

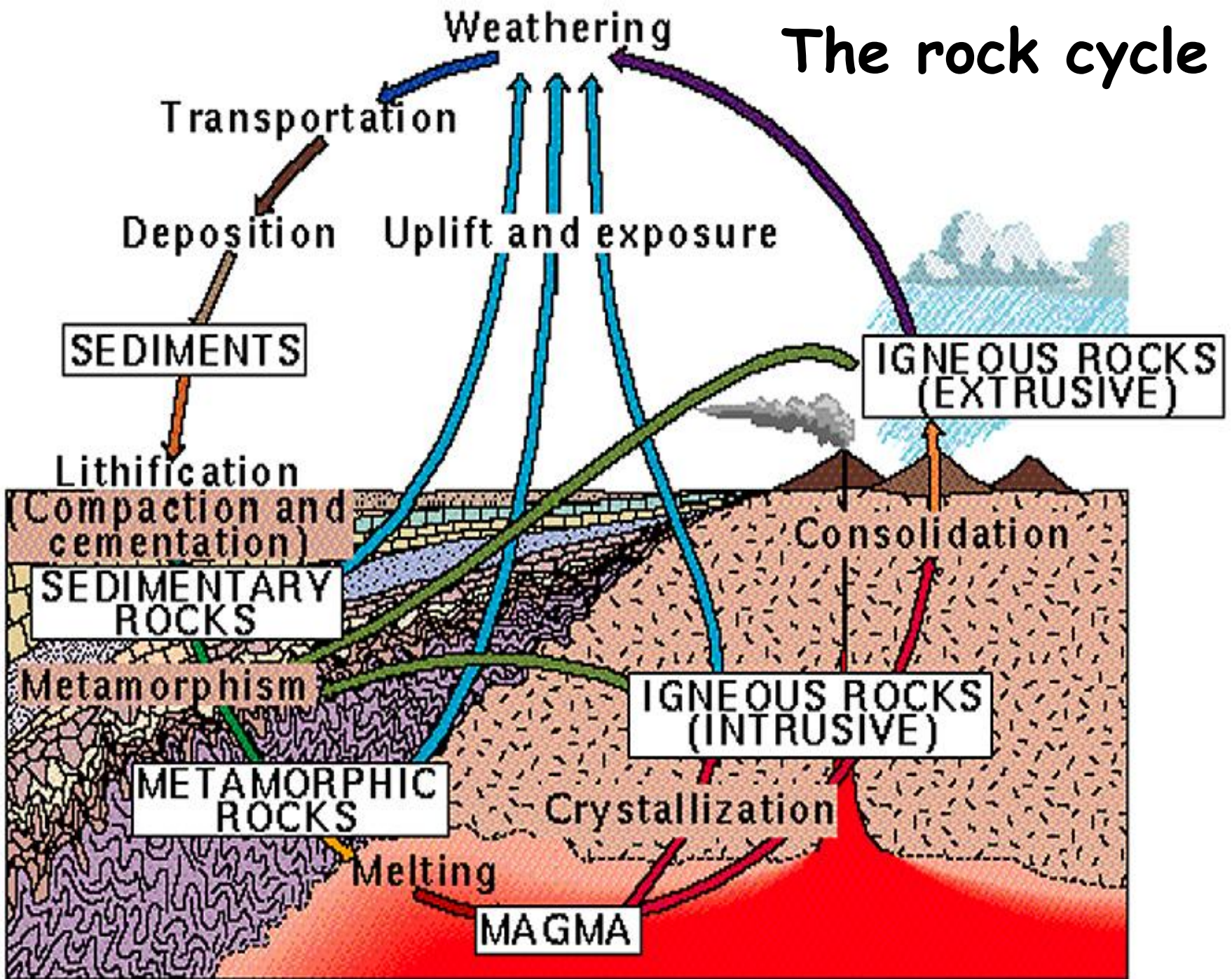
# Categories of Rocks

**Igneous-** cool and crystallize from molten (liquid) material (lava or magma)

**Sedimentary-** pieces of other rocks cemented together or rocks precipitated from water

**Metamorphic-** any type of rock heated without melting, squeezed and mixed with hot fluids

# The rock cycle



# Sedimentary rocks

**Sediment:** (sedimentum: settling)

- fragments of solid material that settle and accumulate
- fragments settle in layers after being transported
  - fragments are products of weathering and erosion
  - easy to see sedimentation in action!

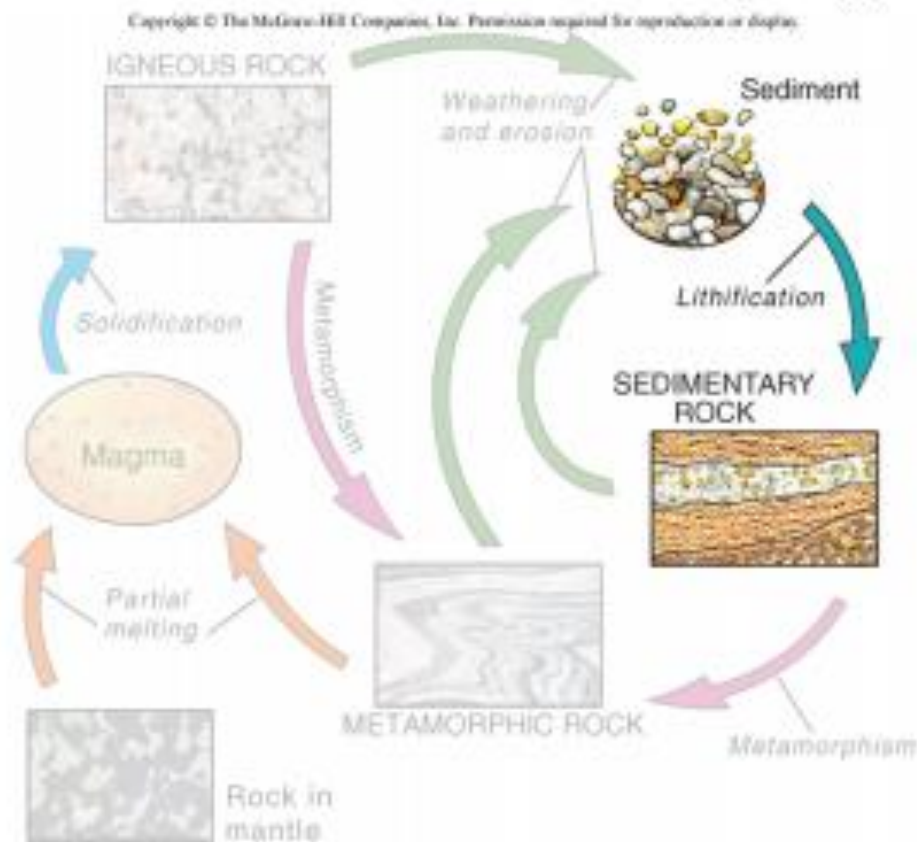
**Sedimentary rock:** “lithified” sediment; “lithos” -- rock

- 75% of all rock exposed on Earth’s land surface
- composition is weathering products of rocks or biological matter
- principal source of coal, oil, natural gas, cement, Al, Fe, groundwater

# sediment: loose, solid particles

originate from:

- weathering and erosion of pre-existing rocks
- chemical precipitation from solution, including secretion by organisms in water



# sediment is classified by *particle size*

- boulder > 256 mm
- cobble: 64 to 256 mm
- pebble: 2 to 64 mm
- sand: 1/16 to 2 mm
- silt: 1/256 to 1/16 mm
- clay: < 1/256 mm

# turning sediment into sedimentary rock

## *transportation*

movement of sediment away from its source,  
typically by water, wind or ice

*rounding* occurs by abrasion during transport  
“particles knocking against each other”



*sorting* occurs as sediment is separated by size  
by transporting agents, such as water

--sediment size decreases with increased transport distance--

sediments may be *angular* or *rounded*

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Photo by David McGeary

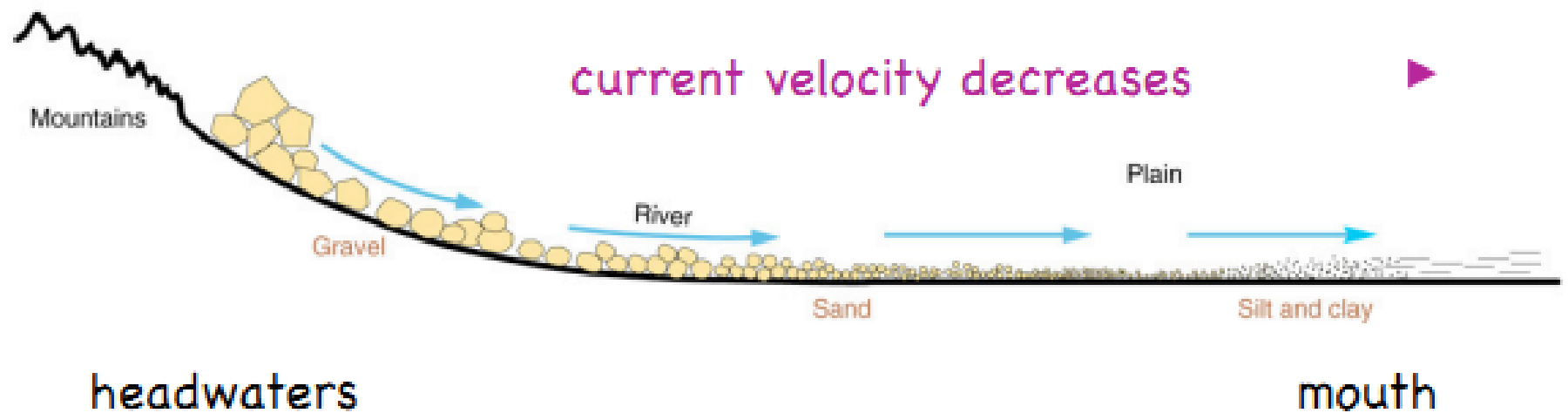
*rounded beach boulders*



*angular fragments*

## particle size sorting by rivers

*as flow slows down, river can no longer carry larger particles*



grade = change in elevation/length

# gravel/boulders at headwaters

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normally  
deposited  
in or near  
steep  
mountains  
at river  
headwaters

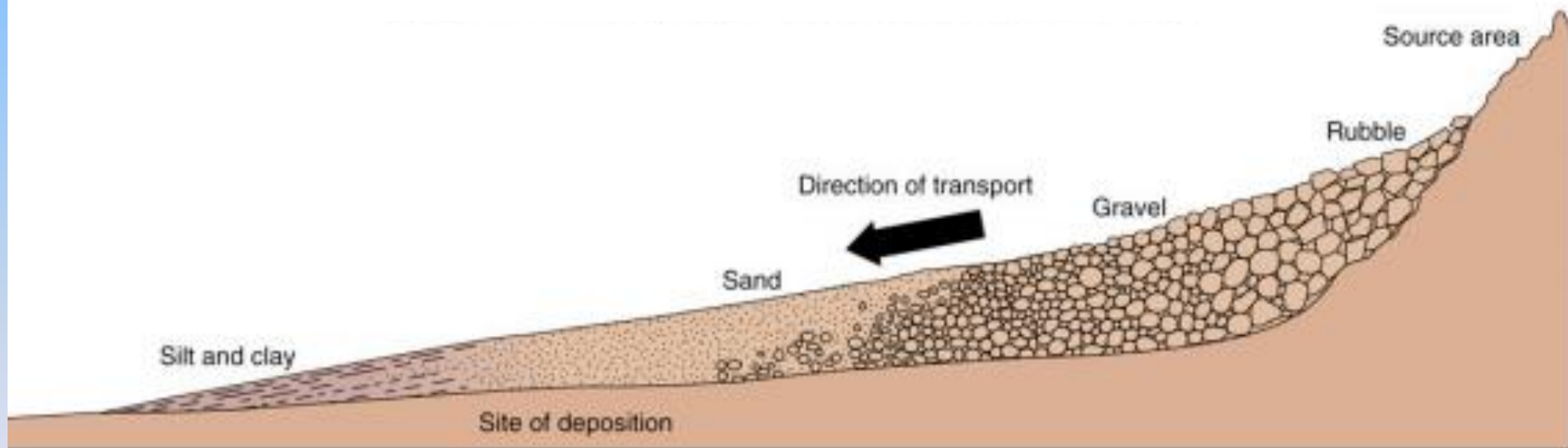


Photo by David McGeary

sand/silt downstream, closer to mouth of river



# Distance from Source



# Transporting agents

sediments may be *poorly sorted* or *well sorted*

**WIND:** most selective transporting agent

-- only picks up sand thus deposits are well sorted

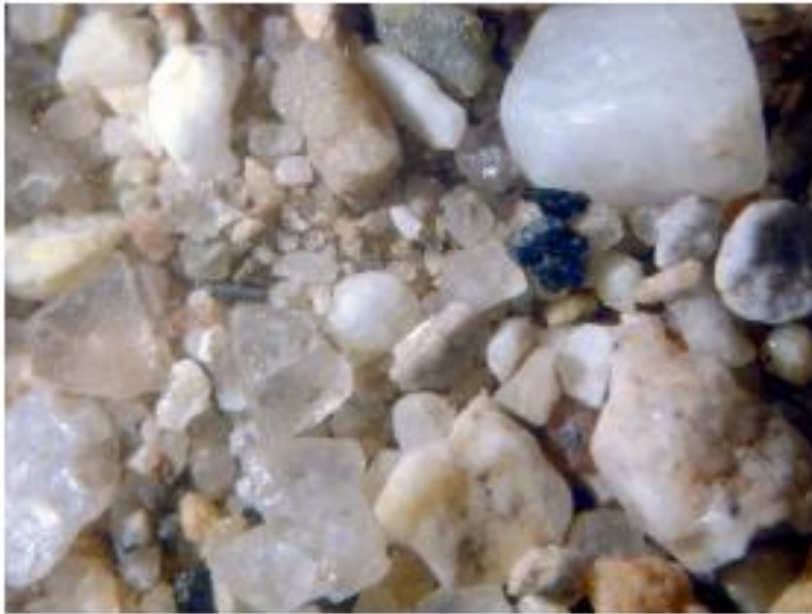


*windblown sand forms dunes*



*note well sorted and rounded grains*

glaciers and flooding rivers are unselective transporting agents



flooding rivers -- fast currents  
...transport all sizes...

*poorly sorted river sediment*



*poorly sorted glacial sediment*

# turning sediment into sedimentary rock

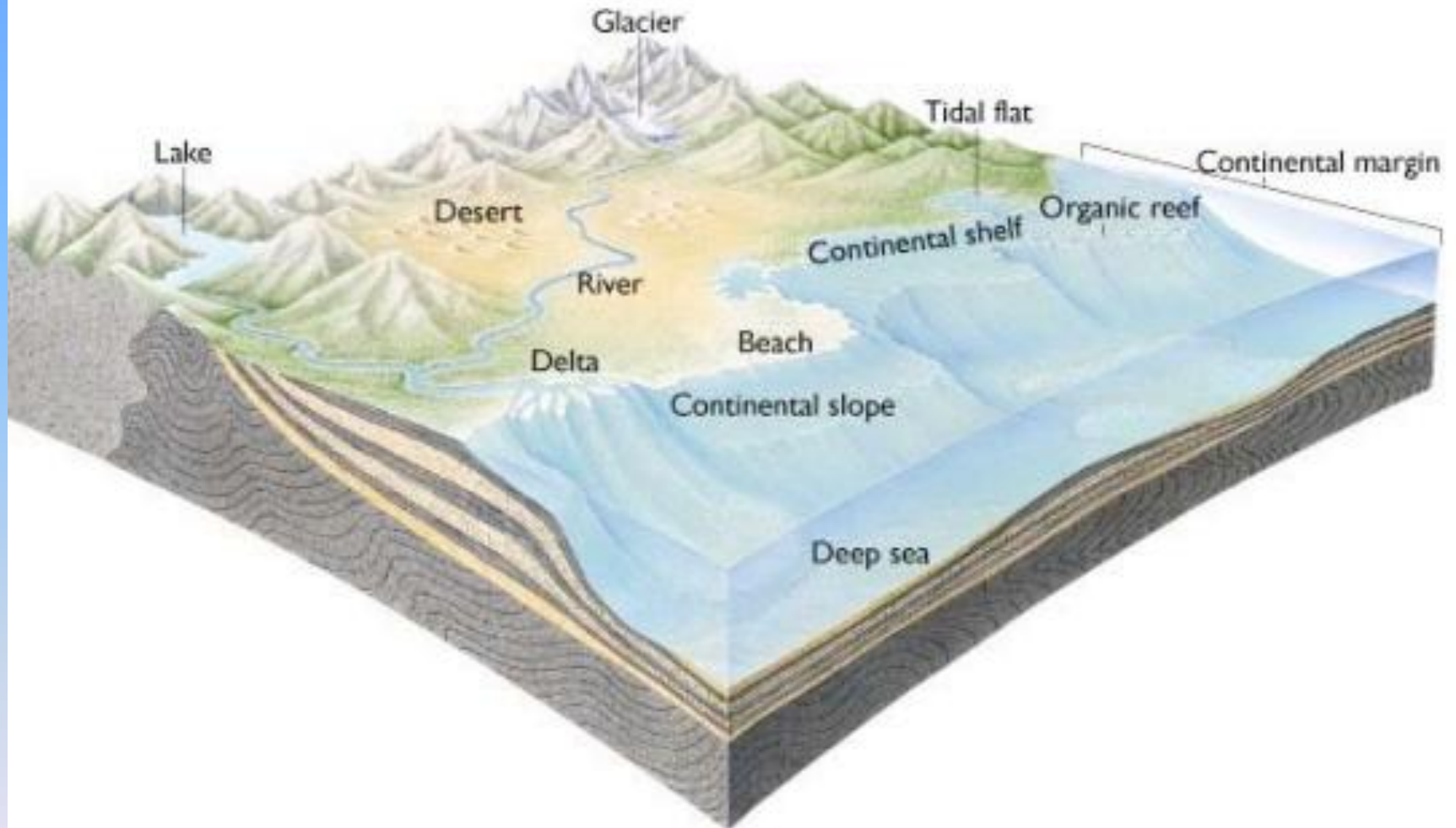
## *deposition*

- settling of transported material
- accumulation of chemical or organic sediments, particularly in water



sediment transported  
from canyon and  
deposited at  
canyon mouth  
at the  
base of the slope

*environment of deposition is setting of deposition*



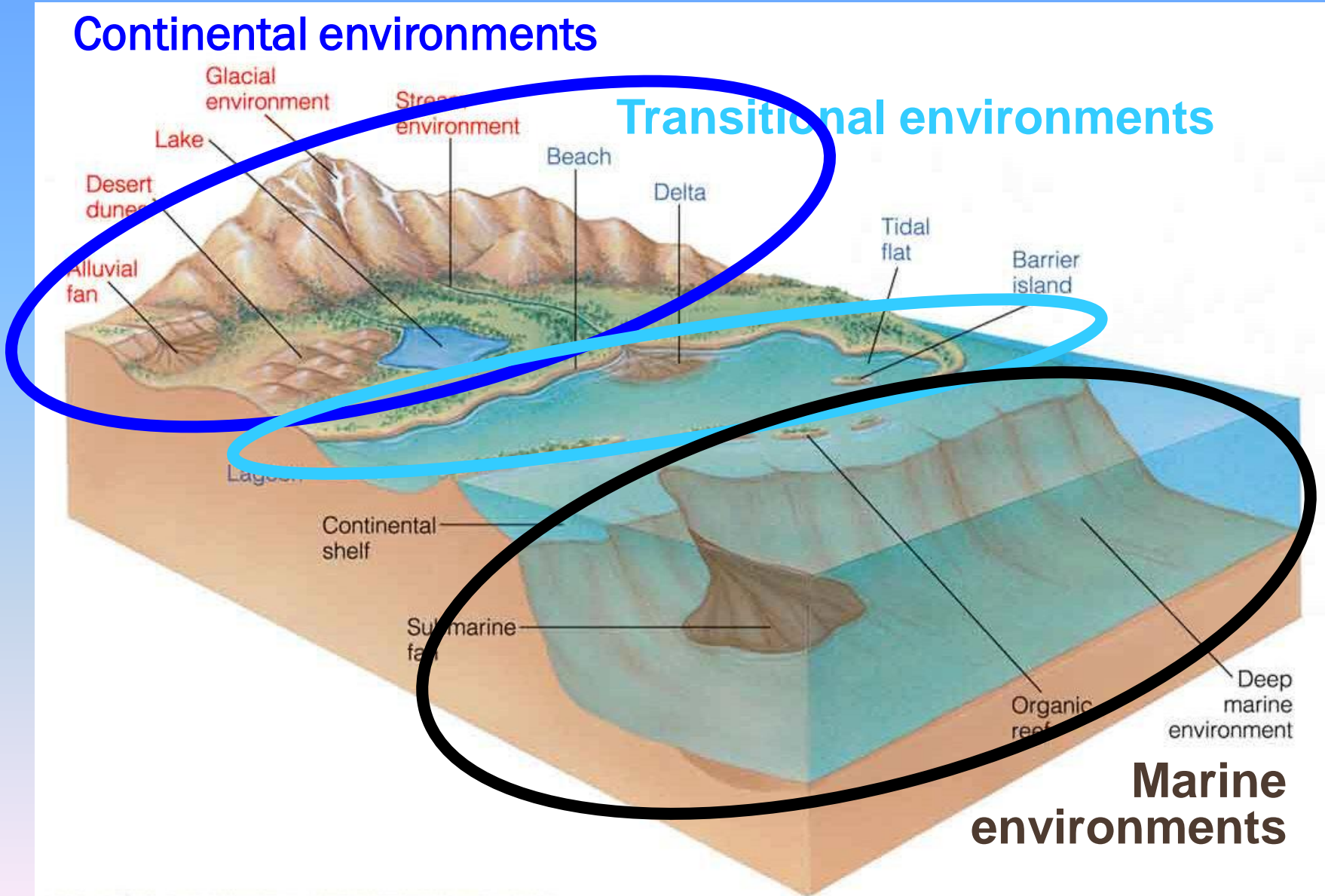
sediments and sedimentary rocks form in many settings

# Depositional Environments

## Continental environments

## Transitional environments

## Marine environments



# turning sediment into sedimentary rock

## *preservation*

- sediments must be preserved to turn into rock
- burial by additional sediments deposited on top

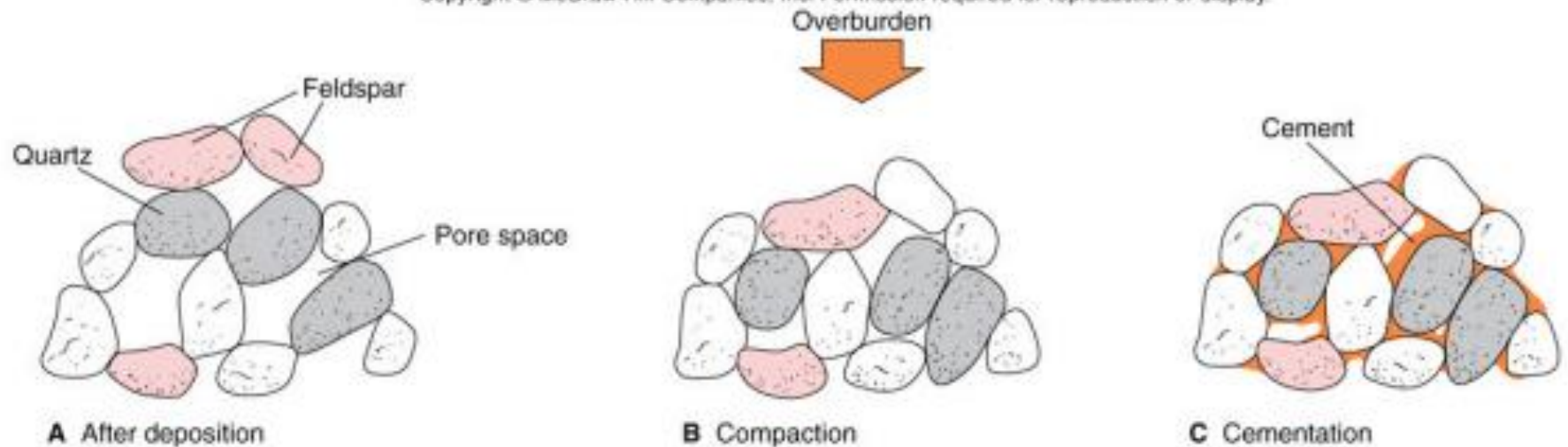


# turning sediment into sedimentary rock

## *lithification*

- sediments must be hardened into rock
- **compaction** and **cementation** occur

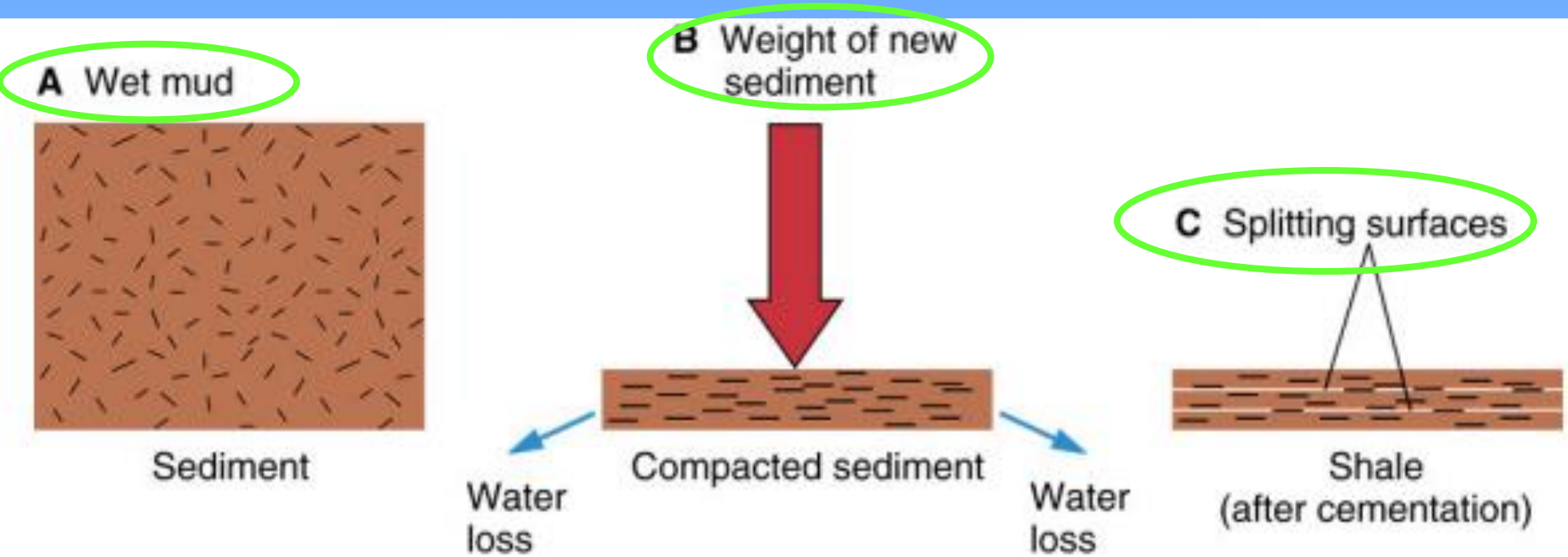
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water is expelled from pore space

other fluids cement grains

# Lithification and compaction of shale



NB volume loss during compaction



# **Sedimentary rocks Classified as-**

## **Clastic, Chemical, or Organic**

**Clastic** - made from small pieces of other rocks

--Conglomerate, Breccia, Sandstone, Siltstone, Shale  
all are common

**Chemical** - precipitate from chemical reactions

--Limestone, chert, rock salt, gyprock

**Organic**- Made from compressed altered plant materials

--Coal

All can have fossils in them- this makes it unique

All are useful for reconstructing past environments

# Basic Clastic Rock Types

- Breccias: angular particles
- Conglomerates: rounded particles
- Sandstones
  - Quartz sandstone: dominated by quartz grains
  - Arkose sandstone: composed of qtz & fsp grains
  - Graywacke: dominated by lithic (rock) fragments
- Shales: mud and silt particles

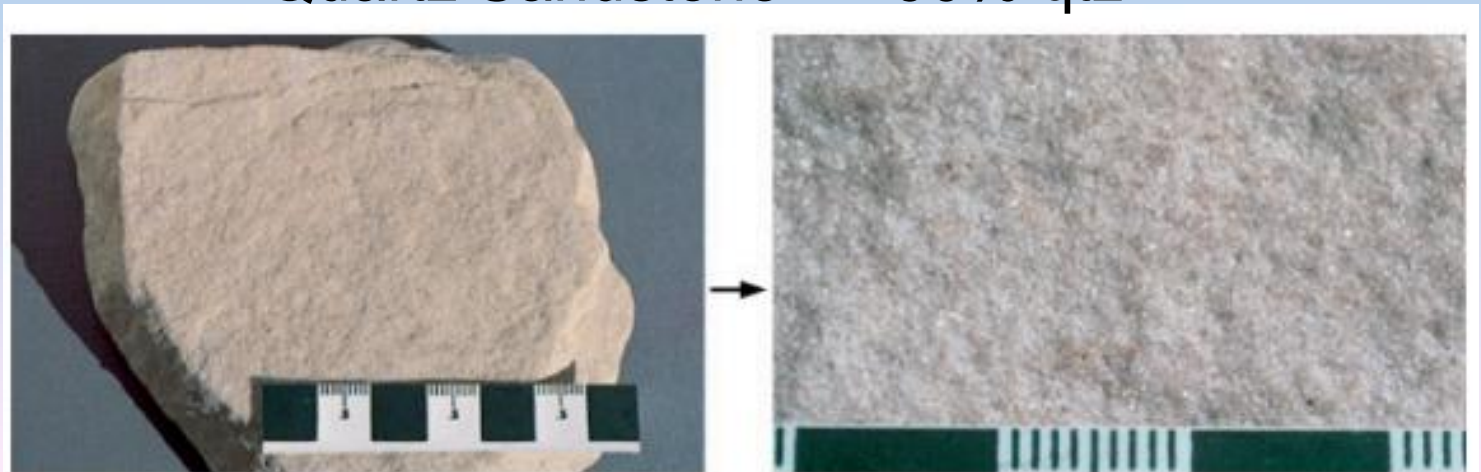
# Coarse Breccia



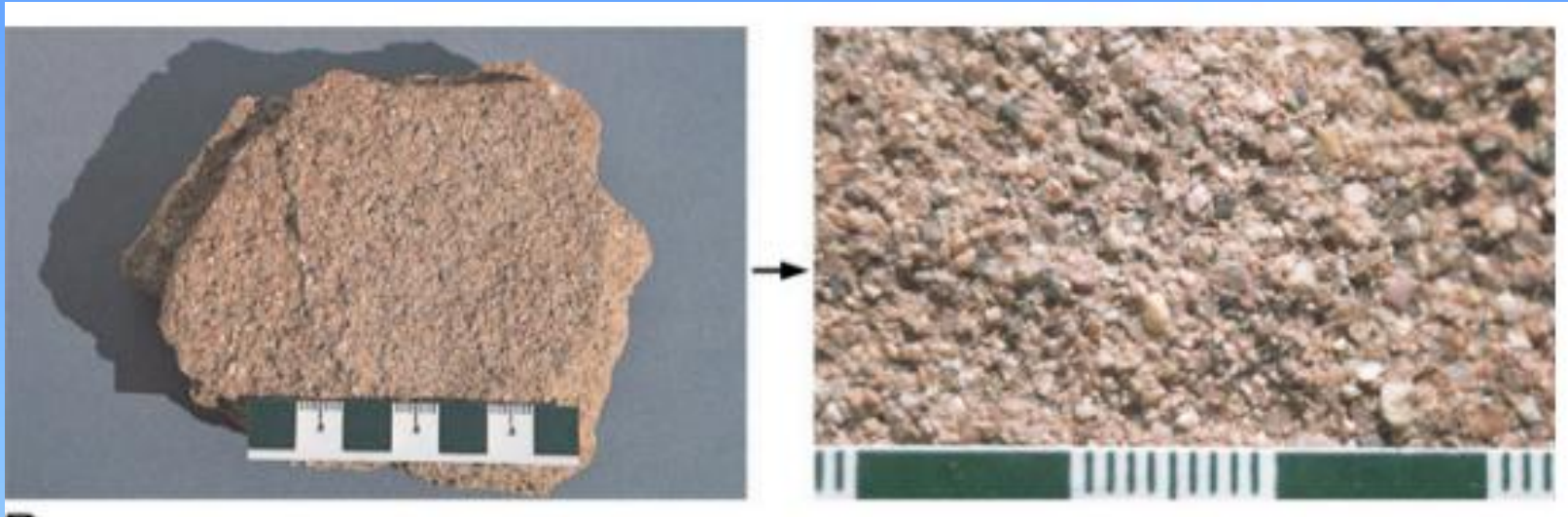
# Conglomerate



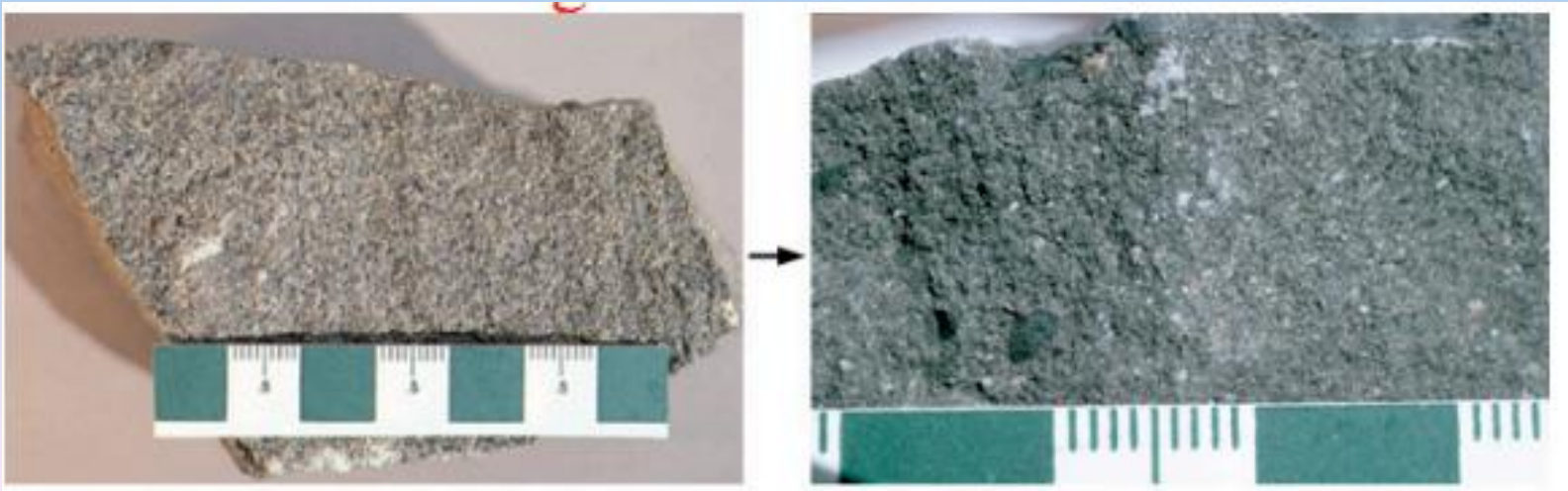
# Quartz Sandstone - > 90% qtz



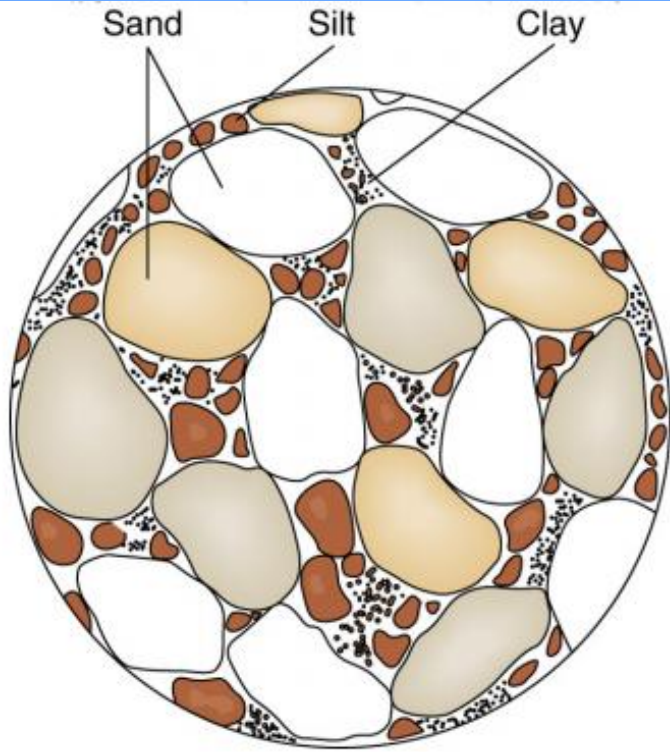
## Arkose Sandstone - Feldspar + Qtz



## Graywacke - lithic fragments in dark fine grained matrix



# Poorly sorted, “dirty” sandstone



Sorting can be based on particle size and/or composition; It yields important constraints on provenance of the clastic particles.

## Shale hand specimens



NB very fine grained and thin laminations

## Chemical Sedimentary Rocks

- Carbonate Rocks (*e.g.*  $\text{CaCO}_3$ )
- Chert (*e.g.*  $\text{SiO}_2$ )
- Evaporites (*e.g.*  $\text{NaCl}$ ;  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ )

# Bioclastic Limestones



Fine grained carbonate mud

Clearly visible fossils

## Fossil Rich Limestone - Coquina

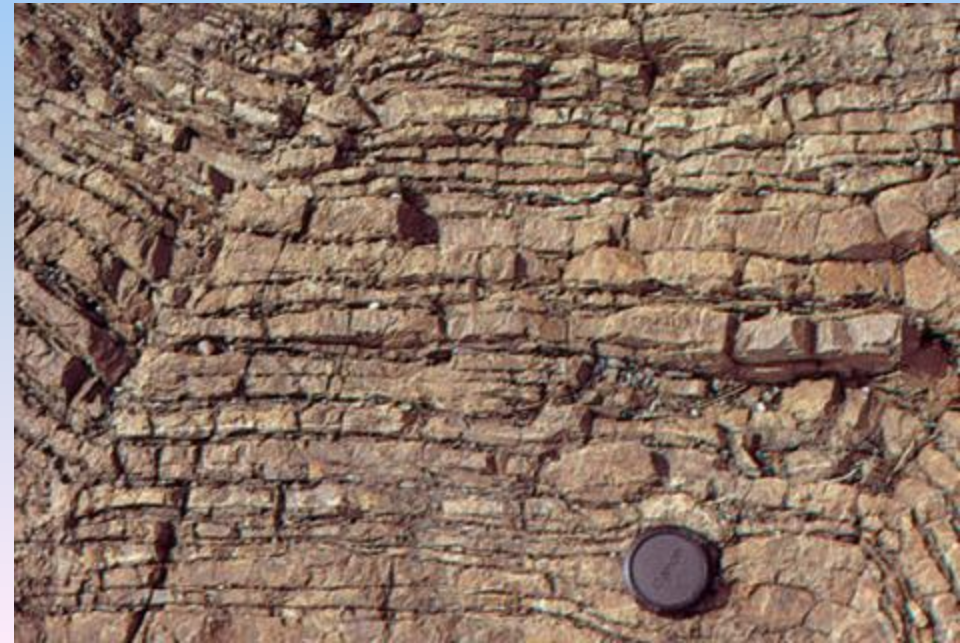


**Nodular Chert**  
(poorly crystalline  $\text{SiO}_2$ )



Redwall limestone, Grand Canyon, AZ

**Bedded Chert**



# Evaporites



Bonneville salt flats

# Coal Bed - Trinidad, CO

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**Composed of decayed plant remains  
- compressed peat bogs**





# Bedding

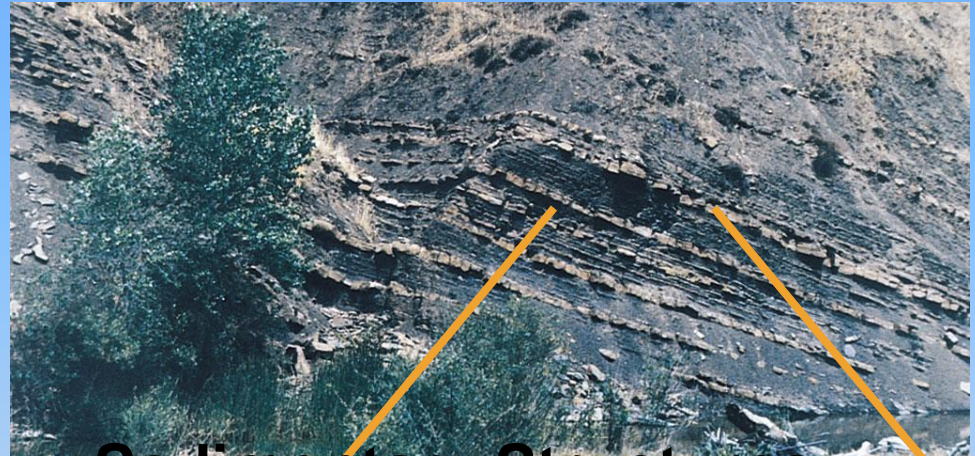
## ➤ Sedimentary rocks generally have **bedding** or **stratification**

– Individual layers less than 1 cm thick are ***laminations***

- common in mudrocks

– ***Beds*** are thicker than 1 cm

- common in rocks with coarser grains

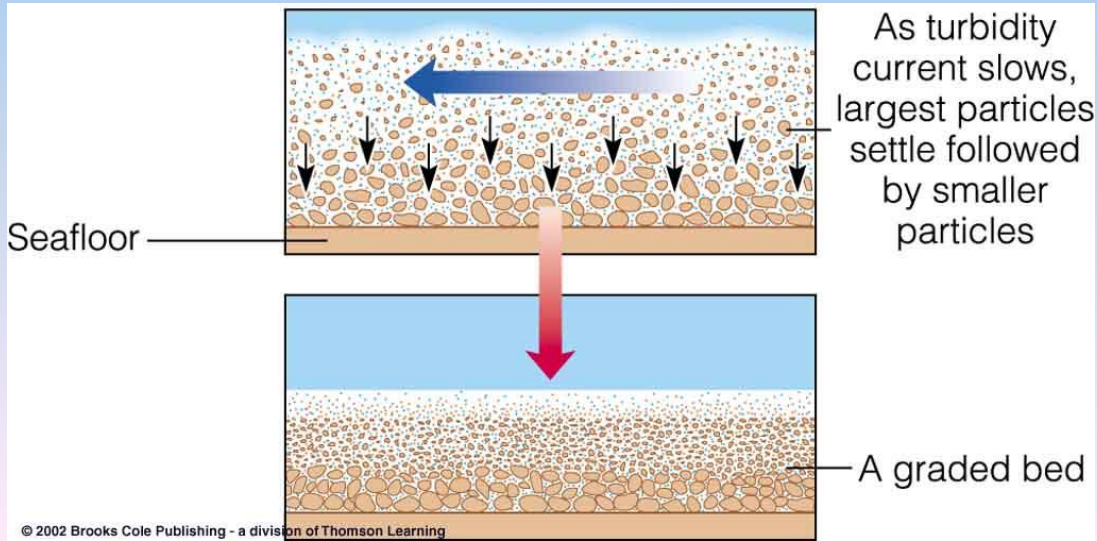
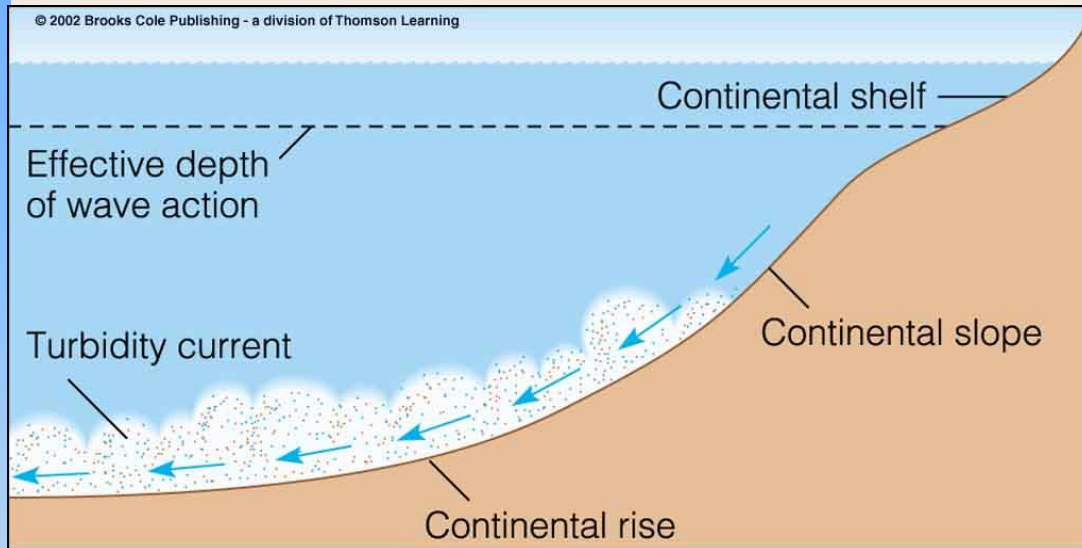


**Sedimentary Structures**



# Graded Bedding

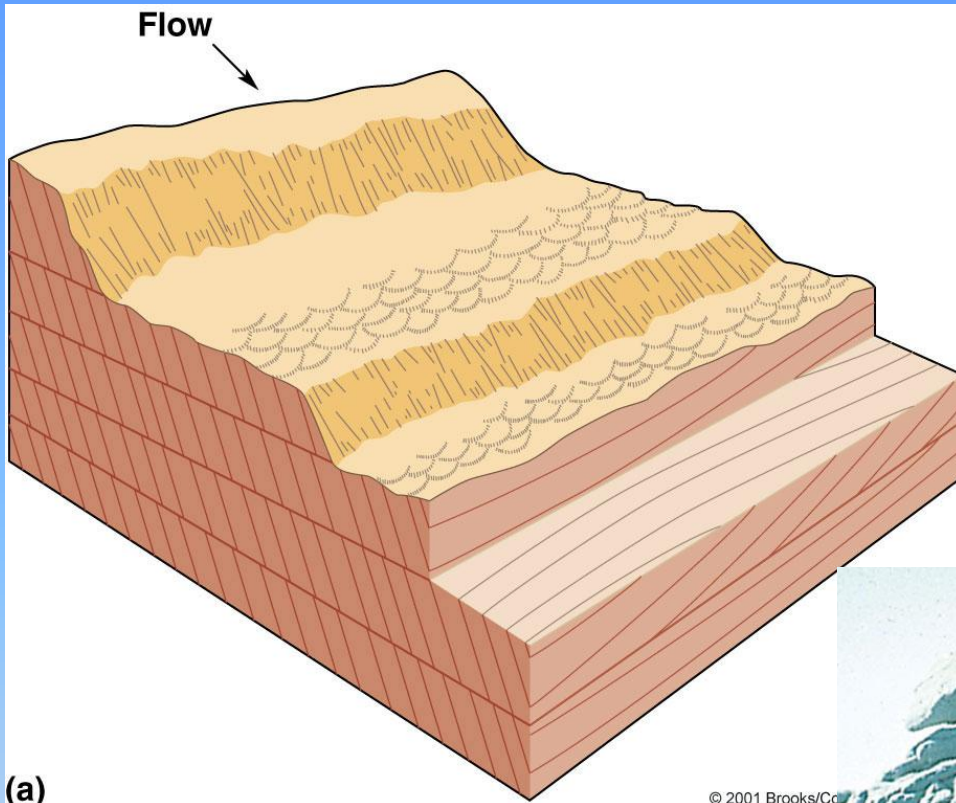
- Some beds show an upward gradual decrease
  - in grain size, known as graded bedding



- Graded bedding is common in turbidity current deposits
  - which form when sediment-water mixtures flow along the seafloor
  - As they slow,
  - the largest particles settle out then smaller ones

# Cross-Bedding

- Tabular cross-bedding forms by deposition on sand waves



(a)

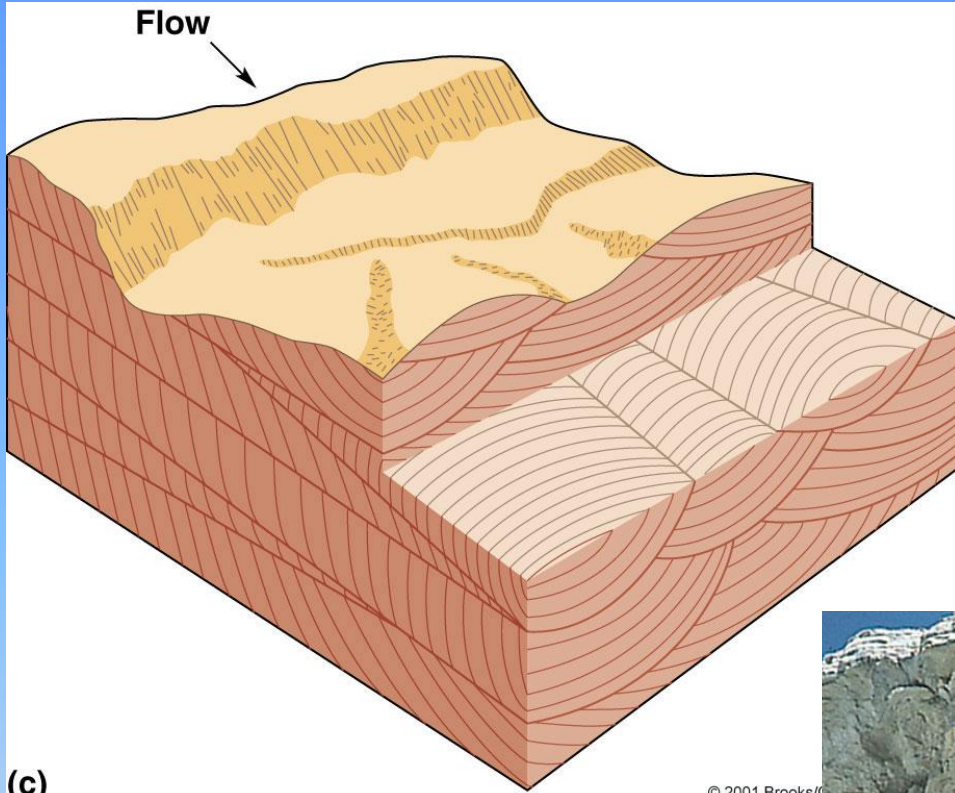
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# Cross-Bedding

- Trough cross-bedding formed by migrating dunes

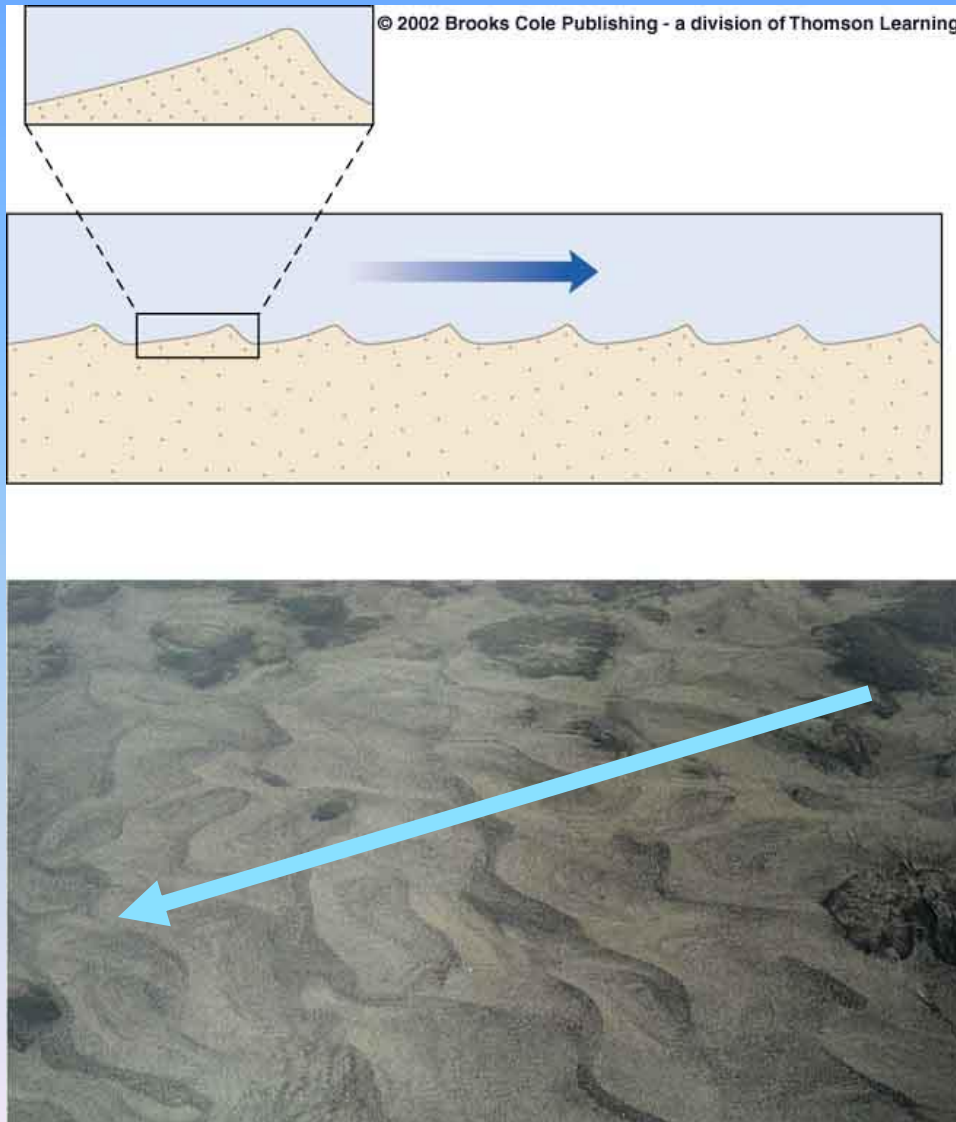


(c)

© 2001 Brooks/Cole

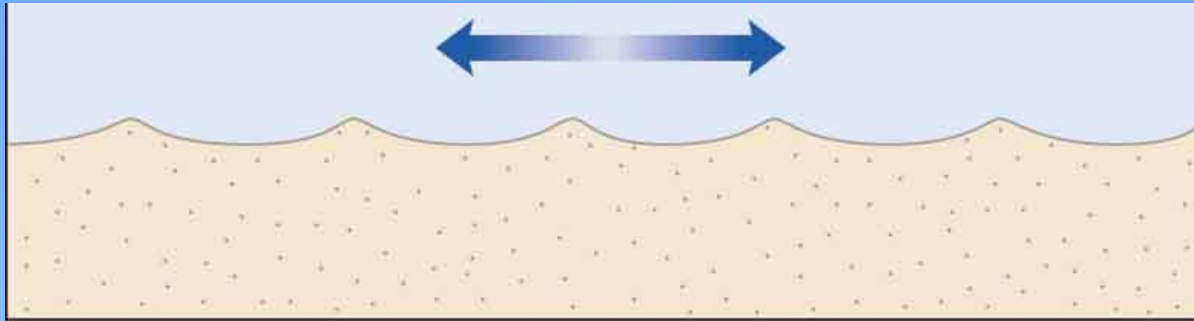


# Current Ripple Marks



- Ripples with an asymmetrical shape
- In the close-up of one ripple,
  - + the internal structure
  - + shows small-scale cross-bedding
- The photo shows current ripples
  - + that formed in a small stream channel
  - + with flow from right to left

# Wave-Formed Ripples



- As the waves wash back and forth,
  - + symmetrical ripples form
- The photo shows wave-formed ripple marks
  - + in shallow seawater

# Mud Cracks

- When clay-rich sediments dry, they shrink
  - + and crack into polygonal patterns
  - + bounded by fractures called mud cracks
- Mud cracks require wetting and drying to form,



- as along a lakeshore
- or a river flood plain
- or where mud is exposed at low tide along a seashore

# Ancient Mud Cracks

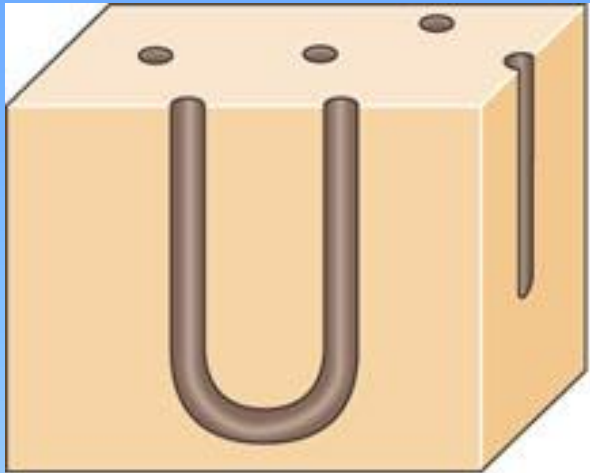
- Mud cracks in ancient rocks
  - + in Glacier National Park, Montana
- Mud cracks typically fill in
  - + with sediment
  - + when they are preserved
  - + as seen here



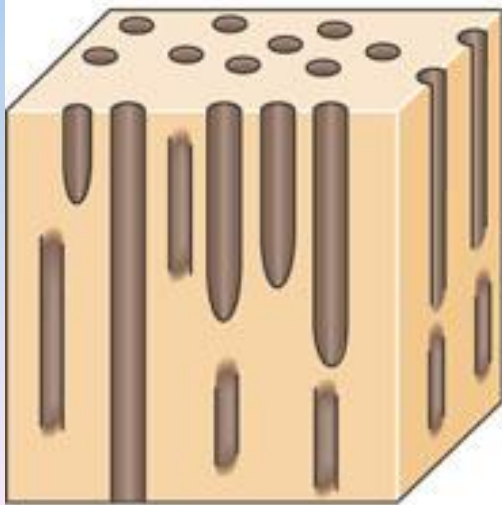
# Biogenic Sedimentary Structures

- Biogenic sedimentary structures include
  - tracks
  - burrows
  - trails
- called ***trace fossils***
- Extensive burrowing by organisms is called ***bioturbation***
- It may alter sediments so thoroughly that other structures are disrupted or destroyed

# Bioturbation



(a)



- U-shaped burrows

- Vertical burrows

# Bioturbation



- Vertical, dark-colored areas in this rock are sediment-filled burrows
  - Could you use burrows such as these to relatively date layers in deformed sedimentary rocks?

# No Single Structure Is Unique to any one environment

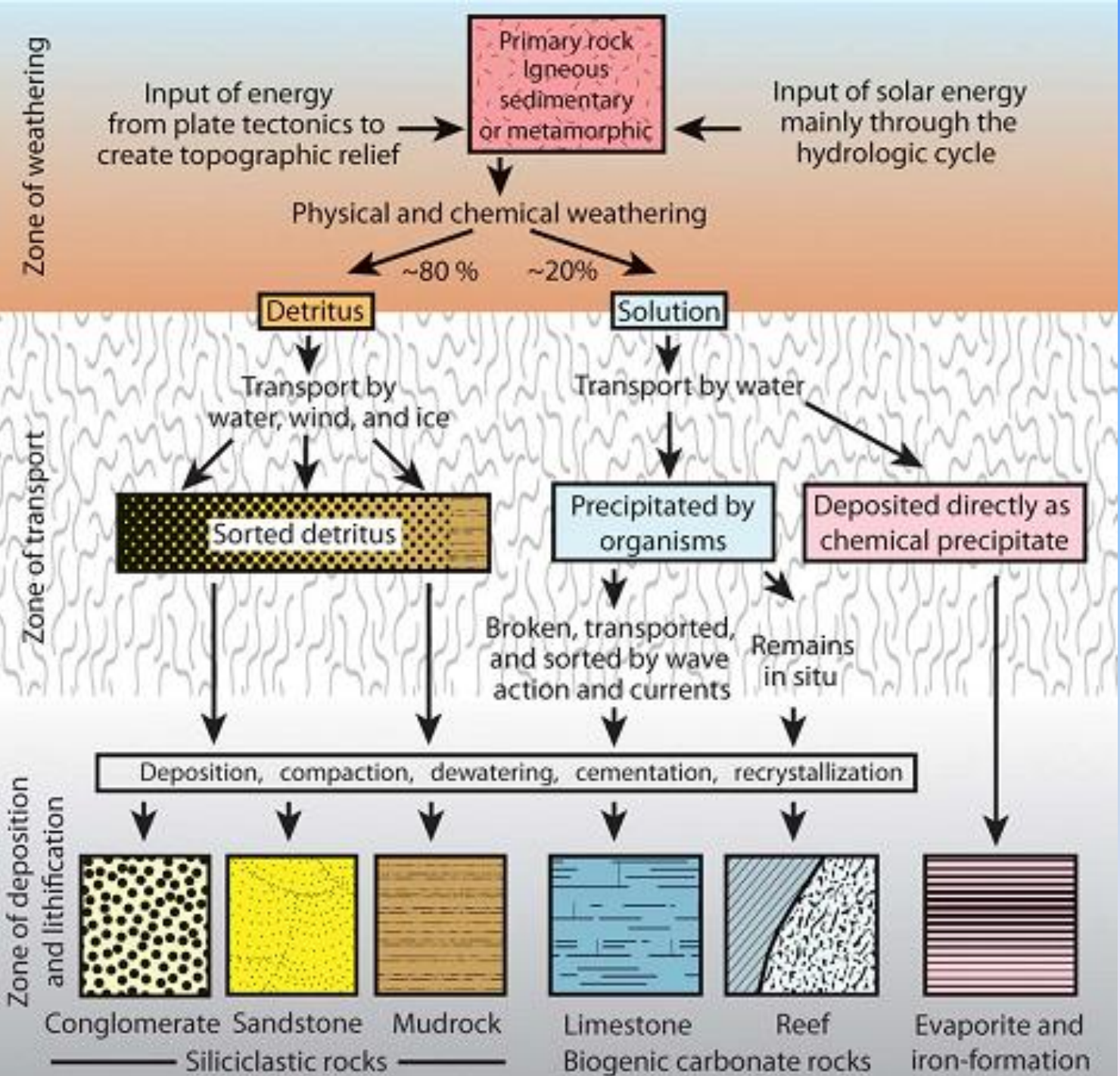
- Sedimentary structures are important
  - + in environmental analyses
  - + but no single structure is unique to a specific environment
- Example:
  - + Current ripples are found
    - in stream channels
    - in tidal channels
    - on the sea floor
- Environmental determinations
  - + are usually successful with
  - + associations of a groups of sedimentary structures
  - + taken along with other sedimentary rock properties

# Fossils Are Constituents of Sedimentary Rocks

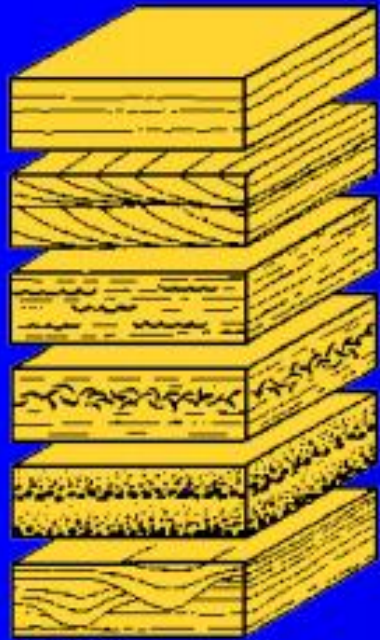


- This variety of limestone,
  - + known as **coquina**,
  - + is made entirely of shell fragments

# Summary



# Sedimentary Structures



Planar bedding

Current bedding showing cross-lamination

Ripple marked bedding

Intrusions (overlapping) fossil shells

Graded bedding

Cut-and-fill bedding

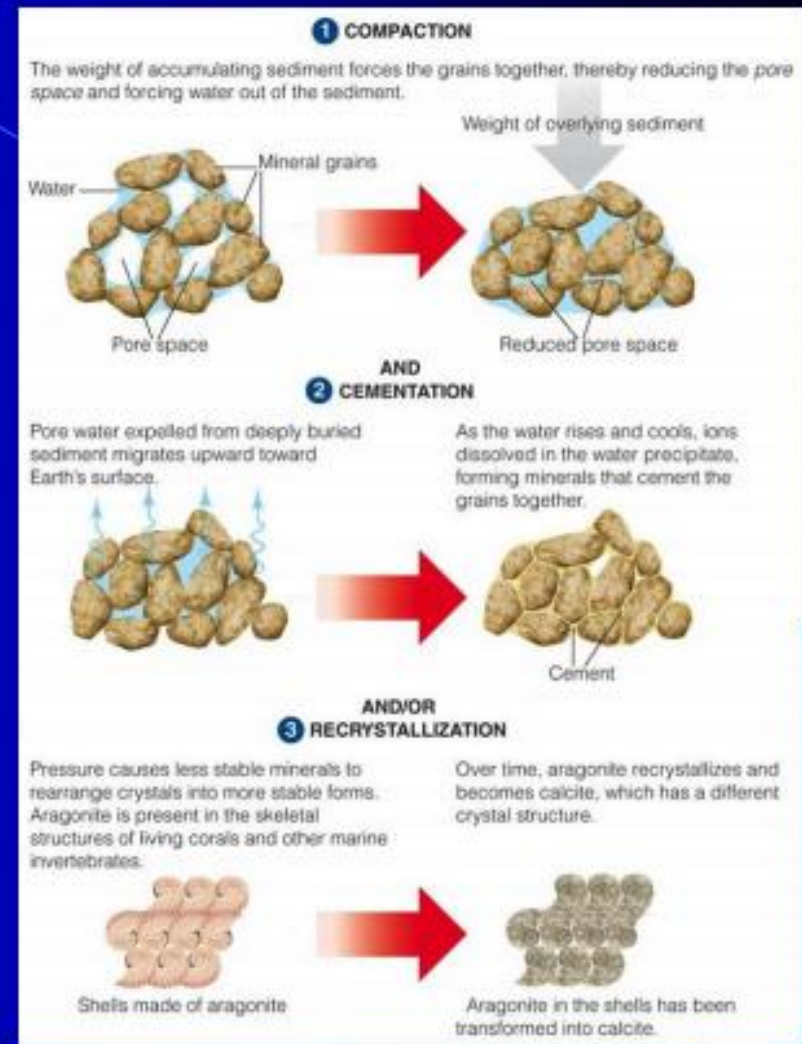


## Clastic Sediments → Lithification



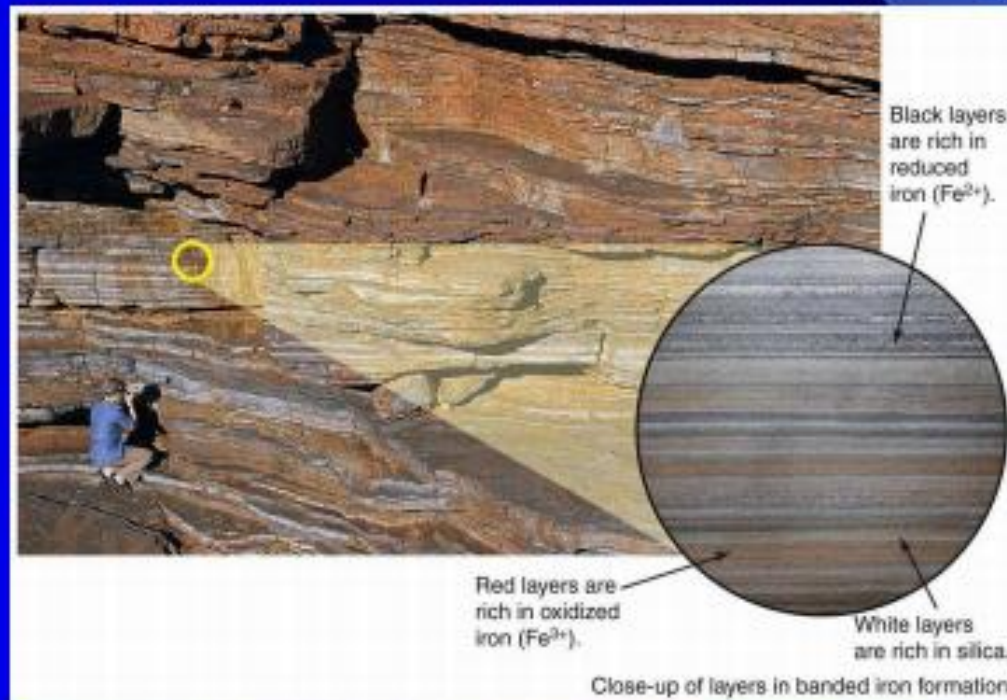
When clastic sediment is lithified, the result is clastic sedimentary rock

- **Conglomerate**: rounded clasts > 2 mm
- **Breccia**: angular clasts > 2 mm
- **Sandstone**: clasts 0.5 - 2 mm
- **Siltstone**: silt and clay-sized particles
- **Shale**: mostly clay-sized particles in a rock that easily splits into sheets
- **Mudstone**: shale that does not split



**Chemical sedimentary rock** results from lithification of chemical sediment formed by precipitation of minerals from water

- **Evaporite:** formed by evaporation
- **Banded iron formation:** formed during an atmospheric change from  $O_2$ -poor to  $O_2$ -rich
- **Limestone:** lithified shells and other skeletal material from marine organisms
- **Chert:** tiny particles of quartz from siliceous skeletons of microscopic sea creatures



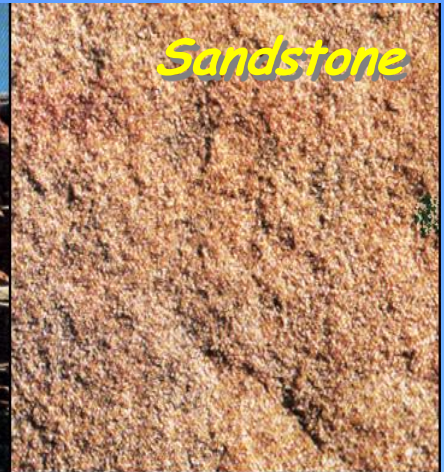
**Sedimentary rocks occur in horizontal layers**



*Conglomerate*



rounded clasts  
Poorly sorted



*Sandstone*

**Clastic-textured sedimentary rocks**

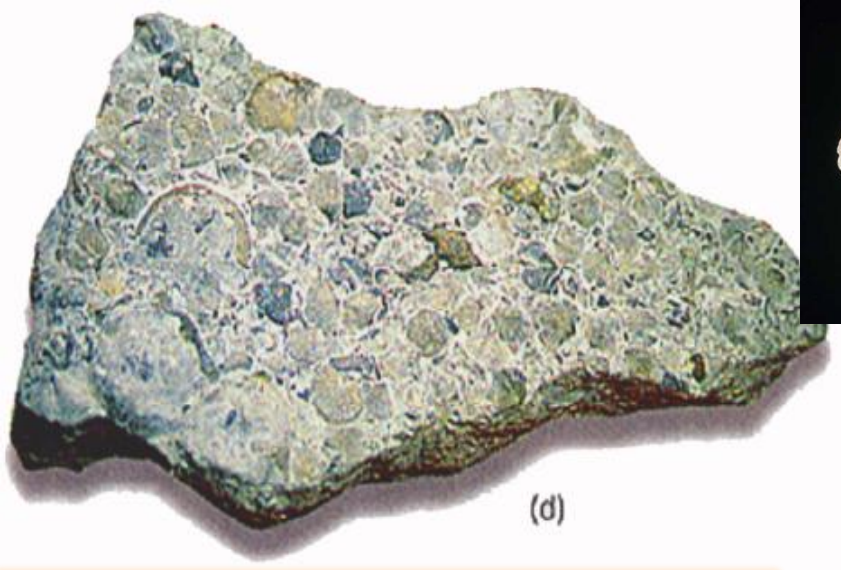
*Breccia*



angular clasts  
poorly sorted



*Siltstone & Shale*



(d)



**Chert**



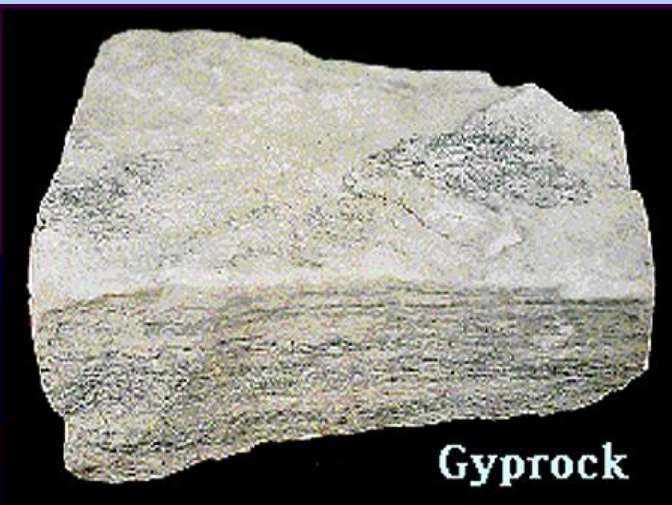
**Coquina**

**fossiliferous limestone**

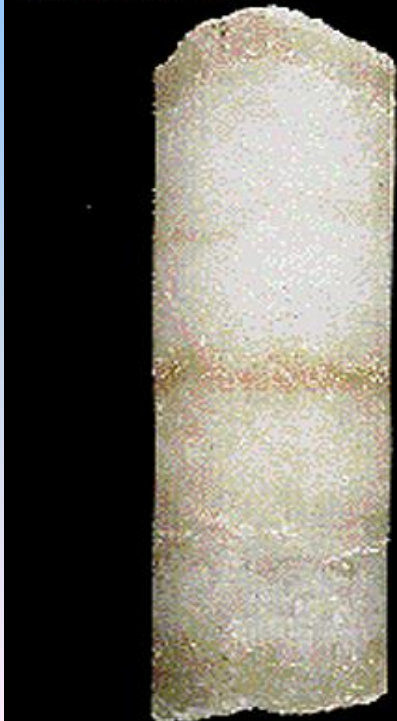
**Rock Salt**



**crystalline limestone**

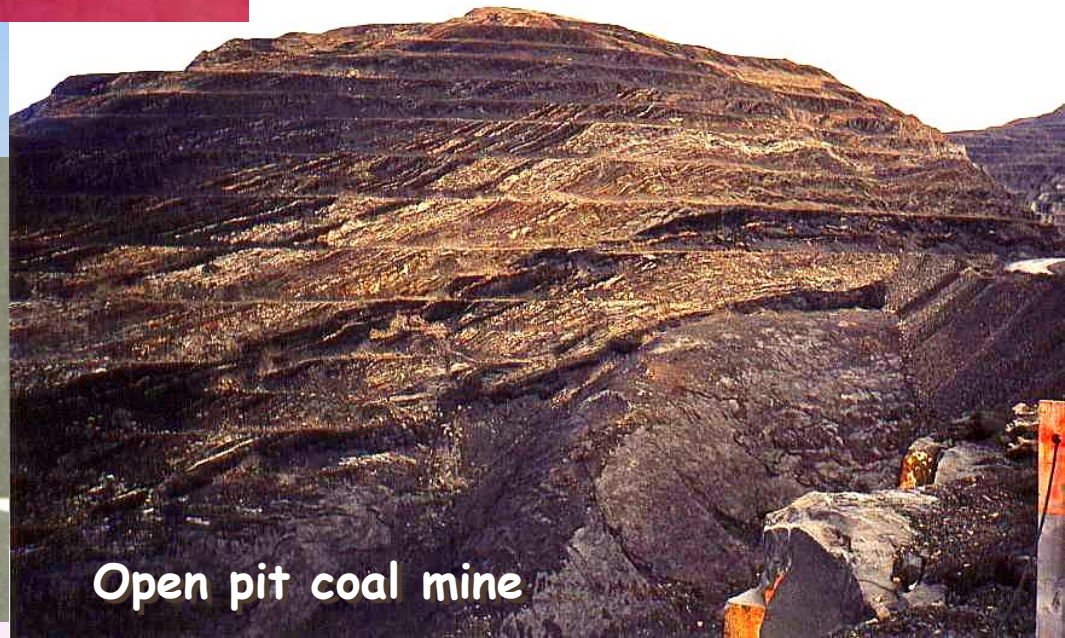


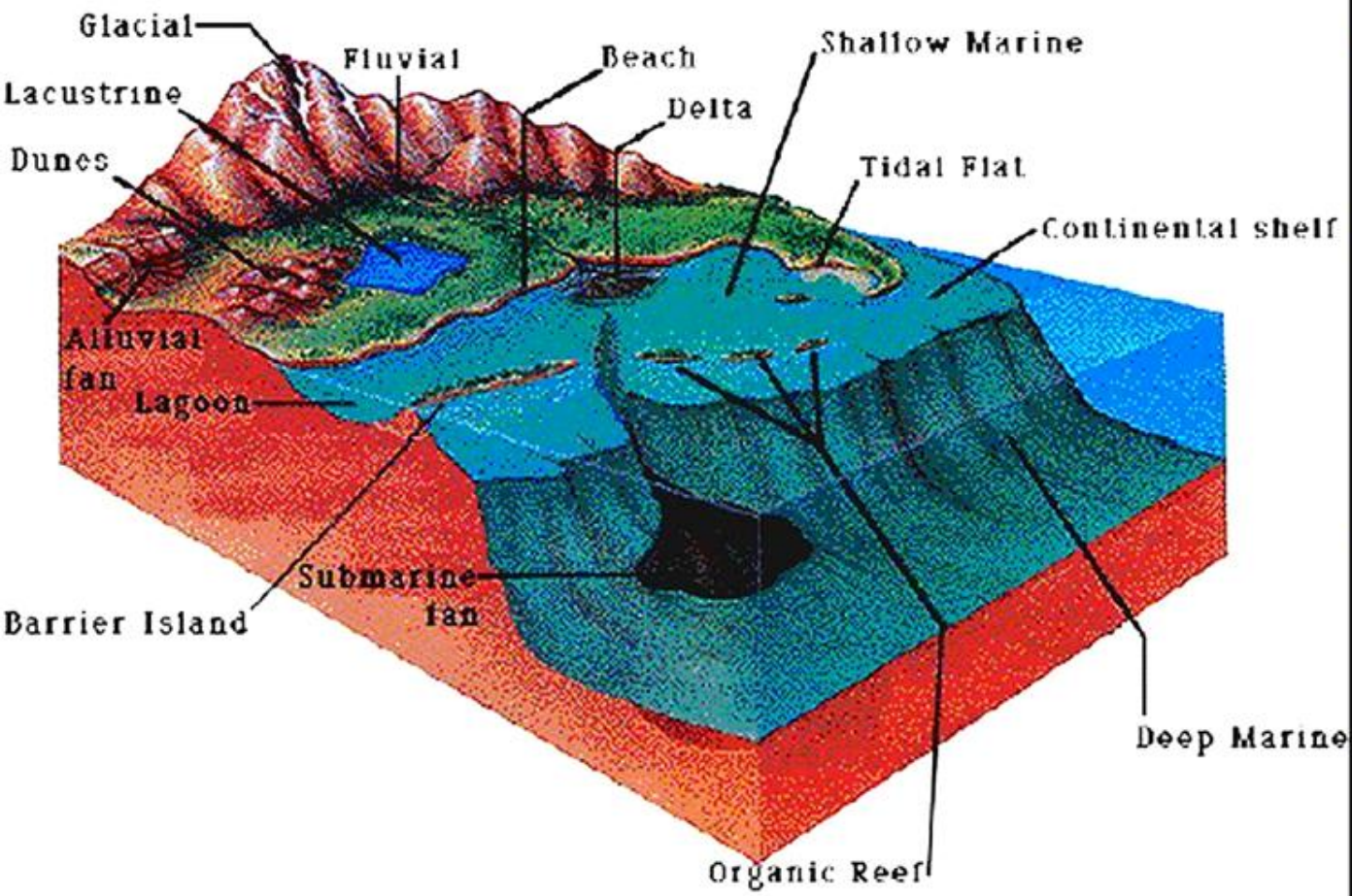
**Gyprock**



**Oolitic limestone**

# Coal- organic textured sedimentary rock





***Chemical***

**Limestones:** lagoons, lakes, shallow and deep marine

**Evaporites:** lagoons, lakes, closed shallow or deep marine systems

***Bio-Chemical***

**Limestones:** organic reefs, beaches, lagoons, lakes, shallow marine

**Chert:** deep marine

**Coal:** swamp, marsh

***Detrital***

**Sandstones:** beach, fan, river, delta, dunes, shallow marine

**Breccia:** fans, glacial

**Conglomerate:** fans, rivers, glacial

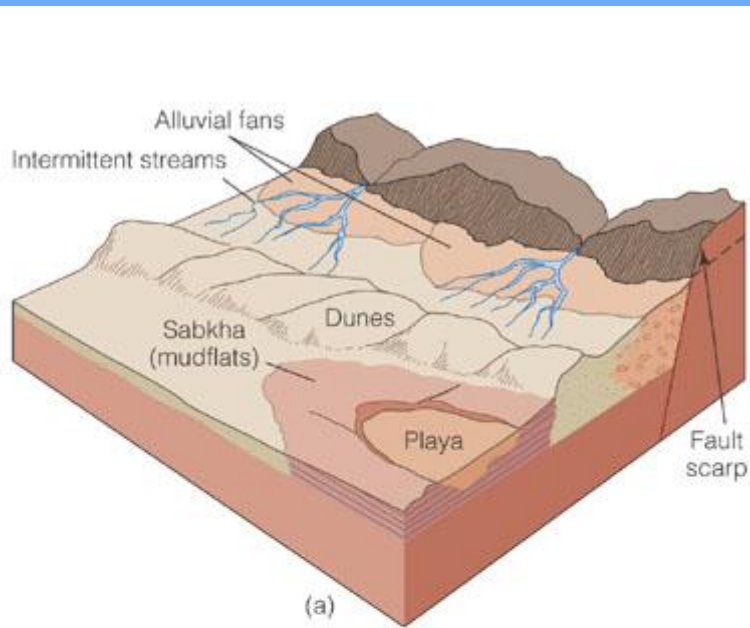
**Siltstones:** river-floodplain, swamp, delta, tidal flat, shallow marine, lagoon

**Shale:** lagoon, swamp, river-floodplain, delta, continental shelf, shallow marine

# Desert Environments

- Desert environments contain an association of features found in
  - + sand dune deposits,
  - + alluvial fan deposits,
  - + And lake deposits
- **Windblown dunes are typically composed**
  - + of well-sorted, well-rounded sand
  - + with cross-beds meters to tens of meters high
  - + land-dwelling plants and animals make up any fossils

# Associations in Desert Basin

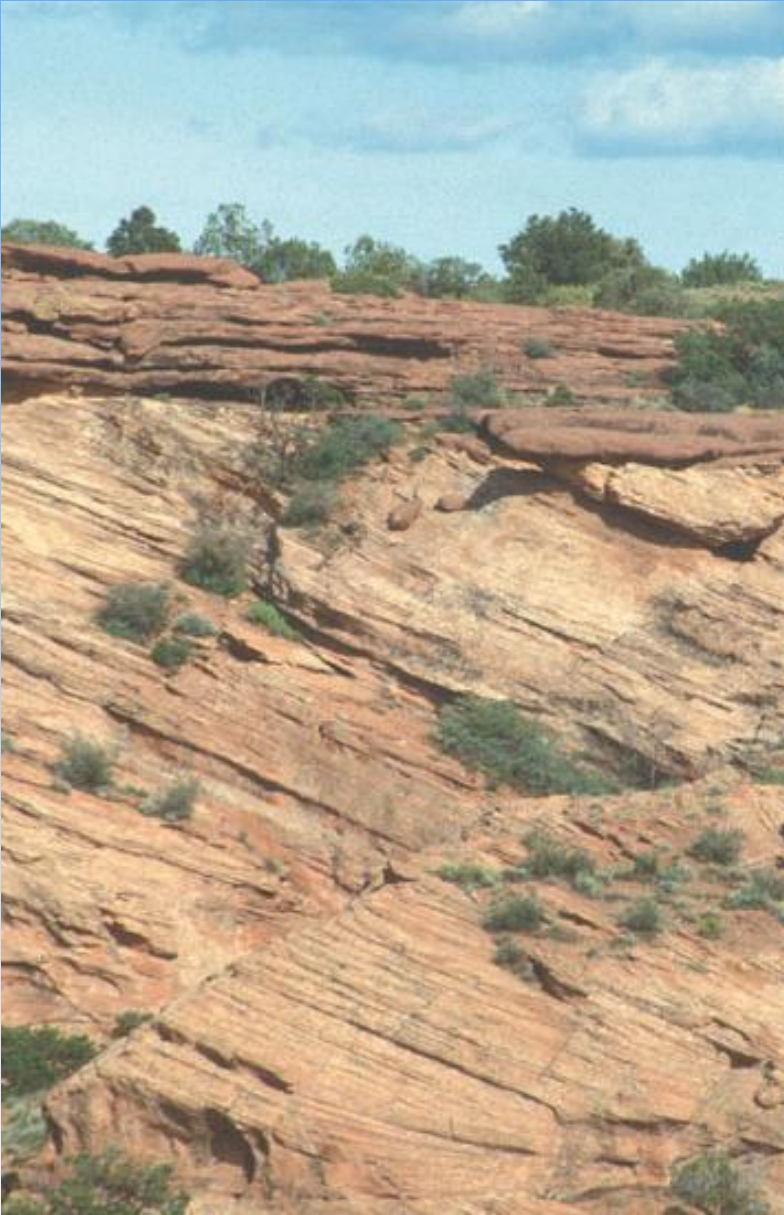


- A desert basin showing the association
  - + of alluvial fan,
  - + sand dune,
  - + and playa lake deposits



- In the photo,
  - + the light colored area in the distance
  - + is a playa lake deposit in Utah

# Dune Cross-Beds



- Large-scale cross-beds
  - + in a Permian-aged
  - + wind-blown dune deposit in Arizona

# Alluvial Fans and Playa Lakes

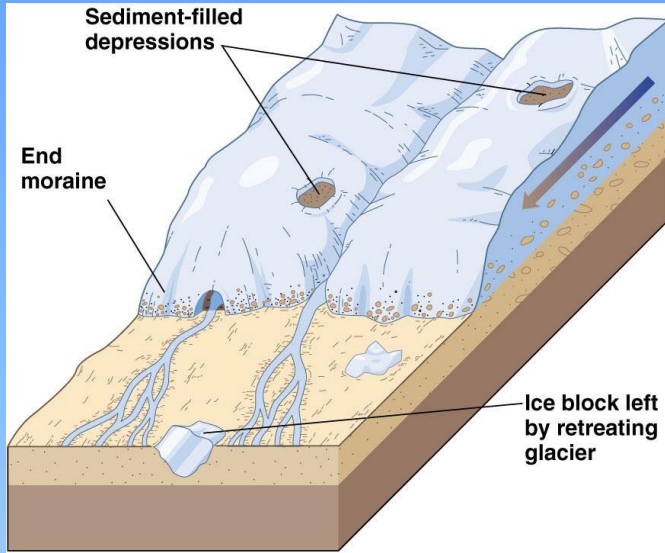
- Alluvial fans form best along the margins of desert basins
  - + where streams and debris flows
  - + discharge from mountains onto a valley floor
  - + They form a triangular (fan-shaped) deposit of sand and gravel
- The more central part of a desert basin
  - + might be the site of a temporary lake, a playa lake,
  - + in which laminated mud and evaporites accumulate

# Glacial Environments

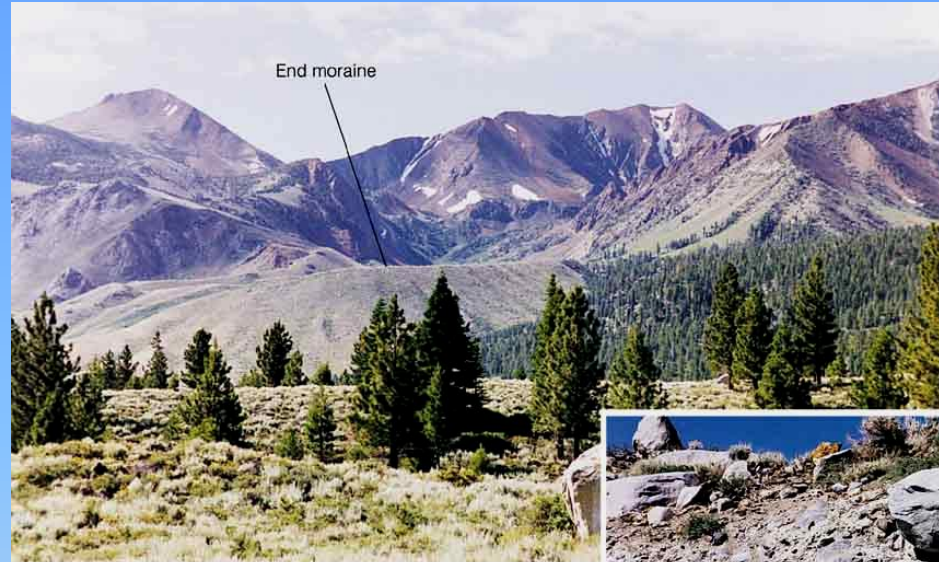
Glacial deposits and environments are collectively called **drift**

- **Till** is poorly sorted, nonstratified drift
  - deposited directly by glacial ice
  - mostly in ridge-like deposits called *moraines*
- **Outwash** is sand and gravel deposited
  - by braided streams issuing from melting glaciers
- The association of these deposits along with
  - scratched (striated) and polished bedrock
  - Indicates that glaciers were involved

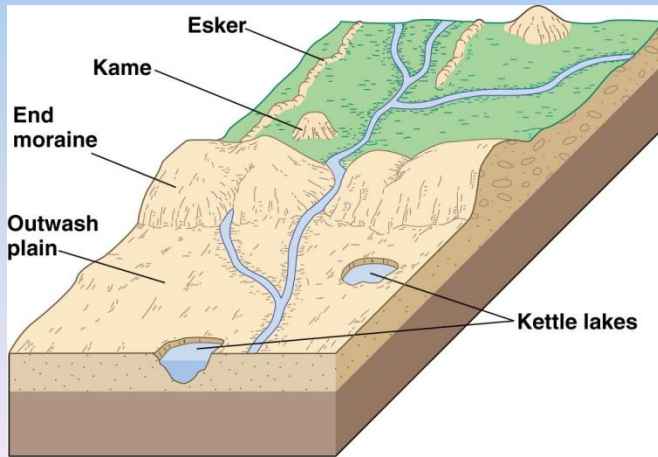
# Moraines and Till



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(b) © 2001 Brooks/Cole Publishing/ITP

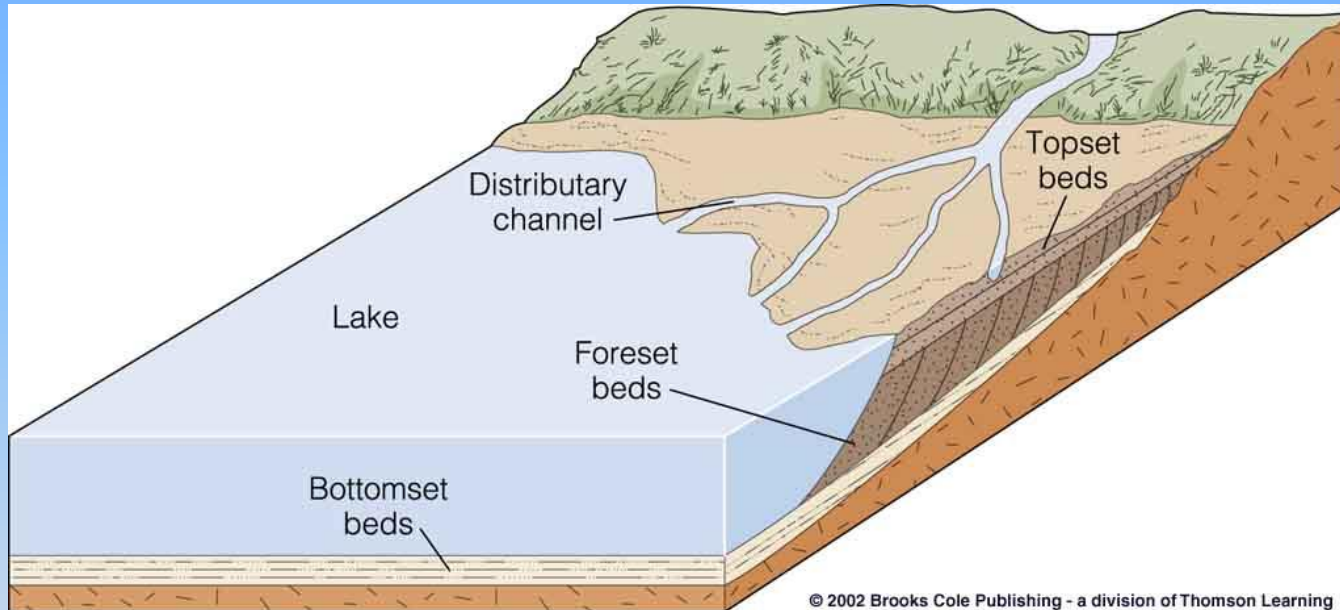
- Origin of glacial drift

# Moraines are made of poorly sorted till



# Simple Deltas

- The simplest deltas are those in lakes and consist of



- topset beds
- foreset beds
- bottomset beds
- As the delta builds outward it **progrades**

- and forms a vertical sequence of rocks
- that becomes coarser-grained from the bottom to top
- The bottomset beds may contain marine (or lake) fossils,
- whereas the topset beds contain land fossils

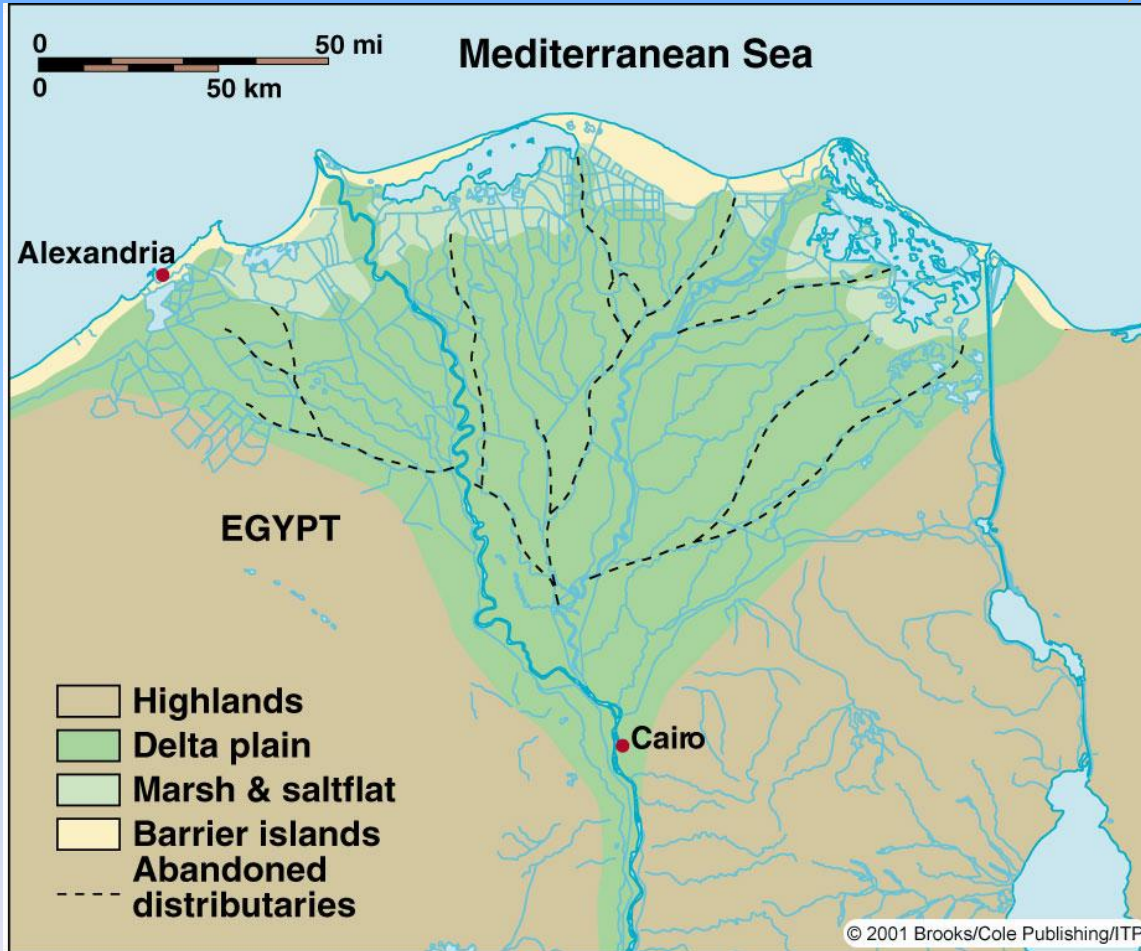


Topset beds

Foreset beds

Bottomset beds

# Wave-Dominated Deltas



## ➤ Wave-dominated deltas

- + such as the Nile Delta of Egypt
- + also have distributary channels
- + but their seaward margin
- + is modified by wave action

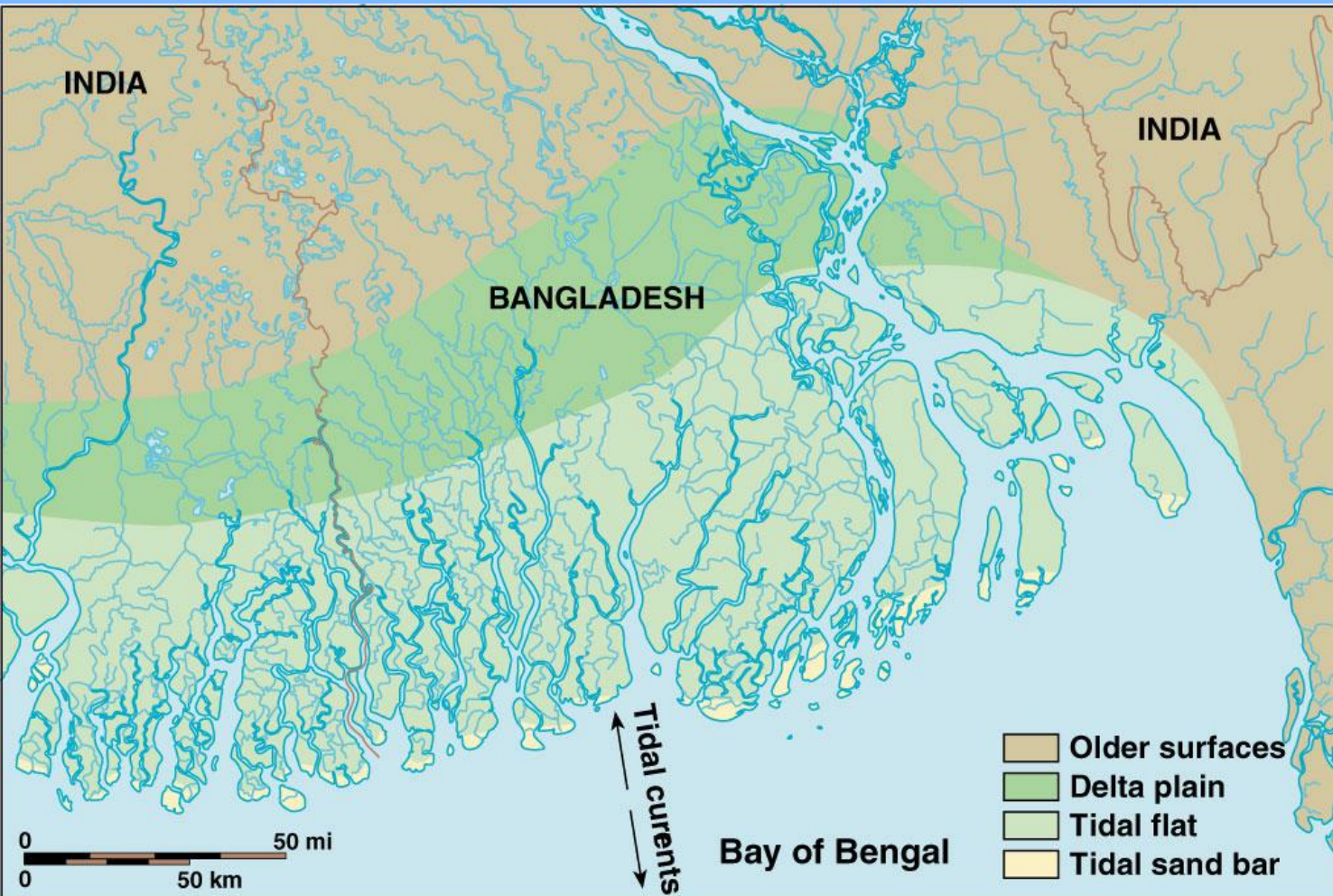
# Stream/River-Dominated Deltas



- Stream/river-dominated deltas
  - + have long distributary channels
  - + extending far seaward
  - + Mississippi River delta

# Tide-Dominated Deltas

- Tide-Dominated Deltas,
  - + such as the Ganges-Brahmaputra delta



- of Bangladesh
- have tidal sand bodies
- along the direction of tidal flow









# 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  $\mu\text{m}$ .
- Siltstone is similar to shale except that it lacks fissility.



Copyright ©Andrew Alden

# 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.



# 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.



South Carolina Geological Survey

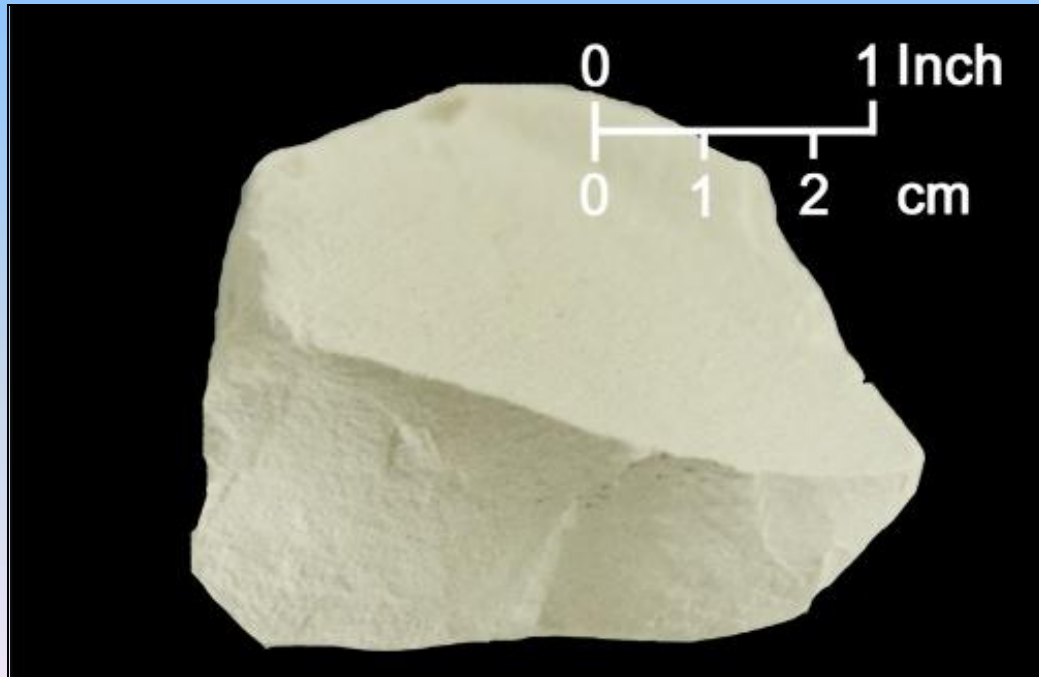
# BRECCIA

- 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.



# 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



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# LIMESTONE

- Limestone consists almost entirely of the mineral calcite ( $\text{CaCO}_3$ ) 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.



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.

# 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.



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# 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



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# CHERT

- Chert represent a group of hard rocks made from micro- and cryptocrystalline silica ( $\text{SiO}_2$ ). 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.
- 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.

Jaspe



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Agate forming inside a coral



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# 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.
- Geologists use characteristics 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



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## Bedding Planes



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## Cross-Bedding



Copyright @Marli Miller

## Mud Cracks



Courtesy NASA Visible Earth

## Ripple Marks



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## Ripples and Mudcracks



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