Mountain Building Part I: *the Grenville Mountains*

North America was not always the shape we see today. The continent was formed over billions of years, and geologic processes continue to shape it today. The Earth is estimated to be 4.5 billion years old. The ***oldest rocks*** that we know of are nearly 4 billion years old. Although these ancient rocks are found on almost every continent, none are found at the Earth's surface in the Northeast. In North America, these most ancient rocks are found exposed at the surface in many parts of Canada. These rocks make up the Precambrian shield, a stable continental landmass that is the core of North America. The dynamic plates of the Earth are constantly in motion, made of rigid continental and oceanic crust overlying the churning, plastically flowing ***asthenosphere*** *(Figure 1.2)*. Plates are pulling apart, colliding into one another, or sliding past each other with great force, creating strings of volcanic islands, new ocean floor, earthquakes, and mountains, melting rock and injecting magma into the overlying crust. As these plates move, the continents resting atop them are continuously shifting position. This not only shapes the land, but also affects the type of rocks and minerals, natural resources, climate and life present.

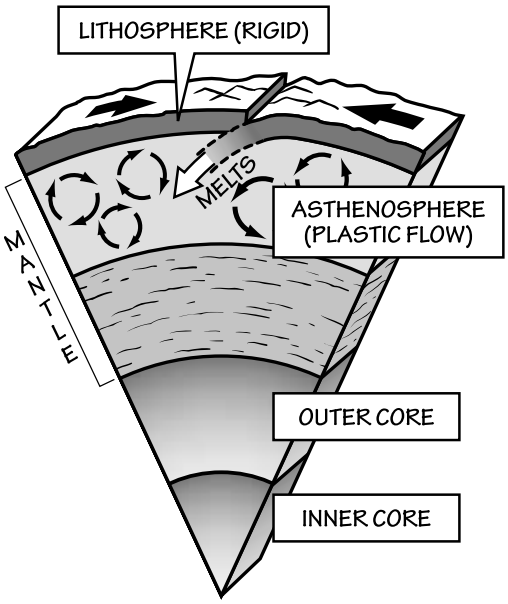


Figure 1.2: The layers of the Earth include the rigid crust of the lithosphere, which is constantly moving over the plastically flowing asthenosphere. Figure by J. Houghton.

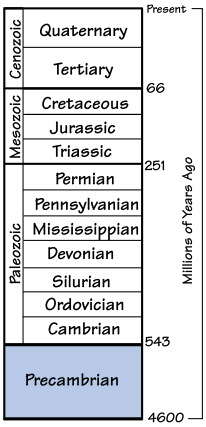
A series of additions of land to North America, compressions from colliding plates, stretching from the pulling apart of plates, and erosion have combined to slowly sculpt the form of the continent. The earliest positioning and shape we can reconstruct of North America dates back billions of years to the formation of continents. Narrow strips of land were smashed together to form the beginnings of North America and what is now the ***Precambrian shield.***

The **oldest rocks** *found on Earth date back 3.9 billion years. Ancient metamorphic gneiss from this time is found in South Africa, Antarctica, Greenland and Northwest Canada. Sedimentary rocks of the same age have been found in western Australia.*

How do plates move?

The **lithosphere** *is the outermost layer of the Earth, a rigid crust and upper mantle broken up into many plates. The heat and pressure created by the overlying lithosphere, make the solid rock of the* **asthenosphere** *bend and move like metal when heated. The flowing rock in the asthenosphere moves with circular convection currents, rising when hot and falling when cool. The plates of the lithosphere move with the underlying asthenosphere, as much as 18 cm/yr (but normally much less.)*

The **Precambrian shield** *has had very little tectonic activity (faulting, folding) for millions of years. Shields are the stable cores of all continents, often covered by layers of younger sediments.*



Geologic History

'Proto-' North America *refers to the ancestral landmass which gradually was shaped into the North American continent that we see today.*

Many geologists believe that North America collided with **ancient Europe**, *also called Baltica in the Precambrian.*

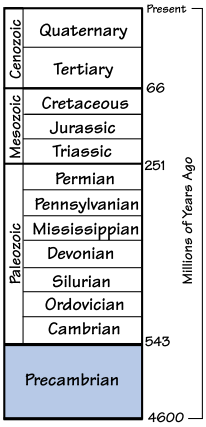
This ***proto-North America*** had sediment eroding off of its continental margins, into the adjacent oceans. The sediments deposited on the eastern margin of proto-North America are called the Grenville belt.

Over 1 billion years ago, proto-North America collided with ***another continent***. The Grenville belt of margin sediments was caught in between the colliding continents and was thrust up onto the side of proto-North America. The collision crumpled the crust, creating a tall mountain range that stretched from Canada to Mexico: the Grenville Mountains. These mountains are the earliest evidence of mountain building in our region, and the rocks remaining from that ancient mountain chain are the oldest rocks that we see exposed at the surface in the Northeast today.

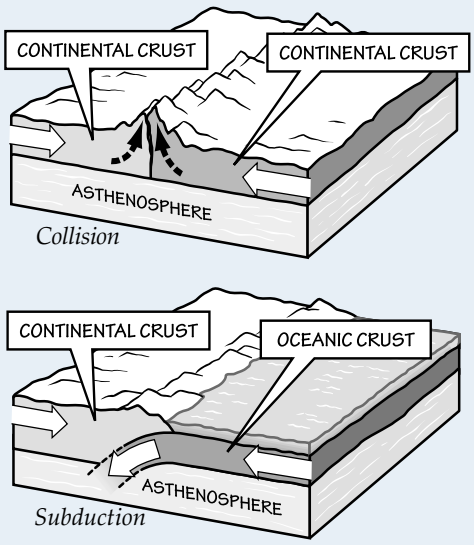
The Grenville rocks themselves have quite a story. The intense heat and pressure generated from the collision produced volcanic material, injected hot molten rock into the crust, and metamorphosed the sediments that had eroded from the margin of the Precambrian shield before the collision occurred. Evidence of this violent past is clear in the Grenville rocks, which are usually metamorphosed sedimentary rocks with igneous intrusions (from the hot molten injections) that have been folded and overturned by the collision-induced compression.

Three types of rock

Minerals are the building blocks of the three basic rock types: igneous, metamorphic and sedimentary. Igneous rocks form from cooling molten rock. Metamorphic rocks form by increasing the temperature and pressures on a pre-existing rock. Sedimentary rocks form by the compaction and cementation of sediment particles resulting from the breakup of pre-existing igneous, metamorphic and sedimentary rocks.



Continental and oceanic crust:



The lithosphere has two types of crust: continental and oceanic. Continental crust is less dense but significantly thicker than oceanic crust. The higher density of the oceanic crust means that when continental crust collides with oceanic crust, the more dense oceanic crust will be dragged (or subducted) under the buoyant continental crust. Although mountains are created at these oceanic/continental crust collisions due to the compression of the two plates, much taller ranges are produced by continental/continental collisions. When two buoyant continental crusts collide, there is nowhere for the crust to go but up! The modern Himalayas, at the collision site of the Asian and Indian plates, are a good example of very tall mountains formed by a collision between two continental crusts. Figures by J. Houghton.

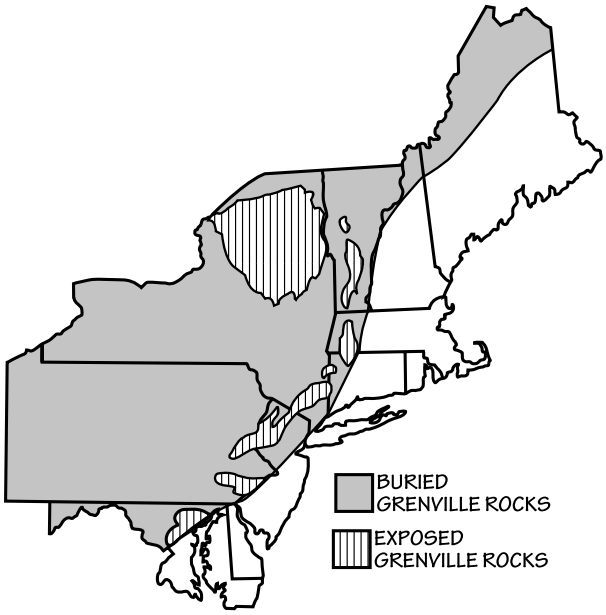


Figure 1.3: Exposures of Grenville-age rocks are found up and down the East Coast and Canada. Figure by J. Houghton.

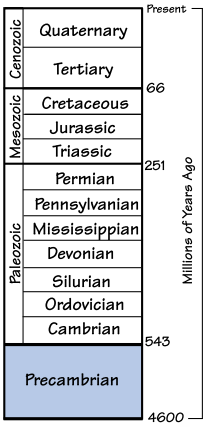
Over time, the Grenville Mountains ***eroded***, just as the Appalachians, Rockies and Himalayan Mountains are constantly being eroded today. By 600 million years ago, weathering and erosion had worn away the mountains, leaving exposed only their innermost cores. These ancient cores are the Grenville rocks that we see exposed today in the Northeast and eastern Canada *(Figure 1.3)*. The Grenville rocks are covered in many areas by younger rocks; however, exposures are found where overlying rocks have been worn away by erosion and the scraping action of glaciers. In the Northeast, the Grenville rocks are exposed in the Adirondacks, the Hudson and Jersey Highlands, Manhattan and Westchester in New York, the Green Mountains of Vermont, the Reading Prong of Pennsylvania, and the Berkshire Hills of Massachusetts.

During the erosion of the Grenville Mountains in the late Precambrian, the geography of the world looked nothing like today. North America was positioned on its side across the Equator, with today's east coast facing south. Sediments were eroding from the Grenville Mountains on either side. The ocean breaking on the shores of the east coast was known as the ***Iapetus*** or ***Proto-Atlantic Ocean***. Given the equatorial position of the continent, the

Weathering and erosion *are constants throughout the history of time. Rocks are constantly being worn down and broken apart into finer and finer grains by wind, rivers, wave action, freezing and thawing, and chemical breakdown. Over millions of years, weathering and erosion can reduce a mighty mountain range to low rolling hills.*

If you could travel back in time to the Precambrian, you would not recognize the Northeast region. Parts of the Northeast were not added on until later and North America was not even in the same spot on the Earth! The Northeast region was just south of the Equator, making for much warmer weather.

The **Proto-Atlantic** *is also known as the* **Iapetus Ocean**. *In Greek Mythology, Iapetus was the father of Atlantis.*



Northeast was experiencing a warm climate. This is the earliest geography of the Northeast region that can be reconstructed. At this point in geologic time, all of New England east of the Berkshires and Green Mountains was not yet part of North America. New England was not assembled for several million more years.

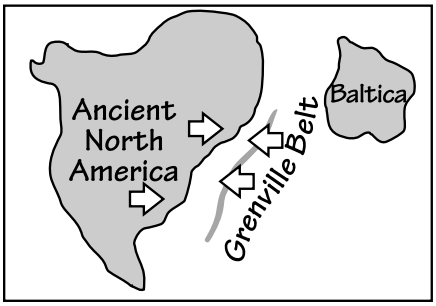
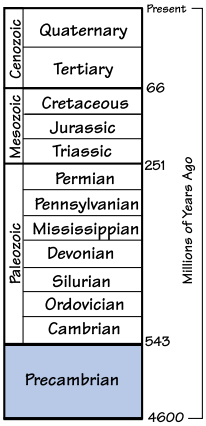


Figure 1.4: Grenville Mountain Building
-Baltica approaches and collides with North America
-Grenville belt pushed onto side of ancient North America
-Grenville Mountains erode away, only roots remain
-North America straddles the equator



Mountain Building Part II: *the Taconic Mountains*

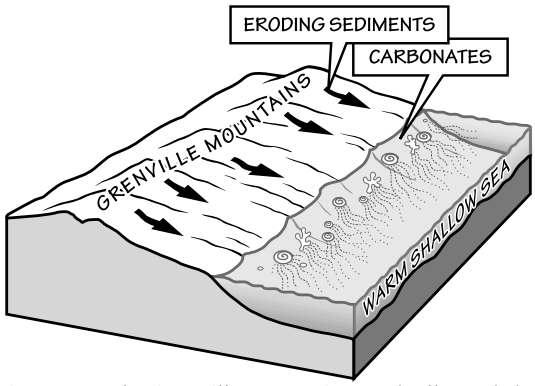


Figure 1.5: The Grenville Mountains gradually eroded over millions of years, depositing sediments on either side of the range, becoming layered with carbonate rocks that were forming in the proto-Atlantic Ocean along the margin of the continent. Figure by J. Houghton.

The continental margin of North America was broad and flat as the Grenville Mountains were wearing down. Sea level at this time, the Cambrian period, was very high worldwide, and warm, shallow seas covered most of the Northeast. The Iapetus Ocean continued to widen during this time. Sediments from the eroding Grenville Mountains were still being deposited on the shoreline to the east, though in far lesser amounts *(Figure 1.5)*. In the Northeast, near the end of the Cambrian, sand deposits were gradually replaced by ***carbonates*** in the Iapetus Ocean. Carbonates were widely deposited on a broad flat shelf along the margin of North America.

Sometime during the middle of the Ordovician period, about 470 million years ago, the Iapetus Ocean began to close as two plates came together. The plate carrying ***Baltica (proto-Europe)*** approached the North American plate from the southeast *(Figure 1.6)*. Though Baltica did not collide with North America until several million years later, the convergence of the two plates created a whole new look for the eastern margin of North America. As the continents approached one another, the oceanic crust in the middle was forced under the Baltica plate. The friction and melting of the crust from the intense pressure of the colliding plates created a string of volcanic islands along the area where the plates converged (known as the subduction zone).

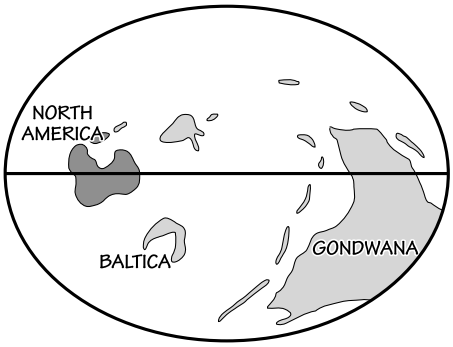
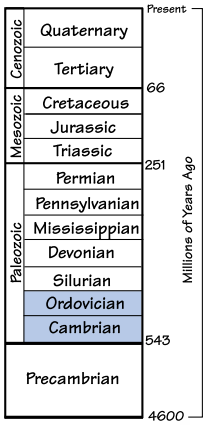


Figure 1.6: Ordovician: 458 million years ago. Shaded areas represent land that was above water.

Carbonates *include limestone and dolostone, formed by the accumulation of calcium carbonate ($CaCO_3$) shells and outer skeletons from aquatic organisms , such as corals, clams, snails, bryozoans and brachiopods. These organisms thrive in warm, shallow waters common to tropical areas. It is not surprising that modern carbonates are observed forming in places such as the Florida Keys and the Bahamas.*

Ancient continents

It has taken millions of years for the continents to take on the shapes we see today. To simplify ancient geography, geologists have given names to the proto-continents to distinguish them from their modern counterparts: **proto-Europe** *(Northern Europe without Ireland and Scotland) is known as* **Baltica***; proto-North America is known as Laurentia; and Proto-Africa was part of a group of continents known as Gondwana.*



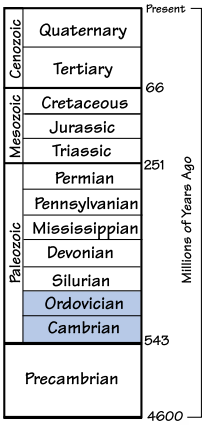
Geologic History

Volcanic islands *are common at subduction zones between colliding oceanic plates. As the plates smash together, one plate is pulled under the other (or subducted). The friction between the plates generates enough heat and pressure to melt some of the crust. The molten rock rises upwards through the crust and creates a string of volcanoes along the edge of the plate.*

The Aleutian Islands are a modern example of volcanic islands forming at a subduction zone.

An **orogeny** *is a mountain-building event (like the formation of the Taconic or Grenville Mountains) caused by colliding plates and compression of the edge of the continents. Orogeny is derived from the Greek word, 'oro,' meaning mountain.*

A **delta** *forms as sediment is eroded from mountains and transported downward by streams. Deltas typically form a wedge-shaped deposit as sediments fan out across the lower elevations.*



The carbonates that had been deposited in the Iapetus Ocean were squeezed and pushed ahead of the ***volcanic islands*** up onto the margin of the continent along with deeper water silts, sands and clays *(Figure 1.8)*. These volcanic remnants may be found in a thin band of rocks in northernmost Vermont that extend through northern New Hampshire, and up the western and northernmost section of Maine.

As the Iapetus Ocean closed, folding, thrust-faulting, uplift, and intrusion occurred along the margin of the continent from the intense pressure of the colliding plates, causing another mountain chain to form in place of the worn-away Grenville Mountains. This mountain-building event is called the Taconic ***Orogeny.***

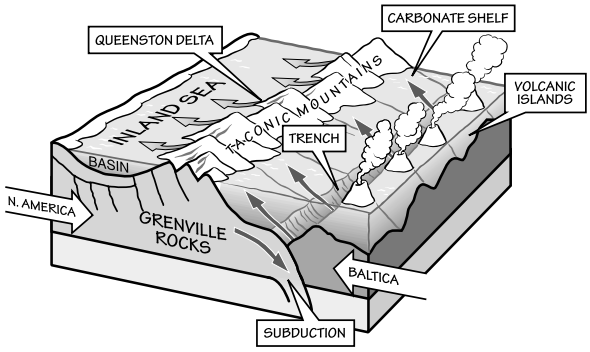


Figure 1.7: Volcanic islands formed where the plates were forced together as the Iapetus Ocean closed. The compression crumpled the crust to form the Taconic Mountains and a shallow inland sea. Figure by J. Houghton.

The compression induced by the collision of the two plates, caused a downwarp in the crust to the west of the Taconic Mountains. This sagging crust became a basin filled with a broad, shallow inland ocean and sediments from the eroding Taconic Mountains. As sediment was eroded from the western side of the Taconic Mountains, the Queenston ***Delta*** deposits formed a wedge of sediments spreading away from the Taconics through New York and Pennsylvania *(Figure 1.8)*. Some of the delta sediments settled in the shallow inland sea, gradually filling the basin. Sediments were also being eroded and deposited east of the Taconics into the

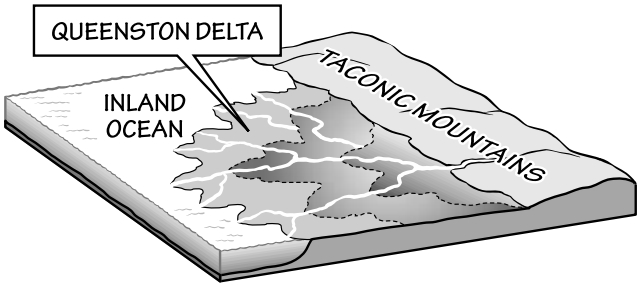


Figure 1.8: The Queenston Delta formed as sediments eroded from the Taconic Highlands and were transported downward by streams, forming the characteristic wedge-shaped delta deposits. Figure by J. Houghton.

trench formed where the plates converged. Eventually, the Taconic Mountains eroded away to only the inner core, as had the Grenville Mountains previously.

The ***Taconic Mountains*** that we see today in eastern New York are not the ancestral Taconic Mountains. Further compression of the crust during the Taconic and Acadian mountain-building events thrust huge slabs of the ancestral Taconic Mountains westward from Vermont and Massachusetts. Thus older, more resistant rocks from the Taconics ended up on top of younger sedimentary rocks from the inland ocean. This is unusual in geology; usually the oldest sediments are on the bottom. The resistant blocks from the ancestral Taconic Mountains weathered much more slowly than surrounding rocks, eventually forming the Taconic Mountains of today.

The rounded Berkshire Mountains of western Massachusetts are the roots of the original **Taconic Mountains**. *Large segments of the Taconic Mountain mass (known as the Taconic Klippe) were thrust westward into eastern New York over younger rocks that had been deposited in the inland ocean.*

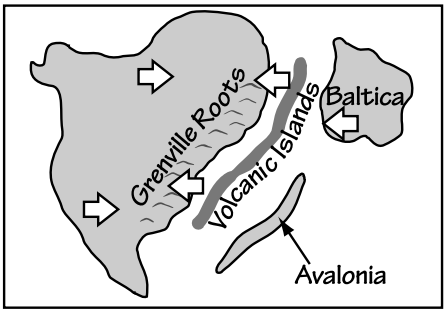
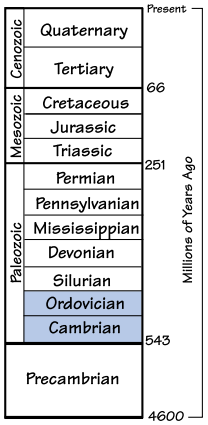


Figure 1.9: Taconic Mountain Building
-Baltica approaches North America after breaking away earlier
-volcanic islands form over subduction trench
-volcanic islands collide with North America, form Taconics
-inland sea forms to the west of Taconics
-Taconic Mountains erode
-Queenston Delta deposited west of Taconics



Exotic Terranes:
the making of New England

Due to their origin from far away, 'exotic' places, **exotic terranes** *have distinctly different geologic characteristics than the surrounding rocks.*

Exotic terranes *are not exclusive to New England. Florida is a good example of an exotic terrane, originating as part of Gondwana. Parts of the West Coast of North America (including Alaska) are also considered to be exotic terranes, sutured on to the coast and repositioned by strike-slip faults (shearing of blocks of crust).*

Until the Ordovician period, North America was missing most of what we know of today as New England. Formed over hundreds of millions of years, New England was slowly pieced together by the addition of several tiny strips of land to the proto-North American continent. These strips of land are called '***exotic terranes***,' small landmasses that originated from somewhere other than North America and were tacked on to the continent as plates converged. Cameron's Line marks the ancient suture line between proto-North America and the exotic terranes of New England. Over several million years, two exotic terranes were added to proto-North America: the Iapetus Terrane and the Avalonia Microcontinent Terrane *(Figure 1.10)*.

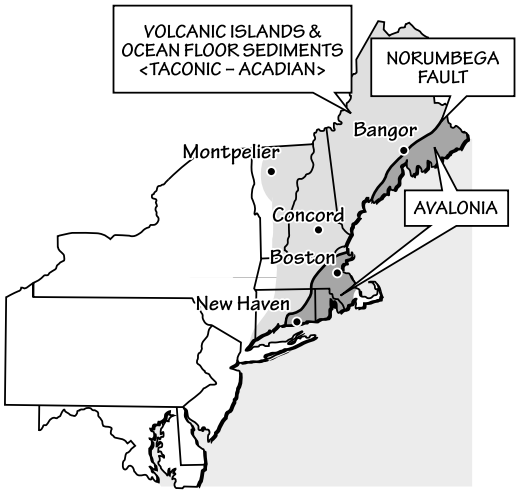
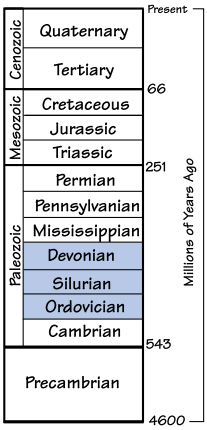


Figure 1.10: New England was not always part of the North American continent. Slices of land known as exotic terranes, collided with North America during the Taconic and Acadian orogenies. Figure by J. Houghton.

During the Taconic mountain-building event, volcanic islands had formed in the Iapetus Ocean, at the subduction zone of the plates carrying North America and Baltica. As the plates merged, the dense oceanic crust of the Iapetus Ocean was pulled down into the mantle where it melted. Some magma from the melting, subducting oceanic crust, rose back up through the plate to form the volcanic islands. Weathering and erosion of the volcanic islands produced sediments that were then deposited in the Iapetus Ocean. The volcanic islands drew closer and closer to proto-North America as the oceanic crust was subducted. Eventually, the volcanic islands were pushed onto the eastern margin of North America, along with sediments that had been eroded into the ocean basin from proto-North America and the volcanic islands. The Iapetus Terrane, including the string of volcanoes and associated



ocean basin sediments from the Taconic mountain-building event, added most of Vermont, New Hampshire, central Massachusetts, Connecticut and Maine to the Northeast.

The exotic terrane Avalonia was a microcontinent, originating from the African plate (Gondwana) in the south and traveling northwards on the moving plates to collide with North America. When the Iapetus Ocean closed in the Devonian, Avalonia was sutured to the East Coast in between the colliding continents of Baltica and North America. Avalonia tacked on the last main bits of New England, including eastern Maine, Connecticut and Massachusetts, and Rhode Island. Only Cape Cod, Long Island and smaller ***islands*** off the coast of New England were yet to be part of the Northeast.

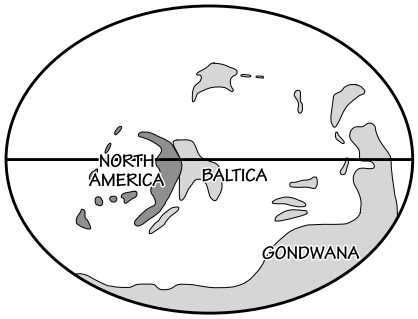


Figure 1.11: Silurian: 425 million years ago.

The Iapetus and Avalonia Terranes that make up New England were added to the Northeast over millions of years during the Taconic orogeny and the later Acadian orogeny (when North America collided with Baltica) from the Ordovician through the Devonian *(Figure 1.11)*. The terranes were squeezed, crumpled, deformed and intensely metamorphosed. This has made for some rather complex geology in the New England area. The intensity of deformation and metamorphism has made it difficult for geologists to distinguish the individual volcanic islands added to the margin of North America or the exact timing of exotic terrane collisions.

The ***islands*** *off the coast of New England did not form until millions of years later during the Cenozoic, as the Northeast was in the grip of the Ice Age. The enormous amounts of material dumped by glaciers as they melted and retreated North created these island landmasses.*

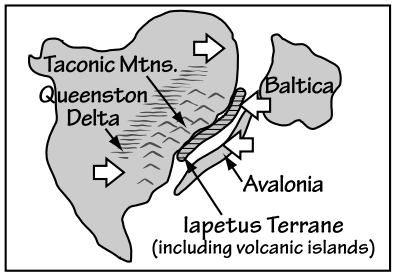
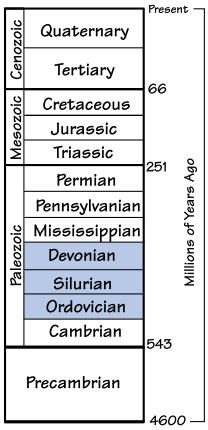


Figure 1.12: Exotic Terranes
-Taconic volcanic island arc collides with North America
-Iapetus Ocean sediments collide with North America
-Avalonia (origin uncertain) collides with North America



Mountain Building Part III: *the Acadian Mountains*

The **Queenston Delta** *formed from sediments eroding off of the Taconic highlands. With the rise of the Acadian Mountains, erosion of sediments was renewed and the Catskill Delta deposits covered over the Queenston delta.*

The Mississippi Delta is a modern delta that is dumping sediment from the Mississippi River into the Gulf of Mexico. Looking at the Mississippi Delta from above, the characteristic wedge shape of a delta is evident.

The sediments of the **Catskill Delta** *are over 1.2 km thick in some places, indicating intense erosion and the enormity of the Acadian Mountains. Close to the source of erosion (the Acadian highlands) the delta sediments are coarser grained and thicker. As the sediments spread west across New York and Pennsylvania, they became finer grained and thinner deposits.*

When Baltica (proto-Europe) finally collided with North America around 380 million years ago in the middle Devonian, the exotic terranes making up New England were in between the colliding continents. The terranes (and the eastern margin of North America) were squeezed, folded, metamorphosed and intruded by magma. This collision with Baltica and North America formed yet another tall mountain chain, the Acadian Mountains, along the eastern margin of North America.

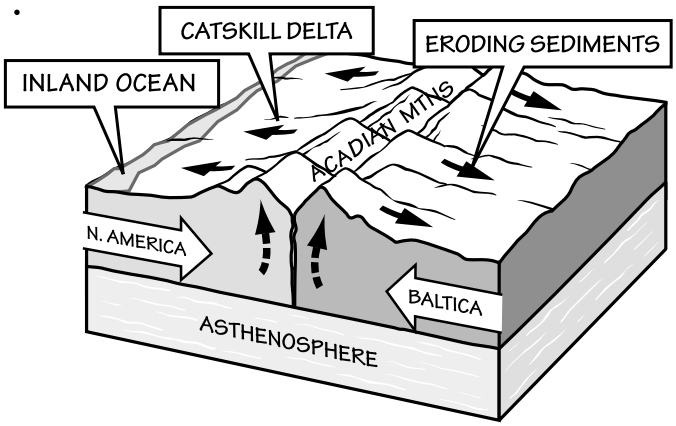


Figure 1.13: North America and Baltica collided finally in the mid-Devonian, crumpling the crust to form the Acadian Mountains. Sediments eroded from the highlands formed

The Acadian mountains were similar to the Taconic and Grenville mountains of the past which had since eroded *(Figure 1.13)*. Just as in the Taconic mountain-building period, compression from the Acadian continental collision warped the crust downward, reinforcing the inland ocean. The ***Queenston Delta*** was buried by new sediments eroding from the western side of the Acadian mountains. These sediments, known as the ***Catskill Delta***, created a new wedge of sediments stretching into a shallow inland sea.

During this time, North America gradually began to move closer to its present geography and assume the north-south alignment we see today. At the time of the Acadian mountain building and subsequent erosion during the Devonian, the Northeast was at the

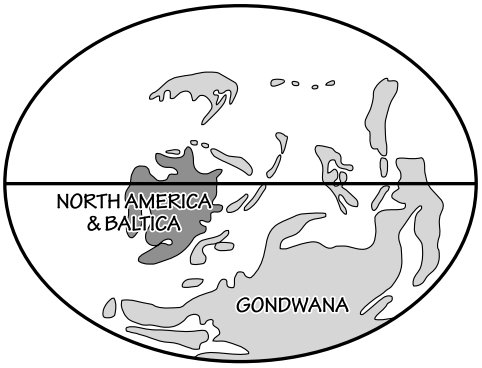
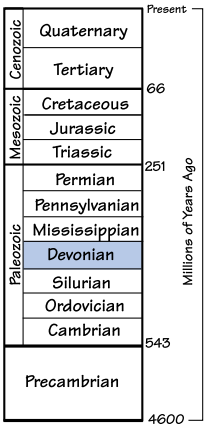


Figure 1.14: Devonian: 390 million years ago.



Equator and experiencing the associated tropical climate *(Figure 1.15)*. Baltica (proto-Europe) and North America were united as one larger landmass. Africa, South America, India, Australia, Antarctica and Florida were all combined as one continent (Gondwana) in the southern hemisphere. The continents were gradually merging to become one.

Pangea, *meaning 'all Earth,' formed over 250 million years ago and lasted for almost 100 million years. All of the Earth's continents were literally joined as one to form a giant super-continent.*

Between mountain-building events: *deposition in the inland ocean*

The Northeast was not continuously experiencing dynamic mountain-building events. There were quieter times as well between the rise of great mountains and crushing crusts of colliding plates. The quiet times were marked by erosion of the highlands and very little plate movement and compression within the Northeast region. The building of the Taconic Mountains was over by the late Ordovician. Throughout the following Silurian period, the Northeast experienced a quiet time in which erosion from the Taconic highlands and deposition in the inland sea were the main events. Huge thicknesses of sedimentary rocks accumulated in and on the margins of the inland sea during part of the Silurian. The inland ocean, which spread across much of New York, Pennsylvania and western Maryland, was similar to the modern Persian Gulf, becoming very salty because of the shallow water, high rates of evaporation and poor circulation.

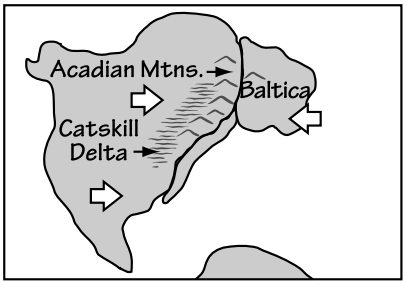
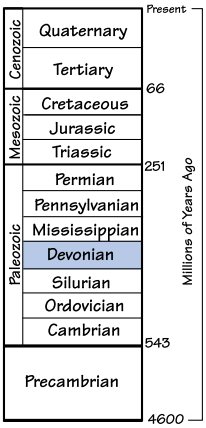


Figure 1.15: Acadian Mountain Building
-Baltica collides with North America
-Acadian Mountains form (northern Appalachian Mountains)
-similar to Taconic mountain building
-inland sea forms west of Acadian Mountains
-Acadian Mountains erode
-Catskill Delta deposited west of Acadian Mountains



Mountain Building Part IV: *the formation of Pangea and the Appalachian Mountains*

Today's Appalachian Mountain chain formed 470 million years ago at the time of the Taconic mountain-building event, with the initial squeeze of the margin of North America. The Acadian mountain-building, 380 million years ago, crunched the crust of North America a bit more. Finally, approximately 250 million years ago, the Alleghanian mountain-building event occurred as ancestral Africa collided with North America to create the central and southern Appalachians during the Permian *(Figure 1.16, Figure 1.17)*. The Acadian orogeny helped to shape the northern Appalachian Mountains, but the Alleghanian orogeny gave the final squeeze to the margin of the continent to form today's Appalachian Mountain chain, extending from Alabama to Maine and beyond into Canada. From the time of the Acadian mountain-building event until the Triassic, the Appalachians were continuous with the Caledonide Mountains of northwestern Europe and Greenland.

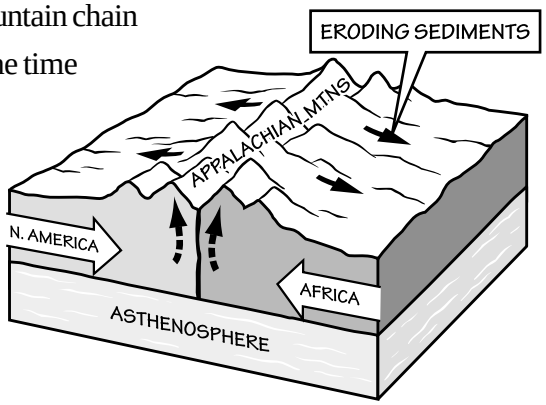


Figure 1.16: When ancestral Africa collided with North America, the Appalachian mountains were formed. Figure by J. Houghton.

The Appalachian Mountains that we see today, however, are merely the worn down remnants of the Appalachians created millions of years ago. At one time the Appalachians were probably as tall as the modern Himalayas, but today the Appalachians are the

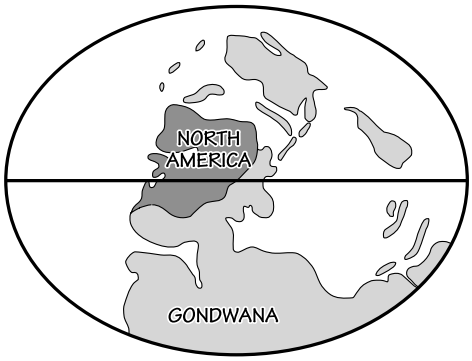
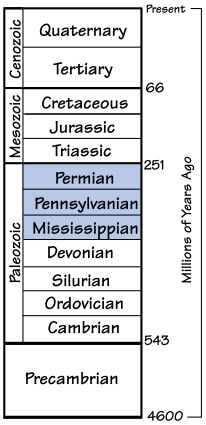


Figure 1.17: Late Pennsylvanian: 306 million years ago.

Why are the Appalachians still here?

Although the Appalachian Mountains were formed over 250 million years ago, they are still around today. The forces of erosion and weathering have worn down the Appalachians over time; periodic uplift of the range, however, has prevented them from completely eroding away.



rounded, weathered and aged peaks of a more mature mountain range that has seen millions of years of erosion and uplift.

The direct cause of the creation of the Appalachian Mountains was the merging of all continents into the supercontinent Pangea as the Iapetus Ocean closed 290 million years ago. Baltica and North America had merged to form one continent during the Acadian mountain-building period in the Devonian, effectively creating the ancestral northern Appalachians. In the meantime, through the Mississippian and Pennsylvanian periods, ancestral Africa (already joined to other continents as Gondwana) drifted closer to North America and Baltica. The Iapetus Ocean narrowed as the oceanic crust was subducted under the North American continental crust. When ancestral Africa finally collided with North America during the Permian, the continental crusts were too bouyant to be subducted like dense oceanic crust. Instead, the crusts crumpled together to create a tall range of mountains. Sediments from the proto-Atlantic ocean basin and the continental shelf and slope of North America, were pushed upwards and squeezed along with the crust.

Though the Appalachian Mountains do not look as tall and rugged as the Himalayas of India, the Appalachians formed through esentially the same geologic processes. The collision of the Indian and Asian plates that is taking place today is raising the Himalaya Mountains, similar to the collision over 250 million years ago between Africa and North America created the Appalachian Mountains.

Evidence For Pangea

How do we know that Pangea existed 250 million years ago? Fossil evidence and mountain belts provide some of the clues. The Permian-age fossil plant, Glossopteris *had seeds too heavy to be blown across an ocean. Yet* Glossopteris *fossils are found in South America, Africa, Australia, India and Antarctica! The mountain belts along the margins of North America, Africa and Europe line up as well and have similar rock types, indicating that the continents at one time were joined as Pangea. The discovery of* Glossopteris *and the evidence in the rocks helped geologists to formulate the theory of Continental Drift, which, when the processes of continental movement were later discovered, was reformulated under the modern theory of Plate Tectonics.*

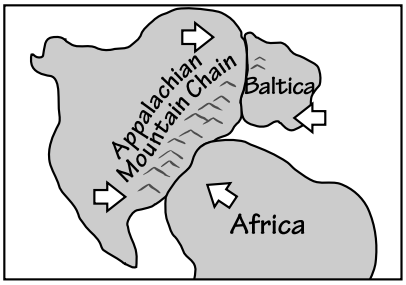
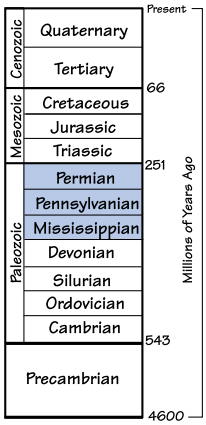


Figure 1.18: Alleghanian Mountain Building
-Africa collides with North America
-central/southern Appalachians form
-Pangea assembled, one supercontinent on Earth



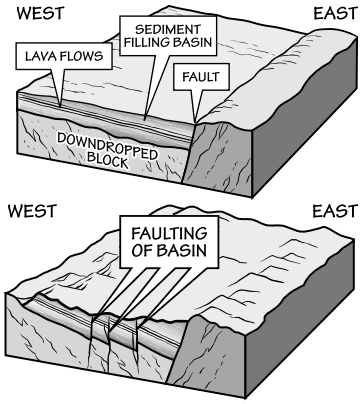
The Breakup:
Pangea comes apart

Rifts *are breaks or cracks in the crust which can be caused by tensional stress as a landmass breaks apart into separate plates.*

The same processes that are today tearing apart **East Africa***, were tearing apart Pangea 180 million years ago. In East Africa, the African plate is pulling away from the Arabian plate, stressing the crust to the point of breaking apart.*

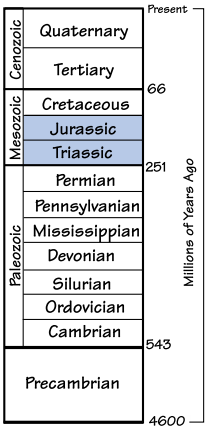
The super-continent, Pangea, lasted 100 million years. But, as we have seen, the Earth's crust is not static. The direction of plate movement shifted over time and the continents began to pull apart rather than converge. ***Rifts*** developed in the crust, eventually breaking completely through the crust and leading to the breakup of the supercontinent. Modern day rifting can be observed in the ***East African*** Rift Valley. Tension (two forces pulling in opposite directions) slowly began to pull North America away from the other merged continents. As the crust was pulled apart, it stretched, thinned and uplifted to the point of breaking.

The rifts occurred along a series of cracks in the Earth's crust roughly parallel to the present coastline. Along a series of faults, blocks of crust slid down the faults to form down-dropped basins bounded by tall cliffs that came to be known as ***Triassic rift basins*** *(Figures 1.19 and 1.20)*. The eroding cliffs filled the adjacent basins with poorly sorted, red-colored sandstones and shales. These basin deposits are part of a sequence of rocks known as the Newark Supergroup, with thicknesses reaching up to 6 km in some places. Deposits are found in the Connecticut Valley of Massachusetts and Connecticut, and in the Newark Basin, which stretches from southeastern New York across New Jersey, Pennsylvania and Maryland. There are more Triassic Rift Basins located off the east coast that are buried by continental shelf sediments *(Figure 1.21)*. During the Jurassic, the final break between the plates of North America, Africa and Baltica occurred many kilometers to the east of today's coastline at what is now the Mid-Atlantic Ridge. Other fragments of Pangea gradually broke into the modern continents, slowly moving into their present positions over the next several hundred million



Figures 1.19 and 1.20: As rifting occurred, blocks of crusts slid down faults to form a basin. The basin was filled with sediments and lava flows. Eventually, the entire basin was tilted and faulted. Figure by J. Houghton.

The long, narrow **Triassic rift basins** *formed through the Triassic and early Jurassic periods.*



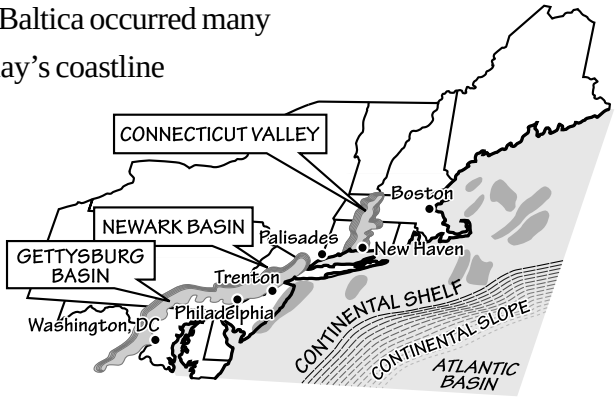


Figure 1.21: The Triassic Rift Basins of the Northeast formed as North America broke away from Pangea during the Triassic and Jurassic. Figure by J. Houghton.

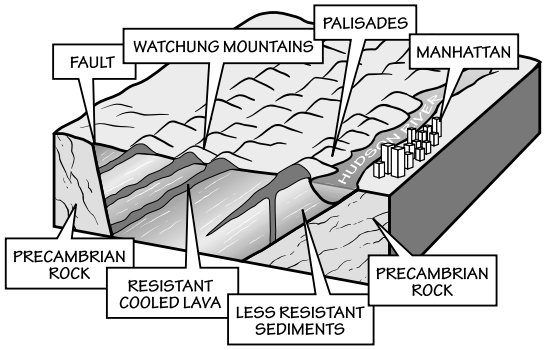


Figure: 1.22: The softer sediments of the Newark Rift basin were quickly worn away, forming valleys between the more resistant ridges of hardened lava flows. Figure by J. Houghton.

years.

The tension released by the pulling apart of plates, resulted in numerous faults and volcanoes. Alternating with the sandstone and shale being deposited in the basins were deposits of ash and lava flows originating from volcanoes along the rift area. The flat-lying beds of the Newark and Connecticut Valley basins were eventually faulted again and tilted, exposing the edges of the layers of sediment and cooled lava. The hardened lava was more resistant to erosion than the sediments in the basin, so ridges of cooled lava were left standing as the sediments around them wore away *(Figure 1.22)*.

As the supercontinent gradually broke apart, the continents moved into the geographic positions we see today *(Figures 1.23 and 1.24)*. The Atlantic Ocean began to widen. The east coast of North America no longer experienced the strong tectonic activity associated with the compression and rifting of a plate margin. Instead, the tectonic activity gradually moved with the Mid-Atlantic Ridge hundreds of kilometers off the coast in the Atlantic Ocean. The Northeast, remaining a 'passive margin' through to the present, began a long period of erosion that would continue through the Cretaceous and into the Tertiary.

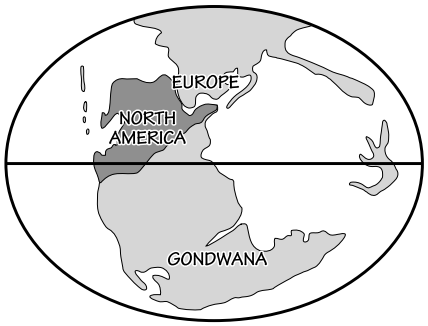


Figure 1.23: Triassic: 237 million years ago.

Rocks that form ridges

Some rocks wear down relatively quickly, while others can withstand the power of erosion for much longer. Softer, weaker rocks such as shale and poorly cemented sandstone and limestone are much more easily worn away than hard, crystalline igneous and metamorphic rocks, or well cemented sandstone and limestone. Harder rocks are often left standing alone as ridges because surrounding softer, less resistant rocks were quickly worn away.

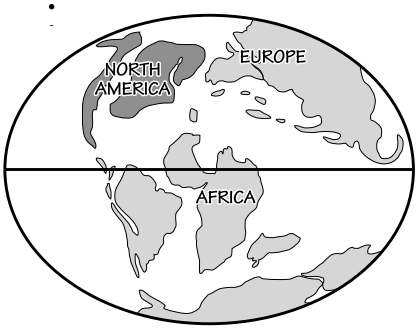


Figure 1.24: Cretaceous: 94 million years ago.

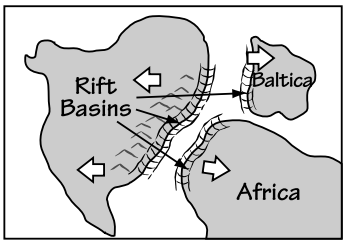
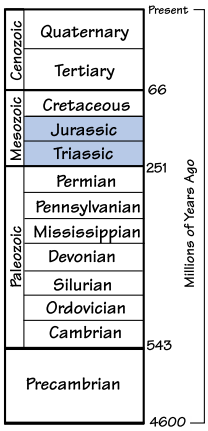


Figure 1.25: Pangea Breaks Up
-Pangea begins to split
-rifts are created in the crust
-Triassic/Jurassic Rift Basins form
-Rift Basins filled with sediments and lava flows
-Rift Basins later tilted, faulted and eroded
-long period of erosion



The Ice Age:
mountains of ice

Although today the plates are still drifting and the Atlantic Ocean continues to widen, the dynamic plate tectonic activity of the geologic past has temporarily quieted along the east coast. However, despite the minimal tectonic activity in the Northeast throughout the Cenozoic (with the exception of periodic uplift and movement of faults), the face of the land continued to change due to erosion and a series of advances and retreats of glacial ice.

A cooler climate contributes to the growth of continental glaciers. The continental glacier that repeatedly covered parts of North America during the Quaternary, had its origin in northern Canada. As the climate cooled, more snow fell in the winter than melted in the summer, causing the snow to pack into dense glacial ice.

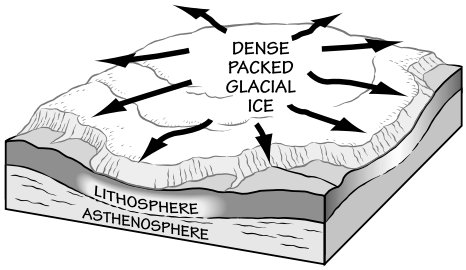


Figure 1.26: As dense glacial ice piles up, a glacier is formed. The ice begins to move under its own weight and pressure. Figure by J. Houghton.

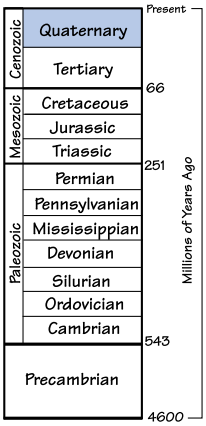
As more snow and ice accumulated on the glacier (and less melted), the ice began to move under its own weight and pressure. The older ice on the bottom was pushed out horizontally by the weight of the overlying younger ice and snow. Glacial ice then radiated out from a central point, flowing laterally in every direction away from the origin *(Figure 1.26)*. And thus, a continental glacier originating in far Northern Canada began to move south towards the north-eastern U.S *(Figure 1.27)*. The ice sheet crept slowly forward, scraping off the loose rock materials and gouging the bedrock beneath the ice as it advanced.

Figure 1.27: The movement of the ice sheet over North America. Figure by J. Houghton.

Nearly two million years ago, the

What happened between the breakup of Pangea and the ice age?

The Northeast gradually rifted away from the rest of Pangea during the Mesozoic. Throughout the Tertiary period (which followed the breakup of Pangea) a warm climate promoted chemical weathering and erosion of rocks of the Northeast. Periodic uplift and significant erosion of the land shaped much of the topography of the Northeast. Though Tertiary deposits are thick along the continental shelf and parts of the Coastal Plain (evidence of significant erosion during this time), there are very few Tertiary deposits on much of the Northeast coast. This is because as the climate began to cool and the ice age set in, glaciers scraped up most of the sediments deposited during the Tertiary and pushed them southward. Uplift during the Tertiary created the Adirondack Mountains of New York.



Earth's climate shifted towards ice age conditions. Since that time, there have been several dozen intervals of glaciation separated by warmer intervals not unlike the present. The most recent glacial advance reached its maximum extent 25-20,000 years ago and lasted until 10,000 years before the present. Though the glaciers are long gone from the Northeast, they have left behind evidence of their advances and retreats, smoothing over the mountains and blanketing the surface with glacial deposits. The Northeast owes a large share of its present topography and drainage patterns to the last glacial advance.

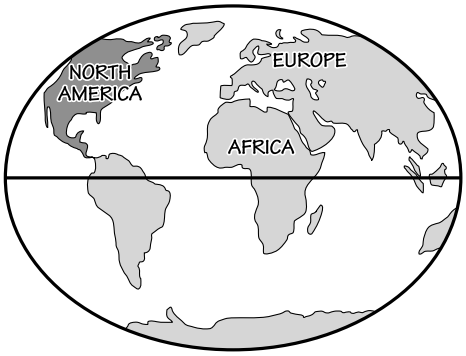


Figure 1.28: Modern geography.

Although the entire Northeast region was affected by the cooling climate during the last advance of the ice sheet, the glaciers only extended as far south as northern Pennsylvania and Long Island. Today, the Earth is technically in an interglacial time, as the ice sheets have retreated for now. There is every reason to believe, however, that the Earth will return to a glacial maximum unless ***global warming*** resulting from human activities pulls the Earth from another ice age.

Throughout the Earth's history, the continents have been periodically plunged into an ice age, dependent upon the climate and position of the continents. Over the last million years, North America has experienced glaciation approximately **once every 100,000** *years and once every 40,000 years during the previous two million years.*

With the coming of the Industrial Age and exponential increases in human population, large amounts of gases have been released to the atmosphere (especially carbon dioxide) that contribute to **global warming.**

see Glaciers, p.57

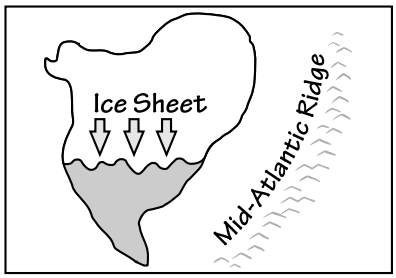
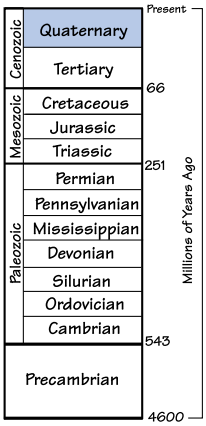


Figure 1.29: Ice Age
-Northern Canadian ice sheet forms
-repeated advances and retreats of ice sheet over the Northeast
-put the finishing touches on the topography of the Northeast



The Last One Billion Years

Figures by J. Houghton; Paleogeography figures after
C. Scotese, Paleomap Project, 2000,
http://www.scotese.com/

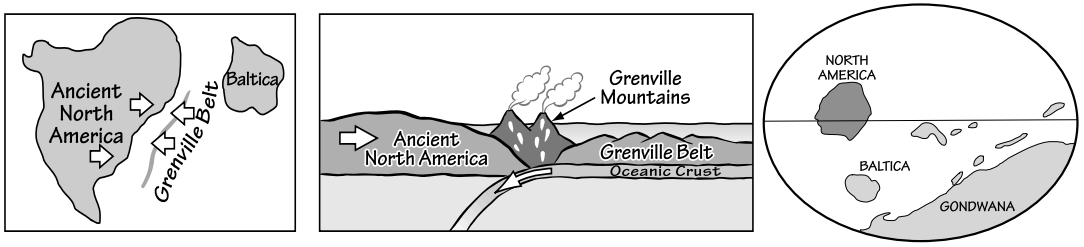
Grenville Mountain Building
-Baltica approaches and collides with North America
-Grenville belt pushed onto side of ancient North America
-Grenville Mountains erode away, only roots remain
-North America straddles the equator

Taconic Mountain Building
-Baltica approaches North America after breaking away earlier
-volcanic islands form over subduction trench
-volcanic islands collide with North America, form Taconics
-inland sea forms to the west of Taconics
-Taconic Mountains erode
-Queenston Delta deposited west of Taconics

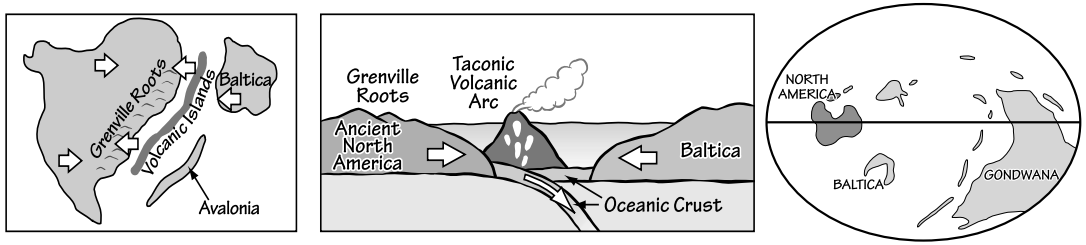
Exotic Terranes
-Taconic volcanic island arc collides with North America
-Iapetus Ocean sediments collide with North America
-Avalonia (origin uncertain) collides with North America

Acadian Mountain Building
-Baltica collides with North America
-Acadian Mtns form (northern Appalachian Mtns)
-similar to Taconic mountain building
-inland sea forms west of Acadian Mountains
-Acadian Mountains erode
-Catskill Delta deposited west of Acadian Mountains

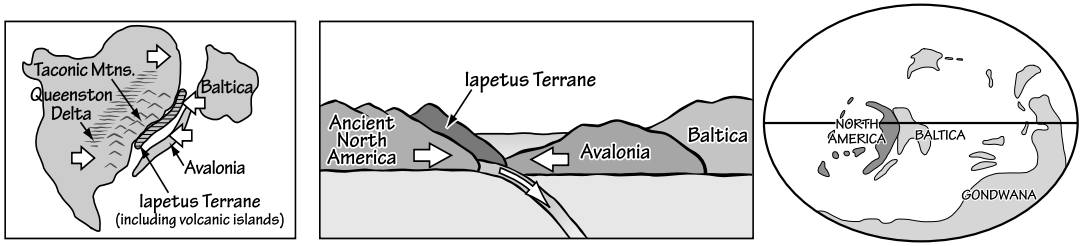
Precambrian (4500-544 mya)



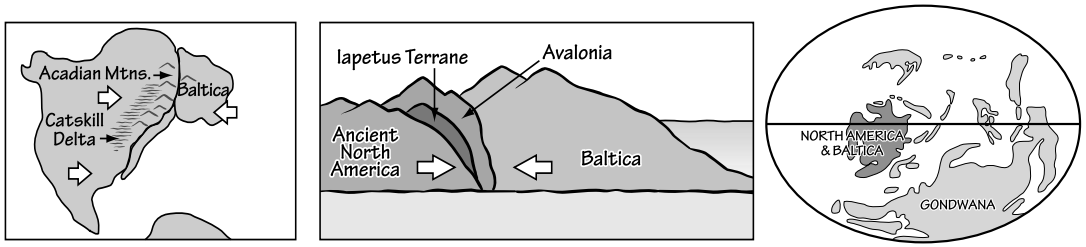
Cambrian/ Ordovician (544-440 mya)



Silurian/ Devonian (440-360 mya)

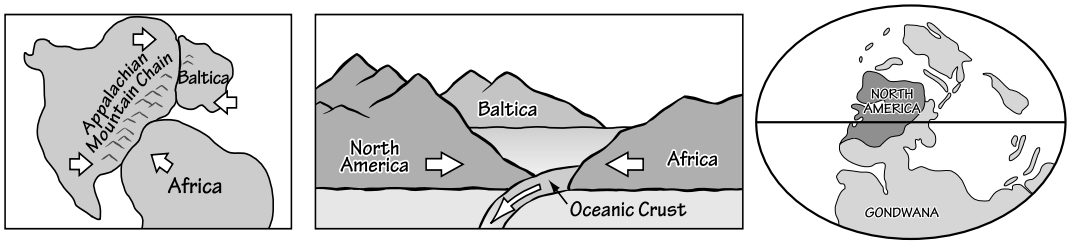


Devonian (410-360 mya)



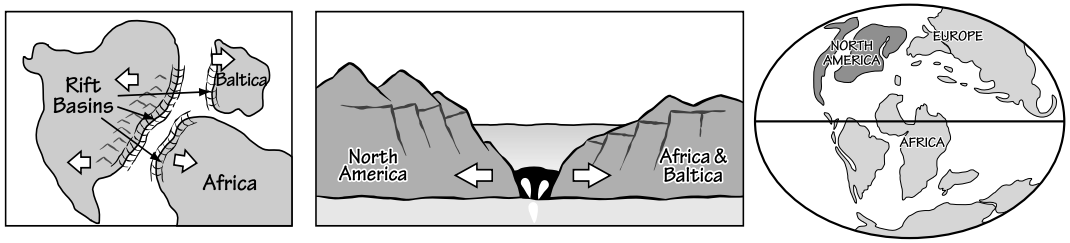
Alleghanian Mountain Building
-Africa collides with North America
-central/southern Appalachians form
-Pangea assembled, one supercontinent on Earth

Mississippian Pennsylvanian Permian (360-245 mya)



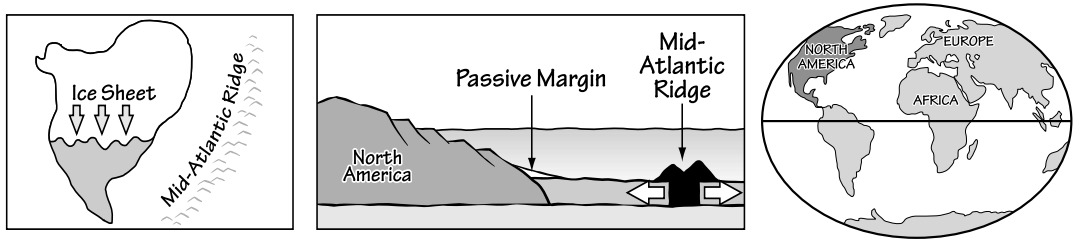
Pangea Breaks Up
-Pangea begins to split
-rifts are created in the crust
-Triassic/Jurassic Rift Basins form
-Rift Basins filled with sediments and lava flows
-Rift Basins later tilted, faulted and eroded
-long period of erosion

Triassic/ Jurassic Cretaceous (245-65 mya)



Ice Age
-Northern Canadian ice sheet forms
-repeated advances and retreats of ice sheet over the Northeast
-put the finishing touches on the topography of the Northeast

Quaternary (1.8 mya-present)



Activities

1. As part of an experimental program to bring together arts and sciences at your school, you are requested to create an art piece that shows in three dimensions — through drawings, sculptures, computer animations, or other forms — the sequence of geologic events that took place in the Northeast United States over the past billion years. It is thought that the sequence of events, represented in different colors and changing shapes, may give an interesting art form as well as illustrating geologic history.

Create your own artistic piece, of the history of the Northeast, showing:
(1) the Grenville passive margin,
(2) the Taconic converge,
(3) the Acadian convergence,
(4) the rifting apart of Pangea, and
(5) the Coastal Plain passive margin.

2. Your art piece is selected to go on display in your local art museum. The Director of Exhibits there asks if you could create another three dimensional piece that represents a stack of rocks of various ages from just your own area. This will help show people at a local scale the influence of these geologic events on the rocks under their feet. You are asked to please use colors consistent with the first piece, so that the two pieces are complementary.

Create a second artistic piece, representing local rocks through time, consistent with (1).

3. You have another creative idea. You apply for and receive a grant to create three more pieces for local geology as in (2), each of them in a different place that, all together, can help tell the large-scale story of number (1).

(a) Create three more art pieces for areas of the Northeast that are each geologically different from each other, so that altogether they represent how large scale geologic events have affected local rocks. You choose the locations. Create an artwork representing the series of rocks present at each location.

You decide each piece of art should somehow include actual specimens of rocks representing each event or geological period. Though it is clear that you can go to the three places and find rocks at the surface, the rocks under the surface from previous geologic periods will be buried; you reason that you can find rocks of similar age and origin exposed at the surface elsewhere. Fortunately you had the foresight to see that you'd need to do some field work, and have a modest travel budget as part of your grant.

(b) Describe in highway travel the most efficient way to collect appropriate samples that represent the subsurface samples you need. Create a travel report listing each segment of the trip, what you collected, how many miles you traveled, and what your travel costs were.

For More Information...

Books

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http://www.geo.wvu.edu/~tsattler/tectonics/adirondack/mountains.html

Deposition of the Catskill Clastic Wedge
http://www.stepahead.net/~schneller/devohist.htm

Geologic Time
http://www.ucmp.berkeley.edu/help/timeform.html

Newark Basin and Connecticut River Basin
http://everest.hunter.cuny.edu/bight/newark.html

Paleomap Project
http://www.scotese.com/

USGS Information on Plate Tectonics
http://geology.er.usgs.gov/eastern/tectonic.html

USGS The Story of Plate Tectonics
http://pubs.usgs.gov/publications/text/dynamic.html

Other Resources

used in compiling this chapter

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Dott, R.H., Jr. and D.R. Prothero, 1994, *Evolution of the Earth*, 5th edition, McGraw-Hill, Inc.: New York, New York.

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Rodgers, J., 1971, *The Taconic Orogeny,* The Geological Society of America, Volume 82, p.1141-1178.

Roy, D. C., ed., 1987, *Northeastern Section of the Geological Society of America: Centennial Field Guide,* Volume 5, Geological Society of America: Boulder, Colorado.

Zen, White, Hadley and Thompson, eds., 1968, *Studies of Appalachian Geology,* Inter Science Publishers: New York, New York.

Special thanks to Robert Hatcher, Bob Darling, and Bosiljka Glumac for information and resources regarding geologic history.

Selected Figures

for overheads & handouts

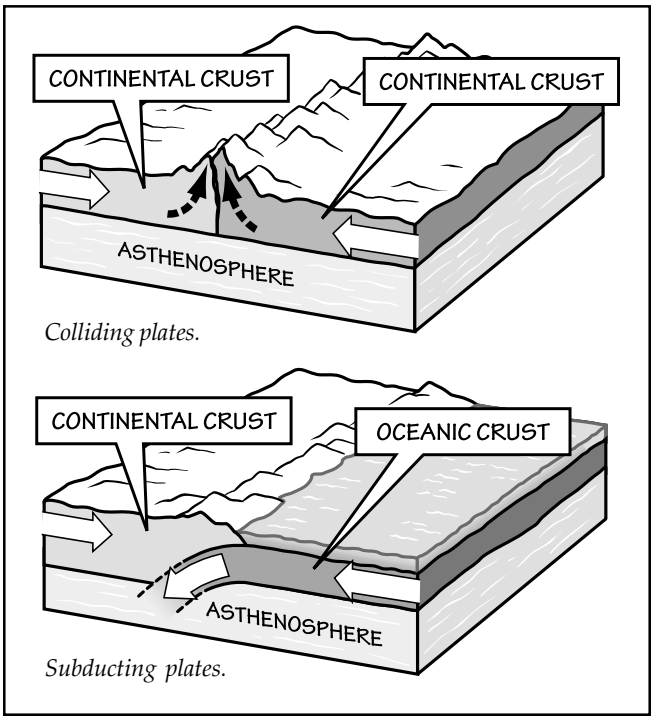


Figure 1.3: Exposures of Grenville-age rocks are found up and down the East Coast and Canada. Figure by J. Houghton.

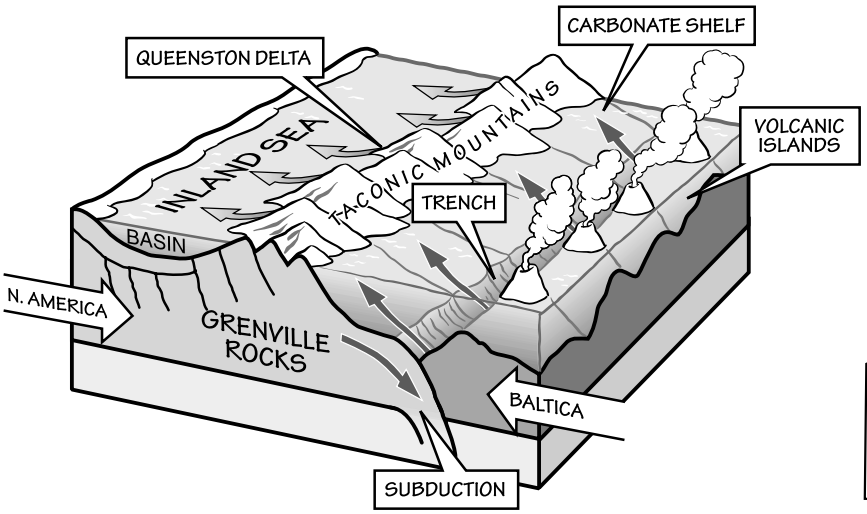


Figure 1.8: Volcanic islands formed where the plates were forced together as the Iapetus Ocean closed. The compression crumpled the crust to form the Taconic Mountains and a shallow inland sea. Figure by J. Houghton.

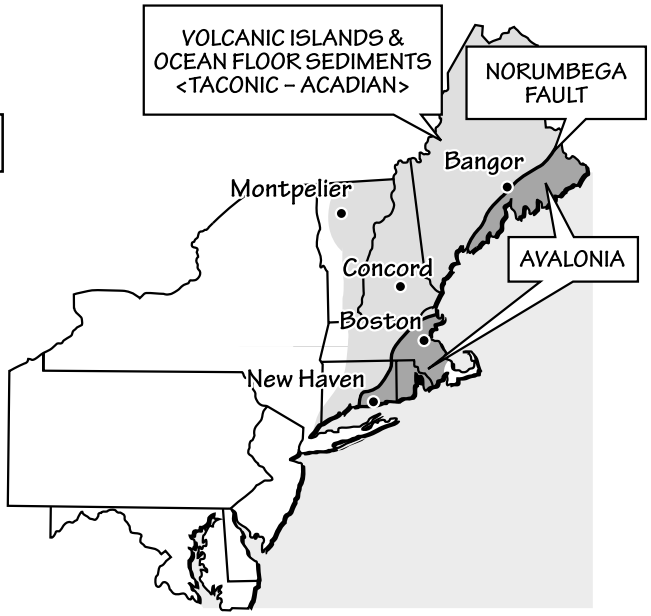
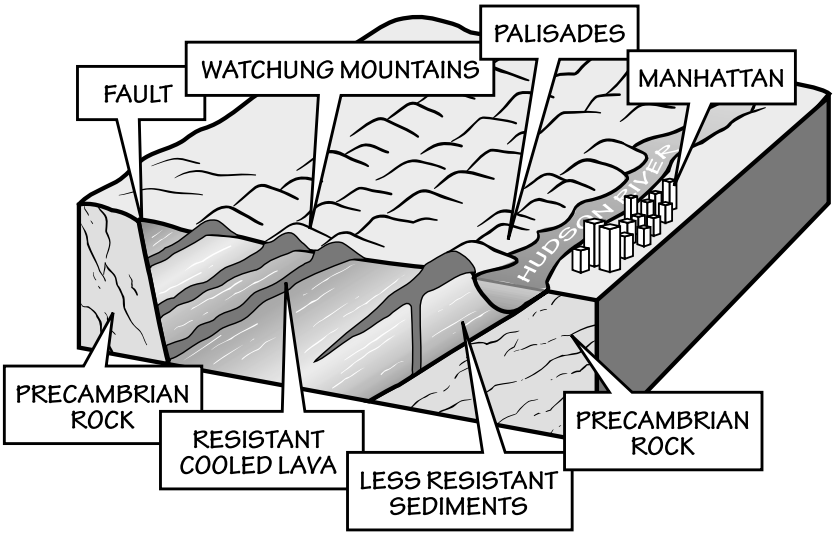


Figure 1.11: New England was not always part of the North American continent. Slices of land known as exotic terranes, collided with North America during the Taconic and Acadian orogenies. Figure by J. Houghton.

Figure: 1.22: The softer sediments of the Newark Rift basin were quickly worn away, forming valleys between the more resistant ridges of hardened lava flows. Figure by J. Houghton.



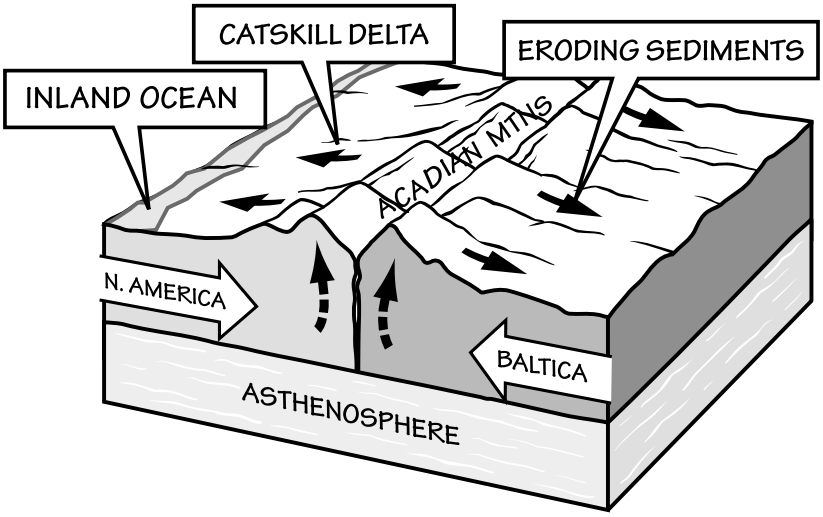


Figure 1.14: North America and Baltica collided finally in the mid-Devonian, crumpling the crust to form the Acadian Mountains. Sediments eroded from the highlands formed the Catskill delta. Figure by J. Houghton.

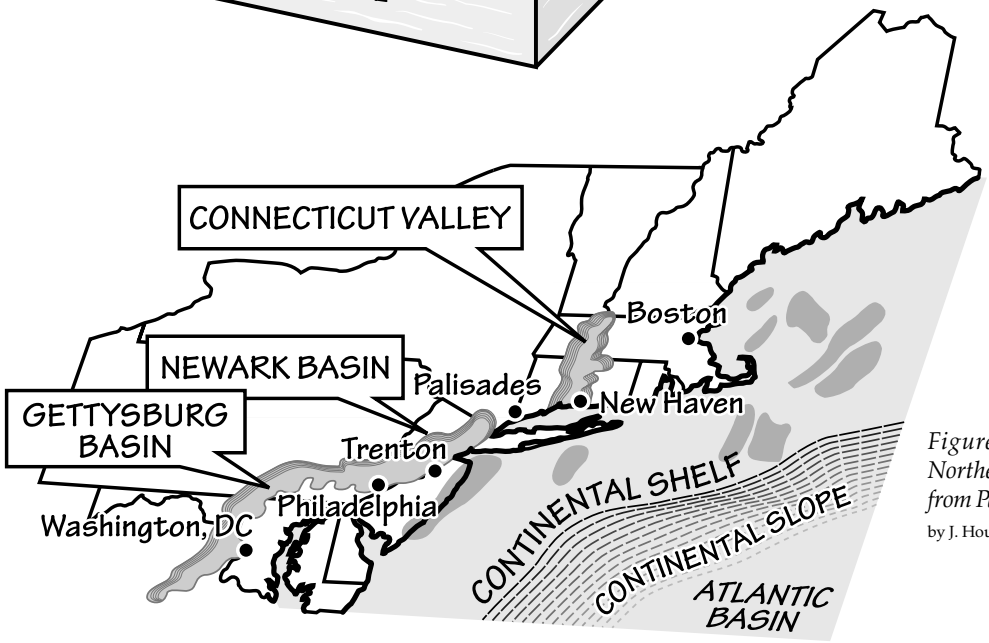


Figure 1.21: The Triassic Rift Basins of the Northeast formed as North America broke away from Pangea during the Triassic and Jurassic. Figure by J. Houghton.