UNDERSTANDING THROUGH INTEPRETATION: A BRIEF TOUR OF GRAND CANYON GEOLOGY

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Working in Grand Canyon, we have the opportunity to learn about a lot of things, so diverse in content and scope, that at the beginning of your career you think there is no way that you will ever know as much as your mentors. But eventually you hear the stories enough times, read the books cover to cover, even crash a few times before you slick it. Then before you know it you are training eager new recruits yourself. Learning how *you* relay information to your passengers is totally unique to you. It is something that evolves over time and with a bit of practice. And everyone has a favorite subject, maybe two. Mine is the rocks. I love geology, and being able to share my passion and understanding with anyone that has an interest. This is my short version of Grand Canyon's geology. A fun way to know the whole story, and one you can share with your folks if you'd like.

First we must travel back in time over 2.2 billion years ago, oxygen had just started to form, and it would take more than another billion years for it to create the atmosphere as we know it today. All that existed of the North American continent was a landmass called the Wyoming shield, hanging out near the equator. And forming off the coast of this ancient continent was a volcanic arc island. These islands were carried on a collision course by an oceanic plate, and as this plate sub-ducted beneath the continent, all of the island material (basalt, volcanic ash, shale and sand) was scraped off and started to build onto the edge of the continent. As the oceanic plate pulled this mix of igneous and sedimentary material from the surface and down to depths of around 16 miles, it was there heated and pressurized which metamorphosed it into various types of schist and gneiss in foliated layers buried deep beneath the surface.

The leading edge of this oceanic plate reached depths where it was hot enough to melt, and this now liquid material tried to rise towards the surface under great amounts of pressure, and it squeezed itself into every crack and fissure in the hot pliable schist, forming all of the awesome bands of pink granite, pegmatite, big plutons (large masses of granitic rocks)and other bizarre igneous intrusions we see down there. On the surface great mountains were forming as all of this material was forcefully welded onto the edge of the continent. Collectively these rocks are called the pre-Cambrian crystalline rocks, or the Vishnu Complex, and they form the basement of the North American continent in this region. 45 million years of erosion followed the continent building collision and the great mountains eroded away to a fairly level plain of low hills and river deltas. This is where the Grand Canyon Super group was deposited.

It is believed that over 12,000 ft of material accumulated during the assembly of an ancient super continent called Rodinia, over 1 billion years ago. The 9 different formations of the Supergroup formed mostly in shallow marine, coastal plain, and broad river delta settings in a basin between North America and the fragments of a few other continents. These oldest of GC's sedimentary layers contain the fossilized remains of some of the first life on earth, in the form of stromatolites and simple celled algal mats. We also find some lava flows and dykes. Then Millions of years after its formation, as Rodinia started to break apart, the continental plates moving away from one another caused the faulting and erosion of this thick sedimentary layer. And because of the tilted fault blocks, and their distribution throughout the Canyon it is believed that sections of these rocks were dropped into long rift valleys similar to those found in east Africa today. With most of these layers now above sea level they were prone to erosion and therefore disappeared, leaving behind only the beautiful colored and tilted sections we see today.

As the continental plates continued to move apart, this area of North America saw an extended period of subsidence during what is called a passive margin, where tectonic plate movement became inactive and the region was inundated by shallow seas during the Cambrian period. 525 million years ago the leading edge of the Tonto sea crashed repeatedly into the continent, eroding away the unprotected remains of the GC Supergroup, and the last vestiges of the pre-Cambrian mountains, turning them into beach sand, and leaving behind the Tapeats sandstone(525 Ma). In most places this younger sedimentary layer is resting directly on top of the much older Vishnu complex, and this creates the Great Unconformity, where over 2 miles of material has been washed away. Representing about 1.2 *billion* years of missing time.

As the Tonto sea advanced and retreated, advanced and retreated, each time advancing a little farther, and with the water deepening off shore, the Bright Angel shale(515 Ma) started to collect as colorful sediment was shed from the landmass and deposited on top of and sometimes mixed in with the Tapeats. Creating an "interfingering" zone. The Tonto sea continued it's rise and march towards the east, the western margin deepened, and the Muav limestone

(505 Ma) was deposited, due to the many lime secreting organisms that flourished in the deep offshore waters.

It is important to note that the surface of Earth at this time in our history was completely devoid of life: more resembling a lifeless Martian landscape, with nothing more than vast expanses of rocks, sand dust and gravels, as our atmosphere had recently formed. But the oceans of the world were another story altogether. Life had evolved, and continued at a remarkable rate, during what is known as the "Cambrian life explosion". In contrast to the pre-Cambrian life forms of simple celled organisms, and bacteria, complex life became predominant in shallow seas worldwide.

There is yet another unconformity recorded in GC's rock layers, between the Muav and the Redwall limestone, this one representing nearly 135 million years of missing time. During this period, life had continued to evolve and to move out of the oceans and onto land, covering the continents with vast forests and swamps. Then 340 million years ago the Redwall limestone was deposited as yet another vast sea teeming with life covered this region. Then the tectonic plates that make up our earths crust continued to move around, and eventually they collided again. This time forming the ancient supercontinent of Pangaea. This collision also formed a massive mountain range called the Ancestral Rockies(315 Ma). These immense mountains were then subjected to another 115 million years of erosion, which turned these great mountains into incredible amounts of sediment, that filled the surrounding low lying basins and broad river deltas, depositing in Grand Canyon, the Supai group(300-280 Ma) and also the Hermit shale (285 Ma), both of which are rich in iron oxide. With the sediments of the Ancestral Rockies having filled up all the low areas, this region was now above sea level, and as the Pangaean supercontinent finished it's assembly, the climate changed across the coastal and inland areas, where huge dunes marched across the land covering it in the windswept sands of a vast desert, and leaving behind the Coconino sandstone (275 Ma) during the early Permian period. Sea levels began to rise once more, and with them the ground water table rose as well, and protected between the dunes of this vast sandy desert, sabkha conditions developed in the offshore areas as groundwater rose to the surface and evaporated, leaving behind evaporate minerals such as calcite and gypsum. These were then covered by erratically changing sea levels, which created the mixed slope of the Toroweap formation (272 Ma). And as the Permian sea rose one final time over the Grand Canyon region, it covered all of the underlying strata with a layer of erosion resistant and fossil filled limestone called the Kaibab(270 Ma) And this is the rock layer that forms the capstone over the entire length of Grand Canyon.

On top of these familiar formations, over 10,000 feet of sediment was deposited over the next 190 million years, most of these layers are still visible elsewhere on the plateau, but have eroded away from the Grand Canyon region, due to the uplift of the Colorado plateau, which started between 70-80 million years ago, as an oceanic plate began to subduct beneath the western edge of our continent. And it was the unusual angle of this subduction which geologists believe caused the plateau to rise to more than 9,000 feet above sea level over a period of about 40 million years, also creating the modern Rocky Mountains.

Which brings us to the formation of the Canyon itself. This is a hotly debated topic, and there are more than a few theories on the subject. One of the newest theories, presented at the GTS land session in 2011 by geologist Wayne Ranney, is the fascinating idea that the Canyon is 70 million years old. This number was reached using a technique called apatite fission track dating, which can tell geologists how deeply buried rocks were at different times in the past. Having started its formation being carved by rivers that were running off the eastern edge of the newly created mountains near the coast of California, and running towards the cretaceous interior seaway, as the oceanic plate pushed it's way underneath the continent. Another theory has the Grand Canyon at 17 million years old, having formed when a series of karst formations under the Kaibab upwarp collapsed, and also the Mogollon highlands collapsed due to crustal extension. And of course the ever popular 6 million year theory. Proven in many minds by the Muddy creek formation near Lake Mead. What does seem pretty certain is that for the past 5.3 million years the mighty Colorado has been flowing thru this magnificent canyon, and has been the architect of the modern Canyon that we love and recognize.

This is of course just a basic outline of a Grand and complex story, if you want to know the whole story I would suggest reading "*Ancient Landscapes of the Colorado Plateau*" By Ron Blakey and Wayne Ranney, or many other fabulous geology books available. Also do some research on your own about all the cool theories on how the Canyon was carved, and decide for yourself which one you believe.