Rocks of the Exotic Terrane

Region 4

see *Geologic History*, p. 10, for more on exotic **terranes.**

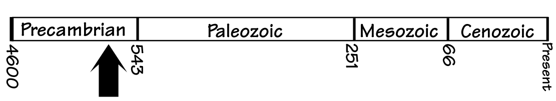
There are two basic divisions of the Exotic Terrane region of New England: the Iapetus Rocks, recording the sediments deposited in the ancient Iapetus Ocean, and the Avalonia Rocks, recording the distinctive rocks of the Avalonia microcontinent, which were caught in the middle of the collision between North America and Baltica. The Iapetus and Avalonia Rocks were not originally part of North America. Indeed, the rocks have distinctly different geologic characteristics than the bulk of North America. The Exotic Terrane region is dominated by igneous and metamorphic rocks. Both the Iapetus ***Terrane*** rocks and the Avalonia ***Terrane*** rocks are cut through with igneous intrusions that formed as magma cooled within the compressed crust, and volcanic rocks that formed from volcanoes as lava broke out of the crust. The remaining rocks of the Exotic Terrane region are metamorphosed sedimentary rocks that originated as sediments on the continental shelf of North America, the floor of the closing Iapetus Ocean basin, and shed off of the approaching volcanic islands. In some places, especially northern Maine, the sedimentary rocks were only weakly metamorphosed and still retain much of their original character.

The origins of metamorphic rocks

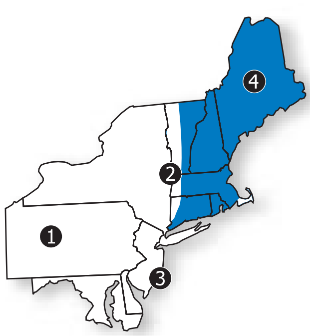
The type of rock produced during metamorphism depends on the composition of the original rock as well as the degree of higher temperatures and pressure. For example, when the sedimentary rock shale is weakly metamorphosed, it becomes slate. Though slate retains much of the original character of the shale, the minerals within the slate have become aligned as the original clays are changed to micas through the pressure of metamorphism. Increased metamorphism produces a phyllite. Finally, with the highest degree of metamorphism, schist is formed as the micas become large, easily observed crystals. Thus, the type of rock in a given area can indicate the degree of metamorphism.

original rock	*weakly metamorphosed*	→	*strongly metamorphosed*	
shale	*slate*	*phyllite*	*schist*	*gneiss*

Precambrian Rocks



Precambrian rock in the Exotic Terrane region is found in eastern Massachusetts, Rhode Island, and Connecticut, and northwestern Maine *(Figure 2.26)*. Eastern Massachusetts, Rhode Island and Connecticut were the Avalonia rocks that collided with North America during the Acadian mountain-building event. Though it is gneiss, the Avalonia gneiss is not the same as the Precambrian Grenville gneiss. The Avalonia rocks were far to the southeast of



North America during the Precambrian.

In northwestern Maine, the mountainous Chain Lakes Massif gneiss stands out as distinctly different from the surrounding rocks. Geologists continue to debate the origin of the Chain Lakes Massif, which is puzzling because of the intensely metamorphosed rocks. It is possible that this mass of gneiss was part of the Grenville belt of sediments.

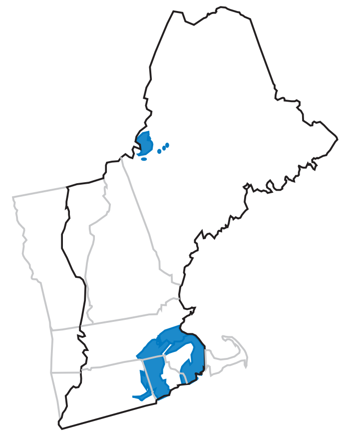


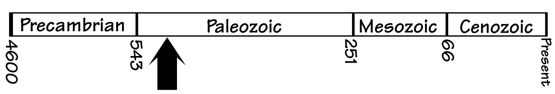
Figure 2.26: Precambrian rocks exposed in the Exotic Terrane.

The Boston Basin

Near the close of the Precambrian, Avalonia was breaking away from Africa, and on a collision course with North America. A rift within the Avalonia rocks created a basin, similar to the rift basins that formed in the Triassic when Pangea began to break apart. The basin filled with Precambrian-and Cambrian-age volcanic and sedimentary rocks. In the Devonian, millions of years later, Avalonia collided with North America to form eastern Massachusetts, Rhode Island, Connecticut and Maine. The rift basin created in the Avalonia rocks during the Precambrian, known as the Boston Basin, is still visible today as the foundation of eastern Massachusetts. The basin may actually extend several kilometers farther east under the Atlantic Ocean. Within the basin is the Braintree Slate, famous for its preservation of an unusually large species of trilobite, Paradoxites.

see Fossils, p.96, for more on the **Boston Basin.**

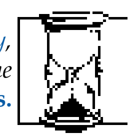
Cambrian-Ordovician Rocks

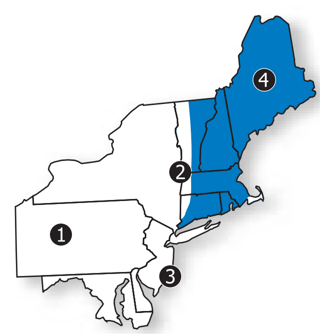


Close to the Chain Lakes Massif of Maine are several occurrences of ophiolites. Geologists believe that the ophiolites were scraped off a subducting oceanic plate and welded onto the Chain Lakes Massif sometime during the Ordovician.

During the late Ordovician, as the ***Taconic*** volcanic islands approached North America, slices of crust were stacked and squeezed like a collapsing telescope across the Exotic Terrane and Appalachian/Piedmont regions. In the Exotic Terrane region, we see the remains of the volcanic island chain that caused the stacking. Though it is difficult to distinguish individual volcanic islands and slices of crust, there is evidence of the volcanic islands and sediments associated with the volcanic activity of the Taconic mountain building period. Ordovician-age metamorphosed sedimentary ***rock*** that originated

see Geologic History, p. 7, for more on the **Taconic events.**





These rocks are all part of the Iapetus Terrane.

Figure 2.27: Cambrian and Ordovician rocks exposed in the Exotic Terrane.

from the Taconic volcanic islands are interwoven with volcanic rocks, including basalt and rhyolite, which form many of the ridges up and down the central New England area *(Figure 2.27)*.

Ordovician-age igneous ***intrusions***, generally granites, are located up and down the volcanic island suture area in and around the sedimentary and volcanic rocks *(Figure 2.28)*. These intrusions are the cooled remains of the magma chambers that formed the Taconic volcanic islands as well as magma formed as the crust compressed during the collision.

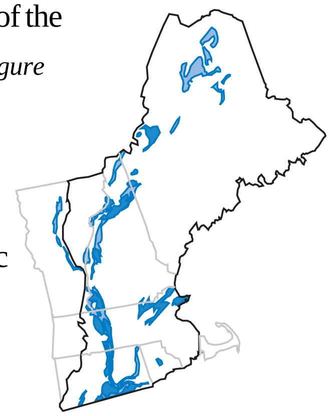


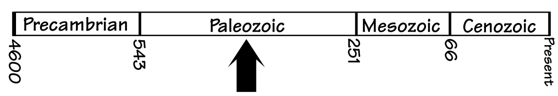
Figure 2.28: Ordovician-age igneous intrusions exposed in the Exotic Terrane.

Volcanic vs. intrusive rocks

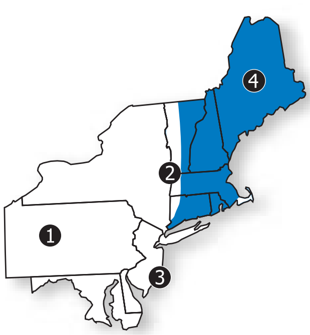
What is the difference between volcanic igneous rocks and intrusive igneous rocks? Hot, molten rock beneath the Earth's crust is called magma. As magma rises, pushing through overlying layers of rock, it will begin to cool. The cooling magma may crystallize and harden to become an intrusive *igneous rock. If, however, the magma rises to the surface without cooling enough to crystallize, the magma may be able to break through the crust at the surface forming a volcano or basalt flow. Geologists call volcanic magma 'lava'. Lava cools much more quickly than magma because it is at the surface and exposed to the atmosphere or ocean water where temperatures are much cooler. Lava thus has less time to crystallize than magma. Though the composition of a magma may be the same as a lava, the texture (mineral crystal size) of the rocks will be quite different. It is because of this difference in genesis that geologists are able to make the distinction between volcanic and intrusive igneous rocks when encountered at an outcrop at the Earth's surface.*

	high iron & magnesium	*low* iron & magnesium
Volcanic:	*basalt*	*rhyolite*
Intrusive:	*gabbro*	*granite*

Silurian-Devonian Rocks

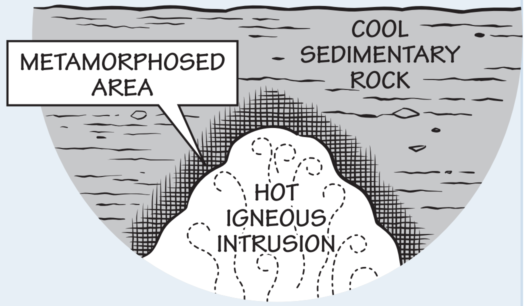


Central New England is predominantly composed of the remnants of the sediments deposited during the Silurian and Devonian in the Iapetus Ocean *(Figure 2.29)*. These rocks were originally sand, silt and mud deposited on the floor of the Iapetus Ocean following the Taconic mountain-building event. The sedimentary rocks were later squeezed tight, folded and metamorphosed during the Acadian and Alleghanian mountain-building events. The metamorphosed sedimentary rocks are now the schists and gneiss of central Vermont, New Hampshire and southern Maine, the region where the temperature and pressure were highest.



Though the degree of metamorphism varies throughout New England, in general the rocks in the west experienced lower degrees of metamorphism than rocks in the east. Likewise, rocks in Northern Maine experienced far less metamorphism because they were not directly affected by the later Alleghanian mountain-building event. Mild metamorphism in the less-stressed areas formed slates and phyllites. Central Maine is known as the Slate Belt because of the weak metamorphism that affected the Silurian and Devonian sedimentary rocks of the area, which were mainly shales. Intrusions of magma pushing up through the crust during the Acadian mountain-building event also played a role in metamorphosing rocks.

Regional and contact metamorphism



The intense heat of intruding magmas often metamorphoses the rocks into which they are intruded. This is known as contact metamorphism. Shale, rather than becoming slate or phyllite or schist (in which the minerals become aligned through pressure), is often simply baked by an intrusion to become hardened shale known as hornfels. Regional metamorphism, on the other hand, refers to metamorphism induced through increased pressure as the crust is squeezed together and folded when plates collide. The Taconic, Acadian and Alleghanian mountain-building events all produced regional stress on the rocks surrounding the collision zones. In this way, the sedimentary rocks of the Exotic Terrane region and parts of the Appalachian/Piedmont region have been regionally metamorphosed. Figure by J. Houghton.

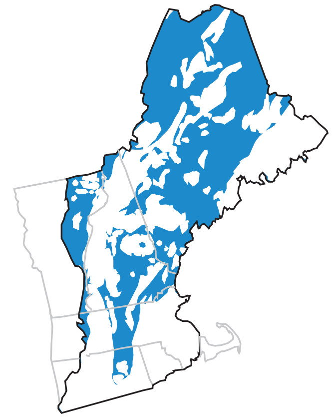


Figure 2.29: Silurian and Devonian rocks exposed in the Exotic Terrane.

The eastern section of the Exotic Terrane Region consists of the rocks of the Avalonia microcontinent. They include most of coastal Maine as well as Rhode Island, eastern Massachusetts and Connecticut *(Figure 2.30)*. In the late Devonian, when the microcontinent Avalonia was caught in the middle of the collision between North America and Baltica, numerous igneous intrusions occurred throughout Vermont, New Hampshire, Maine, Massachusetts and the Avalonia Rocks themselves *(Figure 2.31)*. These intrusions are known as the New Hampshire ***Plutonic*** Series.

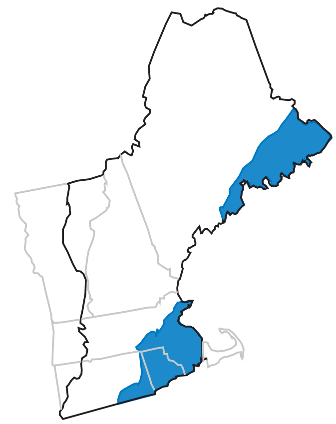


Figure 2.30: Avalonia rocks exposed in the Exotic Terrane.

Intrusions related to this series occur throughout New England and are responsible for several high peaks as the hard granite generally resists erosion better than sedimentary rocks. The famed ***Barre Granite*** of Vermont, commercially valuable for building and monument stone, is also part of the New Hampshire Plutonic Series.

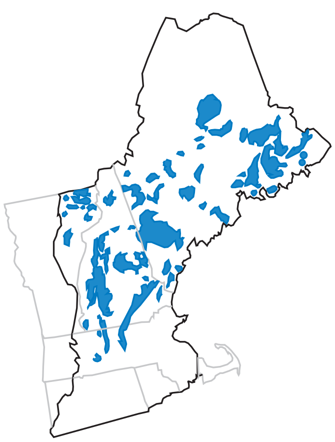
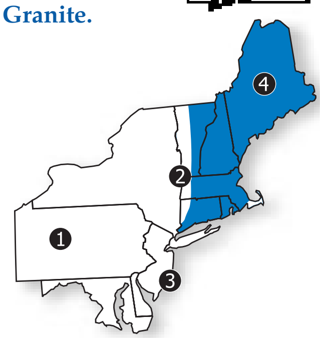


Figure 2.31: Devonian igneous intrusions in the Exotic Terrane.

Pluton *is another name for a large intrusion. The term is derived from Pluto (Hades), the ancient Greek god of the underworld.*

see Non-Mineral Resources, p.166, for more on **Barre Granite.**

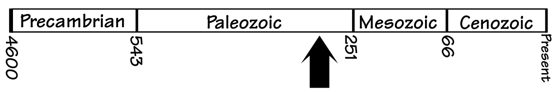


see *Minerals*, *p. 144, for more on* **pegmatites.**

Pegmatites

Pegmatite dikes are frequently found near the Taconic and Acadian igneous intrusions. Hot, molten magma rising through the crust from deep magma chambers (which eventually formed igneous intrusions) put significant pressure on the overlying rocks. The pressure caused the crust to crack in many places, creating additional pathways for magma to intrude and crystallize in dikes. The heat from the rising magma also partially melted some of the overlying crust. Partial melting and the escape of volatiles from slow cooling of continental crust created a unique rock type rich in rare elements: a pegmatite. Their very large crystals, which range anywhere from 2 cm to as much as 5 meters across, easily distinguish pegmatites!

Pennsylvanian Rocks



The youngest rocks of the Paleozoic era in the Exotic Terrane Region, approximately 315 million years old, are found in basin deposits of Massachusetts and Rhode Island. The basins formed as Avalonia collided with North America and the compression downwarped the crust slightly. The basins preserve Pennsylvanian-age sedimentary rocks including sandstone, conglomerate, and siltstone, all of which have experienced varying degrees of metamorphism. They also have layers of coal, which were mined in the past for steam engines and heating homes. The Narragansett Basin, the largest of the Pennsylvanian basins, has layers of anthracite coal up to 12 meters thick and the greatest number of plant fossil species than any other coal basin worldwide. Several smaller basins are found close by, including the Norfolk, Woonsocket, and Northern Scituate Basins *(Figure 2.32)*.

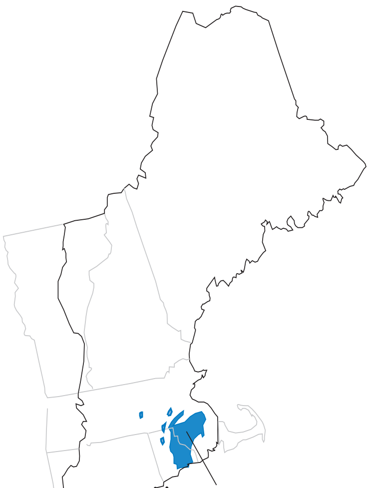
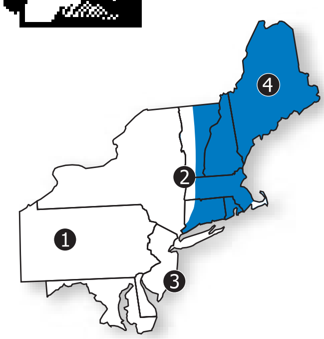


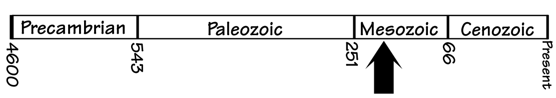
Figure 2.32: Pennsylvanian-age basins in the Exotic Terrane.

see *Geologic History*, *p. 16, for more on* **rift basins.**

see *Rocks*, *p.44, for more on* **rift basins**.



Triassic-Jurassic Rocks



Similar to the Triassic ***rift basin*** of the Appalachian/Piedmont, there is a rift basin that cuts through the Exotic Terrane Region as well, known as the Connecticut Valley Rift Basin. This basin, which cuts through the Iapetus Terrane of the Exotic Terrane region, may have once been continuous with the Newark Rift Basin. The process of formation of the two basins was the same, occurring as the continents of Pangea separated and North America pulled apart from Africa. Likewise, the rocks of the basins are similar, consisting of ridges of basalt and reddish-brown sedimentary rocks *(Figure 2.33)*.

In New Hampshire and southern Maine, late Triassic through Cretaceous igneous intrusions are exposed in a curious arc that extends up into Canada *(Figure 2.34)*. Known as the White Mountain Series, these intrusions are not related to the Rift Basin lava flows, which produced quickly cooled basalts. Rather, these intrusions formed deep within the crust as plumes of magma rose from the mantle. The magma originated at what some geologists think may have been a ***hot spot***. As the plate moved over the hot spot, magma pushed upwards through the crust to form the string of plutons visible at the surface today through erosion. The intrusions form the core of certain mountains in central New Hampshire.

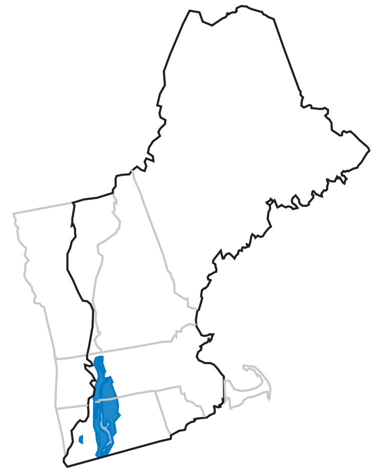


Figure 2.33: Triassic rift basin in the Exotic Terrane.

Hot Spots

Hot spots form from plumes of magma rising off the mantle. Though the hot spot remains fixed, the plates of the lithosphere are moving above it. Magma from the hot spot pushes its way up through the crust, creating an igneous intrusion and sometimes a volcano. As the plate continues to move over the hot spot, magma pushes up next to the previous volcano to form another intrusion or volcano. This gradually produces a chain of volcanic islands such as the Hawaiian Islands or a series of plutons as in New Hampshire (Figure A). Erosion of the volcanoes may eventually wear down the crust to reveal the igneous intrusions that were the magma chamber of the volcano (Figure B). This is one of the proposed explanations for the exposures of the White Mountain Series.

Figures by J. Houghton.

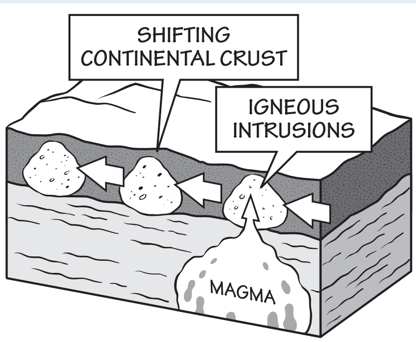


Figure A

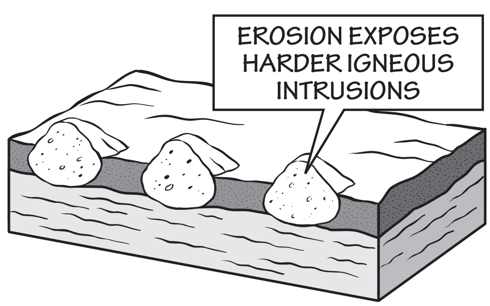


Figure B

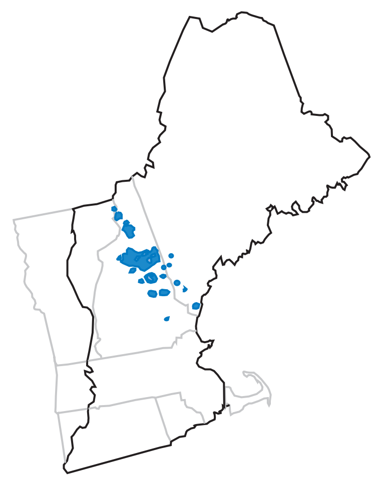


Figure 2.34: The White Mountain Series intrusions in New Hampshire and Maine.