

GY 111 Lecture Note Series

Sedimentary Environments 4: Carbonates

Lecture Goals

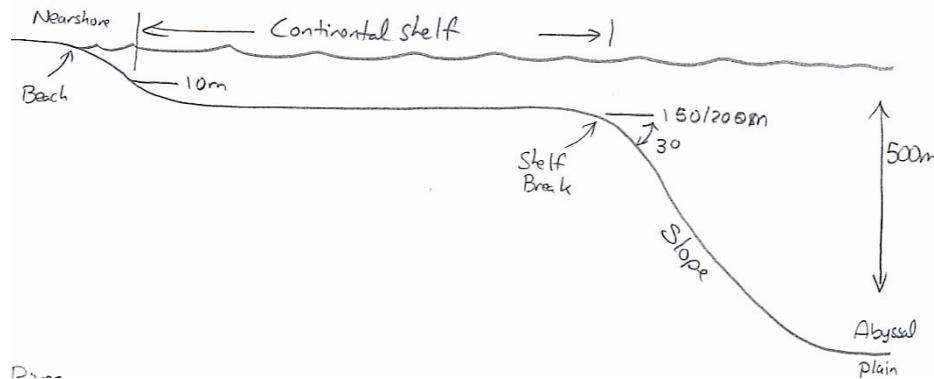
- A) Shelf Terminology
- B) Reefs, atolls and oolites
- C) Evaporites and evaporate basins

*Reference: Press et al., 2004, Chapter 7; Grotzinger et al., 2007, Chapter 5 pages 108, 120-127;
GY 111 Lab manual Chapter 3*

A) Shelf Terminology

So far in the sedimentology component of GY 111, we have focused on siliciclastic sedimentary environments that were restricted to **terrestrial** or shoreline areas (e.g., alluvial fans, rivers, deltas, beaches). Today, we start to get our feet wet.

Continents are surrounded by relatively shallow water. These are the **continental shelves** and they are remarkably inconsistent in width. In the Gulf of Mexico near where we live, the shelf is very wide, almost 80 miles in fact. It is also wide along the eastern seaboard of the United States. In contrast, the shelf along the western seaboard of the country (e.g., California, Oregon) is narrow (in some places, only a few miles wide). The reason is that the west coast is a tectonically active region and the Gulf of Mexico/eastern shoreline is not. We call it a **passive continental margin** which more or less means “boring”, at least as far as volcanoes and earthquakes are concerned. Wide shelves occur along coastlines that are tectonically inactive which are areas where sediment has been being deposited for a long, long, long time. The shelf is officially defined as the region surrounding continents where the water ranges from 10 m¹ to 150 or 200 m in depth.

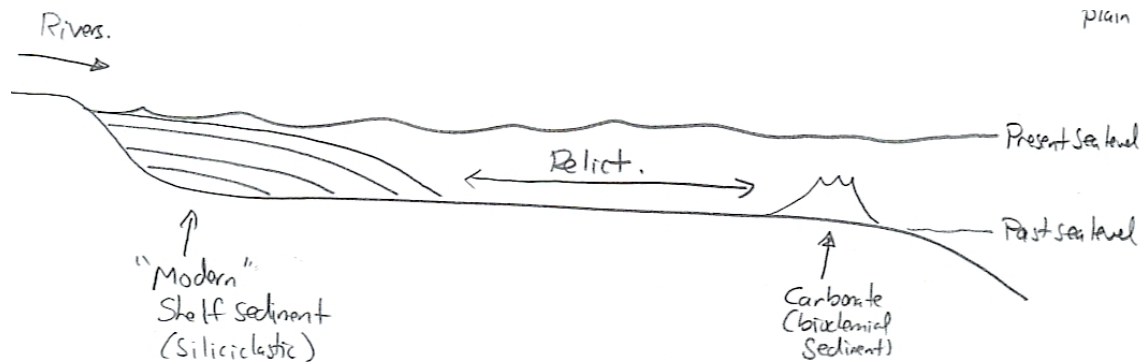


The end of the shelf is marked by a relatively sudden increase in slope at the **shelf break** (from near 0° on the shelf to 3° along the **continental slope**). The deepest part of the ocean (the **abyssal plain**) like the shelf is relatively flat, but here the water is incredibly deep (5000 m or more!).

Sedimentation on most shelves is restricted to the zone nearest the shoreline. The rest of the shelf may be devoid of any recent sediment. These areas are considered **relict** because the last time they received sediment was during the height of the last ice age approximately 18,000 years ago.

¹ You will recall that the nearshore zone which includes beaches extends outward from the shoreline to the place where the water depth reaches 10 m.

At this time, sea level was much lower (150m lower) and what is today's continental shelf was a tree-covered plain. Sea level change is the single most important control of shelf sedimentation.



B) Reefs and atolls

Siliciclastic shelves are areas where vast quantities of sediment can accumulate. In areas like Mobile where large rivers flow into the sea, sediment that makes it onto the shelf is going to be dominated by siliciclastic grains (remember these are the products of weathering and rivers transport these materials away from the source). In areas where rivers are not as abundant, or the topography is flatter (e.g., the Florida Peninsula), siliciclastic sediment may not accumulate in significant amounts on the shoreline or on the shelf. In these areas, other sediments like **biochemical** remains (shells etc.) may be the dominant deposit. Most of the biochemical sediment

that you will see in GY 111 is composed of calcite which everyone will instantly recall has the following chemical composition:



There is another important carbonate mineral that makes up biochemical sedimentary rocks. **Aragonite** has the same formula as calcite (CaCO_3), but a different crystal structure. From our lectures on minerals earlier in the course, you will realize that aragonite and calcite must be polymorphs (like graphite and carbon). You won't be able to distinguish aragonite from calcite in GY 111 labs, but then again, you won't have to. All you have to do is to be able to identify biochemical sedimentary rocks. Since they are comprised of CaCO_3 minerals, the easiest way to identify them is with the acid test. If the rock fizzes, it contains calcite or aragonite. If the entire rock fizzes and therefore must be entirely composed of one or both of those carbonate minerals. If it does, you know it is biochemical in origin. More importantly, that rock is called **limestone**.

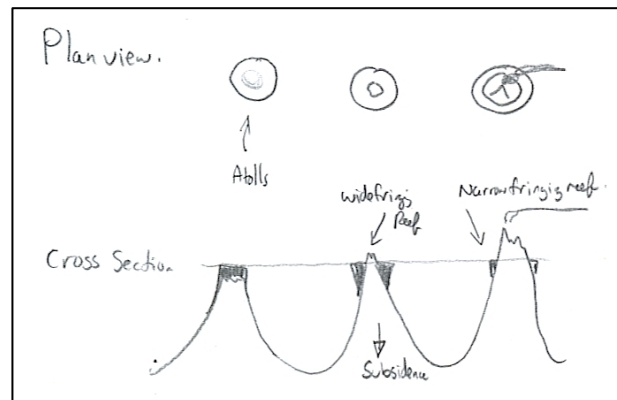
There are several types of limestone which you will see in the lab. In the lecture component of GY 111, it is best to restrict ourselves to major types of limestones. Let's start with one of the most impressive types that is associated with one of the most diverse ecosystems our planet has; **reefs** (see picture at start of this section). The term reef has many different meanings depending upon who you are. If you are a boater, reef means anything underwater that can put a hole in the bottom of your boat if you hit it (e.g., shallow rocks). The geological and biological definition of

a reef is much more specific. It is any framework of organisms (normally composed of calcite and aragonite) that grow in shallow marine (normally tropical) environments that cement themselves to the seafloor. It is the latter part of that definition that will result in a hole in your boat if you hit one. Reefs have been on this planet for an incredible long time. Diverse one with hundreds of different calcium carbonate-producing beasts have been around for over 500 million years (the image to the right is a reconstruction of a 350 million year old reef complex that I photographed in a museum). Less diverse ones that are still clearly reefs have been around for more than 2000 million years (2 BILLION years!). Today we frequently call reefs coral reefs in recognition of one of the more important framework-builders. Coralline algae (not to be confused with brown yucky algae that cover tidal pools) is another important reef builder. Every student should witness the beauty and complexity of a tropical reef once in their lives. I suggest a dive or snorkel over the **Great Barrier Reef** of Australia or the 2nd largest barrier reef complex in the world offshore of Belize. Can't afford the trip "down under", then drive down to the Florida Keys. When you witness a living reef and you see the corals, fish and other beasts that inhabit it, you realize that there is a lot of magic in this world. More importantly, reef ecosystems are completely separate from those in the terrestrial world like us. We could kill ourselves off and they wouldn't care. Sadly however, human activities do impact reef ecosystems. Pollution, over fishing, climate change and boaters putting holes in the bottom of their boats all damage or kill the corals that make up a good chunk of the reef. So I guess you should visit Australia sooner rather than later to see coral reefs that are relatively healthy.



Time to introduce a new rock for GY 111. Any limestone that contains gravel sized fossil fragments (including those deposited in reefs) is called a **fossiliferous limestone**. The fossils can be incredibly diverse and it is unlikely that you could name many at all. You don't have to. You just have to recognize that the limestone contains fossils in order to identify a fossiliferous limestone.

In some biochemical dominated environments (e.g., shell beaches), the sediment consists of only one type of shell. The most common beastie here is a small bivalve (a clam shell) called *Donax variabilis* also known as the "coquina" shell. In honor of these shells, a fossiliferous limestone composed mostly of clam shells is called **coquina**. You will see coquinas in the GY 111 labs.



Now I want to turn our attention to one of the best geological explanations to explain a biogeological phenomenon. It was one of the most impressive ideas that that great geologist² Charles Darwin developed. He observed when traveling through the Tahitian Islands in the southern Pacific Ocean that some of the islands had active volcanoes with thin fringing reefs

² Okay, most of you know that Darwin is considered a biologist. In fact, he was trained as a *naturalist* which at the time involved studying the science of the planet which included geology, ecology and oceanography. Once he came up with the idea of evolution, he became labeled a biologist.

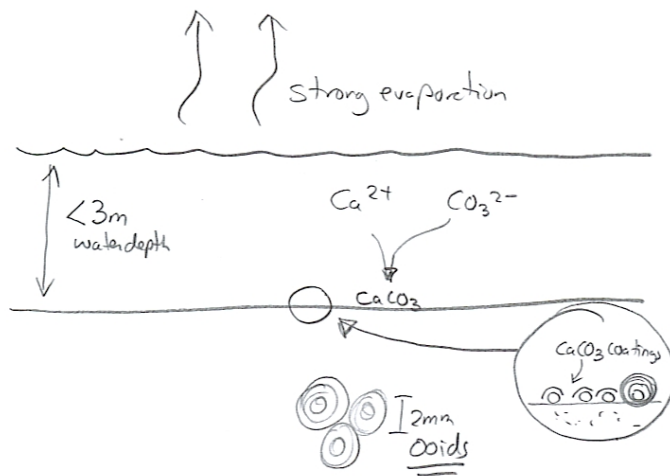
(these are reefs that surround the island in the shallow water interval), where as islands with extinct volcanoes had thicker reefs. Other islands were better described as reefs with minor volcanic cores or just reefs (see cartoon on the bottom of the previous page).

The later type were named **atolls** and up until Darwin's time were a bit of a mystery. It was known that corals could grow rapidly, but they needed to be in shallow water (less than 10 m) to do this. The atolls in the south Pacific were in water 5000 m deep and no one could figure out how the reefs could have grown up from the depths of the ocean into water that shallow. Enter Darwin. He observed that volcanoes underlay other islands in the Tahitian archipelago and realized that as volcanoes went extinct, they became eroded and started to subside as they cooled. In other words, as the volcanoes died, they began to sink below the water surface, but the corals comprising the fringing reefs that surrounded the volcano could grow fast enough to keep pace with the amount of subsidence. Darwin's theory of atoll formation still stands today and illustrates how important observation is to interpretation. By the way, the Tahitian Islands are associated with a hotspot. It's not the same one as the one responsible for the Hawaiian Islands, but because it underlies the same Pacific Plate, the orientation of the Tahitian island chain and the age difference of the islands is exactly the same as seen in Hawaii. Darwin didn't appreciate this aspect of the Tahitian Islands, but to be fair, he made his atoll hypothesis before Wegener came up with continental drift and long before hotspots were even recognized (1960's).

While we are still in the tropics, let's consider one other important type of biochemical sedimentary rock. **Oolitic limestone** (or just **oolite**) is an interesting type of limestone that forms under very special conditions. You need a tropical climate that is pretty dry (this means more evaporation than rainfall) and very shallow marine conditions (less than 3 m water depth). The perfect place to find these conditions is the shallow shelf around the Bahamas Islands. Here the water is so warm and evaporation so rapid that the water actually becomes more saline than normal sea water. Under these conditions, Ca^{2+} and CO_3^{2-} ions in the water begin to combine to form CaCO_3 . The precipitation occurs on the sea floor as thin coatings over sand-sized biochemical particles. Because the water is so shallow, the bottom is constantly agitated by wave action. The result is that the CaCO_3 coatings completely wrap around the grains. Over time, these coated grains get bigger through the addition of multiple layers. These coated grains are called **oids** which should explain why the rocks composed of them are called oolitic limestones.



a photo of ooids each about 2 mm across

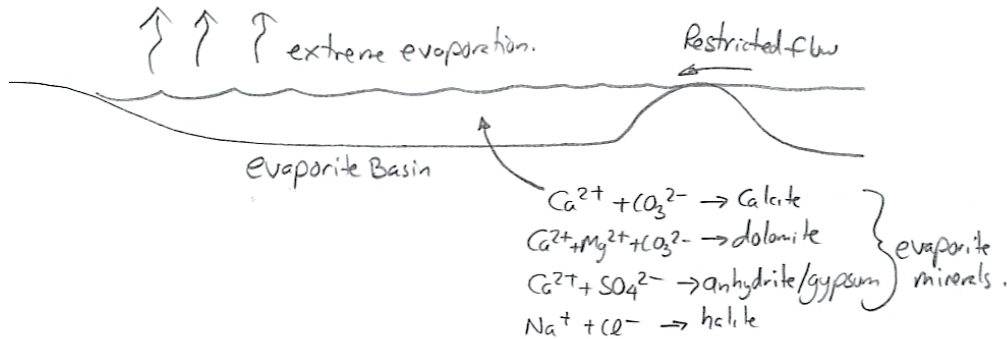


The thing to note is that if you ever see an oolitic limestone, it means that the depositional environment was shallow marine (wave base) and tropical. Many of the rocks that underlay Huntsville, AL are oolitic limestones which means sometime in the past (300 million years ago to

be exact), what is today Huntsville looked exactly like present day Barbados. That is the power of sedimentary rocks. They tell you a lot about ancient conditions during deposition (water depth, climate, geography, etc.).

C) Evaporites and evaporate basins

So far today, we have introduced a new class of sedimentary rocks. Time for another. **Chemical sedimentary rocks** are those that are produced through purely chemical processes. The most important process is evaporation of sea water. This occurs in hot coastal areas where water flow is somewhat restricted and evaporation is extreme. This might sound a bit like the setting I portrayed for you when I was explaining how ooids formed, but it is more extreme than that. If it is very hot and arid (i.e., little to no rainfall), seawater can evaporate almost entirely. Conditions like this occur in the Persian Gulf and some desert saline lakes (e.g., Great Salt Lake).



Under these conditions, the following **evaporite** minerals will form in this order as evaporation proceeds:

- | | | | | | | |
|-----------------|----------|--------|-----------|--------|--|-------------|
| <u>First</u> | | | | | | <u>Last</u> |
| Calcite (ooids) | Dolomite | Gypsum | Anhydrite | Halite | | Sylvite* |

Sylvite is an evaporate mineral, but it only forms under special conditions that do not normally occur in most evaporate settings. By the way, the depositional environment associated with evaporite mineralization is called an **evaporite basin**. The term basin simply means any place where thick layers of sediment accumulate.

Important terms/concepts from today's lecture
(Google any terms that you are not familiar with)

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| <ul style="list-style-type: none"> Continental Shelf Passive continental margin Shelf break Slope Abyssal plain Relict Biochemical sedimentary Aragonite/calcite (polymorphs) Limestone Fossiliferous limestone Coquina Reef Atoll | <ul style="list-style-type: none"> Great Barrier Reef Oolite/oolitic limestone Ooids Chemical sedimentary rocks Evaporite minerals Evaporite basin |
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