Sedimentary 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?

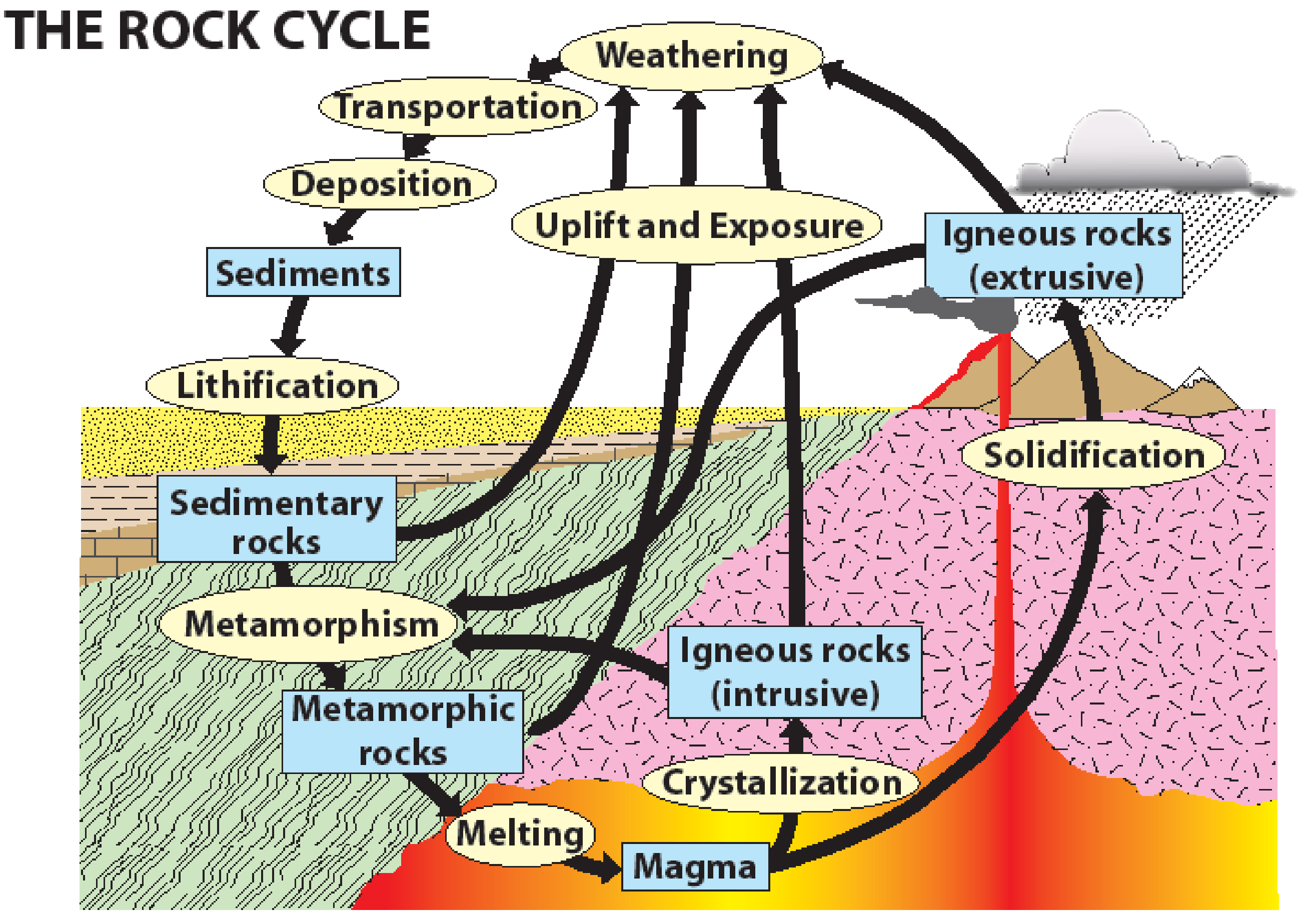
- Most rocks are an aggregate of one or more minerals and a few rocks are composed of non-mineral matter.

- 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 elevated 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

The Rock Cycle graphic is available from the SCGS website: http://www.dnr.sc.gov/geology/images/Rockcycle-pg.pdf

Sedimentary Rocks

- Sedimentary rocks are formed by the lithification of inorganic and/or organic sediments, or as chemical precipitates.
- There are two types of sedimentary rocks: Clastic and Chemical
  - Clastic sedimentary rocks form when existing parent rock material is weathered, fragmented, transported, and deposited in layers that compact, cement, and lithify to form sedimentary rocks.
  - Chemical sedimentary rocks are formed by a variety of processes and are divided into sub-categories including inorganic, and biochemical or organic chemical sedimentary rocks.
    - Inorganic chemical rocks form from chemicals that are dissolved in a solution, transported, and chemically precipitated out of solution.
    - Biochemical or Organic sedimentary rocks form when plant or animal material is deposited and lithified. Those classified as biochemical chemical generally involve some form of fossilization or the accumulation of fossilized organism or organism remains, such as shell fragments. Organic rocks that are classified as clastic, involve the deposition of plant material and formation of peat and coal deposits.
- The physical, chemical, or biological changes that occur during the lithification of sedimentary rocks are described by process collectively referred to as diagenesis.

Diagenesis

- Diagenesis collectively refers to the physical, chemical, and biological changes which may occur during the formation of sedimentary rocks. Recrystallization, compaction, cementation, and lithification, are all examples of diagenetic changes.

  - Recrystallization occurs when unstable minerals recrystallize to form more stable minerals. Recrystallization most often occurs during the formation of chemical sedimentary limestone rocks that previously contained aragonite a chemically unstable form of calcium carbonate ($CaCO_3$).

  - Compaction occurs when sediments are progressively deposited on top of one another, and over time the weight of the accumulated sediments increases and compresses the buried sediments. Continued compression of buried sediments reduces pore-spaces and removes excess water, as a result the closely packed individual grains begin to slowly compact into a solid rock.

  - Cementation involves a chemical change whereby individual grains are cemented together as minerals are precipitated out of saturated solution that is percolating as a matrix between individual sediments. The accumulation of the precipitated minerals causes the grains to cement together. Cementation can occur in combination with the presence of other minerals, rock fragments, or organic constituents such as fossilized organisms.

  - Lithification occurs when unconsolidated sediments are cohesively bound to form a solid sedimentary rock. Compaction and/or cementation are generally the precursor to the lithification process.

Naming and Classifying Sedimentary Rocks

- Geologists name and classify sedimentary rocks based on their mineral composition and texture

- Mineral composition refers to the specific minerals in the rock. For example sandstone will contain predominantly quartz, while limestone will contain mainly calcite (calcium carbonate).

- Texture includes the grain size and shape, sorting, and rounding of the sediments that form the rock.

Texture: Grain Size

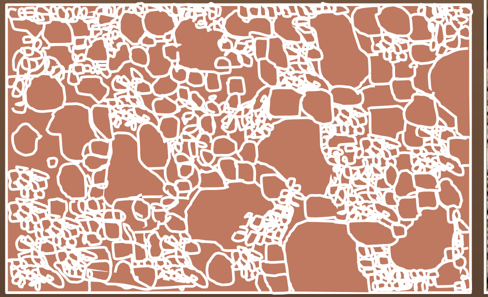
- Grain size is used to describe the size of the individual mineral grains, rock fragments, or organic material that are cemented together to form a clastic or chemical sedimentary rock

Grain Size Categories	Grain Size Divisions	
very coarse-grained	≥	16 mm
coarse grained	≥	2 mm < 16 mm
medium grained	≥	0.25 mm < 2 mm
fine grained	≥	0.032 mm < 0.25 mm
very fine-grained	≥	0.0004 mm < 0.032 mm
cryptocrystalline	<	0.0004 mm (4 μm)

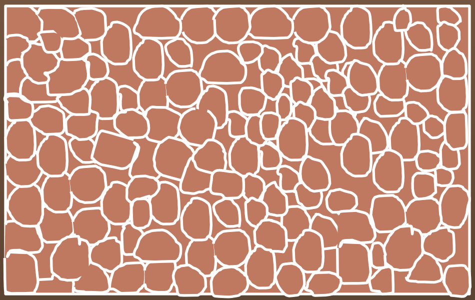
Texture: Sorting

- **Sorting** is used to describe the grain size distribution or range of grain sizes in a rock.
  - **Poorly sorted** rocks contain a variety of different sized grains. Poorly sorted rocks contain a wide range of grain sizes including fine, medium, and coarse.
  - **Well sorted** rocks contain almost all grains of the same size.
  - **Moderately sorted** rocks contain particles of relatively similar grain sizes. Moderately sorted rocks may contain fine and medium grains, or medium and coarse grains.

Poorly Sorted



Well Sorted



Texture: Rounding

- **Rounding** is used to describe the relative shape of the grains. Classifications are describe as deviations from rounded or spheroidal grain shapes.
  - **Well rounded** grains are smooth with rounded edges..
  - **Moderately rounded** grains are in-between the sharp, angular edges of a poorly rounded grain and the smooth, roundness of a well-rounded grain.
  - **Poorly rounded** grains may be sharp or angular.

Well-rounded, spheroidal grains

Poorly–rounded, angular grains

Texture and Weathering

- The texture of a sedimentary rock can provide a lot of information about the types of environments that the sediments were weathered in, transported by, and deposited in prior to their lithification into sedimentary rocks.

- Most sedimentary rocks consist of grains that weathered from a parent rock and were transported by water, wind, or ice before being deposited.

  - Grain size is a good indicator of the energy or force required to move a grain of a given size. Large sediments such as gravel, cobbles, and boulders require more energy to move than smaller sand, silt, and clay sized sediments. Grain size is also an indicator of the distance or length of time the sediments may have traveled. Smaller grain sizes generally indicate greater transport distances and duration than larger grains.

  - Sorting will generally improve with the constant or persistent moving of particles, and thus can indicate if particles were transported over a long distance or for a long time period. Sorting can also indicate selective transport of a particular grain size.

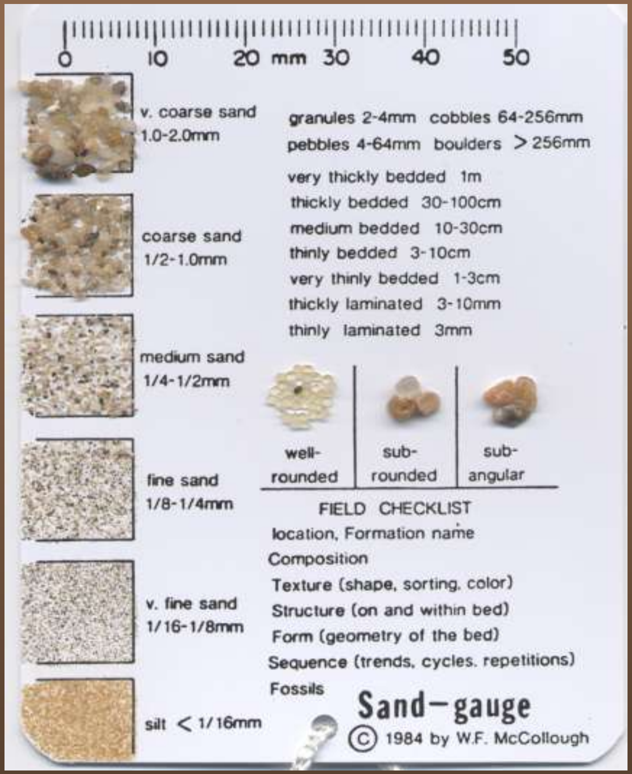
  - Rounding is a good indicator for the amount of abrasion experienced by sediments. In general, sediments that have been transported longer distances will be more rounded than those which have traveled shorter distances.

- An example based on these principles, is that sediments deposited by rapid mass wasting events, such as landlsides are expected to be coarse grained, poorly sorted, and poorly rounded; and sediments deposited by slower, more gradual processes, such as dune formation, are expected to be fine grained, well sorted, and well rounded.

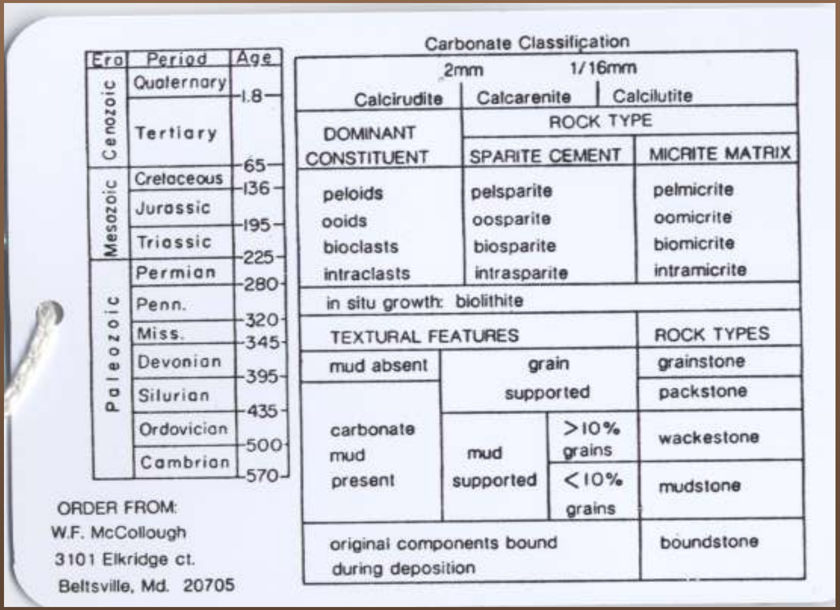
Field Identification

- Geologists often use reference guides to identify and measure textural characteristics of the sediments. This is an example of a card used to aid in the identification textural characteristics. A card like this may be carried in a geologist's pocket or around their neck.

Front of card



Back of card



Classifying Sedimentary Rocks

CLASTIC SEDIMENTARY ROCKS			
TEXTURE	SEDIMENT PARTICLE SIZE	OTHER CHARACTERISTICS	SEDIMENTARY ROCK
CLASTIC	Gravel (> 2 mm)	Rounded rock fragments, Poorly-sorted	Conglomerate
		Angular rock fragments, Poorly-sorted	Breccia
	Sand (0.0625 mm – 2 mm)	Quartz (>50%), Moderate – well sorted	Quartz sandstone
		Quartz with Feldspar, Moderate –Well sorted	Arkose
		Quartz, Feldspar, Clays, Rocky Fragments, Well-sorted	Graywacke
	Mud (< 0.0625 mm)	Fine, thin layers, or cohesive clumps, Well-sorted	Shale, Siltstone, and Mudstone

CHEMICAL SEDIMENTARY ROCKS (INORGANIC AND BIOCHEMICAL)			
GROUP	TEXTURE	CHEMICAL COMPOSITION	SEDIMENTARY ROCK
INORGANIC	clastic or non-clastic	Calcite, $CaCO_3$	Limestone
	non-clastic	Dolomite, $CaMg(CO_3)_2$	Dolostone
	non-clastic	Microcrystalline quartz, SiO_2	Chert
	non-clastic	Halite, NaCl	Rock salt
	non-clastic	Gypsum, $CaSO_4 \cdot 2H_20$	Rock Gypsum
BIOCHEMICAL	clastic or non-clastic	Calcite $CaCO_3$	Limestone
	non-clastic	Microcrystalline quartz, SiO_2	Chert
	non-clastic	Altered plant remains	Coal

Sedimentary Rocks

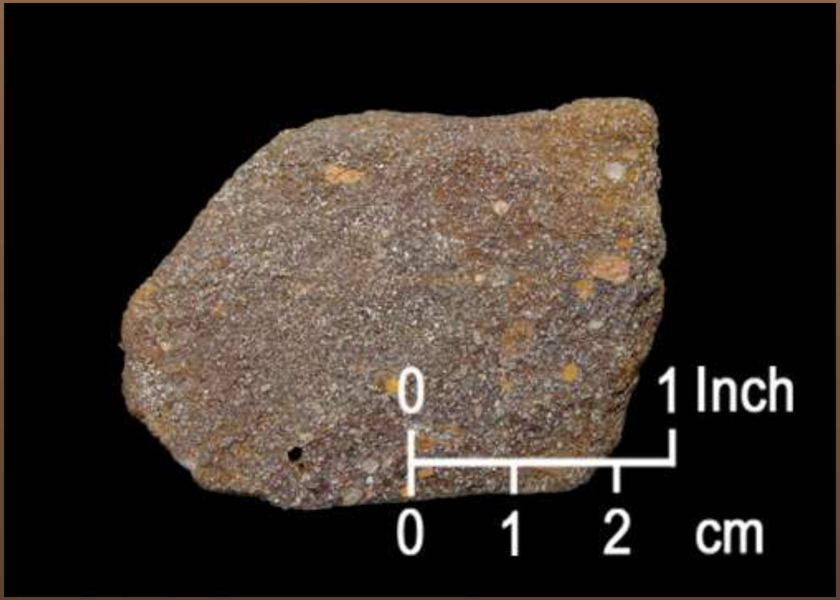
- Clastic
  - Sandstone
  - Siltstone
  - Shale
  - Mudstone
  - Conglomerate
  - Breccia
  - Kaolin
- Chemical Inorganic Sedimentary Rocks
  - Dolostone
  - Evaporites
- Chemical / Biochemical Sedimentary Rocks
  - Limestone
    - Coral Reefs
    - Coquina and Chalk
  - Inorganic Limestone
    - Travertine
    - Oolitic
  - Chert
    - Flint, Jasper, Agate

Sedimentary Rocks in North America

Source: USGS http://pubs.usgs.gov/imap

Sandstone

- Sandstone rocks are composed almost entirely of sand-sized quartz grains (0.063 – 2 mm) cemented together through lithification.
- Sandstone rocks are generally classified as quartz sandstone, arkose (quartz with feldspars), or graywacke (quartz with feldspar, clay, and other coarse-grained mineral fragments).
- Sandstones comprise about 20% of all sedimentary rocks and are formed in a variety of different environments including fluvial (rivers), marine, coastal (oceans and beaches), aeolian (wind blown), and glacial (ice).
- The differences in texture, sorting, and rounding help geologists decipher the environmental conditions that formed the sandstone.



Courtesy: Florida Department of Environmental Protection

Shale

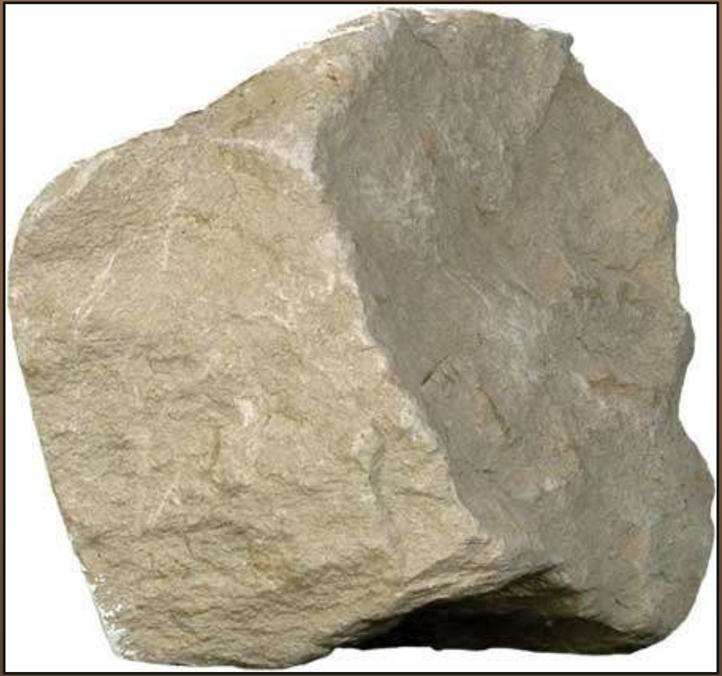
- Shale is a fine-grained, moderately to well-sorted rock formed by the compaction of well rounded silt-and clay-sized grains.
- Shales often contain fine laminations which helps impart fissility to the rock. Fissility is a term used to describe layered laminations formed by compression forces exerted over long-time periods.
- Shale usually contains about 50% silt, 35% clay, and 15% chemical materials, many shales may also contain organic plant materials and fossils.
- Shale is characterized by thinly, laminated layers, representing successive deposition of sediments.
- Shale accounts for about 50% of all sedimentary rocks deposited on the Earth's surface.
- The sediments that form shale are most likely deposited very gradually in non-turbulent, environments such as a lakes, lagoons, flood plains, and deep-ocean basins.

Siltstone

- Siltstone is finer grained than sandstone, but coarser grained than mudstone, and it consists primarily of well-sorted, rounded grains ranging between 3.9 - 62.5 μm.
- Siltstone is similar to shale except that it lacks fissility.

Mudstone

- Mudstone consists of very silt-sized and clay-sized grains (<0.0625 mm) and are often well consolidated with little pore space.
- Mudstones do not contain laminations or fissility, but they may contain bedding-plane features such as mud cracks or ripples. Mud cracks are formed by subaerial drying conditions. Ripples suggest gentle wave activity or water movement during deposition.



http://www.auckland.ac.nz/

Conglomerate

- Conglomerates are poorly-sorted composites of a wide range of rounded grain sizes ranging from sand to cobbles (< 0.062 to > 2 mm).
- Conglomerates usually contain a framework of large grains held together by a matrix of sands, silt, and clay-sized particles.
- The combination of poorly-sorted, predominantly coarse, rounded grains suggests that conglomerates form in high-energy environments such as steep-gradient streams.

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Breccia

- Breccia is a poorly-sorted composite of a wide range of grain sizes ranging from clays to gravels (< 0.062 to > 2 mm).
- Breccias usually contain a framework of gravel-sized grains held together by a matrix of sands, silts, and clay.
- Breccia is similar to a conglomerate except that it consists of angular grains, as opposed to rounded grains.
- The combination of poorly-sorted, predominantly coarse, angular grains suggests that breccias form from rapid deposition in high energy environments such as steep-gradient streams, glacial flood deposits, landslides, talus, alluvial fans, or in association with faulting.

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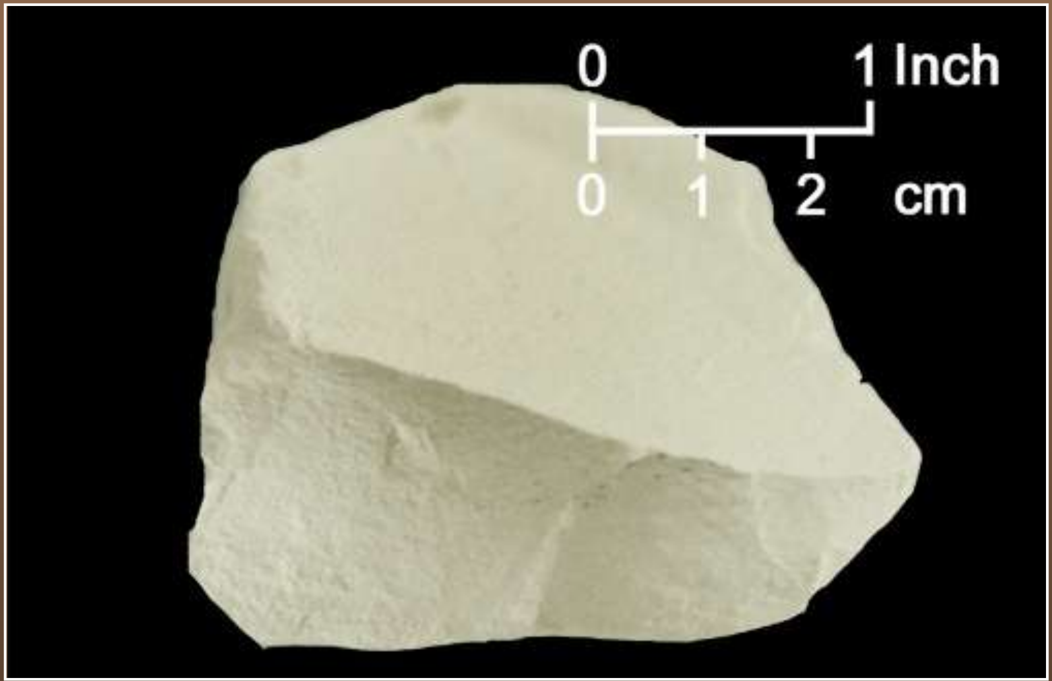
Kaolin

- Kaolin consists of very fine-grained kaolinite clay weathered from feldspar minerals in metamorphic and igneous rocks.
- Kaolin is generally very light colored to off-white.
- Kaolin is mined in several counties of South Carolina, including Aiken, Lexington, Richland, Kershaw, and Chesterfield Counties.



Florida Department of Environmental Protection, Florida Geological Survey

Dolostone

- Dolostone is composed of Dolomite, a calcium-magnesium carbonate mineral.
- Dolostone forms when magnesium in pore water replaces some of the calcium present in limestone. For this reason, dolostone is often preceded by the formation of limestone deposits. Dolostone forms very slowly and is rarely observed forming in modern environments.
- Dolostone abundance increases with age. There are more older than younger dolostones.

Evaporites

- Evaporites are chemical deposits formed when restricted bodies of saline water evaporate, precipitating out a range of minerals.
- Evaporite deposits do not involve a single chemical precipitate, instead they consist of chlorides, sulfides, carbonates, and borates.
- Halite and gypsum are two common examples of mineral precipitates.

Utah's Bonneville Salt Flats

Limestone

- Limestone consists almost entirely of the mineral calcite ($CaCO_3$) and can form by either inorganic or biochemical processes.
- Limestones form under a variety of environmental conditions and for this reason several types of limestone exist.
- Limestone accounts for about 10% of all sedimentary rocks, and of those, limestones with marine biochemical origin are the most common.

This example of limestone formed in a shallow, marine environment where dinosaurs once roamed the Earth. This set of tracks is from an *Arancanthosaurus* track in the Paluxy River in Dinosaur Valley State Park in Glen Rose, Texas.

Coral Reefs

- Coral Reefs are limestone formations created by marine organisms.
- Corals are invertebrate animals which secrete a calcareous (calcite-rich) external skeleton . Over long periods of time coral colonies form massive reef formations. Some of which surround entire islands or extend along the shoreline for 100's of miles.
- The Florida Keys were once an underwater coral reef rich in biodiversity of sea life. Today the Keys are lithified limestone deposits exposed above modern sea level. Living coral reefs exist offshore along the Atlantic Coast of the Keys.

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This is an example of a fossilized brain coral from the Key Largo Limestone formation in the Florida Keys. Interestingly snorkelers and divers can view living brain coral just 20 miles offshore from these fossilized coral reefs.

Coquina and Chalk

- Coquina rock formations are poorly cemented, coarse-textured masses of shells and shell fragments.
- The shells and shell fragments are easily discerned, and they give the rock a rough, sharp texture.
- Chalk is formed from calcareous microscopic marine organisms (nanofossils). When the organisms die their exoskeletons fall to the ocean floor creating a sedimentary layer.

Anastasia Formation coquina

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Travertine

- Travertine is an inorganic limestone that forms when calcium carbonate precipitates out of ground water that discharges from seeps, caves, grottos, springs, or along faults.
- When the ground water becomes exposed to the atmosphere carbon dioxide dissolved in the water escapes, causing calcium carbonate to precipitate out of the solution.
- Travertine also forms where water emerges from hot springs. The picture below is of a hot spring in Yellowstone National Park.

Oolite

- Oolitic limestone is formed by the cementation of tiny spherical grains called ooids.
- Ooids form in warm, shallow marine environments. When small grains of shell roll back in forth in the current, They are coated with calcium carbonate precipitating out of the supersaturated marine water.
- Ooids exhibit growth rings from the accumulation of the calcium carbonate precipitates. The presence of algae and sea-grasses accelerates and increases the formation of ooids.
- Ooid formation and oolitic limestones cover vast areas of the Bahamas creating shoals and tidal flats.

Coal

- Coal is made almost entirely of plant material and other organic deposits that have been buried for millions of years under elevated conditions of heat and pressure.
- Although the chemical composition of coal changes from its organic origins, it often retains fossilized imprints of plant leaves, bark, wood, and organisms that lived during the time the organic materials were deposited.
- It requires very specific environmental conditions for plant material to become coal. The organic material must be deposited in an anoxic (oxygen free) environment to prevent it from decomposing. Most coal beds originated in swampy, saturated, environments.
- Deposited organic material goes through four main phase of coal formation, which are related to increasing heat and pressure :
- 1. Peat
- 2. Lignite
- 3. Bituminous
- 4. Anthracite

Chert

- Chert represent a group of hard rocks made from micro- and cryptocrystalline silica (SiO_2). Chert can develop as a nodules inside other rocks or as rock layers.

- Most cherts are hypothesized to originate from silica derived from one of three sources: solution in water, biochemical sediments, or lava flows and volcanic ash.

  - Silicate materials can be precipitated out of a solution in marine waters, or produced as a byproduct of water dwelling organisms. Diatoms and radiolarians extract it from their surroundings and use it to grow silica-rich skeletons. When these organisms die and settle to the bottom, their skeletons provide the silica source for the chert to develop.
  - Large beds of chert have been found to develop in association with lava flows and volcanic ash. It is thought that the chert is the produced by the decomposition of volcanic ash.

- Chert occurs in a variety of forms including flint, jasper, and agate.

- Chert is a very hard rock that generally breaks along conchoidal fractures, this characteristic makes it possible to carve sharp-pointed edges onto the rock. Native American's used chert to create arrowheads that were attached to primitive spears, arrows, and knives.

Chert

- **Flint** is the most common form of chert. It is often a dark, glassy, colored rock that forms as nodules embedded in limestone. The dark color of the chert comes from the organic matter it contains.
- **Jasper** is a red variety of chert that gets its color from iron oxide.
- **Agate** is a banded form of chert that may contain several different colors layered throughout the rock.

Jasper

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Agate forming inside a coral

Florida Department of Environmental Protection, Florida Geological Survey

Stratigraphy

- Stratigraphy is the study of rock layering, succession, age, distribution, form, and composition of sedimentary rocks.
- Sedimentary rocks form as layers of sediment that accumulate one on top of the other. The individual layers of sedimentary rock are referred to as strata or beds (stratum for singular).
- Law of superposition states that younger sedimentary layers are deposited on top of older layers, and, therefore, younger layers are closest to the surface and older layers are buried below the surface.
- Original horizontality principle states that layers of sediment are originally deposited horizontally. While this applies to most stratigraphic sequences it does not necessarily apply to all. For example, sediments deposited at the base of a slope or at the angle of repose would not exhibit original horizontality.
- Lateral continuity principle states that layers of sediments initially extend in all directions and are therefore laterally continuous. Rock units dissected by valleys, should occur at relatively the same elevation on either side of the valley.
- Each individual stratum is unique and will be slightly different from the one above or below it. This is because each stratum was formed under slightly different environmental conditions.
- Geologist use characteristic of the stratum to infer information about the environmental conditions that were present at the time that particular layer was deposited and eventually lithified

Sedimentary Structures

Laminations

Copyright @ Bruce Molnia, USGS

Bedding Planes

Copyright @ Bruce Molnia, USGS

Cross-Bedding

Copyright @Marli Miller

Mud Cracks

Courtesy NASA Visible Earth

Ripple Marks

Copyright @ Bruce Molnia, Terra Photographics

Ripples and Mudcracks

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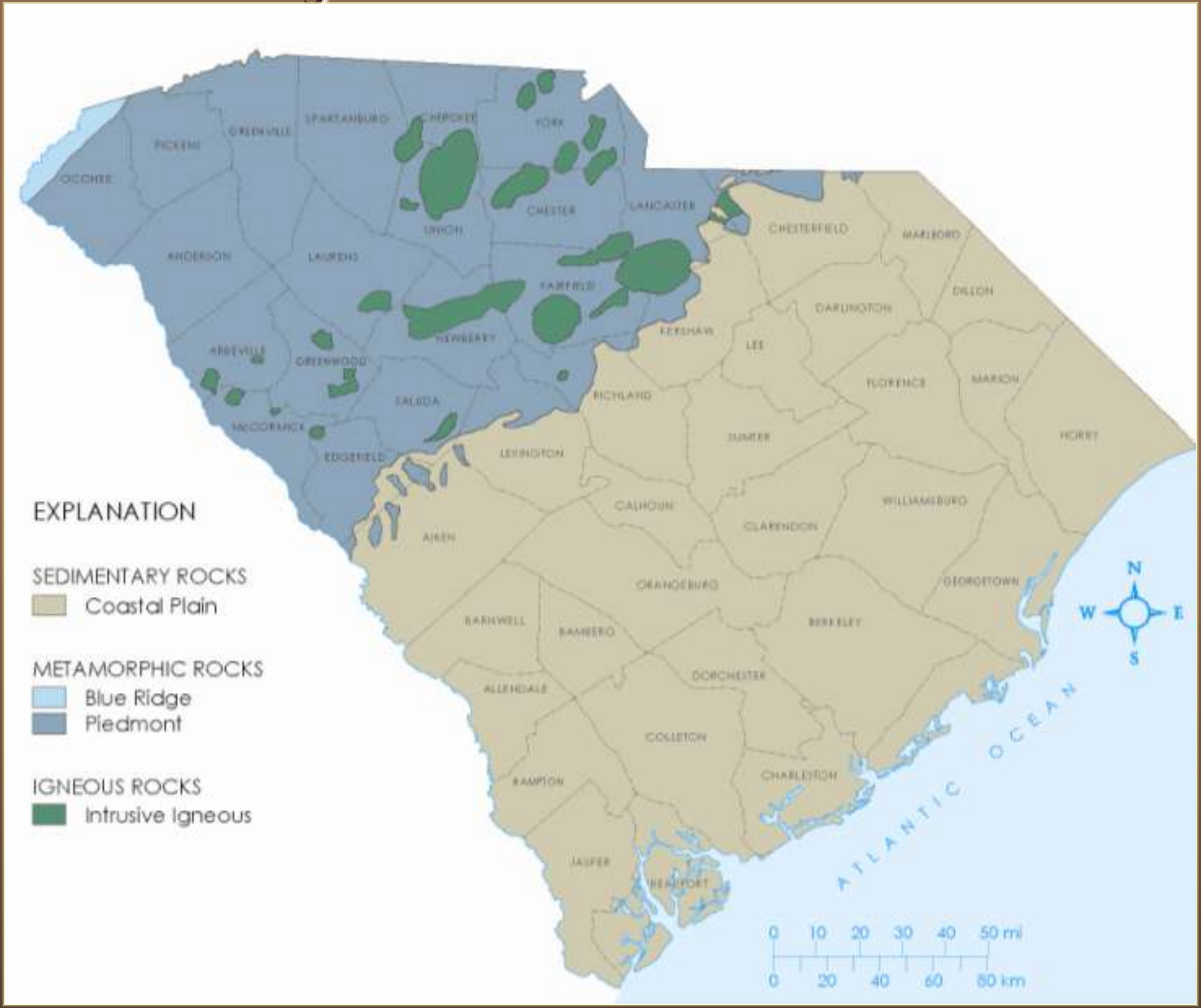
Sedimentary Rocks in South Carolina



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Sedimentary Rocks in the Landscape

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The sedimentary rocks in Arizona's Marble Canyon exhibit a "cliff-slope-cliff" pattern formed by differential weathering of the alternating resistant sandstone and easily erodible siltstone and shale. The Colorado River, winding through the left side of the photo has been carving this majestic landscape for the last 17 million years.

The bright white areas of this aerial photo is where limestone is being mined from the Giant Cement Quarry in the Lower Coastal Plain of South Carolina. These sub-surface limestone deposits were formed 53-36 million years ago when this area was a deep-underwater, marine environment. The limestone in the quarry contains abundant fossilized remains of marine organisms, including sharks teeth that measure several inches across.

www.maps.google. com

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: 3-36)

Resources and References

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