EOSC221

PART 1: EVAPORITES
(and other sediments)

PART 2: SEDIMENTARY FACIES

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- Introduction
- Environments of Deposition
  - Sabkha
  - Basin Deposits
  - Lakes
- Example Evaporite Deposits
- Other Sedimentary rocks
  - Banded Iron Formations
  - Cherts
  - Coal
  - Volcaniclastics
- Sedimentary Facies

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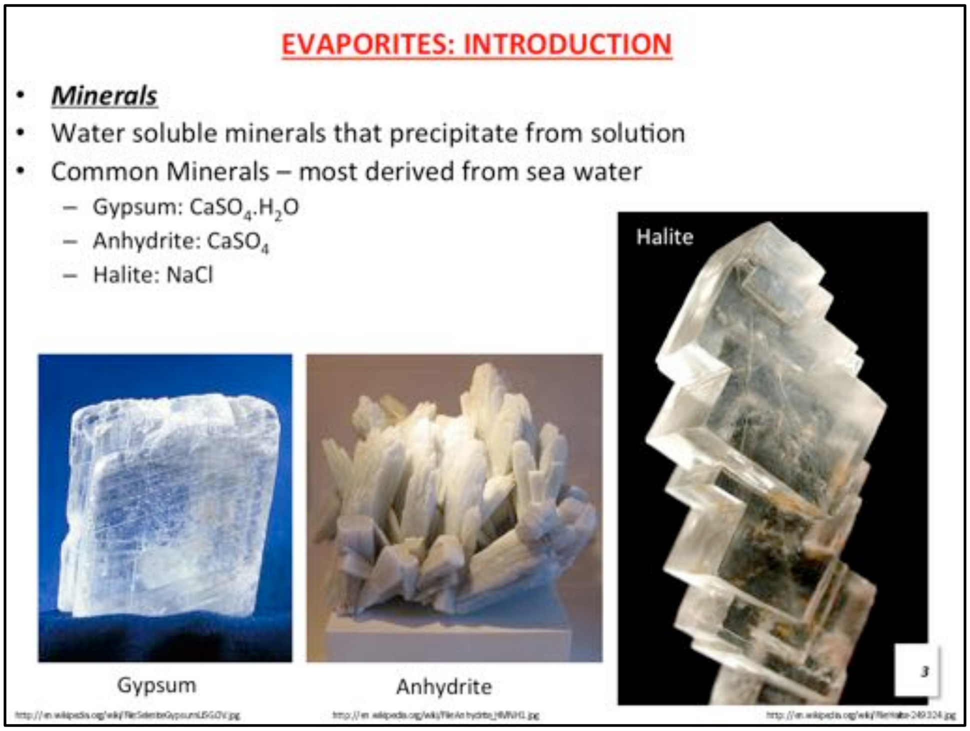

Evaporite - forms by concentration / crystallization of water soluble minerals via evaporation of an aqueous solution. Evaporites can be marine, and non-marine. In addition to precipitating in an open body of water they may also precipitate from pore waters in sediments close to the surface. Most evaporites are derived from evaporating sea water. Chlorine ions (Cl^-) make up 94.5% of seawater and sulfate ($SO4^{2-}$) makes up 4.9 %. This probably explains why the following are the most evaporite minerals:

Halite (NaCl)
Gypsum ($CaSO_4.H_2O$)
Anhydrite($CaSO_4$) – effectively dehydrated gypsum

Evaporite minerlas are extremely valuable to industry. For example, table salt (Halite), Sylvite (KCL "potash"), gypsum and many other evaporite minerals are extremely valuable to the chemical industry. In addition, structures created by "salt tectonics" are often associated with oil and gas plays.

http://ngm.nationalgeographic.com/2008/11/crystal-giants/shea-text

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This fantastic image is NOT from a movie set. These are giant gypsum crystals (some 11m long) in Mexico's Cueva de los Cristales. The crystals grew in the cave when it was filled with mineral-rich water at about 58°C. Mining operations exposed the crystals when the water was pumped out of the cave.

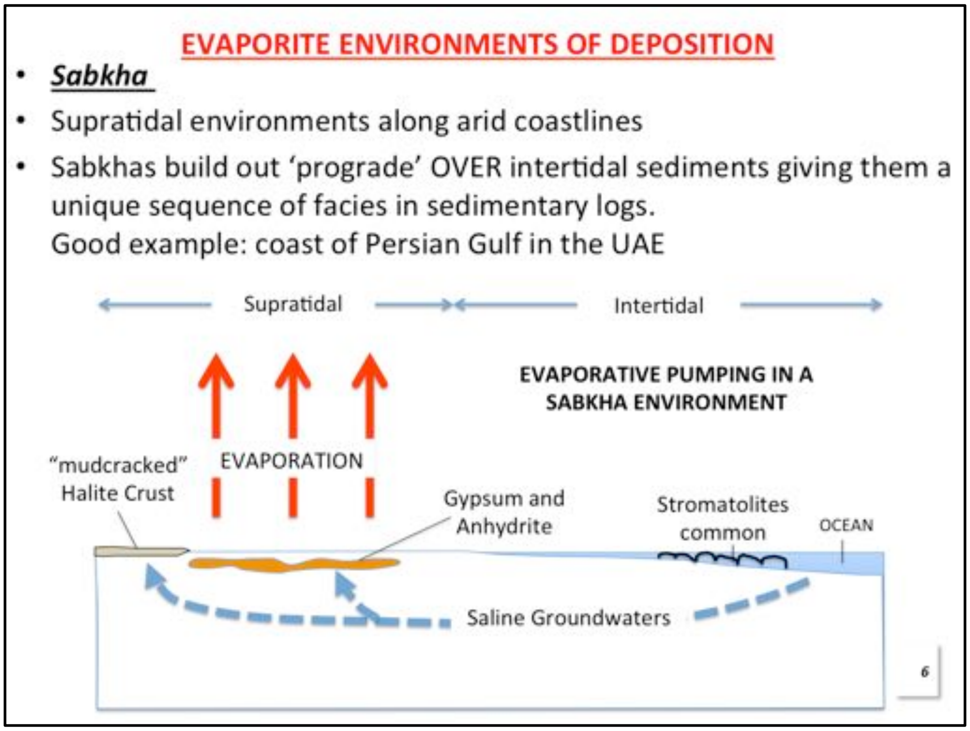
Abundance and Distribution

- 1% of all Phanerozoic (542 – 0MA) rocks
- More evaporite production when conts grouped around equator
- Evaporites highly soluble – rare in outcrop – mostly subsurface

Textbook Fig. 16.1

Of all the sedimentary rocks deposited since the base of the Cambrian, evaporites only make up around 1%. Even so, they can form extensive deposits particularly when continents are grouped around the equator resulting in elevated rates of evaporation in shallow marine settings.

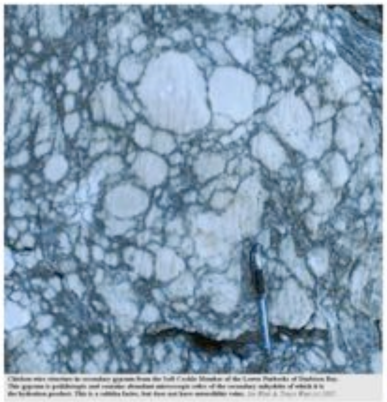
As evaporite minerals are very soluble they are usually fairly rare in outcrop. Most evaporite deposits are known form subsurface sections, often revealed by drilling.



We have already seen this environment in relation to the formation of dolomites. In supratidal environments under hot arid conditions the evaporation of water from the surface of the exposed sediment will draw saline fluids through the sediment pores via EVAPORATIVE PUMPING. As the water is evaporated gypsum is precipitated directly in the sediments. Halite may also form on the top of the sediment forming a "mud cracked" surface. The net deposition of material will cause the sabkha to prograde "build out" into the shallow sea. This will create sedimentary successions with a very distinctive set of facies in a vertical sense.

Good examples of modern Sabkha environments can be found along the coast of the United Arab Emirates and Baja California.

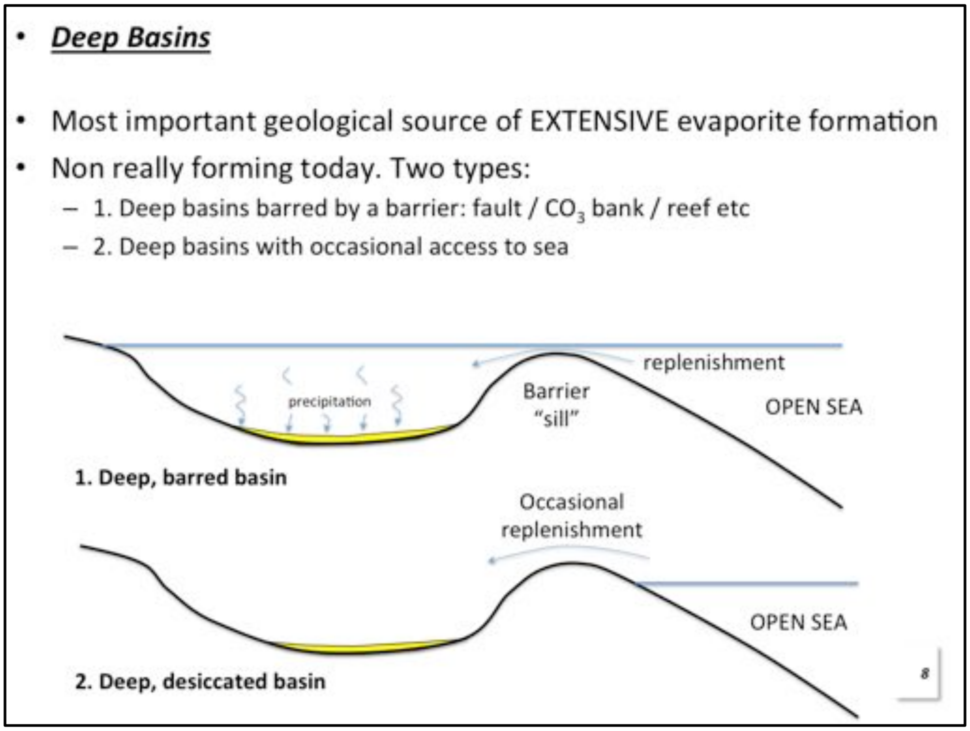
- Gypsum precipitated directly into sediments (also dolomitization)
- Gypsum as nodules / chicken wire structures / enterolithic texture
- May get anhydrite precipitating further landward rather than gypsum



Gypsum and anhydrite will form a number of possible sedimentary structures:

1. Discrete gypsum nodules
2. Chicken wire gypsum: nodules become closely packed and the sediment between them restricted to thin stringers
3. Enterolithic textures: layers of nodules that grow together and contort / fold as they develop

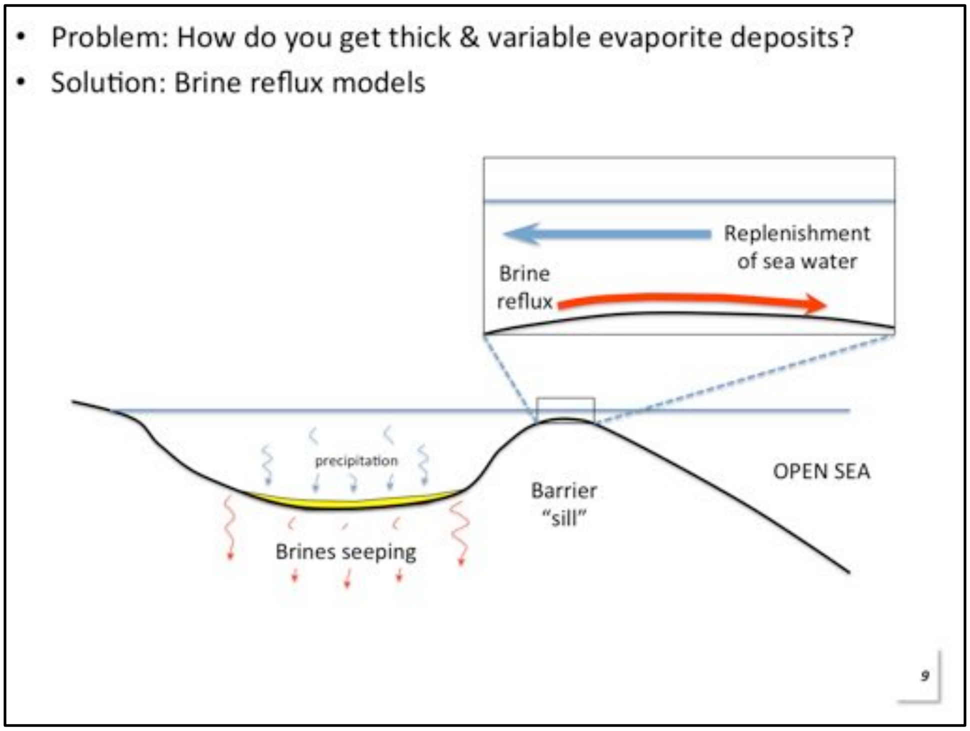
In more landward areas where temperatures are higher you may get the direct precipitation of anhydrite rather than gypsum.



These are probably the most important source of evaporites though in modern times we have no modern analogue. They form when sea water is evaporated from a deep basin. In general marine evaporites will precipitate in the following order:

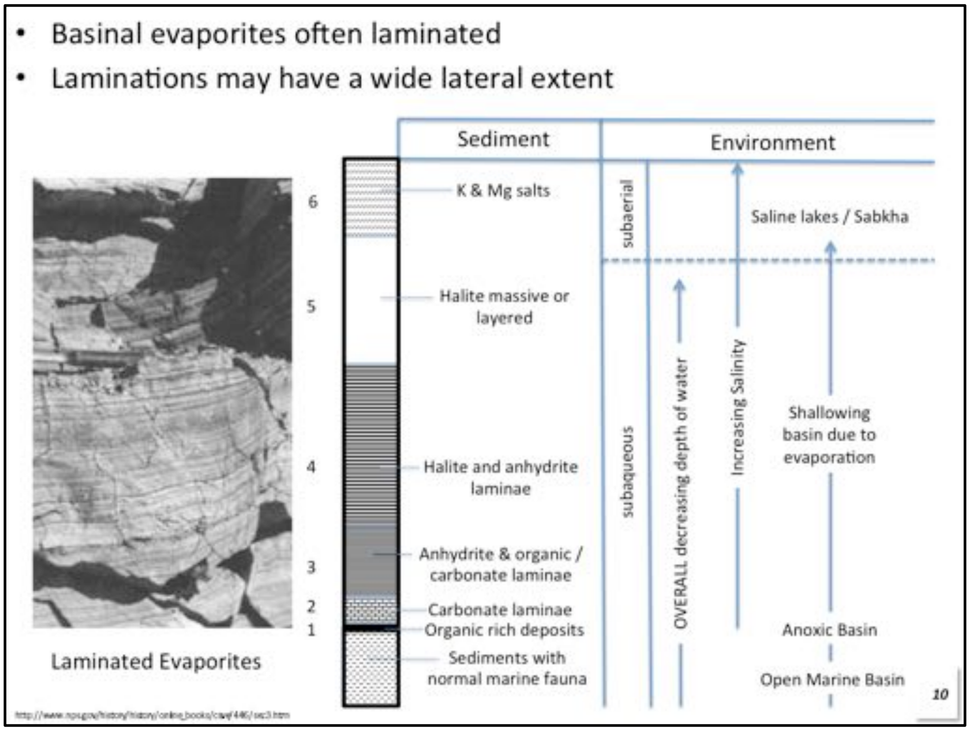
When 50% of marine water is evaporated it is possible for a minor amount of carbonates to be precipitated.
When 84% of marine water is evaporated: Gypsum
When 90% of marine water is evaporated: Halite
When 96% of marine water is evaporated: Potassium salts like Sylvite

These basins will can have a very restricted connection to the open ocean, possibly restricted by a fault, carbonate bank, reef or similar structure. These structures may start to restrict basins during periods of lowering sea level. The may also only receive water occasionally, perhaps during storms which will be evaporated forming salt deposits and at a later receiving more sea water.



There is a problem though. A 1000m column of sea water will only produce 15.9m of evaporite (the majority of it halite). So how do you account for some evaporite deposits that are over 1000m thick with a variable evaporite composition?

ANSWER: Reflux: A reflux model suggests repeated influxes of sea water into the basin replenishing water that has been evaporated to allow the formation of thicker evaporites. IN ADDITION the concentrated brines that are formed during evaporation are dense and will either seep into the underlying sediments or move out BELOW the influx of fresh sea water in the case of barred basins. In this way evaporites will have a mineralogical sequence that might not reflect a simple concentration of sea water and precipitation of minerals at various solubility points. Indeed the reflux of brines can maintain a steady seawater chemistry and deposit just one type of evaporite mineral or if rates of reflux alter can produce a variable sequence of evaporite minerals.



The evaporites that are precipitated in these deep basins often form laminae and beds that have a very wide lateral persistence. A VERY general sequence of facies that might be represented in a vertical sequence of evaporites deposited in basin setting could be:

1. Organic rich sediments formed as the ocean basin starts to stagnate. The circulation in the basin would be reduced and the bottom waters rapidly become anoxic. In these conditions anoxic organic rich shales would form.
2. Laminated carbonate / anhydrite as the water starts to evaporate
3. Laminated anhydrite
4. Laminated anhydrite / halite
   Halite precipitated during LOW periods of reflux (higher salinity), anhydrite during HIGHER periods of reflux (lower salinity)
5. Thick halite deposits would form as evaporation becomes well advanced
6. Final evaporation of brines producing potassium and magnesium salts (eg Sylvite) in isolated saline lakes and sabkha

- ***Lakes***
- Similar minerals (halite, anhydite, gypsum) but also some unique fresh water precipitated minerals
- Mineralogy can be very variable depending on lake chemistry
- Two broad catergories
  - Salt lakes : Halite dominated
  - Bitter lakes: sodium carbonate and sulfate dominated

The Dead Sea, a salt lake.

Mono Lake California, a bitter lake.

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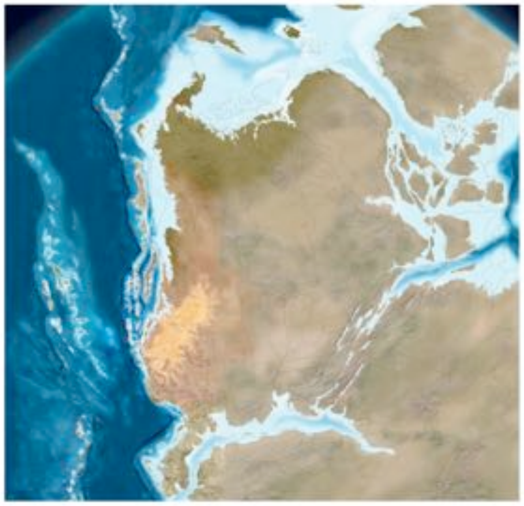
Apart from halite, anhydrite and gypsum lake evaporites can demonstrate some unique fresh water precipitated minerals. The mineralogy of lacustrine evaporites may vary greatly depending on the lake chemistry which will be heavily influenced by the local environment. Two broad categories of evaporite forming lake are:

1. Salt lakes. Dominated by halite deposition. Good examples are the Dead Sea and the Great Salt Lake, Utah.
2. Bitter lakes. Dominated by sodium carbonate and sulfate deposition. Good example: Mono Lake in California and Carson Lake in Nevada.

Lake evaporite deposits commonly exhibit a zonation with the least soluble around the edges of the lake and the more soluble towards the centre.

EXAMPLE EVAPORITES DEPOSITS

- ***The Gulf Coast Salt Basin and the Ochoan Series Delaware Basin***
- Make notes: page 315 – 318 – **NOTE** This is potentially examinable



The Jurassic Gulf Coast Salt Basin. Evaporites form in the rift basins that open up in the early formation of the Atlantic Ocean

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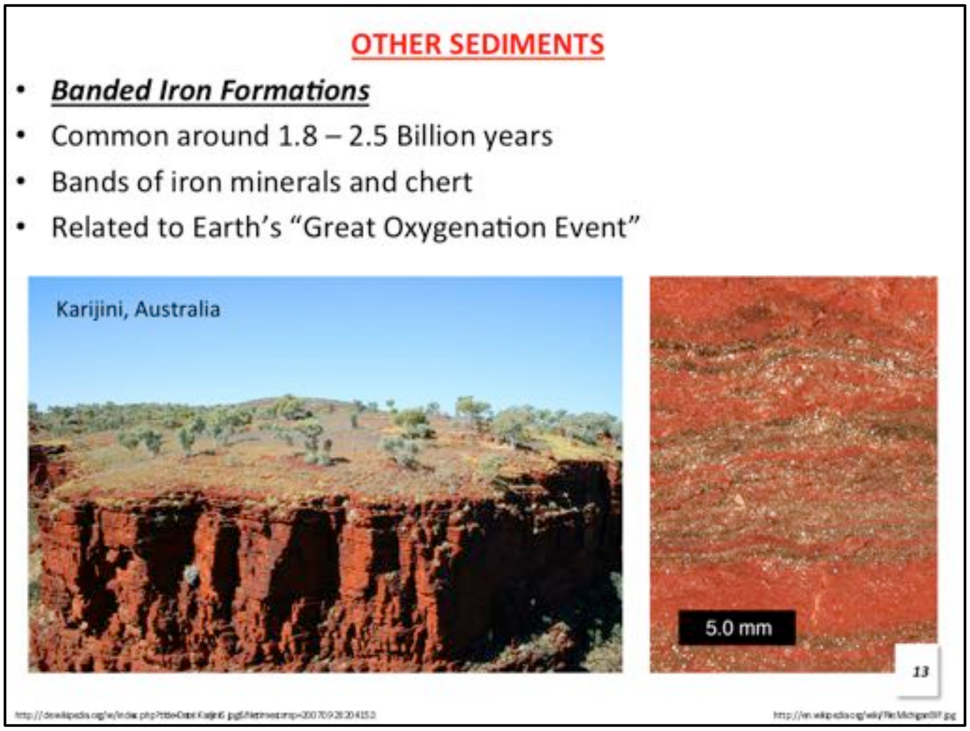
http://jan.ucc.nau.edu/~rcb7/nam180.jpg

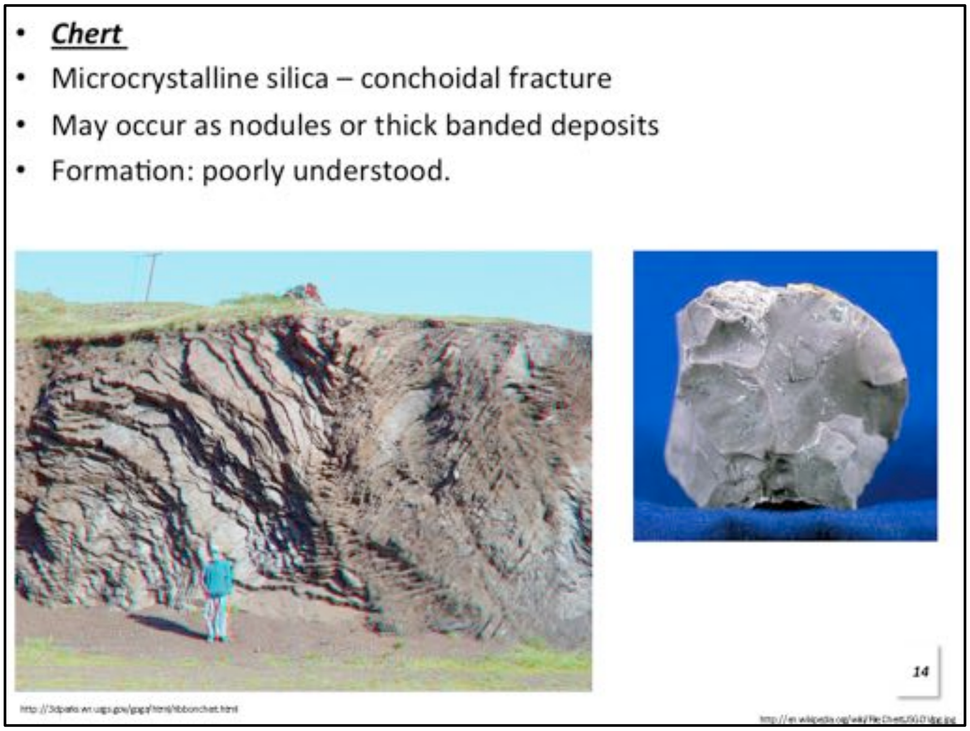
Make notes: page 315 - 318



Unfortunately we don't have enough time to go into a lot of detail with these sediments and I have had to omit some very important sediments like phosphorites.

Banded Iron Formations (BIF's)

A BIF is composed of repeated layers of iron oxides (magnetite (Fe_3O_4) or hematite (Fe_2O_3)) alternating with layers of iron-poor shale and chert. BIF's are most common between 1.8 – 2.5 billion years ago but have not been deposited for around the last 500 million years. The conventional concept regarding their formation is that the iron layers in BIF formed as oxygen was released by photosynthetic cyanobacteria (blue green algae). This increased rate of oxygen production by the biosphere correlates well with the majority of BIF formation (and structures called stromatolites produced by the cyanobacteria) and is called the Great Oxygenation Event. The oxygen produced caused the precipitation of iron in solution in the Earth's oceans to form insoluble iron oxides (rust), forming the thin layers of iron rich sediment in BIFs. Some have suggested that each band may result from cyclic variations oxygen - possibly related to increased photosynthesis (and therefore oxygen release) during summer months. Banded Iron Formations are a very important source of iron ore.



Chert

Fine-grained silica-rich often microcrystalline sedimentary rock. Demonstrates great variation in color but is most often gray /brown. Chert often possesses a conchoidal fracture. The exact mechanism of chert formation is poorly understood. Some cherts can form when the siliceous skeletons of marine plankton are dissolved and the silica reprecipitated during diagenesis.

- ***<u>Coal</u>***
- Concentrated plant material
- Volatile driven off to form coals
- Very common in the Carboniferous of the Northern hemisphere

http://en.wikipedia.org/wiki/File:Sydney_Mines_Point_Aconi_Seam_038.JPG

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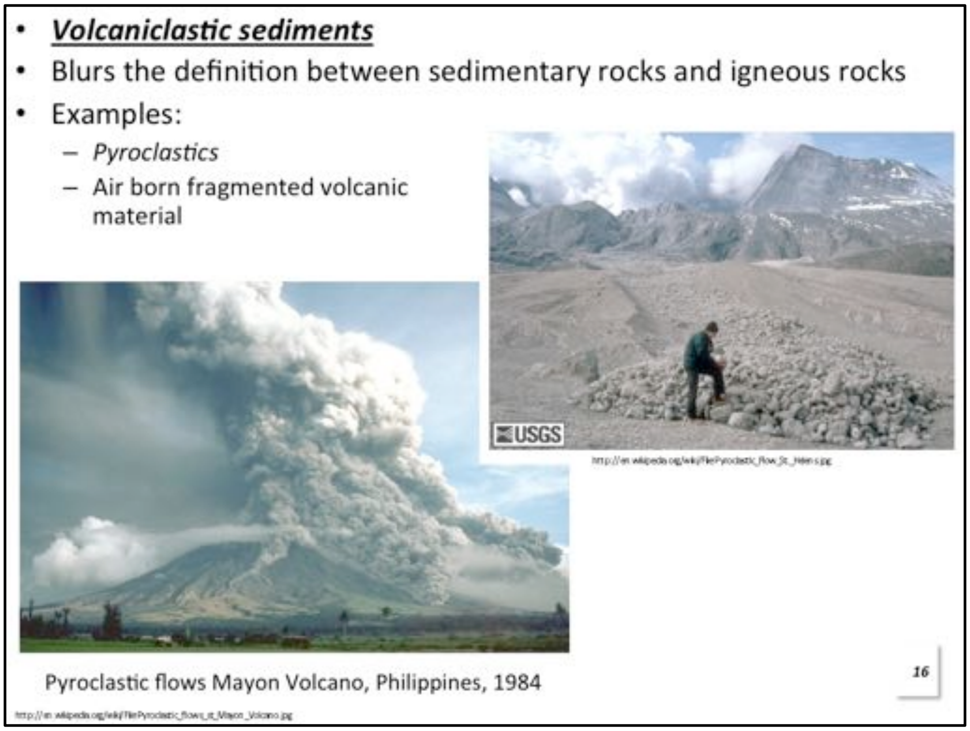
<u>Coal</u>

Black – brown sedimentary rock composed primarily of carbon along with variable quantities of hydrogen, sulfur, oxygen, nitrogen. Commonly found in beds or coal seams. Some forms of coal such as anthracite may be regarded as a metamorphic rock due to the high temperatures and pressures it has been subjected to. Coal forms when organic vegetation collects and is not oxidized. Initially the plant material forms peat but increasing burial temperatures and pressures drive off much of the volatile material, increasing the carbon content and eventually forming a coal.

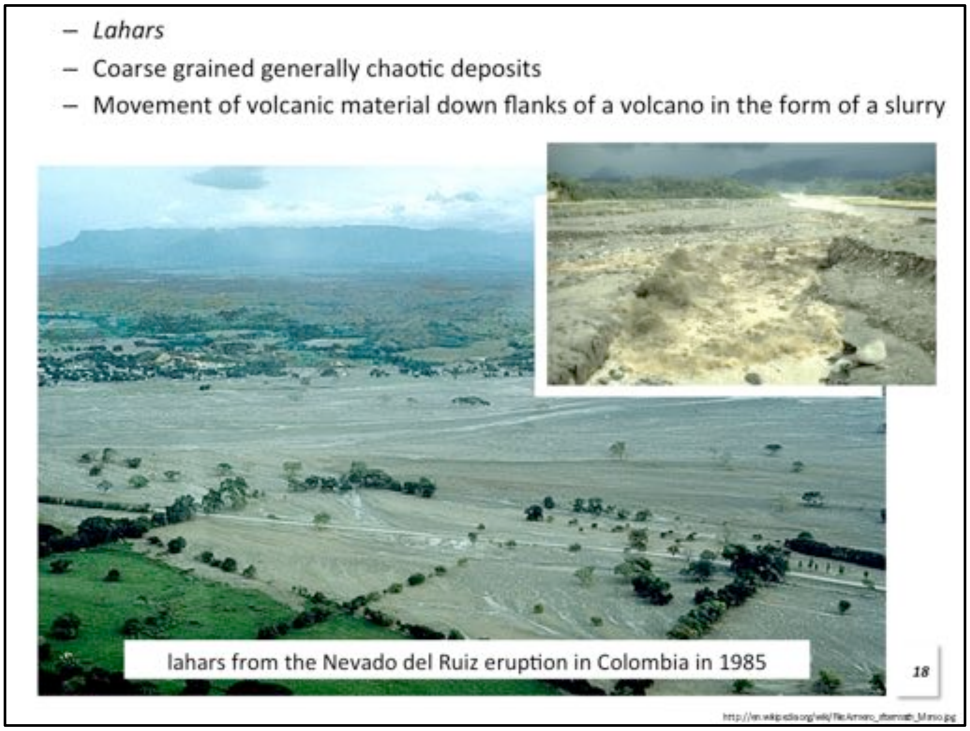


Volcaniclastic Deposits: Clastic rocks composed mostly of volcanic materials that have been transported by wind or water.

Pyroclastic rocks : generated by explosive volcanic activity. Deposits include ash, lapilli and bombs or blocks and may include shattered country rock. Ignimbrites are a type of pyroclastic deposit associated with high-temperature gas and ash flows.

<u>Hyaloclastites</u>

Volcanic breccia containing a high proportion of black volcanic glass fragments.
<u>Hyaloclastites</u>
form when volcanic eruptions interact with water. Fragmentation is caused by force of the volcanic explosion, or by thermal shock when the volcanic material is cooled rapidly by water.



<u>Lahars</u>

Mudflow or debris flow containing a high proportion of volcanic debris. They resemble sedimentary breccias and conglomerates in outcrop. Lahars can reach speeds of 100 kph and flow for over 300 km. Lahars from the Nevado del Ruiz eruption (Colombia1985) killed an estimated 23,000 when the city of Armero was buried under 5 metres of lahar.

Lahars do not have to be associated with volcanic eruption and can be generated during wet conditions (such as might be caused by melting snow and glaciers or by high rainfall) when part of an existing volcanic landscape collapses. Earthquakes could act as a triggering mechanism.

GLOSSARY

All lecture material is potentially examinable. It is up to you to know unfamiliar terms / names / people. Use this space to create your own lecture glossary

TERMS / NAMES	DEFINITION

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TERMS / NAMES	DEFINITION

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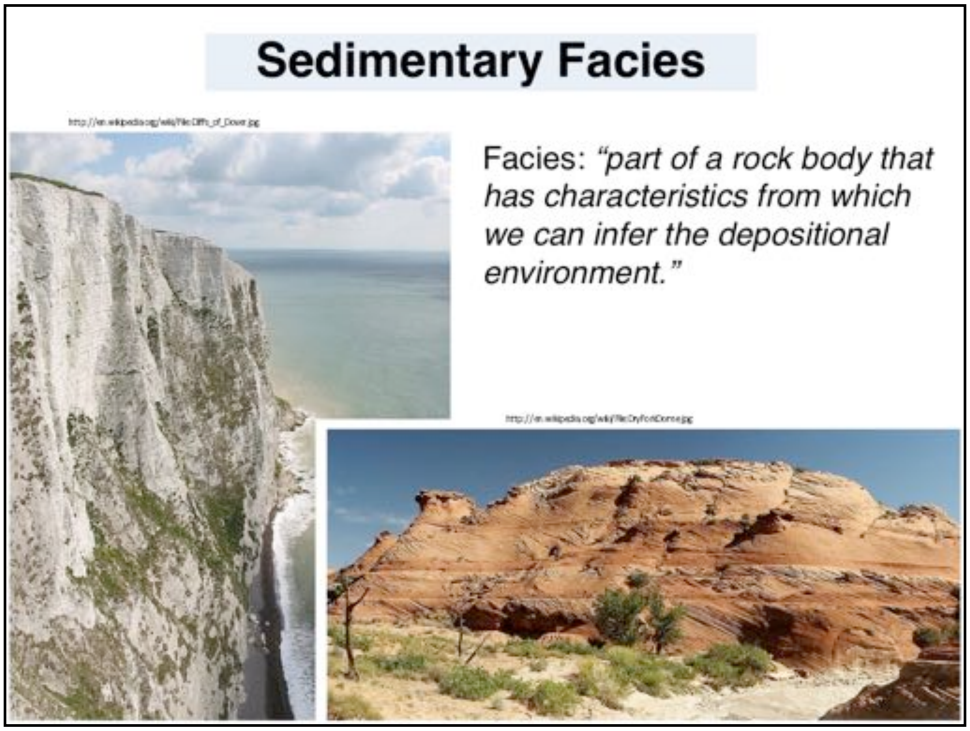
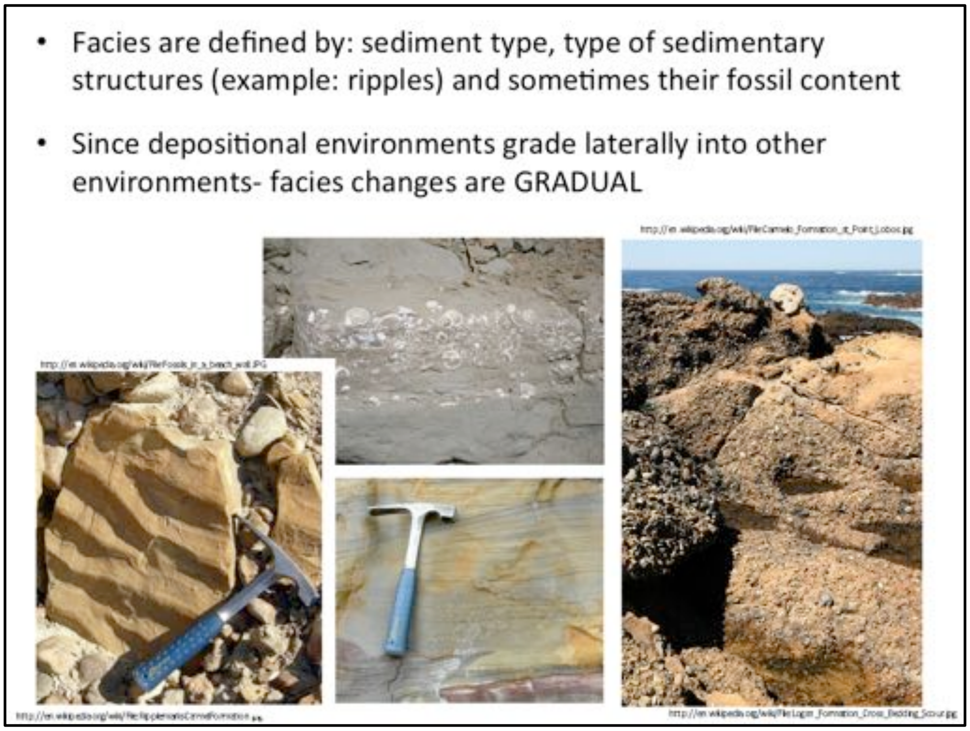
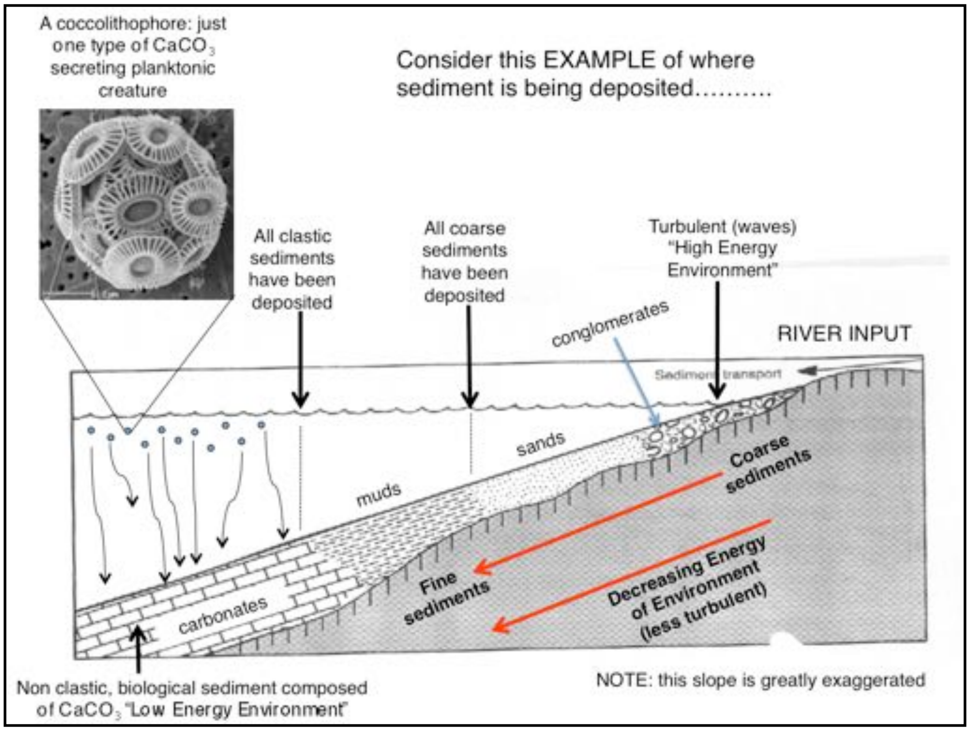


Sedimentary facies – a unit of sedimentary rock with specific characteristics. Generally these characteristics reflect a particular process or environment. For example, the white cliffs of Dover in the image above formed in a specific warm shallow marine setting that allowed for the development of chalk facies. The dune cross bedded sandstone facies in the other photograph formed in a hot arid desert environment.

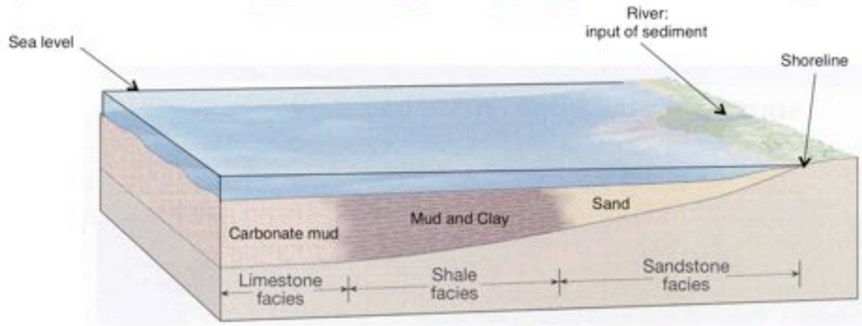


Facies are defined by: sediment type, type of sedimentary structures (example: ripples) and sometimes their fossil content. For example you could use “rippled sandstone facies” a “fossilferous mudstone facies” a “cross bedded near shore facies” or a “conglomeratic facies” to describe the images above.
Since depositional environments grade laterally into other environments- facies changes are often GRADUAL. Consider the next slide…….



This image shows river depositing sediment into a shallow ocean that passes into a deeper marine environment. NOTE: the slope on this diagram is GREATLY exaggerated. As the river brings sediment into this system it deposits its coarsest / heaviest load first, in this case a conglomeratic facies… possibly representing a beach environment. In this shallow / turbulent environment fine sediment will tend to remain in suspension and will not be deposited. The finer component will gradually be deposited in quieter water conditions giving a progression of facies from coarse clastics close to the river mouth with the finest muds deposited in the deepest / quietest conditions. Eventually all the clastic material will have been deposited and in this hypothetical model it is postulated that calcareous sedimentation of coccolithophore tests will become important producing a carbonate facies in the quietest conditions.

i>clicker: Which factors are responsible for the relative positions of the sandstone and shale facies in this figure?



i. Turbulence of water
ii. Size of sedimentary grains
iii. Biology
iv. Water depth
v. Water temperature

A. i. ii. iv. v.
B. i. ii. iii. iv.
C. i. ii. iv.
D. iii. iv. v.
E. iii. iv.

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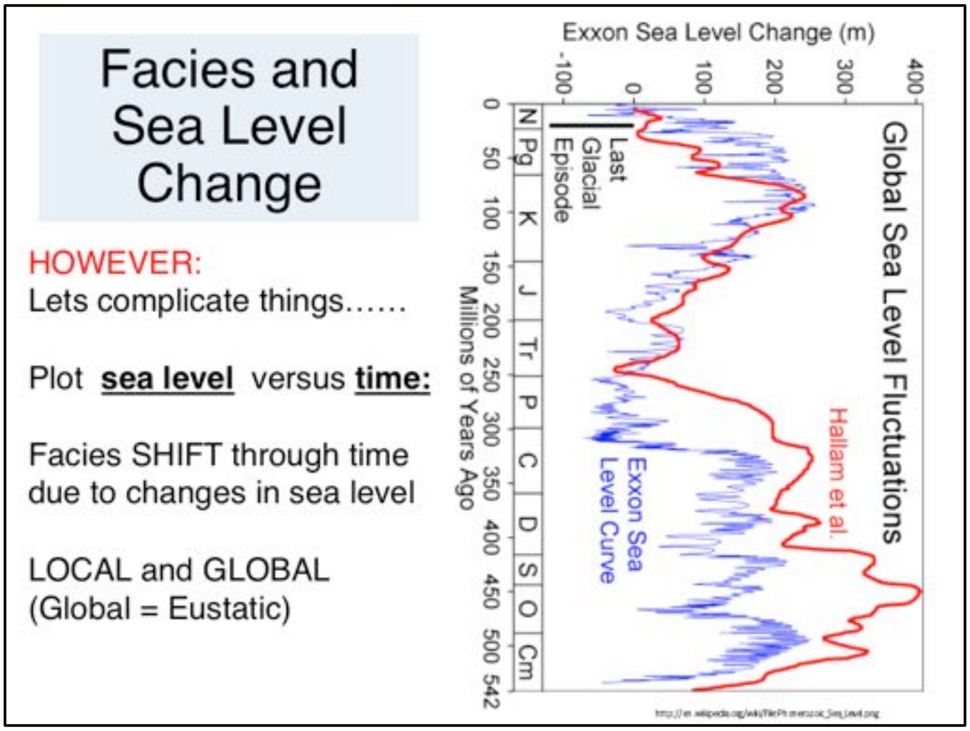
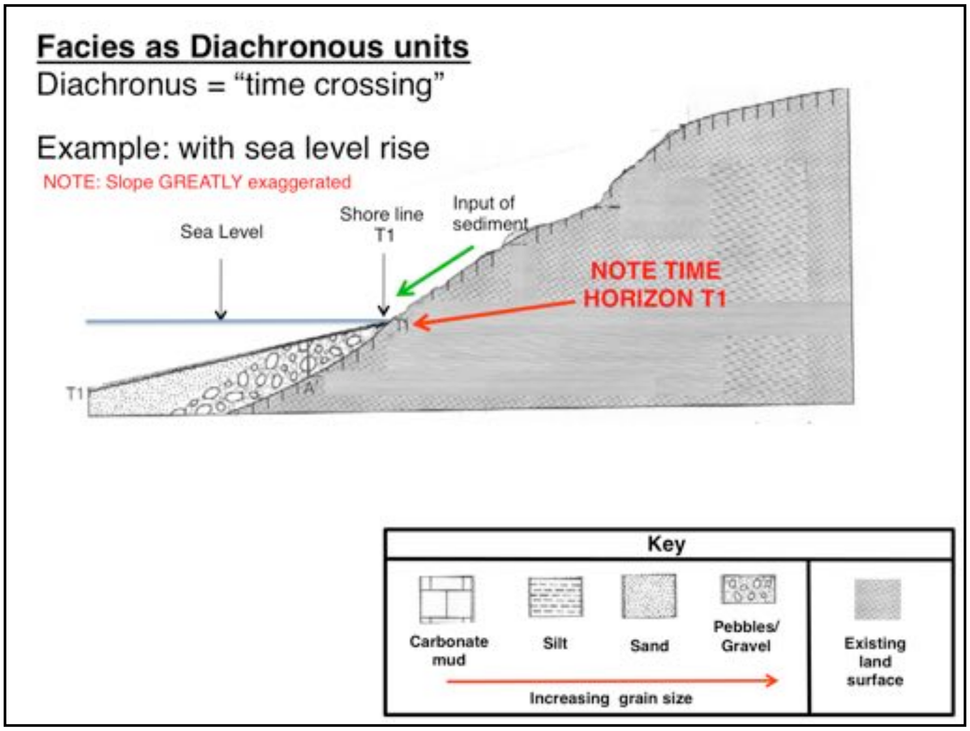


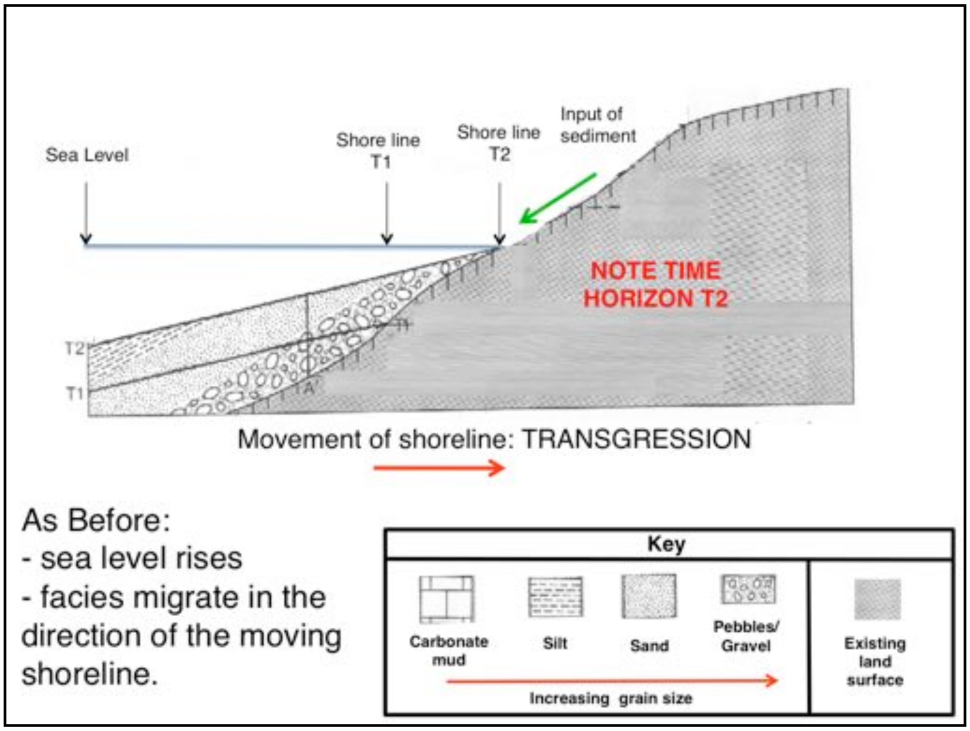
The previous model is not difficult to understand but things get a little more complex when you consider that facies MIGRATE geographically. REMEMBER facies are the sedimentological "finger print" of the ENVIRONMENT in which they are being deposited. The location of particular environmental conditions CHANGES over time… just consider the current advance of the Sahara desert or how fully glaciated conditions are giving way to periglacial (places on the edge of fully glacial areas) in current times. As conditions in specific areas change, the sediments they record over TIME will change as environments AND the facies that form in them MIGRATE. This change in TIME will be represented by change is sediment type VERTICALLY.

One of the major driving forces in the migration of environments and facies is sea level change. Sea level change can be local (for example if an area is experiencing a general down-warping of the crust or if an area is being raised tectonically) or global (eustatic) as the result (for example) of melting of polar ice caps.

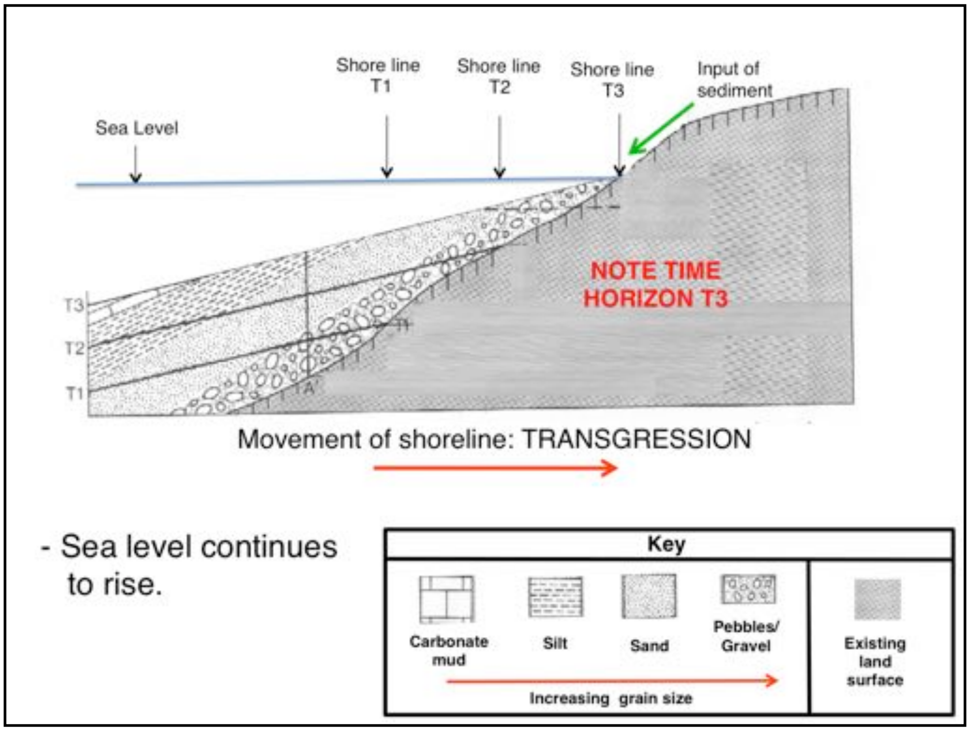


In the following slides we are going to consider the model we looked at earlier of a river depositing sediment into an ocean and see what happens if sea level were to rise (transgression). What I want you to recognize is the manner in which facies MIGRATE OVER ONE ANOTHER over TIME. ALSO NOTE: there is a difference between the FACIES BOUNDARIES and the TIME BOUNDARES. Facies often CROSS CUT time horizons are referred to as DIACHRONOUS.

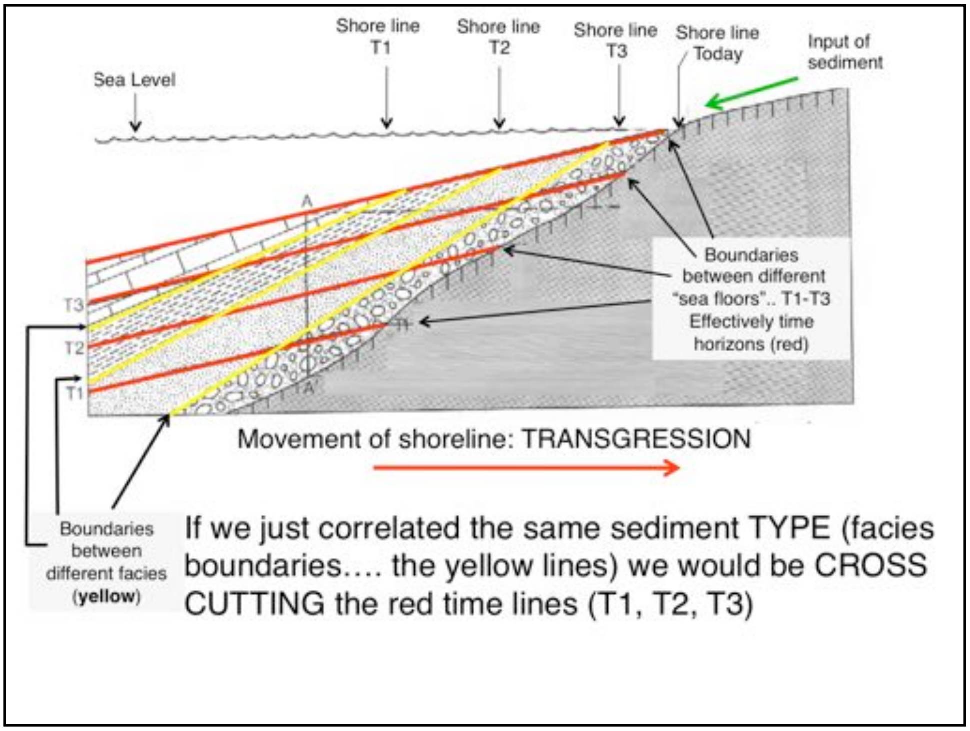
At time 1 we can see we have conglomerates deposited close to shore and sands deposited further off shore.



At time T2 sea level has risen and as a result shore line has moved landward AS HAVE THE BOUNDARIES BETWEEN THE FACIES.

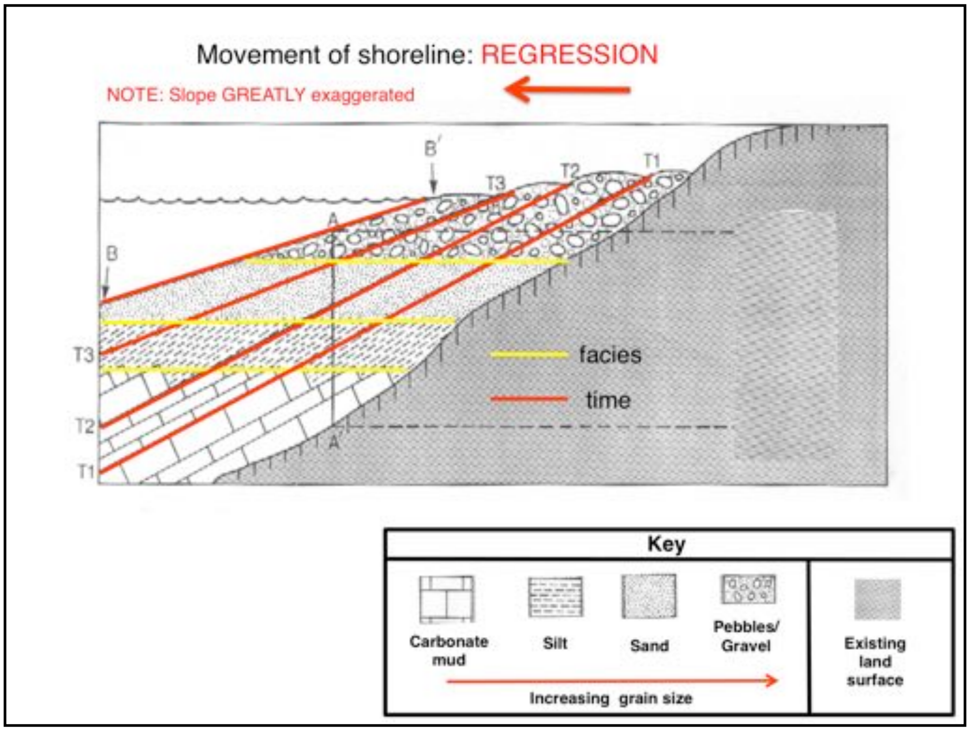


At Time T3 sea level is even higher and the facies and shore line have continued to migrate to the right.



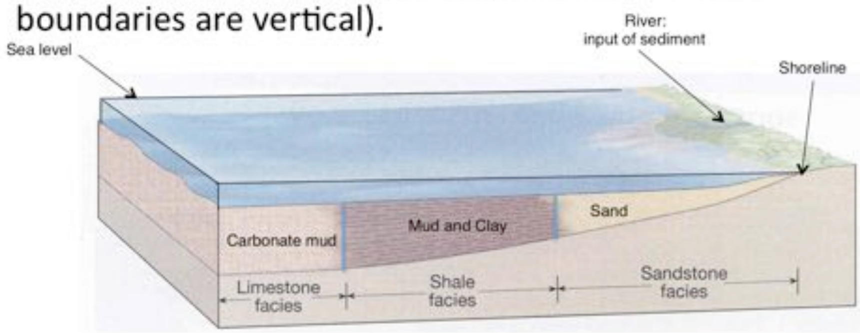
Locate line A-A' on the figure representing one fixed location in space. Note how, as sea level has changed, DIFFERENT FACIES have been deposited at that location. This has occurred because environmental conditions have been changing as sea level increased.

ALSO NOTE: The time planes are represented by the red lines. If you group the facies together (the yellow lines) you can see that the facies CROSS CUT the time horizons… this is what we mean by diachronous.



Migration will also occur in times of sea level fall (regression). Note that at A-A’ the reversed vertical succession of facies will be recorded.

i>clicker: Overall what has been happening to relative sea level as represented by this figure? (assume facies boundaries are vertical).



i. Relative sea level is falling
ii. Relative sea level is rising
iii. Sediment input is keeping pace with any sea level change
iv. Sediment input is not keeping pace with sea level change
v. Relative sea level is constant

A. i. iii. v.
B. i. iv.
C. ii. iv.
D. i. iii.
E. iii. v.

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Walther's Law

SO WHAT IS ALL THIS LEADING TO?

We know the following facts:

1. Facies reflect changing conditions of deposition across our planet. In our example, shallow high energy, near shore conditions are characterized by sand. Deeper, quieter conditions are characterized by finer grained sediments.

2. As conditions change (such as sea level) facies will appear to MIGRATE, "following" their particular environmental conditions.

3. Over time this will lead to patterns of facies as one facies MIGRATES OVER ANOTHER.

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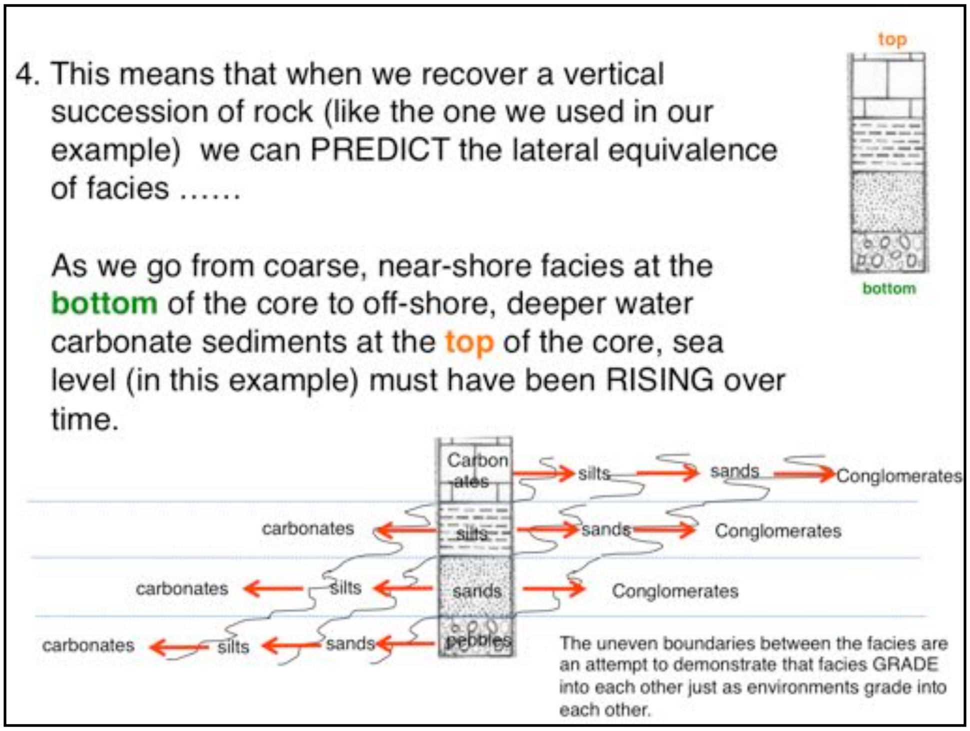
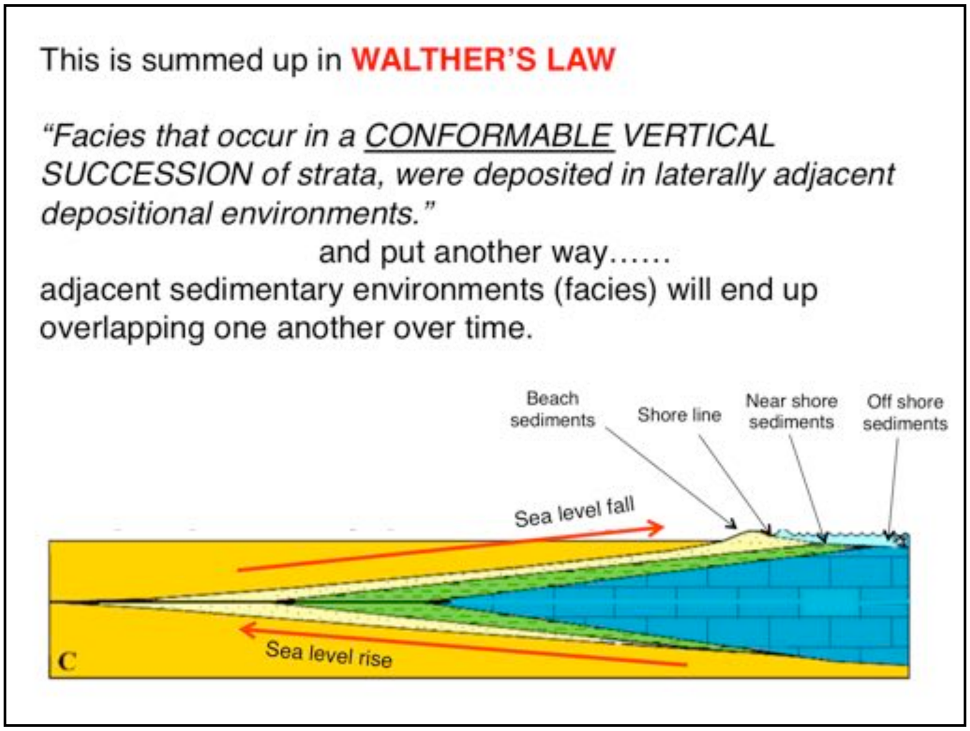


4. This means that when we recover a vertical succession of rock (like the one we used in our example) we can PREDICT the lateral equivalence of facies ……

As we go from coarse, near-shore facies at the **bottom** of the core to off-shore, deeper water carbonate sediments at the **top** of the core, sea level (in this example) must have been RISING over time.



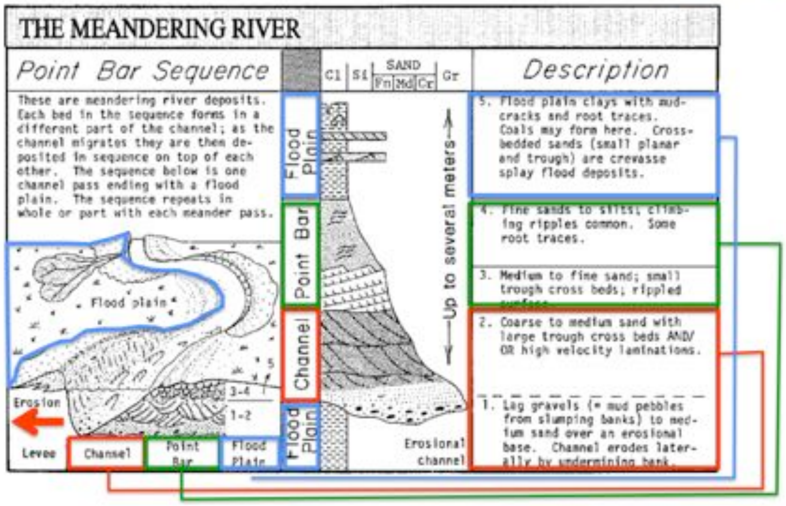
This is summed up in **WALTHER'S LAW**
"Facies that occur in a CONFORMABLE VERTICAL SUCCESSION of strata, were deposited in laterally adjacent depositional environments."

and put another way……

adjacent sedimentary environments (facies) will end up overlapping one another over time.

- Facies occur in ALL sedimentary environments

- Do not just have to be in a marine environment to demonstrate migration and Walther's Law



PLEASE NOTE: the concept of facies changes and Walther's law does not JUST apply to near shore / marine environments. Facies can migrate over each other in ALL Sedimentary environments. Consider a meandering river. As the river migrates across it's flood plain it both erodes (on the outside of the meander loop) and deposits (on the inside of the meander loop) sediments. As the meander migrates it deposits sediments as various sedimentary facies characteristic of particular "environments of deposition" within the river channel system. As the meander migrates these facies are deposited OVER each other in accordance with Walther's Law. NO - You don't have to learn this figure.