

EPSC 201 LECTURE 16 MARCH 15 2016

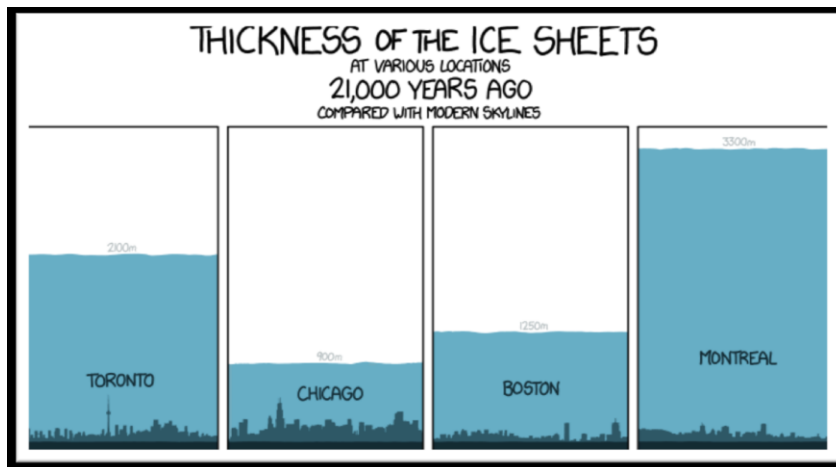
Sediments and Sedimentary rocks only occur in the upper part of the crust, but are uniquely important because they contain a record of the Earth's history and the bulk of Earth's energy resources.

Sediments are loose pieces of rock. Sedimentary rock are the sediments coming together and sticking together in a solid piece. A rock can be weathered (breaking it up) to turn it into sediments. Then these sediments are transported around, they settle, and then condense back through diagenesis into a sedimentary rock.

Sediment cores and Climate Interlude:

Why sediments are related to climate...

At the moment, we have ice in Greenland and Antarctica; the ice cover on Earth at the moment is relatively small. We are in an inter-glacial state. Climate goes through glacial cycles. Many million years ago, the ice cover was larger and then retreated to its current state because the temperature warmed. The angle of the rotation axis of the Earth changes which causes these cycles.

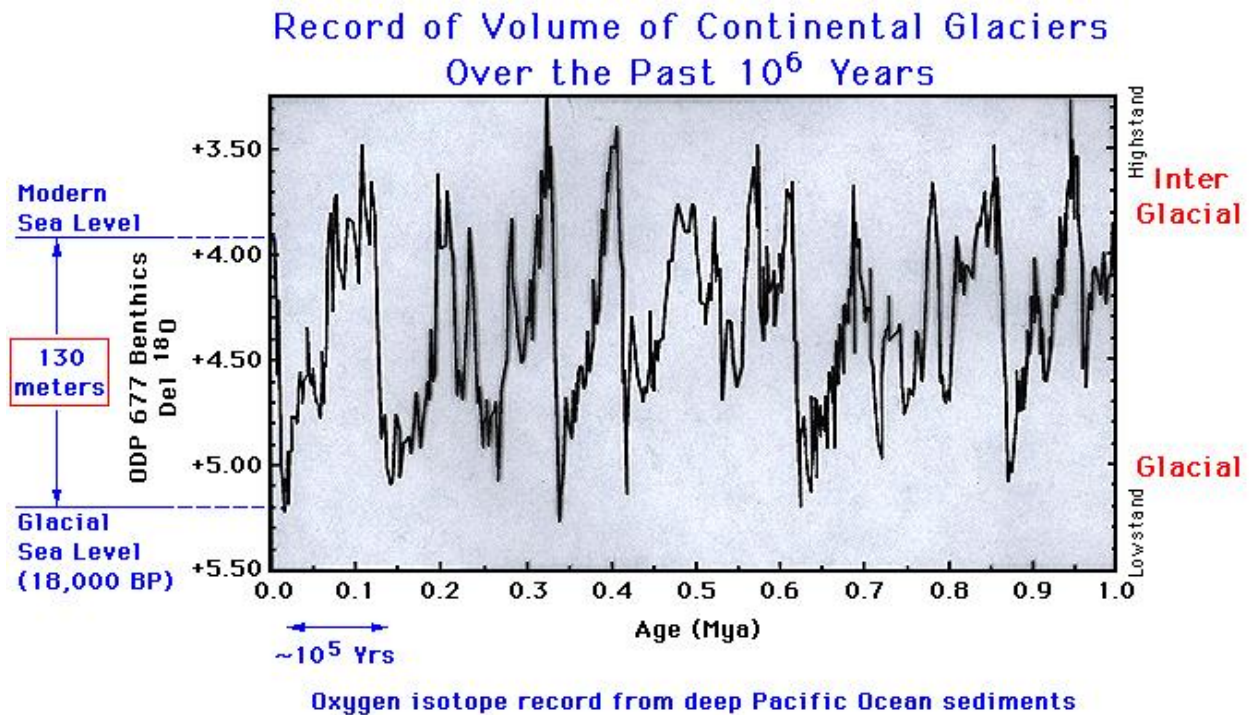


We can look at past inter-glacials where the temperature was warmer to predict what will happen in our current inter-glacial state.

One of the ways that we know about these cycles is by looking at sediments. When glaciers retreat (glaciated state), then we have a different amount of rock/sediments being transported off the continents out towards the ocean. When the ice retreats, it can scrape off bits of rock with it and carry it out to the ocean. We can go on a boat and use a machine which will collect a sediment core from the bottom of the ocean (popular in the Polar Regions). We can analyze a sediment core because it has different layers which formed. The sediments have been shaken around in different ways resulting in different layers. There is a high rate of sediment deposit when large amounts of ice retreat – large bits of rock can be observed in a large layer in a sediment core. The layers go back in time as you dig further down – a timeline of Earth's history.

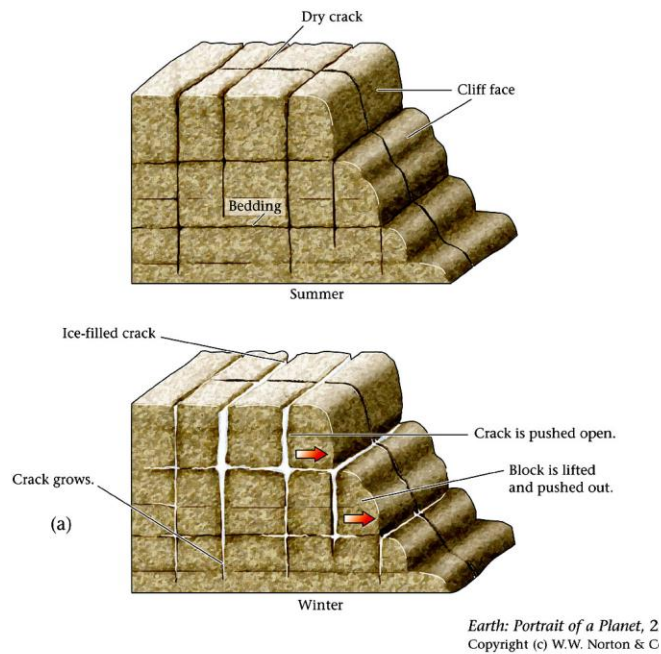
We can take samples from each layer and look at the ratio of isotopes (Oxygen) in the sediments. The ratio of isotopes in the sediments will be different in a state where there is less ice on land and more water in the oceans than if the state is glaciated, i.e. the isotopic ratio is different in ice than in water.

The O^{18} isotope ratio can be plotted based on its concentration. We can take all this information to get a record of how ice cover has changed on Earth over millions of years. O^{18} concentration can be related to ice volume on Earth.



The top peaks represent less ice (inter-glacial state) and the bottom peaks represent high ice volume (glacial states). The O^{18} can thus give us a record of ice volume on Earth. The last glacial maximum (when NA was covered by ice) and today, and you took all that ice that melted and spreaded it evenly over all the world's oceans, the total height would 130m. Sea level was 130 m lower 10^6 years ago because it was ice. The process of taking a rock and converting it to sediment is called **weathering**. There is physical and chemical weathering.

Physical (Mechanical) Weathering: Rocks are broken down or disintegrated by physical processes, but retain the characteristics (minerology, composition) of the original parent rock. Ex. You can have cracks in a rock, and water fills these cracks, and freezes, expanding, thus the rock is breaking apart.



Chemical Weathering: The constituents of the rock undergo a chemical change → decomposition, leaching, and formation of secondary minerals. Ex. Water breaks apart the ions in a rock and disintegrates it, thus resulting in a separation of 2 different types of sediments.

Physical and chemical weathering provide the raw material (sediments; particles and dissolved ions) to form the sedimentary rocks. Geologists define 4 sedimentary rock classes:

Biochemical: cemented shells of organisms. Soluble material produced mostly by chemical weathering and precipitated by biological processes.

Clastic/detrital: Loose rock fragments (clasts) cemented together. Transported as solid particles derived from both mechanical and chemical weathering. Ex. In a stream you may have clastic sediments being transported down stream by physical means. Transported by air, water, or wind, etc.

Chemical: minerals that crystallize directly from water. Soluble material produced mostly by chemical weathering and precipitated by inorganic processes.

Organic: carbon-rich remains of once living organisms. Made of carbon-rich relicts of plants (e.g. coal).

Clastic/detrital

Sediments may be accumulations of materials (mineral grains, rock fragments) that originate and are transported as solid particles derived from both mechanical and chemical weathering

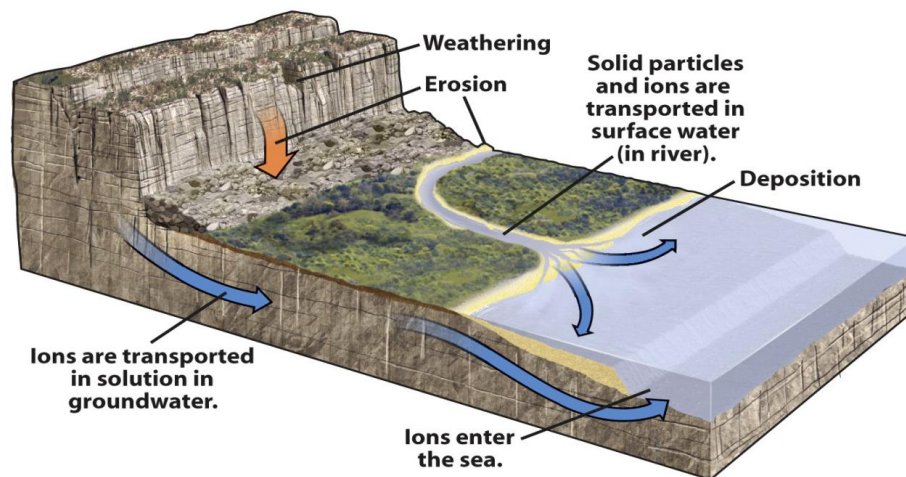
Deposits of this type are termed *clastic or detrital* and the sedimentary rocks that they form are called **clastic or detrital sedimentary rocks**.

The idea is that rock is broken up, the sediments are transported by wind or water, then it will settle. Then something will fill in the gap and the sediments are compressed forming sedimentary rock.

E.g. hornblende, quartz.

Clastic sedimentary rocks are created by:

- Weathering – generation of detritus via rock disintegration
- Erosion – removal of sediment grains from parent rock. Act of taking that rock and moving it away from its source until its means of transportation does not have enough energy to continue its transportation, the rock settles.
- Transportation – dispersal by gravity, wind, water, and ice
- Deposition – settling out of the transporting fluid
- Lithification – transformation into solid rock



Lithification (2 steps): transforms loose sediment into solid rock

- Compaction – burial adds pressure to sediment
 - Squeezes out air and water (transporting fluid)
 - Compresses sediment grains
- Cementation – minerals grow in pore spaces
 - Often quartz or calcite
 - Precipitate from groundwater (happens at the bottom of a river)
 - Glue sediments together

Classifying Clastic Sedimentary Rock: classified on the basis of texture and composition. The following variables produce a diversity of clastic rocks.

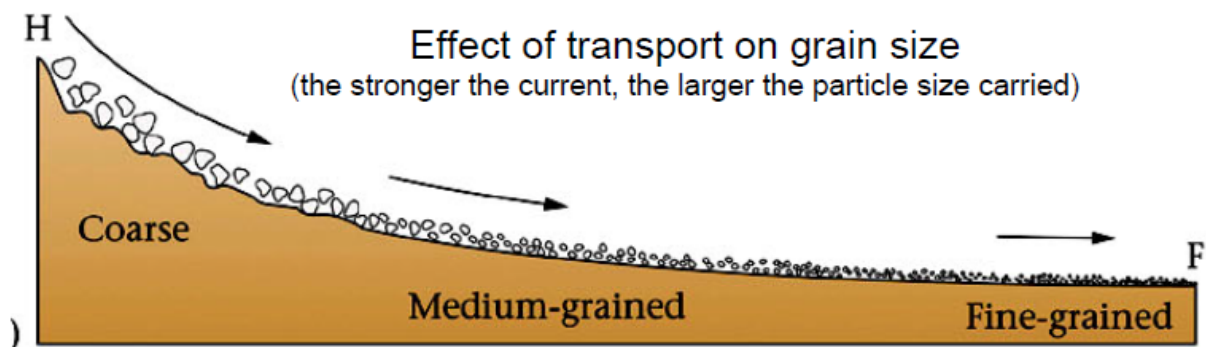
- Clast (grain) size

- Clast composition (mineral composition, what is the rock made of? Which can tell us about where it came from)
- Angularity and sphericity (shape of the piece)
- Sorting (are big pieces on the bottom and small on top, or all random?)
- Character of cement

<i>Size Range (millimeters)</i>	<i>Particle Name</i>	<i>Common Sediment Name</i>
>256 64–256 4–64 2–4	Boulder Cobble Pebble Granule	Gravel
1/16–2	Sand	Sand
1/256–1/16 <1/256	Silt Clay	Mud

Clastic sediments are typically dominated by clays and quartz.

The size of the particles is related to the energy of the transporting medium. Transport of gravel requires swiftly flowing rivers (more energy). Less energy is required to transport sand → dunes and beaches. Silts and clays settle very slowly and accumulate in quiescent environments.



The further it gets transported, the more it gets broken up (especially in a turbulent system). The closer to the parent rock, the bigger the grains. The further away from the parent rock, the finer the grain.

Clast size is a measure of the size of the fragments or grains. Size ranges from very coarse to very fine (gravel, sand, silt, and clay). As transport distance increases, grain size decreases.

Gravel – very coarse (boulder), coarse (cobble), medium (pebble), and fine (pea)

Sand – coarse, medium, and fine

Silt – coarse, medium, and fine

Clay – coarse and fine.

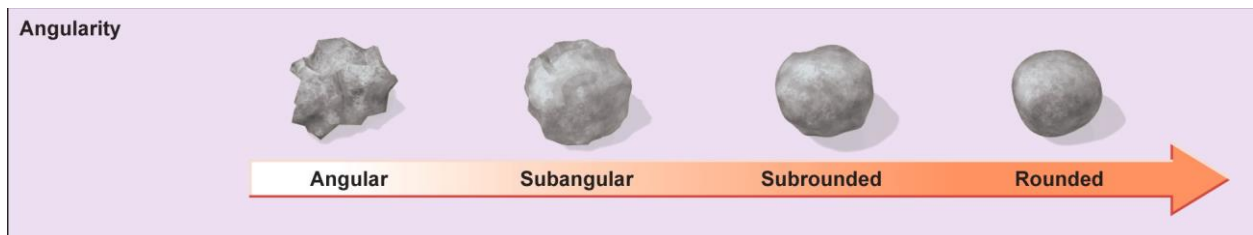
Clast composition – the mineral makeup of sediments

- May be individual minerals or rock fragments
- Composition yields clues about the original source rock

Angularity: - the degree of edge or corner smoothness

Sphericity: - degree to which a clast nears a sphere

- Fresh detritus is usually angular and nonspherical
- Grain roundness and sphericity increases with transport
 - Well-rounded – long transport distances
 - Angular – negligible transport



The grain becomes rounder as it gets further away from the source rock.

Fresh sediment that is recently broken off is more angular and has less sphericity. It takes a lot of travel for the rock to look like a sphere – takes weathering basically.

Sorting: is a measure of the uniformity of grain sizes in a sediment population. Degree of sorting increases with transport distance. Poorly sorted – clasts show a wide variety of grain sizes which means it is near the source. Well sorted – all clasts have nearly the same grain size which means it is further from the source.

Character of cement: minerals that fill sediment pores. Different clastic sedimentary rocks have different cement.

-Quartz and calcite are the most common cements.

TABLE 7.1 Classification of Clastic Sedimentary Rocks

Clast Size*	Clast Character	Rock Name (Alternate Name)
Coarse to very coarse	Rounded pebbles and cobbles Angular clasts Large clasts in muddy matrix	Conglomerate Breccia Diamictite
Medium to coarse	Sand-sized grains <ul style="list-style-type: none">• quartz grains only• quartz and feldspar sand• sand-sized rock fragments• sand and rock fragments in a clay-rich matrix	Sandstone <ul style="list-style-type: none">• quartz sandstone (quartz arenite)• arkose• lithic sandstone• wacke (informally called graywacke)
Fine	Silt-sized clasts	Siltstone
Very fine	Clay and/or very fine silt	Shale (if it breaks into platy sheets) Mudstone (if it doesn't break into platy sheets)

*For precise diameters, see Table B.1 in Interlude B.

Rock characteristics provide clues about:

- Source area
- Depositional environment

Sediment → Lithification → Sedimentary Rock

Example: Conglomerate with sandstone lenses – something we may see near a river. There are big boulders surrounded by sediment. Particles are a range of sizes. The rocks are relatively smooth.

Conglomerate: rounded rock clasts. Clasts are rounded as flowing water wears off corners and edges. Deposited farther from the source than breccia.

Example: Breccia – coarse, angular rock fragments. Angularity indicates the absence of rounding by transport, hence, deposited relatively close to clast source. Formed in areas where a cliff face may have broken off and fallen down until they got buried.

Example: Diamictite – non-sorted conglomerates with a wide range of clasts with up to 25% gravel, typically of glacial origin (moraine or till). Contains a wide range of different sizes of gravel; this is a way the materials would look if it was transported by a glacier.

Example: Sandstone – a clastic rock made of sand-sized particles. Quartz is by far the most common mineral in sandstones. Found in beach or dune.

Quartz sandstone – on the surface, it looks pretty uniform but if you look at it under a microscope, sandstone is poorly sorted (the grains are not all the same size). After shale, sandstone is the most abundant sedimentary rock, accounting for about 20% of the group.

Example: Arkose – sand and gravel with abundant feldspar. Commonly deposited in alluvial fans. Feldspars indicated short transport and arid conditions. Contains coarse clastics – sand and gravel-sized clasts.

Fine clastics are composed of silt and clay. Silt-sized sediments are lithified to form siltstone. Clay-sized particles form mudstone or shale.

- Shale: breaks into thin platy sheets – forms layers
- Mudstone – doesn't break into platy sheets
- Examples: floodplains, lagoons, mudflats, deltas, deep-water basins

Shale: breaks into tiny plates. Shale is deposited in a particle way where it is in layers and breaks apart in these layers. Shale rock consists of silt and clay-sized particles that are compacted together by pressure. Shales account for ~70% of all sedimentary rocks. The reason why it breaks apart is because the clay minerals are flat and they come together and lie together in a flat way which has weak bonds between the layers of mineral pieces.

Clay mineral particles are flat or tabular and usually become tightly packed. They are not prone to cementation because very little water can percolate through them and thus these rocks crumble and weather easily. Shale typically split into layers along well-developed, closely spaced planes.

Example: Mud and shale – in a more restrictive use of the term, shale must exhibit the ability to split into layers along well-developed, closely spaced planes. If the rock breaks apart into chunks or blocks, the name mudstone applies.

Practice Question: Describe how a clastic sedimentary rock forms from its unweathered parent rock?

Answer: Firstly the parent rock needs to undergo weathering so it breaks apart. Then erosion happens next. The rocks are then carried by a fluid (wind, water) to another location. The pieces of rock are further broken apart during the transport. The pieces are then deposited and stop being transported in the medium and is sitting on the floor. Then lithification occurs – you have the clasts (particles which are being squeezed out and push together) and then compaction and cementation occur.

Teacher's Answer: First, physical and chemical weathering break up and alter the parent rock to form detrital fragments of parent material, dissolved ions, and clay. This sediment of weathered grains is then eroded from the parent surface and transported away from the source by water, wind, or glacial ice (or directly by gravity, in the case of large clasts on a slope). Ultimately, the sediment will settle out of the transport medium. Eventually, loose grains of deposited sediment may become buried under additional sediment, compacted, and cemented to form sedimentary rock.

Practice Question: How do grain size and shape, sorting, sphericity and angularity change as sediments move downstream?

Answer: Grain size decreases in size as it moves downstream and the shape increases in sphericity. The clast also becomes less angular. The sorting becomes more uniform.

Teacher's Answer: Mechanical forces such as tumbling and abrasion wear on sediments as they are transported downstream. Angular protuberances are especially likely to be broken off. As a result, grain sizes decrease, with grains becoming more spherical and more rounded (less

angular). The speed at which the water in a stream is traveling decreases along its course, and the capacity of the stream to carry sediment is directly related to its rate of flow. So larger grains are deposited from finer grains (grains become sorted as they travel downstream).

Chemical

Derived from material that is carried in solution (i.e. soluble material) to lakes and seas by surface runoff and groundwaters and precipitated chemically rather than mechanically. Form in cave walls, hot springs where dissolved minerals from fluid precipitated and cooled.

E.g. Opaline silica deposited from hot springs ($\text{H}_4\text{SiO}_4 \rightarrow \text{SiO}_2 + \text{H}_2\text{O}$); Stalactite growing in a cave (calcium carbonate formation, CaCO_3)

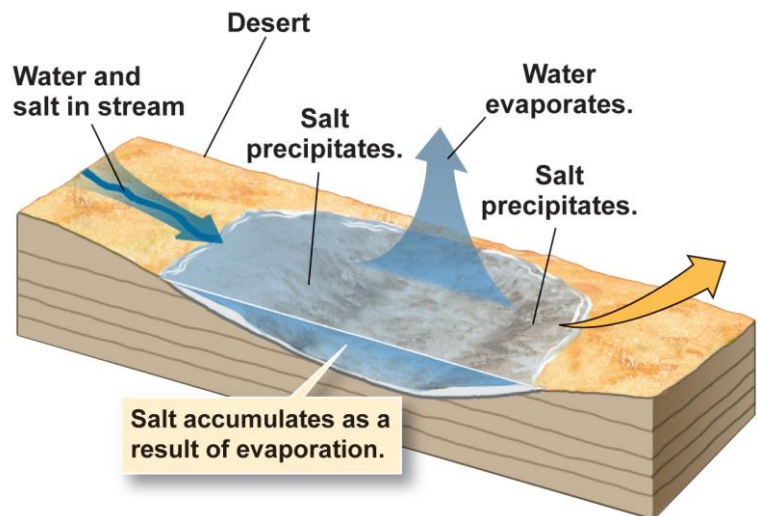
There are several classes:

- Evaporites
- Travertine – e.g. Yellowstone where you have a lot of hot springs. Travertine is deposited when groundwater, containing calcium carbonate, evaporates or is degassed.
- Replacement chert
- Dolostone (or dolomite): $\text{CaMg}(\text{CO}_3)_2$ – the hard cap of the Niagara escarpment

Examples: Dolomite mountains (Italy) $\text{CaMg}(\text{CO}_3)_2$ – Although dolomite can form by direct precipitation in a few rare environments, most probably originates when magnesium in seawater replaces some of the calcium in limestone. There are practically no young dolomite rocks, most are ancient rocks.

Evaporites: Rock from evaporated sea or lake water

- Evaporation triggers deposition of chemical precipitates
- Thick deposits require large volumes of water
- Evaporite mineral include halite (rock salt) and gypsum.
- Requires a large body of water to evaporate
- Example. Large salt plane in Salt Pans in Death Valley, CA. It was a large salt water lake and dried up and the salt evaporite came out. It is also the lowest elevated point in NA, 86 below sea level.



Travertine: Calcium carbonate (CaCO_3) precipitated from ground water where it reaches the surface.

- CO₂ expelled into the air causes CaCO₃ to precipitate.
 - Thermal hot springs
 - Caves – speleothems

Replacement Chert: nonbiogenic

- Cryptocrystalline silica gradually replaced calcite, long after limestone was deposited

Many colors and varieties:

- Flint: colored black and gray from organic matter
- Agate: precipitates in concentric rings
- Petrified wood – wood grain preserved by silica

Petrified wood is chert that forms when silica-rich sediment buries a forest. The silica dissolved in the groundwater percolates through the rotting wood and precipitates a very fine-grained (cryptocrystalline) quartz within the wood, gradually replacing the wood's cellulose and, thus, preserving its original structure.

Biochemical

E.g. Coral reefs. Coral reefs are often used as a measure of sea level. We know that they grow at a particular depth, and so we can look at exposed coral reef and back track the water level before.

Biochemical Sediments derived from the shells of living organisms. E.g. our teeth are mineral.

- Hard mineral skeletons accumulate after death
- Different sedimentary rocks are made from these materials: Calcite and Aragonite (CaCO₃ – limestone)
- Silica (SiO₂) – chert

Limestone is a sedimentary rock made almost entirely of calcite or aragonite (CaCO₃ polymorphs). These minerals are the most common materials used by organisms that make seashells. Limestone often preserves the shells of fossil organisms, sometimes in great abundance.

Example: Coquina – poorly-cemented shells and shell fragments.

Example: Microfossils – micro-organisms which form shells: Coccolithophores (CaCO₃), diatoms (SiO₂), radiolaria (SiO₂), foraminifera (CaCO₃). These can tell us about the environment in the past by knowing the type of micro-organism. What did the world look like for this micro-organism to be alive at this time for this abundance?

Limestone – sedimentary rocks made of CaCO₃

- Fossiliferous limestone – contains visible fossil shells
- Micrite – fine carbonate mud

- Chalk – made up of plankton shells
- Fine grained micro-fossils produce chalk cliffs with chert or flint layers or nodules. Chalk – Plankton foraminifera (CaCO_3). Chert – Plankton radiolaria (SiO_2).

Chert – rock made up of cryptocrystalline quartz; chert is the skeleton of these marine planktons

- Silica (SiO_2) skeletons of some marine plankton

Organic

E.g. Coal – example of all carbon that has been buried. Coal is altered remains of fossil vegetation. It is a black, combustible sedimentary rock and is composed of 50%-90% carbon. It fuels industry since the industrial revolution began.

Unlike any other sedimentary rock, coal is not composed of minerals in the true sense of the word, but of organic matter. A close examination of a piece of coal under the microscope will reveal the presence of various plant remains: leaves, bark, and wood which has been buried through time. It is carbon-rich relics of plants.

Made of organic carbon, the soft tissues of living things.

- Coal – altered remains of fossil vegetation.
 - Black, combustible sedimentary rock
 - Over 50-90% carbon
 - Fuels industry since the industrial revolution began
 - We can see a coal layer if a forest was buried under a layer of sediment and through time it formed a coal layer. You can have a whole area of plant life that gets buried and turns into coal.