Cait Livsey, GEL 230

# Paleontological insights on the environmental evolution of the Grand Canyon

The colorful, flat lying layers that make up the Grand Canyon are iconic. These rocks were deposited over a period of approximately 300 million years and record the history and evolution of the local environment. The various layers correspond to shifts in the depositional environment over time, resulting in each of the formations representing a distinct setting. The changes in depositional environment are controlled by changes in local sea level (either due to variations in global sea level, or movement of the ground relative to sealevel) as well as the local climate regimes. Studying the clues left behind, particularly through the fossils or sedimentary structures, geologists can reconstruct what the environment must have been like during that period. The Paleozoic rocks that are found within the Grand Canyon have undergone negligible deformation, resulting in a sedimentary record that is almost a mile high in places- an occurrence so rare it warrants being named a natural wonder. This paper aims to summarize the evidence left behind by the fossils and sedimentary structures in the Paleozoic rocks of the Grand Canyon (Firgure 1) and explore what these features tell us about the environmental setting in which the layers were deposited.

**Tapeats Sandstone (~525-515 Ma)**

The Tapeats Sandstone is the oldest member of the Cambrian Tonto Group, which makes up the earliest Paleozoic rocks in the Grand Canyon. The Tapeats Formation consists of medium to coarse-grained feldspar and quartz-rich sandstone beds with quartz-rich conglomerate near the bases (Middleton and Elliot, 2003). The sandstone beds are relatively thin (less than 1m thick) and the total thickness of the formation varies across the canyon between 30 and 120 meters due to variations in the outcrops of the Precambrian basement rocks. The majority of the fossils found in this layer are trace fossils, which are records or traces that an organism left behind, without any remains of the actual organism. In this unit, these include the Lower Cambrian index fossil *Skolithos*, which are vertical burrows created by a worm-like organism (Thayer, 2009). Though fossils are rare, the sedimentary structures of the Tapeats Fm. give us deeper insights into the depositional environment. Horizontal and trough cross-bedding, ripple marks, and thinning upwards sequences are the sedimentary structures found within this layer (Middleton and Elliot, 2003).

The depositional environment of the Tapeats Sandstone is interpreted to have been an intertidal marine shelf bordered by sandy dunes ("National Park Service"). The marine shelf likely consisted of tidal flats, braided rivers and beaches due to the sedimentary structures as well as the mineralogy and textures of the grains themselves (Hereford, 1977).

**Bright Angel Shale (~515 Ma-505 Ma)**

The Bright Angel Shale is the second member of the Tonto Group and represents approximately ten million years of deposition. This formation is composed of interbedded sandstone, siltstone and shale with a few coarser-grained sandstone and conglomerate beds (Middleton and Elliot, 2003). The shales are greenish in color due to the abundance of chlorite and kaolinite (Middleton and Elliot, 2003). This formation ranges in total thickness between 82 to 137 meters across the canyon. Fossils found in the Bright Angel Shale are not widespread, but can be locally abundant when found. Brachiopods, trilobites, and *Hyolithes* (trace fossils from worms) have been identified within this layer as well as fragments of sponges, mollusks, echinoderms and algae (Middleton and Elliot, 2003). Additionally, poorly preserved trilobite fossils from 47 species have been identified in the Bright Angel Shale. Some cross bedding, wavy/lenticular bedding, and horizontal laminations have also been found within this formation (Middleton and Elliot, 2003).

Based on fossil and sedimentological evidence, sea level rose between the deposition of the Tapeats Sandstone and the Bright Angel Shale as the ocean transgressed. The Bright Angel formation is interpreted to have been a low-energy continental shelf with occasional higher energy events (Middleton and Elliot, 2003). The shift to finer-grained sediments and horizontal laminations suggest progression to deeper water during this time.

**Muav Limestone (505 Ma)**

The final member of the Tonto Group is the Muav Limestone, which was deposited in the mid to late Cambrian. This unit is resistant and tends to form cliffs. The unit is a limestone with thin interbeds of conglomerate, micaceous shale, as well as fine-grained siltstone (Middelton and Elliot, 2003). The amount of siliciclastics increases as you go east, with a coincident decrease in both amount of carbonate material and thickness of beds. Overall, the Muav Limestone ranges in thickness from 42 to 252 meters across the canyon (Middleton and Elliot, 2003). Both fossils and sedimentary structures are rare within the Muav Limestone, with only sparse trace fossils, sponge spicules, and low-angle cross bedding present in some locations (Middleton and Elliot, 2003).

The gradational shift from the Bright Angel Shale to the Muav Limestone indicates a continued transgression of the sea (Figure 2). The grain size and bed thickness variation indicates that the unit was deposited in a subtidal but still shallow marine shelf (Berthault, 2004). The Tonto Group is capped by an unconformity of more than 150 million years, which has been attributed to a quick drop in local sea level.

**Temple Butte Formation (385 Ma)**

Following a period of erosion (represented by the unconformity, Figure 1), the Devonian Temple Butte Formation was deposited. This unit shows up in discontinuous lenses across the Grand Canyon and consists of dolomitized sandstone with minor beds of sandstone and limestone (Beus, 2003). This layer is commonly reddish-purple in color and contains irregular beds with varying lithologies. The mottled appearance of this unit makes sedimentary structures and fossils hard to find, but a few recognizable fossils have been found. Two fish fossils have been found in the Temple Butte Formation, one identified as *Bothriolepis*, a small placoderm fish (Thayer, 2009). The discovery of conodont microfossils within this layer allowed paleontologists to better constrain the age of the unit to the Upper Devonian (Beus, 2003). Other fossils include stromatoporoids, silicified corals, gastropods and crinoids, but these are so rare and poorly preserved that they cannot be identified even to the genus level (Beus, 2003).

The lens-shaped deposits and fossils found in the Temple Butte Formation allow geologists to conclude that this unit represents estuary fill deposits and tidal channels ("National Park Service"). Some regions of the Temple Butte Formation within the Grand Canyon indicate a more open marine environment, demonstrating that the Temple Butte Formation was deposited in a variable and shifting environment (Beus, 2003).

**Redwall Limestone (~340-320 Ma)**

The Mississippian Redwall Formation forms massive limestone cliffs that are red due to the weathering of overlying units. The Redwall Limestone itself is comprised of four separate members: the Whitmore Wash Member, Thunder Springs Member, Mooney Falls Member, and Horseshoe Mesa Member (McKee and Gutschick, 1969). These are all blueish-gray dolostones, limestones, with interbedded cherts and mudstones (Beus, 2003). The total thickness of the Redwall Limestone ranges between 120 m to 240 m within the Grand Canyon (Beus, 2003). This unit is the earliest unit in which abundant, well-preserved fossils are found. The most abundant fossils are brachiopods and corals, but bryozoans, bivalves, crinoids, cephalopods, blastoids, trilobites, ostracodes, fish teeth and foraminifera are present as well (Beus, 2003).

The Redwall Limestone was likely deposited in a warm, shallow sea indicated by the rich diversity in marine invertebrates ("National Park Service"). Two marine transgression-regressive sequences are evident in the lithology and sedimentology of the four units (Beus, 2003).

**Surprise Canyon Formation (~320-315 Ma)**

The Mississippian Surprise Canyon Formation is another discontinuous, lens-shaped unit that varies greatly across the canyon. Many different lithologies are found within this unit, including: sandstone, conglomerate, skeletal limestone, and siltstone (Beus, 2003). Although the lithologies of this formation vary widely, in many places, the Surprise Canyon Formation is full of diverse fossils. More than 60 species of marine organisms have been identified within the Surprise Canyon. These include brachiopods, bryozoans, foraminifera, corals, conodonts, echinoderms, mollusks, trilobites, shark teeth and ostracodes (Beus, 2003). Additionally, in some outcrops of the Surprise Canyon, plant fossils (including macrofossils, seed ferns, algal structures and palynomorphs) are preserved (Beus, 2003). The conodont and foraminifera biostratigraphy have provided the age constraints on the unit (Billingsley and Beus, 1985).

Following the deposition of the Redwall Limestone, the sea retreated, leaving the unit a few hundred meters above sea level, and thus exposing it to erosion. Limestone is easily eroded due to its solubility in rain/groundwater, resulting in the creation of caverns, sinkholes, canyons and drainage systems typical of karst environments (Thayer, 2009). When sea level rose once again, streams and estuaries dominated the area, and the karst depressions were filled with sediment (Beus, 2003).

**Supai Group (315-285 Ma)**

The Pennsylvanian Supai Group is made up of four formations that consist of mud, silt and sandstones with minor beds of limestone. The four formations from oldest to youngest are the Watahomigi, Manakacha, Wescogame and the Esplanade Formations (Blakey, 2003). The fossil assemblages within these formations include trace fossils, brachiopods, fusulinid foraminifera, plants, and vertebrate track ways (McKee, 1982). Sedimentary structures found in the Supai Group include cross beds, wind-ripple laminae, and climbing cross strata (Blakey, 2003).

Due to the diversity of fossils and sedimentary structures, the Supai Group must have been deposited in a shifting environment. The cross beds and certain trace fossils within sandstone beds indicate a subaerial desert environment with meandering rivers (Thayer, 2009). The vertebrate track ways and plant fossils within mudstone indicate a shift to a widespread fluvial environment periodically. The brachiopods and fusulinids indicate that a shallow sea did occasionally submerge the region as well (McKee, 1982).

**Hermit Shale (280-275 Ma)**

The Permian Hermit Shale overlies the Supai Group and is the distinctive slope-forming unit whose red-brown color stains the underlying layers when weathered. This unit is composed of very fine-grained silt, mud and sandstones and ranges in total thickness between 30-270 meters (Blakey, 2003). Likely due to the incredibly fine-grained texture of this unit, few studies have focused on the Hermit Shale (Blakey, 2003). Sparse fossils and sedimentary structures have been found within the unit and the assemblages seem to reflect those found in the Supai Group (Thayer, 2009). Similarly to the Supai Group, the Hermit Shale was likely deposited in a coastal swamp environment with high oxygen concentrations giving the sediments the rich red color ("National Park Service").

**Coconino Sandstone (275-273 Ma)**

The Permian Coconino Sandstone is a light tan colored, fine-grained, well-rounded, well-sorted quartz sandstone (Thayer, 2009). The total thickness of this unit is 17-183 meters, with variations likely controlled by regional structural features (Middleton et al., 2003). Outcrops of Coconino Sandstone are spectacular due to large-scale cross beds that can be clearly observed on cliff sides (Reiche, 1938). In addition to these striking sedimentary features, the Coconino Sandstone also contains impressive trace fossils of both vertebrate and invertebrate trackways (Figure 3; Mckee, 1933). Using the various sizes and shapes of the trackways, paleontologists have been able to identify a variety of different species that were living either on or around the Coconino Sandstone (Middleton et al., 2003)

The depositional environment of the Coconino Sandstone is a novel environment for this area in geologic history, though, in a way, it is the most similar to how we think of the Grand Canyon today. The lithology and sedimentary structures indicate that this was an eolian desert environment with large rolling dunes (Thayer, 2009). The orientation of the cross beds allowed geologists to infer that the dominant wind regime was from the north to the south (Middleton et al., 2003). The presence of both vertebrate and invertebrate trackways led to experiments to determine what environmental parameters would be necessary to preserve these features (McKee, 1933). McKee concluded that is it possible that the tracks were initially formed on dry sand, but water vapor (mist or fog) dampened the sand enough to preserve the footprints.

**Toroweap Formation (273-270 Ma)**

The Permian Toroweap Formation is markedly different from the Coconino Sandstone. The slope forming Toroweap contains three distinct members, the Seligman Member, the Brady Canyon Member, and the Woods Ranch Member (Turner, 2003). The Toroweap Formation consists of sandstone, muddy limestone, dolomite, and interlayered evaporites of gypsum and halite (Turner, 2003). The only fossils found in the Toroweap Formation are within the Brady Canyon Member and consist of brachiopods, bryozoans, crinoids, rugose corals, bivalves, gastropods and cephalopods (Kirkland, 1963).

The fossils and sedimentology of the Toroweap Formation indicate that there was a large shift in the environment from a desert to a more shallow to open marine environment (Turner, 2003). The fossils assemblages suggest that the seas returned to the area and the marine fauna proliferated once again. However, the evaporite layers indicate periodic shoaling of the sea resulting in supersaturated waters, promoting the precipitation of gypsum and other evaporites (Turner, 2003).

**Kaibab Formation (270 Ma)**

The Permian Kaibab Formation is the uppermost layer in this area and forms the surface of the Colorado Plateau and the rims of the canyon. This formation consists of light grey limestone with occasional thin beds of chert, very similar in composition to the underlying Toroweap Formation (Hopkins and Thompson, 2003). The rims of the canyon are so resistant to erosion due to silicification and dolomitization of the sediments (Hopkins and Thompson, 2003). The Kaibab Formation has a diverse fossil assemblage including brachiopods, bryozoans, crinoids, sponges, corals, sharks, fish, annelid worms and various microfossils. There are a few distinct faunas that have been identified from the Kaibab Formation, each indicating a slightly different environment (Thayer, 2009).

The fossils and lithology of the Kaibab Formation indicate that the location was shifting between a subtidal and shallow marine environment (Hopkins and Thompson, 2003). The shifts between marine fauna within the Kaibab Formation were likely caused by minor changes in sea level (Hopkins and Thompson, 2003)

**Conclusion**

To conclude, though the signature layers that make up the walls and cliffs of the Grand Canyon are spectacular even just to look at, the story they tell through their sediments and fossils provide a much deeper understanding and appreciation of this natural wonder. Analyzing the fossils within the rocks allows one to imagine the sea rising and falling, the environment shifting between intertidal environments to sandy dune-filled deserts, and back to reef-like settings. A deeper story that can be assembled from the paleontology of the section (beyond the scope of this paper, but intriguing nonetheless), is the evolution of not on the environment through time, but also the organisms themselves. Even without explicitly studying the evolutionary shifts that occur through these Paleozoic rocks, the increase in diversity and complexity of organisms through the section is evident. In summary, the history of the Grand Canyon is hidden within its rocks, and the fossils and sedimentary features are the keys to unlocking the narrative.

## REFERENCES

Beus, S.S., Morales, M., 2003. Grand Canyon Geology. Oxford University Press, New York, NY. And references therein, including: Beus, Blakey, Elliot, Hopkins, Middleton, Thompson, and Turner.

Berthault, G., 2004. Sedimentological Interpretation of the Tonto Group Stratigraphy (Grand Canyon Colorado River) 1. Lithology and Mineral Resources 39, 480-484.

Billingsley, G.H., Beus, S.S., 1985. The Surprise Canyon Formation, an Upper Mississippian and Lower Pennsylvanian (?) rock unit in the Grand Canyon, Arizona. US Geological Survey Bulletin A 1605, A27-A33.

Hereford, R., 1977. Deposition of the Tapeats Sandstone (Cambrian) in central Arizona. Geological Society of America Bulletin 88, 199-211.

Kirkland, P., 1963. Permian stratigraphy and stratigraphic paleontology of a part of the Colorado Plateau.

National Park Service Website: https://www.nps.gov/grca/learn/nature/fossils.htm

McKee, E.D., 1933. The Coconino Sandstone: its history and origin. publisher not identified.

McKee, E.D., 1982. The Supai Group of Grand Canyon. US Department of the Interior, Geological Survey.

McKee, E.D., Gutschick, R.C., 1969. History of the Redwall Limestone of northern Arizona. Geological Society of America Memoirs 114, 1-700.

Reiche, P., 1938. An analysis of cross-lamination the Coconino sandstone. The Journal of Geology 46, 905-932.

Thayer, D., 2009. An Introduction to Grand Canyon Fossils. Grand Canyon Association, Grand Canyon, AZ.

## FIGURES

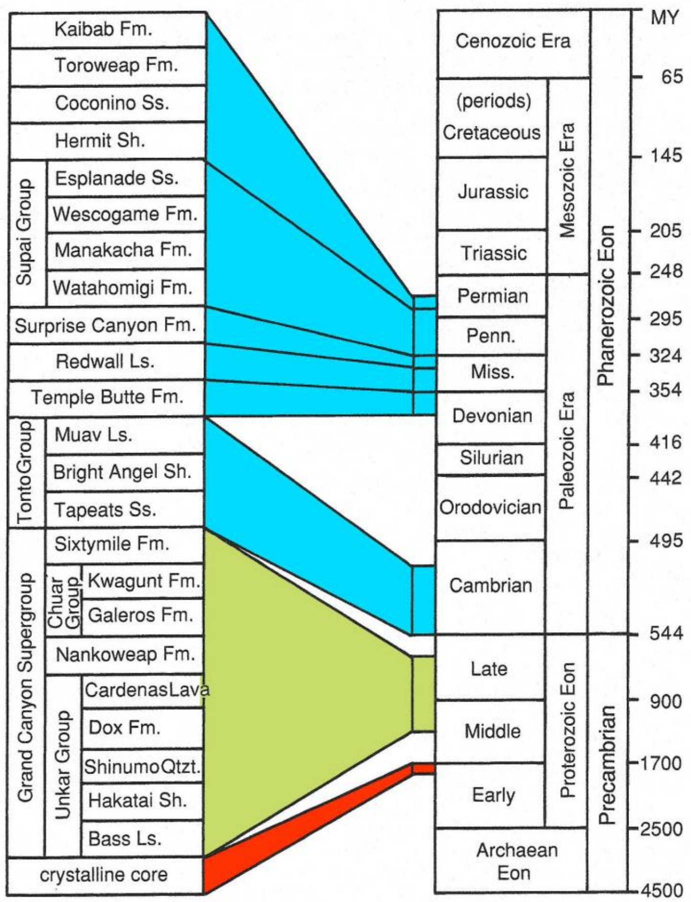


**Figure 1.** Stratigraphic column for the rocks found in the Grand Canyon. Colors correspond to the different time periods in which the rocks were formed (Figure taken from GEL 230 Smartsite resources).

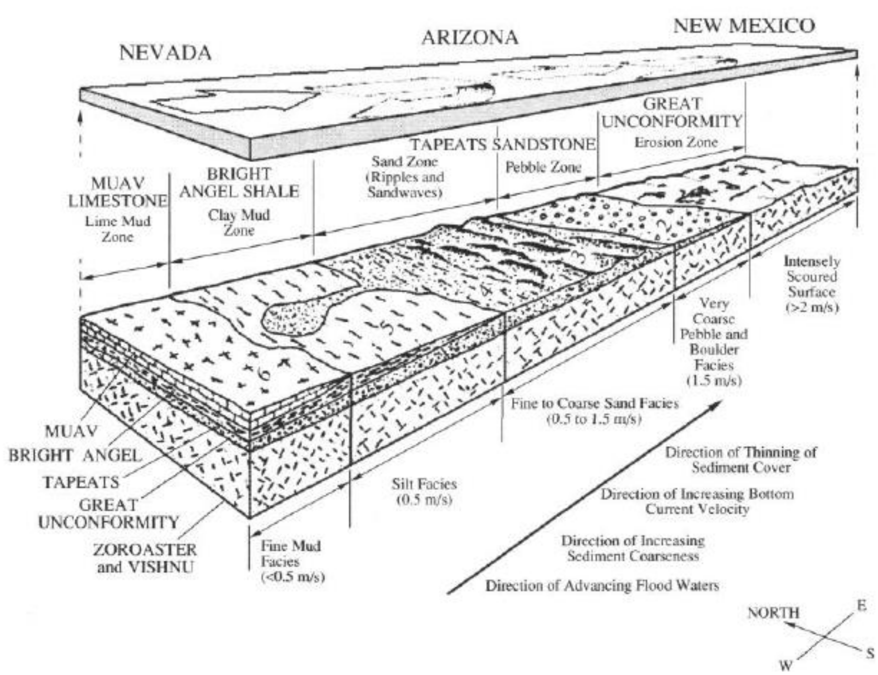


**Figure 2.** Reconstruction of how the environment evolved through the deposition of the Tonto Group across Nevada, Arizona and New Mexico. Figure from (Berthault, 2004).

**Figure 3.** Photograph of trace fossil track ways within the Coconino Sandstone (photo courtesy of Leonard Brand, flickr)