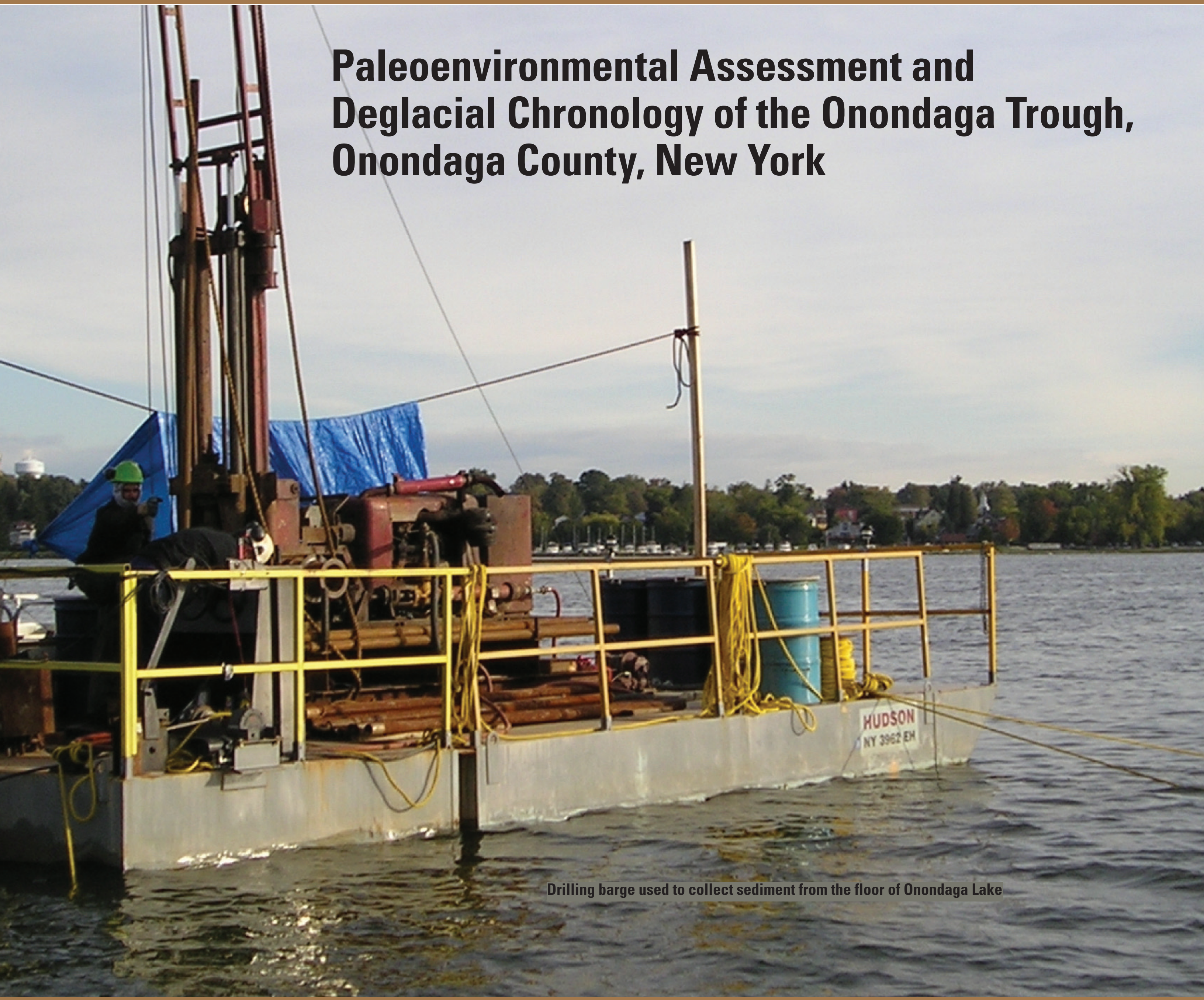
Prepared in cooperation with Onondaga Lake Partnership and Onondaga Environmental Institute

Paleoenvironmental Assessment and Deglacial Chronology of the Onondaga Trough, Onondaga County, New York



Drilling barge used to collect sediment from the floor of Onondaga Lake

The stable carbon-isotope composition ($\delta^{13}C$) and total organic carbon content (TOC) of sedimentary organic matter were measured in a series of split-spoon samples of lakebed sediment sampled from the middle of Onondaga Lake, Syracuse, New York. These samples were analyzed and the results compiled to provide a paleoenvironmental assessment of the lake and its watershed following deglaciation between calibrated radiocarbon age 14,000 and 2,000 years before present (Cal BP).

Carbon-14 (^{14}C) data from split-spoon samples collected in the Onondaga Trough (valley) were used to determine the age of sediment deposition throughout the Trough, and the dates of landslides and other post-glacial events in the Onondaga Trough. These ^{14}C data have also been correlated with the $\delta^{13}C$ data to provide a context for understanding the glacial recessional sequence in the Onondaga Trough.

U.S. Department of the Interior
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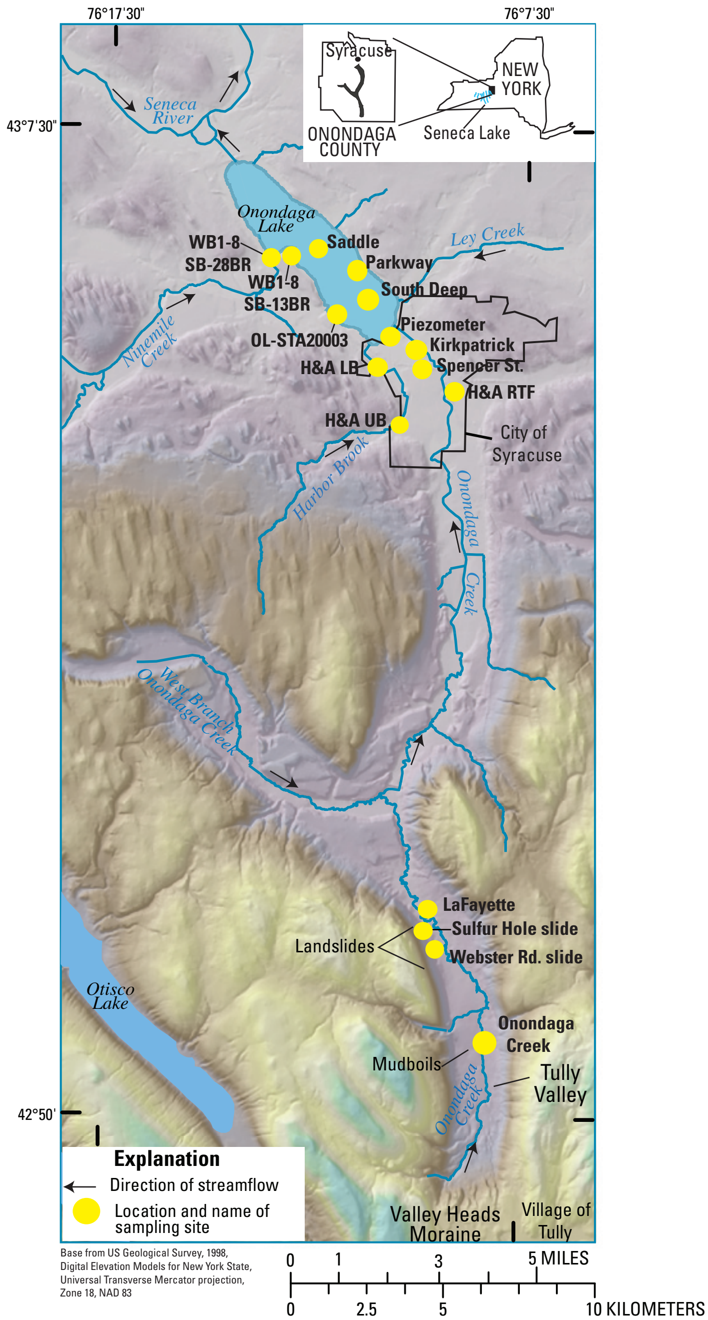

Figure 1. Shaded-relief map of the Onondaga Trough (from the Valley Heads Moraine to Onondaga Lake) and locations where organic samples were collected for age dating.

Introduction

The U.S. Geological Survey, in cooperation with the Onondaga Lake Partnership and Onondaga Environmental Institute, has been studying the hydrogeology of the Onondaga Trough since 2002 to determine the movement and concentration of naturally occurring brine in the glacial valley-fill aquifer. Numerous shallow and deep test holes have been drilled to determine the glacial and water-quality stratigraphy in the Onondaga Trough. Organic materials were recovered from the Onondaga Creek, Ninemile Creek, and Harbor Brook valleys, and from lakebed sediments in Onondaga Lake (fig. 1) and age-dated with carbon-isotope analysis techniques. This report summarizes the carbon-isotope data collected from 1996 through 2006 in the Onondaga Trough. The results of these analyses provide a means to understand the deglaciation of the watershed and the development of the watershed from barren glacial sediment to a forested ecosystem.

Methods of Investigation

A number of shallow, split-spoon samples from recent USGS and ongoing (2006) construction and contaminant-investigation projects yielded an assortment of organic materials (wood, reeds, seeds) and sediment samples that were age-dated using carbon-isotope analysis techniques. The assessment techniques utilized isotopic forms of Carbon-13 and Carbon-14, and the analyses were carried out at the Environmental Science Stable Isotope Laboratory (EaSSIL) at the State University of New York–College of Environmental Science and Forestry (SUNY-ESF) and at several accelerated mass spectrometer laboratories after samples of organic matter were prepared at the USGS Carbon-14 Laboratory in Reston, Virginia.

Determination of Stable Carbon Isotope, Total Organic Matter, and Carbonate Content in Onondaga Lake Sediments

The stable carbon-isotope composition ($\delta^{13}C$) and total organic carbon content (TOC) of sedimentary organic matter were measured in a series of split-spoon samples taken at 5-foot intervals in lakebed sediments in the middle of Onondaga Lake at the 'Saddle' location (fig. 1). Five-centimeter subsections of these split-spoon samples were freeze-dried and ground to a fine powder. This dry sediment was weighed into small silver boats and then fumed under an acidic atmosphere to remove any inorganic carbonate material. These carbonate-free sediments then were analyzed at EaSSIL at SUNY-ESF, Syracuse, using an elemental analyzer coupled to a stable-isotope-ratio mass spectrometer. The total organic carbon and carbonate content were measured by using a loss-on-ignition method. Dry sediment was placed in ceramic crucibles and heated to 550^{o}C to release organic matter; further heating to 1000^{o}C released inorganic carbonate materials (Dean, 1974).

Determination of Carbon-14 Age Dates

The Carbon-14 (^{14}C) technique was used to age-date organic material from split-spoon samples of glacial sediment retrieved in the Onondaga Trough. These samples were obtained without the introduction of contaminant carbon from land surface and near-land-surface sources, such as roots and anthropogenic fill. Under careful examination, the recovered sediment samples occasionally included pieces of organic matter (for example, peat-like material, a large seed, or a piece of wood) that were buried contemporaneously with these sediments, hundreds to thousands of years ago. The organic materials taken from the split spoons were kiln dried, prepared for shipment, and then sent to a ^{14}C laboratory where their ages

Streambank exposure along Onondaga Creek at the sulfur-hole landslide area.

Stable Carbon Isotopes (^{12}C and ^{13}C) and the Environment

The stable isotopes of carbon (^{12}C and ^{13}C) occur naturally in all plants and animals, and the relative amounts of these stable isotopes can be used to understand natural processes and the state of the environment. Carbon exists primarily as the ^{12}C isotope (98.89%), but a small fraction (1.11%) is present as ^{13}C. Although the different isotopes possess the same fundamental chemical properties, in that they both behave chemically like carbon, they differ in the rates at which they react as a result of the difference in their atomic masses, with ^{13}C reacting at a slightly slower rate than ^{12}C.

The ratio of the stable isotopes of carbon ($^{13}C/^{12}C$) is measured using a stable isotope ratio mass spectrometer, and the ratio is expressed in parts per thousand or per mil (‰), relative to an international standard known as Vienna Peedee Belemnite (V-PDB):

$$\delta^{13}C\ (‰) = [(R_{sample}/R_{standard}) - 1] * 1000 \qquad (1)$$

where

R_{sample} = $^{13}C/^{12}C$ of the sample,

and

$R_{standard}$ = $^{13}C/^{12}C$ of V-PDB.

The stable carbon isotope value ($\delta^{13}C$) of sedimentary organic matter has the signature of the organic matter that was present in the lake in the past. Therefore, the $\delta^{13}C$ ratios in sediments can provide information about past environments in and around lakes. The stable isotope signatures of some land plants differ from that of algae; therefore we can use $\delta^{13}C$ ratios to discern major organic inputs to lakes. Additionally, algae and other aquatic plants photosynthesize and preferentially use more ^{12}C than ^{13}C to produce organic material. The stable isotope signature of plant organic matter, which is subsequently preserved in sediments, can be used to determine the rate at which algae are growing. When algae grow rapidly, they utilize more ^{13}C than under normal conditions, and this will be reflected in the production of organic matter that is enriched in ^{13}C, which is reflected in a more positive $\delta^{13}C$ value.

More details on the use of stable isotopes in environmental studies are available at: http://wwwrcamnl.wr.usgs.gov/isoig/res/funda.html were determined. Results of these analyses are reported as an age in calendar years or radiocarbon years "before present" (BP), with 1950 serving as the base year. Analysis algorithms such as the radiocarbon calibration program (Stuiver and Reimer, 1993) can correct for atmospheric variations of ^{14}C over time and report calibrated ages (for example, calibrated years before present (Cal BP)), or calendar years before present (BC/AD).

In the Onondaga Trough, organic matter from several different sediment sources was considered for age dating. The samples included organic matter incorporated into the glacial sediment during and immediately following the last major recession of glacial ice from the Onondaga Trough—from the Tully (Valley Heads) Moraine to the outlet of Onondaga Lake (fig. 1). Possible sources of organic material in post-glacial sediment include (1) alluvial material (carried in a tributary stream) from the surrounding uplands to the valley floor, (2) landslides that incorporated both glacial and post-glacial sediment and organic material, or (3) lake-bottom sediments and organic material which slowly accumulated on the floor of Onondaga Lake and were transported there by tributary streams. The results of these ^{14}C and $\delta^{13}C$ analyses provide the basis for assessing the post-glacial sediment chronology and paleoenvironment of the Onondaga Trough.

Regional Deglaciation Framework

Ridge (2003) provides a basis for dating organic material across the northeastern United States using glacial-lake sediment varves, paleomagnetics, and ^{14}C chronologies. Although much of his study was conducted in New England, dates for glacial retreat in New York State also were provided. Using his regional timeline of Wisconsin-age deglaciation, the following "benchmark" dates have been established for central New York:

- *Last glacial maximum*–The period of greatest glacial advance southward in New York during the Wisconsin period when the glacier was south of the New York-Pennsylvania border. Estimated time of occurrence is about 24,000 radiocarbon years (Cal BP 28,200–27,200 years). (The calibration program does not have any data to support calibrated-age determinations older than 20,300 radiocarbon years; therefore these dates are estimated.)
- *Advanced Valley Heads ice position*–The last major glacial readvance in central New York that created the present Finger Lakes drainage pattern. Estimated time of occurrence is about 14,350 to 13,500 radiocarbon years (Cal BP 17,200–16,200 years).
- *Glacial recession from the northeastern U.S.*–At this time all glacial ice had receded from the northeastern U.S. into Canada. Estimated time of occurrence is about 11,400 radiocarbon years (Cal BP 13,400 years).

These dates provide a general chronology of major glacial events in the Finger Lakes region including the Onondaga Trough. Based on this timeframe, samples analyzed in this study are relatively recent in age—mostly post-glacial sediments deposited within the last Cal BP 14,000 years.

Paleoenvironmental History of the Onondaga Trough

When glacial ice began to recede from southern New York State at about 20,000 years (Cal BP 24,000 years) (fig. 2), the region was virtually barren of vegetation, and erosion rates were substantial. The process of deglaciation in the Onondaga Trough began at about 14,000 years (Cal BP 17,000 years) at the Advanced Valley Heads Moraine position, located near Tully (fig. 1). Since that time, the climate of the region has varied between cold and dry to warm and wet in response to global climate variability. These changes in regional climate and watershed vegetation succession are recorded in the glacial and post-glacial sediments.

Cal BP 14,000 Years to 10,000 Years Ago

Prior to Cal BP 10,000 years ago, terrestrial vegetation in the Onondaga Trough was sparse and algal productivity in what is now Onondaga Lake was limited. These observations are supported by the presence of sediments with relatively low carbonate content (fig. 3A) and low stable carbon isotope ratio ($\delta^{13}C$, fig. 3B). Supporting evidence from analysis of sediments collected from nearby Seneca Lake (about 40 miles southwest of Onondaga Lake) indicates that, during this period, low temperatures and an unstable climate may have resulted in shorter summer growing seasons (Guiles Ellis and others, 2004). Cold periods were common, including those associated with the expansion of glacial Lake Iroquois (Cal BP 14,000 years) and the Younger Dryas cold period (Cal BP 12,900 to 11,600 years) (Guiles Ellis and others, 2004). Low temperatures and short growing seasons that limit algal productivity, are indicated by the small amount of organic and inorganic carbon preserved in sediments from this time period.

In the southern part of the watershed, early vegetation emerged within the Onondaga Trough uplands, but a minimal amount of organic matter was incorporated into the post-glacial sediments on the floor of the valley. The few samples that contained datable material were preserved in deeper lake sediments or in sediment near the lake (OL-STA20003, Piezometer, and Spencer St. sites on fig. 1). Only one location in the upper watershed (Webster Road slide, fig. 1) yielded enough organic material to provide a ^{14}C date from this period. The prevalence of samples collected in the post-glacial lake sediments indicates a dynamic environment during the Younger Dryas period (fig. 2). During this period, cooler temperatures and wetter climatic conditions resulted in the transport of much of the organic matter found in the lake, where it settled to the lake bottom and was preserved. The landslide at Webster Road (Cal BP 11,300 years) apparently occurred in a watershed with limited vegetation during a period of wetter-than-normal precipitation; these conditions may have triggered a landslide that buried small trees at this location.

Typical split-spoon sampler used to collect sediment samples from which organic carbon material was analyzed.

The Theory and Process of Using Carbon Isotopes for Carbon-14 Age Dating

There are three principal forms or isotopes of carbon that occur naturally: Carbon-12 (^{12}C), Carbon-13 (^{13}C), both of which are stable in the environment, and Carbon-14 (^{14}C), an unstable or radioactive isotope of carbon. These isotopes are present in the environment in the following amounts:

^{12}C - 98.89 percent,
^{13}C - 1.11 percent and,
^{14}C - 0.00000000010 percent.

Thus, one ^{14}C atom exists in nature for every 1,000,000,000,000 (quadrillion) ^{12}C atoms in living material. The radiocarbon age-dating method is based on the rate of decay of the radioactive or unstable ^{14}C isotope that is formed in the upper atmosphere through the effect of cosmic-ray neutrons bombarding nitrogen 14 (^{14}N). The reaction is:

$$^{14}N + \text{neutron} \Rightarrow {}^{14}C + \text{proton}. \qquad (2)$$

The ^{14}C formed is rapidly oxidized to carbon dioxide ($^{14}CO_2$) and enters the plant and animal lifecycles through photosynthesis, respiration, and uptake into the food chain. Plants and animals that utilize carbon through food chains take up various amounts of ^{14}C during their lifetimes that are in equilibrium with the ^{14}C concentrations in the atmosphere. That is, the number of ^{14}C atoms and non-radioactive carbon atoms stay about the same over time. As soon as a plant or animal dies, they cease the metabolic function of carbon uptake and the decay cycle of ^{14}C begins. Eventually, the ^{14}C atom emits a beta particle from the nucleus of the ^{14}C atom and decays back to ^{14}N.

The decay rate for ^{14}C was first measured by Libby and others (1949). They found that, after 5,568 years, half of the ^{14}C in an original sample decayed and after the next 5,568 years, half of that remaining material decayed, and so on. Libby measured these half-lives at 5,568 ± 30 years, and this value became known as the Libby half-life. Ten half-lives (representing 50,000 to 60,000 calendar years) is the limit of this age-dating technique due to the very small amount of radioactive carbon present in a sample after this time. By comparing ^{14}C with modern levels of activity (1890 wood corrected for decay to 1950 A.D.) and using the measured half-life, it is possible to calculate a date for the death of the organic material in the sample. Later measurements of the Libby half-life indicated the figure was about 3 percent too low and a more accurate half-life was determined at 5,730 ± 40 years. This is known as the Cambridge half-life. (To convert a Libby age to a Cambridge age, multiply the Libby age by 1.03, although it is common practice to report ages using the Libby half-life.) Information about the comparison of these different age calculations is available at: http://www.c14dating.com/int.html

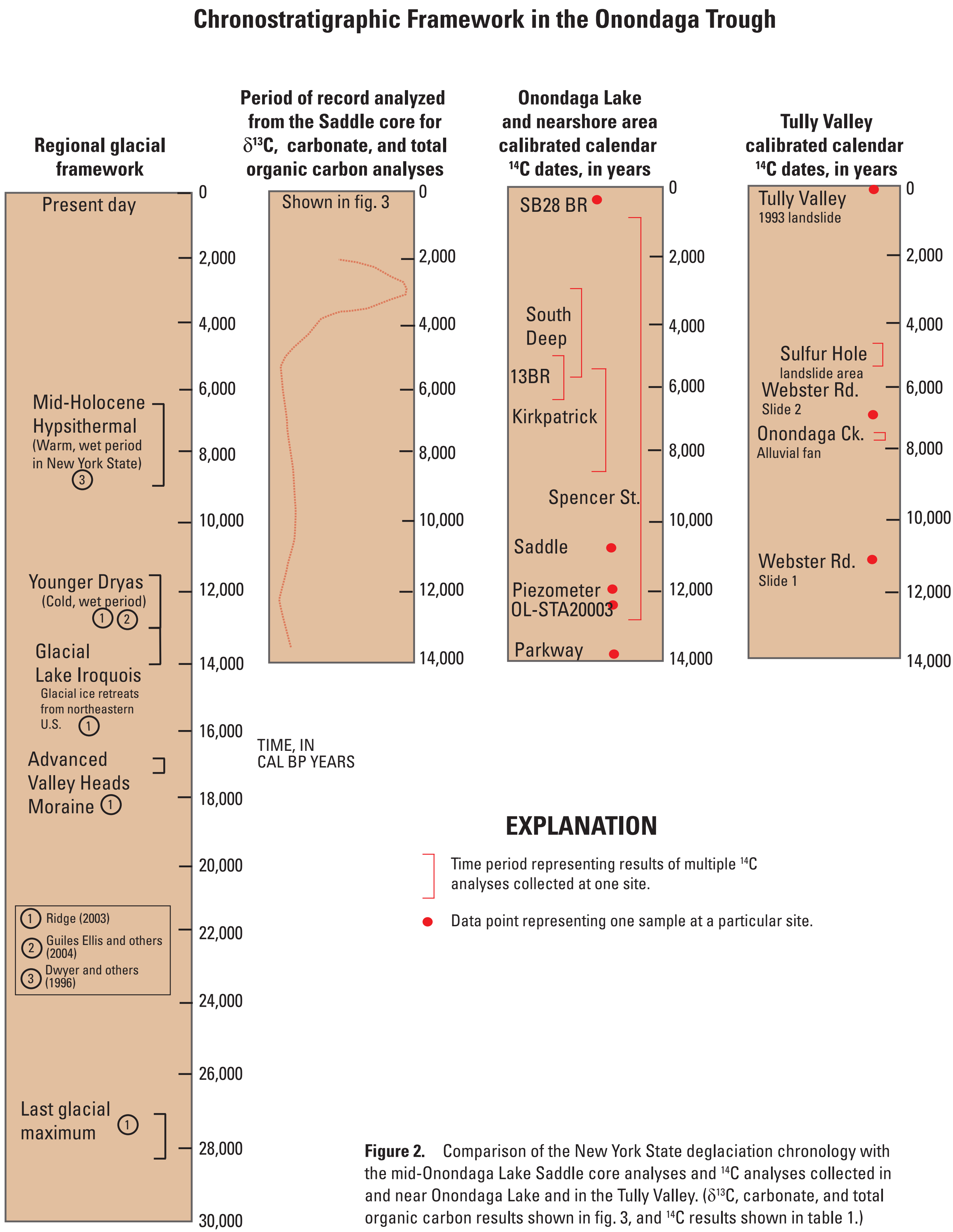

Figure 2. Comparison of the New York State deglaciation chronology with the mid-Onondaga Lake Saddle core analyses and ^{14}C analyses collected in and near Onondaga Lake and in the Tully Valley. ($\delta^{13}C$, carbonate, and total organic carbon results shown in fig. 3, and ^{14}C results shown in table 1.)

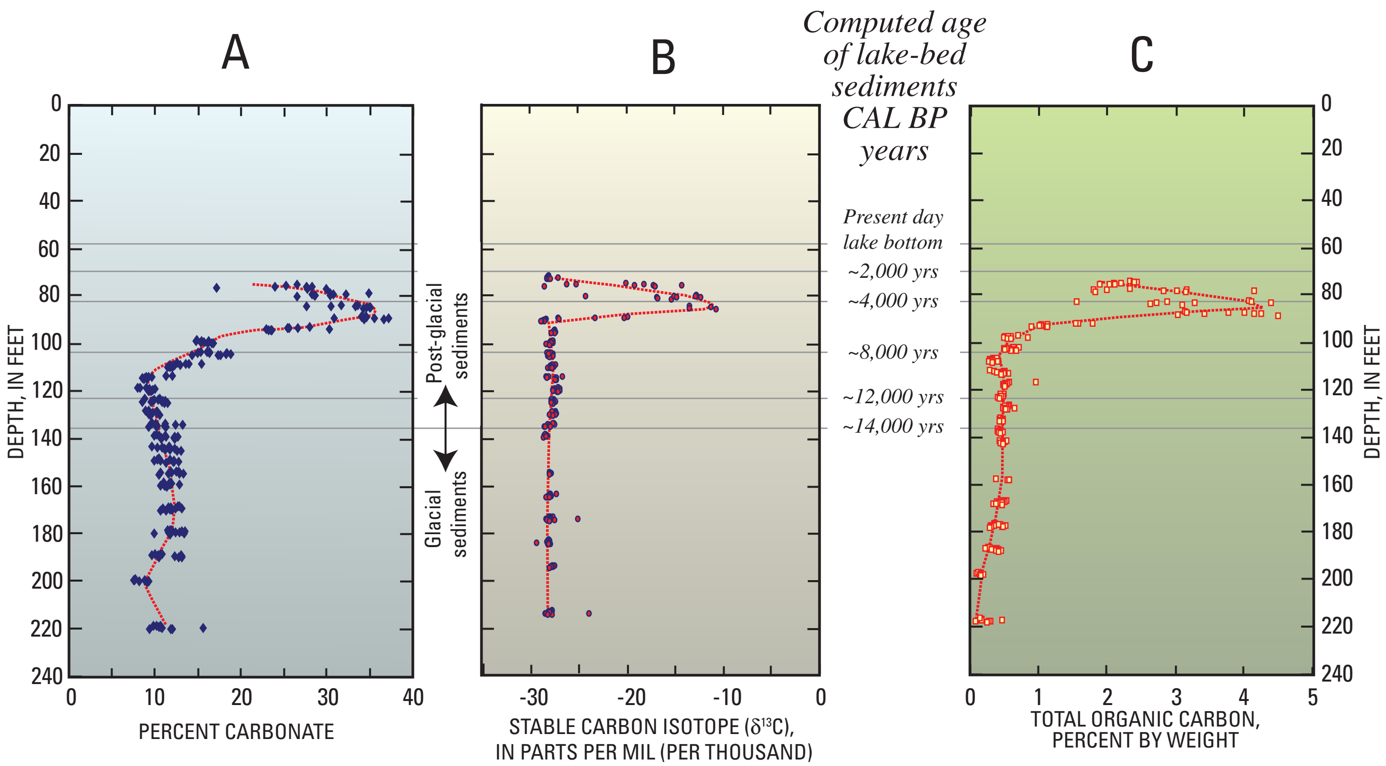

Figure 3. Analytical results from split-spoon samples taken from the middle of Onondaga Lake at the Saddle drill hole (location shown on fig. 1) (*A*) percent carbonate, (*B*) stable carbon isotope ($\delta^{13}C$), and (*C*) total organic carbon.

Cal BP 10,000 Years to 4,000 Years Ago

This period was marked by a rapid increase in the amount of inorganic carbonate and organic matter (measured as total organic carbon) deposited in the sediments (figs. 3A and 3C). The increase in carbonate probably resulted from calcium-enriched surface runoff from the eroding watershed combined with ground water flowing through carbonate-enriched glacial sediments, both of which entered Onondaga Creek and Onondaga Lake. Carbonate bedrock also is exposed along the walls of the Onondaga Trough just south of Onondaga Lake, and water discharging from this bedrock may have been an additional source of calcium-enriched water flowing into Onondaga Creek. Similarly, the increase in organic matter in the lake-bottom sediments may have resulted from an increase in the amount of organic materials delivered to the lake by surface water as early vegetation (grasses, woody shrubs and some small trees) developed after the retreat of the glacial ice. This increase in organic-matter delivery to the lake would have increased the amount and concentration of organic nutrients present in the lake and stimulated the growth of algae.

The large increase in the stable isotope ($\delta^{13}C$) values (to less-negative numbers) in sedimentary organic matter between Cal BP 5,000 and 3,000 years (fig. 3B) further supports the hypothesis that algal productivity increased dramatically in the lake during this period. During periods of rapid growth, algae typically will use more ^{13}C than usual because they deplete the pool of dissolved carbon dioxide in the water, and therefore the amount of inorganic bicarbonate in the lake increases. This rapid growth of algae probably occurred during times of warmer temperatures and when the lake became enriched in carbonate, as evidenced by the increase in carbonate content of lakebed sediments between Cal BP 5,000 and 3,000 years (fig. 3A). The increased inflow of carbonate from the surrounding watershed, together with the increased nutrient input from the developing watershed, would have resulted in algal blooms and associated whiting events (see sidebar, p. 9).

The increased productivity in the watershed is also evidenced by the greater amount of ^{14}C organic matter observed in the post-glacial sediments in the lake and throughout the watershed. In and near the lake, greater amounts of organic material are present within the mid- to upper-sediment sequence. With maturing vegetation during this period, a greater diversity of organic materials is present throughout the Onondaga Trough (table 1). In the Tully Valley, the extension of an alluvial fan buried several large trees (Onondaga Creek #1, table 1) and the landslide at Sulfur Hole and the second landslide at Webster Road indicate that even within a maturing watershed, a period of wetter-than-normal climate conditions could have initiated shallow-slope landslides (Pair and others, 2000) and the burial of organic matter in and near Onondaga Creek.

Table 1. Carbon-14 laboratory results for Onondaga Trough organic samples.

[$\delta^{13}C$, Stable Carbon isotope Carbon-13; ^{14}C, Carbon isotope Carbon-14; years BP, years before present; ft, feet]

Sample Number[1]	Sample identification and depth below land or lakebed surface, if available	Material	$\delta^{13}C$ estimated	^{14}C Age, (Radiocarbon years BP)	Calibrated age (Cal BP years)	Laboratory[2]
WW1863	Onondaga Creek at Webster Road	Wood	-25	9,870 +/- 40	11,243 +/- 60	CAMS
WW2136	Webster Road (interface 10-8)	Wood	-25	6,160 +/- 40	7,045 +/- 117	CAMS
WW2137	Webster Road (interface 10-9)	Peat	-25	6,110 +/- 50	6,973 +/- 121	CAMS
WW3802	Piezometer - 1 (62 ft)	Wood	-25	10,500 +/- 96	12,477 +/- 402	UA-AMS
WW3803	Piezometer - 2A (62 ft)	Wood	-25	10,385 +/- 67	12,304 +/- 374	UA-AMS
WW3804	Piezometer - 2B (62 ft)	Wood	-25	10.356 +/- 79	12,288 +/- 393	UA-AMS
WW3809	Kirkpatrick - 1 (59 ft)	Wood	-25	7,977 +/- 55	8,841 +/- 164	UA-AMS
WW3810	Kirkpatrick - 2 (30 ft)	Wood	-25	4,958 +/- 47	5,673 +/- 78	UA-AMS
WW4205	Spencer Street (8.6 ft)	Wood	-25	840 +/- 40	733 +/- 61	CAMS
WW4206	Spencer Street (13.6 ft)	Wood	-25	7,305 +/- 40	8,095 +/- 82	CAMS
WW4207	Sulphur hole slide - 1 (middle)	Peat	-25	4,180 +/- 40	4,690 +/- 82	CAMS
WW4208	Sulphur hole slide - 2 (bottom)	Wood	-25	4,785 +/- 40	5,530 +/- 69	CAMS
WW4209	Sulphur hole slide - 3 (top)	Wood	-25	4,135 +/- 40	4,652 +/- 85	CAMS
WW4210	Spencer Street (14.2 ft)	Wood	-25	7,245 +/- 40	8,188 +/- 943	CAMS
WW4211	Spencer Street (21.2 ft)	Wood	-25	11,040 +/- 40	13,026 +/- 151	CAMS
WW4213	LaFayette (2.56 ft)	Wood	-25	Modern	Modern	CAMS
WW4724	Parkway (73 ft)	Wood	-25	12,045 +/- 50	14,070 +/- 257	CAMS
WW4868	Saddle (92 ft)	Charcoal	-25	9,595 +/- 35	10,885 +/- 140	CAMS
WW5509	Onondaga Creek # 1	Wood	-25	6,760 +/- 35	7,621 +/- 47	CAMS
WW5564	WB1-8-SB-28BR (43 ft)	Plant material	-25	170 +/- 35	181 +/- 50	CAMS
WW5565	H&A RTF 206 (23-25 ft)	Wood	-25	1,995 +/- 35	1,939 +/- 69	CAMS
WW5566	H&A RTF 202 (18-20 ft)	Seeds	-25	4,120 +/- 35	4,628 +/- 102	CAMS
WW5567	WB1-8SB-13BR (65.5-65.7 ft)	Wood	-25	4,680 +/- 35	5,395 +/- 80	CAMS
WW5568	WB1-8SB-13BR (78.8-80.0 ft)	Peat	-25	5,900 +/- 35	6,723 +/- 72	CAMS
WW5569	WB1-8SB-13BR (85.5-86.0 ft)	Peat	-25	5,985 +/- 35	6,824 +/- 88	CAMS
WW5570	WB1-8SB-13BR (89.5-90.0 ft)	Peat	-25	6,050 +/- 35	6,893 +/- 98	CAMS
WW5571	OL-STA20003 (33-36 ft)	Plant material	-25	10,835 +/- 40	12,845 +/- 40	CAMS
WW5572	Onondaga Creek # 2	Wood	-25	6,300 +/- 30	7,210 +/- 56	CAMS
WW5573	Onondaga Creek # 3	Wood	-25	7,135 +/- 35	7,972 +/- 44	CAMS
WW5574	H&A UB 103-S8 (14-16 ft)	Peat	-25	7,885 +/- 35	8,686 +/- 96	CAMS
WW5575	H&A LB 107 (12-14 ft)	Plant material	-25	2,975 +/- 35	3,161 +/- 102	CAMS
WW5576	H&A LB 109 (26-28 ft)	Wood	-25	10,340 +/- 30	12,147 +/- 98	CAMS
TO1961	South Deep (5.7 ft)	Silt	-25	5,490 +/- 70	6,290 +/- 121	Isotrace
TO1983	South Deep (15.3 ft)	Silt	-25	2,960 +/- 50	3,113 +/- 152	Isotrace

[1] Samples were processed in the U.S. Geological Survey Radiocarbon Laboratory in Reston, VA and the Isotrace Laboratory in Toronto, Ontario, Canada. The "WW" sample designations were assigned by the USGS lab, and the "TO" sample designations were assigned by the Isotrace lab.

[2] Laboratories: CAMS, Center for Accelerated Mass Spectrometer, Lawrence Livermore Laboratory; UA-AMS, University of Arizona, Accelerated Mass Spectrometer Laboratory; Isotrace, Isotrace Radiocarbon Laboratory, Totonto, Ontario, Canada.

Cal BP 4,000 Years to 2,000 Years Ago

The decrease in carbonate, the $\delta^{13}C$ values in sedimentary organic matter, and total organic-carbon content during this period (figs. 3A, 3B, and 3C) all indicate that lake algal productivity decreased. This decrease in algal productivity may have been caused by a number of factors including decreases in temperature and(or) decreases in nutrient input to the lake. This period is known to have been cooler than the preceding period (Mullins, 1998), and evidence from analyses of sediments from Lake Ontario indicate that reduced levels of chemical weathering in its tributary watersheds reduced the amount of carbonate delivered to it (McFadden and others, 2004). The lower temperature would have caused less algal productivity, resulting in smaller amounts of organic carbon and inorganic carbonate delivered to the sediments through whiting events. Continued development of vegetation in the watershed may have also reduced the amount of surface runoff to the lake caused by stabilization of the soil and increased evapotranspiration of mature vegetation. The evidence presented here is consistent with the interpreted development and stabilization of the watershed ecosystem, and the subsequent reduction of sediment loading to the lake through creeks and streams.

Although organic matter continued to be deposited throughout the watershed during this period, little of this material was recovered for ^{14}C analysis. The only samples that contain material from this time period are from a section of the Ninemile Creek channel that was buried beneath waste-bed sediments, and a shallow sample from 8 feet below the land surface at the Spencer Street site. Anthropogenic disturbance of the land surface caused by construction and landfilling, especially in the present city of Syracuse, resulted in the loss of much of these materials. When sediments in split-spoon samples were observed to be possibly disturbed, no organic material was collected for analysis in these cases.

Tree stump in the bed of Onondaga Creek, which was found to be over 7,600 years old (Cal BP years).

Whiting Events

Algal growth is dependent on sunlight and nutrients, and when there is an abundance of both, the growth and productivity of algae can increase rapidly. As algal growth proceeds under these conditions, the algae utilize large amounts of dissolved carbon dioxide which in turn produces large quantities of calcium carbonate due to a chemical shift in the equilibrium between dissolved carbon dioxide and inorganic bicarbonate. The white calcium carbonate precipitate falls to the floor of the lake and is deposited with fine-grained sediment to form marl in what is known as a "whiting event" (Thompson and others, 1997). These whiting events are common in carbonate-rich lakes such as the Finger Lakes in central New York (Lajewski and others, 2003) including Onondaga Lake. These whiting events are characterized by the presence of high concentrations of algae in lakes, known as algal blooms, with accompanying high amounts of organic matter in the surface waters. The stable-isotope composition of the organic matter associated with these algal blooms increases greatly during these events, as does the amount of carbonate present in the water. After several weeks, algae begin to die, coalesce, and sink to the lake bottom. The organic matter from the algae and carbonate produced by the algae are subsequently preserved in the sediments. The sedimentary record of the increased algal productivity, subsequent die-off, and whiting event is characterized by relatively high concentrations of organic matter, greater carbonate content, and increased stable carbon-isotope ratios of the preserved organic matter. This pattern is observed in the sedimentary record of Onondaga Lake. Summer temperatures were 2° to 4°C warmer than today (Pielou, 1991; Guiles Ellis and others, 2004), which further supports the concept of the increased algal productivity in the lake during that period.

Streambank exposure along Onondaga Creek adjacent to tree stump picture on the previous page.

Estimated Sedimentation Rates in Onondaga Lake

Carbon-14 (^{14}C) samples collected from Onondaga Lake sediments also can be used to estimate rates of sediment accumulation on the floor of the lake after the Wisconsin glacial period ended at about Cal BP 14,000 years. Rates of sediment accumulation on the floor of Onondaga Lake were determined through ten analyses of organic material collected from the lake bottom (see figure 1 for locations).

Sedimentation rates in the lake declined from Cal BP 14,000 years to the present based on the depth and computed age of the Parkway, Saddle, and South Deep samples collected respectively at 57 ft, 36 ft, and 15.3 and 5.7 ft below the lake bed surface. Sedimentation rates declined as sedimentation progressed upwards, as shown by the following data.

Depth below lake-bed surface (ft)	Sedimentation rate (in/yr)
0.0 – 5.7	0.02
5.7 – 15.3	.04
15.3 – 36	.05
36 – 57	.08

To verify these rates, samples were collected in 2005 from locations below and adjacent to waste-bed materials deposited along the eastern lakeshore. These samples were denoted as the WB1-8 SB-series on figure 1 and in table 1, and their sedimentation rates were compared to those computed above. From the WB1-8 samples, the early post-glacial sediment at a depth of about 35 feet below the lakebed was dated at Cal BP 12,840 years, and from that layer to just below the marl layer, a rate of 0.075 in/yr was computed. For the uppermost sediment sequence—the Ninemile Creek streambed sample (SB-28BR) down to the uppermost marl sample—a sedimentation rate of 0.016 inches per year was computed. These rates agree closely with the early sedimentation rate of 0.08 in/yr and the computed present-day sedimentation rate of 0.02 in/yr, respectively. The intervening marl/organic layers at this site cannot be used to compute a sedimentation rate owing to the addition of the organic-material layers with the accumulation of fine-grained sediment. Although the lake-bed sediment data were collected from several locations around the lake, the computed rate of sedimentation, which decreases over the last Cal BP 14,000 years, appears consistent around the southern half of the lake.

Concluding Discussion

During and immediately following the recession of glacial ice from the Valley Heads Moraine around 14,000 years (Cal BP 17,000 years), the Onondaga watershed was virtually barren of vegetation. At the time, erosional rates in a series of pro-glacial lake basins in the northward-draining watershed, which would become the Onondaga Creek valley, were substantially greater than they are today. The West Branch valley of Onondaga Creek, when free of glacial ice, discharged large amounts of sediment to the Onondaga Valley floor as the ice front continued to recede to the north and pro-glacial lake levels in the Onondaga Valley declined (Kappel and Miller, 2005). The steep hillsides in the southern two-thirds of the watershed slowly became more stable as over-steepened-slope failures (landslides) diminished. These slopes reached a more stable configuration as a succession of vegetation types (grasses to shrubs and then trees) further stabilized the thin soils on these slopes.

Rapid and repeated changes in the post-glacial climates alternated from cooler to warmer and drier to wetter periods (Dwyer and others, 1996; and Mullins, 1998), These changes influenced the stability of slopes and the ability of the Onondaga Creek drainage network to transport sediment from the steep hillsides of the southern part of the watershed to the flatter northern part of the Onondaga Trough and Onondaga Lake. In the southern part of the Onondaga Trough (the Tully Valley, fig. 1), the two landslides near Webster Road at about Cal BP 11,300 years and Cal BP 7,000 years and the recent (1993) landslide all attest to slope instability well after deglaciation.

Onondaga Lake was part of the much larger Glacial Lake Iroquois during the cooler periods that persisted about Cal BP 14,000 to 13,000 years ago and limited the growth of algae in the lake. Beginning in the mid-Holocene Hypsithermal period Cal BP 9.000 to 6,500 years ago (fig. 2), temperatures began to increase and the lake and surrounding watershed became more productive. Sediment and nutrients from the developing vegetation in the watershed were transported to Onondaga Lake by means of the drainage network. Together with the increasing temperatures and a longer growing season, the sediment and nutrients provided lake algae with ideal conditions for enhanced growth. The productivity of the lake was at a maximum level between Cal BP 6,000 and 4,000 years ago (fig. 3).

Sedimentation rates were relatively low closer to Onondaga Lake in what appears to have been a transitional dry, to wetland, to near-shore environment. The low gradient of Onondaga Creek caused, in part, by (1) post-glacial uplift, (2) the meandering nature of a stream on the flat valley floor, and (3) rising Onondaga Lake water levels also affected where and when sediment would be deposited in this transitional lakeshore environment.

The low gradient of Onondaga Creek also may have decreased the amount of sediment and nutrients that were delivered to the lake as reflected in the decrease in algal growth in the lake beginning Cal BP 4,000 years ago (fig. 3). These decreases in nutrients that algae require to grow efficiently, together with cooler global temperatures during this period, would have further reduced algal growth.

Finally, the deposition rates of mostly fine-grained sediment on the floor of Onondaga Lake were influenced by the ability of Onondaga Creek and the other tributary streams (Ley Creek, Harbor Brook, and Ninemile Creek) to transport sediment from the maturing watershed to the lake. Organic material in the watershed was carried from the uplands to accumulate in the nearshore environments and left age-date markers in the form of organic-rich sediment. The declining sedimentation rate recorded in the lakebed sediments at various depths and locations in Onondaga Lake also supports the concept of a maturing ecosystem in the Onondaga Trough during the past 12,000 years (Cal BP 14,000 years).

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