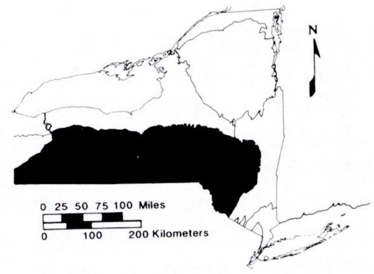
CHAPTER 8

OLDEST FORESTS AND DEEP SEAS

Erie Lowlands and Allegheny Plateau[1]



SUMMARY

The bedrock of the Erie Lowlands-Allegheny Plateau region consists of flat-lying layers of sedimentary rock. This rock records the history of the region during the Late Silurian and Devonian. The rocks of the Upper Silurian (dolostones, evaporites, and shales) and the limestones and shales of the Helderberg Group are the oldest part of this record. From them, we learn that a warm, shallow sea covered most of New York at the beginning of the Early Devonian. We can reconstruct a number of major depositional environments from the variety of rock found in these formations. Above this interval dominated by carbonate rock, we find an unconformity that records the retreat of the sea from the area and the erosion of the exposed Helderberg Group. The Tristates Group records the sea's return, clear water at first, and later muddy. At the end of the Early Devonian, erosion removed almost all of the Tristates Group from western New York. The Onondaga Limestone, which forms the lower Middle Devonian, tells us of a widespread shallow sea with coral reefs and a great variety of bottom-dwelling animals. The Tioga ash beds within the upper Onondaga are clues to volcanic eruptions far to the southeast. The ashes are a sign that an episode of mountain-building was beginning. The next Middle Devonian rocks are those of the Hamilton Group. These rocks record a massive influx of mud and sand that were eroded from a new mountain range to the east during the early part of the Acadian Orogeny. The Tully Limestone above the Hamilton Group marks a pause in this great influx of sediment. An unconformity in the middle of the Tully emphasizes this pause. The Late Devonian began with a renewed influx of mud, sand, and gravel from the east, which continued until the end of the period. This influx was the result of the continuing Acadian Orogeny. Within the Genesee, Sonyea, West Falls, Canadaway, Conneaut, and Conawango Groups, we find a number of major varieties of rock that record different depositional environments. These settings range from the piedmont in the east to the floor of the sea basin in western New York. Their distribution shows how the shoreline and related environments advanced haltingly across the State as a huge sedimentary apron. This apron, called the "Catskill Delta" complex, grew westward and crowded the sea out of the region.

DESCRIPTION OF THE ERIE LOWLANDS AND ALLEGHENY PLATEAU

The Erie Lowlands is the low, flat area southeast of Lake Erie. (See Figure 1.1 and the Physiographic Map on Plate 4 of the *Geological Highway Map.*) To the south, the land rises gently from lake level (175 m above sea level) to the Portage Escarpment (300 to 460 m above sea level). Sandstone layers form this *escarpment*, or cliff, because they resist erosion better than the layers above and below them. The escarpment is the boundary between the lowlands and the Allegheny Plateau to the south.

The southern half of New York State (west of the Hudson River and south of the Mohawk River and Erie Canal) is part of the Allegheny Plateau. (See Figure 1.1 and the Physiographic Map on Plate 4.) Sandstone and shale layers of Middle and Late Devonian age form the

[1]Adapted from a manuscript by L.V. Rickard.

bedrock here. They are part of the "Catskill Delta" complex and were deposited in marine waters that ranged from a deep basin to near sea level during the Acadian Orogeny. (See Chapter 3 for more information.) Millions of years later, these layers of rock were uplifted to their present height well above sea level. They were tilted only slightly by the uplift. After the uplift, erosion carved the plateau into the hilly upland we see today.

The Shawangunk Mountains form the southeastern border of the Allegheny Plateau in New York. These mountains form a steep ridge, called a *hogback*, that runs from Kingston southwest to Port Jervis. (See the Physiographic Map on Plate 4.) This ridge is made of the Shawangunk Conglomerate, which dips toward the northwest. The conglomerate resists erosion strongly because it is nearly pure quartz. It is made of quartz sand and pebbles held together by quartz cement.

The eastern and northeastern border of the Plateau is the Helderberg Escarpment. (See the Physiographic Map on Plate 4.) The limestones of the Helderberg Group, which resist erosion better than the layers above and below them, form this escarpment.

The Allegheny Plateau is relatively high and rugged. The highest points are in the Catskill Mountains, where the Wall-of-Manitou rises 915 m above the Helderbergs and 1130 m above the Hudson Lowlands. The highest peak is Slide Mountain—1282 m above sea level.

This region was once low and flat. It had been eroded to a nearly flat plain by the middle of the Cenozoic. Then, this surface was uplifted to form the Allegheny Plateau. Streams flowing across the plain began to carve it into the hilly terrain we see today. The western part of the region was carved into ridges. The eastern part was higher after uplift, and stream erosion carved away all of the rock except the high peaks of the Catskill Mountains.

The Catskills' highest peaks all have about the same elevation. How did this situation come about? *Geomorphologists* (geologists who study landforms and the processes that produce them) have proposed two explanations. Some say that the tops of the present mountains were once part of the flat surface of the plain before it was uplifted. Following regional uplift and erosion, parts of this plain still remain uneroded between the stream and river valleys. Therefore, the mountain tops wound up at the same height. The second, more recent explanation is that the Catskill high peaks are all formed of rock that is more resistant to erosion that the underlying rock. The peaks have been eroded, but they have all worn down at the same rate. Therefore, they continue to have very similar heights.

Most of the streams in the region flow southwest into the Allegheny, Susquehanna, and Delaware Rivers. The exceptions are Cattaraugus Creek, which flow west; the Genesee River, the Finger Lakes, and Schoharie Creek and others of the Mohawk River drainage, which flow north; and Catskill Creek and other, small streams along the edge of the Catskills, which flow east (see Figure 11.1B).

The Finger Lakes occupy troughs that are cut into the northern edge of the region. During the Pleistocene Epoch, huge ice sheets advanced across New York State many times. The ice widened and deepened former river valleys to make the Finger Lake troughs. In fact, the ice dug two of the lakes, Cayuga and Seneca, so deep that their bedrock floors now lie below sea level.

The Pleistocene glaciers picked up and carried along huge amounts of mud, sand, gravel, and boulders. When they melted, they left this rock debris behind. Such glacial deposits are 180 to 300 m thick in the valleys of the Schoharie Creek, the Finger Lakes, the Genesee River, Chautauqua Lake, and Cassadaga and Conewango Creeks (see Figure 11.1B). Elsewhere in the region, glacial deposits are rarely thicker than 15 m.

The Valley Heads Moraine (see Figure 12.3) is a long ridge south of the Finger Lakes that runs east to west. It is the major drainage divide of central New York. A *drainage divide* is a relatively high ridge that separates streams and rivers that flow in one direction from those on the other side that flow in a different direction. The streams and rivers north of the moraine flow generally north and eventually run into the Great Lakes, then into the St. Lawrence River to the Atlantic Ocean. Streams and rivers south of the moraine flow into south-flowing rivers. There is one exception—the Genesee River, which crosses the moraine.

The Valley Heads Moraine was built by the last Pleistocene ice sheet as it retreated across New York State. When the ice halted temporarily in its retreat, it built the moraine along its southern margin. A small region to the south, which is now Allegany State Park, escaped being covered by the last ice sheet.

See Chapters 12 and 13 for more information on the effects of the Pleistocene glaciers.

Rock of the Allegheny Plateau

The Devonian formations of the Allegheny Plateau represent 50 million years of history. They are the bedrock for a large portion of New York State: south of the Mohawk River and Barge Canal and west of the Hudson River (Figure 8.1). This rock contains remarkable

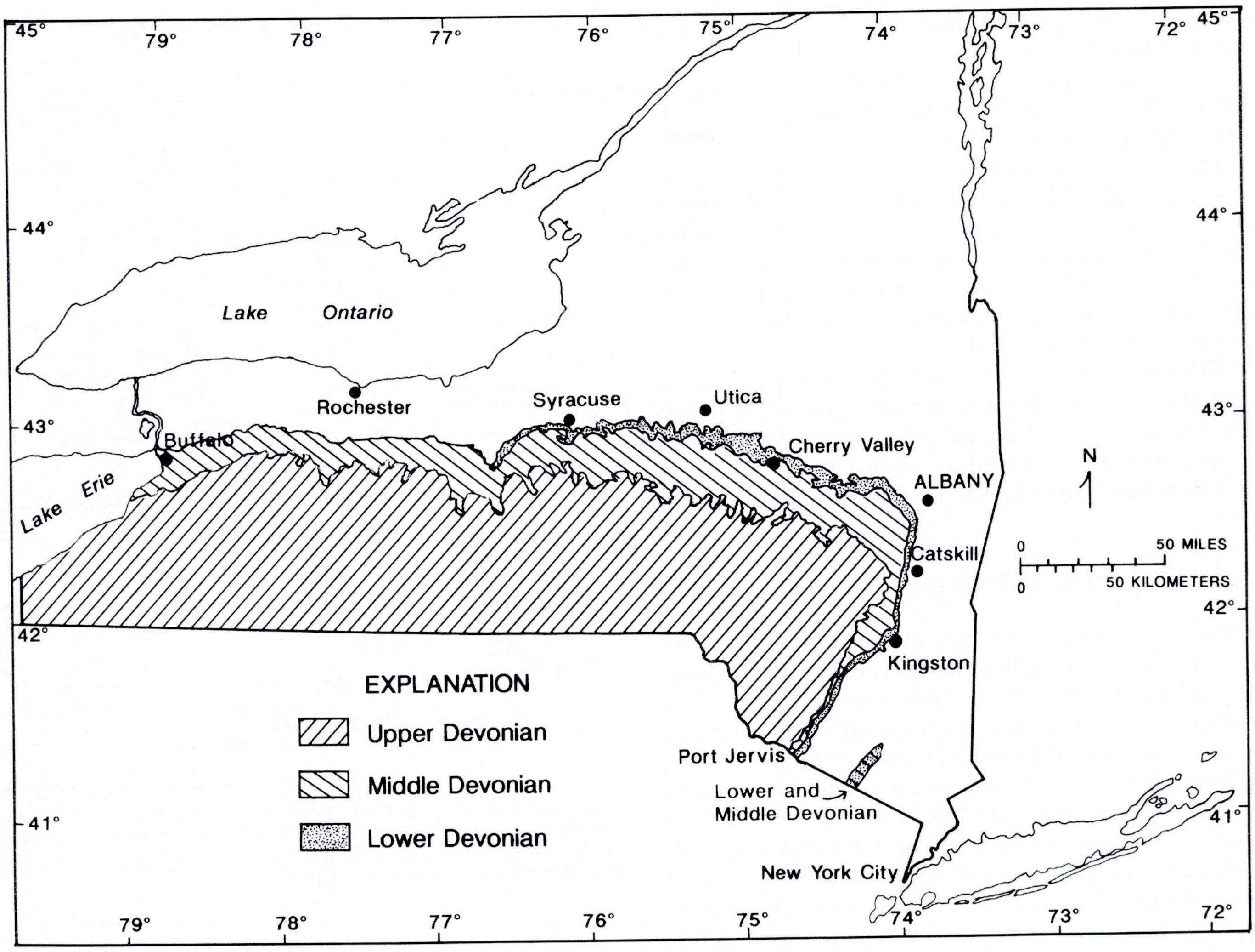


Figure 8.1. Outcrop map of the Lower, Middle, and Upper Devonian rock units in New York State. Notice that the Lower Devonian formations do not extend into the western part of the State. An unconformity cuts across these formations, as you can see on Plate 3. Erosion removed the Lower Devonian units from western New York before sediment was deposited there in Middle Devonian time.

and abundant fossil remains. Among the fossils are some of the earth's first forests, some fearsome fish, and many brachiopods[2] and other invertebrate animals. The first air-breathing fish, from which all other vertebrates have evolved, appeared during the Devonian. However, we have not yet found their remains in New York.

Layers of Lower Devonian rock *crop out* (that is, appear at the land surface) in the eastern part of the Allegheny Plateau from just east of the Hudson River to Cayuga Lake. (The Helderberg and Tristates Groups are Lower Devonian; Plate 3 gives you a more detailed picture of where they are.) Middle Devonian rock makes up most of the Catskill Mountains and extends west to Lake Erie. We find some Upper Devonian units high in the central Catskills, but most Upper Devonian rocks are found in the south-central and western parts of the State. The youngest Devonian rocks in New York are found in the western part of the State along the Pennsylvania border. (See Figure 8.1 and Plate 3.)

Rock of Early, Middle, and Late Devonian age crops out in belts that run east to west across central and western parts of the State The oldest belt is in the north and the youngest in the south (Figure 8.1). This pattern arises because the layers dip gently southward. As the erosion surface of the land intersects the gently tilted layers, it creates the east-west belts shown on the geologic map (Plate 2).

The Devonian rock is about 2450 m thick near the eastern edge of the Catskill Mountains. It gradually decreases to about 1000 m thick near Lake Erie. The Devonian

[2]See Figure A.3 for drawings of brachiopods.

section is thickest in southeast New York, where it is more than 3,050 m thick.

Much of the rock in the Catskill Mountains was deposited by rivers near sea level rather than by sea water. This rock commonly has reddish and greenish colors. The remains of land plants, a few clams, and rare mites, ticks, and spiders are the only fossils in this part of the section. In the rest of New York, most of the Devonian beds were deposited in a *marine* (or sea) environment. They are remarkable for the fossils they contain. The fossils are abundant, well preserved, and represent many different kinds of living things.

The Devonian sequence contains many different kinds of sedimentary rock in a complicated arrangement. (You can get an idea of how complicated by looking at Plate 3. The Devonian rock is represented by various shades of green.) This complex rock record reflects a complex history.

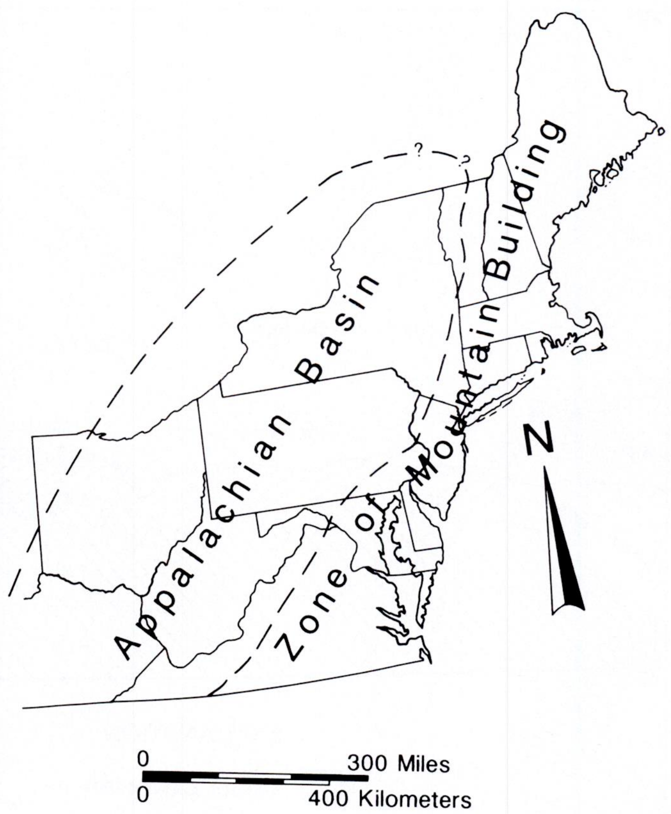


Figure 8.2. Map of the northern part of the Appalachian Basin during Middle and Late Devonian time. Sediment eroded from the mountains on the east was deposited in the Basin as the "Catskill Delta." (See Figure 8.14 for the location of these deposits.)

Early Devonian History

About 410 million years ago, at the beginning of the Devonian Period, a shallow sea covered much of New York. Indeed, most of the eastern edge of proto-North America came to be flooded by sea water. This sea lay in the *Appalachian Basin* (Figure 8.2). From the Late Ordovician through Middle Silurian, marine waters were limited to the western and central parts of New York. Their record can be seen, for example, in the rocks that form the Niagara Escarpment (see Chapter 7). The shoreline of this sea began to move eastward and reached the Helderberg Mountains in the very Late Silurian. The shoreline crossed the area of the modern Hudson River and eventually extended east to the edge of the continent during the Early Devonian. These sea waters merged with the nearshore waters that formed the eastern edge of the Iapetus Ocean. Later, in the Middle Devonian, the sea expanded west to cover some of the central parts of the continent as well.

We reconstruct the history of the Early Devonian from evidence in the oldest Devonian rock. The earliest Devonian rock is a limestone and shale unit called the *Helderberg Group*. It appears at the surface in eastern and southeastern New York, where it reaches a thickness of 135 m. It can be seen especially well in the impressive cliffs along the north and east edges of the Helderberg Mountains southwest of Albany. These cliffs, called the *Helderberg Escarpment*, run from Albany west to Auburn. They form the northern boundary of the Allegheny Plateau in this area and overlie uppermost Silurian strata (Figures 8.3 and 8.4).

Early Devonian sedimentary rock probably once covered northeastern New York, but erosion has removed it from this region. Early Devonian rock occurs at great depths in southern New York State, where it is buried by younger deposits.

The Helderberg Group includes many types of limestones. They were deposited in a shallow sea surrounded by a low, flat landscape. How do we know what the landscape was like? Highlands tend to erode quickly and produce large amounts of mud, sand, and gravel. We don't find much of this kind of sediment in the Helderberg limestones, so we conclude that there were no highlands nearby. In other words, the landscape was low and flat.

The sea in the Appalachian Basin began to deepen in the Late Silurian; as a result, its eastern shoreline moved farther east, and its western shoreline moved farther west. This movement of the shorelines continued in the Early Devonian. As the sea very slowly spread over the land, it deposited the calcareous sediments[3] that later became an important part of the Helderberg Group.

[3]*Calcareous sediments* are composed of calcium carbonate (chemical composition $CaCO_3$) and often made up largely from the hard parts of animals and plants—for example, shells. Limestone, a kind of *carbonate rock*, is formed from calcareous sediments.

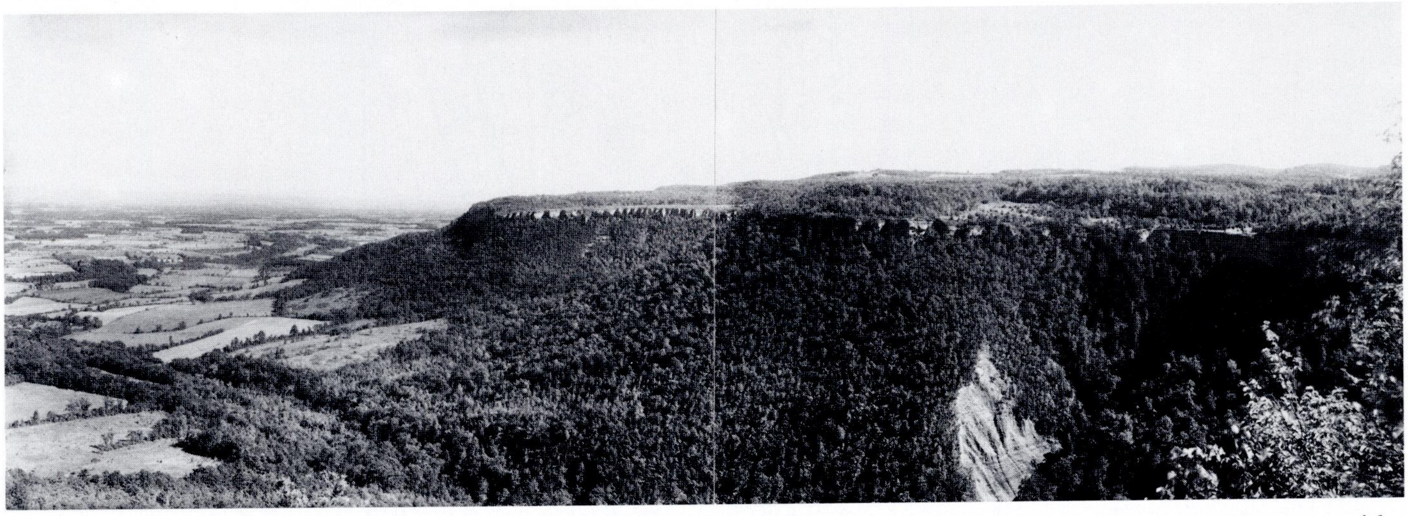


Figure 8.3. The Helderberg Escarpment in John Boyd Thacher State Park, southwest of Albany in Albany County. Lower Devonian limestones of the Helderberg Group form the cliff. They lie on top of Middle Ordovician shales and sandstones of the Schenectady Formation.

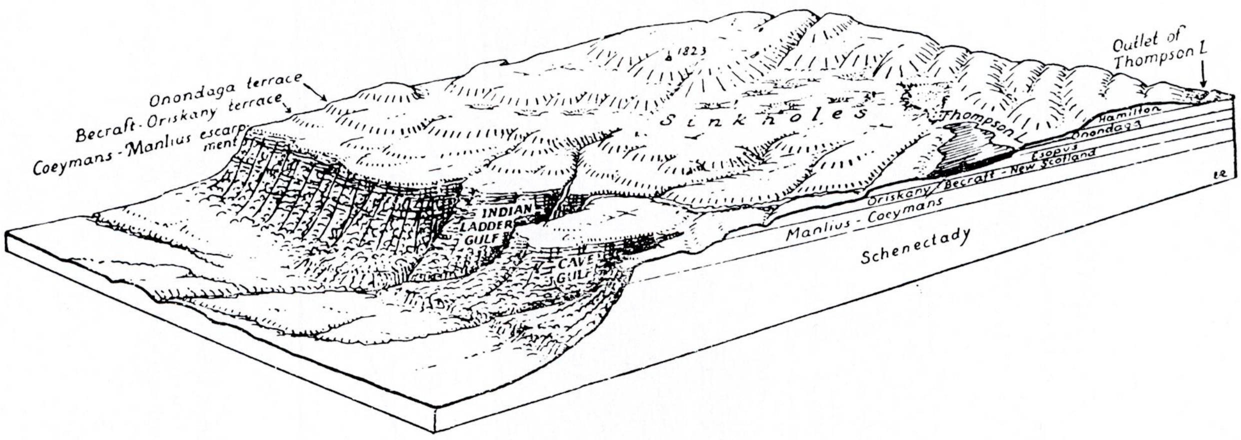


Figure 8.4. This block diagram of the Helderberg Escarpment shows the relationship between the bedrock units and the land surface. The escarpment exists because the limestone of the Manlius and Coeymans Formations (part of the Helderberg Group) is more resistant to erosion than the sandstone and shale of the underlying Schenectady Formation. Locate the place on Plate 3 where the Helderberg Group lies directly on top of the Schenectady Formation. There is a large gap in the rock record in this area.

How do we know that the sea was deepening and its shorelines moving as the Helderberg Group was formed? The answer to that question requires a long explanation.

Each of the different types of limestone in the Helderberg Group formed in its own environment. Figure 8.5 shows the environments where these limestone layers were deposited and how they were arranged. How do we know about these environments? We look for certain clues in the rock layers.

Different types of sediments are deposited at the same time in a wide variety of sea environments. For example, fine limy[4] muds settle out in the deep, quiet water far from shore; some beaches are formed of shells along the sea shore. Wind and waves work the sediment along the shore into a variety of deposits. How do we know about all these differences? We study how sediments are deposited in modern seas.

The layers formed in different environments vary in a number of ways. They may have different colors. They may be coarser or finer grained. They may be made of

[4]*Limy* means rich in calcium carbonate (which is also called *lime*).

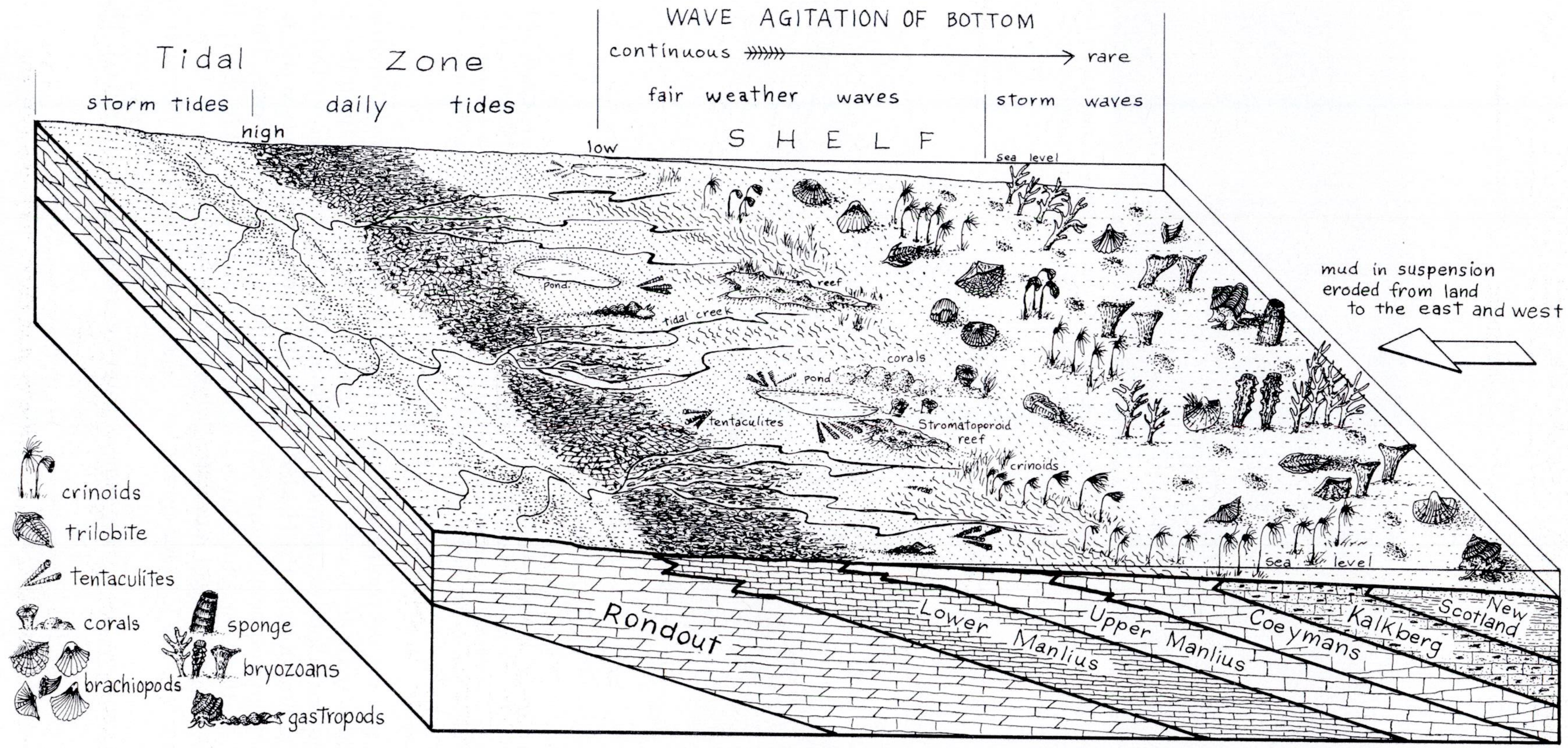


Figure 8.5. Diagram relating depositional environments to the different facies of the Helderberg Group. The water depth increases from left to right. The arrangement of the facies—Rondout through New Scotland—indicates that the depositional environments have been moving from right to left as the deposits accumulated. You can verify this fact by drawing a line through the facies below and parallel to the sea floor. This line will represent the sea floor at an earlier time. Notice that the depositional environments on that earlier sea floor were to the right of the present ones. Compare this figure with Figure 8.6.

sediment eroded from the land (mud, sand, or gravel), or sediment formed in the sea (commonly calcium carbonate), or a mixture of both. The layers may be thick or thin. The *sedimentary structures* (features formed as the sediment was deposited, such as wave or current ripples and cross-bedding (see Figure 7.1)) are different in different environments. When we study the deposits in different modern environments and compare them with layers of sedimentary rock, we often find striking similarities. When a layer of rock looks like a modern layer of sediment, the similarity can be used as evidence that both were deposited in similar environments. Therefore, we can deduce what the environment was like from the appearance of a rock layer.

The fossils in the rock also give us valuable clues to the environment. We can tell the difference between animals and plants that lived on the sea bottom and animals that swam or floated in the waters above. Many creatures that are at home near the shoreline cannot venture into deeper water. By looking at the fossils of the animals and plants that lived there, we find out more about what conditions were like.[5]

Taken together, all the features of a sedimentary deposit—the sediment, sedimentary structures, and fossils—give it a distinctive character or appearance—called its *facies*. Each facies reflects a particular *depositional environment* (that is, an environment in which sediment is deposited). Each environment has a particular water depth, sediment size, and other distinctive characteristics. Each environment is home to a distinct community of plants and animals.

You can think of a facies as the combination of features that identifies the environment of a deposit. In a similar way, a combination of facial features lets us recognize a person's face. Just as closely related people can be similar in appearance, closely related environments can produce deposits with similar facies.

Now we come back to the question of how we know that the shorelines moved and the sea deepened as the Helderberg Group was being deposited. In general, here is how we figured it out. We look at a single facies. We notice that in younger layers it is farther east and west than in the older layers. This arrangement tells us that the shorelines were gradually creeping eastward and westward over time. Then, we look at the rock at one place. We notice that the facies reflect shallower water in the older rock and deeper water in the younger rock. This arrangement tells us that the sea was gradually getting deeper through time. Because the rock of the Helderberg Group records a sea that was growing deeper and shorelines that were creeping eastward and westward, we know that it was deposited in an expanding sea.

Now let's look at the rock in a bit more detail. The Helderberg Group is a series of seven limestone-rich formations.[6] In these formations, we find five major facies; each is named for the formation where it first occurs: Lower Manlius, Upper Manlius, Coeymans, Kalkberg, and New Scotland (Figure 8.5 and 8.6). The facies are listed in Table 8.1. The environment represented by each facies is described in the last column of the table. Notice how the water gets deeper as time goes by.[7] The earliest facies shown were deposited near the shore, just above high tide or between high and low tide. Later facies were deposited in deeper environments farther offshore, first in shallow water, then in deeper.

The five facies of the Manlius, Coeymans, Kalkberg, and New Scotland Formations are partly repeated in the upper part of the Helderberg Group. The Becraft is like the Coeymans, the Alsen is like the Kalkberg, and the Port Ewen is like the New Scotland (Figure 8.6).

After the limestones of the Helderberg Group were deposited, the sea withdrew from the State and exposed the newly formed beds to erosion. How do we know? The unconformity[8] above the Helderberg Group resulted from this erosion. (The unconformity is represented by a pale yellow area on Plate 3.) The sea withdrew first from the northern and western parts of New York. Because the rock there was exposed first and longest, it had the greatest chance to be eroded. Thus, more of the early deposits were removed north of Kingston and in the western part of the State than elsewhere. At Cayuga Lake, only the oldest of the Helderberg formations remain. Farther west, we don't find any at all. Either the Helderberg formations were never deposited that far west or erosion has destroyed them completely.

Later in the Early Devonian, the sea readvanced. The sedimentary rocks formed in this sea are called the *Tristates Group*. We find the Tristates Group mainly in eastern and east-central New York, just like the Helderberg Group that lies underneath it (see Plate 3). The only formation of the Tristates Group in western New York is the Bois Blanc Limestone. It is a thin layer, rarely more than 1.2 m thick. It does not form a continuous sheet but is found in patches.

[5]We have to be careful when we interpret fossils, though. From time to time fossils don't match the environment. For example, after a shallow water animal dies, ocean currents may carry its remains into deeper water. If it became a fossil there, we would find it in an environment where it didn't live.

[6]The limestones from the Manlius, Coeymans, and Becraft Formations are used to make *portland cement*. Portland cement is made by heating a mixture of certain rocks and minerals together in a kiln. For more information, see Chapter 15.

[7]If the sequence is undisturbed, the bottom rock layer is the oldest. Therefore, this table lists the oldest formation at the bottom and the youngest at the top.

[8]When rocks are eroded and younger sediments are deposited on the eroded surface, it leaves a gap in the geologic record because some rocks have been destroyed by erosion. The surface in the rock that represents this gap is called an *unconformity*.

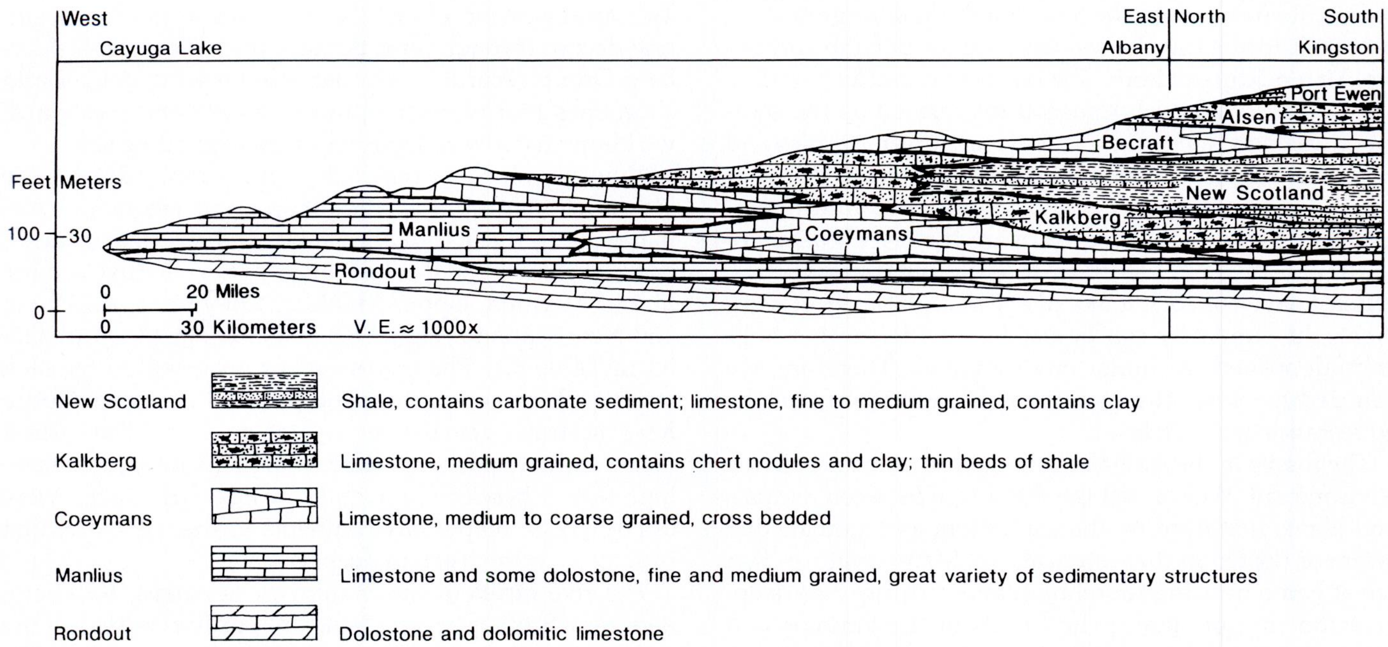


Figure 8.6. Diagrammatic cross section of Lower Devonian formations along the outcrop belt, west to east across central New York State, and north to south along the Catskill Mountain front. The arrangement of the formations shows that the depositional environments of the formations moved as the deposits accumulated. Compare with Figure 8.5. Notice that the Coeymans and Becraft Formations are made up of the same kind of rock. What does this fact suggest about their depositional environments? The Kalkberg and Alsen Formations and the New Scotland and Port Ewen Formations are paired in the same way. Notice that the vertical scale of this cross section is much larger than the horizontal scale. The vertical exaggeration is about 1000 times. We have to exaggerate the vertical dimension in drawings like this one in order to show details because the thickness of sedimentary formations is small compared to their width and length. (Note: A *diagrammatic cross section* is a cross section that is drawn to explain or illustrate a point, rather than to present a realistic picture of the appearance of the subject.)

In eastern New York, the Tristates Group is 100 m thick at Catskill and becomes thicker to the south (225 m at Port Jervis). Except in southeastern New York, there are unconformities above and below the Tristates Group.

Table 8.2 contains a description of the formations of the Tristates Group. Some of these formations strongly resemble some formations in the Helderberg Group. These similarities are indicated in the facies column on the table.

The Port Jervis Formation at the base of the group is found only near Port Jervis. The rock of this formation is similar to that of the New Scotland Formation of the Helderberg Group. Above the Port Jervis is the Glenerie limestone. To the west, the Glenerie becomes more and more sandy until it gradually becomes a sandstone. This sandstone unit is called the *Oriskany Sandstone*.

The Oriskany lies upon the eroded surface of the Helderberg Group (see Plate 3). Remember that the sea withdrew after depositing the Helderberg limestones and exposed them to erosion. The farther west we go, the longer the rock was exposed. Thus, as we move west, the Oriskany lies on top of older and older layers of the Helderberg Group.

The Oriskany Sandstone is found below the surface in south-central New York State. Although it does not appear at the surface, it is well known in this area because it produces large quantities of natural gas. The gas fills the pore spaces between the quartz sand grains in the sandstone and is trapped there by an impermeable rock layer above. People looking for oil and natural gas frequently drill down into the Oriskany Sandstone.

The Esopus, Carlisle Center, and Schoharie Formations form the bulk of the Tristates Group. The rock of these units was formed largely from sand and mud eroded from the land. These formations are as thick as 135 m and occur only in eastern and southeastern New York.

The Esopus, Carlisle Center, and Schoharie Formations are very different from the Glenerie and Oriskany formations beneath them. This abrupt change reflects a change in the environment. The water in the Appalachian Basin

Table 8.1
Helderberg Group

Formation	Facies	Rock Types, Grain Size, Sedimentary Structures	Fossils	Environments
Port Ewen	New Scotland	see New Scotland, below	see New Scotland, below	see New Scotland, below
Alsen	Kalkberg	see Kalkberg, below	see Kalkberg, below	see Kalkberg, below
Becraft	Coeymans	see Coeymans, below	see Coeymans, below	see Coeymans, below
New Scotland (Fig. 8.7)	New Scotland	fine- to medium-grained limestone that contains clay shale that contains calcium carbonate thin to medium layers of uniform thickness	high number & variety of sea bottom dwellers, trilobite-dominated faunas	deepest water of the Helderberg Sea; below motion of fair-weather waves; bottom agitated by storm waves
Kalkberg (Fig. 8.7)	Kalkberg	medium-grained limestone rich in clay & silica chert thin to medium layers	high number & variety: bryozoans brachiopods crinoids corals trilobites mollusks ostracodes	deeper water at or near lowest point reached by fair-weather waves bottom occasionally agitated
Coeymans (Fig. 8.8, 8.9)	Coeymans	clean medium- to coarse-grained limestone scattered small coral and stromatoporoid reefs uneven, medium to thick layers cross-bedding	moderate number pelmatozoans corals brachiopods mollusks trilobites ostracodes	shallow water shelf vigorous wave motion well agitated bottom
upper Manlius (Fig. 8.10)	Upper Manlius	fine- to medium-grained limestone slightly uneven, medium to thick layers scour & fill, birdseye, ripple marks, cross-bedding	low to moderate number & variety stromatoporoids brachiopods mollusks ostracodes trilobites	shallow water near the shore & near low tide moderate wave motion-protected by a barrier
lower Manlius (Fig. 8.11)	Lower Manlius	fine-grained limestone & dolostone, medium to thin layers; some laminations alternating layers of shale rich in carbonate sediments scour & fill, birdseye, desiccation cracks	low number & variety stromatolites oncolites ostracodes brachiopods gastropods tentaculites	between high & low tides and shallow water below low tide

Figure 8.7. In this road cut in Greene County, you can see the Kalkberg Formation (center right) and, on top of it, the New Scotland Formation.

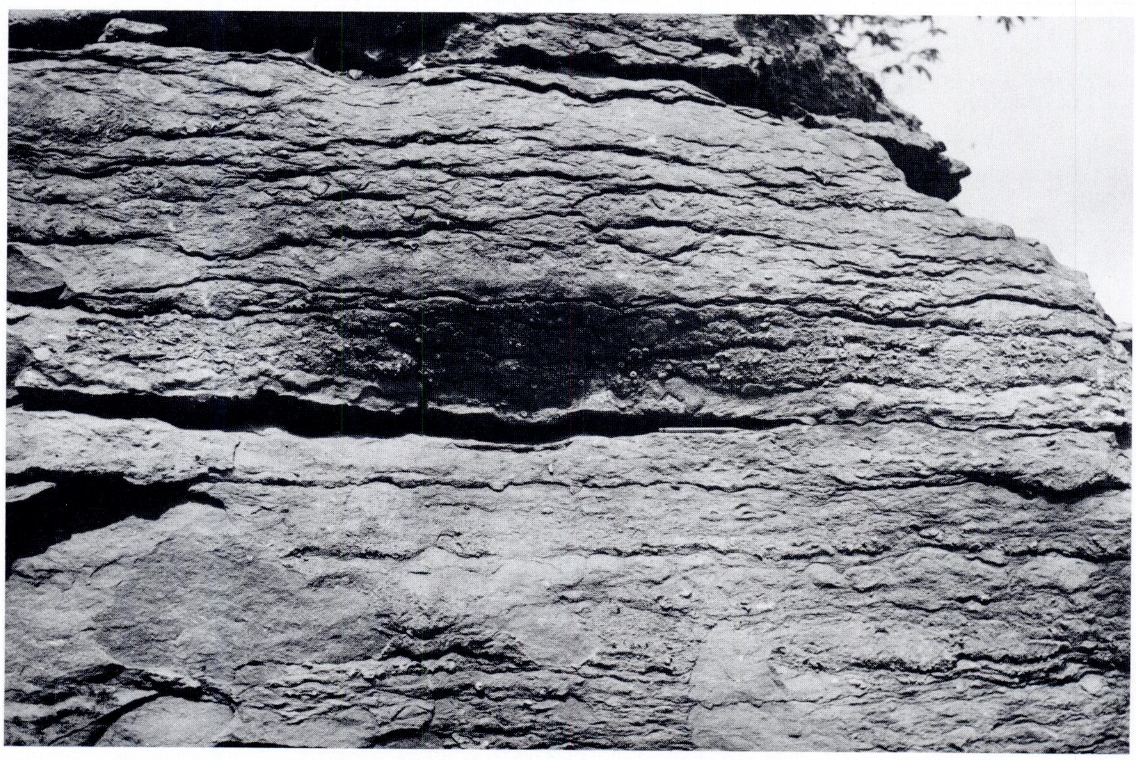


Figure 8.8. Thick, coarse-grained limestone beds of the Lower Devonian Coeymans Formation are seen in this Albany County road cut.

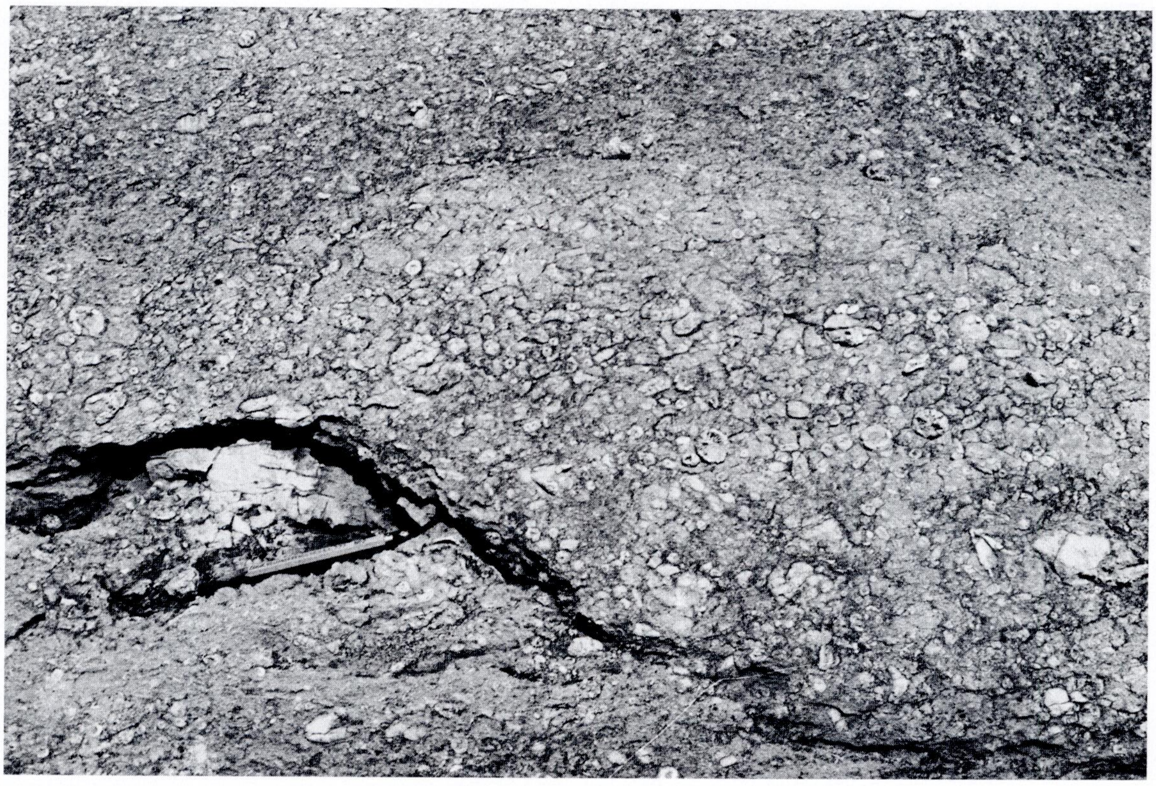


Figure 8.9. This coral reef, called the Knoxboro reef, is found in the Lower Devonian Coeymans Formation in a field in Oneida County. Because it contains abundant fossil shell debris, the rock has a coarse texture and lacks distinct layers.

suddenly became deeper after deposition of the Glenerie-Oriskany. Look at the "Environments" column in Table 8.2. Notice the change between the Glenerie and the Esopus. The water suddenly became much deeper; mud was deposited instead of sand. This mud became the Esopus Formation. The next higher formation, the Carlisle Center, is mainly siltstones. They were deposited in somewhat shallower water. Both the Esopus and Carlisle Center Formations were formed from sediment washed from the land and carried by streams into the Early Devonian sea.

Unlike the Oriskany Sandstone, the Esopus and Carlisle Center Formations contain few fossils of animals with shells or other hard parts. The sea bottom was so soft and the water was so muddy while the Esopus and Carlisle Center were being deposited that few animals with heavy shells could live. We find only one common indication of life in that environment. It is a *trace fossil*[9] called *Zoophycus* that looks like the outline of a rooster's tail on the surfaces of rock units. It was made by a worm-like animal that moved through the sediment in long, curved arcs as it ate mud (Figure 8.12).

The Schoharie Formation is a fine- to medium-grained sandstone that contains some limy material. It also contains abundant body fossils in its uppermost layer. The Schoharie is similar to the Carlisle Springs Formation. However, the sediments are coarser grained and seem to have been deposited in shallower water. As the water grew shallower, brachiopods, cephalopods, and clams (see Figure A.3) appeared on the sea floor. They are preserved as fossils in the top of the formation.

Middle Devonian History

At the end of the Early Devonian, the inland sea of the Appalachian Basin continued to become shallower and shrink. Eventually, it withdrew temporarily from most of New York State; as it went, it exposed the Schoharie Formation to erosion. In the western part of the State, much

[9]A *trace fossil* is a track, trail, or burrow made by an animal or plant root that is preserved as a fossil when the sediment becomes rock. The skeletal remains or impressions of plants and animals are known as *body fossils*.

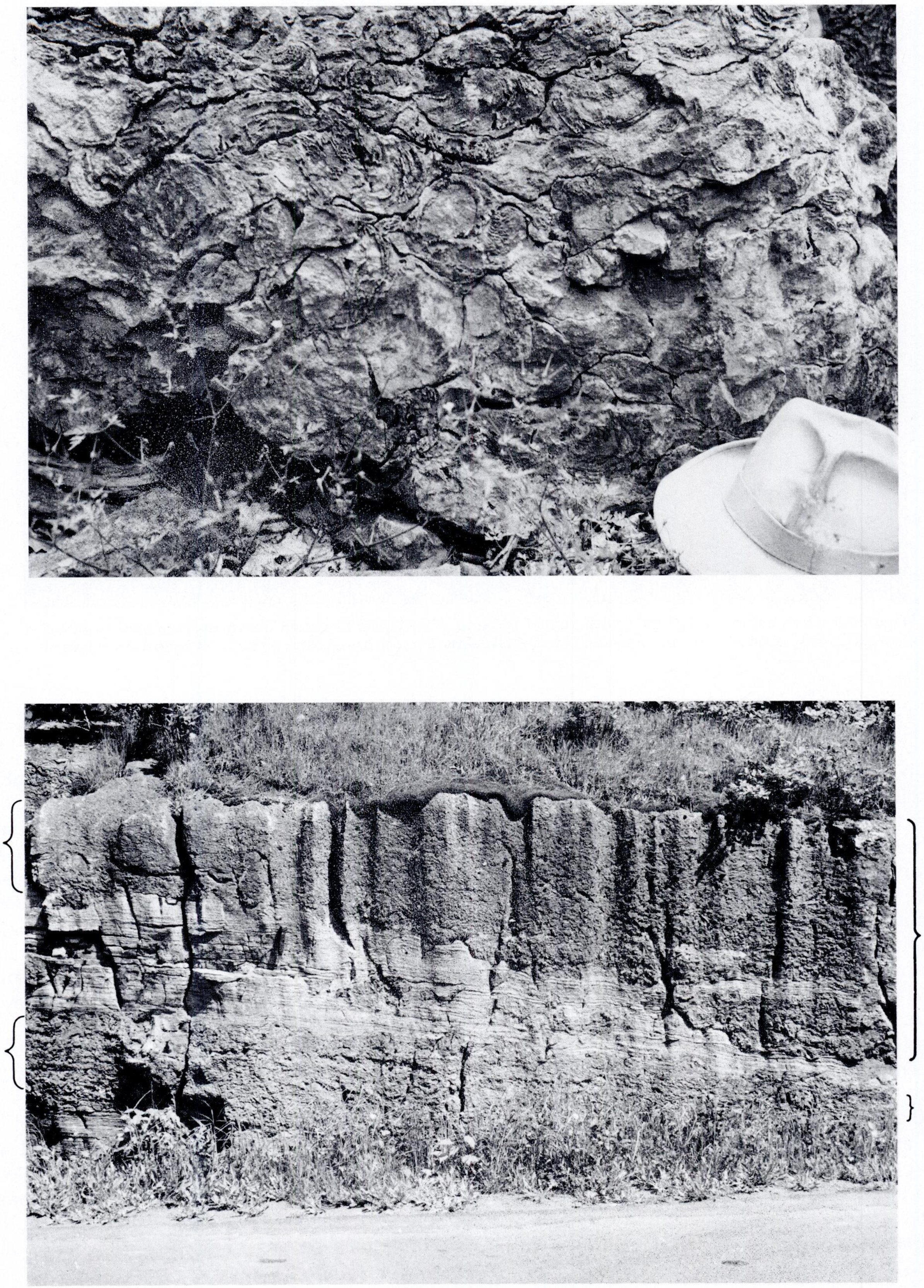


Figure 8.10. These two photos show stromatoporoids in the Manlius Formation. In (A), you can see large, spherical stromatoporoids found in Herkimer County. In (B), you can see small, irregular stromatoporoids in the layers indicated by the brackets. Found in Albany County.

Figure 8.11. These fossils, which have the technical name *Tentaculites gyracanthus* (Eaton), may be members of an extinct group related to mollusks. They are found in the Thacher Member of the Lower Devonian Manlius Formation in Schoharie County.

of the Early Devonian record was destroyed. Only patches remain (see Plate 3).

The Middle Devonian began about 390 million years ago, when a warm, shallow sea again covered New York from the present Hudson River to Lake Erie and farther west. This sea was home to a host of invertebrate animals. Corals were particularly abundant and built reefs in many places. There were also vertebrates—a number of jawless and shark-like fish lived in these waters.

We read this history in the Onondaga Limestone, the first rock unit deposited in the Middle Devonian sea. This limestone unit ranges from 20 to 75 m thick, and throughout much of New York State it lies on a major unconformity. (It is this unconformity that shows us that the sea withdrew temporarily at the end of the Early Devonian.)

As we move west from Cherry Valley, we find the Onondaga Limestone on top of progressively older rocks—the Carlisle Center, the Oriskany, and various formations of the Helderberg Group (Kalkberg, Coeymans, and Manlius). In west and west-central New York, it lies on rock of Silurian age. Near Buffalo, patches of the Bois Blanc Limestone lie between the Silurian formations and the Onondaga Limestone. You can see how the layers stack up on Plate 3.

However, in eastern and southeastern New York, the Onondaga Limestone lies on the Schoharie Formation with no unconformity. The sediment seems to have been deposited continuously here, without any breaks. Thus, the sea must have remained in eastern and southeastern New York through the Early Devonian and into Middle Devonian time.

The facies of the Onondaga limestones are similar to facies in the Helderberg Group. The Onondaga Formation is divided into four members: the Edgecliff, Nedrow, Moorehouse, and Seneca. You can find descriptions of the members in Table 8.3; their locations are shown on Plate 3.

The Edgecliff Member contains corals, as indicated in Table 8.3. We can see these coral reefs in outcrops of the Edgecliff Member. By drilling underground into the Edgecliff Member, we have learned that corals are also present there. These corals have many holes in them. Some of the holes are spaces between coral heads; others are the small tubes in which the coral animals lived. If natural gas is produced underground, these holes can trap and store it. The coral reefs make the Edgecliff Member a source of gas.

In the upper part of the Onondaga Formation, we find several layers of clay. They have a special origin: they are

Table 8.2
Tristates Group

Formation	Facies	Rock Types, Grain Size, Sedimentary Structures	Fossils	Environments
Schoharie Formation	New Scotland	siltstone that contains calcium carbonate and fine quartz sandstone	trace fossils with body fossils present only at top of formation brachiopods cephalopods corals	below fair-weather wave base, well oxygenated, bottom agitated by storm waves
Carlisle Center Formation		siltstone that contains a small amount of calcium carbonate	rare body fossils some trace fossils	moderately deep water, soft bottom, little current activity bottom rarely agitated
Esopus Formation		dark gray shale rich in silica chert	rare body fossils some trace fossils	deep water, soft bottom, little oxygen, little current activity, bottom rarely agitated
Glenerie Limestone	Kalkberg	limestone rich in silica	moderate number, similar to those found in Kalkberg Formation	deeper water near deepest level reached by fair-weather waves, bottom occasionally agitated
Oriskany Sandstone*		quartz sandstone that contains calcium carbonate	large, thick-shelled brachiopods	shallow water near the shore, vigorous wave and current motion, well agitated bottom
Port Jervis Limestone**	New Scotland	medium-grained limestone rich in clay & silica	similar to those found in New Scotland Formation	deep water below motion of fair-weather waves

*The Oriskany lies to the west of the Port Jervis, not on top of it.
**Found only near Port Jervis, NY.

made from layers of ash spread by powerful volcanic eruptions over eastern proto-North America. The clay layers, called the *Tioga ash beds,* show us that there were at least three large volcanic eruptions during the early part of the Middle Devonian. We can trace these clay layers all the way to the Midwest, so we know the volcanic eruptions spread ash over a very wide area. Because they are so widespread, the ash layers are very useful in matching the ages of rock bodies that are far apart. A volcanic eruption lasts for only an instant of geologic time. Thus, if we can trace a volcanic ash into widely separated areas of the country, we can use it for very precise time correlations.

The Onondaga Limestone was the last thick, widespread deposit of limestone in the Devonian of New York. It is relatively resistant to erosion compared to the rock above and below it, so it commonly stands above the rest of the landscape as an escarpment that runs east to west across the State. It is quarried extensively in New York, mainly for crushed stone, which is used in concrete and for other purposes.

An abrupt change in environment stopped deposition of the Onondaga Limestone. Sometime in the early part of the Middle Devonian, the continent of Avalon collided with proto-North America (see Chapter 3). This collision caused a great new mountain-building event called the

Figure 8.12. The surface of this layer in the Lower Devonian Carlisle Center Formation shows feeding burrows of a marine worm called *Zoophycus*. It was found near Cherry Valley, Otsego County.

Table 8.3
Onondaga Formation

Member	Facies	Rock Types, Grain Size, Sedimentary Structures	Fossils	Environments
Seneca Member	New Scotland	shale that contains calcium carbonate and fine-grained limestone that contains much clay less pure (contains much clay) with several thin volcanic ash beds (Tioga ash beds)	brachiopods, including some with pinkish shells shells, called Chonetes lineatus sea floor animals similar to those found in New Scotland Formation	deeper water, below motion of fair-weather waves, bottom agitated by storm waves
Moorehouse Member (Fig. 8.13)	Kalkberg	fine- to medium-grained limestone thin to medium-thick layers varying amounts of chert	many fossils of sea floor animals	shallow, quiet water at or near lowest point reached by motion of fair-weather waves, bottom occasionally agitated
Nedrow Member*	New Scotland	medium-grained limestone (upper) shale that contains calcium carbonate (lower)	platyceratid gastropods and sparse fossils of sea floor animals	similar to New Scotland facies
Edgecliff Member	Coeymans	medium- to coarse-grained limestone medium to thick layers chert blanket-like layers built by corals, scattered coral reefs	similar to those found in Coeymans Formation rugose & tabulate corals pelmatozoans brachiopods trilobites mollusks	shallow water shelf, vigorous wave motion, well agitated bottom

*The Nedrow Member occurs in central New York. To the east and west, it gradually becomes a cleaner limestone with chert in it. There, it is more like the rest of the Onondaga Limestone and less like a separate member.

Acadian Orogeny. Mountains started to rise in New England and the Canadian Maritime Provinces. As the collision went on, it caused faulting, folding, metamorphism, and igneous intrusions.[10] In the area where the Onondaga Limestone was being deposited, the orogeny caused an abrupt deepening of the water. This deepening brought about a drastic change in the environment of the sea floor and, hence, an abrupt change in the kind of sediment deposited there.

The Acadian Orogeny eventually transformed the eastern part of proto-North America into the rugged, lofty Acadian Mountain range. In some areas of southeastern New York, we can see sedimentary layers that were highly deformed and metamorphosed in the Acadian Orogeny. Their twisted and contorted condition shows us the intensity of the event. The indirect effects of the Acadian Orogeny were even more widespread.

Erosion immediately attacked the newly built mountains, and streams carried tremendous quantities of sediment from the mountains westward toward the sea. This process went on through the Middle and Late Devonian.

Figure 8.14 shows the general location of major river systems that flowed from the mountains into the Appalachian Basin in the Late Devonian. How do we know where the rivers were? On their way to the sea, the rivers dropped some of the sediment they carried. They dropped the coarser particles first, at the foothills; they continued dropping finer and finer sediment along their courses to the sea. These processes built an *alluvial plain* between the hills and the shoreline. Where the streams

[10]Chapters 3 and 4 have more information about continental collisions and mountain-building.

Figure 8.13. This photo shows the Moorehouse Member of the Middle Devonian Onondaga Limestone in Otsego County. It includes knobby chert in the layers of limestone.

met the sea, they built deltas of sand and mud. Between the shore and the mountains, the rivers changed their courses from time to time. Thus, the alluvial plains grew sideways and overlapped. The deltas grew out into the sea; they also grew sideways and overlapped. Eventually a huge apron of sediments was formed (Figure 8.14). By looking at the thickness of these deposits and the grain size of the rock in various places, we can deduce approximately where the rivers flowed.

Figure 8.15 will give you a rough idea of the geography at this time. The sedimentary apron extended from the mountains, across the shore, and well out into the sea. As sediment filled in the eastern edge of the basin, the shoreline moved west and the sea retreated. This process continued throughout the Middle and Late Devonian. By the end of the Devonian, the shore was in the western part of the State.

To examine this movement in the Middle and Late Devonian, see the small diagram labelled *Depositional Environments* on Plate 3. Notice how the shore zone (yellow) and the other environments push westward across the State over time. The ragged edges in the diagram show that this movement was not steady and continuous through time. It went by fits and starts, with occasional temporary retreats.

This great apron of sediment became layers of sedimentary rock. We can see these layers in many outcrops in the Catskill Mountains. These outcrops contain many clues that tell us in which environments the sediment was deposited. It was from such clues that we figured out the picture described above—a system of rivers flowing generally westward from a high mountain range on the east to a sea on the west.

We call the sedimentary apron the *"Catskill Delta."* But this great wedge of sedimentary rock is not really a single delta. It was built by many rivers that carried sedi-

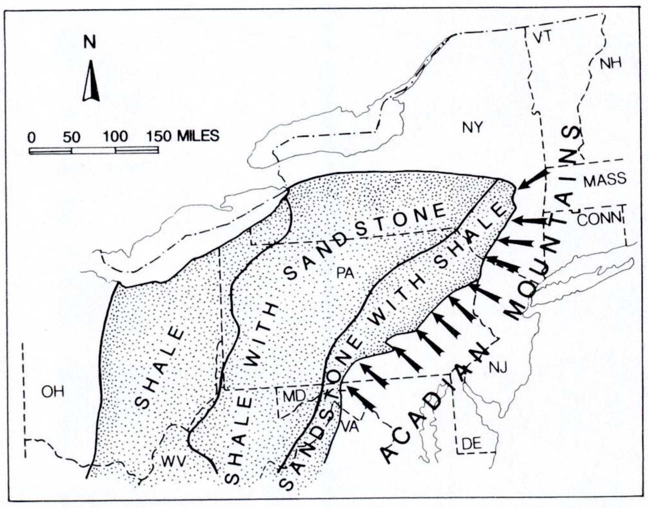


Figure 8.14. Map of the area where "Catskill Delta" deposits exist today. They originally extended farther north across New York, but erosion has removed them from that area. The Acadian Mountains of Middle and Late Devonian time were the source of the sediments of the "delta." The arrows represent a system of large rivers that carried sediment from the mountains to build the "delta." (Modified after W.D. Sevon, Fig. 3 and 6, Guidebook, 53rd Annual Meeting of New York State Geological Association, 1981.)

ment from the west side of the Acadian Mountains (Figure 8.14). We put quotation marks around it to remind ourselves that "Catskill Delta" is not a precise term.

The "Catskill Delta" grew—sometimes rapidly and sometimes slowly—throughout the Middle and Late Devonian. Sediment was washed down from the Acadian Mountains, and the floor of the sea basin was sinking. Both of these things happened at varying rates. How fast the "delta" grew westward and thickened upward depended on how much sediment was washed from the mountains and how fast the sea floor was sinking.

Several factors affected the amount of sediment eroded from the mountains. When the Acadian Mountains grew rapidly and became very high, erosion would be more rapid. When they were worn down to lower elevations, erosion would be slower. Changes in climate would also change the rate of erosion, perhaps drastically if annual rainfall changed markedly. The building of the "delta" took tens of millions of years, so there was time for many variations.

At the same time, the floor of the inland sea was sinking at changing rates. When the sea floor sank slowly, the sediment would fill in at the edge of the basin and push the shoreline westward. When the sea floor sank faster than the sediment could accumulate at the basin's edge, the shoreline would remain in one position or the sea would advance eastward. When the shoreline moved eastward, it covered the newly formed layers of non-marine sediment by depositing marine sediment on top of them. The back-and-forth movement of the shoreline produced alternating layers of marine and non-marine sediment.

The oldest rock in the "Catskill Delta" is found in the Hamilton Group. The Hamilton Group extends across New York State from the Hudson River to Lake Erie. In the east, it is 850 m thick. In the west, it is only 80 m thick. The Hamilton Group includes a number of formations, which are shown on Plate 3. These formations were deposited in five major depositional environments. The formations and facies are described in Table 8.4.

Remember that the "delta" grew by filling in the sea. As the rivers delivered sediment to the sea, marine waves and currents took over and began to move some of it around. These processes tended to sort the sediment into its various grain sizes. Much of this work was done during storms. The storms would churn the shallow water near shore and put a lot of fine-grained sediment into suspension. Currents then moved it around before it was dropped.

The finer material was deposited farther offshore. Finer grained sediment settles more slowly than coarser grained. Thus, fine material stays in suspension longer than coarse. Weak currents and waves will drop coarse grains but can move fine material. Currents and waves tend to become weaker offshore as the water deepens. As currents or waves weaken, they drop the coarser material first, and the fine material is carried farther.

In Table 8.4, notice that the lowest part of the Hamilton Group, which lies directly on top of the Onondaga Limestone, is the black shale of the Marcellus Formation. It was formed from fine black mud deposited in the deep part of the basin where the water was stagnant and had very little oxygen in it. As we mentioned above, a sudden deepening of the inland sea stopped deposition of the Onondaga Limestone. This event also brought about the stagnant basin environment where the Marcellus Shale was deposited. This deepening probably was related in some way to the rapid mountain building to the east. The basin apparently sank rapidly to compensate for the rapid mountain building. As the Acadian Mountains eroded, coarser sediments—silty mud, silt, and fine sand—advanced across the basin and buried the fine mud that formed the shale. In eastern New York, these sediments were later replaced by even coarser ones—muddy sand (together with red and green mud), then quartz-pebble gravel. This succession of sediments crept out into the sea to form the lower part of the "Catskill Delta."

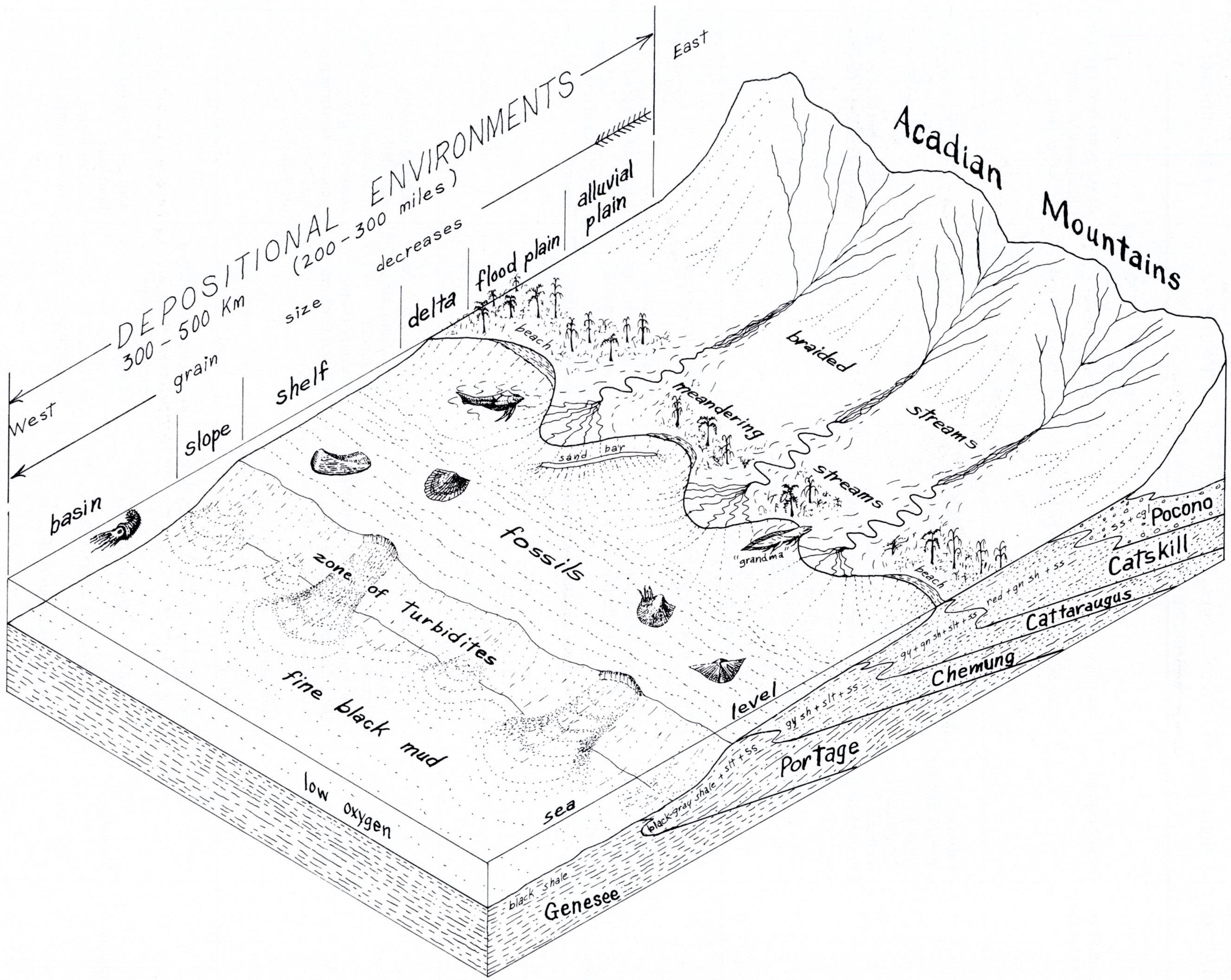


Figure 8.15. Diagram of the depositional environments of the "Catskill Delta" and the facies that were deposited in them. The arrangement of the facies (Genesee-Pocono) shows that the environments have moved from right to left through time as the sediment has filled in the edge of the sea. This process could be reversed by a rise in sea level, which would move the shore zone toward the right. (In this oversimplified diagram, the Pocono facies looks as if it were underneath the Acadian Mountains. It was actually deposited at the foot of the mountains.)

Table 8.4
Middle Devonian Shales, Sandstones, and Conglomerates

Group, Formation, Member, Beds, or Facies	Facies	Rock Types, Grain Size, Sedimentary Structures	Fossils	Environments
Thin limestone units at several levels within the group	New Scotland	limestone rich in clay shale that contains calcium carbonate	high number & variety corals brachiopods bryozoans all types of mollusks crinoids trilobites ostracodes	deeper water below motion of fair-weather waves well oxygenated
Skunnemunk Conglomerate*	Pocono (named after the Pocono Formation of northeast Pennsylvania)	thick layers coarse at the bottom, gradually become finer grained from bottom to top: top: silty shale finer grained sandstone very coarse pebbly sandstone (purple or maroon) bottom: conglomerate pebbles in conglomerate are mainly white quartz or quartzite; also include red and green shale, greenish quartzite, buff sandstone, pink sandstone		braided streams at foot of growing mountain range
Catskill** facies	Catskill	red, green, & gray shale, mudstone & siltstone alternating layers of impure quartz sandstone and pebbly sandstone sandstone is medium to coarse grained sandstone layers gradually become finer grained from bottom to top cross-bedding, root traces, mud cracks, scour & fill	relatively few overall in places, common plants and clams, and very rare fish fossils; land-dwelling arthropods: mites, millipedes, spider-like forms	delta above sea level flood plain and river channels
Hamilton Group	Hamilton	gray shale, mudstone, siltstone mudstone siltstone fine- to medium-grained sandstone flat-pebble conglomerate concentrations of fossil shells laminations, cross-bedding, ripple marks, flute & groove casts, convoluted bedding	high number & variety of shelled animals brachiopods, conodonts, bivalve mollusks, trilobites	deep part of basin open shelf underwater part of delta channels dug by underwater currents tidal flats offshore bars
Marcellus Formation	Marcellus	very thin layers of black or very dark gray shale thin layers of limestone rich in clay shale splits eaily into thin sheets abundant calcareous nodules or concretions abundant pyrite	low number & variety of bottom-dwelling & swimming animals ammonoids conodonts styliolinids brachiopods	deep part of the basin far from land poor circulation limited oxygen

*Found in southeastern New York.
**Found only in eastern New York.

From time to time, the sediment supply was interrupted. At those times, the "delta" would stop growing, and the sea water became less muddy for a time. This environment permitted organisms that produced calcium carbonate to thrive. Their remains accumulated on the sea floor as layers of calcareous sediment. And indeed in the Hamilton Group, we find several thin but widespread limestone layers. We use these limestone beds as markers to separate the Hamilton Group into the formations shown on Plate 3. As you can see in Table 8.4, these limestones contain much clay, so we know that mud (clay) was being washed in from the land. When less mud and sand were deposited, we find limestone rich in clay. When more mud and sand were deposited, it diluted the calcareous sediments and formed limy shales or limy sandstones.

Where the limestone disappears, we know that the sea had again become so muddy that the organisms that produced calcium carbonate couldn't survive or their remains had been too diluted to form limestone. The limestone of the Hamilton Group contains some of the most magnificent Devonian fossils ever found. Here we

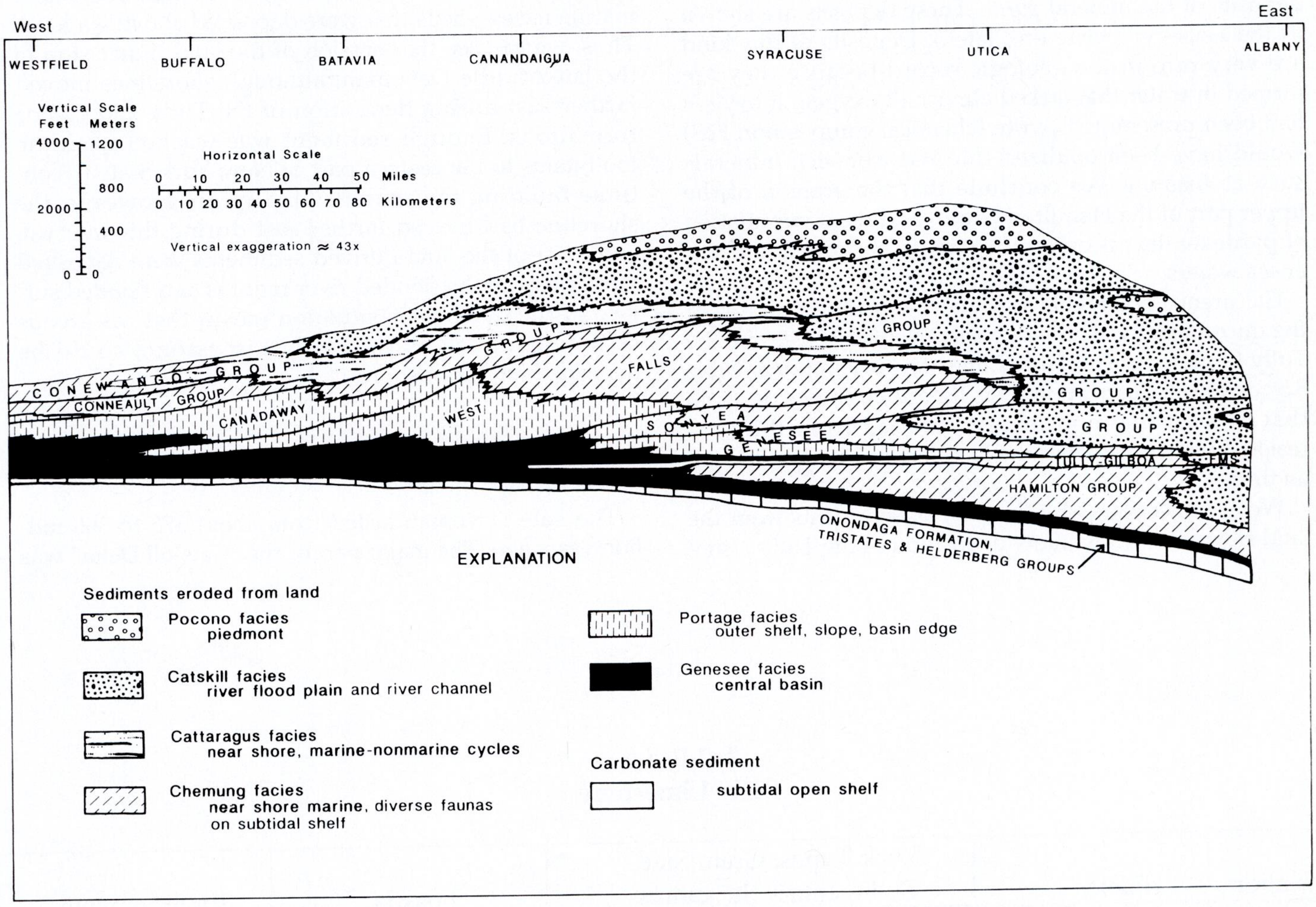


Figure 8.16. Diagrammatic cross section of the "Catskill Delta" east-west across New York State. This diagram is a composite that uses information from the outcrops in New York and in northern Pennsylvania. The cities listed across the top of the diagram generally are north of the main body of the cross section. A line drawn south from a city will cross the facies shown below it, starting with those facies at the bottom of the diagram. The "delta" deposits are divided into groups. Each group includes several facies. Figure 8.15 shows the environments where the different facies developed. Each group records an episode of the "delta's" construction. For example, as the Genesee Group was deposited, the shore zone moved from east to west as the sediment filled in the sea. An abrupt increase in the depth of the water moved the shore zone back toward the east, and deposition of the Sonyea Group began. The opposing processes eventually built the complex of sedimentary rock we call the "Catskill Delta." Notice that this diagram is distorted because the vertical scale is much larger than the horizontal scale. This vertical exaggeration is necessary to show details. However, it gives a false impression because it exaggerates the thickness relative to the width of the units shown.

find a great number and a great variety of shelled animals that lived on or swam above the sea bottom.

The lower part of Figure 8.16 shows how the different Hamilton facies (described in Table 8.4) are stacked up across the State from east to west. You'll notice that this figure shows no Pocono facies in the Hamilton Group. That is because we find the Pocono only in southeastern New York, which is off the line of this cross section.

Toward the end of the Middle Devonian, construction of the "Catskill Delta" slowed down sharply. This slowing marked the end of deposition of the Hamilton Group. In western and central New York, the sea floor was eroded. This erosion is marked by an unconformity. Along this unconformity, we find many lens-shaped deposits of the mineral *pyrite*. These deposits are shown as the Leicester pyrite on Plate 3. Deposits of this kind are very rare in the geologic record because they are formed in water that lacked almost all oxygen. If oxygen had been present, the pyrite (chemical composition FeS) would have been oxidized into red iron-rich minerals such as *limonite*. We conclude that the erosion of the upper part of the Hamilton Group and the accumulation of pyrite on the unconformity surface happened in deeper sea waters.

Calcareous sediments were later deposited on top of the unconformity. These deposits eventually became the Tully Limestone. The Tully Limestone is 9 m thick. Table 8.5 contains a description. This limestone shows us again that little of the mud or sand eroded from the land reached this area during the late part of Middle Devonian time.

We are uncertain why the flow of sediments from the land slowed down to allow deposition of the Tully Limestone. However, an examination of the Tully Limestone and other sedimentary rocks deposited at the same time suggests an explanation.

The Tully Limestone is found only in western and central New York. Farther east, between the Chenango and Unadilla Rivers, the amount of mud and sand in the limestone gradually increases until the limestone is replaced by silty shale, siltstone, and sandstone. These beds and their fossils represent environments like the ones we saw in the Hamilton Group. They are called the *Gilboa Formation*, a marine unit that is underlain and overlain by sandstones laid down in fresh water or on the land. Heading east from the Schoharie Valley, the Gilboa Formation, in turn, gradually changes into a nonmarine facies—beds that were deposited above sea level. Thus, we can see that erosion of the land didn't stop in the late Middle Devonian, although shorelines moved farther east during deposition of the Tully and Gilboa formations. Enough sediment was washed from the mountains to the eastern part of New York State to continue building the sedimentary apron. However, the shoreline had moved farther east during this interval, and most of the land-derived sediments were deposited farther east in the flooded river mouths and flooded surface of the delta. This situation meant that calcareous sediments, such as the Tully Limestone, could be deposited farther offshore.

Late Devonian History

The Late Devonian lasted from about 375 to 360 million years ago. The major part of the "Catskill Delta" was

Table 8.5
Tully Limestone

Formation	Facies	Rock Types, Grain Size, Sedimentary Structures	Fossils	Environments
Tully*	New Scotland	medium to thick layers of limestone rich in clay	moderate variety of sea bottom dwellers brachiopods corals crinoids pelecypods cephalopods trilobites	depth below fair-weather waves well oxygenated

*The Tully is separated into two parts by an unconformity--the Upper Tully and the Lower Tully. Both parts represent similar environments.

built during this time (Figure 8.16). The structure of the Late Devonian part of the "delta" is similar to that of the Middle Devonian Hamilton Group. The coarsest sediment is in the east, closest to the mountains that supplied it. As we move farther west, the sediment becomes progressively finer.

When sediment is deposited, the water near shore becomes shallower. Water depth controls the environment, so all the environments shift in a seaward direction, following their appropriate water depth. Eventually, the sediment replaces the sea water and builds the area above sea level.

If we select a rock unit in the "Catskill Delta" and follow it from east to west, we see the facies change from non-marine to shallow marine water to deep water. The change from non-marine (rivers) to marine (sea) is a major one for plants and animals, because the chemistry of sea water is very different from that of fresh water. This change in facies shows us the various environments that existed at the same time.

As we move from lower (older) layers to higher (younger) layers, we see the facies change as well. For example, they may change from deep water to shallow water to non-marine. These changes show us that different environments existed in a particular place over time. They show us the history of the growth of the "delta."

The major facies of the Late Devonian and the environments they represent are described in Table 8.6. Figure 8.15 shows the geography for the Late Devonian from the basin floor across the shore zone to the mountain front. This diagram relates the environment where each of the facies developed to the landscape and water depth.

Figure 8.16 is an east-west cross section of the "Catskill Delta" that shows how the facies are distributed. Notice how the non-marine facies—Cattaraugus, Catskill, and Pocono—move westward over the marine facies throughout the Middle and Late Devonian. This was a slow, creeping, halting movement. Frequently the sea would temporarily deepen and bring the shoreline and marine environments back east. Marine facies then could be deposited on top of earlier non-marine facies.

As we saw earlier, a number of factors interact to make the shoreline move back and forth: change in sediment supply from the land; rise or fall in sea level; change in the rate of sea floor sinking. Waves and currents might become stronger or weaker, depending on variations in geography, and move the sediments around in different ways. We can see the effects of all these factors in the overlapping, irregular shape of the facies.

In the Upper Devonian part of the "Catskill Delta," nearly all the rock was made from sediment deposited on land or in fresh water. Geologists have divided this great mass of sedimentary layers into six groups. From oldest (bottom) to youngest (top), they are: Genesee, Sonyea, West Falls, Canadaway, Conneaut, and Conewango (Figure 8.16 and Plate 3). The three oldest groups (Genesee, Sonyea, and West Falls) extend completely across the State. The younger ones are found only in the western part of the State. Either they were never deposited in the Catskills, or they were later worn away by erosion. As you can see on Plate 2, the various groups crop out in the Catskills, the Finger Lakes region, the Genesee River valley, and along the shore of Lake Erie.

We'll describe the lower four groups (Genesee, Sonyea, West Falls, and Canadaway) together because they have similar histories. They illustrate the way the "Catskill Delta" developed. All are much thicker in the eastern part of the State (Table 8.7).

The enormous size of the "Catskill Delta," both in thickness and in area, gives us a large problem. How can we tell whether, for example, a reddish sandstone in the eastern part was deposited at the same time as a black clay shale in the western part? The fossil content is not likely to help because the two units represent entirely different environments. In other words, we probably won't find the same kind of fossil in both units—the two environments were home to two different sets of creatures.

One approach to the problem is to carefully examine closely spaced outcrops all the way across the State. Many different geologists have studied parts of the "delta" in this way through the years. However, their conclusions about it have not always fit together.

One feature of the "delta" that has helped sort out the parts of the puzzle are layers of black shale that cross the State in the marine facies. Black shale of this type is deposited in the deeper parts of a marine basin. Only fine mud reaches the area. Commonly, the deeper water in the basin also had a low level of oxygen. Low oxygen allows *organic matter* (the tissues of living things) to accumulate in the sediment instead of breaking down into simpler compounds. In addition, grains and nodules of pyrite (or "fool's gold," chemical composition FeS) grow in dark shales of this type. Organic matter is one of the components that makes the shale black. The other component is pyrite; interestingly, large pyrite grains are golden in color, but very fine-grained pyrite is black in color. When circulation of the bottom water is better, the oxygen content increases and the shale deposited has a lighter color—gray to greenish—because organic matter and pyrite content are low.

There is a relatively uniform sequence of Upper Devonian shale in the western part of the State; thus, we know that a deeper basin environment persisted in this area. Tongues of black shale extend eastward from this main body. A number of black shale tongues lie right on top of other, shallower marine facies in more eastern sites. The upward change to black shale is sudden at these eastern sites. Therefore, we believe that the deeper basin environ-

Table 8.6
Rocks of the Upper Devonian

Facies Name	Environment	Rock Types, Grain Size, Sedimentary Structures	Fossils	Environments
Pocono (Fig. 8.17)	piedmont	conglomerate w/round white quartz pebbles pebbly sandstone & siltstone (purple or maroon) thick layers	rare fossils	braided streams near foot of mountain range
Catskill	river flood plain	red, green, & gray shale green mudstone & siltstone medium to coarse-grained quartz sandstone pebbly sandstone sandstone beds coarser at base and become finer going up cross-bedding in sandstone; scouring, root traces, mud cracks	few fossils overall in places, plant and fish fossils are common	river floodplains with meandering streams shale, mudstone, & siltstone in the floodplains sandstone--in channels
Cattaraugus	near shore marine-nonmarine cycles	gray & green shale, siltstone & sandstone alternating layers of red shale, siltstone, & sandstone gray & green rocks: winnowing, bioturbation, ripple marks red rocks: root traces, mud cracks	low number and variety red rocks contain plant fossils	close to shore, alternately above and below sea level green & gray rocks are marine red rocks are nonmarine
Chemung	nearshore marine, diverse subtidal shelf	gray shale, mudstone, & siltstone fine- to medium-grained sandstone layers of fossil shells flat pebble conglomerate laminations, cross-bedding, ripple marks, flute & groove casts, convoluted sedimentary structures	high number & variety (except in a few environments) of shelled sea animals brachiopods bivalve mollusks	several shallow water environments near shore and in tidal zone: beach, channel, tidal flat, lagoon, swamp, offshore bar, delta, near shore, open shelf underwater: delta, near shore, open shelf
Portage B	open shelf, slope	thin layers of siltstone, cross-laminated, graded turbidities in gray shale	low number & variety of swimmers & sea bottom dwellers	outer part of shelf below motion of fair-weather waves slope
Portage A	base of slope, basin edge	black and medium to dark gray shale, mudstone, and siltstone a few layers of fine-grained sandstone in dark gray shale in siltstone: cross-laminatiaon; casts of grooves, tracks, trails, & flutes convoluted bedding; ripple marks	low number & variety of swimmers and sea bottom dwellers	deeper waters at base of slope to basin margin
Genesee	central basin (like Marcellus)	black shale a few thin layers of dark limestone rich in clay septarian nodules and concretions pyrite shale splits easily into thin sheets	low number & variety of swimmers & sea bottom dwellers: ammonoids conodonts brachiopods mollusks	deep water part of basin far from land very little oxygen near the bottom

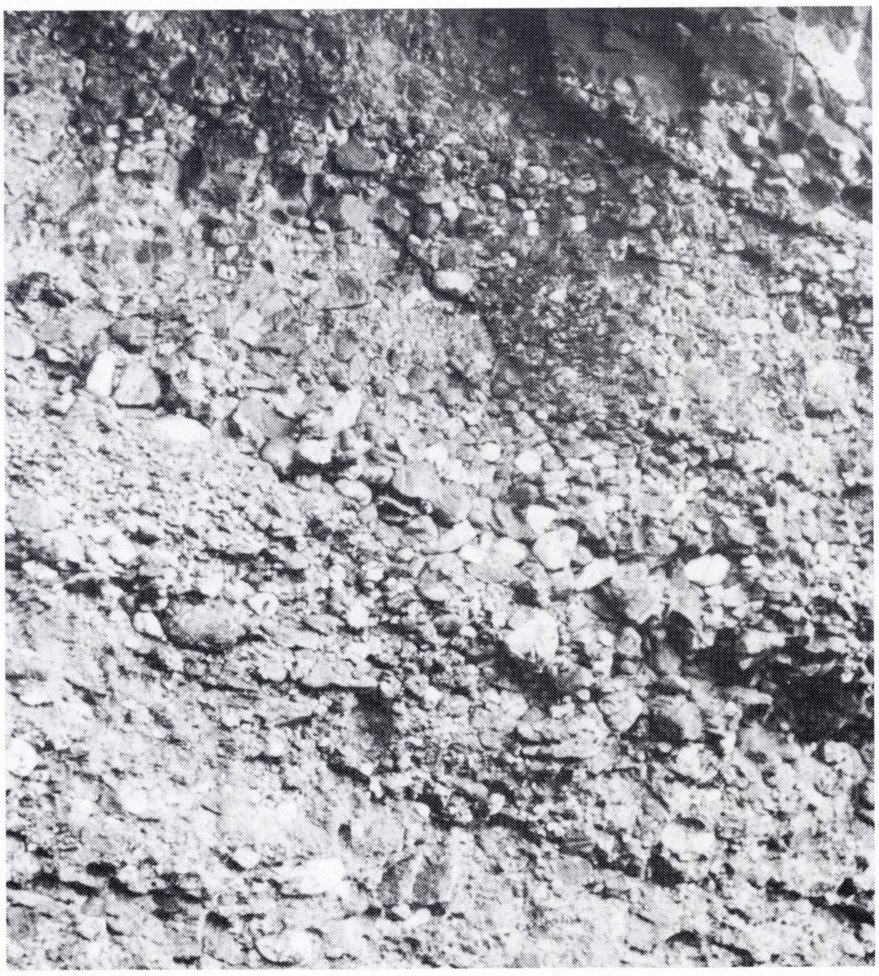


Figure 8.17. This photo shows the Twilight Park Conglomerate, an example of the "Pocono" facies of the Upper Devonian, near Haines Falls, Greene County.

Table 8.7
Comparative Thickness

Group	Thickness at Lake Erie	Thickness in the Catskill Mountains
Genesee	9 m	480 m
Sonyea	15 m	240 m
West Falls	150 m	790 m
Canadaway	335 m	more than 600 m

ment expanded rapidly. Deposition of the black shale tongue would begin everywhere in the expanded basin at almost the same time. If these conclusions are correct, then the base of a black shale tongue is an approximate "time line." In other words, events recorded in the rock at different places just above this time line happened at approximately the same moment in geological time.

What would cause such a sudden expansion of the basin environment? An increase in water depth. And what would increase water depth so quickly? A rapid rise of sea level is one possibility. Another way would be rapid sinking of the floor of the Appalachian Basin. More water would flood in from the ocean to the east, making the inland sea much deeper.

Whatever the cause, a sudden increase in water depth would have several results:

1. The basin environment would expand up the slope and onto the shelf and perhaps even across the old shore zone.
2. The other, shallower depositional environments would move rapidly landward.
3. Low-lying nonmarine environments would be flooded by sea water.

Of course, rivers would continue to carry sediment to the sea. When the increase of water depth slowed or stopped, the sediment would begin to fill in the basin, decrease water depth, and move the environments seaward again.

In western New York, the Genesee, Sonyea, West Falls, and Canadaway groups are each made of a thick layer of black shale with greenish-gray shale on top of it. Tongues of black or very dark gray shale extend eastward from the main body of black shale and mark the base of each of these groups. The lines that separate the groups in Figure 8.16 have been extended eastward beyond the tongues. We use other evidence to mark the base of the groups in the eastern areas.

As we follow a greenish-gray shale above a black tongue from west to east, it gradually changes into a sequence of *turbidites*. Turbidites are beds of siltstones and sandstones that were deposited by *turbidity currents*. (Turbidity currents are density currents caused by churned-up sediment in suspension. They flow downslope along the sea bottom.) As we move farther east, the turbidite sequence changes into other marine facies formed in shallower water (Figure 8.15).

Higher above the black shale tongues, it becomes more difficult to match up the upper parts of the groups. (Remember that each group becomes much thicker and changes facies to the east, but it records the same period of geologic time.) However, there are thin layers of black shale in the upper portion of some groups. Some of these layers continue across the turbidites and help us match up layers from one place to another.

Deposition of each of these four groups began with an eastward advance of the shoreline. As the sea spread east, the water deepened in the east. As a result, the black shale deposited in the deep waters of the basin came to be deposited farther east. This black shale was deposited on top of older deposits that were made in shallower water. These deposits had been formed earlier on the shelf and on the slope between the shelf and the basin. After the sea ceased expanding, deposition again began filling in the edge of the sea and laid down shallower water sediments onto the "delta."

The "delta" then grew until it reached the new sea level, and shallower facies crept across the shelf toward the slope that led down to the basin. When the shore approached the edge of the shelf, sediments piled up near the top of the slope and became unstable. Slumps and storm waves churned them up, put them into suspension, and formed turbidity currents.

Eventually, turbidity currents flowing down the slope into the basin became frequent enough to form the turbidite sequence mentioned above (Figure 8.15). In some of the four groups, though, the shore zone did not reach the top of the slope before the sea level rose again. In those groups, we do not find the turbidites.

The thick black shale at the base of the Canadaway Group represents the last major advance of the sea in the Late Devonian.

The two groups at the top of the "Catskill Delta" complex are the Conneaut and the Conewango. These last two groups were deposited in water that continued to get shallower. By the end of the Devonian, non-marine facies extended almost completely across New York State. Thus, we know that the "delta" had finally grown large enough to push the sea almost entirely out of the State. However, the marine facies were still found in the west.

The Conneaut and Connewango Groups together are 335 m thick in western New York. They are made of gray shale, siltstone, mudstone, and fine sandstone. They contain a moderate variety of fossil shells from marine animals. There are layers of conglomerate at several levels in the Conewango. One is especially easy to see at Panama Rock City in Chautauqua County. In westernmost New York, these two groups form the Chemung facies. Toward the east, the rock gradually changes facies to the red and green Catskill facies in southern Cattaraugus County.

Table 8.6 tells us that much of the Chemung facies, all of the Cattaraugus facies, and much of the Catskill facies were deposited near sea level, either slightly above or slightly below. With this fact in mind, study Figure 8.16 and notice that these facies are hundreds of meters thick in the east-central part of the "delta." Notice also the depositional environments generally moved slowly west through time. What conclusions can we draw? The arrangement of the facies suggests that for millions of years the basin floor sank at about the same rate as sediment was delivered. Then, in the later part of the Late Devonian, the basin was filled faster than its floor sank.

This apparent balance between sediment supply and sediment sink is intriguing. It suggests some cause and effect between the pulses of mountain-building and the sinking of the basin floor. Indeed, some recent studies conclude that it was sinking of the basin floor that caused the sudden increases in water depth in the Appalachian Basin. This sinking, in turn, caused the tongues of black shale to extend eastward far from the central basin. The great influx of sediment that buried the black shale tongues ties this event to a pulse of mountain-building.

Devonian Plants and Animals

There are many fossils in New York's Devonian rock. These fossils show a great variety of living things. This abundance is remarkable when we remember how unusual it is for an animal or plant to be preserved as a fossil.

Only a few of the plants and animals living at a particular time are ever preserved as fossils. It requires a long string of coincidences for any one organism to be preserved. In fact, some kinds of living things may never be preserved at all. They may be too soft or unsuitable in some other way. If they were never fossilized, we will never know that they existed.

New York's Devonian rock contains a great variety and abundance of well-preserved fossils. Clearly, the land and the sea were swarming with life, and the conditions for burial and preservation of plants and animals were good.

Animal life had become much more varied since the earlier parts of the Paleozoic. Corals were extremely plentiful and often large. Broad "carpets" made of bryozoans and crinoids covered the sea floor (Figure 8.18). There were over 700 species of brachiopods (see Figure A.3). (Brachiopods had their greatest variety in the Devonian.) *Pelecypods* (clams) multiplied on the muddy and sandy sea bottoms (Figure 8.19) and developed a variety of types.

The appearance of a new group of cephalopods—called the *ammonoids*—was even more noteworthy. (Figure 8.15 shows an ammonoid swimming in the deep water in the left-hand part of the drawing.) A series of distinctive ammonoid species evolved through time, and we have an unusually good fossil record of Middle and Upper Devonian ammonoids in New York. Therefore, we have been able to determine when a new species developed. This knowledge helps us figure out which Devonian rocks throughout the world are the same age—by matching up the sequence of ammonoids species from different areas.

Conodonts, an extinct group of swimming animals known from tiny tooth-like fossils, also had their greatest

Figure 8.18. This photo shows the crinoid called *Melocrinus paucidactylus* (Hall) from the Lower Devonian Manlius Limestone in Herkimer County. (The crinoid heads are approximately 10 cm long.)

Figure 8.19. These fossil starfish, called *Devonaster eucharis* (Hall), are found in a sandstone slab from the Hamilton Group near Saugerties, Ulster County. Specimens of the pelecypod *Grammysia* are also present. It is possible that the starfish were feeding on the pelecypods. (The starfish are approximately 5 cm across.)

variety in the Late Devonian. Rapid evolution and extinction produced many geologically short-lived species that had worldwide distribution. Because many of the individual conodont species were geologically short-lived, and we can use their first occurrence and how long they survived in different regions to match up rock units of the same age. Because some conodonts had worldwide distribution, they allow us to match up layers from widely separated areas. Thus, conodonts are an ideal group to help us match up rock from different regions.

Devonian fish were especially interesting (Figure 8.20). Several new kinds of fish appeared abruptly. The rapid evolution, increase in diversity, and abundance of fish allows the Devonian to be called *The Age of Fishes*. Shark-like armored fish—some of them 6 m long—were abundant. The first air-breathing fish appeared in the Devonian, and all the higher vertebrates evolved from these air-breathers. Among their evolutionary descendants are the early types of amphibians that first appeared in the Devonian. However, we have not found their remains in New York.

Plant life also became much more varied. For the first time, low-lying land areas were covered by plants. Many of the plants were shrub-like or mosses. However, in some places, forests of tree-like plants developed. The remains of three of the oldest known forests are preserved in the Middle Devonian shale and sandstone near Gilboa, New York (Figure 8.21). These primitive tree ferns once lived on a swampy shore. Their stumps, upright and rooted in the position that they grew, were discovered during excavation for the dam at Gilboa Reservoir.

These trees were the forerunners of a great variety of plants, which would make up large swampy forests during the Mississippian and Pennsylvanian Periods. The remains of these later forests eventually became the Pennsylvanian coal beds of the Appalachian Basin.

The forests that appeared on the "Catskill Delta" changed the low-lying areas of eastern New York into a jungle. The landscape may have looked like the modern forests that grow along some low-lying coasts close to the equator.

Spiders, centipedes, and mites lived in these forests. Their fossil remains were discovered recently in Middle Devonian rock near the Gilboa Reservoir at Blenheim, Schoharie County. Primitive insects and amphibians have been found elsewhere in rock from the Late Devonian. They probably lived in the forests on the younger parts of the "Catskill Delta." The sound of wind in the trees and insect calls first appeared in New York on the "Catskill Delta."

Late Paleozoic History

The Allegheny Plateau contains the only Late Paleozoic sedimentary rock in New York State. It is possible that rocks of Mississippian, Pennsylvanian, and Permian age once covered a large part of the State. However, only scattered patches of Mississippian and Pennsylvanian rock now remain along the western part of the New York-Pennsylvania border. These layers are between 245 and 360 million years old.

Early Mississippian rock in New York is similar to the Devonian sandstones and shales that lie beneath them, and Late Devonian and Early Mississippian rocks can be distinguished only by differences in the fossil species in the rocks. There is no obvious change in facies between the Devonian and Mississippian rocks. This fact tells us that the sea in this region probably lasted from the Late Devonian into the beginning of the Mississippian. There is no rock in New York from later in the Mississippian Period.

The only Early Pennsylvanian rock in New York State is a quartz pebble conglomerate. There are very few fossils in it. This formation is our only clue that a sea existed in New York during that time. The conglomerate, which is well exposed at Olean Rock City, lies on top of Early Mississippian and Late Devonian rock. Rock from the time between the Early Mississippian and the Early Pennsylvanian is missing here.

There is no Permian rock found in New York State. The closest exposures of Permian rock lie to the southwest, in Ohio and Pennsylvania.

During the Late Paleozoic, plant and animal life in the Appalachian Basin changed significantly. Some invertebrates, such as the nautiloids and the crinoids, had many fewer varieties than before. The end of the Permian is marked by a major extinction event. Among the major groups of marine animals, the tabulate and horn corals, graptolites, some bryozoans, cystoids, eurypterids, and trilobites (see Figure A.3) became extinct at this time.

The biggest geologic event in eastern proto-North America in the Late Paleozoic was the Alleghanian Orogeny in the Appalachian mountain belt. This orogeny from the Canadian Maritime provinces south through New York to Texas resulted from the collision of proto-North America and proto-Africa along a transform margin. The collision was part of the formation of the supercontinent of Pangea. (For more detail, see Chapter 3.) This great mountain-building event deformed and uplifted the Appalachian Basin. The deformation during the Alleghanian Orogeny was greatest in the southern and central parts of the basin, where a high and rugged mountain range formed.

EVOLUTIONARY TREE OF FISH

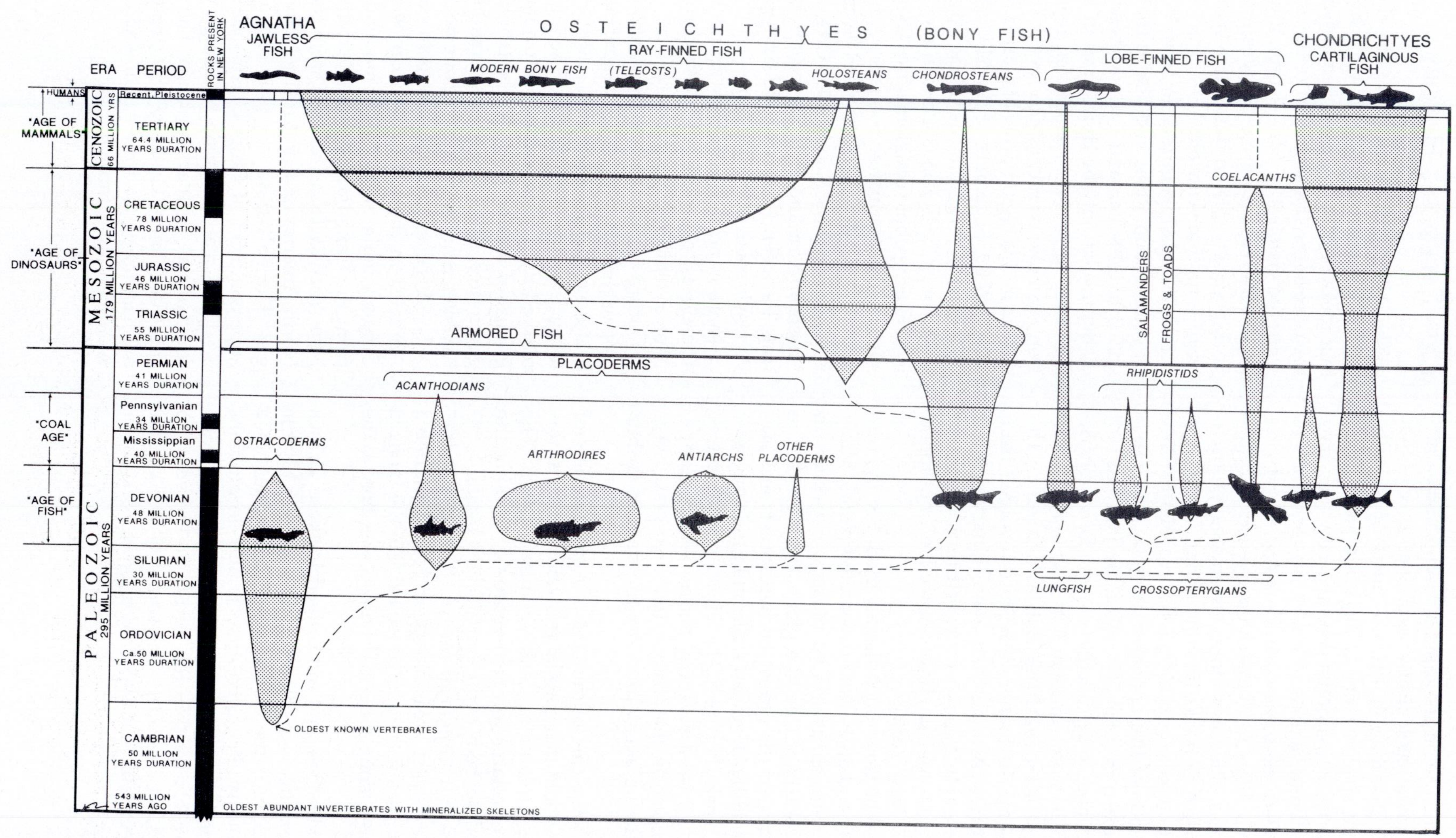


Figure 8.20. Diagram summarizing the history of the evolution of fish. Although this diagram shows sharks and their relatives (Chondrichtyes) as close relatives of lobe-finned fish, they are actually much more closely related to Placoderms.

The rocks of southeastern New York were folded and faulted during the Alleghanian Orogeny. Elsewhere in the State there was regional uplift.

Review Questions and Exercises

Most of the bedrock in this region is which type—igneous, sedimentary, or metamorphic?

Most of the bedrock in this region was formed during what geologic period? What was the environment like then?

What is a *facies*?

What is the "Catskill Delta"? How and where was it formed?

B.

A.

Figure 8.21. These two pictures show the Middle Devonian fossil tree *Eospermatopteris*. These stumps, discovered near Gilboa, Schoharie County, are found in one of the world's oldest known forest. (A) is a fossil stump of *Eospermatopteris*. It is approximately 1 m high. (B) is a drawing of what the living tree probably looked like (published by W. Goldring in 1924). The tree would have been about 8 m high.

Editor's note: The following supplement to Chapter 8 is for students who are interested in a discussion of the subtle structures in the rocks of the Allegheny Plateau. It serves as a case study of the kind of information we can get from close and careful examination of outcrops. A review the Tectonic Map on Plate 4 of the ***Geological Highway Map*** *and the plate tectonic history of New York in Chapter 3 may help you understand this discussion. Also, the Glossary will provide definitions of many unfamiliar terms.*

Deformation of "Undeformed" Rocks: Structures in The Allegheny Plateau

Adapted from text furnished by Professor Terry Engelder, Pennsylvania State University

The structure of rocks in the Allegheny Plateau looks deceptively simple—nothing but nearly horizontal sedimentary rock layers: "layer-cake geology." Folds like those commonly seen in the convoluted rocks of the Adirondacks, the Taconic Mountains, and southeastern New York are absent, and faults are rarely seen. However, despite this simple layer-cake appearance of the rocks of the region, subtle effects of the Alleghanian Orogeny *are* present in most of the rock exposures in central and western New York south of a line between Syracuse and Buffalo (see mustard-colored area on the Tectonic Map on Plate 4). These structures can be seen by the inquisitive eye, and they yield a fascinating structural story. Our goal in this section is to help the reader learn to see these Alleghanian structures, to understand the ways in which they were produced, and to learn what they tell us about the structural history of the Plateau.

Rock Behavior When the Crust Is Squeezed or Stretched

The way a rock deforms depends on the strength of the rock. By strength, we mean a rock's resistance to deformation. When "weak" rocks, such as shale or rock salt, are slowly subjected to increasing stress[11], they deform by flowing, like Silly Putty, modeling clay, or even tar. In contrast, "strong" rocks, such as limestone and sandstone, withstand much greater stress, until finally they deform by breaking. Strong rocks are more brittle.

In the Allegheny Plateau, we can see that the distribution of strong and weak rock layers played a very important role in the way the Plateau deformed. Several basic types of sedimentary rocks are exposed in outcrops of the Plateau: limestone, dolostone, sandstone, shale, and salt. Each of these rock types has a different strength. Limestone, dolostone, and sandstone are strong, whereas shale and salt are weak. It was a layer of salt, which is an extraordinarily weak rock, that had the greatest influence on the way the rocks deformed during the Alleghanian Orogeny.

This salt layer divides the Allegheny Plateau horizontally, like the filling in a two-layer cake. The salt is found in the lower part of the Salina Group of latest Silurian age (see Plate 3). It separates youngest Silurian and Devonian rocks above from lower Paleozoic rocks below. The salt was deposited in a great inland sea that covered an area larger than western New York and northwestern Pennsylvania combined. Both shale and salt deform by flowing, but salt flows much more easily than shale. If we think of the shale behaving like Silly Putty, then we must visualize salt as behaving like a thick split pea soup.

In the Late Paleozoic, the stresses that were produced by the Alleghanian Orogeny pushed northwestward against the rock of the Allegheny Plateau (see the Tectonic Map on Plate 4). The layers below the Silurian salt remained fixed, but the salt layer, which had almost no strength, began to flow. This situation allowed the thick upper layer of Devonian and Carboniferous[12] rocks to slide to the northwest, without folding, like a stiff rug pushed across a slippery waxed floor. The upper section of the Allegheny Plateau thus slid northwestward along a large horizontal fault that developed in the salt layer. This fault, separating the fixed and transported sections, is called a *dècollement*.

Within the layers that slid, which we call *transported* layers, strong units include the Oriskany Sandstone, the Onondaga Formation, and the Tully Limestone, whereas weak units include the Upper Devonian siltstones and shales (see Plate 3). Added together, the weak units are much thicker than the strong units. It is this greater thickness of the weak units that controls most of the structures seen in outcrops of the Allegheny Plateau.

The thickness of the salt beds in the Salina Group exceeds 100 m throughout much of western New York. The salt beds thin out to zero thickness at the edge of the ancient sea. The northern edge of the salt runs east-west along a line south of Buffalo, Rochester, and Syracuse. We find deformation from the Alleghanian Orogeny in the transported layers everywhere above the salt layer. Where the salt layer ends, so does evidence of Alleghanian deformation (see the Physiographic and Tectonic Maps on Plate 4).

[11]*Stress* is the force that is applied per unit of area, such as grams of force per square centimeter or pounds of force per square inch.
[12]*Carboniferous* is another name for the Mississippian and Pennsylvanian Periods combined.

Layer-Parallel Shortening: The Way Rocks Can Deform Without Folding

As the transported rock section was forced to the northwest, it was pushed against the pinchout[13] of the salt. At the pinchout, with no salt to slide on, the upper slab of rock rested directly on the lower slab. Lacking the lubrication of salt, it was anchored there by friction. Despite this fact, compression from the southeast continued to push the slab against the northwest side of the basin. This compression caused the slab to actually become shorter, but *without folding* of the layers. Such deformation is called *layer-parallel shortening* (Figure 8.22). The amount of crustal shortening on the Allegheny Plateau was considerable; an original width of 200 km was shortened by 20 km during the Alleghanian Orogeny.

Layer-parallel shortening occurs in several different ways, depending on the strength of individual layers in the section. Weak shale and siltstone, the most abundant rock types in the Allegheny Plateau, were squeezed together like modeling clay. At the same time, the strong, brittle layers, including the Onondaga and Tully Limestones and the Oriskany Sandstone, broke into giant slabs. These slabs piled up like shingles on a roof (Figure 8.22).

What evidence for layer-parallel shortening can we see in individual rock exposures? We find the evidence in several types of structures, to be explained below: *deformed fossils, pencil cleavage, spaced cleavage, blind thrusting*, and *drape folds*. The first three are associated with flowing in the weak rock layers; the other two are connected with brittle breaks in the strong rock layers.

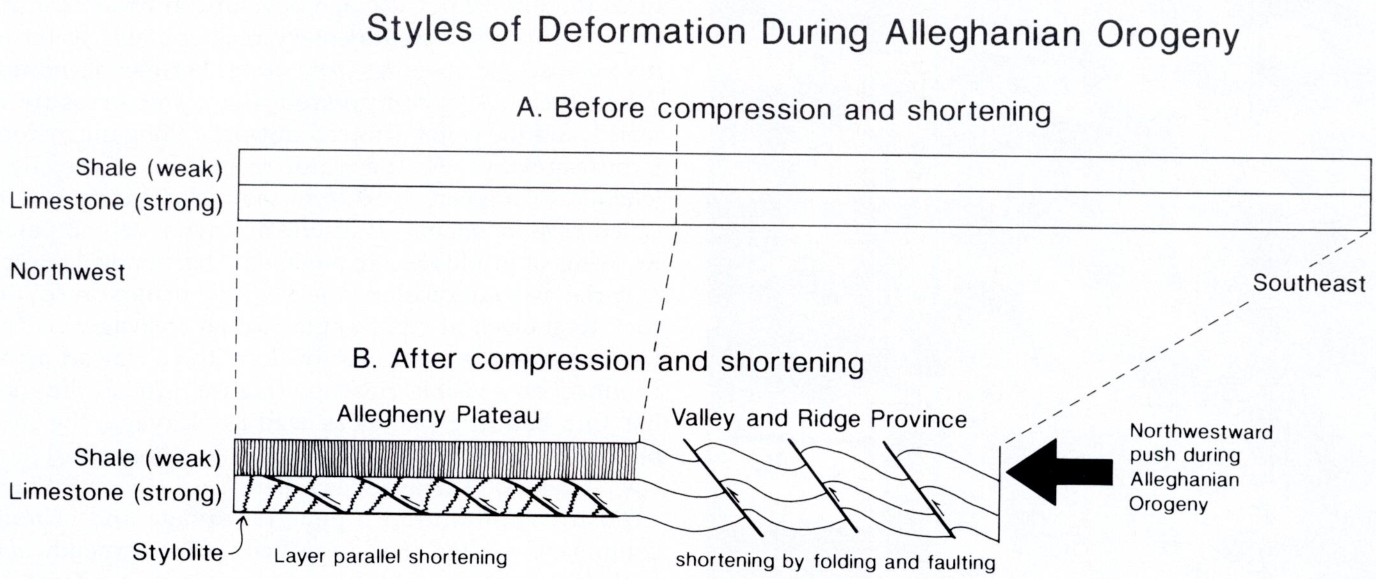


Figure 8.22. Greatly generalized diagram showing some of the ways in which rock on the Allegheny Plateau and the adjacent Valley and Ridge Province deformed when the crust was compressed during the Alleghanian Orogeny. (These provinces are shown on the Physiographic and Tectonic Maps on Plate 4.) In both provinces, the compressed crust became shorter. However, this shortening was accomplished in different ways, for reasons that are still being studied.

The Allegheny Plateau, which is discussed in this chapter, deformed by *layer-parallel shortening*, without folding. As the weak shale was compressed, pore water was squeezed upwards along thin vertical seams. As the water rose, it dissolved and carried away silica (chemical composition SiO_2) and left behind an insoluble seam of clay. The shale tends to break easily, or *cleave*, along these seams, so it is said to possess *cleavage*. (The seams are shown by thin vertical lines in the upper layer in (B).) This process, called *pressure solution*, shortened the layer by removing silica.

As the stronger limestone layers in the Allegheny Plateau were compressed, they, too, shortened by pressure solution. The water dissolved and removed calcite (chemical composition $CaCO_3$) along irregular seams, like those shown in the lower layer in (B). Insoluble clay was left behind in widely spaced seams, producing *spaced cleavage*. These seams are called *stylolites*. The limestone shortened by another process as well: the rock broke into blocks, and these blocks were thrust-faulted westward and stacked like roofing shingles. Arrows in the lower layer in (B) show this westward movement.

The crust in the Valley and Ridge Province, which is not discussed in this book, shortened by folding and faulting, as shown in the right-hand portion of (B), but in a much more complicated manner.

Field studies show that the Alleghanian Orogeny shortened the crust in the Allegheny Plateau by 10 percent and in the Valley and Ridge Province by 55 percent (compare (A) and (B)).

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[13]A *pinchout* is the place where a body of rock that has been getting progressively thinner reaches zero thickness.

Deformed Fossils

Of the structures that are found in weak rocks that have undergone layer-parallel shortening, probably the most common and easiest to spot in outcrop are deformed fossils (Figures 8.23 and 8.24). When we see these misshapen fossils on the Plateau, we can tell that the rocks that contain them have been deformed.

It is easiest to see such deformation by finding a fossil of a *crinoid*, an animal related to the modern starfish. Although it was an animal, it looked much like a flower. It was attached by a stem to the bottom of ancient oceans or to other animals (see Figure A.3). When crinoids died, their stems, which consisted of many cylindrical segments, fell apart into many pieces. These pieces, called *crinoid columnals*, appear on bedding planes like small lifesavers. In undeformed rocks, columnals are perfectly circular. In the Allegheny Plateau, however, they have an elliptical shape. The shortened axes of these ellipses line up roughly in a north-south direction. This alignment is good evidence for layer-parallel shortening of the rocks in that direction. It shows that this part of the Plateau was compressed in a general north-south direction. In western New York, the shortened axes of the ellipses are lined up in a north-northwest direction. These alignments are reflected in the "Limit of Alleghanian Deformation" on the Tectonic Map on Plate 4.

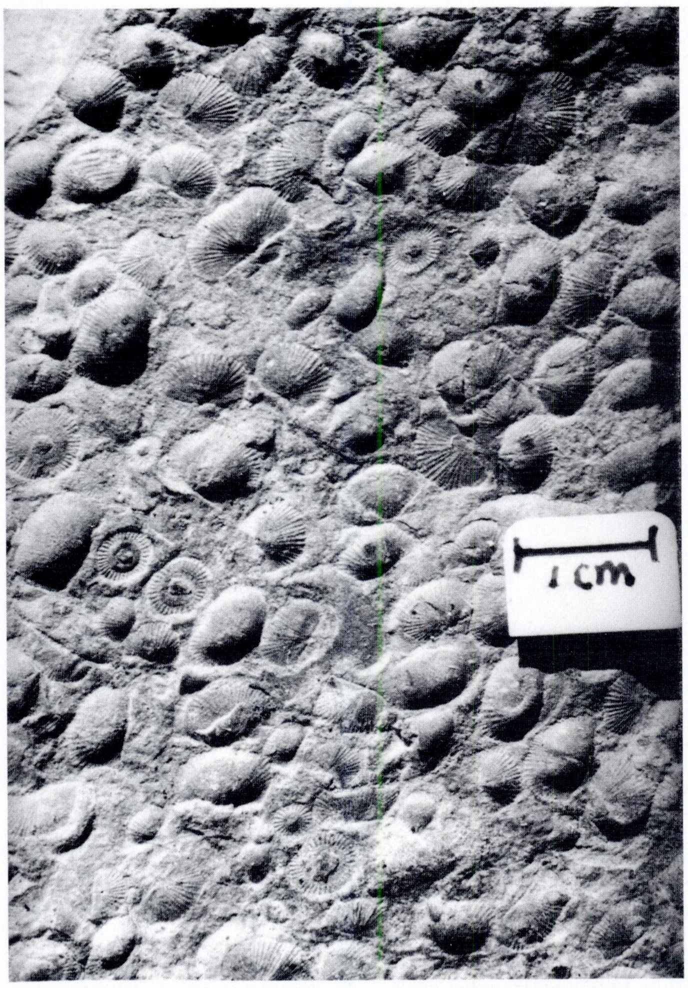


Figure 8.23. This photo is a view looking down on a bedding plane of a Devonian siltstone sampled near Wellsville, New York. Notice that the lifesaver-shaped crinoid columnals that were originally circular have been deformed into elliptical shapes. For a magnified view of a deformed crinoid columnal, see Figure 8.24. Notice also that their shortened axes all have the same orientation or alignment. It is easy to conclude that the rock was shortened along the direction between the upper left and lower right corners of this picture. The other fossils, brachiopods, are also deformed from their original symmetrical shapes (see Figure A.3).

Rock Cleavage and Pencil Cleavage

Rock *cleavage* refers to very closely-spaced parallel fractures (Figure 8.25). Cleavage develops in rocks that are being compressed. Sedimentary rock contains water in the microscopic openings (*pore spaces*) between its grains. When the rock is compressed, the water pressure is raised, and the water is forced upwards along microscopic passageways. As the water rises it dissolves silica (chemical composition SiO_2) in the rock. This process is called *pressure solution*. It results in leaving behind parallel seams of insoluble clay minerals. This removal of rock material by solution along the cleavage planes causes the rock to shorten at right angles to the cleavage. As the rock weathers, it breaks easily along these clay seams to produce very visible cleavage (Figure 8.26). If the rock has thin bedding planes as well as cleavage, the rock breaks along both, to form long narrow pieces called pencils. This kind of cleavage is called *pencil cleavage*. Where exposures contain both pencil cleavage and crinoid columnals, we find that the pencils point perpendicular to the shortened axes of the deformed crinoid columnals. Thus, pencil cleavage also shows that the layer-parallel shortening happened in a north-south direction in the Finger Lakes district.

Spaced Cleavage

Another kind of rock cleavage, called *spaced cleavage*, is a structure found in the Tully and Onondaga Limestones of western New York. Like pencil cleavage, it forms in rocks under pressure, when pore water dissolves part of the rock and leaves an insoluble residue of clay. The mineral that dissolves in limestones is calcium carbonate (chemical composition $CaCO_3$). The insoluble clay seam in limestones are thin, black, irregular surfaces that run through the rock (Figure 8.26). In outcrops of limestone, these irregular structures are called *stylolites*. When lime-faulting. Faulted segments were stacked up like roofing shingles. This faulting and stacking shortened the limestone layers in the manner shown in Figure 8.22. We seldom see this faulting at the surface, however, because there are so few outcrops of the Tully, Oriskany, or Onondaga formations in central and western New York. Because the thrust faulting is below the surface and is only rarely seen, it is called *blind thrusting*.

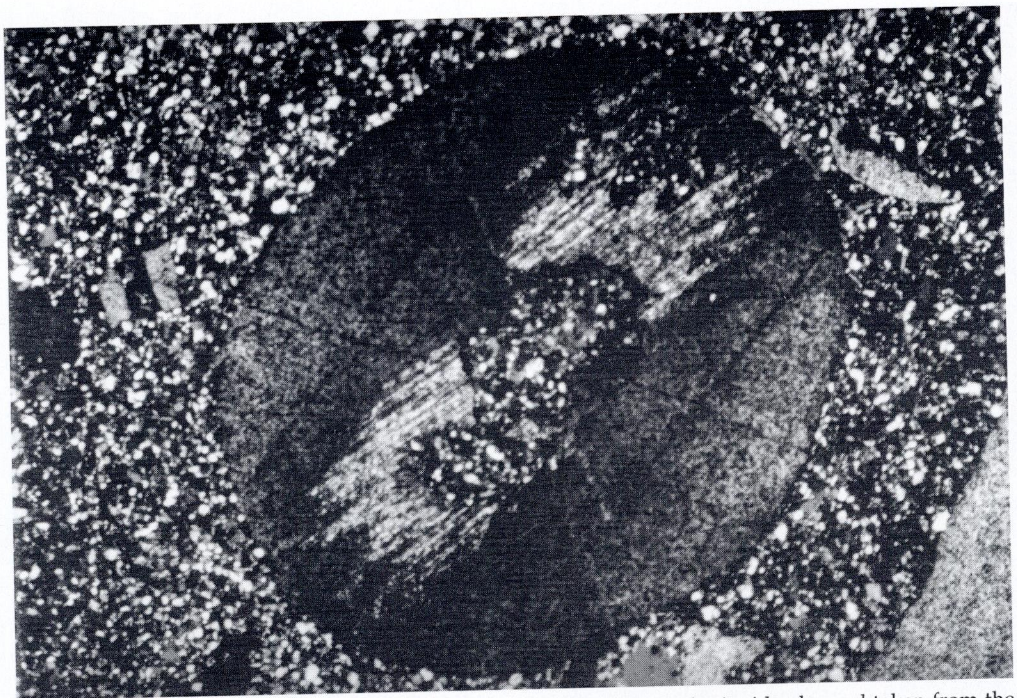


Figure 8.24. Microscope enlargement of a thin rock slice of a deformed crinoid columnal taken from the rock shown in Figure 8.23. The elliptical shape of the crinoid shows the deformation of a fossil that was initially circular in cross section. (This crinoid columnal is about 5 mm in the long direction.)

Drape Folds

The faulting and stacking of the thin, strong limestone and sandstone layers created very low mounds beneath the surface. This arrangement caused the overlying shales to drape over these mounds in long, low, wave-like folds, called *drape folds*. Many of these folds are so gentle that they can barely be recognized. We can see them best along the shores of some of the Finger Lakes, where the lake surface provides a horizontal surface for comparison. We find such subtle folds scattered throughout the Allegheny Plateau.

stones weather, the rock breaks easily along these surfaces. This kind of cleavage is called spaced cleavage because the stylolites form at regular intervals in the rock. The layer-parallel shortening is caused by the solution and removal of calcium carbonate by water rising along these surfaces. The shortening direction is therefore perpendicular to the cleavage, as was the case for the cleavage in shales described above.

Spaced cleavage indicates the same north-south shortening direction shown by deformed fossils and pencil cleavage. However, field studies of the spaced cleavage show that much less layer-parallel shortening has taken place in the limestone layers than in the shale formations that lie on top of it. It is hard to see how one layer could shorten less than one next to it; both would be expected to shorten the same amount. This seeming contradiction suggests that some additional shortening process must also have taken place in the limestone layers. Further field studies confirmed this hypothesis, as described below.

Blind Thrusting

Careful search led to the discovery that while the thick but weak layers of shale shortened by flowing, the thin but strong layers (Tully and Onondaga Limestones and Oriskany Sandstone) shortened equally. They deformed not only by solution along cleavage seams, but also by

Alleghanian Joints

The most common structures in rocks of the Allegheny Plateau are planar cracks, called *joints* (Figure 8.27). Some of the joints formed during the Alleghanian Orogeny. They are found in both the strong, thin layers of sandstone and limestone and the weak, thick shale cover. The high water pressure that developed in the rocks during the Alleghanian Orogeny became great enough to drive vertical cracks through the rock. The rock literally split when the internal water pressure exceeded the strength of the rock.

Outcrops in the Finger Lakes district all show abundant vertical joints that were formed in this way. They may exceed 300 m in length in cliff faces. In general, Alleghanian joints are oriented north-south; this direction is parallel to the direction of the layer-parallel shortening but at right angles to the cleavage discussed above. Thus, the orientation of these joints can be used as another clue to the direction of compression across the Allegheny Plateau during the Alleghanian Orogeny.

Figure 8.25. This photograph shows the vertical face of a Devonian shale near Scio, New York. Bedding is horizontal, as can be seen along the top of the picture. More pronounced, however, is a closely spaced rock cleavage that is perpendicular to the bedding. The explanation of this cleavage is given in the text. When a rock like that shown weathers, the rock parts along cleavage planes and bedding planes to produce the elongate rock slivers, or "pencils," shown. This kind of cleavage is called *pencil cleavage.*

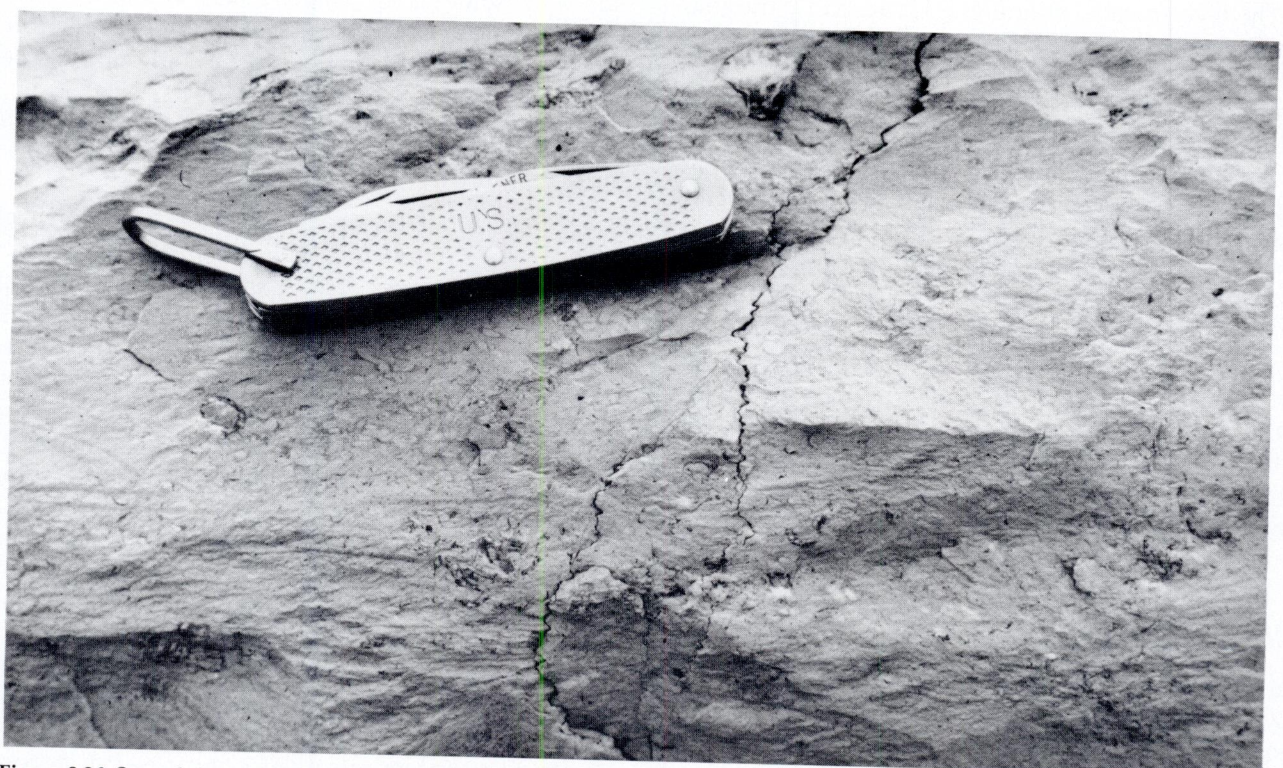


Figure 8.26. Spaced cleavage in the Onondaga Limestone near Geneva, New York. The view is looking down on bedding where very irregular stylolites cut vertically through the bed, as shown to the right of the jackknife.

Figure 8.27. Straight, planar cracks called *joints* are seen here cutting siltstones near Ithaca, New York. These joints, which are oriented north-south, are characteristic of many of the outcrops in the Finger Lakes District of New York.

During the Mesozoic Era, some north-south joints in central and western New York became the passageways for magma that moved upward from the earth's mantle. The magma solidified to form *kimberlite dikes*, which are most concentrated in the vicinity of Ithaca. (*Kimberlite* is a dark-colored igneous rock.) Most of the dikes are a few centimeters thick, but some reach several tens of centimeters in thickness.

Clarendon-Linden Fault Zone

Up to this point, we have been discussing structures that formed during the Alleghanian Orogeny. However, some important structures in the Allegheny Plateau formed at other times. These structures include a prominent fault zone and two different kinds of joints.

The most prominent deformation feature on the Plateau is the *Clarendon-Linden structure* located south of Rochester. At the surface, the structure is a north-south-trending fold (see the Tectonic Map on Plate 4). Drill holes show that at depth it is a fault zone made up of three or more segments. We think that the fault zone originated about 650 million years ago, when the Grenville supercontinent was breaking up, or *rifting* (see Chapter 3).

The Clarendon-Linden fault zone cuts through the entire fixed section and probably extends into the *basement rock*—the Proterozoic metamorphic rock that lies under the younger sedimentary layers. Geologists are still debating whether or not the fault zone also cuts the transported upper section of the Plateau.

Below the surface, some of the Middle and Upper Ordovician sedimentary rock units thicken near the Clarendon-Linden fault zone. This fact suggests that downward movement occurred along one side of the fault at about that time to create low areas where sediments piled up thicker than elsewhere. On this basis, we conclude that the Clarendon-Linden fault zone was either still active or again active in Ordovician time.

Evidence also exists that the fault zone may have been active in Devonian time, during the Acadian Orogeny. At the present time, small earthquakes are detected periodically in the vicinity of the Clarendon-Linden structure. These earthquakes suggest that the fault zone is still active. From all these observations, it appears that the Clarendon-Linden fault zone is the most active structure of the Allegheny Plateau. Periodic activity along this zone dates from Late Proterozoic time to the present day.

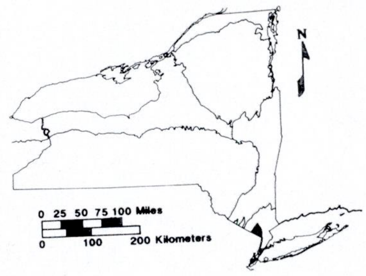
Release Joints

At the time the Allegheny Plateau region was undergoing layer-parallel shortening, sediments were pouring out onto it from a rising mountain range to the southeast that was, at the same time, undergoing vigorous erosion. Later, during the Mesozoic Era, great thicknesses of sedimentary rock were eroded away. Thus rock that was once deeply buried and therefore under great pressure was unloaded and brought closer to the surface. With a lessening of pressure, the rock expanded. This expansion stretched the crust and led to the formation of joints. Joints formed in this way are called *release joints*. These release joints line up roughly east-west in the Finger Lakes district, at right angles to the Alleghanian joints.

Late-Formed Unloading Joints

Other joints formed even later as the rock cooled. These late-formed joints line up roughly east-northeast. This direction is parallel to stresses found in the crust there today. Some geologists have used these late-formed joints to draw a map of the modern stresses in the Appalachian Mountains.

CHAPTER 9
DINOSAUR COUNTRY
Newark Lowlands[1]



SUMMARY

Only the northern part of the Newark Lowlands is in New York State; it lies between the Hudson Highlands and the Manhattan Prong. The region has a gently rolling surface broken by ridges. The Newark Lowlands lie within the Newark Basin, which is filled with the sedimentary rocks of the Newark Group. The Newark Group is divided into the Stockton Formation, the Lockatong Formation, the Brunswick Formation, and the Hammer Creek Conglomerate. The Palisades Sill, a thick layer of igneous rock, intruded the Newark Group 195 million years ago. It forms an impressive vertical cliff along the west bank of the Hudson River. When the Palisades diabase cooled and shrank, vertical fractures broke it into tall, six-sided columns. Another occurrence of igneous rock, the Ladentown Basalt, may have the same source as the Palisades, but the molten rock flowed out on the surface as a lava. Layers of similar basalt probably once lay on top of the Brunswick Formation in New York, but erosion has removed it here. Today, basalt lava flows are well exposed in New Jersey, where they form the Watchung Mountains. The Newark Group is wedge-shaped, and the resistant igneous rocks form ridges. It contains a number of faults and folds. The Newark Basin is the largest of 13 Mesozoic basins along the east coast of North America; these basins formed when the supercontinent of Pangea rifted. The rocks of the Newark Lowlands enable us to reconstruct the Triassic-Jurassic environment of the Newark Basin. By analyzing the gray rocks of the Lockatong Formation, we can tell that they were deposited in a lake that expanded and contracted as the climate became wetter and then drier; we find many such cycles in the rock. The brown rocks of the Stockton and Brunswick Formations were deposited in stream beds and on stream banks. From the distribution of the sedimentary rocks, we conclude that the region consisted of a long, narrow basin with streams flowing from all sides into a central lake. The lake level rose and fell periodically; many plants grew along the shore, and dinosaurs waded in the shallows. Based on radiometric dating of the Palisades Sill and on fossils, we think that the rocks of the Newark Group were deposited over a 35 million-year period during the Late Triassic and Early Jurassic.

INTRODUCTION

The Newark Lowlands lie west of the Coastal Plain and east of the Ridge and Valley Province and Reading Prong[2] (see Figure 1.1 and the Physiographic Map on Plate 4 of the *Geological Highway Map*). The Lowlands extend from the Nyack, New York, area across northeastern New Jersey into Pennsylvania. The New York portion is bounded on the northwest by the Hudson Highlands of the Reading Prong and on the southeast by the Manhattan Prong.[3] Farther south, the Coastal Plain forms the eastern boundary (see Chapter 10).

The Newark Lowlands are lower and flatter than the land to the west because the bedrock, which includes distinctive red sandstone and shale, erodes more easily. The Lowlands have a gently rolling surface that slopes down to the east. This surface is broken by ridges that are made of an igneous rock type called *diabase*, which resists ero-

[1]Adapted from a manuscript by W.B. Rogers.
[2]The Hudson Highlands are part of the Reading Prong. See Chapter 5 for more information.
[3]The Manhattan Prong forms the lowlands of Westchester County and the New York City region. See Chapter 5 for more information.

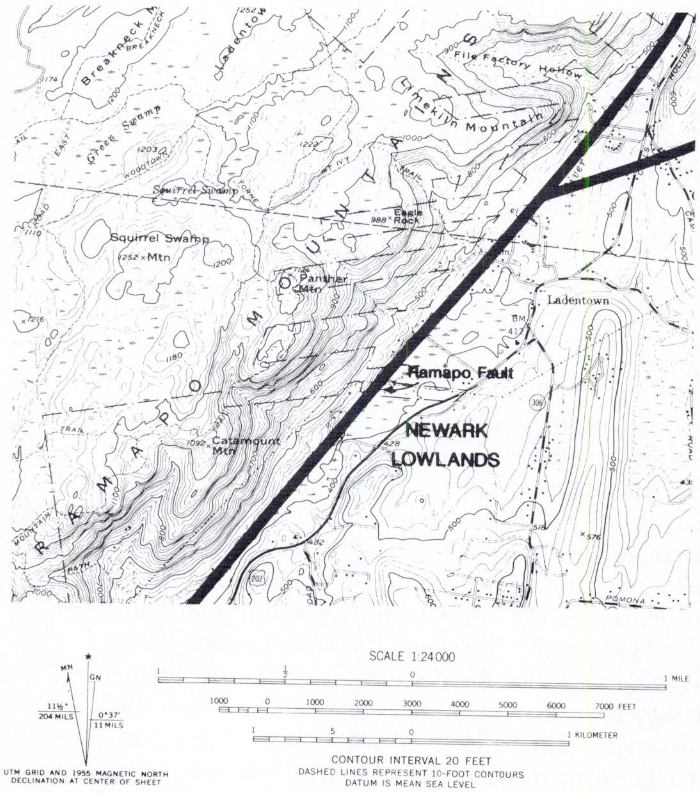


Figure 9.1. Topographic map showing the escarpment formed where the Ramapo Mountains of the Hudson Highlands border the Newark Lowlands on the west. The Newark Lowlands were down-dropped along the Ramapo Fault. The fault lies along the base of this escarpment.

sion. The ridges run northeast-southwest. Streams tend to cut channels in the softer red sandstone and shale between the ridges. Thus, the main valleys, especially in the northern half of the region, also run northeast-southwest and parallel to the ridges. These streams empty into Raritan Bay.

Along the northwest border, the Hudson Highlands rise along an abrupt *escarpment*, or cliff (Figure 9.1). The Hudson River flows along the southeastern boundary, bordered by the Manhattan Prong (Figure 9.2).

Rocks of the Newark Lowlands

The rocks of the Newark Lowlands lie in a large basin called the *Newark Basin* (Figure 9.2). We call the sedimentary rocks in the basin the *Newark Group*. Also present are several igneous intrusions and lava flows.

The Newark Group is divided into four units: the Stockton Formation, the Lockatong Formation, the Brunswick Formation, and the Hammer Creek Conglomerate (Figure 9.3). The lowest and oldest of these units is the Stockton Formation. It contains thick layers of sandstone and conglomerate that are rich in feldspar. These layers alternate with silty and shaley mudstone.

The Lockatong Formation, in the middle of the Newark Group, is not exposed in New York. It contains dark gray to black shales rich in organic materials[4] and limy mudstone. These rocks were probably deposited as sediments in a large lake. The Lockatong contains superb freshwater fossils, especially of fish. The fossils are found in the old Granton Quarry near North Bergen, New Jersey.

The Brunswick Formation consists of reddish-brown shaley mudstone. The mudstone alternates with layers of red-brown sandstone. These rocks gradually merge with the coarse-grained Hammer Creek Conglomerate. This conglomerate contains blocks and boulders (called *clasts*) of various older rocks, mainly Cambrian and Ordovician limestones and dolostones. Some of these clasts are as large as one meter across. We can see the conglomerate best near the western edge of the Newark Basin along the Ramapo Fault.

Of the igneous rocks in the Newark Lowlands, the most prominent is the Palisades Sill. It consists of the rock diabase; it is medium to dark gray when it is freshly broken. Diabase is made mainly of the dark green mineral pyroxene and the light gray mineral feldspar. Together, these two minerals give the rock a dark-colored "salt-and-pepper" appearance. Within the diabase, about 12-15 m above the base, we find a nearly pure layer of the mineral olivine, about 4.5 to 6 m thick.

The Palisades Sill was intruded into the Stockton, Lockatong, and lower Brunswick Formations about 195 million years ago, in Early Jurassic time. The Sill forms an east-facing cliff 120-300 m thick and more than 65 km long, along the west bank of the Hudson River (see Plate 2). It extends from west-central Staten Island to High Tor at Haverstraw, New York. Seen from across the river, the cliff looks like a colonial log stockade (a *palisade*), hence its name (Figure 9.4).

How did the Palisades Sill get its column-like structure? As the rock cooled, it shrank. The shrinkage caused vertical breaks, or *fractures*, in the rock. The fractures run through the rock from top to bottom and break it into tall, six-sided columns. Seen from above, these fractures have a honeycomb pattern.

Another occurrence of igneous rock is at Ladentown. It is *basalt*, which has the same mineral composition as diabase but is much finer grained. The Ladentown Basalt has a smooth, wavy-looking surface and contains gas bubbles[5]. It cooled and hardened at the surface as a lava.

[4] *Organic materials* are carbon-bearing remains of living things, such as plant material that has been partially turned to coal.
[5] This structure is similar to the ancient Watchung lava flows in New Jersey and modern lava flows in Hawaii.

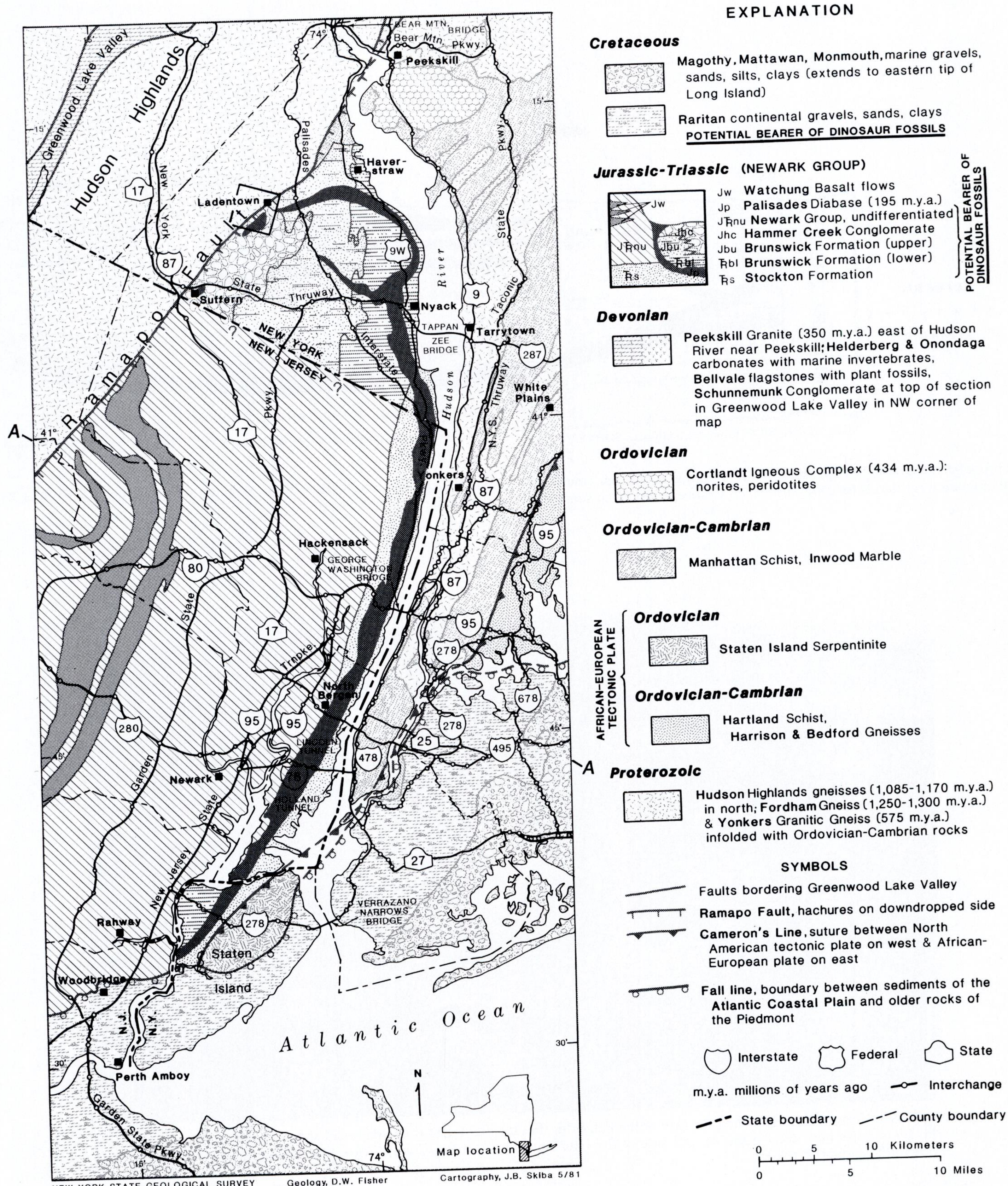


Figure 9.2. Generalized geologic map of the Newark Basin—the oval area between the Ramapo Fault and the Hudson River. It is bordered on the northwest by the Hudson Highlands and on the southeast by the Manhattan Prong east of the Hudson River. Highlighted in the "Explanation" are formations that may contain dinosaur bones and footprints. The box around Ladentown indicates the area shown in Figure 9.1. The cross section in Figure 9.5 follows the line between the letters *A* on the left and right sides of the map.

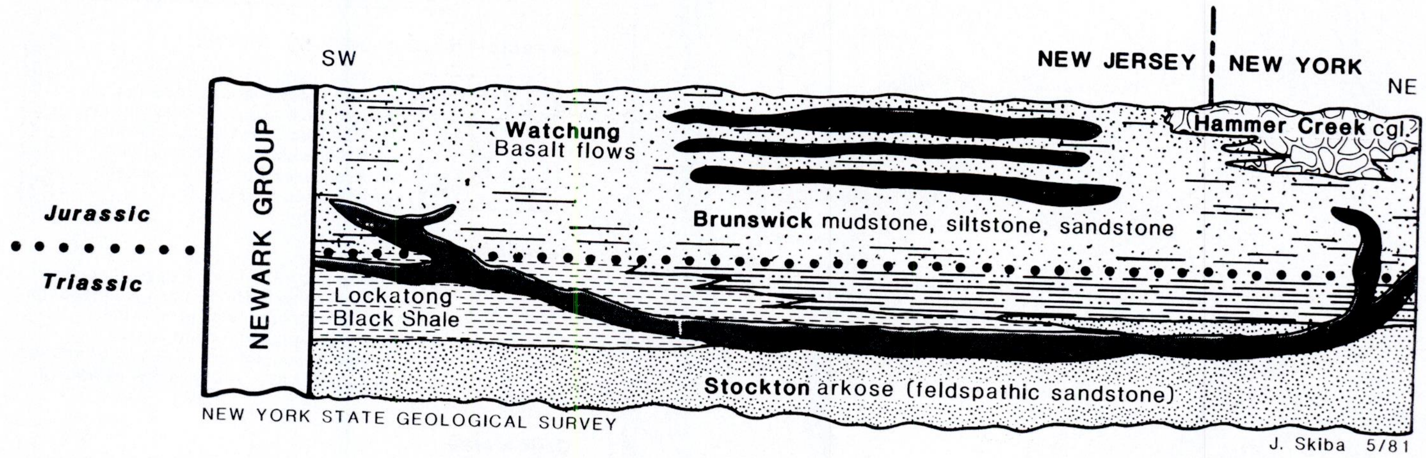


Figure 9.3. Diagram showing the general relationships of rock units in the Newark Group in cross section. These rock units are described in the text. The abbreviation *cgl* stands for *conglomerate. Feldspathic sandstone* means sandstone rich in the mineral feldspar.

Figure 9.4. Vertical columns along the face of the Palisades that formed when the diabase sill cooled and shrank during cooling. This view looks northwest from the east side of the Hudson River near the George Washington Bridge. At this point, the Palisades cliff is about 75 m high.

As it did, it shrank and developed curved fractures. Such curved fractures are commonly found in surface lava flows. The Palisades diabase and Ladentown basalt probably came from the same magma.

As the Brunswick Formation in New Jersey was deposited, basalt lava flowed out on the surface several times, each time to be buried by later sediments as the basin subsided (Figure 9.5). These basalt flows are similar to modern flows in Hawaii and older flows in the northwestern United States. The basalt and intervening sedimentary layers probably once extended over much of the Newark Basin. However, erosion has worn much of them away; they are now found only in the western part of the Newark Lowlands.

The basalt flows are much more resistant to erosion than the sedimentary rocks. Thus, they form the ridges called the Watchung Mountains (Figure 9.5).

Structure of the Rocks

The Newark Group is wedge-shaped in cross section (Figure 9.5). The layers slope 10°-15° toward the northwest. Where the sedimentary rocks have been eroded, some of the more resistant igneous layers form ridges that slope to the west. An excellent example of such a slope can be seen along Interstate 95 in the New Jersey meadowlands west of Manhattan. New Jersey Route 3 runs up the west side of a ridge, over the top, and down to the Lincoln Tunnel. The west side of the ridge is a gentle slope up to the summit of the Palisades Sill. This gentle slope is the upper surface of the igneous layer. On the other side of the ridge, however, the highway drops steeply across the Palisades cliff.

Faults bound the northwestern edge of the Newark Basin. In addition, many short north-south faults cross the northern part of the basin and intersect the border fault at angles of 30°-45°.

Folds, usually perpendicular to the border faults, stretch from the northwest edge of the basin about a fourth of the way across it. Many such folds occur along the border faults.

The Newark Basin is the largest of 13 large basins filled with early Mesozoic rocks along the east coast of North America (Figure 9.6). These basins are scattered throughout the Piedmont, New England, and Canadian Maritime Provinces. They are generally long and narrow, and run parallel to the coast. From their shape and position, scientists have concluded that they formed when the continental crust was stretched and broken. This rifting happened when the supercontinent of Pangea broke apart and the present Atlantic Ocean basin began to open and widen during the early Mesozoic (see Chapter 3 and the Tectonic Map on Plate 4).

What Was the Environment Like?

The gray rocks of the Lockatong Formation tell us a lot about the nature of the environment at the time they were deposited. Most of the formation consists of a cycle with three parts. From bottom up, these rocks are: 1) thin to very thick layers of gray siltstone, 2) thin layers of black to green-gray siltstone rich in calcium carbonate, and 3) thick layers of gray to gray-red sandstone or siltstone with cross-bedding (see Figure 7.1), fossil dinosaur footprints, and holes left by roots of plants. These cycles occur over and over again.

Each of the three rock types matches the kinds of sediments we would find in a lake at three different stages of its development. We would find the first kind in a lake that is expanding as the climate becomes wetter, the sec-

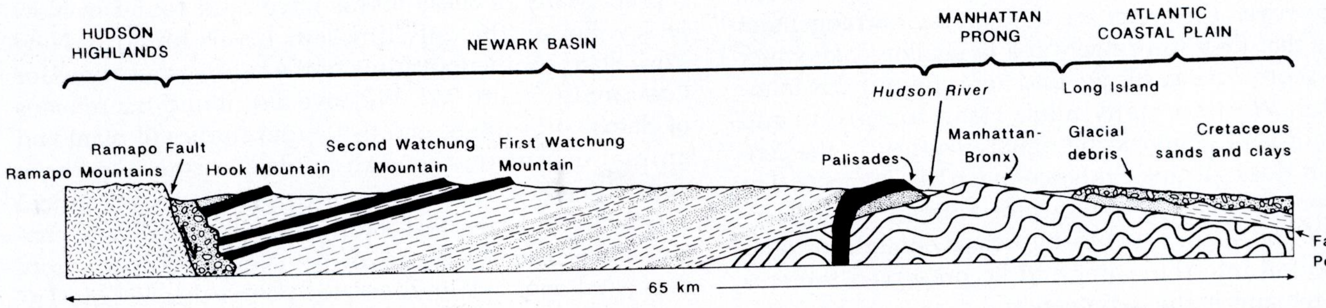


Figure 9.5. Generalized cross section of the Newark Basin. Notice the Ramapo Fault that forms the border between the Ramapo Mountains of the Hudson Highlands and the down-dropped Newark Basin. Intrusions of diabase are shown in black. The sedimentary rocks (shale and sandstone) were deposited horizontally; they were later tilted by downward movement along the Ramapo Fault. (The Hudson Highlands and the Manhattan Prong are discussed in Chapter 5; the Atlantic Coastal Plain and the Fall Zone Peneplain are discussed in Chapter 10.)

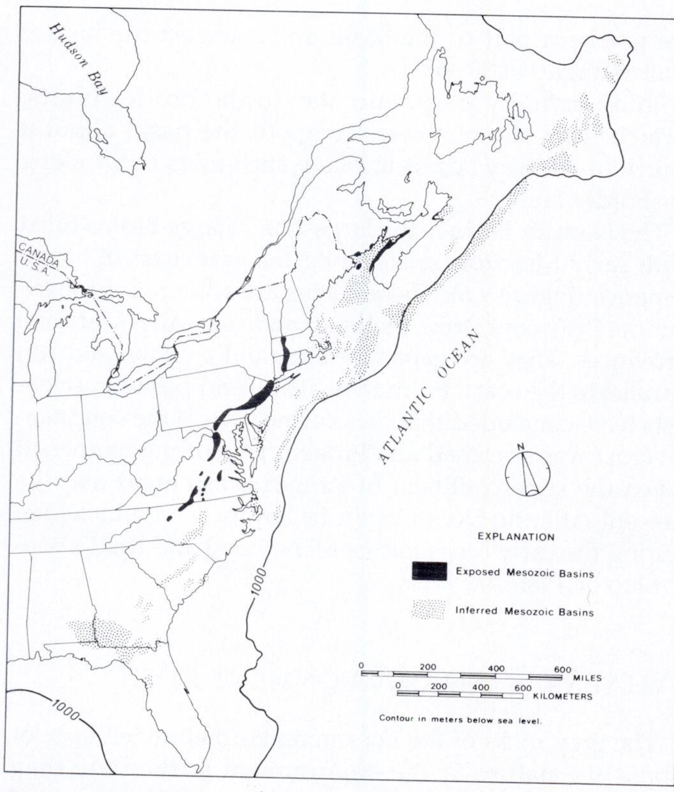


Figure 9.6. Other Mesozoic basins of eastern North America, similar to the Newark Basin. These basins formed when large blocks of crust were dropped down along faults. The basins gradually became filled with Triassic and Jurassic sedimentary rocks and were intruded by diabase. The basins formed because of rifting of the supercontinent Pangea. The Newark Basin is the largest exposed basin in the figure. Notice the inferred basins offshore. The contour line shows where the ocean is 1000 m deep. (See also the Tectonic Map on Plate 4.)

ond kind in a lake that has grown to its largest size in a very wet climate, and the third kind in a lake that had become very shallow as it evaporated under a dry climate.

Many such cycles are found in the center of the basin, where each is about 5 m thick. Toward the edges of the basin, however, the cycles are thinner; their arrangement suggests that they were deposited in shallow lake water close to shore. The fossils we find here support this interpretation. We find many more fossil footprints and remains of land plants at these margins than in the center. What does all this evidence mean? It suggests that the water was shallow enough for animals to walk in. Also, that the shore was nearby—close enough for land plants to fall into the water and be preserved there as organic remains in the sediments.

Most of the brown and reddish brown rocks in the Newark Basin originated as stream sediments. How do we know that? Some of the sandstones have cross bedding, which indicates they were deposited by moving water. The sandstone and the conglomerate are typical of the rocks formed in the stream beds or at the mouths of streams. In the mudstones of the Brunswick Formation, we find the impressions of roots and dinosaur footprints (Figure 9.7). The muds were not deposited in the stream beds, but on nearby stream banks and at stream mouths. In such places, the running water would not wash them away.

When we put all this information together, we can make a good guess about the kind of environment in which the Newark rocks were formed. It was a long, narrow low place in the landscape with streams flowing in from all sides. These streams deposited the sediments that later became the brown rocks in the area. In the central part of the depression was a lake whose shoreline expanded and contracted as the lake level rose and fell. In this lake were deposited the sediments that became the gray rocks of the Newark Basin. The fossils show us that there were many plants along the lake shore and the stream courses. From the footprints, we also know that dinosaurs walked along the water's edge and waded in the shallows.

Radiometric dating tells us that the igneous rocks of the Palisades Sill were intruded into the Newark Group about 195 million years ago, during the Early Jurassic. That age helps us to determine the age of the sedimentary rocks as well. This sill cuts through the lower sedimentary rocks. These rocks must therefore have been deposited before the sill intruded. The upper layers that were not cut by the igneous rocks were deposited after the intrusion took place.

The sedimentary rocks of the Newark Basin have many different kinds of fossils, both plants and animals. We find pollen, spores, and plant remains as well as many holes in the sediments made by plant roots; plants must have been abundant. We have found the footprints and remains of dinosaurs and an early *pterosaur*, or flying reptile. Many of these fossils have been found in New Jersey. So far, the only dinosaur fossils found in New York State are the footprints of the carnivorous dinosaur *Coelophysis* (Figure 9.7). We have also found the remains of clams, arthropods, and fish. From studies of plant and animal evolution through geologic time, we know approximately when these particular plant and animal species lived. Using that information, we are able to conclude that the sediments of the Newark Group were deposited over a 35 million-year period during Late Triassic and Early Jurassic time. An artist's reconstruction of the environment at that time, drawn from information found in rocks of the Newark Basin and rocks of the same age found elsewhere, is shown in Figure 9.8.

Figure 9.7. (A) Evidence that the Newark Basin was once "dinosaur country": three-toed footprints of *Coelophysis* found near Nyack, Rockland County, in the Triassic-Jurassic Brunswick Formation of the Newark Group.

(B) A restoration of this carnivorous dinosaur, which was about 3 m long, and its footprints.

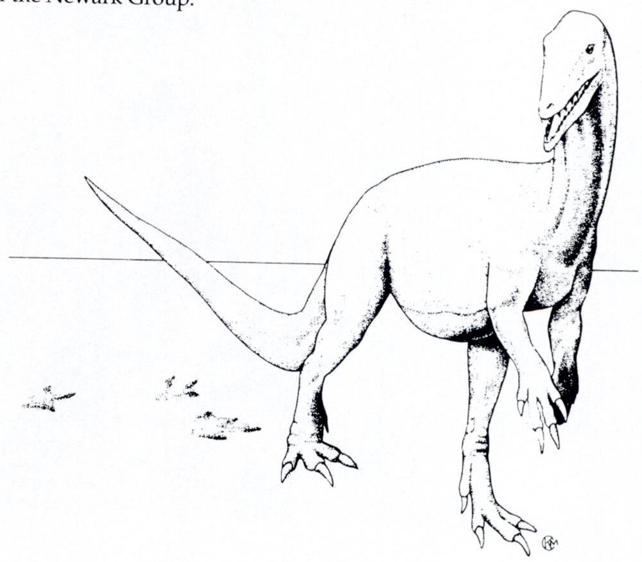


Figure 9.8. The Newark Lowlands, as they may have appeared about 180 million years ago. *Coelophysis*, seen in the right foreground, was about 3 m long.

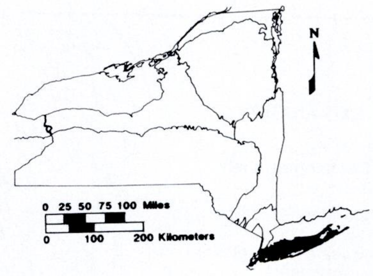
Review Questions and Exercises

Most of the bedrock in this region is which type—igneous, sedimentary, or metamorphic?

There are four major rock formations in this region. Describe them. In what kind of environments did they form?

What was happening in geologic history as the Newark Lowlands bedrock was formed? How did that create the environment where it was formed?

CHAPTER 10
AT THE BEACH
Atlantic Coastal Plain and Continental Shelf[1]



SUMMARY

Along the eastern edge of the continent is a very gently sloping surface that includes the Coastal Plain and the submerged continental shelf. It lies between higher land to the west and north and the continental slope to the east. The Coastal Plain is generally a flat, low-lying area that slopes very gently toward the sea. The inner edge of the Coastal Plain is the edge of a wedge of Cretaceous and younger sedimentary rocks. Underneath the wedge is an erosion surface of much older rocks—the Fall Zone Peneplain. As the younger rocks wear away, the Fall Zone Peneplain becomes exposed to erosion. We have used various techniques to trace the boundary between the softer sedimentary rocks of the Coastal Plain and the underlying basement rocks of the Fall Zone Peneplain. The sedimentary rocks thicken as we move away from land, so we conclude that the eastern edge of North America is slowly sinking. Of the rocks in this wedge, some were deposited slightly above sea level, and others slightly below sea level. Based on fossil evidence, we think that older rocks are found farther offshore; this conclusion reinforces the idea that the edge of the continent is sinking and the shoreline is creeping inland. The rocks of the Fall Zone Peneplain, all older than Middle Jurassic, have been tilted seaward. The younger rocks above the erosion surface were deposited at a time when the edge of the continent was gradually sinking. The edge of North America was heated and uplifted when Pangea rifted; it has been sinking gradually since then. Sediments eroded from highlands to the west built the wedge of sedimentary deposits as the shoreline gradually crept inland. This process began in the Middle Jurassic and continues today. The Coastal Plain slopes gently toward the sea because the edge of the continent has been sinking. The eroded edges of more resistant layers on this tilted surface stand up as ridges. On the continental shelf, we find channels that were cut by rivers when the shelf was above sea level during the Pleistocene Epoch. We also find broad ridges that mark former positions of the shoreline. Great canyons in the edge of the continental shelf and the continental slope may have been cut by currents filled with churned-up sediment when the shelf was above sea level.

INTRODUCTION

The Atlantic Coastal Plain is a very gently sloping land surface near the eastern edge of the continent. It is part of a continuous surface that extends offshore. The underwater section is called the *continental shelf*. The section above the shoreline is called the *Coastal Plain* (see Figure 1.1 and the Physiographic Map on Plate 4 of the *Geological Highway Map*).

The Atlantic Coastal Plain and continental shelf combined run from Newfoundland to Florida (Figure 10.1; see also the Physiographic Map and text on Plate 4). The surface is about 300 km wide for that entire distance. However, varying widths of it are underwater at different places along the coast. North of Cape Cod, for example, the entire surface is submerged. In New York, parts of Long Island and Staten Island are the only parts above water.

The Coastal Plain is bounded by higher ground on the landward side. The eroded Cretaceous rocks of the

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

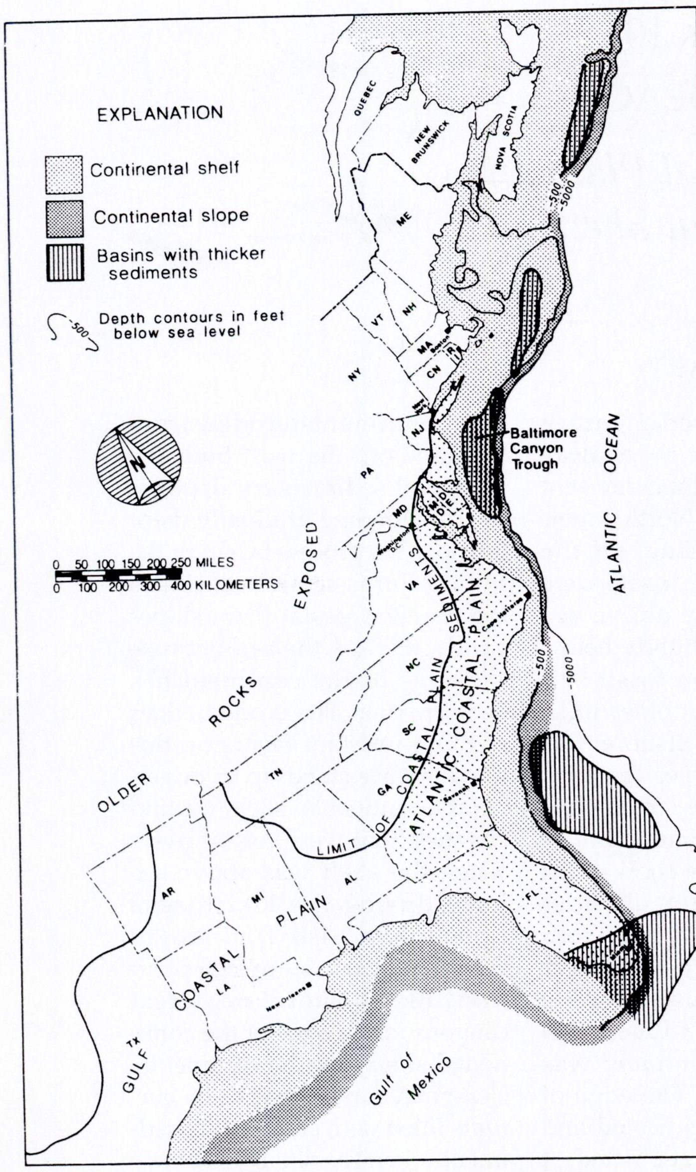


Figure 10.1. Map of eastern North America, showing the Coastal Plain and the continental shelf. Notice that the combined width of the two is fairly constant from Georgia to Nova Scotia. The contact between the Coastal Plain sediments and the bedrock to the west is called the *fall zone*.

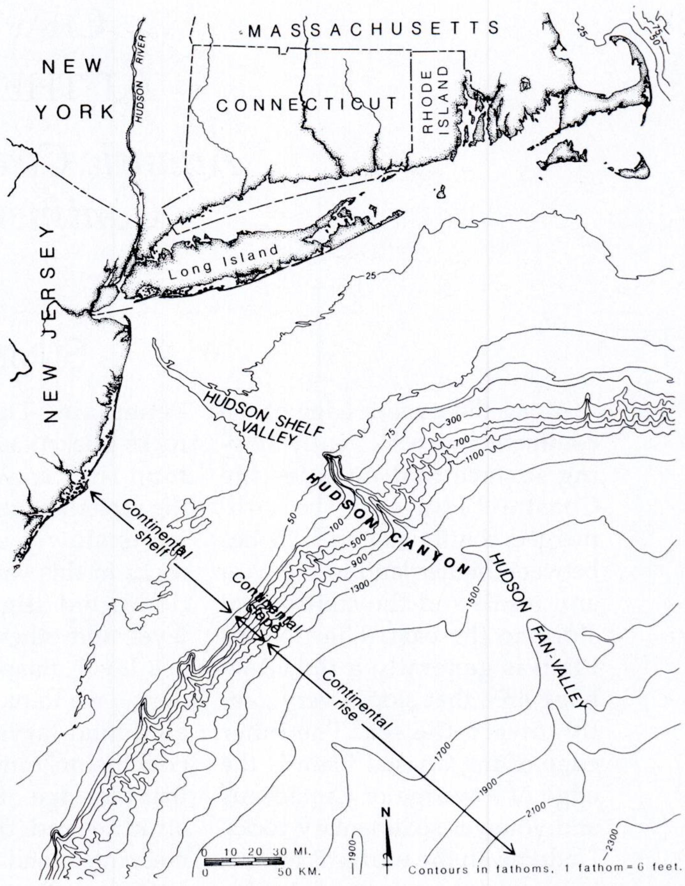


Figure 10.2. This map of the sea floor off the Atlantic coast of North America shows, going seaward, the nearly flat continental shelf, the continental slope, and the continental rise. Contour lines show the depth below sea level in fathoms (1 fathom = 6 feet). The contours reveal the location of the Hudson Shelf Valley on the continental shelf, the Hudson Canyon, and the Hudson Fan-Valley on the continental rise.

Coastal Plain end at this change in topography. The continental shelf is bounded on the east by a gently inclined underwater surface called the *continental slope* (Figure 10.2).

The Atlantic Coastal Plain slopes very gently toward the sea: only about 35 to 85 cm per kilometer.[2] As a whole, it tends to be flat, with rounded, gentle landscapes. In places in New Jersey, the Coastal Plain is more than 105 m above sea level. However, more than half of it in New Jersey is less than 30 m above sea level.

Rocks of the Atlantic Coastal Plain

Cretaceous and Tertiary sediments are part of a wedge of deposits that thins westward towards the inner edge of the Atlantic Coastal Plain. These sediments were deposited in or close to the ocean, some near sea level and some at moderate depths.

Underneath the wedge are older rocks of Early Jurassic to Proterozoic age. These older rocks were eroded to a rather flat surface before the Middle Jurassic. This erosion surface is called the *Fall Zone Peneplain* (see Figure 9.5). The younger and softer sedimentary rocks cover the resistant erosion surface as far west as the edge of the Coastal Plain (Figure 10.1). Beyond that, these older rocks make up the bedrock. The streams that flow eastward across this boundary pass from the resistant rocks of the

[2] The Coastal Plain slopes twice as steeply as the continental shelf. That is still a very gentle slope.

Fall Zone Peneplain to the easily eroded Cretaceous sedimentary rocks of the Coastal Plain. As a result, waterfalls develop there. This boundary of the Coastal Plain is therefore called the *fall zone.*

As the Coastal Plain sediments wear away, the Fall Zone Peneplain is gradually becoming exposed. As the older rocks are exposed at the surface, they also are being eroded. The older rocks slope toward the sea at about 6 m per kilometer. This slope is quite gentle, but the slope of the rest of the Atlantic Coastal Plain is much more gentle.

It was by using the techniques of geophysics that we were able to trace the boundary between the softer sedimentary rocks and the older, underlying *basement* rocks. To find out more about this boundary, we have drilled several holes out to sea beneath the continental shelf. The drilling program, combined with geophysical studies, discovered a large buried trough, the *Baltimore Canyon Trough* (Figure 10.1). This trough is a long basin that lies under the outer part of the continental shelf south of Long Island. The sedimentary rock in the trough appears to be 12 km thick. On the Long Island Platform at the edge of the shelf, the sedimentary rock is about half that thick. At Fire Island on the south shore of Long Island, the sedimentary section has thinned to 600 m.

This information leads us to think that the continent's edge is sinking. As the edge sinks, the sea water reaches farther and farther inland. Thus, it deposits sediments farther and farther inland on the continent. Areas out to sea have been underwater the longest. Thus, we would expect the sedimentary rocks to be thicker as we move away from the land.

Additional details come from deep wells near the edge of the continental shelf. The COST B-3 well was drilled 130 km south of Long Island in the Baltimore Canyon Trough (Figure 10.3)[3]. At a depth of over 4,890 m, the hole had still not reached the basement rock. It stopped in rock of Jurassic age. The rocks from the Early Cretaceous are nearly 2000 m thick in this well, but at the New York shore, they have already thinned to zero thickness.

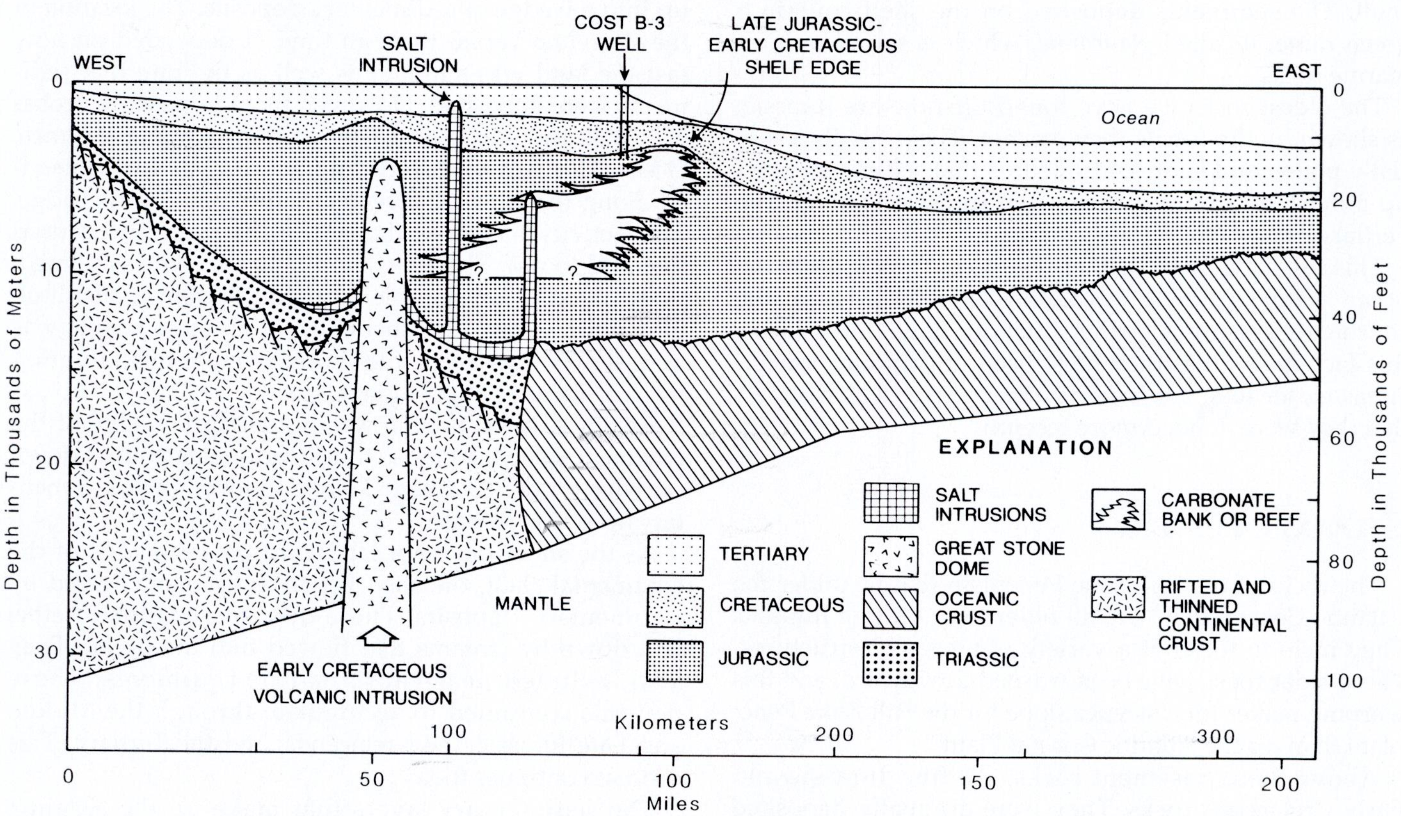


Figure 10.3. Diagram of a cross section of the Baltimore Canyon Trough. The vertical scale is greatly exaggerated. See Figure 10.1 for location of Baltimore Canyon Trough.

[3]*COST* stands for Continental Offshore Stratigraphic Test.

Rocks from the Late Cretaceous are 1000 m thick in the well and 500 m thick at the south shore of Long Island.

These drastic changes in thickness reinforce the idea that the eastern edge of the North American continent is slowly sinking beneath sea level.[4] But there are other reasons for differences in thickness. For example, sediments can, under some circumstances, pile up faster in one place than another during the same time period. In addition, these sediments were deposited on an uneven surface. It was warped and had low spots and high spots. Areas with low basement rocks flooded first as the edge of the sea crept inland, and they received a thicker sequence of sediments. Meanwhile, areas with a higher basement stayed above the water for a longer time. As a result, sediments will be thicker in the areas with a deep basement and thinner in areas with a shallow basement.

Most of the rocks in the sedimentary wedge are sandstone and shale. We also find some clay mixed with carbonate sediments (called *marl*) and a little limestone. Most of these rocks may have been deposited near shore, but slightly above sea level, in rivers and swamps. The rest would have been deposited in shallow water near the shore in an environment like the present continental shelf. The sediments deposited on the shelf contain a green mineral called *glauconite*, which is found only in marine rocks.

The oldest rocks we have found offshore are Jurassic, as shown by the fossils they contain. These fossils, especially pollen and spores, also tell us that sediments piled up almost continuously from the Jurassic through the Tertiary.

This fossil evidence further reinforces the idea that the ocean water is slowly advancing over the edge of the continent. The areas farther offshore have older rocks; this fact shows that they have been underwater longer. Areas closer to shore have younger rocks, which shows that they were flooded more recently.

Geologic History

The rocks of the Fall Zone Peneplain that lie under the Atlantic Coastal Plain are all older than Middle Jurassic. They include rocks of a variety of ages and structures. These older rocks have been warped downward, and this warping makes for a steeper slope for the Fall Zone Peneplain than for the Atlantic Coastal Plain.

Above these basement rocks, we find Jurassic and Early Cretaceous rocks. They were originally deposited near sea level. Today, they are found at much greater depths—5 km below sea level near the edge of the continental shelf. Thus, we deduce that the continental shelf has been gradually sinking as the sediments accumulated. This sinking has allowed a huge wedge of sediment to be deposited along the edge of the continent, a wedge that gets thicker the farther offshore we go.

When Pangea began to break up in the Late Triassic and Early Jurassic (see Chapter 3), eastern North America began to separate from Africa. Convection cells in the mantle transferred heat to the lithosphere in this great area. As the lithosphere was heated, it expanded slightly in volume and floated higher on the mantle as a broad upland. As this upland began to rise, it cracked, and molten rock (*magma*) was injected into the cracks. The convection cells flowed in opposite directions and worked to pull this part of Pangea apart. The Atlantic Ocean began to develop in a rift between eastern North America and Africa. As the edge of the North American continent got farther and farther from the magma that continues, even today, to rise at the rift zone, it cooled, became denser, and gradually sank. As it got lower, the sea crept over its edge.

Sediments were eroded from the highlands in the west and deposited along the seashore. They gradually built up into a wedge of sedimentary deposits. The location of the shoreline varied through time. It depended on how fast the land was sinking, as well as the rate that sediments were deposited. However, more important, probably, was the spreading rate of the growing Atlantic Ocean. During rapid spreading, more lavas were intruded along the rift in the center of the mid-oceanic ridge. This activity increased the size of the ridge and caused sea level to rise. The effect would be the same as piling a ridge of rocks, for example, along the bottom of a bathtub filled with water. The final effect of all these factors was that, slowly but surely, the shoreline crept inland until it reached its present position.

At times, the shoreline was out along the edge of the continental shelf. At those times, sediments poured down canyons on the continental slope to form great sedimentary aprons at its base.

As the shoreline crept landward past the edge of the continental shelf, the shelf began to become covered by sedimentary deposits. These deposits included deltas laid down by streams that flowed into the ocean. They also included near-shore marine sediments. These deposits continued to accumulate through the Middle and Late Jurassic, the Cretaceous, and the Tertiary. This process continues today.

The sedimentary layers that make up the Atlantic Coastal Plain were once horizontal. They now dip gently (between 1/3° and 1°) seaward. This slope was created

[4]According to geophysics, the edge of the continent is on the continental slope. It is there that the crust changes from continental crust to oceanic crust.

by the gradual sinking of the edge of the continent. Some of the sedimentary layers resist erosion better than others. The eroded edges of the harder layers form ridges. They stand up above the softer rocks that have been worn away around them. The ridges and valleys we see on the Atlantic Coastal Plain were formed in this way.

Fifteen thousand years ago, during the Pleistocene Epoch, sea level was 100 m lower than it is today (see Chapter 12). With sea level so much lower, the shoreline was out near the present shelf edge. Rivers flowed to this distant shoreline across what is now the submerged continental shelf. The channels of these rivers were partly filled with sediments as the sea level rose again. However, we can still see them on the shelf. They are called *shelf valleys*. One good example is the Hudson Shelf Valley (Figure 10.2 and the Physiographic Map on Plate 4). It extends from New York Bay across the shelf to the shelf edge, where it merges with the Hudson Canyon.

On the continental shelf, we also find broad ridges. They run generally parallel to the present shoreline. We believe that these ridges are old barrier islands that mark former positions of the shoreline. These islands were flooded as the sea level rose rapidly. Modern currents are gradually wearing them away.

The edge of the continental shelf and the continental slope are cut by great canyons eroded into the sedimentary apron. We don't know exactly how these canyons were formed. However, when the shoreline was close to the present edge of the continental shelf, rivers occupied shelf valleys and flowed to the shelf edge. We think that sediments may have been dumped at the points where the rivers reached the sea near the top of the continental slope. This accumulation caused giant slumps and sediment-laden currents to careen down the continental slope, eroding the underwater canyons on the way.

Review Questions and Exercises

Most of the bedrock near the land surface in this region is which type—igneous, sedimentary, or metamorphic?

How does the thickness of the bedrock in this region vary? How does the age of the bedrock vary?

The variations in age and thickness tell us about a process that is still going on today. What is that process? Why is it happening?