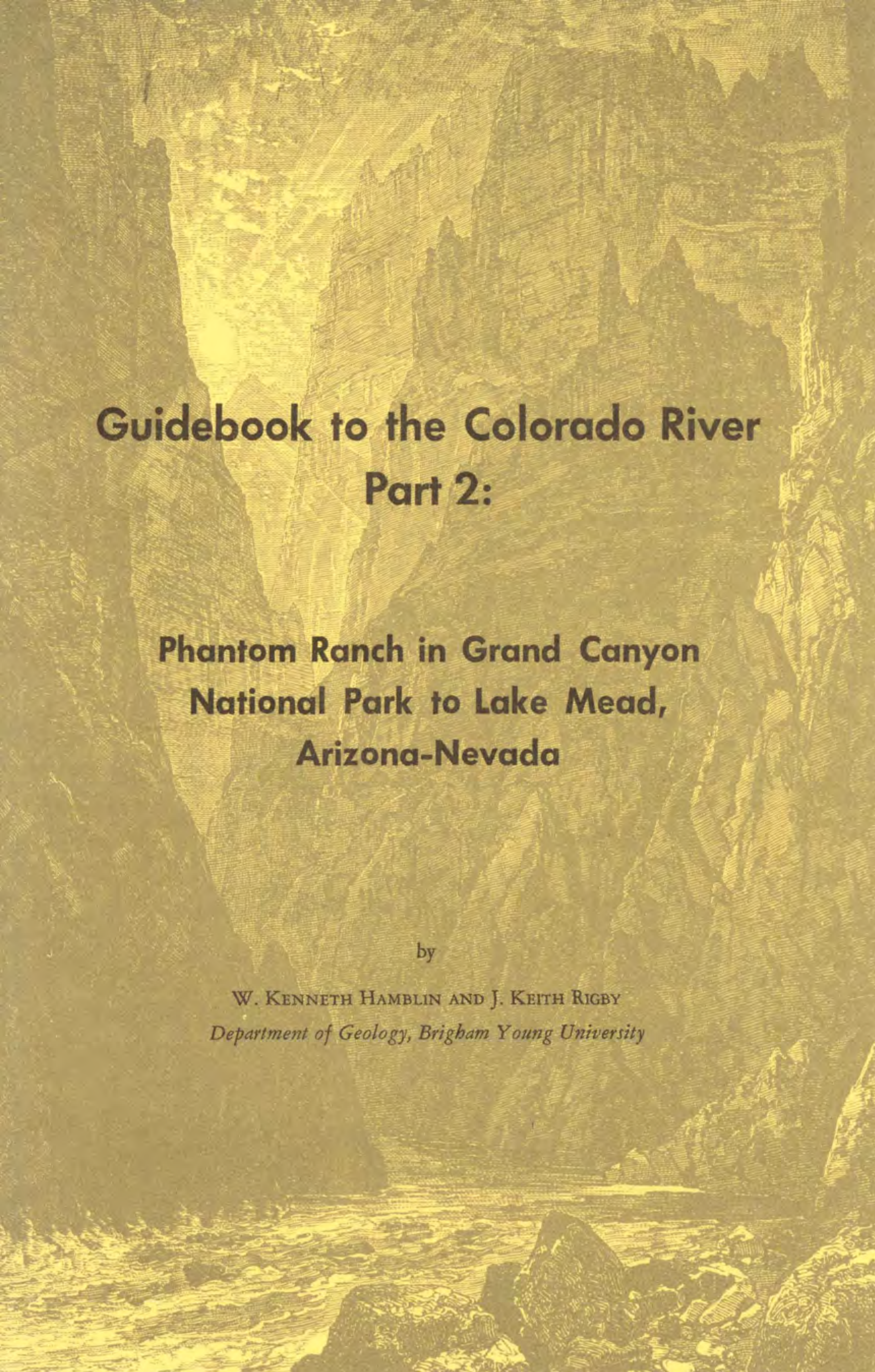

Guidebook to the Colorado River Part 2:

Phantom Ranch in Grand Canyon National Park to Lake Mead, Arizona-Nevada

by

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PREFACE

A trip down the Colorado River through the Grand Canyon is an unique opportunity to study close-at-hand a classic cross section into the earth's crust. Such a trip would not have been practical for students of geology some years ago, but with the innovation of pontoon boats and the establishment of regular float trips through the canyon by experienced boatmen, this trip is now feasible. Experience in taking students down the Colorado River over the past several years as part of their educational program has prompted us to write this and other guidebooks for our geology students and for all interested persons who desire to understand the scenery of the Grand Canyon.

We have written the guide so the trip can be self-conducted. Points are established with reference to mileage downstream from Lee's Ferry, even though this portion of the trip begins at Mile 87.5 at Phantom Ranch. A number of vertical aerial photographs are included in the illustrations and provide complete coverage of the river so that locations can be made without difficulty from the prominent points and mileage labeled on the aerial photographs.

Inasmuch as the scenery of the Grand Canyon is largely a response of geologic phenomena, we have included, in the first part of this guide, brief descriptions of the major features of each formation in the order that they are encountered in the descent from the canyon rim. Interpretation of the environments in which the rocks accumulated is also presented. Individual formations can be examined close-at-hand on both the Kaibab and Bright Angel trails. Trail signs prepared by the Park Service mark the boundaries of each of the major rock units.

This guide is the second in a series being prepared by the staff of the Department of Geology for rivers of the Colorado Plateau where boat trips are feasible. We appreciate the assistance of Mr. William L. Chesser who drew the illustrations, and we are also indebted to Mr. John Cross of Cross Tours who provided boats and equipment on our several trips through the canyon. Dr. Myron Best, Dr. Morris Petersen, and Dr. Lehi Hintze reviewed the manuscript, and together with Dr. Joseph Murphy, accompanied the writers on preliminary trips and offered many valuable suggestions. We are also indebted to personnel of Grand Canyon National Park, Grand Canyon National Monument, and the Lake Mead Recreational Area for their cooperation in assisting us with our research along the Colorado River.

The float trip from Phantom Ranch to Lake Mead offers the opportunity to study and view the examples of practically all of the major geologic features seen within the Grand Canyon. The Paleozoic rocks, which constitute the framework for most of the scenery of the canyon, are seen and studied on the descent from the rim.

The float trip begins near Phantom Ranch within the deep Upper Granite Gorge where ancient metamorphic rocks and isolated patches of Late Precambrian sediments dominate the features seen from the river. The nature of the canyon changes markedly approximately 50 miles downstream from Phantom Ranch, where the float trip proceeds through a deep gorge cut in horizontal Paleozoic rocks beneath the high platform of the Esplanade, approximately 3,000 feet above river level.

Numerous basalt flows are among the major features to be seen in the western segment of the Grand Canyon. These lava flows bear record of repeated cascades of lava into the canyon and of formations of lava dams which modified the late erosional history of the Grand Canyon. Numerous volcanos were also active on the Esplanade and on the Uinkaret Plateau to the north during this stage of canyon development.

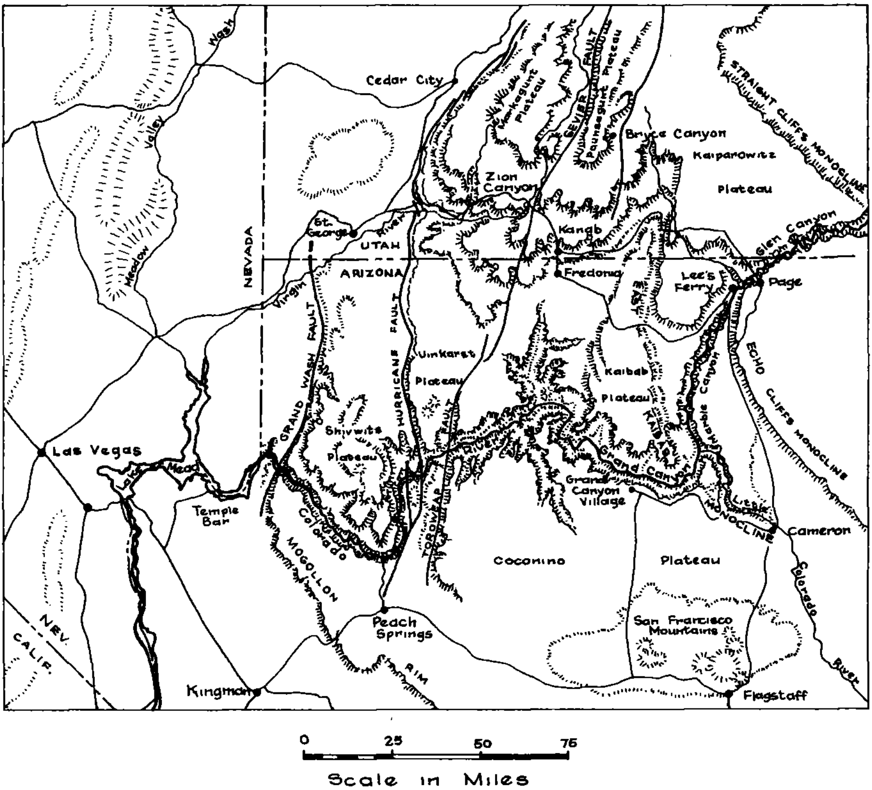
The float trip will proceed through Lower Granite Gorge in the western Grand Canyon and across several major fault zones which have displaced strata many thousands of feet in the western Colorado Plateau. The last few miles of the trip are through a deep vertical-walled gorge cut in Paleozoic formations which produce scenery as dramatic as any along the Colorado River. The canyon ends abruptly at Grand Wash Cliffs where the confining canyon ramparts give way to rolling topography in the Grand Wash region above the serene waters of Lake Mead.

INTRODUCTION

The Grand Canyon of the Colorado River (Text-figure 1) is near the southwestern edge of the Colorado Plateau, a circular area of approximately 130,000 square miles centered around the Four-Corners Area of Utah, Arizona, Colorado and New Mexico. It is a region of primarily horizontal strata in contrast to the deformed rocks of the Basin and Range and southern Rocky Mountains. Many people have referred to the plateau as the "standing up country" for its exceptional rock pinnacles, buttes, mesas, and erosional features are here well expressed. It is also distinguished by great elevation. Except for the canyon bottoms, the region rises to an elevation of 4,000 to 11,000 feet above sea level. It is an arid area where weathered rock debris is moved swiftly to the sea during sudden storms.

The broad Colorado Plateau Province is divided into several sections, each with its own geologic setting and significance. The Grand Canyon section extends from the Utah-Arizona line southward to the Mogollon Rim, a prominent escarpment overlooking the low country of central Arizona, and westward into Nevada to the Grand Wash Cliffs. The Grand Canyon section is characterized by exceptionally broad plateaus formed on top of the Kaibab Limestone. Except for the San Francisco Mountains and other small volcanic patches, the plateau surface is nearly flat, broken only by a few north-south trending faults most of which are located north and west of the canyon (Text-figure 1). Nearly all younger Mesozoic rocks have been stripped from the Kaibab surface and have been eroded back northward to the Utah state line and eastward to the Echo Cliffs.

The Grand Canyon cuts a gorge over a mile deep through the northern end of the flat-topped Kaibab Plateau (Text-figure 1) and exposes a cross section of the earth's crust, which for completeness of exposures and spectacular geo-



TEXT-FIGURE 1.—Map of the southwestern part of the Colorado Plateau showing the major features associated with the Grand Canyon. The Grand Canyon ends at Grand Wash Cliffs which is the boundary between the Colorado Plateau and the Basin and Range Province.

logic features is probably unexcelled in the world. All of the Paleozoic strata beneath the Kaibab Plateau are well exposed in the canyon wall and are readily accessible along the several trails which descend from the rim into the depths of Granite Gorge. In addition, large areas of the basement complex of Early and Late Precambrian rocks upon which the younger strata lie, can be seen in the lower part of the gorge.

Interbedded resistant and nonresistant rock formations in the Grand Canyon produce alternating cliffs and slopes. This pattern is particularly well displayed in the vicinity of Grand Canyon Village and near Phantom Ranch area at the beginning of the boat trip. Bright Angel Shale is thick and has been eroded back some distance from the edge of the inner gorge to form the broad Tonto Platform. Lateral variation in composition of various rock formations, as they are traced toward the west, caused an accompanying change in topographic patterns.

Superposition of several thick carbonate formations in the western canyon produces a vertical-walled gorge and in western exposures the Tonto Platform is poorly expressed. In the same area an upper platform is developed on top of the Supai Formation by lateral retreat of the thick nonresistant Hermit Shale. This western part of Grand Canyon, therefore, is characterized by two rims: an upper rim held up by the Kaibab Formation, and a lower rim held up by the Supai Formation. The broad platform above the lower rim is termed the Esplanade. The upper rim has retreated in most areas far from the rim of the Esplanade in the western part of the Grand Canyon.

Although it is not widely known, it is possible to drive from Kanab or St. George, Utah, southward into the Grand Canyon National Monument region and to camp on the Esplanade at the rim of the inner gorge near ancient volcanos. The National Park Service maintains a gravel road into the Monument region which offers recreational and camping facilities off the beaten path. The scenic region offers an opportunity to escape the crowds that dominate the rim in the central part of the Grand Canyon National Park.

Once one starts down the river below Phantom Ranch there are only a few escape routes from the gorge, all of which would require a fantastic effort. Beyond the park the first of these is in the vicinity of the Havasupai Reservation to the south, or up Kanab Creek to the north. The next downstream is an exceedingly rigorous steep climp up the lava cascades in the vicinity of Vulcan's Throne into the high suspended Toroweap Valley. Exit out of the Grand Canyon, up any of the tributary canyons, would require a hike of many miles without readily available food or water to finally arrive at one of the widely separated southern Utah ranches or towns. A rugged jeep trail is constructed down Whetmore Wash to the canyon rim where a hike of several tens of miles is necessary to reach even a cattle camp unless prior arrangements have been made to be met by four-wheel drive vehicles. The Hualapai Indians have constructed and sometimes maintain a gravel road from Peach Springs, Arizona, down Peach Springs Wash approximately 25 miles to the river near the vicinity of Diamond Peak at Mile 227. Permission is needed from the Hualapai tribal council to use these facilities, and prior arrangements are absolutely essential. The next good exit point downstream is in the headwaters of Lake Mead where the low country west of the Grand Wash Cliffs offers relatively easy access to the river banks. This area, however, is still far removed from civilization. In terms of isolation and rugged terrain in the western Grand Canyon is a region as isolated as any in North America.

TRAILS TO PHANTOM RANCH

Phantom Ranch is located in the deepest part of the Grand Canyon and has limited accessibility (Text-figure 2). It can be approached either (1) down the river from Lee's Ferry by a boat trip, (2) by mule train from either the North Rim or the South Rim through prior arrangements with the concessionaire, or (3) by hiking from either the North Rim or the South Rim along maintained trails. The hike from the North Rim is considerably longer than that from the South Rim since the North Rim is higher and considerably farther away.

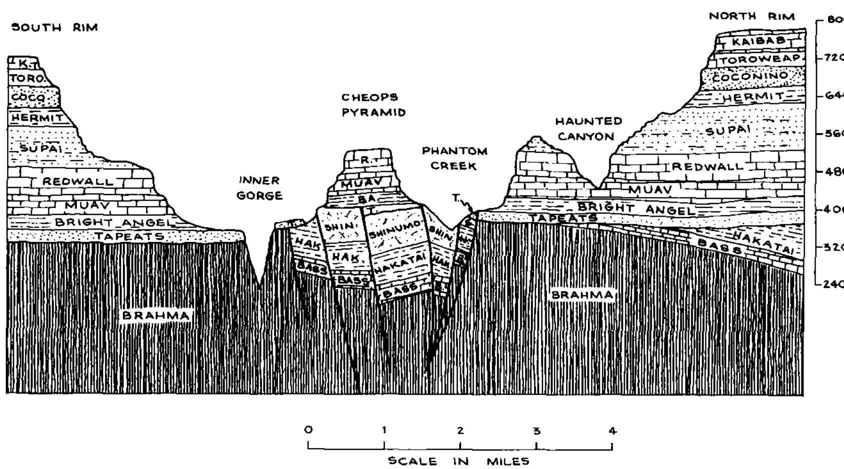
Most ready access is from the South Rim by either the Bright Angel or the Kaibab Trail (Text-figure 2). The Bright Angel Trail leaves the canyon rim in the northwestern part of Grand Canyon Village and descends along Garden Creek and Pipe Springs Creek through Indian Gardens. The Kaibab

TEXT-FIGURE 2.—Aerial photograph of part of Grand Canyon and Grand Canyon Village on the South Rim. The two trails which descend to Phantom Ranch are visible in the lower part of the map. The numbers along the river indicate miles downstream from Lee's Ferry. All of the aerial photographs throughout the text are arranged with the top of the photograph downstream so that objects to the right on the aerial photograph appear to the right when viewed downstream. The Bright Angel Trail to Phantom Ranch drops off the high, forested South Rim along Garden Creek in the central part of the map into the V-shaped inner gorge near where Garden Creek enters the main Colorado River. The broad Tonto Platform, carved in the Bright Angel Shale, separates the prominent vertical cliff of Redwall Limestone from the cliffs of the upper margin of Upper Granite Gorge.

Trail leaves the rim from Yaki Point, approximately four miles east of Grand Canyon Village. The Kaibab Trail from Yaki Point is the shorter of the two trails in from the South Rim but it is almost too steep to be hiked comfortably. Bright Angel Trail is longer but has a lower gradient and, in addition, drinking water is available at points in the upper part of the rim during the normal tourist season and at Indian Gardens throughout the year. No drinking water is available, or, at least, the water which is available is not recommended for drinking, between Indian Gardens and Phantom Ranch. Telephone communication is available at selected points along the Bright Angel Trail. If arrangements have not been made to bring personal gear or camping equipment down from Lee's Ferry as part of a continuing boat trip, pack mules can be arranged from the concessionaire at Grand Canyon Village. Modest amounts of personal gear can be transported in back packs from the South Rim to Phantom Ranch.

It is recommended that at least one full day be allotted for the pack mules to transport personal gear and at least one day is necessary for the hike from the rim to Phantom Ranch. Early arrangements should be made with the concessionaire if any equipment or camping gear is to be transported by mule.

Bright Angel Trail in the upper part of the canyon rim descends through a series of switchbacks and tunnels through the Kaibab and Toroweap formations (Text-figure 3). The normally unbroken vertical wall of the Coconino Sandstone has here been fractured by the Bright Angel Fault, eroded and partially blanketed by talus so a trail could be constructed along the fault trace through the cliff zone. Switchbacks over the Coconino Cliff rubble bring the trail close to the cross-bedded sand in the area above one of the intermediate rest houses. The brick-red Hermit Shale is exposed between the upper and lower rest houses. Here the gradient of the trail slackens somewhat because of the broad slope



TEXT-FIGURE 3.—Cross-section from El Tovar Hotel northward through Cheops Pyramid. The three major rock divisions are clearly shown including the upper sequence of horizontal Paleozoic rocks which form the major walls of the canyon, the tilted Grand Canyon Series beneath Cheops Pyramid, and the old Precambrian metamorphic and igneous rocks in Granite Gorge.

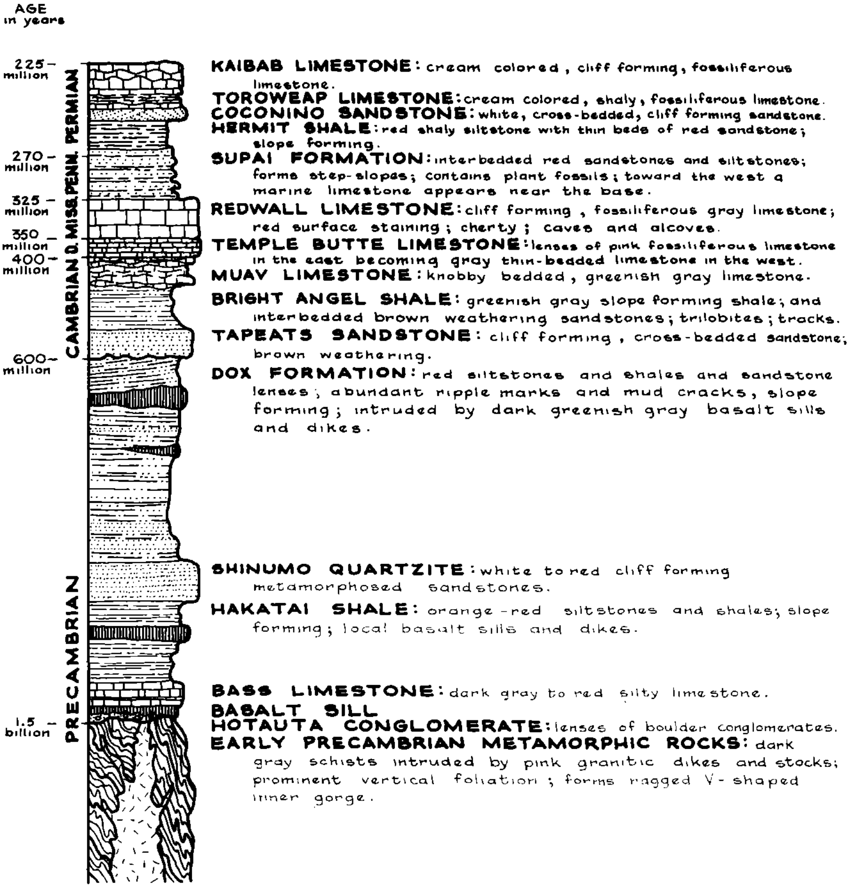
carved on the Hermit beds. The Bright Angel Fault has also offset the high prominent cliff of Redwall Limestone and has allowed construction of a rather steep switchback section of the trail over the Redwall cliff beneath the lower rest house. The gradient of the trail from beneath the Redwall Cliff into Indian Gardens is relatively low, but it steepens again below Indian Gardens in the Tapeats Sandstone where the trail starts down into the Inner Gorge (Text-figure 2). A shady rest is provided by overhangs of Tapeats Sandstone along the trail. In the vicinity of the Tapeats Sandstone the trail swings away from Garden Creek and around into the headwaters of Pipe Springs Canyon where the trail descends in switchback fashion through metamorphosed rocks of the Brahma Schist. The trail continues down the low gradient of Pipe Springs Canyon to a rest house near the inner gorge of the Colorado River. The trail continues upstream along the south bank of the Colorado River through bedrock exposures of Brahma Schist and patches of loose sand, and crosses onto the fan of Bright Angel Creek on a new suspension bridge.

The Kaibab Trail from the South Rim is somewhat shorter than the Bright Angel Trail, but it is steeper and presents a more rigorous hike. Moreover the absence of water makes this a difficult trail in late spring and summer months. As one descends into the canyon the temperature increases rapidly, so without water such a hike could be extremely uncomfortable, if not dangerous. The general trend of Kaibab Trail follows the ridge past O'Neil Butte carved in the Supai Formation. It descends down the steep cliff of the Redwall Limestone past Natural Arches and out onto the Tonto Platform. An excellent view of the inner gorge and the regional aspects of the Grand Canyon can be seen from The Tipoff, a viewpoint on Tapeats Sandstone on the rim of the Granite Gorge. Numerous switchbacks conduct the trail rapidly down to the wall of the inner gorge past exposures of red Grand Canyon Series rocks to the suspension bridge which is abutted in Brahma Schist. The debris fan of Bright Angel Creek and the campground area is downstream a short distance from the bridge.

KAIBAB AND TOROWEAP FORMATIONS (PERMIAN)

The Kaibab and Toroweap formations form the uppermost 500 to 700 feet of strata exposed in the canyon walls (Text-figures 3-5) and constitute the surface upon which the Kaibab Plateau on the north and the Coconino Plateau on the south are carved. They are the most widely-exposed formations in the Grand Canyon region. In the eastern part of the canyon, the Kaibab and Toroweap limestones are separated by a thin, sandy zone which tends to form a slope, so that these two rock formations are generally expressed by two separate cliffs.

Both formations are characteristically well bedded, as seen in many of the outcrops along the trails. When viewed from a distance, however, stratification is generally obscure. There are variable amounts of sandstone and chert in the Kaibab Formation, but the dominant rock type is limestone. The limestone is a creamy yellow-gray although parts of it may be stained reddish-gray from interbedded colored sandstone and siltstone units. Many marine fossils are found in both the formations. More than 80 genera of invertebrate fossils are represented plus a few fossil fish teeth. Where chert is abundant, for example, near the tunnel on the Bright Angel Trail, it generally occurs as nodules and may superficially appear as small boulders and gravel. Many of the spherical nodules are cored by fossil sponges or other invertebrate remains. Large brachiopods, corals,



TEXT-FIGURE 4.—Sequence of rock formations exposed in the Grand Canyon.

some snails, and clams can be seen here and there in cherty limestone beds near the canyon rim on both major trails.

COCONINO SANDSTONE (PERMIAN)

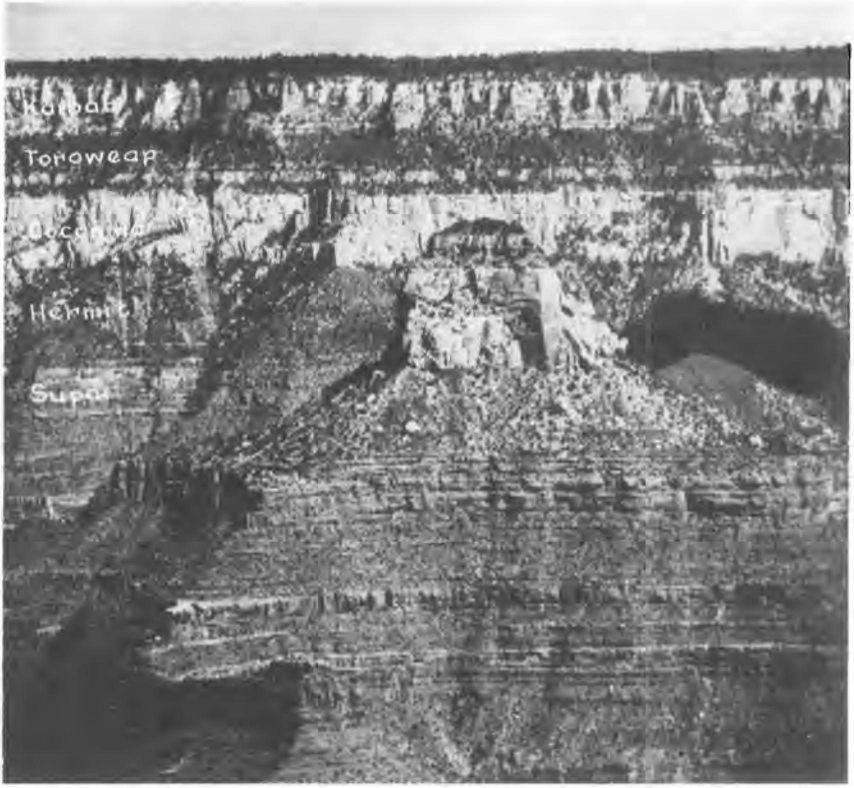
The Coconino Sandstone is the prominent, white-colored, homogeneous, cliff-forming formation beneath the Kaibab and Toroweap limestones (Text-figures 4-6). It is one of the most distinctive and homogeneous formations throughout the Grand Canyon and caps most of the buttes and temples in the national park region. It blends with the Kaibab and Toroweap limestones to form a single unbroken cliff in the eastern part of the park, but near the trails in the central part it forms a single prominent cliff. It is composed of fine-grained, almost pure, quartz sand grains, which are well rounded, pitted or frosted, and show excellent sorting or sizing. The Coconino Sandstone is characterized by well-developed cross-stratification which is the most distinctive and conspicuous feature of the formation when seen from the trails. The cross-

TEXT-FIGURE 5.—The Upper Paleozoic sequence exposed near the top of Kaibab Trail on the South Rim. Hermit Shale forms the slopes near the middle of the sequence of cliffs, with red Supai Formation exposed in step-like fashion below. The prominent light vertical wall above the Hermit slope is the Coconino Sandstone. Overlying broken cliffs are carved in the Kaibab and Toroweap formations.

strata are similar to that in the Navajo Sandstone in Zion Park, and they develop low, sweepingly-inclined laminae, some of which are as much as 70 feet long. Such cross-laminated structure is typical of that found in modern sand dunes. Ripple marks are also preserved in many parts of the Coconino Sandstone, as are a large number of fossil footprints. At least 22 varieties of fossil tracks have been found, all of which have been interpreted as having been made by reptiles. No other fossils or evidences of life have been found in the formation. The dune-like cross-stratification in the Coconino Sandstone, together with the reptile tracks and ripple marks, indicates that the sediments accumulated in a great desert. Its present distribution over 32,000 square miles has led many geologists to postulate a depositional environment similar to that of the present-day Sahara or Arabian Deserts.

HERMIT SHALE (PERMIAN)

The Hermit Shale, a sequence of thin-bedded, red and maroon shales, siltstones, and fine-grained mudstones, occurs beneath the Coconino Sandstone (Text-figures 2, 4, 5), and weathers to a continuous prominent slope. The formation is characteristically deep red and is responsible for much of the red staining of lower units in the Grand Canyon. Along the trail the Hermit Shale



TEXT-FIGURE 6.—Buddha Temple and the North Rim as viewed from the Kaibab Trail. The resistant rock which holds up the pyramid-shaped pinnacle of Buddha Temple is the Coconino Sandstone which also forms the white second cliff below the rim of the canyon on the north rim. The small alternating cliffs and slopes in the red sandstones below are the Supai Formation.

is only 200 to 300 feet thick, but in the western Grand Canyon it thickens to more than 900 feet.

Thirty-five species of fossil plants have been described from the Hermit Shale within the Grand Canyon region, many of which have not been found anywhere else in the world. These plants apparently represent a savannah-type environment with long, dry seasons.

SUPAI SANDSTONE (PENNSYLVANIAN AND PERMIAN)

A sequence of red, thick-bedded sandstone shale and siltstone occurs beneath the Hermit Shale and has been named the Supai Sandstone. This formation characteristically erodes into step-like slopes (Text-figures 5, 6) with individual sandstone beds forming small, nearly vertical ledges, and the interbedded shale eroding back to form small slopes. Throughout much of the park the Hermit Shale is considered only as the upper unit of the Supai Formation. In many places, especially where the Hermit Shale is thin, the contact between the Supai and the Hermit formations is difficult to identify, especially from a distance.

Supai rocks are red-colored in the main and, together with the Hermit Shale, contain a number of fossil plants. Some fossil ferns and other primitive plants, together with numerous tracks of four-footed animals, constitute the only fossil remains found in the middle and upper part of the formation.

Lowermost Supai rocks in the western part of the Grand Canyon are composed of thin-bedded limestones which erode to form a rather prominent slope beneath the more massive sandstone units of the main part of the formation. Marine fossils have been found only within the lenses of these lower limestone units.

REDWALL LIMESTONE (MISSISSIPPIAN)

The Redwall Limestone is one of the most distinctive and prominent formations within the Grand Canyon (Text-figures 2 and 4). It characteristically weathers into an unbroken cliff more than 500 feet high, stained red from the overlying Hermit and Supai formations. The Redwall cliff is located almost midway between the river and the canyon rim in the national park area and is responsible for many of the majestic alcoves, mesas, and buttes within the canyon proper. It weathers and erodes into a vertical cliff in Marble Gorge and has been polished by water action of the river. Powell was impressed at this sight and called this a marble, naming this section of the canyon Marble Canyon.

The Redwall Limestone is medium gray on fresh exposures (Text-figure 7) but is colored by a superficial red stain derived from the overlying formations. It is characteristically well bedded, but, when viewed from a distance, it appears almost as a single massive unit, because the subtle divisions between strata are not etched out in sufficient relief to be seen from the canyon rim. In many places, especially in the lower part of the Redwall cliff, beds of bright red jasper are found, some of which are semiprecious gem quality. The Redwall Limestone is a very pure calcium carbonate rock containing less than one percent sand and shale particles. Its origin is as interesting as its topographic expression. The pure limestone indicates that it was formed in a relatively wide, shallow, quiet sea, far from shale and clay deposition near the shore. Fossil sea shells and a wide variety of other marine life including common corals are found within the Redwall Limestone. Most of the fossils are preserved in remarkable detail.

The Redwall Limestone is susceptible to much solution activity by groundwater and has produced numerous temples (Text-figure 8), pillars, caves, solution caverns, arches, and springs within the canyon. In several places these solution features give rise to a number of important springs, like those along Havasu Creek or Cheyava Falls where large quantities of water can be seen issuing forth from the rocks.

TEMPLE BUTTE LIMESTONE (DEVONIAN)

The Temple Butte Limestone is one of the most inconspicuous formations in the eastern part of the Grand Canyon (Text-figure 4). It was named by Walcott in 1889 for exposures in the vicinity of Temple Butte which is located 3 miles south of the junction of the Little Colorado River. Temple Butte Limestone occurs only as isolated lenses between the Redwall cliff and the underlying Muav Formation throughout the eastern part of Grand Canyon, and often blends with the Redwall Limestone. In order to recognize Temple Butte beds

TEXT-FIGURE 7.—The Redwall Limestone cliff as seen from Kaibab Trail. The nature of the limestone is well exposed in this section of the trail. It is not overlain here by red Supai rocks and hence is not stained its typical red color. The cream-colored to gray limestone is well bedded and most outcrops expose numerous fossils.

from a distance one must carefully examine the exposures for structural breaks or erosional surfaces. The Temple Butte Limestone occurrence, however, does have very important connotations concerning the early geologic history of the Grand Canyon area, because of its unconformable relationship with the Cambrian rocks below and the Mississippian rocks above.

The Temple Butte Limestone in eastern exposures consists of large lenses of medium-bedded limestone which has a characteristic purplish-gray to pinkish-gray color. These lenses vary considerably in dimensions, many more than 400 feet across and 50 feet thick, but some only a few tens-of-feet wide also occur. They are eroded down into the underlying Muav Limestone and generally have a conglomeratic zone near their base. In the western Grand Canyon the

Temple Butte Formation forms a continuous evenly thin-bedded unit more than 200 feet thick. Fossils within the limestone indicate that the formation is of Upper Devonian age and is bounded by two significant unconformities in the Paleozoic sequence. The channeled base of Temple Butte Limestone indicates that after Cambrian sediments were deposited, but before Temple Butte sediments were laid down, this region of the Colorado Plateau was subjected to a period of erosion, during which any Ordovician and Silurian rocks which may have been deposited were removed. The fact that the upper contact of the Temple Butte Limestone is also an erosional surface indicates that prior to deposition of the Redwall Limestone a younger period of erosion occurred in the Grand Canyon region.

MUAV LIMESTONE (CAMBRIAN)

The Muav Limestone (Text-figures 4, 9) occurs beneath the Redwall Limestone in much of the area near the trail as a sequence of alternating gray limestone and greenish gray calcareous siltstone. This formation characteristically erodes into three units within the national park area. The basal cliff is followed by a sequence of small ledges and slopes which is overlain by an upper cliff member nearly twice as thick as the basal unit. The Muav Limestone is greenish-gray and when seen near the river is very thinly bedded. Upon close

TEXT-FIGURE 8.—Sumner Butte on the north side of the inner gorge as viewed from the Kaibab Trail. Sumner Butte is held up by the resistant Redwall Limestone with the slopes below in the Bright Angel Shale. Tapeats Sandstone forms the cliff on top of the ragged-appearing metamorphic rocks of the Granite Gorge.

examination, one can see that individual limestone beds were broken into small fragments by ancient wave and current action immediately following deposition of thin beds, thus producing a somewhat heterogeneous, conglomerate-appearing rock type.

Fossil trilobites and ripple marks appear at various horizons within the Muav Limestone and indicate a relatively shallow marine environment of deposition for the formation. It is the youngest Cambrian formation within the Grand Canyon and is separated from the overlying Redwall or Temple Butte Limestone by an erosional surface into which various channels were eroded.

BRIGHT ANGEL SHALE (CAMBRIAN)

A sequence of fine-grained, mostly thin-bedded, light greenish-gray, silty shale beneath the Muav Limestone is referred to as the Bright Angel Shale (Text-figures 2, 4). The formation ranges in thickness up to 450 feet. The shale is weak and very susceptible to erosion and as a result has been eroded back from the underlying Tapeats Sandstone to form a broad terrace known as the Tonto Platform in the park area (Text-figures 8, 9). This terrace is one of the most significant topographic features within the national park area. It is approximately 3,000 feet below the canyon rim, held up by the Kaibab Limestone. In the western part of the canyon, part of the Bright Angel Shale becomes sandy and the Tonto Platform is less well-developed. Three general types of fossils have been found within the Bright Angel Shale, all of which indicate it is of Cambrian age. Small, thin shells of extinct brachiopods are abundant, as are trilobites and many fossil tracks and trails. The latter are attributed to both trilobites and worms. The Bright Angel Shale is considered to be one of marine origin representing deposition of silty muds in a shallow sea environment.

TAPEATS SANDSTONE (CAMBRIAN)

The Tapeats Sandstone is the lowest Paleozoic formation (Text-figure 4) and is one of the most persistent and prominent rock bodies in the canyon. It is 200 to 300 feet thick and is easily recognized because it characteristically weathers into a nearly vertical cliff immediately below the slope developed on the overlying Bright Angel Shale and forms the ramparts on top of Granite Gorge (Text-figures 2, 8, 9).

Tapeats outcrops characteristically contain horizontal layers which have small-scale internal cross-stratification which can be seen on the trail. The rock commonly weathers to a dark brown, but fresh surfaces are much lighter. It is composed mostly of coarse quartz sand grains, and like the Bright Angel Shale contains several varieties of marine Cambrian fossils. The Tapeats Sandstone can be traced through the entire canyon with only a few interruptions. Where it overlies the Precambrian metamorphic rocks it forms a striking contrast in development of land forms, but where it overlies the gently dipping sedimentary rocks of the Grand Canyon Series the contrast is somewhat less obvious.

THE GREAT UNCONFORMITY

The buried erosional surface beneath the Tapeats Sandstone constitutes one of the most significant boundaries between rock bodies within the canyon (Text-figures 4, 8, 9). This surface marks an important discontinuity within the sequence of rocks and is referred to as the Great Unconformity. In most un-

TEXT-FIGURE 9.—View of Grand Canyon looking west from the Kaibab Trail. Segments of the Bright Angel Trail can be seen leading down across the Tonto Platform to Lookout Point over Granite Gorge.

conformities there is a structural discordance between the rock bodies which indicates an interruption in geologic processes. The older rocks show evidence of deformation and erosion prior to deposition of the younger strata. This is clearly expressed in the Grand Canyon region where the Tapeats Sandstone is deposited on the tilted and eroded edges of either the Grand Canyon Series or on the older metamorphic rocks, so that a marked discontinuity is readily apparent. Geologically, an unconformity is significant because it shows an interruption in rock-forming processes, usually accompanied by geologic events involving structural deformation, uplift, and erosion.

In the Grand Canyon the Great Unconformity probably represents a time interval of many millions of years, for throughout most of the Grand Canyon a sequence of rocks, approximately 12,000 feet thick has been eroded and removed prior to deposition of the Tapeats Sandstone. In most of the canyon the Great Unconformity appears as a nearly horizontal surface. On the trail at The Tip-off on the rim of Granite Gorge this erosional surface is carved upon the tilted red siltstones and shales of the Grand Canyon Series, but when the surface is traced westward and downstream, the Grand Canyon Series has been completely removed and the unconformity is developed upon the ancient metamorphic complex. In much of Granite Gorge the Tapeats Sandstone rests directly upon this erosion surface and over 12,000 feet of rock is represented by the unconformity. In several places the Tapeats Sandstone is absent and resistant units in the underlying Grand Canyon Series, such as the Shinumo Quartzite, are overlain directly by the middle units of the Bright Angel Shale (Text-figure 10). The Shinumo Quartzite obviously existed as erosional remnants or low mountain ridges, some of which were 800 feet high, during the time the Tapeats Sea flooded the region. It was not until Bright Angel time that hills on the Precambrian Grand Canyon Series were completely covered. Close inspection of the unconformity will reveal an ancient "soil," or decayed rock, developed upon the Precambrian rocks. In some places this soil profile is more than 50 feet thick.

TEXT-FIGURE 10.—View of the Granite Gorge from The Tipoff on the Kaibab Trail. The rugged exposures of Precambrian metamorphic rocks are overlain here by the tilted red strata of the Precambrian Grand Canyon Series. Bass, Hakatai and Shinumo formations are exposed beneath Cheops Pyramid. Under the Paleozoic rocks the Hakatai Shale forms the slope below the Shinumo cliff and above the small cliff of Bass Limestone. The gravel bars in the center of the Colorado River are a result of overloading of the river with debris brought in by Bright Angel Creek. Bright Angel Trail follows the shadowed bank near river in the lower left of the photograph.

LATE PRECAMBRIAN ROCKS

THE GRAND CANYON SERIES

A very thick sequence of fine-grained sandstones, siltstones, and shales which have been tilted to angles ranging up to 15 degrees are exposed as isolated remnants in the National Park area. These rocks stand out in marked contrast to the overlying horizontal Paleozoic strata and are referred to as the Grand Canyon Series (Text-figure 4). They are somewhat isolated and are seen in only a few places, hence these rocks have not received the same attention as that given to overlying Paleozoic units. The Grand Canyon Series is remarkable in that it represents an accumulation of silt, shale, and sandstone over 12,000 feet thick, with very little variation in rock type. These rocks are typically nonresistant and where considerable thicknesses of the series are exposed, such as the area below Desert View, the canyon floor is characterized by a wide-open valley with rolling hills.

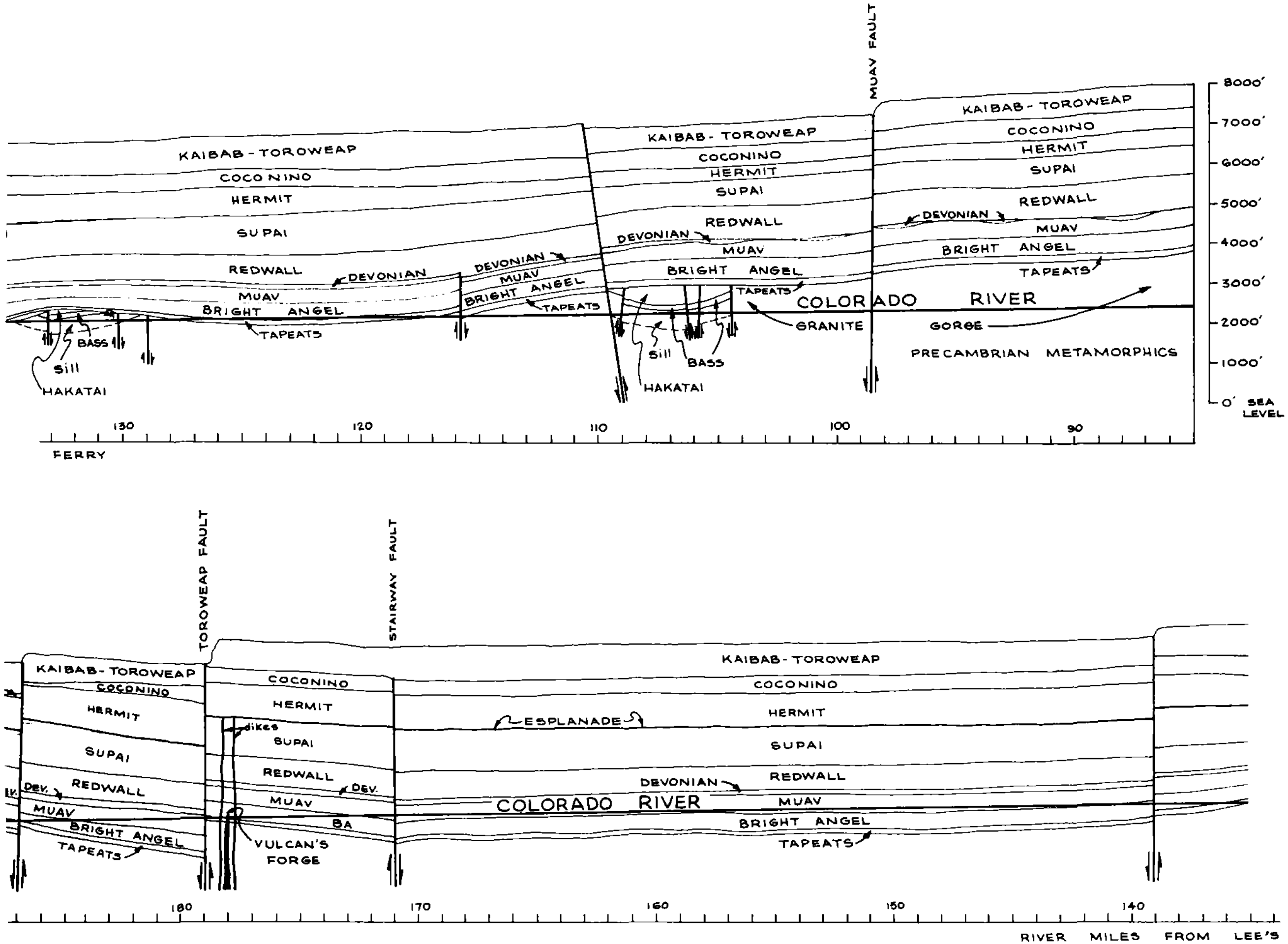
The Grand Canyon Series is divided into two groups of rocks. The upper, or Chuar Group, is not seen on the river trip but is known in fault blocks to the northeast. The lower, or older Unkar Group, is seen in isolated outcrops and is subdivided into the following formations listed from oldest to youngest: (1) Hotauta Conglomerate—the lowest unit in the Grand Canyon Series; (2) Bass Limestone; (3) Hakatai Shale; (4) the Shinumo Quartzite—a relatively clean quartz sandstone and the most resistant formation in the Grand Canyon Series; (5) the Dox Formation—which forms the great bulk of red shale and siltstone overlying the Shinumo Quartzite; and (6) the Nankoweap Formation (not seen in the Phantom Ranch and western Grand Canyon area).

DOX FORMATION (LATE PRECAMBRIAN)

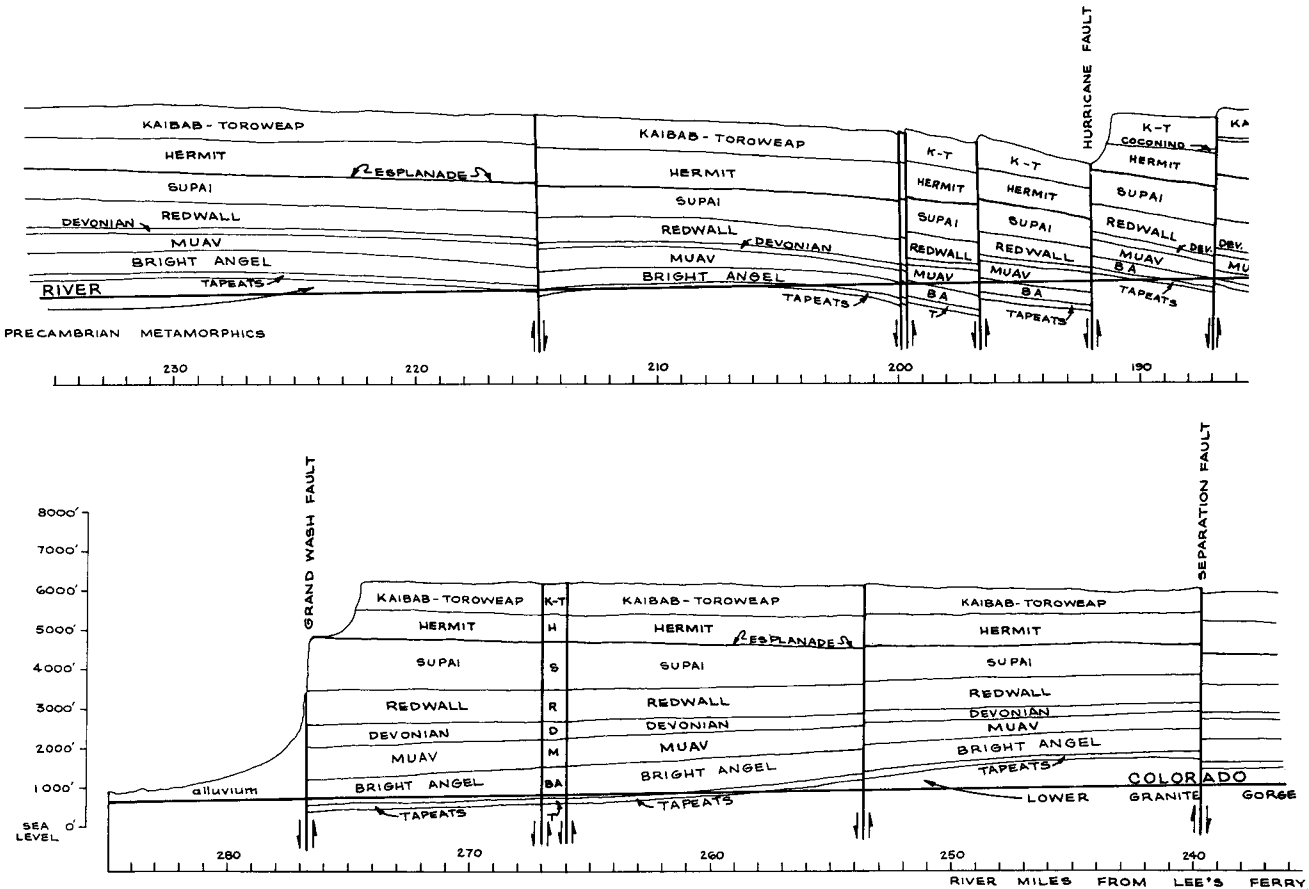
The great bulk of the Grand Canyon Series seen from Desert View and Lipan Point consists of red, thin-bedded shales and siltstones. These rocks are relatively nonresistant to erosion and easily break down into gentle, sloping hills. Where a considerable thickness of the formation is exposed a very broad open area develops unlike any other region in the canyon. Only limited remnants of the Dox Formation are preserved west of Grand View Point and this formation is not seen in the western Grand Canyon, although a small exposure occurs in the headwaters of Bright Angel Creek. Large intrusions of dark basaltic lava have been injected as sills within various layers of the Dox Formation and form very prominent, dark-gray cliffs in the area below Desert View and east of Palisades of the Desert. In addition, a number of small, dark dikes also have intruded into the Dox beds, all of which indicate significant volcanic activity associated with the general period of deposition of the Grand Canyon Series.

SHINUMO QUARTZITE (LATE PRECAMBRIAN)

The most resistant formation in the Grand Canyon Series is the Shinumo Quartzite which directly overlies the Hakatai Shale and is well exposed in several localities within the canyon. One of the largest exposures seen on the trip is below Cheops Pyramid west of Phantom Ranch (Text-figure 10). Shinumo beds can be seen on the trail near The Tipoff on the Kaibab Trail. This formation ranges up to approximately 1,100 feet thick and is characterized by almost pure quartz sandstone, tightly cemented, with silica. On fresh exposures it is reddish-brown to gray. It forms a very resistant cliff and in many



MUAV FAULT
KAIBAB - TOROWEAP
COCONINO
HERMIT
SUPAI
REDWALL
DEVONIAN
MUAV
BRIGHT ANGEL
TAPEATS
COLORADO RIVER
GRANITE
GORGE
PRECAMBRIAN METAMORPHICS
BASS
Sill
HAKATAI
8000′
7000′
6000′
5000′
4000′
3000′
2000′
1000′
0′ SEA LEVEL
130
120
110
100
90
FERRY
TOROWEAP FAULT
STAIRWAY FAULT
ESPLANADE
dikes
DEV.
BA
VULCAN'S FORGE
180
170
160
150
140
RIVER MILES FROM LEE'S



TEXT-FIGURE 11.—Cross-section showing the rock sequence along the river from Phantom Ranch to Grand Wash Cliffs. The profile is along the north or right wall of the canyon.

places can be seen rising above the general surface of the Great Unconformity. The Shinumo Quartzite stands out in marked contrast to the nonresistant red Hakatai Shale below. Shinumo bedding consists of crude horizontal layers which range from a few inches to several feet thick.

HAKATAI SHALE (LATE PRECAMBRIAN)

The Hakatai Shale (Text-figure 10) consists of a sequence of brown and red shale, 600 to 800 feet thick, which occurs below the Shinumo Quartzite and directly overlies the Bass Limestone. Numerous ripple marks and mud cracks are obvious in this formation and indicate very shallow water deposition in which the sediments were repeatedly subjected to dessication. Excellent exposures of the Hakatai Shale are seen on the Kaibab Trail below The Tipoff.

BASS LIMESTONE (LATE PRECAMBRIAN)

The Bass Limestone is a relatively inconspicuous formation within the Grand Canyon, but it constitutes a moderately resistant cliff approximately 250 feet high which can be seen downstream from The Tipoff (Text-figure 10) on the Kaibab Trail. Folded Bass Limestone can be seen from Bright Angel Trail above the rest house at the mouth of Garden Creek. The Bass Limestone is a silty, reddish-gray bedded unit which contains impressions of organisms which are among the oldest direct evidences of life on earth. It is probably of marine origin. The Kaibab Trail crosses the Bass Limestone in the switchbacks above the Gauging Station near Phantom Ranch.

HOTAUTA CONGLOMERATE (LATE PRECAMBRIAN)

The Hotauta Conglomerate occurs in local lenses and contains many of the various rock types found in the underlying metamorphic rocks but is not seen from the trails in the vicinity of Phantom Ranch. The most common are fragments of granite and quartz dikes, as well as some minor fragments of the schist. Most of the cobbles and boulders are well-rounded in the upper part of the Hotauta, but near the base the fragments are highly angular and poorly sorted. The deposit is crudely stratified. The conglomerate is indurated and breaks across, rather than around, the gravels. It occurs as patches and lenses locally above the Vishnu or Brahma Schist but is not a widespread unit.

THE EARLY PRECAMBRIAN UNCONFORMITY

A major erosional surface, similar in most respects to the Great Unconformity, separates the sediments of the Grand Canyon Series from the underlying metamorphosed rocks (Text-figure 4). Only limited exposures of this unconformity are preserved because the Grand Canyon Series has been removed in most areas during the development of the Great Unconformity. When seen along the river the early Precambrian Unconformity appears as a nearly planar surface or a straight line, parallel to bedding in the overlying Grand Canyon Series (Text-figures 10, 11). A significant "soil" profile is developed on this surface and all physical evidence indicates that this discontinuity represents a great interval of time.

Metamorphic rocks like these below the Early Precambrian Unconformity are interpreted to form only at great depth and under high temperatures and pressures. A considerable amount of uplift and erosion is therefore necessary to expose them at the earth's surface. The contact of sedimentary and metamorphic rocks clearly implies that the metamorphic rocks represent exhumed "roots" of very ancient mountains. The folding which produced these mountains took place approximately 1.5 billion years ago, prior to deposition of the Grand Canyon Series.

The Early Precambrian Unconformity is one of the most important boundaries between major rock units within the canyon, and even a person with little geologic background can recognize the sequence of events necessary for its development and can gain an insight into the immense magnitude of geologic time.

EARLY PRECAMBRIAN ROCKS

VISHNU SCHIST, BRAHMA SCHIST, AND ZOROASTER GRANITE

The oldest rocks within the Grand Canyon are exposed within Granite Gorge (Text-figures 2, 4) and are characteristically dark somber gray. They respond to erosion to form a steep-walled V-shaped gorge (Text-figures 12, 13) through which the Colorado River flows downstream beyond Phantom Ranch. These dark colored rocks are evidence of extensive deformation, during which they were subjected to intense heat and pressure and the effects of fluids and gases. The original sedimentary or volcanic characters have been extensively modified and in some cases obliterated. Early Precambrian rocks are not stratified but possess a planar structure known as *foliation,* resulting from reorientation of platy minerals, crystals, and grains in response to deformation. Foliation throughout most of Granite Gorge is nearly vertical which contrasts with the horizontal stratification of the overlying younger rocks.

Three major rock bodies are found within the Early Precambrian complex. The first encountered in the Phantom Ranch area and seen on both trails consists of black to dark green metamorphosed volcanic rocks. This body of rocks is known as the Brahma Schist and is exposed downstream for approximately 6 miles to the vicinity of Granite Rapids. It represents part of the older rocks of the earth's crust and consists primarily of recrystallized basaltic lavas similar to those appearing in unmetmorphosed state starting at Mile 177.

Downstream from Granite Rapids is a different sequence of metamorphic rocks which are brown to gray and consist largely of micas and quartz. These rocks are known as the Vishnu Schist and represent metamorphosed sedimentary rocks. Numerous granitic dikes have intruded into these metamorphic rocks, especially the Brahma Schist. Most of these dikes are nearly vertical and parallel to foliation of the schists and stand out in marked contrast to the metamorphic material. Rocks of the dikes are characteristically pink, and composed of large interlocking crystals of feldspar and quartz, many of which are over a foot in diameter. These intrusions become very numerous in many areas and in some localities make up more than 50 percent of the rock body.

Large granite bodies of the inner gorge are referred to as the Zoroaster Granite and represent a period of igneous activity after deposition and metamorphism of both the Brahma and Vishnu schists but before deposition of the overlying Grand Canyon Series and Paleozoic formations.

To fully appreciate the river trip, one should become familiar with the significant features to be seen in the metamorphosed complex of the Brahma

TEXT-FIGURE 12.—Phantom Ranch as viewed from near The Tipoff on the Kaibab Trail. Bright Angel Creek flooded in 1966 and erosional scars are being repaired. Bedrock above Phantom Ranch is the Precambrian Brahma Schist.

and Vishnu schists, for several rock types are present. The most common is a greenish-black schist which is characterized by nearly vertical foliation. It responds to erosion to form the very rough, jagged walls of the inner gorge. Igneous dikes intrude into the metamorphic complex and are most commonly ridge or ledge-formers or form fins where vertical. In some places these dikes form a laced network, with individual intrusions more than 40 feet thick, although they commonly pinch and swell along the walls of the canyon. One can immediately recognize that intrusion of the dikes took place long before deposition of the overlying Paleozoic rocks, for the dikes terminate abruptly at the contact with the horizontal Cambrian Tapeats Sandstone.

Prior to boat departure from Bright Angel Creek, or if camp or lunch stops are made within Granite Gorge, one can examine the metamorphic rocks and the

TEXT-FIGURE 13.—View of Grand Canyon, northwest from Pima Point on the South Rim, showing the inner gorge, Tonto Platform and the overlying sequence of cliffs of Paleozoic rocks near Mile 93. The Mauv Fault can be seen in the center background as an offset in the Coconino and Kaibab formations. Boucher Rapids at Mile 96 is near the bend in the river visible in the inner gorge.

associated pink granitic dikes closely and see intricate association of intruded igneous material. Large crystals of pink feldspar can be seen along the canyon walls as they reflect sunlight from cleavage planes.

Gneiss is another prominent rock type found in Granite Gorge. Complex folding is commonly present in these banded rocks, as are veins of white quartz. Downstream where Paleozoic rocks are exposed close to river level, one is afforded an excellent opportunity to study the Great Unconformity and erosional surface formed on top of the metamorphic complex.

PHANTOM RANCH

A camp was established along Bright Angel Creek during construction of the North and South Kaibab Trails about the turn of the century. It was a popular campground for tourist parties guided largely by David Rust and became known as Rust's Camp. Rust planted cottonwood and fruit trees and constructed irrigation ditches. Many of the large cottonwood trees in the bottom (Text-figure 12) now are remnants of his initial planting. Teddy Roosevelt stopped at Rust's Camp in 1913 and the name was changed to Roosevelt's Camp until 1922, when it was named Phantom Ranch after nearby Phantom Creek. After the area was taken over by the national park, beginning in 1933, the Civilian Conservation Corps accomplished much of the construction work on the trail and the campgrounds in the Phantom Ranch area. At Phantom Ranch they built a campground, planted more trees, and constructed a swimming pool. Phantom Ranch is operated by a concessionaire. Reservations are necessary for any accommodations such as rooms, meals, or pool. A free campground is maintained near the mouth of Bright Angel Creek. Much of the original beauty and some of the buildings, however, were destroyed during the flash flood of 1967.

The first facility for crossing the Colorado River was a small, flat-bottomed boat ferry system which was operated until 1907 when a suspended cable and cage system was built and operated with pulleys. This system was operated until 1921 when the National Park Service constructed a swinging suspension bridge at the same site. The movement of the bridge made it necessary to dismount and lead the mules across one at a time. The swinging bridge was almost destroyed in 1923 by a violent windstorm, but it was restored and functioned until 1928 when the present rigid suspension bridge was constructed.

This bridge is 440 feet long and is 78 feet above low water. It is supported by eight main steel cables, each 550 feet long, $1\frac{1}{2}$ inches in diameter, and each of which weighs 2,320 pounds. These cables were too heavy to be loaded on mules so it was necessary to hire 42 Havasupai Indians who spaced themselves 11 feet apart, hoisted the cable to their shoulders, and proceeded down the trail like a giant centipede. This necessitated eight trips to transport the main cables. Because of the heat during the summer most of the construction of the bridge was done by night.

The cable crossing upstream from the old suspension bridge is part of a gauging station maintained by the U. S. Geological Survey for measuring discharge and silt of the river.

A newer rigid suspension bridge across the Colorado River was recently constructed for the pipeline which brings water from Roaring Springs on the north wall to the tourist facilities on the South Rim. Materials for this bridge were brought in by helicopter.

THE RIVER

From Lee's Ferry to Lake Mead (Text-figure 1) the Colorado River flows through Marble Canyon and Grand Canyon, a distance of 285 miles. In traversing this distance it falls from an elevation of 3,090 feet at Echo Cliffs to 870 feet above sea level at Lake Mead. The average gradient is approximately 7.7 feet per mile, or more than 25 times that of the Mississippi River. The depth and width of the canyon through which the river flows are directly related to the height of the Kaibab Plateau above the river. The Grand Canyon was cut by the Colorado River through the Kaibab Plateau during great earth movements which elevated the platform as the stream sawed through the rising blocks to maintain its constant gradient.

Between Phantom Ranch and Lake Mead, the canyon is separated into five natural subdivisions as seen from the Colorado River: an Upper, Middle, and Lower Granite Gorge and two intervening sections where Paleozoic rocks form the vertical inner gorge at river level (Text-figure 11). For the first several miles the river trip is through Upper Granite Gorge of the Colorado River in the narrow, deep, V-shaped canyon. In this section the Grand Canyon opens to over 12 miles wide and 1 mile deep and is floored by the broad Tonto Platform above the steep inner gorge (Text-figure 2). Upper Granite Gorge is approximately 28 miles long from Phantom Ranch to where Precambrian rocks disappear beneath river level downstream near Mile 115. Middle Granite Gorge has a relatively narrow, shallow, V-shaped inner gorge because only a relatively limited thickness of Precambrian rocks is exposed from river level to the overlying Paleozoic strata. This distribution is related to the relative minor amount of uplift on the West Kaibab Monocline. Lower Granite Gorge, in the western part of the canyon, is as spectacular but not quite as deep as Upper Granite Gorge in the Grand Canyon proper. Lower Granite Gorge begins near Mile 212 and continues downstream to Mile 259, a distance of approximately 47 miles.

The canyon between Middle and Upper Granite Gorge is only a few miles long and is characterized by a vertical-walled inner gorge with Cambrian rocks at river level. In contrast Middle and Lower Granite Gorges are separated by nearly 75 miles. In this section Cambrian, Devonian, and Mississippian carbonate rocks are superposed and erode to form an imposing deep inner gorge. In addition, volcanic activity is seen in layered ash, cinder cones, frozen "lava falls," and intracanyon flows.

The natural flow of the river has been checked by construction of dams upstream so that now the discharge varies only moderately. Before construction of the dams, however, the stream ranged from 1,300 to 300,000 second feet of water, with an average of approximately 23,000 second feet throughout the year. Depth of the river reaches 50 feet and widths of 300 to 400 feet are common. During the floods before construction of Glen Canyon Dam, the river is reported to have risen 50 or 60 feet and in exceptionally narrow channels rises of 100 feet were noted. Construction of Hoover Dam and the impoundment of Lake Mead have affected development of rapids and the erosional profile in the western part of the Grand Canyon as dramatically as Glen Canyon Dam has affected the erosional pattern in the upper part of the canyon. Thick blankets of silt have accumulated in the headwaters of Lake Mead as a result of flood activity on the Colorado River. With the construction of Glen Canyon Dam, the level of Lake Mead has been lowered, and now a rather distinctive inner channel has been cut through these recent silt deposits.

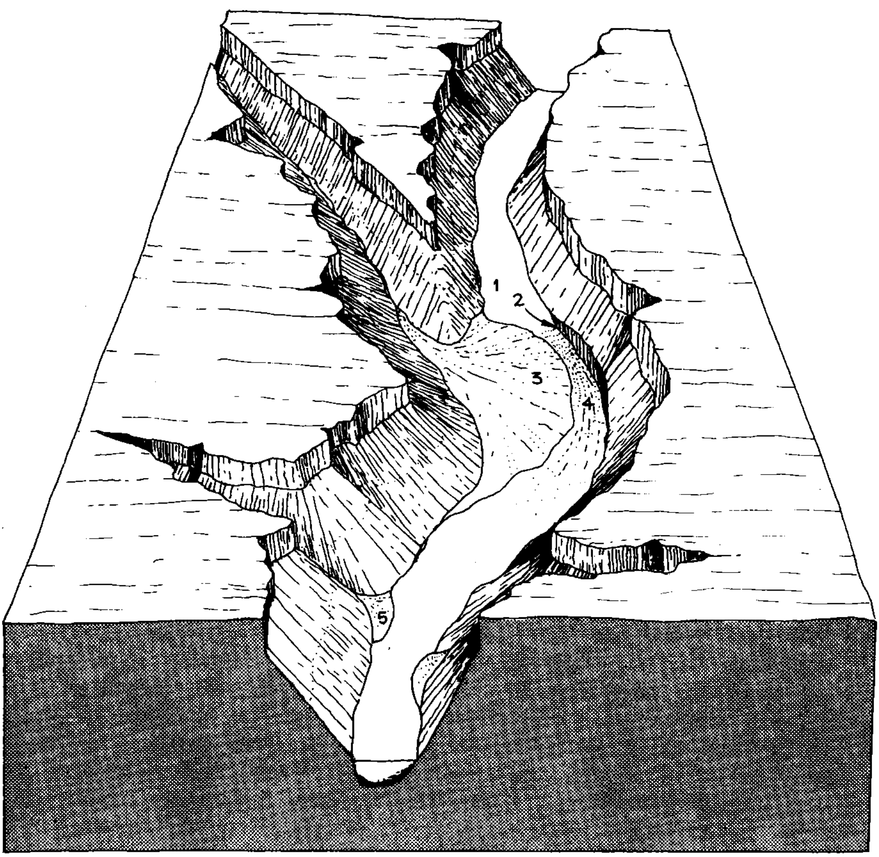
RAPIDS

Rapids in the Colorado River between Lee's Ferry and Lake Mead have long been a favorite of "white water" enthusiasts. There are 161 rapids in the Colorado River in the Grand Canyon region; approximately one-half of these are between Phantom Ranch and Lake Mead (see Tables 1 and 2).

Rapids and falls in most rivers are produced by resistant rocks which project above the general gradient of the stream. A fall is produced, for example, as water cascades over the resistant dolomite lip of Niagara Gorge. With the vast differences in profiles formed on rocks within the Grand Canyon, one would expect rapids or waterfalls to develop over the alternating resistant and nonresistant units. One would expect that rapids might form over the Shinumo Quartzite, the Tapeats Sandstone, Redwall Limestone, or Coconino Sandstone with relatively smooth quiet water on the Hermit and Bright Angel Shales. This is not the case, however, for the gradient of the Colorado River is relatively smooth and consistent across all of the formations from Lee's Ferry to Grand Wash Cliff at Lake Mead. There is no single place on the river where differential erosion of bedrock has produced a resistant ledge sticking above the gradient of the stream bed to produce falls or rapids.

Without exception rapids in the Grand Canyon are produced by debris from tributary streams which have partially choked the main channel of the Colorado River (Text-figure 14). These fans of debris at the mouths of tributaries form virtual dams across the river while rapids are produced at the overflow point in the main channel.

Abnormally steep tributaries are able to transport huge boulders and great quantities of erosional debris down into the Colorado River at a rate far greater than the river is able to move them downstream. One can see on aerial photographs (Text-figure 2) as well as on the ground the accumulation of this debris at the mouth of practically every tributary regardless of apparent size.



TEXT-FIGURE 14.—Diagram showing the origin of the rapids in the Colorado River. Broad fans of coarse debris accumulate at the mouths of steep tributaries and obstruct the flow of the main river. 1. quiet water; 2. eroded face; 3. and 5. debris fans; 4. rapids.

The broad debris fan and minor rapids at the mouth of Bright Angel Creek and the rather rigorous rapids at Crystal Creek, two of the first rapids to be encountered on this part of the river, illustrate this point very well. Huge boulders and blocks, several feet in diameter, have accumulated at the mouths of the creeks and have partially obstructed the channel, causing a steep drop over the edge of the "dam." This pattern is typical of the entire length of this section of the Colorado River gorge where even minor tributaries have developed rapids. Partial blocking of the stream commonly ponds the river to develop areas of abnormally quiet water for a mile or two upstream above each major rapid—the calm before the storm.

In a few isolated instances, bedrock exposures also occur in the central part of the channels in the lower part of the Grand Canyon, but in general these have little effect and do not produce more than minor ripples. The exposures of Precambrian resistant rocks, like those in Bedrock Rapids at Mile 130, is typical of a relatively minor effect that resistant bedrock has on rapid development within the canyon.

The size of the rapids varies somewhat from year to year with the amount of debris brought in by flash floods. In 1967 an abnormally intense cloudburst on the North Rim in the national park caused flash floods to occur along Bright Angel Creek and Crystal Creek (Text-figures 2, 15, 17, 18), several miles on downstream below Phantom Ranch. The debris brought into the gorge constructed new fans and greatly modified and intensified the rapids. Some rapids thus can be drastically altered after a single storm while others may be little affected over a number of years. Erosion by the Colorado River then wears down and removes debris with a tendency toward obliterating and smoothing out the irregularities in gradient which cause the rapids. This, however, is seldom, if ever, accomplished because new material usually is brought in before the older debris can be removed.

Before construction of Glen Canyon Dam near Page, Arizona, the flow of the river through the Grand Canyon was greater than at present. It will be interesting to note during the coming years the effect that this decreased flow will have upon the development of the rapids. One would expect that the small debris fans built up at the mouths of tributaries will grow very large in the future. This is because the small discharge of water down the Colorado River may be unable to accomplish the normal removal of sediments. The net effect will probably be that of making all of the rapids within the Grand Canyon more severe with time. It is not unlikely that some of the more active tributaries could bring down enough debris to completely dam most of the flow of the Colorado River for a short time, forming a temporary lake upstream.

Even within Granite Gorge, where extremely hard crystalline rocks are exposed, there is no evidence at present to suggest rapids forming by a process other than that described above. This process may seem rather unlikely since most of the tributaries of the Colorado River are dry most of the year. It should be remembered, however, that influx of sediments by tributary streams is a very intermittent process. It is usually accomplished only during major flash floods, at which time great quantities of debris are transported and dumped into the Colorado River in a matter of a few hours. When the boatmen stop to survey a course through the rapids, imagine the size of boulders and blocks which have accumulated at the mouths of the tributaries, and imagine the force of water necessary to bring this material down side canyons to the debris fans. Such periodic erosion and transportation is a fundamental process in arid regions and is most vividly displayed here in the Grand Canyon.

TABLE I
RATING OF RAPIDS IN THE GRAND CANYON
(Modified from Jones 1962)

Description	Riffle	Light	Medium	Heavy	Maximum Recommended	Not Recommended
Number of Rapids	78	22 13	17 17 6	6 1 2	3	1
Numerical Designation	(1)	(2)(3)	(4)(5)(6)	(7)(8)(9)	(10)	(10+)

TABLE II
RAPIDS FROM PHANTOM RANCH TO LAKE MEAD
(Modified from Jones 1962)

Mile	*Name*	*Rating*	*Drop*
90	Horn Creek	(10)	10′
92.5	Salt Creek	(1)	5′
93.5	Granite	(9)	17′
95	Hermit	(9)	15′
96.2	Boucher	(6)	13′
99.3	Crystal	(9)	17′
99.9	Tuna Creek	(6)	10′
101	Sapphire	(6)	7′
102	Turquoise Canyon	(3)	2′
104.8	Ruby Canyon	(4)	11′
106	Serpentine	(5)	11′
107.6	Bass Canyon	(4)	4′
108.6	Shinumo	(4)	8′
110.9	Hakatai	(5)	8′
112	Walthenberg	(6)	15′
124.9	Fossil	(3)	15′
129	Specter	(4)	4′
130.2	Bedrock	(5)	7′
131.8	Deubendorff	(7)	15′
133.9	Tapeats	(3)	15′
139	Fishtail	(4)	10′
149.9	Upset	(7)	15′
179.2	Lava Falls	(10)	37′
205.5	Two-Hundred-and-Five-Mile	(4)	13′
217.5	Two-Hundred-and-Seventeen-Mile	(4)	16′
225.6	Diamond Creek	(5)	25′

TEXT-FIGURE 15.—Vertical aerial photograph showing Upper Granite Gorge on the Colorado River in the vicinity of Phantom Ranch.

RIVER LOG

Mile 87.5.—BRIGHT ANGEL CREEK. (Text-figure 2, 15) The boats depart upstream from the small fan of debris built by Bright Angel Creek. This debris has forced the mainstream against the south bank, a vertical cliff of Brahma Schist. Recent flash floods have washed considerable debris down Bright Angel Creek into the canyon bottom, and a new lobe of sand and gravel has built into the river on the upstream portion of the fan.

Downstream for 1½ miles from Bright Angel Creek one can see high-water level expressed as sands and coarse gravels plastered against the canyon walls 40 to 60 feet above the present river level. Much of the sand is protected in small reentrants or small tributary canyons, but the gravel forms a definite line along the main banks of the river. The trail from Phantom Ranch to Bright Angel Lodge, on the South Rim, is cut out of metamorphic rocks on the south side of the canyon and can be seen from the river in many places.

Mile 88.7—GARDEN CREEK. (Text-figure 2) The trail cut into the south side of the Granite Gorge joins the Bright Angel Trail which leads upward to the South Rim. In this vicinity, several faults of significant proportions displace the rock sequence, but because of the homogeneity of the Brahma Schist and the lack of reference planes, they are difficult to recognize from river level. One of the most significant geologic features in this area is the faulting which has displaced the Grand Canyon Series prior to deposition of the overlying Paleozoic sequence. Evidence for this is seen where Shinumo and Hakatai and Bass rocks are faulted against the Brahma Schist below the overlying Paleozoic sequence which is undisturbed.

The river trip from Phantom Ranch to Lake Mead encounters a considerable portion of the metamorphic complex. The trip begins in Granite Gorge proper, where the metamorphic rocks are exposed in a V-shaped gorge over 1,500 feet deep.

Mile 89.—Large debris fan produced by tributary from the north.

Mile 89.2.—The V-shaped profile of Granite Gorge is excellently expressed. The horizontal Tapeats Sandstone, which forms the vertical ramparts which cap the inner gorge, is the oldest Paleozoic formation in the region.

Mile 89.5.—Redwall Limestone and part of the Supai Formation can be seen downstream on the upper canyon wall above the ramparts of Granite Gorge.

Mile 90.2.—HORN CREEK RAPIDS (10) TEN-FOOT DROP. Several good examples of vertical dikes composed largely of feldspar can be seen approximately two-tenths of a mile upstream from Horn Creek Rapids.

Mile 90.5.—Redwall Limestone is exposed on the skyline downstream.

Mile 91.0.—Rocks in the inner gorge are mainly schist with only a few minor dikes.

Mile 91.4.—Trinity Creek enters from the north. Horizontal lineation shows on the west bank in Precambrian schist and gneiss.

Mile 91.5.—The small projection of rock from the south shore is a resistant granite dike.

Mile 92.0.—The Kaibab Limestone, which forms the rim of the canyon, can be seen on the skyline to the left, approximately one mile above the river.

TEXT-FIGURE 16.—Vertical aerial photograph of the Colorado River from Mile 91 to Mile 97. Large alcoves are developed in the Redwall Cliffs on the north side of the river below the Tower of Set.

Mile 92.5.—SALT CREEK RAPIDS (1) FIVE-FOOT DROP, MINOR RIPPLE. Downstream from Salt Creek Rapids abundant pink granitic dikes stand out in marked contrast to the green schist. The dikes are essentially vertical and some are more than 30 feet wide.

Mile 93.0.—The Granite Gorge is relatively shallow in this part of the canyon, and one can see the Upper Paleozoic sequence above the Tonto Platform cut on the Bright Angel Shale.

Mile 93.4.—GRANITE FALLS RAPIDS (9) SEVENTEEN-FOOT DROP. Here the Granite Gorge is much wider than it is upstream above Phantom Ranch. Downstream from Granite Rapids is a large river bar composed of boulders derived from debris brought in by Monument Creek from the south. This bar was probably formed before the construction of the dam at Page, Arizona. Monument Creek is responsible for the debris fan which forms Granite Rapids. The contact between the Brahma Schist upstream and the Vishnu Schist downstream follows the east side of Monument Creek.

Mile 94.4.—Ninety-four Mile Creek brings in debris from the north to form a small ripple. The Tapeats Sandstone forms the ramparts capping Granite Gorge and is well exposed here where Granite Gorge is abnormally wide.

Mile 95.0.—HERMIT FALLS RAPIDS (9) FIFTEEN-FOOT DROP. An abnormally wide granite dike protrudes above the surrounding, more easily eroded schist on the north bank of the river. This dike is approximately 40 feet wide, one of the widest to be seen on the trip.

Mile 95.5.—Very few dikes are present in this section of the canyon. The schist is the dominant rock type and is characteristically dark green. Below high-water level the schist is dark green to black, but higher up the schist is typically lighter green.

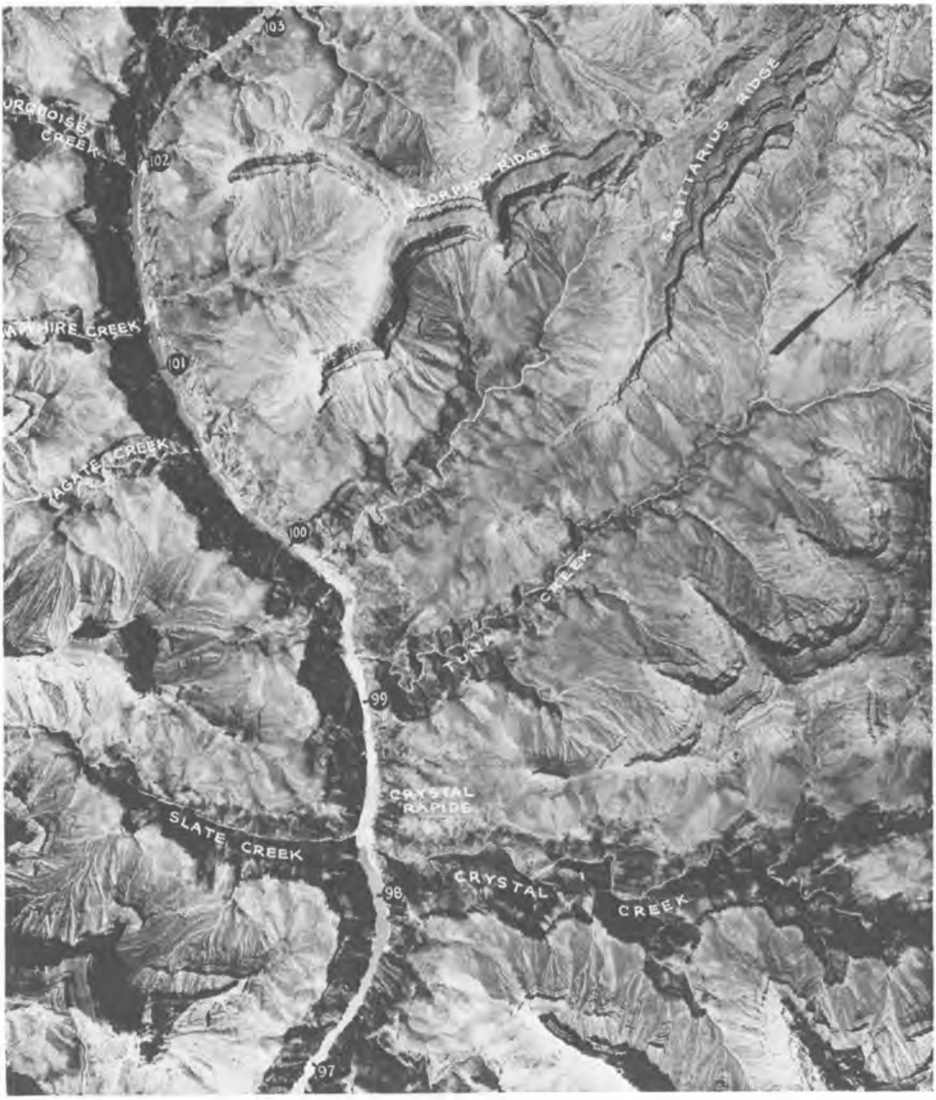
Mile 95.8.—Zoroaster Granite exposed for approximately ½ mile.

Mile 96.5.—BOUCHER RAPIDS (6) THIRTEEN-FOOT DROP. The North Rim of the canyon can be seen downstream from Boucher Rapids.

Lewis Boucher was a quiet man and was called the "hermit" because he lived in the remote area near Dripping Springs at the head of Hermit Canyon. He was picturesque, with a white beard and a white mule and he was a typical prospector. He planted an orchard and garden in what is now called Boucher Canyon where he grew oranges, peaches, pomegranates, figs, and other fruits and vegetables, including tomatoes which he cultivated throughout the year. His orchard of 75 trees was at his copper mine where he also had several cabins for tourists. Boucher located many prospects but none of them were of major economic importance. He finally moved out of the canyon in 1912 to the coal-mine community of Mohrland, Utah. Boucher Rapids on the river, at Mile 96.5, was named after this colorful individual.

Mile 99.0.—Small area of Zoroaster Granite.

Mile 99.3.—CRYSTAL RAPIDS (9) SEVENTEEN-FOOT DROP. Crystal Rapids is one of the most vigorous rapids on the Colorado River due to the recent influx of sediments from a flash flood in 1966, caused by a six-inch rain-



TEXT-FIGURE 17.—Vertical aerial photograph showing the Colorado River from Mile 97 to Mile 103. Crystal Creek is the large tributary entering the Colorado River from the north. It has produced a major debris fan which is responsible for Crystal Rapids. Large alcoves carved in the Redwall Limestone are similar to those seen upstream.

storm which fell in a very small area on the North Rim. The debris brought in by this flash flood is easily recognized by the abnormally large logs of Ponderosa Pine, which grow only on the canyon rim, as well as by the fresh boulders of upper Paleozoic rock (Text-figure 18).

In the vicinity of Crystal Rapids, brilliant pink dikes which intrude the schist across the planes of foliation are in an interlacing fashion. Most of the dikes are 20 to 30 feet wide; many of them can be seen on aerial photographs. One of the dikes is well exposed on the south bank, just above the rapids.

Mile 99.6.—A sharp bend in the river provides a view of the schist laced with a number of granite dikes. Some of the dikes parallel foliation; others, which are somewhat wider, cut across the foliation.

Mile 99.9.—TUNA CREEK RAPIDS (6) TEN-FOOT DROP. Here the pink granite constitutes as much as 30 to 40 percent of the rock in the inner gorge as dikes cutting schist and crinkled gneiss (Text-figure 19). They are characterized by a pink color and large crystals of feldspar which can be seen glistening from the sides of the canyon walls. Inclusions of green schist are seen in many of the large dikes.

TEXT-FIGURE 18.—Debris fan at the mouth of Crystal Creek composed of large boulders and blocks of Upper Paleozoic rocks deposited during 1966 flash floods. Large logs of Ponderosa pine were transported from the forest high on the North Rim.

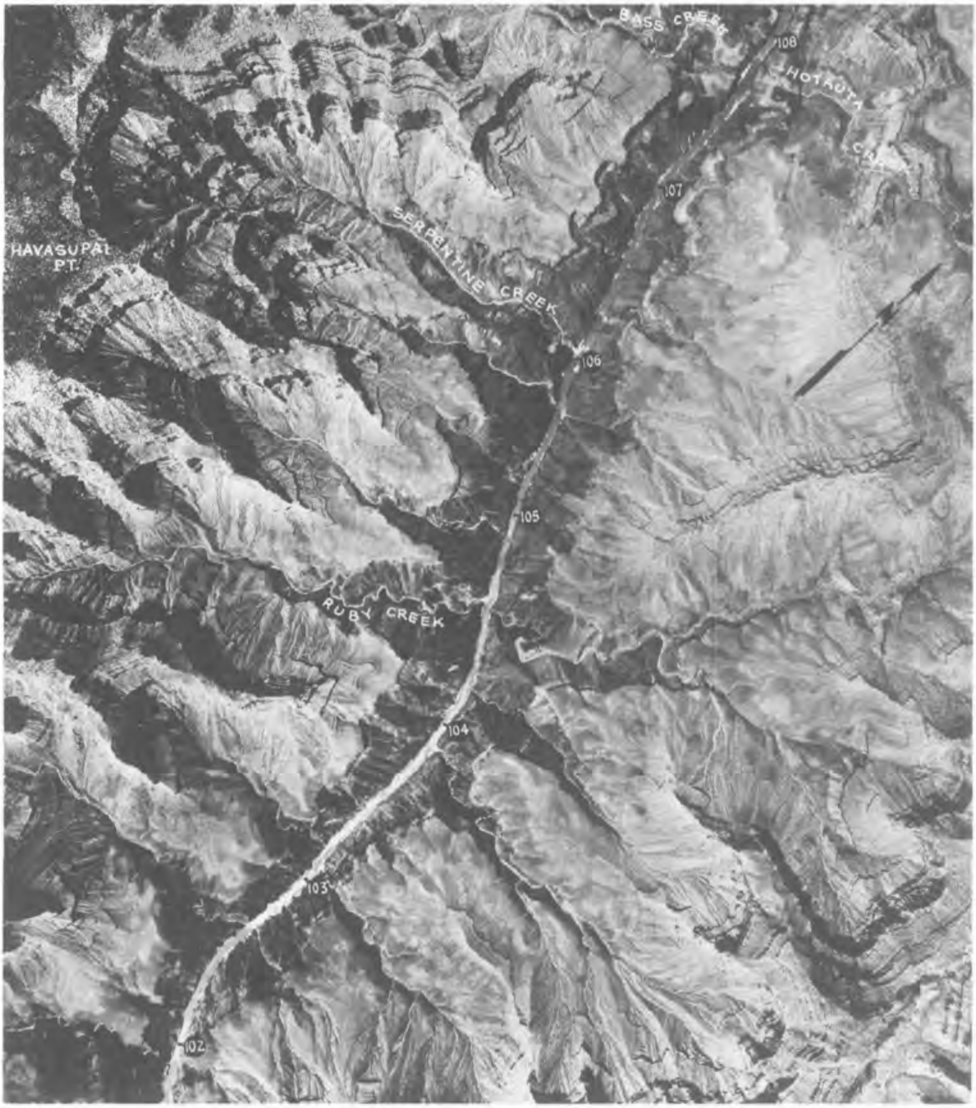
TEXT-FIGURE 19.—Exposure of gneiss in Granite Gorge at Mile 100. The crinkled and crumpled bands express the nature of deformation.

Mile 100.6.—An exceptionally large fin-like remnant of a dike protrudes above the water in the middle of the river and occupies at least half the river channel. This is one of the largest bedrock obstacles within the river throughout its entire course, especially at low water.

Downstream one can see the canyon rim and most of the Paleozoic formations. The stratified red rocks which weather into steps are the Supai Formation; the underlying, massive, red-stained wall is the Redwall Limestone; the white Coconino Sandstone is exceptionally thick and forms the second cliff from the canyon rim; the Kaibab-Toroweap Limestones form the uppermost cliff on the skyline.

Mile 100.8.—Numerous potholes are exposed on the left bank. Granite constitutes a large portion of the rock body in this area.

Mile 101.—SAPPHIRE CANYON RAPIDS (6) SEVEN-FOOT DROP. Small rapids formed by small debris fans.



TEXT-FIGURE 20.—Vertical aerial photograph of the Colorado River from Mile 102 to Mile 108. Light bleached Bass Limestone is visible in the vicinity of Mile 107, near the top of Upper Granite Gorge.

Mile 102.0.—TURQUOISE CANYON RAPIDS (3) TWO-FOOT DROP. Granite intrusive masses constitute almost 95 percent of the rock between Ruby and Sapphire Canyons. Downstream, however, it decreases rapidly and exists only as thick dikes cutting the schist.

Mile 104.8.—RUBY CANYON RAPIDS (4) ELEVEN-FOOT DROP. From Agate Canyon down to Bass Canyon there are small rapids at the mouth of each of the tributary canyons.

Mile 106.—SERPENTINE CANYON RAPIDS (5) ELEVEN-FOOT DROP. Dikes on the upstream end of the rapids are in Vishnu Schist and near here are nearly horizontal and stand out in marked contrast to the vertical dikes at Phantom Ranch. A large granitic body is developed near Serpentine Canyon Rapids.

Mile 107.5.—A large wedge of the lower part of the Upper Precambrian Grand Canyon Series is exposed on the north side of the canyon, above the metamorphosed lower Precambrian sequence. Exposed rocks in the vicinity of Bass Rapids are Bass, Hakatai, and Shinumo formations.

Mile 107.6.—BASS CANYON RAPIDS (4) FOUR-FOOT DROP. An abandoned small metal boat belonging to William Bass is located about 50 feet above the water level on the left bank of the river (Text-figure 21). Bass was a prospector in the area near the turn of the century and was able to extract minor quantities of copper and asbestos from this vicinity, but went broke after he transported only a few loads out of the canyon. Bass's operation is only one of more than 100 attempts to exploit the mineral deposits in the Grand Canyon. All but one have failed. The only mineral exploitation which has proven to be economical to date is a uranium mine which is now operated on the south rim near the Powell Monument west of Grand Canyon Village.

The type section of the Bass Limestone, the lowest formation of the Grand Canyon Series, is near Bass Rapids. Near the base of Bass Limestone are the oldest mudcracks and ripple marks in the Grand Canyon. The oldest fossils in the Grand Canyon are also found near the base of the Bass Limestone.

In 1890 William Bass set up a camp on the rim of the canyon near Havasupai Point and located several copper and asbestos claims inside the canyon, largely in Precambrian rocks. He made friends with the Havasupai Indians and took tourists into the canyon. His camp on the rim was dry but he built a trail down into the canyon to Mystic Springs which was shown to him by the Havasupais. He hauled water from the springs back to the rim. Later he constructed a trail on down to the Colorado River where a boat to cross back and forth was kept near the mouth of Shinumo Creek. He planted a garden along the river and raised vegetables and melons. He also planted a vineyard and an orchard of peach and apricot trees. The Bass Trail connected with trails across the canyon from the North Rim, so that cross-canyon trips were possible. In 1892 he took his future wife, Ada Diefendorf on the trip. They were married two years later and settled at Bass Camp where they raised a family on the rim. The area was dry; so to do laundry Mrs. Bass made the three-day trip down to the Colorado River. Bass constructed a cable crossing across the Colorado River at Mile 108 for better access to his asbestos mine and orchard on the north side of the canyon than was possible with his boat. Some

TEXT-FIGURE 21.—Old Ironsides. This boat was constructed and used by William Bass in his mining and agriculture exploits in Grand Canyon.

of the asbestos from his mine was shipped to Europe where it was used for fireproof theater curtains. Bass died in 1933 and his ashes were scattered over Holy Grail Temple on the North Rim, five miles to the northeast of Bass Canyon. Another cable crossing was later constructed three miles downstream closer to the asbestos mine at Mile 111.3.

Mile 107.8.—A diabase sill in the red Hakatai Shale is exposed on the north wall above the Bass ledges. The Grand Canyon Series is exposed from the vicinity of Bass Canyon to below Shinumo Creek and modifies the V-shaped rugged profile characteristic of the Granite Gorge, to one characterized by cuestas formed on gently tilted strata. L. F. Nobel, a noted geologist, mapped this area in 1908 and named the Hotauta Conglomerate, Bass Limestone, Hakatai Shale, Shinumo and Dox formations from geographic features in this locality. Here the Shinumo Quartzite is the uppermost preserved unit of the Grand Canyon Series. The Cambrian Tapeats Sandstone laps up against the older more resistant Shinumo Quartzite but in places the Shinumo cuesta persists through the entire thickness of Tapeats Sandstone and is overlain unconformably by Bright Angel Shale.

The rim of the canyon downstream from Bass Creek Rapids, with the typical erosional expression of the Kaibab, Toroweap, and Coconino formations on the skyline is part of the Powell Plateau 5,000 feet above the river (Text-figure 22). The lower units, however, are hidden from view by the quartzite ramparts of the Grand Canyon Series in the foreground.

Mile 108.2.—OLD CABLE CROSSING STRUCTURE (Text-figure 23) on the south side of the river was used by William Bass in his mining operations. The cable was recently cut down by the park service as a safety precaution.

The wedge of Grand Canyon Series in the area from Mile 107 to 110 is similar in many respects to the Grand Canyon Series at Phantom Ranch and the large exposure of the Grand Canyon Series in the vicinity of Unkar Rapids. Here, however, there is a greater percentage of sandstone and the shale here, being quite silty, grades almost imperceptibly into the Shinumo Quartzite. The Bass Limestone constitutes the bedded units just above the black ramparts of the metamorphic complex which are exposed at water level.

TEXT-FIGURE 22.—The lower Grand Canyon Series as exposed on the north bank at Bass Creek near Mile 108. Powell Plateau is capped by Kaibab Limestone on the skyline.

TEXT-FIGURE 23.—Vertical aerial photograph of the Colorado River from Mile 107 to Mile 114. Many of the Precambrian formations are named from this region.

In the vicinity of Shinumo Rapids, where the Grand Canyon Series makes a large amphitheater, there are some rather large Indian ruins in the overhanging cliffs in the north bank near the top of the sill.

Mile 108.6.—SHINUMO RAPIDS (4) EIGHT-FOOT DROP. High cliffs on the north bank are formed in the diabase sill which is intruded near the base of the Grand Canyon Series.

Mile 109.2.—The well-bedded Bass Limestone forms the banks of the river below the red Hakatai Shale, with the Shinumo Quartzite forming the cliffs midway to the skyline. The large butte immediately on the skyline is carved in the Redwall Limestone. Glimpses of the high North Rim of the canyon can be seen. The Grand Canyon Series dips to the north at 12 degrees so that there is a sharp structural discordance between these rocks and the overlying horizontal Paleozoic sequence.

Mile 109.3.—The black rock high on the south bank is the diabase sill intruded into the Grand Canyon Series. The bedded sequence lower on the north bank is the Bass Limestone.

Mile 109.7.—A large fault has displaced the Grand Canyon Series in the north wall so that the bedded Bass Limestone is adjacent to the diabase sill. The sill has subsequently been locally injected by small, white, quartz veins.

Mile 110.—The foliated Vishnu Schist is exposed on the walls of the inner Granite Gorge.

Mile 110.5.—The Paleozoic sequence up to the Kaibab Limestone can be seen downstream on the canyon rim. The brilliant red unit is the Supai-Hermit formations and the underlying vertical cliff is the Redwall Limestone. The Tapeats Sandstone forms the cap rock on the inner gorge, which is in a dark somber schist.

The Paleozoic sequence seen from time to time above the inner Granite Gorge exhibits a profile considerably different than that seen near Phantom Ranch (Text-figure 25). A very prominent terrace called the Esplanade is formed on the top of the red Supai Sandstone. This is one of the most prominent topographic features within the western part of the Grand Canyon. Here the Bright Angel Shale is somewhat thinner and the Tonto Platform is not as wide as it is at Phantom Ranch. Within this part of the canyon the Muav Limestone is thicker and lacks the slope-developing middle shale unit. Thus, in the western Grand Canyon a single cliff forms on the Redwall, Temple Butte, and Muav limestones.

Mile 110.9.—HAKATAI RAPIDS (5) EIGHT-FOOT DROP. Type section of the Precambrian Hakatai Shale is in Hakatai Canyon to the north. The asbestos mine worked by Bass is three quarters of a mile up Hakatai Canyon. Asbestos in the larger veins produced fibers up to four inches long. In 1907 this was said to be the best asbestos in the United States. At present quarter-inch fibers are considered commercial.

Mile 111.3.—Remains of another cable crossing can be seen on the south bank of the river. This cable crossing was also put up by William Bass in his mining operation.

Mile 111.5.—The broad flat surface of Marcos Terrace on the skyline, carved on red sandstones of the Supai Formation, is part of the Esplanade Terrace.

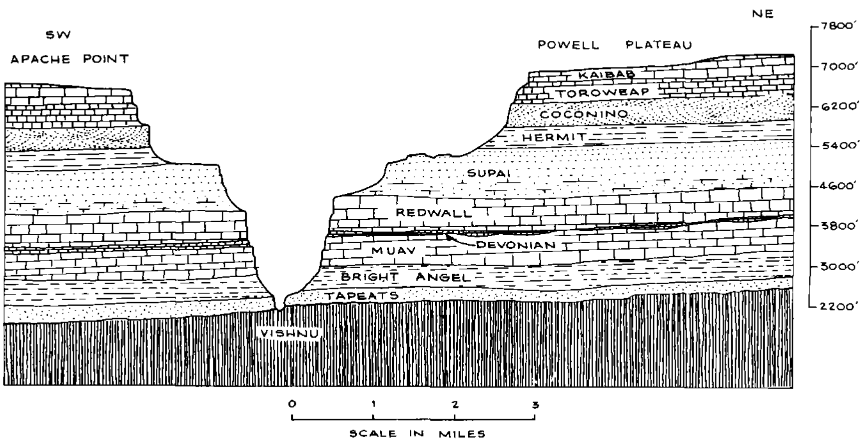
Mile 111.8.—Foliation in the metamorphic rocks in this part of the canyon is as low as 30°. A large pink granite dike can be seen cutting across the green schist downstream. Here Granite Gorge is not as deep as at Phantom Ranch and becomes progressively shallower downstream.

Mile 112.—WALTHENBERG RAPIDS (6) FIFTEEN-FOOT DROP. The Esplanade and the inner gorge cut in the lower Paleozoic rocks can be seen downstream. Large alcoves or amphitheaters are developed in the Redwall Limestone. Foliation in the schist in Granite Gorge is nearly vertical. The contact with the overlying horizontal Tapeats Sandstone is well exposed. A large island-like remnant of schist is preserved in the center of the stream, just upstream from Walthenberg Rapids. At low water this constitutes a major obstruction in the river. Such obstructions are produced by differential erosion but are not enough to form rapids.

Mile 112.2.—Dikes are more numerous in this part of the canyon. Most are pink granite with only a few intrusions of black basic rocks. The criss-cross pattern of dikes does not follow foliation .

Mile 113.—Small rapids. A large fan of debris can be seen on the north bank where small tributaries enter the channel. This material is deposited above high water level.

Mile 113.3.—Large erosional remnants of schist in the middle of the channel



TEXT-FIGURE 25.—Cross-section showing the profile and sequence of rocks in the Grand Canyon at approximately Mile 119. The profile of the canyon in this area is dominated by the broad flat Esplanade Terrace which is carved on top of the Supai Formation. The thick Hermit Shale has eroded back from the rim of the inner gorge.

TEXT-FIGURE 24.—Vertical aerial photograph of the Colorado River from Mile 112 to Mile 121.

might cause difficulty during low water. These remnants would protrude above the high water level as islands but do not form rapids.

Mile 113.5.—Well-exposed crisscrossing dikes, some of which follow the foliation (Text-figure 26).

Mile 115.—Exceptional exposures of the pink granitic dikes which are intruded into the black and dark green Vishnu Schist (Text-figure 26). The Paleozoic sequence forms a more imposing landscape in this part of the canyon and begins to dominate the scenery, for Granite Gorge is now only a few hundred feet deep. The skyline on the south is the top of the Redwall Formation.

Mile 115.5.—Granite Gorge is less than twenty feet deep. This marks the downstream end of the Upper Granite Gorge. The Tapeats Sandstone is the well-bedded sandstone resting on the metamorphic rocks and forms the first cliff on the north bank. On the south bank the Muav Limestone is veneered with travertine so that a single vertical wall forms from the Tapeats up to the Bright Angel and Muav formations. Small flexures and associated minor faulting have displaced the Tapeats Sandstone a few tens of feet in this vicinity.

TEXT-FIGURE 26.—View of the crisscrossed dikes at Mile 116.2 injected into the Precambrian metamorphic complex.

TEXT-FIGURE 27.—The Great Unconformity between Tapeats Sandstone and the metamorphic complex is exposed near river level at Mile 116.5. The prominent cliff in the background is the Redwall Limestone and rocks on the skyline are Supai Formation.

Mile 116.—A small monoclinal flexure and associated minor faulting have displaced the Tapeats Sandstone about 30 feet, with the upthrown block to the west. The direction of displacement is opposite to that of the major faults to the west, in which the western blocks are downthrown. Cliffs on the south bank which form the inner gorge are veneered with considerable travertine. The Tapeats, Bright Angel, and Muav formations form a single, massive cliff (Text-figure 27). Numerous caves have developed within the travertine deposits and one can see stalactites, stalagmites, and other dripstone deposits within the travertine-cemented debris slopes.

Mile 116.5.—Royal Arch Creek enters from the south through Elves Chasm; a natural arch is developed along the creek one mile to the south.

Mile 117.—Beginning of Stephen Aisle. The Tapeats Sandstone is close to river level, with only limited exposure of Precambrian rock. The profile of the canyon is dominated by the horizontal Paleozoic formations (Text-figure 25).

Mile 117.8.—Tapeats Sandstone is exposed at river level due to a minor fault in which the upthrown block is to the east. This is a thrust fault, similar to the one seen at Mile 116 in Stephen Aisle, and has approximately 50 feet of displacement.

Mile 118.—Downstream the large alcove amphitheaters and overhanging cliffs, typical of the Redwall Limestone throughout the canyon, are developed. These features are similar to Royal Arches and Redwall Cavern in the Marble Gorge upstream (Text-figure 28).

TEXT-FIGURE 28.—The Redwall Limestone forms the prominent cliffs along the walls of the canyon at Mile 119 and has been eroded to form typical arches or alcoves. The Tapeats Sandstone forms the small inner gorge at river level. The pile of debris to the right was brought in by a small tributary stream into the Colorado River gorge.

Mile 118.2.—Small exposures of Precambrian rocks appear above river level, but the profile of the canyon is still dominated by the cliffs and slopes on the Paleozoic rocks. The Precambrian rocks here are very dark gray to black and are cut by granitic dikes. One can see the contact between the Precambrian and the overlying Tapeats Sandstone in several places. Ten to twelve feet of relief existed on the buried Precambrian surface which was covered by the Tapeats Sandstone. Foliation of the Precambrian metamorphic rocks extends up to the contact in some places and has been deformed slightly by creep or mass movement.

Mile 119.5.—Another island of Precambrian metamorphic rocks is developed in the center of the river. These isolated remnants of Precambrian rocks protrude through the Tapeats Sandstone and represent ancient mounds or small hills on the Precambrian erosional surface which were buried by the first Paleozoic sea. The hills existed for a brief time as small islands in the Tapeats Sea, but were subsequently buried by Cambrian sediments. Some of these "hills" have a relief of 40 to 60 feet. When seen on a regional scale, however, the Precambian surface is exceptionally flat. The major irregularities were small monadnocks and cuestas formed on the resistant Shinumo Quartzite in the Grand Canyon Series.

Mile 120.—The high rim of the canyon, formed on the Kaibab and Toroweap formations, can be seen downstream, above the very prominent terrace of the Esplanade, formed on the top of the red Supai Formation. Conquistador Aisle is the straight stretch of canyon ahead.

Mile 120.3.—Deposits of river gravel are plastered against the cliffs of Tapeats Sandstone and possibly represent accumulations formed when the river was dammed by lava downstream.

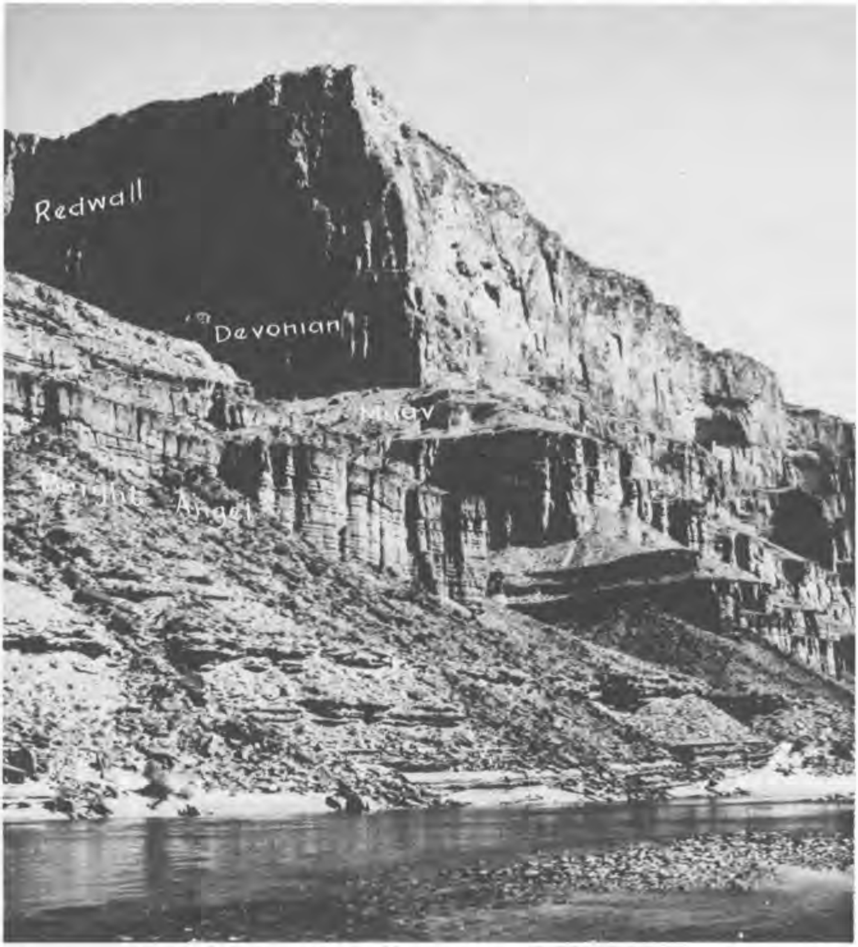
Mile 122.5.—Top of the Tapeats Sandstone is close to river level and is overlain by excellent exposures of Bright Angel Shale, especially on the north side of the canyon. Here the Bright Angel Shale contains several prominent and resistant sandstone beds which appear a characteristic brown and which have a very sharp upper contact. The sandstone beds form the caprock to the peculiar castellate topographic features which are developed in this part of the canyon (Text-figure 30). This topographic expression forms only on the north side of the canyon for the equivalent sandstone beds in the Bright Angel Shale are largely covered with slope wash on the south side.

Mile 123.2.—Large bars of gravel and sand are prominent in this section of the canyon. With controlled discharge of water from Glen Canyon Dam, these bodies of sediment do not move rapidly downstream but remain as obstructions in the channel. Prior to controlled discharge flash floods would probably have moved these bars downstream.

Mile 124.8.—Extensive deposits of slope wash, cemented with travertine, can be seen on the north side of the river. The surface appears as a great jumble of angular fragments.

Mile 124.9.—FOSSIL RAPIDS (3) FIFTEEN-FOOT DROP. A large amount of angular debris is present in river bars within this area. This debris was transported during high water stages in the canyon, prior to the construction

TEXT-FIGURE 29.—Vertical aerial photograph showing the Colorado River from Mile 120 to Mile 128 through the upper part of Middle Granite Gorge.

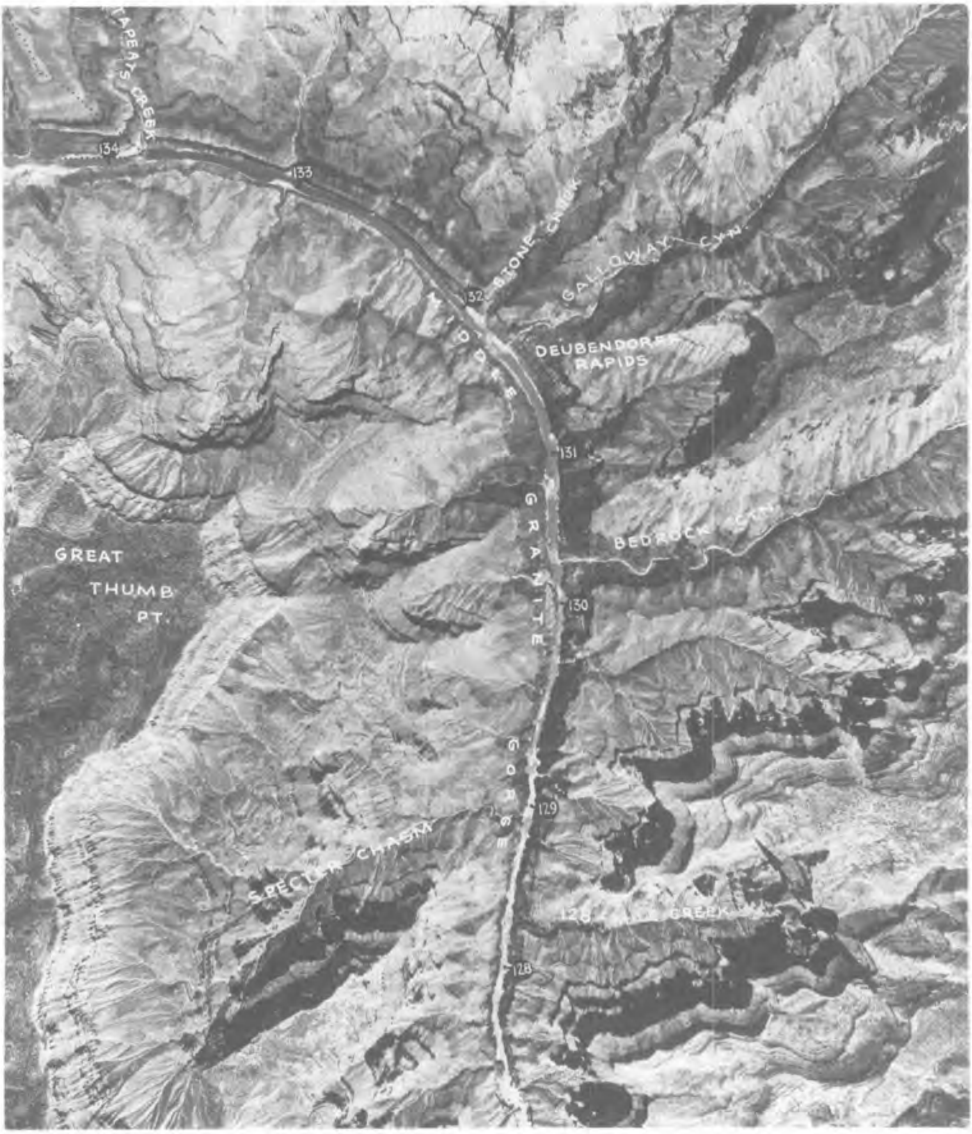


TEXT-FIGURE 30.—Bright Angel Shale is exposed near river level and forms the steep slope ascending to the base of the Muav and Redwall formations at Mile 122.

of Glen Canyon Dam upstream. The upstream surface of the boulders are polished and worn so that they appear to be imbricated like large shingles.

Mile 125.—Numerous piles or cones of debris have accumulated here at the base of a shallow inner gorge formed in the Tapeats Sandstone. Only a few of the debris fans are large enough to cause rapids. A large amount of material, however, is being dumped into the Colorado River—currently more than the river is capable of transporting on downstream.

Mile 125.6.—Small remnants of Precambrian rocks exposed beneath the Tapeats Sandstone on the south side of the river and the additional exposures present on both sides of the river downstream mark the beginning of the Middle Granite Gorge.



TEXT-FIGURE 31.—Vertical aerial photograph of the Colorado River from Mile 128 to Mile 134 in Middle Granite Gorge.

Mile 126.6.—From Mile 126.6 to Mile 129.4 the schist in Middle Granite Gorge is characterized by very dark, somber colors and well-defined foliation, which separates the rock into units or layers dipping downstream at approximately 70 degrees.

Mile 129.—SPECTER RAPIDS (4) FOUR-FOOT DROP. A large island of resistant schist protrudes above the river in the center of the stream channel. This remnant is in the mouth of Specter Canyon, immediately above Specter Rapids. A fault displaces the Precambrian sequence downstream from Specter Rapids so that green schist, with pink dikes similar to those found upstream near Phantom Ranch, constitutes the bedrock of the inner gorge. Middle Granite Gorge at Mile 129.5 has a profile similar to that developed near Phantom Ranch but here it is shallower. A well-exposed network of dikes can be seen in this section of the canyon.

Mile 129.8.—A spectacular waterfall can be seen in the small, unnamed tributary canyon from the north.

Mile 130.2.—BEDROCK RAPIDS (5) SEVEN-FOOT DROP. A wedge of the Grand Canyon Series can be seen downstream on the north side of the canyon. The banded light-colored bedded rock is Bass Limestone (Text-figure 32). The vertical-walled inner gorge is formed in the diabase sill which has

TEXT-FIGURE 32.—The Grand Canyon Series as exposed at Mile 130, downstream from Bedrock Rapids. The light-colored bedded units are bleached Bass Limestone which has been altered by injection of a large diabase sill below. Typical caverns and alcoves etched in the Redwall Limestone are visible on the skyline.

intruded the Bass Limestone. Bedrock Rapids has a resistant remnant of bedrock in the center of the channel. The rapids, however, are the result of influx of sediments from Bedrock Canyon on the east.

Mile 131.—The green-weathering diabase sill intruded into the Grand Canyon Series is the bedrock at river level. It has crude columnar jointing and is overlain by the bedded Bass Limestone which is altered white to cream-colored. The light color of the Bass Limestone is apparently due to baking and bleaching by the intrusion of the diabase sill. The red Hakatai Shale and Shinumo Quartzite are thin in this wedge.

Mile 131.8.—DEUBENDORFF RAPIDS (7) FIFTEEN-FOOT DROP (Text-figure 33).

Mile 133 to Mile 134.—The diabase sill forms the bedrock of the inner gorge. From Mile 132 to 134 the diabase sill forms a prominent palisade along the banks of the river, with the Bass Limestone, Hakatai Shale, and Shinumo Quartzite in the cliffs and slopes above. All of the Precambrian rocks are dipping to the northeast and are capped with the more nearly horizontal

TEXT-FIGURE 33.—Deubendorff Rapids at Mile 131.8. The Grand Canyon Series is exposed in the background below vertical cliffs of Redwall and Muav limestones.

Tapeats Sandstone. The diabase sill at Mile 133.5 has pronounced large columnar joints which extend from water level up to the base of the altered white to pink Bass Limestone.

Mile 133.9.—TAPEATS RAPIDS (3) FIFTEEN-FOOT DROP. Type locality of the basal Cambrian Tapeats Sandstone is in Tapeats Creek Canyon to the north. The Precambrian diabase sill is at water level above the rapids (Text-figure 34).

Mile 134.4.—A normal fault displaces the Grand Canyon Series so that Shinumo Quartzite is faulted down against the diabase sill. The rolling hills on the south side of the canyon are carved in Quaternary silt, deposited in a lake formed behind one of the high Pleistocene lava dams which occurred downstream. The nature of these silt accumulations is identical to that of silt being deposited at the present time in the headwaters of Lake Mead. Kaibab National Forest is on the north side of the canyon and Grand Canyon National Park on the south side from Tapeats Creek downstream to near Mile 144.5.

TEXT-FIGURE 34.—Palisades of the sill injected into the Grand Canyon Series are developed on the north bank at Tapeats Creek at Mile 136.4. Bass Limestone above the sill is bleached white at the contact.

TEXT-FIGURE 35.—Vertical aerial photograph of the Colorado River from Mile 134 to Mile 139 in the lower end of Middle Granite Gorge.

Mile 135.2.—Precambrian schist and granite are exposed near water level at the contact of the tilted unconformity between Early and Late Precambrian rocks. The canyon becomes exceedingly narrow, only 35 feet wide in places, in the schist and granite gorge of Granite Narrows, undoubtedly the most narrow part of the river. The schist is thoroughly injected with dikes of pink granite.

Mile 135.5.—Large cavern developed at the contact of the granite and the overlying Precambrian Grand Canyon Series. These are among the largest caves to be seen at river level in this part of the canyon.

Mile 136.3.—DEER CREEK FALLS. Water from the falls has developed a lush growth of vegetation.

Mile 136.6.—The Tapeats Sandstone forms a cliff on the south side of the river. Rocks above the Tapeats beds have been brecciated, presumably due to slumping and landslide activity. The general brecciation of the Muav Limestone, and possibly some of the Redwall Limestone, is definitely related to landslide movement. Most of the surface of both formations is covered by chaotic debris.

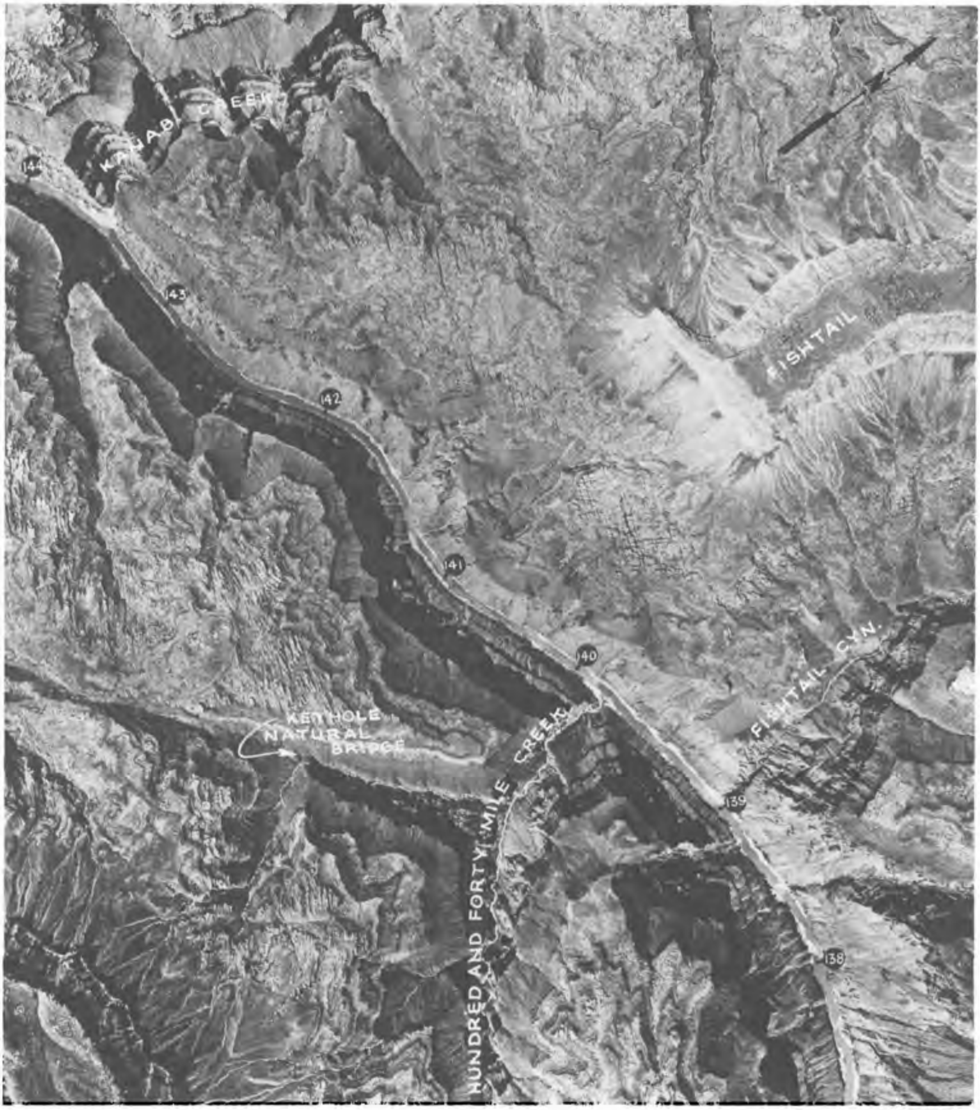
Mile 138.4.—Vishnu Schist protrudes 20 to 30 feet above the river level and forms small exposures. This is the lower end of Middle Granite Gorge. One can see several granaries of earlier Pueblo Indians near the contact of the schist and the overlying Tapeats Sandstone.

Mile 138.5.—Chaotic landslide debris, composed largely of Muav Limestone blocks, is present on the north bank. A small monadnock of granite is exposed in the river bank and extends 40 or 50 feet up through the Tapeats Sandstone, to near the top of the formation. The small canyons above Fishtail Canyon are controlled by the Chikapanagi Fault, a normal fault downdropped on the west.

Mile 139.—FISHTAIL RAPIDS (4) TEN-FOOT DROP. The Tapeats Sandstone is near river level in this vicinity. Characteristics of the Bright Angel Shale are apparent on the north side of the river.

Mile 139.9.—The base of the Bright Angel Shale is exposed near the river level and as a result the canyon takes on a completely different profile. The canyon is dominated by the nearly vertically walled inner gorge, extending from the top of the Supai Formation down to the base of the Bright Angel Shale, some 2,000 feet below. There are several small terraces separating major limestone or resistant rock units but the major feature of the canyon is a single vertical-walled gorge up to the level of the Esplanade.

The Redwall Limestone forms the highest prominent cliff and is underlain by a slope developed on well-bedded Devonian dolomite or the Temple Butte Limestone in this part of the canyon. A series of three poorly defined terraces is carved in the Muav Limestone. The slope near river level is formed on the Bright Angel Shale. This general profile dominates the canyon throughout the next 100 miles. The gorge of the Grand Canyon beneath the Esplanade constitutes one of the most colorful and impressive parts of the river trip. The Esplanade terrace or platform is as much as three miles wide and is relatively flat. Erosion has stripped the relatively soft Hermit Shale from



TEXT-FIGURE 36.—Vertical aerial photograph of the Colorado River from Mile 138 to Mile 144.

above the resistant Supai Formation and below a sequence of cliffs formed on the Coconino, Toroweap, and Kaibab formations.

Mile 143.7.—KANAB CREEK. Major Powell actually made two attempts on the Colorado River because of lost notes and scientific data which resulted from an upset of one of his boats on the first trip. His second trip ended here at Kanab Creek on September 7, 1872, where he abandoned his boats and climbed out of the canyon and returned to Kanab, Utah.

Kanab Creek is one of the major tributaries of the Colorado River from the North Rim. It extends back to the north into Utah and the High Plateaus. Unlike the shorter and steeper tributaries, Kanab Creek does not produce a significant rapid because its gradient it too low to carry large debris. One of the interesting features of Kanab Creek is the entrenched meanders.

Two types of tributaries are recognized in the Grand Canyon section of the Colorado River: (1) Major streams which collect water over a vast region and are characterized by extensive, tight, entrenched meanders. Excellent examples are the Little Colorado River and Kanab Creek (Text-figure 37). (2) Short tributaries which have developed by headward erosion as the canyon deepened. These do not have tight meanders but flow in a relatively straight pattern to the Colorado River.

The entrenched meanders have very low gradients and do not transport large amounts of coarse debris, hence do not construct debris fans which produce rapids. These streams are apparently as old or nearly as old as the Colorado River.

The short tributaries in contrast are the result of headward erosion and have extensively steep gradients. Although they are intermittent, they are capable of transporting large quantities of large boulders which accumulate as debris fans where they empty into the Colorado River. Most of the tributaries in the Grand Canyon are of the second type and their course is commonly influenced by weak zones along faults or the regional slope of the stripped Kaibab surface.

Mile 144.5.—Boundary to Grand Canyon National Monument on the west and Kaibab National Forest on the east with Grand Canyon National Park on the south. The park is along the south shore and the Forest-Monument boundary is north from the mouth of Jewel Spring Canyon and then along the edge of the Esplanade.

Mile 145.—The base of the Muav Limestone is near river level but the contact with the Bright Angel Shale is difficult to see because of the thick cover of slope debris. The Muav Limestone in this part of the canyon is much thicker than in the Phantom Ranch area and here is composed dominantly of limestone with very little shale. In the western part of the Grand Canyon the Muav Limestone is expressed by three poorly-defined cliffs separated only by very narrow slopes. It is difficult to distinguish Muav beds from the overlying Temple Butte Limestone from the river, although the Temple Butte Limestone generally is much thinner bedded.

Mile 147.—Muav Limestone exposed at river level is gently warped. The limestone is dipping as much as ten degrees away from the center of the river

TEXT-FIGURE 37.—Vertical aerial photograph of the Colorado River from Mile 141 to Mile 146.

TEXT-FIGURE 38.—Vertical aerial photograph of the Colorado River from Mile 144 to Mile 151. Grand Canyon National Monument is on the north side of the river. The rugged surface of the Esplanade results from differential erosion along joint patterns above the steep vertical-walled inner gorge of the canyon.

channel (Text-figure 39). The Muav Limestone has probably suffered some flowage due to differential loading. Where the canyon has cut a narrow gorge through Muav and overlying rocks, flowage could occur in the plastic carbonate formations causing these abnormal dips away from the stream channel. With removal of the confining pressure of 2,000 feet of rock, elastic rebound could produce a phenomenon such as seen here in the Muav Limestone.

Mile 148.5.—The Redwall, Devonian, and Muav formations merge topographically to form an almost vertical wall nearly 2,000 feet high on the south wall, one of the most impressive rock faces within the canyon.

Mile 149.5.—The Muav Limestone is fractured here in many areas, and solu-

TEXT-FIGURE 39.—Small flexure in Muav Limestone developed at river level at Mile 148. This minor folding may be the result of release of confining pressure as the river removes the overlying rocks. Axes of these small folds generally are along the trend of the river channel.

tion activity has formed elongate caverns and small openings. These are especially well displayed along the north wall.

Mile 149.9.—UPSET RAPIDS (7) FIFTEEN-FOOT DROP. Jesse "Shorty" Burton capsized his boat in Upset Rapids, June 14, 1967. His life jacket became entangled in the boat line and he drowned, although all of the passengers of his party were saved.

Mile 150.—At Mile 150, the flexing of the Muav Limestone along the axis of the river channel is well expressed. Here the river flows through a small inner gorge carved in the lowest cliff of the Muav Limestone. The weak folding of the Muav Limestone at river level is well expressed in this locality. The vertical cliff plunges straight into the river so that here there are no shores. Downstream one can see the high rim of the canyon carved on the Kaibab-Toroweap limestones. Alcoves and amphitheaters in the Redwall Limestone are reminiscent of the Redwall Cavern upstream. On the north shore, the Muav Limestone is locally veneered with dripstone and travertine derived from solution activity in the limestone sequences above. The travertine deposits are associated with springs which produce more luxurious vegetation. The section of the canyon where the Muav forms a small inner gorge from Mile 148 downstream to beyond Mile 150 is one of the most serene and peaceful parts of the canyon. The water is relatively quiet; the vertical walls of the Muav-Redwall sequence present an impressive scene. This section of the canyon appears to be especially favored by waterfowl which stop here on their migration routes.

Mile 152.—Minor flexing of the Muav Limestone is well expressed on the right-hand side at river level. Fold axes parallel the course of the canyon.

Mile 152.3.—Travertine deposited in the minor tributary stream channels is the result of the great quantity of calcium carbonate dissolved in minor streams and deposited by them as they cascade toward the main Colorado River. This process of deposition is probably best expressed in the Havasupai Indian village, where large quantities of travertine have been deposited in the vicinity of the waterfalls. Some waterfowl inhabit the canyon here and some migratory species are common. Great Blue Herons and Golden Eagles are often seen near Upset Rapids.

Mile 153.—A large cave developed in the Redwall Limestone can be seen high on the South Rim.

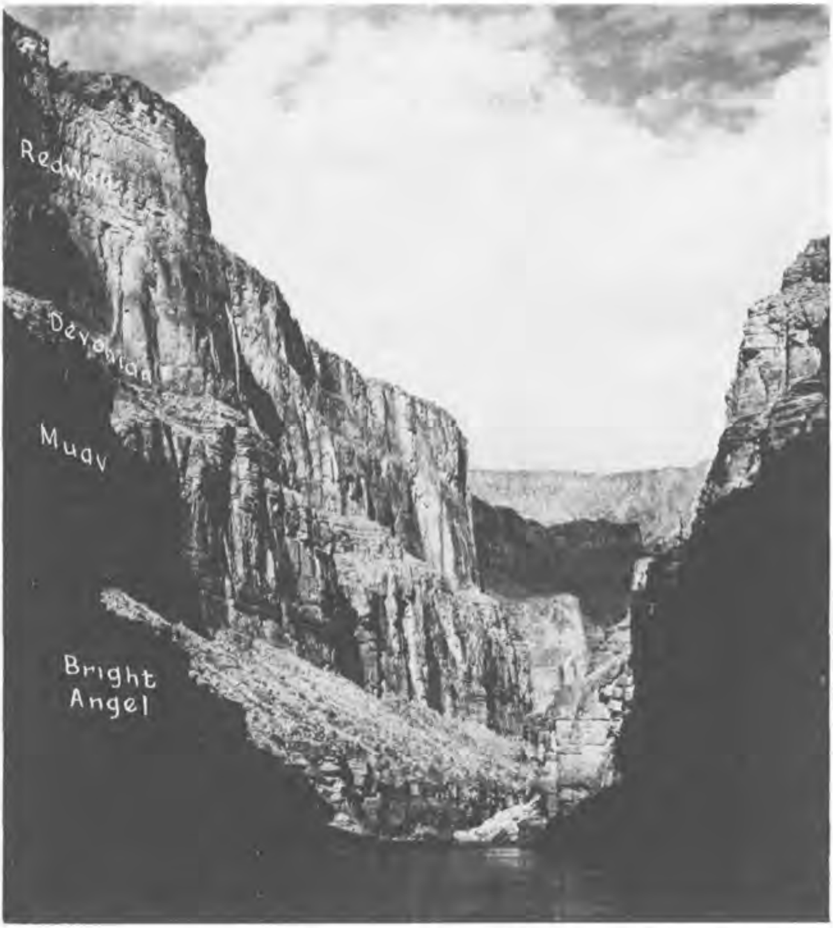
Mile 154.8.—Muav Limestone forms an impressive vertical wall at the edge of the river as it has done throughout the last several miles (Text-figure 41).

Mile 155.—A large rockfall of Muav Limestone protrudes above river level in the center of the channel and forms an obstruction to boats. Only a minor rapid or ripple is developed by this debris, however.

Mile 155.4.—A beautiful display of travertine can be seen in the small valley to the north.

Mile 156.—Minor flexing is well expressed in the Muav Limestone at river level. The dip is away from the stream and the fold axes are in the channel regardless of the trend of the canyon.

TEXT-FIGURE 40.—Vertical aerial photograph of the Colorado River from Mile 150 to Mile 157 near Havasu Canyon.



TEXT-FIGURE 41.—View looking downstream from Mile 154. The nature of the inner gorge below the Esplanade Platform and the outer rim of the canyon can be seen ahead. The Muav Limestone becomes very thick in this area and holds up a sequence of several cliffs between the slopes of the Bright Angel Shale and the prominent Redwall Cliff.

Mile 156.9.—HAVASU CANYON enters the main Grand Canyon from the south (Text-figures 40, 42) and limited deposits of debris form a small rapid at the canyon mouth. The Havasupai Indian Reservation is 12 miles up the canyon to the southeast. Havasu Creek appears to be a minor bright-blue tributary. This narrow defile opens up into a broad canyon with spectacular waterfalls in the vicinity of the Havasupai Indian Reservation. Exposures up Havasu Creek indicate that the dip of the Muav Formation decreases rapidly away from the river and the limestone becomes essentially horizontal.

Havasu Canyon is inhabited by the Havasupai Indians, a small tribe related to the Hualapai Indians who live on the canyon rim, farther to the west. The

TEXT-FIGURE 42.—Vertical aerial photograph of the Colorado River from Mile 154 to Mile 160, past Havasu Canyon.

Havasupai people are the only Indians which presently inhabit the canyon and are the only people to have lived in the canyon since the Pueblo cultures. The name Havasupai means "people of the blue-green waters," a name derived from the beautiful blue-green stream and waterfalls within the canyon.

The people live a double life. During the warm summer months they farm corn, beans, squash, and other vegetables and fruits on the canyon floor; in the winter they hunt and gather wild fruits and nuts on the plateau. This is the reverse of the most comfortable pattern because the Indians are down in the heat of the canyon in the summer and on the cold rim in the winter. However, gathering nuts is an autumn and winter occupation and farming is a summer one, so the decision is probably not one of choice.

Throughout the centuries the Havasupai tribe has numbered about 200 individuals who have survived in an unhospitable environment because they developed ditches and irrigated crops. Their homes are modest wickiup shelters made of willows, brush, and thatch or logs. Contrary to popular belief, the Havasupai Indians are not restricted and isolated in their little Shangri-la but have long traded with their neighbors, the Navajo, Hopi, and Hualapai Indians.

On June 20, 1770, Father Garcias traveled down the deep canyon to Havasu Creek on trails constructed by the Indians. He was probably the first white man to hike down into the canyon and recognized its great depth by the fact that the sun did not rise until 10 a.m. He stayed a short time with the Havasupai Indians and was impressed by their crops and their irrigation systems of dams and ditches. He also noted that the Havasupais had horses and cattle which were probably traded from the Hopi Indians.

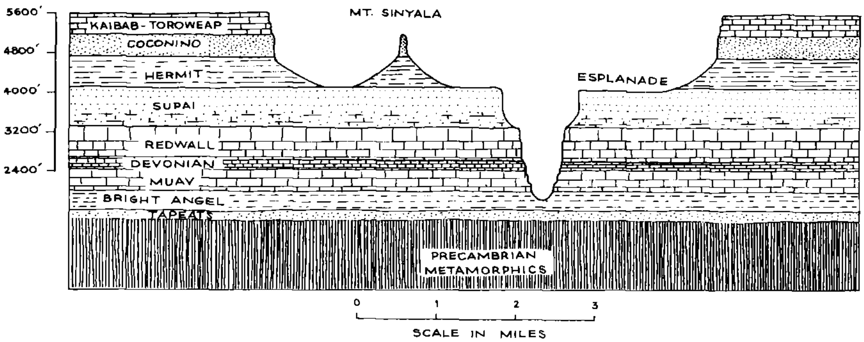
Today Havasu Canyon is a veritable oasis and can be visited by the more ardent traveler. By previous arrangements made with the Indian tribe, a guide will meet a party at the canyon rim and conduct it down to the village, where visitors can stay and explore the canyon as paying guests of the tribe. Arrangement also could possibly be made to come up from the Colorado River, if the entire party decided to lay over at Havasu Canyon for a few days.

Mile 158.—Flexing in the Muav Limestone is expressed as it dips in both directions away from the center of the river.

Mile 159.—The canyon cuts deeply into the Muav Limestone, exposing beds close to the base of the formation. One can see high-water marks on the south bank. The Muav Limestone is stained red above high water level but is colored a typical grayish green below.

Mile 159.5.—The high rim of the canyon which is visible downstream is capped by Kaibab Limestone. The high promontory is known as S. B. Point.

Mile 164.5.—Small rapids are produced by influx of sediments from Tuckup Creek on the north. One can see a natural arch formed in the top of the Redwall Limestone high on the rim to the north. The canyon profile has changed very little from that seen a number of miles upstream where the Muav Limestone is first exposed at river level and where the Muav, Devonian, and Redwall limestones form a nearly vertical-walled gorge. One can see up to the top of the Redwall in most of the canyon, and now and then the rim of the Esplanade is visible on the top of the Supai, but only rarely can one see the Kaibab Limestone upper rim of the canyon.



TEXT-FIGURE 43.—Cross-section across the Grand Canyon near Havasu Creek. The profile of the canyon is divisible into an outer rim held by the Kaibab and Toroweap formation, the broad Esplanade on top of the Supai Formation, and the inner gorge carved into the lower Paleozoic formations.

Mile 164.7.—Hualapai Indian Reservation is on the south side of river for several miles.

Mile 168.—FERN GLEN CANYON. Small rapids are developed. Throughout this part of the canyon rapids form at practically every tributary.

Mile 168.5.—Bright Angel Shale is exposed near river level.

Mile 169.—A large fresh scar from a recent rock fall can be seen on the south wall of the canyon, about midway up in the Redwall Limestone. The rock fall is typical of that found throughout the canyon. Large segments of rock will break away from a bedding plane surface leaving a rectangular joint-controlled face on the cliff. In the vicinity of Mile 169, Bright Angel Shale is characterized by rather dark brown to dark purplish gray sandy shale. It forms a slope near river level in contrast to the segment of the canyon upstream where the vertical cliff of the Muav Limestone was at river level.

Mile 169.9.—Tributary streams to the Colorado River coming in from the south form waterfalls or cascades over the cliff of the lower Muav Limestone. The greater amount of water in such areas causes the development of large amphitheaters or undercut caverns.

Mile 171.—STAIRWAY CANYON to the north. The Stairway-Willow Springs fault cuts across the canyon at Mile 171 (Text-figure 46) and displaces the strata approximately 50 feet. This fault has controlled the position of Stairway Canyon on the North Rim and Mohawk Canyon on the South Rim. The upthrown block of the fault is to the west. Below Stairway Canyon the river cuts deeper and deeper into the Paleozoic sequence and exposes much of the

TEXT-FIGURE 44.—Vertical aerial photograph of the Colorado River from Mile 160 to Mile 165.

upper part of the Bright Angel Shale. The well-developed dolomite, which occurs about 30 feet above the river level, is a prominent member in the Bright Angel Shale and weathers a dark brown to black. This dolomite is a good marker horizon in the Bright Angel Shale in this part of the canyon.

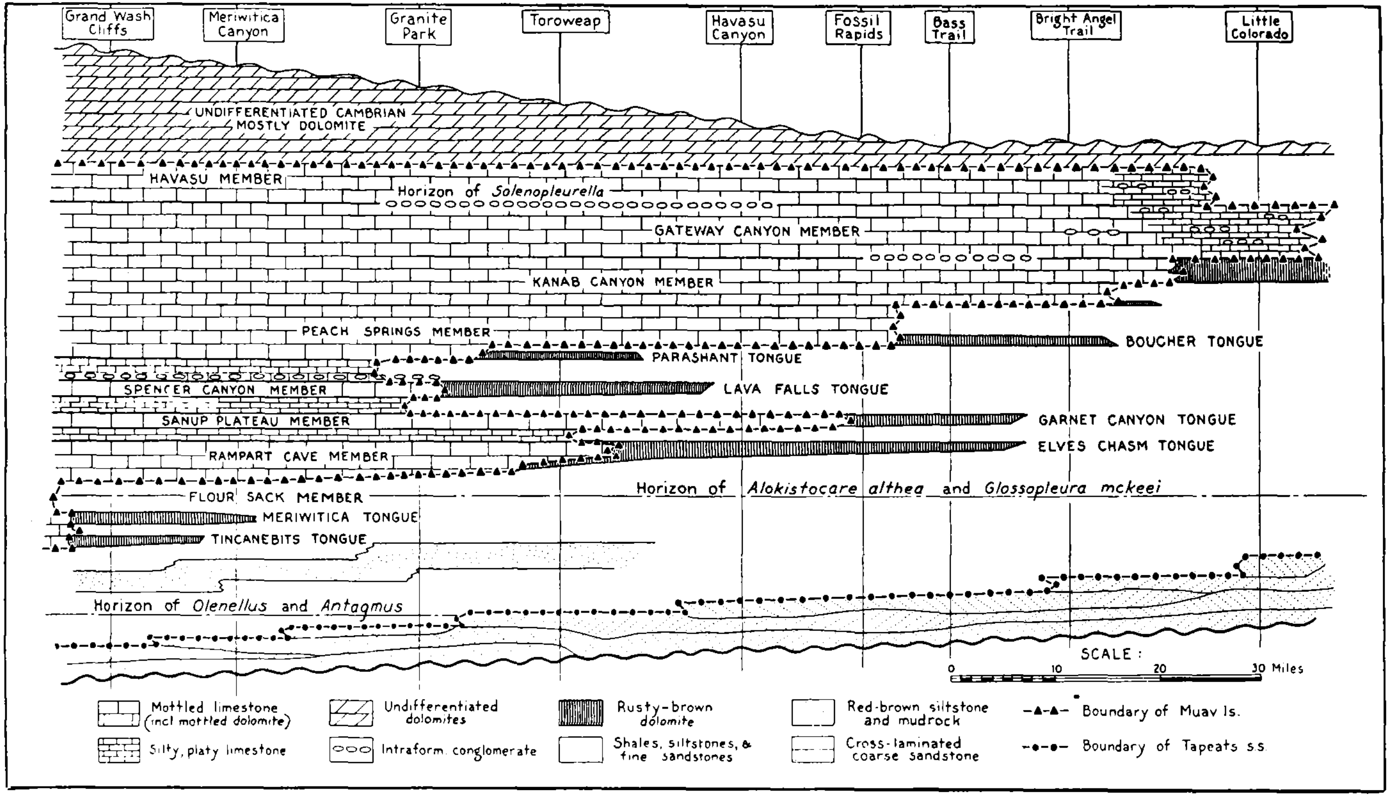
TEXT-FIGURE 45.—Vertical aerial photograph of the Colorado River from Mile 165 to Mile 170.

Mile 173.—The canyon rim can be seen on the skyline downstream above the prominent terrace of the Esplanade (Text-figure 48).

Mile 175.—Red Slide Canyon is seen on the north. A zone of extensive landslide debris occurs on the upper canyon walls. The debris was derived principally from red sandstones of the Supai Formation and from the underlying Redwall Limestone. Green shales of the Bright Angel Shale can be seen on

TEXT-FIGURE 46.—Vertical aerial photograph of the Colorado River from Mile 170 to Mile 175. The straight tributaries of Mohawk and Stairway Canyons are controlled by faulting. Excellent joint systems in the Supai Sandstone are expressed on the upper part of the aerial photograph.

both sides of the canyon just above the river level. They are interbedded with significant amounts of sandstone which tend to form small vertical ledges. The presence of so much sandstone within the Bright Angel Shale and its low position in this part of the canyon explain the absence of the Tonto Platform.



TEXT-FIGURE 47.—*Diagrammatic section of Cambrian rocks seen in the western Grand Canyon between Grand Wash Cliffs, on the west, and Phantom Ranch (Bright Angel Trail), on the east. Gradual change of Muav Limestone in the west into Bright Angel Shale toward the east is evident in the interfingering of the two formations. Time planes are horizontal, as shown by trilobite zones. Actual thickness changes from approximately 1,500 feet in the west to only approximately 800 feet in the east.* (From McKee and Resser, 1945, Fig. 1)

TEXT-FIGURE 48.—View of Grand Canyon from above Mile 176 looking toward the east. The broad platform of the Esplanade, the outer rim carved on the Kaibab-Toroweap, and the inner gorge below show the typical profile of the western Grand Canyon. The Colorado River is 3,000 feet below the level of the Esplanade in the narrow gorge.

Mile 176.5.—A small remnant of basaltic lava is seen approximately 145 feet above the river level on the north bank. This is the first Quaternary lava flow seen in a boat trip down the Grand Canyon.

Mile 177.—A large remnant of lava occurs high upon the canyon rim approximately 1,600 feet above river level. This is one of several high-level remnants which are remains of a lava dam which nearly filled this part of the canyon and ponded Colorado River water for some miles upstream.

Mile 177.5.—First view of the great Lava Cascades from the Esplanade at Toroweap Valley can be seen downstream (Text-figures 50, 51).

One of the most spectacular features in the western Grand Canyon is the display of recent volcanism in the vicinity of Whitmore and Toroweap Valleys and extending downstream from there for more than 80 miles. The volcanic history preserved in the canyon is involved and complex, but it is of such recent origin that many features are easily distinguished. Several types of volcanic features can be seen within the canyon including: valley fill, older intracanyon flows, younger intracanyon flows, cascades, dikes, and cinder cones.

The deposits which either cascaded over the rim of the canyon or originated within the gorge and flowed down the canyon bottom are referred to as intracanyon flows. Remnants of these flows adhere to the canyon wall and are stacked side by side in juxtaposition (Text-figure 52). The relative age is readily apparent, for older flows were excavated before the younger flows were deposited in the canyon bottom. The intracanyon flows are divisible into two groups. The first or older intracanyon flows are preserved near the mouth of Prospect Canyon, Toroweap Valley, and below the Esplanade at Mile 182. These older flows are a sequence of relatively thick basalt units

TEXT-FIGURE 49.—Vertical aerial photograph of the Colorado River from Mile 172 to Mile 178.

TEXT-FIGURE 50.—View of the Esplanade and lava cascades to the west from Mile 176. Vulcan's Throne is the cinder cone near the center of the picture. The dark lava cascades are at Mile 178.

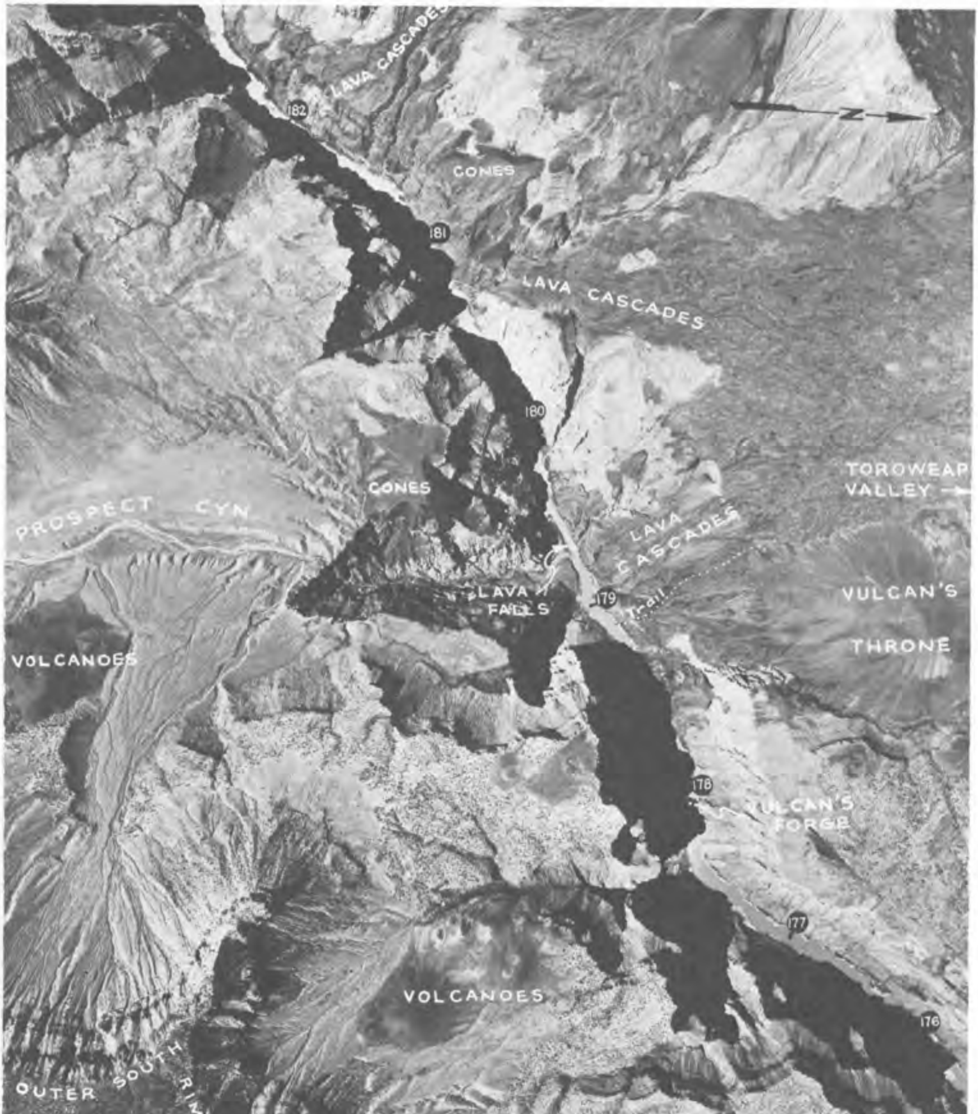
superimposed one upon another. The second or younger intracanyon flows are plastered against the canyon walls and are in lateral juxtaposition with older units. Five distinct younger intracanyon flows have been recognized which, for convenience, are referred to as Flow 1, 2, 3, 4, and 5.

Valley fill of lavas is a third type of volcanic phenomenon observed in the canyon. Several tributary valleys of Grand Canyon are filled with sequences of lava, of which the most notable are those of Toroweap Valley, Prospect Canyon and Whitmore Wash. In Toroweap Valley the lava fill is partially obscured by recent cascades.

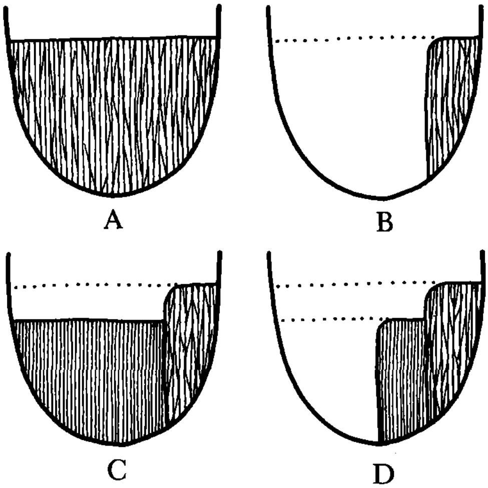
Cascades of lava falling from the rim of the Esplanade down into the canyon are a fourth type of volcanic deposit and are seen in two major areas. These flows are the youngest volcanic features seen in the canyon.

Dikes of basalt, which undoubtedly acted as vents for some of the volcanics high on the canyon rim are also exposed in the inner gorge. Long slender dikes in the vicinity of Vulcan's Forge follow joint systems up the canyon wall. These dikes are rarely more than three feet thick but extend almost 3,000 feet up to the Esplanade Platform. Large dikes are developed on both the north and south side of the Colorado River near the mouth of Prospect Canyon and a dike complex is exposed in the volcanic ash below the Esplanade Cascades near Mile 182.5.

Remnants of cinder cones, a sixth type of volcanic deposit, may also be seen in the canyon. Most of these are in the vicinity of the Esplanade Cascades where patches of volcanic ash adhere to the canyon wall.



TEXT-FIGURE 51.—Vertical aerial photograph of the Colorado River from Mile 176 to Mile 182 in the vicinity of extensive lava flows and volcanos at Toroweap Valley.



TEXT-FIGURE 52.—Diagram showing the origin of juxtaposed basalt remnants in the western Grand Canyon.

In addition to the lavas, cinder cones, and dikes, isolated exposures consisting of laminated or stratified ash, a seventh type of volcanic material, can be seen at Mile 180 and 182. These deposits are probably related to volcanic activity to the west, and are the accumulation in ponds or small lakes formed behind the lava dams.

The stop which will be made at Lava Falls Rapids provides an excellent opportunity to view a variety of volcanic phenomena while the boatman is surveying a course through the rapids. One can also examine the older intracanyon flows, younger intracanyon flows, cascades, and dikes from the rim of the Esplanade in Grand Canyon National Monument.

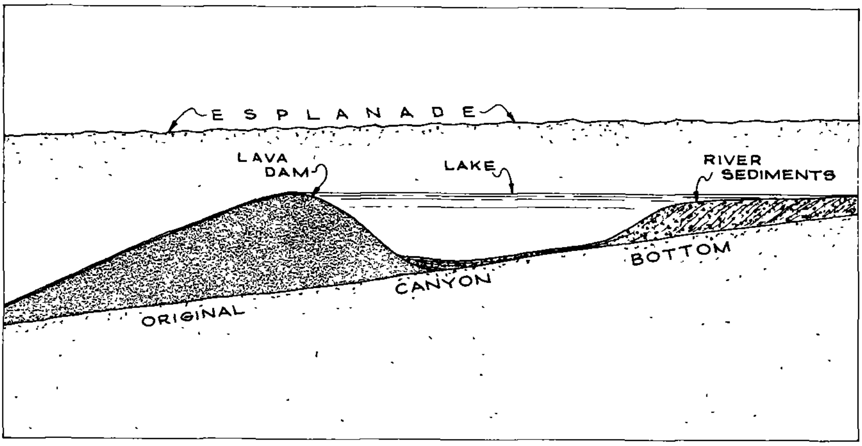
Mile 177.9.—VULCAN'S FORGE. Vulcan's Forge is a neck, the remains of a volcano which was located in the center of the river (Text-figure 53). High-level remnants of lava can be seen plastered against the north wall of the canyon, marking the level of one of the higher lava dams that formed within the canyon. A sequence of four prominent lava flows can be seen downstream along the north wall marking the level of older intracanyon flows.

Mile 178.9.—A volcanic cone can be seen perched on the rim of the inner gorge on the south side of the canyon. This cone is so close to the rim that part of it has sloughed off into the valley below. Additional remnants of the lava dams occur on the south wall upstream from the volcanic cone. These are older intracanyon flows and mark the location of the upstream end of a lava dam (Text-figures 54, 55).

Mile 179.—Prospect Canyon on the south exposes the thickest sequence of lava found within the Grand Canyon. These flows extend to the top of the inner gorge, level with the Esplanade. Vulcan's Throne, one of the best known landmarks in the western part of the Grand Canyon, is located over

TEXT-FIGURE 53.—Vulcan's Forge. This pinnacle of lava is a remnant of a volcanic neck through which lava of some of the intracanyon flows may have been extruded. Scale is indicated by the large pontoon boat.

TEXT-FIGURE 54.—Downstream view of the lava cascades below Vulcan's Throne at Toroweap Valley at Mile 178. Lava of the cascade flowed down Toroweap Valley and over the rim into the bottom of Grand Canyon.



TEXT-FIGURE 55.—Diagram showing the relationships of lava dams and imponded lakes in the western Grand Canyon region.

the upper surface of the flows which filled Toroweap Valley at the level of the Esplanade. This cone is approximately one mile in diameter and is situated on the very brink of the inner gorge. Lava derived from some vents on the south portion of the Uinkaret Plateau have flowed down Toroweap Valley around Vulcan's Throne and cascaded over the rim of the western gorge on the west side of Vulcan's Throne.

Mile 179.2.—LAVA FALLS (10+) THIRTY-SEVEN FOOT DROP. Lava Falls results from erosional debris from Prospect Canyon and is one of the most vigorous rapids on the entire Colorado River. A sequence of four older intracanyon flows are exposed on the north bank (Text-figure 56).

Mile 179.9.—Laminated tuff on the north side of the river was deposited in lakes associated with the lava dams.

Mile 180.—The Esplanade Cascades can be seen downstream (Text-figure 51) and represent a volcanic history similar to that of the Toroweap Cascades, a series of lava flows which filled the canyon within the last million years.

Mile 181.—The sequence of older intracanyon lava flows adhering to the north wall of the canyon is similar to that found at the mouth of Toroweap Canyon. The flows here are capped by a light river gravel and interbedded volcanic ash, similar to that seen at Mile 180. Lavas from the Esplanade Cascade have flowed over the rim here and down approximately 1,100 feet into the inner gorge. Remnants of numerous cinder cones, formed in the inner gorge, are found here clinging to the north wall of the canyon. The largest of these is located high upon the wall near Mile 181.2.

These cinders are easily eroded and debris from the cones form the prominent talus slopes in this vicinity. The abundance of remnants of cones within the canyon indicates that much of the extrusion of the lavas occurred within the inner gorge and only part of the lava originated on the Esplanade and cascaded over the rim of the inner gorge.

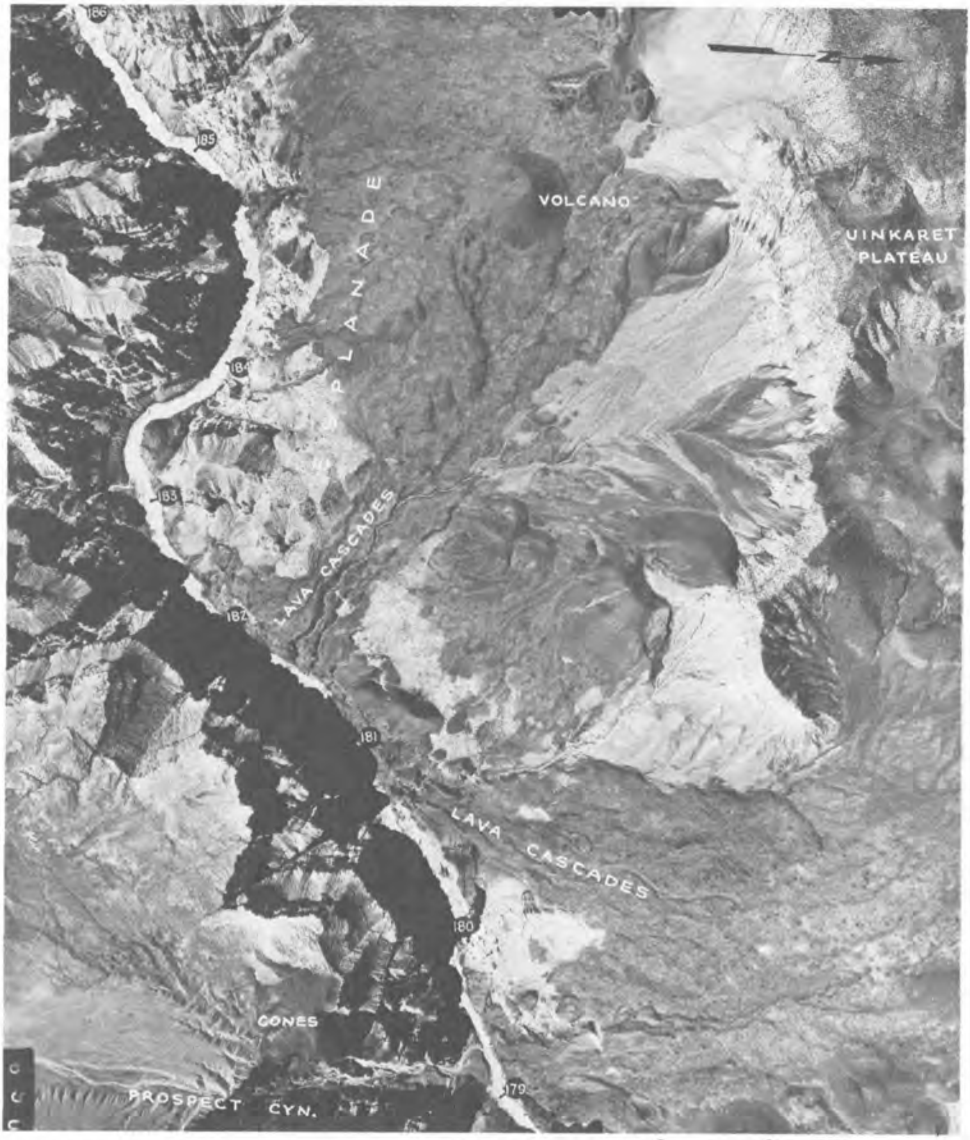
TEXT-FIGURE 56.—Lava Falls Rapids at Mile 179.5. Thick intracanyon flows on the north bank form a vertical cliff 600 feet high above the river. Lava Falls is one of the most vigorous rapids along the canyon and is caused by the influx of debris from Prospect Canyon to the south. Older intracanyon flows are labeled A-D and younger intracanyon flows 1 and 2.

Mile 181.5.—The characteristics of Flow 2 and Flow 4 are very well expressed in canyon-wall remnants (Text-figure 58). Flow 2 is characterized by straight vertical columns and is black, but Flow 4 consists of a sequence of superimposed thinly layered light gray lavas which weather into a very rough ragged surface. In this area Flow 2 is juxtaposed against one of the older intracanyon flows in the sequence at Mile 180 to Mile 181.

Mile 181.6.—A large exposure of volcanic ash similar to that found at Mile 180 is preserved on the north bank and is intruded by numerous dikes approximately 3 feet thick.

Mile 182.1.—A large channel, filled with a sequence of lava flows, can be seen on the north bank and is particularly significant, for the fill is in the ancient canyon through which the Colorado River once flowed (Text-figure 59). The sequence of geologic events in this area would iclude the following:

1. Erosion of the high, older channel by the Colorado River.
2. Deposition of the sequence of lava within this older channel.
3. Erosion of a new channel along the south margins of the lava fill.
4. Subsequent partial filling of the new channel by intracanyon flows.
5. Reexcavation of the present or new channel.



TEXT-FIGURE 57.—Vertical aerial photograph of the Colorado River from Mile 179 to Mile 186 past the Esplanade Lava Cascades.

TEXT-FIGURE 58.—Younger intracanyon flows at Mile 181.5 are stacked side by side against the north wall of the canyon and indicate two separate periods during which the canyon was partially filled with lava. The younger flows on the right form the layered sequence which is plastered against the massive older basalt that is characterized by coarse columnar jointing.

Mile 183.5.—Large exposure of intracanyon Flow 1 is plastered against the north wall of the canyon. This flow indicates that at one time the Grand Canyon was somewhat deeper than it is now because the flow extends well below river level (Text-figure 60).

Mile 184.5.—A rather complex sequence of remnants of basalt occurs in this region. The largest remnant, which is younger intracanyon Flow 4, extends from Mile 184 to approximately 184.4. A number of high-level remnants occur on the North Rim and a large cascade extends from near the top of the Esplanade down to near the river level at Mile 184.9. Bright Angel Shale is exposed at river level.

TEXT-FIGURE 59.—A cross-section of a lava-buried channel through which the Colorado River formerly flowed. The lava fill caused the river to excavate a new channel and displaced the canyon to the left around a meander bend. For scale, the black dot in the center of the sand bar in the foreground is a large rubber raft.

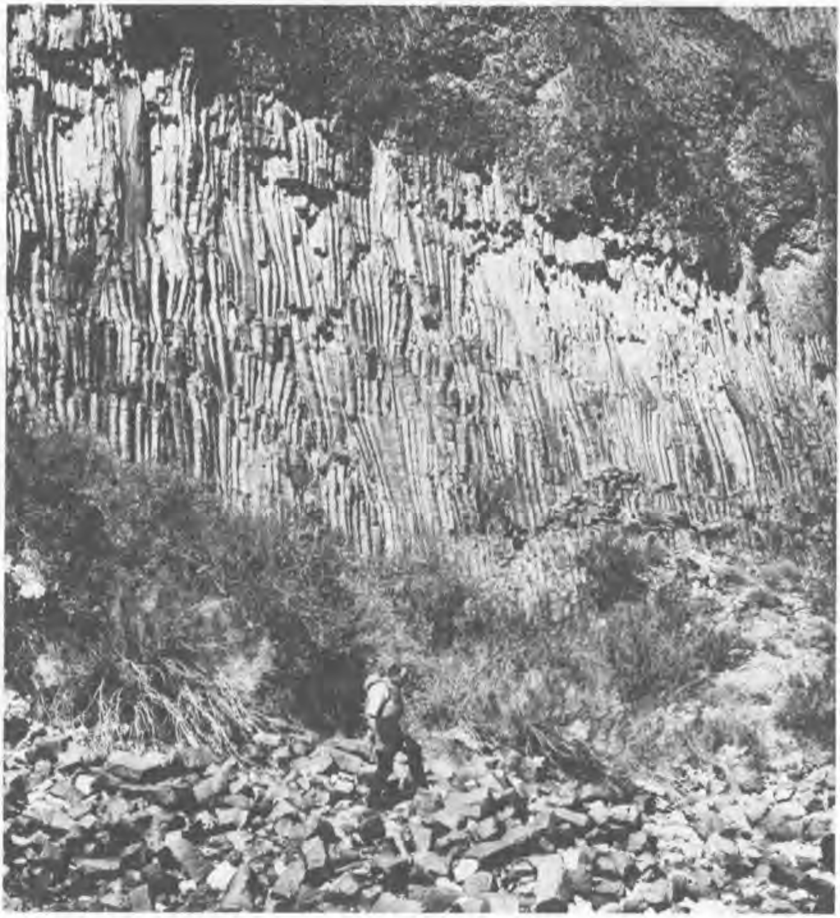
Mile 187.—The relationships of Flows 2 and 5 are well expressed here. Flow 2 is plastered against the walls of the canyon and is capped by gravel. It is characterized by excellent columnar jointing (Text-figure 61). Flow 3 can be seen on top of the sequence of sediments capping Flow 2. Flow 5 is plastered against Flow 2.

Mile 187.5.—WHITMORE WASH is similar to Toroweap and Prospect Canyons. All have been filled with lava to the level of the Esplanade, and the posi-

TEXT-FIGURE 60.—Remnants of intracanyon flows are exposed in the bend in the canyon at Mile 183.2. These flow remnants extend below river level and indicate that the Colorado River channel was somewhat deeper at one time than it is at present. Flow 1 is the earliest younger intracanyon flow.

tions of all three canyons are controlled by major faults. The level of the Esplanade is downdropped nearly 1,500 feet across the Hurricane Fault at Whitmore Wash, although the actual point where the fault trace crosses the river is several miles downstream.

It is possible to drive a jeep down Whitmore Wash to the rim of the inner canyon. This trip, however, crosses a number of lava flows and takes about eight hours, but Whitmore Wash is one of the few points on the river where supplies have been delivered to river runners. Pieces of a plastic hose which was used to refuel jet boats that made the first trip up the river can be seen near the trail. The hose was over 800 feet long and extended from the rim to river level. Whitmore Wash is filled with thin beds of basalt similar to those filling Toroweap Canyon (Text-figures 63, 64). In



TEXT-FIGURE 61.—Columnar jointing developed in intracanyon flows at Mile 186.5, resulting from contraction of the lava as it cooled.

addition the mouth of the wash is veneered with several remnants of Flows 2 and 5.

Mile 188.—Relationships of the intracanyon flows are probably best seen here where Flows 2 and 5 are in juxtaposition against the north wall.

Mile 189.—Remnants of basaltic lava Flows 2 and 5 are well exposed on the east bank and display excellent columnar jointing (Text-figure 66).

Mile 189.8.—A knob of Precambrian granite is exposed on the right bank and represents one of the few buried hills protruding nearly into Bright Angel Shale. Tapeats Sandstone laps onto the Precambrian granite knob, but only 50 to 60 feet is exposed here.

TEXT-FIGURE 62.—Vertical aerial photograph showing the Colorado River from Mile 183 to Mile 191 near Whitmore Wash.

TEXT-FIGURE 63.—Whitmore Wash. The ancient tributary valley is filled with a sequence of thinly bedded lavas. It is possible to drive to the rim of the canyon at this point although the road is extremely rough and 4-wheel drive is advised. The trail leading up to the canyon rim can be seen near the center of the picture. Segments of a hose used to refuel jet boats coming up the river can be seen dangling from the rim near the lip of the basalts and on down past the "castle" to the river below.

TEXT-FIGURE 64.—Aerial view of the lava cascades over the Esplanade into Whitmore Wash and the inner gorge below. Cinder cones on the skyline are developed on the southern tip of the Uinkaret Plateau.

TEXT-FIGURE 65.—Vertical aerial photograph of the Colorado River from Mile 189 to Mile 196 along the Hurricane Fault zone.

Mile 190.—Precambrian granite is seen on both banks with the Tapeats Sandstone resting horizontally upon it. The Precambrian rocks are about 50 percent schist and 50 percent granite. Intracanyon Flows 2 and 5 are exposed above the granite. At Mile 190 a large resistant erosional remnant of the granite protrudes above water level in the middle of the channel. Granite exposures at water level extend from Mile 189.8 to approximately 191.5 where the Hurricane Fault crosses the river. The granite is exposed here because of regional dip to the north and it is terminated on the southwest by the Hurricane Fault.

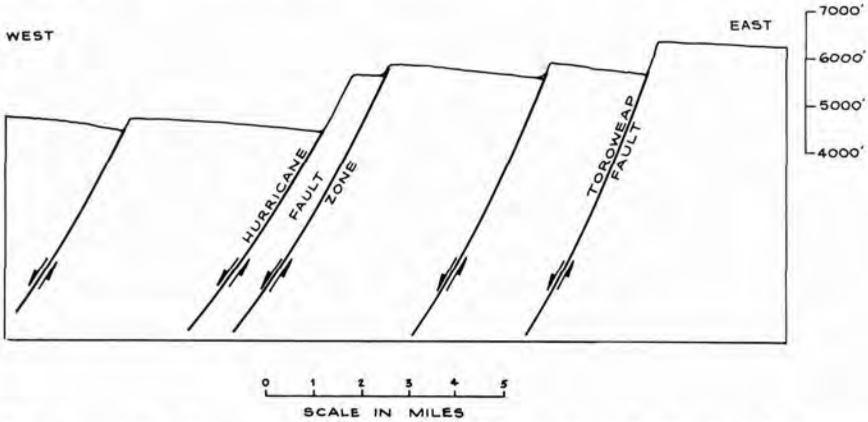
Mile 191.—A remnant of the intracanyon Flow 5 lava is exposed on the south bank. It continues southward downstream for more than a mile.

Mile 191.3.—Looking downstream at Mile 191.3 one can see the Supai Sandstone and Redwall Limestone high on the east skyline of the canyon, but the same strata are approximately 1,500 feet lower on the west side of the canyon across the Hurricane Fault. The tributary canyon which trends due south here is developed along the trace of Hurricane Fault.

Mile 191.5.—The Hurricane Fault zone crosses the canyon here (Text-figure 67, 68). It is one of the major fault zones in the Colorado Plateau and extends from south of Peach Springs in Arizona, across the canyon here, then northward into the Cedar City, Utah area. It has a displacement of 1,500 feet here in the canyon, but the displacement increases northward to more

TEXT-FIGURE 66.—Younger intracanyon flows exposed at Mile 189. The lower flow here is capped by a significant thickness of river gravel which accumulated after the lava had clogged the channel of the Colorado River and has disrupted the course of the stream.

Text-figure 67.—Brecciated rocks of the Hurricane Fault zone looking north from Mile 194.5



Text-f[illegible] 68.—Cross-section showing the displacement along the Hurricane Fault zone [illegible] .e 191.

than 10,000 feet near Cedar City. The Tapeats Sandstone is well exposed above the Precambrian granite on both the north and south side of the river, but it is especially well expressed on the north.

Mile 191.8.—Columnar jointing in Flow 5 is well expressed on the northwest side of the canyon. Older well-rounded, well-bedded river gravels occur

TEXT-FIGURE 69.—Vertical aerial photograph showing the Colorado River from Mile 196 to Mile 202.

below the jointed lava. The imposing vertical inner gorge is lost in this part of the canyon, due in large part to fracturing of the Paleozoic formations in the Hurricane Fault zone.

Mile 192.—Intracanyon Flow 5 is exposed on both sides of the canyon. A remnant of Flow 3 is higher than Flow 5 on the southeast side of the canyon because Flow 5 is beginning to pinch out.

Mile 192.1.—Flow 4 rests on sandstones of the Bright Angel Shale on the left bank of the river. Stream gravels cap Flow 5 on the right bank. Large gravel bars present on the right bank of the river expose the type of sediment being transported.

Mile 193.—High gravel-capped terraces occur on the canyon wall.

Mile 193.6.—Isolated remnants of Flows 2, 3 and 4 are preserved in the canyon for the next three miles above Cambrian bedrock.

Mile 197.2.—Large remnant of Flow 4 occurs just east of Parashant Wash.

Mile 198.5.—PARASHANT WASH. A small remnant of Flow 2 is exposed on the west bank. Several small northwest-trending faults cut across the canyon and displace strata of 50 to 60 feet. The faults are well exposed on aerial photographs.

Mile 199.7.—Small remnant of Flow 4 can be seen on the east bank.

Mile 200.—Remnant of Flow 2 on the west bank. In this area there are numerous wild burros whose ancestors were brought here by early prospectors. The early burros escaped and became wild. Some prospectors such as Bass turned some burros loose to build up their breeding stock.

Mile 202.3.—The large remnant of Flow 2 near river level extends almost a quarter of a mile downstream, a distance of approximately 18 miles from its source. Brown dolomite forms angular ledge at river level.

Mile 203.—The flow remnant extends here below river level, indicating that once the Grand Canyon was deeper than at present. The canyon in this area is rather monotonous with the carbonate units from Muav up to Redwall forming a sequence of nearly unbroken cliffs, separated only by narrow slopes. It is difficult to distinguish these formations from a distance unless one is familiar with details of their physiographic expression. These limestone units are gray rather than stained red because the red Hermit Shale has been eroded back approximately five miles from the rim of the inner gorge. The Supai Sandstone has a thick limestone unit at its base, but it lacks the red color that is so prominent upstream.

Mile 203.2.—A large remnant of a basaltic lava flow is present along the river margin. The remnant is nearly eight-tenths of a mile long and is composed mostly of Flow 2 with only a minor remnant of Flow 4 plastered against the upstream end. The top of Flow 2 is exceptionally smooth and flat.

Mile 204.2.—Large remnant of Flow 2 can be seen on the river bank and with a small adjacent vestige of Flow 4. Only two flows are recognized from

TEXT-FIGURE 70.—A remnant of a younger intracanyon Flow 5 at Mile 197 adhering to the canyon wall 50 to 60 feet above river level. The Muav Limestone forms a series of cliffs up to the Redwall Formation on the horizon. The thin uniformly bedded strata are the Devonian Limestone.

Parashant Canyon downstream; Flow 2 forms the thicker and larger remnants; Flow 4 forms younger and smaller remnants which are plastered against the older Flow 2. The two are commonly preserved together on the inside of the major meanders. Cambrian rocks form the bedrock walls of the canyon.

Mile 205.—The canyon becomes quite wide in this area and considerable landslide debris can be seen on both the west and east walls. The typical low cliffs and small slopes of the Paleozoic rocks are replaced here by large landslide masses. Two remnants of Flow 2 and two remnants of Flow 4 occur near here.

Mile 205.4.—Landslide debris is well exposed at river level on the west or right side of the canyon.

Mile 205.5.—TWO-HUNDRED-AND-FIVE-MILE RAPIDS (4) THIRTEEN-FOOT DROP. Landslide debris on both sides of the river shows typical, slump-block displacement. Some of the blocks are as much as a quarter of a mile long and are tilted toward the canyon wall.

Mile 206.5.—Tapeats Sandstone is exposed at river level. Large exposure of Flow 2 occurs from Mile 206.5 to Mile 207.5. A small remnant of Flow 4 also occurs at Mile 206.5.

TEXT-FIGURE 71.—Vertical aerial photograph of the Colorado River from Mile 201 to Mile 207.

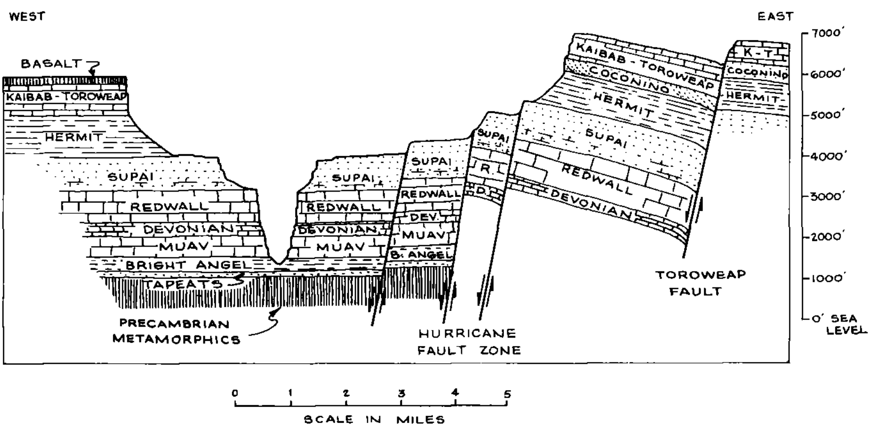
Mile 207.2 to Mile 208.—An exceptionally large deposit of river terrace gravels can be seen on the east or left bank, rising approximately 50 feet above the river. The gravel is relatively well sorted and is crudely cross-stratified. The fragments are mostly of Paleozoic rocks with a minor amount of basalt.

Mile 208.—Precambrian granite and schist are exposed on the left bank, on the upthrown block of a branch of the Hurricane Fault. The Redwall Limestone, the Devonian carbonates, and the Muav Limestone combine to form a high prominent cliff on the canyon wall. Bright Angel Shale forms a small terrace or platform below the limestone cliff, and the underlying Tapeats Sandstone is well exposed in a small vertical cliff above the granite. The granite and schist are green, purple, gray, and brown. In this section of the canyon one can see only the rim of the Esplanade, for the upper rim of the canyon on the Kaibab Limestone has been eroded back several miles to the east and west.

Directly downstream, however, one can see the upper rim of the canyon in the background on the skyline, formed on the Kaibab and Toroweap formations. Remnants of Flows 2 and 4 occur together from Mile 200 to 209, preserved on the inside of meander bends.

Mile 209.5.—A gravel bar forms an island in the center of the river. Higher river gravels, 20 to 40 feet above the river, contain large blocks of lava debris. The Paleozoic sequence exposed in this part of the canyon is well expressed downstream. Indian ruins are common in the lower canyon.

Mile 210.—Moderate amounts of landslide debris can be seen on the west bank. The east bank is typically clear of debris and exposes the Muav to Redwall cliff of this section of the canyon. Bright Angel Shale is normally at river level. Locally beds of sandstone within the Bright Angel Shale are exposed above the water.



TEXT-FIGURE 72.—Cross-section across the western Grand Canyon near Mile 210.

TEXT-FIGURE 73.—Vertical aerial photograph of the Colorado River from Mile 206 to Mile 212.

TEXT-FIGURE 74.—Vertical aerial photograph of the Colorado River from Mile 212 to Mile 218.

Mile 211.—Precambrian black dense metabasalt is exposed on the west bank and is injected with numerous white quartz veins. The exposure of Precambrian is probably part of an ancient hill which protruded above the pre-Tapeats surface.

Mile 212.8.—A remnant of Flow 2 is exposed on the left bank.

Mile 213.—Tapeats Sandstone exposed at river level. At low water a travertine spring can be seen on the left bank where considerable moss and algae are growing, forming a very colorful deposit known as "Charlie Brown's Great Pumpkin."

Mile 213.9.—Large remnant of Flow 2 is preserved on the right bank upon the vertical-walled Tapeats Sandstone and young river gravels. Many wild burros can often be seen in this area.

Mile 215.—Small faults uplift the Tapeats Sandstone and underlying Precambrian metamorphic rocks so that the Precambrian rocks are exposed 50 to 60 feet above the river level.

Mile 215.3.—Remnants of Flow 2 rest upon the top of the Tapeats Sandstone. A natural bridge can be seen from this viewpoint on the skyline to the west. The Tapeats Sandstone stands as a vertical wall which becomes higher and higher downstream until it forms a small inner gorge, beneath the overlying Bright Angel Shale which has eroded into a shallow terrace. The sandy nature of the Bright Angel Shale, however, limits the development of the Tonto Platform here.

Mile 215.9.—Small hills of Precambrian rock protrude above river level, heralding the BEGINNING OF LOWER GRANITE GORGE. Thickness of the Tapeats Sandstone in the Lower Granite Gorge varies somewhat because of the underlying Precambrian hills. The Tapeats Sandstone commonly weathers a dark brown to black and has a purplish red coloration where fresh.

Mile 217.5.—TWO-HUNDRED-SEVENTEEN MILE RAPIDS (4) SIXTEEN-FOOT DROP. Small rapids result from influx of sediment from the stream on the east bank. The river cuts deeper and deeper into the Lower Granite Gorge below the rapids. The outcrops appear as a fine-grained dioritic rock injected with a minor amount of granite. Tapeats Sandstone forms the cap rock of the inner gorge, with the underlying Great Unconformity clearly visible. Lower Granite Gorge has essentially no sand or gravel shores, for the rocks which form the gorge wall plunge steeply into the river channel.

The massive dolomite seen at Mile 202.3 now constitutes the base of the Muav Limestone with a small lens of shale above. The dolomite thicken westward and changes to limestone whereas the sandstone lenses in the lower Bright Angel shale thin westward.

Mile 220.—Limited exposures of metamorphic rocks form the inner gorge. The Bright Angel Shale forms a slope between cliffs of the underlying Tapeats Sandstone and the overlying Muav-Redwall Limestone. Bedrock exposed here in Lower Granite Gorge is massive gabbroic material which lacks the well-defined foliation that is typical of the metamorphic sequence exposed in the Middle and Upper Granite Gorge.

Mile 221.4.—Remnants of Flow 2 can be seen on both banks (Text-figure 76). The prominent landmark known as Diamond Peak projects above the surrounding landscape in the form of a huge pyramid directly downstream (Text-figure 77). The canyon in this section has an asymmetrical profile, due to the

TEXT-FIGURE 75.—Vertical aerial photograph showing the Colorado River from Mile 217 to Mile 223.

TEXT-FIGURE 76.—A large remnant of intercanyon flow at Mile 222. This remnant consists of a single flow which at one time was 370 feet thick. Note the level upper surface of this flow and the Precambrian metamorphic rocks behind. The Hurricane Fault trends north-south, parallel to the river, between the basalt remnant and the Precambrian rocks.

north-south trending Hurricane Fault which is close to the river in this section of the canyon. The Tonto Platform on top of the Tapeats Sandstone is 1,600 feet above sea level on the west bank, but is 3,000 feet above sea level directly to the east of the river, indicating 1,400 feet of displacement along the Hurricane Fault. This displacement is one of the more spectacular expressions of a fault within the Grand Canyon.

Mile 222.5.—Solution caverns can be seen near the top of the Redwall Limestone along the west wall. These are similar to those developed in the park area, where the Redwall Limestone responds to erosion to form great alcoves, amphitheaters and caverns.

Mile 222.8.—Two small remnants of Flow 2 occur on the west side of the river. As can be seen from this point, the top of the flow is much lower than at Whitmore Wash upstream.

Mile 223.—Small alcoves and caves can be seen in the Muav Limestone and near the top of the Redwall Limestone cliff on the west bank.

Mile 224.—Diamond Peak, on the left bank, marks the beginning of a symmetrical profile in the inner gorge. The Hurricane Fault cuts southward across the canyon on the east side of Diamond Peak, and continues southward along Peach Springs Wash. Peach Springs Wash provides the only accessible road route to the Colorado River within the Grand Canyon. Hualapai Indians

TEXT-FIGURE 77.—Diamond Peak as seen from Mile 223 looking downstream. Diamond Peak is a prominent landmark carved on the Redwall and underlying Devonian and Muav formations. The Hurricane Fault trends north-south on the east side of the peak.

have scraped out a road so that one can drive down to river level at Diamond Creek. The canyon profile regains its symmetrical form on the west side of Diamond Peak with the Tapeats Sandstone forming a cap rock to Lower Granite Gorge on both sides of the river. The metamorphic rocks in this part of the canyon are massive and lack well-expressed foliation. The Colorado River flows essentially due south, parallel to the Hurricane Fault which has exerted considerable control upon position of the course of the Colorado River in this section of the canyon. At Diamond Creek the river turns abruptly to the west after leaving the Hurricane Fault zone.

Mile 225.—The rim of the Esplanade can be seen downstream, but the high rim of the canyon cannot be seen from this viewpoint on the river (Text-figure 78).

Mile 225.2.—A small remnant of Flow 2 is seen on the west bank, clinging to the side of the inner gorge of metamorphic rocks. Since basalt and the

TEXT-FIGURE 78.—View of Lower Granite Gorge seen from Mile 225. The Precambrian metamorphic rocks here form the somber rugged V-shaped gorge which contrasts sharply with stratified formations above. The Esplanade is the even surface on the skyline.

metamorphic rocks are both dark, it may be difficult to recognize this remnant.

Mile 225.6.—DIAMOND CREEK RAPIDS (5) TWENTY-FIVE-FOOT DROP. Diamond Creek enters the Colorado River from the east and forms a broad delta. Here the Hualapai Indians have built a road down to the river which terminates in a small picnic area. Shortly after Powell's exploration of the Colorado River, Lt. Wheeler of the Topographic Engineers, with a party of approximately 20 men, brought boats up the river to this point.

The Farley or Diamond Creek Hotel was built in 1894 near the Colorado River at the junction of Diamond Creek and Peach Springs Wash in the bottom of the Grand Canyon. It operated regularly until 1899 when facilities at the higher scenic areas in what is now Grand Canyon National Park were developed. As a result, after 1899 the Diamond Creek Hotel declined in

TEXT-FIGURE 79.—Vertical aerial photograph of the Colorado River from Mile 222 to Mile 228 near Diamond Peak. A road has been built down Peach Springs Wash.

TEXT-FIGURE 80.—Vertical aerial photograph of the Colorado River from Mile 226 to Mile 232.

popularity. Remains of this structure can still be seen a short distance up Diamond Creek. The hotel was reached by a rough road down Peach Springs Wash from the railroad station at Peach Springs. This road is still moderately passable and partially maintained by the Hualapai Indians.

Mile 227.5.—Lower Granite Gorge here is 1,115 feet deep below the top of the Tapeats Sandstone, not quite as deep as Upper Granite Gorge in the vicinity of Phantom Ranch.

Mile 229.—TRAVERTINE CANYON. Travertine Springs on the left bank have formed large travertine deposits along the walls of the small tributary canyon. Travertine is a spring deposit in most areas, but calcium carbonate is exceedingly abundant in surface waters here in the canyon and it is deposited by tributary streams as well as by springs. Some of the most spectacular deposits of travertine found in the world are present here in the Grand Canyon, especially in the western end near the Grand Wash Cliffs and in the Havasupai Indian reservation. In the metamorphic rocks of this area one can find large crystals of garnet.

Mile 230.—TRAVERTINE FALLS on the south bank.

Mile 231.5.—Precambrian rocks here appear similar to those in Upper Granite Gorge in the park. The major rock type is a dark schist injected with innumerable small pink dikes, many of which have been folded.

Mile 234.—The large amount of rock debris along the sides of the canyon is the result of rock falls from the steep canyon walls. Numerous pink granitic dikes intrude the dark metamorphosed basalt near river level. The dikes are rarely more than a foot or two thick and have been intensely folded, indicating multiple periods of deformation in the metamorphic sequence.

Mile 236.9.—The deposit of red hematitic rock on the left bank is six to eight feet wide; and if it were somewhat larger, it could be economically mined. Most of the metamorphic rocks in this area are gneissic. Large alcoves can be seen in the limestone directly downstream near the skyline (Text-figure 82).

Mile 237.—CABLE CROSSING AT BRIDGE CANYON DAM SITE. Additional workings are present along the sides of the canyon. This dam project has been shelved because of objections by naturalists and conservationists to construction of dams on this section of the Colorado River.

Mile 238.—Remains of trails and cabin foundations, used by workmen of the Bureau of Reclamation, were built during investigation of the Bridge Canyon Dam site and can be seen on the south bank.

Mile 239.7.—SEPARATION CANYON is so named because it was here that three of Powell's men left his party and climbed to the canyon rim to the north. Unfortunately all three men were killed soon after they escaped from the canyon by Indians on the plateau to the north. The formidable cliffs of the canyon walls make such a journey almost as difficult as continuation on downstream. At the present time there are no rapids downstream from Separation Canyon because of the backwater of Lake Mead. When Powell ran the canyon, however, there were several severe rapids beyond Separation Canyon.

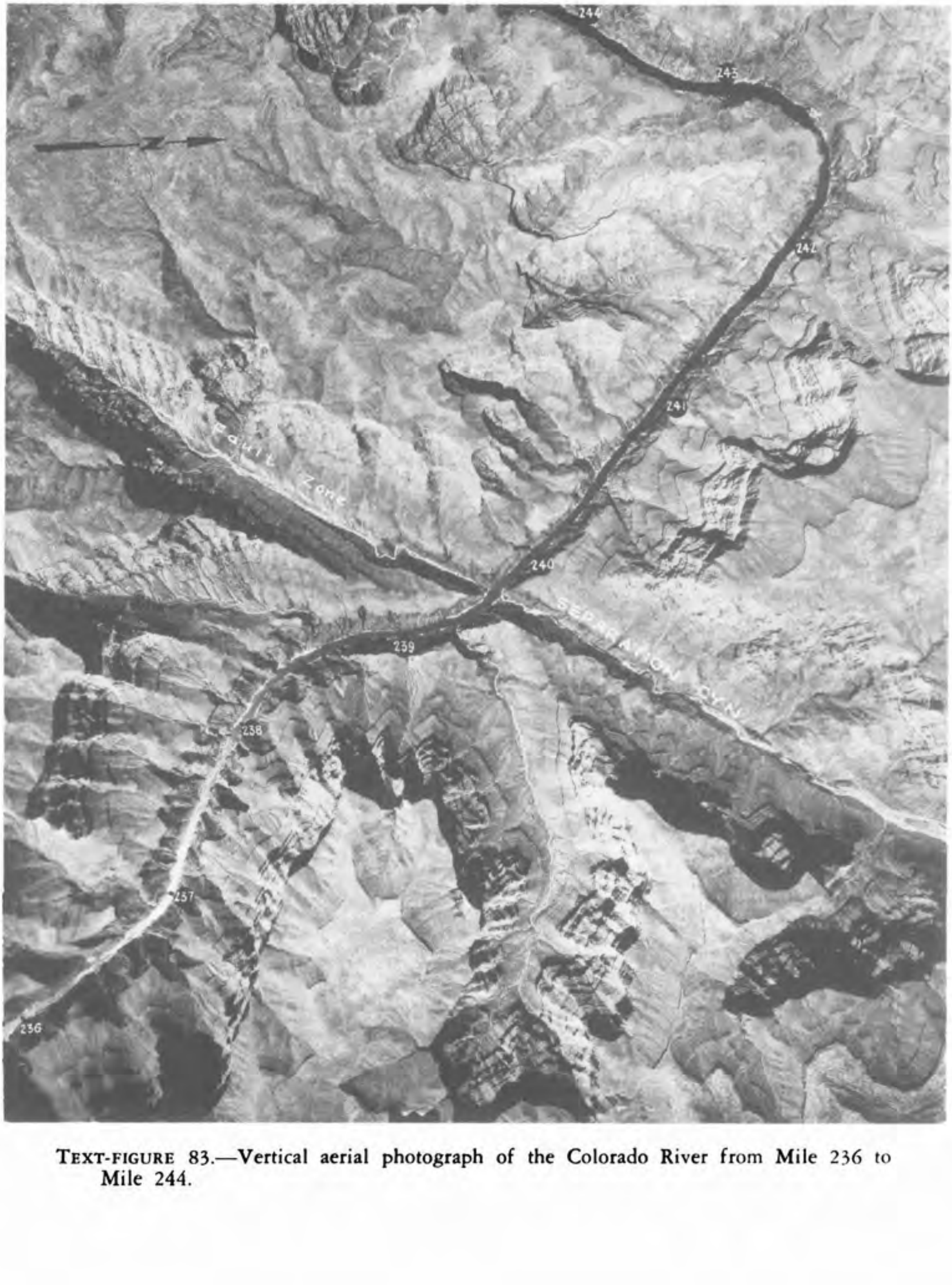
TEXT-FIGURE 81.—Vertical aerial photograph of the Colorado River from Mile 232 to Mile 239.

TEXT-FIGURE 82.—View of Lower Granite Gorge and the overlying Paleozoic rocks seen from Mile 236.5.

Separation Canyon is one of the many tributary canyons in the Grand Canyon which are controlled by fault systems (Text-figure 83). The striking linear trends of canyons, both to the north and south, are impressive, and faithfully express the straight fault trace.

Mile 240.2.—Granitic dikes are less abundant in Precambrian rocks in this part of the Lower Granite Gorge. Those dikes which are present show a great amount of folding and are rather narrow, usually no more than a foot or two wide. Several basic dikes and quartz veins can also be seen.

Mile 242.—The Paleozoic sequence is well exposed downstream (Text-figure 85). The Redwall Limestone is the uppermost massive cliff and is capped by only a few beds of Supai Sandstone. Alcoves, typical of the Redwall beds, are present in red-stained cliffs. Well-bedded limestone in which the strata are distinctly continuous is the Devonian limestone below the Redwall cliff.



TEXT-FIGURE 83.—Vertical aerial photograph of the Colorado River from Mile 236 to Mile 244.

TEXT-FIGURE 84.—Pothole development in Precambrian rocks at Mile 240. This type of erosion is accomplished by pebbles, caught in a depression, which are swirled around by stream action, thereby drilling holes into the bedrock of the stream.

Three cliffs of Muav Limestone occur beneath this sequence, above a minor terrace developed on the Bright Angel Shale. Two large slump blocks in the Muav Limestone and Bright Angel Shale can be seen near the lower two-thirds of the cliff. There is little Tapeats Sandstone above the metamorphic rocks at this particular locality.

Mile 242.5.—The river makes an abrupt turn of approximately 90 degrees and flows southward. Lower Granite Gorge becomes somewhat deeper from this point downstream for several miles. A small remnant of one of the intracanyon basalt flows occurs in a protected area of the tributary streams on the south bank. Rapids in Lower Granite Gorge are not as rigorous as those in Upper Granite Gorge, for Lake Mead at one time backed the river water upstream as far as Mile 217. With construction of the dam at Glen Canyon and regulated discharge from Lake Powell, the level of Lake Mead was lowered

TEXT-FIGURE 85.—Lower Granite Gorge and the overlying Paleozoic rocks as seen from Mile 242. The thickness of the Muav and Devonian limestones is much greater here than in the eastern parts of the canyon. The large landslide debris area below the prominent Redwall Cliff rests on the terrace of Bright Angel Shale in the center of the picture.

approximately 100 feet. The Colorado River has now reexcavated a channel through the silt that had accumulated at the head of Lake Mead. Practically all of the silt which was deposited has been removed from Mile 217 down to Separation Canyon. Below Separation Canyon there still remains considerable silt deposits within the canyon floor. The original rapids below Separation Canyon were filled with silt. When Lake Powell becomes full, greater volumes of water will probably be released through Grand Canyon into Lake Mead and may produce a rise in lake level and resilting.

Mile 246.—A relatively large remnant of lava is exposed on the north bank. The top of the lava is 80 feet above river level and it has been eroded with potholes by abrasive stream action.

Mile 246.5.—Silt from the high-water level of Lake Mead occurs along the north bank and supports much of the luxurious growth of tamarix.

Mile 247.5.—The northwest trend of the river in this section is down the regional dip so that the Paleozoic sequence appears closer to river level and

TEXT-FIGURE 86.—Vertical aerial photograph of the Colorado River from Mile 241 to Mile 250.

TEXT-FIGURE 87.—Vertical aerial photograph of the Colorado River from Mile 250 to Mile 257.

Lower Granite Gorge becomes shallow. Precambrian rocks will disappear beneath river level several miles downstream.

Mile 248.—An excellent exposure of the Precambrian erosional surface and the Great Unconformity can be seen a few tens of feet above river level. A zone of decomposed rock occurs at the top of the metamorphic sequence.

Mile 248.5.—High water level of Lake Mead is expressed by silt deposits in the tributary from the north, as well as in tamarix-covered banks. The Paleozoic rocks visible downstream are Tapeats Sandstone up to Supai Formation at the Esplanade. A considerable thickness of Devonian rocks occurs in this locality. Caves have developed in the upper third of the Redwall Formation.

Mile 252.8.—A MAJOR TRIBUTARY COMING INTO THE COLORADO RIVER FROM THE SOUTH has been effectively dammed by silt from Lake Mead so that at the present time a small lake is formed back upstream from the mouth of the tributary canyon.

Mile 253.6.—A very small remnant of lava occurs in the protective reentrant of the tributary valley coming in from the south. The sequence of Paleozoic rocks is displayed downstream. The Tapeats Sandstone in this locality has a dark, purplish gray lower sandstone unit resting on the Precambrian metamorphic rocks. The Bright Angel Shale forms a gentle slope above the Tapeats Sandstone, and the overlying Muav Limestone erodes to form several cliffs in the middle of the sequence. The Devonian Limestone consists of the well-bedded gray limestone and is capped by the magnificent cliffs of the Redwall Limestone which are as impressive and imposing as in any part of the canyon.

Mile 254.2.—Lava remnants on the north bank are partially covered with recent Lake Mead silt but are in the process of being exhumed (Text-figure 88). These are the lowermost exposed downstream remnants observed in the canyon. All of the remnants are largely obscured by tamarix but can be seen protruding above the vegetation about one-tenth of a mile downstream.

Mile 255.2.—The Tapeats Sandstone is close to river level on the north bank. The Great Unconformity and the low Precambrian hills protruding up into the Tapeats Sandstone are high above the river. This relationship is due to a fault which trends to the northwest, up the tributary canyon where the strata are also visibly displaced. This fault controls the position of the straight segment of the river from Mile 254 to 255.7. It is one of the most clearly expressed faults within the canyon and can be easily examined at close hand on a boat trip.

Mile 255.5.—A large spur which is capped by Tapeats Sandstone presents an imposing exposure of the Cambrian-Precambrian unconformity. The river bends slightly to the left and leaves the fault zone so that the Tapeats Sandstone is at the same elevation on both sides of the river. Lower Granite Gorge is shallow here.

Mile 256.—In this section of the canyon the Tapeats Sandstone and its unconformable relationship with the underlying metamorphic rocks is clearly exposed because of lack of vegetation and slope wash. Pockets of highly decomposed rock occur immediately beneath the Tapeats Sandstone, along

TEXT-FIGURE 88.—Remnants of younger intracanyon flows at Mile 254.2. These basalts originated upstream between Mile 178 and Mile 188 and flowed down the Colorado River gorge as a stream of lava for a distance of over 86 miles.

which erosion has been accelerated. A number of small caves and overhanging cliffs have developed in this contact zone (Text-figure 89).

Mile 257.2.—Large vertical exposures of silt from Lake Mead high-water level form the left bank.

Mile 258.—The Supai Formation can be seen above the Redwall Limestone in the cliffs on the skyline immediately downstream. This is one of the few places below Mile 200 where a good section of the Supai beds can be seen in canyon walls.

Mile 259.—Extensive deposits of travertine on the left bank coat the Precambrian metamorphic rocks.

Mile 259.3.—THE RIVER MAKES A SHARP BEND TO THE LEFT. Excellent exposures of the Great Unconformity can be seen on the north bank. The surface is somewhat undulatory and locally decomposed metamorphic rocks occur in pockets several feet thick. The high cliffs on the south bank are veneered with great deposits of travertine which cement slope debris into a

TEXT-FIGURE 89.—The canyon profile at Mile 256. The Redwall Limestone forms the uppermost bold cliff and is underlain by the well-bedded Devonian limestone and the thick sequence of poorly defined cliffs of the Muav Formation. The Bright Angel Shale forms the slopes visible downstream through the V-shaped gorge. The contact between the Precambrian metamorphic rocks and the Tapeats Sandstone is several feet above river level.

coherent flow-stone surface. Evidence of high-water level can be clearly seen on the south bank where the travertine above high-water has weathered dark gray but that below high-water level is a light buff.

A major fault-controlled tributary coming into the Colorado River has been effectively blocked by the river silt so that a small lake is formed at the mouth of the river similar to that found upstream a few miles.

Mile 259.8.—Travertine has cemented a debris fan on the south bank and has produced a surface similar to that at Mammoth Hot Springs in Yellowstone National Park. On the north bank the contact of the Tapeats Sandstone on the Precambrian metamorphic rocks is exceptionally well exposed.

Mile 260.5.—The Tapeats Sandstone is close to river level on the north bank, but it is several tens of feet above river level on the south bank. This apparently is due to the northward regional dip.

Mile 262.—Exceptionally large banks of lake silts occur along the north side of the river.

TEXT-FIGURE 90.—Vertical aerial photograph of the Colorado River from Mile 257 to Mile 262.

Mile 262.2.—Great alcoves are formed in Redwall Limestone near the skyline on the north.

Mile 262.3.—A large bank of lake silt on the south side effectively blocks drainage coming in from the south, so that small lakes are produced at the mouths of tributaries. Downstream from Mile 259 very few major tributaries enter the Colorado River. All are effectively blocked by thick Lake Mead silt deposits.

Mile 265.9.—Two large steel towers on the left bank are the remains of a cable system used in transporting bat guano excavated from caves in this vicinity up to the South Rim. This mining operation continued until the 1950's when nitrate fertilizer made it an uneconomical venture. The guano was mined from the caves a third of the way up the cliff to the right of the towers (Text-figure 91). It was then hauled by a cable car across the canyon and up to

TEXT-FIGURE 91.—Bat Cave and abandoned cable anchorage at Mile 265.9. Bat guano was mined from the large cave shown in the central part of the picture and was transported by cable across the river and up to the South Rim.

TEXT-FIGURE 92.—Vertical aerial photograph of the Colorado River from Mile 262 to Mile 269.

TEXT-FIGURE 93.—Vertical aerial photograph of the Colorado River from Mile 268 to Mile 272.

the South Rim where it was then shipped by road to market. The two large towers high on the South Rim were the anchors for the cable pillars.

Mile 266.5.—Large mounds of travertine-cemented slope wash are evident on the north bank just above the recent lake silts. Sandstone units within the Bright Angel Shale are exposed on the south bank in step-slope fashion and lead up to the first cliff of the Muav Formation.

Mile 267.5.—Cliffs on the north bank near river level are largely veneered with travertine. This is part of one of the most extensive travertine deposits seen on the river. These deposits are relatively old, as suggested by their degree of erosion. Rocks on the north bank, about midway up to the skyline, are faulted, with displacements of 200 to 300 feet. The faults dip at an angle of approximately 75 degrees to the west. These are a few of a number of small normal faults associated with the major Grand Wash Fault and impart a linear grain to the topography. The general drainage net of tributary canyons in this part of the Grand Canyon is controlled to a large degree by these fractures.

Mile 269.2.—A large vertical cliff of travertine occurs near water level on the north bank.

Mile 296.3.—An extensive accumulation of river gravel extends to a height of 30 to 40 feet above water level. These gravels are well-stratified, well-rounded, sorted river deposits similar to those older gravels associated with the intracanyon lava flows upstream.

Mile 270.—The prominent brown ledge 150 to 200 feet above river level on the north is the upper brown sandstone unit of the Bright Angel Shale.

Mile 270.2.—Landslide debris is exposed on the North Rim, near the horizon of the Muav Limestone.

Mile 270.3.—White cliffs exposed on the skyline are sandstones of the Supai Formation which holds up the Esplanade. Grand Wash Cliffs are downstream just beyond the promontory.

Mile 274.4.—Two small tributaries enter the stream from the south and appear to be fault controlled. The river bends to the north and continues through Lake Mead silt.

Mile 276.—A large mass of travertine is seen at river level on the north bank. This deposit is relatively old for much of the face has been eroded by stream action. High-water level can be seen about one third the distance up the face of this travertine deposit.

Mile 278.—GRAND WASH CLIFFS.

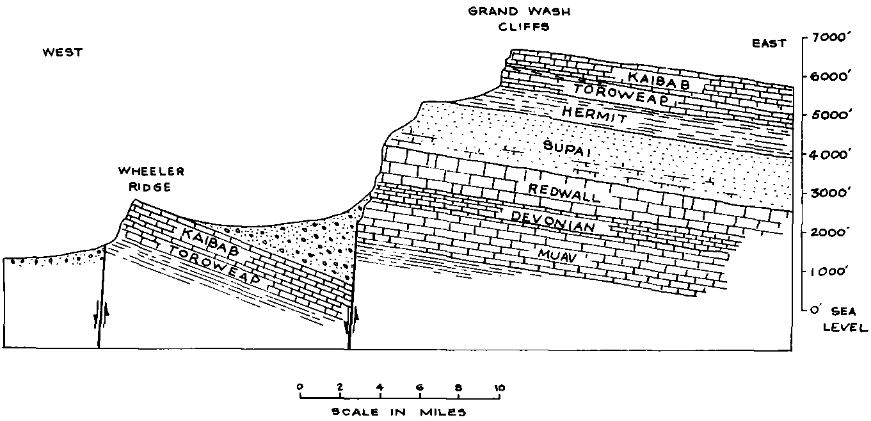
> To night we camp on the left bank, in a mesquite thicket.
>
> The relief from danger, and the joy of success, are great When he who has been chained by wounds to a hospital cot, until his canvas tent seems like a dungeon cell . . . at last goes out into the open field, what a world he sees! How beautiful the sky; how bright the sunshine; what "floods of delirious music" pour from the throats of birds; how sweet the fragrance of earth, and tree, and blossom! The first hour of convalescent freedom seems rich compensense for all—pain, gloom, terror.
>
> Something like this are the feelings we experience tonight. Ever before us has been an unknown danger, heavier than immediate peril. Every waking

TEXT-FIGURE 94.—Vertical aerial photograph of the Colorado River from Mile 271 to Mile 280 at the head of Lake Mead near the Grand Wash Cliffs.

> hour passed in the Grand Canyon has been one of toil. We have watched with deep solicitude the steady disappearance of our scant supply of rations, and from time to time have seen the river snatch a portion of the little left, while we were ahungered. And danger and toil were endured in those gloomy depths, where oft times the clouds hid the sky by day, and but a narrow zone of stars could be seen at night. Only during the few hours of deep sleep, consequent on hard labor, has the roar of the waters been hushed. Now the danger is over; now the toil has ceased; now the gloom has disappeared; now the firmament is bounded only by the horizon; and what a vast expanse of constellations can be seen!
>
> The river rolls by us in silent majesty; the quiet of the camp is sweet; our joy is almost ecstacy. We sit till long after midnight, talking of the Grand Canyon, talking of home . . . (Powell, 1875, p. 102-103).

The Grand Canyon ends very abruptly at the Grand Wash Cliffs (Text-figures 94-95) where the sequence of horizontal strata through which the Colorado River has cut the canyon has been downfaulted west of the cliffs approximately 16,000 feet along the Grand Wash Fault. The Grand Wash Fault marks the western boundary of the Colorado Plateau and the eastern boundary of the Basin and Range Province. West of here the strata are folded and faulted and form the broken mountains of western Utah and Nevada. The Grand Wash Fault forms a high cliff which rises 4,000 feet above the adjacent Basin and Range. At this point the Grand Wash Cliffs have a profile similar to the Grand Canyon. Two major cliffs separated by a broad terrace are present. The lower cliff consists of the sequence from the Bright Angel Shale up to the top of the Supai Formation. A broad terrace corresponding to the Esplanade has developed on the Supai Formation and extends northward into Utah some 30 or 40 miles. The upper sequence of strata, including the Hermit Shale, the Coconino Sandstone, and the Kaibab and Toroweap formations, form the upper Grand Wash Cliffs.

TEXT-FIGURE 95.—*View of the Grand Wash Cliffs looking upstream from Pierce's Ferry. Lake Mead silts form the banks of the river in the foreground.*



TEXT-FIGURE 96.—Cross-section across the Grand Wash Cliffs and fault zone, westward across Wheeler Ridge.

Initial movement along the Grand Wash Fault occurred approximately 20 million years ago, as indicated from radioactive dates of volcanic material found south of here. Since that movement much of the downdropped block has been covered with sand and gravel which can be seen overlapping the lower Paleozoic rocks at the base of the cliff. These sediments form the smooth gently rolling hills which are now dissected with the moderate size gullies. There has been little movement along the Grand Wash Fault in this vicinity since accumulation of these deposits, but farther north a sequence of basalt, six million years old, has been displaced by subsequent movement along the Grand Wash Fault.

Mile 279.—The Colorado River widens into Lake Mead (Text-figure 94). The silt deposit of Lake Mead high water dominates the shore lines from here some distance downstream. Pierce's Ferry operated in this vicinity for some time and was part of a major north and south transportation route across the Colorado River. This ferry, together with Lee's Ferry 280 miles upstream, constituted the only feasible means of crossing the Colorado River up until the late 1920's when the Navajo Bridge was constructed near Lee's Ferry and Boulder Dam crossing was constructed downstream.

The rolling hills on the north and south bank are carved in sand and gravel which filled the fault depression at the base of Grand Wash Cliffs. Thickness of these young deposits is not known but could be as much as 12,000 feet. This debris was derived largely from areas to the west in the Basin and Range and deposited in basins against the Grand Wash Cliffs.

Sand waves, resulting from the rippled bottom of the stream channel, are common in this stretch of the canyon where silt from the Colorado River is being deposited. Local sand bars, only a foot or two below water level, may be encountered here.

TEXT-FIGURE 97.—Vertical aerial photograph of the upper Lake Mead area along the Colorado River from Mile 280 to Mile 285. Wheeler Ridge is the line of hills east of the Wheeler Fault zone.

Mile 283.—WHEELER RIDGE. Northeast-trending Wheeler Ridge is bisected by the Colorado River. The lake has a narrow pass through the partially submerged range. Paleozoic outcrops in the range aid in estimating displacement on the Grand Wash Fault. Strata in Wheeler Ridge includes from the Redwall Limestone up through the Supai Sandstone on the south bank and from Supai Sandstone up to the Toroweap Formation on the north bank. The steeply dipping Kaibab and Toroweap formations, exposed here at river level on the north bank, are the same formations which are exposed high on the upper rim of the Grand Wash Cliffs. A total displacement of 16,000 feet is suggested by projecting the steeply dipping Kaibab and Toroweap formations toward the Grand Wash Cliffs. The west face of Wheeler Ridge is a major fault line scarp parallel to the Grand Wash Cliffs. Topography visible ahead is typical of Basin and Range development where Paleozoic strata form north-south trending ridges and intervening basins are partially filled with erosional debris.

Mile 284.5.—In the narrowest part of the pass through Wheeler Ridge, the Supai Formation is exposed on the north bank and Hermit Shale is exposed on the south bank.

Mile 284.6.—Cross the trace of the Wheeler Fault and enter the Grand Wash Basin (Text-figures 97, 98).

Mile 284.8.—Basalt-capped ridges on the north represent older lava flows which were extruded 40 miles to the north and partially filled the Grand Wash Basin. These ridges represent valley bottom flows. The resistant nature of the basalt protected the valley bottom while the sediments on the side were eroded away. The present ridges used to mark valleys and the present valleys occupy areas which were once ridges.

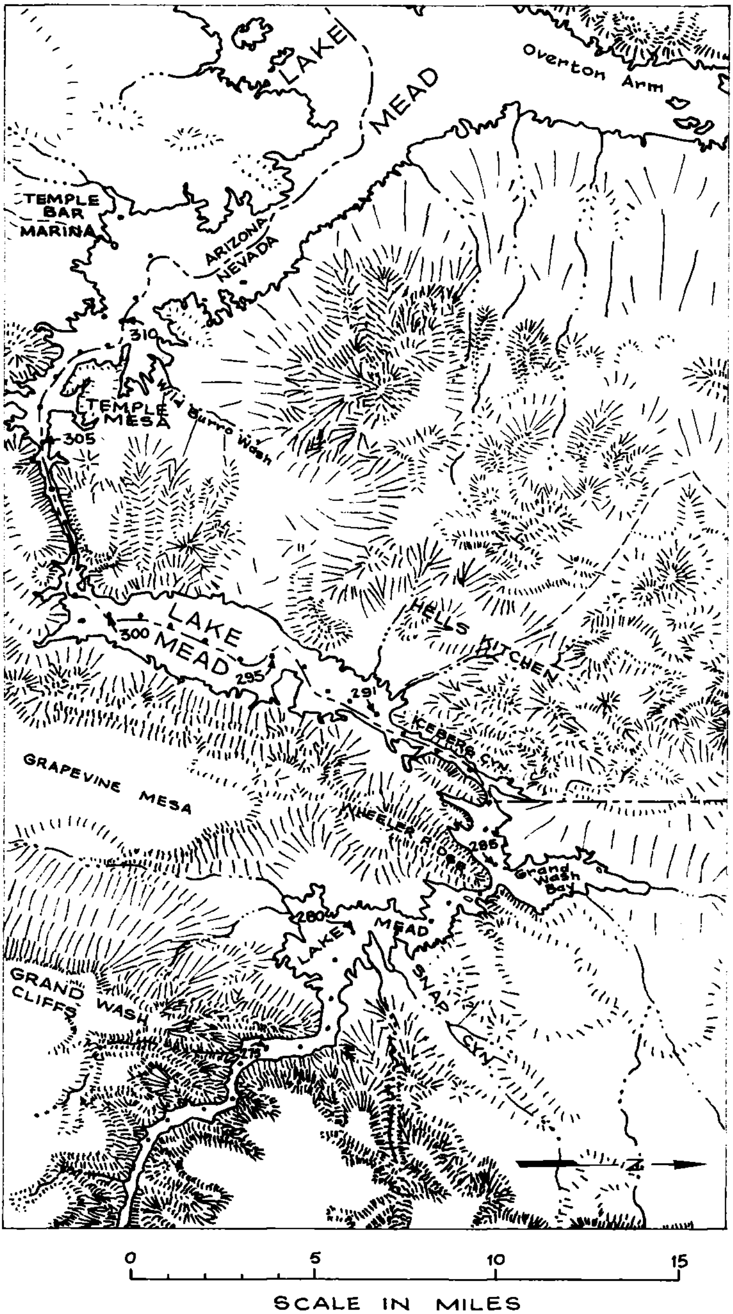
Mile 286.5.—The point to the south exposes Kaibab Limestone.

Mile 287.2.—ENTERING ICEBERG CANYON. The Nevada-Arizona line is here in the center of the lake with Nevada on the north shore and Arizona on the south. Iceberg Canyon is cut through a ridge of Paleozoic formations which dip as much as 65 degrees to the east. Exposed rocks range from Cambrian formations up to the Permian Kaibab and Toroweap formations. Because of their tilted position the bedded rocks are eroded into a rugged serrated ridge. Bedding plane surfaces are well exposed in many areas along Iceberg Canyon. The ridge on the southeast is Iceberg Ridge and the one on the north is Azure Ridge. Cambrian to Mississippian rocks are exposed in Iceberg Ridge. Cambrian to Permian rocks are exposed in Azure Ridge.

Mile 290.—Rocks exposed on the northwest side of the lake are marine limestones equivalent to the lower beds in the Supai Formation. These marine beds are here referred to as the Callville Limestone.

Mile 290.6.—Prominent small point of Callville Limestone protrudes into the lake from the southwest end of Azure Ridge to the right.

Mile 291.—DEVIL'S COVE is the small bay on the north behind the ridge of Paleozoic rocks. This bay is formed in sand and gravel similar to that filling the Grand Wash Basin. Bedrock, a short distance to the west, is



TEXT-FIGURE 98.—Map of the upper part of Lake Mead from the Grand Wash Cliffs west to near Temple Bar Landing.

mainly coarse-grained Precambrian granite, most outcrops of which have a very coarse texture. Feldspar crystals, two inches long, can be seen in weathered boulders in the vicinity of Devil's Cove. These igneous rocks are the same age as those exposed in Granite Gorge in the canyon. They are Precambrian rocks exposed in this vicinity because of major eastward tilting along Basin and Range faults. Devil's Cove is a landing where exit can be made to the north over a rough road which connects to U.S. Highway 91 at Riverside. This is the first road at river level from the north below Lee's Ferry.

Mile 294.—Sandy Point. Rocks exposed in this area are Tertiary intrusive masses, cut into Early Paleozoic rocks. Precambrian granite, intruded into gneisses and schists, is exposed along the western shore of Lake Mead.

Mile 299.—The mountain on the west bank is composed of Precambrian metamorphic gneisses and schists. Tertiary intrusives constitute the bedrock on the east shore.

Mile 301.2.—The large bay to the south is Granite Cove. Exposed bedrock on the southeast is Precambrian gneiss and schist and Tertiary intrusives. Across the lake to the northwest Precambrian gneiss and schist form Hiller Mountains.

Mile 302.—ENTERING VIRGIN CANYON. Precambrian gneiss and schist are exposed on both sides of the lake, which is very narrow in this vicinity. Gneiss and schist are exposed along the narrows of Virgin Canyon for the next five miles.

Mile 308.—The reentrant on the south is termed Gateway Cove and is opposite Temple Mesa on the north. Temple Mesa is composed of sandstone and siltstone of the Tertiary Muddy Creek Formation.

Mile 309.5.—The Tip of the Temple on the north shore is a long promontory which projects westward from Temple Mesa.

Mile 310.—A promontory on the south is capped by basalts, in the same general pattern as that seen in the Grand Wash area.

Mile 312.—THE MARINA OF TEMPLE BAR, END OF THE TRIP. From here one can travel southward along the access road to U.S. Highway 93 and 466, which are about 30 miles south of Temple Bar Landing.

Temple Bar is 312 river miles below Lee's Ferry and 225 miles below Phantom Ranch. The river has dropped to an elevation of 870 feet from a level of 3,100 feet at Lee's Ferry and 2,430 feet at Phantom Ranch. The trip has traversed through much of the Colorado Plateau where Paleozoic and Precambrian rocks are exposed and here ends at Temple Bar in the eastern margin of the folded and faulted Basin and Range. The access road passes through a series of hills composed of Precambrian metamorphic rocks and of younger igneous rocks.

SELECTED REFERENCES

Beal, M. D., 1967, Grand Canyon: KC Publications, Flagstaff, Arizona, 38 p.

Dellenbaugh, F. S., 1904, The romance of the Colorado River: Rio Grand Press, Chicago, 399 p.

———, 1908, A canyon voyage: Yale University Press, New Haven, 277 p.

Dutton, C. E., 1882, Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, 264 p.
Euler, R. C., 1967, The canyon dwellers: Amer West, v. 4, p. 22-27, 67-71.
Granger, B. H., 1960, Grand Canyon place names: University of Arizona Press, Tucson, Arizona, 26 p.
Hamblin, W. K., 1965, Origin of "Reverse Drag" on the downthrown side of normal faults: Geol. Soc. Amer. Bull., v. 76, p. 1145-1164, 4 pls., 17 text-figs.
———, and Rigby, J. K., 1968, Guidebook to the Colorado River, Part 1: Lee's Ferry to Phantom Ranch in Grand Canyon National Park· Brigham Young Univ. Geol. Stud., v. 15, pt. 5, 84 p.
Huges, J. D., 1967, The story of man at Grand Canyon: Grand Canyon Nat. Hist. Assoc. Bull. 14, 195 p.
Hunt, C. B., 1956, Cenozoic geology of the Colorado Plateau· U S. Geol. Survey Prof. Paper 279, 99 p.
Jett, S. C., 1968, Grand Canyon dams, split-twig figurines, and "hit-and-run" archaeology: Amer. Antiq., v. 33, p. 341-351.
Johnson, D. W., 1909, A geological excursion in the Grand Canyon district: Proc. Boston Soc. Nat. Hist., v. 34, p. 135-161, pls. 17-22
Jones, L A., 1962. Colorado River guide (strip map)
Koons, E .D., 1945, Geology of the Uinkaret Plateau, Northern Arizona Geol. Soc. Amer. Bull. v. 56. p. 151-180
Longwell, C. R., 1954, History of the lower Colorado River and the Imperial depression, *in* Jahns, R. H., ed., Geology of southern California· California Div Mines Bull. 170, p. 53-56.
Mathes, F. E., 1962, The Grand Canyon of the Colorado River: Bright Angel Quadrangle Topographic map: U. S. Geol. Survey.
Maxson, J. H., 1961, Geologic map of the Bright Angel quadrangle, Grand Canyon National Park, Arizona: Grand Canyon Nat. History Assoc.
McKee, E. D., 1931, Ancient landscapes of the Grand Canyon region: Northland Press, Flagstaff, Arizona, 24th ed., 1966, 52 p.
———, and Schenk, E. T., 1942, The lower canyon lavas and related features at Toroweap in Grand Canyon: Jour. Geomorph. v. 5, p. 245-273.
———, Wilson, R. F., Breed, W. J., and Breed, C. S., eds, 1967, Evolution of the Colorado River in Arizona· Northland Press, Flagstaff, Arizona, 67 p.
———, Hamblin, W. K., and Damon, P. E, 1968, K-Ar age of lava dams in Grand Canyon: Geol. Soc. Amer. Bull. v. 79, p. 133-136.
Moore, R. C., 1925, A geologic report on the inner gorge of the Grand Canyon of Colorado River· U. S. Geol. Survey Water Supply Paper 556, app. B., p. 125-171.
Noble, L. F., 1914, The Shinumo quadrangle, Grand Canyon district, Arizona: U S Geol. Survey Bull. 549, 100 p.
———, 1923, A section of the Paleozoic formations of the Grand Canyon at the Bass trail: U S. Geol. Survey Prof. Paper 131-B, p 23-73.
Powell, J. W., 1875, Exploration of the Colorado River of the west and its tributaries: Smithsonian Inst. Ann. Rept., 291 p.
———, 1961, The exploration of the Colorado River Doubleday and Company, Inc., New York, 175 p.
Ransome, F. L., 1908, Pre-Cambrian in Grand Canyon Science, v. 27, p. 667-668.
Schwartz, D. W., 1966, A historical analysis and synthesis of Grand Canyon archaeology: Amer. Antiq., v. 31, p. 469-484.
Sharp, R. P., 1940, Ep-Archean and Ep-Algonkian erosion surfaces, Grand Canyon, Arizona: Geol. Soc. Amer. Bull., v. 50, p. 1235-1270
U. S. Geological Survey, 1924. Plan and profile of Colorado River from Lee's Ferry, Ariz., to Black Canyon, Ariz.-Nev., and Virgin River, Nev.: 21 sheets, scale, 1:31, 680.
White, David, 1929, Flora of the Hermit Shale, Grand Canyon, Ariz.: Carnegie Inst. Washington Pub. 405, 221 p., 55 pls.