Part III
Surficial Geology

Chapter 11
The Missing Record
Tertiary Period[1]

Summary

During the Tertiary Period, uplift and erosion of eastern North America carved most of the major features of the State's modern topography. Very few rocks or sediments from the Tertiary are found in New York, although they are important units in the coastal plains of the southeastern U.S. From plant remains and tiny fossils in these Tertiary sediments, we learn that the climate was warm during the early Tertiary but began to cool gradually 22 million years ago. The warm climate of the early Tertiary encouraged chemical weathering in the shaping of New York's landscape. By looking at the modern landscape, we can reconstruct where major rivers were during the Tertiary, before the drainage was changed dramatically by the glaciers of the Pleistocene.

Introduction

The most recent geologic era—the one we're still living in today—is the Cenozoic. It began 66 million years ago, when the extinctions of the dinosaurs and many other species brought the Mesozoic Era to an end. The Cenozoic Era includes the Tertiary Period, plus the Quaternary Period, which is the most recent 1.6 million years.

When the Cenozoic began, New York's bedrock had been formed. But the land surface looked very different from what we see today.

Carving the Landscape

By the Middle Jurassic, New York's bedrock had been eroded down to a flat plain. This erosion surface is called the *Fall Zone Peneplain*. During the middle part of the Cretaceous, the Fall Zone Peneplain was uplifted, and running water began to cut into it. To the east, the Peneplain dipped beneath the widening Atlantic Ocean. There, it was covered by Coastal Plain deposits and is still preserved deep beneath the surface. However, wherever the Fall Zone Peneplain was exposed in New York State, it was destroyed by erosion that accompanied slow uplift along the eastern seaboard.

The modern landscapes of New York developed in the Cenozoic Era. During that time, most of eastern North America continued to be uplifted, weathered, and eroded. As the land was uplifted, water flowed from the high areas down to the seas. The rush of water over millions of years sculpted the features of the landscape.

By the end of the Tertiary, the major features of our modern topography had already been formed. (The circular Adirondack Mountain dome may be an exception. It may have only begun rising at that time.) These features, and especially drainage, were later modified by ice sheets during the Pleistocene Epoch. We'll discuss glacial effects in the next chapter.

Tertiary Rock—Missing on the Mainland

The sediments from the erosion of eastern North America were deposited during the Tertiary Period. In some western states, sedimentary rocks and igneous intrusions from the Tertiary Period are extensive. However, very little rock of that age remains in New York State. Some exists in nearby areas, though. We find a small Oligocene deposit of a kind of brownish-black coal called *lignite* in western Vermont near Brandon. Some Tertiary rock exists in the Coastal Plain deposits of states to the south and offshore on the continental shelf. From

[1]Adapted from a manuscript by W.B. Rogers.

the amount of sediment on the shelf today, we deduce that several kilometers of rock were eroded from New York and New England during the Cretaceous and early Tertiary.

Reconstructing the Tertiary Climate

With no Tertiary rock exposed in New York State, can we still figure out what happened in our region during that time? Yes, we can, with a little geological detective work. For evidence, we look at the Tertiary sediments on the continental shelf and slope off our shore.

Deep holes have been drilled near the coastline of central New Jersey and on the outer part of the continental shelf south of Long Island to sample to rock there. These samples show us that the Tertiary deposits are about 130 m thick along the shore but much thicker—1500 m—near the shelf edge. Much of this increased thickness was deposited during the middle Miocene Epoch.

We know the age of these deposits by studying the fossils found in them. The fossils are small and unspectacular looking, but they give us a great deal of useful information. They include microscopic plants and pollen as well as one-celled animals. These fossils tell us the age of the sediments and whether they were deposited on sea or on land. They also tell us what the climate was at the time.

Where we find tiny one-celled animals called *foraminifera*, we know that the sediment was deposited in the ocean. In contrast, where we find abundant plant pollen, we know that the sediment was deposited on land.

By identifying the pollen found in the sediments, we can see how the climate changed over time. Each type of plant produces its own kind of pollen. Suppose, for example, we found pollen from spruce and fir trees in one layer and pollen from pine and oak trees in a younger layer. Spruce and fir trees live in subarctic to cool temperate climates, which are warmer than arctic climates, but still fairly cold. Pine and oak trees live in temperate climates that are still warmer and more hospitable. A plant succession like the one described in this paragraph would show that the climate gradually became warmer.

We can find similar climate clues in the foraminifera. The various species change, depending on the temperature and depth of the water at the time.

In a manner like that described above, we have assembled the evidence provided by fossil pollen and foraminifera from the Tertiary Period. From this evidence, we have concluded that the Tertiary climate in northeastern North America varied from humid subtropical to arid and cold.

In most of the early Tertiary, New York was much warmer than it is today—it was between warm temperate and subtropical. The average annual temperature was about 5 degrees higher than today's annual average of 8°C. Frosty mornings were rare, even during the winter. About 22 million years ago, the climate began to cool gradually. At the end of the Tertiary, about 1.6 million years ago, a cool temperate climate was established. This climate was interrupted by four long "cold snaps," which will be discussed in the next chapter.

Tertiary Weathering and Erosion

Temperature and precipitation strongly influenced the shaping of New York State's landscapes during the Tertiary. In warm moist climates, chemical weathering is relatively rapid. Rocks are changed chemically by being exposed to water, oxygen, carbon dioxide, and acids derived from the decay of plants.

In the warm climate of most of the Tertiary, New York experienced deep chemical weathering. Water carried away the dissolved and fine-grained products of the weathering. *Saprolites* were left behind—deeply weathered rock material composed of the resistant grains that did not dissolve. Saprolite disintegrates easily and is eroded quickly by runoff, landslides, and the steady pull of materials downslope by gravity. It also becomes hidden by plant growth. Scattered remains of saprolites have been uncovered during highway construction in the Adirondacks, the Catskills, and the New York City area. These remnants are all that is left of the deep soils formed during the Tertiary.

Almost all of the Tertiary soil was carried away by glacial ice during the Pleistocene Epoch—the subject of the next chapter. However, scientists now believe that the worldwide cooling that produced the Ice Age began in late Tertiary time, at least 10 million years before the advance of the glaciers.

Different kinds of rock erode more or less easily. Granite and some conglomerates and sandstones resist both chemical and mechanical weathering. Because they are not easily eroded, they tend to form uplands. On the other hand, shales and limestones are easily altered or dissolved by weathering processes. They are eroded to form lowlands. Thus, the different kinds of bedrock in New York determined how the landscape was shaped by erosion in the Tertiary.

Tertiary River Systems

The shape of the modern landscape gives us clues to how that erosion happened. Careful study of New York's

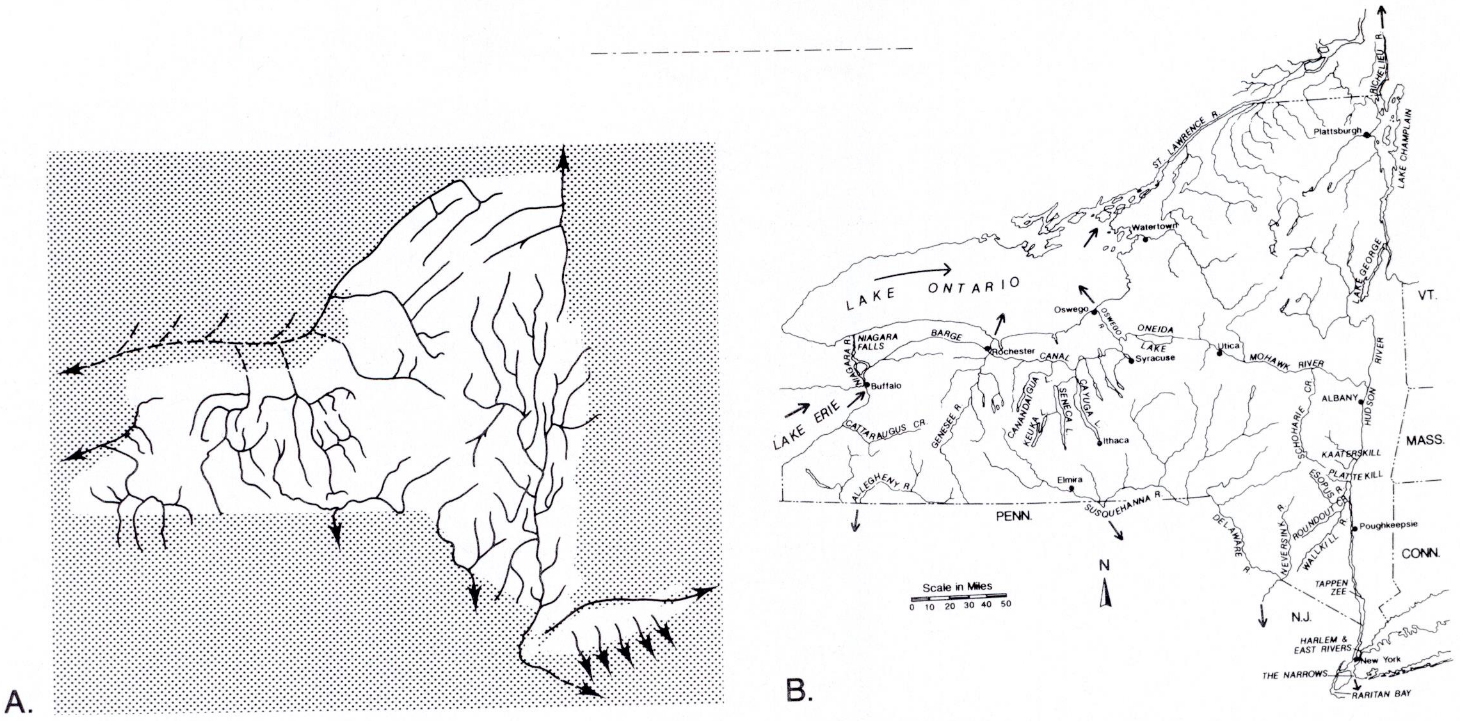


Figure 11.1. The map in (A) is a hypothetical reconstruction of the location of New York State rivers during the Tertiary. The reconstruction is based on the remains we have found of former stream valleys. Compare these rivers with the modern, postglacial rivers in (B). Notice how the drainage divides differ. Notice also that the Great Lakes and Finger Lakes were stream valleys, not lakes, during the Tertiary.

present landscapes lets us deduce earlier drainage patterns. In some places there are V-shaped cuts through upland areas that must have been made by major rivers. However, today these cuts are dry or occupied only by small streams. In other places deep valleys cut in bedrock were later completely filled with sand and gravel. These valleys have been discovered by well drillers.

From information of this kind, we have deduced the locations of major river valleys during the late Tertiary. The reconstructed Tertiary drainage patterns in New York State are shown in Figure 11.1A. For comparison, Figure 11.1B shows New York's modern drainage pattern.

The river that eroded the soft Middle Devonian shales of the Erie Basin has been named the Erian. The river that eroded the weak Ordovician shales of the Ontario Basin has been named the Ontarian. The preglacial Allegheny River flowed into the Erian River, which in turn flowed west into the Mississippi Basin. The Ontarian River drained northwest into Hudson Bay. The preglacial western St. Lawrence and Black Rivers and streams from the western Adirondacks flowed into the Ontarian. So did the rivers that flowed north through valleys in central New York. Today, these latter valleys hold the Finger Lakes.

The preglacial Hudson, Delaware, and Susquehanna Rivers generally flowed south toward the Atlantic Ocean. An eastward-flowing stream, the Sound River, flowed where we find Long Island Sound today.

These ancestral river systems carved the landmasses of New York into the broad outlines of the present landscape. The major hills and valleys were all in place. But if we went back in time, we would not recognize much of the landscape. There was still one large event needed to finish the job. The Ice Age was coming.

Review Questions and Exercises

Where do we find Tertiary sediments in New York? In nearby areas?

What clues tell us about the climate in the Tertiary? What conclusions have we reached about New York's Tertiary climate?

How do we know where rivers flowed during the Tertiary?

CHAPTER 12
THE BIG CHILL
The Pleistocene Epoch[1]

SUMMARY

During the Pleistocene Epoch, which began 1.6 million years ago, climates grew colder around the world for reasons that are not yet clear. Huge ice sheets advanced and retreated several times in the northern hemisphere. The last advance of these ice sheets, which occurred during the Wisconsinan Stage, reached its maximum in New York State about 21,750 years ago. The glacier accomplished spectacular erosion, scraping away soil and loose sediments, wearing away bedrock, and gouging river valleys into deep troughs. It also deposited the rock debris it carried in a variety of distinctive landforms. Glacial debris dammed many rivers and changed the State's drainage profoundly. The Wisconsinan ice sheet retreated from New York about 10,000 years ago. As it melted, it released huge volumes of meltwater. Where glacial debris had dammed valleys, vast temporary lakes were formed. Many of these glacial lakes have long since drained, although small remnants, including the Great Lakes and the Finger Lakes, still exist. At the close of the Pleistocene, meltwater from glaciers around the northern hemisphere raised sea level. The ocean flooded low-lying areas that had been depressed by the weight of the ice. Since then, the land has rebounded, causing the shorelines to shift to their present positions. In spite of the harsh climate during ice advance, a rich variety of plants and animals thrived south of the ice front. Many of the species still exist, but many others have become extinct.

INTRODUCTION

Soils form by chemical and physical breakdown of the underlying bedrock. However, in much of the northern hemisphere, including New York State, the composition of the soil is different from that of the bedrock beneath. The soil, therefore, could not have formed in place. How did New York's soil come to be where it is? How can we explain unusual features of New York's rivers and streams? What unusual landforms do we find, and how did they get here? Why is Whiteface Mountain such a steep-sided peak? Why do ocean tides flow up the Hudson River halfway to Canada? How did the Finger Lakes and the many other lakes in the State come to be? What do the remains of the wooly mammoth and other animals tell us about the past? These questions may seem very different, but the answers are all related. They all have to do with the Pleistocene Epoch—also called the Ice Age.

In this chapter we will discuss what we know about the Ice Age. Why do we think that a continental ice sheet once covered nearly all of New York State? When was the ice here? How do we know which way the ice sheet moved, how thick it was, or how it affected the landscape? These questions and others were asked by geologists in the past, and we continue to seek answers today. From the answers we have so far, we can reconstruct a geologic history of the Pleistocene Epoch.

Nearly all of New York State is covered by a variety of loose rock debris carried southward by glaciers. The glaciers formed in the arctic regions, grew, and merged into large ice sheets that slowly flowed southward into normally temperate zones. Eventually, immense blankets of ice, perhaps 2 km thick, covered much of the northern hemisphere (Figure 12.1). The glaciers changed the landscape at an amazing speed compared to other geologic processes. We see their effects everywhere across New York.

[1]Adapted from a manuscript by D.H. Cadwell.

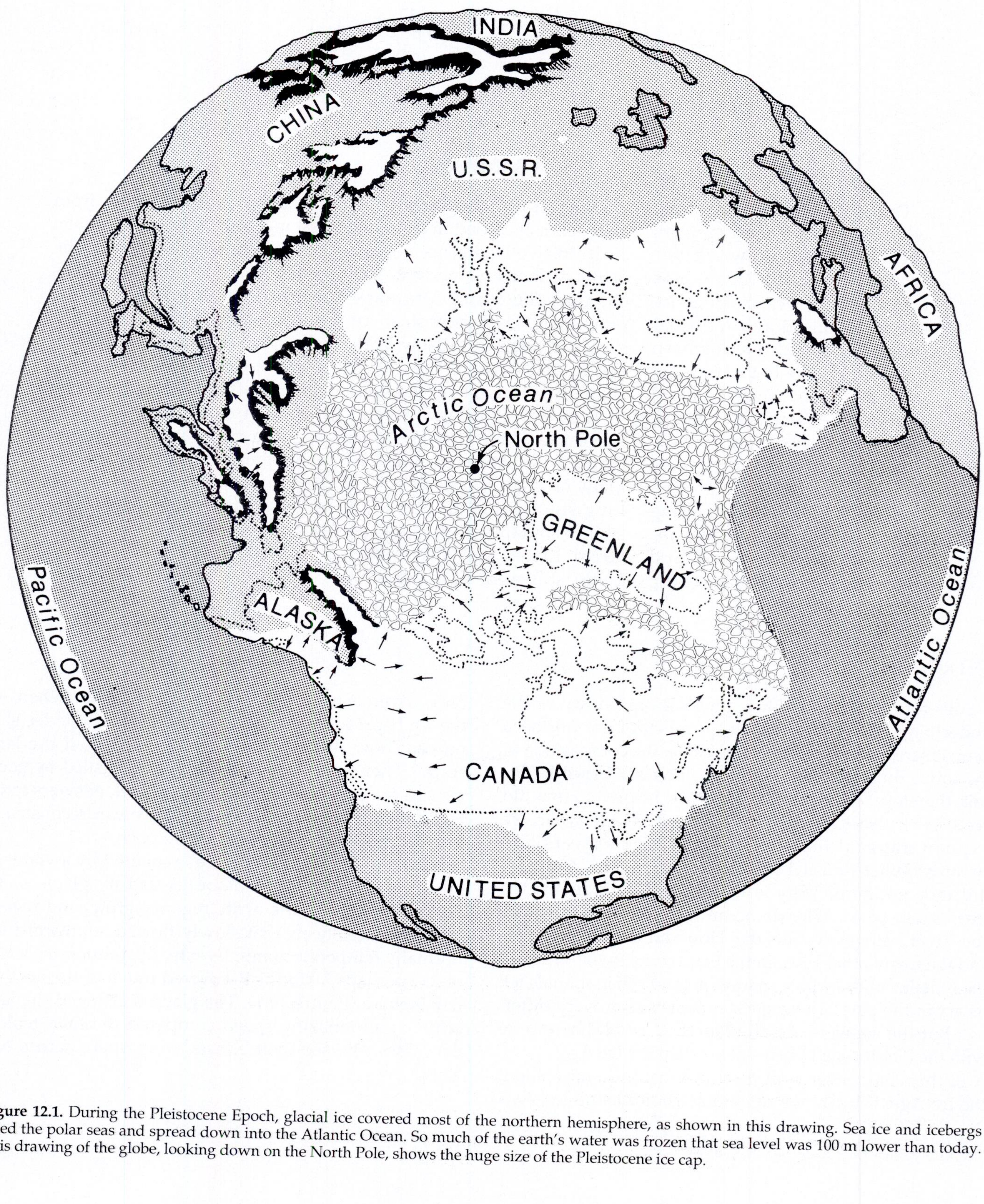


Figure 12.1. During the Pleistocene Epoch, glacial ice covered most of the northern hemisphere, as shown in this drawing. Sea ice and icebergs filled the polar seas and spread down into the Atlantic Ocean. So much of the earth's water was frozen that sea level was 100 m lower than today. This drawing of the globe, looking down on the North Pole, shows the huge size of the Pleistocene ice cap.

How Did the Ice Age Begin?

The Pleistocene Epoch was a very recent chapter in the earth's history. It began about 1.6 million years ago; it ended only about 10,000 years ago, when the last glaciers melted northward. Or did it end? Some scientists believe that the Ice Age isn't over yet. During the Pleistocene, the ice advanced and retreated several times. Today's warmer climates may be just another interglacial lull; the glaciers could return someday. After all, ice sheets still occupy Greenland and Antarctica. We have no sure way of predicting a future ice age, but it is a real possibility.

About 10 million years ago, during the last part of the Tertiary Period, temperatures around the world began to drop. (We can trace the changes in climate by studying fossil plants and their pollen.) Tropical areas became subtropical. In turn, subtropical areas became temperate. Cooling continued. Eventually, the temperatures in the northern hemisphere became low enough to produce the icy climates of the Pleistocene.

In Pleistocene North America, snow remained on the ground all year long as far south as central New Jersey. This year-round winter happened not just on the cold mountain tops, but even at sea level.

During the Pleistocene Epoch, glaciers expanded dramatically in the northern hemisphere around the world. As the depth of the snow cover increased, vast ice sheets called *continental glaciers* began to flow south from arctic and subarctic regions. As they advanced, they merged with smaller *mountain glaciers* that had formed earlier. These mountain glaciers were streams of ice that flowed down the valleys in mountainous regions. The continental ice sheets that spread across northern North America and Eurasia (Figure 12.1) eventually reached 1 to 2 km in thickness. How do we know? We find, for example, scratches and grooves left by glaciers on the highest peaks in the Adirondacks—1.6 km high. This fact tells us that the ice was thicker than 1.6 km. At the height of the Ice Age, almost one third of the earth's land surface was covered by ice.

How low did the temperature have to drop to produce the Ice Age? Surprisingly, average temperatures worldwide were probably only about 5°C lower than today!

The Advance

Continental ice sheets began to flow south from the arctic and subarctic regions 1.6 million years ago. Once the glaciers started to move, a chain of events sustained the frigid new conditions.

When warm air from the south reached the glacier, it rose over the surface of the ice and cooled abruptly. As the air cooled, the moisture in it condensed and fell as snow. More and more snow piled up. The weight of new snow continuously compacted the snow beneath into ice. The pressure continued to build up and forced the ice to flow out in all directions (Figure 12.2). Centimeter by centimeter, kilometer by kilometer, the glacier crept along. How fast did it move? Some modern glaciers advance a meter or so each day. We can guess that the Pleistocene glaciers behaved in the same way.

Eventually the ice front reached a warmer area—either at a lower elevation or farther to the south. When the average temperature was high enough, the ice along the front melted as fast as the ice behind it pushed forward.

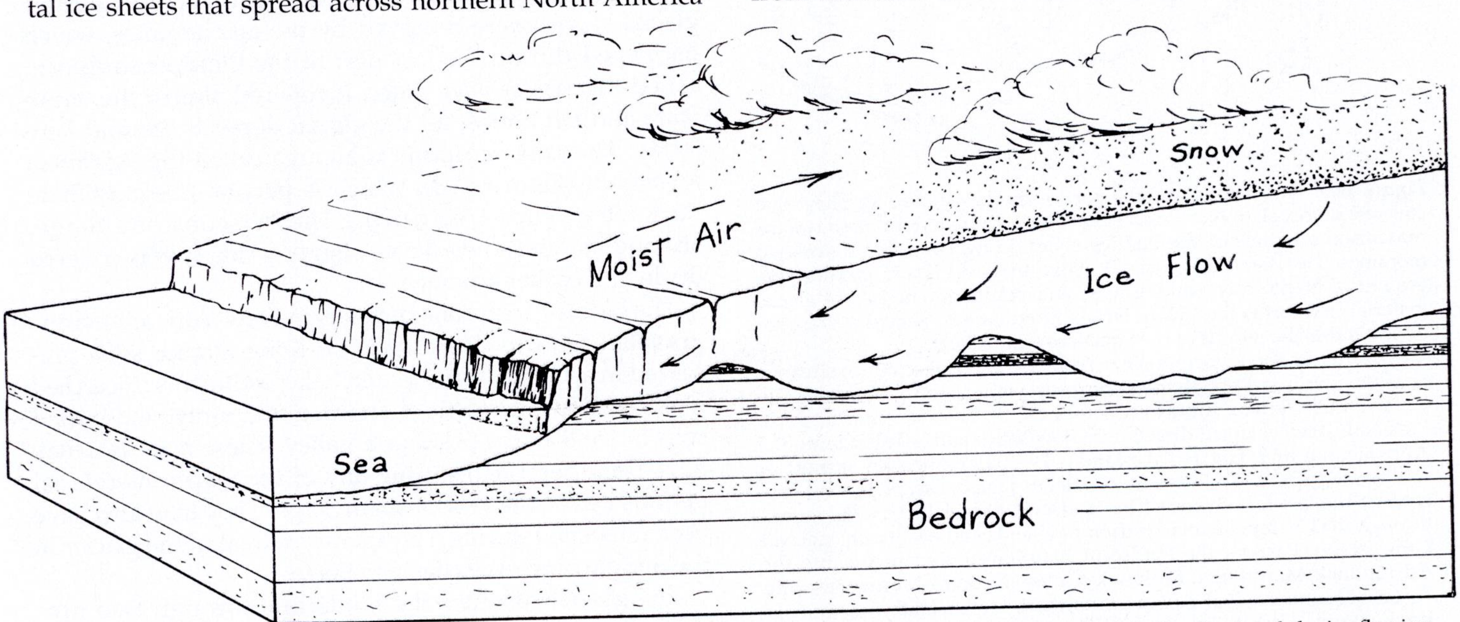


Figure 12.2. This diagram is a simplified cross section of an ice sheet. Notice the snow feeding the glacier behind the ice front and the ice flowing, even riding over low hills. (The vertical scale is highly exaggerated.)

As long as melting balanced forward flow, the glacier's front remained in one place.

The ice sheet that invaded New York is called the *Laurentide Ice Sheet* (Figure 12.3). It started in the Laurentian Mountains of Quebec and the uplands of eastern Quebec and Labrador. Almost all of New York State, nearly 130,000 km^2, was covered by the ice. Even so, that was only about one percent of the total area covered by the ice sheets in North America. About 21,750 years ago, the Laurentide Ice Sheet covered nearly 13 million km^2. Northeast North America looked something like Antarctica does today.

The enormous quantity of water frozen into snow and ice during the Ice Age lowered sea level by about 100 m worldwide. What evidence do we find in New York State for this drop? With sea level that low, much of the continental shelf offshore of New York would have been dry land. Today, we can find channels on the shelf that were cut by rivers. However, the channels are now under the sea and partly filled with sediment (see Chapter 10). Rooted tree stumps have also been found underwater on the continental shelf.

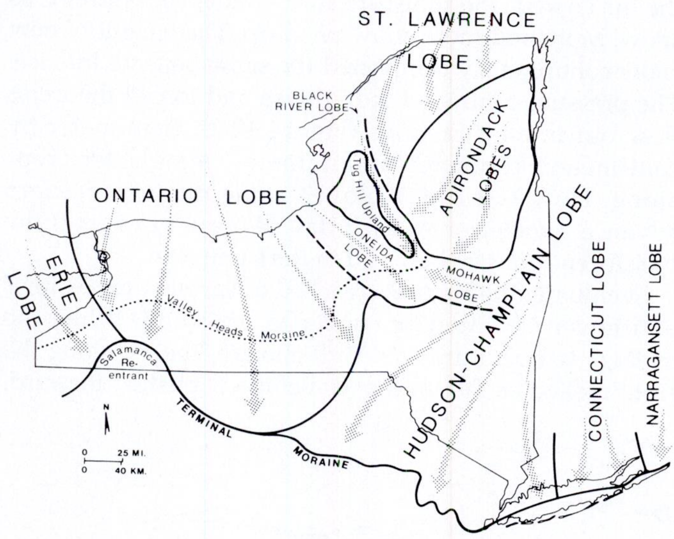


Figure 12.3. This map shows the part of the Laurentide Ice Sheet that covered almost all of New York State. The Terminal Moraine shows the maximum advance of the last ice sheet. Long Island contains two moraines. The island as we see it above sea level is a large dumping ground of glacial clay, sand, gravel, and boulders. The pile of glacial material that forms the Valley Heads Moraine has created a drainage divide across the middle of the State (see Figure 16.1).

The glacier flowed across New York State in connected ice streams, or *lobes*. The Erie Lobe flowed southeast, out of the Erie Basin. The Ontario Lobe flowed southwest across the St. Lawrence and Ontario Lowlands, then changed direction to flow south and southeast into the Appalachian and Tug Hill Uplands. The Salamanca Re-entrant of southwestern New York, where two lobes joined, escaped being covered by the last ice advance. The Hudson-Champlain Lobe advanced through the Champlain and Hudson Lowlands and eventually reached Long Island. Parts of the Hudson-Champlain Lobe spread into the Adirondack Mountains, Mohawk Valley, Catskill Mountains, and Taconic Mountains. It also covered northern Long Island, west of Lake Ronkonkoma. The Connecticut Valley Lobe covered northern Long Island east of Lake Ronkonkoma.

After the continental ice sheet melted, the meltwater raised sea level again—about 100 m. Today ocean tides move up the Hudson River as far north as Albany and Troy. (The salt water does not extend north of Poughkeepsie, though, because the river flow pushes it back.) The Hudson River south of Troy is therefore actually an *estuary*, or arm of the sea. Where it flows through the Hudson Highlands, the Hudson is a *fjord*—a long, narrow bay with cliffs on either side. The water in the lower Hudson is deep enough to accommodate large ships. It was the Ice Age that deepened the Hudson River and enabled Albany to become a port for ocean-going vessels.

How do we reconstruct what the ice sheets did in New York? We look at the many clues they left behind (Figure 12.4). As the glacier advanced, it scratched and grooved the bedrock and streamlined the landscape. Then as it melted, it left great quantities of rock debris in a wide variety of deposits. By examining such clues, we can deduce the directions of ice movement across the State. We find that the ice sheet flowed across New York in "ice streams," or *lobes* (Figure 12.3).

During the Pleistocene Epoch, the Laurentide Ice Sheet made four major advances into the northern United States. Between advances, warm stages caused the ice sheet to retreat back into Canada. During these interglacial lulls, temperatures were probably even a bit warmer than today! How do we know that there were four separate advances? The best evidence for multiple advances comes from glacial deposits in the Midwest. In New York State, however, nearly all traces of earlier glacial stages were removed by the last advance, which happened during the last part of the Pleistocene Epoch, called the *Wisconsinan Stage*. It covered almost the entire State and left almost all the glacial deposits we find here today. The only exception is an area called the *Salamanca Re-entrant* (Figure 12.3), which is part of Allegany State Park. It was ice-free during the Wisconsinan Stage, although scattered evidence suggests that it was covered during an earlier advance.

The oldest Pleistocene deposits in New York are marine gravels found in deep wells on Long Island, soils preserved in a ravine near Cayuga Lake, sediments unearthed in excavations near Otto, Cattaraugus County, and buried soils in wells in the Schoharie Valley. These materials may have been deposited during any of the warm interglacial periods before the Wisconsinan Stage. They may also have been deposited during a temporary retreat of the glacier in the middle of the Wisconsinan Stage.

The glacier affected the landscape through two processes—erosion and deposition. We consider these processes next.

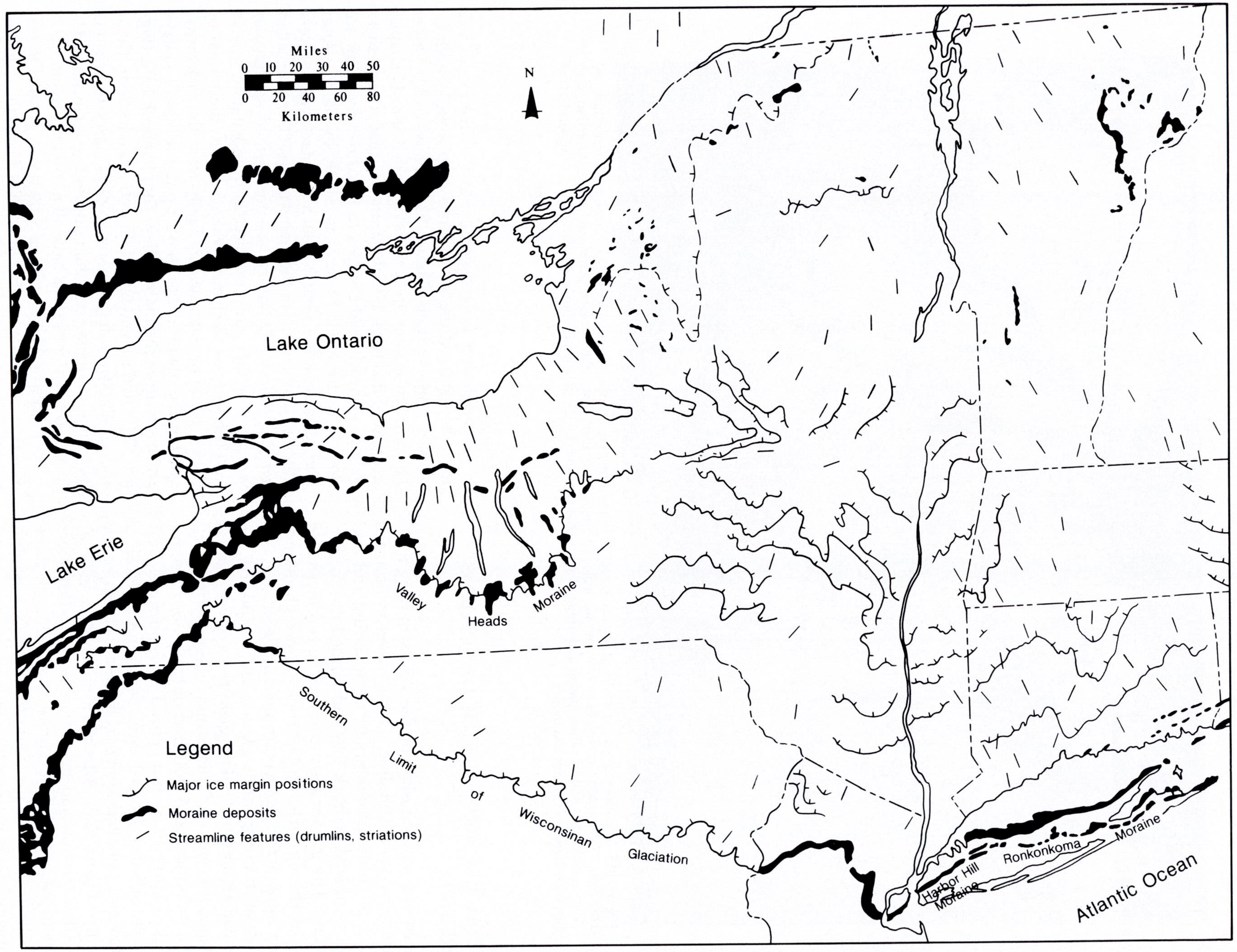


Figure 12.4. This map of New York State and surrounding areas shows the locations of moraine deposits; it also includes features like drumlins and striations that indicate the direction of glacial flow. It was by looking at such evidence that scientists reconstructed the history of the Pleistocene Epoch in New York. The map also indicates position of the edge of the ice sheet at various times.

Figure 12.5. The moving glacier sculpted, scoured, and polished this garnet gneiss, found along U.S. Rte. 4, 5.4 km northeast of Fort Ann, Washington County. Note hammer for scale. The rock was polished by cobblestones, gravel, and sand grains that were "cemented" in the bottom of the glacier and dragged across the exposure by the slowly moving mass of ice. Thus, the glacier acted like a giant piece of coarse sandpaper.

Glacial Erosion and the Landforms It Created

The erosion accomplished by the slowly moving mass of glacial ice was astounding. The ice sheet transported millions of cubic kilometers of pre-existing soil and deeply weathered bedrock that had formed during Tertiary time. The glacier also tore free large blocks and pieces of the underlying bedrock. These chunks of bedrock were carried along embedded in the ice.

Filled with mud, sand, gravel, and boulders, the glacier had an underside like a giant piece of very coarse sandpaper. It ground soft shales and limestones into rock flour. It smoothed and polished outcrops of resistant bedrock (Figure 12.5) and scored deep grooves and scratches (called *striations*) into them (Figure 12.6). It rounded and polished knobs of bedrock, called *roches moutonnées* (Figure 12.7). After the ice melted, large boulders, called *erratics*, had been transported kilometers from their places of origin (Figure 12.8). Some of these erratics have striations that were formed as the erratics were dragged along in the bottom of the glacier.

Where glaciers flowed parallel to V-shaped river valleys, they gouged the valleys into deep troughs with U-shaped cross sections (Figure 12.9). New York's Finger Lakes lie in former river valleys carved into U-shaped troughs of this type. Tributary streams that entered these valleys at nearly right angles to the direction of the ice flow were not eroded nearly as deeply by the ice. After the ice melted, the floors of such tributary valleys were left high on the walls of the main valleys. (They are called *hanging valleys*.) Tributary streams formed spectacular waterfalls as they dropped directly from hanging valleys into the steep-walled main valleys. Since the retreat of the ice, running water has gradually worn the rock away, causing the waterfalls to move up the tributary valleys and away from the main valley. Taughannock Falls (Figure 12.10) and several waterfalls and cascades near Ithaca and at Watkins Glen are striking examples of streams that once plunged from hanging valleys; since the ice sheet retreated, these falls have all moved upstream.

The ancestral Hudson River valley was parallel to the direction of ice flow. Where the river flows through the Hudson Highlands, the glacier scoured the valley's

Figure 12.6. Glacial striations on the Larabee Member of the Middle Ordovician Glens Falls Limestone southeast of Chazy, Clinton County. Such striations can often be found atop road cuts where bulldozers have removed the glacial debris that covered the rock. Notice the knife for scale and the arrow indicating north. The directions of such striations give us a major clue in figuring out the directions of ice flow (shown in Figure 12.3).

bedrock floor to a depth of 240 m below sea level. (We base this figure on drill hole tests made for the Catskill Aqueduct tunnel that crosses the Hudson River at Storm King and carries drinking water to New York City.) Many tributaries, including the Mohawk River, occupied hanging valleys and now cascade down a series of waterfalls and rapids to the Hudson River.

While the main continental glacier was retreating, smaller mountain glaciers lingered in highland areas. Mountain glaciers of this type were especially common in the Adirondack and Catskill Mountains. In contrast to the smoothing effect of the huge ice sheet, these mountain glaciers concentrated erosion within stream valleys and sharpened the landscape (as shown in Figure 12.11). In the Catskills and Adirondacks, they carved river valleys into U-shaped cross sections (Figures 12.9 and 12.11) and steepened the valley walls, often forming spectacular cliffs. At the heads of the valleys, the glaciers created large bowl-shaped amphitheaters called *cirques*. The steep walls of cirques formed where the ice dislodged chunks of bedrock from the mountain. In cold climates, rock is broken into smaller and smaller pieces as water flows into cracks, then freezes. In the glacial climate of the Pleistocene, water repeatedly melted and froze. The water expanded as it froze and pried the rock apart along the natural cracks (called *joints*). As the glacial ice flowed downslope, it plucked the loosened blocks of rock, leaving vertical valley walls. Whiteface Mountain in the Adirondacks has several impressive cirques encircling its peak (Figure 12.12).

Glacial Deposition and the Landforms It Created

Erosion was one of the major effects of the Pleistocene glacier. The other was deposition—the dropping of the rock debris that the glacier carried. With these deposits, the glacier dammed rivers and changed their courses. It left vast amounts of mud, sand, and gravel that covered much of the bedrock. It also created a number of distinctive landforms (Figure 12.7).

We have found buried stream valleys in Chautauqua, Onondaga, and Cortland Counties that existed before the glacier advanced. Today, these valleys are filled with over 300 m of glacial debris. West of Glens Falls, the Hudson River meanders for a short stretch across a

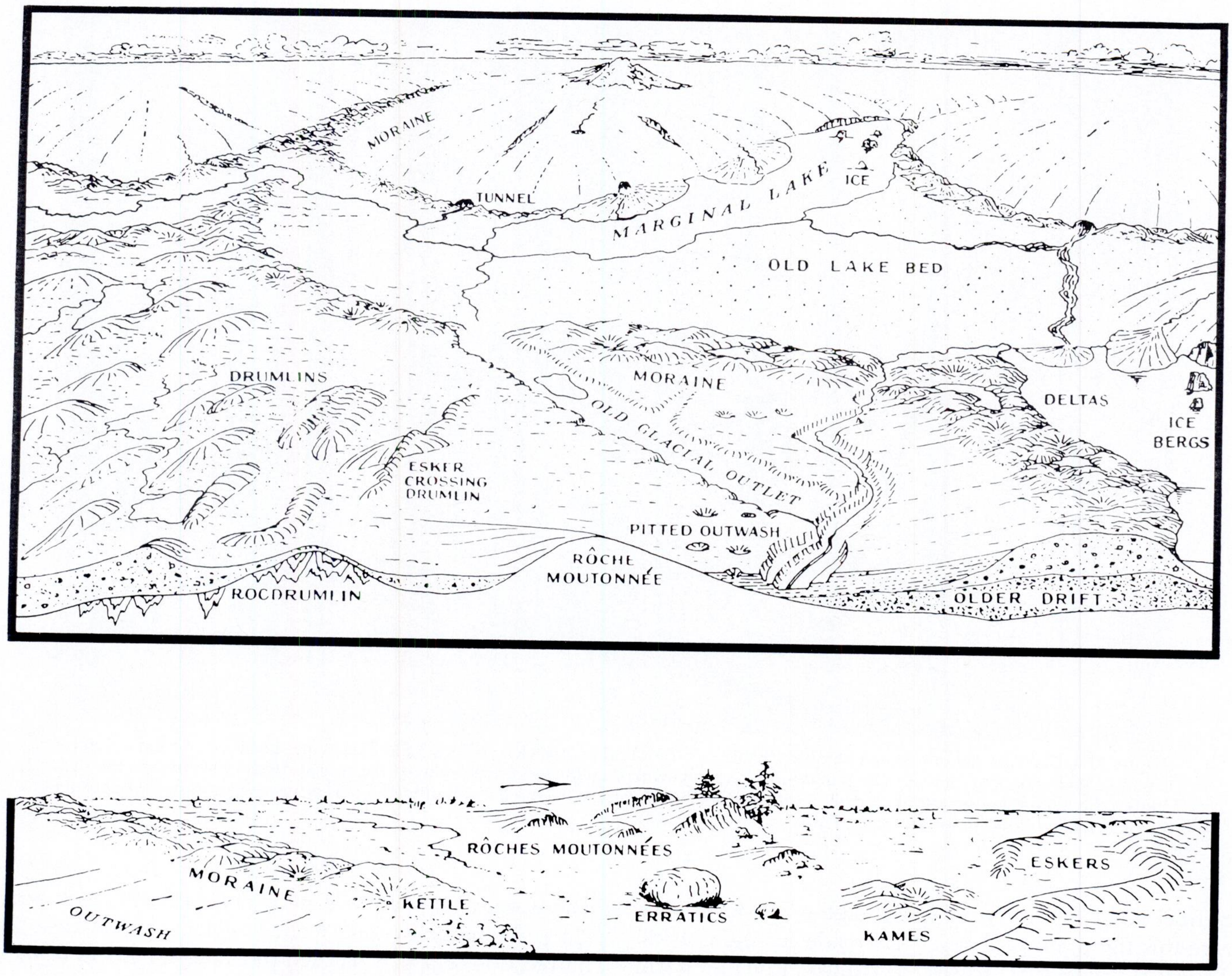


Figure 12.7. These diagrams show various types of landforms and glacial deposits left behind by continental glaciers. We study such features of New York's landscape and compare them with features of areas being glaciated today. With this information, we are able to deduce the glacial history of our State. (From *Geomorphology* by A.K. Lobeck. Copyright© 1939. Published by McGraw-Hill, Inc., New York, NY. Reproduced by permission of McGraw-Hill.)

buried pre-glacial river channel that once drained the Lake George valley. That channel, now filled with glacial debris, passes southward beneath Saratoga Lake and Round Lake. The postglacial Hudson River has cut a new channel to the east.

The most widespread type of glacial debris is *till*. Till is a dense, unsorted mixture of clay, sand, gravel, and boulders (Figure 12.13).

In places, after depositing till, the ice continued to move over it, molding it. In such areas, till deposits are usually streamlined or gently rounded. Cigar-shaped hills of till are called *drumlins*. These hills are steeper on the upstream end—the direction from which the ice flowed (Figure 12.14). Hill Cumorah near Palmyra, where Joseph Smith reported seeing a vision that led him to found the Mormon church, is a drumlin. (It is shown in the lower left corner of Figure 12.15.) Some drumlins have a bedrock core with till plastered on the outside. They are called *rock drumlins*.

The lowland between Rochester and Syracuse is studded with drumlins—some 10,000 of them. (Figure 12.16 shows their general location; see also Figure 12.15 and Plate 1 of the *Geological Highway Map*.) It is one of the greatest drumlin fields in the world.

As glacial ice melted, streams of meltwater flowed over, under, through, and beside the glacial ice. These streams deposited sand and gravel in a variety of forms. Because these deposits were laid down by running

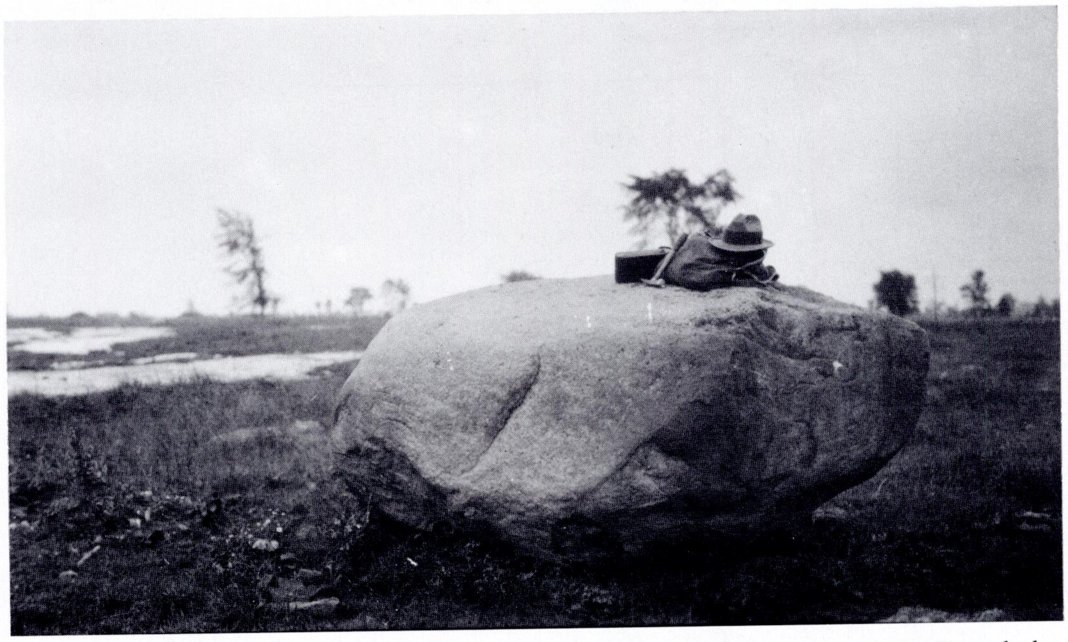


Figure 12.8. Another clue to glaciation, this 2 m erratic, a boulder of metamorphosed anorthosite, is perched on top of Potsdam Sandstone, 1 km northwest of the village of Black Lake, St. Lawrence County. The glacier probably carried this boulder one hundred kilometers or more from its source before leaving it here.

water, they tended to be sorted into layers by size, in contrast to unsorted deposits such as till. An *esker* was formed by a stream flowing in an ice tunnel under or on the surface of a glacier (Figures 12.7 and 12.17). A *kame* is a steep-sided mound of sand and gravel, usually poorly sorted (Figures 12.7 and 12.18). A stream that flowed into a lake between a glacier and the wall of a valley formed a *kame delta* (Figure 12.19).

Huge blocks of ice were commonly buried in the outwash in front of the glacier. When the blocks melted, they left behind *kettle* lakes (Figure 12.20). There are many such lakes in New York State. Some have become overgrown with a mat of floating vegetation and are now quaking bogs. As the vegetation sinks to the bottom and decays, the bogs fill in and become swamps. Still later, the forest encroaches. Poorly drained glaciated terrain has many ponds, lakes, bogs, and swamps.

Moraines include ridges of till piled up or dumped along the edge of the ice. They show where the ice front remained in one place long enough for a ridge of glacial debris to pile up. There are many moraines in the State, as shown in Figure 12.4. An *end moraine* marks the farthest advance of an ice sheet. The end moraine of the Wisconsinan ice sheet is given the special name *Terminal Moraine* (see Figure 12.3). The Ronkonkoma Moraine on Long Island is part of the Terminal Moraine.

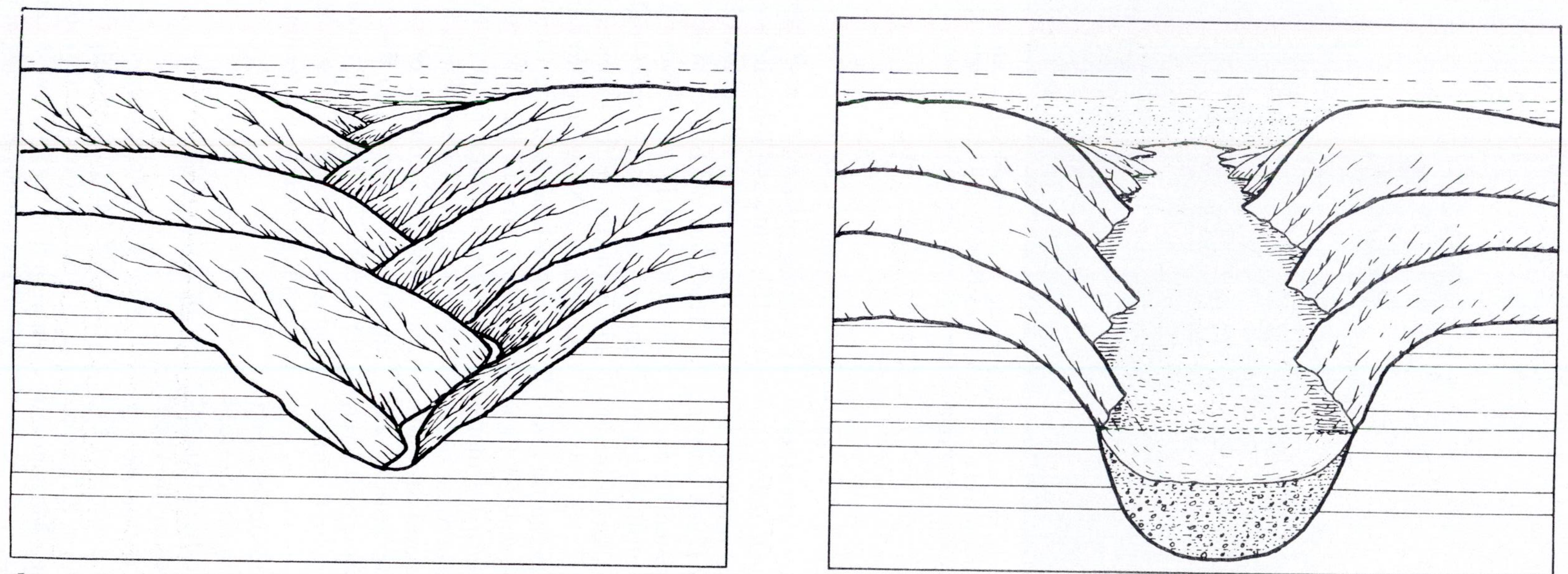
Meltwater streams flowing from the front of a glacier formed a plain of *outwash* beyond the moraine (Figure 12.21B). Outwash deposits were coarser close to the ice and became finer farther away.

At its largest, the ice sheet of the Wisconsinan Stage covered nearly all of New York State and was thick enough to bury the mile-high Adirondack peaks. The southern edge of the ice extended southeast across Pennsylvania and New Jersey to Long Island.

Long Island is made up of mud, sand, gravel, and boulders carried there by glacial advances during the Wisconsinan Stage. Most of this debris was eroded from New York and New England. The part of the island above sea level consists of two moraines, deposited during two advances, with their associated outwash plains (Figure 12.21). These two moraines intersect in western Long Island. South of the moraines we find the outwash deposits carried by meltwater streams.

The Retreat

After Long Island was formed, the climate began to warm. Melting increased. Eventually, although the ice continued to flow southward, melting had speeded up enough that the ice front began to retreat. The ice sheet of the Wisconsinan Stage began its slow retreat to the north about 21,750 years ago (Figure 12.22). It left New York



A

B

Figure 12.9. This "before and after" picture shows the results of a glacier flowing down a river valley. The "before" picture in (A) shows the V-shaped valley cut by a river. The "after" picture in (B) shows the same valley after glaciation—broadened and carved into a U-shape by the glacier. When the end of such a glacially broadened valley is blocked by glacial debris, the valley can become a long, narrow lake. This process formed New York State's Finger Lakes.

Figure 12.10. Taughannock Falls, Tompkins County, formed when a tributary stream perpendicular to the direction of glacial flow remained unmodified while the main valley, parallel to ice movement, was considerably widened and deepened. Thus, the tributary was left as a hanging valley after the ice melted in the main valley. The present falls have eroded back 1.5 km from the main valley since the ice left the valley roughly 15,000 years ago.

State about 10,000 years ago and melted completely in Canada approximately 7,000 years ago. The only remnants of the Ice Age still in mainland North America are small mountain glaciers in the western United States and Canada.

Today, the remains of the huge Pleistocene ice sheets—most glaciers of the Canadian and Soviet Arctic islands, Greenland, and Antarctica—cover a tenth of the earth's land. More than three-fourths of the earth's fresh water is frozen in the Antarctic and Greenland ice sheets. If all that ice were to melt, sea level would rise more than 45 m and flood the world's large coastal cities, including New York City and Boston.

During its retreat, the glacier readvanced slightly from time to time. How do we know? By looking at the moraines left during retreat (Figure 12.4).

The melting ice sheets released unimaginable volumes of water. The meltwater flooded lowland areas to make large lakes in front of the glacier (Figures 12.7 and 12.23). These lakes, called *glacial lakes*, are today extinct; they formed between the ice front and bedrock hills or end moraines. The lakes lasted up to perhaps 5,000 years, and their size and depth changed constantly. As the ice front retreated to the north, it opened new outlets for the meltwater flow and for the lake water. About 15,000 years ago, the Hudson River valley was filled with a large glacial lake that we call Glacial Lake Albany. This lake lasted for at least 4,000 to 5,000 years.

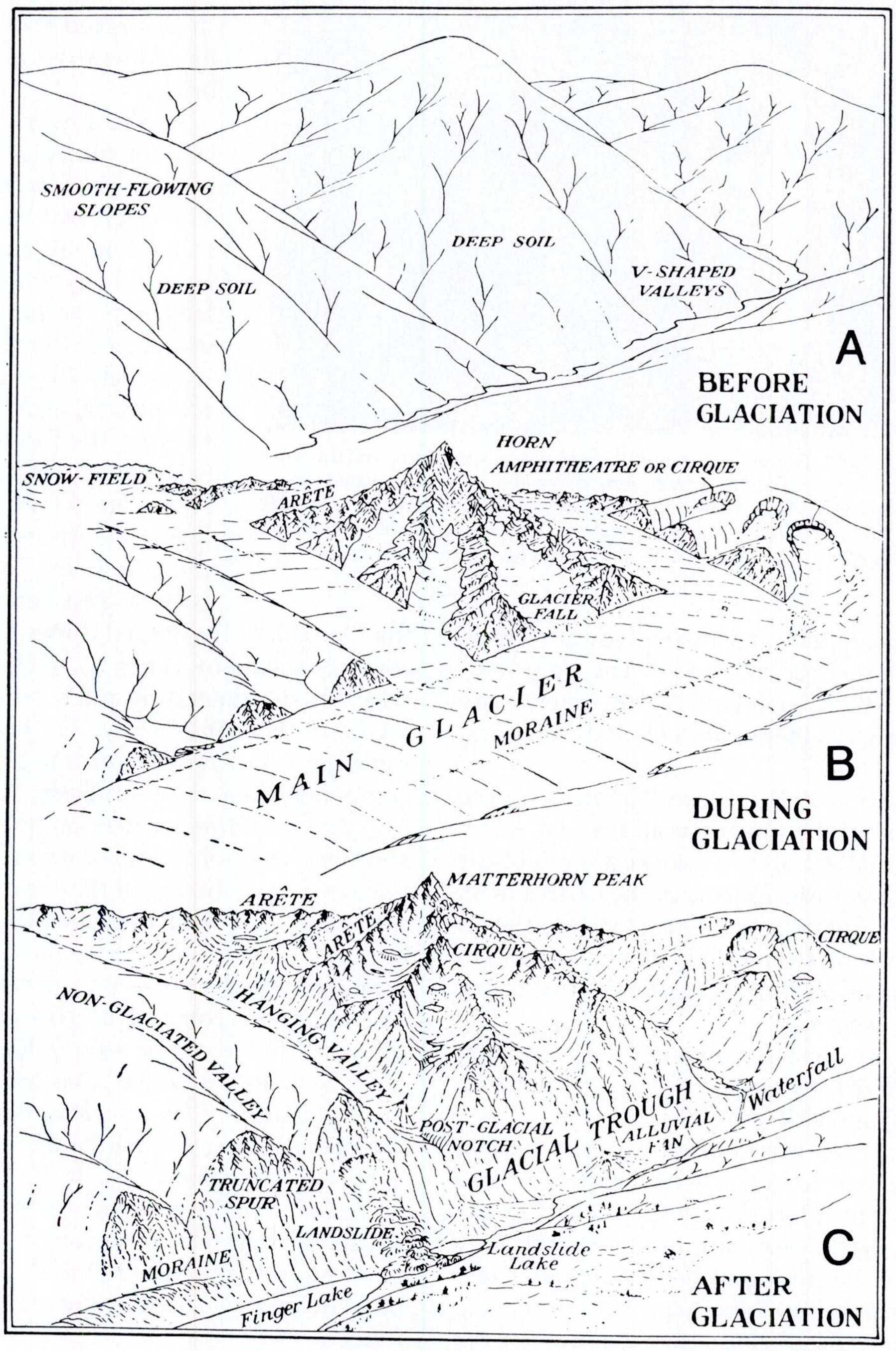
Today, we can tell where the lakes were by the lake bottom deposits they left behind. Many of the lakes lasted long enough for meltwater streams to carry in large quantities of *rock flour*. This very fine-grained material settled out as thick layers of clay in the deeper parts of the lakes. The clay deposits that formed in Glacial Lake Albany have been used extensively to make bricks.

As the streams entered the lake, the coarser material—sand and gravel—was dropped near shore to form deltas. The ancestral Mohawk River built a large delta at the west arm of Glacial Lake Albany where the city of Schenectady now stands. As the lake began to drain, new deltas were built at lower lake levels. Eventually, the lake drained completely, and the wind built a dune field on the former lake floor between Schenectady and Albany north to Glens Falls. The dunes were built from drifting sands derived from the deltas and the lake floor. The dune field between Albany and Schenectady is known as the Pine Bush. These sand dunes have been held in place for thousands of years by a pine-barren vegetation, which is dominated by pitch pine. The tilt of the sand layers in the dunes shows us that the dominant dune-building wind came from the northwest and a lesser component from the southwest.

A major moraine across central New York closed the southern ends of several formerly south-flowing river valleys. The damming of these valleys produced the Finger Lakes. This same moraine, the Valley Heads Moraine (Figures 12.3 and 12.4 show its location), forms an east-west *drainage divide* across the central part of the State. The moraine formed as the glacier receded. This drainage divide can be seen in Figure 16.1, which shows New York State's drainage basins. Streams and rivers on opposite sides of the moraine tend to flow in opposite directions. The moraine has become a drainage barrier between two regions.

Glacial ice in the valleys was thicker and therefore lasted longer than ice in the uplands. It melted slowly in place and became covered with debris carried by tributary streams. Meanwhile, the main ice front continued to retreat.

The receding ice sheet made its last major readvance into northern New York more than 11,000 years ago. The ice readvanced across the Adirondacks and Tug Hill Plateau and across the Erie and Ontario Lowlands (Figure 12.3). In the Erie and Ontario Lowlands, it filled an earlier gorge of the Niagara River with debris and rode over earlier glacial lake deposits.



After W. M. Davis

Figure 12.11. (A) shows the rounded preglacial topography of a mountainous region. (B) shows how mountain glaciers sharpened the topography. In the Adirondacks and Catskills, mountain glaciers didn't last long enough to create a landscape like that shown in (C). The present-day landscape is between (A) and (C). For example, Whiteface Mountain in the Adirondacks begins to resemble the Matterhorn peak in (C), but Whiteface Mountain still retains its original rounded summit, as shown in Figure 12.12. (From *Geomorphology* by A.K. Lobeck. Copyright © 1939. Published by McGraw-Hill, Inc., New York, NY. Reproduced by permission of McGraw-Hill.)

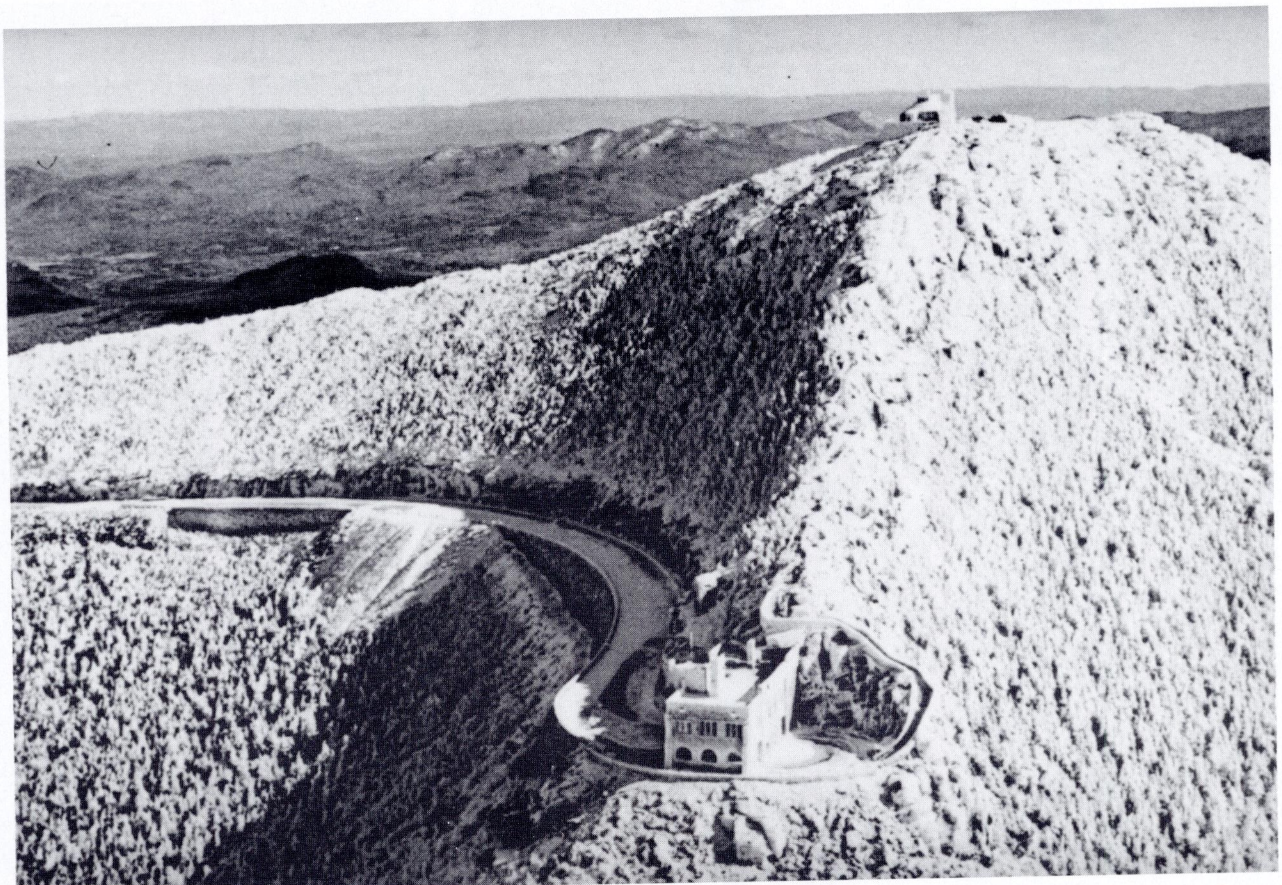


Figure 12.12. Two bowl-shaped cirques are seen in this photo, which looks towrd the east at the summit of Whiteface Mountain. They are separated by a sharp ridge, called an *arête*. A third cirque is out of sight on the other side of the peak. The cirques, steep-walled natural amphitheaters, were formed at the heads of mountain glaciers that surrounded the summit of Whiteface during the Ice Age. These were some of the many mountain glaciers that remained in the Adirondack Mountains after the retreat of the continental ice sheet. The mountain glaciers pried chunks of bedrock off the valley walls and carried away the loosened pieces. If the glaciers had lasted much longer, they would have eroded back to back to produce a sharp horn, similar to the Matterhorn in Switzerland (see Figure 12.11).

Figure 12.13. On the wall of this sand and gravel pit, we can see well sorted layers of glacial deposits. These deposits were left by glacial meltwater. On top of the layers is coarse-grained, unsorted glacial till. Notice the faults in the water-lain layers. These faults formed before the till was deposited. We think that the cause of the faulting was pressure from moving glacial ice nearby. The geologic hammer in the picture is approximately 35 cm long, for scale.

Figure 12.14. One of the thousands of drumlins in New York State. These streamlined hills of glacial till line up in the direction of the glacial flow that shaped them. The steeper end, to the right in this photo, is the northern, upstream end—the direction from which the ice came.

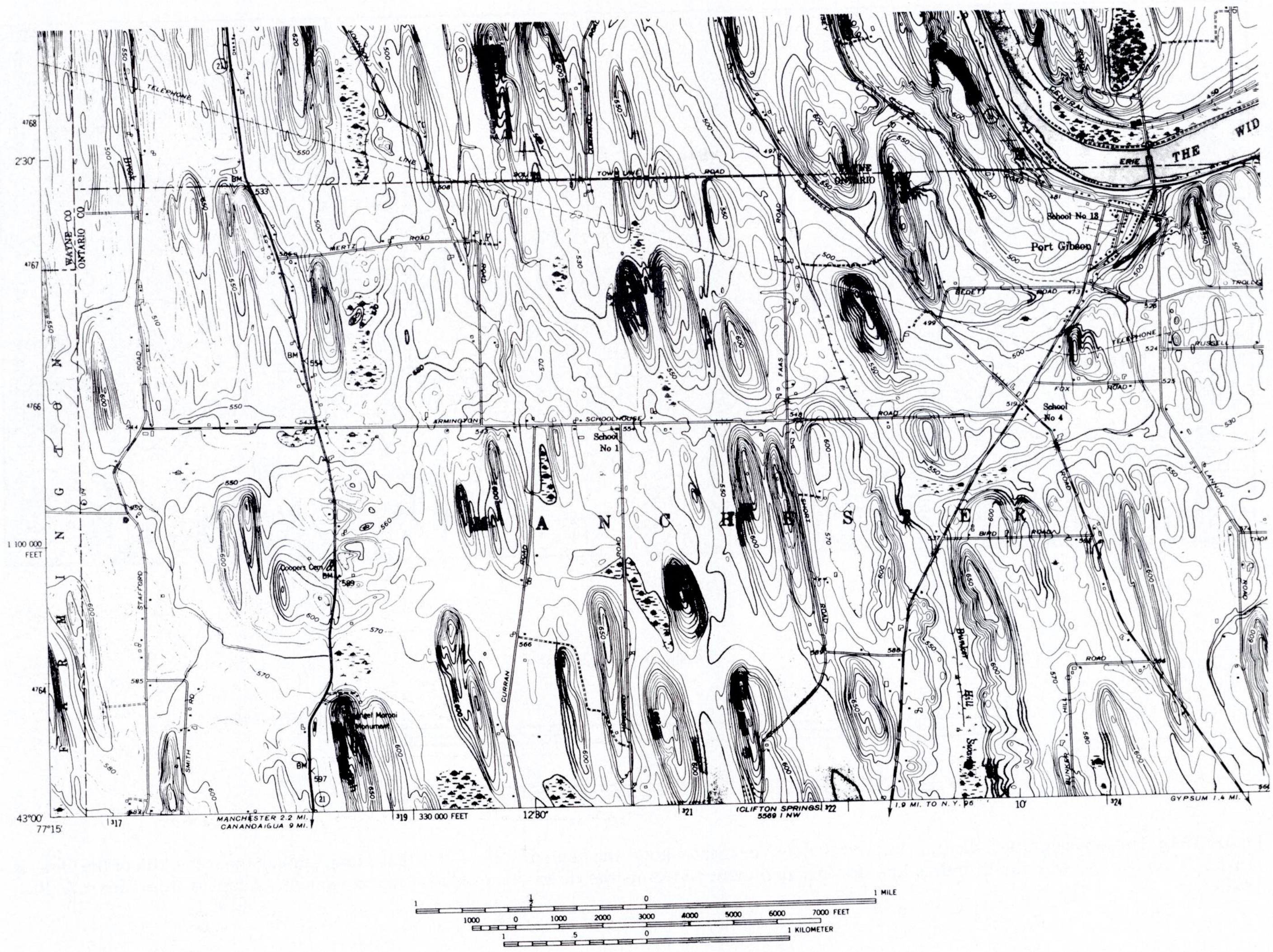


Figure 12.15. This topographic map of a portion of the Palmyra quadrangle shows some of the many drumlins found there.

The largest of the glacial lakes were the ancestors of today's Great Lakes. What remains of Glacial Lake Iroquois, for example, is now Lake Ontario. The shoreline features of these lakes show us that they were huge. (Figure 12.23 shows their largest size.) Ridge Road along the southern shore of Lake Ontario follows a beach ridge of sand and gravel that piled up at the edge of Glacial Lake Iroquois.

The tremendous outflow from Glacial Lake Iroquois flowed east past Syracuse and Little Falls. As the water rushed eastward, it scoured deep circular pits called *potholes* into bedrock at Moss Island in the Mohawk Valley near Little Falls (Figure 12.24). These are some of the best examples of potholes ever found—large enough to climb into.

The glacial ice sheets modified the earlier Tertiary drainage. In some river valleys, it gouged lake basins in the softer bedrock. In other valleys, it built dams by depositing sediments. In this way, the glacier converted the Adirondacks from a land of rivers to a land of lakes.

Through its effects on drainage, the glacier also played an important role in human history. Before highways and railroads were built, water travel was crucial in New York State. It was by far the best means of transportation and communication through the Hudson and Mohawk valleys and west into the Ontario basin. The colonists took advantage of these routes while fighting the Revolutionary War. They used the rivers to move their own troops and supplies but blocked critical waterways to stop the advance of the British.

After the Revolution, the waterways also helped greatly in the industrial development of the State. They were the most efficient way to move goods through New York State. Rivers and streams also became the source of power for grist mills and saw mills.

While glacial ice lay as a thick blanket over New York, the great weight caused the crust to sag. Therefore, as the ice melted, ocean water flooded into the northern parts of the Champlain and St. Lawrence valleys for a short time

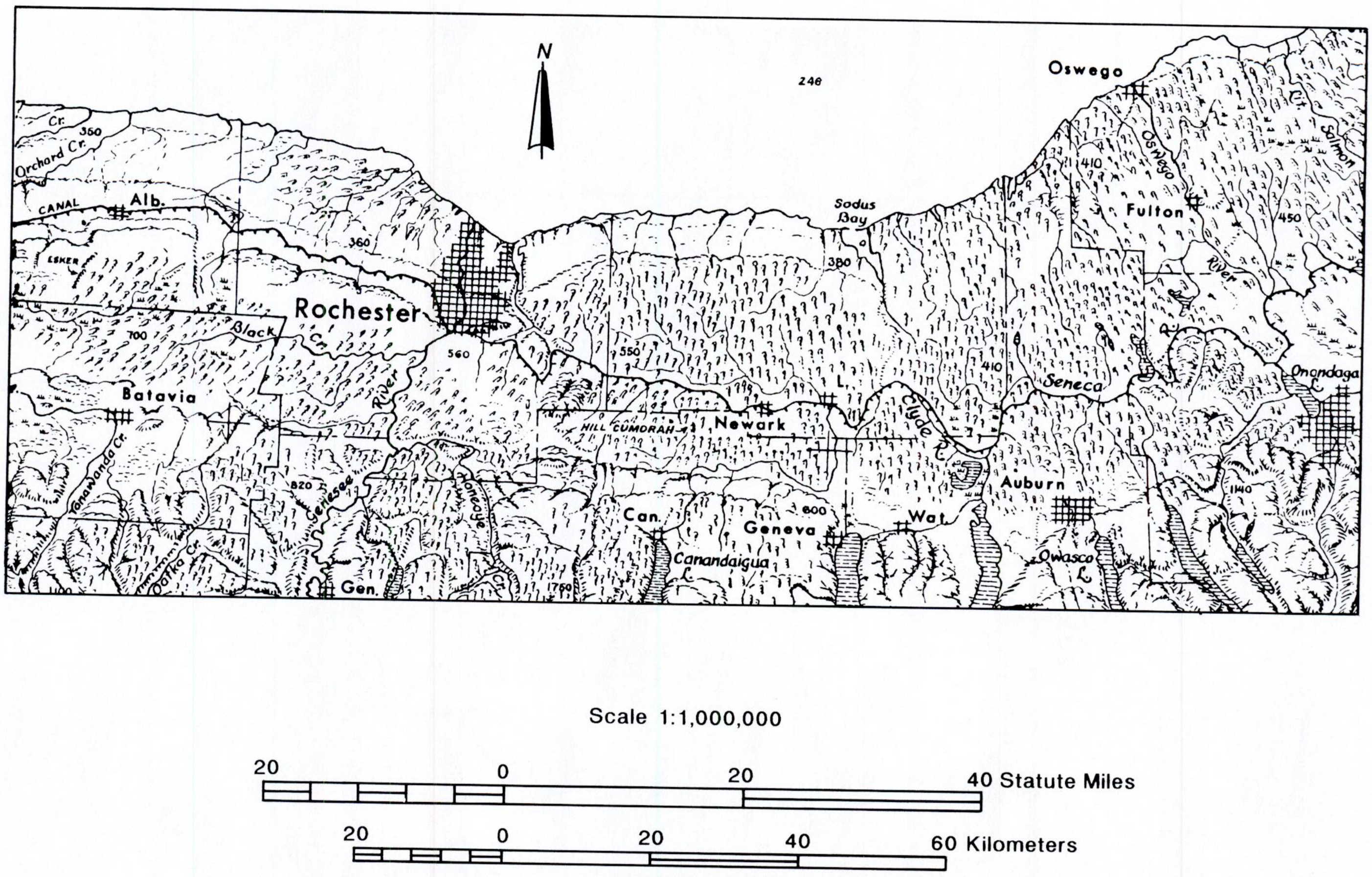


Figure 12.16. This physiographic diagram of central New York State shows the large drumlin fields that extend almost the full width of the Ontario Lowlands. Notice the way the drumlins line up; this alignment shows us the directions of glacial ice movement. (Adapted from James A. Bier, 1964.)

Figure 12.17. An esker 4 km southeast of Defreestville, Rensselaer County, on Rte. 152. This long, curvy ridge snakes along the course once followed by a stream flowing underneath a glacier. The glacial ice formed the walls for the stream; hence, this river deposit makes a ridge.

Figure 12.18. An example of a steep-sided mound called a kame. This one is found 3.2 km northwest of Earlton, Greene County.

(Figure 12.23) to create the ancient Champlain Sea. How do we know about this ancient flood? We find the shells of marine clams and the bones of whales and seals in the glacial sands and gravels in these valleys (Figure 12.25). We also find beach ridges that piled up along the shore of the sea. These ridges are now found as high as 110 m above sea level (Figure 12.26). These features enable us to map the old marine shoreline.

The sea's visit was short lived, geologically. After the ice melted, the land was relieved of the great weight. It began to rebound the way a small boat bobs back up when people step out of it. The rebound gradually raised the area above sea level and forced the sea to withdraw.

Toward the south, the ice had been thinner and the land had been depressed less. As a result, its rebound was less. In northern New York, where the ice had been much thicker, the crust has rebounded as much as 150 m.

Figure 12.19. A kame delta along the east side of the Chenango River Valley near North Norwich, Chenango County. It was formed by a stream flowing between a mountain glacier and the valley wall; it is a special type of stream deposit.

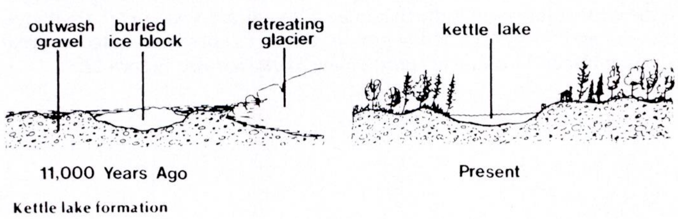


Figure 12.20. This diagram shows how kettle lakes form when an ice block, left behind by a retreating glacier, is buried by glacial outwash deposits. After the glacier retreats, the buried block melts, leaving a hole that fills with water. Debris that once covered the ice collapsed as the ice melted and now covers the lake bottom. Notice how trees and other vegetation have returned to the once barren region. (Drawing by Mike Storey.)

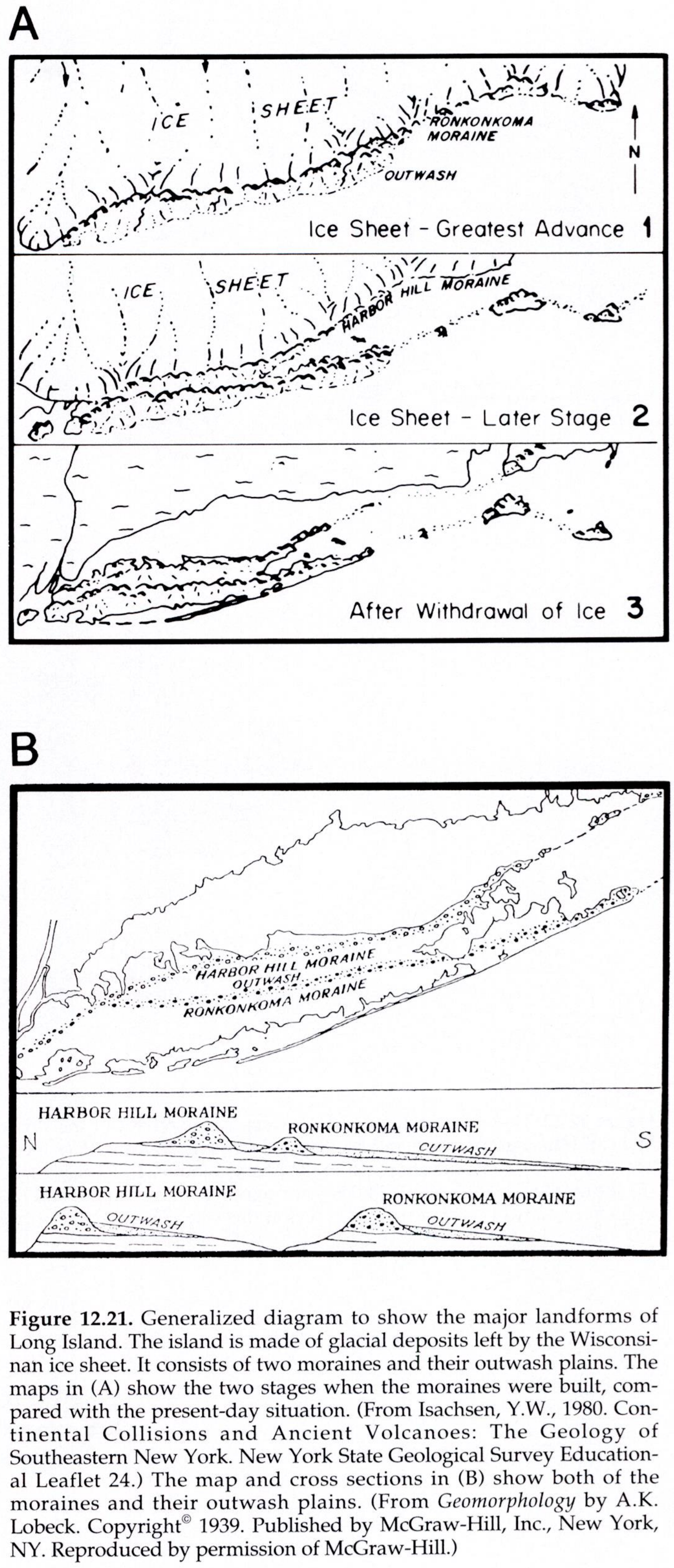


Figure 12.21. Generalized diagram to show the major landforms of Long Island. The island is made of glacial deposits left by the Wisconsinan ice sheet. It consists of two moraines and their outwash plains. The maps in (A) show the two stages when the moraines were built, compared with the present-day situation. (From Isachsen, Y.W., 1980. Continental Collisions and Ancient Volcanoes: The Geology of Southeastern New York. New York State Geological Survey Educational Leaflet 24.) The map and cross sections in (B) show both of the moraines and their outwash plains. (From *Geomorphology* by A.K. Lobeck. Copyright© 1939. Published by McGraw-Hill, Inc., New York, NY. Reproduced by permission of McGraw-Hill.)

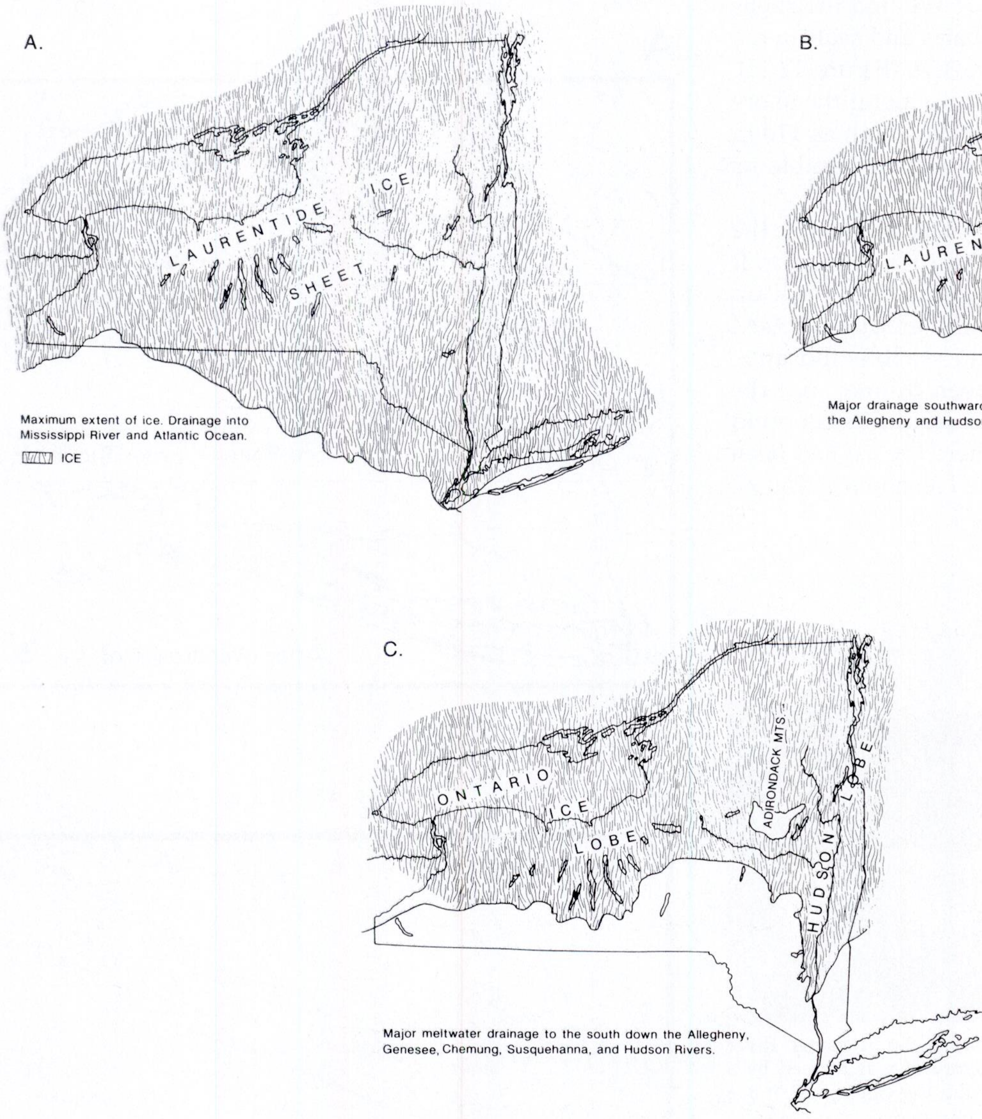
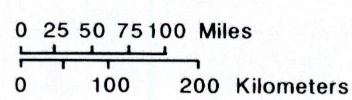
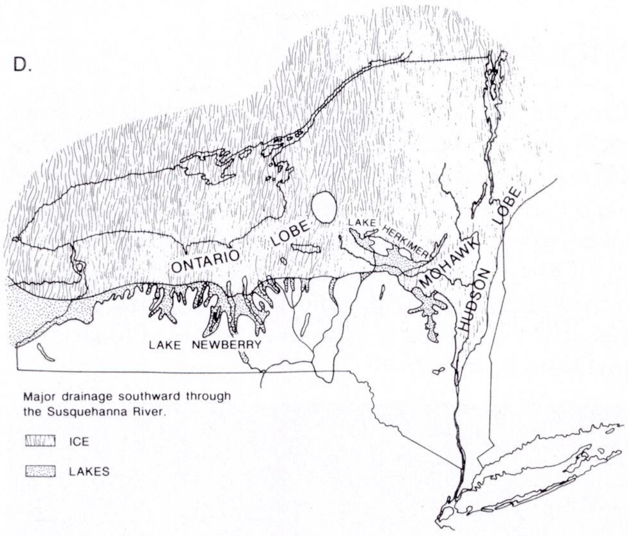


Figure 12.22. These maps show various steps in the retreat of the Wisconsinan glacier. They are based on the glacial deposits we find in New York State and the ages of wood and bone found in these deposits. The ages were found through radiometric dating using the radioactive isotope carbon-14. (A) shows the maximum reach of the glacier, about 21,750 years ago, when the entire State except the Salamanca Re-entrant was covered with ice. (B) shows the situation about 14,000 years ago, when the climate had begun to warm and the glacier had begun to retreat. (C) has been dated approximately 12,000 to 13,800 years ago. It was at this stage that the glacier built the Valley Heads Moraine in central New York (see also Figure 12.3).

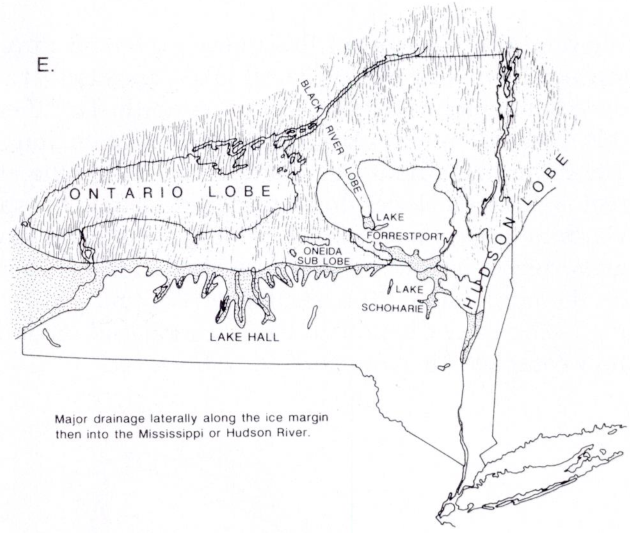


D.



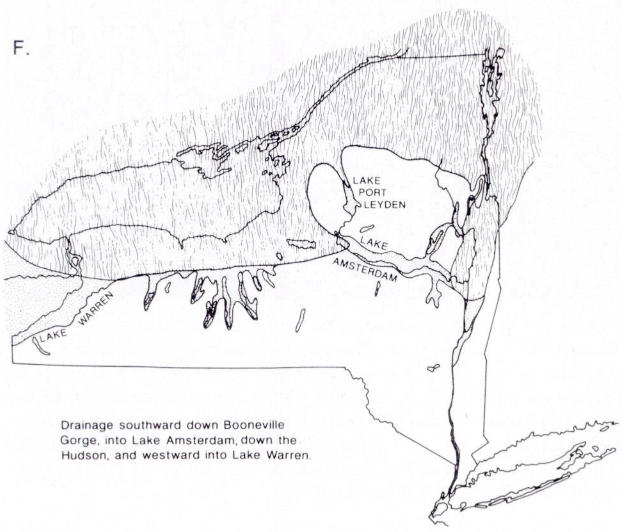
Major drainage southward through the Susquehanna River.

E.



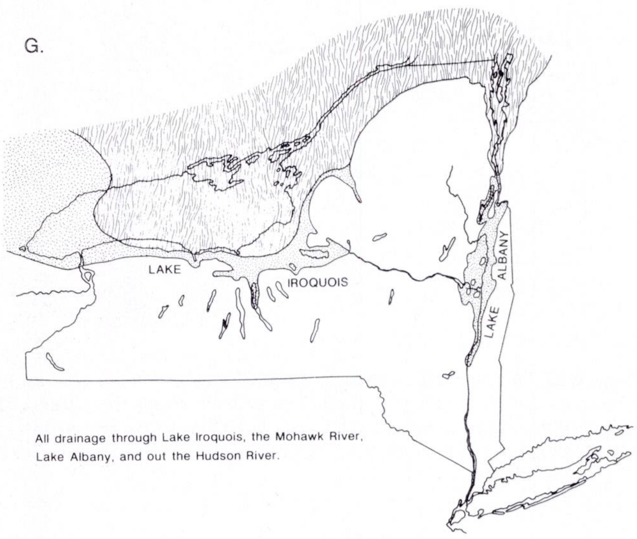
Major drainage laterally along the ice margin then into the Mississippi or Hudson River.

F.



Drainage southward down Booneville Gorge, into Lake Amsterdam, down the Hudson, and westward into Lake Warren.

G.



All drainage through Lake Iroquois, the Mohawk River, Lake Albany, and out the Hudson River.

The next three stages—(D), (E), and (F)—happened between 11,000 and 13,000 years ago. Unfortunately, few of the features that were built by these stages have been dated radiometrically, so we can't be more precise about the ages. However, we can see that the retreat continued. (G), the final stage in the figure, shows what New York State was like approximately 11,000 years ago. (Adapted from Allers, R.H., 1984. Pleistocene geology of central New York State. In B.J. Tewksbury and R.H. Allers, Hamilton College Field Trip Guidebook: Geology of the Black and Mohawk River Valleys, p. 43-61.)

We can see the results of this uneven rebound throughout northern New York. Glacial lake deposits that were once horizontal now slope up to the north. The effect of this rebound on the Lake Ontario basin is quite dramatic. The differing amounts of rebound have tilted the entire region so that it slopes down from the north to the south. Harbors along the south shore of Lake Ontario slowly grew deeper as the lake basin tilted southward. Harbors on the north shore grew shallower. We find similar tilting in the Lake Champlain basin. Postglacial rebound is now completed in New York State, however.

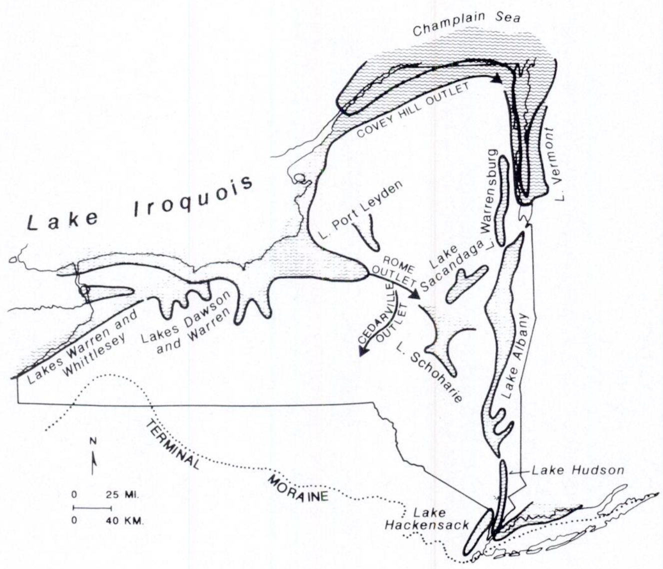


Figure 12.23. These glacial lakes of the Pleistocene formed from meltwater as the ice sheet retreated. The outlets show the directions in which these lakes eventually drained. The Champlain Sea in the north shows the area that was flooded by ocean water as the glaciers melted.

Figure 12.24. This giant pothole is found on Moss Island in the Mohawk Valley near Little Falls. It was scoured into the bedrock by the tremendous outflow from the ancestral Great Lakes rushing to the sea. (Photo by B.K. Goodwin.)

Pleistocene Life

During the Ice Age, colder climates crept down from the north and warmer climates shifted farther south. The climate was similar to modern subarctic regions, such as the barren reaches of the northern Canadian tundra. However, south of the ice front, life was plentiful. A huge variety of plants and animals lived there, including evergreen trees that could withstand the cold. Many of these species still exist today. However, many Pleistocene mammals are now extinct.

Figure 12.25. A close-up view of a groove carved by the glacier in limestone in the Plattsburgh area. The groove contains sand and gravel similar to that left by the glacier. Notice, however, the tiny white clam shells. (They are about 1.5 cm across.) These animals lived in brackish water, not fresh water. Their presence is one piece of evidence that a sea (the Champlain Sea) once covered this area, as shown in Figure 12.23. The sea flooded in as the glacial ice melted and was pushed back as the crust rebounded above sea level.

Figure 12.26. This picture shows a shingle beach. It is just like modern beach ridges found in various part of the world, but this one is high and dry. It marks a former shoreline of the Champlain Sea. After the glacier melted, the sea entered the Champlain Valley via the St. Lawrence River valley, where the crust had sagged under the weight of the ice. This sea lasted only until the unburdened crust slowly rebounded.

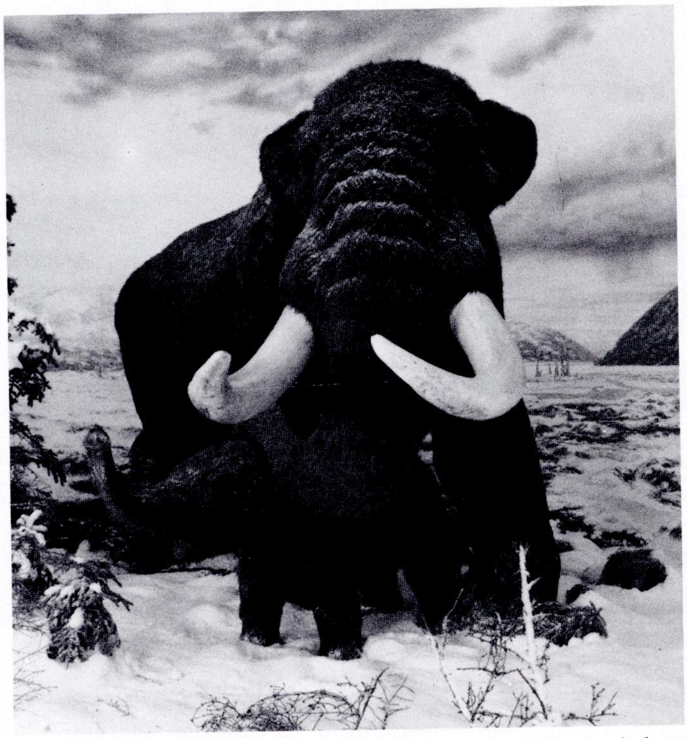


Figure 12.27. The mastodont *(Mastodon americanus)*, which stood about 3 m high, was one of the exotic-looking animals that roamed New York State during the Pleistocene. It is extinct today, but the remains of mastodonts have been found in several parts of the State. This reconstruction is on display in the New York State Museum, Albany.

The wooly mammoth and the mastodont (formerly spelled *mastodon*) are the two largest animals that became extinct. Both were huge, elephant-like beasts with long curved tusks (Figure 12.27). We have found their bones and teeth in peat bogs and at other sites throughout New York State. Mastodont teeth were found in New York as early as 1705.

Some smaller, less exotic animals also became extinct. We have found bones or other remains of ground sloth, bear, musk ox, caribou, moose, moose-elk, peccary (pig), seal, bison (buffalo), deer, elk, horse, giant beaver, and California condor in the Pleistocene deposits of New York (Figure 12.28). The giant beaver and moose-elk are now extinct. We deduce that panther, wolf, arctic fox, wolverine, badger, ptarmigan, and heath hen probably were also part of the State's Pleistocene wildlife. Why do we make this deduction? Because they normally live in the same environments as the animals whose remains we have found.

What caused the great extinctions of large mammals during the Pleistocene? Current evidence indicates that the arrival of human hunters hastened the extinction of late Pleistocene animals in Europe and Asia. Humans arrived in North America later, and North American Pleistocene animals became extinct at a slightly later time. This information indicates that humans probably caused the destruction of many Pleistocene animals.

Review Questions and Exercises

Define the following terms as they are used in this chapter:

mountain glacier	end moraine
continental glacier	Terminal Moraine
Laurentide Ice Sheet	kettle lake
Wisconsinan Stage	glacial lake
lobe	drainage divide

What are the two contrasting processes by which glaciers changed New York's landscape? Define the following terms, and match each with one of the two processes:

cirque	moraine
drumlin	outwash
erratic	rock basin
esker	roche moutonnée
hanging valley	striation
kame	till
kame delta	U-shaped valley
pothole	

Explain why you put each term in that category.

What were glacial lakes? Where were they located? Why were they temporary? What evidence remains of their existence?

What did glaciers have to do with the formation of the Finger Lakes? What was there before the Ice Age? Can you name other large valleys in the region that also run north-south but are *not* lake-filled? Suggest an explanation for their formation. See the Physiographic Map on Plate 4 and a road map.

If a car advances and then retreats, it uses the same process to move in both directions—rolling along on its tires. When the glacier advanced and retreated, though, the processes were different. Explain how a glacier advances and retreats.

Why was sea level lower during the Pleistocene than today? How do we know that it was lower?

What is meant by post-glacial rebound? What evidence do we have that it has occurred?

Name 5 or 10 cities of the world that would be submerged beneath the sea if all of the ice in the world's glaciers suddenly melted. (Hint: Look at a globe or a world map to help you answer.)

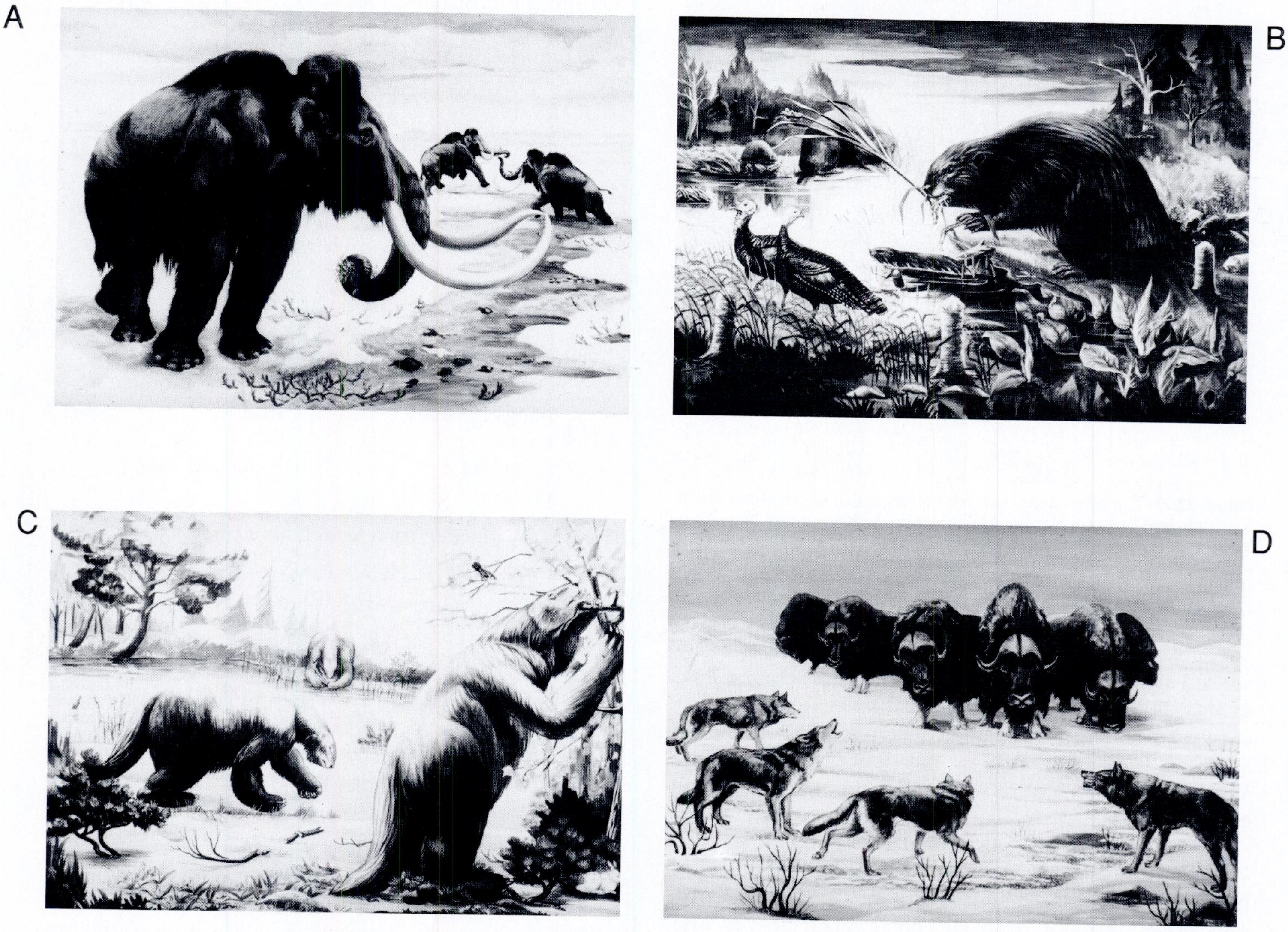


Figure 12.28. Some of the animals that lived in New York State during the Pleistocene Epoch. (A): wooly mammoth. (B): giant beaver with the much smaller modern beaver and wild turkeys. (C): ground sloth. (D): musk oxen and dire wolves.

Figure 12.28 *continued* (E): peccaries, (F): barren ground caribou. (G): woodland bison, which are different from the later plains bison. (Buffalo, NY, was named for a fossil bison, perhaps the only city in the world to be named after a fossil mammal.) (H): woodland caribou.

CHAPTER 13
ICE SCULPTING
Glacial Features of New York State[1]

SUMMARY

Almost all of the glacial deposits in New York State were made during the last advance of the Wisconsinan ice sheet, which occurred during the Woodfordian Substage. The glacier created different kinds of features in regions with different bedrock and physiography. This chapter lists some important glacial features found in each of nine regions across New York State. The regions discussed are the Adirondack Mountains, the Hudson-Mohawk Lowlands, the St. Lawrence-Champlain Lowlands, the Erie and Ontario Lowlands, the Tug Hill Plateau, the Appalachian Plateaus (which include the Allegheny Plateau and the Catskill Mountains in New York), the New England Province (which includes the Hudson Highlands, the Manhattan Prong, and the Taconic Mountains), the Newark Lowlands, and the Atlantic Coastal Plain (including Long Island).

INTRODUCTION

The Pleistocene Epoch was marked by four major intervals of glaciation; some of these intervals had multiple advances of ice. The glacial features we see today in New York State were made by the advances and retreats of the last ice sheet, the Laurentide, during the Wisconsinan Stage. Its last advance occurred during the last part of the Wisconsinan Stage, called the *Woodfordian Substage*. It destroyed nearly all of the signs left by earlier glaciers in our State.

In a few sheltered places in New York we still find evidence of earlier Pleistocene deposits that underlie the deposits of the Woodfordian Substage. Two examples are soils preserved in a ravine near Cayuga Lake and soils near Otto in western New York. These soils are 35,000-60,000 years old and probably formed during a warm interglacial episode. (The last glacier retreated between 8,000 and 15,000 years ago.) We do radiocarbon dating of the plant and animal remains in the soils to find these ages.

As it retreated, the ice sheet of the Woodfordian Substage did not melt uniformly. Sometimes the melting was balanced by the forward flow of the ice; at those times, deposits piled up alongside the stationary front of the ice sheet. Other times the ice readvanced and disrupted earlier deposits and mixed them into new ones. Thus, we have to study each glacial deposit carefully. We need to figure out whether a deposit was formed when the glacier was retreating, when it was standing still, or when it was advancing.

A great variety of glacial deposits are found in New York State. The ice sheets advanced and retreated in different ways and times in different areas. The kind of bedrock and the shape of the landscape in a region strongly influenced the formation of glacial features. For example, the Adirondack Mountains, made up of contorted, hard, metamorphic rocks, have different glacial features than the Allegheny Plateau, with its softer, flat-lying, sedimentary rocks. Because of such differences, we have divided the State into regions (see Figure 1.1) and will look at each region separately.

A list of all the glacial features in each region would be very long. We will discuss only the most important. For an explanation of unfamiliar terms for glacial features, see Chapter 12 or the Glossary.

ADIRONDACK MOUNTAINS

The last glacier moved southwest across the Adirondack Mountains. How do we know the direction? The

[1]Adapted from a manuscript by D.H. Cadwell.

glacier made striations and grooves in the bedrock. It also carved roches moutonnées in the bedrock or left behind rock drumlins. The scratches, grooves, and streamlined landforms point in the direction of the ice movement (compare Figures 12.3 and 12.4).

Till is widespread here, as it is elsewhere in the State, However, in the Adirondacks the till is much more sandy. Why is that the case? The reason is the kind of bedrock nearby. The moving glacier picked up rocks and soil, ground them, and later deposited them. But it didn't carry most of the debris very far—usually less than 15 km. Thus, the till we find in a region is made up of nearby rock. The hard metamorphic rock of the Adirondacks is made of sand-sized or larger mineral grains. Glacial grinding produced sand-sized fragments from this rock. Therefore, the till in the Adirondacks is sandy. In other areas, like the St. Lawrence-Champlain Lowlands, the bedrock is dominantly softer, finer-grained shale and limestone. The glacier ground these rocks into silt- and clay-sized particles. The till in the lowlands is therefore composed of silt and clay, which stick together much better than sand.

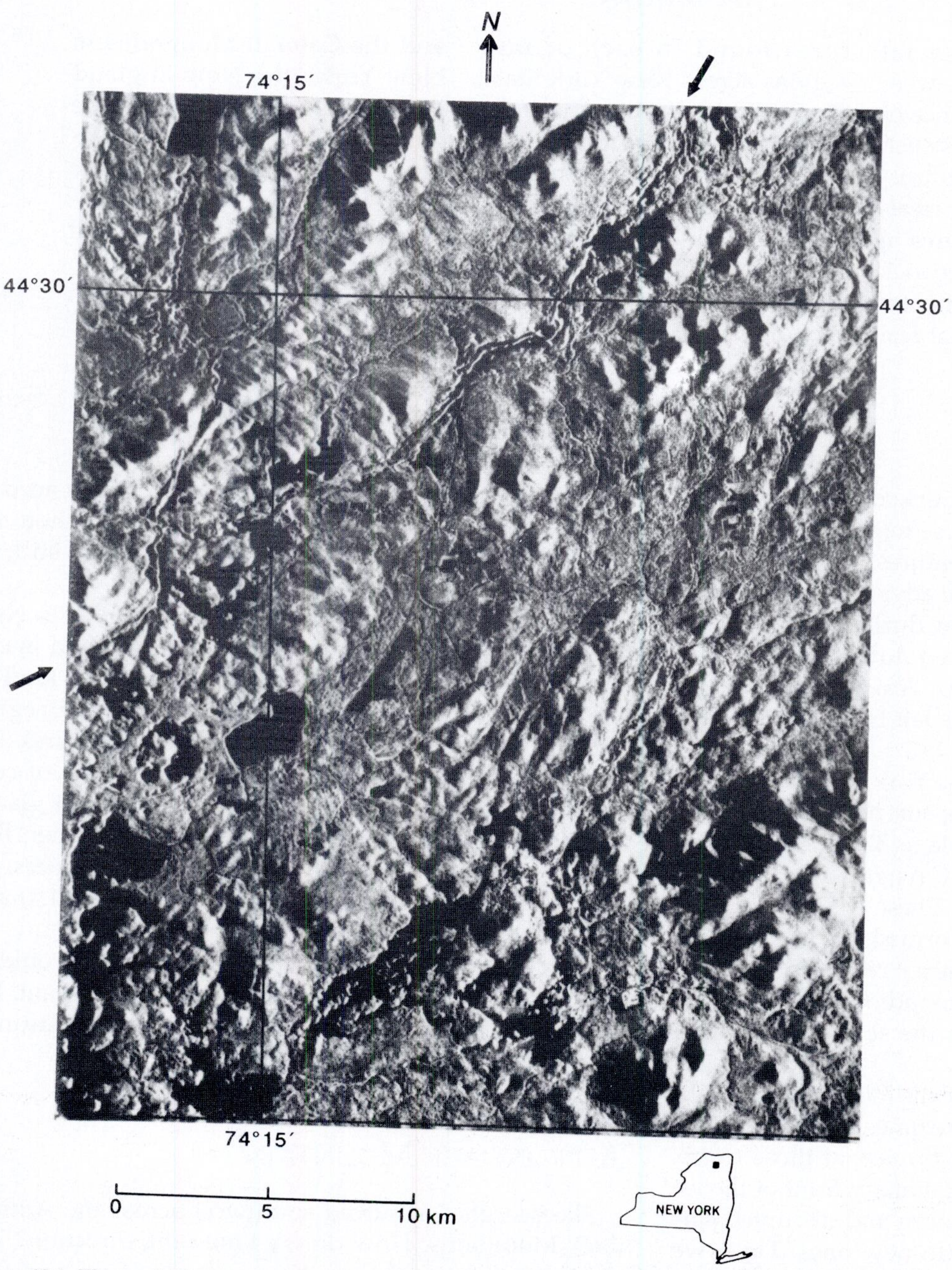


Figure 13.1. This aerial image of a portion of the Adirondacks shows two eskers (indicated by arrows). These long, curving ridges are deposits formed by rivers that flowed in tunnels beneath the ice. Upper Saranac Lake is in the lower left corner of the picture.

Many of the deposits in the Adirondacks were made by water from the melting ice sheet. Long, winding, narrow ridges called eskers are common. Many eskers lie along the shores of Adirondack lakes or project into the lake from the shore. Eskers can be several kilometers long. There are some good examples at Saranac, Tupper, Rainbow, and Cranberry Lakes (Figure 13.1). Eskers are frequently associated with large deltas and kame terraces.

Deltas and sandy beach deposits are clues to vanished glacial lakes. The lakes commonly formed in valleys that sloped downward toward the glacier. They lasted until the glacier retreated far enough to unplug the low places and permit the water to flow out. The lakes then drained.

The Saranac, Placid, Elizabethtown, and Wilmington basins once contained glacial lakes. Before they drained, these lakes overflowed through notches in the southwest rim of their valleys. How do we know that? The overflow formed rivers that left long narrow deposits of sand and gravel in their beds. These deposits end in large deltas, which tell us of another lake downstream.

A very large delta at Forest-port was deposited by water flowing down the Fulton-Chain-of-Lakes and through the Plains area of the Moose River. Glacial Lake Elizabethtown spilled through Underwood Gap into Glacial Lake Warrensburg.

Glacial Lake Warrensburg filled what is now the Schroon River valley. It also stretched from Deadwater Pond to Corinth in the Hudson River valley. The water in this lake was held in by a wall of ice that extended from Glens Falls to Saratoga Springs.

Glacial Lake Warrensburg may have been fed by melt-water from small glaciers that remained behind in the mountains. Why do we infer that? We can still see the cirques formed by these glaciers west of Piseco Lake and on Giant and Whiteface Mountains (see Figure 12.12).

Some ranges in the Adirondack Mountains were at an angle to the direction of ice flow and formed an obstruction to the ice sheet's flow. Such obstructions locally shielded some fragile preglacial soils from glacial erosion. We have found Tertiary soils and deeply weathered bedrock dating from before the Wisconsinan Stage in a number of places where road cuts have been blasted. These Tertiary soils are soft, commonly rust-colored, completely decomposed rock. These exposures therefore quickly deteriorate, but some can be see along Route 9 and the Northway north of Lake George. Others occur near Honnedaga Lake and near Lake Pleasant.

At Tahawus in the Adirondacks also, there are Pleistocene deposits older than the Woodfordian Substage. Here, we have found wood fragments and plant debris more than 40,000 years old in nonglacial lake sediments preserved between two layers of till. This site therefore provides evidence for two episodes of glaciation in the central Adirondack Mountains.

Review Questions and Exercises

How can we tell what direction the glacier moved in this region?

What sort of clues tell us about the locations of glacial lakes?

What is the till like in this region? Why is it different from other regions in the State?

Hudson-Mohawk Lowlands

Between 20,000 and 13,000 years ago, a large lake, Glacial Lake Albany, filled the Hudson Valley (see Figure 12.23). Glacial Lake Albany was 50 km wide at Schenectady, its widest point. It was 320 km long, extending from Glens Falls to New York City. At Albany, it was 120 m deep. Its southern end was dammed by the Terminal Moraine of the Wisconsinan ice sheet, in the New York City area (see Figure 12.3). Its northern end was blocked by the front of the retreating glacier.

At first, the Terminal Moraine extended as a ridge across New York Bay from Long Island to Staten Island (see Figure 12.3). Exactly how Lake Albany drained is still an unanswered question. It may have drained through gaps that developed in the Terminal Moraine. Alternatively, it may have drained farther north, at Sparkill Gap near Nyack: the water could have passed through this narrow gap into the headwaters of the Hackensack River.

Many of the cities and towns of the Hudson Valley are located on deltas built by streams and rivers that drained into Glacial Lake Albany. Examples of such deltas can be found at Croton Point, Newburgh, Kingston, Red Hook, Hudson, Kinderhook, Albany, Schenectady, Schaghticoke, Saratoga Springs, and Glens Falls. On the east side of the Hudson River valley, between Poughkeepsie and Troy, we find old beaches formed on Glacial Lake Albany's shores.

The broad sand plains of today are the ancient lake floors of glacial time. The sand was deposited in shallow water near the shores of the lake. After the lake drained, the wind piled up the sands of the lake floor and beaches into dunes. The Pine Bush between Albany and Schenectady is one such dune field. There are others in Saratoga and Warren Counties. The Northway between Albany and Glens Falls alternately cuts through sand dunes and rides along glacial lake plains.

By looking carefully at the sand in the dunes, we can tell in what direction the winds were blowing. The sloping layers in the dunes tell us that winds generally blew from the northwest.

Moraines are rare in the Hudson Valley, although a large moraine is found northwest of Glens Falls. It was formed between two lobes of the glacier. There is a large channel in it between Fort Ann and Hudson Falls, cut by the water draining from Glacial Lake Vermont.

In the Mohawk Valley, we find clues to the origin of Glacial Lake Schoharie and Glacial Lake Amsterdam. These lakes were created when a tongue of ice called the Mohawk Sublobe occupied the valley near Schenectady. They drained through channels at Duanesburg and West Hill. The channels still exist, but they no longer carry water. The city of Amsterdam is located on a delta built by water flowing into Glacial Lake Amsterdam.

Water draining from Glacial Lake Iroquois in the Ontario Basin flowed over the Glacial Lake Amsterdam and Glacial Lake Schoharie deposits, cutting deep channels. The large size of these channels suggests that they were cut by heavy flows. It may be that water was released suddenly when an ice dam broke.

Whatever the cause, the floods also made the magnificent potholes on Moss Island at Little Falls (see Figure 12.24). They deposited the sand of the Fonda Sand Plain between the Noses and Tribes Hill. When they reached the Hudson Valley, they cut the Ballston Lake, Saratoga Lake, and Round Lake Channels.

Northville, Edinburg, Gloversville, and Johnstown are built on deltas formed by streams that flowed into Glacial Lake Sacandaga. There is also a delta at Saratoga Springs that was built by a large flood of meltwater spilling from Glacial Lake Warrensburg into Glacial Lake Albany through the Kayderosseras Valley.

A number of temporary glacial lakes were formed in the Hudson Lowlands, as the Hudson Lobe readvanced several times. At times it blocked the low points in the northern or eastern parts of valleys and allowed temporary lakes to form in those valleys. Some examples are Lake Tillson in the Wallkill Valley, Lake Elizaville in the Roecliff Jansen Kill Valley, and Lake Durham in the Catskill Valley.

During one brief period of stationary ice, the Hudson Lobe formed the Meadowdale moraine. This moraine was built during a pause in the retreat of the ice front. At the same time, the Hudson Lobe built a kame terrace at Schodack and esker and kame deposits at West Sand Lake.

Review Questions and Exercises

Where was Glacial Lake Albany? What are some of the clues to its existence we see today? What clues tell us about other glacial lakes in this region?

St. Lawrence-Champlain Lowlands

The St. Lawrence Valley is made up of gently rolling farmland. Underneath the soil are glacial sediments deposited during the last part of the Wisconsinan Stage. In places, the glacier molded till into drumlins.

In this region, the ice sheet flowed through the St. Lawrence Valley and into the Adirondacks. When the glacier began to retreat from the lowlands, the meltwater was held in some valleys by the retreating wall of ice to the north. This process created temporary lakes. Today, we find deposits associated with these lakes—kame deltas at Parishville and Stalbird and eskers, including one at St. Regis Falls.

At Chateaugay, there are long, deep channels that no longer carry water. They were created by glacial meltwater as it flowed westward along the edge of the ice into Glacial Lake Iroquois in the Ontario Basin.

As the ice retreated, the long northeast arm of Glacial Lake Iroquois expanded. Beaches and deltas formed along its southern shore. Layers of clay were deposited in deeper, quieter water farther from shore. Potsdam and Malone are built on large Lake Iroquois deltas.

Eventually, the glacier retreated past the northeastern tip of the Adirondacks at Covey Hill near the Canadian border. This retreat provided an outlet that drained Glacial Lake Iroquois abruptly. The roaring torrent carved deep channels. It created waterfalls and plunge pools[2] at Covey Hill. It also eroded the Potsdam Sandstone ledges at Flat Rocks near Altona. Where the flow entered Glacial Lake Vermont, it deposited a large delta near Chazy.

During the Pleistocene, the great weight of the 2 km-thick ice sheet caused the crust and underlying mantle to sag. As the ice melted, the crust slowly rebounded. However, there was a period in between melting and rebound of the crust, during which sea water from the Atlantic flooded the St. Lawrence and Champlain Lowlands.

How do we know that this region was covered by sea water? The retreating glacier had left behind moraines and glacial lake deposits, but on top of these deposits are sands, silts, and clays with abundant marine clams and occasional whale and seal bones as far south as Whitehall. In addition, many of the drumlins in the St. Lawrence Lowlands have boulders on the top. These large stones were left behind when the sea waves swept away the finer sediments.

We have found deltas built by streams that drained north into this Champlain Sea at Malone and Hannawa Falls. Later, northwest winds picked up sand from the delta tops and built dunes. Deltas and sand ridges that formed at the shore of the Champlain Sea can be found from Port Kent to the Canadian border. Such deltas are found at Port Kent and Altona. Well-preserved beach ridges can be seen at Plattsburgh.

In the Champlain Valley, we have found clay and silt without fossils that were deposited in a glacial lake. At higher elevations, we find deltas and beaches from the same lake. This lake, called Glacial Lake Vermont, drained south through a notch called the Wood Creek-Fort Ann Gap. The water poured into the Hudson Valley and carved a channel from Battle Hill to Fort Edward. We can find Lake Vermont deltas at the villages of Morrisonville, Clintonville, Keeseville, Crown Point, and Street Road. There are also beach ridges built by storm waves at Beekmantown. Near Plattsburgh is the Ingraham Esker, a long, snake-like ridge that formed in a meltwater stream beneath the retreating glacier.

The sand deposited in glacial lakes and shallow seas makes rich farmland in the Lowlands. The beaches and

[2]A *plunge pool* is a basin in the bedrock formed at the base of a waterfall by the force of the falling water.

deltas are sources of sand and gravel. They also make good aquifers.[3]

Sand and gravel deposits provide well-drained sites for cities and towns. However, the marine clay is a poor foundation. It has little strength and tends to flow downhill. This property has caused slumps on many hillsides and the collapse of many buildings.

Review Questions and Exercises

What clues tell us what direction the glacier moved in this region?

Where was Glacial Lake Iroquois? Why did it drain? How do we know that?

How do we know the St. Lawrence and Champlain valleys were once extensions of the Atlantic Ocean? Why did that happen? Why are these valleys now above sea level?

Erie and Ontario Lowlands

The Erie and Ontario Lowlands are renowned for their splendid display of drumlins. This drumlin field is one of the largest on earth, extending from Oswego to Batavia (see Figure 12.16). More than 10,000 drumlins rise above the nearly flat plains of the Lowlands. Many of them have been named, for example Chimney Bluffs and LeRoy Island in Sodus Bay, Hill Cumorah near Palmyra, and Mount Olympus at Syracuse. The Ontario Lobe passed across the Lowlands and molded these drumlins from glacial till.

Some drumlins have channels cut in them by meltwater from the retreating glacier. The most spectacular channels are near Syracuse and Newark. The channels were carved as water flowed eastward along the edge of the glacier into the Mohawk Valley. We have frequently found wooly mammoth and mastodont skeletons in peat bogs at the bottom of these old meltwater channels.

Plunge pools are common in the floor of the Syracuse channels. A plunge pool is a basin formed in bedrock at the base of a waterfall, created by the force of falling water. The waterfalls are dry today, but the pools remain. Green Lake, east of Syracuse, is a very fine example.

Many moraines and eskers were formed along the receding ice front. The Pinnacle Hills and Mendon Ponds Kame Moraines near Rochester are among the best known. Other moraines are found near Buffalo, including the Hamburg, Niagara Falls, and Albion Moraines. The Stanwix Moraine lies east of Lake Oneida.

The Erie and Ontario Lowlands also contain one of the finest records of glacial lakes in North America. There are layers of lake sand and silt around many of the drumlins. Old lake beaches lie at the base of the hillsides. Ridge Road runs east-west across the Lowlands along level surfaces and ridges that were built by waves on glacial lake beaches.

These beaches formed the old shoreline along Glacial Lake Iroquois, which once occupied the Ontario Lake Basin. The lake drained eastward into the Mohawk Valley through a wide gap at Rome. There, we find piles of sediments—spits, terraces, and bars[4]—left by the outflow. The city of Rochester is built on a thin layer of lake sediments that cover bedrock. Montezuma Swamp, west of Syracuse, is an unfilled remnant of Glacial Lake Iroquois. Using radiocarbon dating, we conclude that Glacial Lake Iroquois was in existence 12,400 years ago.

Several older lakes, Glacial Lake Warren and Glacial Lake Whittlesey, drained west into the Mississippi River system. We find beaches and deltas at higher elevations along the western edge of the Appalachian Upland. They extend from Pebroke to the Pennsylvania state line. The vineyards of Fredonia grow on these beaches. Tonawanda Creek flows through a clay-filled basin that until 10,000 years ago held a remnant of Glacial Lake Warren. Oak Orchard Swamp is a remnant of Glacial Lake Tonawanda.

Niagara Gorge and Falls are among the best known scenic features in the State (Figure 13.2). About 12,000 years ago, as the glacier retreated, the Niagara River began to flow over the cliff called the Niagara Escarpment. The ancient plunge pool carved by the falling water can still be seen at Lewiston and Queenston. The top layer of the Niagara Escarpment—called the *caprock*—is made of a massive dolostone formation that resists erosion. The dolostone lies on top of the Rochester Shale, a much more erodible rock. The falling water continues to dig a huge plunge pool in the shale and undercut the dolostone caprock. The caprock breaks along *joints* (natural cracks in the rock) and falls down the escarpment in great blocks. Over the past 12,000 years, the falls have crept 11 km upstream because of this erosion. The upper two thirds of the Niagara Gorge, leading to the present falls, was cut after the end of the Pleistocene.

But the present falls are only the latest version of a recurring theme. Before the Woodfordian Substage, an earlier Niagara River cut the St. Davids Gorge, which flows 8 km between the Whirlpool and St. Davids. Today, the gorge is filled with glacial deposits.

[3] An *aquifer* is an underground layer that is porous and permeable enough to let groundwater flow through it.

[4] A *spit* is a small point of land projecting into a body of water from the shore. Spits are commonly composed of sand and gravel that was accumulated by the action of waves and currents. A *terrace* is a relatively flat surface, something like a very broad step. The *bars* we mention here are long, narrow ridges of sand and gravel that accumulated in the floor of a stream.

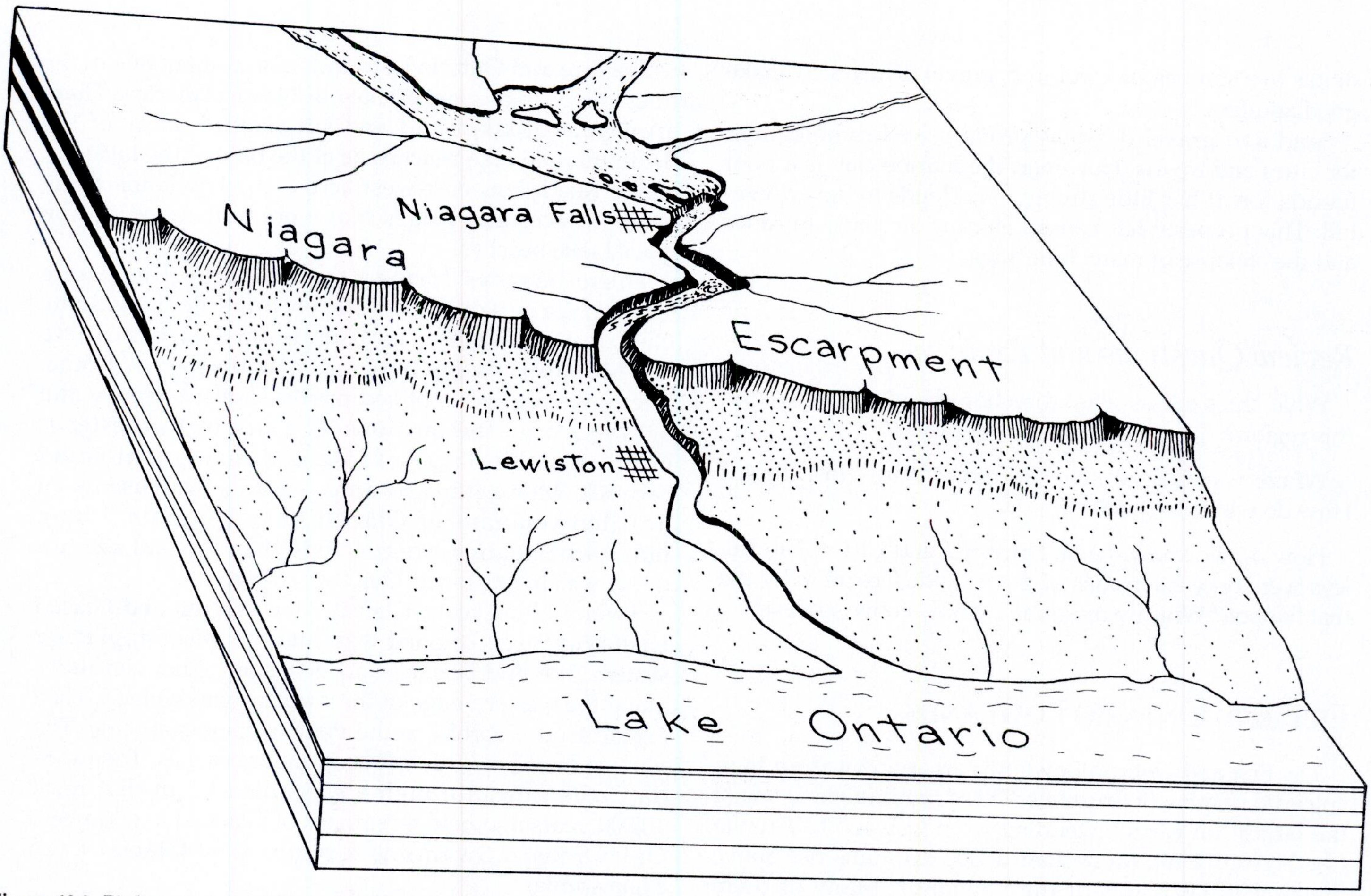


Figure 13.2. Bird's-eye view of Niagara Falls, looking south from the northern shore of Lake Ontario. Notice that the layers of the bedrock, which are of Ordovician and Silurian age, dip south. Notice particularly the Lockport Dolostone (upper dark-colored layer), which forms the Niagara Escarpment and the caprock of Niagara Falls. The Lockport Dolostone resists erosion and lies on top of easily eroded shales. The Niagara River began to flow along its present course about 12,000 years ago, when the Pleistocene ice sheet melted north from the Niagara Escarpment. Since that time, the Niagara River has cut a gorge 11 km long, and erosion of the caprock continues daily. From the lip of the falls, the Niagara River plunges vertically 53 m. It descends another 22 m in the gorge before reaching the Niagara Escarpment. From there to Lake Ontario, a distance of 9 km, the river falls less than 1 m. The lower third of the Niagara Gorge was cut during the end of the Pleistocene Epoch, the remaining two-thirds, leading upstream to the present falls, was eroded during the Holocene Epoch. (In this drawing, vertical distances are exaggerated two times so that you can see the tilt of the rock layers; they actually dip only 1/4°-1/2°.)

Review Questions and Exercises

What feature formed by the glacier in this region is known worldwide?

How can we tell where glacial meltwater flowed in this region?

What are *plunge pools*?

How did the retreat of the glacier relate to the formation of Niagara Falls?

TUG HILL PLATEAU

The few people who live on the Tug Hill Plateau may sense that it is barely free of the Ice Age because it receives such tremendous snowfalls. The winter storms at Booneville frequently produce the lowest temperatures and deepest snows in the State.[5] The stony soils and short growing season discourage farming. Thus, most of the Tug Hill is covered with forest that has reclaimed abandoned 19th-century farms.

The ice that covered the Plateau during the Wisconsinan Stage formed rock drumlins and scratched the exposed rock surfaces. These traces tell us that the ice flowed southeast.

As the flowing ice thinned, the Tug Hill Plateau divided the glacier into several tongues (see Figure 12.3). It

[5]Such storms happen because the Tug Hill Plateau is an upland that is located downwind from Lake Ontario. This lake has little ice cover during the winter. Water evaporated from its surface falls as snow when the moist air masses rise over the Plateau and cool below the dew point.

caused the Ontario Lobe to split into the Oneida and Black River Sublobes. Similarly, the Hudson Lobe was split into the Adirondack and Mohawk Sublobes.

The lobes dammed the Black River and West Canada Creek and thus created glacial lakes. The largest was Glacial Lake Port Leyden. Water draining from Lake Port Leyden carved the Booneville Gorge.

Review Questions and Exercises

What clues tell us about how the glaciers moved in this region?

APPALACHIAN PLATEAUS

In New York State, the Appalachian Plateaus are subdivided into the Allegheny Plateau and the Catskill Mountains (Figure 1.1). The types of glacial activity in these two areas differed. These differences are related to *relief*—the local difference in elevation between valley floors and mountain tops. The Allegheny Plateau has a relief of 245 to 425 m. The relief is much greater in the Catskill Mountains—600 to 900 m. We'll deal with the Allegheny Plateau first.

Allegheny Plateau

Most of the glacial features in the Allegheny Plateau were formed by the continental ice sheet. Except on steep slopes, the bedrock of the hills is generally covered by one to three meters of unsorted till. In many valleys, on the other hand, layered debris may be up to a hundred meters thick. Such layered debris is deposited by the action of water—either streams or lakes or in conical hills called *kames* that formed when sediment-laden streams flowed off the ice front. The action of the water sorts the sediments into different layers by particle size.

When the edge of the glacier was near the head of the Susquehanna River, meltwater flowed freely to the south. It left outwash deposits of sand and gravel in the valleys. When the glacier had retreated a little farther, it sometimes reached an area where water would normally drain to the north. With that direction blocked by the glacier, however, meltwater would collect in the valley. For a time, the forward flow of the ice balanced the melting, and the glacier continued to deposit sediments along its edge. The result was a massive pile of deposits that blocked the valley. This complex, called the Valley Heads Moraine (see Figure 12.3), today divides the Susquehanna and St. Lawrence drainage basins (see Figure 16.1). Streams north of the moraine flow into the St. Lawrence River system, and those south of the moraine flow into the Susquehanna River system.

We find many magnificent examples of glacial erosion in the Plateau. An outstanding one is a series of U-shaped valleys carved out by the glacier. Today, these valleys are filled by the Finger Lakes[6] and other, smaller lakes to the west (Conesus, Hemlock, Canadice, and Honeoye). The Finger Lakes are the remnants of larger glacial lakes that filled the valleys. These extinct meltwater lakes lay between the retreating ice in the north and the Valley Heads Moraine in the south.

The Finger Lake valleys were widened and deepened by the glacier because they ran in the same direction as the ice flow. Stream valleys that were perpendicular to the main ice flow direction were not deeply carved. In such protected ravines, we may still find debris from earlier glaciers. The valleys of Six Mile Creek and Great Gully, which flow from the east into the Cayuga Lake valley, contain this older drift. Layers of stratified drift occur between the sheets of glacial till exposed in these ravines. Radiocarbon dating of plant and animal remains tells us that this water-deposited material has been there more than 30,000 years. At Fernbank on the west shore of Cayuga Lake a few kilometers north of Ithaca, there are sediments that contain plant remains and shells of freshwater organisms. Radiocarbon dating of the plants and shells tells us that the Cayuga Trough held a glacial lake more than 50,000 years ago.

As the glacier advanced, it carved striations, grooves, and roches moutonnées in the bedrock. Such features are usually found along valley walls and in upland areas.

The glacier also deposited a variety of sediments on the valley floors. Most were left by meltwater flowing from the glacier. Moraines and other deposits formed at the edge of the ice are commonly intermixed till and layered deposits made by meltwater. Many examples of such deposits exist in the Susquehanna River basin. A particularly good place to find them is along the Chenango River at the Chenango Valley State Park. Here, we find till, outwash, kames, eskers, kame terraces, and kettles.

Catskill Mountains

In the Catskill Mountains, many of the glacial features may have been formed by mountain glaciers instead of the continental ice sheet. The glacial history of the Catskills is very complicated, especially where local mountain glaciers merged with the main ice sheet.

In much of the Catskills, we find striations, roches moutonnées, cirques, and U-shaped valleys, all features

[6]The seven Finger Lakes are Canandaigua, Keuka, Seneca, Cayuga, Owasco, Skaneateles, and Otisco.

made by glacial erosion. The glaciers also left deposits behind in the Catskills—moraines, kames, outwash, and kame deltas. In addition, there are many kames, kame terraces, and kame deltas left by the continental ice sheet in the valleys of Schoharie Creek and the Batavia Kill.

A large lake formed in front of the ice in the Schoharie Valley. Between North Blenheim and Prattsville, we can find sand and clay from the lake bottom. We can also find sand and gravel deposited in deltas by streams flowing into the lake.

Review Questions and Exercises

What is *relief*?

What are the two subregions of the Appalachian Plateaus in New York State? How are they different? How were the glaciers that affected the two subregions different?

How did the glacier affect drainage in the Allegheny Plateau? How were the Finger Lakes formed? What was there before the Pleistocene?

What kind of evidence did the glacier leave on the walls of valleys in the Allegheny Plateau? On the valley floors?

What kind of glacial evidence do we find in the Catskill Mountains?

New England Province

The landform types of the New England Province are quite varied. The mountainous areas are rather extensive, as you can see on the Physiographic Diagram on Plate 4 of the *Geological Highway Map*. The entire New England region was covered by ice during the Pleistocene. As the ice retreated, it thinned first over the hilly regions. The higher peaks gradually protruded through the ice. The sun warmed the exposed rock, which was darker than the ice around it. The warm rock in turn caused the ice closest to the mountain to melt fastest.

As the ice melted, it left deposits of sediment on the land. These deposits show us where the edge of the ice was. A number of kinds of glacial deposits are found in the mountainous areas: outwash, kames, kame terraces, kame deltas, and eskers. We also find sediments deposited in meltwater lakes near the edge of the ice, channels eroded in outwash by water flowing over it, and moraines with many kames in them.

Near the Rensselaer Plateau, we can find an excellent example of this ice-melting process. First, the mountains in this upland began to peek through the glacial ice. Then, a large kame moraine was built near Grafton Lakes State Park east of Troy. This kame moraine was formed when meltwater streams deposited sand and gravel between the glacier and the mountain. Large kame deltas are also found at Lebanon Springs and Garfield, eskers and kame terraces at Lebanon Springs and Cherry Plain, and marginal lake deposits in the Hoosic Valley.

Farther south, at the northern edge of the Hudson Highlands, the Shenandoah Moraine formed during the retreat of the Wisconsinan glacier. This moraine is made of layers of glacial drift that was deposited next to the melting glacier. While the ice was at this location, meltwater flowed south along Clove Creek and Foundry Brook toward Cold Spring. The meltwater left numerous deposits. We can see kame deltas and outwash from it along Route 9 near the Dutchess-Putnam County border.

Near Pine Plains, we can find more evidence of a melting glacier. The Pine Plains Moraine can be traced around Stissing Mountain. We can also find an outwash plain left by meltwater flowing south from the Pine Plains Moraine into Wappingers Creek.

Commonly, outwash was deposited by meltwater downstream of the moraine at the ice margin. However, not all outwash plains are connected with such moraines. We find major outwash plains without moraines along Fishkill Creek at Hopewell Junction, in the Harlem Valley at Dover Plains, in the headwaters of the Roeliff Jansen Kill between Hillsdale and Ancram, along the Claverack Creek between Chatham and Mellenville, and in the Batten Kill Valley near Cambridge.

Farther south, in Westchester County, we find numerous signs of the ice sheet's passage. Examples of glacial streamlining, polishing, and striations of bedrock can be seen near Pocantico Hills and Peekskill. Near Shrub Oak is an esker and an erratic that was transported some tens of kilometers by the ice. Another erratic, left perched atop three smaller boulders, is found in North Salem. There are a number of drumlins near Granite Springs and an exposure of outwash in a gravel pit near the New Croton Reservoir.

Review Questions and Exercises

How did the ice sheet begin to melt in this region? What sort of evidence did the ice sheet leave behind as it was melting?

Newark Lowlands

A small part of the Newark Lowlands is in Rockland County, New York. Sand, gravel, and clay deposited in Glacial Lake Albany cover the Triassic rocks at Haverstraw. A thick wedge of Lake Albany clay lies under the river-bottom sediments of the Hudson River. Drumlins on the Palisades between DeForest Lake and the state line are made of red till. The glacier made this till by grinding up the red Triassic rocks as it moved south-southwest across the region.

Two moraines are found at Tappen. These moraines were built at the edge of the ice in the Nyack-Croton area.

A gap in the Palisades Ridge is found at Sparkill, near Tallman Mountain State Park. This gap may have been an outlet for water from the Hudson Valley and Glacial Lake Albany. From there, the water would have flowed across the sand plains at Northvale, New Jersey, into the Hackensack Valley.

Review Questions and Exercises

Where did the till in this region come from? Why is it different from till in other regions of the State?

What other kind of evidence was left by the glaciers in this region?

Atlantic Coastal Plain (Long Island)

The highest hills of the islands off the southern coast of New England, including Long Island, Block Island, Fishers Island, and Staten Island, are parts of the Terminal Moraine of the Wisconsinan ice sheet (see Figures 12.3 and 12.21). These moraines are made of debris from the bedrock of New England and New York and from the Cretaceous strata underlying Long Island. As the glacier passed over the region, it picked up pieces of rock, ground them up, and then deposited them. Some of these deposits are completely unsorted tills. Others are outwash, deposited as layers of sand and gravel.

Beneath the glacial deposits of Long Island are relatively soft, crumbly Cretaceous rocks. These weak rocks were easily torn apart by the glacier, then redeposited on Long Island as till and outwash. We have evidence on Long Island for two advances of the ice sheet during the Wisconsinan Stage (see Figure 12.4). The end moraine of the first advance is partly buried by the moraine of the second advance. In places, the younger moraine is separated from the older by marine mud. This fact suggests that the two advances were separated by an interglacial period.

Figures 12.4 and 12.21B show the location of the end moraines on Long Island. Lake Ronkonkoma is an excellent example of a kettle lake that formed in the moraine.

We can see some of the glacial deposits of Long Island in the State and county parks in Nassau and Suffolk Counties. An exposure of glacial outwash and underlying Cretaceous rocks can be seen on the north shore of Long Island in Caumsett Park, north of Lloyd Harbor. The bluff along the beach contains layers of sand and gravel, carried from the glacier by a meltwater stream.

The Stony Brook Moraine extends through Sunken Meadow Park along the north shore near Smithtown. This moraine is made of variable amounts of sand, gravel, and till jumbled together. This varied composition suggests that the deposition of this moraine was complicated. However, its glacial outwash streams deposited sand and gravel in well organized layers. In bluffs along the coastline in Montauk State Park, we can see exposures of glacial till.

An end moraine commonly makes rolling hills. The Manetto Hills Moraine in Bethpage State Park, eastern Nassau County, is a good example.

Review Questions and Exercises

How were the highest hills on the islands in this region built? What does that tell us about the advance of the glacier?

What other kinds of glacial evidence do we find here?

CHAPTER 14
YESTERDAY, TODAY, AND TOMORROW
Holocene Epoch[1]

SUMMARY

We are living in the Holocene Epoch. This epoch follows the Pleistocene Epoch. By studying the pollen in Holocene sediments, we have traced a progression of climate from the earlier cold, dry glacial climate to the warm, moist climate of today. River erosion in the Holocene has carved many spectacular features in our State. Although the material eroded in the State eventually ends up in the Atlantic, some is temporarily deposited as deltas into lakes in many places. In other places, rising ocean and lake water drowns the mouths of streams, forming estuaries. Estuaries are common along the south shore of Lake Ontario; the crust has rebounded unevenly from the weight of glacial ice, thus tilting the entire basin to the south. With the melting of the ice, sea level has risen dramatically in the Holocene. This rise has drowned the Hudson River as far north as Troy, as well as the mouths of many of the Hudson's tributaries. Many of the Holocene environments around us change continually. Wind and water currents rearrange the barrier islands, bars, and spits along the shores of Long Island and in Lake Ontario. Lagoons and marshlands develop behind them, and the wind piles up sand into dunes. Along the banks of rivers, floodplains offer sites for towns and good farmland, although some of them flood nearly every year. Landslides are common along steep river and stream banks; they also occur on the very steep slopes of the Adirondack peaks. The Adirondack Mountains continue to rise in the Holocene.

INTRODUCTION

We live in the Holocene Epoch, sometimes called the Recent Epoch. It is the time since the Ice Age, the most recent part of the Cenozoic Era. It began 10,000 years ago, as the Laurentide Ice Sheet retreated north of the Great Lakes. "Holocene" means "completely modern." The name refers to the fact that the plants and animals of this epoch distinguish the modern world from previous times. Because we are still in the Holocene, we can observe its climates and geologic processes. Many of the features that we see daily—streams, waterfalls, beaches, harbors, soil—were formed or modified during the Holocene.

HOLOCENE CLIMATES

Glaciers are gone from New York State. The continental ice sheet left the State about 12,000 years ago. The last mountain glaciers in the Adirondacks probably melted 10,000 years ago. We must travel to the Rocky Mountains, to Alaska, or to the Canadian Archipelago to see remnants of the Ice Age in North America.

As the continental ice sheet retreated, the climate changed rapidly. What clues do we have to the climate 12,000 years ago? The pollen we find in sediments from that time is especially useful. It tells us what kinds of plants grew then. From this information, we can deduce what the climate was like in the early Holocene.

Climatic conditions along the ice front were very severe. Cold wind poured off the glacier. Frigid meltwaters flowed from its front. Scientists have studied the remains of the plants that grew near the ice front. They have found these plants to be sparse and low-growing, such as grass, lichens, mosses, and herbs. This kind of vegetation is just the sort we see today in tundra climates. Soils were very thin and easily eroded. Silt and sand were blown about by the glacial winds. Coarser particles were carried away by meltwater streams.

[1]Adapted from a manuscript by R.J. Dineen.

Farther south, the climate was less influenced by the glacier. Eighty kilometers from the ice front, black spruce, willow, and birch trees grew with the tundra plants. These trees need a warmer, more stable environment to flourish. We have found the bones of mammoth, mastodont, caribou, and elk there, too. Some of these animals died when they were mired in peat bogs that developed in the tundra and the black spruce forests.

As the ice retreated, the tundra vegetation was replaced by white spruce, balsam fir, jack pine, paper birch, and aspen. This change in plants tells us that the cold, dry, glacial climate had changed into a cool, moist one.

Between 10,000 and 8,000 years ago, the spruce forest was replaced by a white pine forest, indicating that the climate had become warmer and drier. As precipitation decreased, streams became smaller and the vegetation more sparse.

Plant remains tell us that about 8,000 years ago the climate changed to the warm, moist climate we live in today. The forest that developed was dominated by red oak, hemlock, hickory, and chestnut. European settlers exploited this "primeval" forest and almost destroyed it. Today, we can see only small remnants of the forest that once covered most of our State. One example is the Great Basin in Allegany State Park.

Holocene Lakes and Rivers

During the past 12,000 years, river erosion has carved many spectacular features. Cohoes Falls migrated upstream almost 5 km from the point where the Mohawk and Hudson Rivers joined. Niagara Falls migrated 12 km upstream. The 2 km-long Ausable Chasm was formed by the upstream migration of the ancestral Rainbow Falls. Lake George, which used to drain south before it was dammed by glacial deposits, now drains northward through a series of cascades into Lake Champlain at Ticonderoga. The Genesee River carved the magnificent Letchworth Gorge and deposited a large alluvial fan at Shaker Crossing near Rochester. The hanging valleys of the Finger Lakes region were also eroded far upstream since glaciers left the valleys.

In the cool, moist climate that developed after the ice retreated, the rivers flowing through the spruce-dominated forests were larger than today. We know their size from the deposits they left behind. Large fan-shaped deposits of coarse sediments, called *alluvial fans*, were made by streams at the foot of steep slopes. We can still see these fans today along the edges of river floodplains. Some good examples are found along the Hudson River between Waterford and Hudson Falls, and along parts of the Susquehanna and Genesee Rivers.

Similar alluvial fans were deposited along the edges of lakes at Bolton Landing on Lake George, at Sheldrake on Cayuga Lake, and at Seneca Point on Canandaigua Lake. Small villages have been built on these fans. Very large alluvial fans were created at the base of high mountains. The sites of Palenville and West Shokan are good examples; these villages were built on large fans at the foot of the Catskill Mountains. The streams that made the fans are still flowing across them. Along the lower Hudson River in Westchester County, Croton Point is a prominent example of an alluvial fan. It extends almost halfway across the river.

Today, most of the material eroded by rivers in New York is transported to the Atlantic Ocean. However, some of it is temporarily trapped in lakes. Kayderosseras Creek, for example, is building a delta into Saratoga Lake. Ticonderoga Creek and the Ausable and Saranac Rivers are constructing similar deltas into Lake Champlain. At Rochester, a large delta was constructed at the mouth of the Genesee River. A rise in the water level of Lake Ontario has since submerged this delta. Canadaway and Cattaraugus Creeks have built similar but smaller deltas in Lake Erie.

Along some streams flowing into lakes, lake level has risen until it is higher than the mouth of the stream. In such places, the stream does not form a delta. The drowned part of the stream is called an *estuary*. Estuaries are common along the south shore of Lake Ontario. Some examples are Irondequoit, Sodus Bay, Little Sodus Bay, and the Genesee and Oswego Rivers.

Why do so many estuaries exist along the south shore of Lake Ontario? The shore has slowly sunk beneath the waters of the lake. The sinking of the shore allowed the lake waters to flood the mouths of streams. But why did the shore sink? The answer goes back to an effect of the continental ice sheet, discussed in Chapter 12. The weight of the continental ice sheet depressed the earth's crust. The crust was depressed more along the north shore, where the ice was thicker, than along the south shore. Since the ice retreated, therefore, the crust has rebounded more in the north. For this reason, the entire lake was tilted to the south. At the same time as water flooded the mouths of streams along the southern shore, the river mouths along the north shore became shallower.

Sea Level in the Holocene

A rise in sea level can also drown part of a river to form an estuary. The Hudson River became an estuary as far north as Troy partly as a result of the Ice Age. The glacial ice widened and deepened the Hudson Valley; later, meltwater flow eroded the valley deeply. As the Pleistocene glaciers melted, sea level rose. Salt water now extends as far north as Poughkeepsie, and daily tides reach as far north as Troy. Large ocean-going ships regularly sail up the estuary to the port of Albany.

As the level of the Hudson River rose, it drowned the mouths of tributaries flowing into it. Catskill, Hudson, and many other Hudson Valley communities are located at the farthest point reached by daily tides on these drowned tributaries. The mouths of streams flowing into the ocean in southern Westchester County and on Long Island were also flooded by the rising sea.

At the peak of the Ice Age, so much water was stored as glacial ice that the sea level dropped around the world. As the ice melted, sea level began to rise again. We estimate that sea level has risen 100 m during the Holocene. About 7,000 years ago, most of the rise had occurred, but sea level was still 10 m lower than today. About 4,000 years ago, the sea reached approximately its present level. However, sea level is continuing to rise about 15 cm each century.

The Holocene Landscapes—Still Changing

By the end of the Pleistocene, huge quantities of sediment had been deposited in glacial lakes, along the shores of the ocean, and on the continental shelf. Long Island is a prime example of such deposits laid down near the ocean (see Chapter 12 for more information). Since then, the sediments along the coast have been continually rearranged by wind and by water currents. Coastal currents have built a series of barrier islands, bars, and spits along both shores of Long Island and also in Lake Ontario. Waves continue to erode cliffs along the shore. Good examples of such cliffs are visible at Montauk Point on Long Island and Hamlin Beach on Lake Ontario. Such erosion provides more sediments to form temporary bars and offshore islands.

An extensive barrier island chain stretches from Coney Island to South Hampton. These islands can be seen on Plate 1 of the *Geological Highway Map*. Individual islands grow as waves erode the cliffs between South Hampton and Montauk. Spits on the North Shore of Long Island partially block the mouths of bays. The coastal islands and spits are very recent in origin. We know their age because they could only have been built after the sea reached its present level about 4,000 years ago. These coastal landforms are like sandcastles in geologic time. Storms can change their shapes overnight.

As these islands and bars grow, they begin to close off small stretches of sea water near the shoreline. The stretches develop into large pools of salt water (called *lagoons*) and wet marshlands. In a similar way, freshwater marshlands have formed on the south shore of Lake Ontario behind barrier islands, bars, and spits between Braddock Heights and Sandy Point. In such environments, the wind piles beaches into dunes. These dunes change in shape as the wind blows. In most places, dune grasses will grow over the dunes and stabilize them unless careless human activity destroys the plant cover.

Floodplains are another kind of constantly changing Holocene environment. They are flat areas beside rivers. They are built of sediment laid down by rivers during flood stages. Towns and villages are commonly built on floodplains. Floodplains also hold some of the best farmland in New York. Some floodplains flood nearly every year. Good examples are the Stockade in Schenectady, parts of the city of Corning, and the village of Schoharie.

Many cities and towns built on floodplains in the Southern Tier were devastated by Tropical Storm Agnes on June 23, 1972. By studying historical records, which tell of recurring floods, we see that this kind of flooding has been going on for a very long time. We also find evidence of repeated flooding in archeological sites on the floodplains.

Landslides are another way that the landscape is changing today. Parts of the St. Lawrence, Erie-Ontario, Champlain, and Hudson Lowlands are prone to landslides. Silt, clay, and clay mixed with glacial deposits form steep banks along many rivers and streams. Flowing stream water erodes the lower part of the bank, especially during storms and spring melts. This erosion undercuts the slope. Landslide-prone soils are less stable when they are wet. They are also less stable when people build on the upper part of a landslide-prone area. We can find the scars left by landslides along many streams. Some good examples are found along the Normans Kill in Albany County, the Bouquet River in Essex County, Catskill Creek in Greene County, and Cattaraugus Creek in Cattaraugus County.

Dramatic landslides also occur on some of the very steep slopes of Adirondack peaks. Several hours of very heavy rain can soak the forest mat so thoroughly that it slides like a giant carpet down the rock face (Figure 14.1). Whiteface Mountain was named from such a landslide scar.

A surprising Holocene development is that the Adirondack Mountains appear to be rising at the present time. This observation is based on precision measurements of the elevation of surveyors' bench marks across the Adirondacks. Elevations were measured for each bench mark when it was installed. When these bench marks were surveyed again several decades later, their elevations were found to be higher. In addition, the elevations had increased more near the center of the Adirondacks than at its borders. This interesting question of Adirondack uplift is still being studied.

Figure 14.1. In this aerial view of Whiteface Mountain, you can see the long, narrow, light-colored scar left by a landslide. Rock slides like this one can happen on steep, smooth rock slopes. A very heavy, once-in-a-lifetime downpour soaks the carpet of vegetation so thoroughly that it no longer sticks to the rock. Then the forest mat crashes down the mountain.

The slide shown in this photograph is one of 10 that occurred on the mountain on Labor Day, 1971, at about 4:30 p.m. The slides were up to 38 m wide and 5 m deep. The slides were caused by a very heavy local downpour that dropped 7.6 cm of rain in one hour on the summit, while 5 cm fell at the base of the mountain and none in the valley. This odd weather event occurred on a day of record humidity. As the humid air rose over the mountain top, it cooled until it suddenly dropped the moisture it carried.

This photograph was taken looking toward the northeast. Compare it with the photo in Figure 12.12, which was taken from a location just to the left of this one.

Review Questions and Exercises

How did the climate change as the glacial ice retreated and afterwards? How do we know about these changes?

What is an *estuary*? Why do we find many of them on the south shore of Lake Ontario? How did the Hudson River become an estuary?

Name several ways that the landscape is changing today.