Metamorphic Rocks and the Rock Cycle

Designed to meet South Carolina Department of Education 2005 Science Academic Standards

Department of Natural Resources
South Carolina Geological Survey

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What are Rocks?

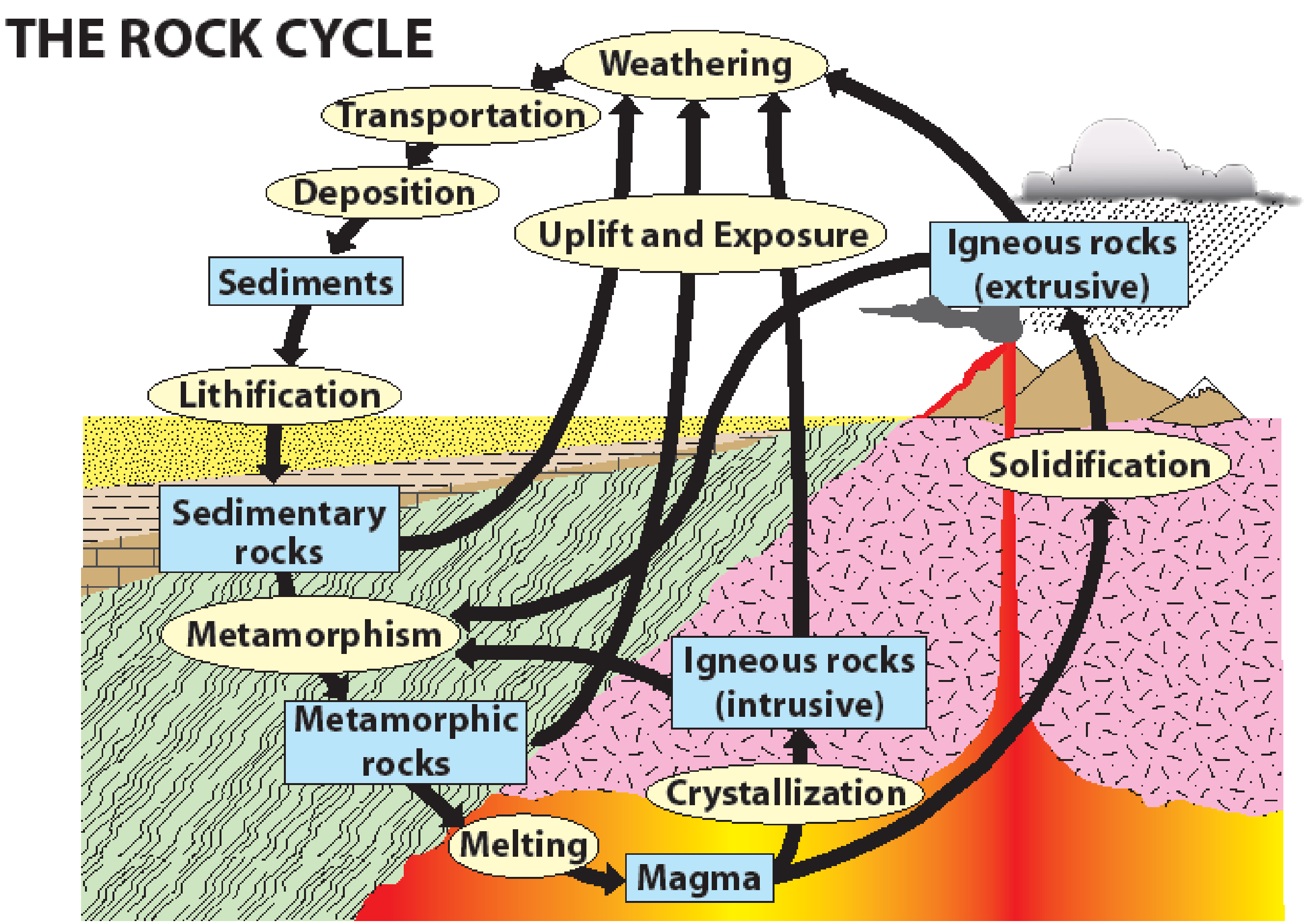
- Most rocks are an aggregate of one or more minerals, and a few rocks are composed of non-mineral matter.

- There are three major rock types:
  - 1. Igneous
  - 2. Metamorphic
  - 3. Sedimentary

Major Rock Types

- **Igneous** rocks are formed by the cooling of molten magma or lava near, at, or below the Earth's surface.
- **Sedimentary** rocks are formed by the lithification of inorganic and organic sediments deposited at or near the Earth's surface.
- **Metamorphic** rocks are formed when preexisting rocks are transformed into new rocks by heat and pressure below the Earth's surface.

The Rock Cycle



Igneous Rocks -
Rocks that form from the cooling of motlen rock (magma), Example: granite and basalt

Sedimentary Rocks -
Rocks that are fromed from pieces of other rocks, Example: sandstone, or that are deposited from the ocean by chemical processes, Example: limestone

Metamorphic Rocks -
Rocks that are changed by heat and pressure without melting, Example: gneiss

Metamorphic Rocks

- Metamorphic rocks are formed when existing parent rocks are transformed (metamorphosed) by heat and pressure deep below the surface of the earth or along the boundary of tectonic plates.
- The three primary causes of metamorphism include one or more of the following conditions: heat, pressure, and/or chemically active fluids.
- During metamorphism, rocks may fold, fracture, or even partially melt to a viscous state and flow before reforming into a new rock.
- Metamorphic rocks change in appearance, mineralogy, and sometimes even chemical composition from their parent rock source.

Metamorphism

- Metamorphism can occur along a range of heat and pressure intensities from low- to high-grade metamorphism.
- Low-grade metamorphism involves lower temperature and compressional forces that result in less overall change to the parent rock. In many cases, after low-grade metamorphic changes the parent rock may still be easily distinguishable.
- High-grade metamorphism results in a total transformation of the parent rock into a new rock whereby its original parent-rock source is difficult to identify.

Metamorphic Conditions

- **1. Contact or Thermal Metamorphism:** occurs when parent rock is intruded by magma (usually an igneous intrusion). Metamorphic changes under these conditions are primarily the result of temperature changes associated with the intruding magma. Additionally, when hot ion-rich water circulates through fractures in a rock, it can also cause chemical changes to the parent rock. These heat-driven, chemical reactions occur with igneous activity and the presence of water.

- **2. Dynamic Metamorphism:** occurs when rocks are subjected to extreme pressure very rapidly. Two situations are noted, (a.) fault zones and (b.) impact craters. (a.) In the upper crust, faults are planar zones of crushed rock. The heat generated by friction during faulting can melt and metamorphose portions of the rock. (b.) Impact craters formed by extra-terrestrial objects (meteorites) colliding with the earth are commonly identified by exotic high-pressure minerals formed during the meteorite crash. Stishovite and coesite, both are high-pressure forms of quartz resulting from meteor impacts.

- **3. Regional Metamorphism:** occurs when rocks are subjected to both heat and pressure on a regional scale. It is caused by burial deep in the crust and is associated with large scale deformation and mountain building. It is the most widespread form of metamorphism.

Causes of Metamorphism: Heat

- Heat provides energy for chemical reactions to proceed resulting in new minerals to form from original minerals in the source rock.
- Heat provides the energy that enables individual ions in the rock to mobilize and migrate between other ions recrystallizing and forming into new minerals.
- Heat involved in metamorphism comes from two main sources:
  - 1. Heat transferred during contact metamorphism from magma or igneous intrusions.
  - 2. Progressive temperature increase associated with geothermal gradient as rocks are transported to greater depths below the Earth's surface.

Causes of Metamorphism: Pressure

- Pressure equals force per unit area: **(Pressure = F/A).**
- Pressure increases with depth as the weight and thickness of the overlying rocks increases.
- Pressure during metamorphism is manifested by two different forces: **body force (confining pressure)** and **surface force (differential stress).**
  - **Body force** —forces are applied equally in all directions (gravity and weight), as a result individual grains are compressed closer and closer together. Extreme confining pressures that occur at great depths may even cause ions in the minerals to recrystallize and form new minerals.
  - **Surface force** —operates across a surface and occurs when rocks are compressed or extended along a single plane (push-pull forces). As a result, the rocks are shortened or extended in the direction the pressure is applied. Near the Earth's surface, the cooler temperatures make rocks brittle and more susceptible to fracturing than folding. Deep below the Earth's surface, higher temperature conditions, make the rocks ductile and they flatten and elongate as oppose to breaking along a fracture, the resulting rocks then exhibit intricate folding patterns.

Causes of Metamorphism: Chemically Active Fluids

- Chemically active fluids that are present between mineral grains during metamorphism act to facilitate ion movement and the re-crystallization of existing and new minerals.
- Higher temperatures increase the reactive capability of ion-rich fluids. When these fluids come in contact with mineral grains, the grains readily dissolve because of differential chemical potentials, and ions migrate to areas of lower potential eventually recrystallizing.
- Chemically active fluids have the ability to move between different rock layers and transport ions from one rock to another before they recrystallize.

The Role of Parent Rocks in Metamorphism

- Parent rocks provide the minerals and ion sources that are transformed into new minerals and rocks.
- In most cases the new metamorphic rock has the same chemical composition as the parent rock that they formed from.

Examples of parent rocks and their metamorphic products:

Sandstone (Sedimentary)	→	Quartzite (Metamorphic)
Granite (Igneous)	→	Gneiss (Metamorphic)
Limestone (Sedimentary)	→	Marble (Metamorphic)

Classifying Metamorphic Rocks by Different Types of Textures

- Texture is used to describe the size, shape, and arrangement of grains within a rock.
- The different textures of mineral grains within metamorphic rocks are used to infer information about the conditions which formed them.
- Many of the mineral grains in metamorphic rocks display preferential orientations where the alignment of the minerals is parallel or subparallel to one another.
- Rocks that exhibit parallel or sub-parallel orientation are categorized as **foliated,** while those that do not exhibit orientations are categorized as **nonfoliated**.

Foliated Rock Textures

- Foliation is broadly defined as any planar arrangement of mineral grains or structural features in a rock. Foliation can occur in both igneous and metamorphic rocks (this section will only focus on foliation in metamorphic rocks).
- Foliation in metamorphic rocks occurs when the minerals in the rock align and recrystallize along planes of parallel orientation as a result of heat and compressional forces.
- Minerals recrystallize into platy, elongated, or flattened grains, according to their original crystal habits. They segregate into thin layers that appear as thinly banded slivers of minerals interlayered together.
- Different textures used to describe foliation include: slaty cleavage, schistosity, and gneissic texture.

Foliated Textures: Slaty Cleavage

- Slaty cleavage is used to describe rocks that split into thin, planar slabs when hit with a hammer.
- Rocks with slaty cleavage often contain alternating bands of different minerals where one type of mineral (usually mica formed from recrystallized clay) forms highly aligned platy grains of foliated minerals. The rock will split into thin sections along these bands.
- Slaty cleavage commonly occurs under low-grade metamorphic conditions.

Photo: SCGS

The weathered exterior of this rock and broken fragments show an example of slaty cleavage from the Carolina Slate belt in South Carolina's Piedmont.

Foliated Textures: Schistosity

- Schistosity describes rocks with foliated mineral grains that are large enough to see without magnification.
- Schistocity occurs under medium-grade metamorphic conditions, and the crystals have a greater opportunity to grow during recrystallization.
- Unlike slaty cleavage, which tends to preferentially affect some minerals more than others, schistosity tends to affect all the different mineral components.
- Rocks with schistosity are generally referred to as schist.

Photo: SCGS

The foliated mineral grains of this schist provide a good example of schistosity. Notice how the rock weathers in flaky sections. Rocks with schistosity can easily crumble or broken into smaller pieces with bare hands.

Foliated Textures: Gneissic

- **Gneissic textures occur when the silicate minerals in the rock separate and recrystallize into alternating bands of light (quartz and feldspar) and dark (biotite, amphibole, or hornblende) grains of silicate minerals.**
- **The mineral alignment in gneissic rocks is less platy and more granular or elongated than slaty cleavage or schistosity.**

Photo: SCGS

The alternating quartz and biotite bands in this rock characterize gneissic texture. This photo also illustrates an example of folding that results from the intense heat and pressure of metamorphic conditions.

Foliated Metamorphic Rocks

- Slate
- Phyllite
- Schist
- Gneiss

Photo: SCGS

South Carolina's Piedmont is composed primarily of foliated metamorphic rocks. In many locations different metamorphic rock types occur in close proximity. Many of the metamorphic rocks in this region are folded and faulted, making for very exciting geology.

Photo: SCGS

Foliated Rocks: Slate

- Slate is a fine-grained rock composed of mica flakes and quartz grains that enable the rock to break into thin slabs of rock, along planes of slaty cleavage.
- Slate forms in low-grade metamorphic environments from a parent rock of either shale, mudstone, or siltstone.
- Slate is commonly thought of as black, but it can also be red when it contains iron oxide minerals, or green when it contains chlorite. Weathered slate may even appear light brown in the example below.

Photo: SCGS

This example of slate is part of the Carolina Slate belt which traverses through the Piedmont of South Carolina. This image also provides a good example of the slaty cleavage that has also been folded.

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Foliated Rocks: Schist

- Schist exhibits schistosity, which is formed by the alignment of platy medium- to coarse-grained minerals formed under moderate- to high-grade metamorphic conditions.
- Schists are primarily composed of silicate minerals such as mica (muscovite and biotite), quartz, and feldspar .
- Shale, siltstone, and some sandstones can provide the parent rock for schist.
- Schist may contain accessory minerals such as garnet, tourmaline, and pyrite.

Photo: SCGS

This schist is from the Piedmont region in South Carolina. Notice how the different layers are weathering at slightly different rates, the layers of darker, mica rich schist are weathering more quickly than the tan, feldspar and quartz-rich layers.

Foliated Rocks: Phyllite

- Phyllite is a low- to moderate-grade metamorphic rock that contains aligned platy mica minerals and has slaty cleavage.
- The individual crystals are fine grained and generally consist of muscovite, white mica, and chlorite (green rocks).
- Phyllite has a satiny appearance and waxy texture.
- Phyllite is a metamorphic form of shale, mudstone, and siltstone.

These samples of phyllite all came from the same quarry in South Carolina. The slaty cleavage of the phyllite is what makes it a foliated rock. As phyllite weathers it parts along the cleavage planes.

Foliated Rocks: Gneiss

- Gneiss is a medium- to coarse-grained rock formed under high grade-metamorphic conditions.
- Gneiss is primarily composed of quartz, potassium feldspar, and plagioclase feldspar with lesser amounts of biotite, muscovite, and amphibole.
- Granites and sometimes rhyolite provide the parent rock for gneiss.

Photo: SCGS

Gneisses are generally light colored because they contain a large amount of quartz and feldspar. The alternating light and dark bands in this gneiss illustrate the segregation of different minerals during crystallization. This example also shows folds in the rock. This gneiss most likely formed from a metamorphosed igneous intrusion. South Carolina's Piedmont and Blue Ridge contain gneissic bedrock.

Nonfoliated Rock Textures

- Nonfoliated rock textures form under two basic conditions, metamorphism of monomineralic rocks and metamorphism in the absence of directed stress.
- Nonfoliated textures form during recrystallization of monomineralic rocks where the distribution of mineral growth is approximately equal, i.e. minerals grow at same rate and to same size.
- In the absence of directed stress, minerals with high aspect ratio are randomly oriented and show no preferential alignment.
- Marble is an example of a metamorphic rock with a nonfoliated texture.

Nonfoliated Rocks: Marble

- Marble is a nonfoliated, coarse-grained metamorphic rock formed from the parent rock limestone or dolostone.
- Because it is formed from limestone or dolostone it is predominantly composed of the mineral calcite, which metamorphoses into various carbonate and other minerals. As calcite recrystallizes, all the grains are active at the same time and they grow to the same size and shape, which leads to its nonfoliated texture.
- Different color schemes in marble are the result of impurities or the presence of weathered materials deposited in or near the limestone.

Marble is used as a building material and is popular for sculpture. The word 'marble' derives from a Greek word that translates as "shining stone" because it can be polished. Limestone that metamorphoses into marble may contain a lot of fossils; however, the heat and pressure of metamorphism destroys preexisting features primarily through recrystallization.

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Quartzite

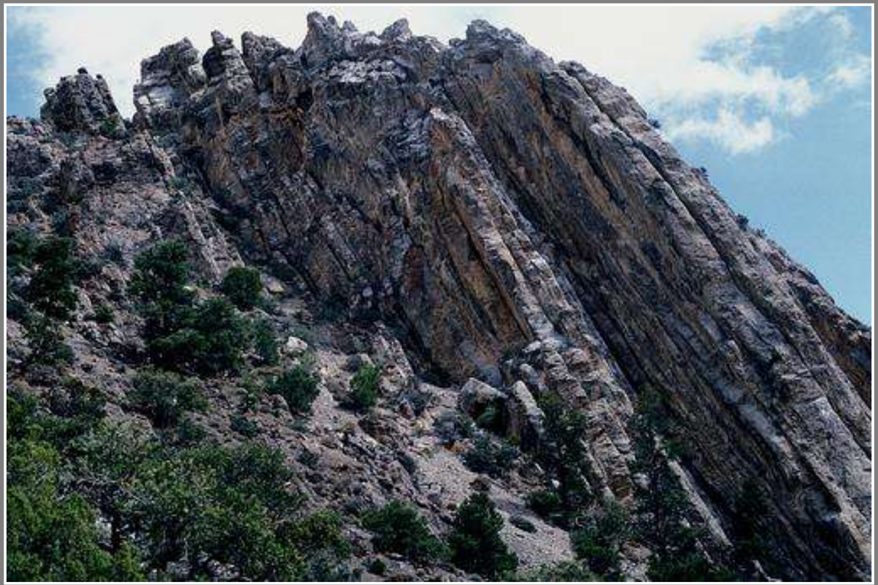
- Quartzite is a metamorphic rock formed under moderate to high-grade metamorphism that exhibits both foliated and nonfoliated structure.
- The parent rock to quartzite is sandstone.
- Quartzite forms from the recrystallization of quartz grains in the sandstone and often the resulting metamorphic rock will preserve vestiges of the original bedding patterns .
- Quartz is predominantly white in color, but can also contain pinkish or grayish shades depending on the presence of iron oxides.

This example of quartzite show a couple of interesting features. First, notice how the different bedding planes have been preserved during the metamorphism. Secondly, there is a fault running though the quartzite that occurred after the formation of the rock. This particular example is of a foliated quartzite (due primarily to the preservation of the bedding planes) however some quartzite rocks are classified as nonfoliated.

Metamorphic Rocks in the Landscape

Grandfather Mountain, in North Carolina, is part of the Blue Ridge Province of the Appalachian Mountains in the Eastern United States. The rocks in this region began undergoing metamorphism nearly a billion years ago. Million of years later rocks from Africa collided with North America, before rifting apart to eventually form the Atlantic Ocean. Today, weathering and erosion of the surrounding landscape exposes the metamorphosed rocks that make up Grandfather Mountain.

http://www.grandfather.com/



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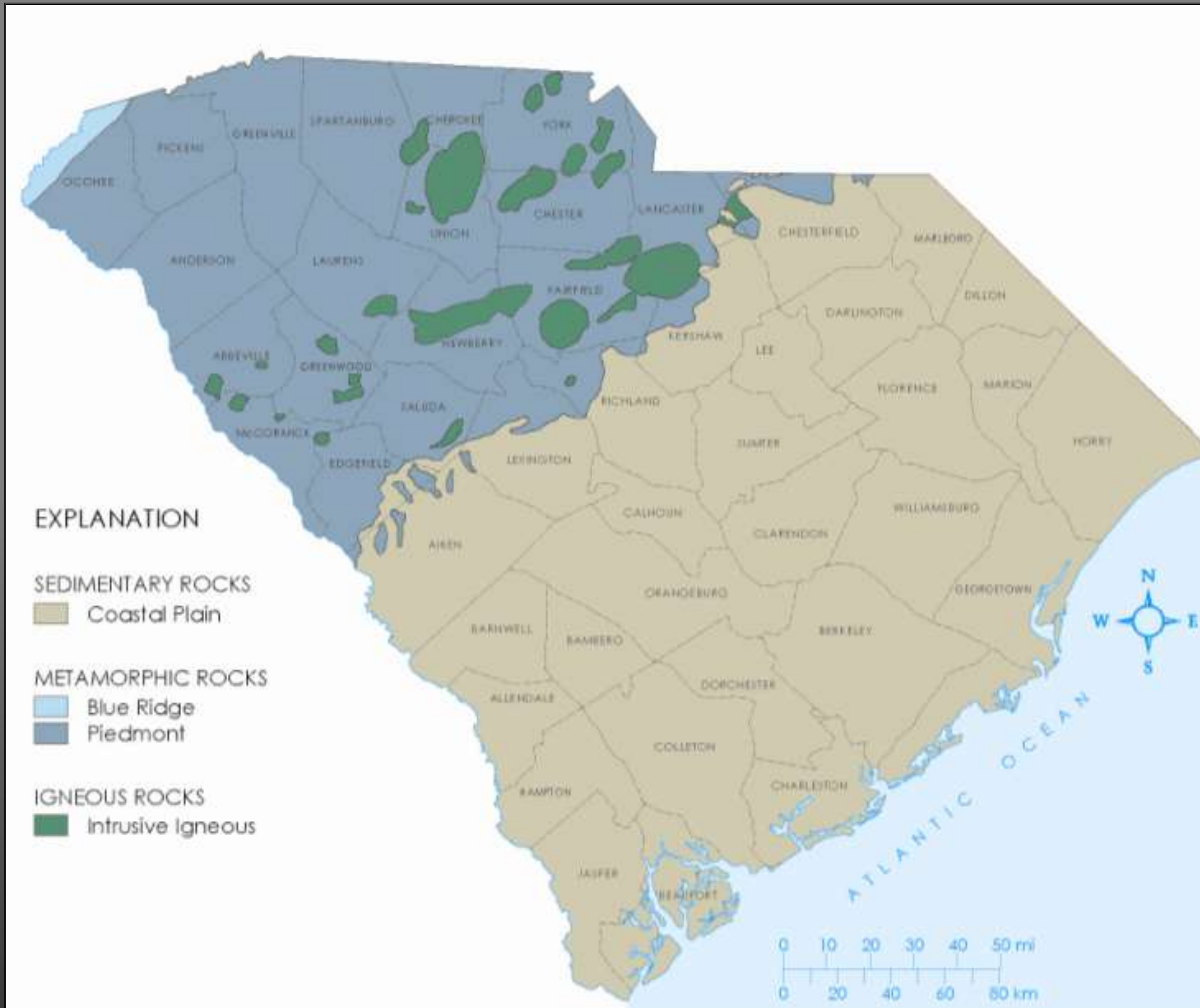
The Snake Range Mountain in Great Basin National Park, Nevada, are metamorphosed sandstone rocks. These vertically oriented bedding planes were once horizontal layers of sediment deposits at the bottom of a sea. Nearly 200 million years ago thrusting, tilting, faulting, and uplifting metamorphosed the sandstone into quartzite. Another major metamorphic event began about 30 million years ago when the earth's crust began stretching in an east to west direction. As a result the rocks faulted into large blocks that tilted, producing the rock orientation we see today.

Metamorphic Rocks in South Carolina



South Carolina Science Academic Standards: Grade 3

1) Earth's Materials and Changes:

Standard 3-3:

The student will demonstrate an understanding of Earth's composition and the changes that occur to the features of Earth's surface. (Earth Science).

Indicators:

3-3.1: Classify rocks (including sedimentary, igneous, and metamorphic). (slides: 3-26)

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Resources and References

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