Sedimentary rocks

Velledits Felicitász

Rock classification

- Magmatic rocks
  - Intrusive (gabbro, diorite, granite)
  - Volcanic (basalt, andesite, rhyolite)



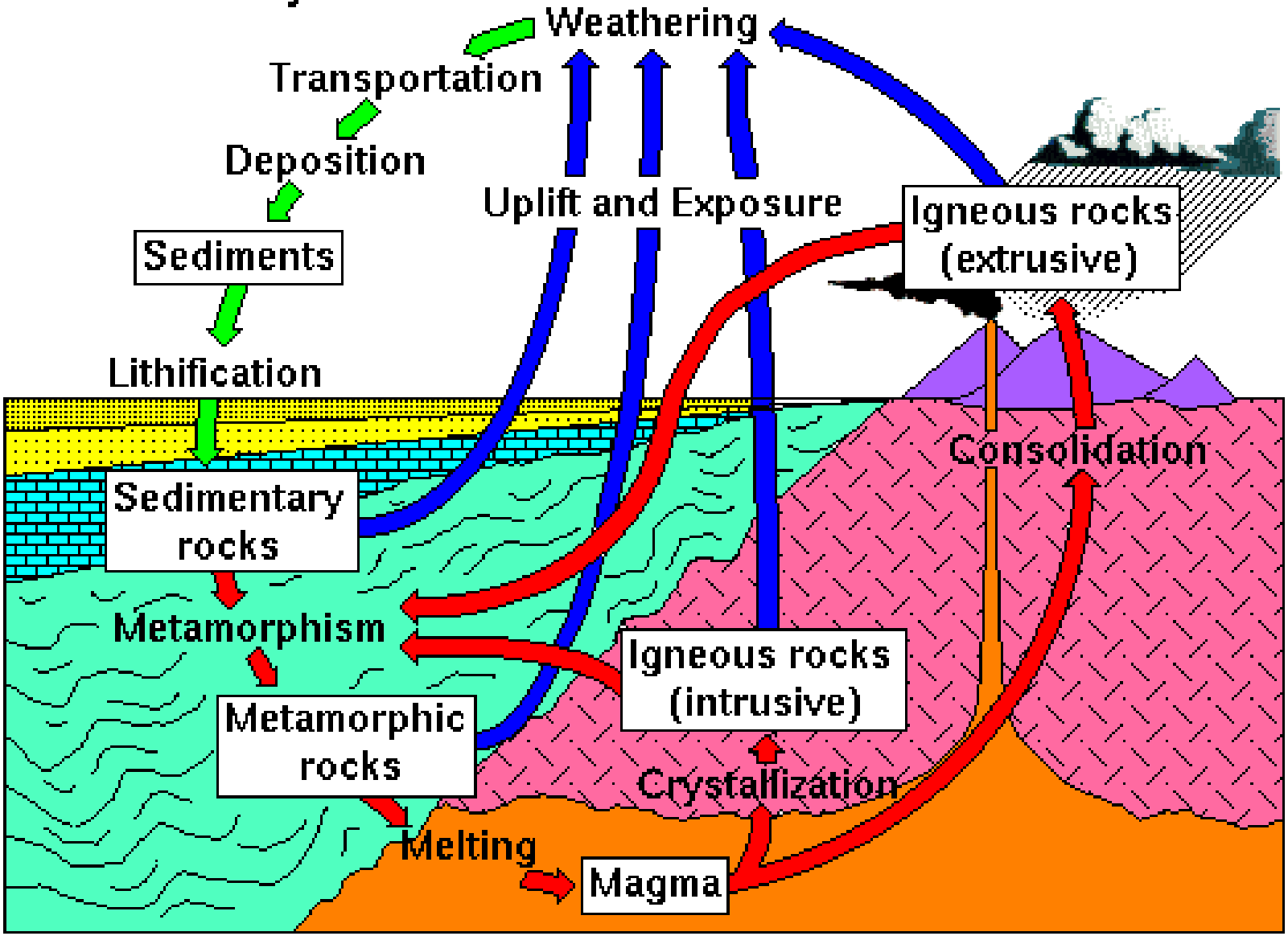
- Sedimentary rocks
  - Clastic (conglomerate, sandstone, siltstone, mudstone /shale)
  - Chemical and biogenic (limestone, dolomite, evaporite manganese rocks)
  - Organic (coal, crude oil, natural gas)



- Metamorphic rocks
  - Very low grade (shale)
  - Low grade (phyllite, serpentinite)
  - Medium grade (schist, amhibolite, marble, quartzite)
  - High grade (gneiss, eclogite)



The Rock Cycle



Sedimentation- Sedimentary rocks (Introduction)

- MUCH OF EARTH'S SURFACE, including its seafloor, is covered with sediments. These layers of loose particles have diverse origins.

- Most sediments are created by **weathering of the continental crust (siliciclastic rocks)**.

- Some are the remains of mineral shells secreted by organisms (**limestone**).

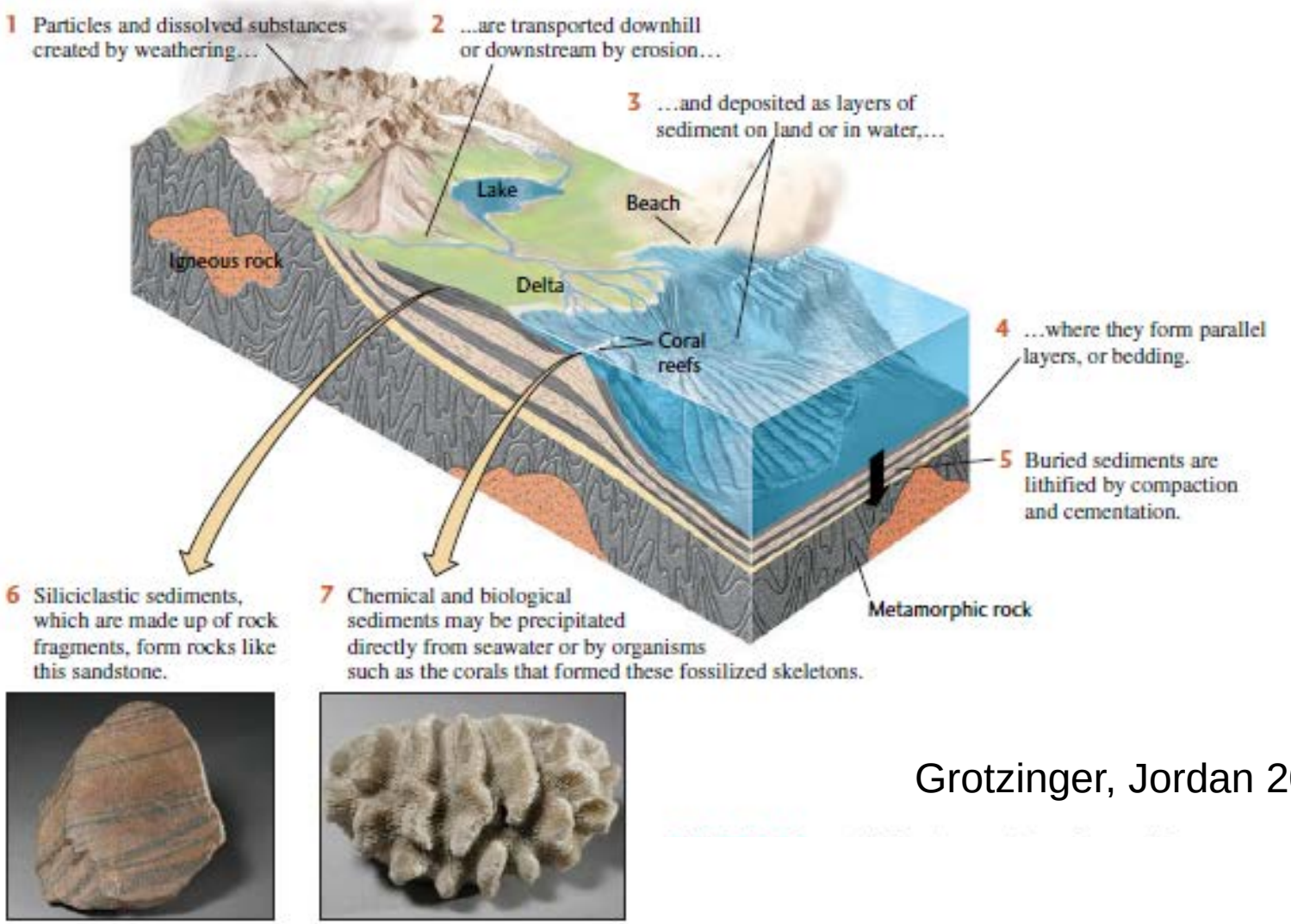
- Others consist of inorganic crystals that precipitated when dissolved chemicals in oceans and lakes (**evaporites**)

- **Sedimentary rocks were once sediments, so they are records of the conditions at Earth's surface when and where those sediments were deposited.**

The top of Mount Everest, for example, is composed of fossiliferous (fossil-containing) limestones. Because we know that such limestones are formed from carbonate minerals in seawater, we can conclude that layers on the Mount Everest must once have been part of an ocean floor! By reconstructing such environments, we can map the continents and oceans of long ago.

Actualism

- **Principle of geological actualism**, which states that all past **geological** action was like all present **geological** action.
  The **principle** of **actualism** is the cornerstone of paleoecology.



Grotzinger, Jordan 2014

About 75 percent of land areas are covered by **sediments and sedimentary rocks. Across the ocean floor**, which represents about 70 percent of Earth's solid surface, virtually everything **is covered by sediment**. **Igneous rocks** are exposed only at the crest of mid-ocean ridges and in some volcanic area. Below the sediments and sedimentary rocks **the basement consists of metamorphic rocks**.

Sedimentary rock types I.

- **Siliciclastic sediments** are made up of physically deposited particles, such as grains of **quartz** and **feldspar** derived from weathered granite. (*Clastic* is derived from the Greek word *klastos,* meaning "broken.") These sediments are laid down by running water, wind, and ice.

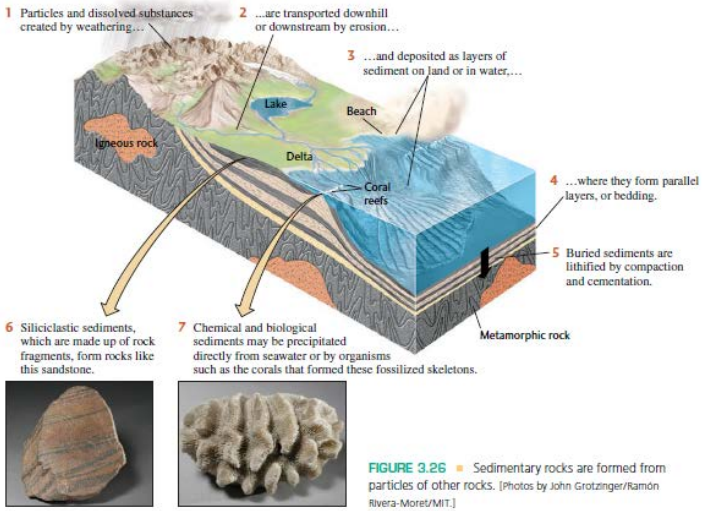


FIGURE 3.26 ■ Sedimentary rocks are formed from particles of other rocks. [Photos by John Grotzinger/Ramón Rivera-Moret/MIT.]

Sedimentary rock types II.

- **Chemical sediments** and **biological sediments.**
- *Halite* is a chemical sediment that precipitates directly from *evaporating* seawater.
- *Calcite* is precipitated by marine organisms to form shells or skeletons, which form *biological*
- *sediments* when
- the organisms die.

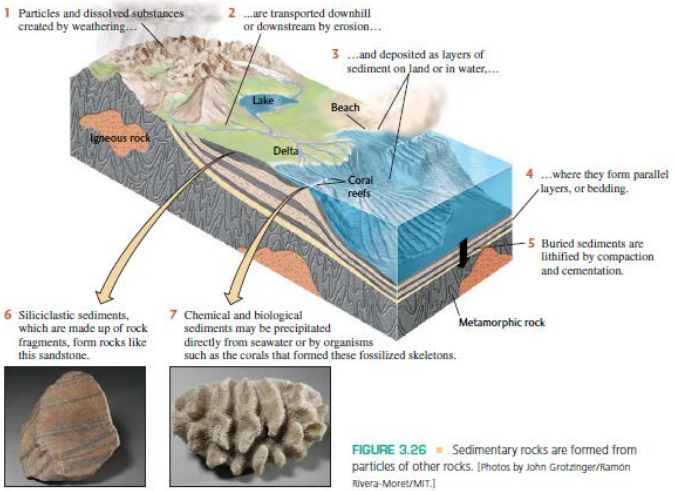


FIGURE 3.26 ■ Sedimentary rocks are formed from particles of other rocks. [Photos by John Grotzinger/Ramón Rivera-Moret/MIT.]

Sedimentary rocks



Conglomerate



Sandstone



Claystone

CLASTIC SEDIMENTARY ROCKS



Fossiliferous limestone



Travertine



Dolomite



Chert



Rock salt

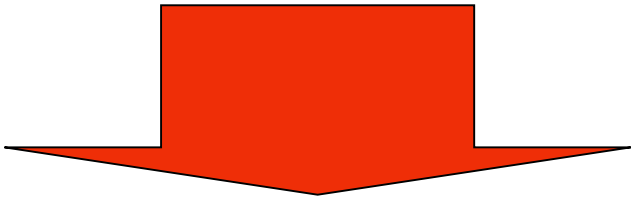
BIOGENIC-CHEMICAL ROCKS

Practical value of sedimentary rocks

- The study of sediments and sedimentary rocks has great practical value as well. ***Oil, natural gas, and coal,*** our most valuable fossil-fuel resources, are found in these rocks.
- A number of other important ***mineral resources*** are also sedimentary, such as the phosphate rock used for fertilizer and much of the world's iron ore.
- **Knowing how these kinds of sediments form helps us to find and use these resources.**

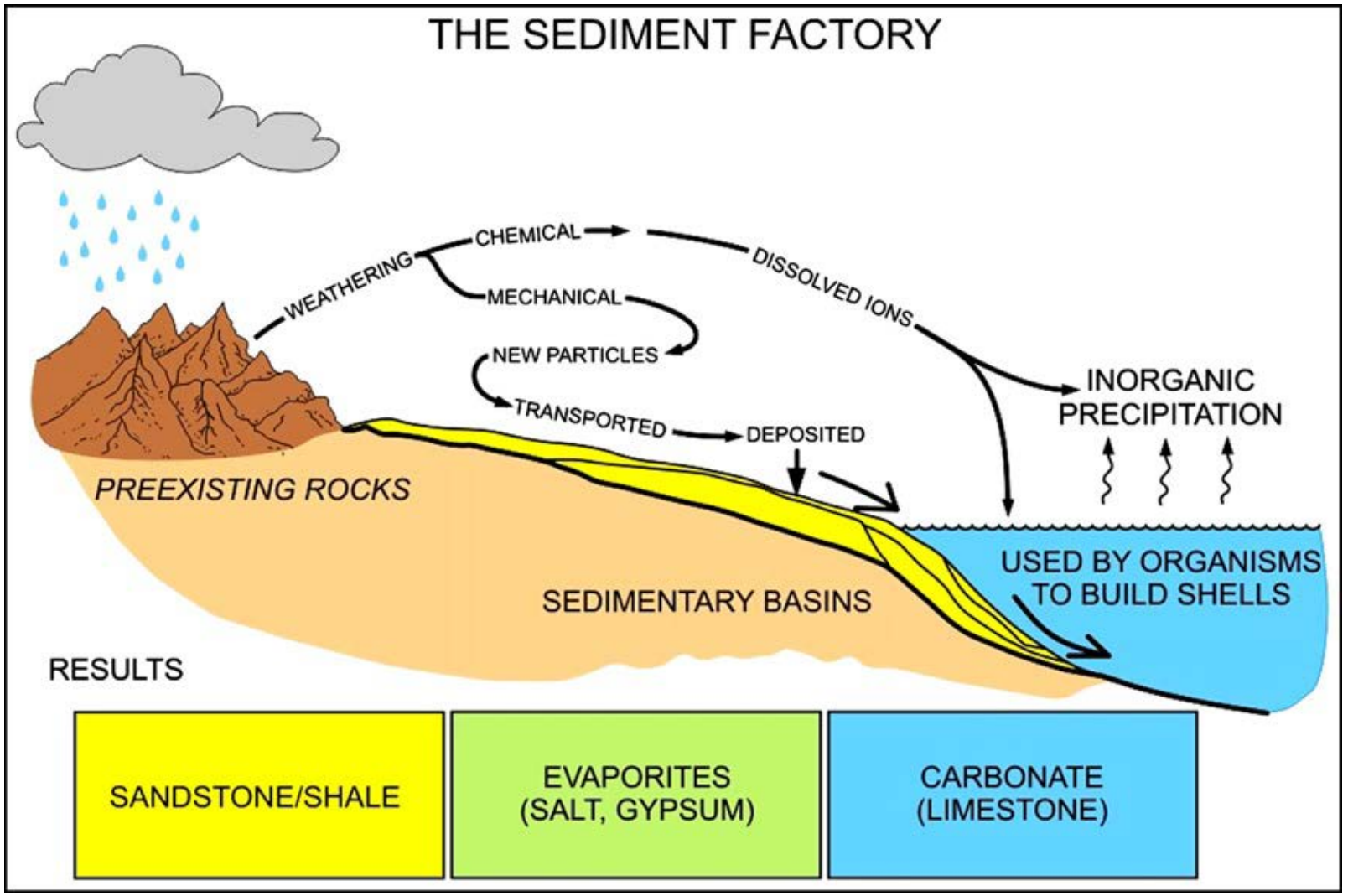
Benefits of fundamental rock properties

- If we recognize and characterize the **texture** (**grain size, sedimentary structures, composition**) in cores and borehole-image logs of reservoir formations



- predict the reservoir's external geometry and internal architecture, the reservoir rock's orientation and trend, and potential interactions between reservoir fluids and reservoir rock.

The three common groups of sedimentary rocks and how they form.



Slatt 2009

Composition of siliciclastic and carbonate sedimentary rocks. Clasts, matrix, cement

Clasts: the fragments that make up a sedimentary rock.

They may range in size from silt through sand to gravel (granules, pebbles, cobbles and boulders).

Matrix: finer-grained material that lies between the clasts.

There is no absolute size range for the **matrix**: the matrix of a sandstone may be silt and clay-sized material, the matrix of a conglomerate may be sand, silt or clay.

Surface processes of the siliciclastic rocks

- **I. Weathering**
- **II. Erosion**
- **III. Transportation**
- **IV. Burial**
- **V. Diagenesis**

- The most important surface processes of the rock cycle that are important in the formation of **siliciclastic sedimentary** rocks

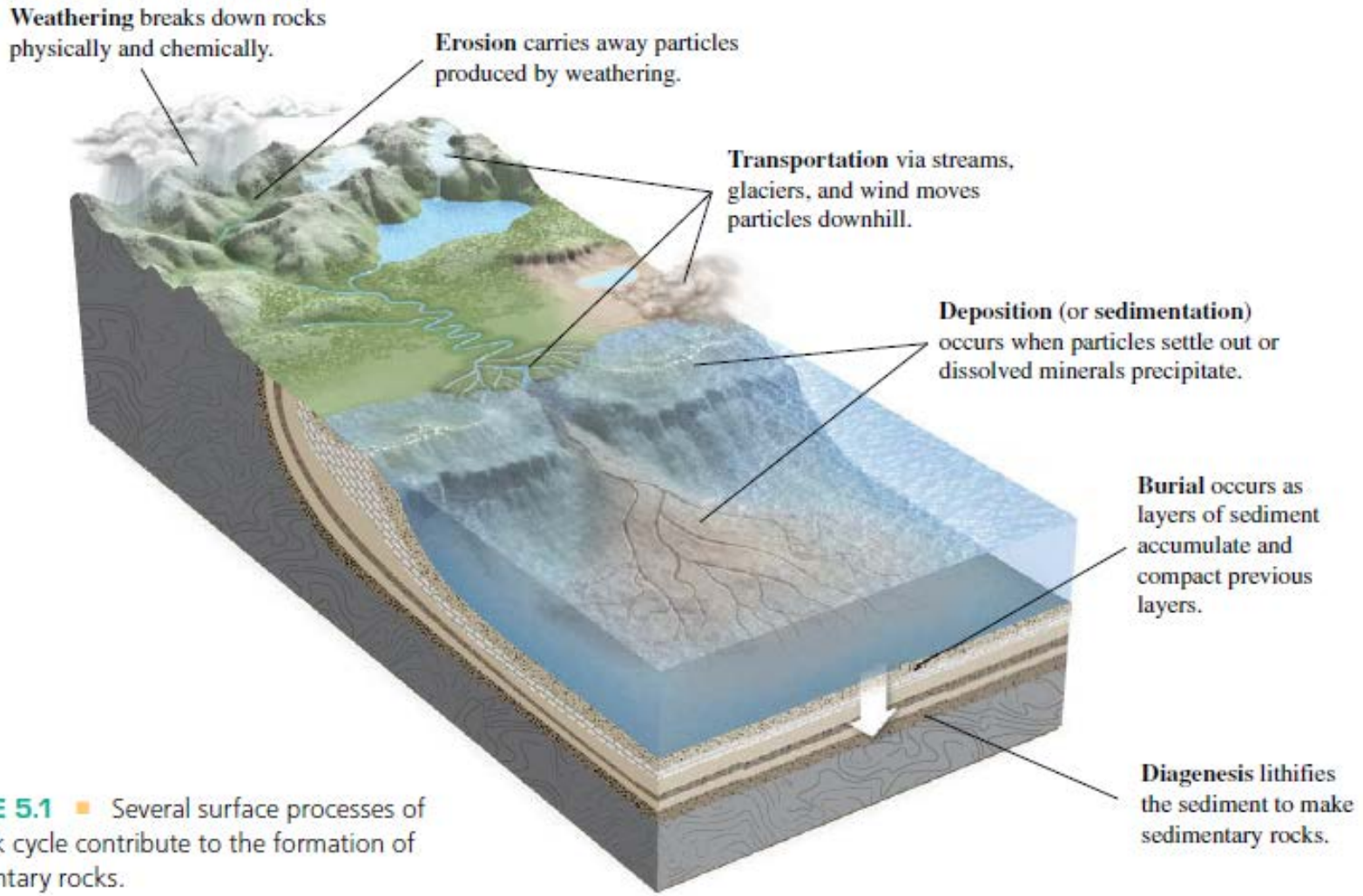


FIGURE 5.1 ■ Several surface processes of the rock cycle contribute to the formation of sedimentary rocks.

Surface processes of the rock cycle
I. **Weathering**

- **<u>I. Weathering</u>**: the process by which rocks are broken down at Earth's surface to produce sediment particles.

There are two types of weathering:

There are two types of weathering:

1) **Physical weathering** takes place when solid rock is fragmented by mechanical processes, such as freezing and melting or wedging by tree roots.

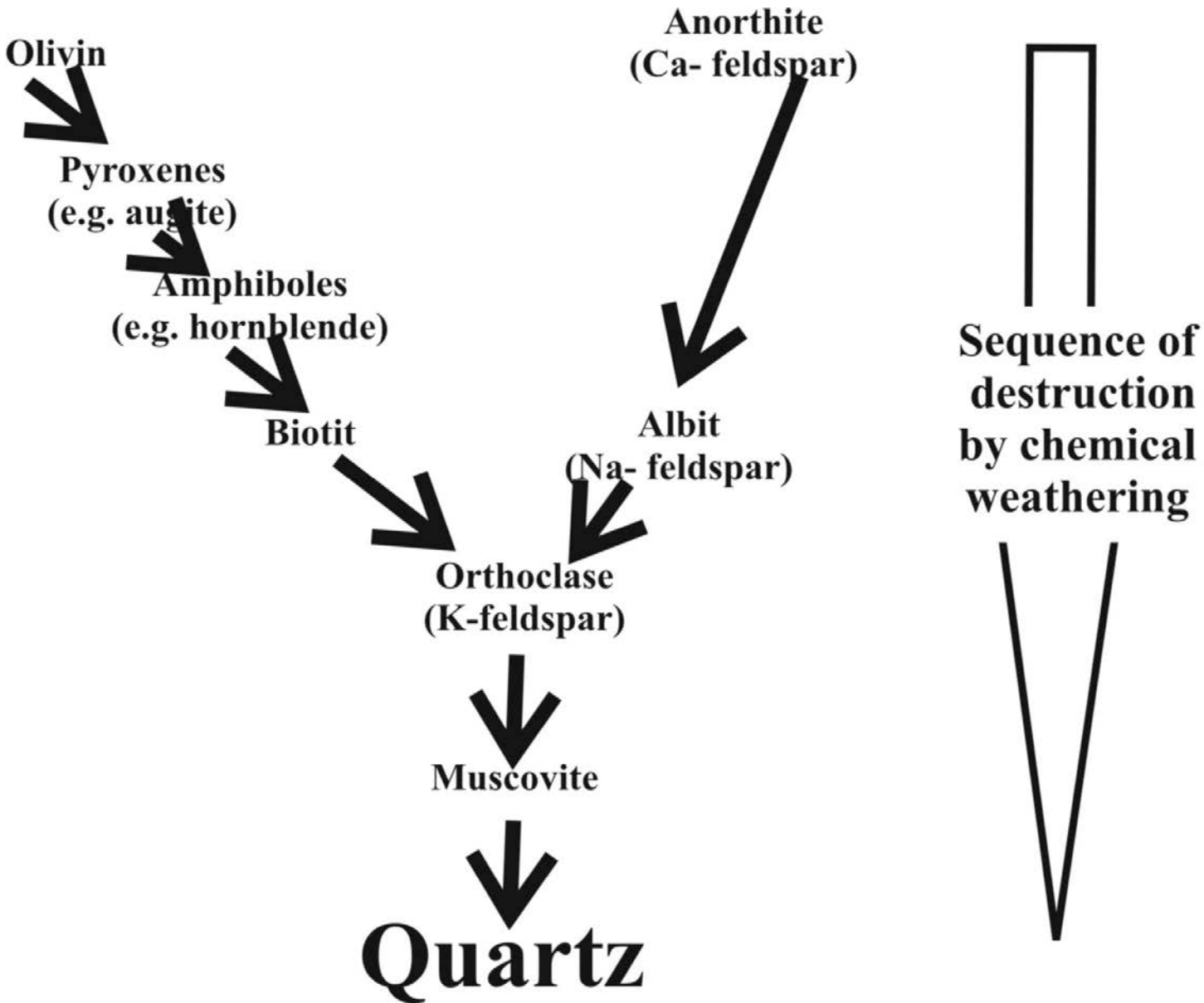
Physical weathering do not change its chemical composition.

The rubble of broken stone often seen at the tops of mountains and hills is primarily the result of physical weathering.

2) Chemical weathering refers to processes by which the minerals in a rock are *chemically altered or dissolved*.

The blurring or disappearance of lettering on old ravestones and monuments is caused mainly by chemical weathering.

Bowen's sequence of crystallization



Chemical weathering

- Ground water is acidic

(dissolved CO_2,
humid acids produced by biological processes in soil)

Relative mobility of elements:

Ca > Na > Mg >K > Si > Fe > Al

(sodium) (potash) (silicon)

Chemical weathering

Separates rock

Solutes | **Newly formed minerals** | **Residuum**

Na, K, rare earth,Mg, Ca Str

↓

Flushed out

↓

Find their way to the sea

↓

Precipitated as limestones, dolomites, evaporites

Clay

Quartz

The residuum of a maturely weathered rock consists of: **quartz, clay (kaolin), bauxite, limonite**

Physical weathering



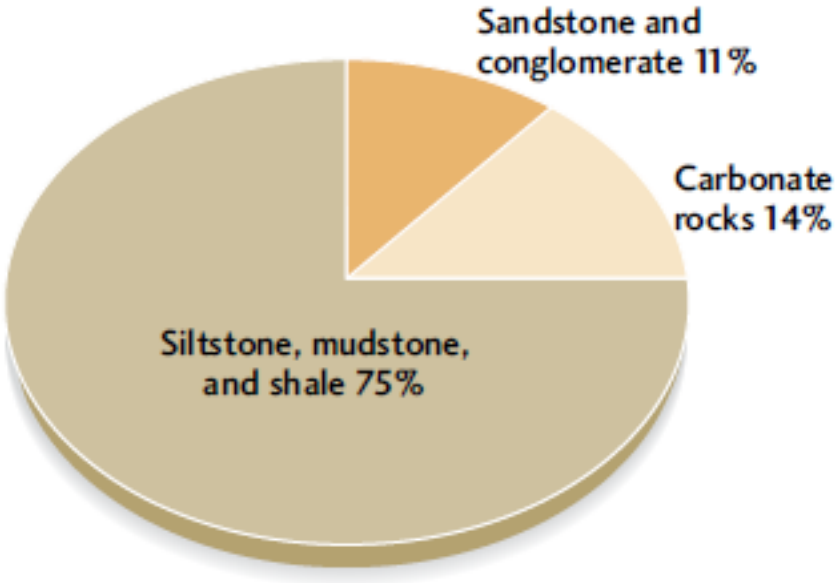


Chemical weathering





The relative abundances of the major sedimentary rock types.



The **fine-grained siliciclastics** are by far the **most abundant**—about three times more common than the coarser-grained siliciclastics. The abundance of the fine-grained siliciclastics, which contain large amounts of **clay minerals**, is *due to the chemical weathering of the large quantities of feldspar and other silicate minerals* in Earth's crust into clay minerals.

Surface processes of the rock cycle II.**Erosion**

- Are the processes that dislodge particles of rock produced by weathering and move them away from the source area. Erosion occurs most commonly when rainwater runs downhill.

Surface processes of the rock cycle III. **Transportation**

- **Transportation**: are processes by which sediment particles are moved to sink areas.
- Transportation occurs when *water, wind*, or the moving *ice* of glaciers transport particles to new locations downhill or downstream.
- Most of the clastic particles produced by weathering on land end up deposited *in various sedimentary basins in the oceans*.
- A smaller amount of siliciclastic sediment is deposited *in sedimentary environments on land*.
- Most chemical and biological sediments are also deposited *in ocean basins*, although some are deposited *in lakes*.

- After clastic particles and dissolved ions have been formed by weathering and dislodged by erosion, they start their journey to a sedimentary basin

- CURRENTS AS TRANSPORT AGENTS:
- Most sediments are transported by currents of **air** or **water**.
- As particles are lifted into the air or water, the current carries them downwind or downstream.

The stronger the current—that is, the faster it flows—the larger the particles it can transport.

Sorting

- Sorting describes the range of particle sizes comprising a particular sediment

- "P**oorly sorted**," a sediment composed of grains of a wide range of sizes.
- **"Well sorted."** the sediment consists of grains of similar diameter.

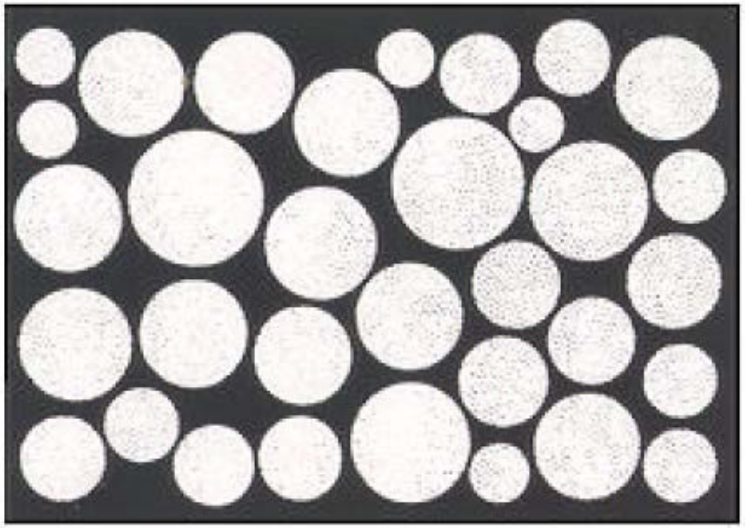
- **Sorting is a function** of the origin and transport history of the detritus.

With increased transport distance or repeated agitation of a sediment, the different sizes tend to become separated.

Sorting controls porosity and permeability

In sandstone, porosity is largely controlled by sorting.

Well Sorted Rock



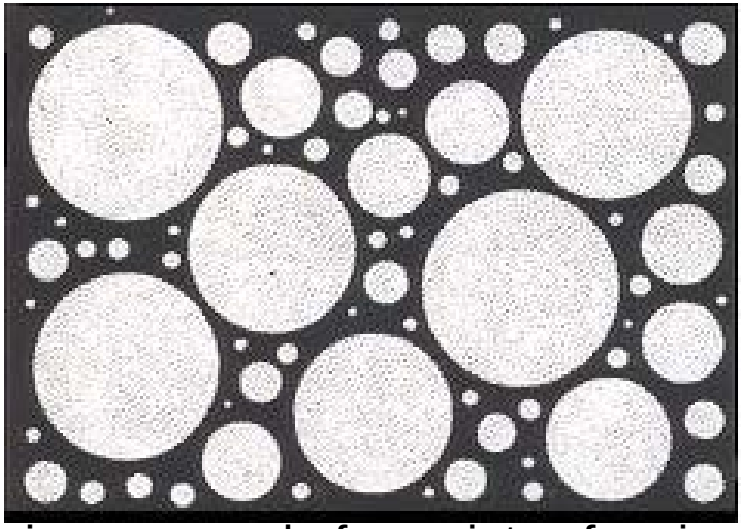
Halliburton 2001

Grains: same size and shape.
If the grains are well rounded and of similar size then they will not fit well together.

Leaving a large amount of pore space between the grains.

Porosity in a well sorted rock is high.

Poorly Sorted Rock



Rock is composed of a variety of grain sizes and shapes.
Porosity can be reduced because smaller grains can be inserted in between the larger grains.

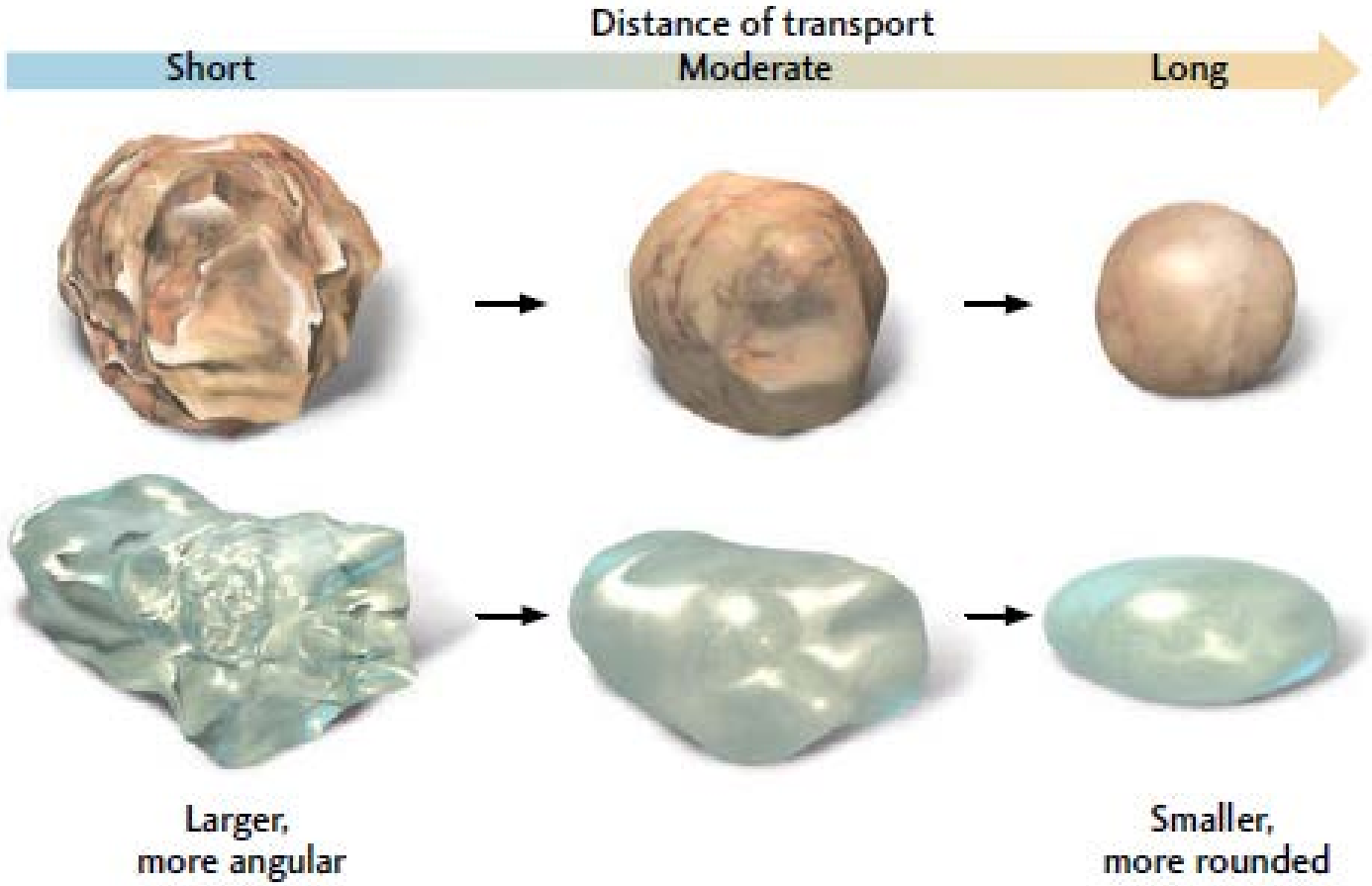
They reduce the amount of pore space.

Porosity in a poorly sorted rock is low.

Clast sphericity

- How close the clasts is to a sphere.
- Discoid or needle-like clasts have a low sphericity.
- Sphericity is an **inherited** feature, that is, it depends on the shapes of the fragments which formed during weathering.
- A slab-shaped clast will become more rounded during transport and become disc-shaped, but will generally retain its form with one axis much shorter than the other two.

Abrasion during transportation



Particles become more rounded and slightly smaller as they are transported, although the general shape of the particle may not change significantly.

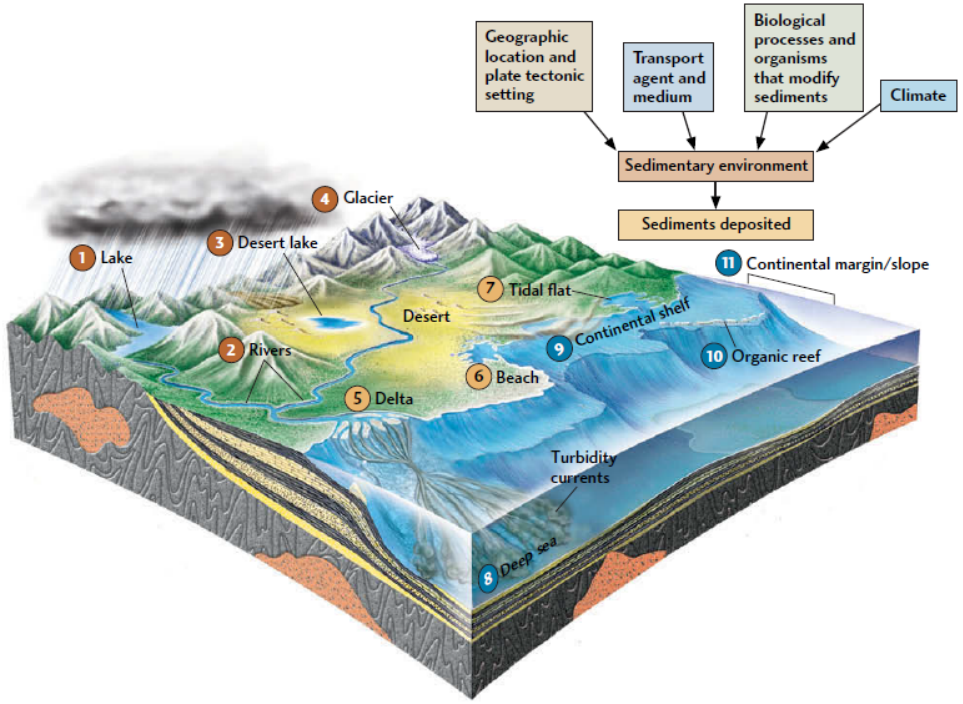
Surface processes of the rock cycle
IV. **Sedimentation**

- *Sedimentation:* refers to processes by which sediment particles settle out as water currents slow, winds die down, or glacier edges melt to form layers of sediment in sink areas.
- Sediments tend to accumulate in depressions in Earth’s crust.

Sedimentary environments

- A **sedimentary environment** is an area of sediment deposition characterized by a particular *combination of climate and physical, chemical, and biological processes*.

Multiple factors interact to create sedimentary environments



Continental Environments	1 Lake	2 Alluvial	3 Desert	4 Glacial
Transport agent	Lake currents, waves	River currents	Wind	Ice, meltwater
Sediments	Sand and mud, saline precipitates in arid climates	Sand, mud, and gravel	Sand and dust	Sand, mud, and gravel
Climate	Arid to humid	Arid to humid	Arid	Cold
Biological processes	Freshwater organisms and precipitates	Organic matter in muddy flood deposits and wetlands	Little biological activity	Little biological activity

Shoreline Environments	5 Delta	6 Beach	7 Tidal flats
Transport agent	River currents, waves	Waves, tidal currents	Tidal currents
Sediments	Sand and mud	Sand and gravel	Sand and mud
Climate	Arid to humid	Arid to humid	Arid to humid
Biological processes	Burial of plant debris	Little biological activity	Organisms mix sediments

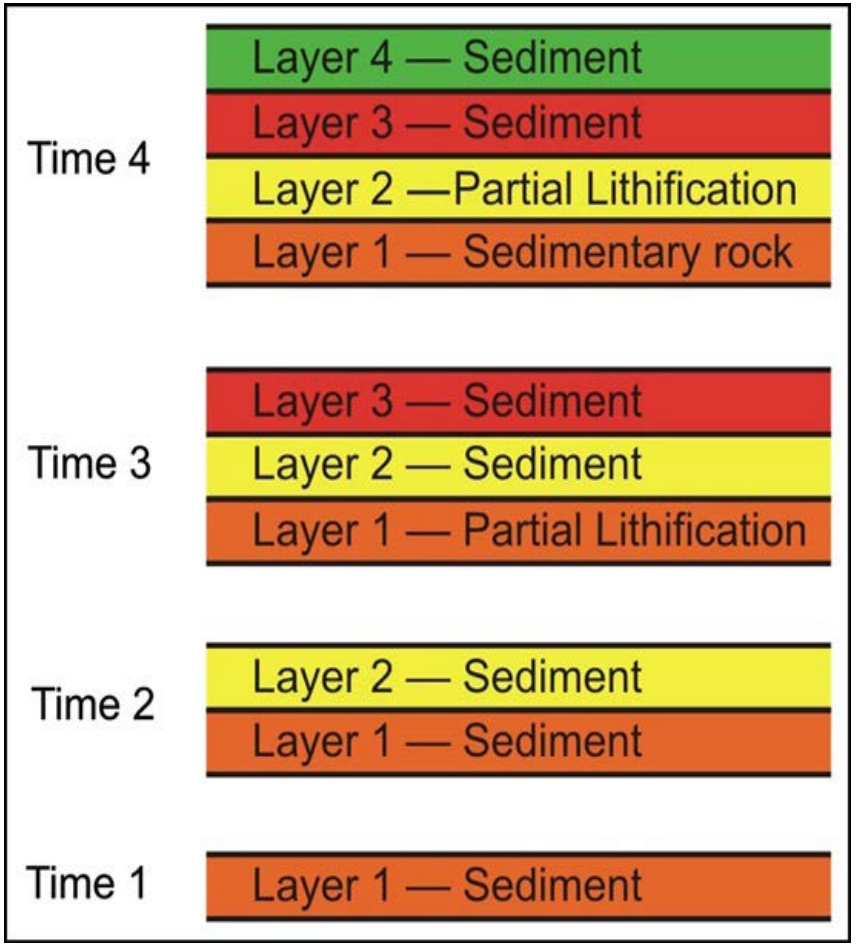
Marine Environments	8 Deep sea	9 Continental shelf	10 Organic reefs	11 Continental margin/slope
Transport agent	Ocean currents Turbidity currents	Waves and tides	Waves and tides	Ocean currents and waves
Sediments	Mud and sand	Sand and mud	Calcified organisms	Mud and sand
Biological processes	Deposition of remains of organisms	Deposition of remains of organisms	Secretion of carbonates by corals and other organisms	Deposition of remains of organisms

V. Burial
VI. Diagenesis

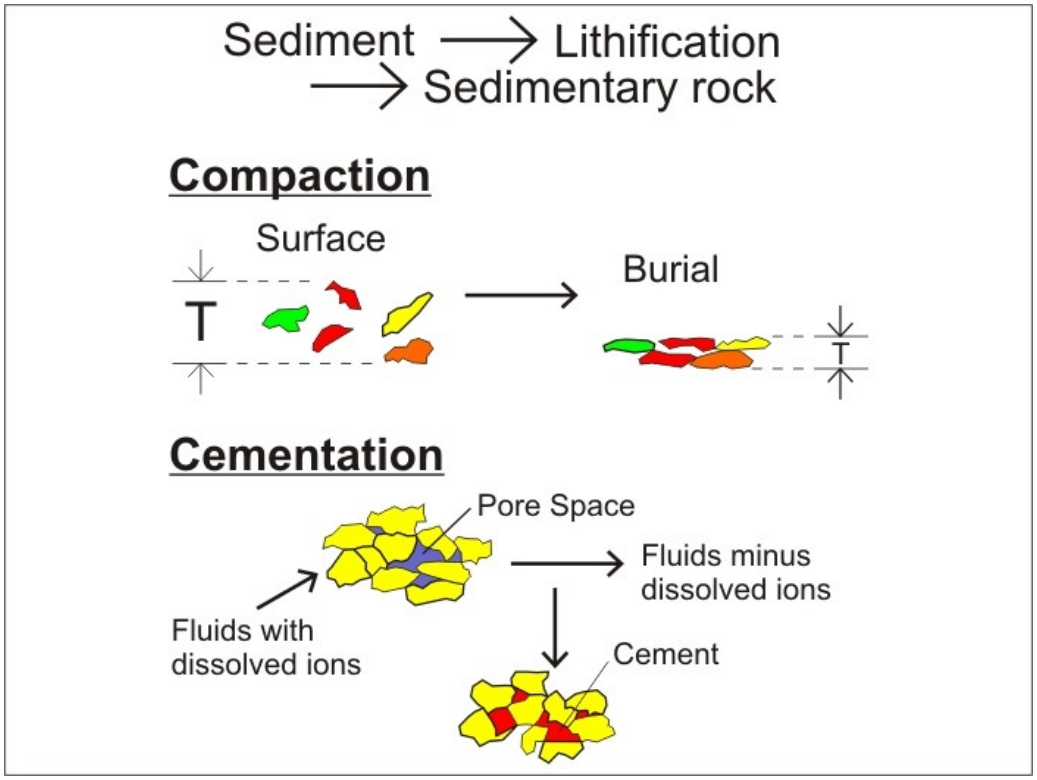
- As the sediments are buried under new layers of sediments, they are subjected to increasingly high temperatures and pressures as well as chemical changes.

Burial

- Temperature and pressure increase with depth beneath the Earth's surface,
- The sedimentary particles become susceptible to modification and lithification (the processes by which a sediment becomes a sedimentary rock) as they are buried deeper and deeper.

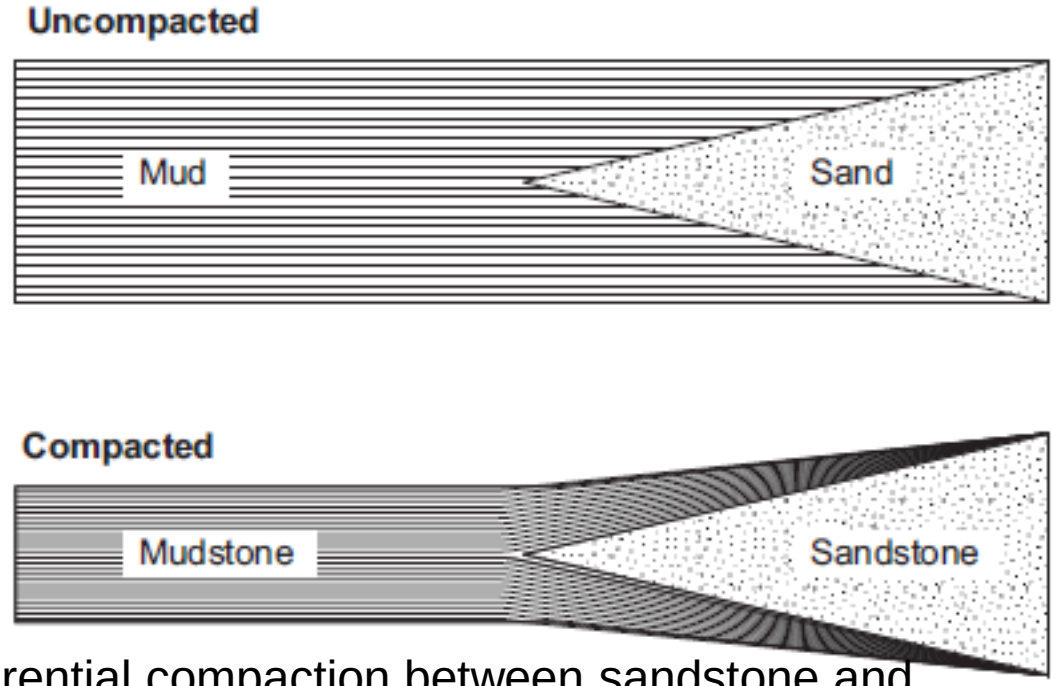


First effect of burial: compaction



- When sediments are buried, they become altered by the combined affects of physical **compaction** and **chemical reactions** under increased heat and pressure. Sometimes the reactions occur between solid grains and sometimes the reactions occur between grains and subsurface fluids.
- **Initial compaction** upon very early burial **reduces the thickness** of a deposit from T to t. But, not all of the pore spaces are eliminated. There is still pore space available for fluids to move through the sediment in the subsurface. These fluids contain dissolved ions that can precipitate in the pore spaces to form cement. Both of these processes lithify sediments.

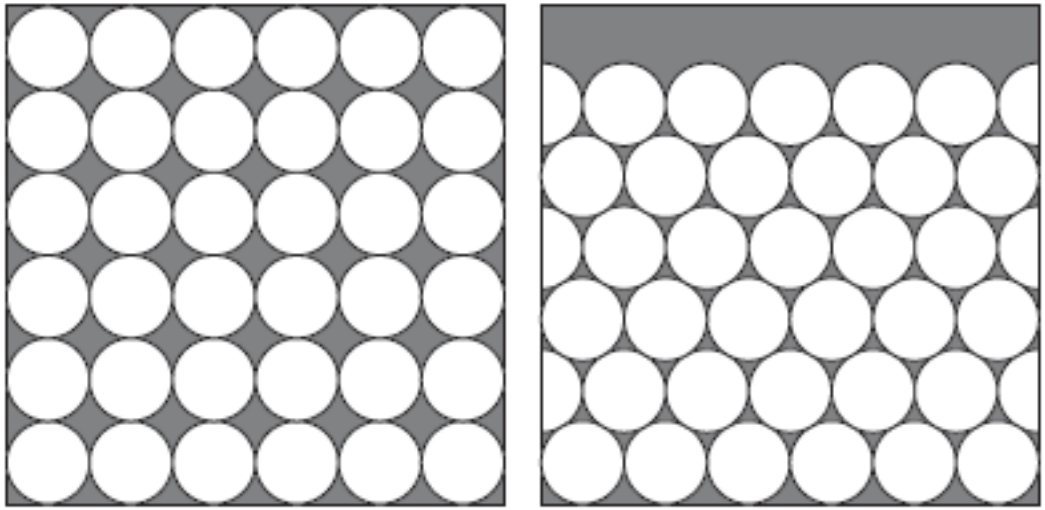
- Different minerals compact differently
- Ductile minerals such as lithic fragments of shale will compact much more than will rigid grains, like quartz and feldspar
- Muds generally compact to a much greater extent than do sands



Differential compaction between sandstone and mudstone results in draping of layers around a sandstone lens.
Quartz retain more space during burial compaction tha mud.

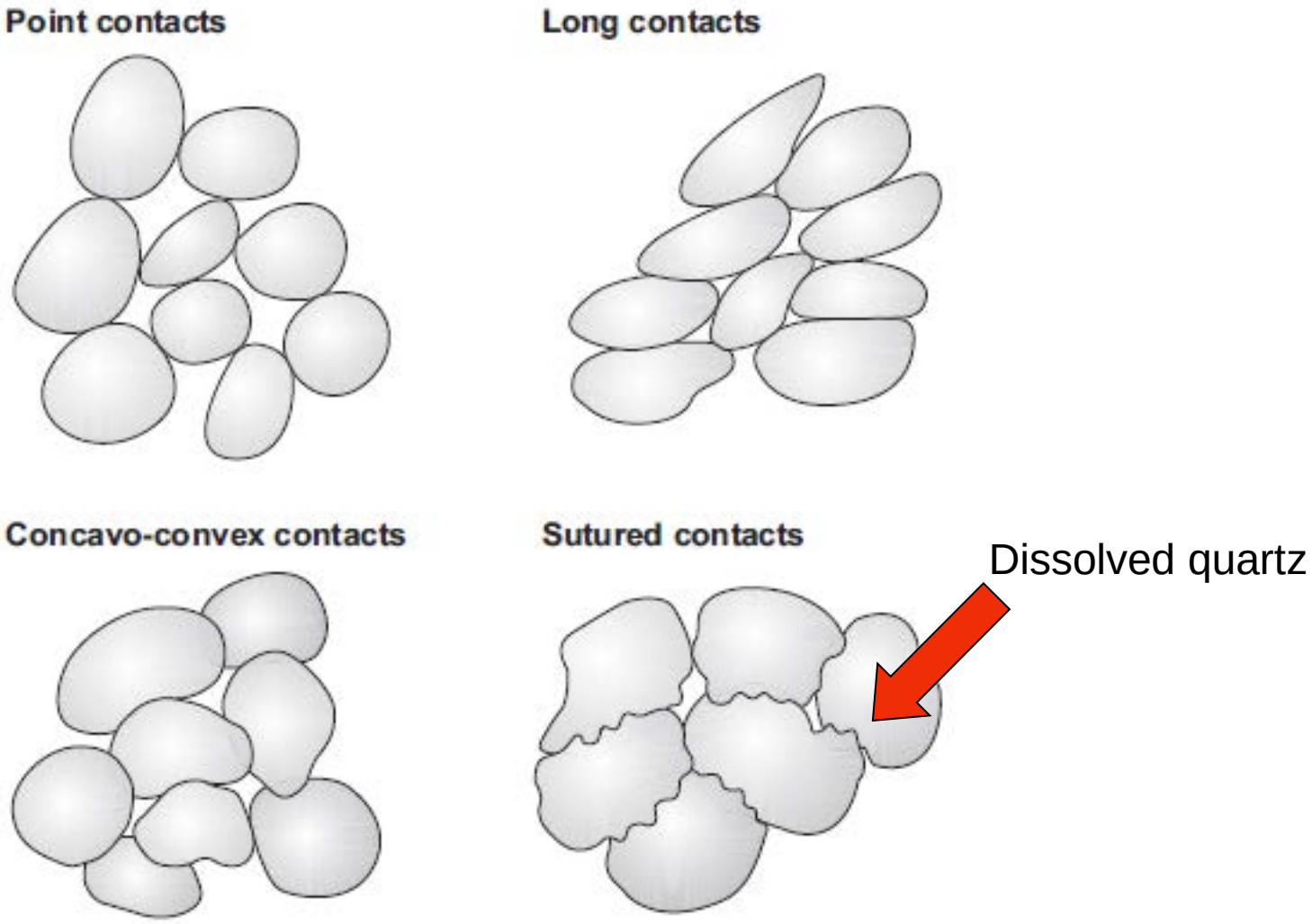


Compaction of layers within a mudrock around a concretion.



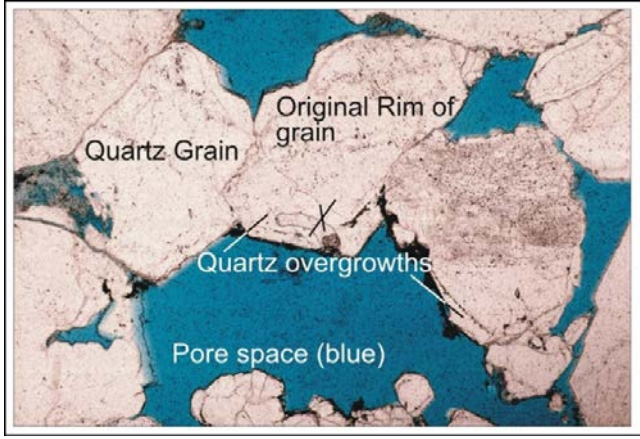
loose packing - pre-compaction tight packing - post-compaction

Changes to the packing of spheres can lead to a reduction in porosity and an overall reduction in volume.



progressive amount of compaction from point, to long contacts (involving a re-orientation of grains), to concavoconvex and to sutured contacts (which both involve a degree of pressure dissolution.

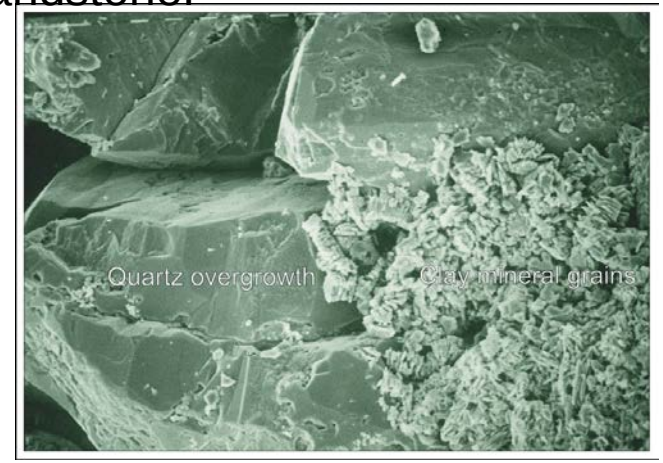
Shallow burial



- Quartz cement precipitates onto grains of quartz, forming **“quartz overgrowths”**

Individual grains are cemented together by quartz overgrowths (quartz cement that has precipitated around the original grain).
The quartz overgrowth cement has reduced the permeability, as well as the porosity of the sandstone.

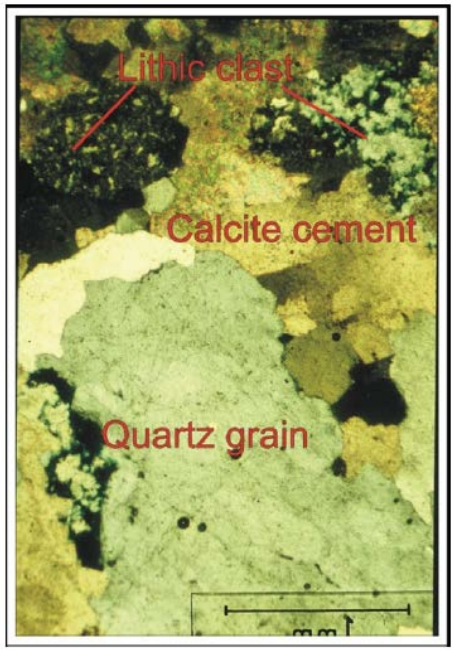
Reduced the permeability, and the porosity

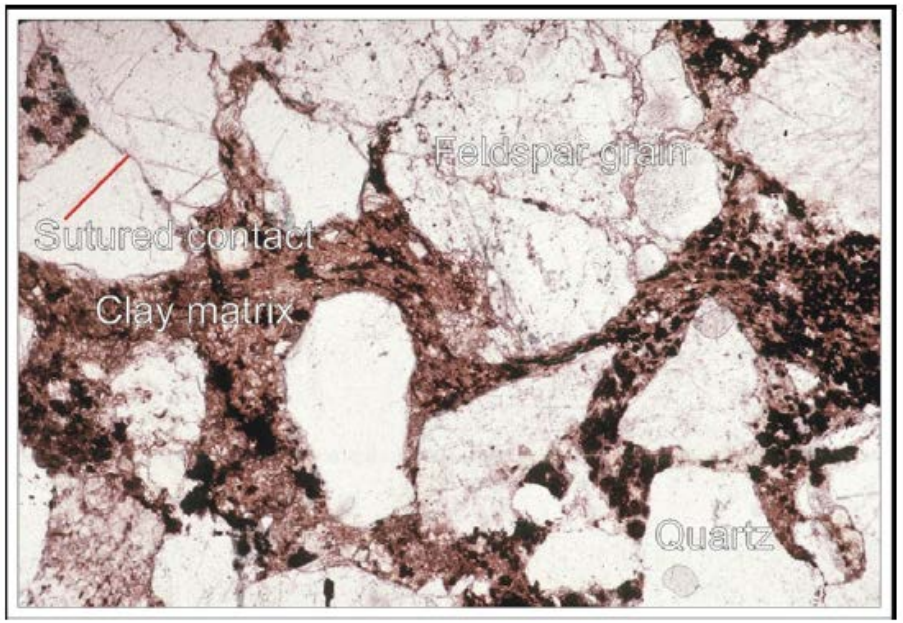


Large crystal faces are quartz overgrowths (cement).
Small crystals are clay minerals that have precipitated in the pore spaces.

Increased burial

- Additional calcite cements or clay minerals can precipitate in the pore spaces, until the sediment is lithified.





Significant burial depths (few thousand meters)

- **Feldspar grains** and **calcite cement** are relatively unstable under such conditions. *Their grains dissolve* and create “secondary” porosity and permeability.
- The *dissolved elements* are then free to react with other minerals in the sediment *to form new (“authigenic”) minerals*, such as *clays*.

- *Dissolution of feldspar*, which *releases potassium* ions (K^+). *If* the clay *smectite* (which swells when it absorbs water) *is present* in the sediment, the *K^+ reacts to convert the smectite into* the clay mineral *illite* (which does not swell). This reaction, in turn, *frees some silica ions* ($Si^{4+)}$ *into solution*, and *they can precipitate later to form quartz cement.*



- Chemically leached feldspar grain. The outline of the original grain is apparent, but almost all of the interior of the grain has been dissolved, as shown by the blue pore space (epoxy) within the grain outline. Slatt 2009.

With continued burial and/or the application of tectonic stresses

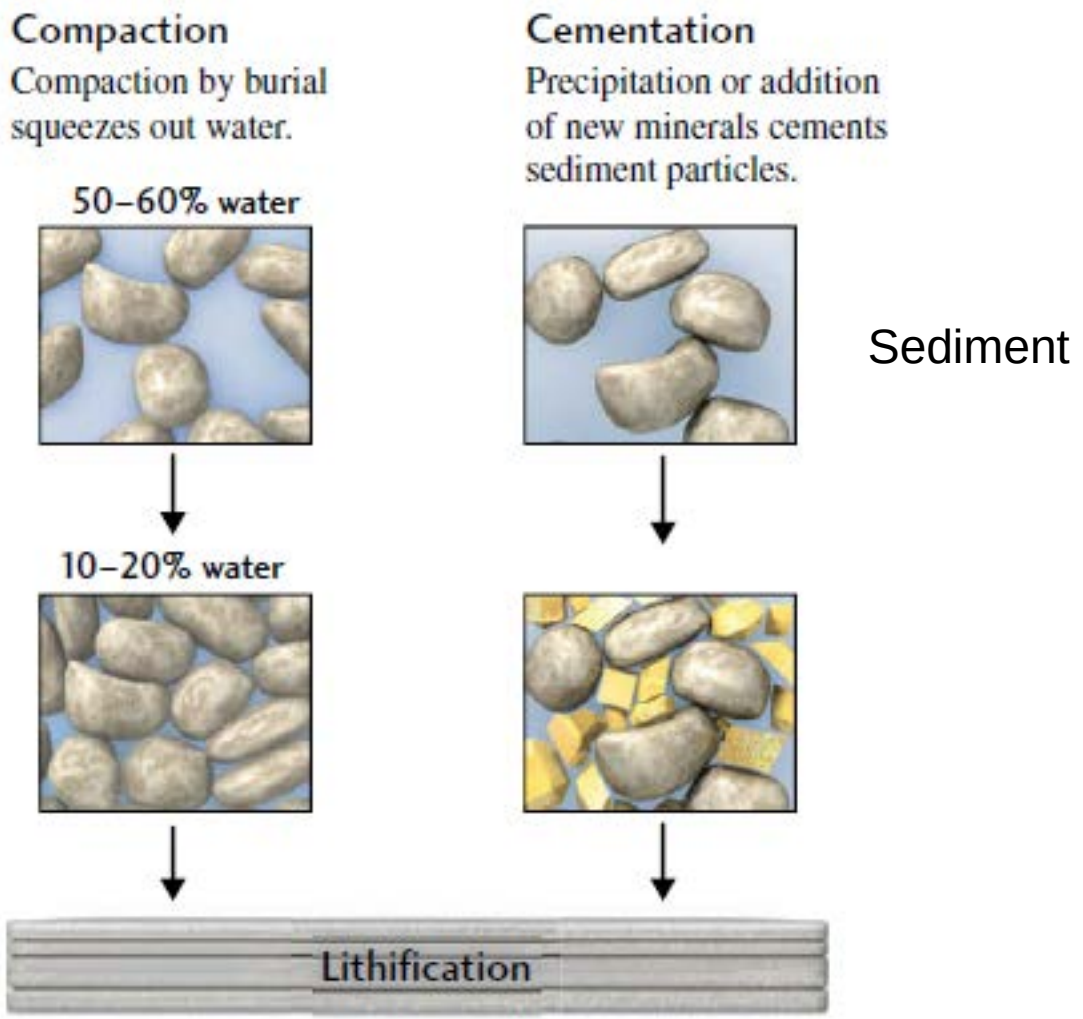
- Brittle rocks can fracture, thereby creating fracture porosity and permeability.

- Minerals in fluids circulating through the fractures can precipitate and seal the fractures from further fluid migration, or the fractures can remain open and act as conduits for hydrocarbon migration.

VI. Diagenesis

- **Temperature** increases with depth in Earth's crust at an average rate of 30C for each kilometre of depth.
- **Pressure** also increases with depth—on average, about 1 atmosphere for each 4.4 m of depth.
- This *increased pressure is responsible for the compaction* of buried sediments.

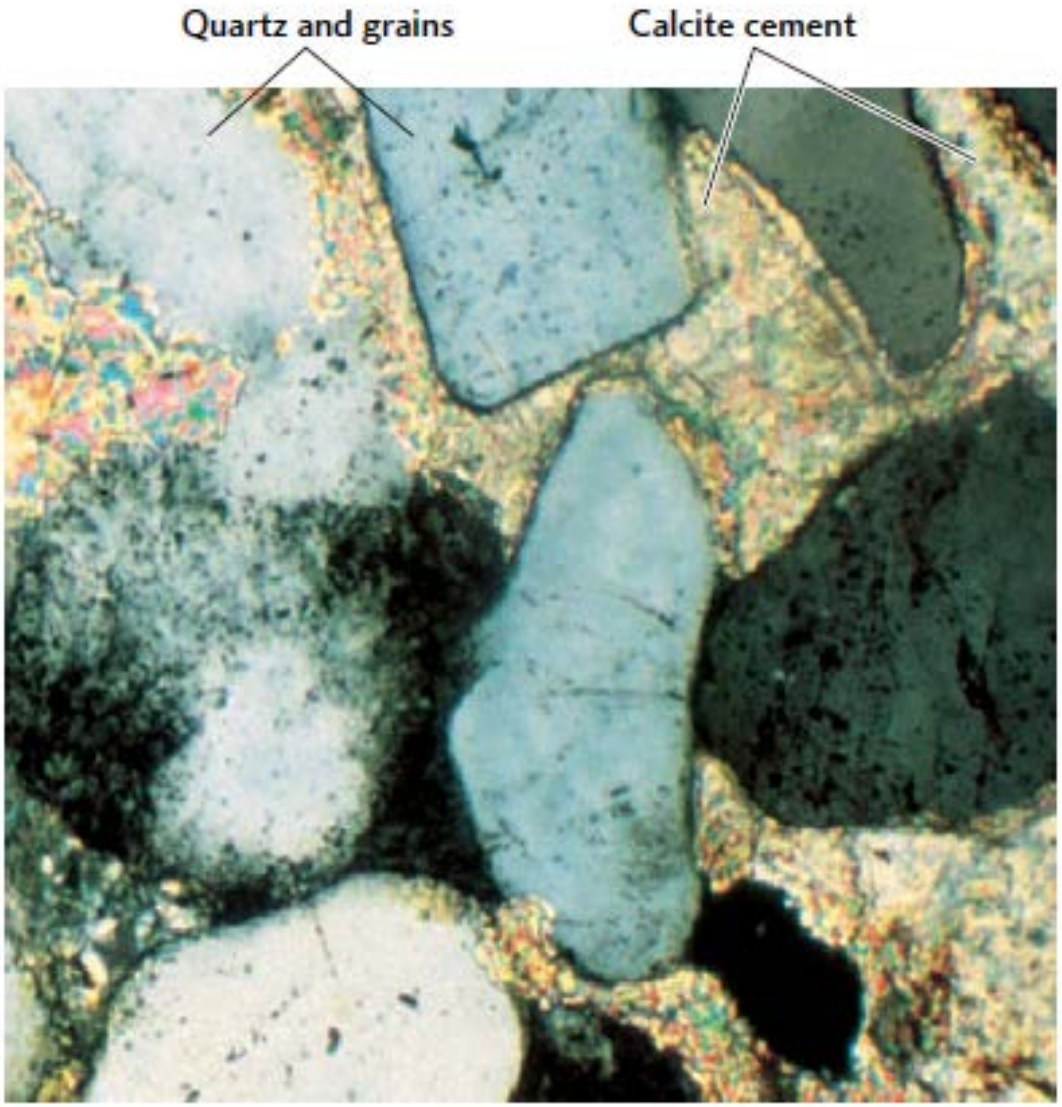
During diagenesis sediments are altered to sedimentary rocks.



Sediment

Sediment

Sediment



Sandstone: quartz grains (white and gray) are cemented by calcite (brightly colored and variegated) precipitated after deposition.

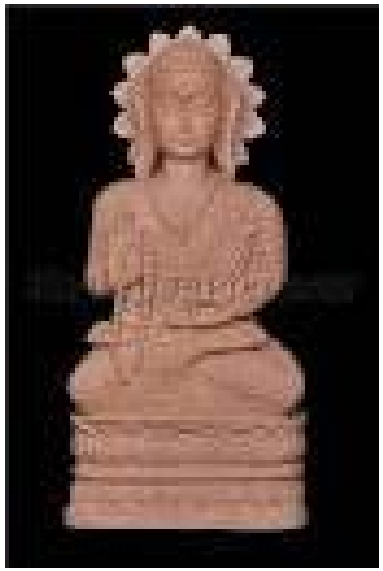
Sediment → Diagenesis → Sedimentary rock

(Lithification)









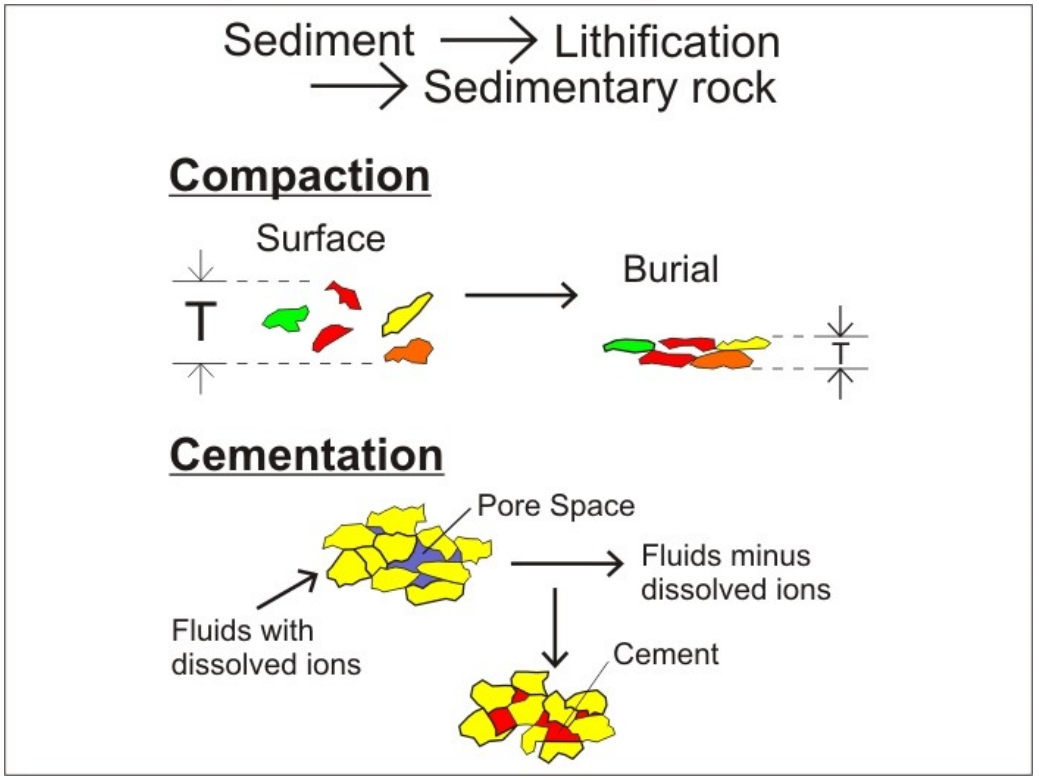
Sediment

- Solid fragmental material that originates
- 1) from weathering of rocks and transported and deposited by water, air or ice (e.g.**gravel, sand, clay**)
- 2) accumulates by chemical precipitation from solution (**evaporites**),
- 3) shells, shells and sceleton fragments secreted by organisms (**calcereous mud**).

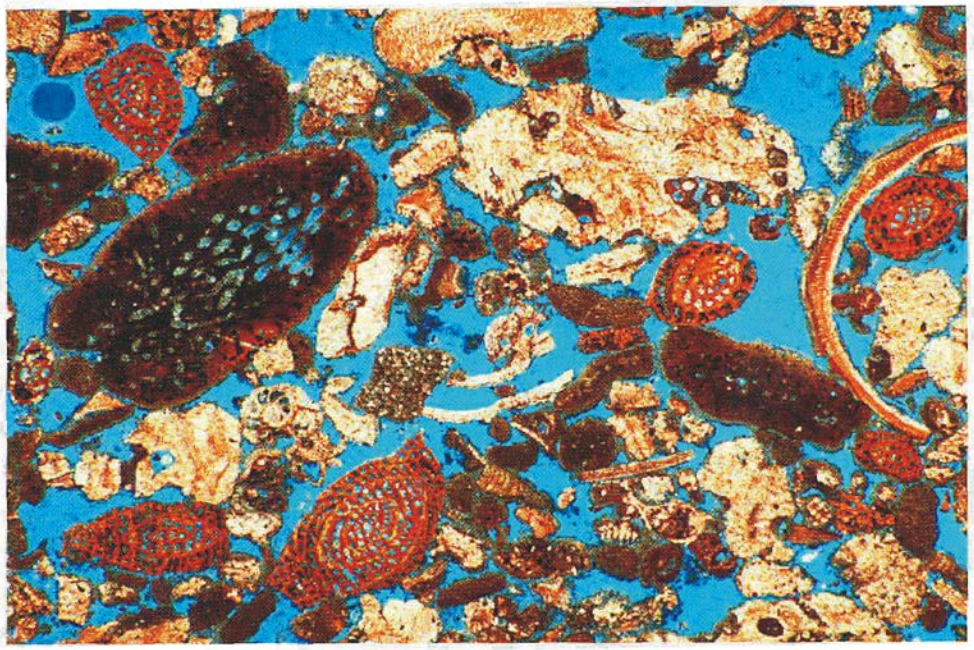
Sedimentary rock

- Rock is resulting from the consolidation of loose sediment that has accumulated layers (limestone, sandstone etc.).

Effect of Diagenetic Processes of Porosity and Permeability



- When sediments are buried, they become altered by the combined affects of physical **compaction** and **chemical reactions** under increased heat and pressure. Sometimes the reactions occur between solid grains and sometimes the reactions occur between grains and subsurface fluids.
- **Initial compaction** upon very early burial **reduces the thickness** of a deposit from T to t. But, not all of the pore spaces are eliminated. There is still pore space available for fluids to move through the sediment in the subsurface. These fluids contain dissolved ions that can precipitate in the pore spaces to form cement. Both of these processes lithify sediments.



Recent

- Pliocene



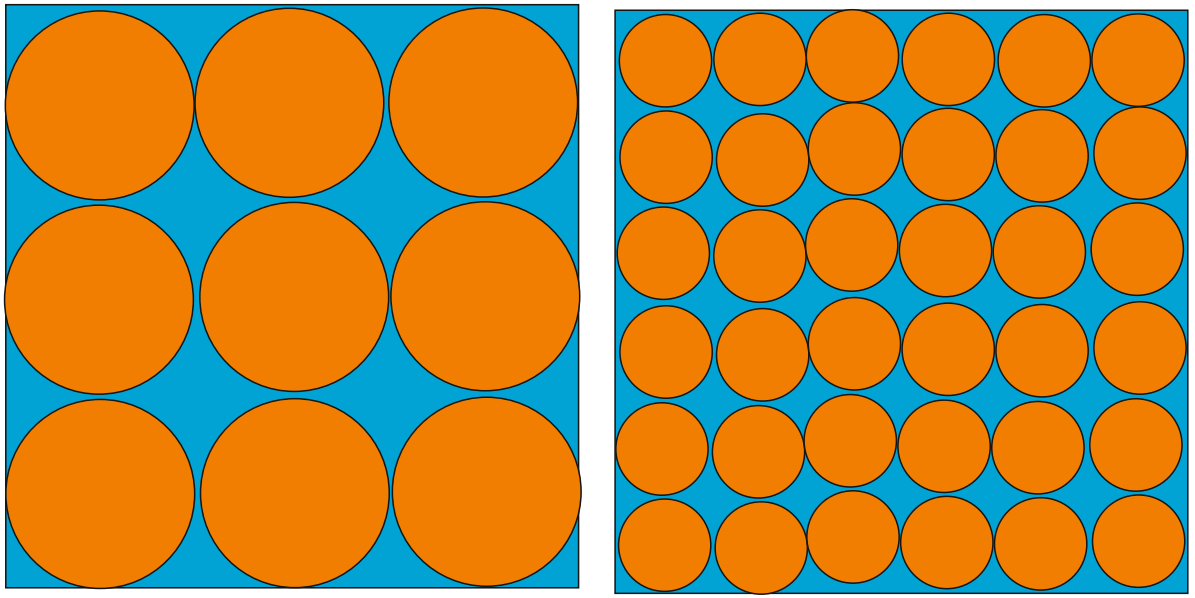
Grain size.

Classification of siliciclastic sediments and sedimentary rocks

Siliciclastic sediments and rocks are categorized primarily by particle size. It refers to the current strength.

Particle Size	Sediment	Rock
Coarse-Grained	**Gravel**	
Larger than 256 mm	Boulder	
256–64 mm	Cobble	Conglomerate
64–2 mm	Pebble	
Medium-Grained		
2–0.062 mm	Sand	Sandstone
Fine-Grained	**Mud**	
0.062–0.0039 mm	Silt	Siltstone
		Mudstone (blocky fracture)
Finer than 0.0039 mm	Clay	Shale (breaks along bedding)
		Claystone

Grain size controls porosity and permeability



r=1 r=1/2

Porosity: $\varphi_1 = \varphi_2$

Permeability: $k_1 = \frac{1}{4} k_2$

- After clastic particles and dissolved ions have been formed by weathering and dislodged by erosion, they start their journey to a sedimentary basin

- CURRENTS AS TRANSPORT AGENTS:
- Most sediments are transported by currents of **air** or **water**.
- As particles are lifted into the air or water, the current carries them downwind or downstream.

The stronger the current—that is, the faster it flows—the larger the particles it can transport.

The fine-grained rocks: mudstones, siltstones, shales, claystones

- Silt (0,062mm-0,0039mm) — Mudstone (blocky fracture); Siltstone
- Clay (>0,0039mm) — Shale; Claystone

Particles that are less than 0.062 mm in diameter, but they vary widely in their ranges of grain sizes and in their mineral compositions.
Fine-grained sediments **are deposited** by the *gentlest currents*, which allow the finest sediment particles to settle slowly to the bottom in quiet waves.

The fine-grained rocks: mudstones, shales, claystones

- **Mudstones** are blocky and show poor or no bedding.
- **Siltstone:** is composed of siltsize particles and contains less clay-size material than shale
- **Shales:** are composed of silt plus a significant component of clay, which causes them to break readily along bedding planes.
- **Claystone**: consists largely of clay minerals. Clay-sized particles are less than 0.0039 mm in diameter.

MUD, MUDSTONE

Mud is a siliciclastic sediment containing water in which most of the particles are less than 0.062 mm in diameter. Mud is made of silt- or clay-sized sediment particles

Deposited by

1) *rivers and tides*.

As a river recedes after flooding, the current slows, and mud, some of it containing abundant organic matter, settles ***on the floodplain***. This mud contributes to the fertility of river floodplains.

2) Muds are also left behind by ebbing tides along many ***tidal flats*** where wave action is mild.

3) ***Deep seafloor*** is blanketed by muds, where currents are weak or absent.

SILT AND SILTSTONE

- the grains are between 0.0039 and 0.062 mm in diameter. Contains mainly silt size particles and less clay-size material.
- It lacks fissility.

Shale

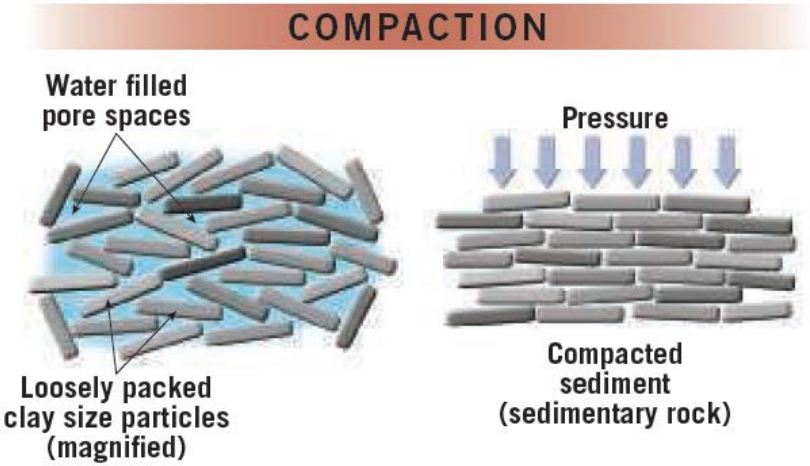
The word shale has two meanings:

1) in a nontechnical context: it means **all fine-grained sedimentary rocks.**

2) In a more narrower usage: shale must exhibit the ability to split into thin layers along well-developed, closely spaced planes. This property is termed **fissility** (*fissilis* = that which can be cleft or split).

As silt and clay accumulate, they tend to form thin layers, which are commonly referred to as *laminae* (*lamin* = thin sheet).

Thin layers in shales



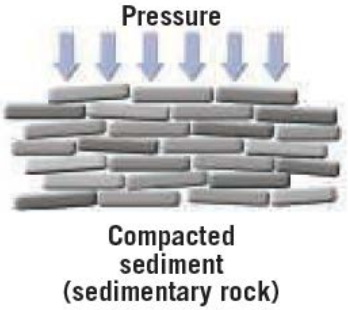
Initially the particles in the laminae are oriented randomly. This disordered arrangement leaves a high percentage of open space (*pore space*) that is filled with water.

As additional layers of sediment pile up and compact the sediment below,

During this phase, the clay and silt particles take on a more nearly parallel alignment and become tightly packed. This rearrangement of grains reduces the size of the pore spaces and forces out much of the water. Once the grains are pressed closely together, **the tiny spaces between particles do not readily permit solutions to circulate.**

Why are shales impermeable?

- Shale's have microscopic pore spaces preventing water penetrate into the rock.



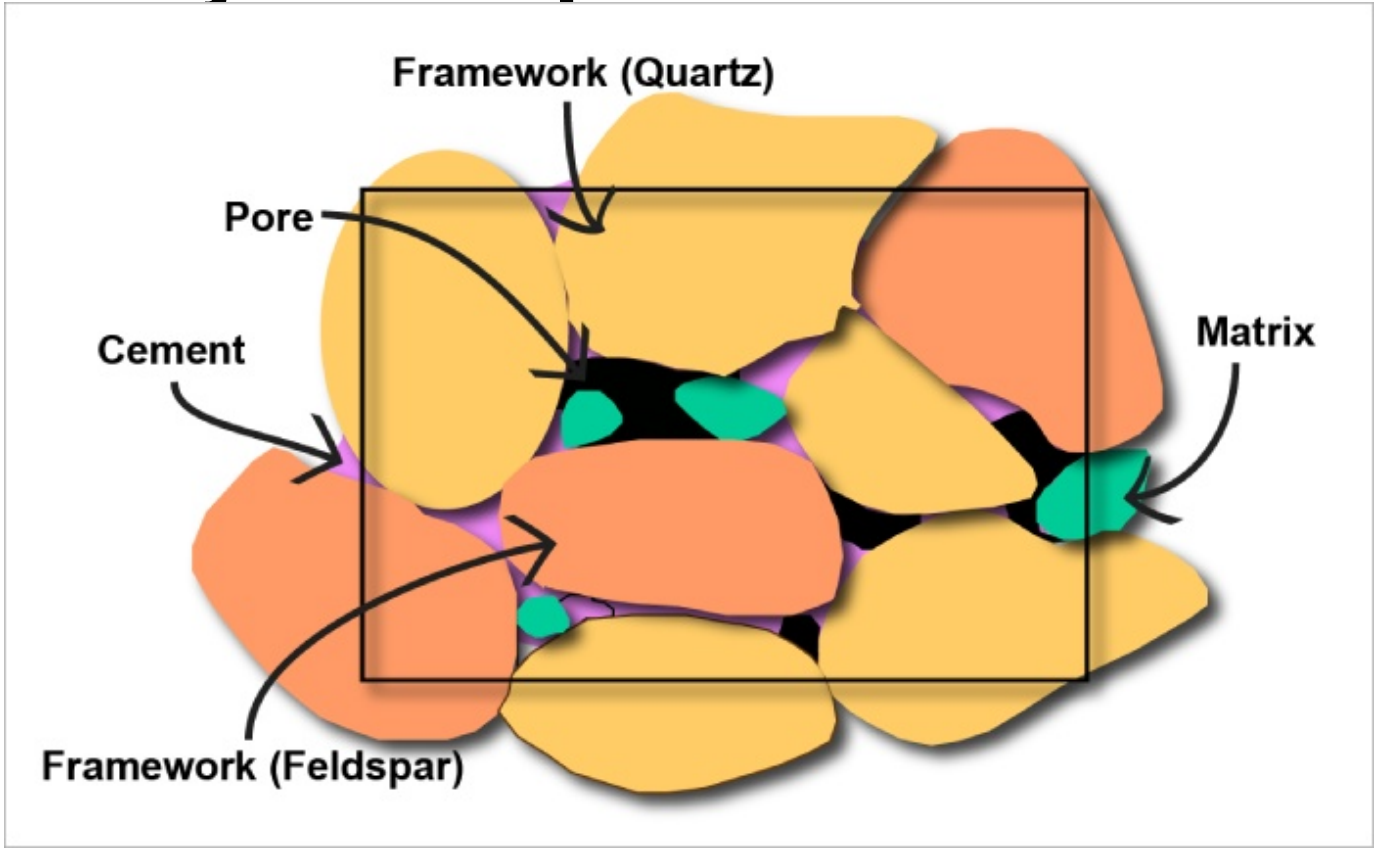
- This is the reason why this rock forms **barriers** to the subsurface movement of petroleum and water.

- 1) **Barriers for petroleum**: hydrocarbones are often capped by shale beds that effectively prevent oil and gas from escaping to the surface.
- 2) **Barriers for water**: rock layers that contain groundwater are commonly underlain by shale beds that block further downward movement of the water.

Sand and Sandstone
Medium-Grained Siliciclastics:

- The second abundant sedimentary rock.
- **Sand:** 0.062 to 2 mm in diameter.
- Moved by moderate currents: rivers, waves at shorelines, and the winds that blow sand into dunes.
- Are subdivided into fine, medium, and coarse grains.
- The average size of the grains in sandstone can be an important clue to the strength of the current that carried them.

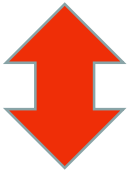
Four major components of sandstone



Framework: sand (and silt) size detrital grains.
Matrix: silt and clay size detrital material. Primary of origine: during deposition.
Cement: precipitated post depositionally. Secondary: during diagenesis cement fills pores.
Pores: voids among the above components.

Composition of the sandstones

- Weathering and transport lead to gradual destruction of weaker and less stable minerals (feldspar, ferromagnesians).



- Quarz is very resistant survive long trip.

Composition of sandstones

- 1) Kvarz sandstone (kvarz arenit) **Kvarc grains are dominant**

- 2) **Arkose**: > 25% feldspar + Q + mica

Derived from granit.

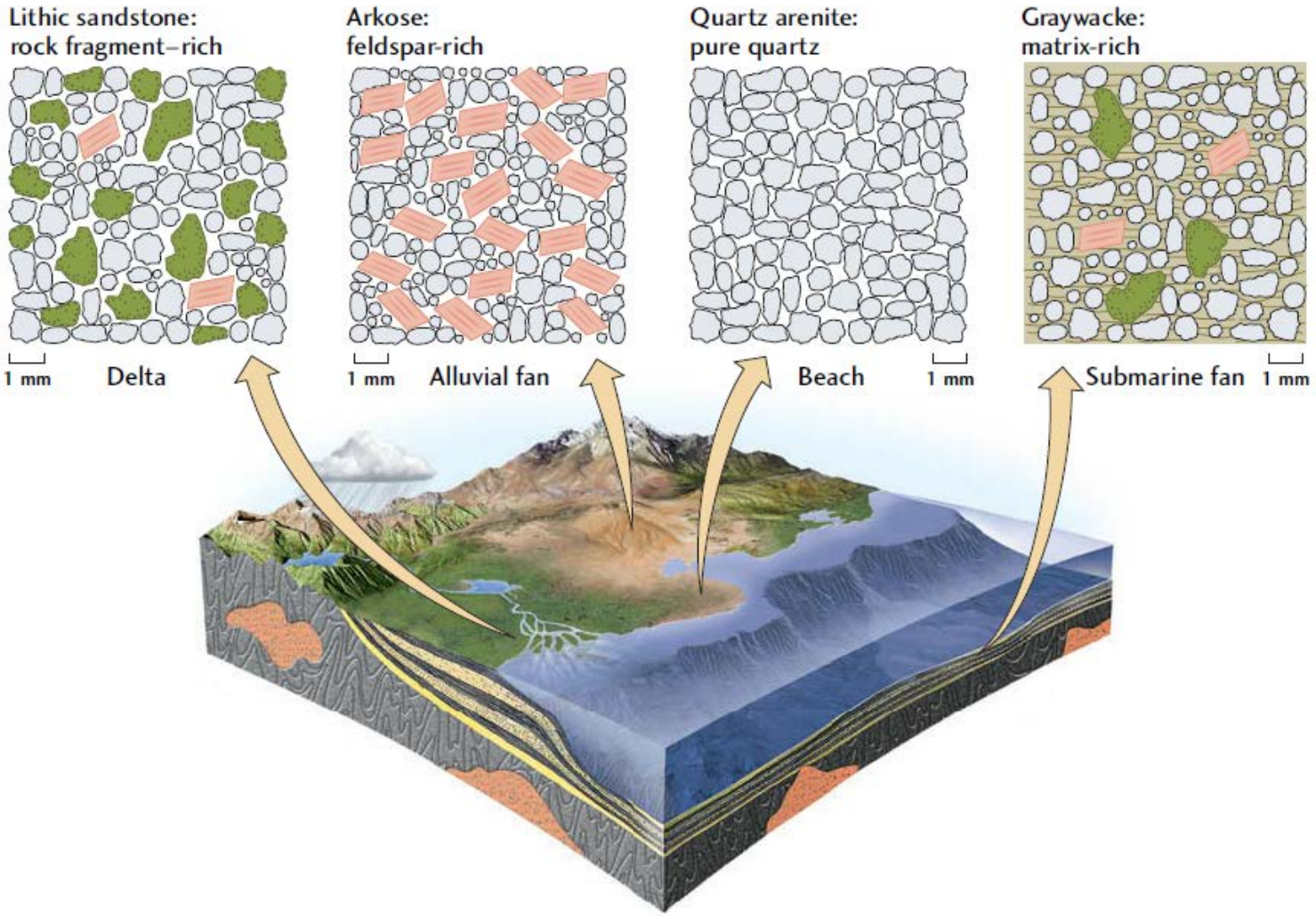
Short transport and minimal chemical weathering. Dry clima, repid deposition and burial.

- 3) **Graywacke**: rock fragments, Q, feldspar. Matrix > 15%.

Short transport, rapid deposition.

Frequently associated with turbidite current.

- 4**) Lithic sandstone**: rich in rock fragments



The mineralogy of four major groups of sandstones and the sedimentary environments where they are most likely to be found.

MINERALOGY OF SANDS AND SANDSTONES

- help identify the parent rocks.

Matured sandstone: quartz arenite

- sandstone with at least 95% quartz grains.

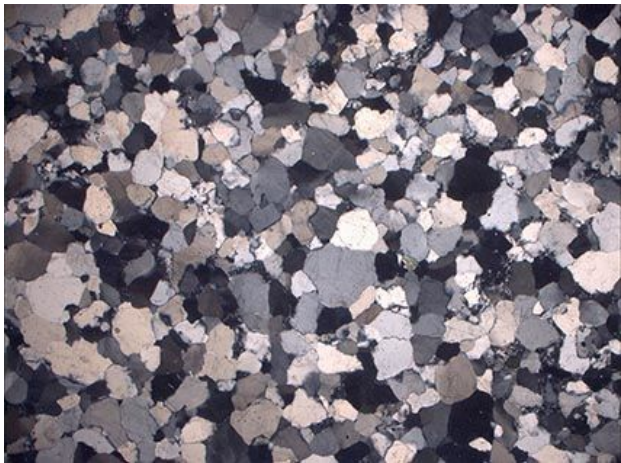
Compositionally and texturally (well rounded, well sorted grains) most matured.

Cements: quartz overgrowth, but calcite is also common.

Product of extensive sediment reworking. All grains other than quartz have been broken down.

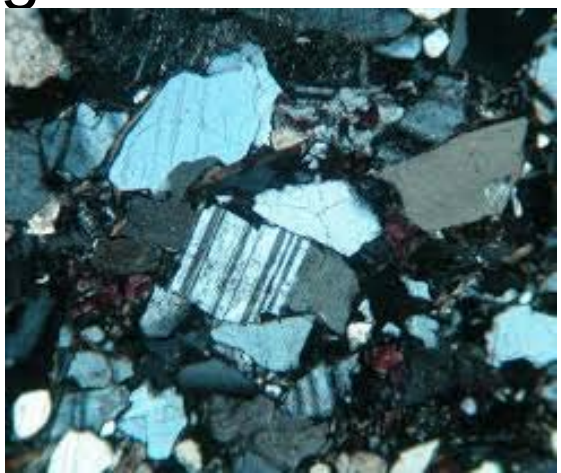
Facies: shallow marine shelf.





Arkose: immatured sandstone

- Condtains *more than 25% feldspar much quartz and some rock fragments*. Detrital micas are also present, and some fine-grained matrix.
- Feldspar is fresh, but some may be altered to kaolinite and sericite.
- Colour: red, or pinc: finally disseminated hemetite.
- Origine: granite, gneiss (feldspar rich rocks)
- Facies: semiarid, glacial climate. Fluviatil environment.



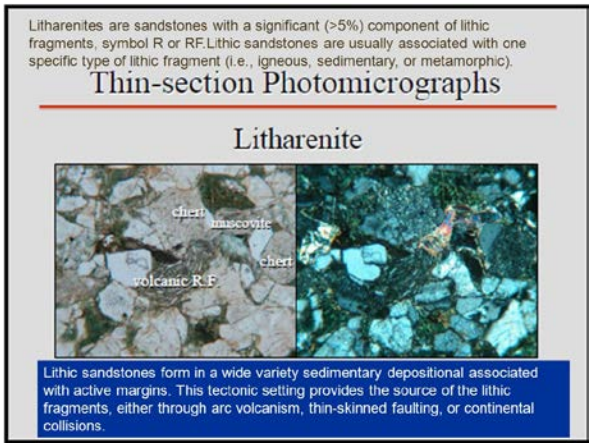


Litharenites: immatured sandstone

- **Lithic sandstones**, or **litharenites**, are *sandstones with a significant* (>5%) component *of lithic fragments*, though quartz and feldspar are usually present as well, along with some clayey matrix.
- Immature composition:
- high rates of sediment production, followed by short transport distances.
- Facies:

- fluviatile,

- deltaic environment.



Greywacke, Graywacke: immatured sandstone

Composed of poorly *sorted angular grains of quartz*, *feldspar*, and *small rock fragments* in a compact, clay-fine matrix. It is a *texturally immature*, generally found in Paleozoic strata. The larger grains can be sand- to gravel-sized, and the matrix constitutes more than 15% of the rock by volume.

Facies: turbidites on the edges of the continental shelves, at the bottoms of oceanic trenches, at the bases of mountain formational areas. They also occur in association with black shales of deep sea origin.





Coarse-Grained Siliciclastics: Gravel and Conglomerate



- **Gravel** is the coarsest siliciclastic sediment, consisting of particles larger than 2 mm. **Conglomerate** is the lithified equivalent of gravel.
- The **size** of the gravel tells us the strength of the currents that transported them.
- Their **composition** can tell us about the nature of the distant terrain where they were produced.

Coarse-Grained Siliciclastics: Breccia

Breccia: the large particles are angular.

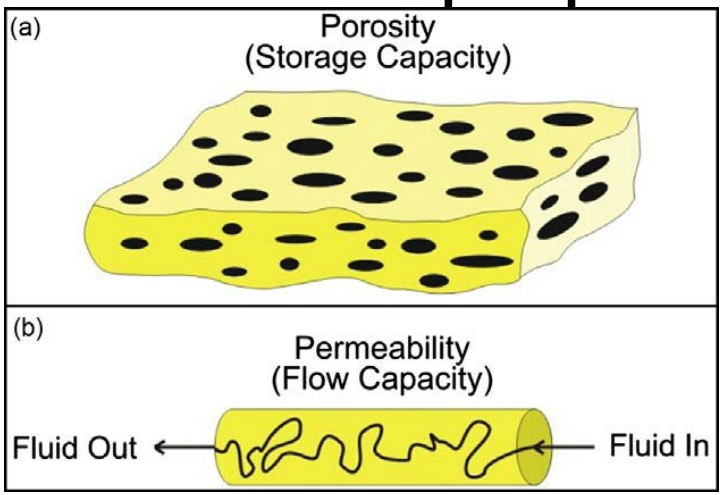
They did not travel far from their source area before they were deposited.

The fragments within a sample identify the source rocks that supplied them.



Reservoir quality (porosity, permeability)

- Microscopic-scale rock properties.

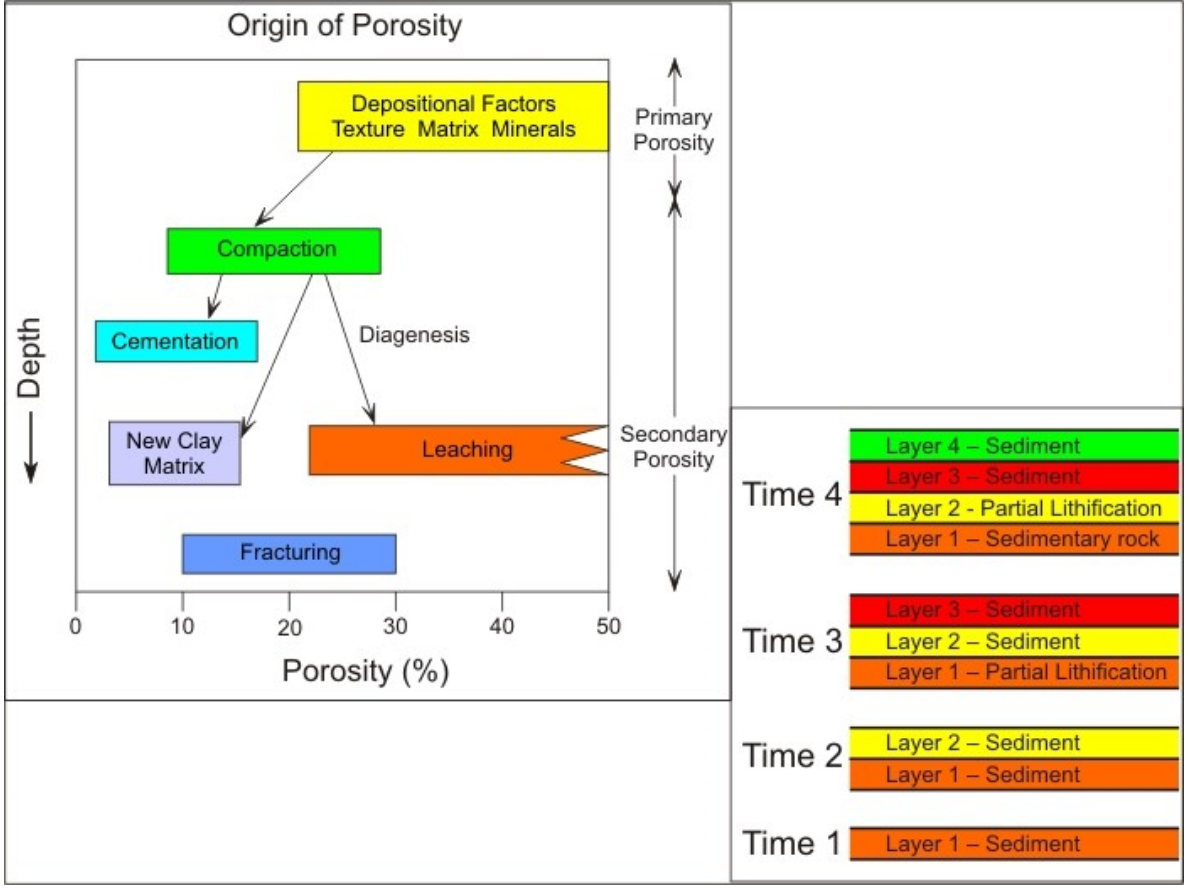


The rock in (a) has good porosity (high percentage of pore spaces), which can contain a large amount of fluid. However, none of the pores are interconnected, so the fluids will not be able to move from one pore to another (the rock has poor permeability).
All properties (grain size, sorting, shpericity) are important in controlling the storage and flow of fluids through the sedimentary rocks in a reservoir.

Reservoir quality (porosity, permeability)

- The reservoir quality of a sedimentary rock is the product of the texture and composition of the original sediment. They are controlled by geologic processes. The original texture and composition are then modified by burial, compaction, diagenesis, and deformation.
- Some of the processes, such as development of secondary porosity, can be beneficial to a reservoir.
- Other processes, like cementation, are detrimental. Thus, it is important that these properties be included in a reservoir characterization.

Pore alteration during diagenesis

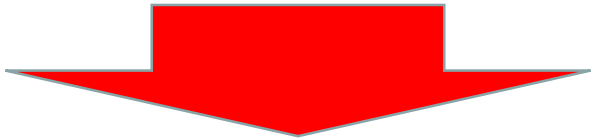


- Plot on the left shows the several stages that a rock goes through as it is buried. The vertical axis is depth. The original porosity and permeability of sediment are those at the ground surface. With early burial, the sediment will **compact**, so that **the porosity decreases** substantially. With further burial, processes of **chemical diagenesis** replace physical compaction. **Mineral cements are precipitated** in the pore spaces, further **reducing the porosity.** However, some fluids can actually work in reverse by **dissolving certain chemically unstable mineral grains**. This process is called "**leaching**," and it actually forms secondary porosity. With further burial, the rock becomes brittle under the heavy weight of overlying rock, at which point it may fracture to produce fracture porosity. Slide on the right shows the steps of burial during 4 time intervals. Between Time 1 and Time 4, Layer 1 has become lithified from a sediment to a sedimentary rock.

Remember!

- The sedimentary environment will primary control -the texture (grain size, sorting, roundness)
  - sedimentary structures
  - composition of the rock.

In the cores we can recognize the texture, sedimentary structures and composition of the rock.



We can conclude the sedimentary environment.



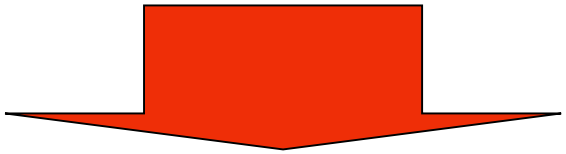
- We can predict the

- reservoirs external geometrie,
- the internal architexture of the reservoir,
- the potential interactions between reservoir fluid and reservoir rocks.

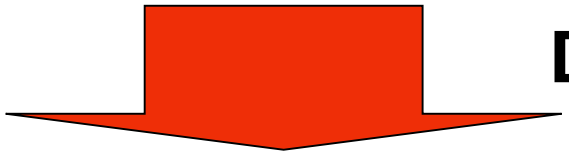
SEDIMENTARY STRUCTURES AND THEIR SIGNIFICANCE

- There are three categories of sedimentary structures:
- (1) those that are produced by physical interaction of sedimentary particles with their environment,
- (2) those that are produced by organisms interacting with the sediment, and
- (3) those that result from chemical interactions of fluids and sediments.

Sedimentary structures



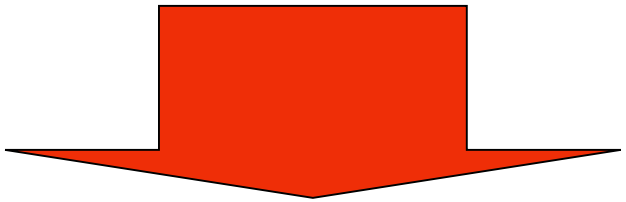
Information on sedimentary environment



Determine

size,
areal extent,
geometry,
thickness,
internal architecture,
reservoir quality (porosity, permeability)
of the reservoir rock body containing HC.

- **The arrangement of sediment grains into specific structures determines**



- **the fluid flow path within the reservoir**

Physical Sedimentary Structures
Structures Formed by Currents and Waves

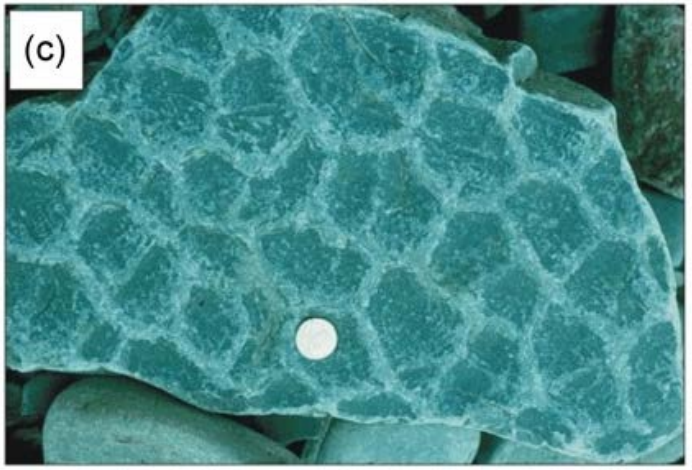
- **1. Dessication cracks**

  - The lake, or the tidal flat dried up

  Polygonal cracks developed (b)

  - The lake is replenished with muddy water, new sediment is deposited on top of this horizon, the polygonal desiccation cracks are filled with deposited mud, and eventually, the cracks are preserved by lithification (c)

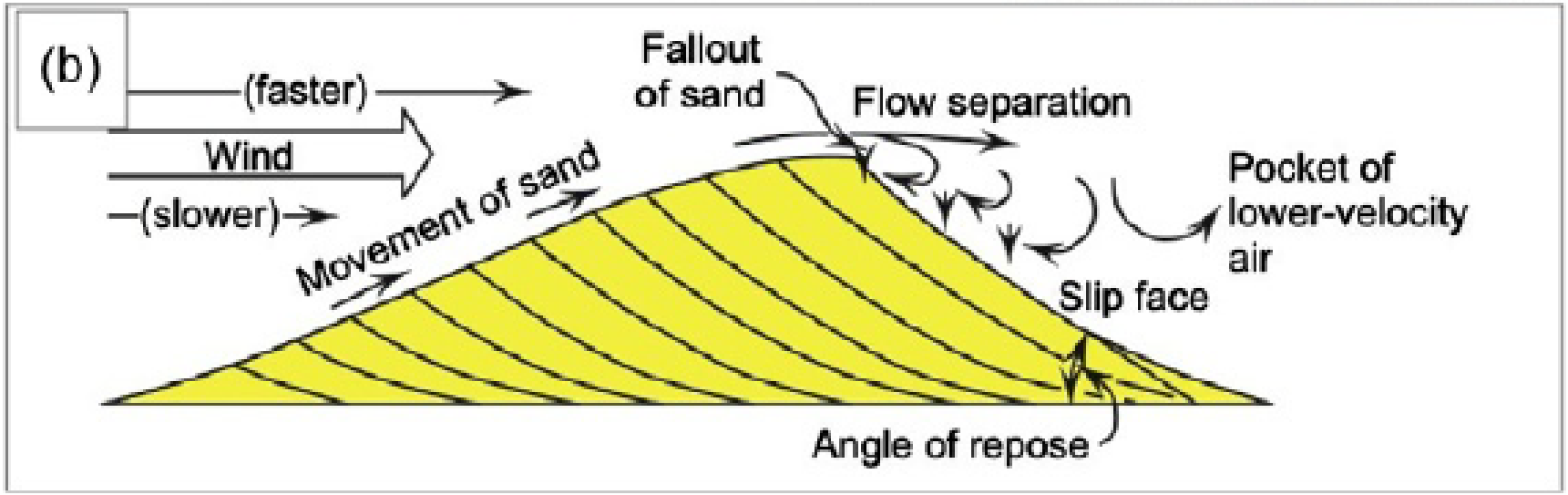




Cross-stratification

- is any layering in a sediment or sedimentary rock that is oriented at an angle to the horizontal.
- These inclined strata most commonly form in sand and gravel.

Structures Formed by Wind



Grains move across the top of the windward side of the dune and fall over the steeper lee side. Over time, the continual downwind movement of grains causes the entire dune to migrate. Direction of transport of the sand by the wind was from left to right, as shown by the orientation of the dune's cross stratification.



John S. Shelton/ University of Washington Libraries

The cutaway section of this sand dune shows the characteristic cross-bedding

The cross-bedding in this sandstone indicates it was once a sand dune

Weathered bedding planes within unit

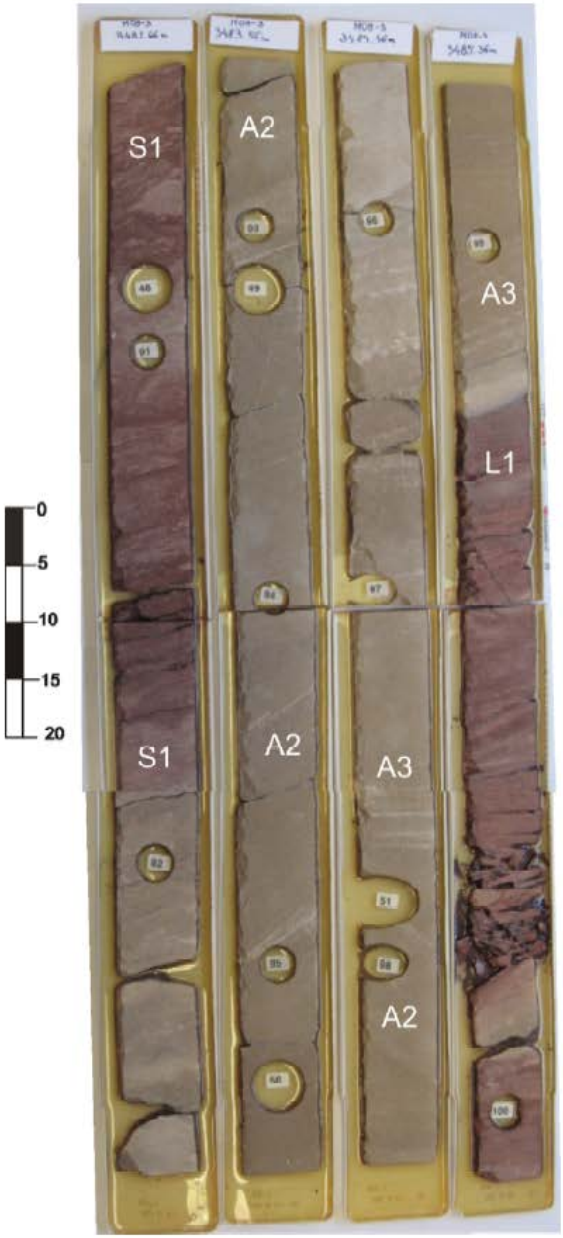
Principal bedding surfaces

Cross-bedding unit

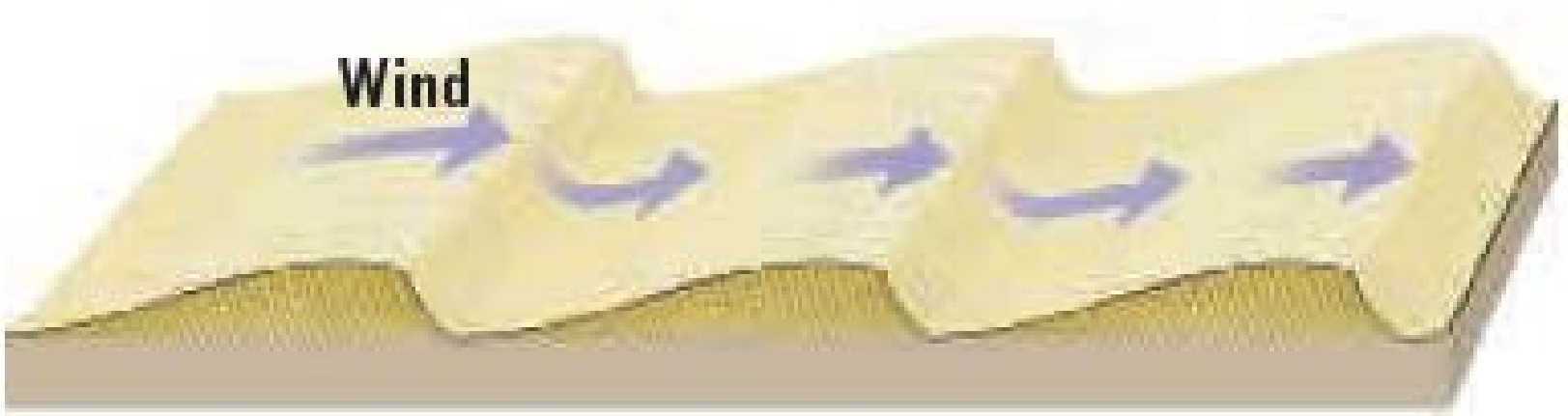
Steep truncated cross-beds

0 1 2 3

meters



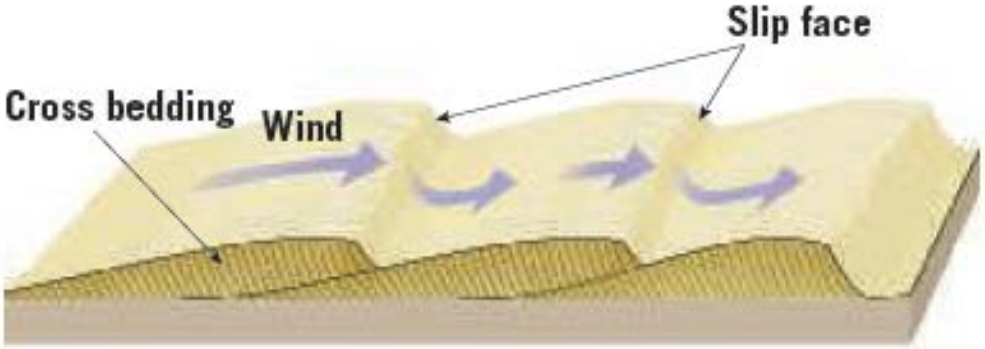
2 Aeolian dune sequence at the top of Unit B in M9-3.



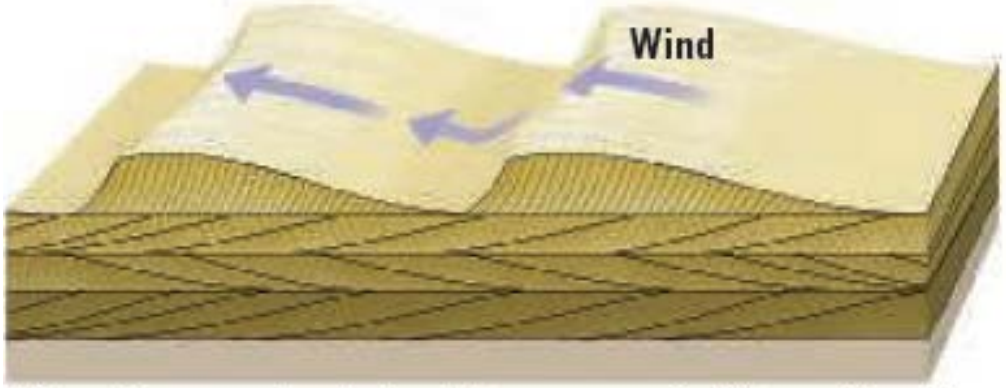
Dunes commonly have an asymmetrical shape and migrate with the wind.



As sand accumulates at the dune crest, the slope steepens and some of the sand slides down the steep *slip face*.



Sand grains deposited on the slip face at the angle of repose create the cross bedding of dunes.



When dunes are buried and become part of the sedimentary rock record, the cross bedding is preserved.

Cross-bedding: as sand is deposited on the slip face, layers form that are inclined in the direction the wind is blowing. With time, complex patterns develop in response to changes in wind direction.



Cross bedding is an obvious characteristic of the Navajo Sandstone in Zion National Park, Utah.

What was the wind direction?

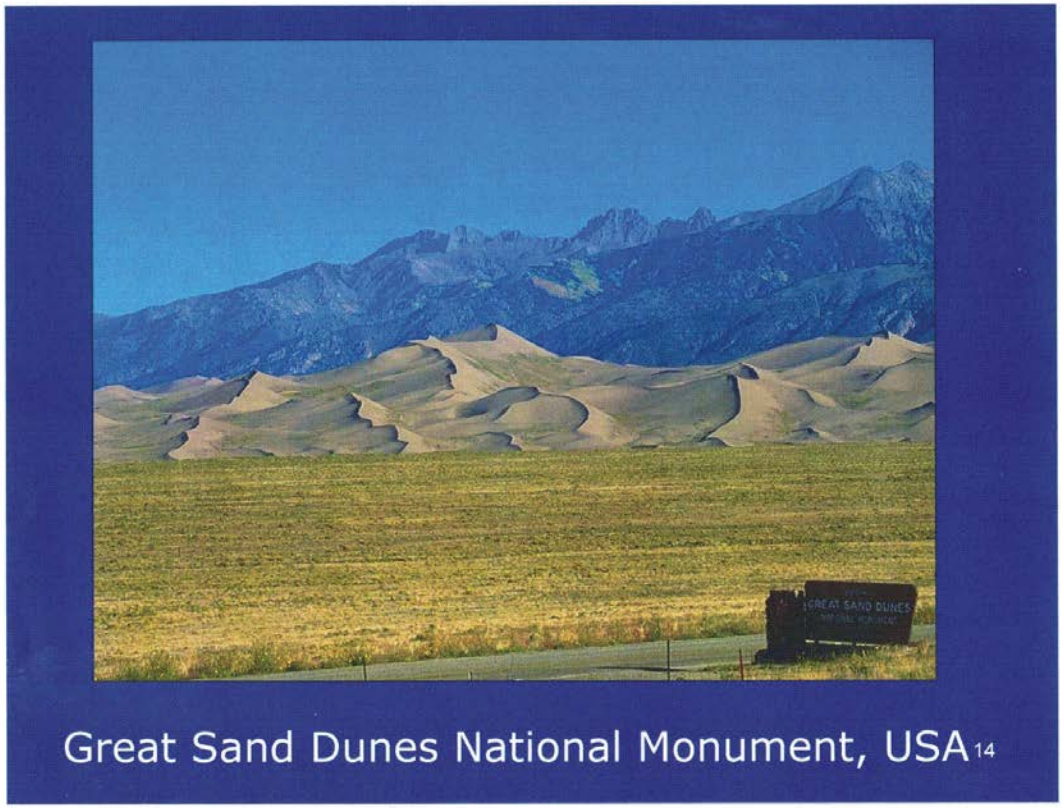
- In any given area, there is **a single dominant wind direction**, and often, that direction can easily be interpreted by the direction of cross-bedding in sedimentary rocks.

Paleowind



- predicting the **areal extent** and trend of eolian reservoirs.

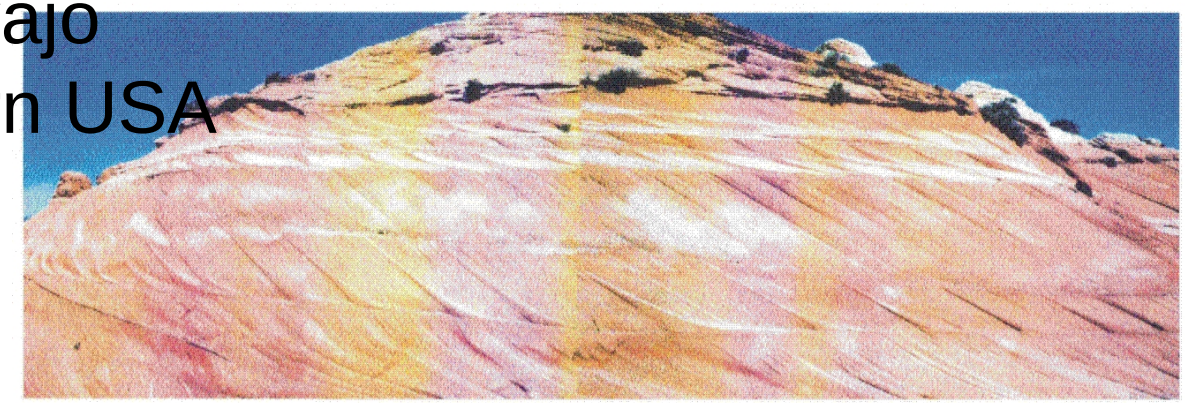
- The process of wind transport tends to segregate rock grains into a limited range of particle sizes, thus **providing excellent sorting**, which in turn can provide **excellent reservoir quality** of an eolian reservoir (unless it is heavily cemented).



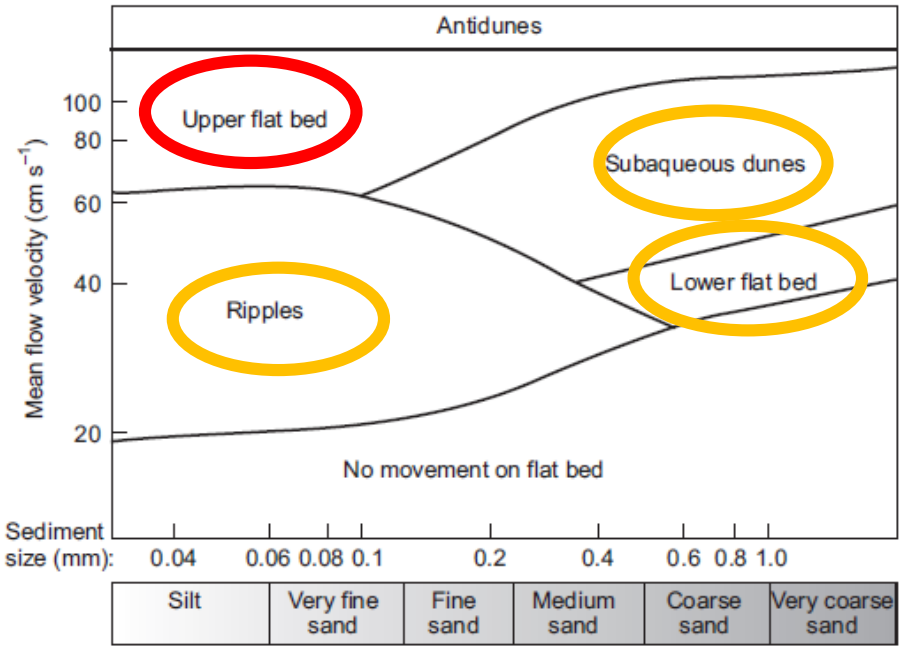
Great Sand Dunes National Monument, USA 14

Present

- Past: Jurassic Navajo Sandstone, western USA



Transport agent: water

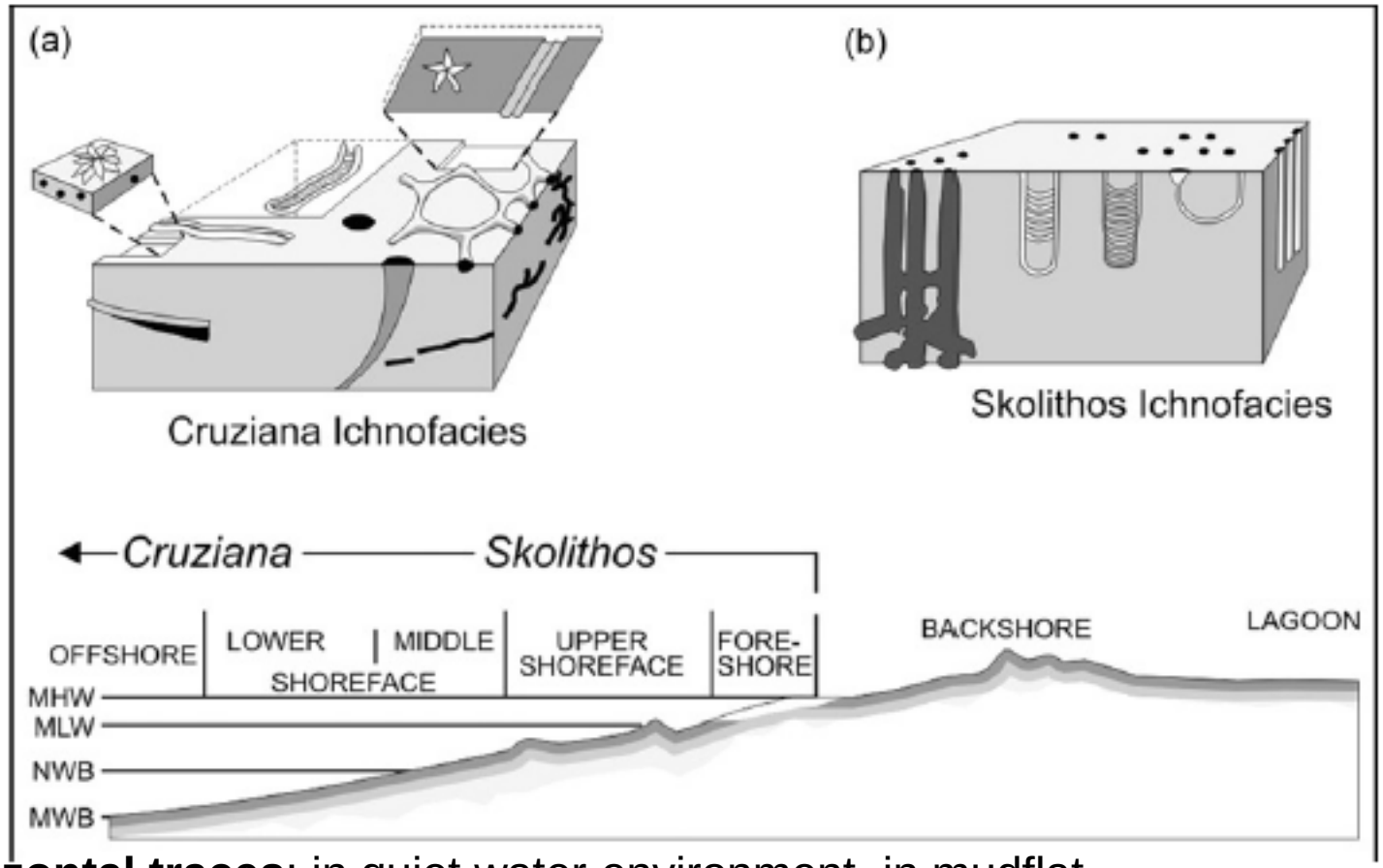


- Bedform stability diagram indicates the bedform that will occur for a given **grain size** and **velocity** and has been constructed from experimental data.
- Two general flow regimes are recognised: **a lower flow regime** in which **ripples, dunes and lower plane beds** are stable and an **upper flow regime** where **plane beds** and antidunes form.



Horizontally bedded sandstone is overlain by cross-bedded sandstone. These two sedimentary structures indicate that the sand was deposited from a flow of progressively decreasing velocity.
The grain size of the lower unit averages 0.2 mm and that of the upper unit averages 0.15 mm.

Biogenic Sedimentary structures
Trace fossils



Horizontal traces: in quiet water environment, in mudflat.
Vertical traces: higher-energy environment, tidal flat: tide and ebb.
The organism burrows beneath the surface and waits for food to come to it on the incoming tide.
Skolithos: sandier facies.

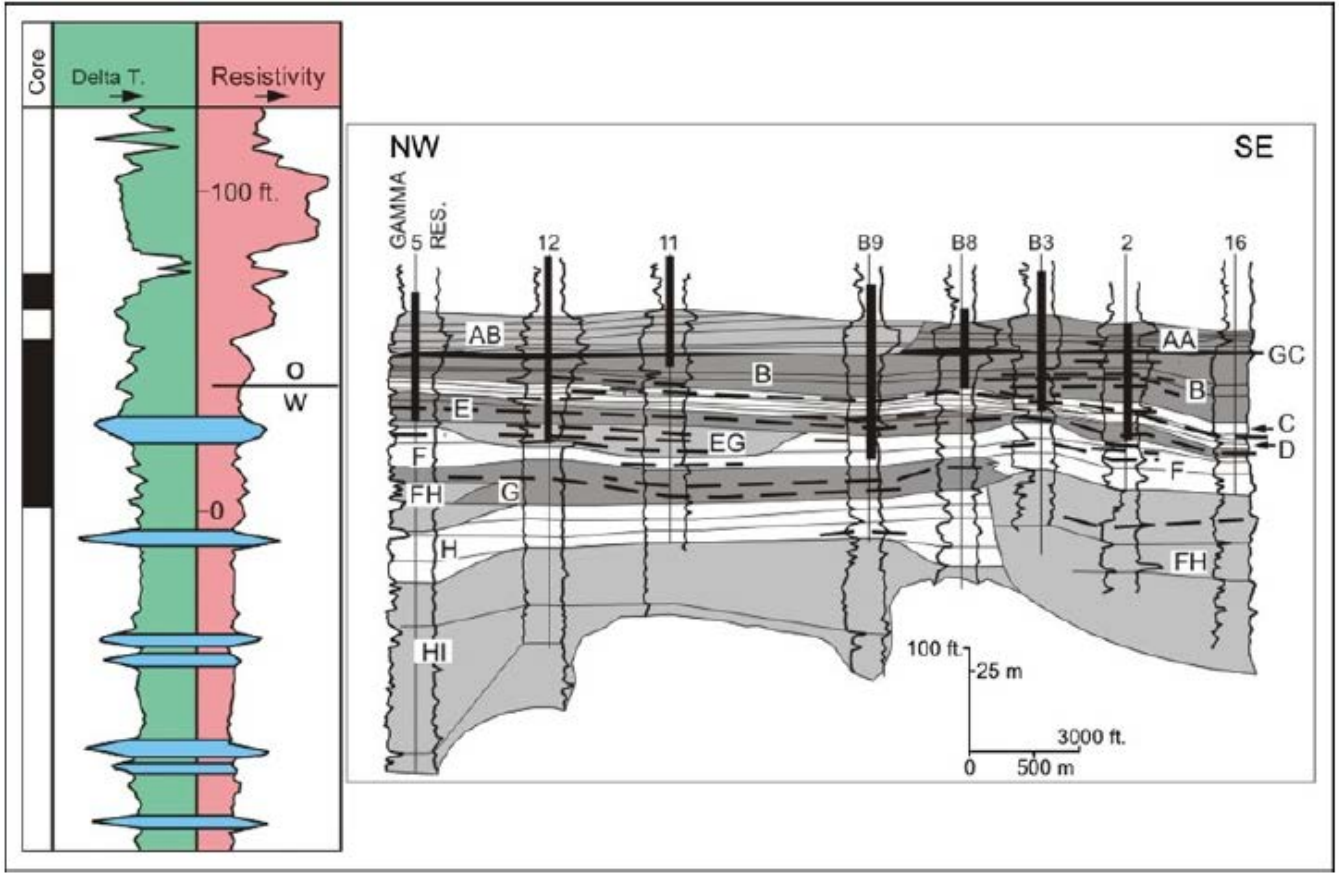
Chemical Sedimentary Structures

- are the product of chemical precipitation of minerals that is traveling/infiltrating within the sediment before it lithifies.
- Often, a sand grain or a shell fragment will act as a nucleus onto which such precipitation will proceed.
- Concretions are very important in log analysis, because often they are composed of the mineral sideriten ($FeCO_3$), which is an iron-rich carbonate.





Concretions can form a layer within a sedimentary rock sequence. If the layer contains enough concretions, it can act as a baffle or permeability barrier to fluid flow.



- Because the density of the minerals in the concretions is greater than that of the surrounding sandstone, the concretion can provide erroneous or misleading well-log responses.
- The concretion zones are characterized by anomalous spikes on sonic and resistivity logs (blue on the logs).
- These spikes can be correlated across several wells (dashed lines), indicating that the concretions form as continuous layers.

Sedimentary environments

- mountain streams,
- rocky beaches with high waves,
- glacier meltwaters—in which currents are strong enough to transport gravel.

Strong currents also carry sand, and we almost always find sand between gravel particles. Some of it is deposited with the gravel, and some infiltrates the spaces between particles after the gravel is deposited

One example: Mississippi River

- **Plate movement lifts up rocks in the Rocky Mountains.**
- **Rainfall in those mountains—a source area—causes weathering of the rocks there.**
- **The river will transport the sediment down to sink areas—sites of deposition, also known as *sedimentary basins*—in the Mississippi delta and the Gulf of Mexico.**
- **In these sedimentary basins, the sediments pile up on top of one another—layer after layer—and are eventually buried deep in Earth's crust.**
- **In the depth they may become filled with valuable oil and natural gas.**



