GEOLOGY 25 - LECTURE 1 - B

COLORADO PLATEAU: GRAND CANYON – part 2

(Textbook: Chapter 3 (p. 40-50), Chapter 1 (p. 18-20)

*If you are studying the notes and images and don't understand something, go to the **lecture videos** and find the place where I discuss that topic to review.*

How do laterally extensive layers of sedimentary rock form?
The seas come in, the seas go out . . .

Sea level is marked by the position of the shoreline along the margins of continents.

In many places, the edges of continents are characterized by low-sloping **coastal plains**. On the US east coast, the coastal plains are broad, but in California coastal plains are either very narrow or non-existent.

A **continental shelf** is the seaward continuation of the coastal plain of continents and may extend outward for tens to hundreds of kilometers. They slope gently seaward until water depths of ~100 m (~330 ft) are reached.

- continental shelves are shallow-water areas where sediment derived from the erosion of continents accumulates, commonly to great thicknesses. Rivers transport eroded sediment to the shoreline where waves, tides and currents redistribute the sediment out onto the shelf.
- continental shelves end where the seafloor abruptly steepens onto the **continental slope**.
- continental slopes are commonly cut by submarine canyons that funnel sediment out into the deep ocean. The seafloor beneath the deep ocean is commonly called the **abyssal plain**.
- the global average depth of the deep ocean is 4 km (~2.5 miles or ~13,000 feet))

But sea level is not stationary and frequently changes through time due to a variety of factors (that we'll talk about later)

- when sea level rises, it simply spills laterally onto the coastal plains then inland. In essence, the continental shelves get broader.

Geologists can map the extent of sea level by looking at the geographic distribution of fossils and ancient beach deposits and visualize the position of sea level by constructing "**paleogeographic maps**." The maps are speculative, of course, but are based on lots and lots of field observations.

In the past, sea level has been high and large areas of the continents were covered by shallow seas hundreds of meters deep.

- you might think of the submerged continents of the past as comparable to the relatively shallow continental shelf that borders all continents today

Transgression and Regression

The rise and fall of sea level is accompanied by the migration of the shoreline onto and off of the continents.

When sea level rises, the shoreline migrates landward over the formerly exposed land surface. This process is called **transgression** and the edges of continents are submerged.

When sea level falls, the shoreline migrates seaward away from the land, leaving behind a land surface exposed to erosion. This process is called **regression** and broad areas of continents are exposed.

- as the shoreline migrates landward or seaward with changing sea level, associated depositional environments migrate along with the shoreline (e.g., coastal rivers & floodplains, beaches, deltas, bays, lagoons, shallow seas)
- as the environments migrate through time, deposition occurs to form broad sheets of sediment, one atop the other, that may extend laterally for thousands of square kilometers
- as sediments accumulate, the sheer weight of the sediment exerts a force on the underlying crust, causing it to sink downward. This process is called **subsidence** and it acts to create more space for more sediment to accumulate on top. (As the crust sinks, weak rocks in the underlying mantle migrate laterally away from the weight of the sediment pile on top.)
- when sea level falls, the environments regress seaward as the shoreline moves with the falling level of the sea . . .

In time, the layers of sediment are buried, compacted and cemented to become sedimentary rock. Much later, the entire region may be uplifted by mountain-building forces (more on this later). With uplift, the newly exposed rocks are eroded by water, ice, and landslides, perhaps forming a deep, river-carved canyon.

In the Grand Canyon, three formations (Tapeats, Bright Angel and Muav) illustrate the transgression of the ancient shoreline about 500 mya . . .

By mapping the distribution and characteristics of formations of equivalent age across a region, a paleogeographic map can be made that shows the shoreline and original depositional systems, in this case the maps show the shifting coastline of the American West about 500 m.y. ago. during deposition of the Tapeats-Bright Angel-Muav formations.

So from what you know now about how these layers are formed, you should be able to visualize these horizontal layers as laterally continuous over a broad region. The inferred widespread extent of sedimentary rock layers is called the **Principle of Lateral Continuity**.

- the rocks of the Tapeats-Bright Angel-Muav extend over a huge region of several thousand square kilometers of the American West, reflecting the transgression of the shoreline around 500 m.y. ago across western North America

After the sedimentary layers were deposited, buried, and solidified to rock, much later they had to have been **uplifted and exposed to erosion** because we can see them today at high elevations. Some of the layers were dissected by erosion and river incision into isolated exposures. In other places, some of the layers may have been uplifted by geologic forces into mountains. So today we might find scattered exposures of a layer in mountain ranges or within canyons. If they look similar, contain similar fossils, occupy the same position between other layers of rock, and thus appear to be the same age, we consider them to have once been originally laterally continuous across the region where they are exposed.

- in the case of rocks of the Grand Canyon, many of the same layers are exposed throughout the Colorado Plateau and the entire American West, attesting to their original widespread extent.
- geologists call any exposure of rock that you can physically see and touch an **outcrop**

- the formations may be exposed within a mountain range that was uplifted or in a deep canyon that was cut by a river. Or the formations may be hidden beneath the surface, buried by younger rocks and only 'visible'' by drilling into the ground. Or in places the formation might have been entirely eroded away. Based on the wide distribution of available outcrops we infer that the formation was widespread across a broad area.

So, the layers of sedimentary rock in the upper Grand Canyon originally accumulated as relatively horizontal sheets, deposited near sea level as the shoreline gradually transgressed and regressed, as climate changed, and as continents shifted position over time (more on this later)
- these layers extend across broad regions of the American West (they just happen to have been exposed by the incision of the Colorado River in the Grand Canyon area)
- some sandstone layers originated as sandy beaches that migrated laterally as the coastline shifted with transgressions and regressions (e.g., Tapeats Sandstone)
- other sandstone layers formed as sand dunes migrated across an ancient desert (e.g., Coconino Sandstone)
- some shale layers formed along a quiet, low-energy, lagoon where fine clay particles could settle out to the seabed (e.g., Bright Angel Shale)
- alternating layers of sandstone, siltstone, and shale formed within stream channels, floodplains and deltas as ancient river systems meandered across the ancestral coastal plain of what would become the Colorado Plateau region (e.g., Supai Group)

Each of these formations in the upper GC formed when the American West was situated at low elevations close to sea level between about 500 m.y.a. and 250 m.y.a. The rocks were uplifted (by geologic forces we'll discuss eventually) to form a broad plateau much later, about 5-6 m.y.a., when they were raised to their current high elevations. This is when the Colorado River began to cut down into the sedimentary rocks of the Plateau to carve the Grand Canyon.

- I don't expect you to remember formation names, but I do want you to know what environments of deposition certain rock types represent, in general.

Fossils and Fossilization

Fossils are the preserved remnants or traces of previously existing organisms.

A few examples of **fossilization** – the process by which the hard parts or traces of formerly living organisms are preserved within sedimentary rocks
- e.g., a clam living in the mud of a lagoon dies. The soft parts inside will decompose via bacterial decay, but the hard shell may remain trapped in the mud and be preserved as a fossil if the lagoonal mud is buried and turned to rock.
- e.g., a dinosaur runs across a sandy tidal flat, leaving footprints behind. The tide comes in and deposits a layer of mud, burying the footprints. Over millions of years, the sediment layers are buried to become rock, then much later the rocks are uplifted to the surface where they are exposed to weathering and erosion. The overlying layers of rock may erode to reveal the sandy layer with the preserved footprints.

Fossils help geologists
1) to determine the environment of deposition for particular rock layers
- trilobites (extinct marine arthropods) found in the Bright Angel Shale tell us that deposition took place in the ocean
- reptile tracks in the Coconino Sandstone tell us that the sand originally accumulated on land with vertebrates scurrying about
- fossils of leaves found in Supai shale suggest forests growing on the floodplain of an ancient Supai river. In fact, the types of leaves tell us the specific type of tree or plant, which by analogy with modern plants, tells us about the climate at the time
- coral fossils suggest deposition in shallow tropical seas, perhaps associated with reefs
2) to determine the **relative** age of the rock in which the fossil is found (more detail on this later).
3) Fossils also provide the physical evidence for evolution.

Another sedimentary rock common in the national parks: Limestone

Not all sedimentary rocks are formed by the erosion of previously existing rocks and the redeposition of the sedimentary particles. Some sedimentary rocks form in place from the accumulated remains of marine organisms on the seafloor. These are **limestones**.

In modern shallow seas located in tropical latitudes (~30°N to 30°S), many marine organisms (corals, clams, oysters, snails, sea stars, many algae, some sponges) secrete a hard exoskeleton composed of calcium carbonate (the mineral **calcite**, $CaCO_3$). When they die, their calcareous exoskeletons are broken up, transported and deposited on the shallow seafloor. This calcareous debris accumulates in enormous quantities that, after burial, compaction, and cementation, form the sedimentary rock known as *limestone.*

We can directly observe limestones forming today in shallow tropical seas (such as the Bahamas and the Great Barrier Reef of Australia) and apply the principle of **actualism** to interpret ancient limestones
- in today's world, hard-shelled marine organisms build their shells in warm shallow tropical seas where the conditions are optimal for growth. Via the principle of actualism, this allows us to infer that ancient limestones must have accumulated in warm, shallow, tropical seas.

Ancient limestones in the Grand Canyon originally accumulated as countless skeletal particles of calcite in shallow tropical seas where innumerable hard-shelled marine organisms lived and died over millions of years
- the Redwall Limestone is a near-vertical 500-800' thick cliff (trails crossing it have to be carved into its side). It was originally laterally continuous along the entire western side of N.A. from Canada to Mexico and represents deposition in a warm, tropical, shallow ocean that was populated by marine invertebrate animals and algae that formed copious amounts of calcareous skeletons that accumulated over several tens of millions of years. The Redwall commonly exhibits the fossilized remains of these creatures.
- about 350 mya, during the deposition of the Redwall, western NA was situated in a more equatorial setting, within tropical latitudes (we'll discuss how this happens later in the course)
- we can create a Redwall paleogeographic map by locating all exposures of the Redwall in North America then using the principle of **lateral continuity** to infer the geographic distribution

(these paleogeographic maps certainly have a degree of artistic license in them, but the position of the shoreline, the extent of the formation, and the transition to deeper water is pretty well established)

The Muav, Redwall, Toroweap and Kaibab limestone formations all represent times when shallow tropical seas covered the American West.
- limestone can be a very hard rock. In the semi-arid climate of the Colorado Plateau, limestones commonly form steep cliffs

Topographic Features of the Grand Canyon Landscape

Why do the sedimentary rocks of the upper Grand Canyon have a "stairstep" topography of alternating cliffs and slopes?

In Grand Canyon, the sandstones and limestones tend to be tightly cemented and resistant to weathering in the arid climate, so they form cliffs. The softer siltstones and shales tend to be less well cemented and are more easily eroded and form slopes between the resistant cliffs. Thus the stairstep topography of the canyon walls is a consequence of **differential erosion**.

As the Colorado River and its tributaries cut down into the underlying layers of rock, and as rainfall and snowmelt dribble downslope along the walls of the canyon, some rocks remain resistant and form cliffs, whereas other weaker layers form slopes.
- vertical cliff faces are also created by **fractures** that cut downward through layers of sandstone and limestone
- rainwater and snowmelt infiltrate downward into the fractures, freeze in the cold of night and expand, wedging the rock on the outside of the fracture away from the main mass of rock; in time, the entire outer block loosens, breaks away, then collapses downward as a rockfall or landslide
- the finer-grained shales and siltstones are cut by fractures as well but don't penetrate as deeply due to the common very thin horizontal beds that characterize these rocks

Why are the rocks various shades of red?

Because of minute amounts of iron oxide in the rocks. Iron is incorporated into the rocks during deposition in oxygen-rich environments (like rivers and floodplains), then is concentrated and distributed through the rocks as groundwater percolates through tiny pores between grains. (the red iron oxide is essentially 'rust.')
- Supai Group is reddish in color because the sediments were deposited in rivers and broad floodplains - oxygenated continental environments
- the underlying Redwall is actually gray limestone. Its outer surface is red from a coating of iron oxides that dribble down over the cliff from runoff of the overlying Supai

Oldest rocks of the deepest Grand Canyon
- metamorphic and igneous rocks of the "basement"

A brief visit to the older rocks of the lower Grand Canyon . . .

The stack of sedimentary rocks of the **upper** GC is about 1500 m (~5000') thick. The basement below extends deep into the crust for >30 km (>18 miles). Below that depth lie the harder rocks of the mantle. (no real need to know about the crust and mantle for this class)

The oldest rocks of the Colorado Plateau (~2 by old) are exposed in the deepest part of Grand Canyon - called the **Inner Gorge**.

- called the Inner Gorge because of the steep slopes and narrow, V-shaped profile of the Colorado River canyon created by the very resistant rocks of the 'basement'
- whereas the wide, stairstep topography of the upper Grand Canyon is formed in less-resistant sedimentary rocks, the older rocks of the Inner Gorge are much harder and more difficult to erode, resulting in the narrow chasm through which the river flows (differential erosion)

Lower Grand Canyon composed of unlayered igneous and metamorphic rocks. Without going into any real detail, igneous rocks are formed by the solidification of rock from a molten fluid like magma. Metamorphic rocks are formed by the transformation of previously existing rocks by intense pressure and temperature. Both of these events commonly occur in the deep cores of growing mountains.

- '**basement'** is a generic term that describes the ancient igneous and metamorphic rock that makes up the foundation of all of the continents.
- the basement rocks of the Inner Gorge represent the oldest igneous and metamorphic rocks upon which the upper, layered sedimentary rocks were deposited later in time.
- the basement forms the largest volume of the crust that underlies all the continents – all younger sedimentary rocks rest on top of the old, hard rocks of the basement
- the crustal rock of the basement extends downward for ~30 km before it meets the underlying, more-dense rock of the mantle.
- transgressions and regressions governed the deposition of bedded sedimentary rocks on top of the basement, accumulating to about 5000 feet in thickness (Tapeats, Bright Angel, etc.)

We'll discuss igneous and metamorphic rocks in more detail later in the course. And we'll return to the lower Grand Canyon and the "basement" to finish the story.
