DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETIN 549

THE SHINUMO QUADRANGLE

GRAND CANYON DISTRICT ARIZONA

BY

L. F. NOBLE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

CONTENTS.

ILLUSTRATIONS.

PREFACE.

By F. L. Ransome.

Ever since Powell's daring boat trip down the Colorado in 1869 geologists have known that the walls of the Grand Canyon display one of the most remarkable and instructive geologic sections in the world. At first glance the impressive feature of that section is the great thickness of nearly horizontal strata through which the river has sunk its bed—strata ranging in age from Carboniferous (Pennsylvanian) at the top, on the brink of the chasm, to Cambrian at the base. Powell found, however, that unconformably below the Cambrian in certain portions of the canyon there are extensive remnants of an older and much thicker series of sediments in beds which had been upturned into mountains and truncated by prolonged erosion before the sands of the Cambrian sea covered them. These beds he called the Grand Canyon group and described as resting with profound unconformity on the vastly more ancient crystalline rocks into which the river has also cut deeply in the so-called Granite Gorge.

In 1882 appeared Dutton's well-known "Tertiary history of the Grand Canyon district," which dealt mainly with the erosional development of the canyon and barely touched upon the earlier chapters of the geologic history recorded in its walls.

Between 1883 and 1895 Dr. Charles D. Walcott, in a number of papers, described in greater detail the Grand Canyon group of Powell, dividing it into an upper or Chuar terrane, 5,120 feet thick, and a lower or Unkar terrane, 6,830 feet thick. He assigned both to the Algonkian system, showed that the conformably overlying sandstone is Cambrian, not Carboniferous, as had been supposed by Powell and by Dutton, and applied the name Vishnu terrane to the fundamental crystalline rocks. These he described as micaceous schists and quartzites cut by granite.

During the next 10 or 12 years not much advance was made in our knowledge of the character and stratigraphy of the older rocks in the Grand Canyon, although the period was by no means barren of geologic literature on other problems connected with the growth of that vast abyss. Yet there were awaiting solution a number of problems fully as interesting to students of stratigraphy and pre-

Cambrian geology as are the processes and results of earth sculpture to investigators who are chiefly concerned with the origin of those forms whose collective aspect constitutes what we term scenery. For example: Much remained to be learned about the lithologic character and divisions of the great masses of strata which Walcott had named the Unkar and Chuar terranes. Doubt existed and still exists as to the true character of the fundamental crystalline complex, some observers failing to find in it material recognizable as metamorphosed sediments and seeing at the localities visited by them only such intrusive and highly metamorphosed rocks as are suggestive of igneous origin and Archean age. Within the Paleozoic series the part of the stratigraphic column most obviously in need of study is that between the Cambrian and the Carboniferous, where the Devonian appears to be represented at some localities and absent at others.

Detailed geologic work demands an accurate topographic base map, and no good map of the Grand Canyon existed until the publication, between 1906 and 1908, of the Vishnu, Bright Angel, and Shinumo topographic sheets, on the scale of 1:48,000, very nearly 1⅜ inches to the mile. The topography of these maps, by François E. Matthes and Richard T. Evans, fully meets the requirements of the geologists, and one sheet, the Shinumo, was immediately utilized by the author of the present bulletin in a study devoted particularly to the lithology and stratigraphy of the Unkar group. Begun as a university thesis, the work was completed under arrangement with the Geological Survey.

In his careful measurement, description, and subdivision of the Unkar group Dr. Noble has not only thrown light on the pre-Cambrian history of the Colorado Plateau region, but has supplied geologists who are working in the southwestern part of the country with a standard of comparison for Algonkian strata exposed elsewhere in that region. In addition to pursuing what may be considered the main purpose of the investigation, Dr. Noble has added much to our knowledge of the general geology and erosional history of the Shinumo quadrangle—that is, of the western part of the Kaibab division of the Grand Canyon—and the map which accompanies this bulletin represents the first geologic mapping done in the canyon that attains the standard of accuracy and detail set for the Geologic Atlas of the United States. By describing examples additional to those previously known he has shown the prevalence and structural importance of pre-Cambrian faults and the recurrence of movement in post-Paleozoic time along these ancient fractures. He has also called attention to the influence of minor joints and of fractures not associated with noticeable displacement in guiding the forces of erosion and in determining topographic form.

Although the bulletin contains considerable lithologic and stratigraphic material that will scarcely interest those who are not geologists, Dr. Noble has very properly remembered that the people as a whole have unusual claims to consideration in any publication dealing with the Grand Canyon, and has skillfully supplied as a setting to his more strictly scientific work much vivid description and lucid explanation which will help all those who take more than a transient and superficial interest in what they see to understand one of the most impressive and significant of the inanimate works of nature.

THE SHINUMO QUADRANGLE, GRAND CANYON DISTRICT, ARIZONA.

By L. F. NOBLE.

INTRODUCTION.

LOCATION AND GEOGRAPHY.

The Shinumo quadrangle, in Coconino County, northern Arizona, is the westernmost of three quadrangles covered by the United States Geological Survey's maps of a part of the Grand Canyon of the Colorado—the Vishnu, Bright Angel, and Shinumo sheets—which show the Kaibab division of the Grand Canyon. The quadrangle is bounded on the north and south by parallels 36° 20′ and 36° 5′. Its eastern and western boundaries are irregular and it lies for the most part between meridians 112° 15′ and 112° 30′, but extends northward somewhat beyond these limits. Its total area is about 270 square miles.

The only permanent habitation in the quadrangle is Bass Camp, which is at the rim of the Grand Canyon on the Coconino Plateau, about a mile west of Havasupai Point. The camp was established by Mr. W. W. Bass some 25 years ago to accommodate tourists. From Bass Camp a trail that has been constructed across the Grand Canyon descends its southern wall through Bass Canyon to Colorado River and ascends its northern wall through Shinumo and Muav canyons. The river is crossed by means of a car that travels on wire cables suspended 50 feet above the surface of the stream, so that men and animals may be transported at all seasons of the year regardless of high water (Pl. XIII, *A*, p. 54). The length of the trail from the southern rim of the canyon to the river is 6½ miles; from the river to the summit of the northern wall it is 10 miles. Mr. Bass has recently discovered in the depths of the canyon deposits of copper and asbestos, to which he has constructed additional trails. The trails afford access with pack animals (Pl. II) to all points of geologic interest in the interior of the canyon and to points on Powell and Kaibab plateaus, as well as to settlements in southern Utah. A permanent camp (Pl. VIII, *A*, p. 28) has been established in the depths of the canyon about a mile up Shinumo Creek from the Colorado, where an irrigated garden (Pl. XII, *B*, p. 52) is now cultivated on the site of one made by the prehistoric inhabitants of the region. Bass Camp is most easily reached from Grand Canyon station on the Grand Canyon Railway, a branch of the Santa Fe System, by a wagon road 25 miles in length. Another road leads southwestward

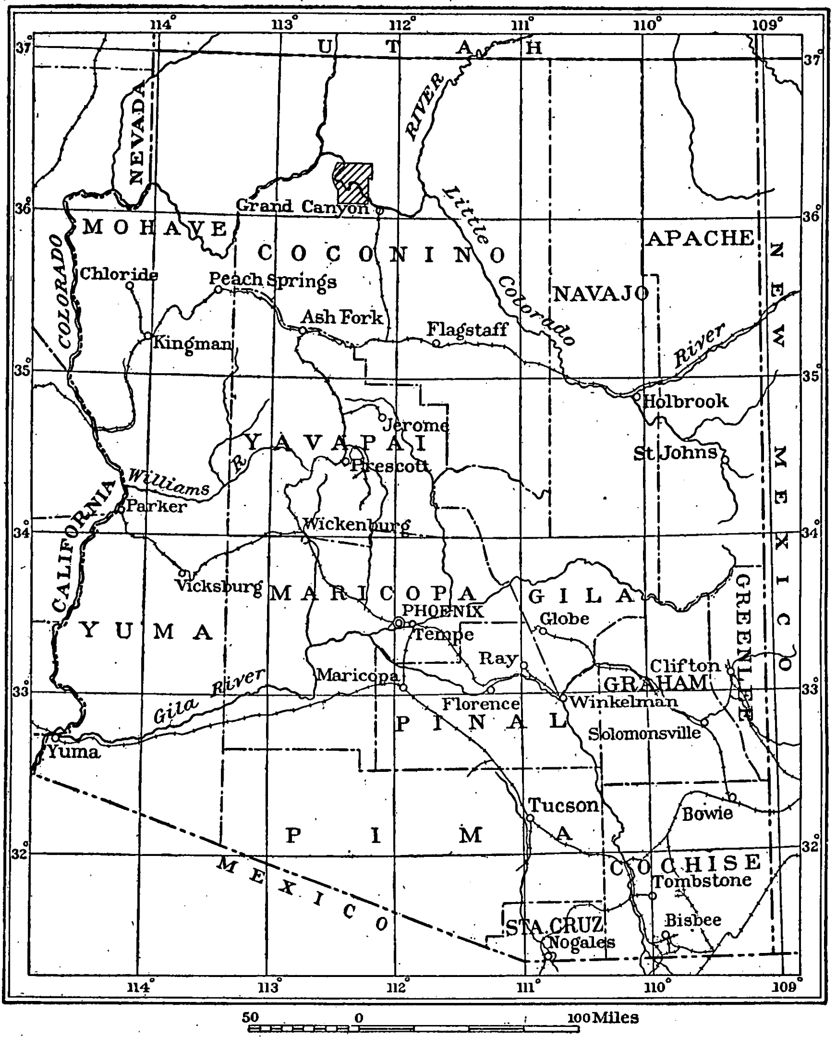
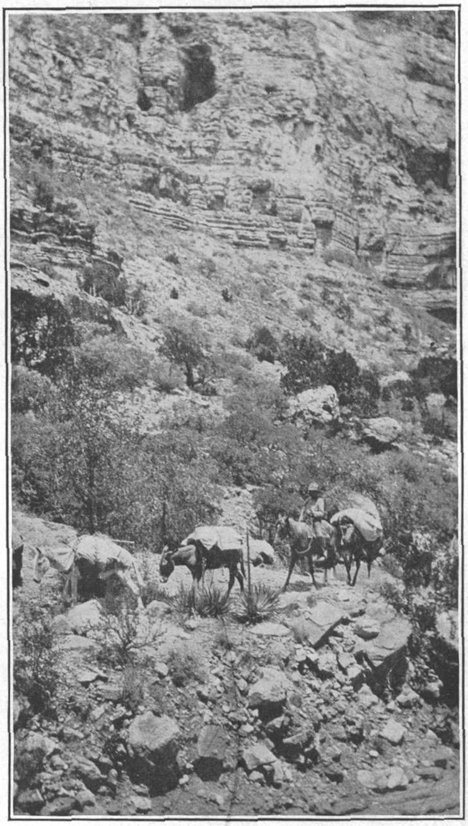
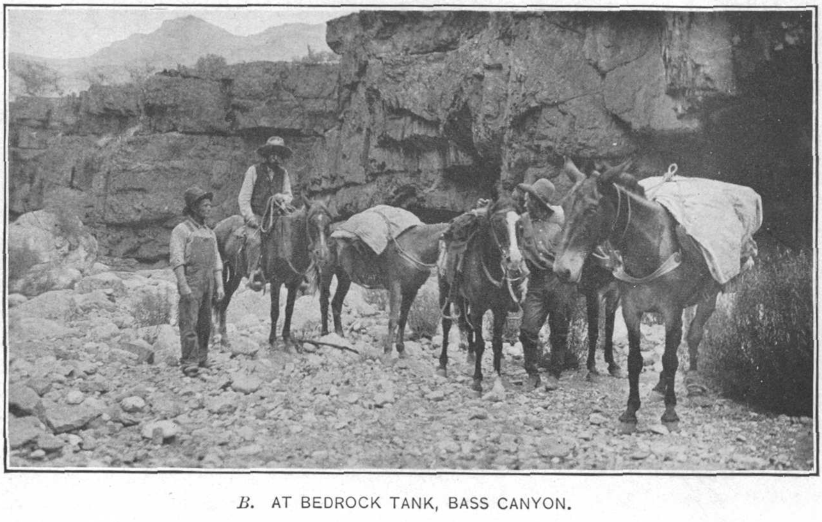


FIGURE 1.—Index map showing location of Shinumo quadrangle.

from Bass Camp to the rim of Cataract Canyon, about 20 miles away, whence a trail descends to the Havasupai Indian village in Cataract Canyon. Roads also lead to the towns of Williams and Ash Fork, about 60 miles respectively south and southwest of Bass Camp. The north rim of the Grand Canyon is reached by a wagon road across the Kaibab Plateau from the town of Kanab, in southern Utah.



A. TRAVELING ON TRAIL IN THE GRAND CANYON WITH PACK TRAIN.



B. AT BEDROCK TANK, BASS CANYON.

FIELD WORK.

The greater part of the geologic field work on which this report is based was done between August 23 and December 12, 1908, in preparation for a thesis which was presented to the faculty of Yale University in 1909 in partial fulfillment of the requirements for the degree of doctor of philosophy. A part of the thesis, dealing with the Archean and Algonkian rocks of the Shinumo quadrangle has already been published.[1]

In February, 1910, the writer returned to the Grand Canyon to complete, on an enlarged base and in greater detail, the geologic map made to accompany the thesis. This work, begun February 24 and ended March 16, 1910, was done under the direction of the United States Geological Survey. The area covered by this map (Pl. I, in pocket) is somewhat over 200 square miles, or about three-fourths of the Shinumo quadrangle, and includes all exposures of Algonkian rocks in the quadrangle and all features of exceptional geologic interest.

LITERATURE.

Maj. Dutton, in his monograph entitled "Tertiary history of the Grand Canyon district,"[2] describes most fully and charmingly the geology of the north rim in this section of the Grand Canyon. Chapter VII describes the surface features and scenery of the Kaibab Plateau in the vicinity of Point Sublime. Chapter VIII is devoted to the panorama disclosed from Point Sublime, and Chapter IX describes in detail the walls of the amphitheaters of the north side. The Muav Saddle and Powell Plateau are described on pages 162–167 and the Shinumo Amphitheater on pages 167–174. Dutton's work, however, did not extend into the depths of the canyon.

J. S. Diller, of the United States Geological Survey, in reports on the production of asbestos, describes deposits of asbestos occurring in the Algonkian rocks of this area near Bass Ferry. Diller's first report[3] contains the earliest mention of Algonkian strata in this part of the Grand Canyon.

BIBLIOGRAPHY.

Barrell, Joseph, Relative geological importance of continental littoral and marine sedimentation: Jour. Geology, vol. 14, pp. 316, 356, 430–457, 524–568, 1906.

Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Needle Mountains folio (No. 131), 1905.

[1] Noble, L. F., Contributions to the geology of the Grand Canyon, Arizona. The geology of the Shinumo area: Am. Jour Sci., 4th ser., vol. 29, pp. 369-386, May, 1910; pp. 497-528, June, 1910.

[2] Dutton, C. E., Tertiary history of the Grand Canyon district, with atlas: U. S. Geol. Survey Mon. 2, 1882.

[3] Diller, J. S., The production of asbestos in 1907; U. S. Geol. Survey Mineral Resources, 1907, pt. 2, pp. 720-721, 1908; also The production of asbestos in 1908: U. S. Geol. Survey Mineral Resources, 1908, pt. 2, p. 705, 1909.

Darton, N. H., Reconnaissance of parts of northern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, 1910.

Davis, W. M., An excursion to the Grand Canyon of the Colorado: Harvard Univ. Mus. Comp. Zool. Bull. 38, geol. ser., vol. 5, No. 4, 1901.

——— An excursion to the Plateau province of Utah and Arizona: Harvard Univ. Mus. Comp. Zool. Bull. 42, geol. ser., vol. 6, No. 1, 1904.

Diller, J. S., The production of asbestos in 1907: U. S. Geol. Survey Mineral Resources, 1907, pt. 2, pp. 720–721, 1908.

——— The production of asbestos in 1908: U. S. Geol. Survey Mineral Resources, 1908, pt. 2, p. 705, 1909.

Dutton, C. E., Tertiary history of the Grand Canyon district, with Atlas: U. S. Geol. Survey Mon. 2, 1882.

Frech, F., Section in Congress Canyon opposite Point Sublime: Internat. Geol. Cong., fifth session, Compte rendu, pp. 476–481, 1894. (The supposition that Congress Canyon is opposite Point Sublime is erroneous. Point Sublime is 25 miles west of a point opposite Congress Canyon.)

Gilbert, G. K., Report on the geology of portions of Nevada, Utah, California, and Arizona examined in the years 1871 and 1872: U. S. Geog. Surveys W. 100th Mer., vol. 3, pt. 1, pp. 17–187, 1875.

Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah: Harvard Univ. Mus. Comp. Zool. Bull. 42 geol. ser., vol. 6, No. 5, 1904.

Ives, J. C., Report upon the Colorado River of the West: Senate Ex. Doc., 36th Cong., 1st sess., pt. 1, general rept., pp. 13–131, 1861.

Johnson, D. W., A geological excursion in the Grand Canyon district: Boston Soc. Nat. Hist. Proc., vol. 34, pp. 135–161, 1909.

Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, 1908.

Newberry, J. S., Report upon the Colorado River of the West: Senate Ex. Doc., 36th Cong., 1st sess., pt. 3, geol. rept., pp. 1–154, 1861.

Powell, J. W., Exploration of the Colorado River of the West and its tributaries. Explored in 1869, 1870, 1871, and 1872 under the direction of the Secretary of the Smithsonian Institution, 1875.

——— Geology of the eastern portion of the Uinta Mountains, U. S. Geol. and Geog. Survey Terr., 1876.

Ransome, F. L., Geology of the Globe Copper district, Arizona: U. S. Geol. Survey Prof. Paper 12, 1903.

——— The geology and ore deposits of the Bisbee quadrangle, Arizona: U. S. Geol. Survey Prof. Paper 21, 1904.

——— A comparison of some Paleozoic and pre-Cambrian sections in Arizona: Science, new ser., vol. 27, pp. 68–69, 1908.

——— Pre-Cambrian sediments and faults in the Grand Canyon of the Colorado: Science, new ser., vol. 27, No. 695, pp. 667–669, 1908.

Robinson, H. H., The Tertiary peneplain of the Plateau district and adjacent country in Arizona and New Mexico: Am. Jour. Sci., 4th ser., vol. 24, pp. 109–129, Aug., 1907.

——— A new erosion cycle in the Grand Canyon district, Arizona. Jour. Geology, vol. 18, No. 8 (Nov.-Dec., 1910), pp. 742–763, 1910.

——— The single cycle development of the Grand Canyon of the Colorado: Science, new ser., vol. 34, No. 864, 1911.

Walcott, C. D., The Permian and other Paleozoic groups of the Kanab Valley, Arizona: Am. Jour. Sci., 3d ser., vol. 20, pp. 221–225, 1880.

——— Pre-Carboniferous strata in the Grand Canyon of the Colorado, Arizona: Am. Jour. Sci., 3d ser., vol. 26, pp. 437–442, 484, 1883.

Walcott C. D.
~~RANSOME, F. L.,~~ Study of a line of displacement in the Grand Canyon of the Colorado in northern Arizona: Geol. Soc. America Bull., vol. 1, pp. 49, 1890.

——— Pre-Cambrian igneous rocks of the Unkar terrane, Grand Canyon of the Colorado, Arizona, with notes on the petrographic character of the lavas, by Joseph P. Iddings: U. S. Geol. Survey Fourteenth Ann. Rept. for 1892–93, pt. 2, pp. 497–519 (Walcott) and 520–524 (Iddings), 1894.

——— Algonkian rocks of the Grand Canyon of the Colorado: Jour. Geology, vol. 3, No. 3, pp. 312–330, 1895.

ACKNOWLEDGMENTS.

In 1901 Mr. Charles D. Walcott and Mr. G. K. Gilbert spent several days at Bass Camp and on Shinumo Creek and worked out the structure of the pre-Cambrian sediments, which Mr. Walcott correlated with the section described by him in Unkar Valley. His notes, however, are unpublished, and it is due to his kindness and courtesy that the writer is enabled to present the first description of the area. To Mr. Walcott the writer is also indebted for the identification of Cambrian fossils, for a list of the Cambrian fossils found in the region, and for assistance in interpreting the stratigraphy.

To Prof. Joseph Barrell, to Prof. Charles Schuchert, and to Prof. Louis V. Pirsson, all of Yale University, the most sincere thanks are due for continued interest and advice during all stages of the work.

PHYSIOGRAPHY OF THE GRAND CANYON DISTRICT.

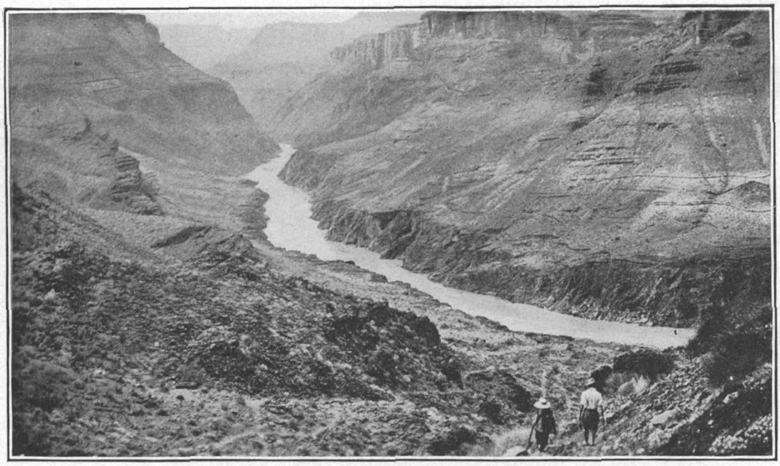
The great physiographic province of which the Shinumo quadrangle is a part is known as the Colorado Plateau. It is a region of nearly horizontal strata, and most of its surface lies a mile or more above sea level. The strata are beds of sandstone, shale, and limestone, which show by their character and the marine fossils they contain that they accumulated as sediments beneath the sea. It is therefore clear that after the beds were deposited and consolidated into rock they were lifted high above sea level to form the present plateau, and that the uplift was equal and general over the whole region, for the beds retain very nearly the horizontal attitude that they originally had on the sea bottom. As the strata are prevailingly horizontal, the region is preeminently a land of mesa scenery—of broad, level or slightly tilted platforms which stretch evenly away for miles, rising to younger or dropping to older formations of rock by lines of cliff; a land of encanyoned valleys whose walls descend by steps and ledges; of long, even sky line, the sweep of which is broken here and there by one or more isolated mountain masses of volcanic rock or by fantastic buttes and mesas that suggest ruined masonry. The higher portions of the region are comparatively moist and are heavily wooded with forests of spruce and pine; the middle altitudes are semiarid and are covered with a scattered growth of juniper and pinyon; the lower levels are deserts, the surfaces of which either take the color of the underlying rock or are gray with the desert brush. The scenery is, above all, orderly and symmetrical, for through every land form except the volcanoes run continuous parallel layers of level strata, and each cliff shows in all its parts similar vertical profiles.

In few other regions are the topography and scenery so closely related to the character and structure of the underlying rocks. Every platform is the summit of a resistant stratum; each cliff is its edge. The gentler slopes are on the edges of weaker strata.

Nowhere else are geologic relations revealed on so vast a scale and yet so clearly, for any departure from the horizontal structure appears with startling distinctness. A great fault traversing the plateau may be expressed by a line of cliffs many miles in length; the slightest break in the beds in the walls of a canyon at once catches the eye; and the sweep of a great fold or monocline may dominate an entire landscape. The walls of the deep canyons cut by the larger streams display great natural geologic vertical and cross sections; the mountains are masses of volcanic rock which either have been poured out upon the surface of the plateau or have cut into and domed the strata. The arid climate tends to keep rock surfaces bare of soil and cliff profiles sharp and fresh, and the clear air extends the range of vision over vast distances. The prevailing aridity of the region and the impassability of the steep-walled canyons that traverse it have kept large areas untouched by civilization to the present day. In the past its lonely canyons were the home of the cliff dwellers. To-day it is the refuge of tribes of Indians who still retain their primitive customs. The natural conditions thus described make the Colorado Plateau the most fascinating region in the world for geologic study.

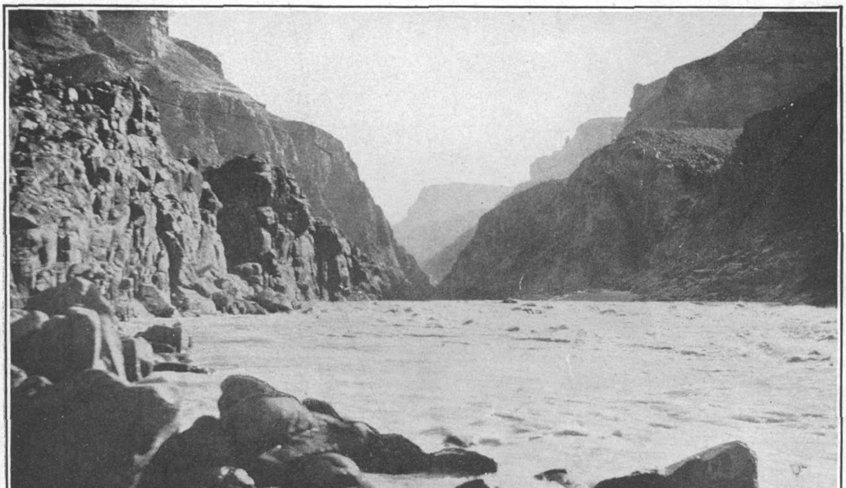
The southwestern part of the Plateau province, marked off by certain structural and topographic features, is the Grand Canyon district. This district has long been known through the writings of Newberry, Ives, Gilbert, Powell, and Dutton; and the work of these geologic explorers, combined with the later studies of Walcott, Davis, Robinson, Huntington, and Johnson, has given rise to a voluminous literature and has made it a classic region for geologists.

The Grand Canyon district lies in northwestern Arizona and coincides with a local uplift, or structural swell, in the Colorado Plateau. Its area is about 16,000 square miles and over practically all of this nearly level expanse one geologic formation, the Kaibab limestone, is the surface rock. This great platform is abruptly elevated above the Basin region that lies west of it by a sharp break (or fault) in the earth's crust, on the east side of which the strata stand at an elevation several thousand feet higher than the same strata on the west side. Along the eastern border of the district a sharp downward



A. GRANITE GORGE NEAR CABLE CROSSING.

Showing open gorge due to the presence of weak and easily eroded strata of the Unkar group. Cable crossing is at the narrowest point on the river, in the center of the view.



B. GRANITE GORGE ABOVE CABLE CROSSING.

Showing somber, V-shaped profile of the gorge where the massive, resistant Vishnu schist forms its walls and no weak stratified rock is present.

VIEWS UP COLORADO RIVER NEAR CABLE CROSSING.

bend, known as a monocline, carries the beds to a lower level, where they resume their nearly horizontal attitude and continue eastward beneath the higher strata of the Colorado Plateau. The upturned edges of these higher strata face the district as Echo Cliffs. On the north the district is walled in by another line of cliffs and terraces, running east and west along the southern border of Utah. These have been carved by erosion out of the higher strata of the Colorado Plateau and rise in huge steps northward to elevations of 11,000 feet or more. The southern border of the district is marked by an abrupt descent to lower country along a series of cliffs carved from the plateau strata.

The northern portion of the Grand Canyon district is divided into five minor platforms or plateau blocks by great lines of fracture or flexure, which trend north and south and are roughly parallel. The fractures are represented in the topography by cliffs and the flexures by steep slopes, so that the blocked plateaus are sharply separated from one another. The westernmost plateau, the Shivwits, is the lowest; its surface lies about 6,000 feet above the sea. Next in order toward the east are the Uinkaret, Kanab, and Kaibab plateaus, each elevated about 1,000 feet above its western neighbor by a fault. Most of the Kaibab Plateau lies above an altitude of 8,500 feet. East of the Kaibab is the fifth plateau, the Marble platform, which has been dropped 2,500 feet below the Kaibab by an eastward-dipping flexure.

Colorado River crosses the plateau province from northeast to southwest. It has carved a series of canyons whose total length exceeds 500 miles. All these canyons are clear-cut deep gashes in nearly level platforms, and their steplike walls descend abruptly by alternations of bold cliffs and narrow ledges. The river at the bottom (Pl. III) carries the drainage from the whole western front of the Rocky Mountains in Colorado and southwestern Wyoming. It is swift and turbulent and in many places flows between sheer walls. Because of the general impassability and the inhospitable character of the bordering deserts, these canyons form a barrier to human travel more effective than the Rocky Mountains. The Colorado is unbridged for 700 miles, a distance about equal to that directly between New York and Chicago.

In the high blocked plateaus of the Grand Canyon district the canyons reach their culmination in size and grandeur. The pathway of the river across these plateaus is the most remarkable valley in the world. The section that traverses the Marble platform is known as the Marble Canyon; it is 60 miles in length. The part cut through the Kaibab, Kanab, Uinkaret, and Shivwits plateaus is the Grand Canyon. The Grand Canyon is about 220 miles long and averages a mile in depth and about 10 miles in width, from rim to rim. The

Kaibab division is 50 miles in length, the Kanab 50 miles, the Uinkaret 25 miles, and the Shivwits 75 miles.

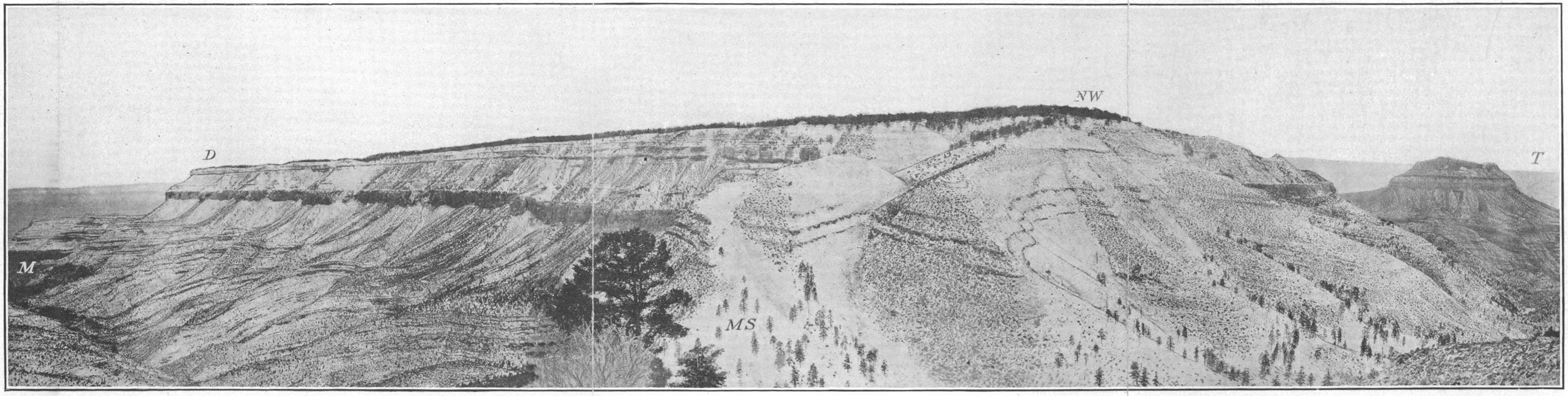
The lines of displacement that bound the plateau blocks die out in the area south of the Grand Canyon in the part of the Grand Canyon district that is known as the San Francisco Plateau. The high part of the San Francisco Plateau lying just south of the Grand Canyon is called the Coconino Plateau.

The south end of the Kaibab Plateau stands 2,000 feet above the Kanab Plateau, which lies southwest of it, and the San Francisco Plateau, which lies south of it, but it has attained this higher elevation by a gentle tilting of the earth's crust instead of by a fault or monocline. The strata around the south end of Kaibab Plateau descend very gently toward the south and southwest until they reach the level of the Kanab and San Francisco plateaus.

The Kaibab division of the Grand Canyon is cut through the highest land and is the deepest part of the canyon. Here the walls are intricately carved by erosion, and here the visitor finds that wealth of fantastic architectural detail for which the canyon is noted. This division is a relatively wide valley, which presents to the observer not a deep and gloomy gorge, but a vast, bright, open expanse. In the depths of the canyon near the base of the series of horizontal Paleozoic rocks there is a wide shelf, known as the Tonto platform, or "lower plateau" (Pl. V). A trail known as the Tonto trail runs along the Tonto platform throughout the Kaibab division. The river has cut through this platform below the base of the Paleozoic rocks into the Archean rocks, on which it flows in a V-shaped gorge whose walls descend by a steep, unbroken slope that contrasts strikingly with the steplike profile of the walls in the Paleozoic rocks above. This gorge in the bottom of the canyon is known as the Granite Gorge. (See Pls. III, V, and VIII, *B*, p. 28.)

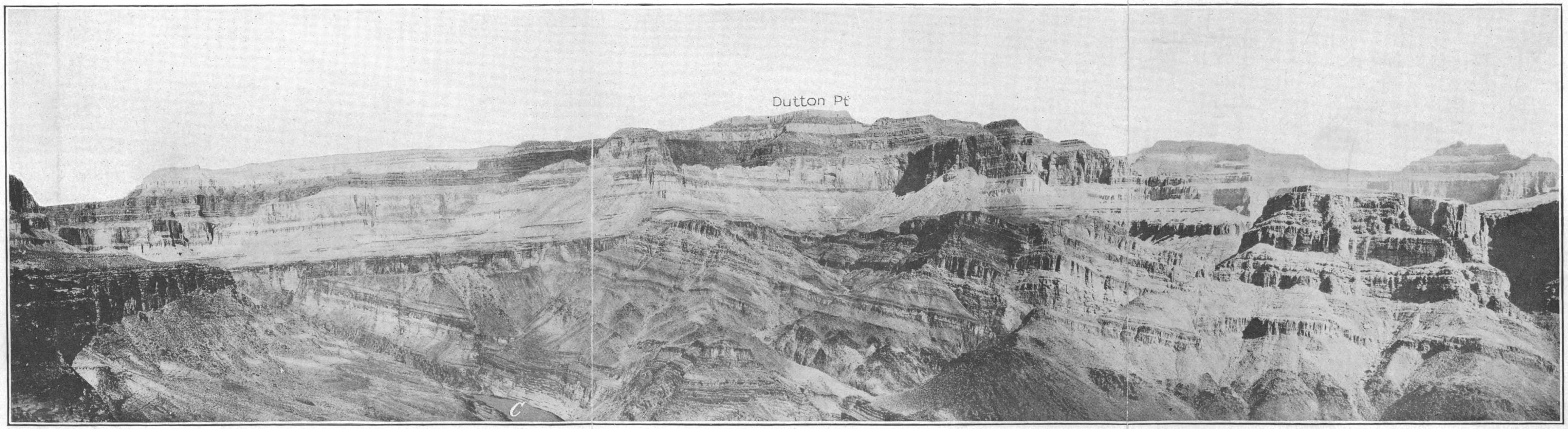
The Kaibab division does not lie in the highest part of the Kaibab Plateau; it crosses, rather, the higher part of the inclined plane that bounds the Kaibab uplift on the south, in a direction nearly at right angles to the dip of the strata. Consequently the position of the canyon with respect to the bordering lands in this division is a peculiar one for a river valley. The Kaibab Plateau, which lies north of the canyon, slopes gradually toward the rim, and the Coconino Plateau, which lies south of the canyon, slopes gradually away from the rim, so that the canyon is a huge trench dug along a hillside.

The three divisions of the canyon west of the Kaibab are cut through lower plateaus and are not so deep as the Kaibab division. The scenery is no less imposing but is very different. In the upper part of the wall there is a platform, several miles wide, named by Dutton the Esplanade (Pl. VI), in which the main canyon is cut in a sharp gorge that has nearly vertical walls. This inner gorge is far



A. PANORAMIC VIEW OF POWELL PLATEAU ACROSS MUAV SADDLE FROM THE KAIBAB.

D, Dutton Point; *NW*, Northwest corner of Powell Plateau; *M*, Muav Canyon; *MS*, Muav Saddle; *T*, Tapeats Amphitheater. The effect of the West Kaibab fault may be seen in Muav Canyon in the flexed beds of sandstone of the Supai formation and at the Muav Saddle, where the beds of Kaibab limestone that form the surface of Powell Plateau plunge downward into the saddle directly toward the observer.



B. PANORAMIC VIEW OF UNKAR WEDGE FROM TONTO PLATFORM, ON SOUTH SIDE OF COLORADO RIVER.

C, Colorado River.

narrower in proportion to its depth than any part of the Kaibab division and corresponds more nearly to the popular idea of a canyon. Its walls are not greatly carved by erosion, and its scenic effect is somber and grand rather than bright and fantastic. The Kanab division shows best this somber type of scenery. In the Uinkaret division floods of lava have been poured over the walls from a great volcanic center on the Uinkaret Plateau and have reached the river. The Shivwits is the only division west of the Kaibab in which the river has cut beneath the base of the Paleozoic rocks.

The surface of the southern or Coconino Plateau slopes to the southwest, away from the canyon rim, at the rate of about 100 feet to the mile. The drainage of the plateau surface is carried in a series of shallow, open-floored valleys which have gently sloping sides, and contain no living streams. These valleys trend southwestward from the canyon rim as a consequence of the general slope of the plateau surface in that direction and drain into the broad, shallow synclinal basin occupied by Cataract Canyon. By the slow wearing back of its steep southern wall the Grand Canyon has encroached on the heads of many of these streamways, so that their truncated valleys appear along the rim as shallow notches. So general is this phenomenon that the stranger who loses his way on the Coconino Plateau has only to keep in mind the fact that if he will follow any main valley far enough headward he will come out upon the rim of the Grand Canyon.

The surface of the northern or Kaibab Plateau likewise slopes gently to the southwest and is covered with a similar system of southwestward-trending valleys. The drainage system of the Kaibab, however, runs directly into the Grand Canyon instead of away from it. Neither plateau bears a living stream.

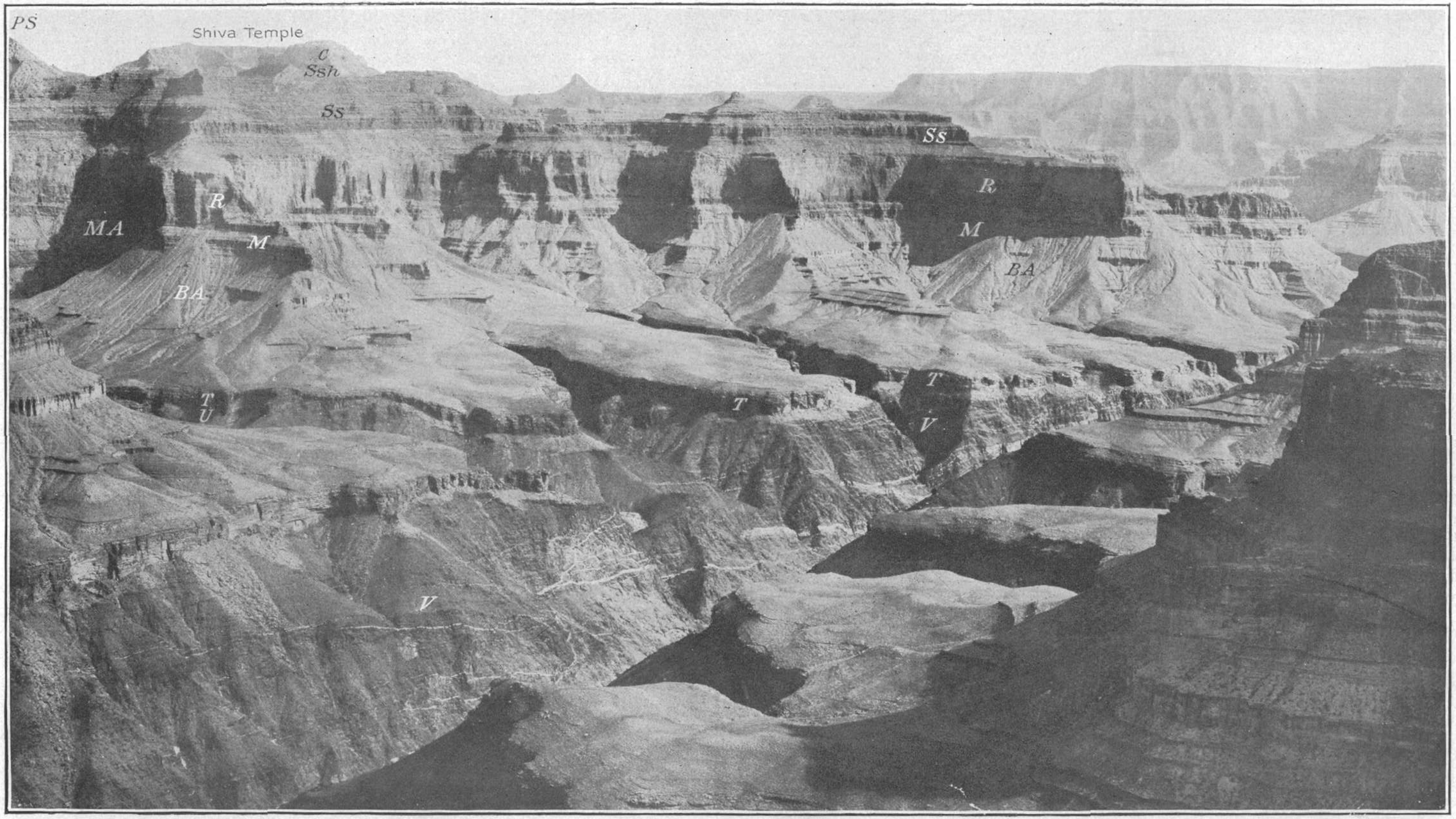
Powell Plateau (Pl. IV, *A*) may be regarded as a disjoined part of the Kaibab Plateau. It formed on beds that lie at the same horizon in the Kaibab limestone as the Kaibab Plateau but slopes more steeply to the southwest than the Kaibab or the Coconino, its grade being about 200 feet to the mile. Powell Plateau is really a great butte, surrounded on three sides by mile-deep canyons and isolated from the Kaibab Plateau by erosion in the line of the West Kaibab fault. A narrow isthmus, notched 800 feet below the surface of the plateaus in the line of the fault, connects Powell Plateau with the Kaibab. This isthmus or gap, which is known as the Muav Saddle, forms a sharp divide that separates Muav Canyon from a lateral gorge of Tapeats Amphitheater on the north. The trail up the northern wall of the Grand Canyon divides in Muav Saddle, one branch leading to the Powell Plateau and another to the Kaibab Plateau.

In many places along the north wall of the Grand Canyon the deep side gorges of the great amphitheaters have encroached upon the valley system of the Kaibab Plateau in the same way in which the south wall of the Grand Canyon has beheaded the streamways of the Coconino Plateau. Along the eastern edge of Powell Plateau several of these shallow valleys are truncated headward by the southern wall of Muav Canyon and the same phenomenon may be noted at other places, as along the eastern edge of the Rainbow Plateau, a promontory of the Kaibab Plateau. These beheaded valleys of the Rainbow Plateau illustrate a phenomenon which is described by Dutton[1] as characteristic of other parts of the Kaibab wall east of the Shinumo quadrangle: "We often find an old ravine suddenly cut off on the brink of the abyss, and the continuation of the same ravine upon the other side of the amphitheater." In some places where the capture of a ravine is imminent, but not yet accomplished, the ravine will run along for a considerable distance parallel to the rim of the Grand Canyon and so near to it that one may stand in the bottom of the ravine and hurl a stone over the narrow divide that separates it from the great gorge. Examples are Dutton Canyon, on Powell Plateau; Saffron Valley, on the Kaibab; and the long ravine that lies east of Crescent Ridge and runs for 3 miles parallel to the rim of Shinumo Amphitheater.

The Shinumo quadrangle is on the southwest border of the Kaibab uplift and shows the transition from the Kaibab to the Kanab division of the Grand Canyon. In all the region north of the quadrangle the western boundary of the Kaibab Plateau is the West Kaibab fault, which throws the strata downward to the west and forms an abrupt topographic break. This great displacement runs into the Shinumo quadrangle, but it has here become so changed in character that it affects the strata only locally; in the greater part of its course across the quadrangle its usual westward throw is reversed, the strata being dropped on its east side. West of the Kaibab Plateau the drop is accomplished, not by a fault but by a warping of the strata. Throughout the quadrangle the Paleozoic strata dip southwestward away from the highest part of the Kaibab uplift, at a rate varying from 100 to 200 feet to the mile. This dip is well shown by the corresponding southwestward slope of the plateau surfaces, all of which accord with the rock structure. A zone of maximum warping, about 5 miles in width, runs diagonally across the quadrangle from northwest to southeast, carrying the strata downward to the southwest at the rate of 200 feet to the mile. Elsewhere in the quadrangle the dip is about 100 feet to the mile. This zone of maximum warping is shown by the surface of Powell Plateau, which drops 1,000 feet from Dutton Point at its eastern end to Ives Point at its western end.

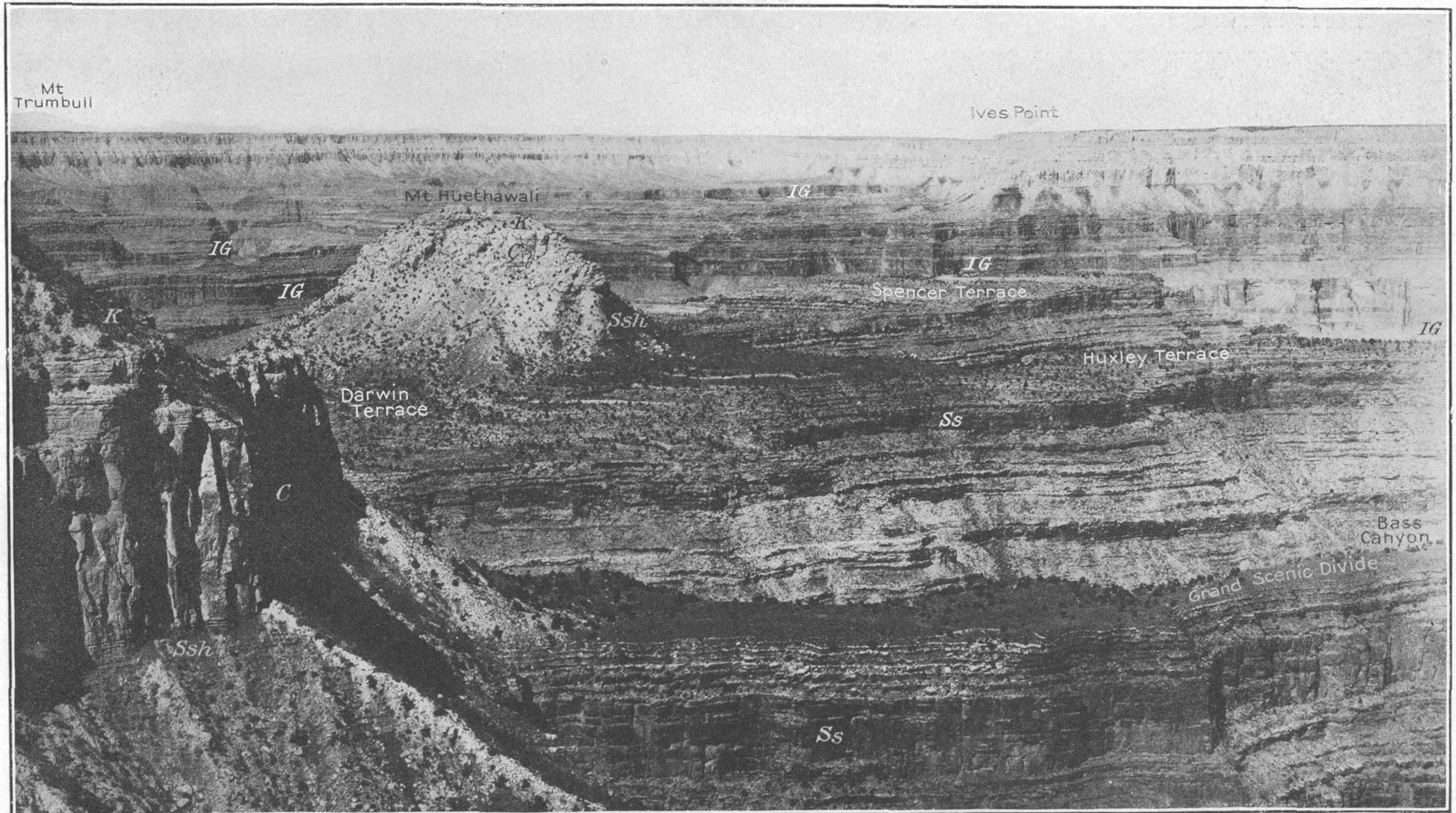
---

[1] Dutton, C. E., op. cit., p. 170.



TONTO PLATFORM: VIEW EASTWARD UP KAIBAB DIVISION OF GRAND CANYON FROM LEVEL OF THE ESPLANADE DIRECTLY UNDER HAVASUPAI POINT.

PS, End of Point Sublime; *MA*, Monadnock Amphitheater; *V*, Vishnu schist; *U*, Unkar group; *T*, Tapeats sandstone; *BA*, Bright Angel shale; *M*, Muav limestone; *R*, Redwall limestone; *Ss*, sandstone of Supai formation; *Ssh*, shale of Supai formation; *C*, Coconino sandstone. Photograph by N. W. Carkhuff.



THE ESPLANADE; VIEW NORTHWESTWARD THROUGH THE GRAND CANYON FROM HAVASUPAI POINT.

Powell Plateau; *IG*, Inner Gorge of Colorado River; *Ss*, sandstone of Supai formation; *Ssh*, shale of Supai formation; *C*, Coconino sandstone; *K*, Kaibab limestone. Photograph by N. W. Carkhuff.

Colorado River begins to flow across the zone of maximum warping at the mouth of Shinumo Creek. This point therefore marks the west end of the Kaibab division of the canyon.

TOPOGRAPHY OF THE SHINUMO QUADRANGLE.

In the Shinumo quadrangle the surfaces of the plateaus through which the Grand Canyon is trenched are developed on the highest Paleozoic formation occurring in the canyon wall—the Kaibab limestone—the Mesozoic and Tertiary formations having been eroded back to the terraces of southern Utah.

Within the Shinumo quadrangle the profile of the wall of the Grand Canyon changes from that which is characteristic of the Kaibab division to that which is characteristic of the Kanab. The most accessible outlook from which to view this scenic change is the end of Havasupai Point (Pl. VII, *B*), the longest promontory that runs out from the southern wall of the Grand Canyon. To the east is a vista of 40 miles through the characteristic scenery of the Kaibab division (See Pl. V.) The walls are greatly dissected, particularly on the northern side; great amphitheaters, filled with fantastic buttes and temples and trenched with innumerable side gorges run far back into the walls. The profile of the wall is especially distinctive; the edges of the Paleozoic strata descend abruptly through a series of cliffs, steep slopes, and narrow ledges to the Tonto platform, 3,000 feet below the rim of the canyon, and within the Tonto platform is the Granite Gorge.

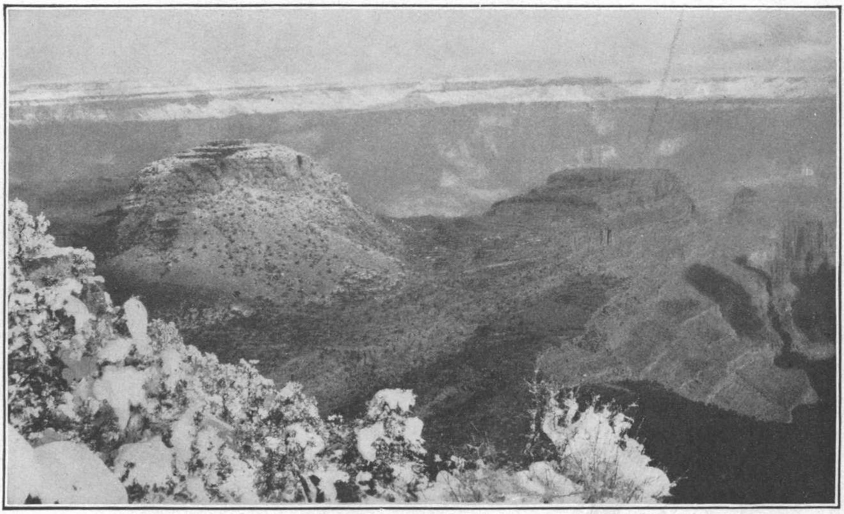
On turning westward the spectator beholds a striking change. (See Pl. VI.) Directly below him, about 1,000 feet beneath the rim, a great flat-topped spur of red sandstone of the Supai formation runs far out into the canyon. Farther west more and more of these spurs appear, each capped with a similar platform, which everywhere lies upon the same layers of red sandstone. Gradually the platform widens and becomes a broad expanse of red rock, which is covered with patches of scanty soil and dotted with scrubby trees—juniper and piñón. The buttes and temples disappear; the walls are much less dissected by side gorges and extend along the canyon's sides in solemn palisades. The profile of the canyon wall is simpler, consisting of a wide outer valley whose floor is the great red platform, or Esplanade, and a deep inner canyon. The wall of the inner canyon is stupendous, the edges of the Tonto, Redwall, and Supai strata appearing almost as a single cliff 3,000 feet in height. The long red spurs of the Esplanade platform (Pl. VII, *A*) form a strange and impressive feature of the landscape and attract the attention as strongly as do the buttes and temples of the Kaibab division. Many of them have been named: Drummond Plateau, Grand Scenic Divide, Huxley Terrace, and Spencer Terrace, on the south side of the river; Masonic Temple, Marcos, De Vaca, Tobar, Alarcon, and Garces terraces, on the north side.

The profile of the canyon wall in the central part of the Shinumo quadrangle is a combination of two types of topography, for both the Esplanade and Tonto platforms are present, separated vertically by over 2,000 feet. This feature is well seen in the wall of Shinumo Amphitheater, directly opposite Havasupai Point.

The canyon wall is more deeply dissected in the Kaibab division than in the Kanab division, the transition taking place in the Shinumo quadrangle. The dissection not only diminishes from east to west but also differs strikingly in amount in the opposite walls of the canyon in the two divisions. In the Kanab division, beyond the western border of the Shinumo quadrangle, the river flows in the very center of the canyon and the northern wall is no more dissected than the southern wall, but in the Kaibab division the north rim lies three times as far back from the river as the south rim; the great amphitheaters and their limiting promontories, which extend far into the canyon, the buttes and temples, and the deep lateral gorges all belong to the north side of the canyon. The south wall presents a simpler aspect; few of the side gorges extend back into the rim of the canyon, there are few buttes and outliers, and the great amphitheaters are wholly lacking. When compared with that of the fantastic topography of the north side, the scenic effect of the precipitous south wall is somber.

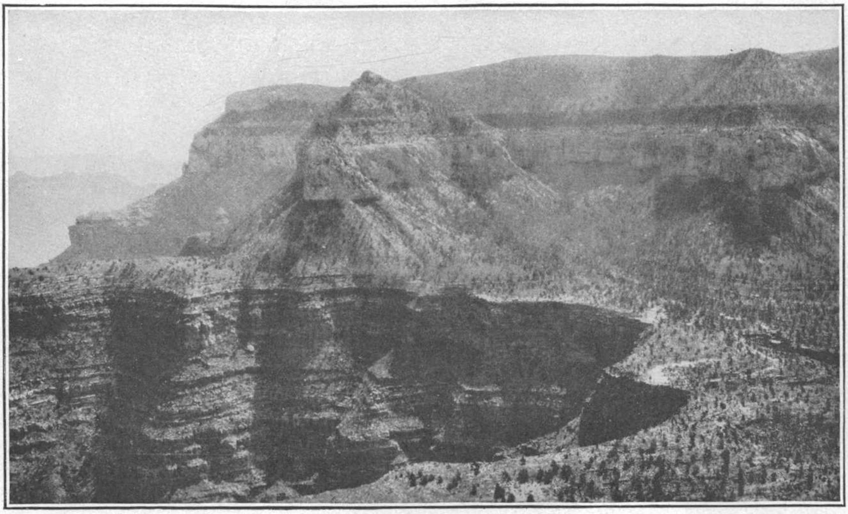
The variations in the amount of dissection of the canyon wall depend upon climatic and structural conditions, whereas the change from east to west in the profile of the wall is explained by certain variations in the thickness and character of the Paleozoic strata. The origin of these topographic features will be discussed elsewhere in this report after the conditions upon which they depend have been described.

The Colorado maintains its general northwesterly course through the Kaibab division into the Shinumo quadrangle as far as the mouth of Shinumo Creek, where it bends westward and flows across the zone of warping that marks the boundary of the Kaibab uplift. Swinging in two great loops, first to the south and then to the west, it doubles back again and flows northeastward around Powell Plateau, passing thence beyond the northern boundary of the quadrangle. Several miles beyond the northern boundary of the quadrangle Tapeats Creek enters the river from the east, draining a great amphitheater of the same name which lies north of Powell Plateau. At the mouth of Tapeats Creek the river bends to the southwest and maintains a southwestward course for 40 miles through the Kanab Plateau, nearly the entire length of the Kanab division.



A. VIEW NORTHWARD FROM BASS CAMP, SHOWING MOUNT HUETHAWALI, A BUTTE ON THE ESPLANADE (AT THE LEFT) AND HUXLEY TERRACE, A DISSECTED SPUR OF THE ESPLANADE.

Mount Huethawali was once part of a great promontory of the Coconino Plateau but has been isolated by erosion. Its summit is composed of two formations of rock that are very resistant to erosion, the Kaibab limestone and the Coconino sandstone. These make a cap that prevents the soft shales of the Supai formation, which are in the lower part of the butte, from wasting rapidly away. As time goes on the cap will dwindle to a mere knob, like that which surmounts Holy Grail Temple; finally it will disappear entirely, and the soft shales beneath, being no longer protected, will be removed from the floor of the Esplanade. This view, which was taken after an exceptionally heavy fall of snow, shows about the maximum extension of the snow line downward into the Canyon in winter.



B. VIEW EASTWARD FROM THE SUMMIT OF MOUNT HUETHAWALI, SHOWING FOSSIL MOUNTAIN AND HAVASUPAI POINT.

The cirque in the foreground is the head of Bass Canyon, down which Bass trail descends to Colorado River. The peaklike promontory in the center of the view is Fossil Mountain, which is gradually being isolated from the Coconino Plateau by erosion and will in time become a butte or outlier like Mount Huethawali. The same fate, though it is more remote, awaits Havasupai Point, the high promontory at the left of Fossil Mountain.

The general course of the great gorge itself is not affected by the smaller bends of the river and may be considered simply as northwesterly through the Kaibab division and beyond, to the mouth of Tapeats Creek, and thence southwesterly through the Kanab division.

The Granite Gorge, which forms the interior of the canyon through the Kaibab division, is not continuous in the Shinumo quadrangle west of the mouth of Garnet Canyon, because of changes in the course of Colorado River with reference to the rock structure. Thus the bend westward and southward at the mouth of the Shinumo causes the river to flow in the direction of the dip of the Paleozoic strata, and as the dip is greater than the grade of the stream the river bed is gradually carried out of the Archean rocks into the basal sandstone of the Tonto group, which terminates the Granite Gorge a short distance below the mouth of Garnet Canyon. Through Stephen Aisle and Conquistador Aisle the bed of the river is in the Paleozoic strata. Beyond the end of Alarcon Terrace the river bends and again flows northeastward, taking a course that soon carries the bed back into the Archean rocks, so that the Granite Gorge reappears in this part of the canyon, continuing until the river finally turns southwestward, at the mouth of Tapeats Creek. This section is called the Lower Granite Gorge. In all the Kanab division west of the mouth of Tapeats Creek the river flows in Paleozoic strata.

The actual length of the course of the Colorado across the quadrangle, measured along the surface of the stream, is 31½ miles. The mean elevation of the surface of the river where it enters the quadrangle on the east is 2,285 feet; where it leaves the quadrangle on the north, 2,035 feet. The total descent of the river within the quadrangle is therefore 250 feet, and the average declivity is 7.9 feet to the mile. The declivity, however, is not uniform. East of the mouth of Garnet Canyon it is 10 feet to the mile; west of this point it is 6.2 feet to the mile. The difference is explained by the fact that above Garnet Canyon the river flows upon resistant Archean rocks, whereas below Garnet Canyon it flows chiefly upon less resistant sedimentary rocks. At the Cable Crossing the width of the river is 300 feet, its depth is 50 feet, and its average rise at times of high water is 40 feet.

The only living tributary of the Colorado in the quadrangle is Shinumo Creek (Pl. XIV, *A*, p. 55), the master stream that drains Shinumo Amphitheater, of the north wall. It is of the same size and kind as Bright Angel Creek, 20 miles to the east, and its clear water presents a striking contrast to the muddy torrent of the Colorado. The length of Shinumo Creek from its source at Big Spring, on the rim of the Kaibab, to its confluence with the Colorado is 12 miles, and in this distance it falls 5,400 feet, its average declivity being 450 feet to the mile.

The topography of Shinumo Amphitheater, besides presenting an equal development of both the Esplanade and Tonto platforms, is remarkable in another way. In the other great amphitheaters of the Kaibab division the master gorges trend southwestward, the tributary gorges trend in the same general direction, and lateral gorges perpendicular to the main axes of the amphitheaters are of minor development. In Shinumo Amphitheater the lateral gorges have become dominant features, so that the main axis of the amphitheater trends northwestward, lying at right angles to the course of the master stream and parallel to the course of the Colorado. The greatest lateral gorge extends entirely across Shinumo Amphitheater from Point Sublime on the southeast to the Muav Saddle on the northwest. Only a mile of this lateral gorge is occupied by the master stream of Shinumo Amphitheater; the remainder is occupied by two small intermittent streams. The western part of the gorge, which extends from the Muav Saddle to Shinumo Creek, is drained by Muav Creek and White Creek and is called Muav Canyon; the eastern part, extending from Shinumo Creek to Point Sublime, is drained by Flint Creek and has no local name. The entire lateral gorge will be referred to as the "Muav-Flint Canyon." This remarkable rectilinear depression is situated upon the line of the West Kaibab fault. Two smaller lateral gorges cross the heart of the amphitheater parallel to the Muav-Flint Canyon; these are situated upon minor lines of fracture.

The course of Shinumo Creek through the canyons of Shinumo Amphitheater everywhere lies in one of two main lines which are perpendicular to each other. The course in the northeast-southwest line, which carries the stream onward toward its junction with the Colorado, is consequent upon the dip of the Paleozoic rocks; the course in the northwest-southeast line, which holds the stream in the lateral gorges, is controlled by the West Kaibab faults and by fracture lines. (See pp. 75–80.)

The highest point in the Shinumo quadrangle is the surface of the Kaibab Plateau in the northeast corner of the quadrangle, where the elevation is 8,450 feet; the lowest point is the bed of the Colorado River, at the place where it flows beyond the northern boundary of the quadrangle, where the elevation is about 2,000 feet. As the surfaces of the plateaus and of the platforms within the canyon are everywhere accordant with the rock structure, the altitudes of these surfaces diminish progressively toward the southwest in all parts of the quadrangle in conformity with the dip of the Paleozoic rocks.

For example, the elevation of the Kaibab Plateau at the head of Shinumo Amphitheater is 8,000 feet; but at Point Sublime, 5 miles south, it is only 7,500 feet. Farther southwest, on the opposite side of the Grand Canyon, at Havasupai Point, the Coconino Plateau stands at 6,750 feet; 10 miles farther southwest it stands at 5,900 feet. At the head of Shinumo Amphitheater the elevation of the Esplanade, a platform within the canyon, is 6,750 feet; at Holy Grail Temple, in the center of the amphitheater, it is 6,100 feet; farther southwest, across the river, at Darwin Plateau, it is 5,400 feet, and in Aztec Amphitheater it is 5,000 feet. The Tonto platform stands at 3,750 feet under Dox Castle; directly opposite, on the south side of the river under Tyndall Dome, its altitude is 3,300 feet.

The wall of the Grand Canyon drops most abruptly at Dutton Point (Pl. XVIII, p. 86), where it descends 5,355 feet from Powell Plateau to the river in 3 miles; and at Havasupai Point, where it descends 4,500 feet in a mile and a half, presenting the most precipitous descent in the Grand Canyon.

The greatest width of the Grand Canyon in the quadrangle is in the stretch from the head of Aztec Amphitheater to the head of Shinumo Amphitheater, a distance of 16 miles. The narrowest point is between Apache Point and Ives Point, 4¾ miles. Even at this narrowest point the width is over five times the depth.

CLIMATE.

The climatic differences within the Shinumo quadrangle are remarkable. The range in climate between the Kaibab Plateau and the bottom of the canyon is as great as that between the mountains of Colorado and the Mojave Desert. The winters on the Kaibab Plateau are extremely severe; from November to April the snow lies deep in the woods, in places accumulating to a depth of 10 feet. Even in midsummer the nights are chilly and the days are delightfully cool. Within the canyon, however, snow rarely falls below the level of the Esplanade, and on the Tonto platform a fall of snow is practically unknown. In the depths of the canyon the winters are mild and freezing temperatures are rare. From April to October, whenever the days are cloudless, the entire interior of the canyon concentrates the solar heat and becomes a veritable oven. All day the bare rocks absorb the heat of the sun, becoming so hot as to burn the hand; by afternoon the wind is like a furnace blast, and the rocks continue to radiate their heat long after dark. The summer heat is tempered greatly on the cloudy days during the period of rains. The climate of the southern or Coconino Plateau at Bass Camp is characterized by more open winters as well as by warmer summers than the Kaibab. Snow rarely accumulates on the surface to a great depth and as a rule vanishes entirely within three days after a storm; and in summer many days are unpleasantly hot.

The climate of the Kaibab Plateau is decidedly moist, the precipitation being probably twice as great as that received upon the Coconino Plateau, across the canyon. This difference is due chiefly to the greater altitude of the Kaibab Plateau. In winter the precipitation on the Kaibab takes the form of snow; in summer it comes in thundershowers which occur during the afternoon and evening. Looking across the canyon from Bass Camp on the south rim on almost any summer evening one may see storm after storm sweeping over the surface of the Kaibab Plateau, most of them accompanied by violent electrical display, while the sky overhead and to the west over the Kanab Desert remains as clear as crystal. Another factor that contributes to the greater rainfall of the Kaibab seems to be the presence of the Grand Canyon itself. Every general winter storm that visits both sides of the canyon alike is followed on the south rim by a day of clearing; but the clouds that rise out of the canyon after the storm sweep back over the north wall and reprecipitate on the surface of the Kaibab. Few of these secondary storms return over the south rim. The climate of the Coconino Plateau in the quadrangle is semiarid; in spring and early summer no rain may fall for a month. The precipitation is greatest in winter and in the months of July, August, and September. Much of the rain that falls within the canyon evaporates before it reaches its lower part, which is therefore more arid than the Coconino Plateau.

Powell Plateau (Pl. IV, A, p. 18), whose higher eastern portion stands at the same altitude as the Kaibab rim and whose lower western portion stands at the altitude of the Coconino, has a climate that is intermediate between those of these two divisions. Its situation in the canyon, where it forms an island, serves to moderate the cold in winter, for the warm air which rises out of the deep canyons that surround it acts as a radiator; snow does not accumulate so deep on its eastern end as on the Kaibab, and on its western end does not accumulate at all. It is a resort in winter for game and cattle that are driven out of the Kaibab by snow. Its higher eastern end receives abundant rainfall, whereas its lower western end is semiarid. Owing to its exposed position it is at all times of the year subject to violent gales of wind.

The variation in the amount of rainfall with difference in altitude is the chief cause of the variations in the degree of dissection of the canyon walls. The plateaus on both sides of the canyon in the Kaibab division are much higher than those in the Kanab division, where the rainfall is therefore much greater and the forces of erosion more active, and the walls are consequently far more dissected in the Kaibab than in the Kanab division. The much greater dissection of the northern than of the southern wall of the canyon in the Kaibab division may be similarly explained, the higher altitude of the northern wall giving it much greater rainfall than the southern wall.

In this dissection the rock structure is also important. Since the surface of the Kaibab Plateau slopes toward the rim of the canyon, all the surface water within a radius of many miles finds its way into the canyon over the northern wall. Even the water that sinks underground—which far exceeds the surface water in quantity because of the system of caves, sink holes, and underground drainage channels with which the Kaibab limestone is honeycombed—eventually finds its way southwestward along the dip of the strata and reappears as springs in the northern wall of the Grand Canyon, feeding the tributary streams of the Colorado and increasing the activity of the forces of erosion on that side of the river.

The waters of the semiarid Coconino Plateau, on the contrary, both surface and underground, are carried directly away from the Grand Canyon by the slope of the surface and by the southwesterly dip of the strata; consequently the forces of erosion are less active in the southern wall of the canyon.

VEGETATION.

The variation in the flora in the Shinumo quadrangle is as great as that in the climate. The surface of the Kaibab Plateau is covered with a magnificent open forest of yellow pine; the trees grow large and far apart and the ground is free from undergrowth, so that the plateau has the aspect of a great park. Englemann spruce grows on the north slopes of the washes, and cottonwood, aspen, and scrub oak in their bottoms. A minor flora of flowering plants exceedingly rich in species covers the floor of the forest. The flora of the Coconino Plateau in the quadrangle differs completely from that of the Kaibab. The surface is covered with a dwarf forest of gnarled juniper, piñón, and "mountain mahogany" (*Cercocarpus ledifolius*); the little trees grow wide apart and the open stretches are covered with sagebrush and "Mormon tea," with occasional cactus, "mescal," and other plants of the century family.

This difference between the floras of the two plateaus is due to differences in precipitation and temperature, which vary directly with the altitude, and for this reason the floras of the plateaus furnish an almost unfailing index of their elevation, a fact that is strikingly shown on the southwestward-sloping surface of Powell Plateau. The whole eastern half of this plateau lies at an elevation of 7,000 to 7,500 feet and is covered with the open pine forest characteristic of the Kaibab, but at an elevation of about 7,000 feet the flora changes, passing into the dwarf forest of juniper and piñón that characterizes the southern plateau across the canyon.

In the region farther east, beyond the border of the Shinumo quadrangle, the Coconino Plateau attains a much greater altitude and the flora there becomes more like that of the Kaibab Plateau.

Within the canyon itself the variation in the flora is just as great, and is again an index of the elevation.

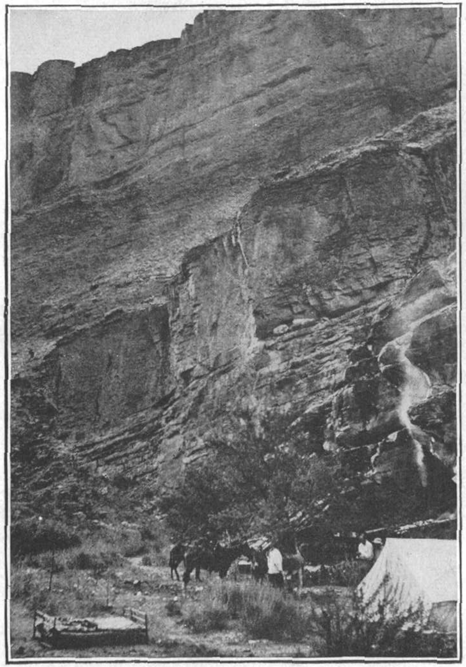
The flora of the Esplanade platform, a thousand feet below the south rim, consists of stunted juniper and piñón with *Coleogyne ramosissima* (locally known as "greasewood") as the predominant bush in place of the sagebrush of the Coconino Plateau. Cacti and plants of the century family are more abundant than on the plateau, but less abundant and smaller than in the bottom of the canyon, a condition due to the fact that the Esplanade level is within reach of the winter snows and frosts. On the north side of the canyon, where the elevation of the Esplanade is much greater than on the south side, mountain mahogany, manzanita, live oak, and other dwarf trees appear in the flora, making a thick chaparral that cloaks all the slopes with a dense mantle of green.

The flora of the Tonto platform, 3,000 feet below the south rim, and of all the interior of the canyon below the Red Wall is the flora of a hot and arid desert. The dominant plants are *Coleogyne ramosissima*, "Mormon tea," and other small gray perennial shrubs of various species, each plant standing apart by itself in the formal manner characteristic of desert vegetation. Cacti, aloes or agaves, and yuccas here attain their densest growth and greatest size, the cacti being particularly rich in species. Every plant in the flora is either prickly or aromatic, leaf surfaces are reduced to a minimum, devices for storing water attain the greatest perfection, and the dominant color is a dull gray. The somber colors and the reduction of leaf surfaces are likely to deceive the observer both in regard to the richness of the flora in species and the abundance of plant life, which is far greater than one would suspect. Small trees of *Acacia greggi*, or "cat claw," and here and there a few of *Cercis occidentalis*, or "red bud," grow in the beds of washes that contain living or intermittent streams.

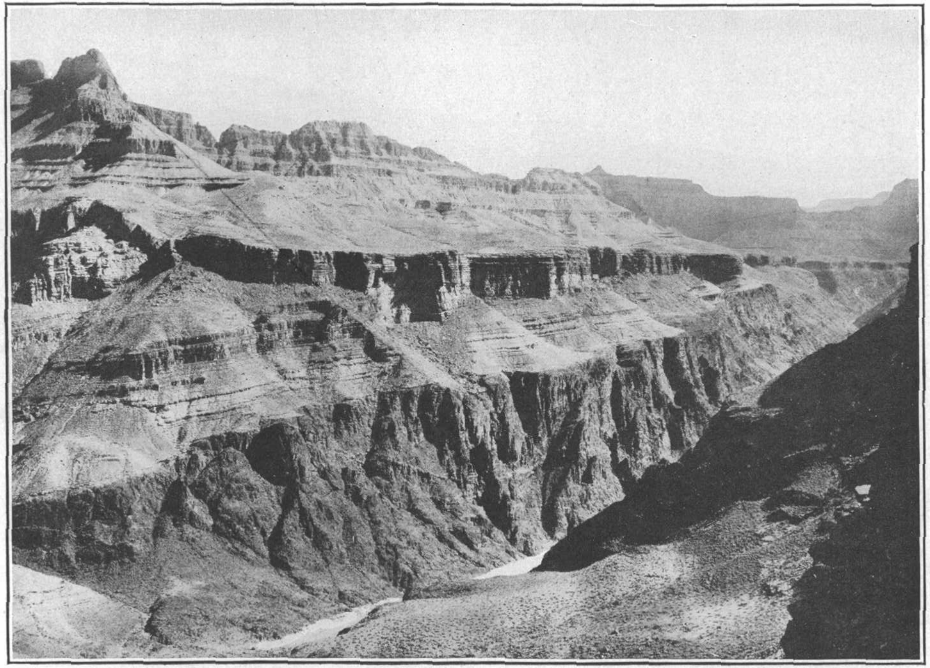
The vegetation in the bottoms of the canyons of the north side of Shinumo Amphitheater that contain living streams is beautiful beyond description and affords a refreshing contrast to the desert flora of the Tonto platform. Tall cottonwoods grow in the lower canyons, maiden-hair ferns hang on the walls in shady places, thickets of willow border the streams, and grass grows on the banks where there is soil. Higher up in the canyons, oaks, maples, and other deciduous trees grow, and in some places there are beds of tall rushes. The most characteristic bush of these upper north-side canyons is the manzanita, which apparently does not grow on the south side of the Grand Canyon in the quadrangle.

INDIAN RUINS.

Evidences of former human occupation are found everywhere in the Grand Canyon region and the observant traveler will see them in many places in the Shinumo quadrangle, but as few of these ruins are well preserved he must not expect to see anything so spectacular as the wonderful ruins of the Mesa Verde in southwestern Colorado or the Canyon De Chelly in northeastern Arizona. Ruins are most numerous in the canyons of Shinumo Amphitheater and consist of



A. EAST WALL OF CANYON OF SHINUMO CREEK NEAR SHINUMO GARDEN.



B. VIEW EASTWARD UP COLORADO RIVER FROM A POINT NEAR THE MOUTH OF BASS CANYON, SHOWING GRANITE GORGE.

the fallen and crumbled walls of rude stone houses. Some of these ruins are perched high under overhanging ledges which still show the blackening of smoke; others lie among huge blocks of débris that have fallen from the cliffs; still others stand in the open, away from any natural shelter. The only well-preserved structures are tiny storehouses, built high up along the crevices in the canyon walls. Numerous relics have been found by digging in or around the ruins, among them mealing stones, mortars, pestles, corncobs, ropes of yucca fiber, arrowheads, and various stone implements. Fragments of pottery are littered about and remains of irrigation ditches are still visible in Shinumo Canyon, where gardens were cultivated. The walls of the ruins on the plateaus have crumbled to almost shapeless heaps of stone, and in some of those on Powell Plateau tall pine trees are growing. The only ruin that is at all well preserved is at the head of Bass trail, on the Coconino Plateau. It is supposed that most of these ruins are the work of the cliff dwellers, the ancestors of the present Pueblo Indians of the Southwest.

The trails into the Grand Canyon on both sides of the river follow old Indian trails. All the way down Bass trail and all the way up the trails through Shinumo and Muav canyons the traveler will see at intervals the blackened ruins of circular pits where the Indians have roasted the "mescal," a species of agave that grows everywhere in the canyon. These mescal pits are found in every canyon on the south side of the river. The Havasupai Indians, who dwell in Cataract Canyon, 25 miles southwest of Bass Camp, still make occasional use of a trail that descends to the Esplanade at Apache Point.

GEOLOGY.

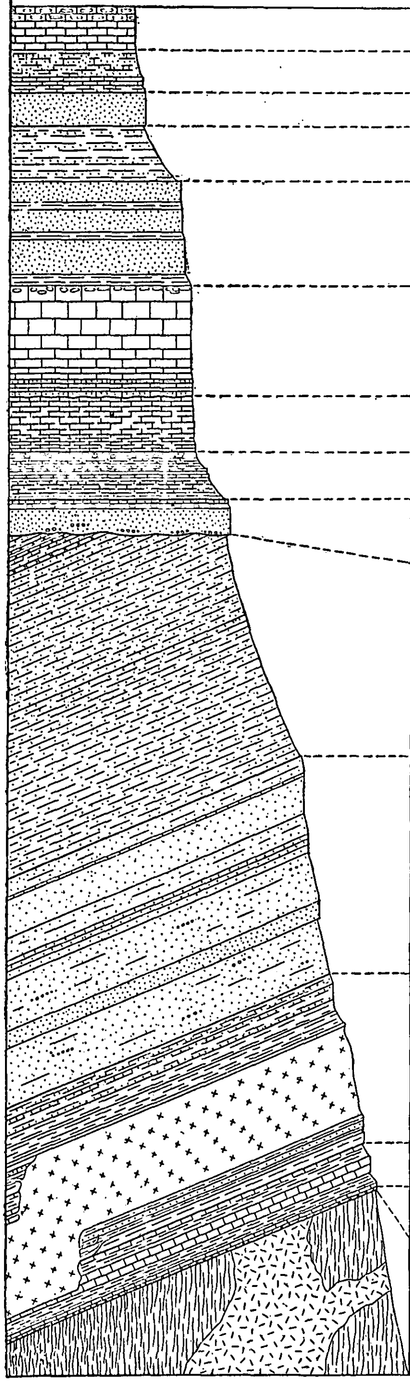
AGE AND CHARACTER OF THE ROCKS.

Four great systems of rock are exposed in the walls of the Grand Canyon in the Shinumo quadrangle. (See Pl. IX.) These systems represent three of the earliest eons of geologic time, the Archean and Algonkian periods and the Paleozoic era, the last being represented by the Cambrian and Carboniferous systems.

The foundation rocks of the region are crystalline schists, gneisses, and granitic rocks of Archean age. The schists and gneisses are metamorphic rocks, whose original character has been changed by pressure, so that they are gnarled and crumpled. These metamorphic rocks are known as the Vishnu schist. The granitic rocks are igneous. They invaded the metamorphic rocks in a molten state and are massive in aspect. The Archean rocks form the walls of the Granite Gorge (Pls. III, p. 16, and VIII, *B*) in the bottom of the canyon. All types of these Archean rocks are about equally resistant to erosion, and consequently they form a continuous ragged slope, which gives the walls of the Granite Gorge a V-shaped profile. In color they are dark and somber. By these features and by their lack of stratification they may be readily distinguished from the Algonkian and Paleozoic rocks.

The Archean rocks are separated by a profound unconformity (Pls. VIII, *B*, and XVIII, p. 86) from a series of overlying sedimentary rocks, which is inset in the Archean rocks by block faulting and is of Algonkian age. The sedimentary rocks (Pls. IV, *B*, p. 18, and XI, p. 39) are as little altered as the still higher Paleozoic rocks. Unlike the Paleozoic rocks, however, they do not lie in their original horizontal position but are inclined at various angles. They comprise limestones, shales, sandstones, and intrusive masses of diabase, and are found only within the greater depths of the Grand Canyon.

The Archean and Algonkian rocks are alike separated by another profound unconformity (Pl. XVIII) from the Paleozoic rocks, consisting of limestone, shale, and sandstone. The Paleozoic rocks (Pl. XVIII) lie in a nearly horizontal position, practically as they were laid down. They form the floors of all the plateaus and the greater part of the walls of the Grand Canyon and have determined the whole character and spirit of the scenery. The huge scale and the infinite multiplication of the characteristic architectural rock forms make the scenery of the Grand Canyon seem strange and unreal, yet it is but the supreme expression of all that is most characteristic in the land sculpture of the Plateau province. The processes of earth sculpture are going on here, as in other regions, under the attacks of rain, running water, frost, and wind. The erosion is spasmodic, because of the aridity of the climate, yet it is none the less effective. Slopes are kept partly bare because the desert plants grow far apart, so that the concentrated energy of a single torrential shower wreaks more havoc here than a season's rainfall on the densely covered slopes of a humid region. But these forces are working on rocks which, as we have seen, lie in nearly level beds that are continuous over great areas. Therefore they produce everywhere forms that are nearly identical in the vertical element, or profile, though varied and irregular in plan, as might be seen on looking down on them from a balloon or examining their outlines on the map. As the beds, from top to bottom, show infinite variations in their resistance to erosion, every part of the canyon wall, every pinnacle and butte, is characterized by its own steplike alternation of cliff and terrace or slope, in delicate response to the varying character of the strata. In the canyon wall the cliffs are determined by the edges of the harder strata. Upon the plateaus the soft rocks have been washed away over miles of the country, leaving platforms whose floors are a hard stratum. As erosion goes on, parts of the plateau become separated by growing canyons or ravines and stand as solitary outliers, capped by remnants of the harder rock; these are the buttes. Finally, all these land forms, which in a moister region would soon be dulled or obscured, are kept sharp and fresh by the prevailing aridity, the effect of which is to



Lithologic character	Formation	Group	Series	System
Dense crystalline limestone containing chert at the top. Fossils are present in great abundance	Kaibab limestone, 400-600 feet	Aubrey	Pennsylvanian	Carboniferous
Buff limestone and calcareous sandstone				
Massive buff sandstone of very fine and even grain, characterized by cross-bedding on a huge scale	Coconino sandstone, 250-350 feet			
Soft red shaly sandstone and red shale	Supai formation, 1,250-1,400 feet			
Hard fine-grained cross-bedded sandstone, with interbedded layers of red shale				
Alternating layers of calcareous sandstone, thin-bedded mottled limestone, and dense blue-gray crystalline limestone in lower portion; passing upward into dense blue-gray crystalline limestone, the bedding of which is obscure. Fossils are present but not well preserved	Redwall limestone, 600-700 feet		Mississippian	
	Unconformity			
Impure thin-bedded bluish-gray limestone which has a characteristic mottled appearance imparted by numerous thin bands or lenses of buff or greenish shaly material	Muav limestone, 450-475 feet	Tonto		Cambrian
Soft greenish micaceous sandy shale with two thin layers of brown crystalline limestone locally present in the middle of the formation. Contains fairly abundant fossils	Bright Angel shale, 25-375 feet			
Brown slabby cross-bedded sandstone. Basal portion contains lenses of conglomerate, the pebbles of which are rounded. Rests on a moderately even surface produced by erosion	Tapeats sandstone, 0-285 feet			
	Great unconformity			
Micaceous shaly sandstone; greenish gray in lower portion, red-brown and vermilion above. Characterized by ripple marks and cross-bedding. Cut by thin sills of intrusive diabase	Dox sandstone, 2,297 feet plus unknown thickness removed by pre-Cambrian erosion	Unkar	Grand Canyon	Algonkian
Hard, compact cross-bedded sandstone and quartzite, usually of fine and even grain	Shinumo quartzite, 1,564 feet			
Argillaceous red shale, grading upward into arenaceous red shale and sandstone. Nearly all beds contain sun cracks and ripple marks. Cut by a thick sill of intrusive diabase, which has converted the shale into slate and jasper near the contact	Hakatai shale, 580 feet			
White crystalline limestone alternating with beds of argillaceous and calcareous red shale containing sun cracks. Cut by a thick sill of intrusive diabase	Bass limestone, 335 feet			
Arkose conglomerate characterized by lack of sorting and transportation. Rests on an extremely even surface produced by erosion	Hotauta conglomerate, 0-6 feet			
	Great unconformity			
Quartz, mica, and hornblende schists. Cut by quartz diorite and granitic pegmatite intrusives	Vishnu schist			Archean

1,000 0 1,000 2,000 3,000 Feet

GENERALIZED COLUMNAR SECTION OF THE ROCKS OF SHINUMO QUADRANGLE.

maintain clean-cut cliff profiles and to retard the formation of soil and the growth of dense vegetation to mantle the slopes.

The strata are as easily distinguished by their colors as by the shapes they have taken under erosion. In the color scheme of the Grand Canyon these Paleozoic rocks play the dominant part. They are of the familiar shades of red, brown, buff, and gray shown by sedimentary rocks throughout the Rocky Mountain and Plateau regions of the western United States, and although the colors are neither so brilliant nor so varied as the visitor at the Grand Canyon is commonly led to expect, their general effect is very striking. They appeal to the eye and to the imagination through the stupendous panorama extending over many miles; through the extreme contrast between the vast, bright expanse of bare rock of the unforested interior of the canyon and the verdant wooded plateaus on the rim, and through the rigorously architectural effect imparted by the wide extent of the horizontal strata. Much of the charm of the varied tints, like that of most western desert coloring, lies in their dullness and oddity. They are mostly old, subdued shades, which vary just a little from conventional hues. The most beautiful effects, however, are wrought not so much by the colors of the rocks as by the purple haze that late in the afternoon, particularly in midsummer, often hangs over the canyon.

SERIES OF ROCKS DISCRIMINATED.

The lithologic representatives of the Permian, Mesozoic, and Tertiary, which, as shown by Dutton, once covered the region, have been removed by erosion. The following table shows the systems, series, groups, and formations discriminated in the quadrangle:

Generalized section of the rocks of the Shinumo quadrangle.

System.	Series.	Group.	Formation.
Carboniferous.	Pennsylvanian.	Aubrey.	Kaibab limestone. Coconino sandstone. Supai formation.
	Mississippian.		Redwall limestone.
Unconformity of erosion without unconformity of dip.			
Cambrian.		Tonto.	Muav limestone. Bright Angel shale. Tapeats sandstone.
Great angular unconformity.			
Algonkian.	Grand Canyon.	Unkar (intruded by sills of diabase).	Dox sandstone. Shinumo quartzite. Hakatai shale. Bass limestone. Hotauta conglomerate.
Greatest angular unconformity.			
Archean.			Vishnu schist (intruded by masses of quartz diorite and by dikes of pegmatite).

The names employed in this report for the Paleozoic formations have been recently authorized by the United States Geological Survey to supplant older descriptive and duplicated names and to bring them into conformity with present usage. The following table gives equivalents of the older in the newer nomenclature.

Present nomenclature.	Former nomenclature (reports of Dutton, Gilbert, and Walcott).
Kaibab limestone	Cherty limestone.
Coconino sandstone	Cross-bedded sandstone.
Supai formation	Lower Aubrey sandstone.
Redwall limestone	Redwall limestone.
Muav limestone	Marbled (or mottled) limestone.
Bright Angel shale	Tonto shale.
Tapeats sandstone	Tonto sandstone.

PROTEROZOIC ROCKS.

ARCHEAN SYSTEM.

VISHNU SCHIST.

NAME.

The name Vishnu terrane has been given by Walcott[1] to the fundamental crystalline complex of the Grand Canyon region that underlies the unaltered sedimentary rocks of Algonkian age and is separated from them, as well as from the overlying Cambrian, by a profound unconformity. The type locality is on Colorado River, 30 miles east of the mouth of Shinumo Creek, at the base of one of the great buttes called "Vishnu's Temple," from which Walcott derived the name.

DISTRIBUTION IN THE GRAND CANYON.

In the Kaibab division the Vishnu schist is exposed continuously for more than 40 miles in the walls of the Granite Gorge (Pl. VIII, *B*). In the eastern part of the Kanab division it is exposed in Lower Granite Gorge and is probably exposed in other places in the Kanab division between the end of Lower Granite Gorge and the mouth of Kanab Creek, for Powell,[2] in his account of this portion of his journey down the river, mentions "passing for a short distance through patches of granite, like hills thrust up into the limestone." The Vishnu is exposed through the greater part of the Shivwits division and around the southwestern border of the Grand Canyon district.

OCCURRENCE AND DISTRIBUTION IN THE SHINUMO QUADRANGLE.

The length of the exposure of the Vishnu schist in the Granite Gorge along the course of the river is about 17 miles; in Lower Granite Gorge it is 4 miles. A small but interesting exposure in

[1] Walcott, C. D., Pre-Cambrian igneous rocks of the Unkar terrane, Grand Canyon of the Colorado, Arizona, with notes on the petrographic character of the lavas, by J. P. Iddings: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, pp. 497-519, 520-524, 1894.

[2] Powell, J. W., Exploration of the Colorado River of the West and its tributaries; explored in 1869, 1870, 1871, and 1872, under the direction of the Secretary of the Smithsonian Institution, p. 92, 1875.

the depths of the Muav-Flint Canyon lies on the northeast side of the West Kaibab fault and extends for 3 miles southeastward in the canyons of White, Shinumo, and Flint creeks, and for 1 mile northeastward up the canyon of Shinumo Creek.

No detailed study of the Vishnu schist was made in the Shinumo quadrangle beyond that required to locate and determine the various types represented in the area shown on the geologic map, and owing to the small extent of these exposures it was not possible to determine the general Archean structure from a study of this area alone. The rocks here are a metamorphic complex of quartz, mica, and hornblende schists and are invaded by a batholithic mass of quartz diorite and injected by veins of pegmatite and aplite. East of the Shinumo quadrangle and west of the mouth of Walthenberg Canyon in the Shinumo quadrangle the prevailing rocks are gneisses.

TYPES OF THE SCHIST.

Three main types of rock are found in the formation within the area studied:

The first type is a quartz schist that grades into mica schist. It comprises the greater part of the Vishnu schist that is exposed in the gorge of the Colorado River west of the Cable Crossing and is also exposed in the canyon of White Creek and in the canyon of Flint Creek just above its junction with Shinumo Creek.

The second type is a quartz schist that grades into quartz-hornblende schist. It is exposed chiefly in that part of the Muav-Flint Canyon that is occupied by Shinumo Creek, grading both eastward and westward into the quartz-mica schist.

The third type is a hornblende schist. It occurs in one small outcrop, about 200 feet wide, on the east side of a dry wash that joins the valley of Shinumo Creek just below the mouth of White Creek, and is sharply bounded on both sides by the quartz-mica schist.

The rocks are typically schistose. The planes of schistosity generally stand almost vertical and trend northeastward, though their direction varies from place to place. The schists are locally much twisted and contorted.

LITHOLOGY OF THE TYPES.

The less micaceous phase of the quartz-mica schist is dark greenish gray and its fresh surfaces have a satiny luster. Its cleavage is imperfect, its texture is fine grained, and it contains no visible mineral constituent except quartz. The microscope shows that it is composed almost entirely of fine interlocking grains of quartz, and some small flakes of white mica, arranged in parallel lines. The extreme quartzose phase of the schist contains very little mica—just enough to impart a satiny luster to the rock.

Freshly fractured surfaces of the micaceous phase of the schist are grayish, with either a pinkish or greenish tinge, but the weathered rock is red. This phase shows a rather distinct cleavage and a texture ranging from fine to coarse. The unaided eye can distinguish both quartz and mica in the rock, and the microscope shows that it is composed of interlocking grains of quartz and an almost equal amount of mica, the flakes of mica being arranged in parallel lines. The mica is chiefly muscovite, but includes some flakes of brown biotite.

Locally the schist is garnetiferous, and in one place tourmaline was observed. All gradations between the quartzose and the micaceous phases occur, but in no specimen does the mica exceed the quartz in quantity.

The quartz-hornblende schist is a dark-green, dense, hard rock, with imperfect cleavage and fine-grained and uniform texture. Its mineral constituents can not usually be distinguished in the hand specimen without the aid of the lens, but the microscope shows that it consists of about equal proportions of quartz and green hornblende. The quartz occurs in interlocking grains and the hornblende tends to form automorphic crystals whose longer axes are roughly parallel. No other minerals were observed in the slides examined. Some phases of the rock contain more quartz than hornblende.

The hornblende schist is a dark-green, soft, coarse-grained rock, considerably disintegrated, and crumbles under the hammer. Megascopically it consists almost entirely of dark-green hornblende and exhibits no schistosity. The microscope shows that it consists almost wholly of large crystals of green hornblende in all stages of alteration, with a small amount of interstitial quartz, the quartz granules being strung out in roughly parallel lines. The rock is much altered and a thin section of it is unsatisfactory.

ORIGIN OF THE SCHIST.

The rocks in the Shinumo area afford no clear evidence of the original character of the Vishnu schist—no evidence of banding that can be clearly referred to original sedimentary bedding and no evidence of original clastic texture—but the mineralogic composition of the quartz schists of the mica and hornblende type suggests their sedimentary origin. Either type might have resulted from the regional metamorphism of an arkose sandstone or shale.

Such rocks would become either quartz-mica or quartz-hornblende schist, the type assumed being determined by the proportion of iron in the original sediments. Certainly the great preponderance of quartz in these rocks creates a presumption against their igneous origin. The present aspect of the schists is doubtless due to processes connected with regional metamorphism, namely, subsidence and deep burial, subsequent folding and mashing, and slow recrystallization.

The original character of the hornblende schist described as occurring in a narrow outcrop between the other schists can not easily be determined. The fact that the rock consists of little else than hornblende suggests that it was originally an igneous rock of a basic type. The fact that the microscope discloses in it a schistose structure shows that it is at least earlier than the period of regional metamorphism in which the schists wherein it is inclosed assumed their present structural and mineralogic character.

AGE AND CORRELATION.

The Vishnu schist consists of rocks which, in the light of present knowledge, can be conceived to have acquired their character only at great depths beneath the earth's surface, in what is technically known as the "zone of flowage." It is therefore evident that the unconformity which separates them from the overlying Algonkian sediments of the Grand Canyon series represents a vast amount of erosion and a long period of time—a period much greater in events even than that represented by the profound unconformity which separates the succeeding Grand Canyon series from the overlying Paleozoic. The Vishnu schist is therefore assigned to the Archean system. It seems likely, as stated by Ransome,[1] that it may be correlated with the Pinal schist of the Globe and Bisbee regions, and that it presents "somewhat different aspects of the fundamental crystalline complex of Arizona."

These rocks have not yet been studied in detail in the Grand Canyon region, and their internal structural relations are unknown. A careful study of their exposures in the Kaibab division, in the Shivwits division, and along the southwestern border of the Plateau province may reveal the general Archean structure and the relation of these rocks to the fundamental complex of the southern part of Arizona.

INTRUSIVE QUARTZ DIORITE AND DIKES OF PEGMATITE ASSOCIATED WITH THE VISHNU SCHIST.

The Vishnu schist is intruded by masses of quartz diorite and by dikes of pegmatite.

QUARTZ DIORITE.

So far as observed, quartz diorite constitutes all the Archean system in the Shinumo quadrangle that is exposed in the Granite Gorge of Colorado River for half a mile east of Cable Crossing. Its western contact is well defined, but its eastern limit was not located.

The quartz diorite in the river gorge east of Cable Crossing is a coarse-grained, dense, resistant rock of typical granitic texture,

[1] Ransome, F. L., The geology and ore deposits of the Bisbee quadrangle, Arizona: U. S. Geol. Survey Prof. Paper 21, p. 21, 1904.

which tends to weather into roughly angular blocks and thus to assume forms that distinguish it in the mass from the Vishnu schist. It is dark gray, looks remarkably fresh, and contains visible particles of white striated feldspar, dark hornblende, and glistening black biotite. The rock is uniform in texture throughout the exposures observed, is apparently without contact modifications, and shows no gneissoid banding.

Under the microscope it is seen to be a coarse-granular rock of granitic texture. Its dominant mineral constituents are plagioclase and common hornblende, the plagioclase ranging from oligoclase to labradorite. Microcline, orthoclase, and quartz are present in about equal proportions, but their total amount does not equal that of the plagioclase. Brown biotite appears in somewhat less quantity than the hornblende, and titanite and magnetite are accessories. Occasionally the quartz is poikilitic in the orthoclase. The feldspathic and ferromagnesian minerals occur in about equal proportions. If it were not for the preponderance of plagioclase the rock might be classed as a quartz monzonite or granodiorite, but it is probably best classed as a quartz diorite with a monzonitic aspect. The microscope reveals no cataclastic structure nor other evidence of dynamic action, and the minerals are fresh and unaltered.

The origin of the quartz diorite is reasonably clear. As it is a coarse-grained igneous rock of plutonic aspect occurring over a large area, sharply cutting the Vishnu schist, and showing no textural modifications at the contact, it doubtless represents a deep-seated igneous invasion of a large mass, of the type known as a batholith. As the rock is unaltered and shows no gneissoid or cataclastic structure the batholithic invasion probably occurred after the period of regional metamorphism that produced recrystallization and schistosity in the inclosing schists. The invasion of the batholith may in itself have aided in producing this recrystallization and schistosity, but the field evidence seems to be adverse to such a conclusion, for the schist shows no change either in texture or in mineral composition with increase of distance from the contact.

PEGMATITE.

A granitic pegmatite occurs in dikes that cut all types of the Vishnu schist and that may readily be divided into two generations. The older generation is folded with the schists; the younger generation is a great network or mesh of dikes that cuts both the quartz diorite intrusive and the Vishnu schist. A vertical section covering a thousand feet exposes a huge mesh of these dikes in the wall of the Granite Gorge east of the mouth of Hotauta Canyon. (See Pl. VIII, *B*, p. 28.)

The pegmatites are pink, very coarse-grained rocks, composed chiefly of quartz and pink orthoclase, and in places contain large crystals of silvery-white mica. Most of the dikes exhibit typical comb structure inward from their walls and a graphic arrangement of the quartz and feldspar. Along the walls of some of the dikes the texture becomes aplitic.

The older pegmatite dikes are folded intimately with the Vishnu schist. Their injection may have either preceded or accompanied the regional metamorphism. The younger pegmatite dikes cut both the Vishnu schist and the intrusive quartz diorite. Where they cut the schists they break clean across the schistosity. The injection of these dikes is the latest recorded event in the igneous activity of Archean time within the area.

ALGONKIAN SYSTEM.

GRAND CANYON SERIES.

NAME.

The unaltered pre-Cambrian sedimentary rocks of the Grand Canyon region were first recognized by Powell [1] and were afterward more carefully studied by Walcott [2] at the eastern end of the Kaibab division of the canyon. They are described by Walcott as a series of sedimentary rocks 12,000 feet in thickness, comprising limestones, shales, sandstones, and interbedded flows of lava, separated both from the underlying Vishnu schist and from the overlying Cambrian sediments by profound unconformities, and exposed over a considerable area in the greater depths of the Grand Canyon and in the intercanyon valleys of the north side. To this series of sedimentary rocks Powell [3] gave the name Grand Canyon group, which was modified by Walcott to Grand Canyon series.

A slight unconformity of erosion was found in the middle of the series. The stata lying below this minor unconformity were called by Walcott the Unkar terrane, the name being derived from Unkar Valley, in which the strata are typically exposed. The rocks above the minor unconformity were called by him the Chuar terrane from typical exposures in Chuar Valley. These two valleys are parallel intercanyon valleys of the north side of the Colorado in the area described by Walcott. According to the Survey classification the Unkar and Chuar are designated as groups.

DISTRIBUTION IN THE GRAND CANYON.

At six localities in the Grand Canyon between the mouth of the Little Colorado, in the eastern end of the Kaibab division, and the mouth of Tapeats Creek, some 80 miles below, in the eastern part of

[1] Powell, J. W., Exploration of the Colorado River of the West, p. 212 and fig. 79, Washington, 1875.

[2] Walcott, C. D., Pre-Cambrian igneous rocks of the Unkar terrane, Grand Canyon of the Colorado, Arizona, with notes on the petrographic character of the lavas by J. P. Iddings: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, pp. 497–519, 520–524, 1894.

[3] Powell, J. W., Geology of the eastern portion of the Uinta Mountains: U. S. Geol. and Geog. Survey Terr., p. 70, 1876.

the Kanab division, the strata of the Grand Canyon series are exposed between the crystalline schists of the Archean and the basal sandstone of the Cambrian. Five of the localities are within the Kaibab division; the sixth is within the Kanab.

The first of these localities is the classic area below the mouth of the Little Colorado, described by Walcott. This is the largest areal exposure of these rocks in the Grand Canyon, and includes both the Unkar and Chuar groups. It extends northwestward across the canyon of Vishnu Creek and into the canyon next west of it.

The second locality lies 5 miles west of the first, at the head of the inner gorge of Clear Creek, on the north side of Colorado River, within the depths of Ottoman Amphitheater. The exposure is limited to less than a square mile. It comprises a small portion of the basal part of the Unkar group and is structurally a unit with the first locality.

The third locality lies along the north side of Colorado River at the mouth of Bright Angel Creek (Pl. X, *B*), opposite the railroad terminus and hotels of the Grand Canyon Railway, Sante Fe System. About 1,000 feet of the basal portion of the Unkar group is there represented and the areal extent of the exposure is about 3 square miles. This locality has already been described chiefly by Ransome.[1] It lies about 10 miles west of the type locality and extends southeastward across Colorado River into the canyon of Cremation Creek, along the line of a flexure in the Paleozoic strata.

The fourth locality comprises a small exposure of basal Unkar strata in the depths of Hindu Amphitheater, on the north side of the Colorado about 3 miles up Crystal Creek from its mouth, some 20 miles west of the type locality. The exposure covers about 1 square mile and has not yet been described.

The fifth locality, to be described in the present report, lies near the mouth of Shinumo Creek, about 30 miles west of the type locality. The exposures cover between 10 and 12 square miles and include rocks representing nearly the entire Unkar group.

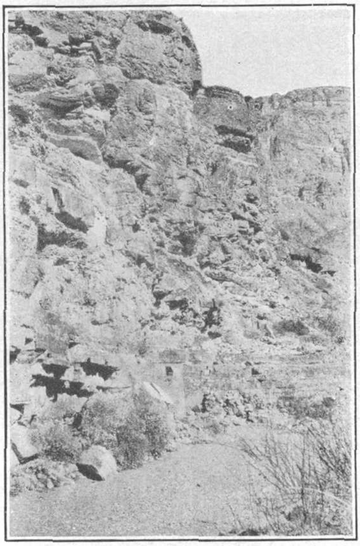
The sixth locality is in Lower Granite Gorge just above the mouth of Tapeats Creek, in the Kanab division of the canyon. It lies 42 miles northwest of the type locality and 12 miles directly northwest of the Shinumo area. It extends about 3 miles along the river and includes about half of the total thickness of the Unkar group. This locality has not yet been described.

Dutton[2] figures "rocks of Lower Silurian and Archean unconformable" in the bed of the river beneath the "basal Carboniferous," in the western part of the Kanab division, in a section across the Grand Canyon at the foot of Toroweap Valley. As Dutton means by

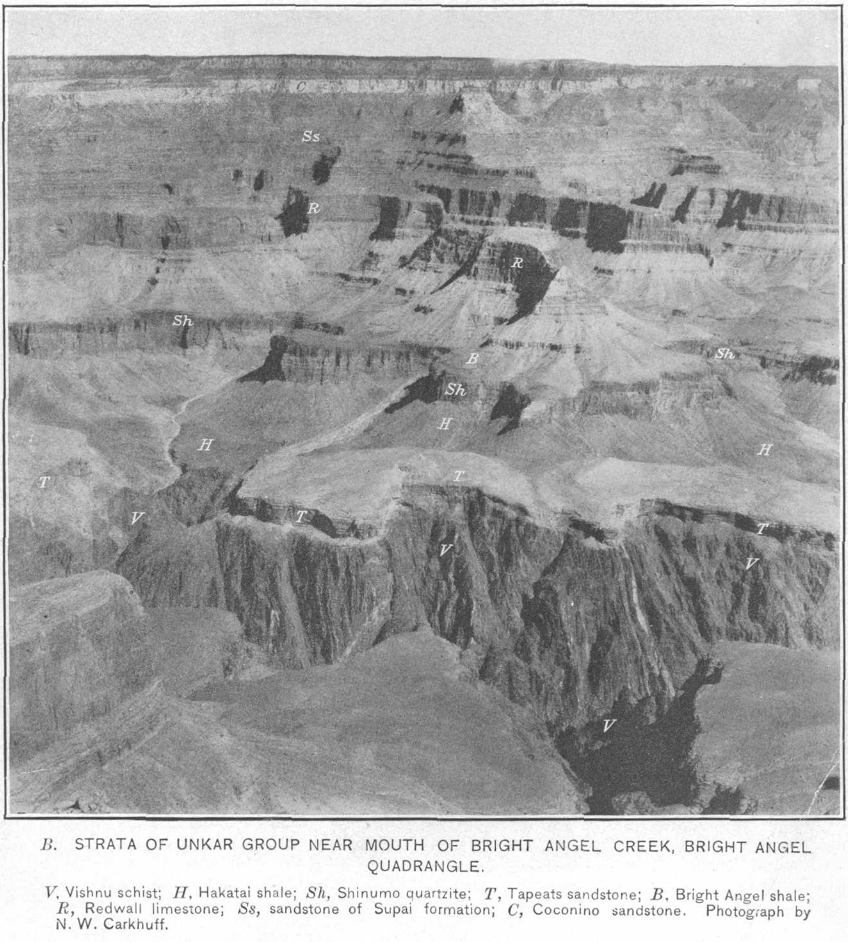
---

[1] Ransome, F. L., Pre-Cambrian sediments and faults in the Grand Canyon of the Colorado: Science, vol. 27, No. 695, 1908.

[2] Dutton, C. E., Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, p. 88, 1882.

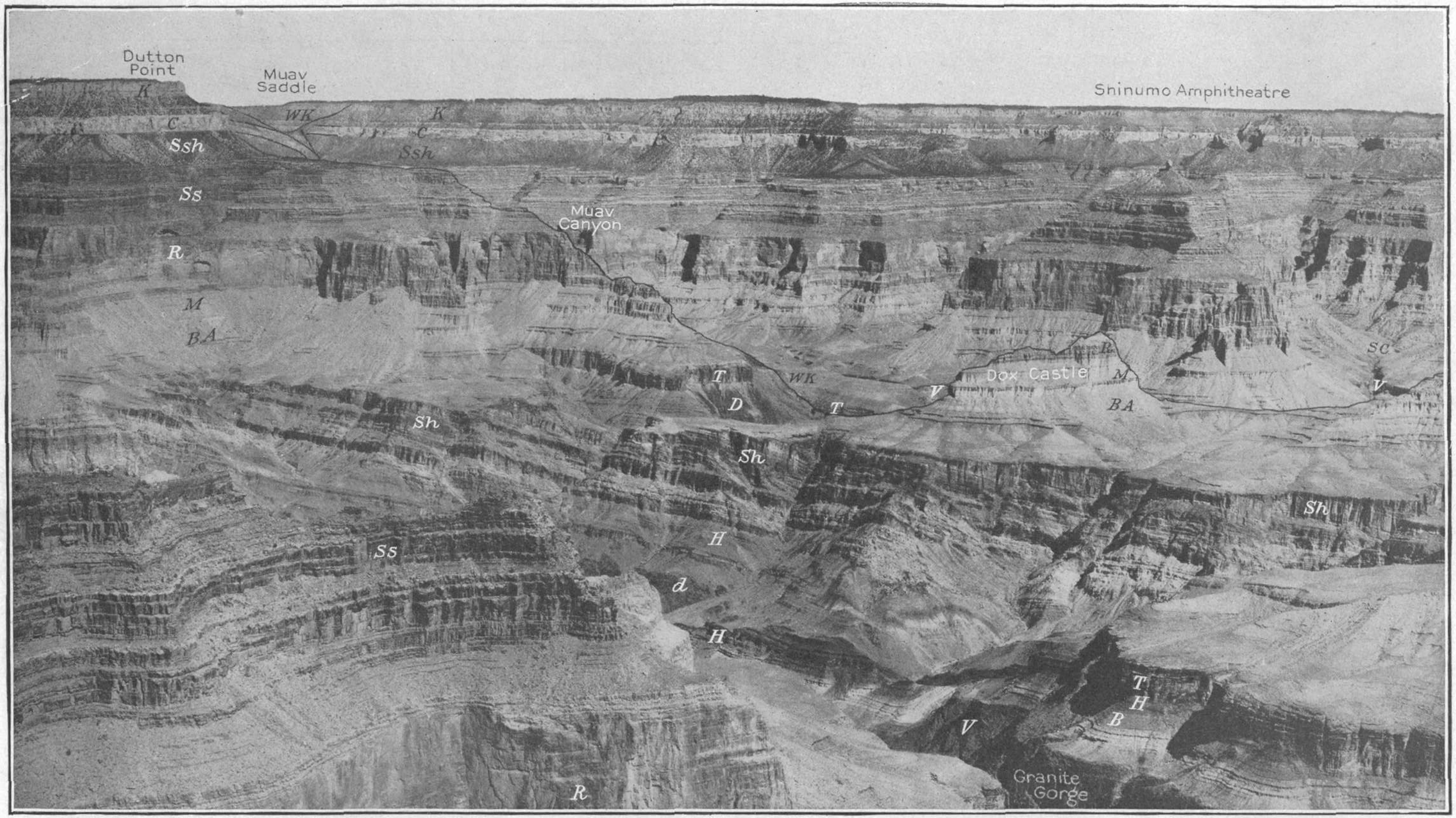


A. BASS LIMESTONE IN HOTAUTA CANYON.



B. STRATA OF UNKAR GROUP NEAR MOUTH OF BRIGHT ANGEL CREEK, BRIGHT ANGEL QUADRANGLE.

V, Vishnu schist; *H*, Hakatai shale; *Sh*, Shinumo quartzite; *T*, Tapeats sandstone; *B*, Bright Angel shale; *R*, Redwall limestone; *Ss*, sandstone of Supai formation; *C*, Coconino sandstone. Photograph by N. W. Carkhuff.



VIEW NORTHWARD ACROSS THE GRAND CANYON FROM THE END OF GRAND SCENIC DIVIDE.

SC, Shinumo Creek; *V*, Vishnu schist; *B*, Bass limestone; *H*, Hakatai shale; *Sh*, Shinumo quartzite; *D*, Dox sandstone; *d*, Diabase intrusive; *T*, Tapeats sandstone; *BA*, Bright Angel shale; *M*, Muav limestone; *R*, Redwall limestone; *Ss*, sandstone of Supai formation; *Ssh*, shale of Supai formation; *C*, Coconino sandstone; *K*, Kaibab limestone; *WK*, West Kaibab fault. Photograph by N. W. Carkhuff.

"basal Carboniferous" what is now known as the basal sandstone of the Tonto group, of Cambrian age, it is possible that the "Lower Silurian" rocks in that locality are the Grand Canyon series. In the Shivwits division, according to Powell,[1] these rocks occur at least in one place.

STRUCTURE AND DISTRIBUTION IN THE SHINUMO QUADRANGLE.

Practically all the exposures in the quadrangle belong to the mass about the mouth of Shinumo Creek. (See Pls. IV, *B*, p. 18, and XI.) The rocks of the Grand Canyon series here lie in a wedge-shaped body, the apex of which is the intersection of the unconformities by erosion that separate them from the Archean below and from the Paleozoic above. The apex of the wedge lies near Colorado River, parallel to its northwestward course. The mass as a whole constitutes a great tilted block, which in turn consists of a great number of smaller faulted and tilted blocks pitching at successively greater angles to the northeast, away from the apex of the wedge. In the Muav-Flint Canyon, about 3 miles northeast of the apex of the wedge, the whole mass is dropped by a profound fault, which brings up the underlying Archean rocks from a great depth on the northeast side of the fault plane and produces a structure that strikingly resembles that of areas of similarly faulted Triassic blocks in the Connecticut Valley. The strike of the strata of the wedge is N. 40° W.; the dip varies from place to place. The strata of the fault blocks near the apex of the wedge generally dip 10°–15° NE.; those near the center of the wedge dip on an average about 25° NW.; but those near the great limiting fault on the northwest are completely overturned by the "drag" along the fault plane. This pre-Cambrian structure is truncated by the unconformity at the base of the Tonto group. (For structure, see Pl. I, sections, in pocket.)

The great pre-Cambrian fault that limits the wedge on the northeast is the West Kaibab fault, which displays in a most spectacular manner a phenomenon analogous to that on the line of the East Kaibab monocline, described by Walcott.[2] On the line of this ancient fault in the Shinumo quadrangle two later displacements took place after the deposition of the Paleozoic strata of the canyon wall and probably later strata. The first of these is a monoclinal flexure which reverses the throw of the pre-Cambrian fault; the second is a still more recent fault superposed upon the line of the monoclinal flexure. (Pl. I, sections, in pocket.)

On the north side of the Colorado the strata of the Grand Canyon series are exposed continuously along their strike for about 7 miles in the wall of Granite Gorge (Pl. XI), the exposures running back several

[1] Powell, J. W., op. cit., p. 62.

[2] Walcott, C. D., Study of a line of displacement in the Grand Canyon of the Colorado in northern Arizona: Geol. Soc. America Bull., vol. 1, p. 49, 1890.

miles from the river in the larger side canyons, which are cut beneath the base of the Paleozoic. These side canyons, named from east to west, are Hotauta, Shinumo, Burro, and Hakatai canyons. They are trenched directly across the strike of the strata and reveal them in cross section. The higher formations of the wedge are exposed for about 3 miles along the strike in that part of the interior gorge of the Muav-Flint canyon which lies southwest of the West Kaibab fault.

On the south side of the Colorado the exposures are confined to the basal formations and are small, for the wedge thins out in that direction. The rocks are exposed along the strike in the wall of Granite Gorge between the small canyon east of Serpentine Canyon and the mouth of Copper Canyon, a distance of 3 miles. The only long exposure across the strike is in Bass Canyon (Pl. XVI, *B*, p. 78).

The gorge of the Colorado has everywhere been trenched deep enough to expose the Archean rocks along the river beneath the Grand Canyon series (Pl. III, *A* and *B*, p. 16), for the stream flows close to the apex of the wedge.

The hard quartzite strata of the wedge resisted the erosion that preceded the deposition of the Cambrian sandstone and stood as a long, narrow residual hill or "monadnock" in the pre-Tonto plain (Pl. XVIII, p. 86). When the Tonto sea came in over the plain the monadnock formed a long rocky inland extending for an unknown distance from northwest to southeast parallel to the strike of the Algonkian strata. In many places the rocks of this island-monadnock project well above the basal sandstone of the Tonto group and are exposed in narrow outcrops above the Tonto platform, forming isolated outliers of the main mass of Algonkian strata. The largest of these outliers is in Monadnock Amphitheater, 2 miles southeast of Hotauta Canyon.

The strata of the Grand Canyon series that are exposed in Lower Granite Gorge are structurally a part of the Shinumo wedge. They represent strata of the wedge that are prolonged northwestward along the strike and reappear beyond Powell Plateau. These exposures lie just beyond the northern boundary of the Shinumo quadrangle, beginning about 2 miles down Colorado River from the north of Specter Chasm. They include about 4,000 feet of the Unkar group, which strike northwest-southeast and dip about 15° NE.

UNKAR GROUP.

CHARACTER AND SUBDIVISIONS.

The greater part of the Unkar group of the Grand Canyon series, of Algonkian age, is represented in the Shinumo quadrangle. The upper or Chuar group is not represented. Although these pre-Cambrian sediments show no more evidence of alteration or metamorphism, apart from local igneous contact phenomena, than the overlying Paleozoic beds, they are destitute of fossils or of other evidence of life. In the absence of fossils the rocks of the group may be divided into formations by their lithology, according to which the portion of the Unkar group in the Shinumo quadrangle is divisible into five formations, which appear in conformable stratigraphic succession. The importance of this division should not be greatly emphasized, its chief value lying in the fact that it furnishes a means of comparing the lithologic succession of the Unkar group in this area with that in the type locality described by Walcott, 30 miles to the east, as well as a means of distinguishing in a broad way the main changes in the physical conditions under which these sediments were laid down.

At the base, resting upon the profoundly eroded and base-leveled surface of the metamorphic rocks of the Vishnu schist, is a thin conglomerate. Upon the conglomerate lies a series of limestones and calcareous shales. These grade upward into argillaceous and arenaceous shales which are locally intruded by a thick sill of diabase and are overlain in turn by great thicknesses of sandstone and quartzite. The uppermost exposed formation of the group in the quadrangle is a thick series of micaceous shaly sandstones.

The following section shows the geologic plan of the group and the formations into which it has been subdivided:

Section showing relations and subdivisions of Unkar group.

Tonto group.
Unconformity.
Unkar group:[1]

	Feet.
Dox sandstone (micaceous shaly sandstone)	2, 297
Shinumo quartzite (sandstone and quartzite)	1, 564
Hakatai shale (argillaceous and arenaceous shale)	580
Bass limestone (calcareous shale and limestone)	335
Hotauta conglomerate (basal conglomerate)	6
	4, 782

Unconformity.
Vishnu schist.

These strata lie in a wedge-shaped mass that is inset in the Vishnu schist (see Pl. I, sections)—a wedge composed of a great number of small tilted fault blocks, the relations showing that nowhere in the Shinumo area can the thickness of these rocks be measured in one unbroken section. As the lithologic characters of the strata are constant and the beds easily recognized, however, and as the throw of the faults that bound the tilted blocks seldom exceeds 100 feet, a section showing the unbroken sequence can be easily obtained.

Detailed sections were made from the base of the Unkar upward through each fault block until its limit was reached, and the highest

[1] The diabase that was included by Walcott in his Unkar "terrane" but that is now known to be intrusive is, in accordance with modern practice, excluded from the Unkar group.

bed measured was then located in the next block to the northeast and the measurement resumed at that point. All sections except those in the highest formation of the group were measured with a tape along the nearly vertical walls of the canyons of the Shinumo and other washes that cut across the strike of the strata. The strong drag of the great fault on the northeast has flexed and contorted the shaly strata of the Dox sandstone in such a manner that accurate measurement with the tape alone was impossible. Their thickness was computed trigonometrically, by using the combined data afforded by the tape, the topographic map, and the observed strikes and dips.

The section here given was made in two places. The greater part of it was measured in a traverse up Shinumo Canyon. This part of the section includes all the strata above the diabase sill, which is intruded midway in the Hakatai shale in that locality. A complete section of the group could have been made in a traverse of the course of Shinumo Creek from the basal unconformity at the mouth of the creek to the great fault 3 miles above, although four faults cross the creek between its mouth and the place where the diabase sill dips beneath the bed of the stream, but a place was found in Hotauta Canyon where all the strata between the basal unconformity and the diabase sill lie in a continuous unfaulted section, in a fault block that is tilted about 10° NE., so the section of the basal members of the group was measured in this locality.

HOTAUTA CONGLOMERATE.

Base of the formation.—The surface of erosion represented by the unconformity upon which the Hotauta conglomerate rests is an almost perfect plane, for nowhere in the 7 linear miles exposed in the Shinumo quadrangle is there a difference in relief exceeding 20 feet. The depth of weathering below this surface appears to be slight, in spite of the enormous amount of rock that has been removed, and the weathering appears to be the result of physical disintegration rather than of chemical decomposition.

Name and character.—The name of the formation is that of the canyon in which the lower part of the geologic section was measured.

The Hotauta conglomerate is an arkose conglomerate which varies in thickness from 1 to 6 feet in the Shinumo quadrangle. It is composed of angular or subangular fragments of the rocks of the underlying Vishnu schist, cemented by a matrix of red arkose mud, which generally contains small fragments of pink feldspar and sporadically small rounded grains of quartz.

This conglomerate varies greatly in hardness, from place to place, ranging from a hard, dense, siliceous rock, which fractures across matrix and inclosed rock fragments alike, to an easily disintegrated rock in which the matrix crumbles away from the inclosed fragments. The degree of hardness, however, does not depend on original cementation, but on local metamorphic effects produced by the diabase sill that is intruded in the overlying rocks, the degree of induration depending on the depth of the conglomerate below the contact of the sill.

The matrix everywhere is generally of the same composition, but the character of the inclosed fragments depends on the character of the underlying Vishnu schist. The rock that underlies the conglomerate in Hotauta Canyon is the quartz diorite of the batholith already described. The diorite for 3 feet below the conglomerate is divided into roughly angular blocks by joints, which are filled with the red arkose material of the matrix. Above the diorite lies a layer of the conglomerate a foot thick, composed of weathered fragments of diorite cemented with the red arkose. Above this lies a layer, 6 inches thick, of small rounded quartz pebbles and fragments of chert like that in the overlying limestones. The whole is cemented with the red mud. Although the contact of the diorite with the mica schists in the underlying Vishnu formation is not 200 yards distant, no fragments of the mica schist were observed in the conglomerate.

In Hakatai Canyon, 4 miles west of Hotauta Canyon, the underlying rocks are mica schists and veins of quartz and pegmatite. Here the Vishnu schist is scarcely weathered at all below the unconformity. The overlying conglomerate is 6 feet thick and consists of angular fragments of the underlying mica schists, fragments of pegmatitic feldspar and vein quartz, and the arkose cement described above. The rock here is very hard, and when fractured breaks across the grains like a dense quartzite. This hardness is an effect of the intrusion of the diabase sill, the lower contact of which in Hakatai Canyon, lies only 150 feet above the basal conglomerate, whereas in Hotauta Canyon it lies 550 feet above.

Summary.—The Hotauta conglomerate is characterized by two important features—an arkose nature and a lack of sorting and transportation of its component fragments.

BASS LIMESTONE.

Name and subdivisions.—The name of the Bass limestone is derived from Bass Canyon, where the strata are typically exposed. (See Pl. X, *A*.) The following section was measured on the west side of Hotauta Canyon. The typographic arrangement shows the natural order of the beds, A representing the top bed of the section and 1 the top member of each bed.

Section of Bass limestone in Hotauta Canyon.

	Ft.	in.
A. Blue slate and white limestone	108	2
B. White limestone	105	2
C. Argillaceous and calcareous red shale and limestone	85	5
D. Basal white limestone	6	0
	304	9

Order, character, and thickness of subdivisions of the Bass limestone.

	Ft.	in.
A. Blue slate and white limestone:		
1. Layers of dense white crystalline limestone separated by bands of pale-green talcose material	2	0
2. Dense red and black banded jasper, weathering green between the layers and forming a cliff. The layers contain shrinkage cracks and ripple marks	11	4
3. Layers of dense white crystalline limestone separated by thin bands of pale-green talcose material	10	0
4. Pinkish-green fissile siliceous slate of a jaspery appearance, forming a cliff	5	0
5. Dense, lumpy white crystalline limestone	2	0
6. Fissile blue slate	7	0
7. Thin-bedded platy white limestone	4	6
8. Calcareous blue slate, forming a cliff	3	0
9. Very thin lamellar fissile blue slate	3	0
10. Thin-bedded platy white limestone	2	6
11. Dense blue crystalline limestone, forming small cliff	2	3
12. Gnarly layers of fine lamellar blue calcareous slate with a very coarse concretionary structure and irregular nodules of chert in the middle part of the bed	33	0
13. Thin-lamellar spotted blue slate	6	6
14. Same as 16, forming a small cliff		8
15. Same as 17	2	2
16. Dense purple crystalline limestone, forming a small cliff		7
17. Thin-bedded purple crystalline limestone	1	2
18. Fissile blue slates with fine partings	7	0
19. Hard blue slate, forming small cliff	1	0
20. Soft purple shale	3	6
	108	2
B. White limestone:		
1. Very hard, dense layer of flint, forming small cliff		5
2. Gnarled and nodular white cherty limestone	7	0
3. Thin-bedded crystalline white limestone	5	6
4. Thick-bedded crystalline white limestone of the same character as 8, forming a strong cliff	3	6
5. Red shale below and purple shale above, separated by a thin layer of chert	5	0
6. Undulatory-banded cherty limestone, becoming crystalline above	10	0
7. Same in thinner beds	6	6
8. Thick-bedded layers of pure, homogeneous white marble, forming the strongest cliff in the second formation of the Unkar group	6	8

	Ft.	In.
B. White limestone—Continued.		
9. Layers of undulatory-banded nodular chert in a matrix of earthy white limestone	3	10
10. Purple shale	3	3
11. Dense crystalline blue limestone		4
12. Homogeneous thin-bedded white limestone, crumbling to a white powder and weathering into plates like a shale	15	0
13. Dense blue crystalline limestone, forming a small cliff	3	0
14. Soft purple shale	1	10
15. Thin-bedded crystalline white limestone	3	10
16. Soft purple shale	1	0
17. Thin-bedded white limestone crumbling to white powder or weathering into thin plates like a shale	2	0
18. Layer of gnarled and twisted chert nodules in a matrix of white talc whose surface is covered with dendritic markings	2	0
19. Soft purple shale		5
20. Layers of undulatory-banded bluish chert	1	10
21. Purple shale	(?)	
22. Lumpy and gnarly white limestone carrying chert in large, irregular nodules. Crumbles to a white powder	2	6
23. White limestone carrying a large amount of chert in undulatory and gnarled bands	2	4
24. Homogeneous thin-bedded white crystalline limestone containing occasional thin bands of chert and nodules resembling Cryptozoon	8	6
25. Dense homogeneous white crystalline limestone, forming a cliff. Upper part is thin bedded	3	8
26. Nodular white cherty limestone. The chert occurs in irregular-shaped nodules. The upper part of the stratum has a paper-thin bedding, giving it the aspect of a calcareous shale. The limestone weathers to a white powder. Bears dendritic markings	2	0
27. Thin-bedded white cherty limestone, carrying the chert in parallel bands and containing three paper-thin layers of purple shale. Weathers to a white powder. Bears dendritic markings	2	0
	105	2
C. Argillaceous and calcareous red shale and limestone:		
1. Blue calcareous shale with an onion-like concretionary structure on a large scale	5	0
2. Dense purple calcareous shale, carrying bands of pink calcite and forming a cliff. Contains occasional thin bands of chert	9	6
3. Alternating layers of buff and red shale	13	6
4. Compact red shale, forming a cliff	8	0
5. Cherty white limestone		4
6. Red shale	4	4
7. Pink limestone	1	0
8. Blue limestone		2
9. Red shale	1	0
10. Blue limestone		3

C. Argillaceous and calcareous red shale and limestone—Con.	Ft.	in.
11. Red shale	11	0
12. Red crystalline limestone	1	0
13. Red shale	1	0
14. Red crystalline limestone	1	0
15. Calcareous red shale with three thin bands of purple limestone	9	10
16. Purple limestone		6
17. Red shale	3	10
18. Blue limestone		4
19. Red shale	1	5
20. Blue limestone, white for 1 inch at the base and showing dendritic markings		5
21. Alternating layers of buff and chocolate-red shale with a splintery habit of weathering and a roughly concretionary structure. Like all the succeeding shales and sandstones of the Unkar group, they are mottled with light spots, generally circular or elliptical in form and of all sizes	5	6
22. Purple crystalline limestone	1	0
23. Purple shale with occasional bands of purple calcite	4	0
24. Purple cherty limestone	1	0
25. Soft purple shale		6
	85	5

D. Basal white limestone:		
1. White cherty limestone carrying the chert in thin parallel bands, which are etched out by the weather on the cross sections. The surface of each chert layer shows polygonal cracks suggestive of sun cracks in shale. This structure belongs to each separate chert layer and is not a columnar structure. The weathered surfaces of these chert layers are dotted with small cubic depressions which were apparently formed by the leaching out of some mineral of cubic form	4	6
2. White nodular cherty limestone. The chert occurs in nodules having a roughly concentric structure somewhat suggestive of the structure of Cryptozoon	1	6
	6	0

Specimens of these limestones when examined in the laboratory proved to be more or less magnesian, and all those of division B were found to be dolomites.

Thin sections were cut from specimens taken from 20 separate beds in division B. Eighteen of these slides were cut from the limestone strata and two from the red shales. The sections of the limestones were cut both from the chert bands and nodules and from the limestone itself, for the purpose of ascertaining the exact mineralogical character of these rocks and in the hope that they might reveal traces of a structure that could be referred to something organic. The microscope revealed no minerals other than calcite and quartz in any of the slides. The silica of the chert bands and nodules appeared in the form of interlocking grains of quartz. None of these grains were rounded and there was no evidence that the quartz grains represented an inwashed sand. No trace of organic structure was revealed either in the chert or in the limestone. The purer limestones were found to consist of calcite (or dolomite) alone, the crystalline forms having the typical structure of marble. The impure varieties were seen to consist of mixtures of quartz and calcite in all proportions, the greater part of the limestone being of this impure character. The shales were found to consist of a fine, impalpable ferruginous or calcareous mud, containing here and there a minute grain of quartz.

Summary.—The section of the Bass limestone shows several interesting features. Ripple marks and sun cracks appear for the first time in the shales in stratum 2 of division A, just below the limestone stratum at the summit of the formation. An increase in the intensity of local metamorphism in the section from the base upward was also noted, the rocks becoming harder and changing in color with increasing proximity to the lower contact of the diabase sill, which is intruded in the overlying Hakatai shale. Nearly all the shales of division C are red, but from the summit of this division upward they are purple and blue. The shales below division A are soft and crumbly; those in this division, however, have become dark-blue slates, and those in the upper part of the section have become extremely hard, siliceous jaspers.

The section is broadly characterized by oft-repeated alternations of limestone and shale, and according to the dominance of one or the other type of rock the four divisions A, B, C, and D, are separated: D is entirely limestone; C is alternating limestone and shale; B is predominantly shale; A is largely slate and jasper. Thus there are four major cycles of oscillation of sediments upon which the minor cycles are superimposed.

A comparison of the above section in Hotauta Canyon with a section measured in Hakatai Canyon, 4 miles to the west, is of interest. In Hakatai Canyon the "basal white limestone" (D) has a thickness of 30 feet, contrasted with a thickness of 6 feet in Hotauta Canyon. The thickness of lower stratum of "white, nodular, cherty limestone" in Hakatai Canyon is 7 feet 9 inches, whereas in Hotauta Canyon it is only 1 foot 6 inches. The upper stratum of this section, a parallel-banded, cherty, white limestone, which is 4 feet 6 inches thick in Hotauta Canyon, is 22 feet 3 inches thick in Hakatai Canyon, and contains in the middle an intercalated layer of purple shale and near the top a thin layer of rather fine arkose conglomerate. In Hakatai Canyon the "argillaceous and calcareous red shales and limestones" of division C are 88 feet thick, but in Hotauta Canyon they are 85 feet 5 inches thick and have not the red color that characterizes them in Hakatai Canyon, being purple and blue and much indurated. This change of color and difference in hardness are due to their closer proximity to the diabase sill in Hakatai Canyon.

The correspondence in the lithologic character and vertical succession of the beds of these two sections, 4 miles apart, is so close that the individual strata of the sections can be matched bed for bed. The only marked contrast in thickness occurs in the basal white limestone (D).

HAKATAI SHALE.

The name of the Hakatai shale is taken from Hakatai Canyon, where the formation is typically exposed.

Section of Hakatai shale.

	Ft.	In.
A. Alternating vermilion arenaceous shale and sandstone	78	1
B. Alternating vermilion argillaceous shale and sandstone	109	4
C. Red argillaceous shale	81	0
D. Blue slate	100	0
E. Blue slate and quartzite	20	0
F. (Intrusive diabase.)		
G. Red and blue jasper	31	0
H. Sandy quartzitic jasper	52	0
I. Cliff-forming jasper	17	6
J. Blue slate with calcareous band	18	0
K. Cliff-forming jasper	73	0
	579	11

Order, character, and thickness of subdivisions of the Hakatai shale.

	Ft.	In.
A. Alternating vermilion arenaceous shale and sandstone	78	1
B. Alternating vermilion argillaceous shale and sandstone	109	4
C. Red argillaceous shale, sun cracked throughout. The rock is very soft and forms a slope together with the underlying blue slate	81	0
D. Blue slate, forming a slope	100	0
E. Blue slate and quartzite, forming a cliff	20	0
F. At this horizon is intruded a sill of diabase whose thickness varies from 650 feet on Shinumo Canyon to 950 feet or more in Hakatai Canyon. The section from A to F was measured in a traverse up the Shinumo, starting with the upper contact of the diabase sill.		
G. Red and blue jasper:		
1. Red and black banded jasper	9	0
2. Banded blue jasper with curious spots, sun cracked throughout	22	0
	31	0
H. Sandy quartzitic jasper:		
1. Fine-grained pink sandy jasper, sun cracked	11	0
2. Fine-grained pink quartzite	4	0
3. Pink quartzitic jasper	5	0

	Ft.	in.
H. Sandy quartzitic jasper—Continued.		
4. Fine-grained pink quartzite, ripple marked	1	0
5. Slaty-blue spotted jasper with sun cracks	6	0
6. Fine-grained pink quartzite	4	0
7. Slaty-blue spotted jasper	12	0
8. Fine-grained pink quartzite, ripple marked	5	0
9. Slaty-blue spotted jasper	4	0
	52	0
I. Cliff-forming jasper:		
1. Dense, hard layer of blue-black jasper mottled with red spots, having a soft, slaty layer at the base and forming with the bed below a strong overhanging cliff	3	6
2. Same as 1, without soft layer	14	0
	17	6
J. Calcareous blue slate:		
1. Slaty-blue jasper with small red spots	4	6
2. Pink crystalline limestone	1	6
3. Slaty black jasper, sun cracked throughout	12	0
	18	0
K. Cliff-forming jasper:		
1. Dense, hard layer of blue-black jasper, showing banded structure, with a soft layer at the base	12	0
2. Same as 1	14	0
3. Same general character as 2. The lower 2 feet are slaty and weather out, giving the cliff an overhang	19	0
4. Dense, hard layer of blue-black jasper, mottled with red spots and showing no banding in the mass, forming with the three layers above a strong perpendicular cliff. This is the most resistant rock in the Unkar group. Where the under surface shows beneath the overhang of the cliff, it is sun cracked on a large scale and in several generations	28	0
	73	0

The sandstone in series A is white, compact, and fine grained. It is cross-bedded and ripple marked throughout. The under surface of each sandstone layer is sun cracked where it rests upon the arenaceous shale. The shale is vermilion in color, soft, and very sandy. Sun cracks occur throughout.

The succession is as follows:

	Ft.	in.
1. Sandstone	1	0
2. Arenaceous shale	24	0
3. Sandstone	2	0
4. Arenaceous shale	11	8
5. Sandstone	9	0
6. Arenaceous shale	21	1
7. Sandstone	9	4
	78	1

The alternations in series B are remarkably regular. The sandstone is white, compact, and fine grained and is cross-bedded and ripple marked throughout. The shales of the alternating beds are very soft and weather out, leaving etched-out bands between the sandstones, which are very conspicuous in the cliff faces. On the under surface of each sandstone layer are well-preserved sun cracks. The shales are fine grained, fissile, and argillaceous.

The succession in this alternating series is as follows:

Order and thickness of beds of sandstone and shale in series B of Hakatai formation, with thickness of groups of beds representing each sandstone-shale cycle.

	Ft.	In.	Ft.	In.
1. Shale	4	0	7	0
2. Sandstone	3	0		
3. Shale	6	6	8	6
4. Sandstone	2	0		
5. Shale	2	6	6	4
6. Sandstone	3	10		
7. Shale	1	0	3	0
8. Sandstone	2	0		
9. Shale	0	6	4	0
10. Sandstone	3	6		
11. Shale	4	0	11	6
12. Sandstone	7	6		
13. Shale	3	6	9	6
14. Sandstone	6	0		
15. Shale	3	6	9	6
16. Sandstone	6	0		
17. Shale	2	6	8	6
18. Sandstone	6	0		
19. Shale	3	0	8	0
20. Sandstone	5	0		
21. Shale	10	6	17	6
22. Sandstone	7	0		
23. Shale	2	0	3	0
24. Sandstone	1	0		
25. Shale	3	0	5	0
26. Sandstone	2	0		
27. Shale	3	10	8	0
28. Sandstone	4	2		
Total	109	4	Average 7	10

Thin sections were cut from several specimens of the jaspers, but they were unsatisfactory, because of the exceedingly fine grain of the rock. The highest power of the microscope revealed nothing more than an impalpable silicified mud. A slide of the "quartzitic jasper" showed that the rock was a somewhat arkose sandstone indurated to a siliceous quartzite, composed chiefly of small rounded quartz grains about which secondary silica had been deposited, lying in a fine arkose matrix made up of small fragments of pink feldspar. A thin section was also made from a specimen of sandstone taken from one of the layers in the "alternating argillaceous shale and sandstone" of division B. The rock proved to consist of small, well-rounded grains of quartz, cemented by silica in the form of secondary quartz. It is a pure, fine-grained sandstone.

The metamorphic effects produced by the diabase sill intruded at the horizon F are seen in the section marked "I." This metamorphic action produces induration by silicification, forming jaspers; induration by baking, forming slates; decoloration, red changing to blue and black.

In the summary of the features of the Bass limestone it was noted that the shales became successively slates and jaspers above, while their color changed from red to blue. In division I of the Hakatai formation the shales are represented entirely by jaspers and quartzites. (See Pl. XIV, *B*, p. 64.) Just below the contact, at the top of division G, the induration is very great, and the jaspers are tough and vitreous; their prevailing color is blue or black. Above the contact the overlying rocks are hard blue slates for 20 feet, succeeded by 100 feet of less indurated slate, grading up into the original red shale.

The metamorphic effects above and below the contact differ in intensity as well as in kind; above the contact the induration and decoloration characterize only about 100 feet of strata; below the contact they extend through 300 feet. Above the contact the strata have been baked and decolored only, the red shale changing to a blue slate; below the contact considerable silica has been added, transforming the red shales to blue and black jaspers; added to this are the effects of baking and decoloration.

The Hakatai formation is characterized by argillaceous shales in its lower portion, which grade upward into arenaceous shales and sandstones through the interesting series of alternations described in division B. Nearly every stratum in the formation bears marks of shallow-water origin—sun cracks, ripple marks, or cross bedding.

SHINUMO QUARTZITE.

The following section of the Shinumo quartzite was made in the canyon of Shinumo Creek (see Pls. VIII, *A*, p. 28, and XII, *B*), whence the name of the formation is derived:

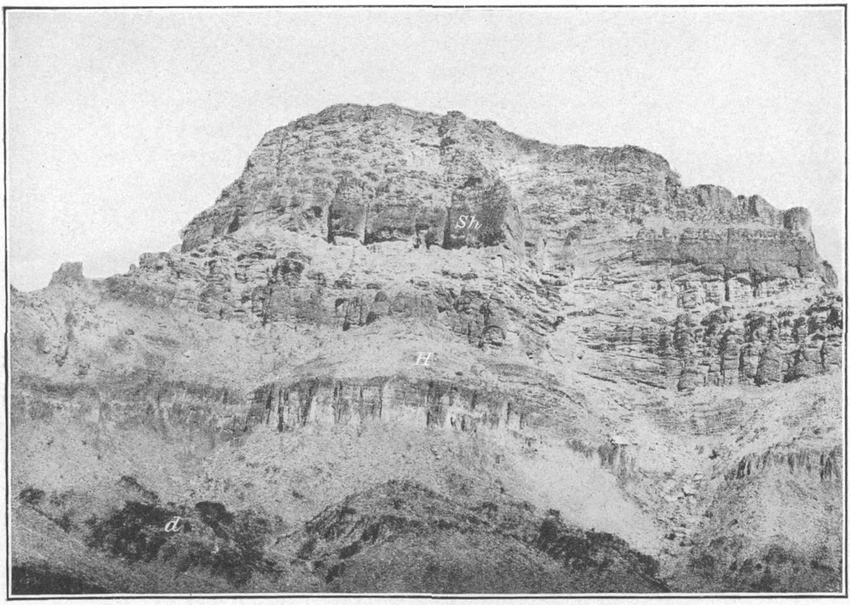
Section of Shinumo quartzite in Shinumo Canyon.

	Feet.
A. Irregularly bedded sandstone:	
1. Cross-bedded green sandstone	21
2. Banded purple sandstones	20
3. "Curiously twisted and gnarled layers" of fine-grained white sandstone containing large red spots of circular and elliptical form. The upper part of the bed is more massive. The twisted and gnarled structure seems to have been a phenomenon of the original	

	Feet.
deposition and suggests that the original sand was moist and plastic and once flowed by rolling over and over in the form of a quicksand	105
(A bed of this character is described by Walcott in his section in Unkar Valley. (Walcott, Fourteenth Ann. Rept. U. S. Geol. Survey, p. 511.) It occurs at the same horizon as the bed described above and contains the same red spots.)	
B. Banded white quartzite	20
C. Compact cliff-forming white quartzite of the same character as G below, though not so massive in structure	250
D. Fine-grained purple sandstone with a white band in the middle. The white band is constant and is a conspicuous feature by which this sandstone can be distinguished at a distance of several miles. The rock is cross bedded and in some places displays a "twisted and gnarled" structure	150
E. Banded white quartzite, stained magenta on the exposures and forming a cliff	120
F. Purple-brown fine-grained sandstone containing lenses of conglomerate and thin beds of shale	353
G. Compact white quartzite of fine and uniform grain, displaying a faint cross-bedded structure. This quartzite is the most resistant rock in the formation. It is exposed everywhere in one massive perpendicular cliff face, which does not display the slightest break except where it is cut by faults. Wherever its base rests upon a shaly lens its under surface displays well-preserved mud cracks. The face of the cliff is stained magenta by the ferruginous cement that washes down from the shale lenses in the overlying sandstones	119
H. Purple-brown sandstone of fine grain containing in some places an occasional lens of fine conglomerate and a thin local bed of red or purple shale. Cross bedded throughout	406
	1, 564

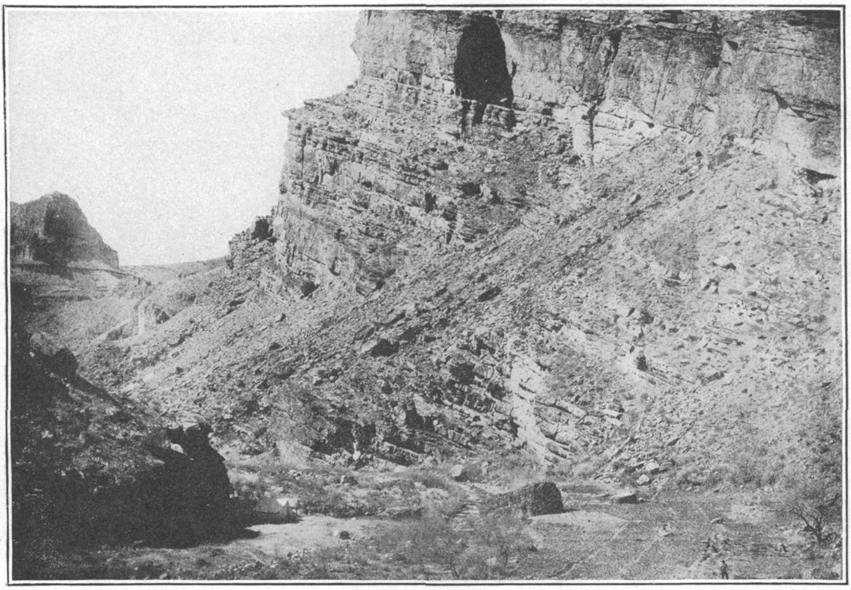
An examination of slides cut from several specimens of the sandstones and quartzites showed that they consist of small rounded quartz grains, few of which exceed 0.7 millimeter in diameter. This extreme fineness and roundness of the grains, as well as the cleanness of the sorting, is remarkable. The cement is generally siliceous, in places slightly ferruginous. A slide made from a specimen taken from one of the small conglomerate lenses in division H showed that the rock consisted of small rounded quartz pebbles lying in a fine arkose matrix, and disclosed also occasional large angular fragments of orthoclase and microcline.

The Shinumo quartzite (Pl. XII, *A*) is the most resistant rock in the Grand Canyon series, its beds forming the Algonkian monadnocks, which appear in all parts of the Grand Canyon. In the canyons that are cut across the strike of the strata, such as the deep canyons of the



A. SHINUMO QUARTZITE NORTH OF CABLE CROSSING.

Sh, Shinumo quartzite; *H*, Hakatai shale; *d*, Diabase intrusive.



B. QUARTZITE IN CANYON OF SHINUMO CREEK.

Shinumo Garden, irrigated from Shinumo Creek, is shown in lower right corner of view.

Shinumo, these beds stand in great plunging cliffs (Pls. VIII, *A*, p. 28, and XII, *B*).

The Shinumo quartzite includes great thicknesses of pure, fine-grained, uniform sandstone. All its beds are very resistant and form cliffs, and many of them show ripple marks and cross bedding.

DOX SANDSTONE.

The name Dox sandstone is derived from Dox Castle, underneath which a typical section is found beneath the formations of the Tonto group, which make the castle. The following section was measured on the west side of the canyon of Shinumo Creek (Pl. XIII, *B*):

Section of Dox sandstone in Shinumo Canyon.

	Feet.
A. Red and vermilion micaceous shaly sandstones, cross bedded and ripple marked, with arenaceous and argillaceous shaly partings, which display well-preserved mud cracks. The shaly partings are either green or red	1, 197
B. Gray-green, pinkish-green, and brown micaceous shaly sandstones, cross bedded and ripple marked, varying in character only through gradations in color. Many arenaceous and argillaceous shaly partings occur, causing the rock to weather like a soft sandy shale. Most of the shale partings are green. Some of the sandy layers near the base show a "gnarled and twisted structure"	1, 100
	2, 297

The beds above the top of this section have been removed by erosion, the top of the highest bed of division A marking the plane of the pre-Tonto unconformity. The highest beds of this division lie at the upper end of the dry wash that joins the canyon of Shinumo Creek from the north just below the mouth of White Creek. The beds are dragged up against the Vishnu schist by the great pre-Cambrian fault, and the whole series is overlain by the basal (Tapeats) sandstone of the Tonto group. (See Pl. I, sections, in pocket.)

The Dox sandstone may be summarized as a series of micaceous shaly sandstones of uniform character, varying only in color and bearing marks of shallow-water origin throughout.

COMPARISON WITH TYPE SECTION IN UNKAR VALLEY.

A comparison of the above section of the Unkar group with that described by Walcott[1] in the type locality, 30 miles to the east, reveals the fact that the two sections correspond closely in thickness and in lithologic succession; only in their lower parts do they differ materially. The type section in Unkar Valley is characterized by a greater thickness of the basal conglomerate and by only a third as

[1] Walcott, C. D., Pre-Cambrian igneous rocks of the Unkar terrane, Grand Canyon of the Colorado, Arizona: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, 497-519, 1894.

much limestone in the members that correspond to the Bass limestone; the deficiency in limestone is made up by a greater thickness of arenaceous and argillaceous shales. The beds farther up in the section, in that division of Walcott's section which corresponds to the Hakatai shale, contain a greater proportion of sand. The succeeding members correspond closely in character and thickness even to the minor divisions, an example being the "gnarled and twisted layers" previously cited.

The writer had the privilege of examining Mr. Walcott's field specimens in the National Museum at Washington and was particularly impressed by their absolute lithologic identity with the series collected by himself from corresponding horizons on Shinumo Creek. The two series of specimens, those of rocks altered by local metamorphic phenomena, might have come from the same locality.

AGE AND CORRELATION OF THE GRAND CANYON SERIES.

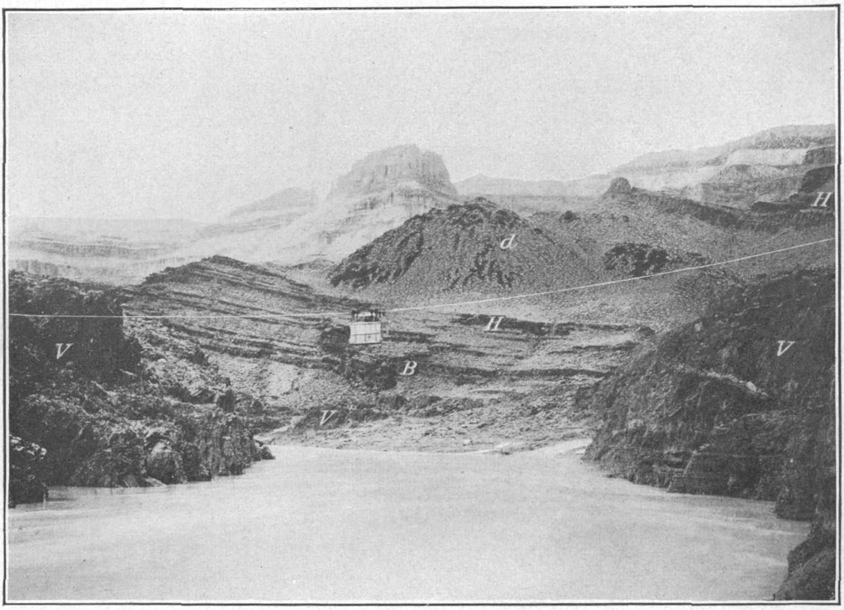
By the usage of the United States Geological Survey the Grand Canyon series is referred to the Algonkian system. It has been tentatively correlated with the Keweenawan series of the Lake Superior region by Walcott,[1] and according to Darton [2] it may also be correlated with a series of Algonkian rocks that occur in the Fort Apache region in Arizona.

During the summer of 1909 the writer had the opportunity of studying the rocks of the San Juan Mountains in southwestern Colorado, under the direction of Mr. Whitman Cross, and was particularly impressed with the similarity of the Needle Mountains group (Algonkian) to the Grand Canyon series, both in stratigraphic position and general lithology.[3] Like the Grand Canyon series, the Needle Mountains group (consisting of the Vallecito conglomerate below and the Uncompahgre formation, composed of quartzites and slates, above) rests unconformably upon a very old metamorphic complex and is likewise separated from an overlying Cambrian sandstone by a great angular unconformity which represents a base-leveled surface of erosion and truncates the pre-Cambrian structure as completely as does the pre-Tonto unconformity in the Grand Canyon region. The basal Cambrian sandstone of the San Juan region is similar in every respect to the basal (Tapeats) sandstone of the Tonto group and should doubtless be correlated with that formation. Lithologically the Needle Mountains group resembles the Grand Canyon series in the great amount of cross-bedded quartzitic sandstone it includes, but it differs from the Grand Canyon series in containing a great thickness of coarse conglomerate in its basal part and in exhibiting

1 Walcott, C. D., Pre-Cambrian igneous rocks of the Unkar terrane, Grand Canyon of the Colorado: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, p. 518, 1894.

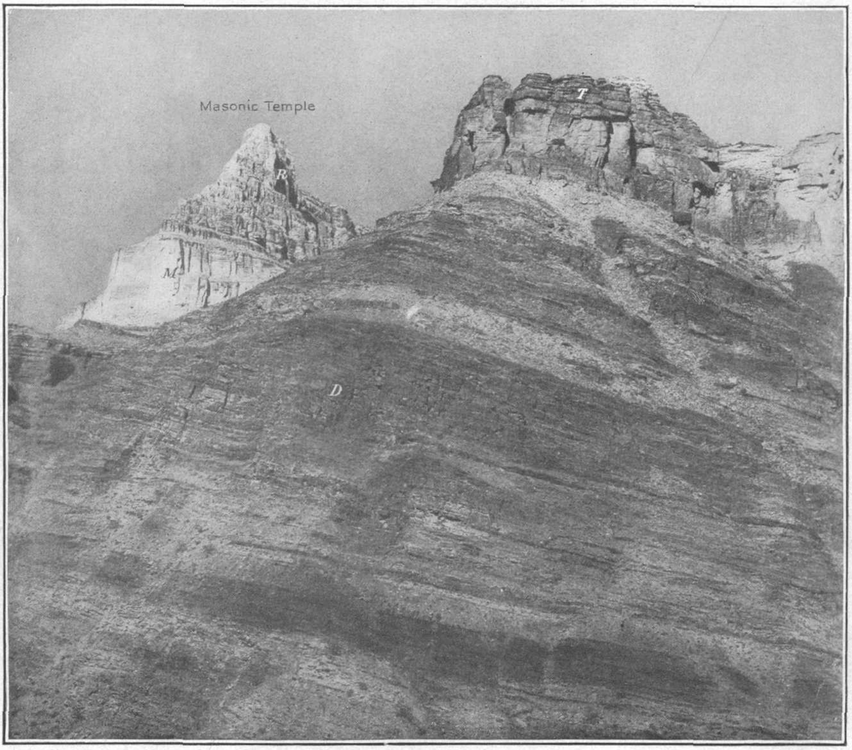
2 Darton, N. H., A reconnaissance of parts of northwestern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, 1910.

3 Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Needle Mountains folio (No. 131), 1905.



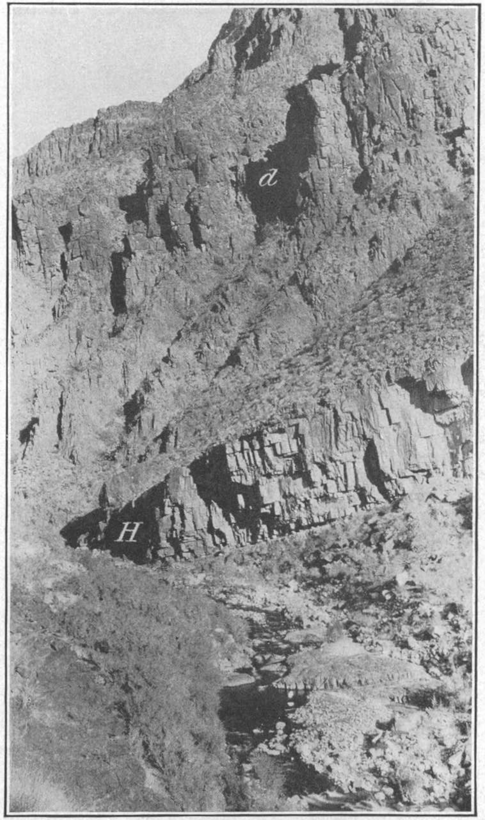
A. VIEW NEAR CABLE CROSSING, LOOKING DOWN COLORADO RIVER.

V, Vishnu schist; *B*, Bass limestone; *H*, Hakatai shale (jasper); *d*, Diabase intrusive.

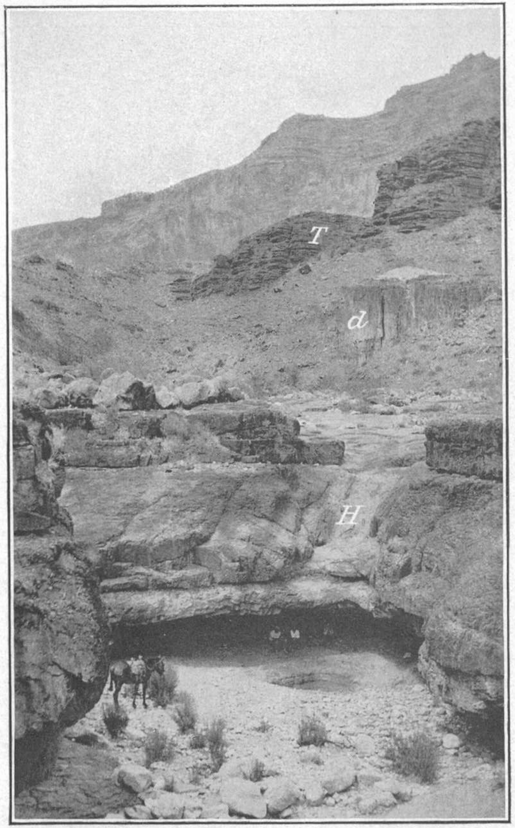


B. DOX SANDSTONE IN CANYON OF SHINUMO CREEK, OVERLAIN UNCONFORMABLY BY TAPEATS SANDSTONE OF THE TONTO GROUP.

D, Dox sandstone; *T*, Tapeats sandstone; *M*, Muav limestone; *R*, Redwall limestone. Photograph by N. W. Carkhuff.



A. SHINUMO CREEK.



B. BEDROCK TANK, BASS CANYON.

LOWER CONTACT OF DIABASE SILL.

H, Hakatai shale, here converted to jasper; *d*, Diabase; *T*, Tapeats sandstone.

metamorphism by pressure, whereas the Grand Canyon series is unaltered. In the opinion of the writer there is little doubt that the Needle Mountains group is the correlative of the Grand Canyon series.

INTRUSIVE DIABASE ASSOCIATED WITH THE UNKAR GROUP.

OCCURRENCE.

The diabase in the Shinumo quadrangle occurs in the form of intrusive sheets, or sills, which lie between the beds of the Unkar group.

In the uppermost part of division A of the Dox sandstone are four thin sills of diabase, the largest less than 25 feet thick, which are extremely rotten, weathering green and crumbling to small fragments. They occur between vermilion beds of sandstone and shale, and their intrusive character is shown by the fact that the vermilion beds are baked and decolorized for a few inches above and below the diabase, the vermilion color having been changed to purple. The diabase of these sills is too much weathered to permit an exact petrographic determination of its character in a thin section.

The greater part of the diabase forms a single mass, which occurs at three or more stratigraphic horizons in the sediments of the Unkar group in different parts of the quadrangle. (See Pls. XIII, *A*, XIV, *A* and *B*, and XVIII, p. 86.) In Hakatai Canyon, 3 miles west of Shinumo Creek, it lies within the Bass limestone. On the east side of Hakatai Canyon it rises out of the Bass limestone and enters the Hakatai shale, breaking clean across the edges of the intervening strata. Most of the lower and part of the upper contact of the eruptive rock are clearly displayed in the walls of this canyon. Between the exposures in Hakatai Canyon and the main exposures of the Unkar group about the mouth of Shinumo Creek the pre-Cambrian structure is hidden beneath the basal (Tapeats) sandstone of the Tonto platform. In all the region about the mouth of Shinumo Creek the diabase lies within the Hakatai shale at a horizon 400 feet above that at which it occurs in the Bass limestone in Hakatai Canyon. (See Pls. XIII, *A*, and XIV, *A* and *B*.) East of Hotauta Canyon, on the Colorado, the Unkar structure is again hidden beneath the Tonto platform, but about 3 miles up the river from Hotauta Canyon small outcrops of the basal formations of the Unkar group are again exposed in the intercanyon valleys on both sides of the river, where the lower contact of the diabase lies just at the summit of division B of the Bass limestone.

So much of the exposed portion of the sill is traversed by faults that lie parallel to the strike of the strata that it is impossible to measure it exactly. Its thickness reaches a maximum of about 1,000 feet on the west side of the Hakatai Canyon and decreases gradually eastward.

PETROGRAPHY.

Megascopic features.—Fresh specimens typical of the greater part of the mass show that the diabase is a tough, heavy, holocrystalline rock of medium to coarse grain and of gray color. The minerals visible to the unaided eye are plagioclase, olivine, augite, and an occasional grain of magnetite. Although the olivine exceeds the augite in amount, it is less conspicuous to the eye. Aside from a somewhat waxy luster of the feldspars the rock is remarkably fresh. The weathered surface has a characteristic warty appearance, imparted by the presence of lumps or balls which are more resistant than the mass of the rock and of coarser grain and different texture. These lumps and balls consist of coarse ophitic intergrowths of augite and plagioclase. The diabase weathers by mechanical disintegration to a greenish-olive sand, in which lie innumerable lumpy kernels of all sizes derived from the ophitic masses described above. The rock has no typical columnar structure, but generally displays a rough vertical jointing, such as is characteristic of granite.

Microscopic features.—The slides examined show that the typical rock consists primarily of plagioclase feldspar (near labradorite) and olivine in about equal amounts, a subordinate quantity of augite and brown biotite, and very little magnetite. The feldspar is somewhat altered, but all the other minerals are fresh. The olivine occurs characteristically in rather large rounded crystals of automorphic habit. The augite is confined chiefly to the globular masses, which weather out as lumps and kernels, and does not characterize the rock as a whole. Slides cut from these kernels show that they are composed entirely of augite and feldspar. The augite is inclosed within the feldspar, displaying fine examples of ophitic texture. Several of the magnetite crystals have rims of brown biotite. The small amount of magnetite is rather remarkable, and it seems likely on this account that the olivine is rich in magnesia. Because of the predominance of olivine and plagioclase in the greater part of the rock, the diabase is classified as an olivine diabase with a troctolitic aspect.

VARIATIONS IN CHARACTER.

All parts of the mass are subject to variations in texture and composition toward a coarser grain. These variations are of two types. The first type occurs in the ophitic intergrowths of augite and plagioclase of the lumps and balls described above, and is a segregation phenomenon characterizing the mass as a whole. In some places this texture becomes very coarse, the separate crystals of augite or plagioclase being an inch in length. The second type occurs in typical pegmatite dikes, which cut the diabase in many places and vary in width from a few inches to several feet. The minerals are plagioclase and augite and the texture is usually, but not invariably, ophitic. In some of these dikes crystals of plagioclase exceeding 3 inches in length were observed.

The contact facies of the diabase are in places fine grained or glassy, but for only a few inches from the contact. The slides typical of this zone reveal a hyalopilitic arrangement of glass, with skeleton crystals of magnetite between much altered crystals of feldspar.

For about half a mile east and half a mile west of the canyon of Shinumo Creek a pink holocrystalline rock of medium grain occurs in the upper part of the diabase sill along the upper contact. Its contact with the overlying blue slates is sharp and well defined, and it appears to grade downward into the normal diabase, no definite line of contact having been anywhere observed.

A slide cut from a specimen taken from the middle of a pink mass of the sill showed that it is a granular rock of medium texture, consisting of rather fresh crystals of orthoclase, with subordinate quartz and a somewhat altered ferromagnesian mineral, which appeared to have been originally a hornblende. Some of the quartz displayed a micrographic arrangement within the feldspar. The rock is a typical hornblende syenite and is apparently an interesting example of differentiation in place within the diabase sill.

In Hakatai Canyon both the lower and upper eruptive contacts of the diabase are ragged and considerably injected. Many small dikes penetrate the country rock from the main mass. They are glassy in texture and greatly altered.

Ransome[1] describes a diabase of post-Carboniferous age occurring in thick sills in the pre-Carboniferous sedimentary rocks in the Globe Copper district in Arizona. This diabase closely resembles the Algonkian diabase described above both in mineralogic character and in the presence of the ophitic balls of plagioclase and augite. The analogy is made the more striking by the fact that several small masses of pink hornblende syenite are described as occurring within the diabase sills of the Globe district, possibly as segregations within the diabasic magma.

CONTACT METAMORPHISM.

As the diabase sill occupies different horizons in the Unkar group in the canyon of Shinumo Creek and in Hakatai Canyon, and as the strata between which the sill is intruded in Shinumo Canyon lie in undisturbed sedimentary contact in Hakatai Canyon, and vice versa, the effects of the intrusion on the invaded strata can be easily noted.

The contact effect upon the shales that lie above and below the diabase along Shinumo Creek has already been described in the

[1] Ransome, F. L., Geology of the Globe Copper district, Arizona: U. S. Geol. Survey Prof. Paper 12, p. 80 et seq., 1903.

detailed section of the Unkar group, where the shales were shown to be altered to jaspers by baking and silicification (Pl. XIV, *B*). The intensity of metamorphic action was much greater below the sill than above, extending through 300 feet of strata below the lower contact and through only 100 feet above the upper contact. In Hakatai Canyon these rocks lie in undisturbed sedimentary contact and are there unaltered red shales.

The contact effect on the limestones can be studied in Hakatai Canyon, where the diabase sill lies intruded within them. Immediately below the lower contact of the diabase, which is sharp and well defined, is a thin layer of green serpentine. Below lie layers of pure crystalline limestone (dolomite) alternating with similar layers containing bands and nodules of serpentine. Within one of the layers containing the bands and nodules of serpentine are cross-fiber veins of golden-yellow chrysotile asbestos, which are parallel in general trend to the bedding of the limestone. These limestones are the layers at the base of division B of the Bass limestone. They overlie the red shales of division C, which are here baked to blue slates.

The following section, including a part of the Bass limestone beneath the lower contact of the diabase near the tunnel of the Asbestos mine in Hakatai Canyon, shows effect of local metamorphism in the strata. The numbers of the beds correspond (so far as the beds can be identified) to the numbers used in the detailed section of the Unkar group (pp. 40–53). The printed section represents the natural order, B, 24, 25, being at the top.

Section of part of the Bass limestone beneath diabase sill at the Asbestos mine in Hakatai Canyon.

		Ft.	in.
Diabase sill		1,000±	
B, 24, 25.	Layer of green serpentine	2	
	Pure white crystalline limestone	1	6
	White crystalline limestone, with bands and nodules of serpentine	2	
	Serpentinous nodular and banded layer carrying veins of asbestos	1	
	Banded crystalline limestone, with bands and nodules of serpentine	10	
B, 26, 27.	Nodular cherty limestone	4	
C, 1.	Soft blue slate	3	
C, 2.	Dense purple calcareous slate	9	

ASBESTOS.

Occurrence.—The limestones above the upper contact of the diabase contain several alternating layers of green serpentine and narrow veins of asbestos, which occur at several horizons near the contact.

The geologic occurrence of the asbestos is fully described by Diller.[1] A microscopic study was made of 25 thin sections cut from the limestones, the bands and nodules of serpentine, and the veins of asbestos. Aside from the serpentine and asbestos no other minerals were revealed in the limestones than the dolomitic calcite and interlocking grains of quartz in the slides cut from the limestones of the same horizon in the section in Hotauta Canyon, where the same strata lie in undisturbed sedimentary contact. The limestones have the texture of marble. The serpentine of the bands and nodules shows no trace of alteration in structure due to derivation from pyroxene, hornblende, or olivine. The slides cut across the veins of asbestos showed that they are later than the serpentine in which they are generally inclosed. A great number of microscopic veins of asbestos were revealed in some of the slides where their presence was unsuspected. Some of these veins cut across both the sepentine and the limestone in the same slide.

The asbestos in the larger veins is of high grade and is said by Diller to be the best yet found in the United States.[2] Locally its cross fiber is 4 inches in length and is of great tensile strength. The larger veins, so far as known, are confined to the limestones that lie beneath the diabase sill, the veins above the sill, though more widely distributed through the limestones, being generally smaller. The veins below the sill are not absolutely constant in stratigraphic position; they may lie anywhere from 3 to 15 feet below the contact. The width of these veins varies greatly from place to place, so that a vein that is 3 inches wide in one locality may be represented by a zone of innumerable small veins in another, but the actual continuity of the zone that carries the asbestos is rarely broken.

Origin.—The limestones contain serpentine and asbestos only where the strata are invaded by the diabase sill; the shales that are invaded by the diabase do not contain these minerals, which in no place in the area occur within the diabase itself. They are therefore a product of the contact metamorphism of the limestones by the diabase, and, as Diller suggests,[3] the serpentine that incloses the veins of asbestos is probably derived from some mineral in the limestones and not from the diabase. The limestones themselves are magnesian and contain bands and nodules of chert. In another part of the area the shales in contact with the diabase were converted to jaspers, the change indicating that the fumarolic action accompanying the injection of the diabasic magma was characterized by aqueous and probably siliceous emanations and was fairly intense.

[1] Diller, J. S., U. S. Geol. Survey Mineral Resources, 1907, pt. 2, pp. 720–721, 1908; idem, 1908, pt. 2, p. 705, 1909.

[2] Diller, J. S., U. S. Geol. Survey Mineral Resources, 1908, pt. 2, p. 705, 1909.

[3] Diller, J. S., loc. cit.

The fumarolic action on the magnesian limestones may have converted their more siliceous portions into serpentine. The occurrence of the asbestos in veins that cut across both the nodules of serpentine and the limestones shows that the cross-fiber asbestos was formed somewhat later in the sequence of events attending the fumarolic action.

AGE OF THE DIABASE.

The sills of diabase are displaced by the faults of the wedge in the same manner as the inclosing strata, the invasions having evidently occurred before the faulting. (See Pl. I, sections, in pocket.) The diabase of the Shinumo quadrangle is closely related in chemical and mineral composition to the basalt of the lava flows described by Iddings,[1] which are interbedded with the sediments of the upper part of the Unkar group in the type section in Unkar Valley. As the diabase lies at a much lower horizon than the lava flows, it is probably an intrusive rock of the same cycle of igneous activity, the sills and flows being probably contemporaneous.

PALEOZOIC ROCKS.

RESULTS OF PREVIOUS WORK IN THE REGION.

In a large and general way the distribution and broader character of the Paleozoic rocks of the Grand Canyon are familiar to every geologist through the writings of Newberry, Ives, Powell, Gilbert, Dutton, and Walcott.[2] A thorough analysis of their topographic and scenic expression in the canyon has been made by Davis.[1]

The details of the stratigraphy, however, are not yet known. Sections have been made at several widely separated places in the canyon wall—in the eastern part of the Kaibab division, by Walcott and by Frech; at Kanab Canyon, in the Kanab division, by Walcott; and at Diamond Creek and at the Grand Wash, in the Shivwits division, by Gilbert.[2] A recent report by Darton [2] gives a compilation of these sections and some additional data collected by himself at many points in the region. In all these sections and in this report certain groups of strata, particularly the Tonto, are given in detail, but no single section includes all the beds of all the groups in the Paleozoic rocks at any one place. A close and accurate comparison and correlation of the thickness and character of the Paleozoic formations from place to place in the Grand Canyon must therefore depend on the results of future detailed work at many points.

---

[1] Walcott, C. D., Pre-Cambrian igneous rocks of the Unkar terrane, Grand Canyon of the Colorado, Arizona, with notes on the petrographic character of the lavas, by J. P. Iddings: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, pp. 520 et seq., 1894.

[2] See Bibliography, pp. 13-15.

GENERAL SUCCESSION OF THE PALEOZOIC ROCKS.

At the base of the Paleozoic is the Tonto group, of Cambrian age. This group is divisible into three formations. At the base, resting in some places upon Archean and in other places upon Algonkian rocks, is the Tapeats sandstone. Overlying the sandstone is the Bright Angel shale, containing Middle Cambrian fossils. The highest formation of the group is the Muav limestone. No representatives of the Ordovician, Silurian, or Devonian were discriminated in the area studied, the Muav limestone being succeeded without apparent stratigraphic break by the Redwall limestone, of Carboniferous age. The Redwall limestone is overlain by the Aubrey group, which is also of Carboniferous age, and is divisible into three formations. At the base of the Aubrey group is the Supai formation composed of sandstone and shale, which is in turn overlain by the Coconino sandstone. The highest formation of the group, and likewise of the Paleozoic in the quadrangle, is the Kaibab limestone, containing a Pennsylvanian fauna. (See Pl. XVIII, p. 86.)

CAMBRIAN SYSTEM.

TONTO GROUP.

TAPEATS SANDSTONE.

The Tapeats sandstone rests upon an eroded surface which bevels the upturned and truncated edges of the Vishnu schist and Grand Canyon series. This unconformity is in plain view in the walls of the Granite Gorge throughout the entire Kaibab division of the canyon and is probably the clearest and most spectacular illustration of such a geologic feature in the world. Except in localities where remnants of Algonkian strata are preserved, the Tapeats sandstone in this division everywhere rests upon Archean rocks, yet we know from the record in the Vishnu quadrangle that at least 12,000 feet of Algonkian strata was deposited horizontally upon the Archean and that these Algonkian rocks were profoundly tilted and faulted before they were eroded away. So vast was the erosion that all but a few remnants of Algonkian strata were removed and the Archean rocks make the greater part of the floor on which the Tapeats sandstone was laid down. This floor, like that upon which the basal strata of the Unkar group were deposited, represents a surface base-leveled by erosion. This surface was not nearly so even as that represented by the more ancient pre-Unkar unconformity, yet it formed a comparatively level plain. Here and there a knob of more resistant Archean rock projects into the Tapeats sandstone, and in Monadnock amphitheater the rocks of the Unkar monadnock project 600 feet above the base of the sandstone, almost cutting out the overlying Bright Angel shale, but the relief of even these exceptional projections is small in comparison with the horizontal extent of the floor.

The name Tapeats sandstone is derived from Tapeats Creek, below the mouth of which, just north of the Shinumo quadrangle, the bed of the Colorado River lies within this formation.

The Tapeats sandstone shows little variation in lithologic character in the Kaibab division. The following is a typical section in the Shinumo quadrangle (reading from the top downward, A being the top bed, underlain by B and C):

Section of Tapeats sandstone.

	Feet.
A. White cross-bedded sandstone containing "Scolithus"	35
B. Shaly brown or greenish sandstone	50
C. Brown slabby sandstone or pebbly grit, composed chiefly of particles of quartz and characterized by cross bedding. The basal portion generally includes beds of coarser grit, or conglomerate, made up of the harder fragments of the underlying rocks. Most of the pebbles are rounded. The member contains here and there thin lenses of shale. The sandstone is commonly indurated to quartzite and the entire member is very resistant to erosion and makes a conspicuous brown cliff along the rim of the Granite Gorge. The thickness depends on the relief of the underlying surface; where greatest it is	200
	285

No fossils were found in the formation.

Within the Tapeats sandstone is a record of marine planation that in these vertical sections, which include no soil, is preserved with a clearness that is almost beyond belief. The long southwestern face of the Unkar island monadnock was undercut by the waves of the sea in which the sandstone was deposited, and a cross section of this old sea cliff preserved in the Tapeats sandstone in the southern wall of Hotauta Canyon near the Colorado reveals clearly every detail of the structure; at the base of the cliff huge angular blocks of Shinumo quartzite are incorporated in the Tapeats sandstone in the places where they fell and lodged; farther out lie masses of bowlders, worn and rounded by the pounding of the waves; and these bowlders run into lenses of fine pebbly conglomerate, representing the shingle of the ancient beach, dragged out by the undertow. No more striking example of a fossil sea cliff can be imagined.

BRIGHT ANGEL SHALE.

The name of the Bright Angel shale is derived from Bright Angel Canyon, in the walls of which the formation is well exposed.

The section following was measured on the north side of Colorado River between Hakatai and Burro canyons, in the central part of the Shinumo quadrangle.

Section of Bright Angel shale on north side of Colorado River between Hakatai and Burro canyons.

A. Upper division (alternating layers of shale and purplish-brown sandstone in upper part; soft, greenish, micaceous sandy shales below; the lower part makes a moderate slope and the upper part a steep slope):

	Feet.
1. Shale	16
2. Sandstone	2
3. Shale	16
4. Sandstone	3
5. Shale	6
6. Sandstone	1
7. Shale	5
8. Sandstone	2
9. Shale	80
	131

B. Middle division (locally known as "Snuffy limestone"; two cliffs of resistant limestone separated by a slope of soft shale; see Pl. XVIII, p. 86):

1. Dense snuff-colored limestone, somewhat sandy, with platy partings	10
2. Very dense, snuff-colored crystalline limestone	12
3. Soft shales, including a very thin layer of glauconite (?) containing linguloid brachiopods	25
4. Limestone like 2	10
	57

C. Lower division (soft, green, micaceous sandy shales with occasional thin layers of resistant sandstones, which form small cliffs; the entire division makes a very gentle slope):

1. Cross-bedded greenish sandstone	6
2. Extremely soft shales with a few very thin interbedded layers of fossiliferous sandstone and phosphatic limestone, made of the shells of linguloid brachiopods. A layer of glauconite (?) a few inches thick occurs in the center of the shales.	75
3. Sandstone, containing fossils	1
4. Shale	7
5. Sandstone	2
6. Shale	9
7. Cross-bedded brown sandstone, containing fossils	3
8. Shale	55
9. Reddish-brown quartzite, in many places conglomeratic	2
	160
Total thickness of Bright Angel shale	348

Most of the fossils were found in certain layers of brown sandstone, indicated in the section, but some were collected from the shales, through which fossils are also scattered, though much less abundantly. All the specimens found in the sandstones bear marks of grinding and attrition.

The following forms were identified: By Prof. Schuchert: Worm trails; *Lingulepis spatulus; Lingulella acutangula.* By Mr. Walcott: *Obolus westania,* var. *themis.* By Mr. Bassler: Phyllopod—*Indiana faba* U. and B.

In addition, Mr. Walcott collected at the same horizon in the Shinumo quadrangle in 1901 numerous worm trails, *Lingulella limolata, Lingulella perattenuata,* and *Lingulepis spatulus.*

These fossils show that the Bright Angel shale is of Middle Cambrian age. Whether the underlying unfossiliferous Tapeats sandstone represents the Middle or the Lower Cambrian system is not yet known. Walcott[1] thinks it probable that the erosion interval represented by the unconformity at the base of the Tapeats sandstone represents the whole or a large part of the Lower Cambrian.

The Bright Angel shale, like the formations of the Unkar group, is characterized by curious circular or elliptical spots that appear throughout all the shaly and sandy strata, some caused by local leaching, some by local addition of a ferruginous mineral.

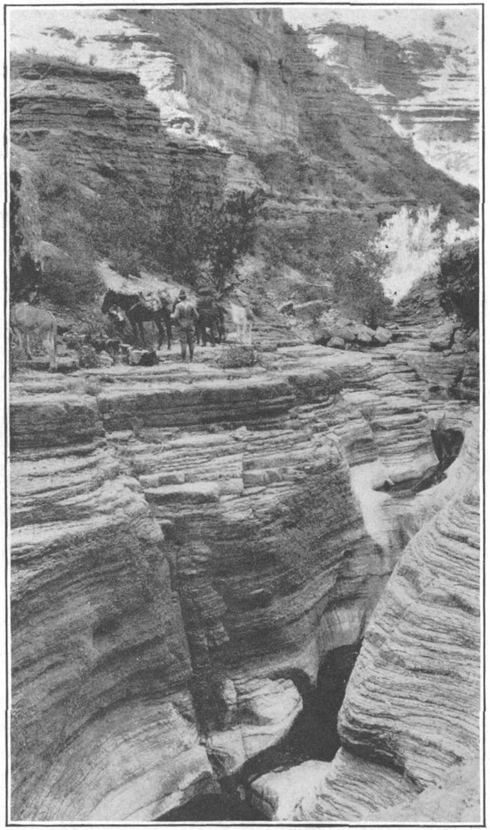
MUAV LIMESTONE.

The name of the Muav limestone is derived from Muav Canyon, in the lower part of which the formation is particularly well exposed. (See Pl. XV, *A*.) It designates the predominantly calcareous part of the Tonto group.

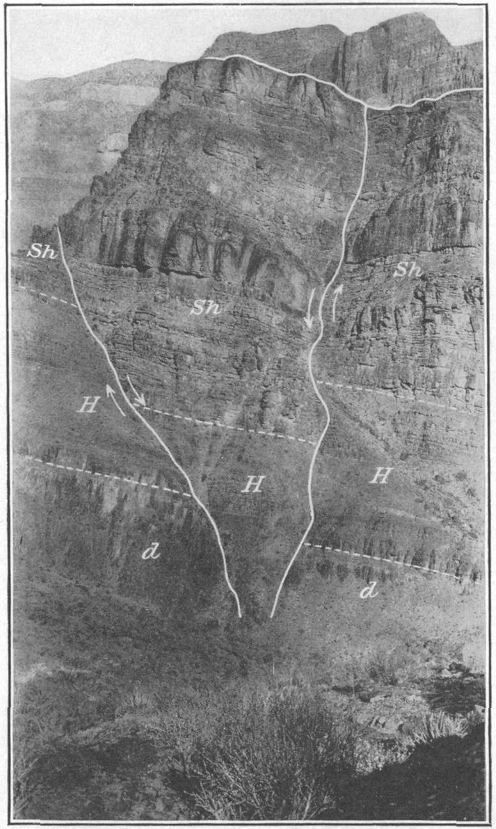
The limestones of the formation are of a peculiar and distinct type. Characteristically, they are impure thin-bedded bluish-gray limestones which have a mottled appearance, imparted by infinitely numerous thin bands or lenses of buff or greenish shaly material. By this mottling and the thin banding the formation can be readily distinguished at a distance. On closer inspection the limestones are seen to contain numerous imperfect coralloid or fucoidal markings. The upper part of the formation contains layers of sandstone and some layers of massive buff crystalline limestone, but most of the beds are slightly impure and mottled. The shaly material of the mottlings is locally finely micaceous, and in places the rock comprises more shale than limestone. In other places the formation contains layers that have the appearance of a shale conglomerate, made up of rounded, flattened fragments of shale and limestone. Some of the fucoidal mottlings are composed of buff or green shale and some layers of the limestone are cherty. Infinite variations of all phases occur throughout the formation. The sandstones and the purer portions of the limestones make cliffs and the impure portions make slopes. The upper part of the formation unites with the layers at the base of the overlying Redwall limestone to form the lower part of a single great cliff.

---

[1] Walcott, C. D., Pre-Cambrian igneous rocks of the Unkar terrane: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, p. 518, 1894.



A. MUAV LIMESTONE IN MUAV CANYON.



B. FAULTS IN UNKAR WEDGE IN CANYON OF SHINUMO CREEK.

The wedge outlined includes 1,000 vertical feet of strata. *d*, Diabase; *H*, Hakatai shale; *Sh*, Shinumo quartzite.

The following section was measured in Bass Canyon:

Section of Muav limestone.

	Feet.
Massive layers of buff crystalline limestone (cliff)	30
Fine-grained calcareous buff sandstone (cliff)	90
Sandy mottled limestone (steep slope)	85
Fine buff sandstone	5
Mottled limestone (cliff)	200
Impure shaly mottled limestone, fine-grained buff sandstone, and snuff-colored crystalline limestone in thin laminæ	45
	455

No fossils were found in the Muav limestone in the Shinumo quadrangle. The similarity in lithologic character, however, leaves little doubt that the beds are the same as those of the "mottled limestone" (earlier nomenclature), from which Walcott collected an abundant Middle Cambrian fauna both in Kanab Canyon, farther west, and in the eastern part of the Kaibab division.

CORRELATION OF TONTO GROUP.

According to Ransome,[1] the Tapeats sandstone is apparently equivalent to the Apache group of the Globe district, to the Coronado quartzite of the Clifton district, and to the Bolsa quartzite of the Bisbee district. The Bright Angel shale and the Muav limestone are apparently represented by the Abrigo limestone of the Bisbee region.

UNCONFORMITY.

In certain parts of the Grand Canyon, both east and west of the Shinumo quadrangle, the Cambrian Muav limestone is separated from the overlying Carboniferous Redwall limestone by a peculiar unconformity of erosion without unconformity of dip. The studies that revealed the presence of this unconformity were made by Walcott.

In Kanab Canyon, 20 miles west of the Shinumo quadrangle, Walcott[2] reports the presence of Devonian beds separated by a strong line of erosion from the underlying Cambrian and by a similar line of erosion from the overlying Redwall. The writer had the privilege of examining sketches made by Mr. Walcott showing the details of these unconformities. In one place canyons 80 feet deep were eroded in the "mottled limestone" (Muav limestone) and these depressions were filled by limestones and sands containing a Devonian fauna.

[1] Ransome, F. L., A comparison of some Paleozoic and pre-Cambrian sections in Arizona: Science, new ser., vol. 27, p. 69, 1908.

[2] Walcott, C. D., The Permian and other Paleozoic groups of the Kanab Valley, Arizona: Am. Jour. Sci., 3d ser., vol. 20, pp. 221-225, 1880.

The observations of Walcott at the east end of the Kaibab division reveal a similar condition. He writes:[1]

> In places the Devonian is entirely absent, either through erosion or nondeposition, so that the Redwall limestone rests directly upon the massive calciferous strata of the upper Tonto. It rarely has a thickness of more than 100 feet.

In the south wall of the Grand Canyon between Ruby Canyon, in the Shinumo quadrangle, and Pipe Creek, in the Bright Angel quadrangle, the unconformity between the Muav limestone and the Redwall is well marked and in many places Devonian beds lie in small hollows eroded in the Muav limestone. These Devonian beds are clearly separated from the underlying Muav and from the overlying Redwall by unconformities of erosion. In the Shinumo region, however, this double unconformity is not clearly evident, and in order to determine the stratigraphic relations in Bass Canyon with certainty it will be necessary to trace the beds at the horizon of the unconformity westward from Ruby Canyon into the Shinumo region.

CARBONIFEROUS SYSTEM.

REDWALL LIMESTONE.

The type locality for the Redwall formation is Redwall Canyon, in the Shinumo quadrangle. The name was applied to the formation long ago by Gilbert.

Because of the lack of fossils and the failure to detect the line of erosion that would mark a division between the Muav limestone and the Redwall in Bass Canyon it has been necessary to fix tentatively the base of the Redwall by means of lithology. The Muav limestone is here overlain by alternating layers of calcareous sandstone and dense blue-gray crystalline limestone, which have a thickness of 110 feet. These layers are taken arbitrarily as the base of the Redwall. The remainder of the formation comprises beds of pure, dense, bluish-gray crystalline limestone, the bedding of which is generally so obscure that they have the appearance of a single stratum. The bedding is thinner in the lower than in the upper part of this limestone. These beds of limestone appear in a single great cliff, the highest in the Grand Canyon. The face of the cliff is generally stained red by the weathering of the overlying red shales of the Supai formation. These obscurely bedded limestones are about 500 feet thick in Bass Canyon.

The cliff-making limestone of the Redwall formation has produced some of the most remarkable scenery in the canyon. Throughout the canyon the faces of the cliffs it forms are recessed with great niches and alcoves and are penetrated by many caves. The niches

[1] Walcott, C. D., Pre-Carboniferous strata in the Grand Canyon of the Colorado, Arizona: Am. Jour. Sci., 3d ser., vol. 26, p. 438, 1883.

and alcoves are described, but left unexplained, by Dutton [1] and are explained by Davis.[2] Their grandest development in the region is found in the walls of Walthenberg Canyon, in the Shinumo quadrangle. Two of the largest caves in the Redwall are found in Bass Canyon and in the upper part of Muav Canyon.

The total thickness of the Redwall limestone in Bass Canyon is 610 feet, of which at least 30 feet at the base is probably of Devonian age.

The only fossils obtained in this formation by the writer were some obscure forms collected about 325 feet above its base in Bass Canyon. These comprise some cross sections of a cyathophylloid coral and some small brachiopods, which were identified by Prof. Schuchert as Schuchertella. They may belong to either a Mississippian or a Pennsylvanian fauna.

In Kanab Canyon, 20 miles west of the Shinumo quadrangle, Gilbert [3] found abundant fossils in the Redwall and concluded that the base of the formation in that locality represents "Lower Carboniferous" (Mississippian) and the summit "Upper Carboniferous" (Pennsylvanian) time, the transition taking place without break.

Similar evidence was obtained later by Lee [4] in the western part of the Grand Canyon region. The paragraphs presenting this evidence are here quoted:

In Truxton Canyon two small collections of fossils were obtained from the Redwall limestone. These were examined by G. H. Girty, of the Geological Survey, who reports the following lists:

At Yampai, near the top of the exposed section, the following were obtained:

Derbya (?) sp.
Composita.
Aviculipecten.
Myalina sp. aff. M. Meliniformis and M. cogeneris.
Edmondia (?) sp.

These fossils, according to Girty, indicate a Pennsylvanian or "Coal Measures" age.

Lower in the section, near Nelson, Ariz., Mississippian forms were obtained, as follows:

Menophyllum excavum.
Schuchertella inequalis.
Spirifer centronatus.
Spirifer striatus var. madisonensis.
Straparollus sp.

Girty states that this is the Eo-Mississippian fauna, which has a wide range over the West, correlating it with the lower "Wasatch limestone of Utah, the Madison limestone of Yellowstone Park, and the Chouteau limestone of Missouri."

Lee believes that in the locality described by him the upper part of the Redwall is Pennsylvanian and the lower part is Mississippian,

---

[1] Dutton, C. E., Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, chap. 14, 1882.

[2] Davis, W. M., An excursion to the Grand Canyon of the Colorado: Harvard Univ. Mus. Comp. Zool. Bull. 38, vol. 5, No. 4, p. 178, 1901.

[3] Gilbert, G. K., op. cit., p. 178.

[4] Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull 352, p. 15, 1908.

the line of division being drawn between the upper massive and the lower laminated members of the formation.

The fossils found by the writer of the present report in the lower part of the formation in the Shinumo quadrangle are apparently similar to forms found in the part of Lee's section which is referred to the Mississippian by Girty, but correlation can not be based upon evidence so doubtful.

The limestone beds in which Pennsylvanian fossils were found by Gilbert and Lee may be the correlatives of the layers of cherty limestone that lie at the base of the Supai in the Shinumo region, and the line of separation between the Mississippian and Pennsylvanian may consequently be the base of the Supai formation in Bass Canyon, but until this question has been decided by further study the base of the Redwall may be assigned to the Mississippian and the summit to the Pennsylvanian.

AUBREY GROUP.

All the strata above the Redwall limestone in the canyon wall belong to the Aubrey group. The group is divisible into three formations—the Supai, the Coconino, and the Kaibab.

SUPAI FORMATION.

Lithology.—This is the basal formation of the Aubrey group. The name was given by Darton[1] and is derived from the Indian village of Supai in Cataract Canyon, which is designated as the type locality. The Supai formation is easily distinguished by its color, for it contributes most of the red to the canyon landscape. Its upper part is made of soft red shale, which appears in a gentle, waste-covered slope beneath the Coconino sandstone cliff. Its lower part consists chiefly of layers of hard sandstone, which make a long, steplike succession of cliffs, each of which corresponds in height to the thickness of the bed that determines it. The shale of the upper part wastes back from the summit of the sandstone of the lower part and leaves the Esplanade platform. (See Pls. VI and VII, *A* and *B*, pp. 21, 22.)

Sandstone of the Supai formation.—The basal member of the lower division of the Supai formation in Bass Canyon, which is about 100 feet thick, consists of red shales alternating with beds of massive blue-gray crystalline limestone containing bands and nodules of red chert. These beds waste back from the summit of the Redwall, leaving a narrow ledge. The remainder of the lower division consists almost entirely of fine-grained cross-bedded sandstone. At a horizon 575 feet above the summit of the Redwall, however, some remarkable beds of limestone conglomerate are here and there interbedded with the sandstones. The conglomerate occurs in lenses, which alternate

[1] Darton, N. H., A reconnaissance of parts of northern New Mexico and northern Arizona: U. S. Geol. Survey Bull. 435, p. 25, 1910.

with beds of fine red shaly sandstone. The total thickness of the beds that carry the conglomerate lenses is 20 feet. The pebbles, which are derived from a rock of much the same character as the massive part of the Redwall limestone, are well rounded and their average diameter is about an inch. The matrix is red mud. The thickness of the sandstone division of the Supai formation is 850 feet in Bass Canyon and shows little variation in the quadrangle.

Shale of the Supai formation.—The upper member of the higher division of the Supai formation consists chiefly of soft red shaly sandstones, which make a slope rising from the Esplanade platform and are largely masked by fans of gray waste shot down from the overlying Coconino sandstone. In the walls directly above Bass Canyon the formation is 400 feet thick but its thickness varies greatly in the quadrangle.

The total thickness of the Supai formation in this locality is 1,250 feet.

In the Shinumo region the Supai formation appears to be separated from the underlying Redwall limestone by a slight unconformity of erosion. According to Darton [1] it is "distinct from the gray sandstone [Coconino] throughout northern Arizona, but their separation from the underlying Redwall is not everywhere so clear as could be desired."

COCONINO SANDSTONE.

Darton writes: [2]

> The name Coconino sandstone is proposed for the cross-bedded gray to white sandstone of the Aubrey group, which is so conspicuous in the walls of the Grand Canyon. It underlies the entire Coconino Plateau, as well as the extensive plateau country north of the Grand Canyon.

The Coconino sandstone is buff to creamy-white, is of uniformly fine grain, and is characterized throughout by cross-bedding. It forms a single great, massive bed, which makes the highest cliff in the upper wall of the canyon, whose white color presents a striking contrast to the red color of the shales of the Supai formation in the slope beneath. The huge scale of the cross-bedding is remarkable. The inclined beds dip in a general southerly direction and each layer is evenly truncated above, so that it forms a wedge. Many of the wedges attain a thickness of 100 feet. No ripple marks or sun cracks have ever been found in the Coconino sandstone and, with the exception of the Tapeats sandstone, it is the only Paleozoic formation of the canyon wall in which fossils have not been found. Its thickness varies considerably in the quadrangle and is everywhere in inverse ratio to that of the underlying shale of the Supai formation. Under Havasupai Point, near Bass Canyon, its thickness is 335 feet.

[1] Darton, N. H., idem.

[2] Darton, N. H., idem, p.27.

KAIBAB LIMESTONE.

The name Kaibab has been applied to the next highest formation by Darton[1] from the fact that it forms the surface of the Kaibab Plateau. The Kaibab limestone overlies the Coconino sandstone and is the highest formation in the canyon wall. Upon it are developed the surfaces of all the plateaus of the Grand Canyon district. The upper portion of the formation consists of layers of dense buff or cream-colored limestone, which are composed largely of the remains of sea animals and contain great quantities of lumpy flint or chert. Fossil Mountain (Pl. VII, *B*, p. 22), near Havasupai Point, is so named because of the abundance of fossils on its southwest slope. The layers of limestone are very resistant to erosion and make the first cliff that drops away at the rim of the canyon. The middle and lower portions of the formation consist of beds of sandy limestone, which decay more easily and make a series of weak cliffs and steep slopes in the wall.

The unequal hardness of the upper and middle parts of the formation has produced a curious scenic feature in the north wall of the canyon. Rain erosion has carved the rock into colossal pillars or "hoodoos," which stand like sentinels along the rim of Shinumo Amphitheater (Pl. XVI, *A*, p. 78). Each pillar is preserved by a cap of the hard summit limestone, which protects the softer sandy limestone beneath.

The absence of surface streams on the Kaibab Plateau is due to the fact that its floor is made of limestone. As is usual in limestone regions of abundant rainfall, the rock is honeycombed by a system of underground drainage channels which have been dissolved by rain water that descends along lines of joint and fracture. In only a few places do the surface waters flow far before they sink and join this underground system, in which they continue southwestward with the dip of the strata and burst out as springs in the north wall of the canyon, feeding the perennial streams of the amphitheaters. The map shows small circular depressions here and there on the plateau. These are sink holes, each of which has in its bottom an outlet that communicates with the underground channels. Where the outlets become clogged up the sinks hold small ponds in wet weather. Fen Lake is one of these ponds.

Section of Kaibab limestone near Fossil Mountain, Coconino Plateau.

	Feet.
A. Crystalline limestone, containing many nodules of chert in its upper portion. The cherty layer caps the remarkable "pinnacles of erosion" along the northern rim of the canyon in the Kaibab division	75

[1] Darton, N. H., idem, p. 28.

	Feet.
B. Very fossiliferous white crystalline limestone, forming a cliff...	200
C. Bed of soft and crumbling calcareous sandstone, locally a conglomerate made up of fragments of soft calcareous sandstone.	20
D. Calcareous red and white sandstones	135
E. Buff, crystalline, siliceous limestone, making a cliff	40
F. Calcareous white sandstone, making a ledge and slope at the summit of the Coconino sandstone	50
	520

The fossils of division B are abundant wherever the beds of that horizon are exposed in the quadrangle. A collection made at Fossil Mountain and in the Muav Saddle was examined by G. H. Girty, of the Geological Survey, who reports that the forms comprise all those which are included in a similar collection in his possession obtained at the same horizon in the Kaibab limestone at Parusi-Wompats Spring, just north of the Shinumo quadrangle, on the Kaibab Plateau.

The list from Parusi-Wompat is as follows:

Sponges.
Lophophyllum n. sp.
Crinoid stems.
Fistulipora sp.
Meekopora sp.
Stenopora sp.
Septopora sp.
Polypora sp.
Lingulidiscina convexa?
Derbya sp.
Meekella pyramidalis.
Chonetes aff. hillianus.
Productus occidentalis.
Productus ivesii.
Productus aff. irginæ.
Productus subhorridus var. rugatulus?
Productus sp.
Pugna osagensis var.
Heterelasma n. sp.
Squamularia guadalupensis?
Spiriferina campestris?
Composita subtilata.
Aviculipecten 2 sp.
Acanthopecten occidentalis.
Pseudomonotis aff. hawni.
Pseudomonotis? sp.
Anisopyge perannulata?

In a letter concerning this fauna Girty writes:

> The list is typical of the fauna of the upper Aubrey, the general character of which has long been known through similar lists made up by Meek and others. I have been tentatively correlating the Aubrey with the Manzano group of New Mexico and with the upper part of the Hueco formation of western Texas. Consequently, it would be older than the Guadalupe group, which overlies the Hueco formation. The fauna listed above, however, contains a number of species which are very similar to or identical with species that occur in the Guadalupian fauna, and in spite of the fact that most of the Guadalupian species have not been found in the Aubrey group, it seems less improbable than it did several years ago, when the Guadalupian fauna was under investigation, that the Kaibab limestone is of the same geologic age.

VARIATION IN THE THICKNESS OF THE PALEOZOIC STRATA.

The table following shows the variations in thickness of the Paleozoic strata in the quadrangle.

Approximate thickness, in feet, of the Paleozoic formations in different parts of the Shinumo quadrangle and in Bright Angel quadrangle.

[The letters (as NE. NW.) after each locality indicate the part of the quadrangle in which it is situated.]

	Thompson Point (NW.).	Apache Point (W.).	Wheeler Point (NW. center).	Dutton Point, Masonic Temple (N. center).	Tyndall Dome (center).	Havasupai Point (center).	Point Sublime (E.).	Diana Temple, Topaz Canyon (SE.).	Monadnock Amphitheater (E.).	Maximum thickness in quadrangle.	Minimum thickness in quadrangle.	Bright Angel trail, in Bright Angel quadrangle.
Kaibab limestone	600	600	550	600	....	550	600	500	....	600	400	560
Coconino sandstone	250	300	300	250	....	335	250	350	....	350	250	385
Supai formation:												
Shale	550	550	550	450	....	400	400	300	....	550	300	260
Sandstone	850	....	850	900	....	850	850	950	....	950	850	930
Redwall limestone	700	....	....	700	625	....	....	625	625	700	600	550
Muav limestone	475	....	....	450	450	....	....	450	450	475	400	385
Bright Angel shale	375	....	....	375	350	....	....	325	25	375	25	325
Tapeats sandstone	275	....	....	280	285	....	....	235	0	285	0	265
Total Paleozoic system	4,065	....	....	4,005	....	....	....	3,735	....	....	....	3,660

The Kaibab limestone varies considerably in thickness from place to place, but this variation is only apparent, being due to the fact that the summit of the formation has undergone unequal erosion in different parts of the quadrangle. The original thickness was probably nearly uniform.

The Coconino sandstone decreases steadily in thickness toward the north and west.

The shale of the Supai formation increases steadily in thickness in the same directions.

The sandstone of the Supai formation varies only slightly, its thickness decreasing toward the west.

The Redwall limestone increases in thickness toward the north and west.

The Muav limestone becomes slightly thicker toward the west.

The Bright Angel shale is nearly uniform in thickness throughout the quadrangle except in places where the Unkar monadnock projects into it. Its texture becomes firmer toward the west.

The thickness of the Tapeats sandstone depends entirely on the relief of the underlying eroded surface and therefore shows an exceedingly irregular variation.

The total thickness of the Paleozoic system increases gradually toward the north and west.

EFFECT OF THE VARIATION IN THE THICKNESS OF THE PALEOZOIC STRATA UPON THE TOPOGRAPHY OF THE CANYON WALL.

The profile of the canyon wall in the Paleozoic strata everywhere shows a direct relation to the variations in thickness and character of the strata of this era. It has been emphasized that each resistant stratum makes a cliff and each weak stratum a slope, and that each ledge in the wall is made by the wasting back of weak strata from the summit of a resistant, cliff-making stratum below. The width of a ledge invariably increases with the thickness of the weak strata, and is also controlled by the relative thickness and strength of the overlying strata which defend the retreat of the wall above. Although this relation has always been recognized in the smaller ledges in the canyon wall, a different explanation of the two widest ledges, the Esplanade and Tonto platforms, is found in most geologic literature—an explanation based on a theory advanced by Dutton.

Dutton [1] explains the Esplanade (Pl. VI, p. 21) by a pause in the uplift of the region during the cutting of the Grand Canyon. By this pause a temporary base level of erosion was produced, the topographic expression of which was a mature valley whose floor was the Esplanade.

> Again the country was hoisted, this time more than before * * *. Swiftly the inner gorge was scoured out and the chasm assumed its present condition.

[1] Dutton, C. E., op. cit., p. 121.

The reader is led to infer that the Tonto platform (Pl. V, p. 20) represents the prolongation of the same base level into the Kaibab division.

The physiographic studies of Davis in the canyon region, however, have made it clear [1] that the Esplanade is associated with the same changes in character and thickness of strata that produced the smaller benches in the canyon; that the Esplanade may be regarded simply as a structural bench; and that it is not therefore necessary to postulate more than a single cycle for the cutting of the Grand Canyon.

The writer of the present report is entirely in accord with Davis. The Shinumo quadrangle is the critical area for the study of the origin of the platforms, for the profile of the canyon wall here changes from that which is characteristic of the Kaibab division to that which is characteristic of the Kanab. This change, which takes place opposite Havasupai Point, has already been described, and the variations in thickness and character of the Paleozoic strata have just been outlined. The perfect correlation of the character of the rocks with the topography in the two greatest platforms will now be shown.

In the Kaibab division the Bright Angel shale of the Tonto group is uniformly weak and has wasted back rapidly from the summit of the Tapeats sandstone, leaving the wide ledge known as the Tonto platform. As the Bright Angel shale is traced westward into the Shinumo quadrangle, layers of resistant snuff-colored limestone begin to appear in the middle of the formation. These layers, known locally as the "Snuffy limestone" (Pl. XVIII, p. 86), gradually increase in thickness toward the west, making two delicate parallel cliffs which form a conspicuous feature in the interior of the canyon. Similarly the overlying Muav limestone and the massive Redwall limestone become gradually thicker toward the north and west, and the innner canyon narrows as these strata become more and more effective in defending the retreat of the wall.

In the Kanab division the Supai formation of the Aubrey group consists of weak red shales in its upper portion and resistant sandstone below. The shales waste back from the summit of the sandstone, leaving the Esplanade platform. In the western part of the quadrangle, where the Esplanade is developed, the thickness of these shales is 550 feet, whereas that of the overlying massive Coconino sandstone, which defends the retreat of the outer wall, is only 250 feet. East of Havasupai Point, in the Kaibab division, the thickness of the shale of the Supai formation decreases to 300 feet, whereas

[1] Davis, W. M., An excursion to the Grand Canyon of the Colorado: Harvard Univ. Mus. Comp. Zool. Bull. 38, geol. ser., vol. 5, No. 4, pp. 181 et seq., 1901; An excursion to the Plateau province of Utah and Arizona: Harvard Univ. Mus. Comp. Zool. Bull. 42, geol. ser., vol 6, pp. 31 et seq., 1904.

that of the Coconino sandstone has increased to nearly 400 feet. The Esplanade fades to a narrow ledge in this part of the canyon.

If the Esplanade and Tonto platforms represent base levels of erosion there is no reason why every bench in the canyon wall should not represent a similar base level. In the Kaibab division at least two benches are better developed than the bench that locally represents the Esplanade. The writer agrees with the conclusions of Robinson, who, in discussing the same problem from observations made in the Bright Angel quadrangle, says:[1]

> It is hardly reasonable to expect such a nice adjustment of base levels, three or four in number, to suit definite structural horizons. It must be concluded, rather, that the benches are simply what they appear to be—the stripped surfaces of resistant formations which have been successively exposed in the progressive downcutting of the Colorado River through the plateau.

The facts that the Esplanade and Tonto platforms are both widely developed in the central part of the Shinumo quadrangle and that they are there vertically over 2,000 feet apart show that they do not represent a common base-level of erosion.

STRUCTURAL GEOLOGY.

WEST KAIBAB FAULT.

Perhaps the most interesting structural feature in the quadrangle is the West Kaibab fault, in the Muav-Flint canyon, where the line of the fault is laid open to study for a vertical mile by the deep cutting of the gorge, which has revealed three separate displacements along the same line. These displacements occurred at widely separated periods of geologic time. (See Pl. I, sections, in pocket.)

The earliest of these displacements is recorded in the pre-Cambrian rocks in the depths of the canyons of Shinumo and Flint creeks, and is the great fault that limits the Unkar wedge on the northeast, bringing up the Vishnu schist on the opposite side of the fault plane.

The strike of the fault in this part of the Muav-Flint canyon is in general northwest-southeast, but its extension is undulatory, as may be seen from the geologic map. The dip of the fault plane is 60° SW. in the only locality where a vertical cross section could be observed. The strata of the Unkar group are dragged up against the fault line throughout its exposure, the drag sharply reversing their usual northeasterly dip. The fault plane is marked by cemented breccia wherever it crosses the harder beds of the Vishnu schist or the quartzites of the Unkar group. Between the Dox sandstone and the Vishnu schist it is characterized by a soft talcose selvage.

The pre-Cambrian age of the fault is established by the fact that the entire structure is truncated by the base-leveled surface of erosion

[1] Robinson, H. H., The single-cycle development of the Grand Canyon of the Colorado: Science, new ser., vol. 34, No. 864, p. 90, 1911.

at the base of the Tapeats sandstone. The total amount of displacement can never be known; the highest beds of the Unkar group which abut against the fault belong to the Dox sandstone, lying stratigraphically 5,800 feet above the Archean surface upon which the Unkar group rests, but this can be only a minimum measure because of the truncation of higher beds by the pre-Tonto unconformity, as explained above.

The two later displacements which took place along the same line are recorded in the Paleozoic strata.

The earlier of these displacements is a monoclinal flexure, which dips northeastward. This flexure is clearly defined throughout the Muav-Flint Canyon, from Muav Saddle to the gap between Point Sublime and Sagittarius Ridge, a distance of 10 miles, in which it displays everywhere about the same amount of throw and the same radius of curvature. The throw ranges from 400 to 500 feet and the curvature is accomplished within a quarter of a mile. Southeast of Point Sublime the flexure diminishes in throw to about 50 feet and crosses the river near the eastern boundary of the quadrangle at the mouth of Slate Creek. Boucher trail, in the Bright Angel quadrangle, ascends the canyon wall for a part of the way in the line of the flexure.[1] The course of the displacement north of Muav Saddle is described on page 79.

The deep Muav Canyon affords an excellent opportunity to study the effect of folding in the Paleozoic beds. The beds of the massive formations—the Kaibab limestone, Coconino sandstone, Supai formation (sandstone division), Muav limestone, and Tapeats sandstone—bend downward in a graceful arc. The entire Redwall limestone curves downward as a single stratum. The soft sandstones of the Supai formation and the Bright Angel shale, however, are greatly mashed and crumpled.

The later displacement is a fault along the line of flexure. In the upper part of Muav Canyon the strata west of the fault are dropped; farther down the canyon the fault dies out for about half a mile and reappears with the throw reversed, the strata this time dropping on the northeast side of the fault, which finally dies out under Point Sublime, at the head of the canyon of Flint Creek.

The compound displacement gives a peculiar profile to the walls of the Muav-Flint Canyon: On the northeast side of the canyons of Shinumo and Flint creeks the combined throw of the fault and flexure drops the Tonto platform 500 feet below the level at which it stands on the opposite side, but in the upper part of Muav Canyon the throw of the fault just compensates that of the flexure. (See Pl. I, sections, in pocket.)

---

[1] Davis, W. M., An excursion to the Grand Canyon of the Colorado: Harvard Univ. Mus. Comp. Zool. Bull. 38, geol. ser., vol. 5, No. 4, p. 165, 1901.

A description of this fault in Muav Saddle is given by Dutton,[1] whose observations, however, did not extend southward into the canyon. North of the Muav Saddle the fault crosses Tapeats Amphitheater and its throw increases greatly until it becomes the immense break which drops the strata nearly 2,000 feet to the west and forms the western boundary of the Kaibab Plateau.

The flexure probably originated when the Paleozoic rocks were buried under a considerable load of Mesozoic strata, for the thick and massive Paleozoic beds yielded by bending rather than by breaking, as is shown in Muav Canyon. This movement must have occurred not long after erosion began in the region and therefore early in Tertiary time. The fault that breaks the flexure may have occurred at any time after the greater part of the mass of the Mesozoic strata had been eroded away.

FAULTS OF THE UNKAR WEDGE.

In addition to the great fault that limits the wedge on the northeast, a large number of smaller faults traverse the Unkar strata. (See Pl. I, sections.) These faults are exceedingly numerous, there being in some places as many as 30 to the mile. The amount of displacement ranges from almost nothing up to 400 feet, but by far the greater number have a throw of less than 50 feet. Only those whose throw exceeds 50 feet are recorded on the map. The general trend of the faults is northwest-southeast, parallel to that of the limiting West Kaibab fault and to the strike of the strata. The fault lines are very crooked, owing to the fact that they traverse a rugged region (Pl. XVII, *B*).

All the faults are of the normal type and divide the strata into crustal blocks. At many places two fault planes dip toward each other, a vertical wedge of strata lying between them. The fault blocks and wedges are of all sizes, ranging from those included between the larger faults down to those formed by the innumerable faults of small throw. A cross section of one of the wedges is clearly exposed in the cliff of the west wall of Shinumo Canyon about half a mile above its junction with Burro Canyon. (See Pl. XV, *B*, p. 64.) Every detail of the wedge is revealed from its summit, where it is truncated by the pre-Tonto unconformity down to its apex, a vertical distance of 1,000 feet.

Where the fault planes traverse the harder strata they are characterized by fault breccia and slickensided surfaces. The breccia is usually cemented with milky quartz and in nearly all such places a small amount of copper has been deposited, so that the weathered fault planes have a greenish stain.

[1] Dutton, C. E., op. cit., p. 162.

In Bass Canyon a sharp monoclinal flexure has been formed in the Unkar strata as a result of a compressive force acting from the southeast. This flexure runs northeastward through Bass Canyon, crossing the Colorado just above the mouth of Hotauta Canyon. It has long been known to visitors as the "Wheeler fold." (See Pls. XVI, *B*, and XVII, *A*.) Its throw is about 300 feet. It is finely displayed in cross section in the wall of the Granite Gorge on the north side of the Colorado. Here the diorite that intrudes the Vishnu schist has been buckled and shoved into the limestones, shales, and jaspers of the lower Unkar and the flexure is passing into a thrust fault.

All these smaller faults, like the great limiting fault, are truncated by the pre-Tonto unconformity (see Pl. I, sections) and were likewise undoubtedly formed by the great crustal movements that uplifted the Algonkian mountains.

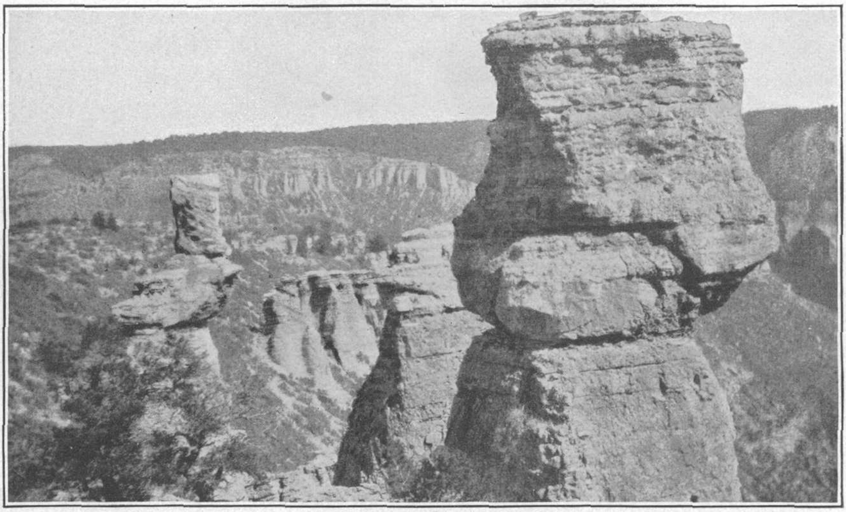
DISPLACEMENTS OF THE PALEOZOIC STRATA.

In addition to the West Kaibab faulted flexure a number of smaller displacements of various types are recorded in the Paleozoic strata.

Flexures.—A number of very gentle flexures run northwest-southeast parallel to the strike of the southwestward warping of the strata. All dip southwestward and are hardly more than slight swells upon the warped surface. The most prominent of these flexures may be traced through Powell Plateau, near the head of Walthenberg Canyon. It runs southeastward through the great butte of Redwall limestone that stands between Hakatai and Burro canyons, and is exactly on the line of strike of the Unkar monadnock. A similar swell may be detected in the strata between Fossil Mountain and Bass Camp. These swells are in the zone of maximum southwestward warping heretofore described, and many similar swells may be detected in the quadrangle.

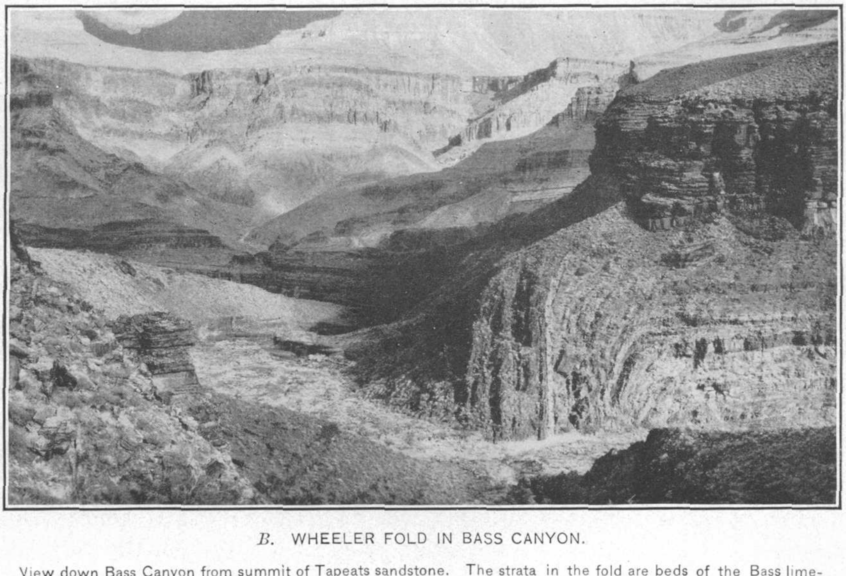
Faults.—In this part, as in other parts of the Grand Canyon, a number of minor faults are found which have no apparent relation to the greater lines of displacement that bound the blocked plateaus. They are haphazard in trend, have small throws, and most of them persist for only a few miles. The long straight gorge of Slate Creek coincides with a fault of about 125 feet. Another fault of this character runs through Bass Canyon and has guided the erosion of that gorge. It is directly on the line of the Algonkian displacement known as the Wheeler fold.

At least two displacements in the adjoining Bright Angel quadrangle are on the line of Algonkian faults, and in each the throw of the Paleozoic displacement reverses that of the Algonkian fault. One of these is the well-known Bright Angel fault, in the canyon of Garden Creek; the other is a faulted flexure which runs southeastward across the quadrangle in the gorges of Phantom, Cremation, and



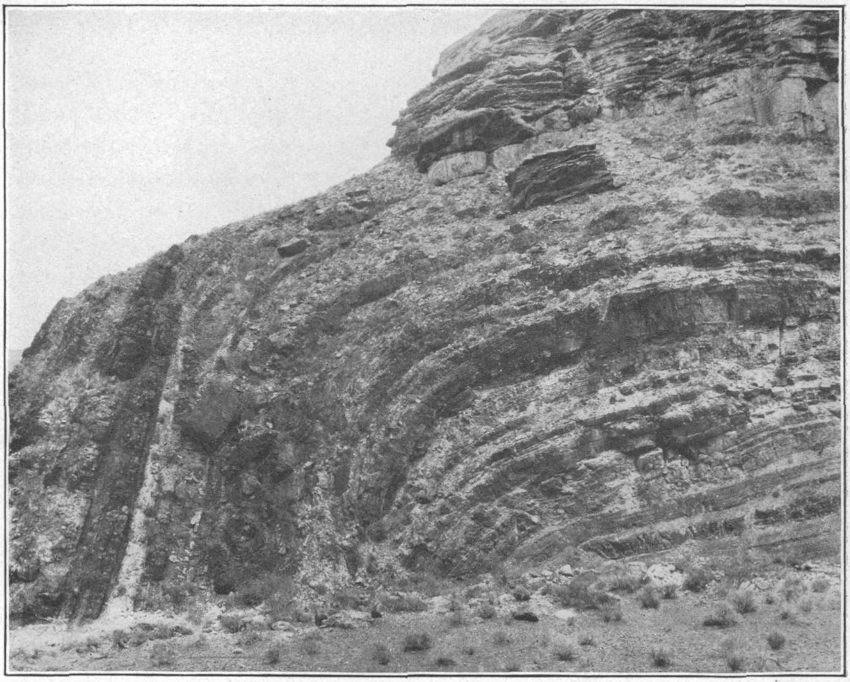
A. PINNACLES OF EROSION IN KAIBAB LIMESTONE ALONG RIM OF KAIBAB PLATEAU.

These pinnacles or "hoodoos" are characteristic features of the scenery along the north rim of the Grand Canyon in the Kaibab division. They are carved in the Kaibab limestone by rain erosion. Each column is capped by a portion of the resistant cherty layer at the summit of the formation, which protects the softer and more easily eroded beds beneath. Although the cherty layer is also present on the south side of the Grand Canyon, the pinnacles are rarely formed there, for the rainfall is less.



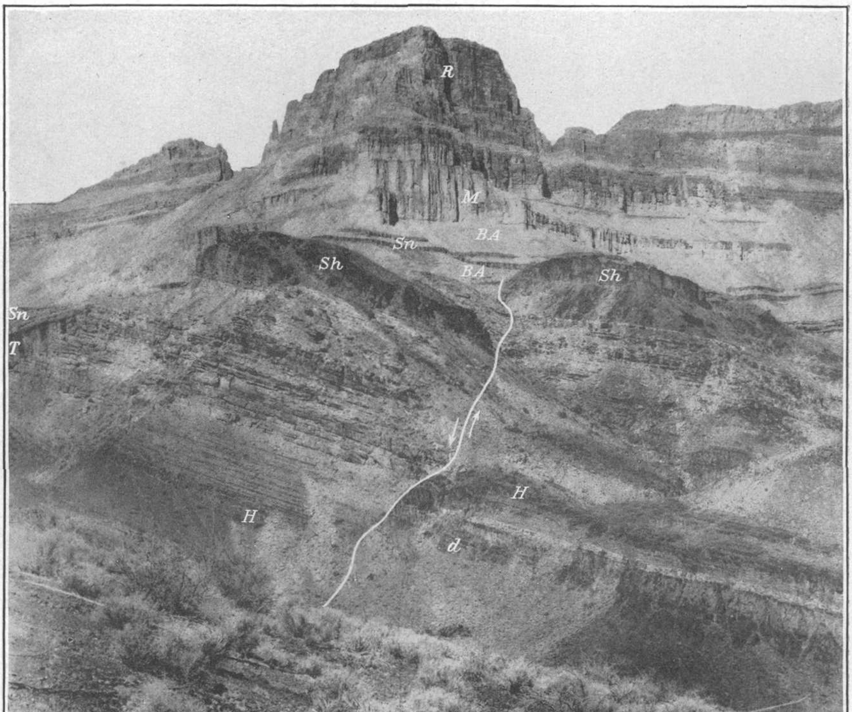
B. WHEELER FOLD IN BASS CANYON.

View down Bass Canyon from summit of Tapeats sandstone. The strata in the fold are beds of the Bass limestone. The fold is overlain uncomformably by the Tapeats sandstone, which appears in the upper right corner of the view.



A. NEAR VIEW OF WHEELER FOLD FROM BED OF BASS CANYON.

Photograph by N. W. Carkhuff.



B. FAULTING IN STRATA OF THE UNKAR WEDGE IN BURRO CANYON.

d, Diabase intrusive; *H*, Hakatai shale; *Sh*, Shinumo quartzite; *T*, Tapeats sandstone; *BA*, Bright Angel shale; *Sn*, "Snuffy limestone" in Bright Angel shale; *M*, Muav limestone; *R*, Redwall limestone. Photograph by N. W. Carkhuff.

Grapevine creeks and limits the mass of Algonkian strata at the mouth of Bright Angel Creek in the same way that the West Kaibab fault limits a similar mass in the Shinumo region. This displacement is the northwestern extension of the great flexure that bounds the Coconino Plateau on the northeast and is known as the Coconino fold. If to these are added the Butte fault on the line of the East Kaibab monocline in the Vishnu quadrangle it becomes apparent that the reopening of a line of displacement after the lapse of a very long time is common in the Grand Canyon district.

The faults in the Grand Canyon have exerted a marked influence on the topography, as they form lines of weakness which, under the searching action of erosion, have determined the location of side gorges, such as the lateral gorge of the Muav-Flint canyon and the gorges between Sagittarius Ridge and Point Sublime, on the line of the West Kaibab fault. North of the Muav Saddle, beyond the boundary of the quadrangle, a similar lateral gorge in the line of the same fault runs northward entirely across the head of Tapeats Amphitheater, at right angles to the main course of Tapeats Creek, the master stream. Examples of the same phenomenon in the Bright Angel quadrangle are the canyons of Monument, Horn, Garden, Bright Angel, Phantom, and Cremation creeks and the upper part of the canyon of Grapevine Creek. Among other examples in the Vishnu quadrangle are Red Canyon, the canyon of Vishnu Creek, and the gorges in the line of the Butte fault.

Lines of fracture without displacement.—In addition to the faults the lines of fracture in the Shinumo quadrangle (and presumably in other parts of the canyon) have exerted a marked influence on the topography, although their importance has not been recognized in the literature of the Grand Canyon. In tracing many of the side gorges of the Grand Canyon to the walls at their heads the writer found in the Paleozoic strata lines of shattering that were directly on the main axes of the gorges. These lines of fracture can not be classed as faults, for they exhibit no appreciable throw, yet along each of them a sufficient amount of shattering has taken place to constitute a line of weakness, which has guided the erosion of the gorge.[1] The peculiar arrangement of the drainage lines of the Shinumo Amphitheater, heretofore described, affords a striking example of this phenomenon, for Merlin Abyss and the similar parallel lateral gorge that crosses the amphitheater between Lancelot Point and Elaine Castle lie along lines of fracture, and many other examples occur in the quadrangle.

Many of the buttes and temples in the Grand Canyon owe their isolation to lines of fracture. Elaine Castle is a good example, and

[1] Mr. Francois Matthes, of the Geological Survey, made an extensive study of these fracture lines in the Kaibab division several years ago and reached the same conclusions as to their significance.—Oral communication.

another is the great butte, capped by sandstone of the Supai formation, which forms the north arm of Monadnock Amphitheater. Among other examples are Explorers Monument, at the south end of Marcos Terrace, and Castor, Pollux, Diana, and Vesta temples, along the rim of the Coconino Plateau.

GEOLOGIC HISTORY.

THE SEDIMENTARY AND EROSIONAL RECORD.

The earliest decipherable record of the geologic history of the Shinumo quadrangle—a blurred and mangled record—is found in the Vishnu schist. Far back in geologic time a thick series of more or less arkose sands and muds was accumulating upon the subsiding floor of a great mediterranean sea. So much may be reasonably inferred from the mineralogic character of the quartz-mica and quartz-hornblende schists of the Vishnu formation. So dim and vague is the record that the base of the series, the floor upon which it was laid down, its thickness, and the location of the land mass from which it was derived must perhaps remain forever unknown. After a long period, in which sediments were accumulated and buried, a mountain-making movement wrote its story across the older manuscript in a later and bolder hand, blurring the ancient chronicle with a record of deep-seated regional metamorphism and imparting to the manuscript the aspect of a palimpsest. The regional metamorphism is conceived to have been brought about by deep burial of the sediments and by their subsequent folding and compression, which in slow process of time engraved upon them the characters of recrystallization and schistosity and were accompanied by their elevation into lofty mountains. Somewhat later the cores of these mountains were penetrated and their summits were farther uplifted by intrusions of great masses of igneous rock, here becoming quartz diorite, the injection of which was followed by injections of magma of pegmatite. Doubtless while this mountain-making movement was still in progress the forces of denudation were already at work, beginning a cycle of widespread erosion, which was carried through to a remote end and which planed away the ancient mountains to their bases and reduced hard and soft rocks alike to a flat, unbroken plain. This ancient surface is represented by the unconformity at the base of the Unkar group and marked the final cycle of this great unknown and unnamed eon of Archean time.

The next event is the beginning of another great cycle of sedimentation, which resulted in the deposition of the Grand Canyon series, of Algonkian age. This cycle was ushered in by the invasion of the land by a shallow sea, which swept over the featureless surface of the Vishnu plain.

The Hotauta conglomerate, at the base of the Unkar group, was the first formation deposited in this sea and was made from the mantle of loose rock and soil that covered the surface of the plain. The lithology of the formation is a possible clue to the climate of that time. Its lack of chemical weathering, locally shown by the freshness and the arkose nature of its component fragments and the red color of its matrix, indicating a lack of vegetation and of abundant moisture to decompose the soil and to reduce the iron which imparts to it its red color, point, to an arid climate. It is therefore possible that the Vishnu plain was a vast desert at the incoming of the sea. The lack of transportation, sorting, and rounding of pebbles in the Shinumo region indicates that the waves had little chance to rework the soil mantle. It seems impossible to account for these phenomena except by supposing a sudden invasion of the sea across the Vishnu plain. If we seek to interpret the past in the light of the present our only means of gaining an understanding of the conditions that then existed is to try to picture some present condition on the earth which is comparable with that preserved in the geologic record. A possible clue may lie in the present conditions about the Caspian Sea, where there is a desert that lies below the present level of the Black Sea, so that a sudden rise in the level of the ocean might cause that sea to overflow the low barrier which separates it from the Caspian and suddenly inundate the desert.

The succeeding Bass limestone was deposited in a permanent body of water into which mud was frequently washed. The section of this formation shows that the alternations in the character of its beds are almost innumerable. The exact cause of these alternations is unknown and is still a subject of speculation. Possibly they were due to climatic oscillation, for a change from an arid to a semiarid climate would load the rivers with sediment and arid intervals would retard their flow or dry them up entirely, resulting in a temporary clarifying of the sea and the deposition of limestone. Whether these limestones were formed by organic agencies or by purely chemical precipitation is also a matter of speculation, as the rocks contain no traces of life. The water was probably for the most part shallow, for sun cracks appear in the shales in the upper part of the member below the highest limestone stratum.

The most striking feature of the Hakatai shale is the great abundance of sun cracks in the shaly strata and of ripple marks and of cross bedding in the sandstones. Research by Prof. Joseph Barrell has shown that extensive sun cracking is most likely to be preserved on broad flood plains or deltas in an arid climate.[1] In the opinion of

[1] Barrell, Joseph, Relative geological importance of continental littoral and marine sedimentation: Jour. Geol., vol. 14, pp. 524-568, 1906.

the writer of the present report the extreme abundance of these cracks in the formation is hard to account for except by postulating wide delta flats or flood plains. Furthermore, the bright-red color of the shaly strata, taken in connection with the mud cracks, seems to bespeak an arid climate, with little or no vegetation to reduce the iron. It is certain that the Hakatai shale was deposited in very shallow water, which often evaporated entirely, leaving broad mud flats exposed to a hot sun. In the upper part of the formation, as may be seen from the section, the alternations of shale and sandstone are notably regular. The sandstone layers are composed of fine, cleanly sorted, and rounded quartz grains and are ripple marked and cross bedded, and the shales were a fine red mud. The cleanness of the sandstone in this alternating series is probably a mark of climatic oscillation. A climatic movement toward a wetter climate, if increasing the ratio of run-off to erosion, causes the rivers to flow on a lower grade and to sweep seaward the piedmont deposits of sand and gravel, and as the clay was largely sorted from those deposits when they were first laid down, their redistribution and their secondary sorting on a delta surface or sea bottom would be marked by extreme cleanness.

Great thickness, clean sorting, and extreme fineness and roundness of grain are the characters that distinguish the Shinumo quartzite, which is composed entirely of sandstones and quartzites. Most of the beds show cross bedding and ripple marks, bespeaking shallow water. Clean sorting and extreme fineness indicate long transportation, so the rivers that carried this material to the sea may have flowed through a great desert of dune sands, picking up and carrying material such as is to-day deposited in the delta of the Indus from a similar source. Scattered lenses of fine conglomerate within some of the strata suggest scoured and filled stream channels.

The Dox sandstone, again, bears all the marks of shallow-water origin; it is throughout characterized by mud cracks, ripple marks, and cross bedding. The addition of micaceous material and of some feldspar gives a slightly arkose character to the rocks; so possibly a crustal movement rejuvenated the land mass that supplied the sediments. Here, again, are marks of aridity, seen in the vermilion color and the vast development of mud cracks.

In the Shinumo quadrangle all subsequent Unkar and Chuar deposits have been removed by the truncation of the pre-Cambrian structure by the plane of the base-leveled surface of erosion beneath the Tapeats sandstone. In the Vishnu quadrangle, where these subsequent deposits are preserved, they also bear evidence of deposition in shallow water. It is not unlikely that a considerable portion of the Grand Canyon series was deposited in deltas or in the flood plains of rivers. The evidence obtainable from the Unkar group in the Shinumo region indicates that an arid climate prevailed at least during the greater part of Unkar time.

The predominance of clastic sediments in the part of Walcott's section in the Vishnu quadrangle that corresponds to the Bass limestone in the Shinumo quadrangle suggests that the Vishnu region was nearer the shore line of the early shallow sea. The close correspondence in the lithology of the succeeding formations in both regions indicates uniform conditions of deposition over at least the distance between these quadrangles.

The next event that can be deciphered in the geologic record in the Shinumo quadrangle is the invasion of the Unkar strata by sheets of diabase. If these invasions are to be regarded as contemporaneous with the lava flows of the Vishnu quadrangle, they must have taken place before the deposition of the Chuar strata, which are assumed to have once overlain the Unkar group in the Shinumo region.

After at least 12,000 feet of Unkar and Chuar strata had accumulated, a mountain-making movement of block faulting and tilting, accompanied or succeeded by elevation, broke the Algonkian strata into great crustal blocks, which must have formed high ranges of mountains. Doubtless these mountains were in character and aspect at one time not unlike the faulted ranges of the Great Basin or the desert ranges of Arizona and California at the present day.

Then began a second long period of erosion that gnawed slowly but surely into these faulted mountains, reducing them in slow process of time through stages of youth, maturity, and old age, and finally eating down into the Archean rocks beneath and planing away all but the stumps of the faulted mountains, leaving the broad expanse of a base-leveled surface. This surface is the spectacular unconformity at the base of the Paleozoic. The remnants of the tilted and faulted Algonkian strata were left inset as wedges in this plain of Archean rocks. The monotony of the surface was broken here and there by a monadnock of Shinumo quartzite, which resisted the forces of erosion in that ancient plain by the same adamantine hardness by virtue of which these strata to-day wall in the deep box canyon of the Shinumo. These monadnocks of the Cambrian plain may be compared with the Baraboo ridges of Huronian quartzite, which by virtue of their homogeneity and hardness still stand as prominences that have weathered repeated cycles of erosion. This cycle of erosion was probably not completed until Cambrian time.

The next notable event in the region is the sinking of the plain and the incoming of the Tonto sea, which probably spread over a surface that strongly resembled the present surface of the great Laurentian peneplain of Canada, with its broad areas of crystalline rocks, in which are inset occasional blocks of sedimentary strata, and above which stand scattered monadnocks of quartzite.

The Tapeats sandstone is a deposit formed on the beach of the invading sea. When the sea came in over the ancient plain the mantle of rock waste that covered the surface was ground and reworked by the waves until only its most durable particles remained, making a quartz sand. The conglomerates in the basal part of the formation represent the coarse shingle of the beach, worn and rounded by the pounding of the waves; the grits and sandstones are the shifting sands along the ancient shore. The monadnocks of Shinumo quartzite stood as islands in the sea. The striking record of marine planation revealed in the cliff faces of these monadnocks has already been described.

After the deposition of the Tapeats sandstone, quantities of micaceous sand were washed into the gradually deepening sea. These sands formed the Bright Angel shale. Twice during this epoch the sea became locally clear and the layers of the so-called "Snuffy limestone" were deposited. The highest islands of quartzite of the Unkar group were finally buried by the uppermost sands of the Bright Angel shale. The fossils found in the Bright Angel shale are the first clear evidence of life in the Paleozoic sea; the fauna of Middle Cambrian age which they represent belongs far down in the scale of the world's life history.

After the deposition of the Bright Angel shale the sea became clearer and the Muav limestone was laid down. Small quantities of mud were still being washed into the sea, imparting to the limestone its mottled appearance.

Then followed an interval in regard to which the record is nearly silent—a period lasting through Silurian and Devonian time. During the first part of that period the sea retreated and the upper part of the Muav limestone was exposed to erosion, probably as a low-lying land. During the Devonian period the sea came in over this land and deposited material that formed sandstone and limestone. Again the land was gently uplifted without deformation and was subjected to erosion which removed nearly all the Devonian strata except those that lay in depressions in the Muav limestone. So much may be learned from the study of the unconformity at the base of the Redwall limestone in the Grand Canyon region.

The next recorded event, coming in early Carboniferous (Mississippian) time, is a submergence in a sea that first received deposits of material that formed sandstone and limestone but rapidly became clear, depositing material that formed the massive Redwall limestone. The purity of this limestone is evidence of the clearness of the waters, and the presence of large cup corals indicates that the sea was warm.

After the deposition of the Redwall limestone the sea became very shallow, and into it large quantities of sand and mud were alternately washed. These sands and muds are the alternating red shales and sandstones of the Supai formation, the lowest of the Aubrey group of strata. In some parts of the Grand Canyon region the sea was clearer and layers of limestone are there interbedded with the shales and sandstones of the lower part of the formation. A fauna of late Carboniferous (Pennsylvanian) age lived in that clearer portion of the sea. It is probable that the pebbles of the limestone conglomerate in the sandstone division of the Supai formation of the Shinumo region were derived from these limestones by erosion.

The origin of the overlying Coconino sandstone is an interesting problem. A counterpart of this formation in the Plateau province is the great sandstone 50 miles north of the Shinumo quadrangle, in the terraces of southern Utah, to which Huntington and Goldthwait have given the name Colob sandstone. The origin of this sandstone is discussed by Huntington and Goldthwait as follows: [1]

> The white sandstone is cross-bedded on a scale so large that a single layer attains a thickness of from 5 to 50 feet. * * * Everywhere the deposit consists of uniformly fine white sand without a trace of pebbles or coarser sand so far as has yet been observed. The uniformity of texture is emphasized by the total lack of ripple marks, which, as Cornish has shown, result from the mixture of sand grains of different sizes. That such a formation could be due to marine or lacustrine action of any kind seems contrary to what we know of such agencies. It is generally recognized that cross-bedding of a marked type is a proof that the deposits were formed close to the shore or on land. The uniform thickness of the Colob sandstone over so great an extent renders it antecedently improbable that it is a shore deposit; the total absence of ripple marks, rill marks, and other characteristic shore features lends support to this, and lastly the perfect smoothness and horizontality of the planes which truncate the tops of the strata render this still more improbable. * * * The same facts of structure, together with the total absence of gravel, of fossil stream beds, and of lateral unconformities render it equally improbable that the Colob was deposited by fluviatille processes. The only remaining possible agent is the wind. We can not yet be certain that the Colob sandstone is a wind formation; nevertheless none of its characteristics seem to oppose such an hypothesis. The uniformity and fineness of the component quartz grains, the steepness of the cross bedding, its general uniformity with interesting minor variations, the even truncation of the successive cross-bedded strata, and the tangency of the overlying layers to the plane surface thus formed suggest a series of great white dunes marching forward to the east and south from the base of the Basin Range Mountains. * * * It seems to be a fair question whether the cross-bedded strata of the Kanab and Colob formations may not be continental deposits laid down by the wind.

The Coconino sandstone differs little, except by its lesser thickness, from the sandstone just described, and many beds of sandstone in the underlying Supai formation resemble the Coconino sandstone, but are still smaller. It seems probable that whatever may have been the origin of these sandstones it must have been analogous to that of the sandstone of southern Utah described by Huntington and Goldthwait. If their interpretation is correct the region must have become land during the deposition of the Coconino sandstone and at

[1] Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah: Harvard Mus. Comp. Zool. Bull 42, geog. ser., vol. 6, No. 5, pp. 214 et seq., 1904.

intervals during the deposition of the Supai formation, and the sandstones represent deposits of dune sand.

Again the sea invaded the land and laid down the sandy, calcareous sediments forming the base of the Kaibab limestone. The clarifying of the sea resulted in the deposition of the pure and richly fossiliferous limestones in the upper part of the formation. The fossils represent the typical fauna of the western sea in Pennsylvanian time. Life was easy, for the forms are fat and well nourished, as well as exceedingly abundant. The waters were probably shallow and warm as well as clear, for the rocks deposited in them contain great quantities of bryozoa, which possibly even formed reefs, and with the bryozoa are mingled the remains of echinoids, corals, crinoids, brachiopods, gasteropods, and sponges.

So much of the geologic history may be read from the actual rock record in the Shinumo quadrangle.

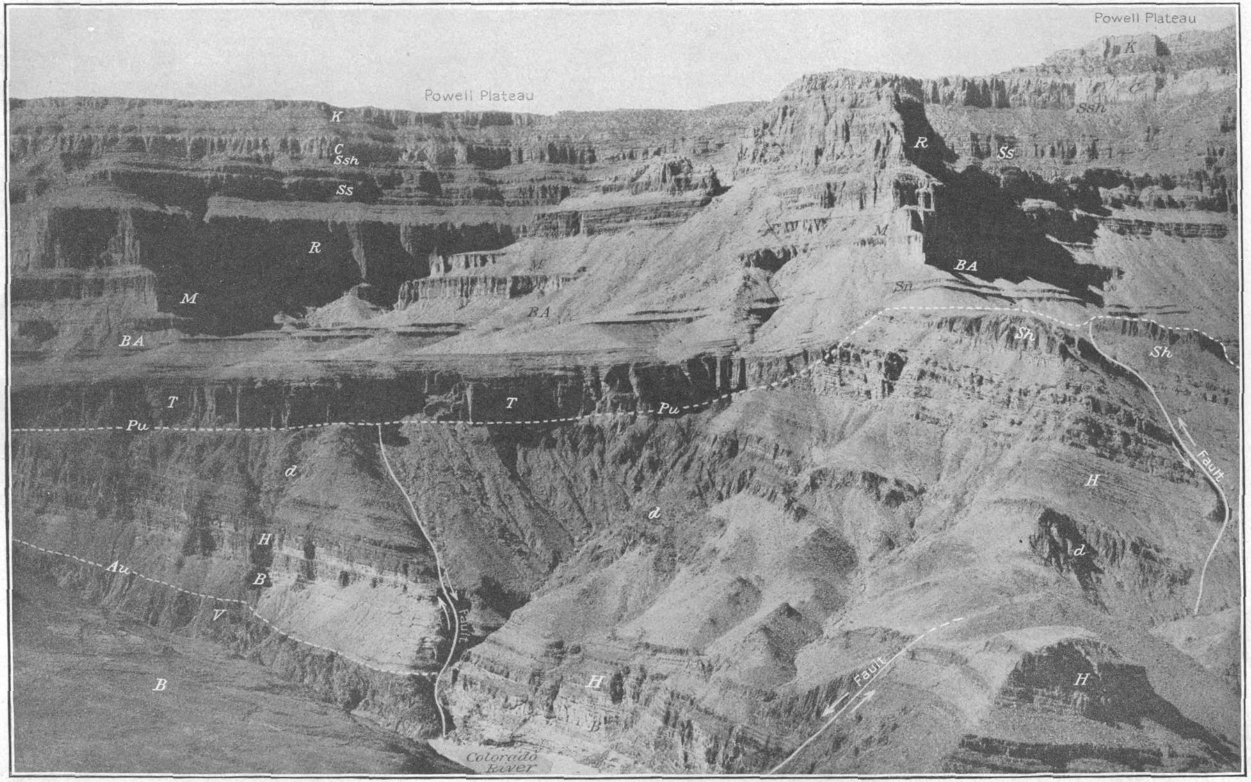
One who looks across the broad plateaus on either side of the Grand Canyon finds it difficult to realize that the deposition of strata did not end with that of the Kaibab limestone, upon which he stands, but the cliffs and terraces that rise to higher and higher levels along the northern border of the Grand Canyon district, as well as Echo Cliffs, on its eastern border, represent the eroded edges of strata that were once deposited horizontally bed upon bed upon the Kaibab limestone and that once extended continuously across the whole region where the Grand Canyon lies.[1] At the base of the cliffs on the north lie strata of the Permian epoch, completing the record of the Carboniferous and also of the Paleozoic; above lie strata of Mesozoic age—Triassic, Jurassic, and Cretaceous. The highest beds belong at the base of the Tertiary.

After the deposition of the Kaibab limestone, the accumulation of the Mesozoic and Tertiary strata went on quietly and almost continuously. The presence of occasional unconformities of erosion without unconformity of dip shows that whatever uplifts occurred were unattended by horizontal deformation. The strata were deposited "with almost rigorous horizontality."[2] By the end of Mesozoic time these strata had accumulated to a thickness considerably greater than that of the entire Paleozoic section of the canyon wall.

During the early part of the Tertiary period, after the accumulation of 6,000 feet or more of strata, deposited bed after bed above the Kaibab limestone, the Grand Canyon district began to be uplifted high above the surrounding country, and a period of erosion was begun which has lasted to the present day. This erosion was not continuous; there were pauses in the uplift of the region, during which the forces of erosion worked far along toward producing a mature topography;

---

[1] Dutton, C. E., op. cit., pp. 61 et seq. [2] Dutton, C. E., idem.



GEOLOGIC HISTORY OF THE SHINUMO QUADRANGLE AS REVEALED BY THE LITHOLOGIC RECORD IN THE CANYON WALL.

V, Vishnu schist; *Au*, Unconformity, separating the Archean and Algonkian systems; *B*, Bass limestone; *H*, Hakatai shale; *d*, Diabase (intrusive); *Sh*, Shinumo quartzite; *Pu*, Paleozoic unconformity, separating Algonkian and Paleozoic rocks; *T*, Tapeats sandstone; *BA*, Bright Angel shale; *Sn*, "Snuffy limestone" in Bright Angel shale; *M*, Muav limestone; *R*, Redwall limestone; *Ss*, sandstone of Supai formation; *Ssh*, shale of Supai formation; *C*, Coconino sandstone; *K*, Kaibab limestone. A vertical mile of strata is in view. Photograph by N. W. Carkhuff.

then again the country would rise and the attack be renewed more vigorously. Out of all these vicissitudes of uplift and erosion two major cycles stand clearly forth, and the result of the work in each is stupendous.

The work of the earlier and greater cycle is known as the "great denudation." As a result of the erosion in this period nearly all the 6,000 feet of Mesozoic and basal Tertiary strata was removed from the surface of the Grand Cañyon district, their edges retreating to a line 50 miles north of the Shinumo quadrangle, to the cliffs along the border of Utah. Toward the end of the great denudation the surface of the region was reduced to a base-level of erosion. Fragments of this peneplain are preserved beneath the San Francisco Mountains, Red Butte, and the hills of the Uinkaret Plateau by floods of lava that were poured out upon the plain during the last stages of its formation. This resistant lava has protected the underlying strata from subsequent erosion.

The work of the second and lesser cycle is the cutting of the Grand Canyon by Colorado River and the removal of whatever remnants of soft strata were left upon the surface of the plateaus at the end of the great denudation. This cycle, which is still in progress, is known as the "canyon cycle" of erosion.

The course of Colorado River across the region became established before the beginning of the uplift which began the canyon cycle of erosion. As the land rose the river entrenched itself in its original course, continuing to cut deeper and deeper. The present stage of the valley is the Grand Canyon, which is thus wholly a product of erosion. It has been excavated by Colorado River and is deep, because the land is high and because in this arid region the river, fed by the snows of the Rocky Mountains, has cut down its bed much faster than the erosion due to strictly local agencies could lower the adjacent plateau. The walls have retreated slowly in comparison with those of most valleys, because the strata that determined them are unusually massive and because the forces that attacked them have been comparatively weak and have worked in the way characteristic of arid regions.

By far the most impressive feature of this wonderful country, to the traveler and the geologist alike, is the mile-deep pathway of the Colorado River of the West across the great plateaus. The stupendous and glaring record of erosion revealed in the cutting of this mighty gorge has almost blinded us to the immensity of the vastly greater record revealed in its walls (Pl. XVIII), but the erosion of the canyon becomes only an episode in the geologic history of the region in comparison with the story told by the two intersecting unconformities in the bottom of the gorge. These unconformities represent two ancient cycles of sedimentation, uplift, and erosion carried to a remote end, separated by long intervals of time whose record is hopelessly lost, resulting twice in the planing down of lofty mountain ranges to their very cores, written vaguely at first on a blurred and time-worn record and later in an increasingly clearer and bolder hand, telling of the slow accumulation of the strata of the canyon wall on the floor of the Paleozoic sea, of the subsequently erased record of the accumulation of vast thicknesses of Mesozoic and Tertiary strata, at times separated by great intervals of erosion, and even telling of the "great denudation," which has stripped these later strata back 50 miles to the terraces of Utah—all these events representing a lapse of time which compared with that consumed in the cutting of the Grand Canyon is but as the passing of a summer afternoon compared to the procession of a season; for in the light of present knowledge according to the fossil record, it may be said that the Grand Canyon was all cut since man has inhabited the earth.

THE PLATEAU PROBLEM.

Since the history of the region from early Tertiary to the present time is entirely a record of uplift and erosion, that record should be interpreted wholly by means of the science of physiography. The salient events, as outlined above, were established beyond a doubt by the work of Dutton and Powell. The science of physiography, however, has grown remarkably since the work of these pioneer observers was done.

In 1900, 1901, and 1902 the region was visited by Davis,[1] whose studies confirmed the broader conclusions of Dutton, but brought to light evidence that the history of erosion in the region is far more complex than was formerly supposed.

It was shown that the great denudation was complicated by repeated movements of uplift, after each of which erosion may have reached an advanced stage.

It was discovered that the great displacements of the region began at an earlier date than was formerly supposed. The absolute antecedence of the Colorado River to the displacements, regarded by Dutton and Powell as proved, is therefore open to question.

It was made clear that the exact dates of the various events of the Tertiary and recent history are still unknown.

It was shown that these problems can be solved only by a great amount of further detailed observation, not only in the Grand Canyon district but in the neighboring regions.

Since the work of Davis, parts of the region have been studied in detail by Robinson, Huntington and Goldthwait, and Johnson,[1] and

[1] See Bibliography, p. 14.

many data bearing on these problems have been accumulated. Owing to the vastness and inaccessibility of the region a great amount of work of this kind still remains to be done.

The detailed interpretation of this complex erosional history has become known as "the plateau problem."

The most absorbing question of the plateau problem is that which concerns the date and the method of the establishment of the course of the Colorado River across the region. Two theories have been entertained.

The earlier theory is found in the writings of Dutton and Powell. These observers found that the general course of the river lies across the great lines of displacement that bound the blocked plateaus and were led to the conclusion that the course of the river was established before the first movements along the lines of displacement occurred. As the displacements came into existence the river continued to cut down in its original channel faster than they rose across its path. It was thought that the displacements did not begin until the end of the great denudation.

An alternate theory has been advanced by Davis and supported by Robinson, Huntington, and Johnson. The work of these men brought to light evidence that the first movements along the lines of displacement had begun early in the period of the great denudation; that the peneplain developed in the later part of this period represented a stage of erosion so far advanced that hard and soft rocks alike were reduced to a nearly even level and the initial relief produced by the displacements was almost effaced. The drainage system of the Colorado first became established upon this peneplain, the configuration of the surface of that time guiding the course of the river. The fact that the relief produced by the displacements was largely effaced in the peneplain would account for the course of the river across them.

In order to confirm this later theory that the Colorado is a superposed stream let down from the surface of an ancient peneplain it is necessary to restore in imagination the topography of the region as it existed in the later stages of the peneplain—that is, the topography to which the ancestral drainage system of the Colorado adjusted itself, and this restoration can be made only by careful detailed study. A study of the structural irregularities that date back to the time of the great denudation may afford a partial restoration of the ancient topography. Even the smallest folds or faults may have influenced the adjustment of the drainage by exposing strata of unequal resistance. Since practically all the Permian and higher strata that may have affected this adjustment of the drainage have been removed by erosion, it is obvious that these structural irregularities are open to study only in the Paleozoic rocks of the present plateau surface. The writer of this report believes that such detailed study may show that the course of Colorado River between Kanab Creek and the Little Colorado, at least, is related to lines of structure. Davis[1] has shown that such a relation probably exists in the Kaibab division immediately west of the Little Colorado.

If similar speculation concerning the Bright Angel and Shinumo quadrangles is undertaken, it seems significant that the northwesterly course of the river is parallel to the strike of the northeastward-dipping flexures of the Coconino fold and of the West Kaibab fault. The great loop of the river around Powell Plateau is a local deflection from this general northwesterly course and it is of interest to note that just beyond the boundary of the quadrangle, west of the end of Alarcon Terrace, there is a faulted flexure which trends northeast-southwest and resembles on a smaller scale the West Kaibab faulted flexure in Muav Canyon. The river apparently flowed westward until it encountered this displacement, and its course was then deflected toward the north and northeast, possibly following a belt of weak Permian rocks on the thrown side of the displacement. Doubtless the river was held up for a time at this displacement, and the loop around Marcos Terrace may represent a meander, subsequently entrenched, which dates back to that time.

It is now thought that the greater lines of displacement of the Grand Canyon district were blocked out in the first broad uplift that started the erosion known as the great denudation. More and more evidence has been found of movements that have taken place along these lines at intervals throughout all succeeding time. Each successive faulting is correlated with a fresh uplift and a revival of the forces of erosion, necessitating the recognition of more and more cycles in the erosional history of the region.

An interesting feature of these displacements is their location upon ancient lines of displacement in the basement rocks. This coincidence is the rule in the Kaibab division, as has been shown in this bulletin, and it therefore seems probable that it applies to other faults in the district whose prolongation into the basement rocks can not be studied. The history of the displacements thus has its beginning in the mountain-making movements of Algonkian time.

The dating of the numerous events of the complex erosional history in geologic time is the most difficult riddle of the plateau problem. A discussion of this subject has no place in the present report, for the Shinumo quadrangle affords no evidence whatever concerning it. A brief outline, however, will show how complex the interpretation has become since the publication of Dutton's monograph.

[1] Davis, W. M., An excursion to the Grand Canyon of the Colorado: Harvard Univ. Mus. Comp. Zool. Bull. 38, geol. ser., vol. 5, No. 4, pp. 164–165, 1910.

A summary of the Tertiary history as worked out by Dutton is as follows:

I. The period of great denudation, lasting until the close of the Miocene.
II. Uplift by folding (?) and faulting at close of Miocene.
III. Canyon cycle of erosion:
(*a*) Cutting of outer gorge of Grand Canyon during the Pliocene.
(*b*) Uplift by faulting at close of Pliocene.
(*c*) Cutting of inner gorge of the canyon during the Quaternary.

The following summary, given by Robinson [1] in a recent publication, is the most recently published interpretation of the Tertiary history. The dates of the events are assigned tentatively by that writer:

I. Period of folding and flexing during the later half or at the close of the Eocene.

II. Erosion period during the Miocene.

III. First period of faulting at close of the Miocene. A period of extensive faulting. It is correlated with the faulting that gave rise to the Basin Ranges of southern Nevada as tilted block mountains.

IV. The peneplain cycle of erosion during the Pliocene. The Miocene and Pliocene erosion, which are considered as constituting the later and greater part of the period of the great denudation, closed with the widespread development of a peneplain. This is correlated with the mature topography and local peneplains of the Basin Range country of southern Nevada and of Arizona. Relief produced by previous faulting (III) largely and at some localities entirely obliterated. Widespread volcanic activity, marked by the eruption of basalt, occurred shortly after the development of the peneplain and most probably while the region still stood close to sea level.

V. The second period of faulting at the close of the Pliocene. Movements probably of less magnitude than those of the first and third periods.

VI. The post-peneplain cycle of erosion during the first part of the Quaternary. Widespread stripping of Permian and Triassic strata and development of a mature topography of low relief, principally on the upper Aubrey limestone, at a horizon ranging from zero to 1,000 feet below the level of the peneplain. Further retreat of the high cliffs on the north and east sides of the district. Land stood at no great height above the sea.

VII. The third period of faulting, with broad regional uplift, during the middle or latter part of the Quaternary. Region raised from 4,000 to 6,000 feet above the position it occupied at the close of the post-peneplain cycle of erosion.

VIII. The canyon cycle of erosion during the latter part of the Quaternary. Marked by the development of a canyon system of drainage of extreme youthfulness. Refreshing of cliff profiles. Erosion otherwise very slight. Colder atmospheric conditions prevailed during part of this cycle, at least as indicated by the existence of a small glacier on San Francisco Mountain.

SCENIC INTEREST OF THE SHINUMO QUADRANGLE.

The views from the northern wall of the Grand Canyon in the Shinumo quadrangle have long been famous through the descriptions of Dutton.[2] The most celebrated outlook is Point Sublime, the promontory that forms the eastern arm of the Shinumo Amphi-

[1] Robinson, H. H., A new erosion cycle in the Grand Canyon district, Arizona: Jour. Geology, vol. 18, No. 8 (Nov.–Dec., 1910), pp. 763ff.

[2] Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, chaps. 8 and 9, 1882.

theater. The view from this point is the subject of the three magnificent panoramic drawings by Holmes which illustrate that part of Dutton's monograph that is devoted to the scenery of the canyon.

A scarcely less comprehensive view may be obtained from Havasupai Point (Pl. VII, B, p. 22), on the south side of the canyon. The view within the canyon itself from this point is even more extensive than that from Point Sublime, directly across the canyon. Point Sublime, however, like all points on the northern rim in the Kaibab division, has the advantage of greater altitude, which extends the outlook far over and beyond the southern rim of the canyon.

By far the most interesting scenic ground in the quadrangle is Powell Plateau (Pl. IV, A, p. 18), on the north side of the canyon, accessible by trail from the Muav Saddle. The scenic advantage possessed by this great butte is due to its peculiar situation with reference to the course of the Grand Canyon and to its great altitude. As it lies almost in the middle of the canyon, just at the elbow of the great bend where the general course of the river changes from northwest to southwest, directions maintained in either direction for over 50 miles, the views from the north and south ends of the high eastern portion command a greater stretch of the interior of the canyon than can be seen from any other place in the region. And since this eastern portion of the plateau is higher than any land in the quadrangle outside of the Kaibab, it is possible to obtain from these two places an outlook in every direction except to the northeast over an expanse of country extending nearly a hundred miles to the horizon and including the greater part of the Grand Canyon district.

The outlook from Dutton Point, at the south end of Powell Plateau includes the entire Kaibab division of the canyon, seen along the very center of the pathway of the river. Below, on the northeast, is Muav Canyon, where the consequences of the West Kaibab fault are clearly revealed. Directly below, to the east, in the interior of the canyon, is the wedge of Unkar strata about the mouth of the Shinumo. To the south, in the canyon, the topography of the wall is changing from east to west, the Esplanade appearing and the Tonto platform fading gradually. Beyond the southern wall the Coconino Plateau slopes away from the canyon rim, merging gradually into the broad expanse of the San Francisco Plateau, upon whose surface the San Francisco Mountain volcanic group is in full view, 80 to 100 miles away.

The north end of Powell Plateau lies just beyond the northern border of the map. Here the outlook is still more extended. To the southwest the canyon is visible through the Kanab division for 50 miles; beyond are the white outer walls of the outer canyon in the Uinkaret and Shivwits plateaus. South of the canyon the San Francisco Plateau stretches far away into central Arizona; across it may be seen the walls of Cataract Canyon. North of the Grand Canyon lies the surface of the Kanab Plateau, broken only by the gorge of Kanab Creek; along the western border of the Kanab Plateau, beyond the mouth of Toroweap Valley, rise the mountains of the Uinkaret, a group of lava flows and recent cinder cones dominated by Mount Trumbull; many of the cinder cones are clearly visible. Along the northern border of the Kanab are the cliffs and terraces of Mesozoic strata, beginning with the Vermillion Cliffs, composed of Triassic strata, and receding step by step to Pink Cliffs, which are composed of Tertiary strata. To the northwest the promontories of Vermillion Cliffs fade below the horizon 100 miles away.

In the foreground, directly below, is Tapeats Amphitheater, an expanse of Esplanade 12 miles across, trenched by the single gorge of Tapeats Creek and by two arms of the great lateral gorge which runs northward from Muav Saddle across the head of the Amphitheater in the line of the West Kaibab fault. Along Colorado River above the mouth of Tapeats Creek may be seen the mass of Unkar strata which lies in the Lower Granite Gorge and represents the prolongation of the Shinumo wedge northwestward underneath Powell Plateau.

To the geologist these two views from Powell Plateau are encyclopedic. The rocks that are visible represent in turn a portion of every great geologic age, and the stratigraphic position of each system of rock is apparent at a glance. Every great earth-making process is illustrated; sedimentation by a thickness of over 16,000 feet of unaltered strata reaching from Algonkian to Tertiary; regional metamorphism by the Archean rocks; contact metamorphism by certain Unkar strata; vulcanism by deep-seated invasions in the Archean, by intrusive sheets in the Unkar strata, and by surface eruptions in the San Francisco Mountains and the hills of the Uinkaret Plateau; deformation by the mashed and crumpled Archean rocks, by the faulted Algonkian rocks, and by the great displacements that traverse the Paleozoic strata. Perhaps the most impressive record of all is that of the processes of uplift and erosion—the ancient cycles denoted by the unconformities that separate the systems of rock; the later cycles by the removal of vast thicknesses of strata and the production of the surface of the region in its present aspect.

The panorama is probably the most complete geologic revelation in the world.

COPPER DEPOSITS OF THE SHINUMO QUADRANGLE.

Occurrence.—With one exception all the copper deposits in the quadrangle are found in the Archean and Algonkian rocks in the depths of the canyon.

History.—The discovery and exploration of the deposits is the work of Mr. W. W. Bass and Mr. John Walthenberg. A large amount of prospecting has been done and claims have been located in Copper Canyon, Bass Canyon, Granite Gorge near Cable Crossing, Shinumo Canyon between White Creek and Flint Creek, along the line of the West Kaibab fault, and on Muav Saddle.

The most valuable bodies of ore so far found are in Copper Canyon, from which about 25 tons of ore were taken in 1908. The ore was carried to the rim of the Grand Canyon on burros, and hauled thence 20 miles by wagon to Grand Canyon, a station on the Grand Canyon Railway, of the Santa Fe system. Some exploratory work has been done at the other localities, but so far no attempt has been made to take out ore for shipment.

Geology.—The claim in the Muav Saddle is the only one in the Paleozoic rocks. It is just at the point where the trail up Muav Canyon enters the saddle, at an elevation of 6,700 feet. Some copper mineralization occurs along the contact of the Supai formation and Coconino sandstone, where the beds are shattered by the West Kaibab fault, and this mineralized zone is now being explored by an open cut. The copper here is doubtless of the same age and origin as that of the deposits found on the surface of Kaibab and Coconino plateaus in other parts of the Grand Canyon district.

The deposits in Copper Canyon are, in method of occurrence, a fair type of all the deposits in the Archean and Algonkian rocks in the quadrangle. As they are the only ones now accessible to underground study a description of them will also serve in a general way for those at the other localities.

The country rock of the interior of Copper Canyon beneath the Paleozoic is the Vishnu schist, of the Archean system. At the end of the great pre-Cambrian erosion the basal strata of the Unkar group of the Algonkian extended part way across the Granite Gorge of Copper Canyon, terminating there as the apex of the Algonkian wedge. Only a few layers of these strata in that locality, however, have escaped the present cycle of erosion. These lie high up under the cliff of Tapeats sandstone, in the eastern wall of the Granite Gorge of Copper Canyon.

The ore bodies in Copper Canyon all lie in the rocks of the Vishnu schist which in this locality are quartz-mica schists and pegmatites. The ores are found in two main veins, which will be described.

The outcrop of the first vein runs northwestward across the Granite Gorge of Copper Canyon. The vein is almost vertical, dipping slightly southwestward. On the east side of the creek, at the bottom of the canyon, a tunnel has been driven in southwestward for over 100 feet along the strike of the vein. This tunnel is about half a mile from Colorado River, at an elevation of about 2,800 feet. A vertical shaft has also been sunk 50 feet on the vein which it followed down the dip from the surface outcrop. This shaft intersects the tunnel at a point 15 feet below the surface of the ground and 25 feet from the mouth of the tunnel. All the ore that has been taken from Copper Canyon for shipment has come from these workings.

The ore minerals of the vein in this locality are cuprite, bornite, and chalcocite. The first two minerals make by far the greater proportion of the ore mined. The chalcocite has come from the most recent workings at the bottom of the shaft. The gangue of the vein is chiefly brecciated mica schist cemented by milky quartz and some calcite. The vein shows the usual pinches and swells, and averages about 1 to 2 feet in width. The minerals on the outcrop of the vein are considerably weathered, making incrustations of malachite and green silicate of copper.

The second vein crosses the creek bed a few hundred feet north of the first vein. Its strike is nearly east and west and its dip is about 60° N. About 200 feet above the level of the bed of the creek where it is crossed by the vein a tunnel, known as the Hakataia tunnel, has been driven westward along the strike of the vein for 75 feet. The vein at the tunnel in about a foot wide. The ore minerals taken from the tunnel include cuprite, bornite, chalcopyrite, and argentiferous galena. The gangue is quartz. Near the surface the ores are leached of their values by weathering but grow richer underground.

The two veins converge toward the west in the western wall of Copper Canyon. Their inclined dip would also cause them to converge upward on the eastern side of the canyon, but this part of their apex has been removed by erosion.

The second vein was traced upward in the eastern wall of Copper Canyon to the base of the Unkar strata and was found to be on the prolongation downward into the Archean rocks of one of the Algonkian faults. It is therefore a simple mineralized fault fissure. The first vein was similarly traced upward but was found to be truncated by the pre-Tonto unconformity just beyond the apex of the Algonkian wedge, so that its relation to the Algonkian faulting could not be positively determined. It represents, however, a filled fissure produced by a normal fault of small throw, the evidence of which is found in the offset of certain pegmatite veins that are sheared by the fault. This fissure is doubtless the downward prolongation of an Algonkian fault like that on which the other vein is located.

All the other deposits in the Archean and Algonkian rocks occur either in similar fissure veins, which represent the mineralized fault planes of normal Algonkian faults, or in the zone of shattering along the line of the Algonkian displacement of the West Kaibab fault. All the faults belong to the same period of disturbance, the one in which the great mountain-making movement came at the end of Algonkian time.

Age.—The primary ore deposition undoubtedly occurred in Algonkian time, as all the ore-bearing fissures are truncated by the unconformity at the base of the Paleozoic.

Origin.—The origin of the primary ore deposition is not clear. The event with which it is obviously connected is the Algonkian mountain-making movement, but the specific causes that set up the circulation of the mineral-bearing solutions are a matter of speculation. It is possible that some sort of a genetic connection may have existed between the mineral-bearing solutions and the igneous activity manifested by intrusions of diabase in the Unkar strata of the Shinumo region, although it is clear that the intrusions in this locality were earlier than the faulting that gave rise to the mineral-bearing fissures.

Value.—The deposits in Copper Canyon are locally of high grade, but not enough work has been done to give an accurate idea of their extent and quantity.

INDEX.

○