

= Geology of the Grand Canyon area =

The geology of the Grand Canyon area includes one of the most complete and studied sequences of rock on Earth . The nearly 40 major sedimentary rock layers exposed in the Grand Canyon and in the Grand Canyon National Park area range in age from about 200 million to nearly 2 billion years old . Most were deposited in warm , shallow seas and near ancient , long @-@ gone sea shores in western North America . Both marine and terrestrial sediments are represented , including fossilized sand dunes from an extinct desert . There are at least 14 known unconformities in the geologic record found in the Grand Canyon .

Uplift of the region started about 75 million years ago during the Laramide orogeny ; a mountain @-@ building event that is largely responsible for creating the Rocky Mountains to the east . In total , the Colorado Plateau was uplifted an estimated 2 miles ( 3 @. @ 2 km ) . The adjacent Basin and Range province to the west started to form about 18 million years ago as the result of crustal stretching . A drainage system that flowed through what is today the eastern Grand Canyon emptied into the now lower Basin and Range province . Opening of the Gulf of California around 6 million years ago enabled a large river to cut its way northeast from the gulf . The new river captured the older drainage to form the ancestral Colorado River , which in turn started to form the Grand Canyon .

Wetter climates brought upon by ice ages starting 2 million years ago greatly increased excavation of the Grand Canyon , which was nearly as deep as it is now by 1 @. @ 2 million years ago . Volcanic activity deposited lava over the area 1 @. @ 8 million to 500 @, @ 000 years ago . At least 13 lava dams blocked the Colorado River , forming lakes that were up to 2 @, @ 000 feet ( 610 m ) deep . The end of the last ice age and subsequent human activity has greatly reduced the ability of the Colorado River to excavate the canyon . Dams in particular have upset patterns of sediment transport and deposition . Controlled floods from Glen Canyon Dam upstream have been conducted to see if they have a restorative effect . Earthquakes and mass wasting erosive events still affect the region .

= = Deposition of sediments = =

= = = Vishnu Basement Rocks = = =

At about 2 @. @ 5 and 1 @. @ 8 billion years ago in Precambrian time , sand , mud , silt , and ash were laid down in a marine basin adjacent to an orogenic belt . From 1 @. @ 8 to 1 @. @ 6 billion years ago at least two island arcs collided with the proto @-@ North American continent . This process of plate tectonics compressed and grafted the marine sediments in the basin onto the mainland and uplifted them out of the sea . Later , these rocks were buried 12 miles ( 19 km ) under the surface and pressure @-@ cooked into metamorphic rock . The resulting Granite Gorge Metamorphic Suite , which is part of the Vishnu Basement Rocks , consists of the metasedimentary Vishnu Schist and the metavolcanic Brahma and Rama Schists that were formed 1 @. @ 75 billion to 1 @. @ 73 billion years ago . This is the resistant rock now exposed at the bottom of the canyon in the Inner Gorge .

As the volcanic islands collided with the mainland around 1 @. @ 7 billion years ago , blobs of magma rose from the subduction zone and intruded the Granite Gorge Metamorphic Suite . These plutons slowly cooled to form the Zoroaster Granite ; part of which would later be metamorphosed into gneiss . This rock unit can be seen as light @-@ colored bands in the darker garnet @-@ studded Vishnu Schist ( see 1b in figure 1 ) . The intrusion of the granite occurred in three phases : two during the initial Vishnu metamorphism period , and a third around 1 @. @ 4 billion years ago . The third phase was accompanied by large @-@ scale faulting , particularly along north ? south faults , leading to a partial rifting of the continent . The collision expanded the continent from the Wyoming ? Colorado border into Mexico and almost doubled the crust 's thickness in the Grand Canyon region . Part of this thickening created the 5 @-@ to @-@ 6 @-@ mile ( 8 to 10 km ) high

ancestral Mazatzal Mountains .

Subsequent erosion lasting 300 million years stripped much of the exposed sediments and the mountains away . This reduced the very high mountains to small hills a few tens to hundreds of feet ( tens of meters ) high . Geologist John Wesley Powell called this major gap in the geologic record , which is also seen in other parts of the world , the Great Unconformity . Other sediments may have been added but , if they ever existed , were completely removed by erosion . Such gaps in the geologic record are called unconformities by geologists . The Great Unconformity is one of the best examples of an exposed nonconformity , which is a type of unconformity that has bedded rock units above igneous or metamorphic rocks .

= = = Grand Canyon Supergroup = = =

In late Precambrian time , extension from a large tectonic plate or smaller plates moving away from Laurentia thinned its continental crust , forming large rift basins that would ultimately fail to split the continent . Eventually , this sunken region of Laurentia was flooded with a shallow seaway that extended from at least present @-@ day Lake Superior to Glacier National Park in Montana to the Grand Canyon and the Uinta Mountains . The resulting Grand Canyon Supergroup of sedimentary units is composed of nine varied geologic formations that were laid down from 1 @.@ 2 billion and 740 million years ago in this sea . Good exposures of the supergroup can be seen in eastern Grand Canyon in the Inner Gorge and from Desert View , Lipan Point and Moran point .

The oldest section of the supergroup is the Unkar Group . It accumulated in a variety of fluvial , deltaic , tidal , nearshore marine , and offshore marine environments . The first formation to be laid down in the Unkar Group was the Bass Formation . Fluvial gravels initially accumulated in shallow river valleys . They later lithified into a basal conglomerate that is known as the Hotauta Member of the Bass Formation . The Bass Formation was deposited in a shallow sea near the coast as a mix of limestone , sandstone , and shale . Diagenesis later altered the bulk of the limestone into dolomite . It is 120 to 340 feet ( 37 to 100 m ) thick and grayish in color . Averaging 1250 million years old , this is the oldest layer exposed in the Grand Canyon that contains fossils ? stromatolites . Hakatai Shale is made of thin beds of marginal @-@ marine @-@ derived mudstones , sandstones , and shale that , together , are 445 to 985 feet ( 136 to 300 m ) thick . This formation indicates a short @-@ lived regression ( retreat ) of the seashore in the area that left mud flats . Today it is very bright orange @-@ red and gives the Red Canyon its name . Shinumo Quartzite is a resistant marine sedimentary quartzite that was eroded to form monadnocks that later became islands in Cambrian time . Those islands withstood wave action long enough to become re @-@ buried by other sediments in the Cambrian Period . Dox Formation is over 3 @,@ 000 feet ( 910 m ) thick and is made of sandstone with some interbedded shale beds and mudstone that were deposited in fluvial and tidal environments . Ripple marks and other features indicate it was close to the shore . Outcrops of this red to orange formation can be seen in the eastern parts of the canyon . Fossils of stromatolites and algae are found in this layer . At  $1070 \pm 70$  million years old , the Cardenas Basalt is the youngest formation in the Unkar Group . It is made of layers of dark brown basaltic rocks that flowed as lava up to 1 @,@ 000 feet ( 300 m ) thick .

Nankoweap Formation is around 1050 million years old and is not part of a group . This rock unit is made of coarse @-@ grained sandstone , and was deposited in a shallow sea on top of the eroded surface of the Cardenas Basalt . The Nankoweap is only exposed in the eastern part of the canyon . A gap in the geologic record , an unconformity , follows the Nankoweap .

All formations in the Chuar Group were deposited in coastal and shallow sea environments about 1000 to 700 million years ago . The Galeros Formation is a mainly greenish formation composed of interbedded sandstone , limestone , and shale . Fossilized stromatolites are found in the Galeros . The Kwagunt Formation consists of black shale and red to purple mudstone with some limestone . Isolated pockets of reddish sandstone are also found around Carbon Butte . Stromatolites are found in this layer . The Sixtymile Formation is made of tan @-@ colored sandstone with some small sections of shale .

About 800 million years ago the supergroup was tilted  $15^\circ$  and block faulted in the Grand Canyon

Orogeny . Some of the block units moved down and others moved up while fault movement created north ? south @-@ trending fault @-@ block mountain ranges . About 100 million years of erosion took place that washed most of the Chuar Group away along with part of the Unkar Group ( exposing the Shinumo Quartzite as previously explained ) . The mountain ranges were reduced to hills , and in some places , the whole 12 @, @ 000 feet ( 3 @, @ 700 m ) of the supergroup were removed entirely , exposing the basement rocks below . Any rocks that were deposited on top of the Grand Canyon Supergroup in the Precambrian were completely removed . This created a major unconformity that represents 460 million years of lost geologic history in the area .

= = = Tonto Group = = =

During the Paleozoic era , the western part of what would become North America was near the equator and on a passive margin . The Cambrian Explosion of life took place over about 15 million years in this part of the world . Climate was warm and invertebrates , such as the trilobites , were abundant . An ocean started to return to the Grand Canyon area from the west about 550 million years ago . As its shoreline moved east , the ocean began to concurrently deposit the three formations of the Tonto Group .

Tapeats Sandstone averages 525 million years old and is made of medium- to coarse @-@ grained sand and conglomerate that was deposited on an ancient shore ( see 3a in figure 1 ) . Ripple marks are common in the upper members of this dark brown thin @-@ bedded layer . Fossils and imprint trails of trilobites and brachiopods have also been found in the Tapeats . Today it is a cliff @-@ former that is 100 to 325 feet ( 30 to 100 m ) thick . Bright Angel Shale averages 515 million years old and is made of mudstone @-@ derived shale that is interbedded with small sections of sandstone and shaly limestone with a few thin beds of dolomite . It was mostly deposited as mud just offshore and contains brachiopod , trilobite , and worm fossils ( see 3b in figure 1 ) . The color of this formation is mostly various shades of green with some brownish @-@ tan to gray parts . It is a slope @-@ former and is 270 to 450 feet ( 82 to 137 m ) thick . Glauconite is responsible for the green coloration of the Bright Angel . Muav Limestone averages 505 million years old and is made of gray , thin @-@ bedded limestone that was deposited farther offshore from calcium carbonate precipitates ( see 3c in figure 1 ) . The western part of the canyon has a much thicker sequence of Muav than the eastern part . The Muav is a cliff @-@ former , 136 to 827 feet ( 41 to 252 m ) thick .

These three formations were laid down over a period of 30 million years from early @-@ to @-@ middle Cambrian time . Trilobites followed by brachiopods are the most commonly reported fossils in this group but well @-@ preserved fossils are relatively rare . We know that the shoreline was transgressing ( advancing onto land ) because finer grade material was deposited on top of coarser @-@ grained sediment . Today , the Tonto Group makes up the Tonto Platform seen above and following the Colorado River ; the Tapeats Sandstone and Muav Limestone form the platform 's cliffs and the Bright Angel Shale forms its slopes . Unlike the Proterozoic units below it , the Tonto Group 's beds basically lie in their original horizontal position . The Bright Angel Shale in the group forms an aquiclude ( barrier to groundwater seeping down ) , and thus collects and directs water through the overlying Muav Limestone to feed springs in the Inner Gorge .

= = = Temple Butte , Redwall , and Surprise Canyon = = =

The next two periods of geologic history , the Ordovician and the Silurian , are missing from the Grand Canyon sequence . Geologists do not know if sediments were deposited in these periods and were later removed by erosion or if they were never deposited in the first place . Either way , this break in the geologic history of the area spans about 65 million years . A type of unconformity called a disconformity was formed . Disconformities show erosional features such as valleys , hills and cliffs that are later covered by younger sediments .

Geologists do know that deep channels were carved on the top of the Muav Limestone during this time . Streams were the likely cause , but marine scour may be to blame . Either way , these depressions were filled with freshwater limestone about 385 million years ago in the Middle

Devonian in a formation that geologists call the Temple Butte Limestone ( see 4a in figure 1 ) . Marble Canyon in the eastern part of the park displays these filled purplish @-@ colored channels well . Temple Butte Limestone is a cliff @-@ former in the western part of the park where it is gray to cream @-@ colored dolomite . Fossils of animals with backbones are found in this formation ; bony plates from freshwater fish in the eastern part and numerous marine fish fossils in the western part . Temple Butte is 100 to 450 feet ( 30 to 137 m ) thick ; thinner near Grand Canyon Village and thicker in western Grand Canyon . An unconformity representing 40 to 50 million years of lost geologic history marks the top of this formation .

The next formation in the Grand Canyon geologic column is the cliff @-@ forming Redwall Limestone , which is 400 to 800 feet ( 120 to 240 m ) thick ( see 4b in figure 1 ) . Redwall is composed of thick @-@ bedded , dark brown to bluish gray limestone and dolomite with white chert nodules mixed in . It was laid down in a retreating shallow tropical sea near the equator during 40 million years of the early @-@ to @-@ middle Mississippian . Many fossilized crinoids , brachiopods , bryozoans , horn corals , nautiloids , and sponges , along with other marine organisms such as large and complex trilobites have been found in the Redwall . In late Mississippian time , the Grand Canyon region was slowly uplifted and the Redwall was partly eroded away . A Karst topography consisting of caves , sinkholes , and subterranean river channels resulted but were later filled with more limestone . The exposed surface of Redwall gets its characteristic color from rainwater dripping from the iron @-@ rich redbeds of the Supai and Hermit shale that lie above .

Surprise Canyon Formation is a sedimentary layer of purplish @-@ red shale that was laid down in discontinuous beds of sand and lime above the Redwall ( see 4c in figure 1 ) . It was created in very late Mississippian and possibly in very earliest Pennsylvanian time as the land subsided and tidal estuaries filled river valleys with sediment . This formation only exists in isolated lenses that are 50 to 400 feet ( 15 to 122 m ) thick . Surprise Canyon was unknown to science until 1973 and can be reached only by helicopter . Fossil logs , other plant material and marine shells are found in this formation . An unconformity marks the top of the Surprise Canyon Formation and in most places this unconformity has entirely removed the Surprise Canyon and exposed the underlying Redwall .

= = = Supai Group = = =

An unconformity of 15 to 20 million years separates the Supai Group from the previously deposited Redwall Formation . Supai Group was deposited in late Mississippian , through the Pennsylvanian and into the early Permian time , some 320 million to 270 million years ago . Both marine and non @-@ marine deposits of mud , silt , sand and calcareous sediments were laid down on a broad coastal plain similar to the Texas Gulf Coast of today . Around this time , the Ancestral Rocky Mountains rose in Colorado and New Mexico and streams brought eroded sediment from them to the Grand Canyon area .

Supai Group formations in the western part of the canyon contain limestone , indicative of a warm , shallow sea , while the eastern part was probably a muddy river delta . This formation consists of red siltstones and shale capped by tan @-@ colored sandstone beds that together reach a thickness of 600 to 700 ft ( around 200 m ) . Shale in the early Permian formations in this group were oxidized to a bright red color . Fossils of amphibian footprints , reptiles , and plentiful plant material are found in the eastern part and increasing numbers of marine fossils are found in the western part .

Formations of the Supai Group are from oldest to youngest ( an unconformity is present at the top of each ) : Watahomigi ( see 5a in figure 1 ) is a slope @-@ forming gray limestone with some red chert bands , sandstone , and purple siltstone that is 100 to 300 feet ( 30 to 90 m ) thick . Manakacha ( see 5b in figure 1 ) is a cliff- and slope @-@ forming pale red sandstone and red shale that averages 300 feet ( 90 m ) thick in Grand Canyon . Wescogame ( see 5c in figure 1 ) is a ledge- and slope @-@ forming pale red sandstone and siltstone that is 100 to 200 feet ( 30 to 60 m ) thick . Esplanade ( see 5d in figure 1 ) is a ledge- and cliff @-@ forming pale red sandstone and siltstone that is 200 to 800 feet ( 60 to 200 m ) thick . An unconformity marks the top of the Supai Group .

= = = Hermit , Coconino , Toroweap , and Kaibab = = =

Like the Supai Group below it , the Permian @-@ aged Hermit Formation was probably deposited on a broad coastal plain ( see 6a in figure 1 ) . The alternating thin @-@ bedded iron oxide , mud and silt were deposited via freshwater streams in a semiarid environment around 280 million years ago . Fossils of winged insects , cone @-@ bearing plants , and ferns are found in this formation as well as tracks of vertebrate animals . It is a soft , deep red shale and mudstone slope @-@ former that is approximately 100 to 900 feet ( 30 to 274 m ) thick . Slope development will periodically undermine the formations above and car- to house @-@ sized blocks of that rock will cascade down onto the Tonto Platform . An unconformity marks the top of this formation .

Coconino Sandstone formed about 275 million years ago as the area dried out and sand dunes made of quartz sand invaded a growing desert ( see 6b in figure 1 ) . Some Coconino fills deep mudcracks in the underlying Hermit Shale and the desert that created the Coconino lasted for 5 to 10 million years . Today , the Coconino is a 57 to 600 feet ( 17 to 183 m ) thick golden white to cream @-@ colored cliff @-@ former near the canyon 's rim . Cross bedding patterns of the frosted , fine @-@ grained , well @-@ sorted and rounded quartz grains seen in its cliffs is compatible with an eolian environment . Also fossilized are tracks from lizard @-@ like creatures and what look like tracks from millipedes and scorpions . An unconformity marks the top of this formation .

Next in the geologic column is the 200 @-@ foot ( 60 m ) -thick Toroweap Formation ( see 6c in figure 1 ) . It consists of red and yellow sandstone and shaly gray limestone interbedded with gypsum . The formation was deposited in a warm , shallow sea as the shoreline transgressed ( invaded ) and regressed ( retreated ) over the land . The average age of the rock is about 273 million years . In modern times it is a ledge- and slope @-@ former that contains fossils of brachiopods , corals , and mollusks along with other animals and various terrestrial plants . The Toroweap is divided into the following three members : Seligman is a slope @-@ forming yellowish to reddish sandstone and siltstone . Brady Canyon is a cliff @-@ forming gray limestone with some chert . Wood Ranch is a slope @-@ forming pale red and gray siltstone and dolomitic sandstone . An unconformity marks the top of this formation .

One of the highest , and therefore youngest , formations seen in the Grand Canyon area is the Kaibab Limestone ( see 6d in figure 1 ) . It erodes into ledgy cliffs that are 300 to 400 feet ( 90 to 100 m ) thick and was laid down in latest early Permian time , about 270 million years ago , by an advancing warm , shallow sea . The formation is typically made of sandy limestone sitting on top of a layer of sandstone . This is the cream to grayish @-@ white rock that park visitors stand on while viewing the canyon from both rims . It is also the surface rock covering much of the Kaibab Plateau just north of the canyon and the Coconino Plateau immediately south . Shark teeth have been found in this formation as well as abundant fossils of marine invertebrates such as brachiopods , corals , mollusks , sea lilies , and worms . An unconformity marks the top of this formation .

= = = Mesozoic deposition = = =

Uplift marked the start of the Mesozoic and streams started to incise the newly dry land . Streams flowing through broad low valleys in Triassic time deposited sediment eroded from nearby uplands , creating the once 1 @,@ 000 @-@ foot ( 300 m ) -thick Moenkopi Formation . The formation is made from sandstone and shale with gypsum layers in between . Moenkopi outcrops are found along the Colorado River in Marble Canyon , on Cedar Mountain ( a mesa near the southeastern park border ) , and in Red Butte ( located south of Grand Canyon Village ) . Remnants of the Shinarump Conglomerate , itself a member of the Chinle Formation , are above the Moenkopi Formation near the top of Red Butte but below a much younger lava flow .

Formations totaling over 4 @,@ 000 to 5 @,@ 000 feet ( 1 @,@ 200 to 1 @,@ 500 m ) in thickness were deposited in the region in the Mesozoic and Cenozoic but were almost entirely removed from the Grand Canyon sequence by subsequent erosion . The geology of the Zion and Kolob canyons area and the geology of the Bryce Canyon area records some of these formations . All these rock units together form a super sequence of rock known as the Grand Staircase .

= = Cenozoic regional uplift and erosion of the canyon = =

= = = Uplift and nearby extension = = =

The Laramide orogeny affected all of western North America by helping to build the American cordillera . The Kaibab Uplift , Monument Upwarp , the Uinta Mountains , San Rafael Swell , and the Rocky Mountains were uplifted , at least in part , by the Laramide orogeny . This major mountain @-@ building event started near the end of the Mesozoic , around 75 million years ago , and continued into the Eocene period of the Cenozoic . It was caused by subduction off the western coast of North America . Major faults that trend north ? south and cross the canyon area were reactivated by this uplift . Many of these faults are Precambrian in age and are still active today . Streams draining the Rocky Mountains in early Miocene time terminated in landlocked basins in Utah , Arizona and Nevada but there is no evidence for a major river .

Around 18 million years ago , tensional forces started to thin and drop the region to the west , creating the Basin and Range province . Basins ( grabens ) dropped down and mountain ranges ( horsts ) rose up between old and new north ? south ? trending faults . However , for reasons poorly understood , the beds of the Colorado Plateaus remained mostly horizontal through both events even as they were uplifted about 2 miles ( 3 @. @ 2 km ) in two pulses . The extreme western part of the canyon ends at one of the Basin and Range faults , the Grand Wash , which also marks the boundary between the two provinces .

Uplift from the Laramide orogeny and the creation of the Basin and Range province worked together to steepen the gradient of streams flowing west on the Colorado Plateau . These streams cut deep , eastward @-@ growing , channels into the western edge of the Colorado Plateau and deposited their sediment in the widening Basin and Range region .

According to a 2012 study , there is evidence that the western Grand Canyon could be as old as 70 million years .

= = = Colorado River : origin and development = = =

Rifting started to create the Gulf of California far to the south 6 to 10 million years ago . Around the same time , the western edge of the Colorado Plateau may have sagged slightly . Both events changed the direction of many streams toward the sagging region and the increased gradient caused them to downcut much faster . From 5 @. @ 5 million to 5 million years ago , headward erosion to the north and east consolidated these streams into one major river and associated tributary channels . This river , the ancestral Lower Colorado River , started to fill the northern arm of the gulf , which extended nearly to the site of Hoover Dam , with estuary deposits .

At the same time , streams flowed from highlands in central Arizona north and across what is today the western Grand Canyon , possibly feeding a larger river . The mechanism by which the ancestral Lower Colorado River captured this drainage and the drainage from much of the rest of the Colorado Plateau is not known . Possible explanations include headward erosion or a broken natural dam of a lake or river . Whatever the cause , the Lower Colorado probably captured the landlocked Upper Colorado somewhere west of the Kaibab Uplift . The much larger drainage area and yet steeper stream gradient helped to further accelerate downcutting .

Ice ages during the Pleistocene brought a cooler and wetter pluvial climate to the region starting 2 to 3 million years ago . The added precipitation increased runoff and the erosive ability of streams ( especially from spring melt water and flash floods in summer ) . With a greatly increased flow volume the Colorado cut faster than ever before and started to quickly excavate the Grand Canyon 2 million years before present , almost reaching the modern depth by 1 @. @ 2 million years ago .

The resulting Grand Canyon of the Colorado River trends roughly east to west for 278 miles ( 447 km ) between Lake Powell and Lake Mead . In that distance , the Colorado River drops 2 @, @ 000 feet ( 610 m ) and has excavated an estimated 1 @, @ 000 cubic miles ( 4 @, @ 200 km<sup>3</sup> ) of

sediment to form the canyon . This part of the river bisects the 9 @, @ 000 @-@ foot ( 2 @, @ 700 m ) -high Kaibab Uplift and passes seven plateaus ( the Kaibab , Kanab , and Shivwits plateaus bound the northern part of the canyon and the Coconino bounds the southern part ) . Each of these plateaus are bounded by north to south trending faults and monoclines created or reactivated during the Laramide orogeny . Streams flowing into the Colorado River have since exploited these faults to excavate their own tributary canyons , such as Bright Angel Canyon .

= = Volcanic activity in the western canyon = =

Volcanic activity started in Uinkaret volcanic field ( in the western Grand Canyon ) about 3 million years ago . Over 150 flows of basaltic lava dammed the Colorado River at least 13 times from 725 @, @ 000 to 100 @, @ 000 years ago . The dams typically formed in weeks , were 12 to 86 miles ( 19 to 138 km ) long , 150 to 2 @, @ 000 feet ( 46 to 610 m ) high ( thicker upstream and thinner downstream ) and had volumes of 0 @. @ 03 to 1 @. @ 2 cubic miles ( 0 @. @ 13 to 5 @. @ 00 km<sup>3</sup> ) .

The longevity of the dams and their ability to hold Colorado River water in large lakes has been debated . In one hypothesis water from the Colorado River backed up behind the dams in large lakes that extended as far as Moab , Utah . Dams were overtopped in short time ; those that were 150 to 400 feet ( 46 to 122 m ) high were overtopped by their lakes in 2 to 17 days . At the same time , sediment filled the lakes behind the dams . Sediment would fill a lake behind a 150 @-@ foot ( 46 m ) -high dam in 10 @. @ 33 months , filled a lake behind an 1 @, @ 150 @-@ foot ( 350 m ) -high dam in 345 years , and filled the lake behind the tallest dam in 3000 years . Cascades of water flowed over a dam while waterfalls migrated up @-@ river along it . Most lava dams lasted for around 10 @, @ 000 to 20 @, @ 000 years . However others have proposed that the lava dams were much more ephemeral and failed catastrophically before overtopping . In this model dams would fail due to fluid flow through fractures in the dams and around dam abutments , through permeable river deposits and alluvium .

Since the demise of these dams the Colorado River has carved a maximum of about 160 feet ( 49 m ) into the rocks of the Colorado Plateau

= = Ongoing geology and human impact = =

The end of the Pleistocene ice ages and the start of the Holocene began to change the area 's climate from a cool , wet pluvial one to dryer semi @-@ arid conditions similar to that of today . With less water to cut , the erosive ability of the Colorado was greatly reduced . Mass wasting processes thus began to become relatively more important than they were before . Steeper cliffs and further widening the Grand Canyon and its tributary canyon system occurred . An average of two debris flows per year reach the Colorado River from tributary canyons to form or expand rapids . This type of mass wasting is the main way the smaller and steeper side canyons transport sediment but it also plays a major role in excavating the larger canyons .

In 1963 Glen Canyon Dam and other dams farther upstream started to regulate the flow of the Colorado River through Grand Canyon . Pre @-@ dam but still historic flows of the Colorado through Grand Canyon ranged from 700 to 100 @, @ 000 cubic feet ( 20 to 2 @, @ 832 m<sup>3</sup> ) per second with at least one late 19th century flood of 300 @, @ 000 cubic feet ( 8 @, @ 500 m<sup>3</sup> ) per second . Discharge from Glen Canyon Dam exceeds 48 @, @ 200 cubic feet ( 1 @, @ 360 m<sup>3</sup> ) per second only when there is danger of overtopping the dam or when the level of Lake Powell otherwise needs to be lowered . An interim conservation measure since 1991 has held maximum flows at 20 @, @ 000 cubic feet ( 570 m<sup>3</sup> ) per second even though the dam 's power plant can handle 13 @, @ 200 cubic feet ( 370 m<sup>3</sup> ) per second more flow .

Controlling river flow by use of dams has diminished the river 's ability to scour rocks by substantially reducing the amount of sediment it carries . Dams on the Colorado River have also changed the character of the river water . Once both muddy and warm , the river is now clear and averages a 46 ° F ( 8 ° C ) temperature year @-@ round . Experimental floods approaching the 48

@, @ 200 cubic feet ( 1 @, @ 360 m<sup>3</sup> ) per second level mentioned above have been carried out in 1996 and 2004 to study the effects on sediment erosion and deposition .

Grand Canyon lies on the southern end of the Intermountain West seismic belt . At least 35 earthquakes larger than 3 @. @ 0 on the Richter Scale occurred in the Grand Canyon region in the 20th century . Of these , five registered over 5 @. @ 0 on the Richter Scale and the largest was a 6 @. @ 2 quake that occurred in January 1906 . Major roughly north ? south trending faults that cross the canyon are ( from west to east ) , the Grand Wash , Hurricane and Toroweap . Major northeast @-@ trending fracture systems of normal faults that intersect the canyon include the West Kaibab and Bright Angel while northwest @-@ trending systems include the Grandview ? Phantom . Most earthquakes in the region occur in a narrow northwest @-@ trending band between the Mesa Butte and West Kaibab fracture systems . These events are probably the result of eastward @-@ migrating crustal stretching that may eventually move past the Grand Canyon area .

= = Trail of Time and Yavapai Geology Museum = =

The Trail of Time is an outdoor geology exhibit and nature trail on the South Rim of Grand Canyon National Park . Each meter walked on the trail represents one million years of Grand Canyon 's geologic history . Bronze markers on the trail mark your location in time . The trail begins at Yavapai Geology Museum at 2 billion years ago , and ends at Verkamp 's Visitor Center . Along the way are samples of the Canyon 's rocks , as you would encounter them going from the river up to the rim , and displays explaining the geologic history of the Canyon . The trail opened in late 2010 .

The Yavapai Geology Museum include three @-@ dimensional models , photographs , and exhibits which allow park visitors to see and understand the complicated geologic story of the area . The museum building , the historic Yavapai Observation Station ( built 1928 ) , located one mile ( 1 @. @ 6 km ) east of Market Plaza , features expansive canyon views . A bookstore offers a variety of materials about the area .