural trade route to the continental interior and in 1679 they established a fort, Fort Conti, at the mouth of the Niagara River to control ship access to the Lake and Fort Frontenac to the east. That initial fort burned after just one year but was later replaced, in 1687 Marquis de Denonville, governor of New France established a new and larger Fort Denonville as part of his effort to eradicate the Iroquois from the area of the portage. However, the fort became isolated besieged by natives and was eventually abandoned again after little more than a year. It was not until the 1720s, with the Five Nations somewhat weakened, that Louis-Thomas de Joncaire was able to establish a trading post at the site of the present Artpark (Lewiston) with permission of the Iroquois (Senecas) and in 1725 a new “French castle”: Fort Niagara, was at the river’s mouth.

The Iroquois largely kept Europeans from establishing major settlements, but they were engaged strongly in fur trade and in battles with the Hurons and Neutrals over control of that region; the latter tribe was literally decimated. It was also during this time the British settlers in New York began to take an increased interest in the Niagara portage and the lucrative fur trade afforded by the area.

Tensions between the French and British increased in the third colonial conflict, King George’s War of 1744-1748, and the French strengthened Fort Niagara and it subsequently became a staging ground for French military expeditions to the southwest into the Ohio Valley. Still further tension culminated in the French and Indian War of 1754 to 1763 during which the French strengthened Fort Niagara with earthworks but the British were able to garner an alliance with the Iroquois and, in July of 1759, 2,400 soldiers and 1000 allied Iroquois besieged and bombarded the fort.

Eventually, the French commander surrendered and Fort Niagara and the Niagara portage fell under British control for the next 37 years, until 1796. They had an uneasy alliance with the local Senecas and a rebellion by the natives, known as Pontiac Uprising, erupted in 1763. In that year the vulnerability of the poorly guarded portage road became clear in the ‘Devils Hole massacre” when more than 80 British soldiers, as well as wagon drivers and draft animals were ambushed, killed, and thrown into the Gorge by Seneca warriors.

Despite this setback the British continued to control Fort Niagara, and the Niagara Frontier for nearly four decades Even in that same year a peace treaty ended hostilities between Britain and France and the negotiator William Johnson managed to obtain an agreement from the Senecas to cede a one-mile-wide strip of land along the Niagara Gorge for the portage road.

Although Fort Niagara was rather weak and poorly manned, the British held this post through the American Revolution and even managed to martial an alliance with the Senecas against the American colonists. Following the Sullivan campaign when many Seneca nation villages were destroyed by the colonist forces, the British even gave shelter to members of the Iroquois league. The British managed to hold on to the Fort even after the Treaty of Paris in 1783 officially ended the Revolutionary War. However, the Fort fell within territory ceded to the new United States and with the Jay Treaty of 1796 the British peacefully abandoned Fort Niagara and crossed the Niagara River to set up a new garrison, Fort George, on the Canadian side.

In 1812 President James Madison declared war on Canada; the so-called War of 1812, which actually lasted for nearly three years, was fought in part along the Niagara Gorge. Skirmishes like the Battle of Queenston Heights (October 13, 1812) proved a decisive victory for the British controlled Canadians, even though their heroic leader Sir Isaac Brock lost his life in the battle. Subsequently, however, the Americans successfully captured York (Toronto) and in a huge exchange of cannon fire across the mouth of the Niagara River, in 1813, Fort George was badly damaged while Fort Niagara prevailed, and Americans occupied the remains of Fort George. That, however, was the end of American victories and after a series of losses in battles in southwestern Ontario, and after burning Fort George to the ground the Americans led by McClure retreated to Fort Niagara.

Remarkably, in December 13, 1813, British soldiers were able to ambush and retake Fort Niagara. British troops and their Iroquois allies then marched up-river to Manchester (present Niagara Falls, NY) and then Buffalo burning homes and devasting the newly developing Niagara Frontier, perhaps in revenge for the American attack on Canada. The British were able to maintain and strengthen the Fort. However, when the War of 1812 was ended by the Treaty of Ghent, Christmas Eve of 1814, the conflict was over, and Fort Niagara was once again turned over to United States control. The fort was never again a strategic structure and indeed by this time the Iroquois were largely disbanded and interest in fur trade and the portage road diminished.

With the second takeover of Fort Niagara by colonists there ensued a long period of relatively peaceful development of American cities including Lewiston and Niagara Falls along the New York side of the Niagara River. Beginning in the late 1800s new interest centered development and the use of the vast power of the Niagara. Waterpower of the Falls attracted mills and ultimately, with the development of dynamo-generated electricity and especially the development of alternating current transmission by Nikolai Tesla, became the site of development of the great hydroelectric power plants the Sir Adam Beck Plant on the Canadian side and the Robert Moses power station south of Lewiston near site of the infamous Devils Hole Massacre. After a period of intense industrial development, which eclipsed the falls and made it difficult to even get a good view of the cataract, there was renewed excitement in the “tourist industry” and eventually the importance of the spectacular falls as a World tourist center and “honeymoon capital” was realized.

NOTE ABOUT THIS GUIDEBOOK

Aside from this brief overview of geomorphology and Pleistocene and human history, this guide is primarily intended to discuss the stratigraphy, facies, paleoenvironments and paleoecology of latest Ordovician, Silurian, and Middle Devonian in the Niagara Frontier area of western New York and to provide a guide to a few of the classic localities. To this end the remainder of this guidebook is divided into two principal parts. The first is on the latest Ordovician to Silurian, as well as some broader points about Pleistocene and Holocene history of the Niagara County area, with an emphasis on Niagara Gorge and Falls. The second is an overview of Middle Devonian paleoenvironments, sequence stratigraphy and paleoecology of western New York.

AKNOWLEDGEMENTS

Many people have facilitated this field trip and the past research leading to our present synthesis. First and foremost, regarding this trip, we are indebted to Jeff Over for help in organizing the SDS meeting in Geneseo.

Carl Brett also acknowledges important help and insight from several former students and colleagues, including Derek Armstrong, Sam Ciurca, Craig Clement, Brad Cramer, James Eckert, Bea-Yeh Lin (Eckert), William Goodman, Steve LoDuca, Patrick McLaughlin, Mark Pearce, David Ray, Nick Sullivan, Wendy Taylor, Dorothy Tepper, James Thomka, and Chris Wade, among others, for partnership and inspiration in field studies of Silurian stratigraphy and paleontology in New York, Ontario, Kentucky, Indiana, Ohio, and Pennsylvania. Carl also acknowledges the late Parker Calkin (formerly at SUNY at Buffalo) for his mentorship in studies of Quaternary geology in the Niagara region. As always, CB thanks his wife, friend, and partner, Dr. Betty-Lou Brett, for all of her help and support for nearly 50 years (as an aside, we were literally married on a tiny island in the Niagara River in 1974 and took the wedding party to Goat Island to see a temporary exposure of ancient river shells I was working on with Parker at the time!).

REFERENCES

Antevs, E., 1931, Late glacial correlations and ice recession in Manitoba: Geological Survey of Canada, Memoir 168: 20-24.

American Falls International Board, 1974, Preservation and enhancement of the American Falls at Niagara: Final Report to the International Joint Commission, Appendix C - Geology and Rock Mechanics, 71 p. and Appendix D - Hydraulics, 41 p.

Barnett, P. J., 1979, Glacial Lake Whittlesey: The probable ice frontal position in the eastern end of the Erie Basin: Canadian Journal of Earth Sciences, v. 16, p. 568-574.

Brett, C.E., 1981, Ancient Niagara River gravels and their fossils, p. 54-57. In I.H. Tesmer (ed.), Colossal Cataract: The Geological History of Niagara Falls. State University of N.Y. Press. Albany, 219 p.

Brett, C.E. and Calkin, P.E. 1987, Niagara Falls and Gorge, New York-Ontario, *in* Roy, D. C. (ed.), Centennial Field Guide Volume 5, Northeastern Section of the Geological Society of America: Geological Society of America, Boulder, Colorado, p. 97-105.

Brett, C.E. and Calkin, P.E., 1996, Silurian stratigraphy and Quaternary geology of the Niagara area. A Guidebook for Fieldtrips in Niagara County, New York for the Northeast Section Meeting of the Geological Society of America, State University of New York at Buffalo, Buffalo, New York, 93 p.

Calkin, P. E. and Brett, C. E., 1978, Ancestral Niagara River drainage: stratigraphic and paleontological setting: Geological Society of America Bulletin v. 89, p. 1, 140-1, 154.

Calkin, P. E. and Feenstra, B. H. 1985, Evolution of the Erie-Basin Great Lakes, *in* Karrow, P. F., and Calkin, P. E., eds., Quaternary Evolution of the Great Lakes: Geological Association of Canada Special Paper 30, p. 149- 170.

Coakley, J. P. and Lewis, C. F. M., 1985, Postglacial levels in the Lake Erie basin, *in* Karrow, P. F. and Calkin P. E. (eds.) Quaternary Evolution of the Great Lakes, Geological Association of Canada, Special Paper 30, p. 195- 210.

Conlin, J.H., 1986, National Register of Historic Places: Inventory and Nomination: Fort Niagara. National Park Service.

D'Agostino, J. P., 1958, Lake Tonawanda: History and development [M.A. thesis]: State University of New York at Buffalo, 70 p.

Dreimanis, A., and Karrow, P. F., 1972, Glacial history of the Great Lakes-St. Lawrence region, the classification of the Wisconsin(an) Stage, and its correlatives, *in* Proceedings International Geological Congress, 24th Session, Montreal, section 12, p. 5-15.

Dudley, P., 1722, An account of the falls of the Niagara River, taken at Albany, October 10th, 1721; from Monsieur Borassaw, a French Native of Canada. Philosophical Transactions of the Royal Society of London, April-May 1722, p..69-72.

Fisher, D. W., Isachsen, Y. V., and Rickard, L. V., 1970, Geologic map of New York: New York State Geological Survey, Map and Chart Series No. 15.

Flint, J. J. and Lolcama, J., 1986, Buried ancestral drainage between Lakes Erie and Ontario. Geological Society of America Bulletin, v. 97, p. 75-84.

Forsyth, J. L., 1973, Late-Glacial and postglacial history of western Lake Erie: Compass, v. 51, p. 16-26.

Gilbert, G. K., 1891, The history of the Niagara River: Annual Report of the Smithsonian Institution, v. 6., p. 231-257.
Gilbert, G. K., 1907, Rate of recession of Niagara Falls: U. S. Geological Survey Bulletin. 306, p. 5-25.
Grabau, A. W., 1901, Guide to the geology and paleontology of Niagara Falls and vicinity (with a chapter on post-Pliocene fossils of Niagara by E. J. Letson): New York State Museum Bulletin 45, v. 9, 284 p.
Hall, J., 1838, Second annual report on the Fourth Geological District of New York: New York Geological Survey, Annual Report 3, p. 287-339.
Hall, J.,1842, Niagara Falls - their physical changes and the geology and topography of the surrounding country: Boston Journal of Natural History, v. 4, p. 106--134.
Hall, J.,1843, Geology *of* New York (IVth District), Albany, Carol and Cook,683 p.
Hall, J.,1844, Niagara Falls, their physical changes and the geology and topography of the surrounding country: Boston Journal of Natural History, v. 4, p. 206--234.
Hennepin, L. 1683, Description de la Louisiane, Nouvellement Decouverte au sud-ouest de la Nouvelle France, par Ordre du Roy, Chez la Veuve Sebastien Hure, Paris.
Hough, J.L., 1958, Geology of the Great Lakes: Urbana, University of Illinois Press, 310 p.
Hobson, G. D., and Terasmae, J., 1969, Pleistocene geology of the buried St. Davids Gorge, Niagara Falls, Ontario: geophysical and palynological studies: Geological Survey of Canada, Paper 68-67, 16 p.
International Joint Commission, 1953, Preservation and enhancement of Niagara Falls: Washington, D.C., 354 p.
Johnson, P. F., 1928, The age of the Upper Great Gorge of the Niagara River: Royal Society of Canada, Proceedings and Transactions (3rd Series), v. 22, p. 13--29.
Karrow, P. F., 1973, Bedrock topography in southwestern Ontario: A progress report: Geological Association of Canada, Proceedings, v. 25, p. 67-77.
Karrow, P. F. and Terasmae, J., 1970, Pollen bearing sediments of the St. Davids buried valley fill at the Whirlpool, Niagara River gorge, Ontario: Canadian Journal of Earth Science/ v. 7, p. 539-542.
Kindle, E. M., and Taylor, F. B., 1913, U. S. Geological Survey Geological Atlas, Niagara Folio 190.
Krajewski, and Terasmae, J, 1981, Appendix A, Road guide for points of interest, *in* Tesmer, I. H., ed., Colossal Cataract; The geologic history of Niagara Falls: Albany, Sate University of New York Press, p. 173-196.
Lash, G.G. 2006. Top seal development in the shale-dominated Upper Devonian Catskill Delta Complex, western New York State. Marine and Petroleum Geology, 23:317-335, Amsterdam.
Lash, G.G. and Blood, D.R. 2006. The Upper Devonian Rhinestreet black shale of New York State – Evolution of a hydrocarbon system. In Jacobi, R. (ed.), Field Trip Guidebook, New York State Geological Association, 78th Annual Meeting.
Liberty, B.A., 1981, Structural Geology. In. Tesmer, I. H. (ed.) 1981, Colossal Cataract: The Geologic History of Niagara Falls. State University of New York Press, Albany, NY; 219 p. 57-62.
Lyell, C., 1860, Principles of Geology: London, Murray.

Lyell, C., 1838-1842, A memoir on the recession of the Falls of Niagara; Geological Society of London Proceedings, v. 3, 595 p.
Muller, E. H. and Calkin, P. E., 1993, Timing of Pleistocene glacial events in New York State: Canadian Journal of Earth Science, v. 30, p. 1829-1845.
Muller, E. H. and Prest, V. K., 1985, Glacial lakes in the Ontario Basin: *in* Karrow, P. F., and Calkin, P. E., eds., Quaternary Evolution of the Great Lakes: Geological Association of Canada Special Paper 30, p. 215-229.
Philbrick, S., S., 1970, Horizontal configuration and the rate of erosion of Niagara Falls: Geological Society of America Bulletin, v. 81, p. 3, 723-3, 732.
Philbrick, S., S.,1974, What future for Niagara Falls?: Geological Society of America Bulletin, v. 85, p. 91-98.
Pohlman, J., 1889, The life history of Niagara: American Institute of Mining Engineers Transactions, v. 17, p. 322-338.
Prest, V. K., 1970, Quaternary Geology of Canada, *in* Geology and economic minerals of Canada: Geological Survey of Canada, Economic Geology Report 1, 5th ed., p. 675-764.
Sanford, B. V., 1956, Welland County: Geological Survey of Canada, Paper 55-20 (2 maps).
Spencer, J. A., 1894, The duration of Niagara Falls: American Journal of Science, 3rd Series, v. 48, p. 455-472.
Spencer, J.A.,1907, Falls of the Niagara: Their evolution and varying relations to the Great Lakes; characteristics of the power and effects of its diversion: Geological Survey of Canada, Publication 970, 490 p.
Spencer, J.A.,1910, Interruption in the flow of the Falls at Niagara in February 1904: Bulletin Geological Society of America. v. 21, p. 443-448.
Taylor, F. B., 1933, Niagara Falls and Gorge: Washington, DC, International Geological Congress, 1116th, Guidebook 4 - Excursion A-4, p. 78-103.
Terasmae, J. 1981. Quaternary Geology. P. 41-54. In. Tesmer, I. H. (ed.) 1981, Colossal Cataract: The Geologic History of Niagara Falls. State University of New York Press, Albany, NY; 219 p
Tesmer, I. H. (ed.), 1981, Colossal Cataract: The Geologic History of Niagara Falls. State University of New York Press, Albany, NY; 219 p.
Tinkler, K., 1993, Field guide: Niagara Peninsula and Niagara Gorge, Third International Geomorphology Conference: McMaster University, Printing Services, McMaster University, Hamilton, Ontario, 24 p.
Tinkler, K, 1987, Niagara Falls 1750-1895: The idea of a history and the history of an idea: Geomorphology, v. I; p. 69-85.
Tinkler, K. J., Pengelly, J. W., Parkins, W. G., and Terasmae, J., 1992, Evidence for 1iigh water levels in the Erie basin during the Younger Dryas Chronozone: Journal of Paleontology, v.7, p. 215-234.
Tinkler, K. J., Pengelly, J. W., Parkins, W. G. Asselin, G., 1994, Postglacial recession of Niagara Falls in relation to the Great Lakes: Quaternary Research, v. 42, p. 20-29.
Upham, W . E., 1898, Niagara Gorge and Saint Davids Channel: Geological Society of America Bulletin v. 9, p. 101-110.

Carl Brett with University of Cincinnati Students in Niagara Gorge near
Art Park, Lewiston, New York 2012.