

GEOLOGY OF GRAND CANYON NATIONAL PARK, NORTH RIM

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Introduction

The Grand Canyon of the Colorado River is one of nature's most awesome works. Poets and artists have tried to capture its beauty and its size, but the only way to truly appreciate it, is to stand on the rim and see it for yourself. One of the most impressive aspects of the Grand Canyon is its enormous size, the average width is about 10 miles, depth 1 mile and length 277 miles. In addition to its enormous spatial

dimensions the Grand Canyon has one of the most extensive records of geologic history, representing over 2 billion years of sedimentation, mountain building and erosion.

We will visit the North Rim of the Grand Canyon. Due to the gentle, south-westerly dip of the beds, the North Rim is approximately 800 feet higher than the South Rim. We will stop at Bright Angel Point, Point Imperial, and the Unkar Creek View Area, and

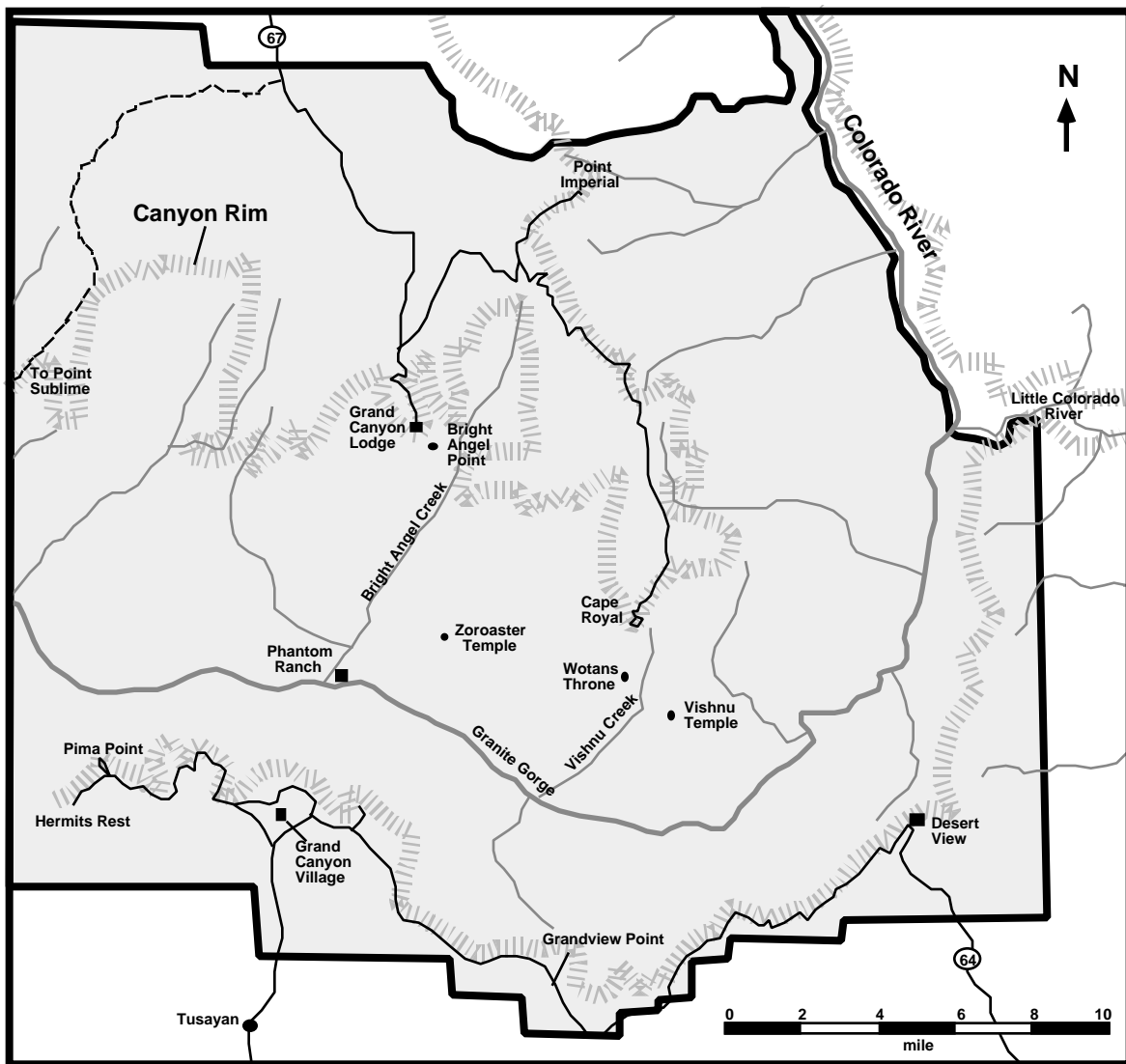


Figure 1. Map of eastern Grand Canyon National Park. (after national park service map)

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hike the Cape Royal and part of the Ken Patrick Trails (figure 1). If you are ambitious you can hike down into the canyon on the North Kaibab Trail on your day off.

Stratigraphy

Rocks of the Grand Canyon range in age from Proterozoic (Precambrian) to Permian (figure 2), however, the geologic record is incomplete with Ordovician, Silurian, Mesozoic and Cenozoic rocks missing. Breaks in the geologic record are termed unconformities and the time periods that are not represented by

rock units are termed hiatuses. There are 14 major unconformities in the stratigraphic section exposed in the Grand Canyon. There are three different types of unconformities, all of which can be observed at the Grand Canyon (figure 3). A nonconformity is where sedimentary rocks are deposited directly on igneous and metamorphic basement. Nonconformities occur where the Precambrian Vishnu Schist is in contact with the Precambrian Grand Canyon Supergroup and Cambrian Tapeats Sandstone. When the rocks below the unconformity have been tilted due to mountain building it is termed

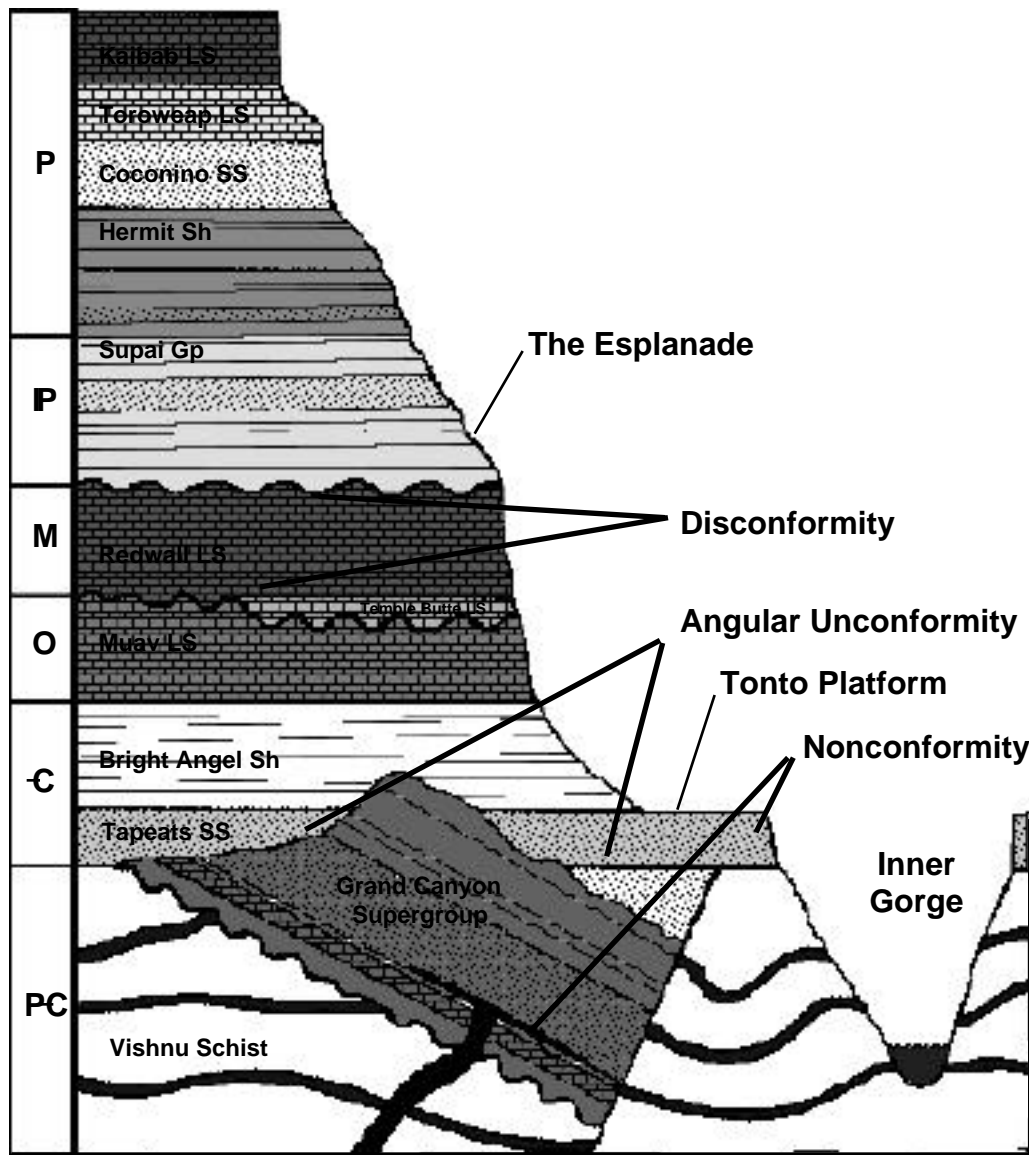


Figure 3. General stratigraphic section of the Grand Canyon showing the major types of unconformities.

Age	Thick. (ft)	Description
Quaternary		Q Unconsolidated alluvium (Qal), fluvial terrace deposits (QTg), landslide deposits (QTI)
		Unconformity
Permian	250-350	Pk Kaibab Formation Gray limestone, dolomite, and sandy limestone with some thin beds of gray shale. Contains chert nodules. Forms a ledgy cliff.
		Unconformity
Permian	200-250	Pt Toroweap Formation Divided into the following three members: Woods Ranch Member Pale red and gray siltstone and dolomitic sandstone. Forms a slope. Brady Canyon Member Gray limestone with some chert. Forms a cliff. Seligman Member Yellowish to reddish sandstone and siltstone. Forms a slope.
		Unconformity
Permian	375-650	Pc Coconino Sandstone Buff to white, cross-bedded quartz sandstone. Forms a cliff.
		Unconformity
Permian	160-275	Ph Hermit Shale Alternating thin-bedded red siltstone and sandstone. Forms a slope.
		Unconformity
Pennsylvanian		PPs Supai Group Divided into the Esplanade, Wescogame, Manakacha, and Watahomigi Formations:
Pennsylvanian	225-300	Esplanade Sandstone Pale red sandstone and siltstone. Forms ledges or cliffs.
		Unconformity
Pennsylvanian	100-225	Wescogame Formation Pale red sandstone and siltstone. Forms ledges and slopes.
		Unconformity
Pennsylvanian	200-275	Manakacha Formation Cliff forming pale red sandstone and red shale. Forms slopes
		Unconformity
Pennsylvanian	90-175	Watahomigi Formation Gray limestone with some red chert bands, sandstone, and purple siltstone. Forms a slope
		Unconformity
Mississippian	0-40	Msc Surprise Canyon Formation Dark red-brown siltstone, sandstone and conglomerate. Forms a slope.
		Unconformity
Mississippian	450-525	Mr Redwall Limestone Thick-bedded, gray limestone and dolomite. Contains white chert lenses. Forms a cliff.
		Unconformity
Devonian	250-375	Dtb Temple Butte Limestone Gray ledges of limestone and dolomite interbedded with purple shale. Forms a slope.

Figure 2. Description of Stratigraphic Units at Grand Canyon National Park (from Billingsley and Breed, 1986 and Beus and Billingsley, 1989)

Age	Thick. (ft)	Description
		Unconformity
Cambrian		Tonto Group Divided into the Muav Limestone, Bright Angel Shale and Tapeats Sandstone.
Cambrian	250-375	Cm Muav Limestone Rusty-brown, thin-bedded, cliff forming dolomite interbedded with green shale.
Cambrian	325-400	Cba Bright Angel Shale Very thin-bedded green siltstone. Interbedded with a few thin beds of dolomite and sandstone. Forms a slope.
Cambrian	250-300	Ct Tapeats Sandstone Brown, thin-bedded sandstone and conglomerate. Forms a cliff.
		Great Unconformity
Precambrian		Unkar Group Divided into the Nankoweap Formation (pCn), Rama Formation (pCr), Dox Sandstone (pCd), Shinumo Quartzite (pCs), Hakatai Shale (pCh), and Bass Limestone (pCb)
		Unconformity
Precambrian		pCz Zoroaster Plutonic Complex Granite and granodiorite
Precambrian		pCv Vishnu Group Predominantly mica schist.

Figure 2 cont. Description of Stratigraphic Units at Grand Canyon National Park (from Billingsley and Breed, 1986 and Beus and Billingsley, 1989)

an angular unconformity. The contact between the Precambrian Grand Canyon Supergroup and the Tapeats Sandstone is an example of an angular unconformity. Disconformities represent periods of nondeposition where the rocks above are parallel to the rocks below the unconformity. Disconformities form in response to the lowering of sea level. The unconformities within the Paleozoic section, such as the one between the Mississippian Redwall Limestone and the Pennsylvanian Supai Group, are disconformities. Paleosols, ancient soil horizons, often occur at disconformities.

The Lower Paleozoic of the Grand Canyon is similar to rocks throughout the North American. During this time, the North American craton and its continental margins were relatively stable. The craton experienced a series of major transgressions and regressions where sea level rose, and flooded the continent, followed by a lowering of sea level. L. L. Sloss (1963) observed this similarity in cratonic rocks of North America and divided the sedimentary record into six cratonic sequences which he named after the Plains Indians (figure 4). Each cratonic sequence is a large-scale

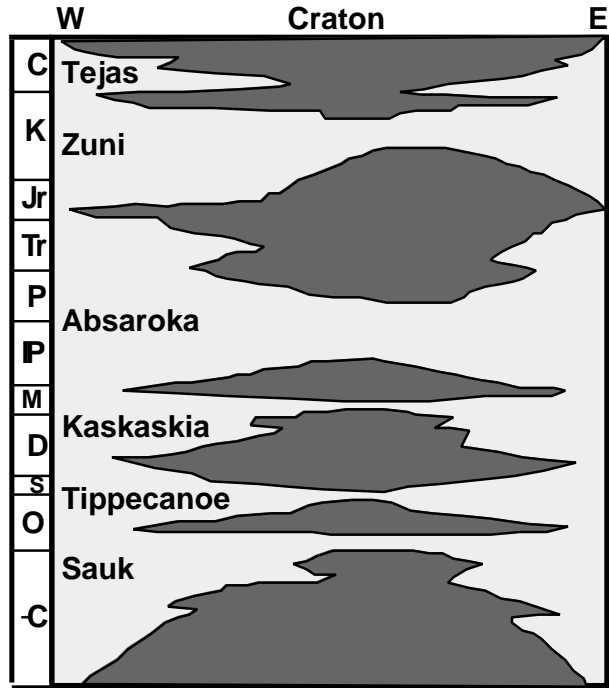


Figure 4. Cratonic sequences of North America. Unconformities shown in dark gray.

lithostratigraphic unit, bounded by unconformities, that represent a major transgressive followed by a regression. The

Sequence	Grand Canyon
Absaroka	Kaibab LS Toroweap LS Coconino SS Hermit Sh Supai Gp
Kaskaskia	Redwall LS
Tippecanoe	Temple Butte LS
Sauk	Muav LS Bright Angel Sh Tapeats SS

Figure 5. Cratonic sequences of the Grand Canyon.

sequence boundaries are not restricted to North America and can be correlated with sequences on other continents, suggesting they represent eustatic or global sea level fluctuations. Stratigraphic units of the Sauk, Tippecanoe, Kaskaskia and Absaroka sequences can be observed at the Grand Canyon (figure 5).

Geologic History

The oldest rocks exposed in the Grand Canyon are the Proterozoic Vishnu schist. Approximately 2 billion years ago, 25,000 feet of sediments and volcanic material were deposited on the sea floor. These sediments were metamorphosed during a mountain building episode 1.7 billion years ago. The rocks were folded, uplifted, and intruded by granites (Zoroaster Granite), resulting in the formation of a mountain range that is believed to have been 5 to 6 miles high. Between 1.7 and 1.2 billion years ago, these mountains were eroded till only the roots remained. 1200 to 800 million years ago, a sea covered the area and sediments of the Grand Canyon Supergroup were deposited. Mountain building, 800 million years ago, characterized by normal faulting, resulted in a series of horst and grabens. Subsequent erosion removed most of the Grand Canyon Supergroup except where it was down dropped in one of the fault blocks.

Approximately 550 million years ago global sea level began to rise and the Sauk sequence was deposited. As this sea transgressed over the Grand Canyon area the following units, which represent a transition from near shore to offshore environments, were deposited: Tapeats Sandstone, a beach to near shore deposit; the Bright Angel Shale representing a muddy sea floor; and the Muav Limestone an offshore deposit. A lowering of sea level during the Ordovician resulted in erosion and formation of a disconformity. During the late Devonian the Temple Butte Limestone was deposited in a fresh to brackish water environment. Deposition of the Redwall Limestone, a marine unit, during the Mississippian marks a rise in sea level. A drop in sea level at the end of the Mississippian resulted in subaerial exposure of the Redwall Limestone and the development of an ancient karst landscape. The Pennsylvanian through Permian Supai Group was deposited in a delta to near shore beach environment. The Coconino Sandstone is an eolian deposit, and the Toroweap Formation and Kaibab limestone are marine units.

A thick sequence of Mesozoic rocks was deposited and subsequently eroded from the Grand Canyon area. 65 million years ago the Laramide orogeny produced the Kaibab monocline. Normal faulting and uplift began in the Miocene (10 myrs.) and continued through the Pliocene. During the Late Cenozoic volcanic eruptions produced basaltic lavas that flowed into the Grand Canyon.

Structure

The Grand Canyon section is structurally the highest part of the Colorado Plateau. Structural relief is a measure of the elevation difference of corresponding stratigraphic units. At Bright Angel Point the Kaibab Limestone is at an elevation of 8000 feet above sea level, whereas, at Bryce Canyon it occurs in the subsurface 0 to 1000 feet above sea level. Because of its high structural relief most of the younger Mesozoic units have been removed by erosion from the Grand Canyon section. The eastern Grand Canyon is centered on the Kaibab upwarp, a broad flexure or open fold that is bounded by the East Kaibab and West Kaibab Monoclines. The monoclines

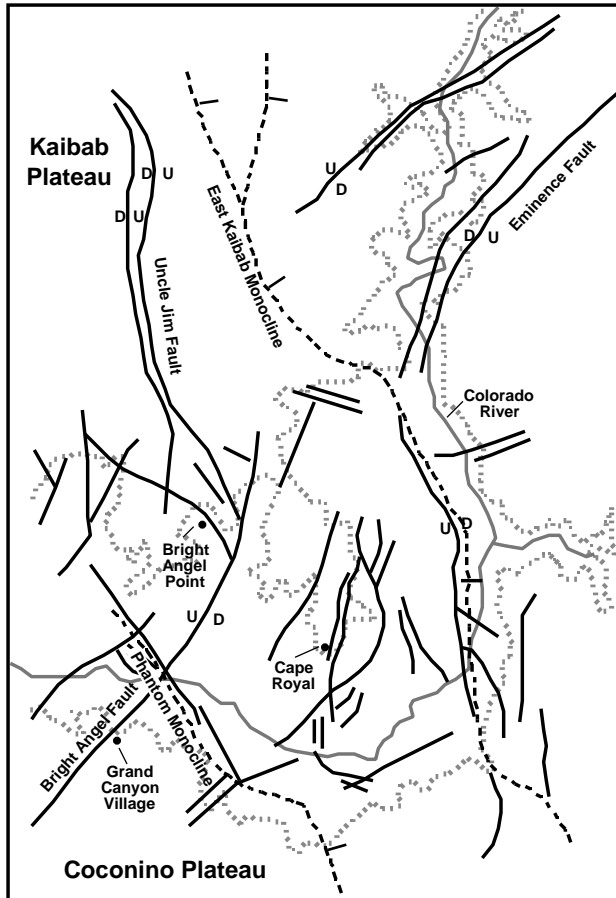


Figure 6. Faults and monoclines of eastern Grand Canyon (after Chronic, 1983).

trend north-south and occur above Precambrian basement faults that were reactivated during the Laramide Orogeny. Numerous normal faults dissect the Grand Canyon region (figure 6). These faults formed in response to extensional tectonics associated with formation of the Basin and Range. The Bright Angel Fault is a prominent fault that controls the location of Bright Angel Canyon.

Carving of the Grand Canyon

How old is the Grand Canyon and how quickly was the Grand Canyon cut? How did the river cut across the many belts of high ground along its course? These are some of the questions that need to be addressed when interpreting the history of the Grand Canyon. One would think that a canyon of its size would take an extremely long time to form, which is precisely what the 19th century geologist believed. According to their models the

Colorado River established its course at the beginning of the Tertiary Period (Paleocene or Eocene) and as the plateau was uplifted the river maintained its course by increasing its rate of erosion. It later became apparent that the history of the Grand Canyon was more complex, controlled by tectonic events, climate change and a complex system of stream capture, episodic entrenchment and aggradation (Elston and Young, 1989). Three main lines of evidence help us to constrain the age of the Grand Canyon (Lucchitta, 1989). First, the Miocene (5-6 myrs) Muddy Creek Formation which outcrops at the mouth of the Grand Canyon records a period of interior drainage and is evidence that a through flowing drainage system across the Basin and Range Province did not exist at this time. Second, the Bouse Formation (late Miocene) of western Arizona is a brackish water estuarine deposit that contains fossils eroded from the Mancos Shale of the Colorado Plateau. This evidence indicates that the Lower Colorado River was established by this time. Finally volcanics in the western Grand Canyon are evidence that the canyon was as deep as it is today about 1.2 million years ago. These data suggest that the Grand Canyon is young and downcutting of the Canyon was rapid.

One model for the origin of the Grand Canyon is illustrated in figure 7. During the Miocene the Kaibab Uplift separated the upper Colorado from the lower Colorado, or Hualapai drainage system, which flowed into the Gulf of California. Headward erosion of Hualapai tributaries eventually allowed them to break through the Kaibab uplift and “capture” the ancestral upper Colorado River. This process known as stream piracy caused the upper Colorado River to be diverted to the Hualapai channel. The rate of downcutting was suddenly increased due to the lowering of the base level and increased discharge as the two rivers joined, thus forming the Grand Canyon.

Recent studies of the volcanic deposits of the western Grand Canyon have led to new understandings on the rates of canyon cutting. Numerous volcanic lava flows cascaded over the outer rim of the Grand Canyon in Toroweap and Whitmore wash forming “frozen” lava falls. These lava flows formed a series of great barriers or lava dams across the Colorado

River. Hamblin (1989) has identified 12 major lava dams that formed during the past 1.2 million years. Relative age dating and calculation of erosion rates indicate that it took approximately 20,000 years for each dam to form and subsequently be destroyed. Following formation of each dam the Colorado River rapidly eroded through the dam down to its original level but no further. This suggests that the Colorado River is in a state of equilibrium and when that equilibrium is disturbed, such as by the formation of a lava dam, erosion to arrive at the equilibrium profile takes place almost instantaneously in a geologic time frame.

There are still a number of questions concerning the origin of the Colorado River system that need to be resolved, such as the direction that the upper Colorado River flowed prior to stream capture, and inconsistencies in the age of different sections of the Colorado River.

North Kaibab Trail

This is the only maintained trail into the canyon from the North Rim. For a days hike, decide how many hours you wish to hike, when 1/3 of your time has elapsed turn around and start hiking out. The trip to Roaring Springs takes a full day (8 hours). Roaring Springs is 2041 feet below the rim and is a 9.5 mile hike round trip. There is no water between Roaring Springs and the rim so carry AT LEAST 2 QUARTS OF WATER PER PERSON.

A hike down to Roaring Springs takes you through the Paleozoic section. Roaring Springs occurs at the contact between the permeable Muav Limestone and the impermeable Bright Angel Shale. You can reach the "Great Unconformity" between the Cambrian Tapeats Sandstone and Precambrian Dox Formation by hiking another half mile to the emergency telephone.

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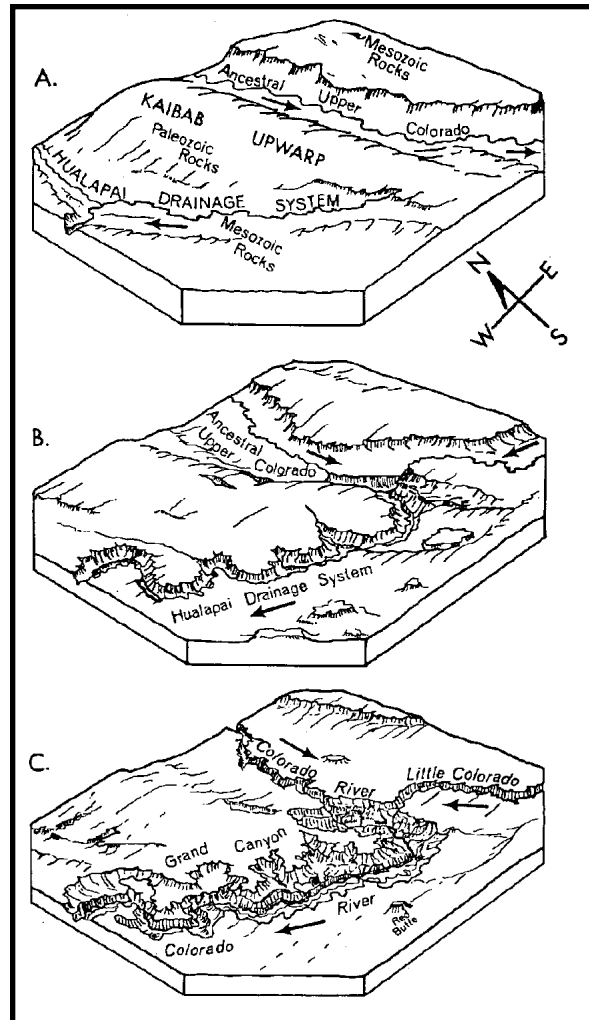


Figure 6.7 Stages in the development of the Colorado River drainage system and carving of the Grand Canyon (Baars, 1983)

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Exercises

To orient yourself stratigraphically look for the prominent cliff formed by the Redwall Limestone (Mississippian), and the Tonto Platform underlain by the Cambrian Tapeats Sandstone.

- 1) At Bright Angel Point and Cape Royal (Unkar Creek View Point) Observe the characteristics of the canyons carved by Bright Angel and Unkar Creeks. Compare your observations to the geologic map (figures 8 and 9)

Bright Angel Creek

Unkar Creek

2) From your observations answer the following questions:

a) Which canyons follow a major fault line?

b) What are the erosional characteristics of the Precambrian rocks at each canyon?

c) What type of unconformity occurs between the Precambrian rocks and the Tapeats Sandstone for each canyon (Nonconformity, angular unconformity or disconformity)?

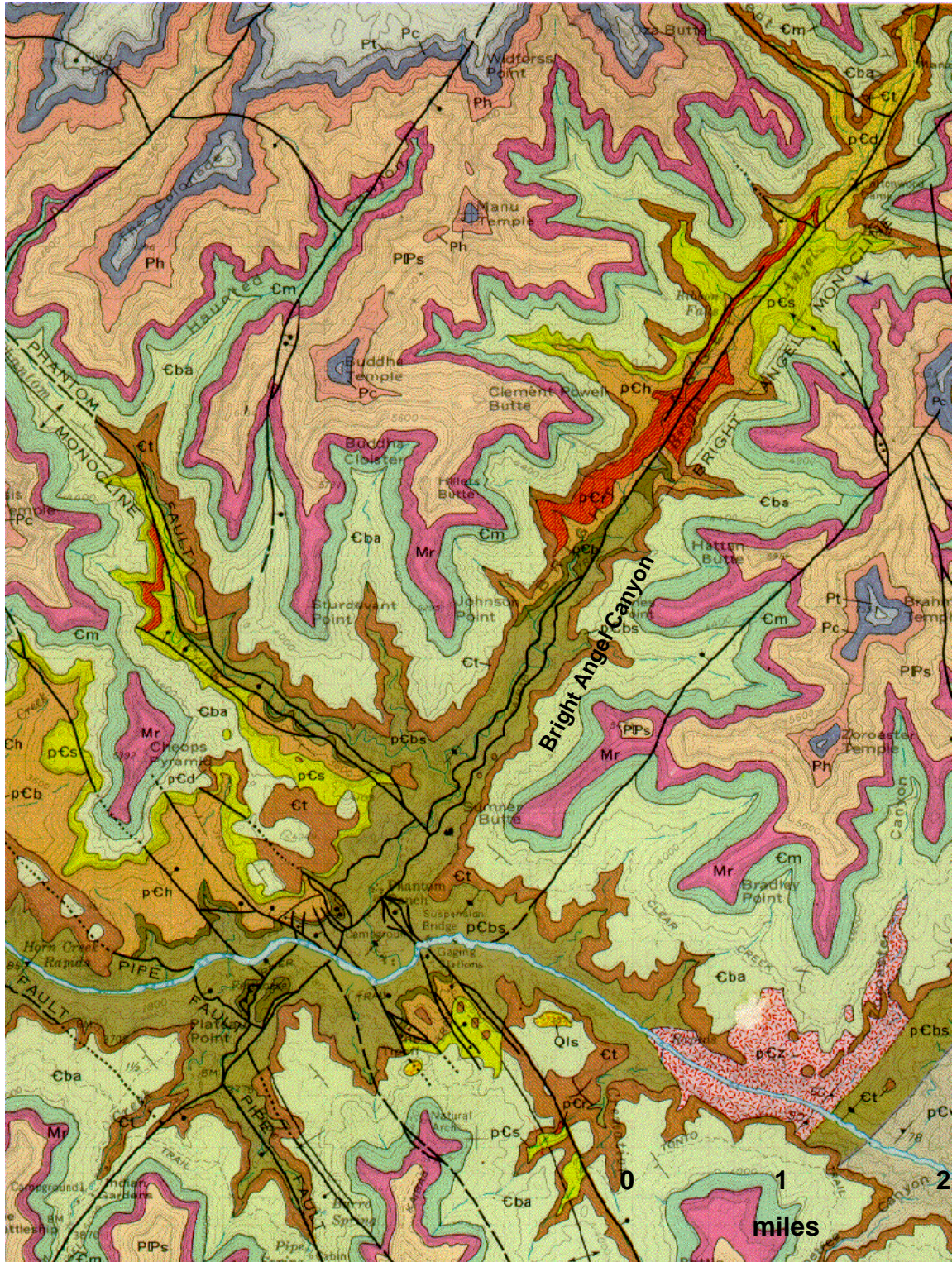


Figure 8. Geologic map of Bright Angel Canyon. See figure 2 for symbols.

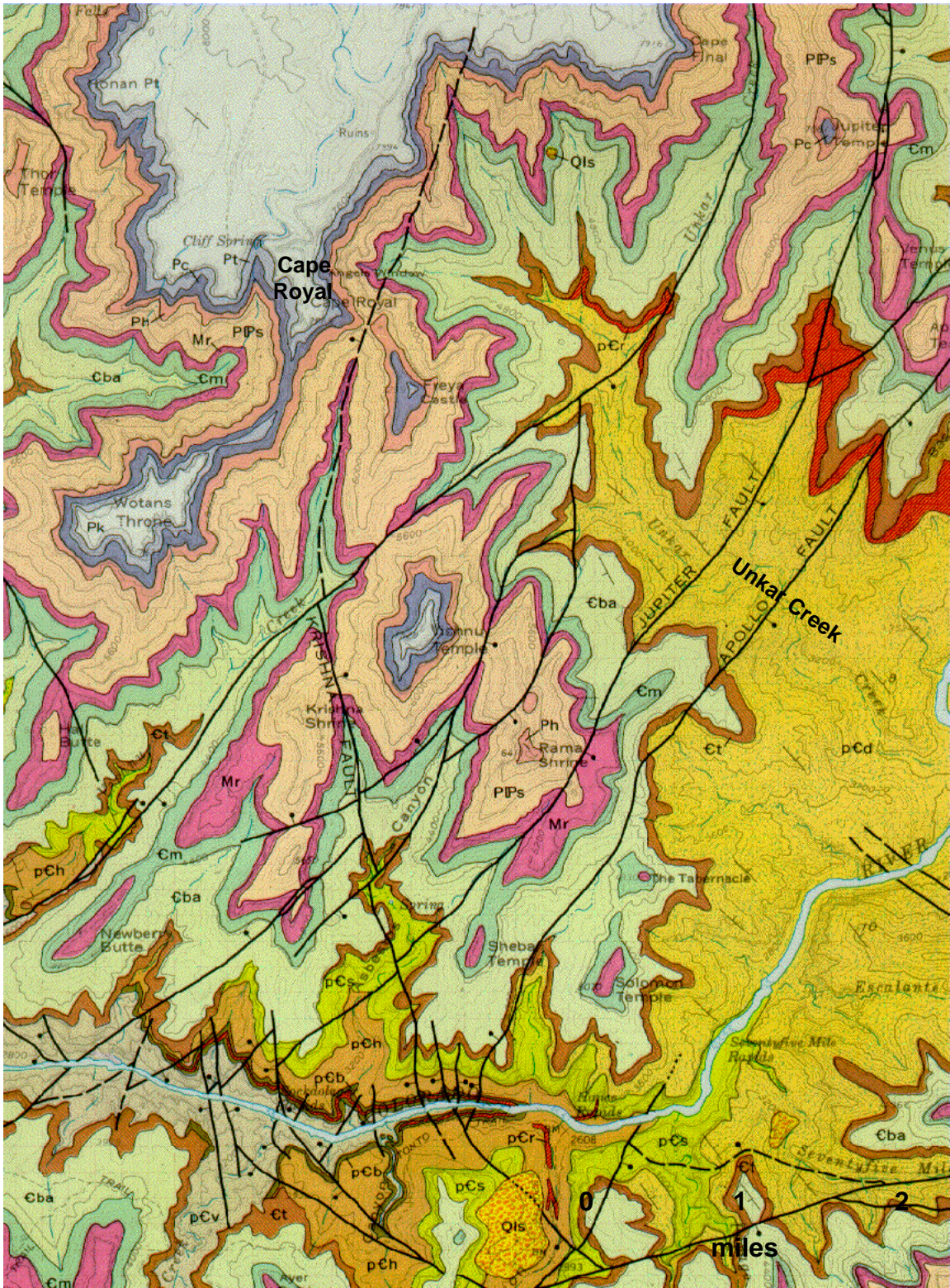


Figure 8. Geologic map of Unkar Creek Canyon. See figure 2 for symbols.

3. Define the following terms and give examples of each feature.

Angular Unconformity

Disconformity

Nonconformity

Stream capture

Superposition

Window