

# GRAND CANYON

ORIGIN AND SCENERY

By John H. Maxson

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GRAND CANYON NATURAL HISTORY ASSOCIATION

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COVER ILLUSTRATION: THE GRAND CANYON —  
VIEW WESTWARD FROM LIPAN POINT

PRINTED IN THE UNITED STATES OF AMERICA BY  
NORTHLAND PRESS  
FLAGSTAFF, ARIZONA

## Bulletin No. 13

This booklet is one of a series published by the Grand Canyon Natural History Association to further visitor understanding and enjoyment of the scenic, scientific and historic values of Grand Canyon National Park. The Association cooperates with the National Park Service of the United States Department of the Interior and is recognized as an essential operating organization. It is primarily sponsored and operated by the Interpretation Division in Grand Canyon National Park.

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Grand Canyon, Arizona



PUBLISHED IN  
COOPERATION WITH  
THE NATIONAL  
PARK SERVICE

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## INTRODUCTION

The great canyon cut by the Colorado River across northern Arizona for a distance of more than 200 miles is one of the earth's most impressive sights. It is huge in size and its rock walls are vividly colored. Although it is extraordinary in magnitude it is just a river valley excavated by normal processes of erosion acting in an orderly fashion. It is not the result of a spectacular cataclysm.

Although the Grand Canyon is relatively deep in proportion to its breadth, being nearly a mile deep near the village of Grand Canyon and only 13 miles wide, there are other valleys in the world which are steeper walled though not as deep. There are other valleys that are deeper though their side slopes are gentler.

About a million people visit Grand Canyon each year. What causes the Grand Canyon to have such attraction? It is the fact that its geologic structure, faithfully revealed by processes of erosion, is on a large scale and produces interesting lineaments both vertical and horizontal. The regularity of the great and continuous cliffs with their subjacent benches is elaborated in plan in an apparent confusion of spired promontories and deep alcoves. To these lineaments is added the fascination of vivid and contrasting coloration provided by the geologic constitution of the rocks themselves. Since geologic circumstances are responsible for the peculiar attraction of Grand Canyon scenery, an understanding of why it exists and what caused it will certainly add to the enjoyment of any visitor who is even mildly curious. The relationship of scenery to geology is relatively simple and the understanding should come easily. This booklet is especially designed for the visitor who does not have a technical background. Technical terms are avoided when possible. When used, they are, it is hoped, self-explanatory.

### HISTORY OF EXPLORATION

A long time has elapsed since the Grand Canyon was discovered by the Spaniard, Garcia Lopez de Cardenas, in 1540. For more than 200 years after discovery there is no record of human visits. During the later part of the eighteenth century the

canyon was visited by Spanish priests, and during the early part of the nineteenth century it was occasionally seen by traders, hunters, and prospectors. Through all these years of occasional visits, the depths of the Grand Canyon remained a mystery.

In 1869 the geologist, Major John Wesley Powell, a one-armed Civil War veteran, started down the river from Green River, Wyoming. He began the journey with nine men and four boats and concluded it 3 months later and a thousand miles down the stream after losing two boats on the river. Three men left the expedition en route at Separation Canyon. They thought that this canyon offered access to the north rim. They were tired of the constant wettings and other hardships which the river trip entailed. Since no one had ever made the trip before, no one could be sure that even greater rapids than those through which they had managed to pass did not lie ahead. Abandoning the main party proved a mistake, for the three men were murdered by Indians when they reached the north rim; the remainder of the party a short time later passed the last rapids. Powell found the Grand Canyon to be replete with spectacular geologic phenomena and he did not abandon his exploration after the first dangerous and difficult trip. In 1871, he again led an expedition down the Colorado.

Since Powell's time, hundreds of people have descended the Colorado River, some to survey, to study geology, botany, to photograph, and some simply for adventure. Some have used rowboats, speedboats, outboard motorboats, and some rubber life rafts. Despite these sallies down the river and trips along the rims, the tributary canyons, amphitheaters, and the Outer Canyon are rarely visited.

## GEOGRAPHIC SETTING

### COLORADO PLATEAU

After leaving its headwaters area in the high Rocky Mountains of Colorado, the Colorado River flows through a series of canyons incised in the Colorado Plateau. From the Grand Canyon it emerges in the desert basin and range country of Nevada, whence it finds its way to the Gulf of California. In its lower course, it forms the boundary between California and Arizona. Figure 1 gives the setting of the Colorado River system.

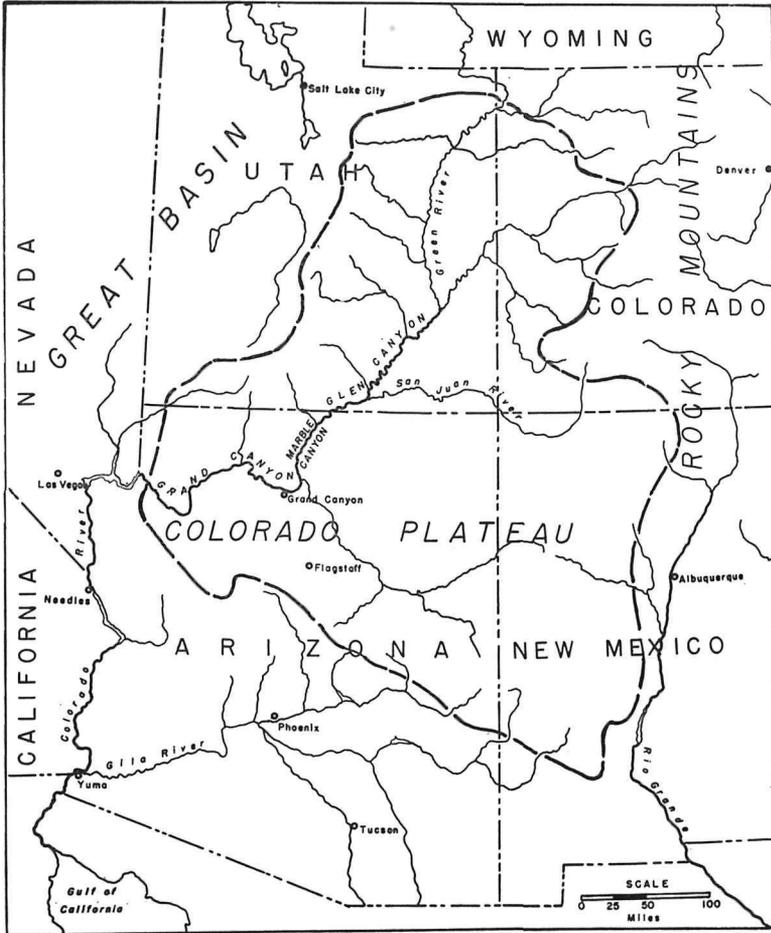


Figure 1. Location of the Colorado Plateau.

The Colorado Plateau is an enormous, high-lying area in southwestern Colorado, southern Utah, northwestern New Mexico, and northern Arizona. Its area exceeds 130,000 square miles and it is usually between five and ten thousand feet above sea level.

Over this huge area the rock layers, or strata, are nearly horizontal. There are a few broad swells and wrinkles which

disturb the beds of sedimentary rocks. Generally speaking they are now nearly flat-lying as they were at the time they were deposited under the sea many eons ago. At their base they include strata containing fossils of the earliest complicated types of plants and animals dating back as much as 500 million years. The relative lack of disturbance means that the Colorado Plateau has been, compared with adjacent areas, as subject to uplift and subsidence but not as subject to lateral compression and deformation. In this sense it has been relatively stable. Its more recent history, for the last few million years, has been one of uplift and downcutting by streams. Deep canyons have been eroded in the plateau while nearly horizontal beds have been stripped away from the top. Thus the Colorado Plateau is a country of canyons.

The region is mostly arid to semiarid. Where the rainfall is least, at the lower elevations, there may be a growth of cactus and the region is a desert. At somewhat higher levels up to about 7,000 feet there may be scattered growths of juniper and pinyon. Many of the areas above 7,000 feet receive enough rain to support pine forests.

#### GRAND CANYON DISTRICT

The Grand Canyon District of the Colorado Plateau has experienced greater uplift than the surrounding region. It is an upward bulge on the plateau. The strata slope to the north from the bulge so that in Utah the beds are younger. The thicker and stronger groups of strata stand out in cliffs. The three main rows are the Vermilion Cliffs, the White Cliffs (exposed at Zion Canyon), and the Pink Cliffs (exposed at Bryce Canyon). The Grand Canyon District of the Colorado Plateau is itself subdivided into several subordinate plateaus as shown in Figure 2.

#### KAIBAB PLATEAU

This is the highest plateau of the group and it lies north of the Grand Canyon opposite the village of Grand Canyon. The high point of the upward bulge is located on this plateau and north of the river. It reaches from 7,500 to more than 9,000 feet in elevation. It is essentially a north-south elongate block. Streams flow in shallow valleys on the plateau surface. Here and there are basins or parks with no through drainage. (See Figure 3.)

The east flank of the Kaibab Plateau is formed by a sharply eastward sloping flexure or monocline which brings the strata down 2,500 feet and more to the lower level of the Marble Plateau.

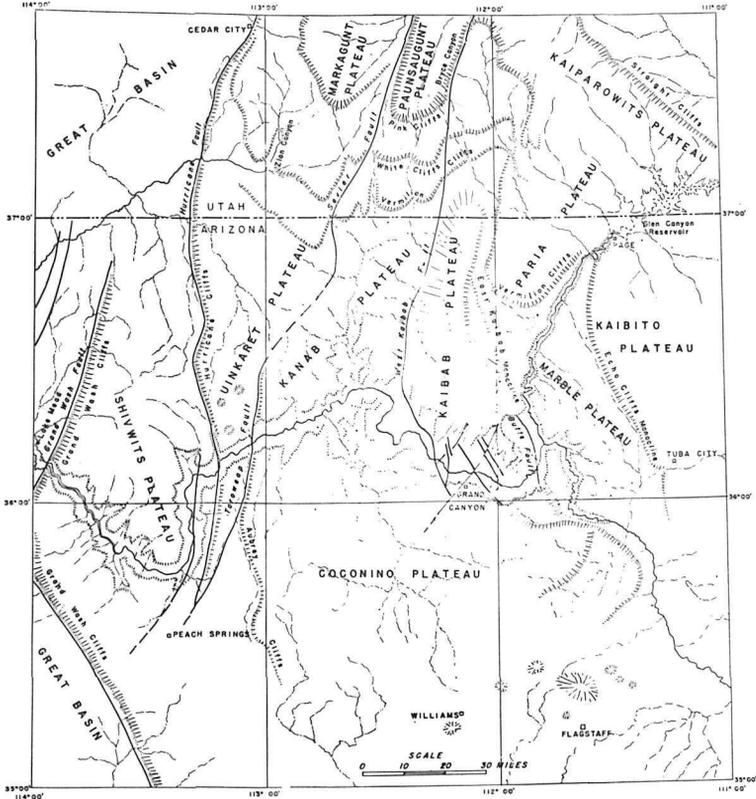


Figure 2. Subdivisions of the Grand Canyon District of the Colorado Plateau.

### MARBLE PLATEAU

The Marble Plateau, 5,000-6,000 feet in elevation, is likewise a north-south segment. It is bounded on the east by another east sloping flexure of strata, the Echo Cliffs monocline. The Marble Plateau is traversed by Marble Canyon, sometimes regarded as part of the Grand Canyon. At the east end of Marble Canyon is the lower end of Glen Canyon of the Colorado River.



*Figure 3. Park on the Kaibab Plateau.*

#### KANAB PLATEAU

Downdropped by flexure and fault to the west of Kaibab Plateau is the Kanab Plateau, a broad desert expanse draining southward from the High Plateaus of Utah to the Colorado River.

#### UINKARET PLATEAU

Downdropped to the west of Kanab Plateau on the Toroweap Fault is the Uinkaret. This plateau is notable in being the site of extensive volcanic activity since the Grand Canyon was cut. Some of the flows of lava descend the canyon walls and extend for many miles along the river course.

#### SHIVWITS PLATEAU

This westernmost unit of the Grand Canyon District is separated from the Uinkaret on the east by the Hurricane Fault. On the west it is separated from the Great Basin by the Grand Wash Fault which has a displacement of some 7,000 feet. The margin of the plateau is formed by the Grand Wash Cliffs, an imposing and continuous scarp.

## COCONINO PLATEAU

The Coconino Plateau, also known as the San Francisco Plateau, is the large, relatively unbroken unit lying south of the Grand Canyon and extending from the Marble Plateau on the east to the Grand Wash Cliffs on the west.

The surface of the Coconino Plateau like that of the other plateaus in the Grand Canyon District is formed by heavy limestone strata. A few isolated remnants of soft, sandy, red shales and mudstones occur on top of the limestone here and there. It is inferred that these red beds once covered the whole region in considerable thickness.

## GEOLOGIC SETTING

### SEQUENCE OF FORMATIONS

The different rock strata encountered by the Colorado River as it cut downward are controlling factors in the development of the Grand Canyon. The younger beds were worn away first

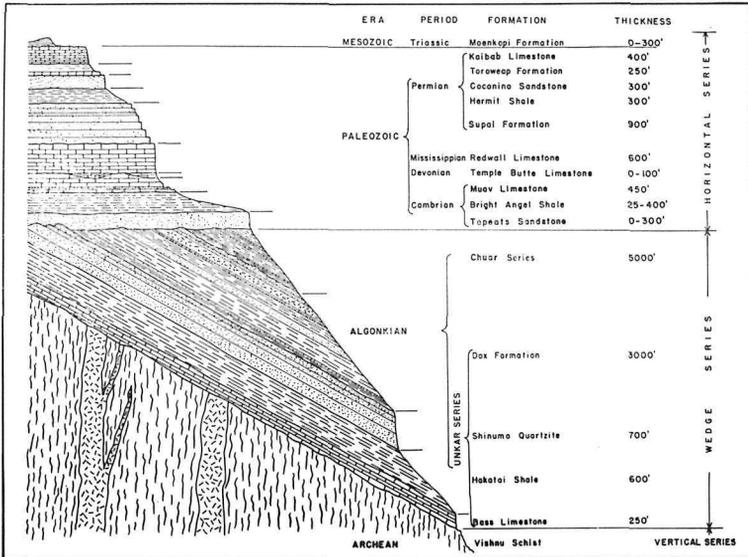


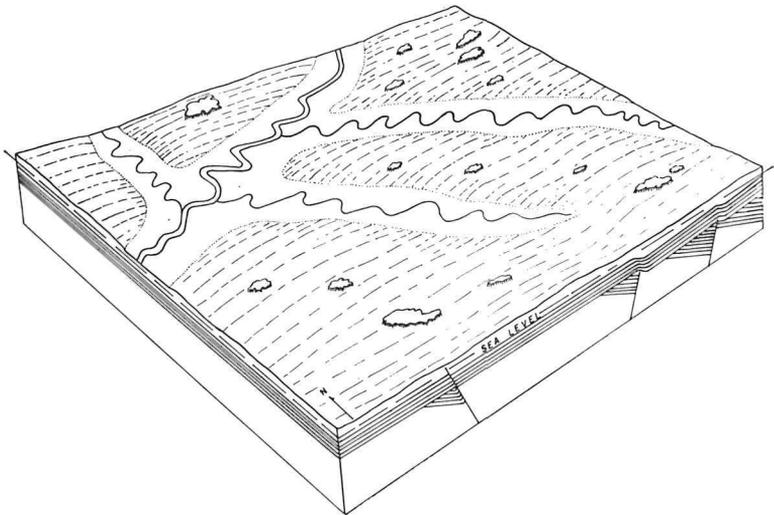
Figure 4. Rock section in the vicinity of Grand Canyon National Park.

and gradually older and older beds were exposed underneath. A detailed knowledge of the sequence of formations is not required for understanding Grand Canyon scenery. It is sufficient to know that basically there are three great series which we have designated by terms descriptive of their position in the canyon. The upper and younger strata lie nearly horizontal forming the walls of the Outer Canyon. We refer to these as the Horizontal Series. Their relationship is shown in Figure 4. Beneath the Horizontal Series in numerous places are tilted blocks of strata which we refer to as the Wedge Series. Underneath the sedimentary strata of the Horizontal and Wedge Series is the basement of old schists and granites which we term the Vertical Series. The Vertical Series form the walls of the Inner Gorge.

## SEQUENCE OF DEVELOPMENT

### *Stage 1. The Ancestral Colorado Plain.*

The earliest landscape with which we are concerned was virtually a plain cut on red sandstones and shales of the Moenkopi formation. This surface is depicted diagrammatically in Figure 5. For our purposes it is satisfactory to consider that this



*Figure 5. Stage 1, ancestral course of Colorado River on Colorado Plateau. Course is independent of underlying rock structure.*

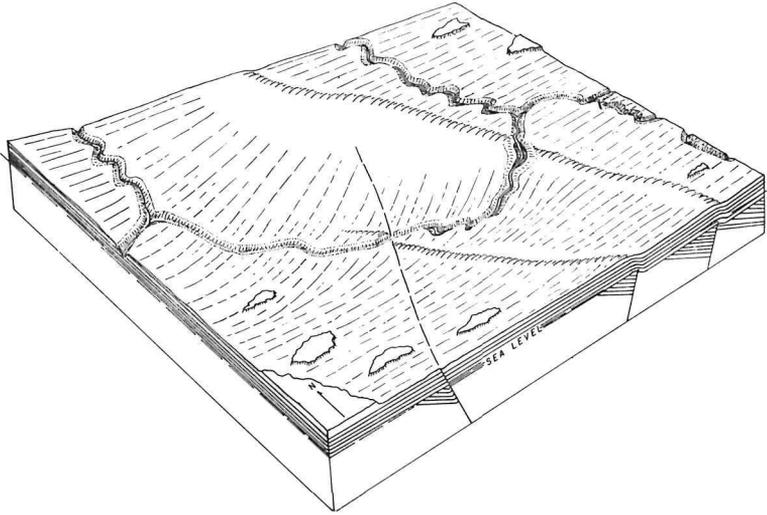
erosion surface was completed several million years ago. It is physically possible that the Grand Canyon could be cut in as short a time as a million years. Some geologists believe that 7-9 million years have elapsed since it was started. Some believe that its history extends over a much longer period of time.

The land stood near the level of the sea and the Colorado River was broad and sluggish as it flowed southwesterly in its wide and gentle valley. On a smaller scale it may have resembled portions of the courses of the Missouri and Mississippi rivers as it wound about and meandered over its flood plain. Oxbow lakes, cut-off and isolated meanders, flanked the stream. The water of the river was dark and loaded with red mud and silt. The surrounding country possessed little relief, but here and there were residual low sandstone-capped buttes and mesas.

### *Stage 2. Regional Uplift Initiates New Cycle of Erosion – The Ancestral Canyon*

Following regional uplift, although erosion of the canyon proceeded without interruption, we may conveniently analyze the development during several successive periods of time. During stage 2, as the streams quickened to new life and erosional strength, they began to actively scour their channels dislodging rock particles and transporting them toward the Gulf of California. The loose sands and gravels of the flood plain were carried away and all of the streams began to be influenced by the structure of the rocks underneath. The streams were dropped down into positions from above and were thus “superimposed” on the structure below.

Figure 6 is a block diagram of the eastern part of Grand Canyon National Park some time after beginning of the canyon cycle. The old direct course of the river southwesterly across the area shown in Figure 5 has disappeared and the stream forms a big bend or southward loop down the east flank of the East Kaibab Monocline, crossing the upwarp on its south slope or plunge. The reason for this pronounced deflection is slipping of the stream channel down the slope or dip of the strata. The river was able to cut the soft Moenkopi shales and remove fragments easier from the down-dip bank. The river was fixed in position north of the village of Grand Canyon where it encoun-

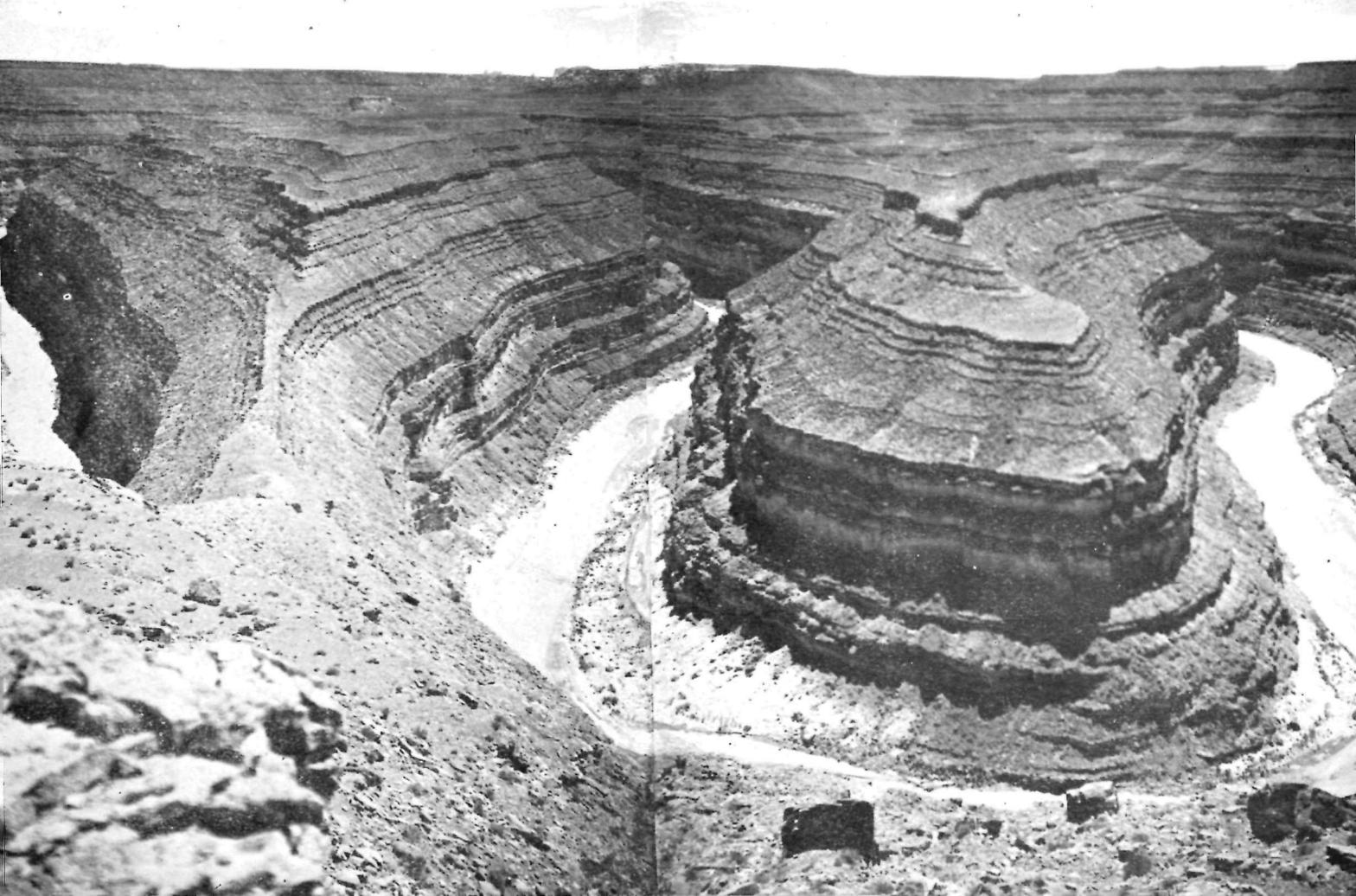


*Figure 6. Stage 2, Colorado River course after uplift, cutting through shale veneer, and adjusting to major structure.*

tered a gap in the Grandview Monocline caused by offset on the Bright Angel fault.

Figure 6 shows the Colorado River course in approximately its present configuration as the stream had cut through the Moenkopi shales and started to entrench in the thick and homogeneous strata of Kaibab limestone. This is shown particularly where the river crosses the Kaibab upwarp. As the channel was entrenched, it became relatively fixed in position because of the greater resistance of the limestone to stream erosion. The large and solid joint blocks were more difficult to quarry than the thin shales and sandstones above. The slight slope of the anticlinal nose was no longer able to significantly shift the focus of stream erosion.

Elsewhere in the regions of nearly flat strata, the river merely cut down and did not slip much. Bends and meanders developed on the ancestral Colorado Plain were superimposed and were inherited by the later course. The Goosenecks of the San Juan River shown in Figure 7 are such features. In the western part of Grand Canyon National Park the meander pattern is retained after deep canyon-cutting as shown in Figure 8.



COCONINO PLATEAU

KANAB  
PLATEAU

ESPLANADE





*Figure 9. The winding upper course of Diamond Creek suggests the probable appearance of the plateau during an early phase of canyon-cutting.*

So the plan of the master stream, the Colorado River, became virtually permanent. As Stage 2 drew to a close, a narrow, steep-walled canyon in the Kaibab limestone was formed resembling that of the Little Colorado River shown in Figure 10.

### *Stage 3. Erosion of the Outer Canyon.*

Erosion in the Horizontal Series proceeded by sapping of the soft, bench-forming shales and sandy shales underlying massive, jointed, cliff-forming sandstones and limestones. As the sapping progressed, the cliffs retreated. The stepsided canyon grew in width and depth until it looked much like that of the Little Colorado River near its mouth as shown in Figure 11.

Eventually the Outer Canyon was to reach a breadth of 13 miles and more and a depth below the rim of 4,000 feet and more. Figure 12 is a block diagram representing the Grand Canyon in its present condition after erosion of the Outer Canyon (Stage 3) and erosion of the Inner Gorge (Stage 4). It is the final member of the sequence introduced by Figures 5 and 6.

*Figure 8. Meanders of the Colorado River in the western part of Grand Canyon National Park inherited from the pre-uplift cycle of the Colorado Plateau. The broad flat surface at intermediate level, the Esplanade, is not a stream terrace. It originated by retreat of the Coconino cliffs through sapping of the relatively soft underlying Hermit shale. The stripped surface is on thick-bedded sandstone of the upper Supai formation.*



*Figure 10. High oblique view of the Little Colorado River Canyon cut in Kaibab and Toroweap formations.*

#### A. PROCESSES OF EROSION

##### *1. Controlling depth.*

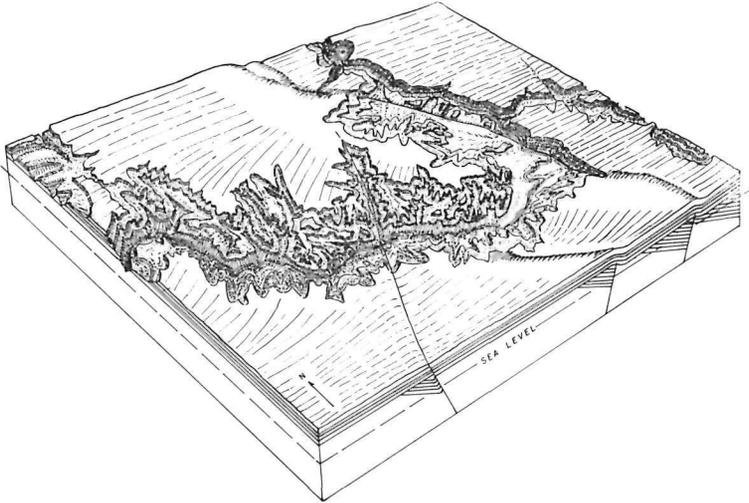
The Colorado River itself is the means of digging the stream channel deeper and deeper. Although the river is swift and turbulent during the low water stages of autumn and winter, it becomes a raging torrent during the high water of the spring and summer snowmelt in the Rocky Mountains. During flood the dis-



*Figure 11. Junction of canyon of the Little Colorado River with Grand Canyon.*

charge may reach 125,000 second feet with a mean velocity in the total cross section of the river of 10 feet per second. As much as 27,600,000 tons of suspended matter has been recorded passing the Bright Angel gaging station in the Grand Canyon in a single day. The bed load carried along or near the bottom by rolling and bouncing probably accounts for 20% more in transported debris. If some 33 million tons of rock can be mechanically transported by the water in one day, it is clear that the Colorado River is doing an enormous amount of work moving debris shed from the canyon sides and scouring the channel. The endless barrage of silt particles, borne by turbulent, high-velocity stream currents, operates as a sand blast, actively abrading the channel walls and boulders in the channel. Soft rocks like limestone are fluted in accordance with the turbulence pattern.

In addition to the rock particles transported mechanically, the river carries a huge quantity of various salts in solution.



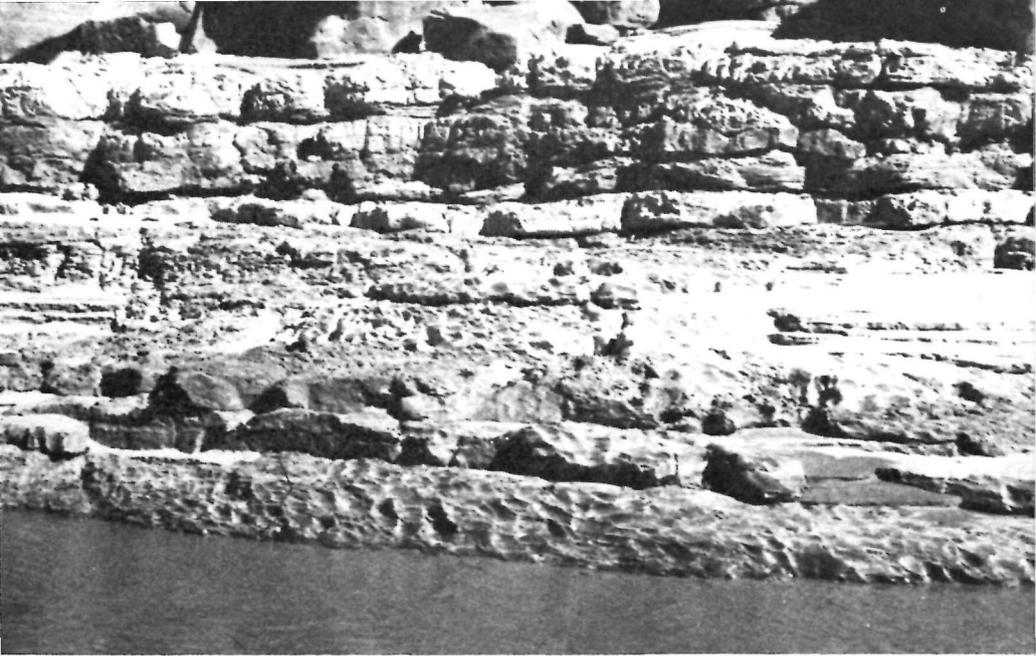
*Figure 12. Stages 3 and 4. Present Grand Canyon after further uplift, River downcutting. More detailed adjustment to rock structure.*

With a discharge of 52,000 second feet at Bright Angel gaging station, the daily load of dissolved solids was computed to be 137,000 tons. A large traction of this solution load is calcium carbonate, the main constituent of limestone.

## *2. Controlling breadth.*

The tributary streams, almost all intermittent, carry large quantities of debris and calcium carbonate to the river and control the recession of the valley sides. These streams are longer on the north side because the southerly slope of the Kaibab and Kanab plateaus affords an extensive gathering area for rainfall. Because of the southerly slope of the Coconino plateau on the south side of the river, the drainage divide is at or near the rim, the rainfall gathering area is small, and the tributaries are short. The canyon cross profile is, therefore, asymmetric, the north side being longer and gentler, the south side shorter and steeper.

The climate of the Outer Canyon is arid and mechanical weathering is predominant. Daily temperature changes from the heat of the blazing midday sun to the cool of night lead to cracking and fracturing. During the cold season frost may pry apart



*Figure 13. Fluting developed on limestone strata of Colorado River channel in Marble Canyon.*

fragments. The shaly strata are disintegrated into fine particles and the heavier strata of sandstone and limestone are broken into blocks. The limestone, where homogeneous, spalls, peeling off curved layers of rock. Gravity plays an important role in moving rock fragments toward the river. Conspicuous landslide scars occur where large masses of debris have broken away from the canyon walls. There are many rock slide areas where fragments are piled at the angle of repose, inching their way downward with daily expansion and contraction, sliding occasionally when lubricated by rain. The wind from time to time blows dust and sand away from site of origin and into the stream channels. So by one means or another the rock fragments are carried to a stream course and thence down to the river.

On the exposed limestone blocks and cliffs solution is effective in removing material. Limestone faces long exposed to the weather are pocked and fretted by solution. This is in spite of the rarity of showers and the paucity of rainfall.

#### B. VERTICAL CONTROL IN THE HORIZONTAL SERIES

The cross profile of the Outer Canyon is controlled by relative resistance to erosion of the various members of the Horizon-



*Figure 14. Recent landslide from Kaibab limestone cliff in Marble Canyon.*

tal Series. This resistance is determined by the thickness of bedding, amount of fracturing, fineness of component particles, degree of cementation of particles, and solubility of the cement. In general, the thinner bedded, more fractured, and lighter cemented rocks are more easily eroded. They form the gentler slopes and benches of the canyon wall. The heavier, more solid and hard rocks form the steeper slopes and cliffs. Relationships are shown diagrammatically in Figure 4.

Rocks of the Horizontal Series in the Outer Canyon are the ones usually seen from the rim. They are the ones responsible for the general color effect. At the top are the grayish-white

*Figure 15. View looking westerly over Grand Canyon and Coconino Plateau from over vicinity of Trinity Creek. This view illustrates vertical control and topographic features within the canyon. 1. Vertical Archean schists; 2. Tapeats sandstone, lying on flat erosion surface and forming cliff separating Inner Gorge from Outer Canyon; 3. Bright Angel shale, eroding back to form Tonto Platform; 4. Muav limestone, forming cliffs and slopes; 5. Redwall limestone, major cliff-forming member of the Horizontal Series; 6. Supai formation, consisting of red sandstones and sandy shales; 7. Hermit shale, fine-grained red shale forming low slope; 8. Coconino sandstone, prominent white, cliff-forming stratum of cross-bedded, wind-laid sandstone; 9. Toroweap formation of impure limestones and silty sandstones forming steep slope; 10. Kaibab formation of heavy grayish-white limestone forming cliff.*

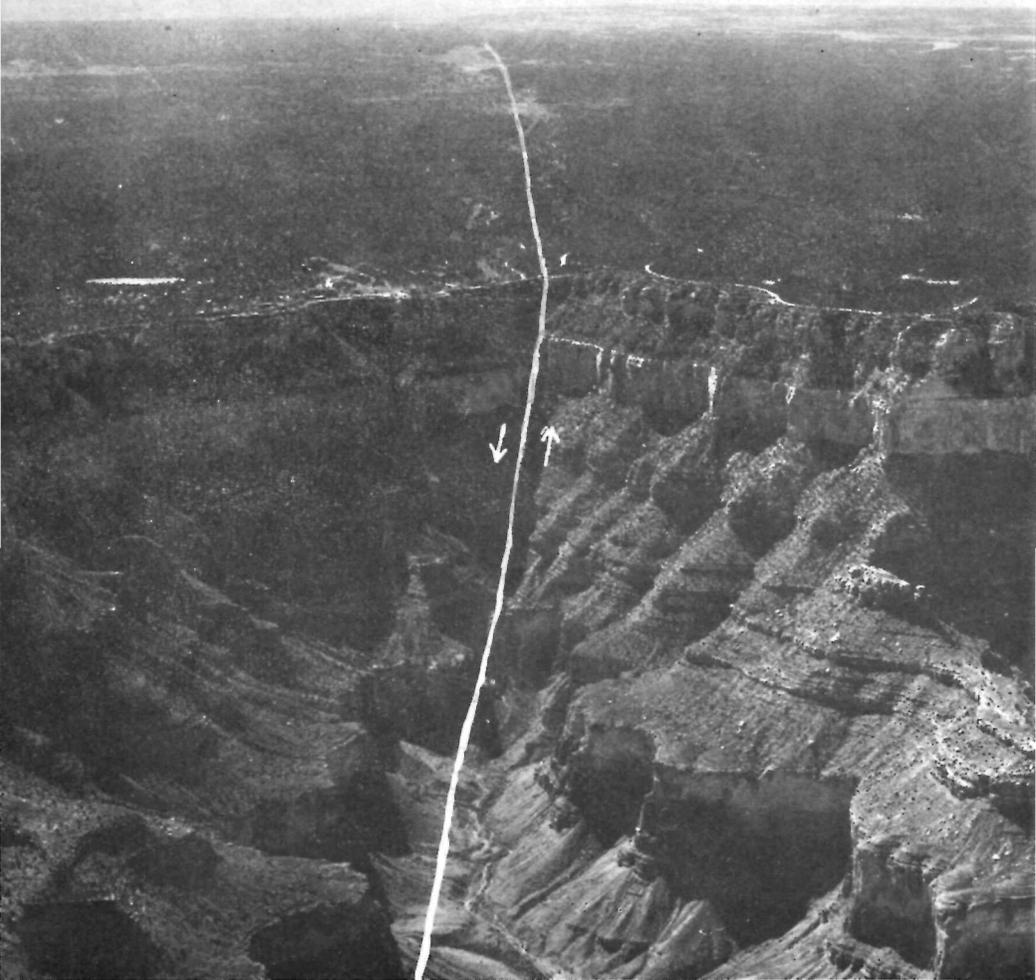
COGONINO PLATEAU



TOWER  
OF SET

cliffs of the Kaibab limestone. The plateau surface on the Kaibab limestone bears the green mantle of pine forests. Below the Kaibab limestone is a steep slope formed by alternating cliffs and benches of the Toroweap formation which is composed of reddish sandstone and gray limestone. The general effect of the Toroweap section as a whole is drab. Underneath the Toroweap the massive, white to buff colored, wind-laid Coconino sandstone everywhere forms a prominent cliff. It is the first conspicuous cliff, recognizable from a distance, below the plateau. Under the Coconino is the deep red Hermit shale. Its bench is not very well developed in the eastern part of Grand Canyon National Park, but in the western part it has eroded far back on top of heavy sandstones in the upper Supai formation forming the Esplanade. The Supai formation lies under the Hermit shale and has the same dark red color. It forms alternating cliffs and benches. The red wash of iron oxide from these formations has descended over the great Redwall limestone cliff underlying them and given it the same coloration. However, where the Redwall stands alone without a Supai cap (as it does where the Kaibab trail descends) it is grayish-white on fresh surfaces and drab gray on weathered surfaces. The Redwall cliff is 600 feet high and is the main topographic break in the middle part of the Outer Canyon. Here and there in the eastern part of the Grand Canyon channels in the Muav limestone under the Redwall retain a filling of Temple Butte limestone. Occurrences are so infrequent that the formation does not contribute to the overall landscape of the canyon. A lens crossed by the Kaibab trail has a lavender color. The upper limestone cliff of the Muav formation often merges with the overlying Redwall. Below it is a slope and lower limestone cliff. The rocks are light buff or beige on fresh surface but they are weathered almost everywhere to a dark yellow brown. Below the Muav is the Bright Angel shale which generally has a light pastel color from pale brown to pale green. The bench, eroded in the Bright Angel shale, is known as the Tonto platform. It is one of the characteristic topographic features of the lower part of the Outer Canyon. An old Indian trail follows it for many miles on the south side of the river. Although the trail is not used much by man, it is in many places maintained as a recognizable way of passage by wild burros. Below the Bright Angel shale is the Tapeats sandstone, lowest and oldest formation of the Horizontal Series. It





*Figure 17. Looking south along Bright Angel fault trace in Outer Canyon and on Coconino plateau. Grand Canyon village is immediately left of trace on rim. A post-Paleozoic normal fault of 175 feet displacement, it overlies an old thrust fault of opposite direction of displacement. It illustrates the V-shaped re-entrant in the canyon walls where erosion has been facilitated by rock brecciation along a fault.*

forms a precipitous cliff at the outer boundary of the Inner Gorge and the lower boundary of the Outer Canyon. It is dark brown in color.

The stepped topography of the Outer Grand Canyon is due to the fortuitous alternation of beds having widely different resistance of erosion. Also, by chance, there is an alternation of light-colored beds and dark-colored beds, with intermediate red beds. The colors are generally subdued, yet they have extensive distribution in horizontal pattern. They interest the eye whether seen in the contrast of bright sunlight and deep shadow of mid-day or in the soft, diffused light of sunrise and sunset. The variety and intricacy of sculpture, the subtle blending of the natural colors, offset in perspective, as well as the hugeness of void of the chasm, produce a never-ending fascination.

### C. CONTROL OF PLAN IN THE HORIZONTAL SERIES

The pattern of the eastern portion of the Grand Canyon, is represented in Figure 16. The criss-cross network of valleys and promontories determined by *faults*, or breaks in the crust, is readily apparent. There are two main systems, one on the diagonal northwest-southeast, the other on the diagonal northeast-southwest. The northeast system is nearly parallel to the foliation or grain of the basement schists which we term the Vertical Series. The northwest system is nearly parallel to the major joint system of these rocks. So, in plan, the basic control is inherited from very ancient structures. We may picture the underlying metamorphic basement as consisting of immense polyhedrons, in some cases roughly rhombohedrons, measuring miles on a side. As compared with the mile of horizontal strata lying over them, they possess unlimited strength. Therefore, stresses within the crust have been adjusted by movement of the underlying blocks, accompanied by faulting and flexing of the weak overlying veneer, in cases of considerable movement, or just by shattering of the overlying veneer above the old faults, in cases of small displacement.

Crustal stresses developed in separated periods of geologic time in the Grand Canyon district and operated in different directions on two occasions. During the first period of stress, with which we are concerned, the northeast trending fractures were developed as thrust faults by compression acting in a direction normal to them—namely, southeast-northwest. The north and northwest trending faults were normal faults resulting from tension or lack of compression. Displacement on these faults during



*Figure 18. West branch of Butte fault on Colorado River north of Desert View. After Wedge Series deposition the left (west) side went down. During post-Paleozoic time west side went up producing the East Kaibab Monocline.*



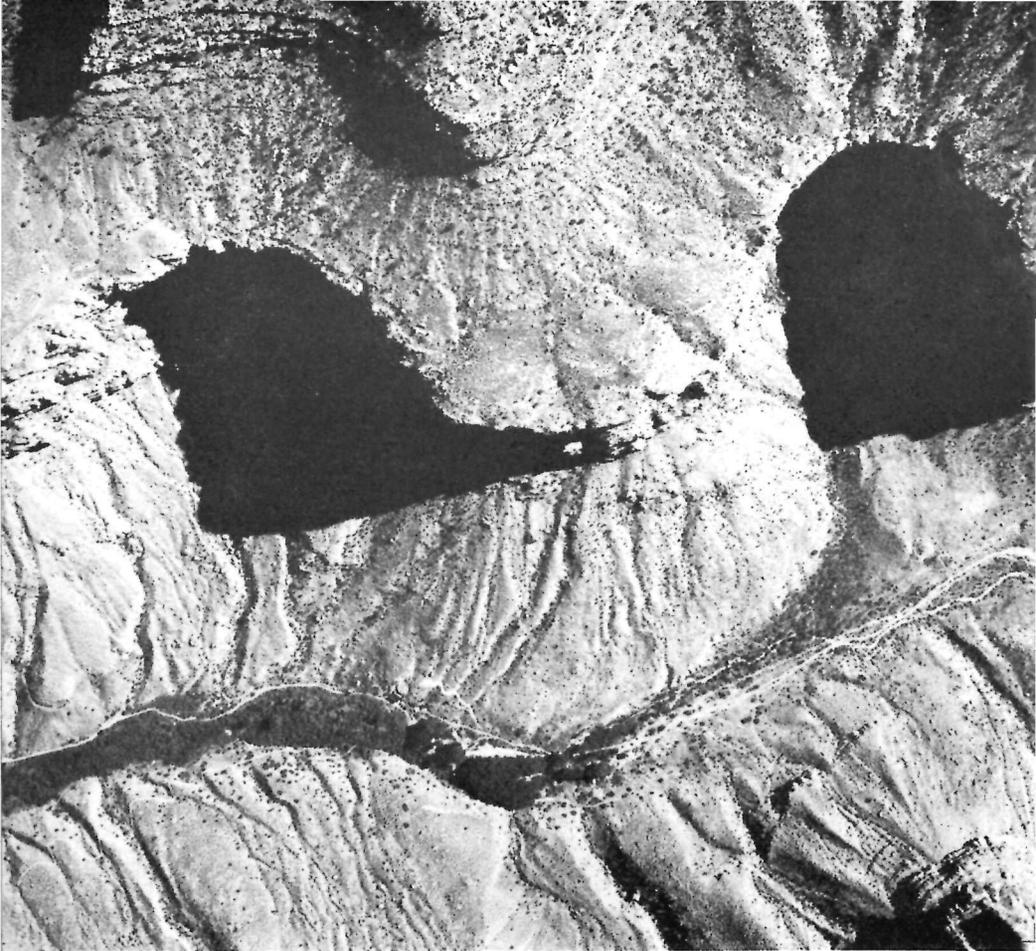
Figure 19. Cirques of Redwall cliff on south face of Zoroaster Temple. Note the development of overhang.

and after deposition of the Wedge Series caused blocks of the strata to be tilted and set into the monotonous schist terrain like an inlaid design.

Some time after the Horizontal Series (Paleozoic) forming the Outer Canyon walls had been deposited, stresses were again applied to the underlying blocks, but in opposite directions. Now the north and northwest trending faults were subjected to compression, and movement on them was reversed, forming thrusts and monoclines in the overlying sediments. One of the best examples is the Butte fault shown at the Colorado River in Figure 18.

The shattered rocks of fault zones are more easily further broken up and carried away by running water. Thus as the Colorado River persistently cut its channel to lower levels, tributary streams draining the canyon sides carved canyons in the shatter zones and extended their courses headward. Such tributaries, controlled in their growth by structure, are known as *subsequent* streams. These subsequent streams have eroded the network of the Outer Canyon. They account for the amphitheatres and cruciform valleys.

The picturesque forms of the spurs between the subsequent streams, the spired promontories and stepped temples with their cliffs, curved deep embayments and re-entrants, are the impressive and memorable features of the Grand Canyon as a whole.



*Figure 20. Vertical view of cliff-bench topography near Indian Gardens. Heavy shadows are caused by Redwall limestone cliff, which is controlling factor, virtually a temporary base-level, in recession of cliffs in overlying Supai sandstones. Note their parallelism with the Redwall cliff. Where there is no concentrated drainage from above, sapping operates with equal effectiveness at the base about the periphery of a re-entrant, and it is expanded in sub-circular outline to form a cirque.*

To the imaginative they suggest buildings, castles and temples, ships, and other creations of fantasy. On the spurs there is very little rainfall, so water flows only at rare intervals. Reduction proceeds through sapping at the cliff base and cliff retreat. The Redwall limestone, largest of the cliff-forming elements, suffers reduction of its cliff face by falling of gigantic spalls producing

and enlarging rounded embayments or cirques. Here and there arched overhang and shallow caves form. Figure 19 shows a typical Redwall cliff face.

Viewed in plan the cirques show varying curvature. The larger the amount of water that flows over the cliffs, the narrower is the zone of streamlet channels, and the greater is the curvature of the cirque. Figure 20 illustrates this point. The cirque on the right has greater curvature and more stream development than the cirque on the left. The more rapid enlargement of the cirque on the right might ultimately result in its cutting through the spur and forming a butte. Where there is no concentration of streamlets the cirque enlarges concentrically as in the case at the left. An advanced stage in the development of cirques is shown in the Tower of Set in the lower right portion of Figure 5. A cirque of large radius of curvature faces in the direction of the river. Other cirques expanding away from the tributary valleys meet in sharp cusps at the outer ends of long narrow tongues of Redwall limestone. To the right of the Supai pinnacle, forming the Tower of Set, is a saddle caused by the reduction of the cliff-bench forming members above two Redwall cirques on the two sides of the ridge which are approaching each other in their retreat. The detailed plan of the inter-tributary spurs, controlled by concentrically expanding cirques of cliff retreat, resembles dough from which cookies have been punched. Dependent upon the intersection or approaching intersection of circles of cliff retreat are the various stepped buttes and stepped temples of the Outer Canyon.

#### *Stage 4. Enlargement of Outer Canyon and Cutting of Inner Gorge.*

The uplift of the Colorado Plateau continued, the river deepened its channel, and the Outer Grand Canyon expanded in size. At last the river cut through the Horizontal Series in places and impinged on high mounts formed by tilted members of the Wedge Series. These wedges of strata downdropped on faults occur at various places in the Grand Canyon. They are next to the oldest group of rocks and are much older than the Horizontal Series above.

The largest area of the Wedge Series lies adjacent to the big bend of the Colorado River at the east end of the park.

It may be seen to the north of Desert View. Here the beds are relatively soft and uniformly bedded sandstone and shale. In the broad Lava Creek and Nankoweap Creek basins smoothly rounded slopes are eroded on the Chuar Series. Its cream to buff color produces a light expanse. The underlying Dox formation is generally a brick red. In its upper part is a thick series of black lava flows which form an imposing cliff.

Beneath the Dox is a massive hardened sandstone, the Shinumo quartzite, which stands in sheer cliffs of brown rock. The quartzite strongly resists erosion and often forms hills on the ancient land surface cut after faulting of the Wedge Series. Beneath the Shinumo is the Hakatai shale, a thin-bedded, bench-forming sequence of the most vividly colored strata in the canyon. Some of the beds are bright vermilion. Beneath them is the cliff-forming Bass limestone which weathers to a dark chocolate brown. The Kaibab trail descends from the Tonto platform to the Inner Gorge at the suspension bridge on downdropped blocks of the Wedge Series. A large area may be seen above the Inner Gorge west of Bright Angel Canyon. Other wedges occur in Bright Angel and Phantom canyons and in the Ottoman and Hindu amphitheaters. Except north of Desert View, the Wedge Series is not very conspicuous or important as a landscape element. It provides only a local variation in the structural and color patterns.

#### THE INNER GORGE

The Colorado River cutting through the Horizontal Series and isolated blocks of the Wedge Series began to erode the narrow canyon known as the Inner Gorge (or Granite Gorge). It has precipitous walls and just a few miles above the mouth of Bright Angel Creek is about 1500 feet deep although only 1700 feet wide. It extends for miles through the central part of the park with a depth of 1000 feet below the Tonto platform at the base of the Horizontal Series.

#### LAND FORMS IN THE VERTICAL SERIES

As the name implies, the Vertical Series consists of rocks which are standing on end. They are mostly ancient strata and lavas which were so changed by heat and pressure when buried deep that the original features were almost obliterated. They



*Figure 21. California Institute-Carnegie Institution expedition of 1937 passing a stretch of quiet water in the Inner Gorge.*

have been invaded by molten granite and have soaked up granitic emanations until it is sometimes difficult to tell whether original rock or granite is present in greater quantity. The metamorphosed ancient sediments (Vishnu schist) weather to brownish black and black. They are cut by a network of pink granite dikes which here and there give a lace-like aspect to the terrain. These most ancient rocks of the Grand Canyon may be a billion and a half years old yet they must be much younger than the original lost crust of the earth.

The various rocks of the Vertical Series are all hard and all are resistant to erosion. From the standpoint of cutting and abrasion they are essentially homogeneous. So the walls of the Inner Gorge are uniformly steep and precipitous, not stepped like those of the Outer Canyon. Except where tributary streams have deposited great boulder deltas, there are few places where a person can walk or even stand along the river. The vigorous stream erosion with its blast of brown silt and mud has fluted and polished the hard rocks of the channel as shown in Figure 13. In places rock fragments or tools have swirled in violent currents cutting potholes like those in Figure 22.



*Figure 22. Granite of the Colorado River channel honeycombed by potholes.*

The Inner Gorge is a dark and somber place. Except at midday, the shadows are long and continuous. In the vicinity of the deltas, great rapids make a constant roar that reverberates through adjacent parts of the Inner Gorge.



*Figure 23. Phantom Ranch, an oasis of comfort and hospitality at the bottom of the canyon.*

## CONCLUSION

The Grand Canyon, awe-inspiring though it is in magnitude and fascinating though it is in coloration and intricacy of lineament, is but the valley of a stream. It was carved by normal and natural processes over a period of several million years. Earth history extending over a billion and a half years is recorded in the Grand Canyon, yet its revelation by canyon-cutting has required only the last brief instant of geologic time. Full enjoyment of this unique national heritage derives not only from its appeal to the human senses but also from its understanding by the human mind.

