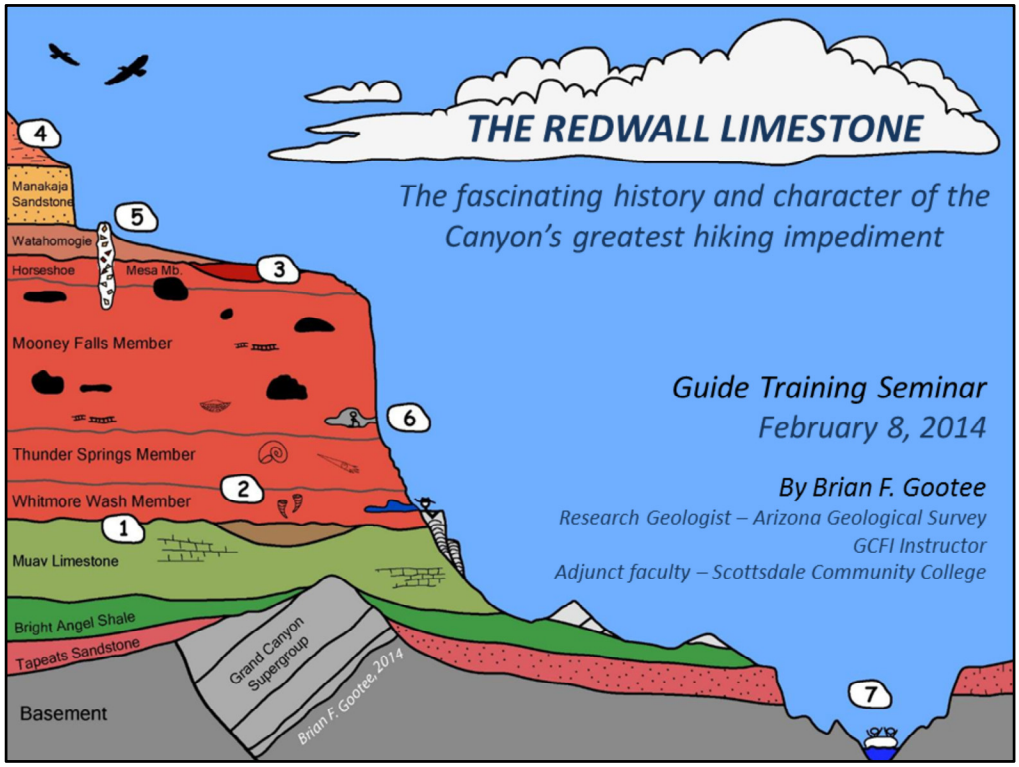
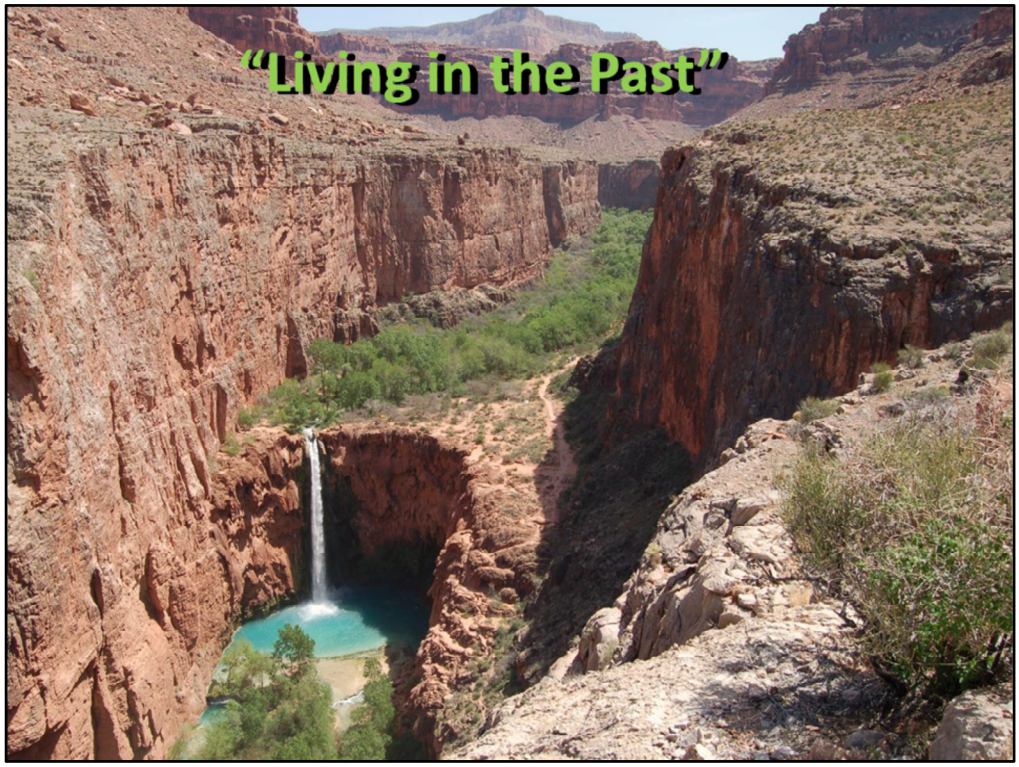


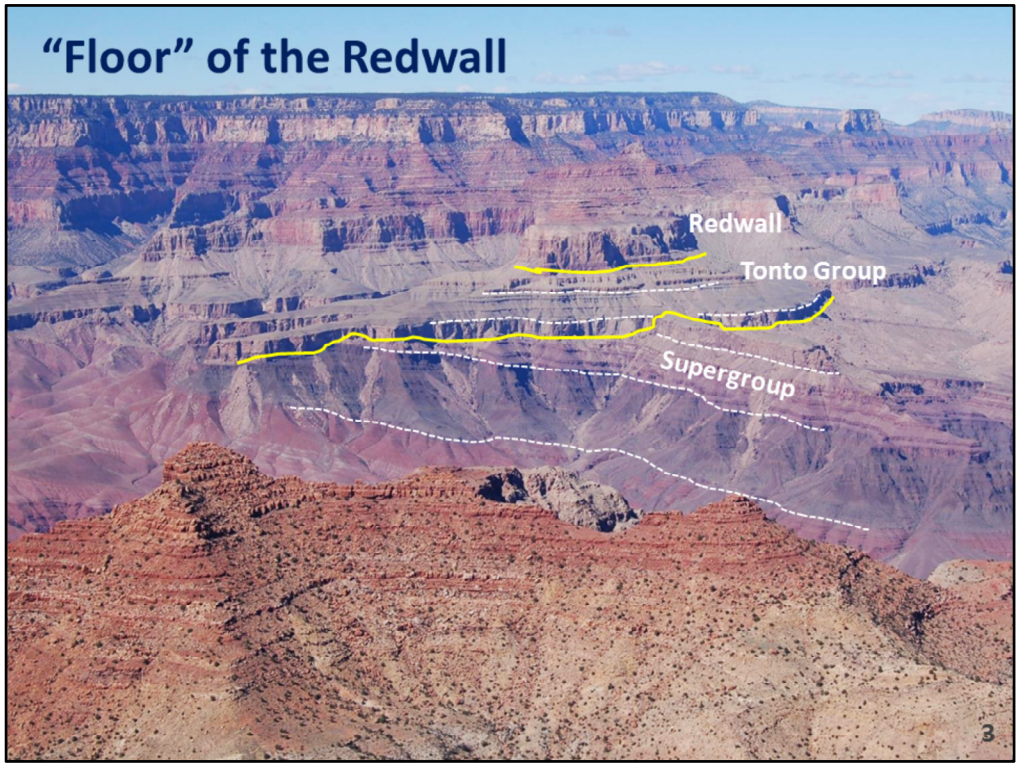
The Redwall Limestone:

- What makes the Redwall Limestone unique from other formations in the Grand Canyon?
- What geologic events mark major aspects of this Canyon formation?
- And how do each of these events play a role in the Redwall Limestone that we are a part of today?



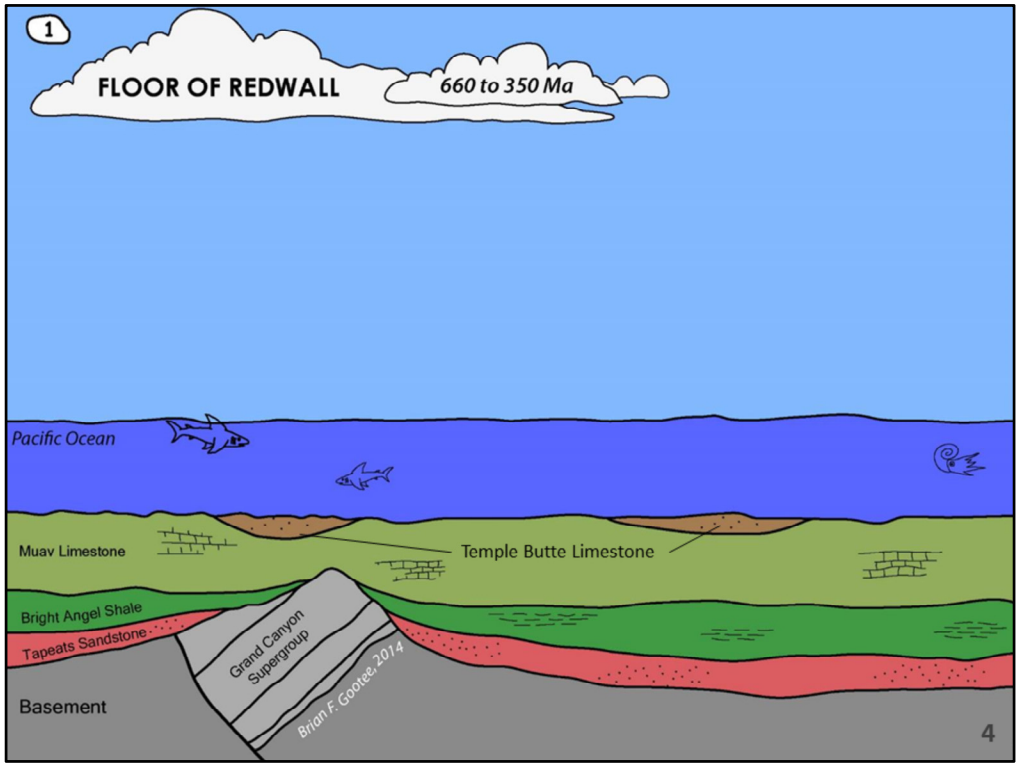
Amazing Aspects of the Redwall Limestone:

- Diverse and long history over the last 350 million years.
- Magnificent cliffs and red walls.
- Composed of ~99.5% pure limestone, ~95% of which is biologically formed in the presence of organisms.
- Forms very chemically-resistant cliffs, yet it is a very soft rock (slightly harder than a finger nail).
- Has 1,000's of miles of interconnected caverns spread out over the Colorado Plateau.
- Has many caverns, some with ancient and modern speleothems.
- Is the source of carbonate for the growth of abundant travertine deposits.
- Provides precious minerals, trace metals and uranium in breccia pipes
- Is a major source of high-quality groundwater to numerous and voluminous springs in the canyon and region, consumed by most visitors to the canyon.
- "Living in the Past" implies the past of the Redwall Limestone is living with us today.



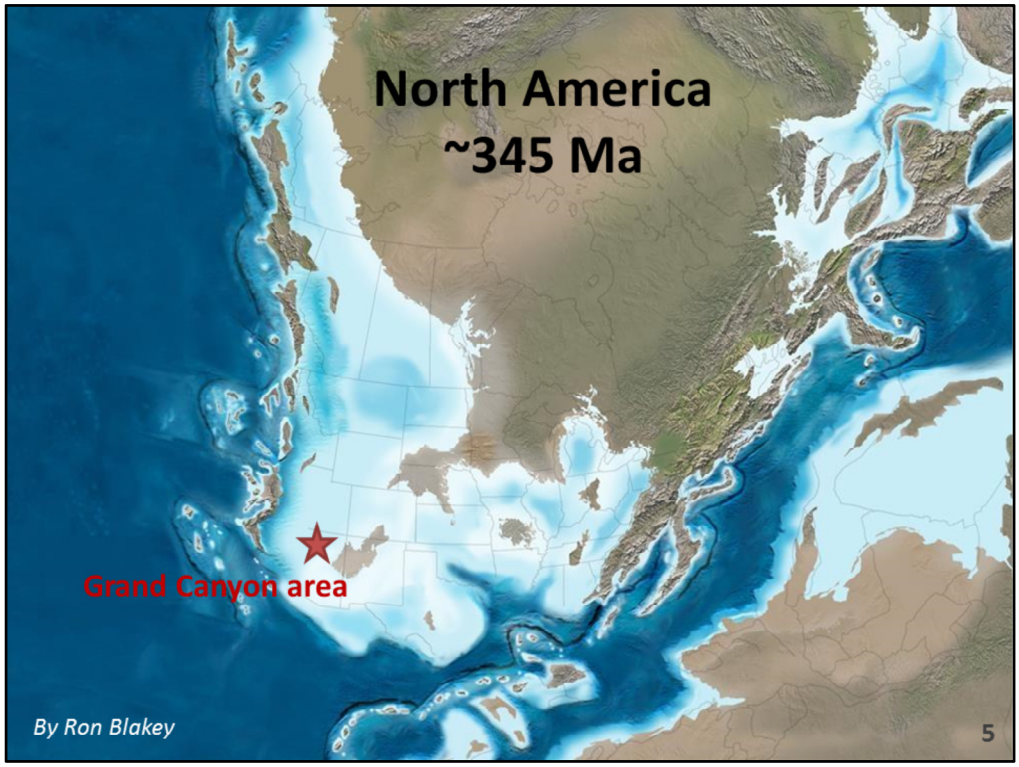
Visualizing the base of the Redwall:

- The Supergroup layers are faulted, tilted, and subsequently eroded to produce the Greatest Unconformity (lower yellow line).
- The Tonto Group underlying the Redwall represents a worldwide sea level rise onto all continents from ~550 to 500 Ma.
- A significant unconformity of ~100 million years (Ma) separates the Redwall Limestone and Tonto Group (upper yellow line).



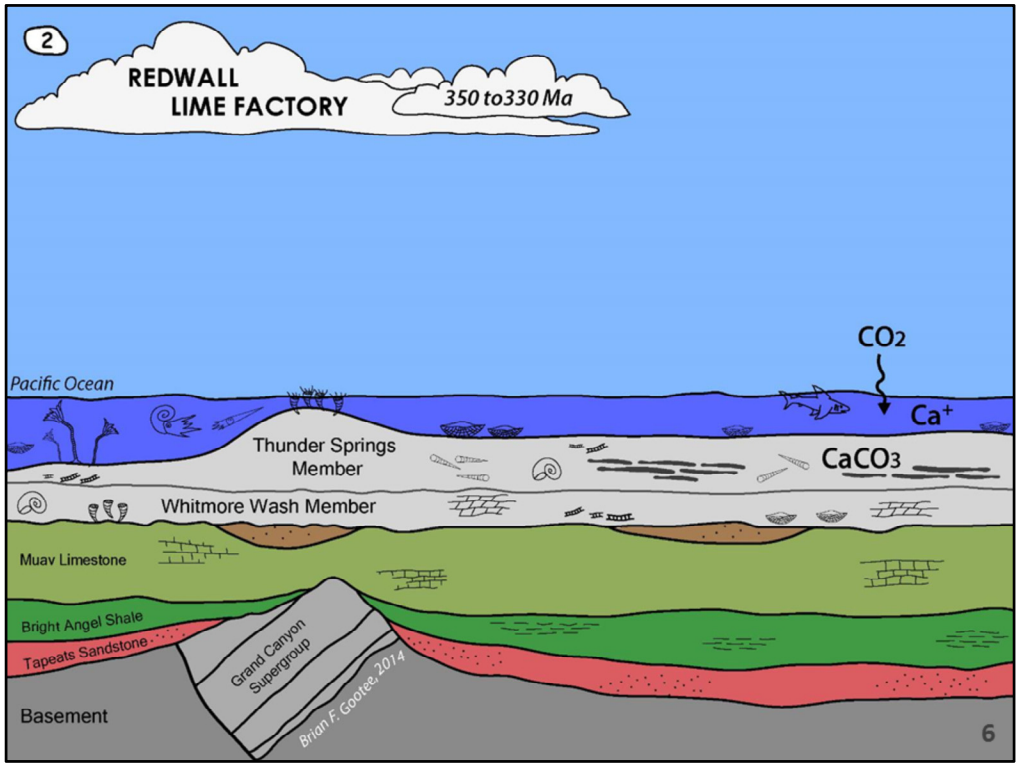
Creating the floor of Redwall:

- Supercontinent Rodinia splits apart and sea levels rise worldwide, creating the Sauk Transgression whereby marine waters slowly rise over lands and cover up sands with muds, then lime, hence Tapeats sandstone, covered by Bright Angel Shale (mudstone), and then Muav Limestone.
- The Tapeats, Bright Angel and Muav formations make up the Tonto Group.
- The Great Explosion of Life occurs around 550 Ma. Life has evolved tremendously by Redwall time (350 Ma).



Deposition of the Redwall Lime:

- Seas were vast, very warm, and shallow, teeming with life.
- Land masses were around but isolated with very little relief.
- Rivers were relatively absent, and as such very little to no mud was delivered.
- However, wind-blown silt and clay was deposited in shallow seas, which would later become insoluble residue.

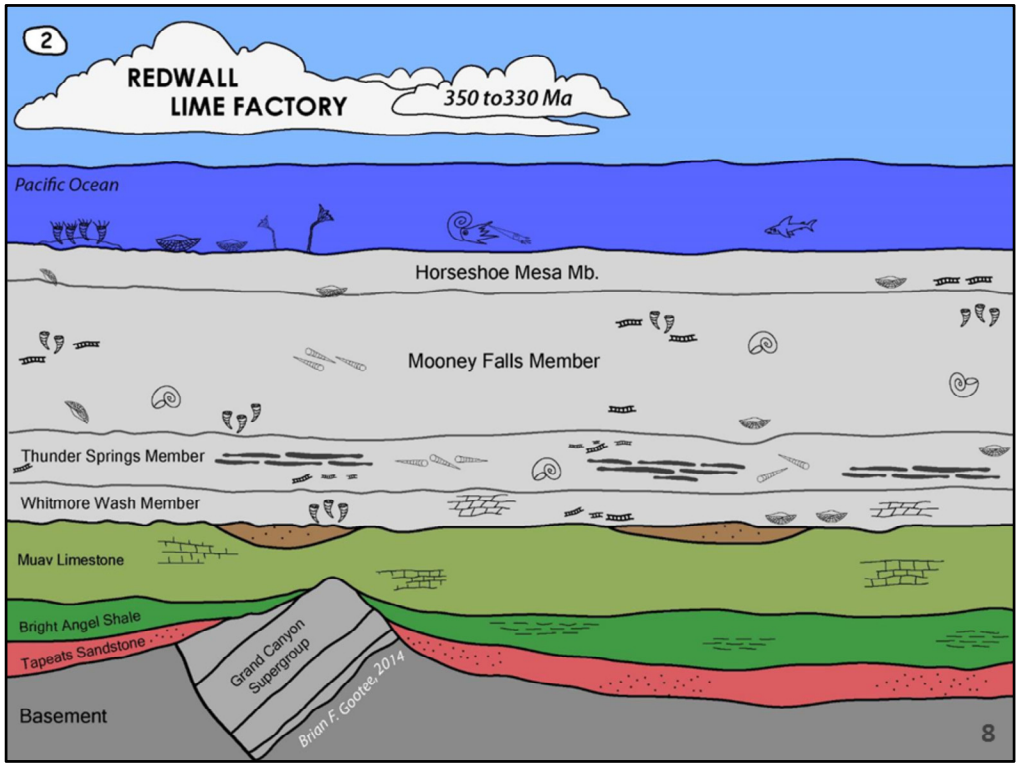


The Carbonate or Lime Factory:

- The shallow continental shelf inundated by warm seas that allow for deposition of calcium carbonate
- Conditions must be just right for carbonate to be deposited involving many factors. This is referred to as the Goldilocks zone.
- Several portions, especially the lower two members of the Redwall, were exposed to shallow meteoric groundwater and exposures to the elements. This caused limestone to recrystallize and undergone several physical changes, most prominently compaction, silicification (parts cemented with silica), and dolomitization (parts recrystallizing into dolomite, CaMgCO3). The resulting changes produced dark-white gray bands in the Thunder Springs member, which can be seen nearly everywhere in the Canyon.
- The banded appearance of the Thunder Springs member is thought to represent algal mats in shallow water, within the tidal zone near a beach setting.
- An unconformity (erosional surface) is present between the Whitmore Wash and Thunder Springs members, and Thunder Springs and overlying Mooney Falls members.

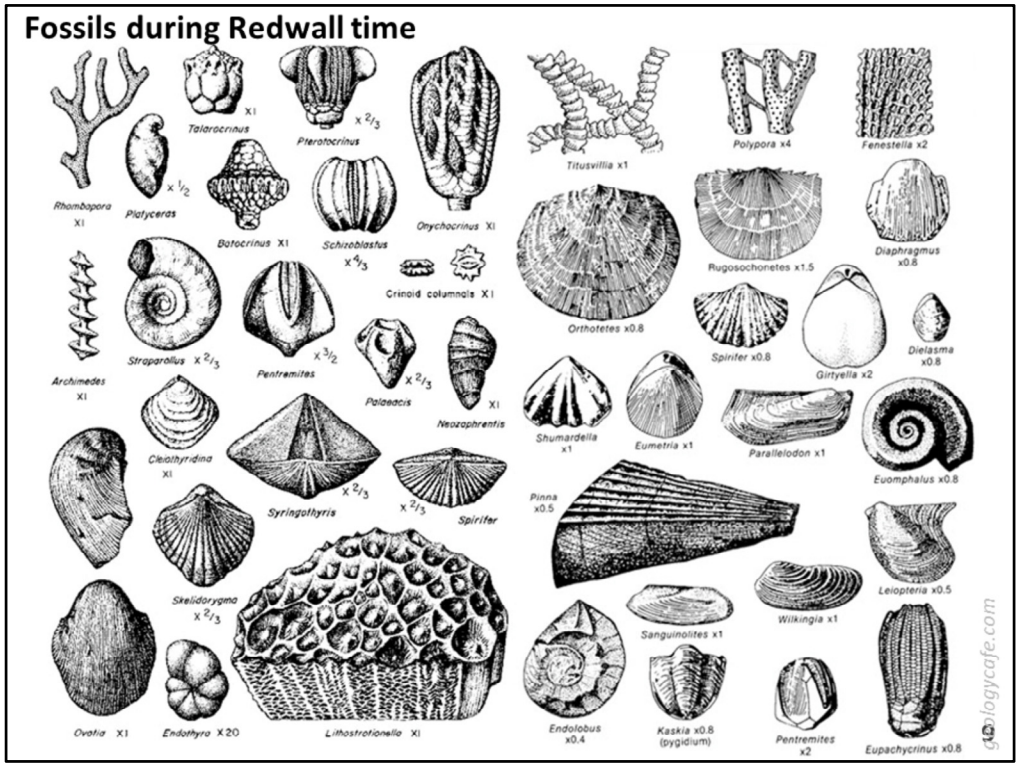
Mississippian Gardens:

- Mississippian refers to a period in geologic time, 360 to 324 Ma.
- This period is also referred to as the “Age of the Crinoids” or sea lilies.
- In this artists rendering are nautiloids (cone-shaped cephalopods), trilobite front center, sponges (green domes), crinoids stems with yellow and pink heads, corals that resemble cactus flowers, and numerous pelecypods and brachiopods on the floor. Sharks are not too far away.
- This setting represents the back-reef flats near the equator, only a few meters deep in high tide, ideal for abundant life.
- Warm seas, shallow oceans and protection from storms creates a “Goldilocks zone” for ideal growing conditions.



Deposition of the Redwall Continued:

- Following minor uplift and erosion of the underlying Thunder Springs and Whitmore Wash members, seas transgress, land subsides, or both, to deposit the Mooney Falls member.
- The Mooney Falls member has some reef-forming structures, which make up the relative homogenous appearance. Conditions were deeper, up to 30 meters deep.
- The Mooney Falls member ranges from 200 ft thick towards the eastern GC, to 400+ feet thick near Havasu Falls.
- The overlying Horseshoe Mesa member marks a slow regression of the seas with shallow-water limestone similar to the Thunder Springs member

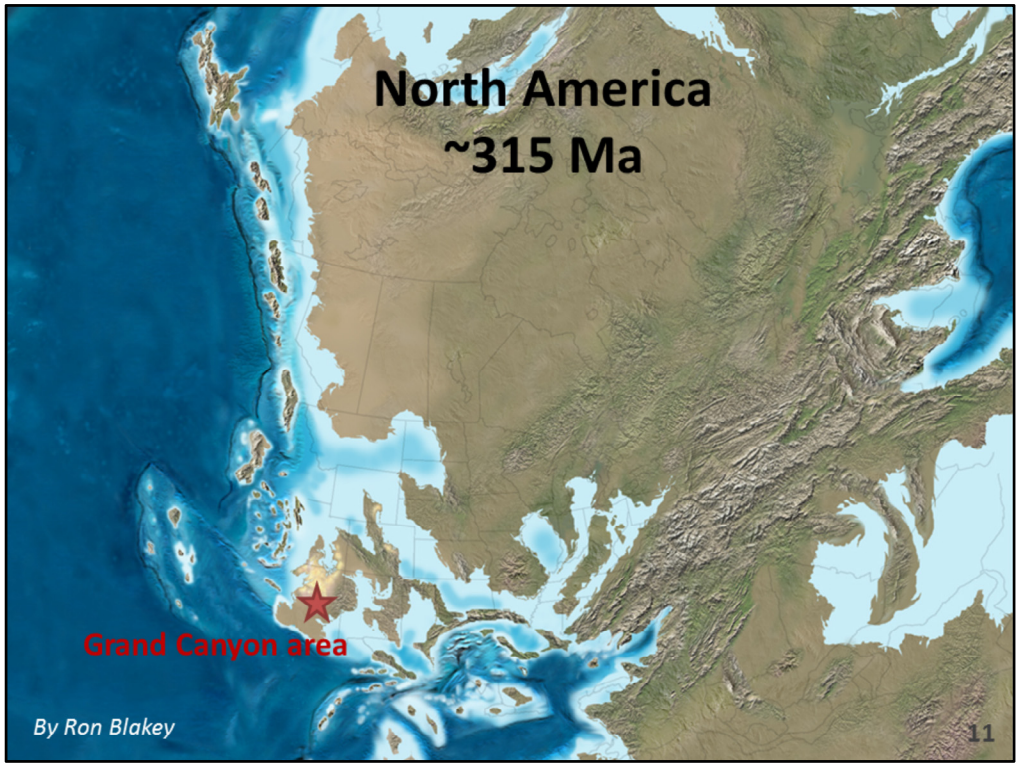


Fossils common to the Redwall Limestone:

- A small number, but representative collection of fossils that can be found in the Redwall Limestone.
- Well preserved fossils are commonly found where chert beds are present, in the lower part of the formation.

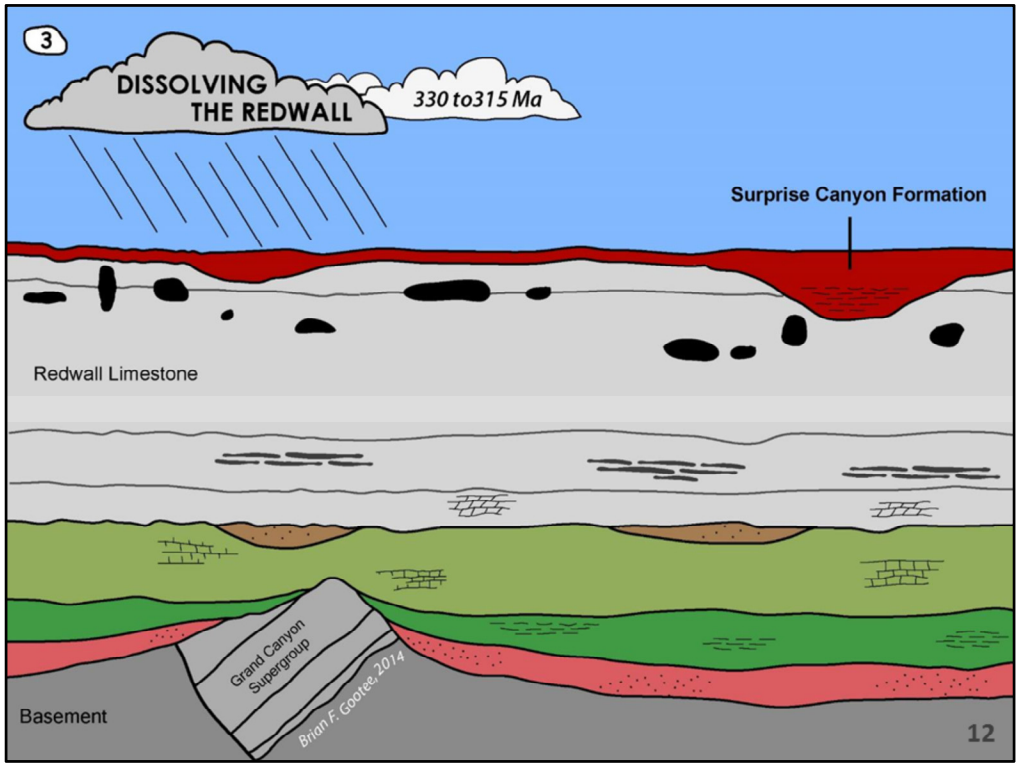
Field photographs of some common fossils:

- With the exception of the ammonite, these fossils can be found in the Redwall Limestone
- The best places to look for these are in washes below the Redwall, where boulders have persisted in place and weathered. There is much more surface area exposed on a boulder to look for fossils as compared to a cliff wall of the Redwall.
- Many fossils are small, less than a few inches and enjoyable to look for, especially with a 3x lens



Surprise Canyon time in North America – a paleogeographic setting:

- Land in the Grand Canyon area was uplifted, in addition to seas possibly dropping
- Redwall Limestone is uplifted and exposed to chemical and physical weathering. A system of rivers will drain across and through caverns in the Redwall towards the Pacific Ocean.
- Remnants of this erosional period are left behind as the Surprise Canyon Formation.
- Collision with Eurasia creates the Appalachian Mountains which will eventually result in larger land mass area, and dropping sea levels.
- Major river systems will eventually head west into the Grand Canyon region, carrying abundant sand and mud, materials which will eventually deposit the red mudstones and sandstone of the Supai Group and Hermit Shale



Surprise Canyon Formation continued:

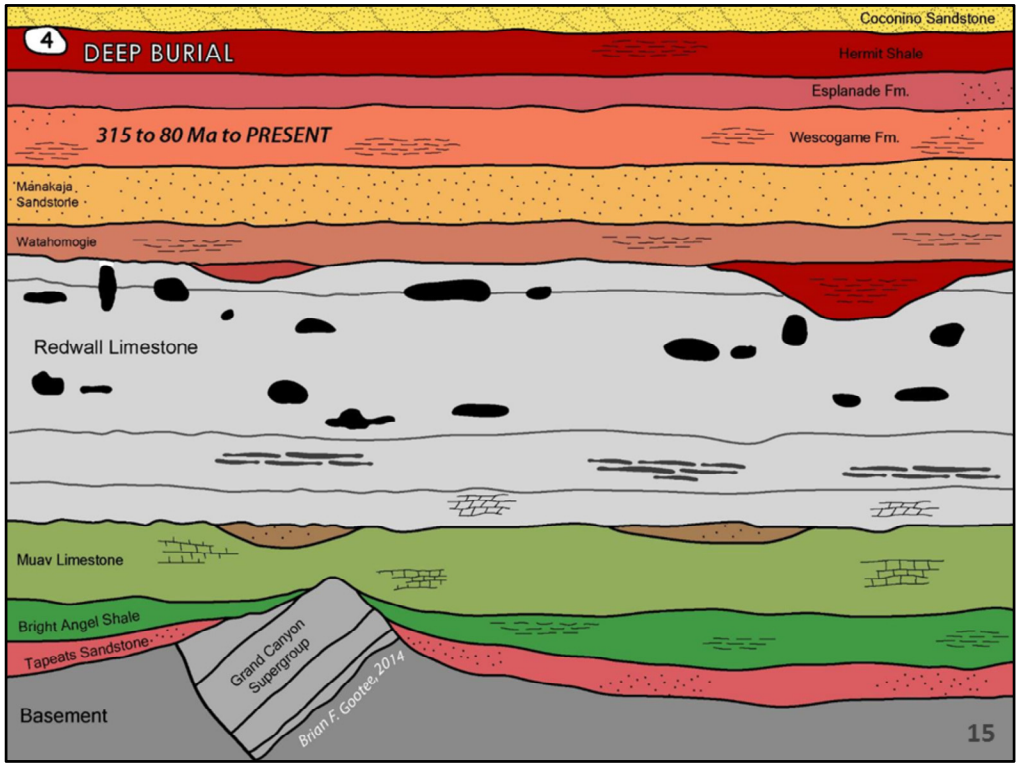
- Supercontinent Pangaea starts to form, dropping sea levels worldwide and locally.
- Minor uplift of the Redwall occurs in addition to sea level fall.
- Exposure of Redwall occurs up to several hundred feet, causing dissolution of the limestone, and formation of caverns as far down as the lower Mooney Falls member.
- 1,000's of miles of interconnected caves form during this period.
- An dark red clay known as "terra rosa" (red Earth) is the insoluble residue after limestone is dissolved. This is also known to make an ochre pigment. Example: 5,000 gallons of dissolved limestone will have about 50 to 500 gallons of pure red clay left over! This builds up near the surface and along cavities and caves. The red clay may likely originate from wind-blown silt and clay that dusted the shallow marine carbonate shelf during Redwall time.
- Caves formed during this period will later become pathways for groundwater to move up, down and laterally in the region for millions of years to come.

Surprise Canyon Setting:

- An artists rendition of plants and animals present during the early Pennsylvanian period.
- Some of these features are present in the Surprise Canyon formation.

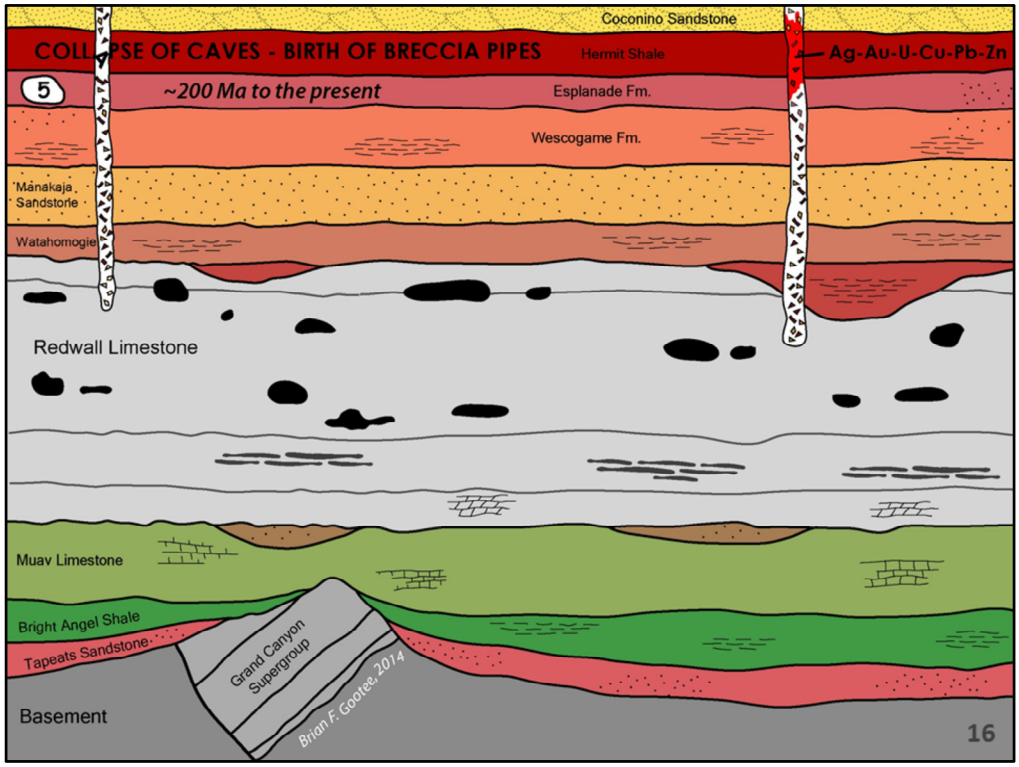
Cave of the Domes:

- ~13,000 feet of interconnected caves underlie Horseshoe Mesa. The air quality is poor however.
- Inside the cave the Redwall Limestone is actually white to very light brown-white.
- Parts of the cave have speleothems (dripstone formations) that are inactive, but some stalactites are active.
- Notice the overlying Supai Group is relatively absent, thus the Redwall is weathering more closely to its true color.



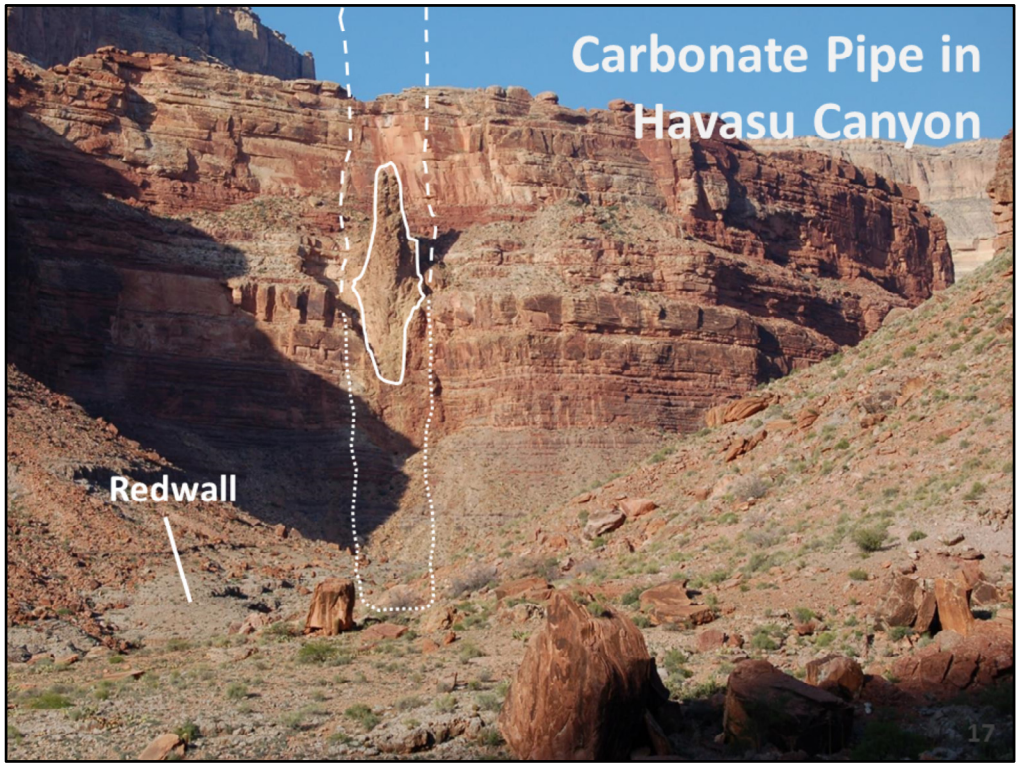
Deep Burial:

- Following deposition of the Surprise Canyon formation is ~12,000 to 15,000 feet of overlying sedimentary rock.
- These strata date ~315 to 80 Ma.
- During this time some caves may have collapsed or started to collapse.



Birth of the Breccia Pipes:

- During and following deep burial, the roofs of caves collapsed.
- The roofs of caves would collapse or stope upward into the overlying rock strata, like an air bubble rising to the surface.
- The pipe-shaped feature is vertical, cylindrical and consists of angular bits and pieces from the overlying rock, a texture called breccia, hence the name breccia pipe.
- After the pipes were created, geothermally (?) heated groundwater or brines rich in metals would migrate through the Redwall and or Esplanade sandstone and migrate upwards.
- In general, these fluids would encounter the impermeable clays of the Hermit formation, which would impede flow and allow for metals to precipitate.
- These features produce high-grade ores, including uranium, silver and copper.

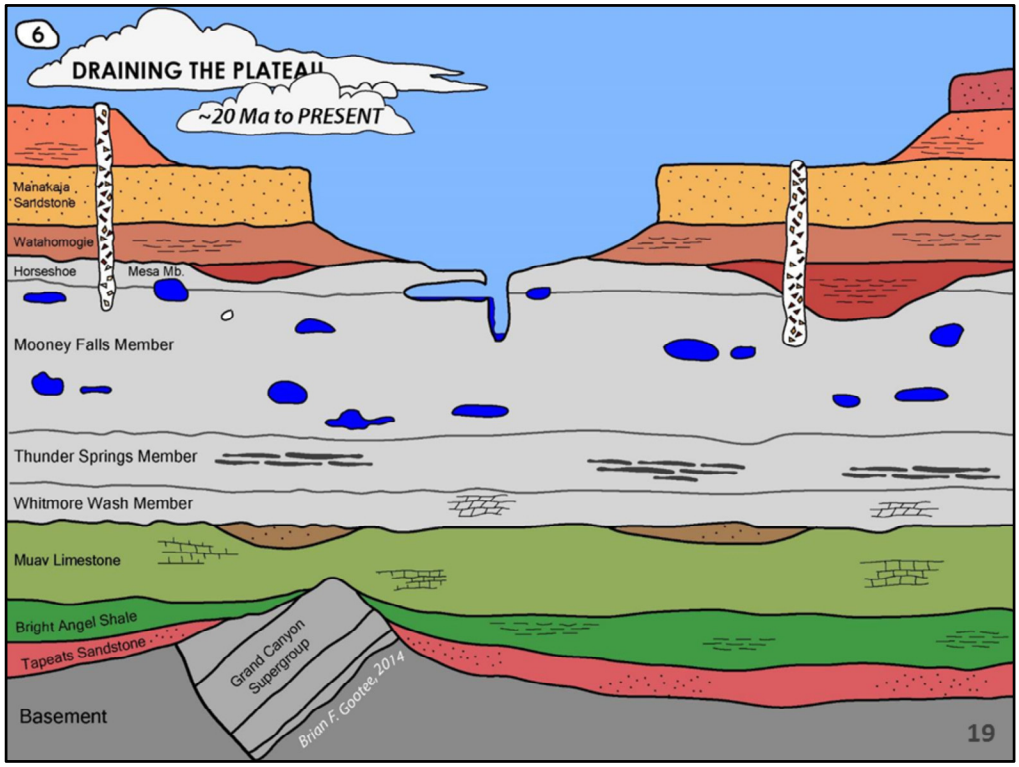


Carbonate Breccia Pipe:

- Also known as “Sullivan’s Pipe/Chimney”.
- Approximately 0.5 mile from the mouth of Carbonate Canyon, above Redwall.
- Short walk along top of Redwall this can be seen.
- Refer to Billingsly and others, 1997 (GCA).
- Other popular examples include the South Kaibab and Organ (Organ pipe mine below Maricopa Point) pipes.

South Kaibab Breccia Pipe:

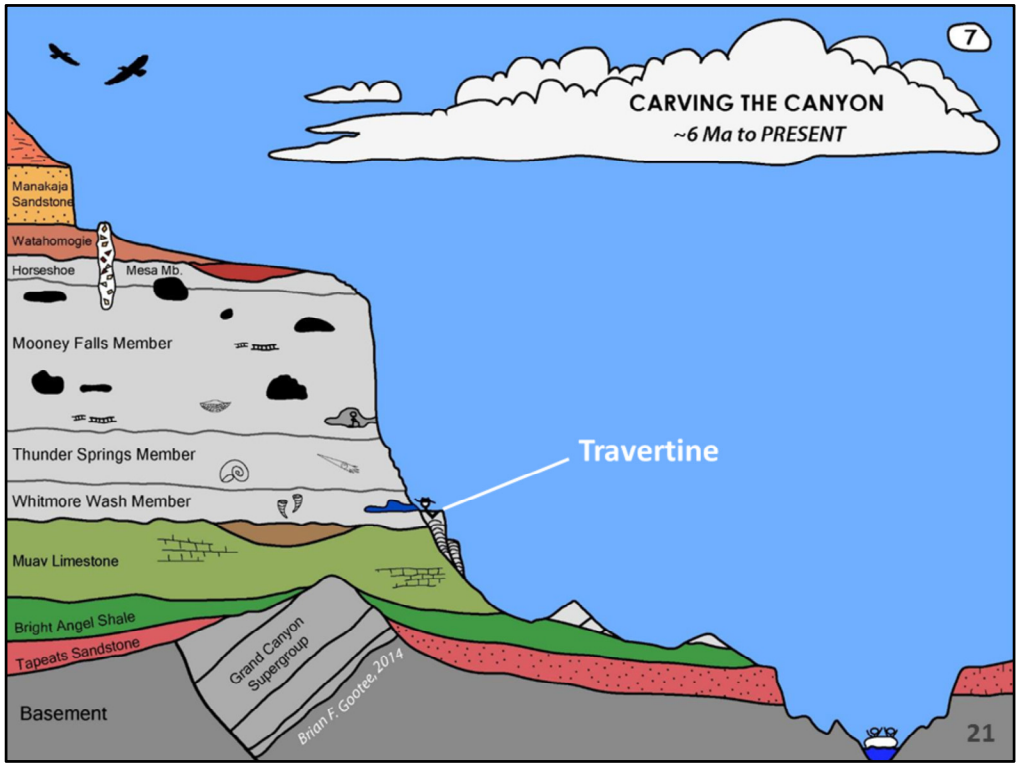
- This pipe is located below O'Neil Butte about 50 feet west of the S. Kaibab Trail.
- Iron content in the breccia blocks (Supai Group) have likely been reduced.



Draining the Colorado Plateau:

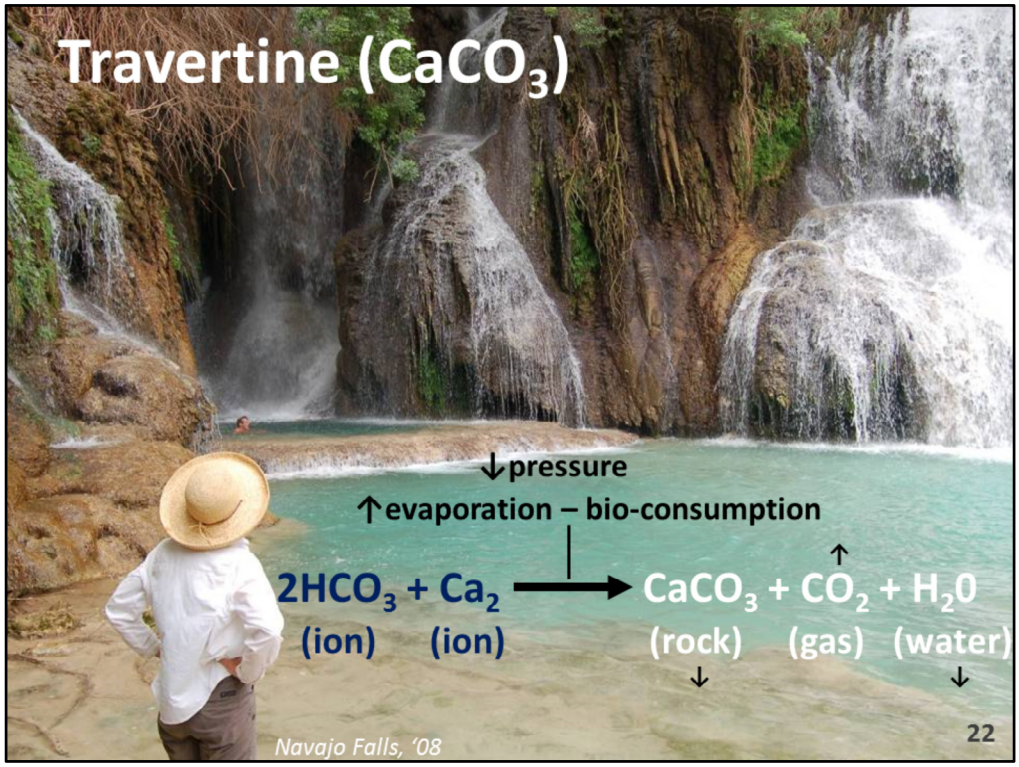
- Early incision of Paleozoic rocks down to the top of the Redwall Limestone likely provided an escape for large volumes of groundwater to lower elevations.
- This "draining" of the Plateau groundwaters may have started as early as ~20 Ma.
- Example: abundant Hualapai Limestone may owe its carbonate content in part to springs discharged from the Redwall.


Draining the Redwall
Beaver Spring, Havasu Canyon, 2009



Redwall Limestone in the Modern Grand Canyon:

- During the last ~6 Ma the Redwall Limestone produces some abundant and common features, especially travertine.
- Travertine deposits inside and outside the Redwall Limestone appear to have been active throughout carving of the Canyon.

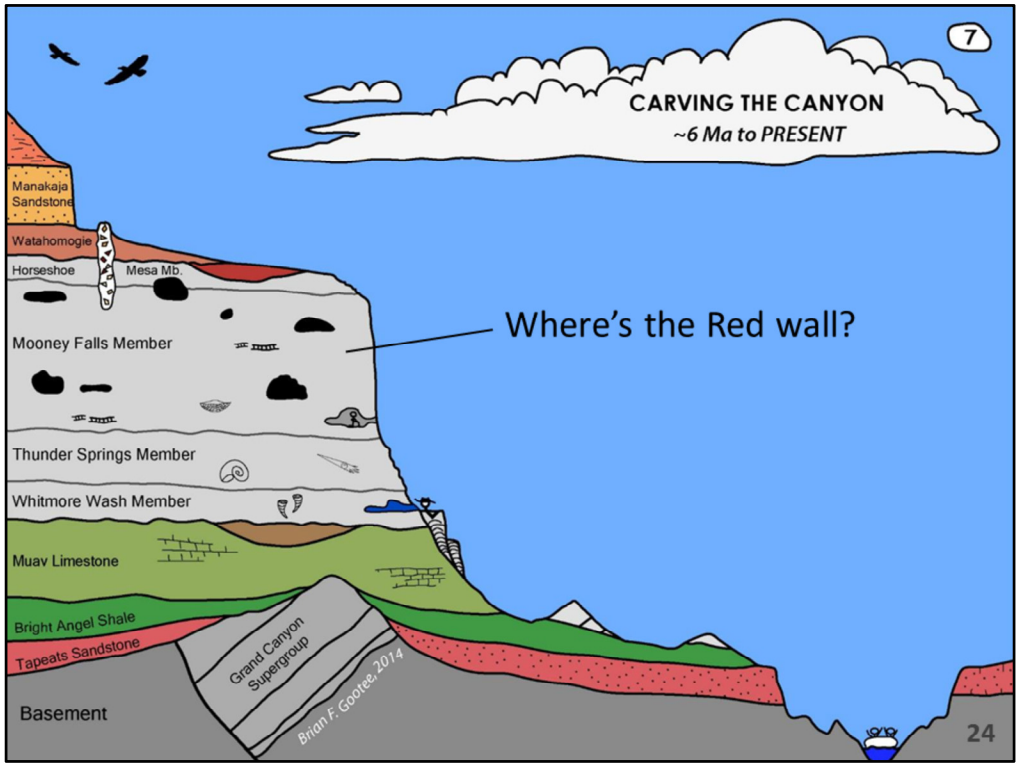


Travertine Formation:

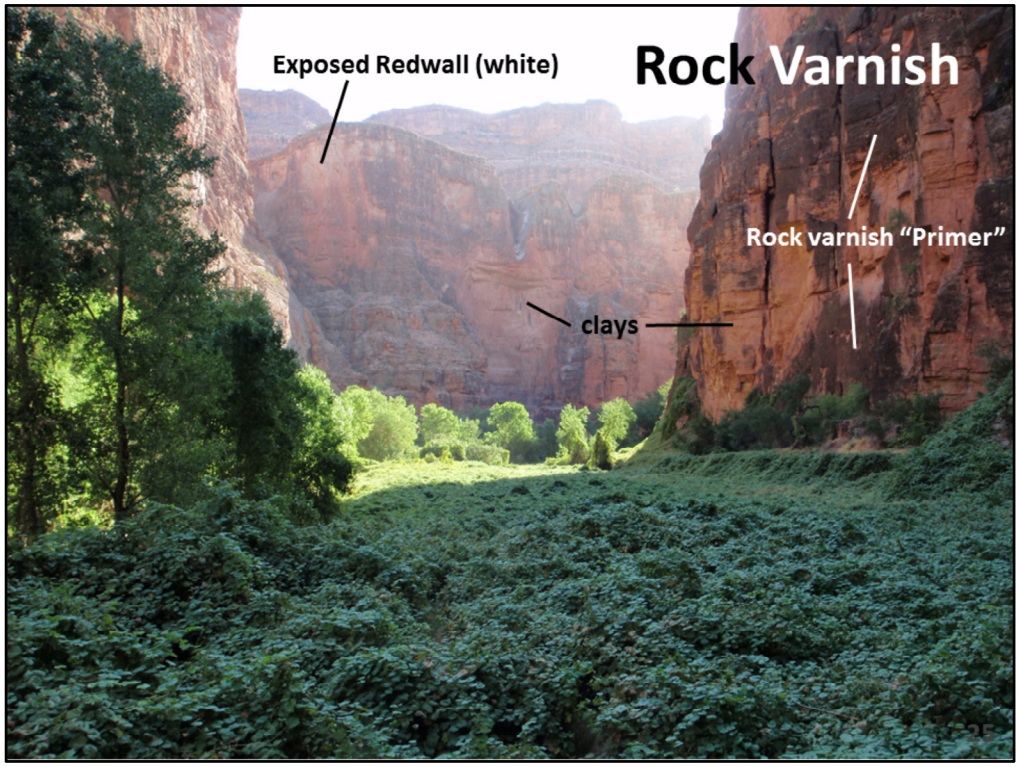
- Havasu Springs in Havasu Canyon is referred to as a natural geochemical laboratory.
- This waterfall comes from springs about a mile upstream and has been exposed for about 2.5 hours.
- The average age of this water is about 11,000 years old.
- Flow is about 30,000 gallons per minute.
- Bicarbonate (HCO3) is dissolved from the Redwall Limestone and transported to the surface.
- Travertine begins to crystallize at a specific pressure and temperature, in this case 2 hours since it reached the surface.
- Algae and other organisms metabolize dissolved bicarbonate (HCO3) and produce CO2 gas, which results in small crystals of calcium carbonate (CaCO3) forming a biogenic ooze mud that settles on the bottom of the pool. Evaporation will also form travertine but is relatively minor in comparison to organisms.
- Thus all travertine is derived from the Redwall Limestone is liberated in a "second life".
- It is estimated that Havasu Canyon forms about 35 tons of travertine a day during summer temperatures.

Dropping Acid:

- Geologists use acid to test for the presence of $CaCO_3$ (carbonate)
- In the above reaction hydrochloric acid is added to $CaCO_3$ to break apart the $CaCO_3$ into an aqueous solution of $CaCl_2$ and H_2O, and an effervescent (bubbly) CO_2 gas, bonds that were initially formed ~340 Ma!
- Fossils also react when acid is poured on them.
- Everyone likes to see this reaction occur. A recipe to make your own is on the last slide.

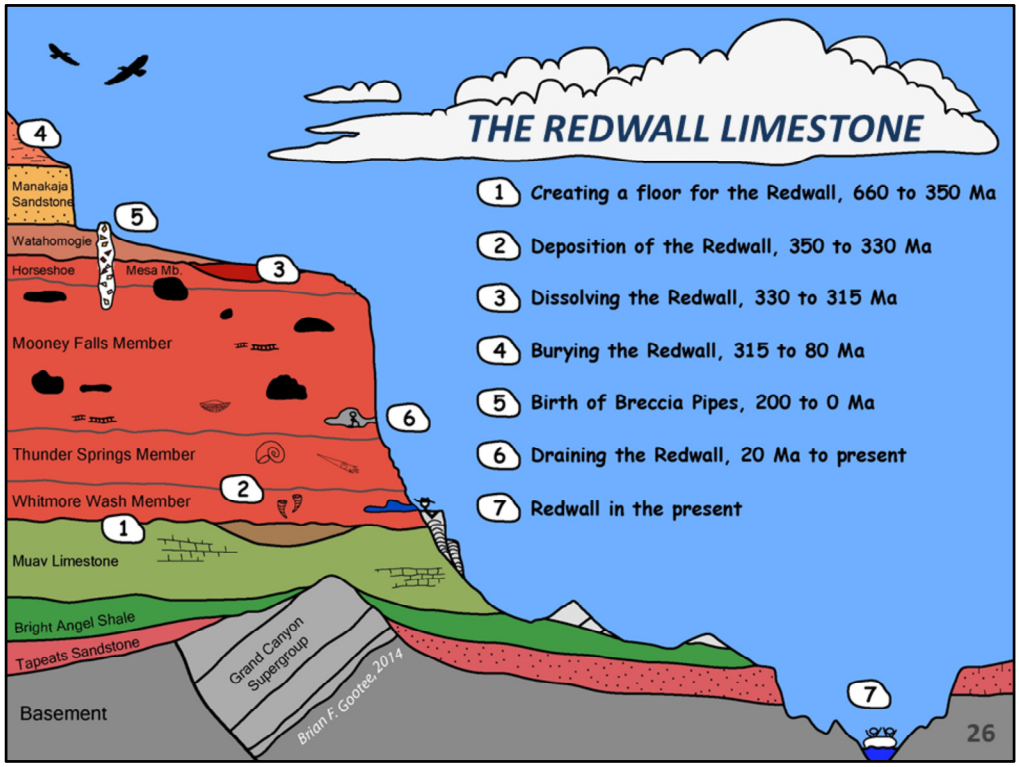


Why is the Redwall Limestone red in appearance?



Rock Varnish:

- Redwall gets its name (Gilbert, 1872) from the overlying red, oxidized mudstones in the Supai Group which runoff onto the underlying walls of the Redwall cliffs.
- The actual color of the Redwall Limestone is white to off-white, seen above as small patches.
- The clays on the Redwall cliffs help to foster a surface for biological communities, specifically algae, moss, lichen and other bacteria (the dark and light grays above)
- Windblown dust also gets added to the surface.
- A combination of clay, dust and biological communities create a "primer" on the wall, which with time gets darker and darker gray. The byproduct of these elements make up **rock varnish**, a manganese oxide.
- In many places on flat stable surfaces rock varnish can be a few millimeters thick, black and shiny like metal, and as much as 2 million years old still sitting out exposed to the elements!



The Redwall Limestone, Inside and Out:

- A brief summary of geologic events which led to the formation of the Redwall Limestone over nearly 700 million years to the present.
- These seven events are my personal approach to breaking down individual events which mark significant changes over a roughly 700 million-year period.

Geologic Toolbox

- A 3x lens for others gives them a 3x experience, and you can photograph through a lens well.
- To make your own acid:
  - Add weak muriatic acid (14%) to water; roughly 1 part acid to 1.5 parts water (not the other way around!).
  - Seal tightly in plastic container.
  - Keep in Ziploc bag.
- Fossil rubbings with pencil or putty casts are great ways to take the fossil with you.
- Remember, boulders of the Redwall Limestone found in washes offer much more cleaned surface area than actual outcrops of the formation such as cliffs or inside caves.
- Read "The Chambered Nautilus" by Oliver Wendell Holmes

27