GEOLOGY OF THE MOHAWK AND BLACK RIVER VALLEYS - A FIELD TRIP FOR EARTH SCIENCE TEACHERS

Barbara J. Tewksbury
Department of Geology, Hamilton College, Clinton, NY 13323

Robert H. Allers
Vernon-Verona-Sherrill High School, Verona, NY 13478

Rocks exposed in the Mohawk and Black River Valleys consist of a sequence of Late Precambrian metamorphic rocks unconformably overlain by a sedimentary succession ranging from Cambrian through Silurian in age. A veneer of unconsolidated Pleistocene sediments mantles the bedrock. Changes in plate tectonic setting with time are reflected both directly and indirectly in the changing character of the rock record, and Pleistocene deposits in the region provide clues to Late Wisconsinan deglaciation. The purpose of this field trip is 3-fold: 1) to examine the character of the bedrock, 2) to see how changes in plate tectonic setting are mirrored by changes in the rock record, and 3) to study the record of Late Pleistocene glacial and peri-glacial environments of central New York. The introductory text provides background on the bedrock geology, plate tectonic setting, and Pleistocene history of the region.

Precambrian Basement Rocks

Late Precambrian metamorphic rocks underlie all sedimentary rocks in central New York State and are exposed at the surface east of the Black River Valley and north of the Mohawk River Valley. The Black River Valley, in fact, lies essentially along the unconformity, separating gently southwest-dipping Paleozoic sedimentary rocks from Precambrian basement of the Adirondack dome to the east. These rocks consist of a complex sequence of sedimentary and igneous rocks intensely deformed and metamorphosed during an event known as the Grenville Orogeny. We know enough about the geology of Precambrian rocks in New York State to begin to put together a picture of events that unfolded during the Late Precambrian. There are enormous gaps in our knowledge, however, and we are forced to speculate at nearly every stage of our reconstruction.

What was the environment like during accumulation of the sedimentary and volcanic rocks? The presence of stromatolites, evaporites, quartz sandstones, and limestones suggests a shallow sea over continental crust. The volcanic rocks, impure sediments, and possible hot springs metal deposits may indicate rifting, perhaps during the early stages of development of a passive margin or a back-arc basin. Radiometric dates tell us that the oldest of these rocks were probably deposited about 1300 million years ago. Until we know more about the original sequence of rock units, we will probably not be able to say much more.

What happened during the Grenville Orogeny? The crust experienced a major shortening event — folding and ductile shearing combined to deform and thicken the crust, deeply burying rocks that had at one time lain at the surface of the Earth. These rocks recrystallized at high temperatures and pressures. Early in the sequence of events, anorthositic magmas seeped up from the mantle, perhaps derived by fractional crystallization of basaltic magmas trapped at the base of the crust. Heat transferred from the hot anorthosite partially melted the surrounding crust, and silicic magmas of varying compositions rose upward. Even when solidified, the anorthosites were less dense than the surrounding country rocks. They rose slowly upward through the deforming mass of crust, the smaller masses forming mushroom-shaped domes, and the largest masses spreading laterally into great sheets with several "roots". The presence of highly foliated margins and unfoliated cores suggests that the anorthosites moved upward by ductile shear along the margins of the bodies. Folding and ductile shear continued throughout the region, refolding the country rock and deforming nearly all of the igneous rocks after they had solidified.

It is difficult to say exactly when the Grenville Orogeny began. If we believe that the anorthosite magma was intruded during the early phases of deformation, the radiometric dates on the anorthosite ranging from 1300 to 1100 million years tell us that the Orogeny was under way at least 1100 million years ago, perhaps earlier. Deformation and metamorphism appear to have peaked between 1020 and 1100 million years ago. By about 900 million years ago, the rocks had cooled enough that most of the sensitive radiometric clocks had been set.

Now, we come to the "why" of the Grenville Orogeny. In proposing a model, we need to keep a number of things in mind: 1) the presence of what may have been a rift basin or passive margin sequence, 2) major crustal shortening during the Grenville, directed from east to west or southeast to northwest, and 3) the presence of crust that was twice as thick as normal continental crust at the end of the Grenville Orogeny.

A number of people have proposed that a continent-continent collision akin to the modern collision of India with Asia is a reasonable model for the Grenville Orogeny. This is a logical conclusion to draw, because, at present, we know of no way other than a major accretionary event to double the normal thickness of continental crust. Such a collision would have severely compressed the crust, causing major overthrusting, repeated folding, and ductile shearing as large slabs of crust were driven northwestward. Figure 1 illustrates a plausible sequence of events for the Grenville Orogeny.

When we look at more modern examples, we see that welding of large terranes such as those involved in the Grenville Province is typically a complicated event, typically involving a number of smaller terranes. So much has been eroded from the Grenville Province that we have no way of guessing how complicated the collision might really have been. How many terranes collided with the margin is unclear. In fact, it isn't even clear where a suture or sutures might lie. The lack of an obvious candidate for a suture zone is one of the main arguments used against a plate tectonic interpretation for the Grenville Orogeny. Those in favor of a plate tectonic interpretation simply place the suture out of sight, buried beneath younger rocks to the east.

What happened after the Grenville Orogeny? Over the course of nearly 400 million years, erosion and tectonic unroofing stripped enormous volumes of rock off the great mountain range, until nearly 30km of material had been removed.

Paleozoic Sedimentary Rocks

Paleozoic sedimentary rocks in Central New York State range in age from the very latest Precambrian through the end of the Silurian, a time span of about 200 million years. No other region in the State preserves such a complete sedimentary record from this period of time. Although rocks of the Taconic region are similar in age, they are complexly deformed and more difficult to interpret. This time period is an important one in the geologic evolution of New York State, because it includes rifting of the eroded supercontinent of Grenvillia, opening and widening of the Iapetus Ocean, closing of the western Iapetus, and collision of the Taconic Island Arc Terrane with the eastern margin of Laurentia (the "North American" segment of rifted Grenvillia) during the Taconic Orogeny. We should be able to find important clues to these events in the rocks of this region. This region is also important to our understanding of the evolution of life during the Silurian Period — the record in New York State is nearly complete and is the best known Silurian record anywhere in eastern North America.

The sediments in this region are remarkably varied. They range from poorly-sorted feldspar-rich sandstones to clean quartz sands, bedded iron ores, layers of salt, fossiliferous limestones, and unfossiliferous black shales. We find such a variety of sediment types that we might begin to suspect quite a variety of sedimentary settings as well. What were these sedimentary settings like? How did they change with time? What do the changes tell us about the geologic evolution of New York State?

Rather than trying to digest the entire section at once, we will divide the sedimentary record into 3 packages, the first representing deposition during the Late Precambrian through Early Ordovician, the second representing the Middle and Late Ordovician, and the third the Silurian. Each time period corresponds to a distinctly different regional tectonic setting — opening of the Iapetus, accretion of the Taconic Island Arc Terrane during the Taconic Orogeny, and aftermath of the Taconic Orogeny. One of the intriguing questions we will want to answer is how an undeformed sedimentary sequence can record significant evidence of major regional tectonic events such as these.

Latest Precambrian Through Early Ordovician. Rocks from this interval of time are represented by scattered patches of poorly-sorted feldspar-rich sandstones of latest Precambrian age overlain by regionally-extensive shallow water marine sandstones and dolostones of Late Cambrian and Early Ordovician age.

What kind of picture emerges when we tie together inferences about the rocks and their sedimentary settings? Between 600 and 650 million years ago, the crust was stretched, and major normal faults trending north-northeast broke the crust. These faults are very different from the ductile shear zones of Grenville age. Because they formed at shallow levels in the crust, they are marked by shattered rocks known as breccias. Basaltic dikes were also intruded at this time. The rift valleys must have looked much like the modern East African and Rio Grande Rifts. Rare deposits of poorly sorted, locally-derived feldspathic sands (the Nicholville arkoses) date from the very end of the Precambrian and suggest that fault-bounded basins were probably scattered throughout the Adirondack region at this time. During the Late Cambrian, a shallow sea advanced across the region from east to west, spreading a blanket of beach sand (the Potsdam Sandstone) on eroded Precambrian basement and on scattered remnants of Late Precambrian rift basin sediments. As the shoreline transgressed westward and sand supply diminished in the Early Ordovician, carbonate sediments were deposited in widespread nearshore dolomitic layers (the Little Falls Formation, which contains Herkimer diamonds, and the Theresa Formation) and thicker offshore limestone reefs and banks to the east. Throughout the Late Cambrian and Early Ordovician, the east coast of Laurentia would have looked much like an unvegetated version of the Florida Coast, with a wide ocean stretching off to the east. Early in the Middle Ordovician, however, this quiet shelf environment was temporarily interrupted by subaerial erosion severe enough to remove part or all of the sedimentary record. In the Black River Valley, all of the Potsdam Sandstone and Theresa/Little Falls Formations were eroded during this event.

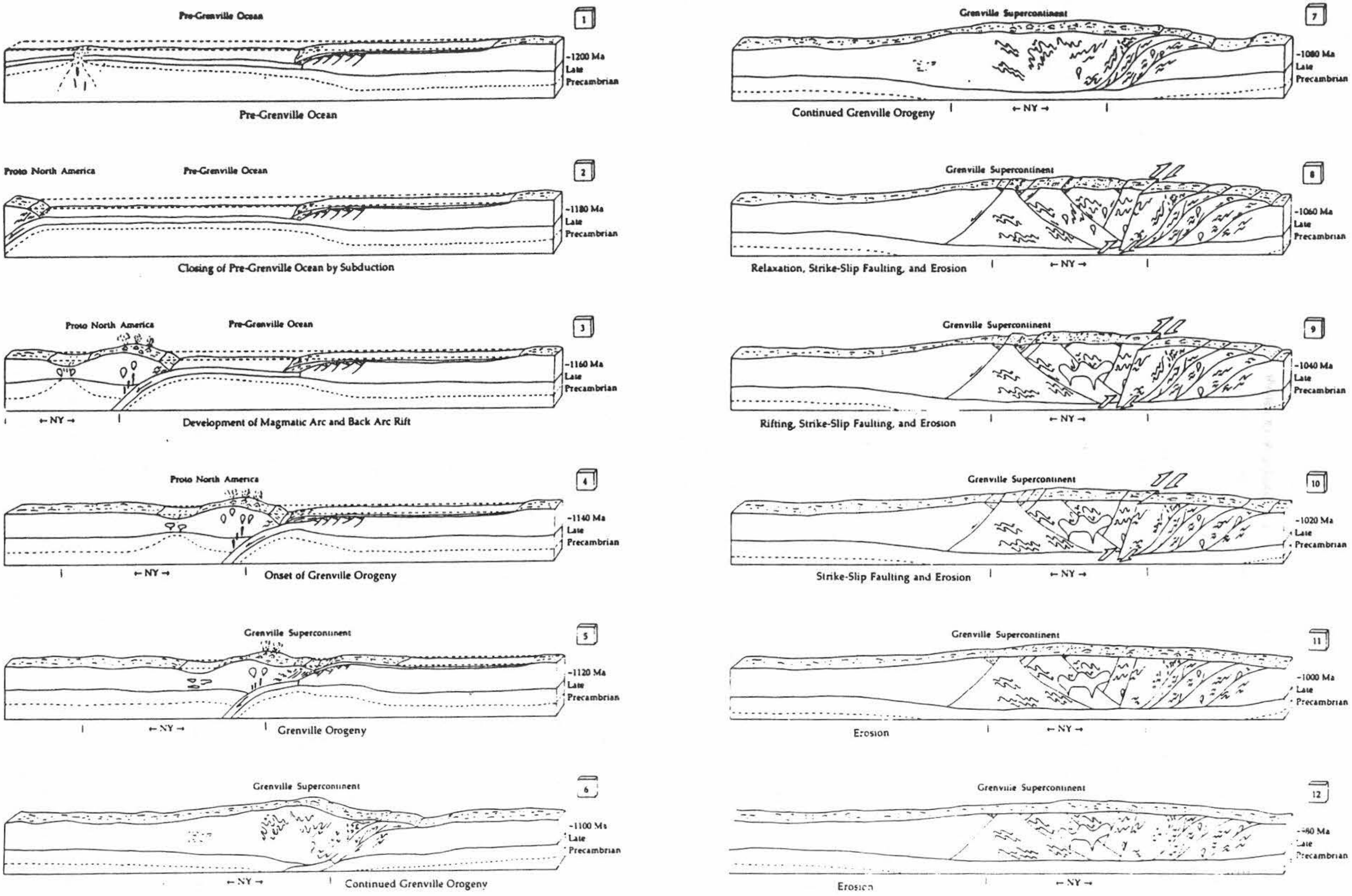


Figure 1. Possible plate tectonic model for Grenville orogenic events.

Why did these events happen? Our current plate tectonic model suggests that the supercontinent of Grenvillia rifted into a number of fragments during the very Late Precambrian (figure 2). The rift valleys in New York State reflected stretching and thinning of Laurentia as rifting proceeded. As the Iapetus Ocean grew, Laurentia moved away from the spreading center. The east-sloping continental margin slowly subsided, and a shallow ocean gradually transgressed westward. Formation of the Iapetus Ocean rather suddenly increased the volume of the Cambrian world rift system. Because spreading centers are topographically high, the effect of adding to the world rift system is much the same as dropping rocks into a bathtub. Displaced water likely spread over the continents in a world-wide rise in sea level. Both subsidence and sea-level rise were probably involved in marine transgression across New York State.

From the Late Cambrian through the Early Ordovician, the passive margin of Laurentia slowly accumulated sediments, with sands coming from the continent to the west. Unbeknownst to the unsuspecting trilobites, however, the Taconic Island Arc was slowly advancing toward Laurentia (figure 2). The Knox Unconformity, reflected in the absence of Late Cambrian and Early Ordovician sediments in the Black River Valley, may have been the herald of the inevitable collision. As the collision began, the Laurentian continental shelf may have buckled up above sea level in a great bulge, exposing the shelf to extensive erosion.

The Middle Through Late Ordovician. The general character of sediments deposited in the region changed dramatically as the Middle and Late Ordovician unfolded. Thin, widespread carbonate sediments were succeeded by interlayered carbonates and shales. Tremendous thicknesses of black shale then blanketed the carbonates. Finally, sands, silts, and shales were deposited across the region.

When we summarize our inferences about the Middle and Late Ordovician, we can see immediately that the picture is more complicated than it was for the Early Ordovician. The Middle Ordovician opened with gradual subsidence of an east-sloping carbonate shelf (the Black River Group – see the stratigraphic column in Plate I). Volcanic ash and muds derived from the east gradually appeared in the record (the Trenton Group) and tell us that open ocean no longer lay to the east. Then, the carbonate shelf buckled and foundered in the east. Earthquakes appear to have shaken loose great slurries of sediments that slid off the shelf to the west and into the basin to the east (turbidites of the eastern Trenton Group and Utica Shale).

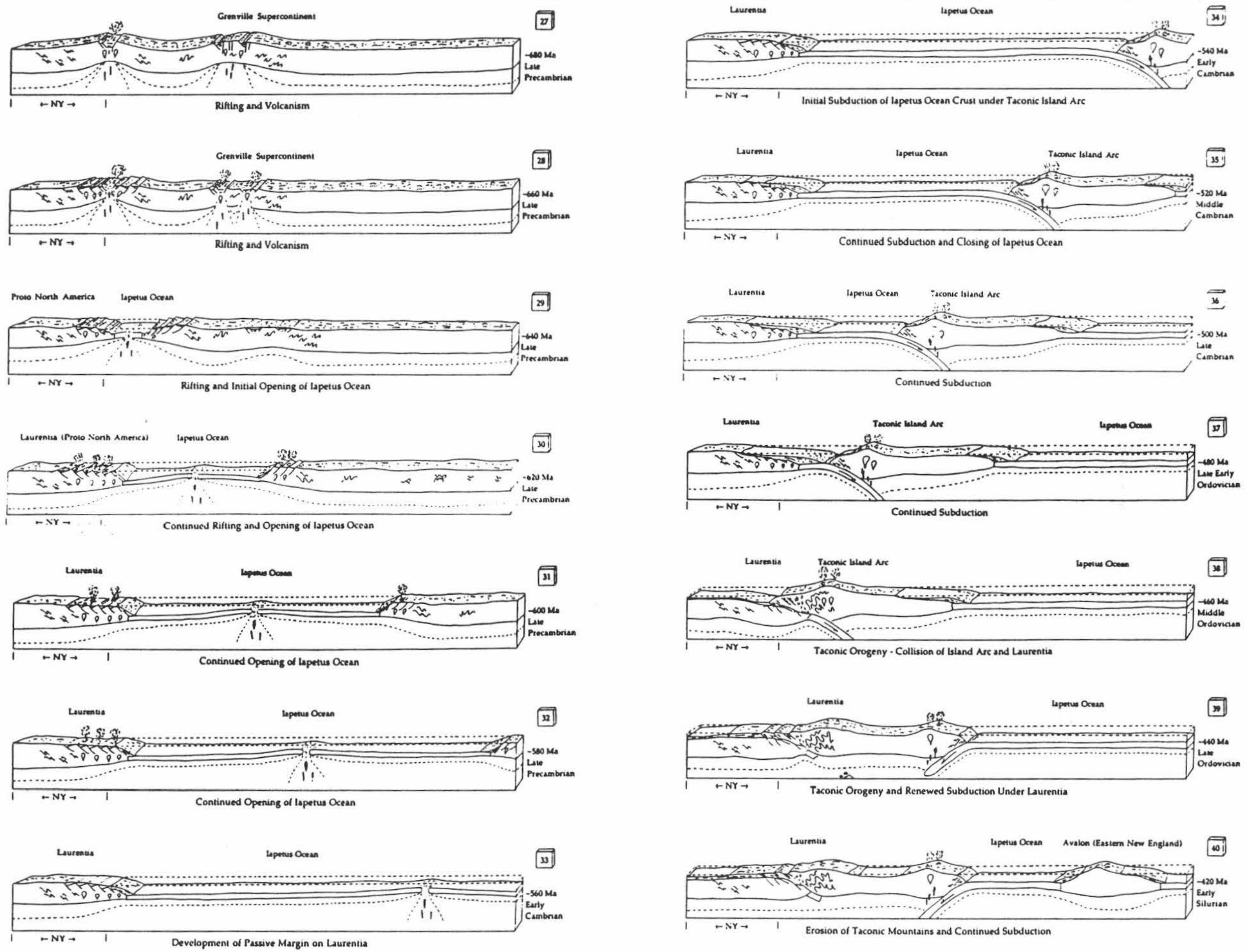
The "hinge" of the basin moved westward as the water deepened to as much as 500m, and major carbonate deposition died out altogether. The eastern shoreline of the basin lay in the vicinity of eastern New York, the western shoreline well to the west of the State. As the basin slowly filled with sediment derived from the east, deep water shales (the Utica and Whetstone Gulf Shales) gave way to shallow water siltstones, shoreline sands (the Pulaski Shale and Sandstone and the Oswego Sandstone), and subaerial sediments of the Queenston Delta (the Queenston Shale) (Plate I).

Why did these events happen? These events span the time of the Taconic Orogeny. Although the sedimentary rocks of Central New York State are essentially undeformed, the changes in sedimentary environments reflect major tectonic events taking place farther east. Our current plate tectonic model suggests that collision of the Taconic Island Arc with Laurentia began in earnest in the Middle Ordovician (figure 2). As the arc rode up over the eastern edge of the continental shelf, the margin of Laurentia foundered. At first, subsidence was slow, and deposition of shallow-water carbonates kept pace with the subsidence. Volcanic ash wafted in from the Taconic Island Arc to the east. As the relentless advance of the arc telescoped the continental shelf, the shallow marine basin in New York State buckled and subsided rapidly along great fault blocks. Sediments eroded from the rising Taconic terrane and arc to the east poured westward into the deepening basin, and carbonate sedimentation was extinguished altogether. We do not know whether the flood of Late Ordovician sediments forming the Queenston Delta reflects renewed uplift to the east or simply extensive erosion accompanying a world-wide drop in sea-level related to a major glacial event.

Accretion of the Taconic Island Arc Terrane produced dramatic results in this region. As collision buckled the margin of the continent, water deepened from at most a few tens of meters to over 500 meters. That's almost twice as deep as the North Sea!

The Silurian. Silurian rocks are exposed along the southern margin of the Mohawk River Valley, where they dip gently south beneath the great mass of Devonian rocks exposed on the Appalachian Plateau. Silurian rocks lie above an unconformity developed on the Ordovician Queenston Shale and are exposed at the surface along a wide band extending east from Niagara Falls and narrowing to nothing east of Canajoharie.

The general picture that emerges for this short interval of geologic time is one of terrestrial and nearshore sedimentation in a complexly changing set of environments. Overall, carbonate deposition increased in importance over deposition of sandstones, siltstones, and shales as the Silurian progressed. Although the dramatic changes of the Ordovician are missing, the changes in both sediments and fossils as a result of irregular fluctuations in shoreline and marine circulation patterns tell us an intriguing story.



Rifting and Volcanism

Rifting and Volcanism

Rifting and Initial Opening of Iapetus Ocean

Continued Rifting and Opening of Iapetus Ocean

Continued Opening of Iapetus Ocean

Continued Opening of Iapetus Ocean

Development of Passive Margin on Laurentia

Initial Subduction of Iapetus Ocean Crust under Taconic Island Arc

Continued Subduction and Closing of Iapetus Ocean

Continued Subduction

Continued Subduction

Taconic Orogeny - Collision of Island Arc and Laurentia

Taconic Orogeny and Renewed Subduction Under Laurentia

Erosion of Taconic Mountains and Continued Subduction

Figure 2. Plate tectonic model for development of an Early Paleozoic passive margin and the Taconic Orogeny.

From the end of the Ordovician through the earliest part of the Silurian, the entire region must have lain above sea level, because we have no rock record from that time. In that respect, New York State is little different from most other places in the world. The unconformity itself, though, is typically very difficult to locate, especially where Lower Silurian deltaic deposits overlie very similar Ordovician rocks of the Queenston Delta.

Shallow seas washed the region throughout much of the Silurian. During the Early Silurian, an ocean briefly advanced eastward as far as Medina, then shrank westward until it once again lay past the border of the State. Several million years later, the ocean readvanced eastward as far as Oneida and Utica. Gravels (the Oneida Conglomerate) (Plate I), sands, silts, and muds (the Clinton Group) accumulated on deltas, beaches, and tidal flats early in the Silurian. Unusual marine water conditions resulted in the formation of Clinton-type iron ores at the time of deposition of some of the Clinton Group sediments. Clastic sediments eventually gave way to carbonates deposited on extensive shallow water shelves (the Lockport Group). Nowhere was the water very deep. Near the end of the Silurian, evaporation and poor circulation produced large tracts of very salty lagoons and tidal flats, in which eurypterids played and layers of salt accumulated (the Vernon Shale and the Salina Group) (Plate I).

What was the tectonic setting of the region during the Silurian? The Taconic Orogeny was over by the end of the Ordovician. By the time the Early Silurian had arrived, the Taconic Island Arc Terrane was not only securely welded to Laurentia but quite thoroughly eroded as well. Major tectonic activity occurred far to the east along the plate boundary, where west-dipping subduction slowly consumed crust of the central Iapetus Ocean (figure 2). New York State itself was a quiet foreland basin, much like the shallow ocean lying between Australia and New Guinea. The origin of the very gentle upwarping and downwarping reflected in shoreline migrations throughout the Silurian is not particularly well understood and may be related to convergence along the plate boundary to the east.

The Fossil Record. Early Paleozoic seas were dominated by invertebrate organisms - brachiopods, clams, worms, snails, trilobites, corals, bryozoans, nautiloids, graptolites, echinoderms, tentaculitids, and ostracodes. Evolution of individual species is beyond the scope of this summary, but a number of landmark evolutionary events deserve comment.

Middle Ordovician seas supported a host of new creatures. A new invertebrate group, the bryozoans, appeared and became important as colonial rock builders. Another conspicuous new arrival, the coral-like stromatoporoids, constructed extensive mound-like reefs. True corals likewise made their initial appearance — the oldest known coral reef in the world is found on Isle La Motte in Lake Champlain.

The Silurian Rochester Shale preserves a remarkably diverse fauna of over 200 species, including 84 of bryozoans alone. There were hosts of ostracodes and stalked echinoderms, and even larger numbers of brachiopods. Although trilobites were on the decline, the surviving families were still important. The tentaculitids, a steadily increasing group of tiny, conical ringed shells, became important. Corals, snails, clams, and nautiloids, though less abundant, also continued to evolve and disperse. The seas were well-populated, and competition for food and survival was keen. It is hardly surprising that air-breathing arthropods began to evolve at this time and eventually colonized the land.

Masked in the generally sparse record of the Silurian is the history of a great evolutionary advance — the lineage of the earliest vertebrates, the fishes. Although fishes are known in the Lower Ordovician and may have appeared even as early as the Cambrian, the Silurian is characterized by appearance of a number of more modern types. During the ensuing Devonian Period, a great variety of fishes populated the seas, but armor-skinned fishes were preserved as fossils in the Silurian Vernon Shale.

Land plants had not made an appearance even as late as the end of the Silurian. When we try to visualize the region at this time, we must picture a bare landscape devoid of trees and grasses — a bleak scene with no vegetation to protect the surface from the onslaught of wind and water.

The Pleistocene

During the Pleistocene, New York State was covered by a succession of continental ice sheets. Little evidence of early ice sheets remains, but the last and most extensive glaciation left a strong stamp on landforms seen in the region today. The Laurentide ice sheet covered northeastern North America during Wisconsinan time and had its center in the Laurentian Mountains of Quebec and the uplands of eastern Quebec and Labrador. The ice sheet was nearly equal in size to the present Antarctic ice sheet and covered up to 12.3 million square kilometers. At the maximum extent about 54,000 to 63,000 years before present (ybp), the Wisconsinan ice sheet covered all of New York State with the exception of the Salamanca Reentrant (figure 3a).

The Laurentide ice sheet flowed across New York in four major "ice streams" or lobes. The lobes formed in response to differential flow within the ice sheet and were probably affected by underlying topography. In north-central New York

State, the Ontario lobe and the Mohawk, Oneida and Black river sub-lobes have been identified through grooves and striations, and by the deposits they left behind. The Wisconsinan ice lobes obliterated earlier proglacial river systems and accentuated the depths and widths of the earlier valleys. Isostatic subsidence reduced gradients and lowered elevations by as much as 120 to 130m (Flint, 1971).

Recession began to take place as the climate warmed and melting of the ice sheet exceeded the southern flow. Recession was probably marked by many still-stands and readvances of varying durations. Today, the locations of these former ice margins are marked by looping morainal belts draped across the hills and valleys. Geologists have identified several stages in retreat of the ice as the margin migrated northward across the State. The first two well-defined stops are called the Binghamton and the Valley Heads stages. The Binghamton Stage has been identified at about 14,000ybp, and the Valley Heads Stage at 12,000 to 13,800ybp. The Valley Heads stage formed a very distinctive line of moraines that can be traced from Cooperstown through Oriskany Falls, Munnsville, to Tully and westward across the State. At this time, major meltwater drainage was primarily southward through the Allegheny, Chemung, Susquehanna, and Hudson Rivers (figures 3b and 3c).

During the 2000-year interval between the Valley Heads Stage and the formation of Glacial Lake Iroquois, ice retreat and readvance formed a very complex series of erosional and depositional features. Regrettably few of these features have been dated radiometrically. As the ice sheet stagnated, sediment-laden meltwater poured into depressions on, in, under, or adjacent to the ice. Meltwater also scoured deep channels as it worked its way toward lower elevations.

As the Ontario lobe retreated up the western Mohawk Valley, and the Hudson lobe retreated toward present-day Albany, meltwater was impounded between the two lobes. This formed glacial lake Herkimer, which ranged from a maximum level of 439m (1440') to a low level of about 305m (1000') (figure 3d). These levels are given in terms of present elevations above mean sea level and reflect some isostatic rebound. Lake Herkimer drained to the south down the Unadilla and Chenango Rivers through a col or low pass at Cedarville and into the Susquehanna River (Ridge *et al.*, 1984). Glacial Lake Newberry was formed by water trapped between the ice margin to the north and the Valley Heads Moraines to the south at an elevation of about 366m (1200'). Lake Newberry formed a series of interconnected finger lakes that filled the through-valleys and were joined by meltwater channels that cut the north-south trending drainage divides (Hand, 1978).

As the ice thinned and retreated, lower drainage channels opened and allowed the ice-marginal lakes to drop to lower levels. Lake Hall to the west dropped to the 274m (900') level and Lakes Amsterdam and Schoharie to the east formed at the 189m (620') and the 207m (620') levels (LaFleur, 1979) (figures 3f and 3g).

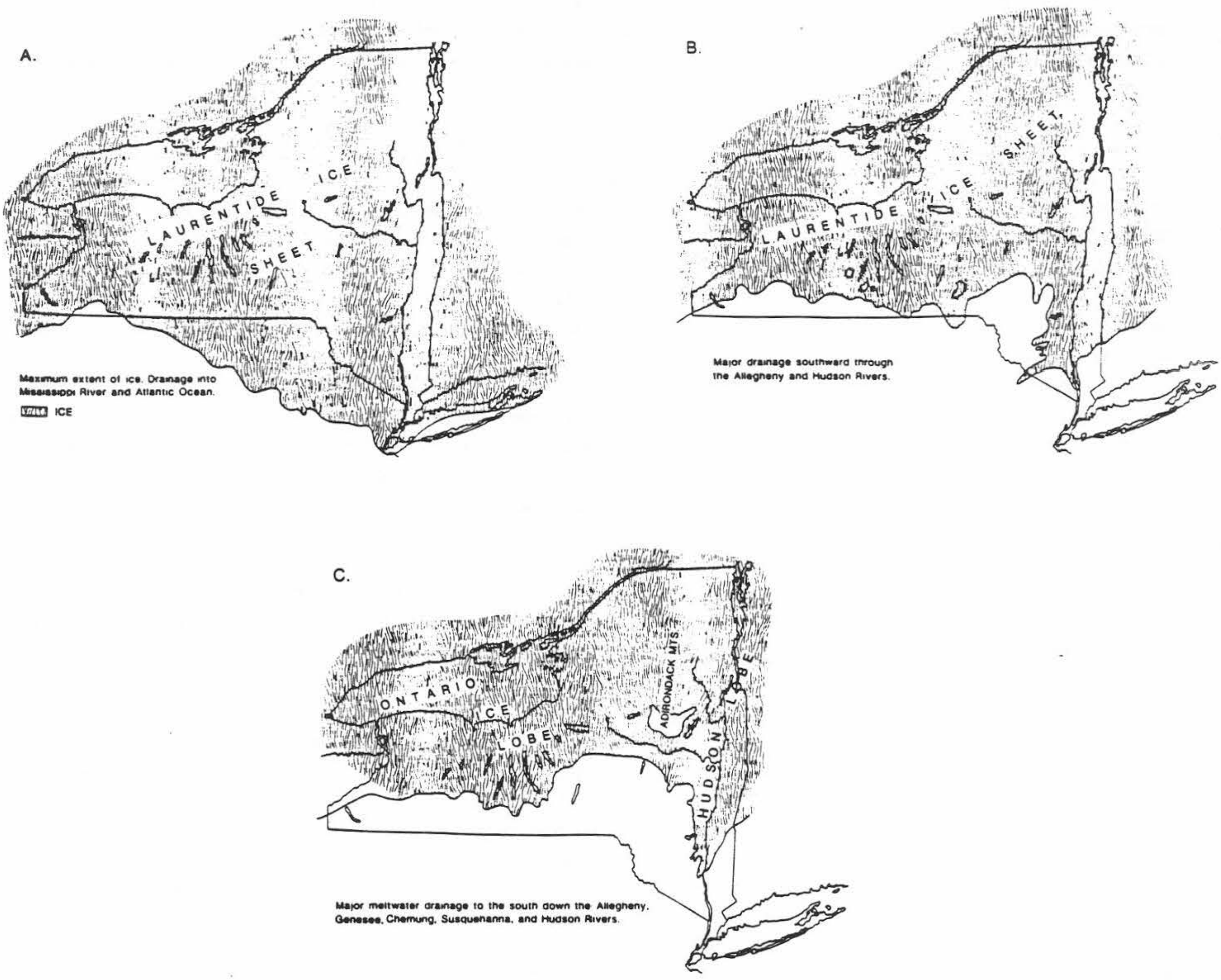
As the ice margin continued its northerly retreat from the edge of the Appalachian Plateau, drainage was largely to the east along the southern margin of the ice. Along the southern edge of the ice margin, meltwater formed another lake that was bounded on the south by the higher elevations of the plateau. This large lake, named Lake Iroquois, drained to the east through the Mohawk Valley via an outlet at Rome at an elevation of 137m (450')(figures 3g and 4b).

Excellent examples of Lake Iroquois sediments are preserved just north of Canastota, where varved clays, marl, silt, and peat (in ascending order) record both deposition in and drainage of this large lake. Drainage from Lake Iroquois proceeded eastward through the former Lake Amsterdam channel and into Lake Albany at about 100m (300'). When the ice dam just south of Albany opened, these two lakes drained southward down the Hudson River (LaFleur, 1977). Eastward drainage at Rome continued until northward retreat of the ice opened the St. Lawrence valley to northeastward drainage at a lower level.

The Black River Lobe filled the Black River Valley at the times of Lakes Herkimer, Amsterdam and Iroquois. Meltwater was trapped between the retreating ice tongue and the southeastern edge of the Tug Hill Plateau, forming a series of ice-marginal lakes in this region as well. Lakes Forestport and Port Leyden filled the southern end of the valley and drained to the south. Meltwater pouring from Lake Port Leyden into Lake Iroquois roared down Lansing Kill and scoured the Boonville Gorge out of soft and easily-eroded Utica Shale. A large delta formed as the end of the gorge on the northern side of Lake Iroquois, giving modern day Lake Delta its name.

During retreat of the ice, the land immediately south of the ice margin was predominantly covered with tundra vegetation at higher elevations and grassland in lower regions. As the ice margin crept northward, grasses and forests of spruce and pine developed on the bare glacial deposits. Vegetation apparently took hold fairly rapidly after the ice cleared an area (Flint, 1971). Pollen studies, occurrence of wood fragments, and deposits of pine needles in glacial lake sediments provide evidence of the wide variety of plants in the region. Elk, mastodont, beaver, and Stone Age humans were among the mammals living just south of the ice margin.

After drainage of the proglacial lakes, barren lake bottoms and shorelines lay exposed to the elements. Although vegetation quickly covered much of the area, especially the fertile lake beds, the sandy beaches were exposed to wind erosion. Prevailing westerly winds picked up large amounts of sand on the eastern edges of former lakes and moved it eastward. Just east of the city of Rome, a series of large dunes are preserved in the Rome Sand Plains. The Sand Plains are formed of cross-



A. Maximum extent of ice. Drainage into Mississippi River and Atlantic Ocean.

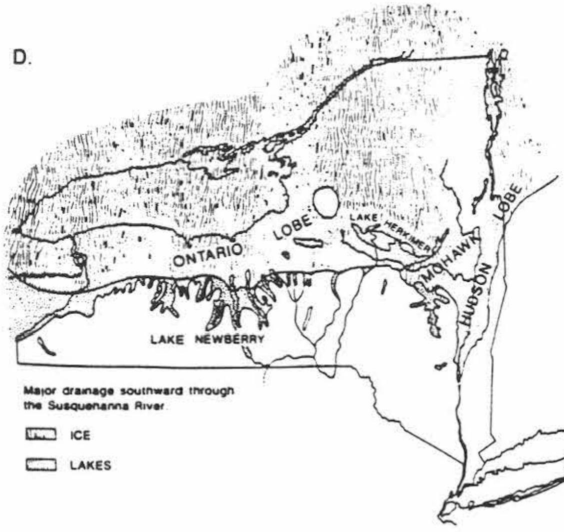
B. Major drainage southward through the Allegheny and Hudson Rivers.

C. Major meltwater drainage to the south down the Allegheny, Genesee, Chemung, Susquehanna, and Hudson Rivers.

Figure 3. These maps illustrate selected stages during retreat of Wisconsinan ice in New York State. Inferred locations of ice margins and lakes are modifications of maps done by Fairchild (1909), with modifications based on work done by Ridge *et al.* (1984). The diagrams have been further modified by the New York State Geological Survey and appear on pages 178 and 179 of Isachsen *et al.*(1991).

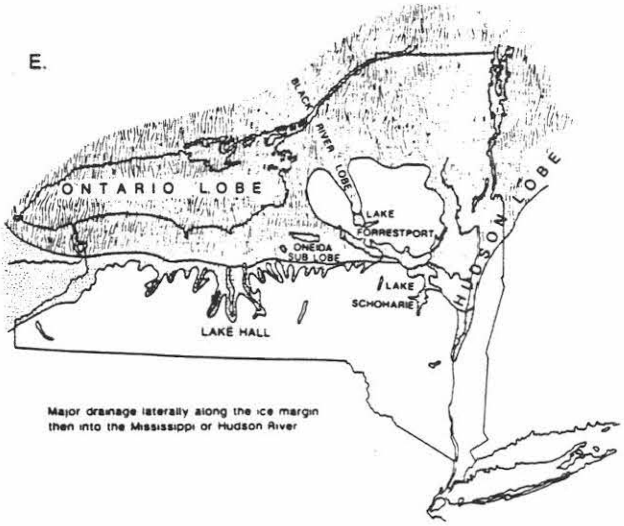
During deglaciation, ice retreat was neither continuous nor regular. Sporadic and localized readvances, still-stands, and retreats caused major changes in paleogeography by closing or opening an important drainage channel or outlet. The maps are presented to give the reader a general overview of the complex series of events that probably occurred in Central New York.

D.



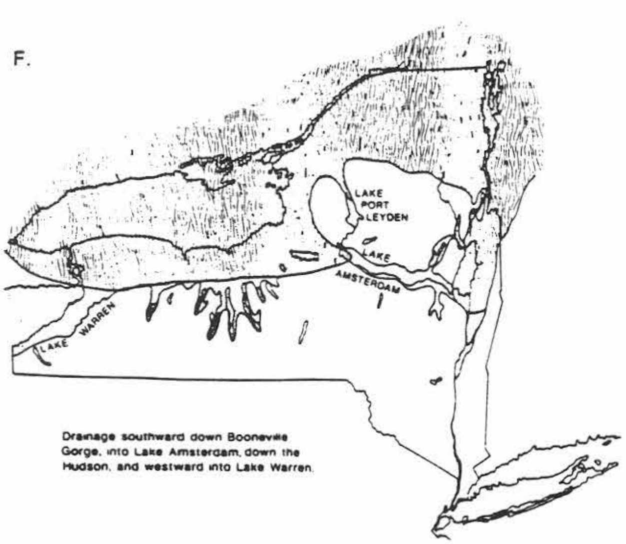
Major drainage southward through the Susquehanna River.

E.



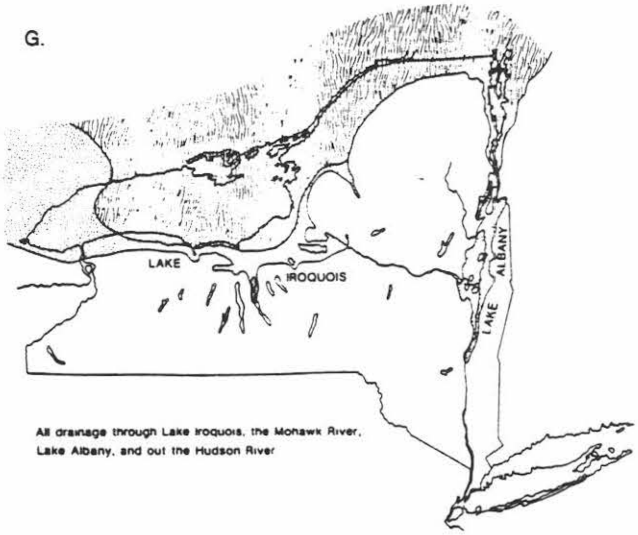
Major drainage laterally along the ice margin then into the Mississippi or Hudson River

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

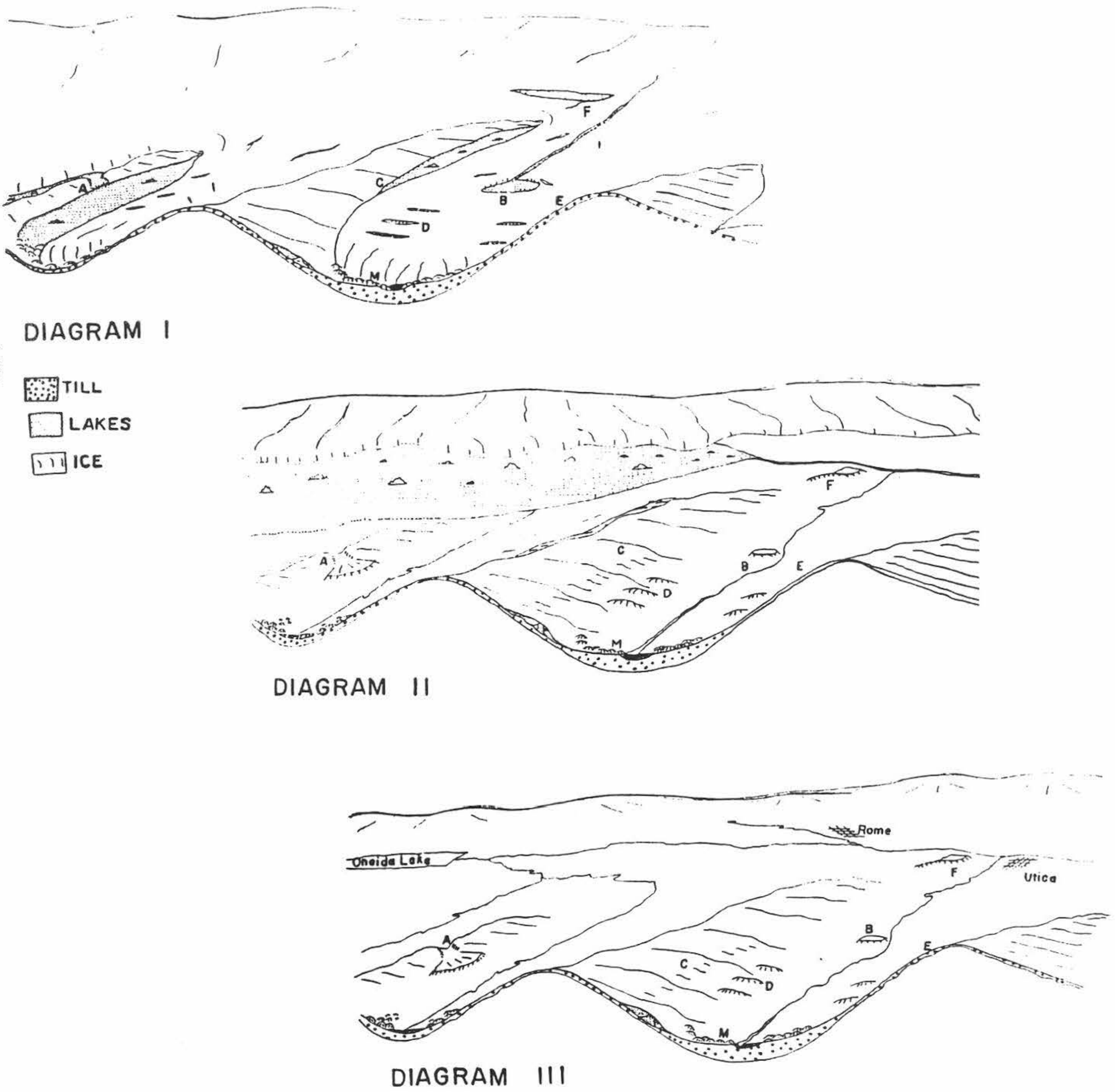


Figure 4. Idealized sketches showing an interpretation of deglaciation of the western Mohawk Valley. Sketches are drawn from a hypothetical aerial vantage point above Oriskany Falls, New York. **Diagram I** shows the looping moraines associated with the Valley Heads Readvance (M). With stagnation and thinning of the ice, meltwater laden with sediment collected along the edges of the ice, forming small lakes (B, C). Just south of Vernon Center, a metlwater channel formed on the west seide of Eaton Hill (A). The channel was cut into bedrock at first, and then flowed north along the ice margin until it was blocked or diverted by ice and cut east across the ridge, forming a large delta slightly west of route 26. Meltwater also formed a large delta in the Oriskany Valley south of Clinton between route 12B and Dugway Road (B). Along the walls of the valley, kame terraces formed from the remains of lateral moraines and sediment left against the ice by meltwater. As the ice melted, away, these deposits slumped and were faulted and broken (C). Crevasses on the ice also filled with sediment, and en echelon crevasse fillings occur in Oriskany Creek Valley along route 12B south of Deansboro (D). Ground moraine was deposited in layers ranging from a few centimeters to tens of meters thick (E). In the Mohawk Valley, an esker and delta formed where metlwater flowed off the stagnant ice into glacial Lake Amsterdam (F). **Diagram II** shows a generalized view of the same area at the time of glacial Lake Iroquois (also see figure 3). The ice margin lay on the northern side of the Mohawk Valley, forming the northern shore of the lake, with drainage eastward from Rome down the Mohawk River at an elevation of 148m (450'). **Diagram III** shows the area in diagrams I and II as it appears today.

bedded, well-sorted, fine grained sand held in place by pine forest. These very distinctive land forms have been set aside and preserved by the Nature Conservancy and the New York State Department of Environmental Conservation.

FIELD TRIP LOG

Many of the outcrops around New York State display beautiful and rare geologic features, and these outcrops should be conserved. No geologist should remove specimens from an outcrop "just for the sake of having a piece." Samples should be collected with an eye to a specific use and should be labelled and documented. Even researchers should think twice about whether removal of an exquisite sample is truly necessary. Talus should be collected whenever possible, in order not to damage exposures for future workers.

PLEASE ENCOURAGE YOUR STUDENTS TO PRACTICE OUTCROP CONSERVATION. Please never let them succumb to indiscriminate hammering. In fact, none of the field trip stops in this guidebook require hammers, so we would encourage you to bring only 1 hammer into the field – your own. Should you wish to make a documented collection for your school while you are on this trip, please let us know, and we'll assist you.

The road log begins at the intersection of routes 412 and 12B in the village of Clinton. All distances in the left margin are in miles. The stops in this road log lie on the following $7^1/_2$' quads: Boonville, Brantingham Lake, Clinton, Croghan, Glenfield, Lowville, Oriskany Falls, Port Leyden, Trenton South, Utica East, and Utica West. Geologic relationships are well portrayed on both the New York State Geologic Map (Rickard and Fisher, 1971) and on the New York State Geological Highway Map (Rogers *et al.*, 1990).

0.0	Go south on route 12B.
2.7	Kame delta on tree-covered hill to the east.
3.8	Hamlet of Deansboro; intersection of routes 315 and 12B.
5.7	Kame terraces on west side of road (see description under STOP 1).
6.2	Crevasse fillings on west side of road (see description under STOP 2).
8.5	Eastern Rock Products Quarry; good outcrops of Devonian Helderberg Group.
9.3	Junction route 26, Oriskany Falls; turn right at flashing light and proceed north on College Street.
9.4	Turn right in upper driveway of former Oriskany Falls School. This is STOP 1.

STOP 1: VALLEY HEADS MORAINE, ORISKANY FALLS

Looking south from this vantage point, one can see topography very different from that to the north in Oriskany Creek valley. At Oriskany Falls, a flat-floored valley gives way to irregular hills and hummocky topography. These hills and depressions are known as kame and kettle topography and are part of the Valley Heads Moraine. These deposits at Oriskany Falls are part of a large belt of recessional moraines marking a still-stand or readvance of the Wisconsinan glacier in New York State. The Valley Heads Moraine marks the southernmost extent of the ice sheet to be visited on this field trip. The Olean and Binghamton stages are also marked by similar deposits farther to the south, but the Valley Heads Moraine is the most distinctive belt of morainal deposits in central New York.

The hummocky terrain at Oriskany Falls formed by differential melting of sediment-laden ice at the glacier terminus. Ice advance from the north and ablation (primarily due to melting) must have reached equilibrium, and, for a time, the ice front neither advanced nor retreated. Judging from the size of the Valley Heads Moraine, this still-stand may have lasted for as much as 100 years.

The moraine loops across the valley, marking the lobate shape of the glacier. Some of the morainal deposits were created as dirty ice melted and released entrained sediment. This process is similar to the process that forms the piles of sediment one finds along roadsides or driveways when snowbanks melt in the spring. Unsorted, unlayered sediment marks the areas where snowbanks were piled in the winter. By analogy, piles of ablation till mark the terminus of the ice sheet and are composed of generally unsorted and unstratified sediment. Stagnant ice blocks trapped in the sediment later melt out, leaving depressions known as kettles (figure 5).

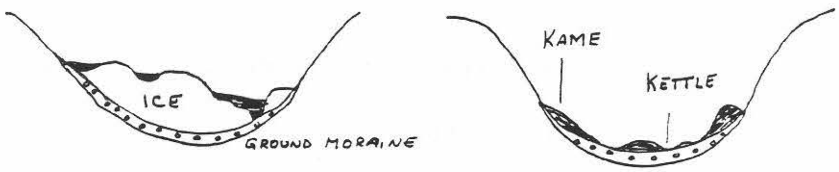


Figure 5. Formation of kame and kettle topography.

Many moraines contain considerable quantities of stratified drift in addition to unstratified ablation till. These stratified sediments are deposited in depressions on the moraine surface by running water — primarily meltwater from the wasting ice sheet. Within individual layers, sediments are typically moderately well-sorted, although grain size ranges widely from layer to layer. Many of the sediments are fluvio-glacial, and cut and fill structures and cross-bedding are common. While buried ice blocks remain intact, stratified drift occupies depressions in the morainal surface. Once buried ice blocks melt and produce kettles, the topography inverts, producing hills of stratified drift known as kames. The inversion process commonly disrupts stratification in the kame deposits. This hummocky topography is known as a kame and kettle moraine. Most kame and kettle moraines are also dissected by meltwaters that spread the eroded material down-valley in outwash plains. Were we to drive south of Oriskany Falls to route 20, we would be able to see the broad flat outwash valleys developed south of the Valley Heads Moraine. Scattered kettles occur on the outwash plain, and one of the best sits in the front yard of the Madison School on route 20.

In the valley to the north of Oriskany Falls, one can see crevasse fillings (at road log mile point 6.2). These kames of stratified drift were formed as sediment accumulated in large cracks or crevasses in the ice. When the ice melted, these sediments were left as en echelon ridges parallel to one another but at an angle to the valley walls. In addition, one can also see examples of kame terraces along the valley walls to the north (road log mile point 5.7). These formed along the sides of the stagnant ice, as sediment-rich meltwater and rainwater poured off the ice and hills separating the ice tongues. As with all kame deposits, these are composed of stratified drift. However, many of the kames show disrupted stratification, produced as ice melted and removed support from the sediment, causing slumping and faulting.

Return to College Street, and continue north. College Street becomes Skyline Drive.
16.2 Large glacial erratic on the west side of the road.
16.8 Good view to the west over Sconondoa Valley and Oneida Lake. Meltwater channel and delta complex can be seen south of Vernon Center in Sconondoa Valley.
17.8 Stop sign at intersection of Skyline Drive and College Hill Road. Turn right.
20.5 Flashing light at intersection of College Hill Road and route 233. Continue straight.
21.4 Traffic light at Clinton village square; follow 12B through Clinton.
23.7 Intersection of routes 5 and 12B; continue on 12B.
25.8 Intersection of routes 12, 5, and 12B. Go north on route 12; 4-lane highway starts.
31.5 Turn right into Riverside Mall, and proceed to the north end of the parking lot behind the Bradlee's store. STOP 2 is on the slope and field north of the parking lot.

STOP 2 - RIVERSIDE MALL

Here, we will see a very different type of Pleistocene deposit than the one we saw at Oriskany Falls. Sediments of the Valley Heads Moraine are ice contact deposits; the sediments at Riverside Mall are pro-glacial lake sediments, deposited in glacial Lake Iroquois or Amsterdam. The slope north of the parking lot is underlain by dark-colored, very fine-grained, finely laminated sediments. At the top of the slope, sediments are conspicuously coarser, composed of fine to medium sands with some pebbly layers.

The fine-grained sediments are varved clays, or rhythmites, composed of layers of gray clay alternating with organic-rich silty layers. Overall fine grain size indicates a low-energy environment, away from lake inlets and deltaic complexes. The layers represent seasonal accumulations, and each couplet (varve) represents one year of sediment accumulation. The silty layers form during rapid sediment influx and probably represent summer accumulation, when the ice is melting and releasing sediment to the lake. The clays accumulate during the winter, when the ice is delivering little sediment to the system and pro-glacial lakes are iced over. Winter accumulations consist only of very finely-divided material that settles very slowly out of the water column. Such material accumulates year-round but is swamped during the summer by coarser detritus fed into the system. Summer layers here are thinner than the winter layers, probably because of the short duration of the melting season.

Clays are notoriously unstable when wet—witness the periodic devastation caused by clay-lubricated mudslides in California. With the right amount of water, clays and silts are very susceptible to liquefaction when shaken. Vibration causes particles to lose frictional contact with one another, and the mass becomes temporarily liquified and has no shear strength. Once vibration stops, the mass regains its shear strength. A close look at the mall parking lot will reveal many humps and swales, and even more numerous patches. The parking lot is underlain by varved clays and silts. When moisture content is right, vibration from vehicles induces some liquefaction, and the parking lot surface deforms in response to flow of material beneath it. A good drainage plan would have prevented much of the problem.

As you walk northward up the slope from the parking lot, you will notice a distinct change in sediment from varved clays to fine-grained sands. These sands were deposited in an environment of higher energy than that in which the varved clays were deposited.

Sediments at this stop exhibit a nice vertical facies change, indicating a change in lake depth with time. In a typical lake, the coarsest sediment settles in shallow, high energy water nearest the shore and lake inlets. As coarse sediment settles out, only finer material passes into deeper water, and only clays and organic material accumulate in the deeper portions of the lake. The change upslope at Riverside Mall from varved clays to sands indicates shallowing of water with time, either by progradation of a delta or by general lowering of lake level during ice retreat.

In some of the glacial lakes (especially Lake Iroquois), carbonate-producing animals and plants flourished, and layers of marl occur between the coarse sand zones and the silt zones. Marl is a calcareous sediment; in this area, marls are typically rich in shells of tiny gastropods and pelecypods and remains of a calcareous plant known as chara.

Return to route 12 and proceed north. Route 12 climbs up Deerfield Hill and traverses a series of Pleistocene beach terraces and deltas.

42.7 Junction of routes 12 and 28; stay on route 12.
51.4 Well-developed Pleistocene ground moraine on west side of road.
54.4 Junction of routes 12 and 28; stay on route 12.
56.6 Nice field of Pleistocene erratics to west of road.
59.9 Well-sorted Pleistocene fluvio-glacial sands to west of road.
61.2 The large, elongate hill east of the road is Park Hill and consists of dissected Pleistocene outwash. Several sand and gravel operations exploit the deposit.
61.4 Intersection of routes 12 and 12D; stay on route 12.
62.4 Traversing bottom of glacial Lake Port Leyden.
69.0 Crossroads in downtown Port Leyden; continue straight.
74.2 Glacially-polished bedrock knobs east and west of the road.
76.8 The horizon to the east across the Black River Valley has a very uniform elevation. That straight horizon corresponds to a well-developed, flat topographic surface at an elevation of about 1200-1250' that shows up very well on the topographic maps of the Brantingham and Port Leyden quads. These flat surfaces are delta tops, formed as sediment was deposited into glacial Lake Port Leyden during the last part of the Pleistocene. Glacial Lake Port Leyden must have been at least as deep as the tops of the deltas; it was no small lake. A look at the topographic maps will show many closed depressions on the delta tops; these were presumably formed as grounded ice, partially covered with deltaic sediments, melted and caused subsidence. The delta slopes have been somewhat dissected since. Glacially-sculpted Deerlick Road lies in the Black River Valley east of the road; it appears to be a roche moutonée.
77.3 Good exposure of glacially-polished bedrock east of the road.
81.5 Route 12 crosses Roaring Brook.
85.7 Junction of routes 26 and 12; continue north on 12.
86.3 Junction of routes 12 and 812. Turn right on 812 at the light.
86.9 Stop sign. Turn left on route 812 and proceed north.
89.8 Floodplain of the Black River, which floods with great regularity.
91.6 Downtown New Bremen.
95.3 Pleistocene boulder fields on west side of road.
95.7 STOP 3, at corner of Brewery Road and route 12, south of Croghan.

STOP 3: CROGHAN ROADCUT (and that's no baloney!)

The rocks in this spectacular roadcut are part of the suite of metasedimentary and metaigneous rocks that make up the bulk of the Adirondacks. These rocks were deformed and metamorphosed during the Grenville Orogeny (1020-1100 Ma), at depths of about 25km below the surface, temperatures of 700-720°C, and pressures of about 7 kilobars. They are quite thoroughly cooked. They are also deformed, and all lithologies in this outcrop, including the ones of igneous parentage, show compositional layering and/or planar alignments of minerals (foliations) acquired during deformation.

There are 3 major lithologies present in this roadcut 1) a mildly-foliated, coarse-grained pink granitic gneiss consisting of pink K-feldspar, plagioclase, quartz, and variable amounts of hornblende with accessory magnetite, biotite, apatite, and zircon, 2) a foliated, very coarse-grained pink augen ("eye") gneiss, with enormous pink feldspar grains up to 2-6cm long set in a matrix of plagioclase, hornblende, and quartz, and 3) well-foliated, banded gneisses composed of black, pyroxene-biotite and hornblende-biotite gneisses interlayered with pink to gray granitic and augen gneisses. The dark-colored gneisses are composed of biotite, plagioclase, and hornblende or pyroxene, with accessory apatite, zircon, and magnetite. The light-colored interlayers are similar in composition to the granitic gneisses in the outcrop.

In addition to these 3 major lithologies, this outcrop contains minor amounts of amphibolite, biotite-oligoclase augen gneiss, quartzofeldspathic hornblende gneiss, and biotite-plagioclase schist all interlayered with granitic gneisses and granitic augen gneisses.

The foliation is defined differently in each of the 3 main lithologies. In the granitic gneiss, the foliation is defined both by the parallel alignment of dispersed biotite and by alternating layers of different grain size (but similar composition). In the augen gneiss, the foliation is defined by large, flattened and streamlined K-feldspar grains outlined by ribbons of quartz. The foliation defined by the flattened grains is enhanced by an irregular compositional layering defined by lenses of pink K-feldspar (commonly strung out into layers) alternating with stringers of quartz, plagioclase, and hornblende. In the banded gneiss, foliation is defined primarily by alternating layers of different compositions, one light-colored and rich in quartz and feldspar, the other dark-colored and rich in mafic minerals. Within the dark-colored gneiss, foliation is enhanced by the parallel alignment of biotite. None of the 3 major lithologies has enough mica in it for the foliation to also be a good rock cleavage direction. As a result, all of the major lithologies are blocky and tough.

Although these rocks are metamorphic, the outcrop displays many classic relict igneous features. The granitic gneisses were evidently originally granitic magmas that thoroughly and intimately invaded a country rock of dark-colored gneisses. The dark-colored gneisses, then, might well be xenoliths, remnants of the country rock caught up during intrusion of granitic magmas. The great variety of grain size amongst the granitic gneisses, and the complicated multiple cross-cutting relationships attest to a period of multiple intrusions. Evidence in this outcrop also suggests that deformation was going on as the magmas were being intruded (*i.e.*, that the granitic magmas were syntectonic). Some folds in the dark-colored gneisses are truncated by the granitic gneisses, implying intrusion after folding. On the other hand, some granitic gneisses interlayered with the dark-colored gneisses are folded right along with the dark-colored gneiss. In fact, some of the extremely flattened augen in the augen gneisses are folded. Both suggest folding *after* granite emplacement. Folding after and folding before granite emplacement implies protracted and syntectonic intrusion. Because all units are foliated, deformation must have outlasted the intrusive episodes.

The other relict igneous features in this outcrop are the augen in the augen gneisses. The augen gneiss may also be referred to as a megacrystic gneiss, in allusion to the enormous size of the deformed feldspar crystals that make up the augen. The metacrysts or augen are very likely relict phenocrysts formed during early slow cooling of a granitic magma with a two-stage cooling history.

As suggested in the previous paragraph, the protolith (pre-metamorphic rock type) for the granitic gneiss was probably a granite. Metamorphism did very little to its original mineral composition, because temperatures during metamorphism were nearly as high as the temperature of a granitic melt at those depths. In other words, the minerals in the granite were perfectly happy under the conditions of metamorphism. Even though the overall mineral content did not change appreciably during metamorphism, individual mineral grains did become unstable and recrystallize in new orientations in response to deformation in the rock. In this manner, the granite acquired a foliation of recrystallized and aligned biotite and became a granitic gneiss. The foliation defined by interlayers of different grain sizes is likely due in part to inheritance of primary textural differences and in part to deformation.

The protolith for the augen gneiss was probably a porphyritic granite. Its metamorphic minerals are not substantially different from those in the protolith, but deformation and recrystallization produced a well-developed foliation in the rock. If you look carefully at the augen gneisses in this outcrop, you will see that there is a range in texture from blocky pink feldspars set in a poorly-foliated matrix to stringers of pink feldspar set in a well-foliated matrix. These differences in texture undoubtedly result from differences in intensity of deformation. As the amount of shearing in a layer increases, the feldspar tabs flatten. Strain is highest along the margins of the grains, particularly at the corners; the edges and corners of the feldspars begin to recrystallize into networks of tiny, stable feldspar grains (figure 6). These tiny grains are then no longer part of the larger feldspar tab - they have been, in effect, transferred to the matrix. Plastic flattening of the grain, then, is accompanied by some grain size reduction and a change of grain shape from blocky to eye-shaped. Some of the large feldspar grains are also fractured, if plastic deformation in the grain can't keep up with deformation in the rock. Changes are also happening in the matrix minerals. Platy and prismatic minerals such as biotite and hornblende recrystallize parallel to the flattening plane of the feldspar tabs, creating a foliation wrapping around the developing augen. Coarse quartz grains become flattened, ribbon-shaped grains oriented parallel to the foliation and wrapping around the augen. Many of these deformed quartz grains undergo the same kind of dynamic recrystallization that affects the margins of the feldspars. New, tiny grains of quartz form from the old strained grains. Quartz is very susceptible to the dynamic recrystallization process and undergoes grain size reduction much more readily than feldspars. Therefore, when you look at the augen gneiss, realize that some of the disparity in grain size between augen and matrix was produced during deformation. In fact, many augen gneisses of the world began life as uniformly coarse-grained rocks; not all augen gneisses had porphyritic parents.

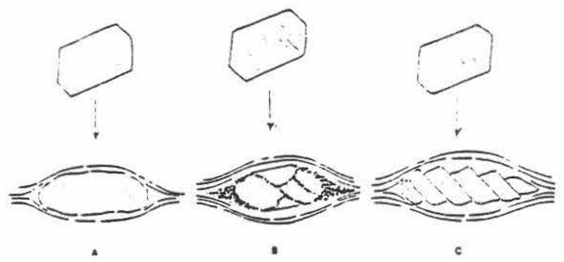


Figure 6. Formation of augen by crystal plastic processes (a), dynamic recrystallization (b), and brittle fracture (c). These processes need not operate separately.

Determining the protolith for the dark-colored gneisses is somewhat more problematic, and both igneous and sedimentary protoliths are possible. The dark-colored gneisses are intimately interlayered with light-colored gneisses and augen gneisses to form packages of conspicuously banded gneiss. Questions concerning the origin of the banding cannot be answered unequivocally. The fact that many of the light-colored layers can be traced to larger masses of granitic gneisses suggests that at least some of the banding may be intrusive, the result of intimate interfingering of dark gneiss and granitic magma (a lit-par-lit gneiss). Layers that cannot be traced to a granitic mass may be either light-colored layers in the original country rock, or granitic material derived very locally by partial melting of the dark-colored gneiss and creation of migmatites. Considering that metamorphic temperatures were very close to the minimum melting temperatures of many types of metasediments, the ultimate source of the large volumes of granitic magma in the Croghan area was very likely the metamorphic complex itself. Local partial melting of the dark gneisses may have taken place as well.

After viewing the Precambrian geology, let's jump ahead about a billion years to see what effect the Wisconsinan ice sheet had on this locality. The top of the outcrop is a smoothed and polished surface, produced as glacial ice with entrained sediment sand-papered and rounded the hard Precambrian rock. Some differential erosion can be seen along zones of dark gneiss. The grooves and shallow potholes suggest that the outcrop may not only have been glacially scoured but also eroded by running water. Marginal or subglacial meltwaters, particularly related to a stagnant ice mass, are good candidates.

Proceed eastward over the top of the outcrop to a low exposure of Precambrian bedrock about 30m away. This outcrop displays distinctive scratches and grooves (glacial striae) trending S10-20°W, parallel to the last ice movement direction in the area. Looking south from this outcrop, you will see a hill with a sand quarry. This hill is part of a series of hills extending the entire length of the Lowville quadrangle. The line of hills trends north-south, with a slight dog-leg near this stop. The deposits that underlie these elongate hills are largely unconsolidated sediments dating from the late Pleistocene. As discussed at stops 1 and 2, Pleistocene deposits in this area include ground moraine (both ablation and lodgement till), morainal ridges (typically composed of till overlain by patchy stratified drift), kame terraces and crevasse fillings (stratified drift), eskers (stratified drift), outwash (fluvial deposits), and pro-glacial lake deposits (beach and deltaic deposits, varved clays, etc.). Each of these deposits has distinctive characteristics, and examination of the deposits in this quarry should allow us at least to rule out some of the possibilities. This deposit was originally described by Buddington (1934) as a moraine. However, close examination shows structures consistent with sediment deposited by running water, rather than directly by melting ice. If these deposits are ice contact sediments, deposition was dominated by fluvioglacial processes.

Sediments in the quarry are conspicuously stratified. Scour and fill structures are common. Cross bedding occurs at many different scales, but many layers exhibit planar laminae. A majority of the deposit consists of sand-sized grains, although there are some layers of very fine grains as well as some layers of pebbly sand. Individual layers are typically moderately well-sorted to well-sorted. The characteristics of sorting and stratification in these sediments indicate deposition from a moving current; direct ice deposition does not produce stratified and sorted sediments. Therefore, these sediments are not tills.

Cut and fill structures, cross-bedding, and some pebble imbrication are consistent with fluvial deposition. At this stop, stratified sediment lies directly on water-scoured Precambrian bedrock; there is no intervening morainal till. It appears, then, that at least this portion of the deposit does not represent a veneer of stratified drift over ridges of morainal debris.

Some of the horizons in the quarry consist of thinly laminated find sand and silt. Cross-bedding is absent, and individual layers are laterally extensive and easily-traceable. These may represent sediments deposited in closed depressions such as small ponds. Some of these fine-grained layers contain cobbles that may well be dropstones.

The fact that these deposits are part of an elongate but not sinuous ridge system suggests that these deposits are not part of an esker, a pro-glacial lake, or an outwash plain (although dissected outwash is a possibility). A stratified ice contact deposit is the most logical choice - perhaps an ice-marginal deposit or a very large crevasse filling in stagnant ice. The fact that slopes on the west sides of the hills are steeper than those on the east sides suggests that the main ice contact side of the deposit may have been on the west.

Turn around, and return south on route 812 towards Lowville.

97.4 Spectacular view to the west of the Tug Hill Plateau, underlain by Middle and Upper Ordovician sedimentary rocks.
99.8 New Bremen bridge.
101.0 An even better view of the Tug Hill Plateau.
103.3 STOP 4. Pull off the road across from the Dadville Quarry.

STOP 4: DADVILLE QUARRY

After repeated searches, neither of us has ever found an exposure of the Precambrian/Paleozoic unconformity (Plate I) in the Black River Valley, although such exposures have been reported in the literature (Miller, 1910). The unconformity *is* spectacularly exposed in roadcuts near Kingston, Ontario, but that's a bit far away for this field trip. The outcrops at the Dadville Quarry constrain the position of the unconformity better than almost anywhere in the Black River Valley, and we'll have to settle for that.

Precambrian granitic gneisses crop out on the north side of the road in front of the Highway Department Building. Standing on the Precambrian, one can look east and see many knobs of Precambrian rock scattered throughout the Black River Valley and nearly buried by Pleistocene sediments. Directly southeast across the road, Middle Ordovician limestones of the Black River Group are exposed in an active quarry. The trace of the unconformity must lie just below the quarry floor, swinging around the base of the hill and across the road west of where we are standing. From the base of the hill, the unconformity dips very gently (only a few degrees) to the southwest.

Why can't we see the unconformity in the quarry? Surely they must have quarried through to the Precambrian in places, you think. In point of fact, they haven't quarried to the Precambrian, and a look at the stratigraphic column in Plate I will tell us why. The quarry owners are interested in limestones, and the Black River Group has good limestones in all but the Pamelia Formation at the bottom of the Group. As soon as they reached the Pamelia, they stopped quarrying.

A look at the topographic map would show that the position of the unconformity is marked here by a distinct break in topography. As we continue to drive south, you might find it interesting to check the topographic map for other breaks in slope, and examine the countryside and outcrops to see whether those breaks in slope mark the Precambrian/Paleozoic unconformity or not.

104.0 Continue south on route 812. The houses on the left are perched on a bench in the Paleozoic that marks the contact between the Black River Group and the Trenton Group, both of Ordovician age. That bench and contact can be traced south on the topo map from stop 4. The next major bench to the west lies at a stratigraphic horizon within the lower portion of the Denley Limestone.
104.4 Turn right on E. State Street (route 812).
105.0 Junction routes 12 and 26; turn left, and go south on routes 12 and 26.
105.6 Bear left at the Y, and proceed south on route 12.
109.6 Crossing Roaring Brook. Precambrian basement rock is exposed in the field to the east of the bridge, and Paleozoic sediments crop out immediately west of the bridge in the stream channel. The unconformity must lie somewhere between the 2 exposures, although the actual contact is not exposed at the surface.
111.7 Rounded knobs of Precambrian gneisses dot the field to the east of the road; Paleozoic sediments begin to the west of the road at the first topographic rise.

Town of Glenfield to the east. The topo map shows how well the topography reflects the geology. The base of the first sharp slope west of Glenfield lies at the Precambrian/Paleozoic unconformity. The first bench marks the top of the Black River Group. The second major bench marks a horizon within the lower Denley Limestone. The third bench marks the top of the Denley, and the 4th bench marks the top of the Steuben Limestone. The base of the major slope at the Whetstone Gulf Campground marks the contact between the Steuben Limestone and the Utica Shale. The last bench lies at the contact between the Utica Shale and the Lorraine Group (equivalent to the Frankfort Shale).

111.9 Pleistocene glacial deposits mask most of the rocks near the unconformity.

117.1 Route 12 lies on Precambrian bedrock; an outcrop of the Pamelia Formation (lower Black River Group) lies approximately 50m west up Snugsboro Road.

118.8 Outcrops of the lower Black River Group line the lower part of Turin Road to the west.

119.3 Between the last mileage point and this one, the road has crossed the unconformity; outcrops of the Lowville Formation (Black River Group) lie immediately west of the road.

119.6 Junction with 12D; continue south on route 12.

119.9 From here south, the railroad tracks approximately follow the unconformity.

120.4 Outcrop of Precambrian granitic gneiss east of road; glacial deposits blanket much of the Precambrian in this area.

122.3 Crossroads at Port Leyden. Continue south on route 12.

124.1 Precambrian diopside-quartz-phlogopite gneiss on the east side of the road. The protolith for these metasedimentary units was probably a dirty carbonate, such as a sandy dolomstone.

125.5 Historic marker for the Black River Canal. The Canal was completed in 1855 and linked Carthage and Rome. In a 35-mile stretch through the steepest terrain, workers constructed 109 locks. The locks were built with limestones quarried from the Black River Group, as were many of the dove-gray stone buildings in the North Country.

126.5 STOPS 5 AND 6. Park well off the road north of the bridge. Watch your socks.

STOP 5: SUGAR RIVER, EAST OF ROUTE 12

THIS IS PRIVATE PROPERTY. You *MUST* obtain permission from Barrett Paving Company (the quarry owners) if you wish to examine the rocks along the Sugar River. The owners have been very generous in the past in allowing groups to visit the exquisite features on their property. However, repeated unauthorized entry by inconsiderate geologists to properties at many other places around the country has rightfully angered many property owners. As a result, many classic localities are now completely off limits, even to those who properly seek permission. Don't take a chance on spoiling the Sugar River spot for everyone else. Be *sure* to get permission. Encourage others to do the same.

ALSO - BEWARE THE UNUSUALLY LUSH AND PREDATORY POISON IVY.

These beautiful gray limestones are part of the Watertown Formation at the top of the Black River Group (Plate I) and were deposited as a subtital[1] sequence on the North American passive continental margin during the Early Middle Ordovician. At several stops on this field trip, we will be examining carbonate sequences. Limestones and dolostones, composed of calcite and dolomite respectively, exhibit a wide range of textures and structures, but all share the common characteristic of being *biogenically-derived*. Very few post-Precambrian carbonates are pure, non-biogenic chemical precipitates. In addition, one should keep the distinction in mind between detrital clastic rocks such as sandstones and shales, whose fragments are derived from weathering of a *distant* source, and carbonates, whose fragments are derived very locally by organic precipitation of calcite. Neither animals nor plants precipitate dolomite, and virtually all dolomite in the sedimentary record results from replacement of calcite by its magnesium-rich counterpart, dolomite.

In order to help unravel the environment of deposition of a carbonate rock, it is useful to know in what form the calcite or dolomite occurs in a rock. Calcite can occur in a carbonate rock as skeletal debris, carbonate mud, sparry calcite, intraclasts, and pellets; dolomite can occur as early dolomite or secondary dolomite.

- *Skeletal debris* consists of the remains of organisms, sometimes well-preserved in life position and not transported very far. Skeletal debris commonly consists of broken and disarticulated fossils and may be as fine as silt-sized particles.
- When communication by currents or biologic activity reduces fossil fragments to mud-sized particles, the material is called *carbonate mud*. Lithified carbonate mud is referred to as "micrite" – microcrystalline calcite.
- *Sparry calcite* is coarsely crystalline calcite precipitated as a secondary mineral in pores and burrows. Some

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[1] *subtital*: almost always below low tide; *intertidal*: almost always between high and low tide; *supratidal*: almost always above high tide.

skeletal carbonates have a micritic matrix, others have a sparry matrix, depending upon whether the environment winnowed out very fine carbonate particles at the time of deposition.

- *Intraclasts* are non-skeletal fragments >.2mm in size and associated with erosional intervals. They represent fragments of previously-deposited and partly-consolidated sediment (very locally-derived, of course).
- Many *pellets* are probably intraclasts <.2mm in size, although some may well be fecal pellets.
- *Early dolomite* commonly occurs in thin laminae and forms by migration of magnesium-rich waters upward through the sediments, followed by penecontemporaneous replacement of calcite by dolomite. Early dolomite is almost always found in supratidal settings.
- *Secondary dolomite* forms well after deposition of the sediment and is highly variable, filling vugs, replacing calcite, or cementing clastic rocks.

A given carbonate rock may be composed of any combination of the ingredients listed above. Which components are combined and how they are combined governs the appearance of any individual carbonate rock. The word "limestone" describes anything from a hash of boulder-sized fossil fragments to a featureless, ultrafine-grained micrite. In self-defense, sedimentologists have derived a whole raft of esoteric terms to convey more than simple "limestone". The following definitions should help you to wade through most field guides:

calcirudites: carbonate equivalent of conglomeratic grain size
calcarenites: carbonate equivalent of sandstone grain size
calcisiltites: carbonate equivalent of siltstone grain size
calcilutites: carbonate equivalent of mudstone grain size
micrite: limestone formed from a carbonate mud
biomicrite: limestone formed from skeletal debris & carbonate mud
biosparite: limestone formed from skeletal debris & sparry calcite

Grain size is generally indicative of the energy of the environment, although one must bear in mind that large *fossils* do not by themselves indicate a high energy environment, because the animals *lived* in the environment and were not transported there.

If exposed to periodic exposure and dessication, carbonates may show mudcracks and local erosion surfaces. If deposited by currents, carbonate sediments may be cross-stratified. If burrowing organisms lived and fed in the carbonate substrate, the sediment may show burrows (horizontal or vertical). Active bioturbation (i.e., churning of the sediment by burrowing organisms) may completely destroy any fine-scale depositional structures such as bedding or lamination.

The Watertown Formation is a very dark gray limestone with fossils and fossil fragments floating in a very fine-grained matrix. The matrix is micritic, and "clumpiness" of the micrite has prompted Walker (1973) to suggest that the micrite may have been pelletal. Bioclasts (both unabraded fossils and abraded fossil fragments) generally make up 10-30% of the rock, although percentages range as low as 4% and as high as 53% (Walker, 1973). The more fossiliferous lithologies would be properly called biomicrites. In all cases, bioclasts "float" in a matrix of micrite. Black chert nodules are common throughout the unit.

Stratification is virtually absent in the Watertown Formation, because the carbonate muds were completely churned by burrowing organisms who ate their way through the soft sediment. Much of the pelletal texture in the micrite may have originated as fecal pellets excreted as these organisms reworked the sediment. Networks of horizontal burrows thoroughly mottle this limestone and show up well on weathered horizontal surfaces. Mudcracks are absent, as are intraclasts and erosional intervals. Sparry calcite is confined to burrows.

Fossils in the Watertown Formation are illustrated in figure 7 and include:

rugose (horn) corals (*Lambeophyllum*)
tabulate corals (*Foerstephyllum*)
stromatoporoids (*Stromatocerium*)
echinoderm fragments
straight-shelled nautiloid cephalopods (*Actinoceras & Endoceras*)
bryozoans (*Eridotrypa*)
calcareous algae (*Hedstroemia*)
rare brachiopods (*Dalmanella & Strophomena*)

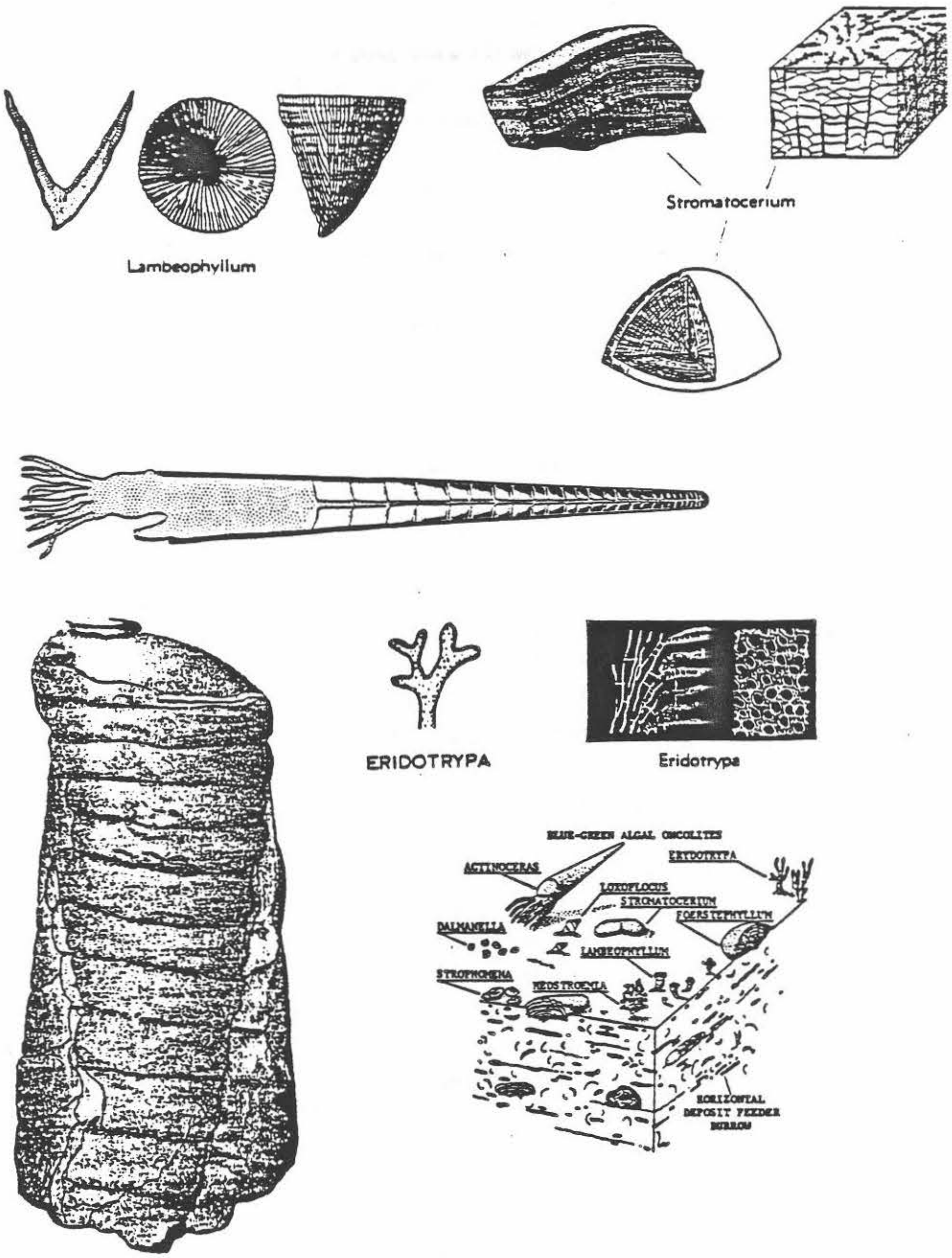


Figure 7. Fossils from the Watertown Formation. Diagrams from Cameron et al., 1972; Moore et al., 1952; Tasch, 1980; Titus, 1977; Walker and Laporte, 1980.

rare coiled gastropods (*Loxoplocus*)
horizontal burrows of deposit feeders

How high was the energy of the environment in which the Watertown was deposited? The fact that the rock is micrite-dominated suggests that the environment was a quiet, low-energy one, generally incapable of transporting anything but fine to very fine grains. How, then, do we explain the abundant sand-sized bioclasts (which can be felt by rubbing a hand over a weathered surface - they feel like sand scattered in a nice coat of varnish)? Walker (1973) has suggested that most of the sand-sized bioclasts are porous echinoderm fragments. Porosity would reduce their densities and allow them to "behave" as smaller particles would in a current. Okay, but then how do we explain the very large fossil fragments, like the 3-meter-long nautiloids? Large fossil fragments can easily accumulate in a very fine-grained matrix if the animals lived on the bottom or died in the water column above and sank to the bottom. Currents are not required to move them to their sites of accumulation. One would expect that these large pieces might not be significantly abraded, although they may well be broken if someone had dined on the carcasses before they were buried. Lastly, how do we explain the presence of large chert nodules? It turns out that chert nodules are a secondary phenomenon and are formed in a sediment after deposition. Solutions rich in silica soak through the sediment and replace portions of the rock with silica, creating chert nodules. In a carbonate rock, it's not immediately obvious where the silica should come from. In the Black River Group, silica may have come from leached beds of volcanic ash or from solution of fragments of siliceous sponges. Volcanic ash is a good candidate, because thin volcanic ash layers blown from eruptions in the approaching Taconic Island Arc occur sporadically throughout the upper Black River Group.

What clues have emerged regarding the environment of deposition of the Watertown Formation? Fine grain size of the matrix points to a dominantly low-energy environment. Lack of mudcracks, intraclasts, and erosional intervals suggests that the bottom was always below low tide (a subtidal environment). Lack of deep burrowers supports this, suggesting that organisms did not need to burrow deeply to escape a hostile environment. The fauna consists of animals related to those in the Recent that require normal marine salinities (Walker, 1973) and prefer not to be bothered by daily tides. Modern calcareous algae require water depths of less than 80m in clear water in order to photosynthesize, and Walker (1973) suggests that carbonate mud might have made the water turbid enough during deposition of the Watertown that 10m might have been the maximum depth for photosynthesis. If we put this all together, we come up with an offshore shallow marine environment with good circulation and rare turbulence. The area would have normally been below wave base, but rare storms likely stirred up the bottom. The water would also likely have been warm, because central New York State was located about 20° south of the equator during the Ordovician. A pleasant place to live.

The limestones along the Sugar River display spectacular solution features, particularly in the massively-bedded Watertown Formation. One is first struck by the smooth, rounded, doughy-looking outcrops, and then by solution enlargement of joints, producing huge blocks of limestone along the streambed. Farther downstream, a magnificent train of potholes lines the stream channel, many containing pothole stones. Solution is as important as abrasion in creating these potholes. The most spectacular solution features, however, are the swallow holes. During a dry summer or fall, the Sugar River vanishes completely into swallow holes and never reaches the confluence with the Black River. However, during high water, a decrease in volume is difficult to see. Some of the lost water emerges as substantial springs along the face of the quarry. A look at the quarry face will suggest to you that the subsurface flow takes place through solution-enlarged joints, many along bedding surfaces, rather than through gigantic subterranean tunnels. DO NOT WALK TO THE EDGE OF THE QUARRY FACE - MUCH OF IT IS OVERHUNG AND UNSAFE. If you walk a short distance northeast, you will find the outlet for most of the swallowed Sugar River water — the Little Sugar River heads in a spectacular blind valley just easy of the quarry. The blind valley shows up well on the topographic map.

Glacial erratics dot the Black River Valley, and there is a *very* large granitic gneiss erratic smack in the middle of the Sugar River channel. The Sugar River probably makes headway in moving it about once every 200 years or so. (By the by, why aren't there any glacial striae on the bedrock at the Sugar River??)

STOP 6 - LOWER TRENTON GROUP, SUGAR RIVER

The fine-grained, fossiliferous limestones and interlayered shales in this outcrop are part of the lower portion of the Trenton Group (Plate I) and were deposited in shallow Middle Ordovician seas at a time when the Taconic Island Arc Terrane had just begun to collide with the continental margin of North America.

The lower 2/3 of the outcrop belongs to the Napanee Limestone, the upper 1/3 to the Kings Falls Limestone. Both are part of the Trenton Group. Geologists who have studied the Trenton have chosen to divide the sequence into a total of 6 formations, only 2 of which are exposed here, and it is interesting to consider why they have done so and on what basis. Rock sequences are divided into formations within which rock types show some degree of internal homogeneity or sequence that distinguishes them from adjacent sequences. Some genetic connotation is implied, and one generally views the conditions or range of conditions of formation for a particular formation to be different from those in adjacent units. If they weren't, they'd all be part of the same formation. Formations must also be thick enough to be mappable at a reasonable scale. Some formation boundaries are obvious. For instance, there is a conspicuous difference between the Napanee Limestone and the Watertown Formation, which we just visited. Anyone would put them into different formations. However, we did not see the upper Watertown or lower Napanee. If they grade into one another, you might not place the formation boundary at the same place I would, and there's nothing wrong with that. Other formational boundaries are not so obvious. Take the one in this outcrop, for instance. The formation boundary between the Napanee below and the Kings Falls above separates thinly interbedded limestones and shales from thickly interbedded limestones and shales. One's first reaction is that there's not that much difference between the 2 units and that it all ought to be one formation. But, when we examine the details, we find that the limestone in the Napanee is dominantly very fine grained and sparsely fossiliferous, while the limestone in the Kings Falls is coarse and very fossiliferous. The subtle change in thickness of beds also marks a change in the environment of deposition, and it *does* make sense to place a formation boundary between the two.

The limestones in the Napanee are primarily sparsely fossiliferous micrites composed dominantly of carbonate mud (some pelletal) with infrequent, discontinuous skeletal laminae. There are some highly fossiliferous micrites (biomicrites), with many fossils and fossil fragments set in a carbonate mud matrix, and rare biopelmicrites, a fossil and pellet hash cemented by secondary calcite. The limestones are interlayered with black, sparsely-fossiliferous calcareous shales. In general, the coarser, fossiliferous limestones increase in abundance upward (Cameron *et al.*, 1972). The coarser layers show some ripples and cross-stratification, but none of the layers contains mudcracks. The limestones display some vertical burrows, but they are not thoroughly burrow-mottled, as the Watertown Formation is.

In contrast, limestones in the Kings Falls are primarily shelly limestones and fossil hashes; matrix material is dominantly sparry rather than micritic. These limestones are referred to as biosparites or shelly calcarenties. Layers of thinly bedded calcareous shale alternate with layers of limestone, as they do in the Napanee, but limestone layers are considerably thicker in the Kings Falls than in the Napanee. Limestones in the Kings Falls show abundant high energy features, including cross-stratification, ripples, erosional surfaces, intraclasts, and an absence of micritic material (Titus and Cameron, 1976). These limestones accumulated as a collection of fossil fragments in an environment that winnowed out carbonate mud; spaces between fossil fragments were later filled with secondary, coarsely crystalline (sparry) calcite. A close look at a talus block from one of the Kings Falls layers will show you reflections from calcite cleavage surfaces 1mm or more across - these are calcite grains of the secondary sparry matrix.

The fauna is brachiopod-dominated — about 1/3 of the species present are brachiopods (Titus, 1977). Fossils in the Napanee Limestone are illustrated in figure 8 and include:

brachiopods (*Triplesia, Dalmanella, Sowerbyella, Rafinesquina, Strophomena, Paucicrura, Hesperorthis*)
broyzoa (*Prasopora, Stictopora, Amplexopora*)
crinold fragments
trilobites (*Flexicalymene, Isotelus, Ceraurus*)
snails - particularly in the lower Kings Falls (*Sinuites, Liospira, Subulites, Hormotoma, Loxoplocus,*
    Phragmolites)
ostracodes
coral - in the lower Kings Falls (*Lambeophyllum*)

The fauna in these 2 formations is dominated by low filter feeders (such as brachiopods and bryozoa), with some grazers (such as trilobites, gastropods, and ostracodes).

What clues have emerged regarding the environment of deposition of the Napanee and Kings Falls Limestones? The absence of mudcracks and other evidence of dessication in both formations, taken together with the abundant remains of marine organisms (few of whom could have managed a twice-daily low tide), suggest a subtidal environment. The dominance of sparry matrix in the Kings Falls and micritic matrix in the Napanee indicates that the Kings Falls was deposited in a high energy environment that winnowed carbonate mud, while the Napanee was deposited in a quieter environment that enabled carbonate mud to accumulate. However, presence of shaly laminae in the Kings Falls suggests that quiet water prevailed from time to time. The presence of cross-stratification, ripples, and erosional intervals, particularly in the Kings Falls, indicates that the environment was frequently above wave base. This conclusion is supported by the presence of fossil hash (coquina) layers, particularly in the Kings Falls. These layers are composed of disarticulated and broken skeletal materials, transported to the site of deposition by currents. Taken together, the evidence indicates deposition in shallow water, in a high subtidal

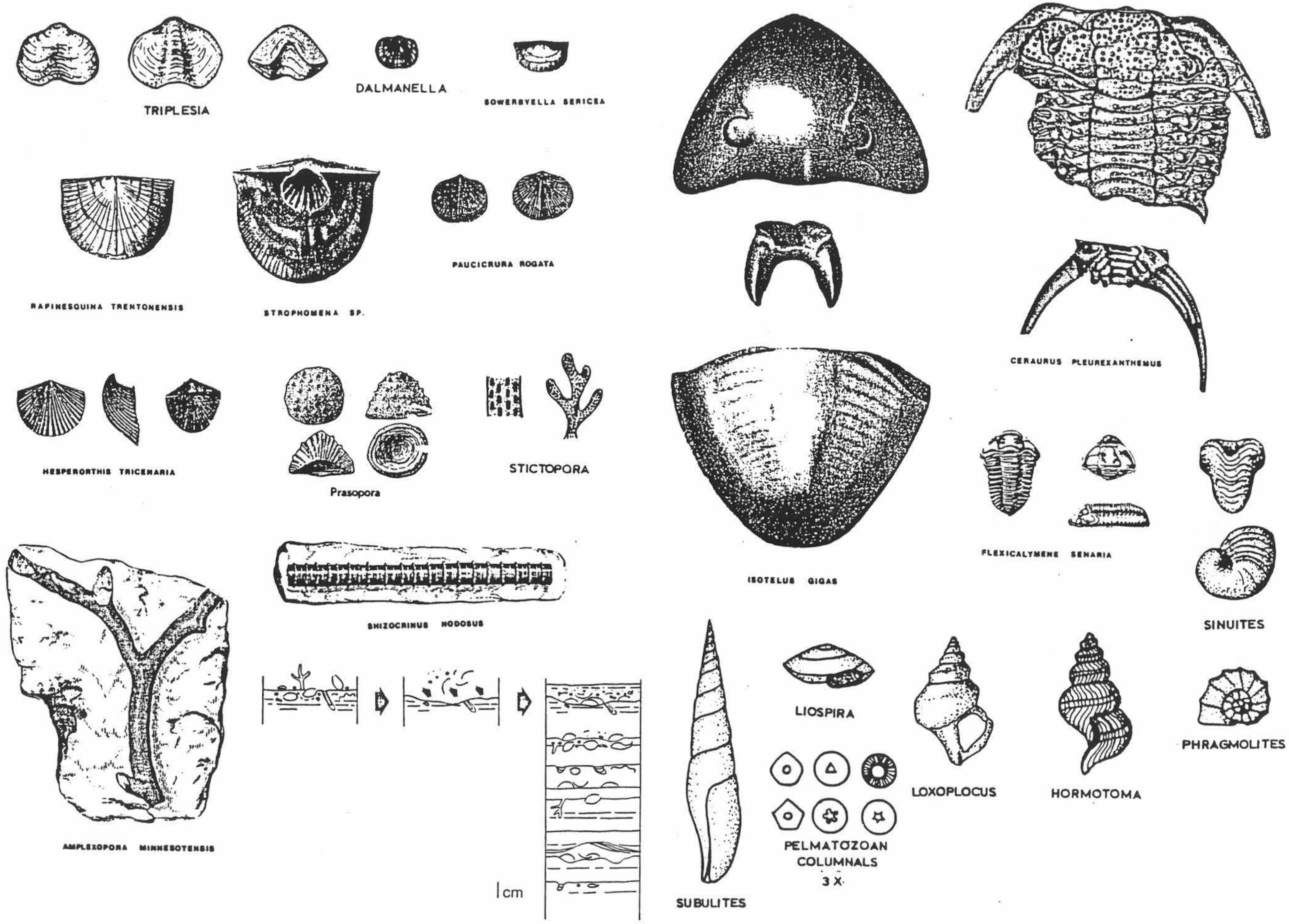


Figure 8. Fossils from the Lower Trenton Group. Diagrams from Cameron er al., 1972; Moore et al., 1952; Titus, 1977; Tasch, 1980.

environment. The Napanee was probably deposited in a shallow, shelf-lagoon, while the coarse, sparry Kings Falls was deposited in a waveswept offshore shoal (Cameron *et al.*, 1972; Titus and Cameron, 1976). Both were deposited in water shallower (or at least more agitated) than that characteristic of the Watertown Formation, which we just visited.

The repetitious interlayering of limestone and shale is an interesting puzzle. D.W. Larson (pers. comm., 1984) suggests that the interlayering is a storm-generated phenomenon, with the following scenario. Clay mixed with some carbonate may well have been the steady-state, everyday, slowly-accumulated sediment. The product would have been a calcareous clay mud deposited in a quiet-water environment incapable of transporting the silt-sized to coarse sand or pebble-sized carbonate grains and fossil fragments characteristic of the limestone layers. During storms, energy in the environment would have increased dramatically, bringing coarser carbonate detritus in from adjacent, higher-energy environments, and redistributing carbonate material previously deposited locally. The energy during storms would have been enough to winnow clays at the sediment/water interface, and carbonates of silt size or greater would have accumulated relatively rapidly. If you look carefully, you might even be able to convince yourself that some of the limestone layers in the Napanee are graded, with coarse fossil fragments decreasing in both abundance and size upward from the base of a layer.

In this scenario, the limestone layers represent relatively rapid, storm-related deposition. The rare, thin skeletal laminae within and at the top of limestone layers presumable contain fossils in or near life position and represent a community of organisms developed on the bottom after a storm. Storm-sequence deposition is illustrated in figure 8.

As one goes east in the Trenton Group, sediments record features of deeper water deposition. Here, too, limestones alternate with shales, but the limestones are very different in character. They show features that suggest deposition by turbidity currents in quite deep water. Earthquakes may well have shaken carbonate sediments lying on the shallow shelf to the west, mobilizing them into a great slurry that slid eastward just above the bottom. As the turbidity current slowed, layers of lime sands and muds settled out of the water, draped over the clay muds normally deposited in the environment.

Studies of features such as this tell us that the Trenton Group was deposited in sedimentary environments that ranged from low-energy lagoons to wave scoured barrier shoals, shallow and deep shelves, and a slope connecting the shelf to the west with a basin to the east. One shoreline appears to have lain well to the west of New York State. A shallow shelf extended as far east as the Black River Valley. East of there, water depths varied a surprising amount. Deep water changed to shallow water and back to deep water again several times between Utica and Albany. We think that indicates the presence of a number of fault blocks - horsts and grabens - in the transition zone from the western shelf to the eastern basin (Cisne *et al.*, 1982; Kidd, 1991). The eastern shoreline of the basin lay approximately at the eastern border of New York State at the beginning of Trenton time.

Return to the vehicles, and go ***north*** on route 12.

127.9 Port Leyden
130.1 Turn right and follow the spur to route 12D south.
130.3 Blinking light at base of hill. Continue westward on 12D.
133.2 Turn right at intersection with route 26 north.
140.1 Whetstone Gulf Park entrance. STOP 7.

STOP 7 WHETSTONE GULF

Throughout the region, the limestones and interlayered shales of the Trenton Group that we saw at Stops 5 and 6 are overlain by hundreds of meters of black Utica Shale (Plate I). Over the past few thousand years, Whetstone Creek has carved a steep walled gorge into the very fine-grained, soft black shales and siltstones of the Utica Shale and overlying Whetstone Gulf siltstones and shales. The sediments are much finer grained than any others we will see today and were deposited in an environment little stirred by significant currents. The black color derives from abundant unoxidized organic matter, suggesting that the sediments were deposited in a putrid, anoxic environment incapable of oxidizing dead material as it settled quietly to the bottom of the sea. The Utica Shale in central New York State is considerably thicker (over 10X thicker!) than the earlier sediments we have examined, indicating that significant subsidence must have taken place in order to make room for such a thick accumulation of sediment. The muds accumulated in a basin estimated to have been as much as 500 meters deep, produced as the edge of the Laurentian continent foundered as it collided with the Taconic Island Arc.

The change in fossil assemblages is as striking as the change in rock types. The brachiopods, corals, bryozoans and trilobites that are so common in the Trenton Group and characteristic of well-aerated, warm, shallow waters are missing from the overlying shales. Instead, we find scattered remains of graptolites and trilobites preserved in a rock full of unoxidized organic material. Poor circulation in the deep basin produced an oxygen- and food-deficient environment that was highly charged with iron and poisoned by hydrogen sulfide. The water depths were so foul that no organisms lived there. All of the fossils are of organisms that were swimmers or floaters. Their remains evidently settled to the poisonous bottom when they died, and nothing was there to eat them.

Limestones of the Upper Trenton Group in the western part of the region were being deposited at the same time as the black shales in the Champlain Valley and central Mohawk Valley. If we were to look at a number of sections, we would see that the black shale environment gradually spread westward, until all of the Trenton limestones were blanketed by black muds derived by erosion of a high sediment source in the east.

As the Ordovician drew to a close, the sediments changed yet again. The Utica Shale and Whetstone Gulf shales and siltstones are overlain by Pulaski and Oswego Formations (Plate I). It is these more resistant units that hold up the Tug Hill Plateau above Whetstone Gulf. There are many indications that water became progressively shallower in the Late Ordovician basin. Younger sediments are coarser in grain size, reflecting higher energy environments. The graptolite and trilobite-bearing Whetstone Gulf Formation is overlain by the Pulaski Sandstone, with abundant shallow-water marine clams and brachiopods. These are in turn overlain by the poorly-fossiliferous coarse beach sands of the Oswego Sandstone. The last units deposited during the Ordovician are not even marine - the basin had been completely filled in. The distinctive red shales siltstones, and sandstones of the Queenston Shale, remants of which cap the Tug Hill Plateau, show all the features of an enormous deltaic deposit that spread westward across the State.

While walking along the stream channel, notice that the shale and siltstone layers are strongly jointed. Also keep a sharp eye open for fossils in the talus and along the stream bed. Many cephalopods, brachiopods, trilobites, and graptolites can be found. Some of the cephalopods have been replaced by pyrite and look like tiny rolls of gold coins.

Return to the vehicles, and leave Whetstone Gulf State Park. Return to Route 26, and head south.

147.8 Turn left at intersection with route 12D North
149.9 Flashing light at base of hill.
150.1 Turn right toward 12S.
152.3 Turn left onto Route 12 South.
156.7 Barrett Paving Co. Quarries. Continue south on route 12.
155.5 Good view of Pleistocene delta tops to the northeast and southeast across the Black River Valley. If you look carefully, you can see sand and gravel quarries in the deltaic deposits. Notice how well these delta tops show up on the topo map.
156.8 Turn right on Schuyler Street (at sign to Boonville business district).
157.0 Turn left on route 46 at the stoplight.
157.1 Intersection of routes 294 and 46; continue south on route 46.
157.7 Valley floor near head of Boonville Gorge.
158.7 Sand quarry in Pleistocene meltwater deposits.
159.2 Channel narrows into Gorge, where Pleistocene meltwaters were channeled into Lansing Kill. This was the outlet for glacial Lake Port Leyden, and the topographic feature is known as a meltwater channel. Boonville Gorge was cut by meltwaters relatively quickly during the Pleistocene and has been little modified since. The topo map on the next page shows the abandoned channel north of Lansing Kill and the knickpoint where the channel drops into Boonville Gorge.
160.3 View southward down steep-walled meltwater channel; Lansing Kill is now a small stream in a large, steep-sided valley.
160.9 Outcrop of Middle Ordovician Utica Shale (the uppermost formation in the Trenton Group); the Pleistocene meltwater channel in Boonville Gorge was easily incised into the soft shales of the Utica.
163.3 Entrance to Pixley Falls State Park.
163.5 More Utica Shale.
167.5 For about 1km, undercutting along meanders in Lansing Kill is well-developed.
170.3 Valley widens; erratic on floor to west of road.
170.4 Delta Lake State Park entrance.
171.1 Good view of Delta Lake.
179.9 Traversing floor of glacial Lake Iroquois (before it dropped to the 450' elevation level).
181.4 Junction of routes 26 and 46. Continue south on route 46.
181.8 Traversing glacial Lake Iroquois floor at Fort Stanwix.
181.9 Traffic light; turn left on East Dominic Street.

182.2 Turn right at traffic light, and proceed south on Mill Street.
182.7 Cross Barge Canal.
182.8 At light, turn left on Martin Street.
183.3 Continue straight on route 233.
183.6 Junction of routes 233 and 69; continue south on route 233. The road passes upward from the floor of glacial Lake Iroquois (at 450' level).
189.4 Crossroads and light at Westmoreland; continue south on route 233.
192.2 Intersection of routes 5 and 233; continue south on route 233.
192.7 Kames or dissected esker in fields to east of road.
193.4 Turn left on Norton Avenue.
193.9 Kame or esker remnant at Christmas Knob to north of the road. This feature shows up best during the winter when the leaves are off the trees.
194.5 Turn left onto Kirkland Avenue near the Clinton Arena.
194.6 Take first right, and proceed east on McBride Avenue.
194.7 Crossing filled Chenango Canal.
194.8 Turn left onto Utica Street (route 12B), and proceed north.
195.2 Turn right onto Brimfield Street.
195.4 STOP 8.

STOP 8: CLINTON IRON ORES

The sediments of the Clinton Group (Plate I) are a sequence of extremely varied clastic rocks deposited in nearshore marine environments during the Middle Silurian. Sources for the detritus lay to the east in the eroding highlands of the accreted Taconic Island Arc Terrane. At stop 7, we will have a look at spoil piles dumped during extraction of the Westmoreland Hematite, one of the 2 iron ore horizons in the Clinton Group.

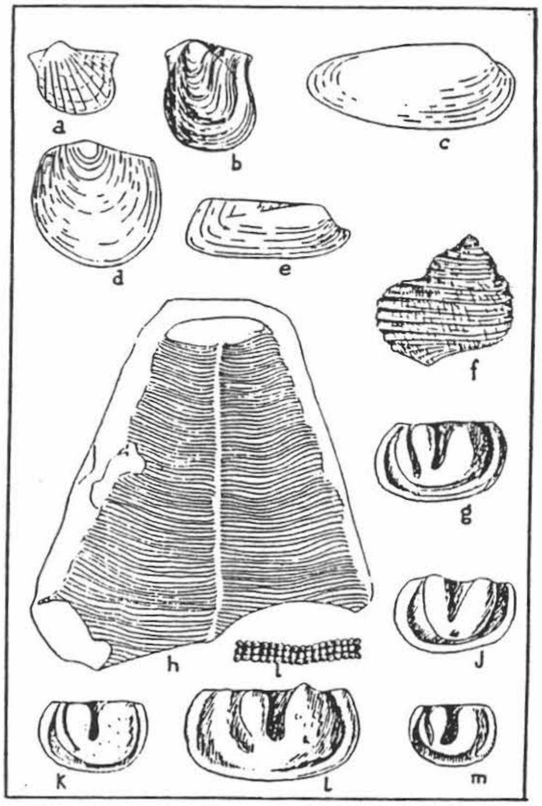
The samples in the spoil piles are dominated by brownish-red calcareous oolitic hematite ore from the Westmoreland Hematite. The ooliths (pron. *oh-oh-liths*) are approximately 1mm in diameter and range in shape from spheroids to oblate spheroids. The ooliths are composed of concentric layers of hematite and chamosite (an iron-silicate mineral) deposited around a nucleus, commonly a well-rounded quartz grain (Dale, 1953; Muskatt, 1972). Sliced in half, the ooliths resemble an old-fashioned fireball candy. Ooliths form when minerals precipitate chemically from seawater around a sand grain or fossil fragment nucleus. As currents roll the ooliths around on the bottom, they acquire layer upon layer of chemical precipitate, in snowball fashion. Calcite ooliths are currently forming on wave-agitated portions of the Bahama banks. In the Westmoreland Hematite, ooliths accumulated hematite instead of calcite. The ooliths are accompanied by rare fossil fragments and are set in a matrix of hematite, sparry calcite, and dolomite (Muskatt, 1972). In some layers, hydration has converted hematite to limonite or goethite, giving the layers an orange, rather than red-brown, color.

In addition to oolitic hematite, specimens in the spoil pile contain layers of gray-green siltstone (no ooliths), fossiliferous red shale (with some ooliths), fossiliferous and burrowed green shale, and sparsely oolitic layers with an abundance of rounded intraclasts and quartz fragments up to 1cm across. Layers are lense-shaped and somewhat discontinuous. Some specimens show well-developed trough cross-stratification, and many of the oolitic hematites show hints of cross-stratification. Megaripples with a wavelength of about .5m occur along the path east of the spoil pile.

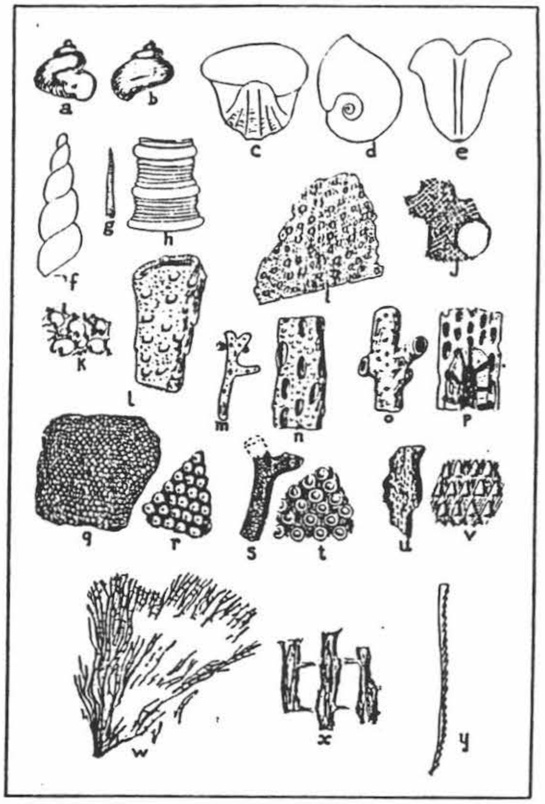
Fossils include brachiopods, trilobites, cephalopods, ostracodes, crinoids, conularids, and traces of many burrowing organisms. Fossils from the Clinton Group are illustrated in figure 9.

What clues emerge concerning the environment of deposition of these units? Presence of cross-stratification, megaripples, coarse detrital particles, intraclasts, erosional intervals, and ooliths all point to a well-agitated environment for the rocks in which these features occur. Finer-grained lithologies demand a quieter environment, and, predictably, these are the lithologies with most of the animal remains and trace fossils. An area above wave base and perhaps occasionally above low tide level is consistent with both sediment types and fauna. Tidal flats, channels, and lagoons interfingering with one another seem to be a reasonable scenario for these rocks.

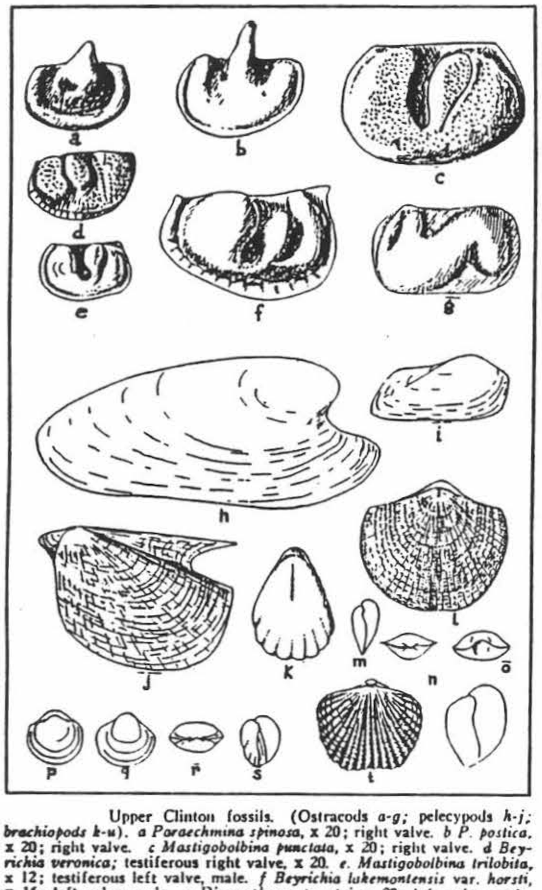
The hematite in these rocks is primary — it accumulated in the sediment right along with the clastic material. The most curious aspect of this, however, is the fact that the iron must have been in solution in the seawater in order for hematite to have precipitated and accumulated as ooliths. This may not seem like must of a problem; after all, seawater is a real soup of dissolved material. The problem is that, under oxidizing marine conditions, iron is extremely insoluble. (Salt water may rust your car, but, once it's rusted, sea water won't dissolve iron oxides off the rusty spots on your car.) Modern marine waters and most river waters contain very little dissolved iron, and there is no evidence to suggest that Middle Silurian seas were very must different overall.



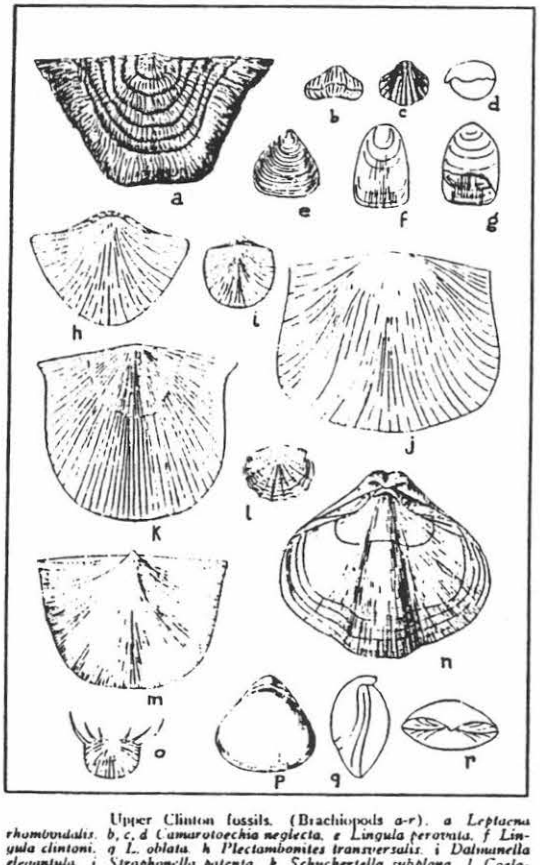
Middle Clinton fossils. (Pelecypods *a-e;* gastropod *f;* conularids *h, i;* ostracods *g, j-m*). *a Pterinea emacerata. b. Leptodesma rhomboidalis. c Ctenodonta machaeriformis. d Cyrtodonta alata. e Orthonota curta. f Cyclonema varicosum. g Mastigobolbina lata;* squeeze of right valve; x 8. *h, i Conularia niagarensis;* with surface detail x 5. *j Zygobolbina conradi;* squeeze of right valve, x 8. *k Mastigobolbina clarkei;* squeeze of right valve, x 8. *l M. vanuxemi;* natural cast of interior of right valve, x 8. *m M. lata;* squeeze of right valve, x 8. (Drawings by V. Caldwell)



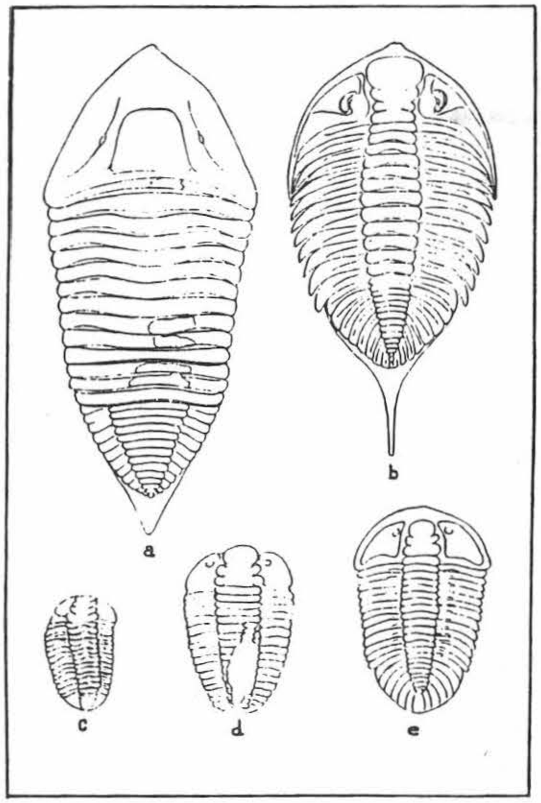
Upper Clinton fossils. (Gastropods, *a, b;* pteropod, *g, h;* bryozoans, *i-v;* graptolites, *w-y*). *a, b Strophostylus cancellatus. c, d, e Bucania bellerophon. f Hormotoma subulata. g, h Tentaculites niagarensis* with enlargement. x 5. *i, j Clathropora frondosa* with enlargement, x 5. *k, l Lioclema asperum* with enlargement, x 5. *m, n Acanthoclema asperum* with enlargement, x 5. *o, p Eridotrypa solida* with enlargement, x 5. *q, r Rhinopora verrucosa,* with enlargement, x 5. *s, t Stictotrypa punctipora* with enlargement, x 5. *u, v Fistulipora crustula* with enlargement, x 5. *w, x Dictyonema sculariforme* with enlargement, x 5. *y Monograptus clintonensis.*



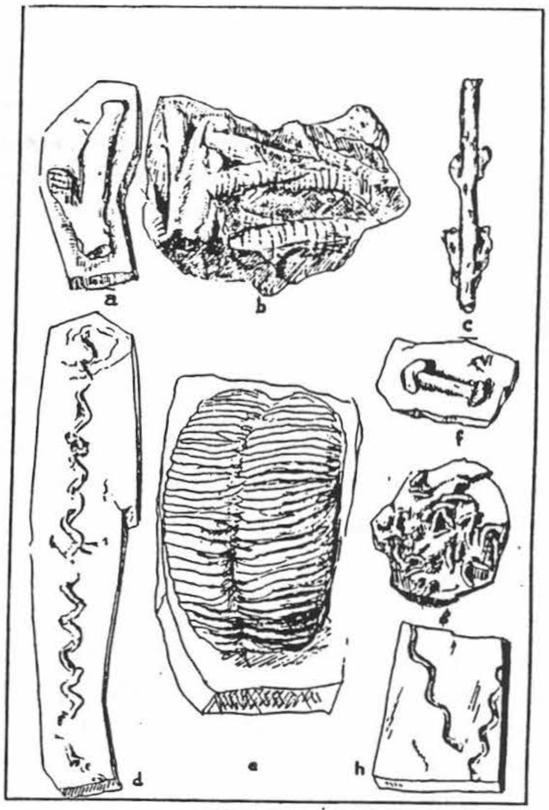
Upper Clinton fossils. (Ostracods *a-g;* pelecypods *h-j; brachiopods k-u*). *a Paraechmina spinosa,* x 20; right valve. *b P. postica,* x 20; right valve. *c Mastigobolbina punctata,* x 20; right valve. *d Beyrichia veronica;* testiferous right valve, x 20. *e. Mastigobolbina trilobita,* x 12; testiferous left valve, male. *f Beyrichia lukemontensis* var. *horsti,* x 16; left valve, male. *g Disygopleura proutyi,* x 20; left valve, male. *h Modiolopsis valida. i M.subcarinata. j Pterinea emacaeata. k Camarotoechia acinus. l, m, n, o Atrypa reticularis. p, q, r, s Nucleospira pisiformis. t, u Atrypa nodostriata.* (Drawn by V. Caldwell)



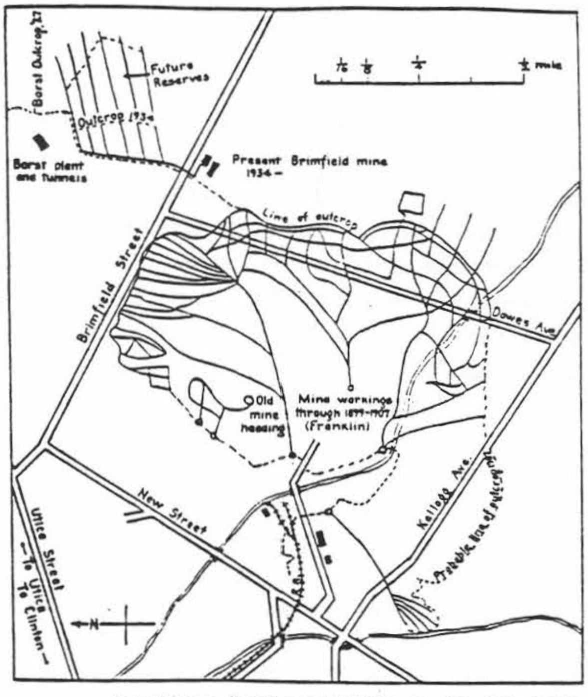
Upper Clinton fossils. (Brachiopods *a-r*). *a Leptaena rhomboidalis. b, c, d Camarotoechia neglecta. e Lingula perovata. f Lingula clintoni. g L. oblata. h Plectambonites transversalis. i Dalmanella elegantula. j Strophonella patenta. k Schuchertella subplana. l Coelospira hemispherica. m Rafinesquina obscura. n "Spirifer" radiatus. o Chonetes cornutus. p, q, r Whitfieldella intermedia.* (Drawings by V. Caldwell.)



Clinton trilobites. *a Homalonotus delphinocephalus*, x ⅓. *b Dalmanites limulurus*. *c Liocalymene clintoni*. *d Calymene conradi?* *e C. niagarensis*.



Clinton fossils. (Sea weeds *a, b, c, e, g*; worm burrow *f*; trail of gastropod *d, h*.). *a Buthotrephis impudica*. *b Arthrophycus alleghaniensis*. *c* Stem of sea weed? *d* Trail of gastropod. *e Rusophycus biloba*. *f* Worm burrow. *g* Stems of marine plants? *h* Trail of gastropod, Herkimer sandstone. (Drawn from specimens by V. Caldwell)



Plan of long wall mining at the Clinton hematite mines. A composite map sketched from property and working maps provided through the courtesy of the Clinton Metallic Paint Co. Stripping operations carried on entirely prior to 1897 are omitted, but followed the 700-foot contour in general; openings being made between New Hartford in the Sauquoit valley and at Clinton, Kirkland, Lairdsville and Hecla Works.

Figure 9. Fossils from the Clinton Group and map of hematite mine workings in Clinton, New York (Dale, 1953).

So, what can make iron soluble? Iron dissolves in very acidic waters and very reducing waters; neutralize or oxidize such water, and the iron with precipitate out. Many workers have suggested that sedimentary iron ores such as the hematitic ores of the Westmoreland formed where hot or cold submarine springs debouched acidic and/or reducing water laden with dissolved iron. Upon mixing with normal marine water, iron oxides and silicates precipitated as ooliths or replaced calcite in fossil material (as in the Kirkland Hematite or "red flux") (Stanton, 1972).

Sedimentary ironstones like the Westmoreland and Kirkland ores are referred to all over the world as "Clinton-type ores", names for the Clinton Group and Clinton, New York. Clinton-type ores have been important sources of iron in the past, supporting such famous steel towns as Birmingham, Aabama. Ores in the Clinton, New York area were exploited as early as 1797, and active mining of ore for pig iron continued until the end of World War I (Dale, 1953). As the huge easily-extractable ores of the Lake Superior Iron Ranges were developed during World War I, mine owners found it less and less profitable to extract ore from the 1-2m-thick hematite layers in Clinton. After World War I, iron ore was extracted for paint and brick pigment only. The operations at stop 7 were run by the Clinton Metallic Paint Company, and workings were entirely underground. Operations began on Brimfield Street in 1928 and shut down in 1963. The map in figure 9 shows the areas of Clinton undermined by iron ore extraction. Many claim that these underground workings have adversely affected groundwater flow in this area.

195.5 Continue east on Brimfield Street.
196.1 Turn right on Dawes Avenue, and proceed south.
196.3 Bridge over Dawes Creek. Herkimer Sandstone (Clinton Group) crops out east of the bridge. Megaripples of two different orientations grace the bedding surfaces along the creek.
197.1 Turn right on Kellogg Street, and proceed west.
197.3 Intersection of Kellogg Street and route 12B. Go straight, and proceed through Clinton on route 12B.
201.9 Intersection of routes 12B and 412. Turn left, and proceed south on route 12B.
204.5 Hamlet of Deansboro.
214.1 Eastern Rock Products Quarry and STOP 9. Park in the parking area east of the road. At the end of this stop, we will return to Clinton via route 12B.

STOP 9: EASTERN ROCK PRODUCTS QUARRY, ORISKANY FALLS

At this stop, we will be interested primarily in glacial features exposed at the rim of the quarry. However, we will have a look at the bedrock if time permits.

Portions of 5 Devonian formations are exposed in the quarry. The lower 35m of gray limestones belong to the Helderberg Group, including 12-15m of the Manlius Formation, 15m of the Coeymans Formation, and 2m of the Kalkberg Formation. 3m of white Oriskany Sandstone forms the prominent band high on the quarry face above the gray Helderberg. 20m of gray Onondaga Limestones at the top of the quarry face is overlain by glacial tills of variable thickness. All of the bedrock units were deposited in shallow epicontinental seas during the Early Devonian, after substantial erosion of the accreted Taconic Island Arc Terrane, and prior to accretion of the Avalon Terrane. In a trip eastward from the ocean here at Oriskany Falls during the Early Devonian, one would have encountered a low, broad landmass in what is now New England, more ocean (this time a real ocean basin with oceanic crust), and, finally, the small continent of Avalon.

The Helderberg limestones are a varied lot. Differences in lithology reflect differences in environment of deposition. Carbonate mud matrix in some reflects relatively low energy environments, while sparry matrix in others suggests high energy. Mudcracks show dessication in some, but not all units. Some of the limestones are cross-stratified and were deposited above wave base; others show evidence for being affected by waves only during storms.

The Manlius shows features consistent with environments oscillating between supratidal, intertidal, and shallow subtidal lagoon environments. Walker and Laporte (1970) have suggested that good analogies may be drawn between these limestones and their environments of deposition and those in the early Middle Ordovician Black River Group. The organisms in the communities are, of course, different species, but they occupy similar nitches in strikingly similar rocks.

Water deepened episodically but progressively during deposition of the Helderberg. The Coeymans Formation was deposited on a discontinuous barrier shoal in environments that ranged from high to low energy, and the Kalkberg was deposited in a shallow, open marine environment dominantly below wave base (Laporte, 1969; Walker and Laporte, 1970).

The Oriskany Sandstone lies disconformably on the Helderberg Limestone and represents a shoreline sand sequence deposited at the base of the last transgressive sequence in the Early Devonian. These sandstones are coarse-grained and contain remains of enormous brachiopods. Evidently, the energy in the environment was either too high to preserve more delicate fossils, or else was too high to allow less robust organisms to live happily. In southwest New York State, the Oriskany

Sandstone is hundreds of meters below the surface and serves as a good reservoir rock for petroleum.

The lower Onondaga Limestone is chertier and coarser-grained than much of the Helderberg Group, but individual pieces on the quarry floor are difficult to distinguish from the gray limestones of the Helderberg. Environments during deposition of the Onondaga were primarily those on wave-affected, shallowly-submerged lagoonal shelves (Lindemann, 1979). Reefs are common and are known to contain natural gas. The Onondaga has been used extensively for building stone, and, obviously, is quarried for aggregate.

At the top of the Devonian sediments in this quarry, we find a very distinctive erosion surface that shows conspicuous evidence of glaciation. If you examine the limestone carefully, you will be able to find examples of striae, crescentic gouges, and chatter marks. The pebbles, cobbles, and boulders that were stuck in the underside of the ice or pressed between ice and rock acted like sandpaper, forming the scratches, grooves, and gouges. Friction between the pebbles and the bedrock caused the pebbles to jump like chalk on a blackboard, forming chatter marks. Direction of striae indicate that this area was overridden both by south-flowing ice from the Laurentide ice sheet and by southeastward-flowing ice from the Ontario lobe.

Unsorted, unstratified glacial till overlies the Devonian rocks and makes up the overburden in this quarry. The till is removed and used by local municipalities as fill. In the unstratified till, you can see the direct contact of lodgement till (ground moraine) with the underlying bedrock. In some of the overburden, areas of stratification occur, where meltwater poured off the ridge to the northeast onto or along the ice sheet that filled the valley.

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PLATE I

Composite Stratigraphic Section for Central New York State - Precambrian through Early Devonian

Late Silurian, Early and Middle Devonian

			lithologic description	fossils	inferred sedimentary environ.	inferred tectonic environment	references	
Mid. Devonian	Hamilton Gp.	*Marcellus Fm. (Union Springs Mbr.)* *4-5m thick*	***Black Shales*** black, thin-bedded, thinly laminated, calcareous shale with black , thin-bedded, fine-grained limestone or limestone concretions; no burrows	sparsely fossiliferous; planktic organisms; cephalopods, hitchhiking bivalves, terrestrial wood	deep, anoxic basin conditions, quiet water; no large animals dwelled on the foul, mucky bottom; source of clastics to the east; analagous to Utica Shale environment.	foreland basin immediately cratonward of accreted Taconic Island Arc; accretion of Avalon Terrane east of the Taconic Arc Terrane (Acadian Orogeny) caused uplift in the Taconic Arc region and subsidence in the foreland basin; in the deepening basin, limestone deposition was extinguished and replaced by clastic sedimentation; Trenton/Utica re-run time. No good modern analog.	Rickard, 1975 Brower et al, 1975 Grasso, 1978 Grasso & Wolf, 1977 Selleck et al, 1977	Hamilton, NY area
Early Devonian		*Onondaga Limestone* *20m thick*	***Limestones*** middle and upper: very fine grained limestones with some interlayered clastic mud derived from the north during deposition of the middle Onondaga. lower: light gray, coarse grained, crinoidal limestone with well-developed coral bioherms; chert nodules. gas-bearing reefs first discovered in 1967.	rugose & tabulate corals brachiopods bryozoans gastropods trilobites	shallowly submerged lagoonal shelves with extensive tracts of carbonate reef-building organisms; lower member in shallow wave-affected waters; middle and upper members deposited below wave base; deposited in west-transgressing sea; slow submergence.	foreland basin immediately cratonward of accreted Taconic Island Arc Terrane; tectonic activity limited to intermittent uplift and subsidence of limited magnitude, presumably caused by plate margin activity east of the Taconic Arc Terrane. As the accreted and inactive Taconic Arc Terrane was progressively eroded, sediments changed from dominantly clastic (Silurian) to dominantly carbonate (Devonian). Modern analog: Arafura Sea between Australia and New Guinea.	Lindemann, 1979 Lindemann & Simonds, 1977 Rickard, 1975	Clinton/Oriskany Falls area
		disconformity						
		Oriskany Sandstone *3m thick*	***Calcareous Quartz Sandstone*** yellowish-brown, thick bedded, medium to coarse grained calcareous quartz sandstones.	large, robust brachiopods	shoreline deposit; preserved in discontinuous lenses in central New York State		Rickard, 1975	
		disconformity						
	Helderberg Group	*Kalkberg Fm.* *2m thick*	***Limestones*** blue, generally massive to irregularly bedded, med to fine grained limestones with fossil fragments set in a carbonate mud rather than sparry matrix; horizontal-burrowed; some black chert beds; no cross stratification or mudcracks; bentonites.	bryozoans brachiopods ostracodes trilobites	shallow water, stable, open marine environment with good circulation on an extensive shelf seaward & eastward of shoal environment of the Kalkberg; below wave base; not far enough east to receive terrigenous detritus fromTaconic Arc Terrane.		Anderson et al, 1978 Dale, 1953 Fisher, 1980 Laporte, 1967 Laporte, 1969 Rickard, 1975	
		Coeymans Fm. (Deansboro Mbr) *15m thick*	***Limestones*** blue, irregular to massive bedded, med grained fossiliferous limestone with fragments of brachiopods and crinoids set in a matrix of dominantly sparry calcite rather than carbonate mud; erosion srufaces with intraclasts; abundant burrow-mottling, both vertical and horizontal; cross stratification.	crinoids and brachiopods tabulate corals bryozoans ostracodes	discontinuous barrier/shoal of shallowly submerged crinoidal mounds and meadows separating open ocean to the east (Kalkberg environment) from protected lagoon (Manlius environment); both high and low energy.			
		Manlius Fm. *14m thick*	***Limestones and Argillaceous Limestones*** the following are complexly interbedded: **a)** blue and drab, thinly laminated, fine grained dolomitic limestones; bird's-eyes; mudcracks; no burrows. **b)** dark blue, thin and even bedded, fine grained limestone interlayered with med to coarse grained fossiliferous limestone; some mudcracks and flat pebble conglomerates; scattered vertical burrows. **c)** blue thin to med bedded, fine grained limestones interlayered with gray, massive and irregularly bedded crinoidal and "reefy" limestones; no mudcracks; scattered vertical burrows.	**a)** fossils scarce; ostracodes, algal laminae **b)** types few but individuals abundant; ostracodes, brachiopods, stromatolites **c)** abundant diverse fauna requiring submergence; ostracodes, rugose corals, brachiopods, stromatoporoids	supratidal (a), intertidal (b), and shallow, protected subtidal broad shelf lagoon (c); little circulation; little tidal effect (storm waves only); first in westward transgressive sequence showing intermittent (punctuated), rather than continuous, submergence.			
		Rondout Fm. *15m thick*	***Argillaceous Dolostones*** argillaceous and shaly dolostones interlayered with dolostones	bryozoans, tabulates, rugose corals	shallow water; dolomite probably secondary		Fisher, 1980 Rickard, 1975	
Late Silurian	Salina Gp.	*Bertie Formation* *16m thick*	***Dolostones and Shaly Dolostones*** gray to brown, thin to thick bedded, finely laminated dolostone; brown, thin bedded, finely laminated shaly dolostone; some bedded gypsum; mudcracks, small erosional channels; burrows; halite hoppers; flat-pebble conglomerates.	attack of the eurypterids ostracodes	intertidal to low supratidal, restricted, hypersaline environment; much like the Syracuse Formation.		Ciurca, 1978 Dale, 1953 Fisher, 1957 Fisher, 1980 Rickard, 1975 Treesh, 1972	Clintn./Utica area

compiled and prepared by Barbara Tewksbury, Hamilton College, 1992

PLATE I

Middle and Late Silurian

			lithologic description	fossils	inferred sedimentary environ.	inferred tectonic environment	references	
Late Silurian	Salina Group	*Camillus Shale* *70-100m thick*	***Dolomitic Shales and Dolostones*** red and olive dolomitic shales with some interbedded 1) rippled and mudcracked dolostone, 2) gypsum, and 3) quartz sandstone with well-rounded grains; dolomite content increases upward.	no fossils	?marginal marine with some aeolian sand?	ditto previous page	Ciurca, 1978 Dale, 1953 Fisher, 1957 Fisher, 1980 Rickard, 1975 Treesh, 1972	Clinton/Utica area
		Syracuse Fm. *30m thick*	***Dolostone, Shales, and Evaporites*** light gray to gray green, thin to thick bedded, thinly laminated dolostones with halite crystal casts and gypsum nodules replaced by calcite; abundant mudcracks, ripples, and flat-pebble conglomerates. Correlative with subsurface salt beds.	algal mounds ostracodes pelecypods eurypterids	intertidal to low supratidal, restricted, hypersaline environment; salt beds intercalated with peritidal dolomites; modern analog - Persian Gulf sabkhas			
		Vernon Shale *50-100m thick*	***Shales*** bright red, poorly fissile, unfossiliferous, mudcracked shale with green reduction spots and cracks. Local beds of 1) green, poorly fissile shale, 2) med dark gray gypsiferous and fossiliferous shale, 3) greenish-black eurypterid-bearing dolomitic shale, 4) sandstone, 5) gypsum.	in entirety, fossils very rare; in hypersaline marine members, fossils include eurypterids, brachiopods, ostracodes, pelecypods, cephalopods, & gastropods.	delta silt of river flowing into restricted lagoons or playa-type lakes (littoral & deltaic env.); temporary marine encroachment brought hypersaline conditions and a majority of the Vernon fossils; beginning of transgressive, hypersaline sequence accomplished by basin subsidence. Modern analog: Gulf of California (for sed., but not tect., env.)			
		disconformity						
Middle Silurian	Lockport Gp.	*Ilion Shale* *25m thick*	***Shales and Mudstones with Thin Dolostones*** green-gray to gray-black mudstones and very fissile shales with thin interlayers of dark gray, fine grained argillaceous dolostones containing stromatolites and edge-wise conglomerates; abundant ripples and mudcracks. Stromatolites are vuggy and contain sphalerite, dolomite, calcite, and quartz.	fossils rare, but lingulid brachiopods and stromatolites are the most common	shallow water, tidal flats in the eastern reaches of shallow embayment in Lockport Sea; salinity normal due to proximity to shore and influx of fresh water; rest of Lockport Sea restricted & became hyersaline; eastern source for Clinton Gp. clastics petered out by Lockport time and supplied only fine silt & clay.		Dale, 1953 Fisher, 1980 Rickard, 1975 Zenger, 1965	
	Clinton Group	*Herkimer Fm.* *(Joslin Hill Mbr)* *25m thick*	***Sandstone, Siltstones, Sandy Shales and Dolomitic Sandstones*** variably interbedded sequence of 1) dark gray, thin to thickly laminated, generally unfossiliferous silty shale; 2) gray to brownish-gray, fine to med grained dolomitic sandstone; 3) gray calcareous siltstone; 4) hematitic sandstone; and 5) phosphatic layers. % sandstone in sequence increases to east. Small and large scale ripples, cross stratification, channels, mudcracks, rounded fossil fragments, no carbonate mud.	abundant trilobite trace fossils; crinoidal in upper part	high energy, near-shore environment; tidally-influenced; grades eastward into beach facies of Jordanville Member east of Joslin Hill		Dale, 1953 Fisher, 1980 Muskatt, 1972 Rickard, 1975 Zenger, 1971	
		Kirkland Dolostone *1.5m thick*	***Fossiliferous Hematitic Dolostones*** grayish red to moderately red, coarse grained to conglomeratic fossil fragmental, calcareous, slightly sandy dolostone; irregularly and discontinuously bedded; fossils replaced by hematite; 10-40% hematite; not oolitic; thin interbeds of green shale; known locally as the "red flux".	brachiopods bryozoans crinoids coelenterates	lensoid unit; shallow marine; lagoonal environment?			
		Willowvale Shale *10m thick*	***Shales with Sandy Dolostones*** upper: gray silty shale with interlayered light gray to dark gray fossiliferous sandy dolomitic limestone and sandy dolostone. Lower: greenish shales and shaly mudstones with some interbedded siltstones.	most fossiliferous formation in Clinton Gp; abundant brachiopods, pelecypods, & crinoids; upper units show broken & rounded fossil fragments; cephalopods	shallow, subtidal environment ranging from quiet to agitated; may be lagoon/offshore bar sequence or lagoon/tidal flat and channel sequence.			
		Westmoreland Hematite *1m thick*	***Calcareous Oolitic Hematite*** red to dull brown, med to coarse grained, calcareous oolitic hematite ore with some sandy layers; oolites composed of layers of hematite and chamosite around quartz grains and fossil fragments.	trilobites ostracodes brachiopods	shallow, agitated water, intertidal to shallow subtidal.			

PLATE I

Middle Silurian, Late and Middle Ordovician

			lithologic description	fossils	inferred sedimentary environ.	inferred tectonic environment	references	
Middle Silurian	Clinton Gp.	*Sauquoit Formation* *40m thick*	***Shales with Siltstones and Sandstones*** green, fissile shales interbedded with med gray to greenish-gray siltstones, gray shales, sandy shales, and gray to red, fine to coarse grained, cross-bedded quartz sandstone; ferruginous beds are rare; shale content decreases eastward. Ripples and mudcracks abundant; phosphate nodules locally.	few fossils in the sandstones; mudstones & siltstones contain pelecypods, brachiopods, & ostracodes; gastropods & trilobites are rare	tidal flats and channels with shoreline east of Utica; interfingers east of Joslin Hill with non-marine Otsquago redbeds.	ditto previous page	ditto previous page	Clinton/Utica area
		Oneida Conglomerate *3-10m thick*	***Pebbly Quartz Sandstones and Conglomerates*** light gray, thickly bedded, quartz-cemented conglomerate with interbedded light gray to rusty, finely cross-laminated, fine to coarse grained quartz sandstone	few fossils, some trace fossils and broken fragments of inarticulate brachiopods.	shallow water, high energy marine environment, probably near shoreline; some fluvial component; sediment sources to the east.			
		disconformity						
Late Ordovician		*Queenston Shale* *200m thick*	***Red Shales with Interbedded Siltstone & Sandstone*** distinctive reddish shale with subordinate interlayers of siltstone and sandstone.	unfossiliferous	deltaic environment and terrestrial environments; sediment source to the east.	deltaic deposits blanketing the last of the sediments deposited in the foreland basin of the Taconic Orogeny. These deposits are known as the Queenston Delta.		Black River Valley Area
	Lorraine Group	*Oswego Sandstone* *35m thick*	***Massive Sandstone with Rare Shale Beds*** gray, fine-grained, massive, unfossiliferous quartz sandstone with a few thin black shale interbeds; some cross bedding in the sandstones.	unfossiliferous	shallow water, high energy marine environment, probably a nearshore or beach environment; sediment source to the east.	slowly-filling foreland basin immediately cratonward of accreted Taconic Arc Terrane. Modern analog: Arafura Sea between Australia & New Guinea	Bretsky, 1970 Bretsky & Thomas, 1978 Dale, 1953 Fisher, 1977 Fisher, 1980 Miller, 1910	
		Pulaski Shale & Sandstone *200m thick*	***Sandstone, Siltstone, and Shale*** gray, fine-grained sandstone beds alternating with black to dark gray shale, siltstone, and occasional thin beds of impure limestone; ripple marks, mudcracks, burrows.	highly fossiliferous crinoids, trilobites brachiopods gastropods, bryozoans	tidal to subtidal environment; sediment source to the east			
		Whetstone Gulf Shale *65m thick*	***Black Shales with Thin Sandstone Layers*** black to dark gray shales with occasional thin beds of fine-grained sandstone.	not very fossiliferous trilobites graptolites	shallow basin, water depth below wave base, but basin no longer anoxic as it had been during Utica time; sediment source to the east.			
	Trenton Group	*Utica Shale* *230m thick*	***Black Shales*** black and gray, fissile to massive, graptolite-bearing shales intercalated with lenses of black massive calcareous mudstone. A monotonous sequence.	graptolites trilobites (pyritized) cephalopods (pyritized)	deep anoxic basin conditions over vast area and long period of time; source of clastics to the east.	shelf deepening into basin on plate being subducted beneath Taconic Arc Terrane. Taconic Arc Terrane collides with continental margin of ancestral North America (Laurentia) during the Taconic Orogeny; attempted subduction of Laurentian continental crust results in thrusting of continental slope and rise sediments back on the Laurentian continental shelf (emplacement of the Taconic thrust slices in eastern NYS) and development of a rapidly deepening trough whose axis migrates westward from eastern to central NYS, accumulating first a transgressive limestone/shale sequence, then a deep basin euxinic shale; bentonites record activity in the Taconic Arc Terrane shortly before collision. Source of clastics is the advancing Taconic Arc Terrane. Modern analog: Australian shelf/Timor Trough in the Southwest Pacific; island of Taiwan.	Anderson et al., 1978 Cameron, 1972 Cameron et al., 1972 Cisne et al., 1982 Dales, 1953 Fisher, 1977 Fisher, 1980 Larson, 1984 Titus, 1977 Titus & Cameron, 1976	
Middle Ordovician		*Steuben Limestone* *8m thick*	***Limestones*** dark gray, heavy-ledged, med to coarse grained massive crinoidal limestone with little interbedded shale; cross laminations and burrows are common; forms scarp above Denley.	abundant crinoids & brachiopods; gastropods, trilobites, & rugose corals less common	subtidal, higher energy environment than Denley; shallower shelf; at, near, and above wave base.			
		Denley Limestone *70m thick*	***Limestones and Calcareous Shales*** variable sequence of dark gray to blue-gray fine grained to very fine grained limestones and argillaceous limestones interlayered with dark gray, thinly laminated calcareous shales; some coquinal limestones; horizontal burrow networks; bentonites; overall finer grain size than earlier Trenton. Lower Denley contains slump breccias at Trenton Falls.	brachiopods bryozoans trilobites cephalopods crinoids	subtidal, relatively deep shelf, with a silty substrate; storm-influenced sedimentation			
		Sugar River Limestone *16m thick*	***Limestones and Calcareous Shales*** thinly interlayered 1) dark gray to black, thin to med bedded, fine to med grained, non-shelly, highly fossiliferous limestones and 2) dark gray, thinly laminated calcareous shales; carbonate mud matrix content higher than Kings Falls. No coquina beds; bentonites; some burrows.	diverse fauna bryozoans crinoids trilobites brachiopods	subtidal; quiet shelf environment; relatively deep; increase in carbonate mud content over Kings Falls Unit.			

PLATE I

Middle Ordovician and Precambrian

			lithologic description	fossils	inferred sedimentary environ.	inferred tectonic environment	references	
Middle Ordovician	Trenton Group	*Kings Falls Limestone 20m thick*	***Limestones and Calcareous Shales*** upper: interlayered 1) dark gray, med to thick bedded, coarse grained, non-shelly fossiliferous limestone and 2) dark gray, thinly bedded calcareous shale; limestones have lower % sparry calcite and higher % carbonate mud in the matrix than the lower unit. lower: coarsely interlayered 1) dark gray, med to thick bedded, coarse grained very fossiliferous shelly limestone and coquina and 2) dark gray, thinly bedded calcareous shale; high energy features; limestones have high % sparry calcite and low % of carbonate mud matrix.	middle & upper bryozoan-dominated but includes trilobites, brachiopods, gastropods, & crinoids; lower is also brachiopod-dominated but contains some corals	middle and upper part were offshore, shallow shelf, quieter and deeper than shoal of lower part; lower part was high subtidal to low subtidal, waveswept offshore shoal.	ditto previous page	ditto previous page	Black River Valley Area
		Napanee Limestone 6m thick	***Limestones and Calcareous Shales*** thinly interlayered 1) dark gray, very fine grained sparsely fossiliferous limestone with infrequent, discontinuous laminae of fossil fragments and 2) dark gray, thinly laminated, fossiliferous calcareous shale. vertical burrows; no mudcracks, bentonites; med grained, fossiliferous limestones increase in abundance upward.	brachiopod-dominated low diversity bryozoans gastropods trilobites	very high to high subtidal; shallow shelf-lagoon; normal salinity.			
		disconformity						
	Black River Group	*Watertown Fm. 3m thick*	***Limestones*** dark gray, thick to very thick, lumpy discontinuously bedded, fine grained limestone with fossil fragments floating in the matrix; thoroughly horizontal burrow-mottled; black chert nodules common; bentonites; more biogenic reworking than other Black River Group units and contains more fossils.	nautiloids calcareous algae stromatoporoids tabulate & rugose corals horizontal burrowers	subtidal, level bottom; water depth probably about 10m; reflects maximum transgression.	passive (rifted) margin shelf; local shoreline to the east against a low island or islands of Precambrian on the shelf; Taconic Arc Terrane not yet impinging on continental margin; bentonites record proximity of the arc, however; slow subsidence of the shelf is reflected in transgressive sequence. Modern analog: Bahamian carbonate banks	Cameron & Kamal, 1977 Fisher, 1977 Fisher, 1980 Walker, 1973	
		Lowville Fm. 18m thick	***Limestones with Some Dolostones, Incl. Bentonites*** the following are complexly interbedded: a) pale to med gray, thin bedded, wavy laminated fine to coarse limestone; vertical burrows, mudcracks, scour structures. b) dark gray, med to thick bedded, thinly laminated fine to very fine grained stylolitic limestone and med gray thick bedded, thinly laminated coarse fossiliferous limestone. c) medium dark gray, thin to med lumpy bedded, coarse bioclastic limestone d) lithology similar to upper Pamelia (see below)	trilobites (a,b) deep burrowers (a) shallow burrowers (b,c) ostracodes (a, b, d) tabulate corals (c) gastropods (c) bryozoans (c) pelecypods (b)	middle and upper: oscillating restricted intertidal mudflats (a), protected subtidal lagoons and channels (b), and aerated shoals seaward of the lagoons (c). lower: supratidal dolomitic mudflats (d). Oscillation of environments was caused by intermittent subsidence.			
		Pamelia Fm. 6m thick	***Sandstones and Sandy Dolostones*** upper: pale gray to buff, thin to med bedded, wavy to thinly laminated, fine to med grained dolostone; small-scale mudcracks; bird's eyes. lower: tan, thin to med bedded, med to coarse grained dolomitic sandstone	ostracodes some trilobites vertical burrowers	supratidal dolomitic mudflats and supratidal regolith on the Precambrian; transgressive to the east; paleoshoreline in the Black River Valley ran approx. north-south			
		nonconformity						
Precambrian		*various lithologies (no formal stratigraphic units in the Black River Valley)*	biotite and hornblende granitic gneisses; granitic augen gneisses; biotite-plagioclase-quartz gneisses; pyroxene-biotite gneisses; migmatites; quartz-feldspar gneisses with garnet and/or sillimanite; amphibolite; syenitic and charnockitic gneisses; alaskitic gneisses. all lithologies are metamorphic and deformed, including those with igneous protoliths.	rare stromatolites in marbles near Balmat, NY	conditions of metamorphism in the Black River Valley area: 700-720°C 7.5 kilobars ~25km depth	convergent margin, continent/continent collision; Grenville sediments (perhaps deposited on a rifted margin or in an arc-related basin) were deformed and metamorphosed as a terrane or terranes of unknown size and extent collided with the Grenville continent. Deformation and metamorphism was complex and multiphase, stretching over a time range from roughly 1250Ma to about 1000Ma. Deformation and metamorphism related to this event are referred to as the Grenville Orogeny. The suture zone may lie southeast of exposed Grenville rocks. modern analog: Himalayan Range/Tibetan Plateau collision was followed by Late Precambrian rifting. modern analog: Red Sea area	Buddington, 1934 Fisher, 1980 Whitney et al., 1989	